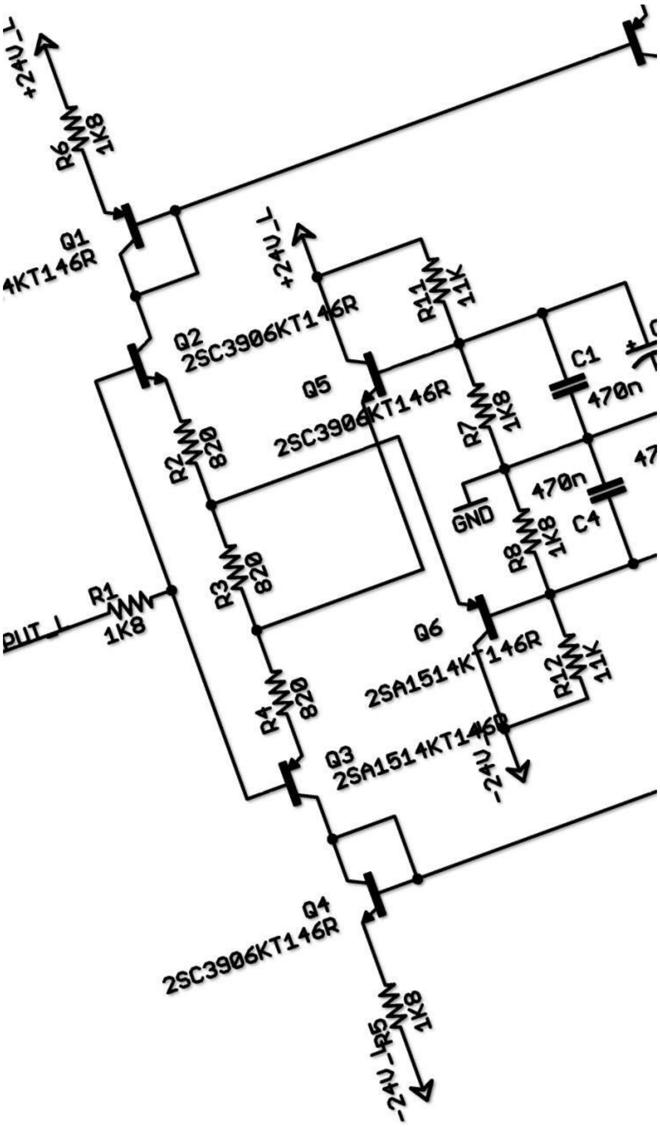
x MONASH University
Engineering

ECE2131

Electrical Circuits

Laboratory Notes



2022 Edition

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2022

3 Transient Responses of Second Order Circuits

3.1 LEARNING OBJECTIVES AND INTRODUCTION

Following the practical experience with first order RC and RL circuits obtained in Laboratory 2, this experiment is intended to provide further practical experience of and familiarity with the step- responses of simple series circuits which contain two energy-storage elements, along with other associated lumped elements. The circuits will be driven by a square wave voltage source so that they can be mathematically described by second-order differential equation with a zero or a constant forcingfunction. The detailed mathematical analysis of such circuit has been discussed in lectures. You may need to consult the lecture notes to complete the Preliminary Work and experiment tasks in this laboratory session.

By the end of this lab you should:

- Understand how voltage and current behave in second order circuits
- Understand that electrical components have some parasitic features that cause them to be imperfect
- Characterise how an RLC circuit oscillates

3.2 EQUIPMENT AND COMPONENTS

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

- breadboard
- 100nF capacitor
- 100 mH inductor
- potentiometer (variable resistor)

In LTSpice, resistances in wires and internal resistances in inductors and capacitors are by default 0Ω. However, we already know that in real physical circuits, these resistances are not 0Ω. Therefore, to recreate non-zero internal resistances in wires, inductors and/or capacitors in LTSpice simulations, we need to manually set these values in LTSpice.

