# Experiment 8
# First Order Circuits

Ahmet Akman 2442366

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# Contents

# 1 Introduction

In this experiment, as students, we are expected to experiment with first-order circuits by completing the steps described in the eight experiment laboratory manual. The simple RC and RL circuit structures are expected to be learned throughout the first step. The output versus input characteristics and $\tau$ value are obtained by connecting the signal generator to the oscilloscope and the circuit. Then, characteristics of variable $\tau$ value are expected to be expressed and experimented with. The results of the steps are recorded and plotted for further comments.

# 2 Experimental Results

In this section, the results of Experiment 8 are discussed.

## 2.1 Step 1

In this step, circuit shown in the Figure 1 is constructed.

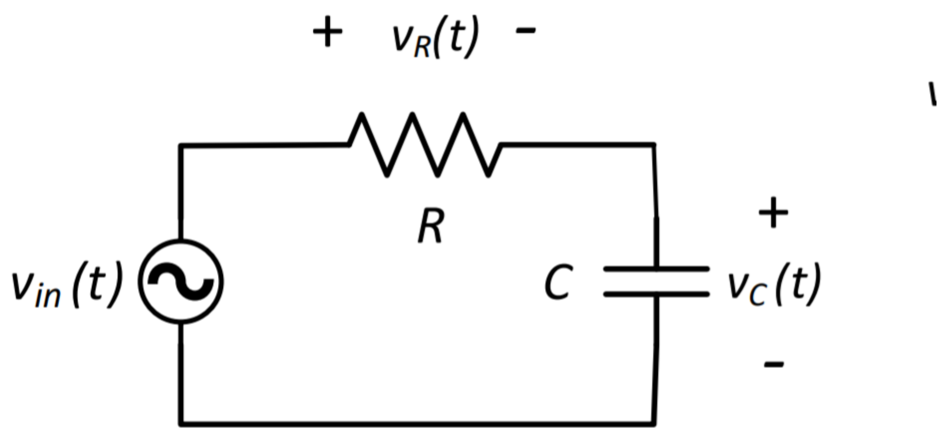


Figure 1: Circuit schematic for the step 1

The square waveform generator is adjusted as given in Figure 2.

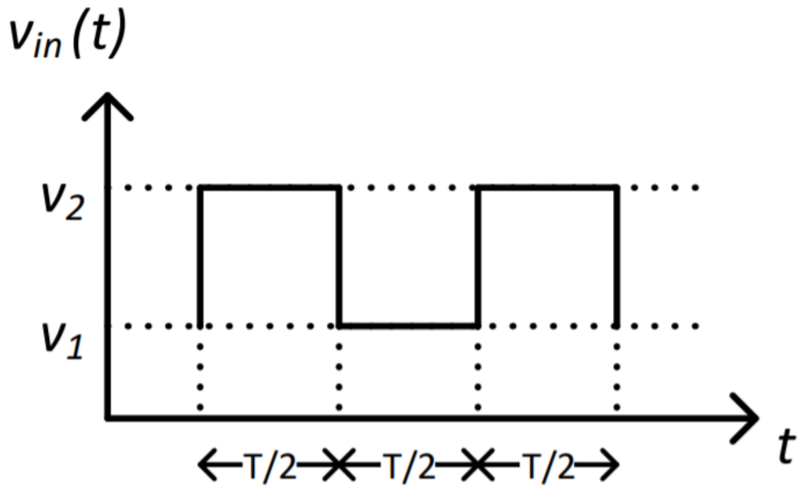


Figure 2: Waveform for the step 1

#### 2.1.1 a)

The set of data given in Table 1 is used for the measurements.

Table 1: RC circuit parameters

| $f$ (kHz) | R (kΩ) | C (nF) | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|---|---|
| 2 | 3.3 | 4.7 | 15.51 |
| 2 | 3.3 | 10 | 33 |
| 2 | 68 | 10 | 680 |

The theoretical calculation of $\tau$ is obtained from the general time constant equation of RC circuits;

$$\tau = R \times C$$

The result of the circuit with parameters of first row is given in Figure 3.

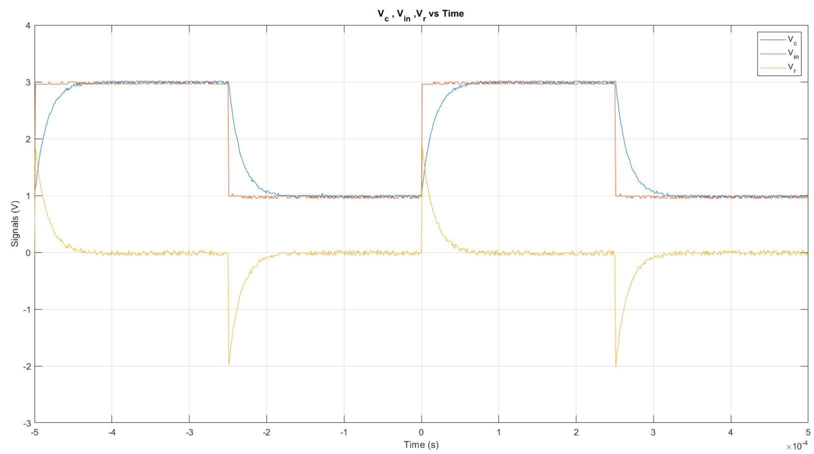


Figure 3: Waveform for the step 1

To measure time constant experimentally following data is obtained from the plot.

