Faculty of Engineering and Technology

Electrical and Computer Engineering Department

CIRCUITS AND ELECTRONICS LABORATORY– ENEE2103

Experiment No. 3 Report

First and Second Order Circuit

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Abstract

The purpose of this experiment is to analyze and test the timing response of first order circuits such as in RC and RL circuits and in second order circuits such as RLC circuits using oscilloscope measurements and circuit analysis techniques, we are required to measure the time constants, steady-state values, and response type for RLC circuit, and understanding how any change on the parameters can show a change on circuit behavior.

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Theory

1. RC Circuit:

An RC circuit is a circuit built with a resistor (R) and a capacitor (C). The capacitor has the ability to store energy and the resistor placed in series with it will control the rate when it charges and discharge. This process produces an exponential time characteristic and a crucial parameter called time constant τ, where $\tau = R \times C$.

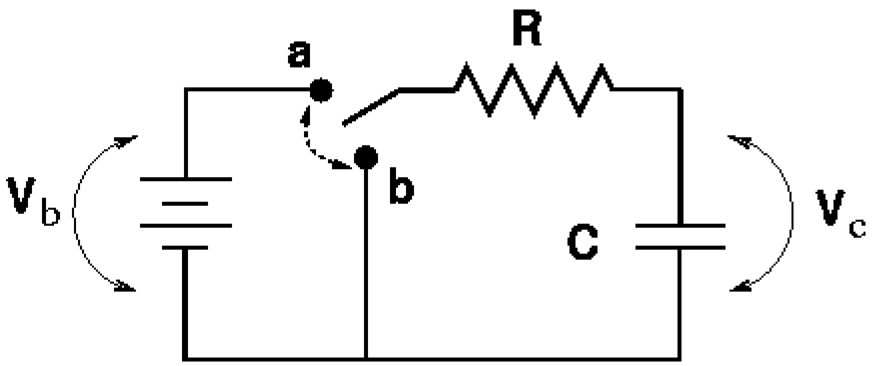


Figure 1 RC circuit

Closing circuit to a, will cause the capacitor to charge at t =0 when the capacitor has no charge, and when closing the circuit to b, it will cause it to discharge at t=0, when the capacitor has a charge. [1]

The capacitor (C), charges up at a rate shown by the graph. As the capacitor charges up, the potential difference across its plates begins to increase with the actual time taken for the charge on the capacitor to reach 63% of its maximum possible fully charged voltage, in our curve 0.63Vs, being known as one full Time Constant (τ).

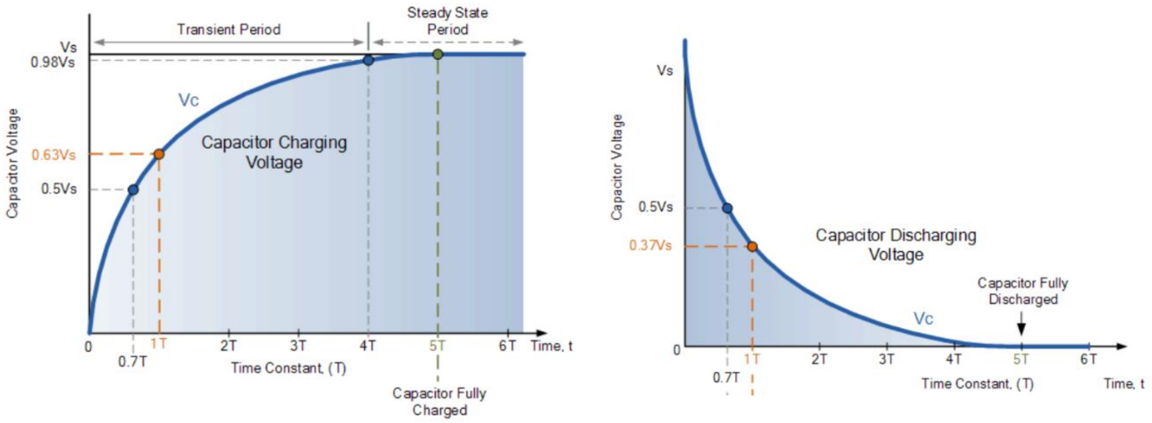


Figure 2 Capacitor charge and discharge

The capacitor continues charging up and the voltage difference between Vs and Vc reduces

Then at its final condition greater than five-time constants (5T) when the capacitor is said to be fully charged, $t = \infty$, $i = 0$, $q = Q = CV$. At infinity the charging current finally reduced to zero and the capacitor acts like an open circuit with the supply voltage value entirely across the capacitor as $V_c = V_s$.[2]

2. RL Circuit:

RL Circuits (resistor – inductor circuit) or RL filter, is a type of circuit that have a combination of inductors and resistors and is usually driven by some power source which is voltage in our circuit.

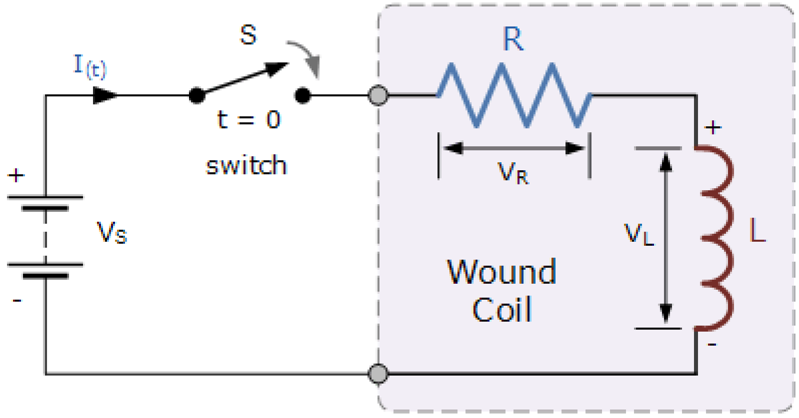


Figure 3 RL circuit

The Time Constant, (τ) of the LR series circuit is given as L/R and in which V/R represents the final steady state current value after five-time constant values. Once the current reaches this maximum steady state value at 5τ, the inductance of the coil has reduced to zero acting more like a short circuit and effectively removing it from the circuit.[3]