For this experiment, we will only set residual resistances in inductors. However, remember that residual resistances in inductors are not identical values. Inductors from the same batch manufactured can have varying amounts of residual resistances. Therefore, we should also mimic this situation as much as possible in LTSpice. Although you and your friend can have the inductors of the same inductance values, its residual resistance values would most likely be different.

To create residual resistances in LTSpice, perform the following steps:

[Compulsory for online students]

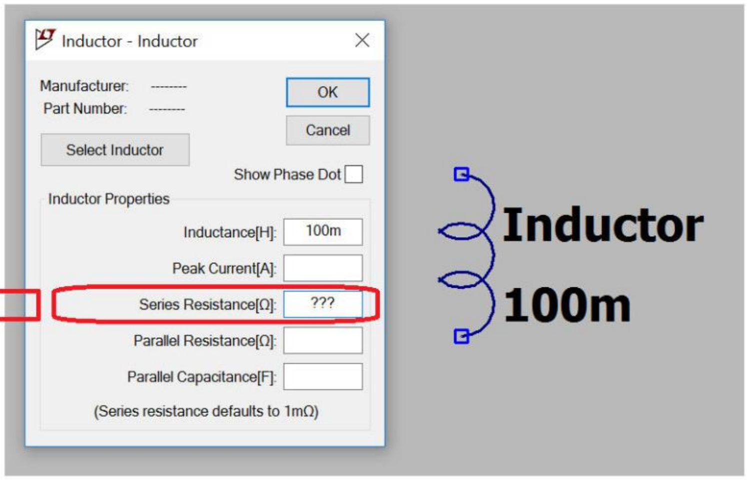
Right-click the inductor component in LTSpice.

Enter the series resistance (SR) value using the formula below:

SR = 2.5 + (0.##)x1.5

is the last two digits of your Monash student ID.

For example, if your ID is 12345678, then ## would be 78



The SR that you MUST use for the entirety of your Lab 3 circuits and report is:

SR = 2.5 + (0.78)x1.5 = 3.67Ω

Show this value in your report, preferably using screenshot.

After setting this residual resistance, you will continue to do your LTSpice simulations as per the instructions in next sections of this lab manual. Throughout this lab manual, all inductors must used this series resistance value. **Screenshot this and put it in your lab report, anywhere that does not block the other contents of the lab manual, or as appendix.**

When asked about residual resistances in the inductor, you "cannot" know its exact value, similar to how we don't know the exact residual resistances in a physical capacitor or inductor that we use the laboratory. However, it is still possible to estimate the resistance using equations and/or formulas from your lecture notes.

3.3 EXPERIMENTAL WORK

3.3.1 SERIES RLC CIRCUIT

In the series RLC circuit under study, the “common” terminal of the square wave generator and the “common” terminal of the DSO should be connected together. It should also be constructed 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.

3.3.1.1 MEASUREMENT OF ω_0 AND ω_d

As investigated in the preliminary quiz, α and ω_d, the two important parameters of the zero-input response, are the same for both the circuit current and the capacitor voltage. In fact they are also the same for the inductor voltage! Thus, they can be measured from observation of either the circuit current or the capacitor voltage. However, it is more convenient to measure the capacitor voltage ratherthan the current, since this is possible even when the variable resistor is set to zero. Are there any complications associated with observing the inductor voltage directly? Describe below:

In the circuit, the inductor is connected to the ground. Once the inductor reaches steady state, both of the nodes where the inductor is located will be grounded and thus have a voltage of 0V as current is no longer changing in the inductor. This will cause the inductor to act as a short circuit and allow a large amount of current to pass through the voltmeter. If the current amount exceeds the safe level allowable through the voltmeter, it will cause potential damage to the voltmeter. There could also be complications or inaccurate readings when taking measurements as the inductor voltage have a tendency to change instantaneously.

