Experiment 6
Operational Amplifiers-II

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Contents

1 Introduction

In this experiment, as students, we are expected to experiment with different kinds of Op-Amp circuits by completing the steps described in the sixth experiment laboratory manual. Throughout these steps, some characteristics of Op-Amps and the behavior of the Op-Amp circuits are expected to be learned. The output versus input characteristics is observed by connecting the signal generator to the oscilloscope and the circuit. The non-ideal behavior of the components is compared with the ideal simulation plots. Also, some measurements are expected to be finalized via manipulating the output. The results of the steps were recorded and plotted for further comments.

2 Experimental Results

In this section, the results of Experiment 6 are discussed. Before the experiment begins, necessary adjustments are made to the DC power supply. LM 741 operational amplifier integrated circuit is used in this experiment. Capacitors are placed to the power line in order to prevent unstable supply behavior by compensating the line for short time intervals.

2.1 Step 1

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

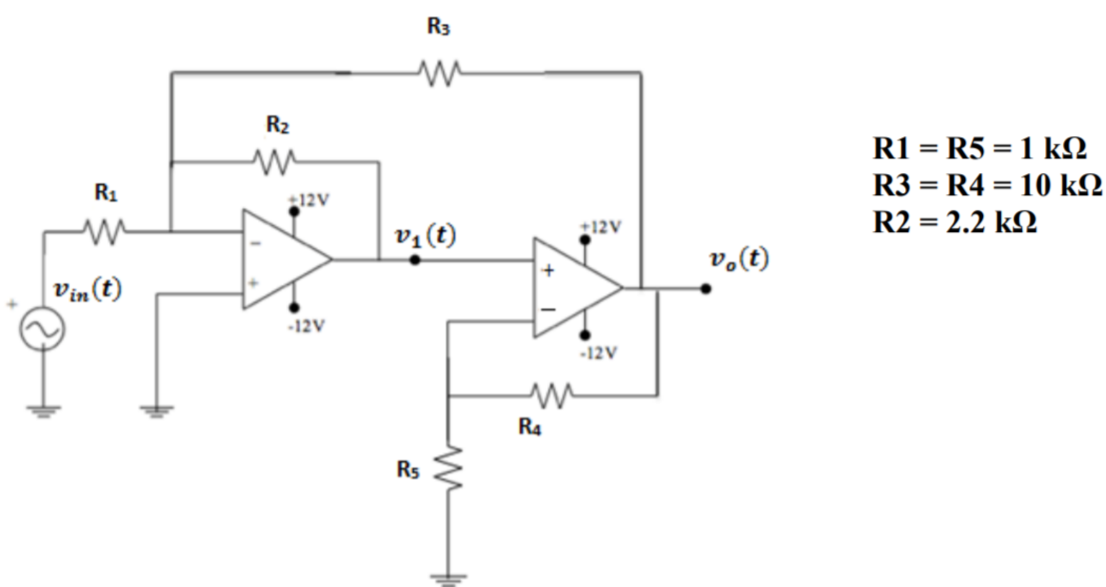

Figure 1: Circuit schematic for Step 1

2.1.1 a)

In the circuit given in Figure 1 , V_{in} is selected as $0.4sin(1000\pi)$ V. Then, V_{out} versus V_{in} characteristic is plotted and shown in Figure 2.

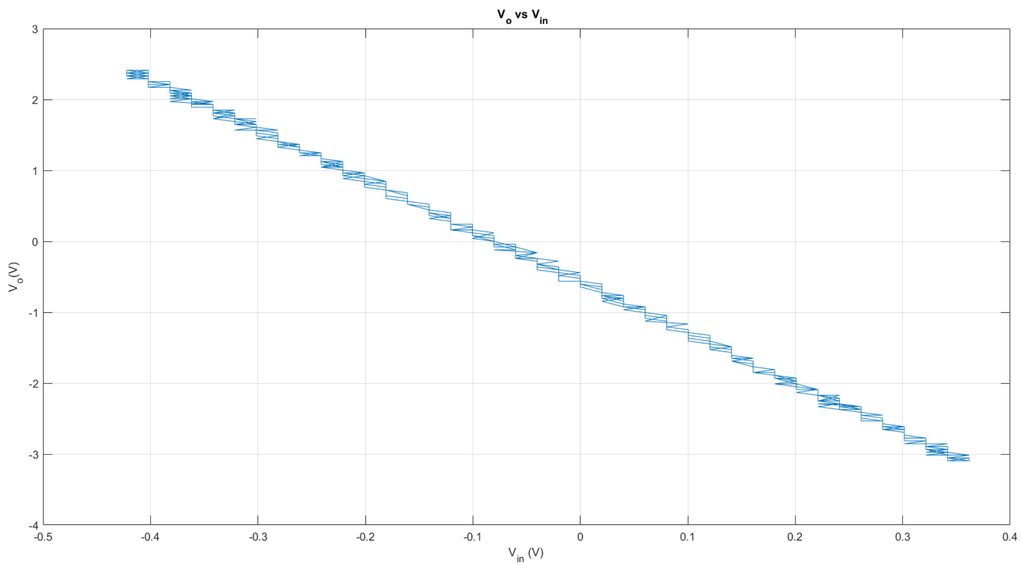

Figure 2: V_o vs V_{in}

The V_o , V_{in} waveforms are observed and plotted in MATLAB shown in Figure 3.