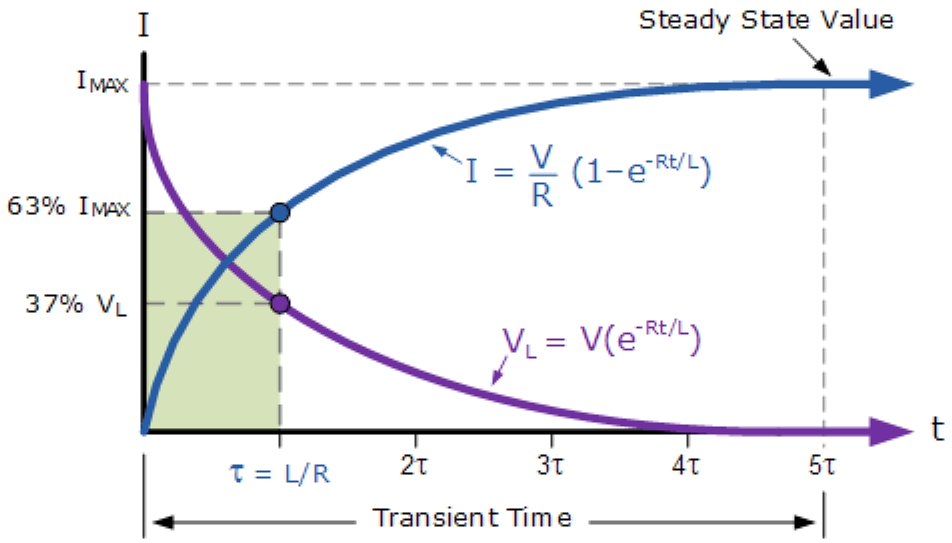


Figure 4 Transient Characteristics Curves

the current in the circuit initially increases slowly due to the inductor's opposition to changes in current so we will find changes in charge and discharge of the inductor.

In the first time constant τ after closing the switch, the current rises from zero to $0.632I_0$, and 0.632 of the remainder in every subsequent time interval τ. $I=I_0(1-e^{-1}) = I_0(1-0.368) \Rightarrow 0.632I_0$ which we usually present it as 63%I approximating.

In the first period of time $\tau = L/R$ after opening the switch, the current falls to 0.368 of its initial value, since $I=I_0e^{-1}=0.368I_0$. which we usually present it as 37%I approximating.

3. RLC Circuit:

RLC Circuits (resistor – inductor - capacitor circuit), is a type of circuit that have a combination of inductors and resistors and capacitors and is usually driven by some power source which is voltage in our circuit, and they are connected in series.

RLC circuits are classed as second-order circuits because they contain two energy storage elements, an inductance L and a capacitance C.

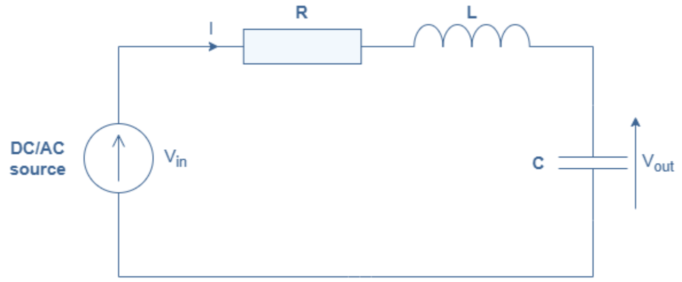


Figure 5 RLC Circuit

In the RLC circuits the inductors usually presented as a component that opposes the variation of currents because the current in the circuit initially increases slowly as the inductor resist the change in current, the current dynamically changes back and forth between the capacitor and inductor as the energy stored in each component is exchanged.

(the capacitor store energy and inductor as well resist the energy).

In theory, there are three cases for the way a series RLC circuit will respond when the switch is closed at time t=0, which are underdamping, overdamping and critical damping, all can be determined theoretically and with observation of the results.

aperiodic as overdamped, pseudo-periodic as underdamped, and critical regime as critical damped response. [4]

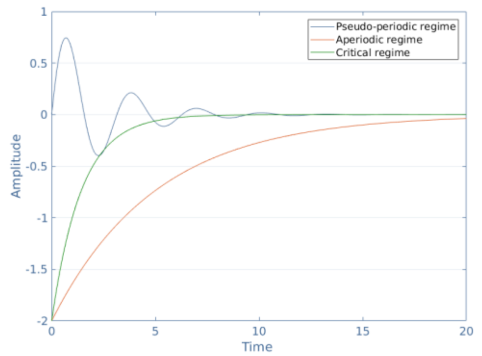


Figure 6 RLC responses

4. Oscilloscope:

Oscilloscope is the device we will use to measure time response in the circuits, it will display the output of the circuit as a graph of either voltage or current depending on the input we will connect to its channel.[5]

Figure 7 Oscilloscope

Procedure and Data analysis

1. RC Circuit:

First, we started with setting the resistance Decade Box to the value of R3= 22kΩ, then measured the value of C1 using the RLC meter, which will give us C=100nF.
We connected the circuit of Fig 8 by Setting the signal generator to square wave 5Vp-p and 50Hz with dc offset=2.5V.
Lastly, we connected the Oscilloscope to the Capacitance terminals, and answered the manual questions.

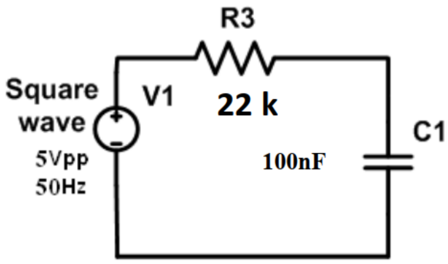


Figure 8 RC circuit, procedure.