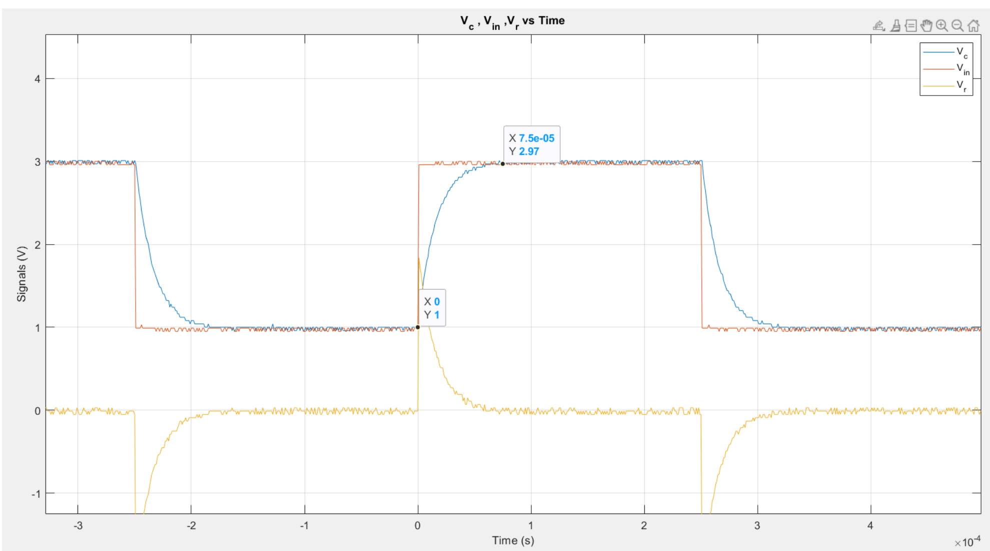


Figure 4: Data from plot

The result is obtained using 5 $\tau$ method. Timepoint, where the capacitor is charged, is marked. Then it is divided into 5. The calculation result of $\tau$ is given in Table 2.

Table 2: RC circuit parameters

| Experimental Calculation $\tau$ ($\mu$ sec | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|
| 15 | 15.51 |

It can be stated that 5 $\tau$ method is consistent with the theoretical calculations.

The result of the circuit with parameters of second row is given in Figure 5.

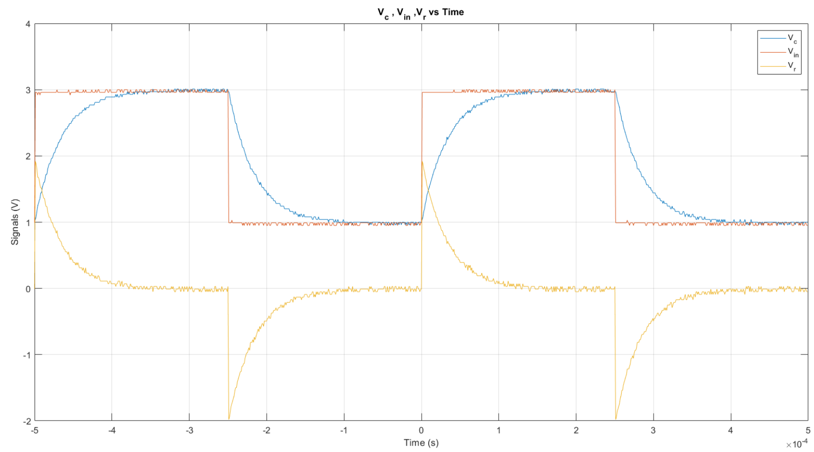


Figure 5: Waveform for the step 1

To measure time constant experimentally following data is obtained from the plot.

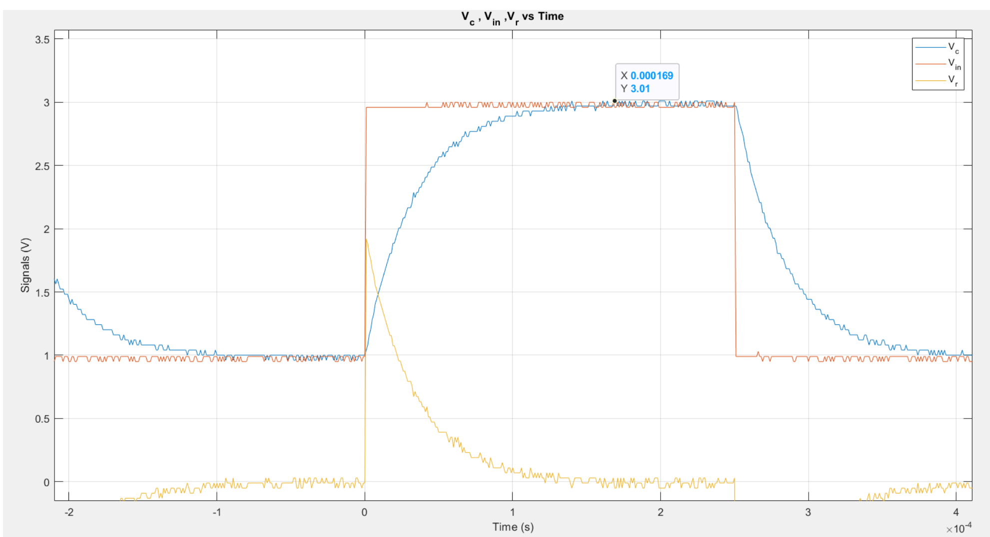


Figure 6: Data from plot

The result is obtained using 5 $\tau$ method. Timepoint, where the capacitor is charged, is marked. Then it is divided into 5. The calculation result of $\tau$ is given in Table 3.