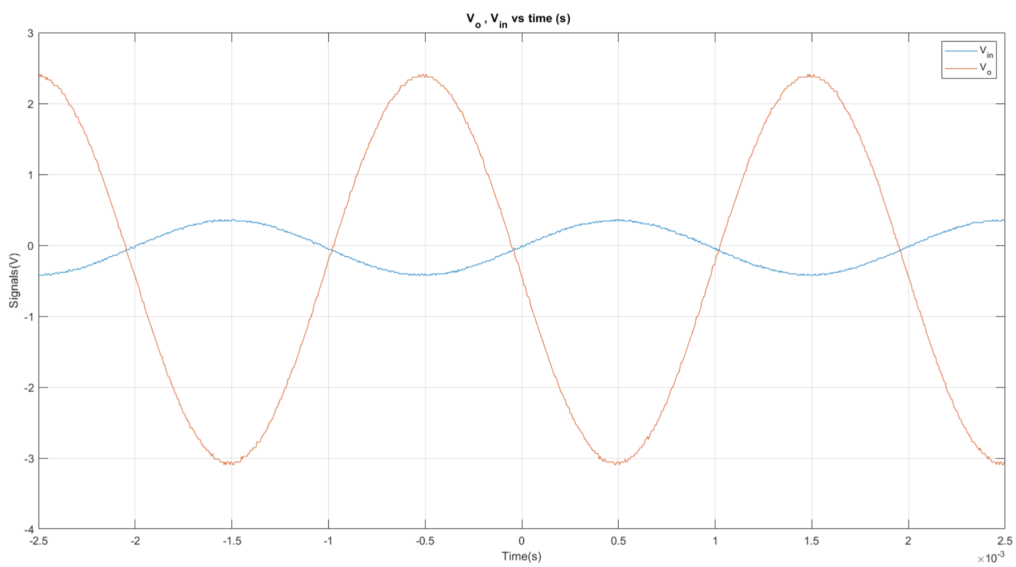

Figure 3: V_o , V_{in} vs time (s)

It can be said that this circuit stays in the linear region with this setup. The input signal is inverted and amplified. In this setup, one inverting and one non-inverting amplifier circuit are combined. So the output is inverting.

2.1.1.1 Comparison with the simulation results

The simulation is run in preliminary work according to the circuit shown in Figure 4.