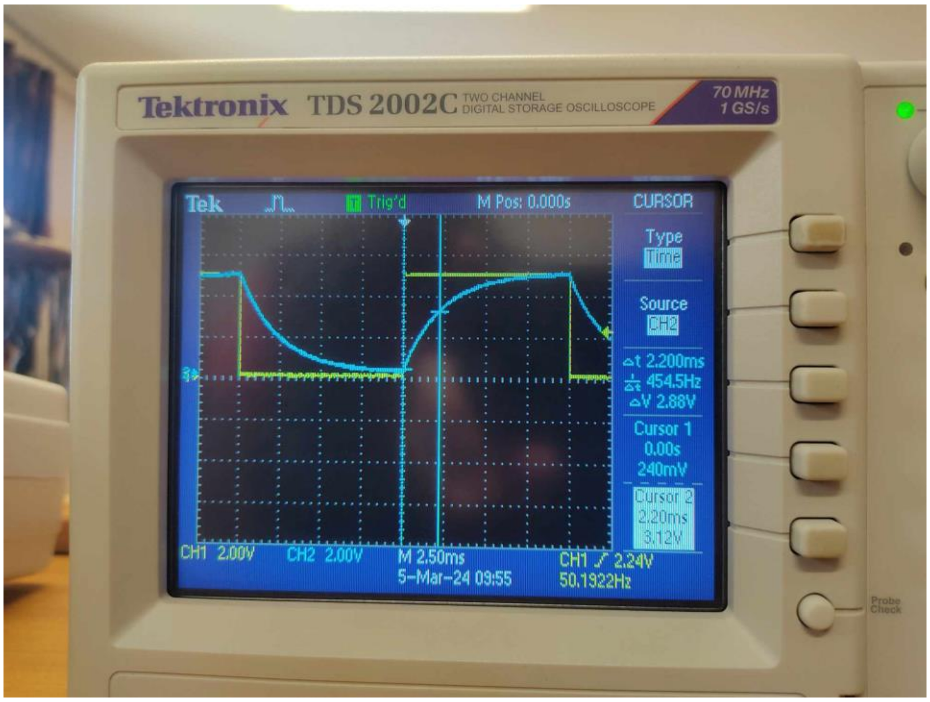


Figure 9 Time constant of RC

After we had determined the voltage at 4.19 Volt for steady state, we need to calculate the value of (τ) which is 63%Vs as its equal to 3.12 Volt.

From analyzing the picture of the oscilloscope: τ is equal to 2.2ms.
Theoretically τ = R x C = 22k x 100n = 2.2ms.

Both values were identical in practical and theoretical for τ.

From τ = 2.2ms, the capacitance is 100nF practically.

2. RL Circuit:

First, we Connected the circuit of Fig 10.
then we sat up the signal generator to generate a periodic square waveform with 10Vp-p and frequency=500Hz with a dc offset=5V.
We Connected the oscilloscope to display the voltage response of the inductor.

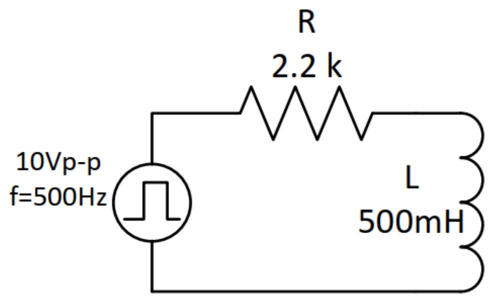


Figure 10 RL circuit, procedure.

Section A: normal state:

Oscilloscope output showed that the max input voltage on the inductor was 9.8 Voltage at t=0, and slowly declined until it reached Zero at steady state of the inductor.

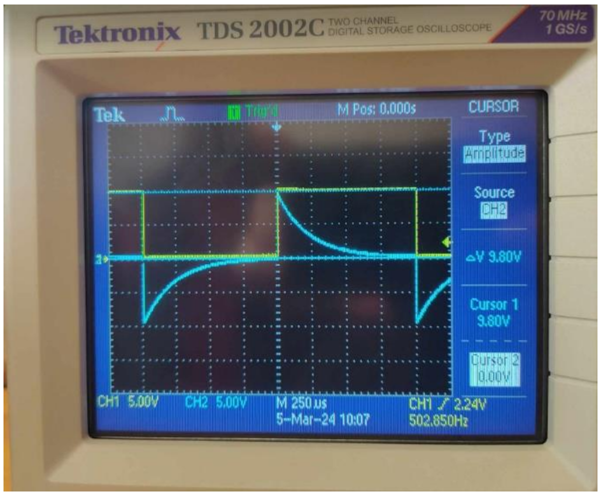


Figure 11 RL circuit, Voltage output

To find the steady state of the current practically by dividing Voltage over resistor as 9.8/2.2k = 4.45mA, meanwhile theoretically 10/2.2k = 4.54mA

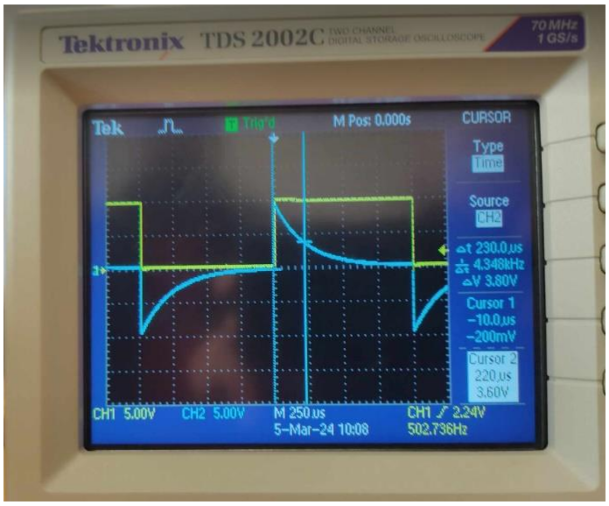


Figure 12 RL circuit, Time constant

Theoretically to find (τ): L/R which here is 500m / 2.2 k = 0.227ms
Although practically its equal to 0.37Volt = 3.626V, (τ) its equal to around 0.230ms as shown in the oscilloscope.
Both values were close to the theoretical part although there was a small error.