Table 3: RC circuit parameters

| Experimental Calculation $\tau$ ($\mu$ sec | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|
| 33.8 | 33 |

It can be stated that 5 $Tau$ method is consistent with the theoretical calculations.

The result of the circuit with parameters of third row is given in Figure 7.

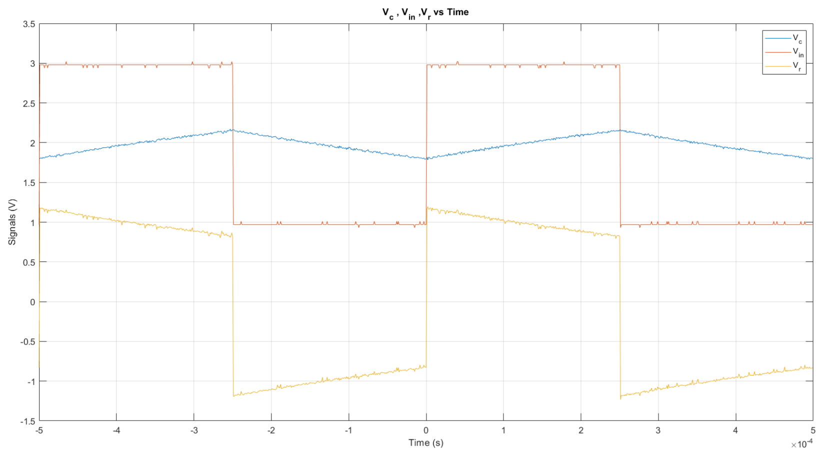


Figure 7: Third waveform for the step 1

To measure time constant experimentally following data is obtained from the plot.

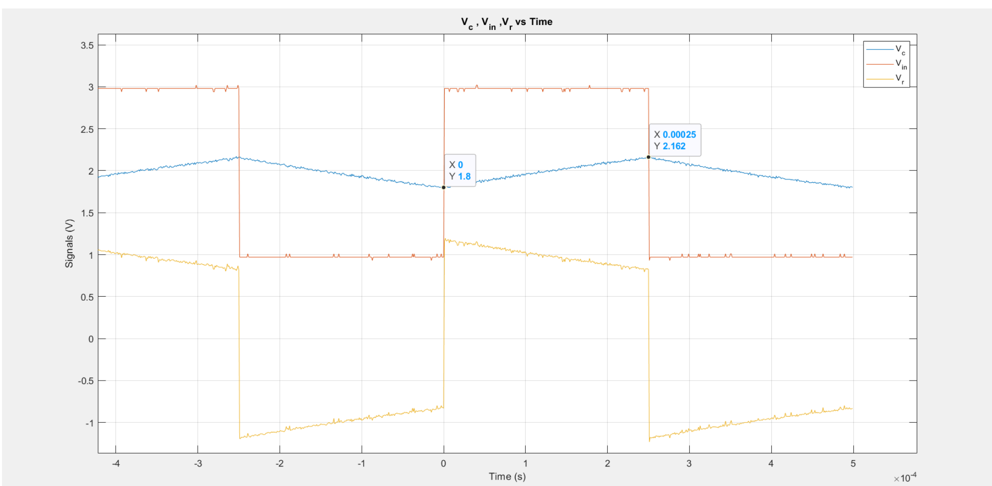


Figure 8: Data from plot

The calculation result of $\tau$ is given in Table 4. The $\tau$ can not be obtained using 5 $\tau$ method because of the fact that charging and discharging processes are not completed in a cycle. To obtain the $\tau$ value both graph data and the equation $V_c(t) = 3 - 1.2e^{-\frac{t}{\tau}}$ are used. The time points where the charging and the discharging of the capacitor are marked. When a half cycle is completed, 0.25 millisecond passes, so when we set t to 0.25 millisecond, we should get the $V_c = 2.162$ Volts. The calculation result of $\tau$ is given in Table 3.

Table 4: RC circuit parameters

| Experimental Calculation $\tau$ ($\mu$ sec | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|
| 696 | 680 |

It can be concluded that our theoretical calculations are quite consistent with the experimental results.

#### 2.1.2 b)

For this part, the capacitor element in the previous part is replaced with an inductor. Apart from capacitor-inductor swap general outline of the setup is conserved. The set of data given in Table 5 is used for the measurements.

Table 5: RL circuit parameters

| $f$ (kHz) | R (k$\Omega$) | L (H) | Theoretical Calculation $\tau$ $\mu$ ( sec) |
|---|---|---|---|
| 2 | 3.3 | 0.1 | 30.3 |
| 2 | 2.2 | 0.1 | 45.45 |
| 10 | 3.3 | 0.1 | 30.3 |

The theoretical calculation of H is obtained from the general time constant equation of RL circuits;

$$\tau = \frac{L}{R}$$

The result of the circuit with parameters of the first row is given in Figure 9.