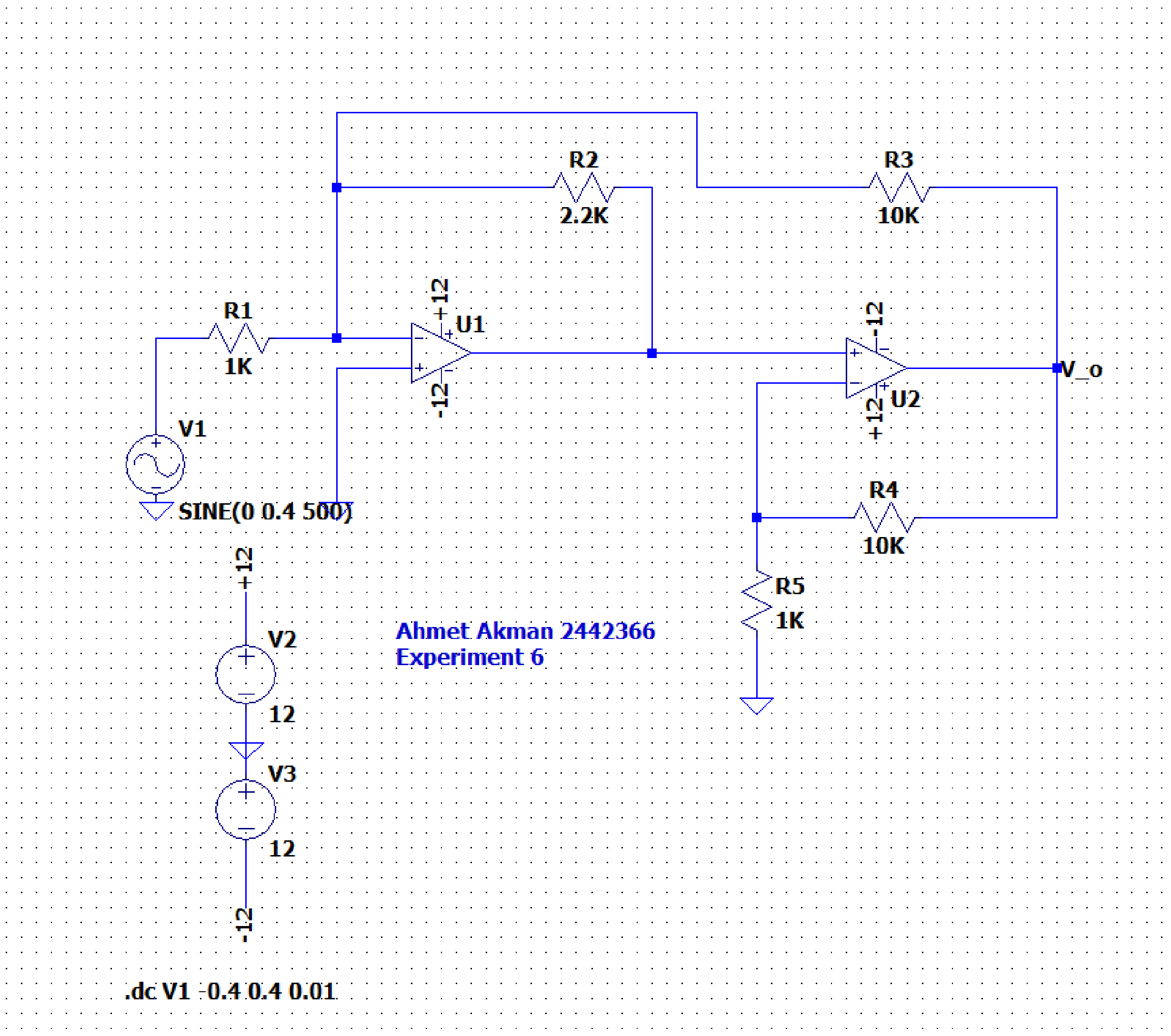

Figure 4: LTSpice schematic for the simulation 1a

Then the plot given in Figure 5 is obtained.

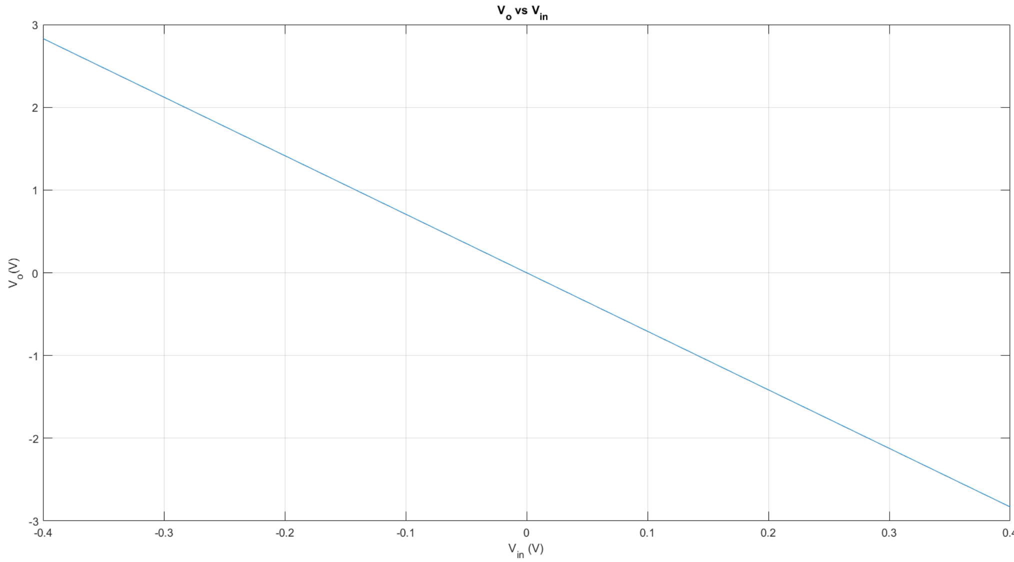

Figure 5: V_o vs V_{in}

So, it can be concluded that the theoretical result obtained in preliminary work is quite consistent with the simulation and real-world data. The expression relating V_o and V_in is;

$$V_{in} = V_o(\frac{-1}{10} + \frac{-5}{121})$$

There is a slight offset of signal in the actual plot. This is predicted to be stemmed from the non-ideality of either the LM741 component or the power line of the power supply.

2.1.2 b)

In the circuit given in Figure 1 , V_{in} is kept as $0.4sin(1000\pi)$ V. Then $R3$ is removed from the circuit. The V_{out} versus V_{in} characteristic is plotted and shown in Figure 6.

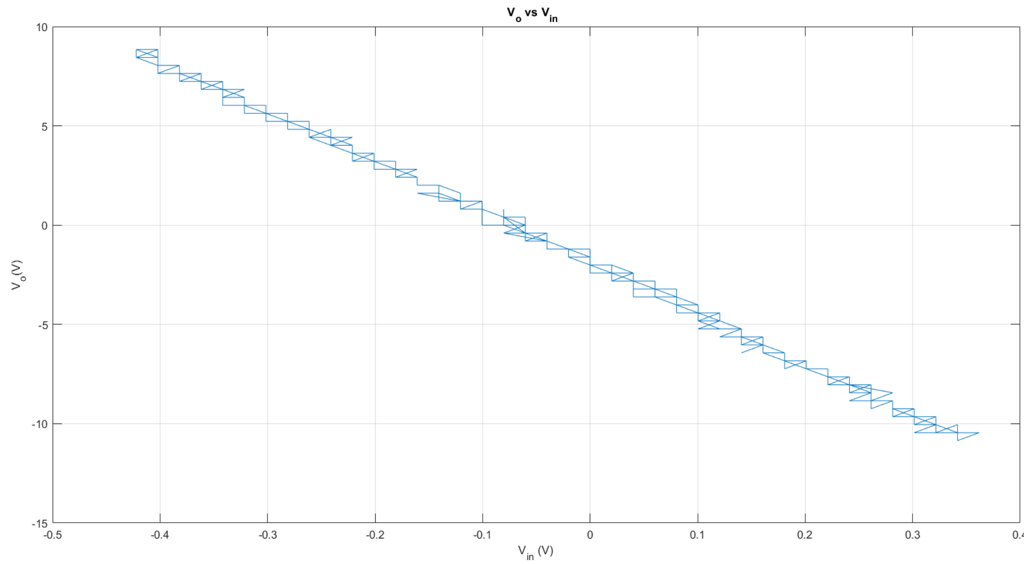

Figure 6: V_o vs V_{in}

The V_o , V_{in} waveforms are also observed and plotted in MATLAB shown in Figure 7.