Section B: Changing the period:

After we changed the period to (2τ) the frequency is 2.2633kHz, which lead to change of voltage and also current visually as in the below figures:

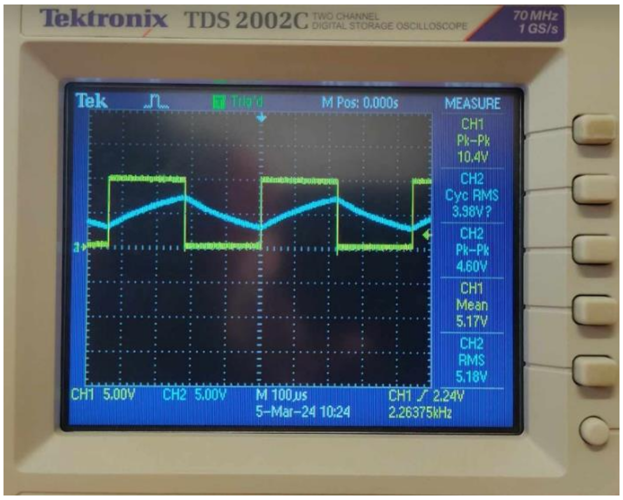


Figure 13 RL Circuit, Current change with f

To find the current we had connected the oscilloscope to the resistor as it will show the figure above.

We noticed how the current didn't reach the steady state to be fully charged instead it increase and decrease with each period without reaching it.

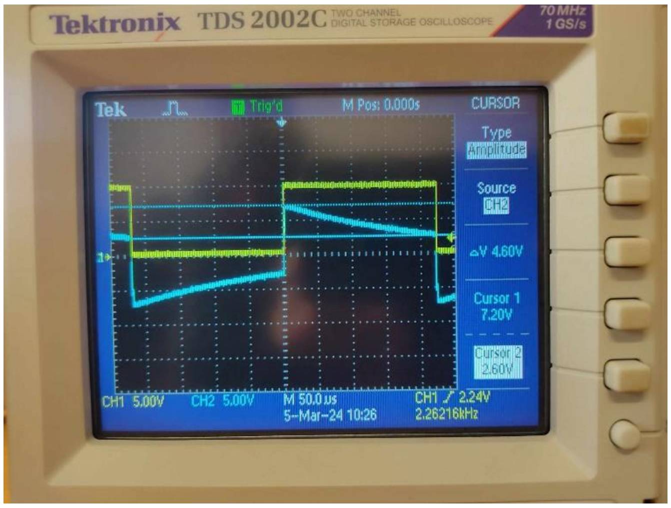


Figure 14 RL Circuit, Voltage change with f

noted how the inductor didn't have enough time to reach it steady state as well in voltage, the voltage didn't reach Zero in charge as shown above.

This goes right with our theory that to reach steady state we need at least 5τ, but here since the period is shorter it didn't have enough time to reach steady state.

3. RLC Circuit:

Section A: Response type:

We connected the ciruit in figure 15 , then we sat the signal generator to generate a periodic square waveform with ± 2.5 volts and 30Hz, dc offset=2.5V, we observed the oscilloscope for the type of damping then changed the resistor according to the critical resistor value, and watched the type of damping.

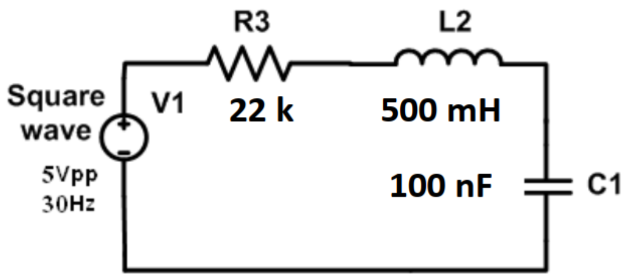


Figure 15 RLC Circuit

Overdamping:

After we observed the first resistor at 22k, we noticed that the shape matches being overdamped, as the capacitor charges slowly, hence it takes more time to charge.

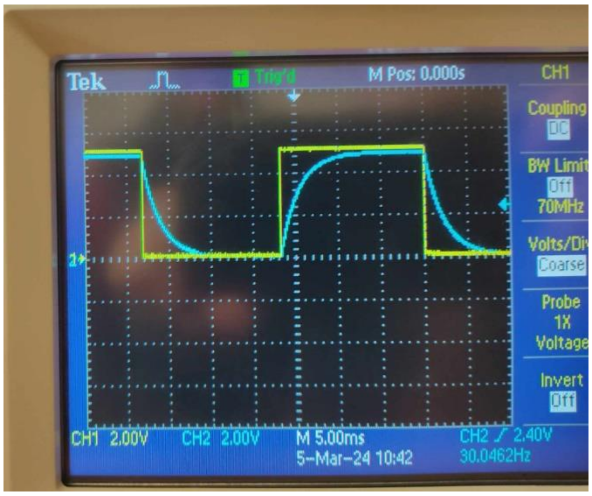


Figure 16 RLC circuit overdamping

Critical damping:

To find critical damping resistor = 1/ √LC => 1/ √500m ∗ 100n = 4.472kΩ.

After we sat the new resistor of resistor decade box and analyzed the oscilloscope, we noticed that the shape shows a critical damping.