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

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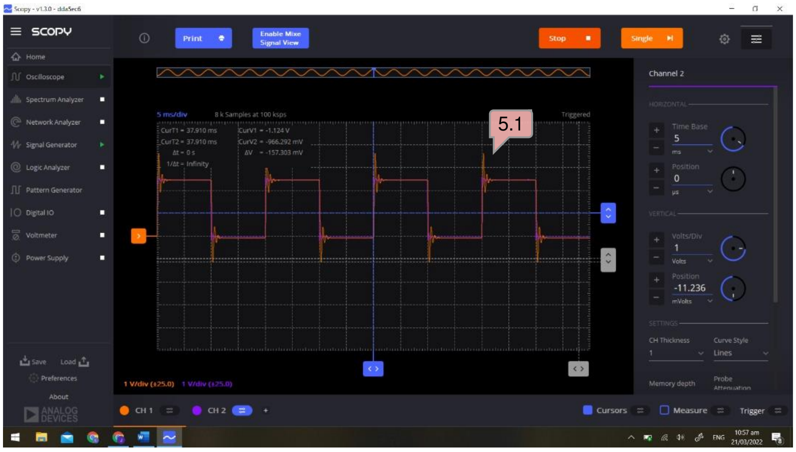
Connect the RLC circuit so that the capacitor voltage can be displayed directly on the DSO (i.e. one of the terminals of the capacitor must be connected to the “common” terminal). Note that ω_0 is the limiting value of ω_d when ζ=0, corresponding to R=0. As the total circuit resistance cannot practically be made equal to zero, one can only get an approximate value for ω_0 by reducing R to a minimum. Describe what factors determine the total resistance of the RLC circuit (the **whole** circuit)?

The total resistance of a RLC circuit is given by the total impedance of every component of the circuit. The impedance is divided into 3 parts, impedance of the resistor, Z_R given by R, impedance of capacitor, Z_C given by $-j\omega C$, and impedance of inductor, Z_L given by $j\omega L$. The arrangement of the components also determines the total impedance (resistance of the circuit). Components arranged in parallel is given by Z_{eq} = Z1||Z2…. ||Z2, giving a lower value. Components in series is given by Z_{eq} = $Z_1 + Z_2 \ldots + Z_n$, which is why if there are more components in series, the impedance and thus the resistance of the circuit will be larger.

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

Set the variable resistance to zero (or short circuit) and display the capacitor voltage on the DSO. Measure the frequency of oscillation f_0 by measuring the time for a suitable number of complete oscillations. If you have trouble, try using a smaller square wave of input.



The period obtained between two peaks is 631.118 μs. Using the equation $f_0 = \frac{1}{t_o}$, we will obtain a frequency of 1584.49 Hz.

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

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Determine the frequency ω_d from your measurement and compare it with the theoretically predicted ω_0 and comment on the discrepancy (remember these are ω, not f). You should measure at the frequency at the zero crossings (or using the frequency measurement function of the DSO)

Measured Value:
Using the formula $\omega_d = 2\pi f$ and the value of f obtained from above, we will get $\omega_d = 2 * \pi * 1584.49$ which equates to 9955.6 radians.

Predicted Value:
Based on the given formula from the lecture notes which is $\omega_0 = \frac{1}{\sqrt{LC}}$ and the given values of inductance and capacitance, we will get ω_0 to be $\frac{1}{\sqrt{100*10^{-3} * 100*10^{-9}}}$ which equates to 10000 radians.

This discrepancy is due to the internal resistance of the wires and the inductor. The predicted value obtained is based on the assumption that there is no external resistance or internal resistance acting on the circuit. The observation that the measured value is lower than the predicted value is expected. When there is resistance in the circuit, this would impede the voltage which would cause the voltage to oscillate at a lower frequency.