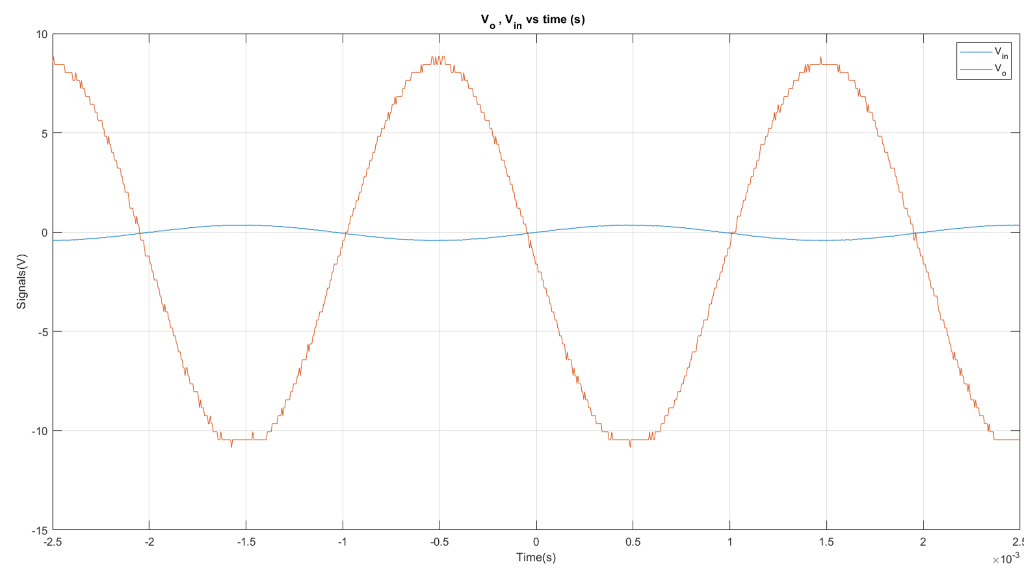

Figure 7: V_o , V_{in} vs time (s)

It can be stated that in this configuration, the first opamp is not propagated with negative feedback from the V_o, so the signal is amplified more.

2.1.2.1 Comparison with the simulation results

The simulation is run in preliminary work according to the circuit shown in Figure 4 by removing the R3 connection. So the V_o vs V_{in} result is shown in Figure 8.

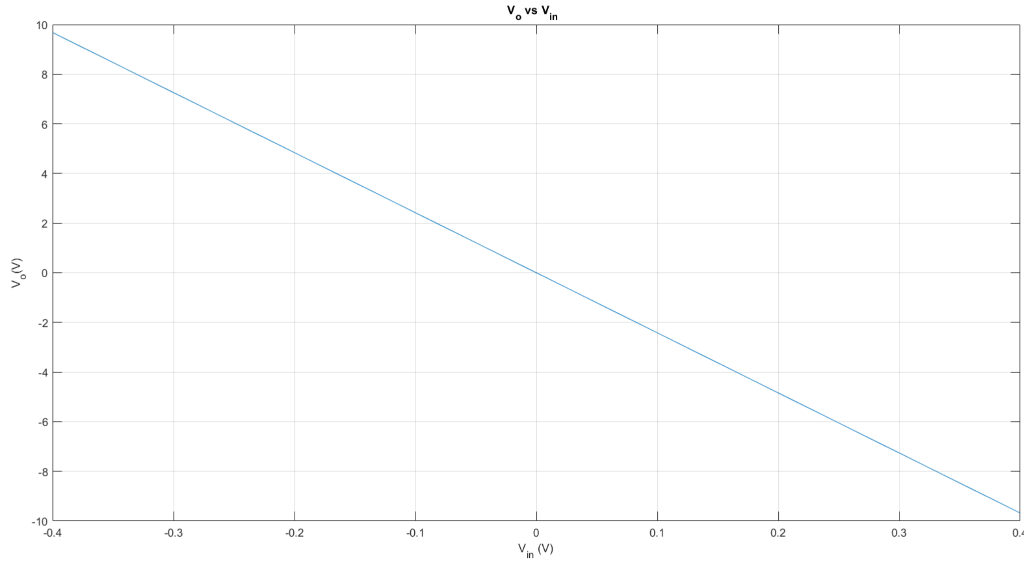

Figure 8: V_o vs V_{in}

It can be concluded that the laboratory results and simulation results are quite consistent. The relation found in preliminary work seems to behold which is;

$$V_{in} = \frac{-5V_o}{121}$$

Also, there is a shift towards the negative side in the laboratory plot. This is predicted to be sourced from the non-ideality of either the LM741 component or the power line of the power supply.

2.1.3 c)

The circuit setup is conserved in this section. The V_{in} is selected as $1sin(200\pi)$ V this time. V_o vs V_{in} is obtained as shown in Figure 9.