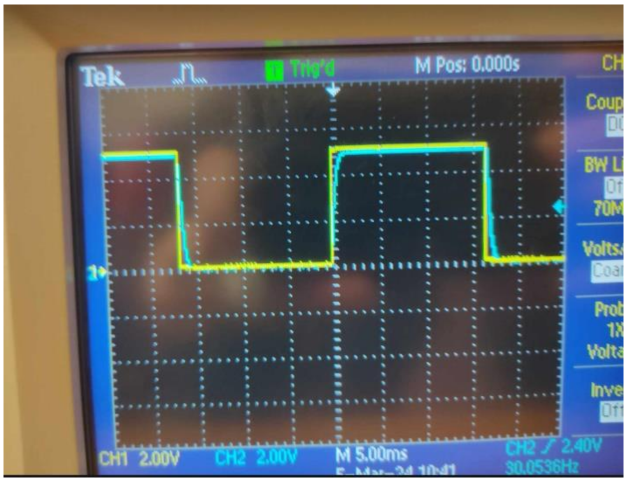


Figure 17 RLC Circuit Critical damping

We noticed how in critical damping the capacitor charges and discharges reach steady state faster than overdamping.

Under damping:

To show underdamping results we had sat the resistor into a value less than critical value of the resistor, in our case we used 500Ω.

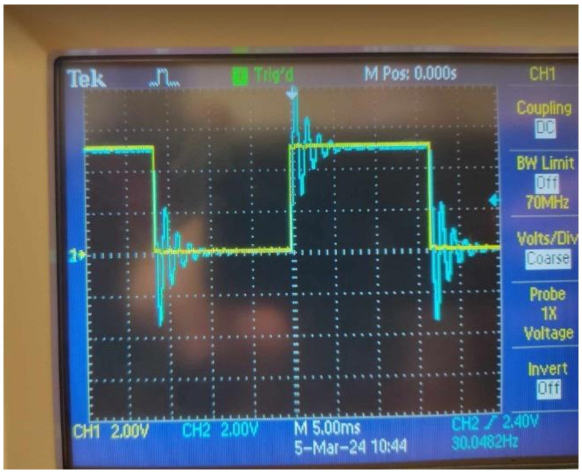


Figure 18 RLC Circuit Underdamping

We noticed how in underdamping the capacitor behaved differently since it reached the maximum value faster, leading the oscillator to return to steady state with the amplitude gradually decreasing to zero.

Section B: Response parameters:

First case:

After we had sat the value of R3 into 750Ω, to show underdamping, to decay time constant we used the following formula:

$$\tau = \frac{tb - ta}{ln\left(\frac{Va - Vin}{Vb - Vin}\right)}$$

Damping Coefficient $\alpha = 1/\tau$.

Damping radian frequency ω_d (theoretically) = $1/\sqrt{LC}$

And by figure, $\omega_d = 2\pi/(tb - ta)$.

From the following shape of the oscilloscope, we measured the first value of voltage at ta which is equal to 7.84V.

And the following method to also measure the second voltage value which is equal to 5.92Volt.

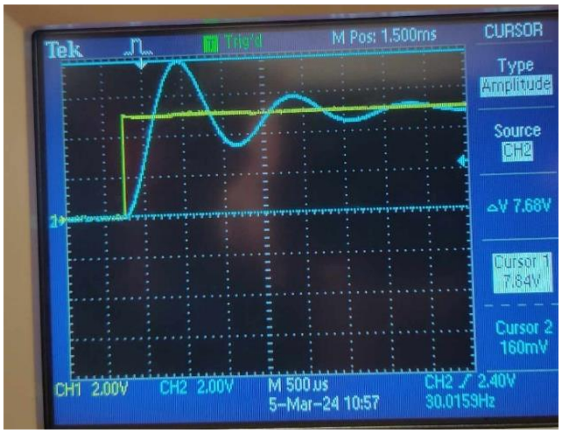


Figure 19 RLC Circuit, response parameter V1

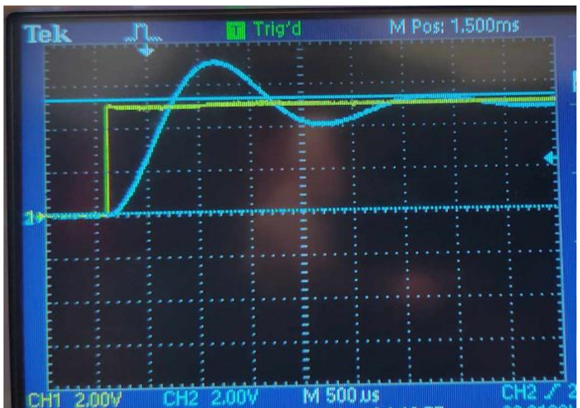


Figure 20 RLC Circuit, response parameter V2

Lastly to measure ta and tb we sat the cursers of the oscilloscope to the middle of the highest first value to get ta, and to the highest second value to get tb, and the oscilloscope measured the difference between the two values like in the picture:

Figure 21 RLC Circuit, response parameter ta,tb

Which showed ta = 460µs

And tb = 1.86ms.

$$\tau = \frac{1.86-0.46}{ln\left(\frac{7.84-5}{5.92-5}\right)} = 1.242\text{ms}$$

α = 1/ τ = 0.805. krad/sec

ω_d = 2π/ (1.86-0.46) = 4.4879. krad/sec

Theoretically:
τ = 2L/R => 1.333ms

α = 0.750 krad/sec

ω_d = 4.4721 krad/sec

We noticed there's a difference in values of τ and other parameters that's due the error of voltage amount since we usually use approximated values around 5V as well as the frequency which wasn't 30Hz exactly.

second case:

we had to set the capacitors on parallel to double amount C to get 200nF instead of 100nF, which gave us the values of Va = 7.04Volt (from data), Vb = 5.28V, ta = 640µs, tb = 2.74ms.

$$\tau = \frac{2.74-0.64}{ln\left(\frac{7.04-5}{5.28-5}\right)} = 1.057\text{ms}$$

α = 0.945 krad/sec

ω_d = 2.991 krad/sec.

Theoretically:
τ = 2L/R => 1.333ms (doesn't change)
α = 0.750 krad/sec
ω_d = 3.1622 krad/sec.

we noticed that the values of τ and a have more different values, but the damping radian frequency, changed more than the previous case.