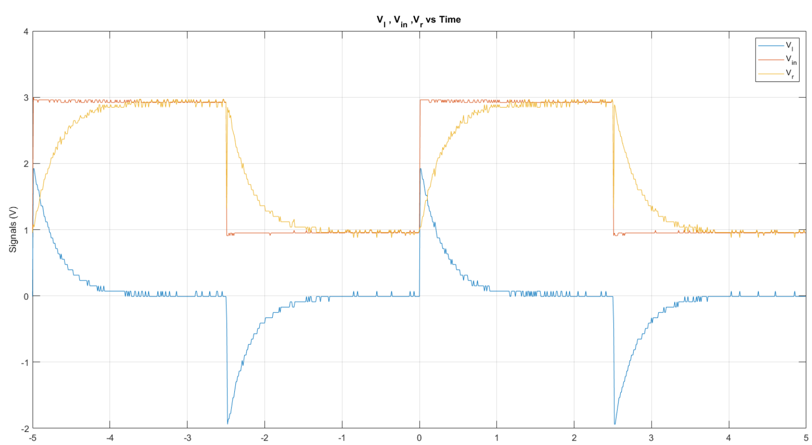


Figure 9: Waveform for the step 1 part 1 first row

To measure time constant experimentally following data is obtained from the plot.

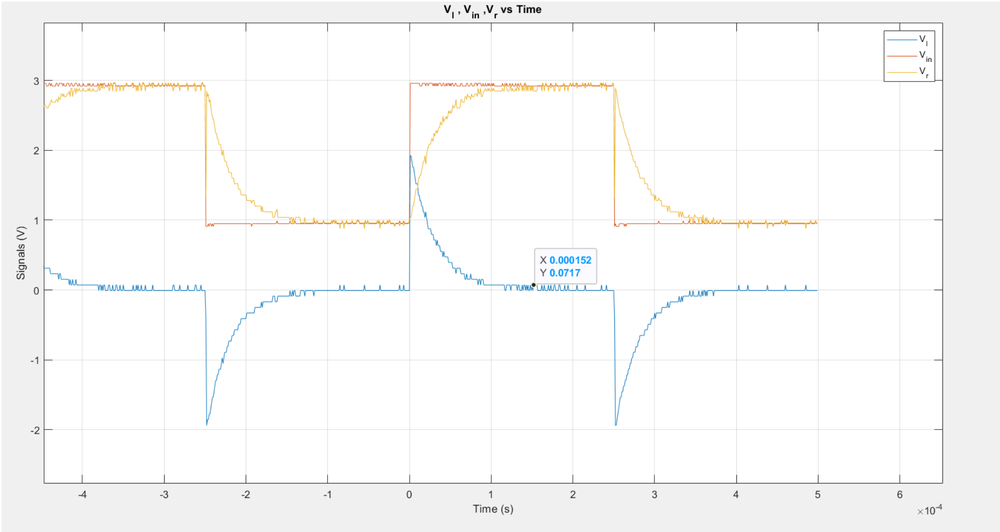


Figure 10: Data from plot

The result is obtained using 5 $\tau$ method. The time point where the charging of the inductor completed is marked. Then it is divided into 5. The calculation result of $\tau$ is given in Table 6.

Table 6: RL circuit parameters

| Experimental Calculation $\tau$ ($\mu$ sec) | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|
| 30.4 | 30.3 |

It can be said that 5 $\tau$ method is consistent with the theoretical calculations.

The result of the circuit with parameters of the second row is given in Figure 11.

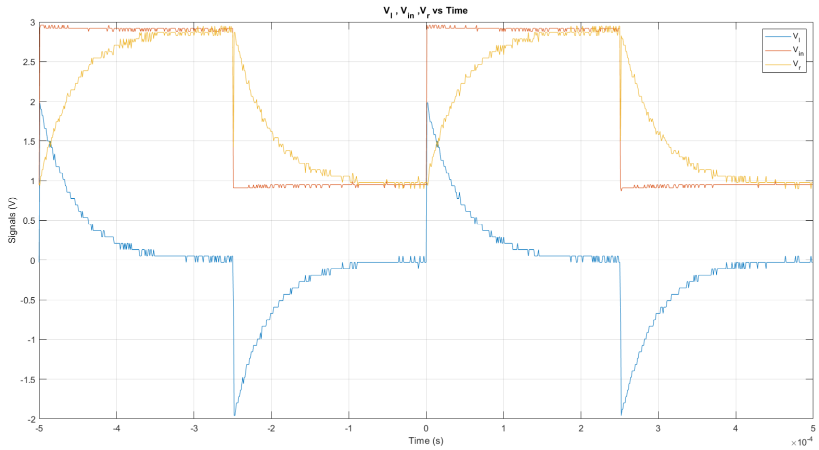


Figure 11: Waveform for the step 1 part b second row

To measure time constant experimentally following data is obtained from the plot.