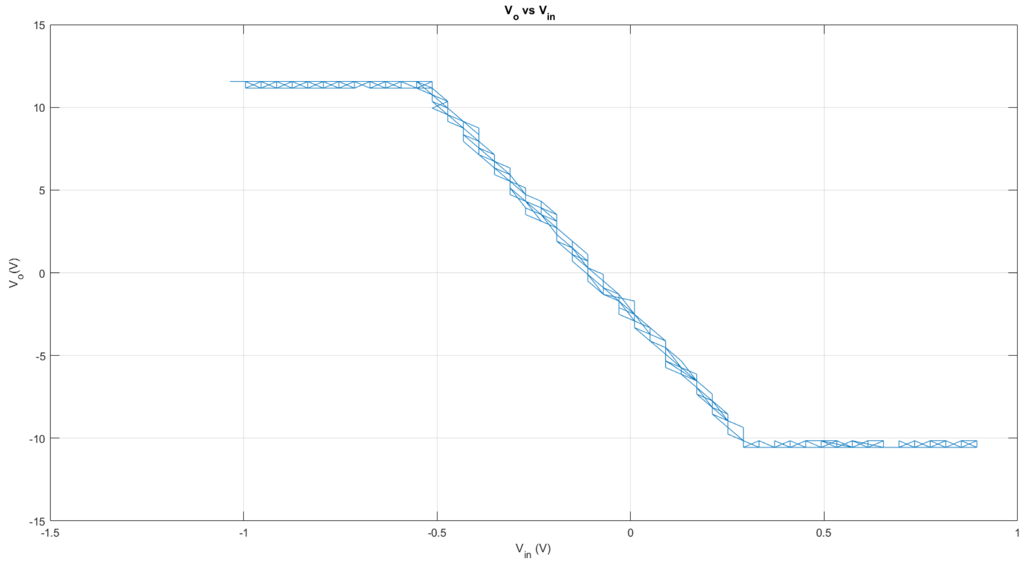

Figure 9: V_o vs V_{in}

The waveforms V_0 and V_{in} are observed and plotted in the time domain is given in Figure 10.

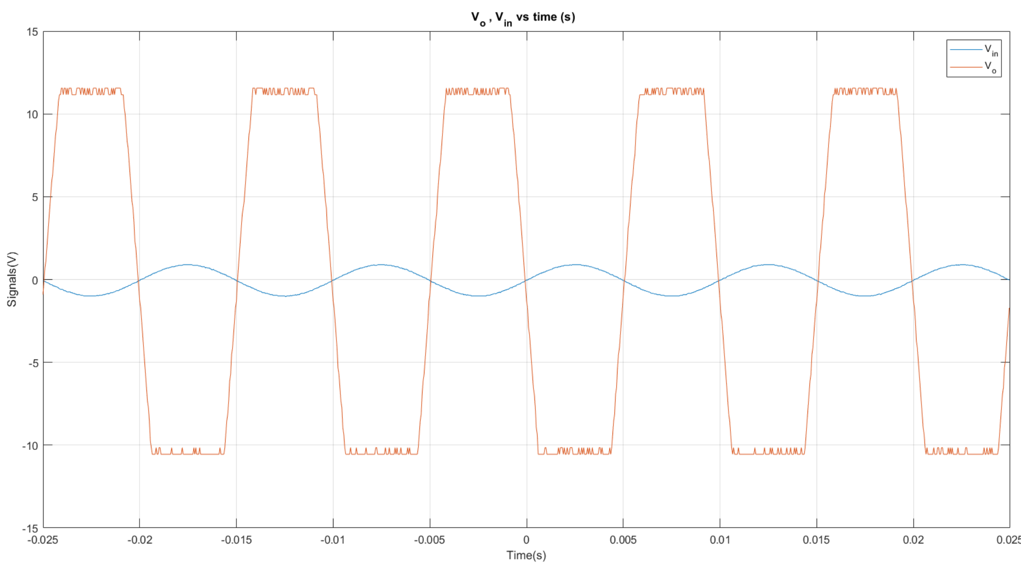

Figure 10: V_o , V_{in} vs time (s)

As a result, it can be stated that when the signal amplitude increases, the opamp(s) may not stay at their linear region can be saturated. This circuit setup, in principle, always amplifies the signal and inverts it.

2.2 Step 2

In this step the non-linear inverting amplifier circuit given in Figure 11 is set. The V_{in} is set to $3sin(200\pi t)$.