Third case:

After second case, after the capacitor returned to its original values 100nF, then setting the inductor to 250mH, we analyzed the value on the oscilloscope we had Va = 7.26V, Vb = 5.52V, ta = 320μs, tb = 1.32ms.

$\tau = \frac{1.32 - 0.32}{ln\left(\frac{7.26 - 5}{5.52 - 5}\right)}$ = 0.680ms

α = 1.4692 krad/sec

ω_d = 6.283 krad/sec

theoretically:

$\tau =$ 0.666ms

α = 1.5 krad/sec

ω_d = 6.3245 krad/sec

we noticed how the values between theoretical and practical values are similar with small difference between them, we noticed as well how the change of the inductor changed the time constant and damping Coefficient more than the capacitor, on the other hand both the capacitor and inductor affected the Damping radian frequency.

Conclusion

In conclusion we learnt how to implement first order circuits such as (RC resistor-capacitor circuit and RL resistor-inductor circuit) and second order circuits using resistor, and a capacitor and inductor (RLC), and determining time constant as well as Voltage and current and the dramatic changes that happen to the circuit when changing one of its component values all observed using the oscilloscope, and how can this help us in building filtering circuits further on.

References

[1] https://web.pa.msu.edu/courses/2000fall/phy232/lectures/rccircuits/rc.html (15:52 Friday, March 8, 2024)

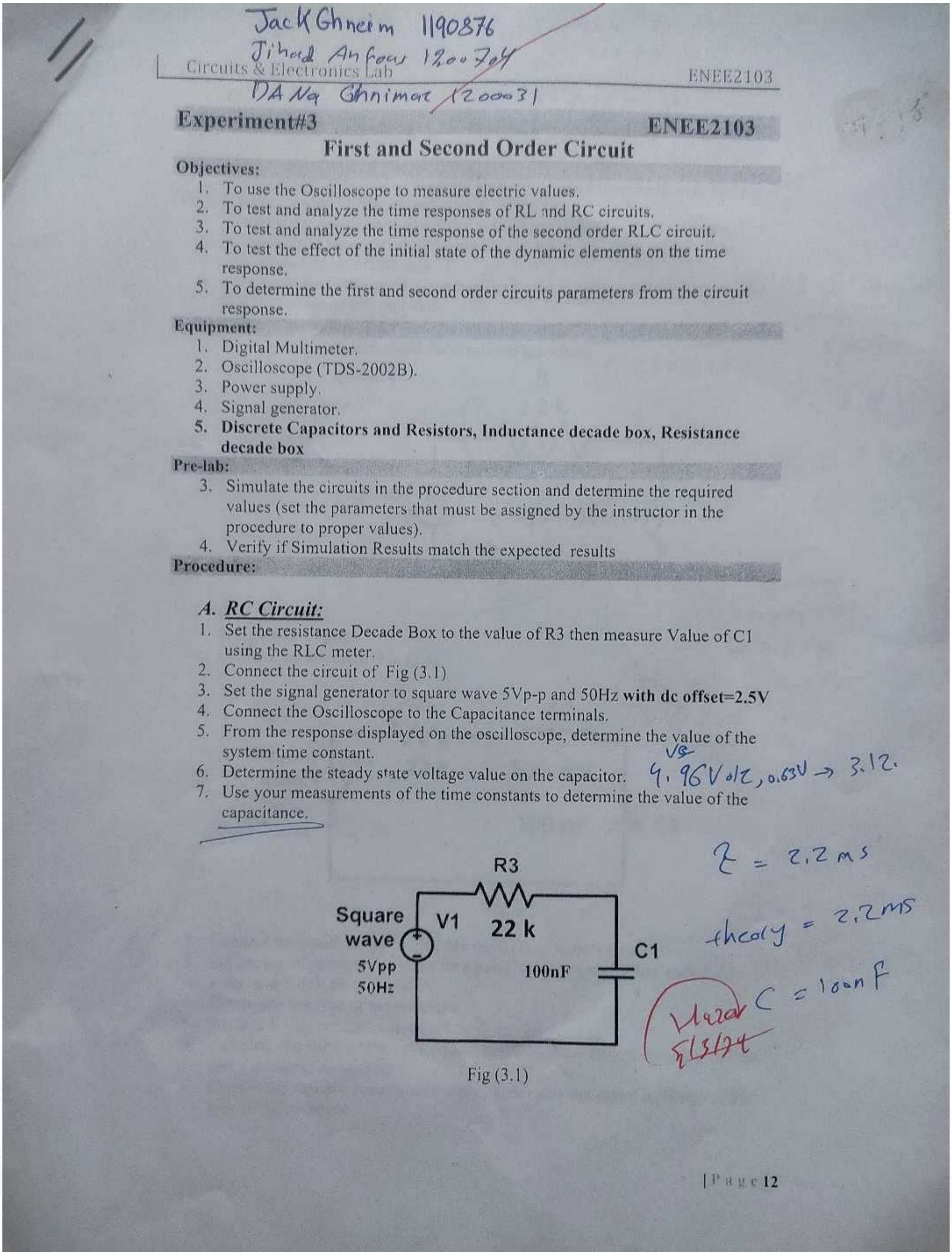
[2] https://www.electronics-tutorials.ws/rc/rc_1.html (16:20 Friday, March 8, 2024)

[3] https://www.electronics-tutorials.ws/inductor/lr-circuits.html (19:17 Saturday, March 9, 2024)

[4] https://www.electronics-lab.com/article/series-rlc-circuit-analysis/ (22:16 Saturday, March 9, 2024)

[5] https://www.tek.com/en/blog/what-is-an-oscilloscope (23:53 Saturday, March 9, 2024)

Appendix



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Circuits & Electronics Lab ENEE2103

Experiment#3 **ENEE2103**

First and Second Order Circuit

Objectives:

1. To use the Oscilloscope to measure electric values.
2. To test and analyze the time responses of RL and RC circuits.
3. To test and analyze the time response of the second order RLC circuit.
4. To test the effect of the initial state of the dynamic elements on the time response.
5. To determine the first and second order circuits parameters from the circuit response.