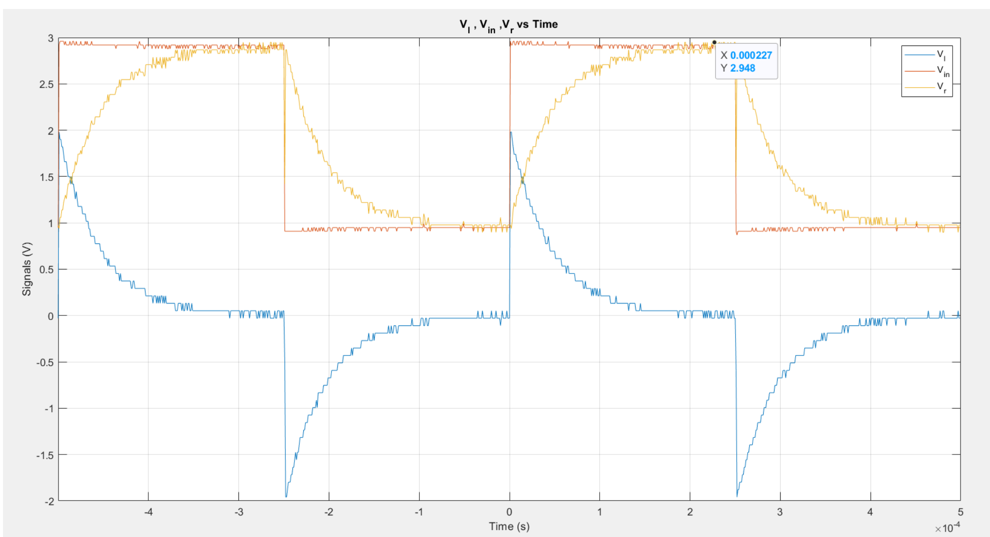


Figure 12: Data from plot

The result is obtained using 5 $\tau$ method. The time point where the charging of the inductor completed is marked. Then it is divided into 5. The calculation result of $\tau$ is given in Table 7.

Table 7: RL circuit parameters

| Experimental Calculation $\tau$ ($\mu$ sec) | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|
| 45.4 | 45.45 |

It can be said that 5 $Tau$ method is consistent with the theoretical calculations.

The result of the circuit with parameters of third row is given in Figure 13.

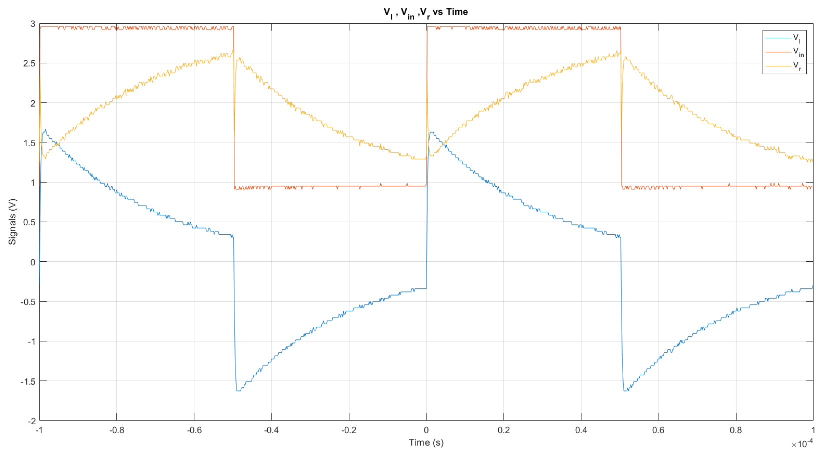


Figure 13: Third waveform for the step 1 part b

To measure time constant experimentally data in Figure 14 is obtained from the plot.

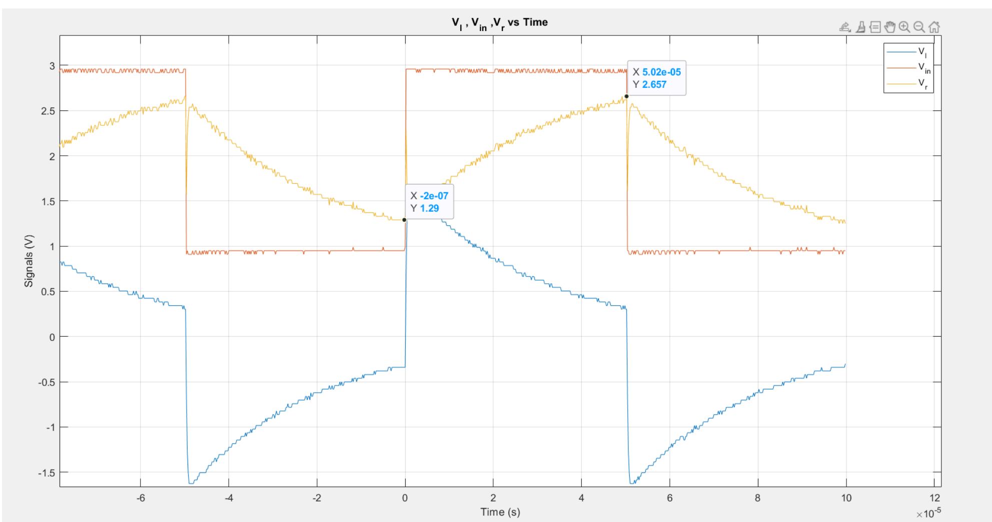


Figure 14: Data from plot

The calculation result of $\tau$ is given in Table 8. The $\tau$ can not be obtained using 5 $\tau$ method because of the fact that is charging and discharging processes are not completed in a cycle. To obtain the $\tau$ value both graph data and the equation $i_l(t) = 10^{-3} * (0.91 - 0.52e^{-\frac{t}{\tau}})$ are used. The time point where the charging and the discharging of the inductor are marked. When a half cycle is completed, 0.05 millisecond passes, so when we set t to 0.05 millisecond, we should get the $i_c = 0.8052 * 10^-3$ Amps. The calculation result of $\tau$ is given in Table 8.