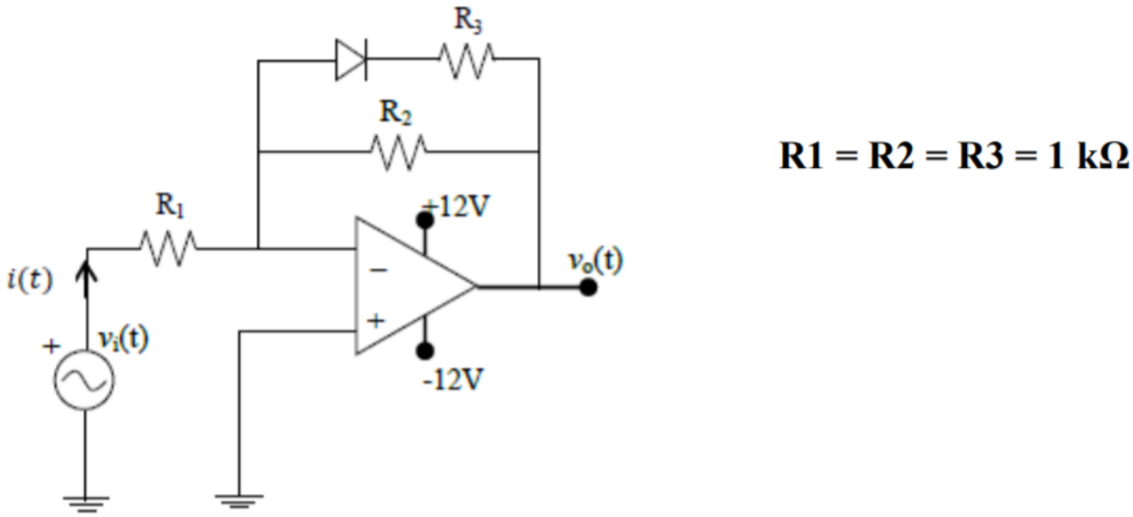

Figure 11: Circuit schematic for Step 2

The V_o versus V_{in} data is plotted and shown in Figure 12.

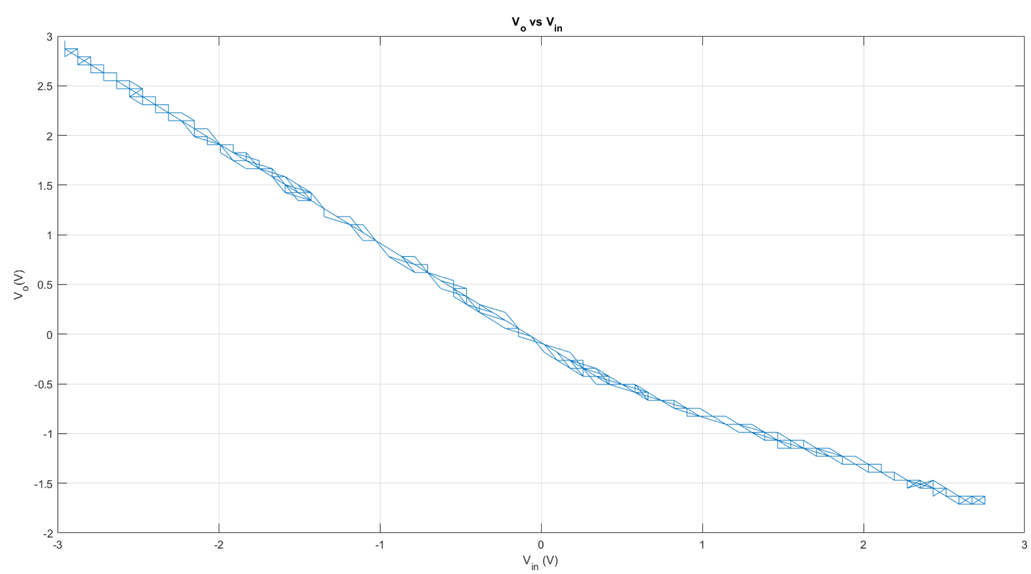

Figure 12: V_o vs V_{in}

The waveforms V_o and V_{in} are plotted in the same graph given in Figure 13.

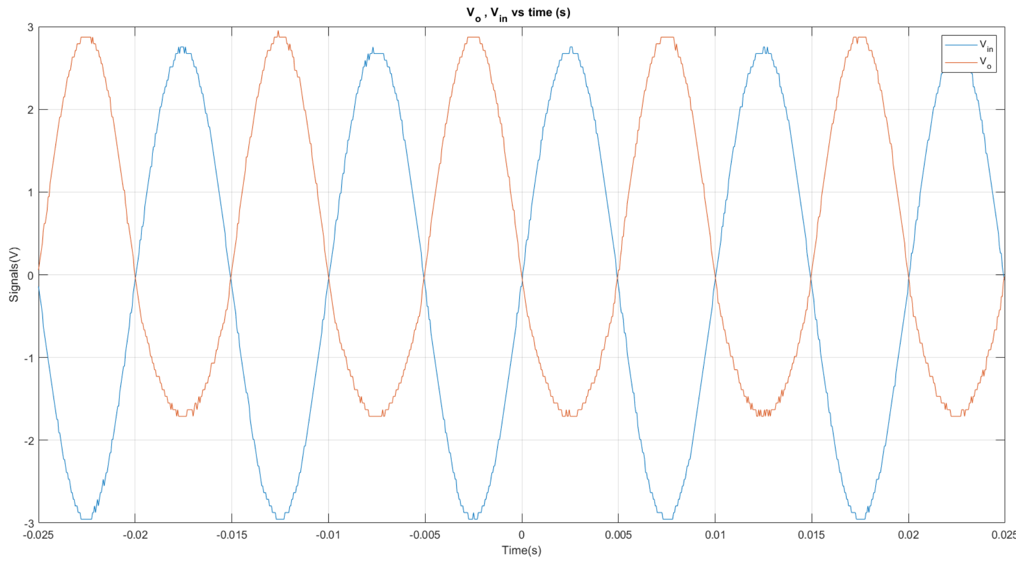

Figure 13: V_o , V_{in} vs time (s)

As a result, the comment can be made such that the amplifier stays in the linear region ,and when the diode is on negative feedback, resistance is lower than the situation diode is off. So, the slopes of the negative and positive areas are different.

2.2.1 Comparison with the simulation results

The circuit given in Figure 14 is constructed in LTSpice environment.