Equipment:

1. Digital Multimeter.
2. Oscilloscope (TDS-2002B).
3. Power supply.
4. Signal generator.
5. **Discrete Capacitors and Resistors, Inductance decade box, Resistance decade box**

Pre-lab:

3. Simulate the circuits in the procedure section and determine the required values (set the parameters that must be assigned by the instructor in the procedure to proper values).
4. Verify if Simulation Results match the expected results

Procedure:

A. RC Circuit:

1. Set the resistance Decade Box to the value of R3 then measure Value of C1 using the RLC meter.
2. Connect the circuit of Fig (3.1)
3. Set the signal generator to square wave 5Vp-p and 50Hz **with dc offset=2.5V**
4. Connect the Oscilloscope to the Capacitance terminals.
5. From the response displayed on the oscilloscope, determine the value of the system time constant.
6. Determine the steady state voltage value on the capacitor. Vs 4.96 Volt, 0.63V → 3.12.
7. Use your measurements of the time constants to determine the value of the capacitance.

τ = 2.2 ms

theory = 2.2ms

C = 100nF

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Fig (3.1)

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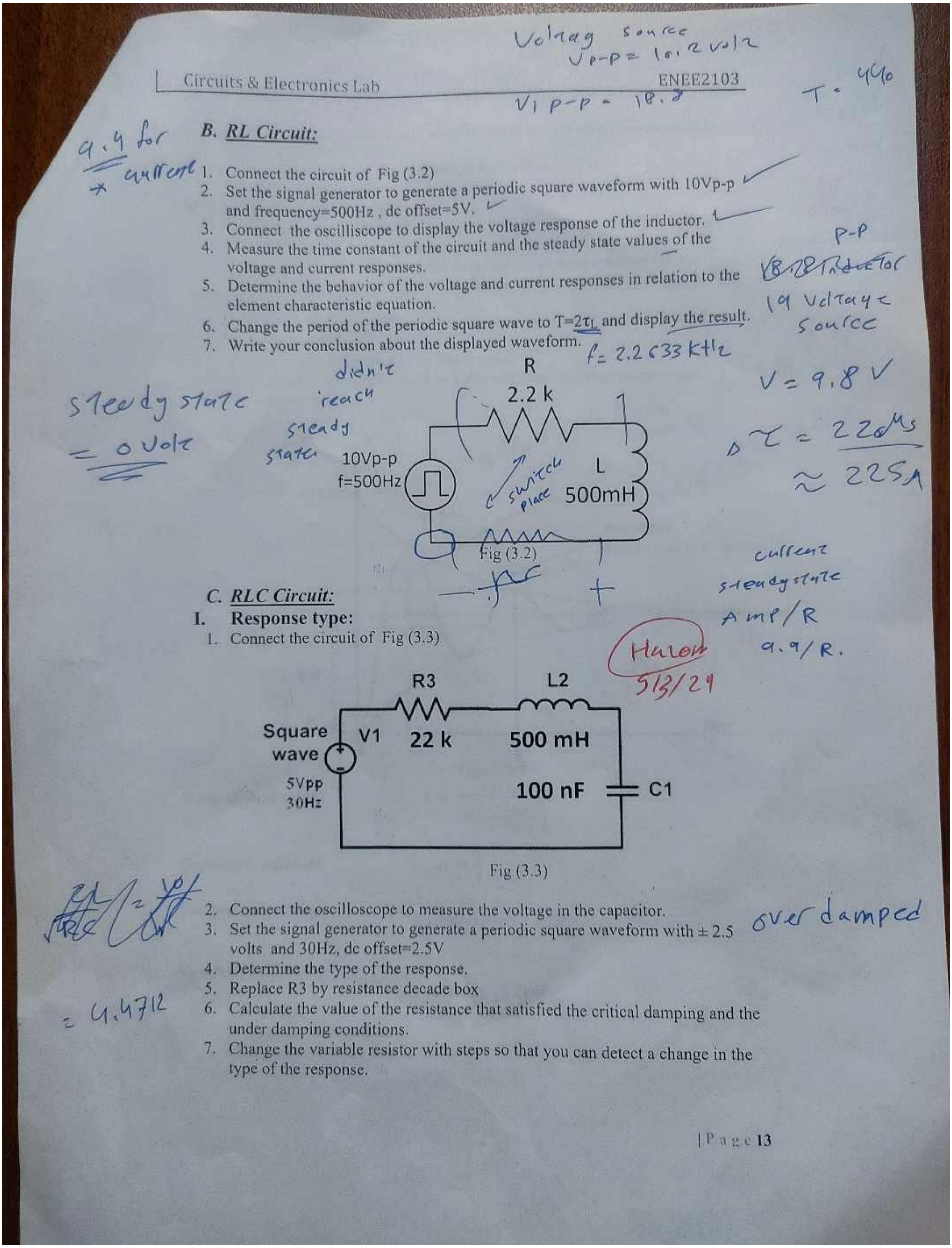
Figure 22 lab signed paper1



Voltag source
Vp-p = 10.2 volt
V1 p-p = 18.8
T = 440

B. RL Circuit:

9.4 for current

1. Connect the circuit of Fig (3.2)
2. Set the signal generator to generate a periodic square waveform with 10Vp-p and frequency=500Hz , dc offset=5V.
3. Connect the oscilliscope to display the voltage response of the inductor.
4. Measure the time constant of the circuit and the steady state values of the voltage and current responses.
5. Determine the behavior of the voltage and current responses in relation to the element characteristic equation.
6. Change the period of the periodic square wave to $T=2\tau_L$ and display the result.
7. Write your conclusion about the displayed waveform.

P-P
18.28 Inductor
19 Voltage source
f= 2.2633 kHz
V = 9.8 V
$\Delta\tau$ = 220 μs
≈ 225 μ

steady state = 0 Volt
didn't reach steady state

Fig (3.2)

current steady state
Amp/R
9.9/R.