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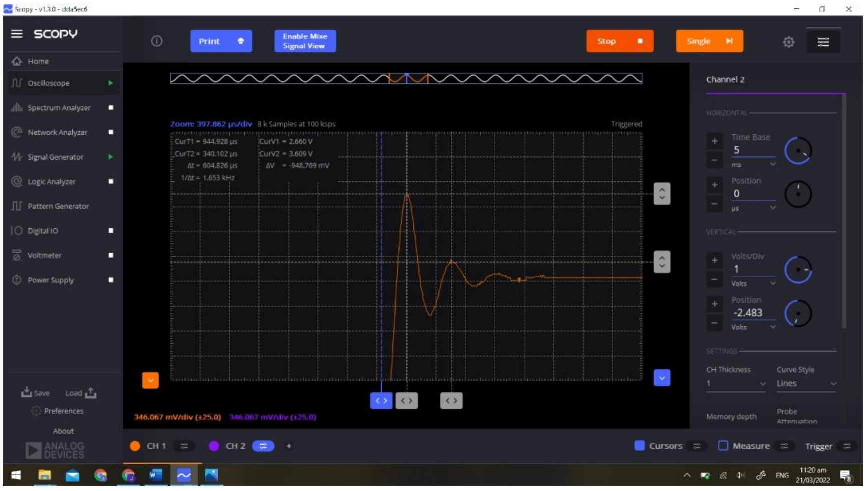
Is the oscillation underdamped? Why do you say this?



Yes, the oscillation is underdamped. Based on the visual observation of the graph above, we can say that the voltage will oscillate at a decreasing amplitude and eventually converges to a point. This means that there is a power loss through the capacitor during the zero-input state.

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

3.3.1.2 A MORE PRECISE DETERMINATION OF THE OSCILLATION FREQUENCY

The envelope of the peaks of the waveform $v_{Cp}(t)$ (the capacitor voltage) decays according to the equation $v_{cp} = v_c(0)e^{-\alpha t}$ as shown in Figure S2.1

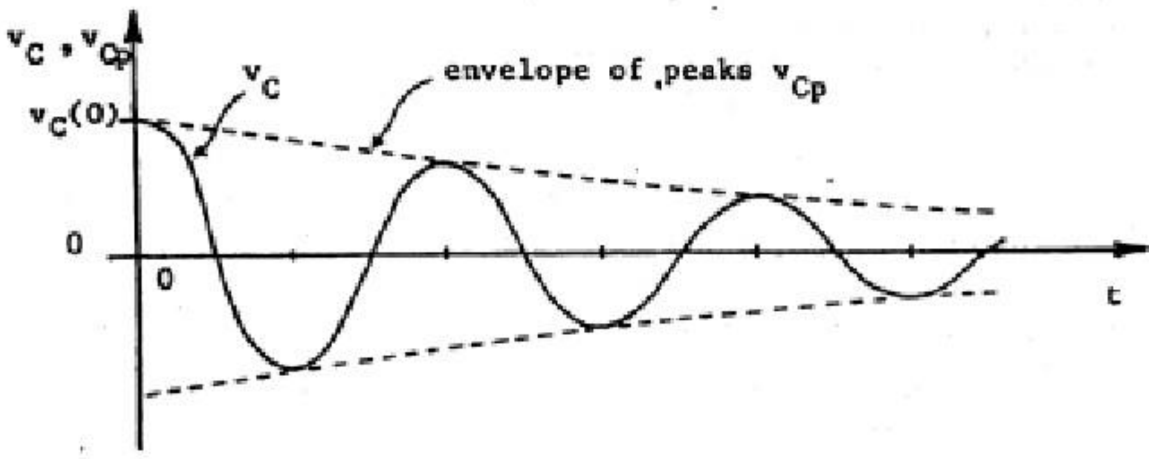
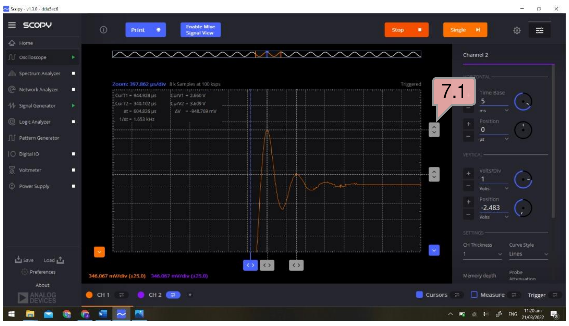


Figure S2.1 Capacitor voltage waveform when ζ << 1.