Table 8: RL circuit parameters

| Experimental Calculation $\tau$ ($\mu$ sec ) | Theoretical Calculation $\tau$ ($\mu$ sec) |
|---|---|
| 31.25 | 30.3 |

It can be concluded that our theoretical calculations are quite consistent with the experimental results regarding the error being approximately a tenths of a millisecond.

## 2.2 2

The circuit given in Figure 15 is constructed. The function generator is adjusted so that it supplies square waves with a frequency of 100Hz and $V_{pp} = 6$Volts.

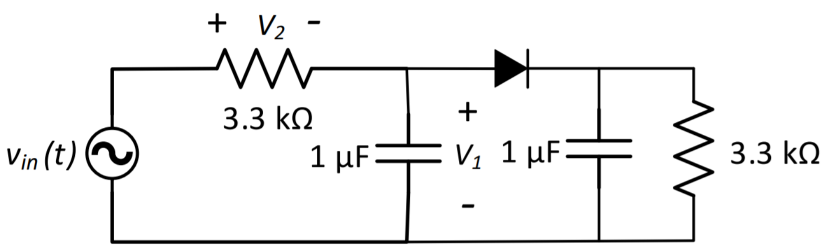


Figure 15: Circuit schematic for step 2

Then the plot shown in Figure 16 is obtained.

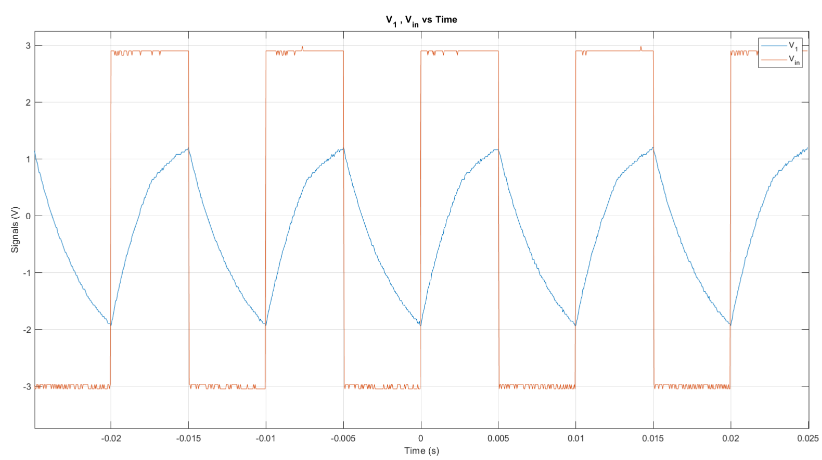


Figure 16: $V_1$ and $V_{in}$ vs Time

Now, the time constant $\tau$ can be obtained for two states, of which signal is positive and negative. For the negative region, it can be calculated theoretically easily by multiplying R and C. On the other hand, for the positive region, it can be obtained after finding the

Thevenin equivalent of the circuit. But, those values also can be obtained from the plot given in Figure 16. To do this, the measurements on the plot are made and given in Figure 17.

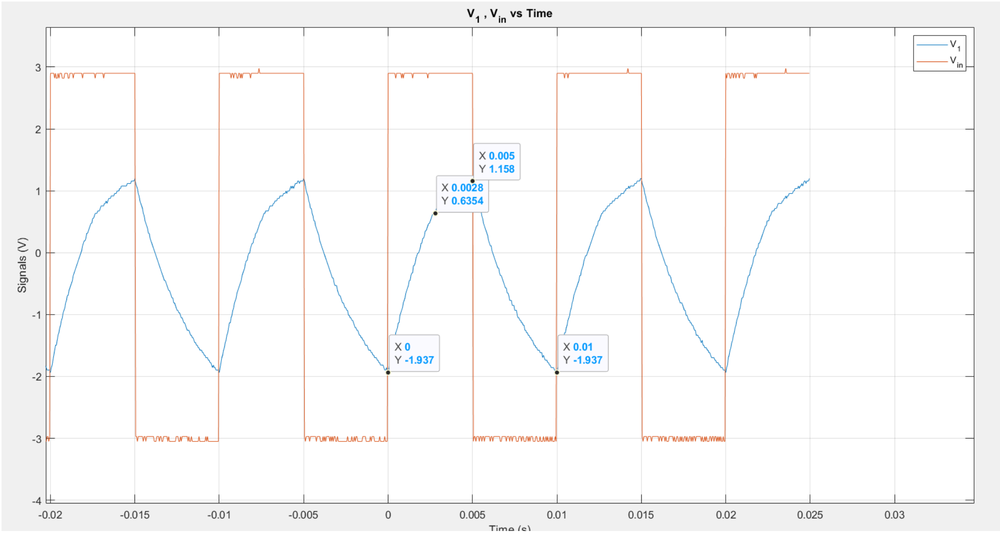


Figure 17: Data marks for the step 2

Again, for this step 5 $\tau$ method can not be used since the period of charge and discarge is not complete. For positive region before diode opens the equation is;

$$V_c = 3 - 4.937e^{-\frac{t}{\tau_+}}$$

$$1.158 = 3 - 4.937e^{-\frac{0.0028}{\tau_+}}$$

For positive region after diode opens the equation is;

$$V_c = 3 - 2.3646e^{-\frac{t}{\tau_+}}$$

$$1.158 = 3 - 2.3646e^{-\frac{0.0022}{\tau_+}}$$

For negative region the equation is,

$$V_c = -3 + 4.158e^{-\frac{t}{\tau_-}}$$

$$-1.937 = -3 + 4.158e^{-\frac{0.005}{\tau_-}}$$

So the results of experimental calculations are given in Table 9.