C. RLC Circuit:

I. Response type:

1. Connect the circuit of Fig (3.3)

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5/3/24

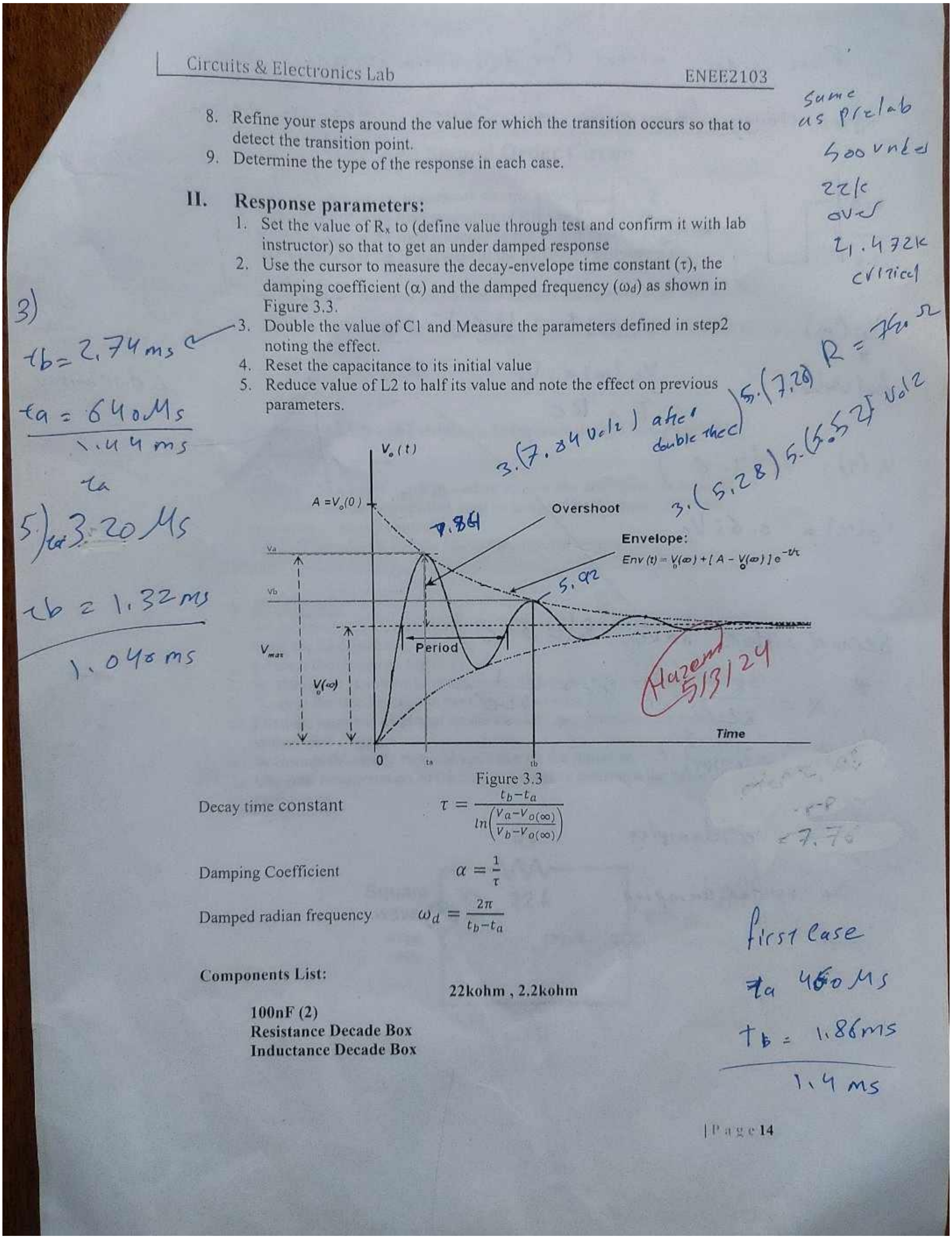
Fig (3.3)

2. Connect the oscilloscope to measure the voltage in the capacitor.
3. Set the signal generator to generate a periodic square waveform with ± 2.5 volts and 30Hz, dc offset=2.5V
4. Determine the type of the response.
5. Replace R3 by resistance decade box
6. Calculate the value of the resistance that satisfied the critical damping and the under damping conditions.
7. Change the variable resistor with steps so that you can detect a change in the type of the response.

over damped

= 4.4712

Figure 23 lab signed paper2



8. Refine your steps around the value for which the transition occurs so that to detect the transition point.
9. Determine the type of the response in each case.

same as prelab
500 under
22k over
2,472k critical

II. Response parameters:

1. Set the value of R_x to (define value through test and confirm it with lab instructor) so that to get an under damped response
2. Use the cursor to measure the decay-envelope time constant (τ), the damping coefficient (α) and the damped frequency (ω_d) as shown in Figure 3.3.
3. Double the value of C1 and Measure the parameters defined in step2 noting the effect.
4. Reset the capacitance to its initial value
5. Reduce value of L2 to half its value and note the effect on previous parameters.

3)
tb = 2.74 ms
ta = 640 μs
1.44 ms
ta

5) ta 3.20 μs
tb = 1.32 ms
1.048 ms

R = 76 Ω
5.(7.20)
3.(7.84 volt) after double the C)
3.(5.28) 5.(6.52) volt

Figure 3.3

Decay time constant $\tau = \dfrac{t_b - t_a}{ln\left(\dfrac{V_a - V_{o(\infty)}}{V_b - V_{o(\infty)}}\right)}$

Damping Coefficient $\alpha = \dfrac{1}{\tau}$

Damped radian frequency $\omega_d = \dfrac{2\pi}{t_b - t_a}$

Components List:

22kohm , 2.2kohm

100nF (2)
Resistance Decade Box
Inductance Decade Box

first case
ta 460 μs
tb = 1.86 ms
1.4 ms

Figure 24 lab signed paper3