From this relation, determine α by <u>measuring</u> the peaks of V_{Cp} at two different times separated by a few cycles (don't select subsequent peaks). Then use these measurements and the equation above to find the value of α. Then use this measured value of α and the measured value of ω_d from the previous section to obtain an estimate of the natural frequency, ω_0. Compare the two values of ω_0 from this section and from section 3.3.1.1. What can you observe?



As stated by the question above, the time and voltage value are taken from the two peaks shown in the graph obtained. The time difference between the two peaks is 604.826 µs. The initial voltage obtained would be 3.601 V and the voltage obtained at the other peak is 2.660 V. Using these values, we can calculate the measured value for α using the equation Vcp $=$ Vc(0)$e^{-\alpha t}$. The calculated value for alpha would be 500.78. Using the formula $\omega_d = \sqrt{\omega_0^2 + \alpha^2}$ and the value of wd and alpha, we can rearrange the equation to $\omega_0 = \sqrt{\omega_d^2 + \alpha^2}$. Using the rearranged formula and the measured value, we will obtain 9968.19 radians. We will obtain a more accurate value although it still deviates from the theoretical value by some margin.

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

Make use of the value of α and the nominal L to estimate the 'residual' resistance remaining in the LC circuit. Describe where this resistance comes from?

Using the equation given in the lecture notes

$$\alpha = \frac{R}{2L}$$

We can rewrite the equation to get R

$$R = 2 * L * \alpha$$

where L = 100*10^-3 and α = 500.78

We will get R to be 100.156 Ohms

The 'residual' resistance comes from the internal resistance of the inductor, capacitor and wires. These internal resistances have contributed to the loss of energy and caused the damping of the circuit. This residual resistance may also arise due to the inaccuracy of the measurement made by the device itself or human error made during the visual observation of the graph.

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

3.3.2 VARIATION OF ω_d WITH R

Adjust the resistance R of the series RLC circuit until oscillations in the capacitor voltage just vanish. Measure this value of R_C, which should be close to the critical resistance R_{crit} (see lecture notes). Compare R_C with the theoretically predicted value of R_{crit}. Sketch the graph of the capacitor voltage for a few interesting values of R: (i) R_C (ii) $2R_C$ (iii) $0.5R_C$ (iv) $0.25R_C$. Explain the differences that you observe from the graphs.

Legend: Blue –2Rc , Green - Rc, Pink – 0.5 Rc, Orange – 0.25 Rc

Measured Value can be calculated by putting the potentiometer in a voltage divider circuit with a resistor of a known value and then measuring the voltage drop across the potentiometer.

R_c = 870 Ohms // Critically Damped
2 R_c = 1740 Ohms // Overdamped
0.5 R_c = 435 Ohms // Underdamped
0.25 R_c = 217.5 Ohms // Underdamped

The theoretically predicted value can be calculated using the formula

$$R = 2 * \sqrt{\frac{L}{C}}$$

with L having a value of 100mH and 100nF.

We will get a value of 2000 Ohms.

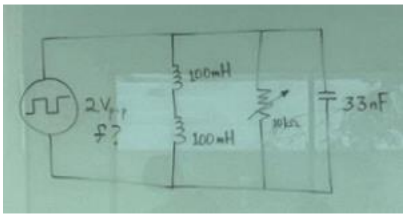
The measured value of the critical resistance will be lower than the calculated theoretical critical resistance. This could be due to the circuit not being ideal and there is residual resistance from the inductor.