Table 9: RC circuit parameters

| | Experimental Calculation $\tau$ ( sec ) | Theoretical Calculation |
|---|---|---|
| $\tau_+(before diode opens)$ | $3.8 * 10^{-3}$ | $3.3 * 10^{-3}$ |
| $\tau_+(after diode opens)$ | $8.8 * 10^{-3}$ | $3.3 * 10^{-3}$ |
| $\tau_-$ | $3.666 * 10^{-3}$ | $3.3 * 10^{-3}$ |

As mentioned, the theoretical results are obtained using several calculations, but it can be convenient to use an experimental approach because of its simplicity. To sum up, the circuit operates in positive and negative regions. In the positive region, both of the capacitors are charging. The right capacitor starts charging after the diode exceeds its opening voltage (approximately 0.7 volts). In the negative region, both of the capacitors are discharging, but while the left capacitor charges from the opposite direction, the right capacitor discharges its energy to the rightmost resistor. Also, even though $\tau$ values of the positive region and negative region are the same in a theoretical manner since the internal resistances and jump conditions of capacitors were neglected, there are deviations in the results.

## 2.3 3

The circuit given in Figure 18 is taken as the reference for the differentiator setup.

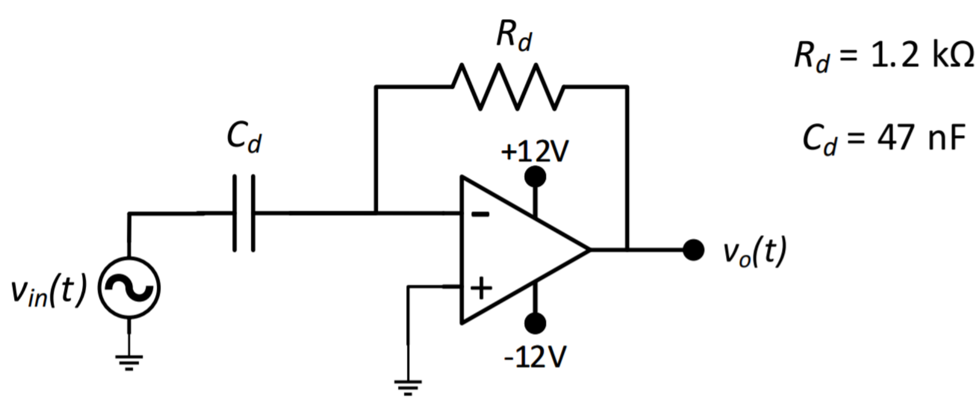


Figure 18: Differentiator circuit schematic

Then the circuit is constructed in LTSpice environment which is shown in Figure 19.

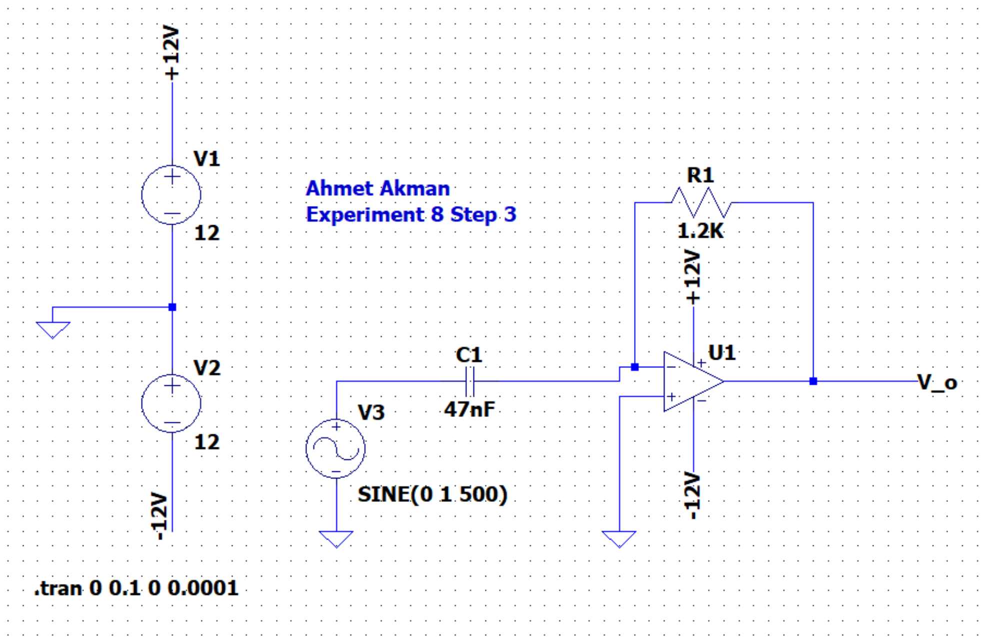


Figure 19: Differentiator circuit in LTSpice

Then the input versus output characteristics are obtained as given in Figure 20.