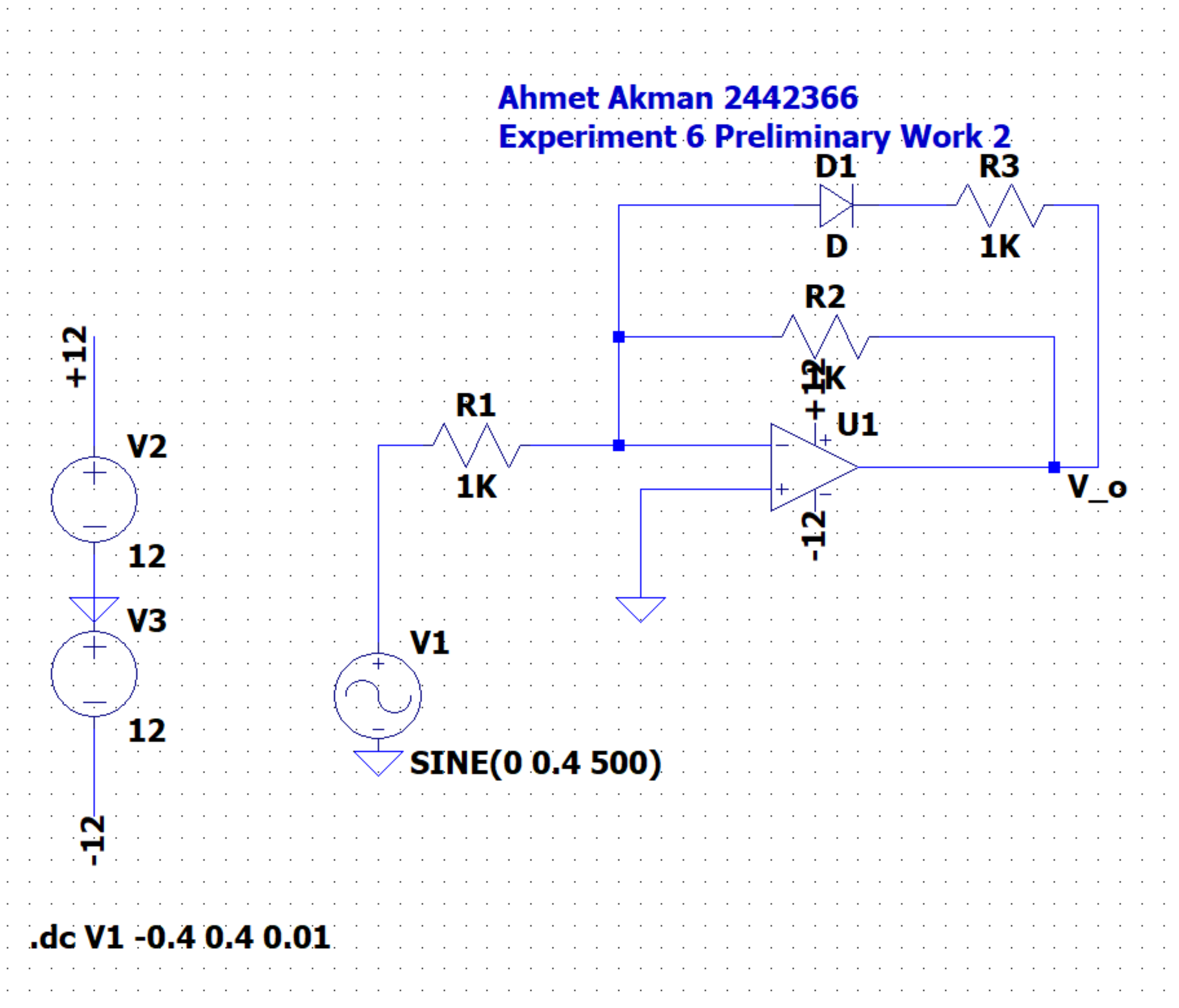

Figure 14: LTSpice schematic for the simulation 2

Then V_o versus V_{in} is obtained and shown in Figure 15.

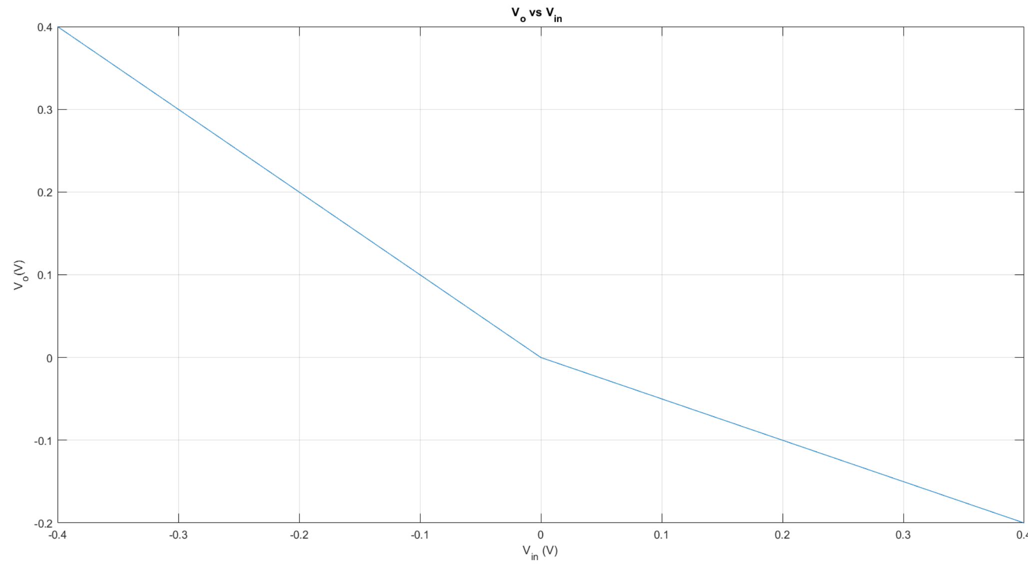

Figure 15: V_o vs V_{in}

It can be concluded that the measurements are consistent with the simulation and the equation obtained in the preliminary work. The equation is,