When the critical damped stage has been reached, increasing of R would cause overdamping of the circuit in which the voltage takes longer to reach steady state. If we decrease R by half, there would be an underdamping of the circuit and oscillations can be seen before steady state is reached. R value would affect the time taken for capacitor and inductor to reach steady state. If R is low, it will not be enough to limit the current.

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

Lab Assessment

Given Circuit:



The calculated theoretical resistance can be found using the following formula:

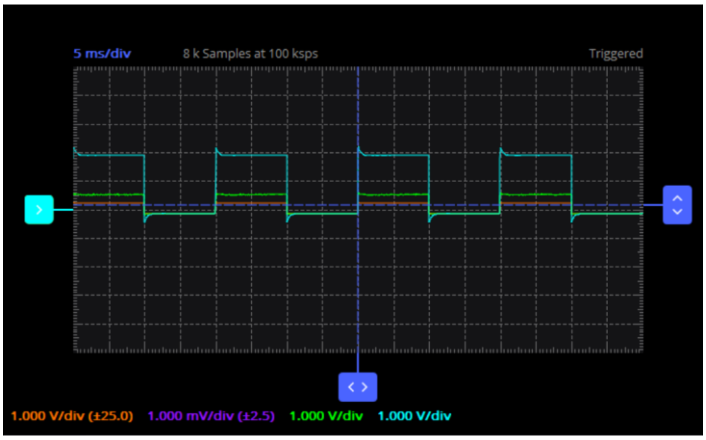
$$R = 0.5 * \sqrt{\frac{L}{C}}$$

Total L will be 100mH + 100mH = 200mH
Capacitance will be 33nF

Based on the formula and the given value, we will get 1230.9 Ohms as our answer.

Based on the multimeter that is used to measure the potentiometer, we got 70.3 Ohms as our critical resistance.

There is a huge discrepancy between the two values. This could be due to the internal resistance of the inductor and the circuit in general. There could also be a misintrepretation of data made by human as there is not a definitive point on where the critical resistance will be based on the visual observation made on the graph.



Legend: Green Line – Rcrit , Blue Line – above Rcrit, Red Line – Below Rcrit

The similarities between the series RLC and the parallel RLC graphs is that the two circuits use the same component as each other. The difference is that for the series RLC circuit, the current will be the same in each of the element while in the parallel RLC circuit, the voltage will be the same for each component. It will be more convenient to use impedance for calculations in the series RLC circuit and it would be more convenient to use admittance for calculations in the parallel RLC circuit. At resonance, when $X_L = X_C$, the circuit will have minimum impedance while when $X_L = X_C$ in a parallel circuit, the circuit will have maximum impedance.

For both the series and parallel RLC Circuit, when there is an input of a square wave voltage, we can observe a transient response between the potentiometer. There will be a sudden peak or trough in the transient response if it is underdamped and there would be a gradual increase in the peak or trough if overdamped. However, a constant voltage will eventually be obtained.

We can also observe the differences between the series and the parallel RLC Circuit. When the resistance of the potentiometer is increased, decreased in damping can be observed. However, in the series RLC Circuit, there would be an increase in the damping. We can also observe that the voltage between the potentiometer will stagnate in height when there is a change in resistance. This is the opposite for the parallel RLC Circuit in which the magnitude of the constant voltage when steady state is achieved will be reduced as the resistance decreases. This could be due to the fact that the potentiometer will be closer to a short circuit when there is a reduction in resistance.

We can also observe that no oscillations can be seen in the parallel RLC graph but there are oscillations in the transient response of the series RLC Circuit. This could be due to the fact that both the capacitor and the inductor will generate current in the same direction when both of the components are connected in parallel.

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: 19/03/ 2022

TOTAL: ________(/7)

ASSESSOR: ________

Index of comments

5.1 make the graph clearly

7.1 make graph clearly