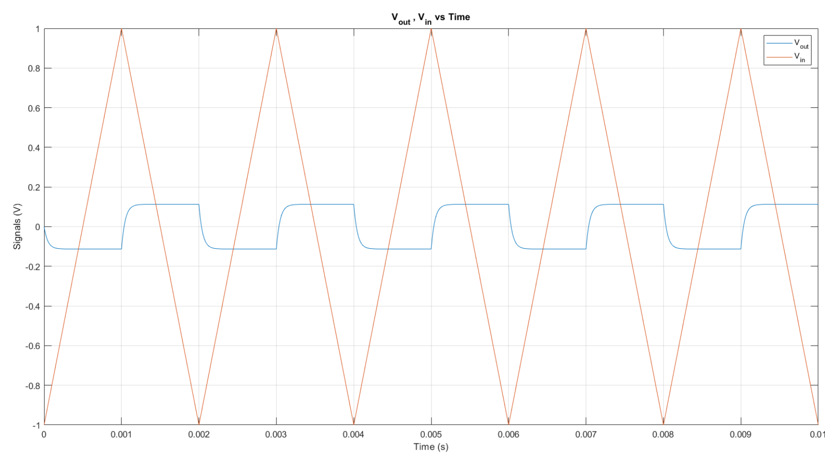


Figure 20: Differentiator circuit output

As a result, it can be said that this circuit configuration is able to differentiate the given signal. Because of the non-ideality of the components (e.g., the internal resistance of the capacitor), the resulting signal is not exactly a square wave. The differentiation of a triangular wave is a square wave, as observed. So, the relating expression signal is as follows,

$$V_{out} = \frac{dV_{in}}{dt}$$

The circuit shown in Figure 21 is constructed.

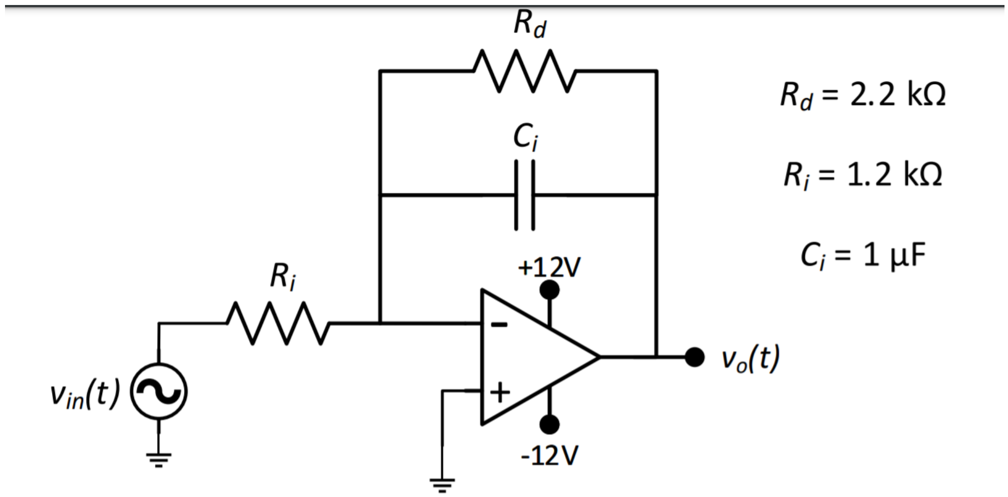


Figure 21: Integrator circuit schematic

Then the output plot given in Figure 22 is obtained.

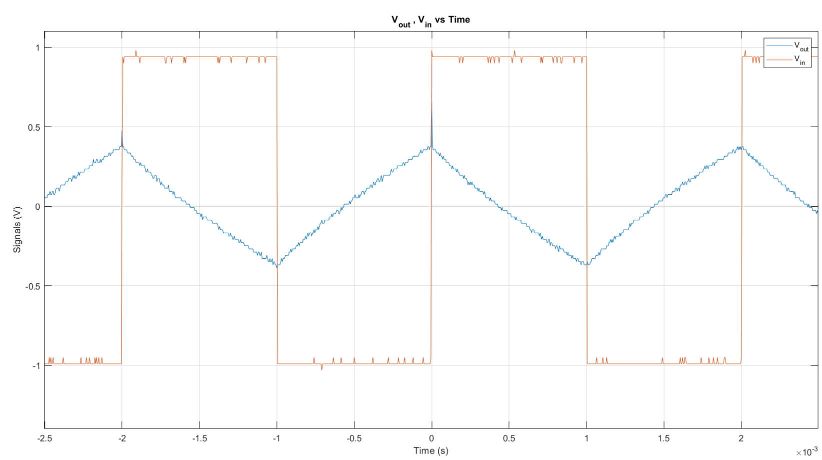


Figure 22: Integrator circuit output

As a result, it can be said that this circuit setup integrates the input signal, so that the output signal is oscillating between 0.3 V and 0.3 V approximately. The integration of the square wave is the triangular wave, as observed. So the expression for the signal is as follows,

$$V_{out}(t) = \int V_{in}(t)\, dt$$

# 3 Conclusion

In conclusion, in experiment 8, "First Order Circuits," as students, we have learned how various RC and RL circuit setups are constructed. As students, we have seen how the time constant $\tau$ can be determined from the plot. We have inferred the time constant of RC and

RL circuits experimentally and compared them with the theoretical ones. The 5 $\tau$ method is used and observed when it can not be used. Then, the behavior of an RC circuit with a diode was observed and commented on. Lastly, basic differential circuits and their behaviors are observed, and signal outputs verify the mathematical expressions. To sum up, in this experiment, as students, we have experimented with various RC circuits and their responses, then we have compared them with the expected responses.

# Appendix I

Total time spent on/during:

- Report writing: 10 hours

# Appendix II

The outputs of the simulations are fetched from LTSpice and plotted in MATLAB.