$$\text{if } V_- > V_o,\ -2V_o = V_{in}$$
$$\text{if } V_- < V_o,\ -V_o = V_{in}$$

So the results are also consistent with the theoretical calculations. Also, there is a shift towards the negative y-axis in the laboratory plot. This is predicted to be sourced from the non-ideality of either the LM741 component or the diode component.

2.3 Step 3

In this step, the circuit called negative resistance converter, which is shown in Figure 16, is constructed.

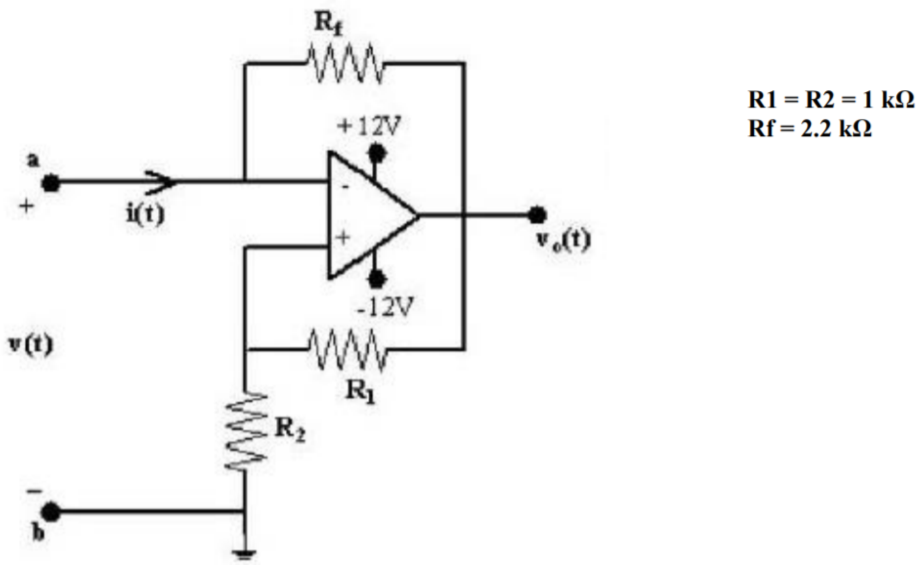

Figure 16: Circuit schematic for Step 3

2.3.1 a)

Figure 17 shows the V_o versus V_{in} characteristic obtained when $V_{in} = 10sin(200\pi t)$.

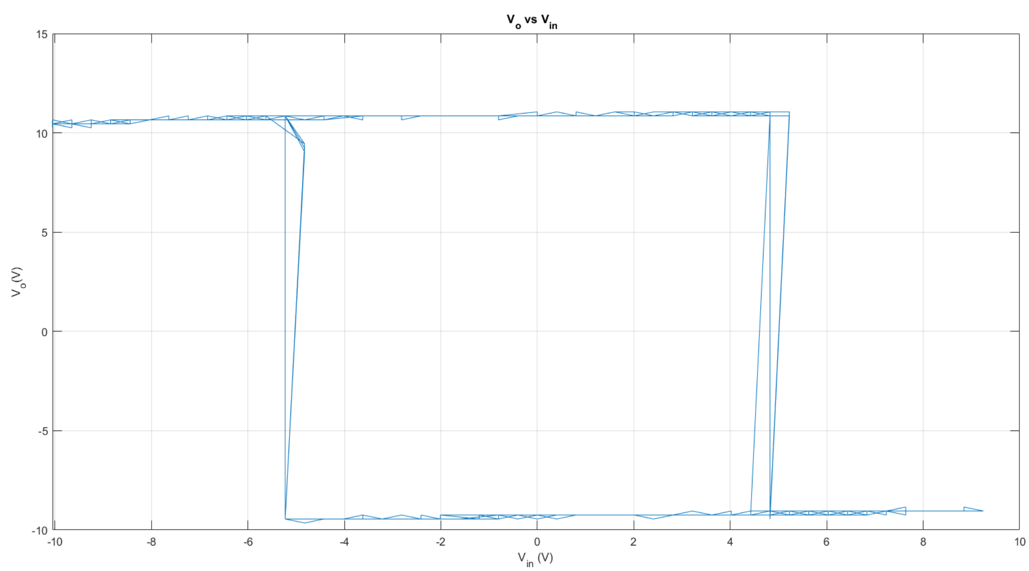

Figure 17: V_o vs V_{in}

In order to plot i_{in} versus V_{in} , the same data can be used. If we subtract V_{in} from V_o and divide it by R_f we can get the V_{in} value and plot it. So the resulting plot is given in Figure 18.

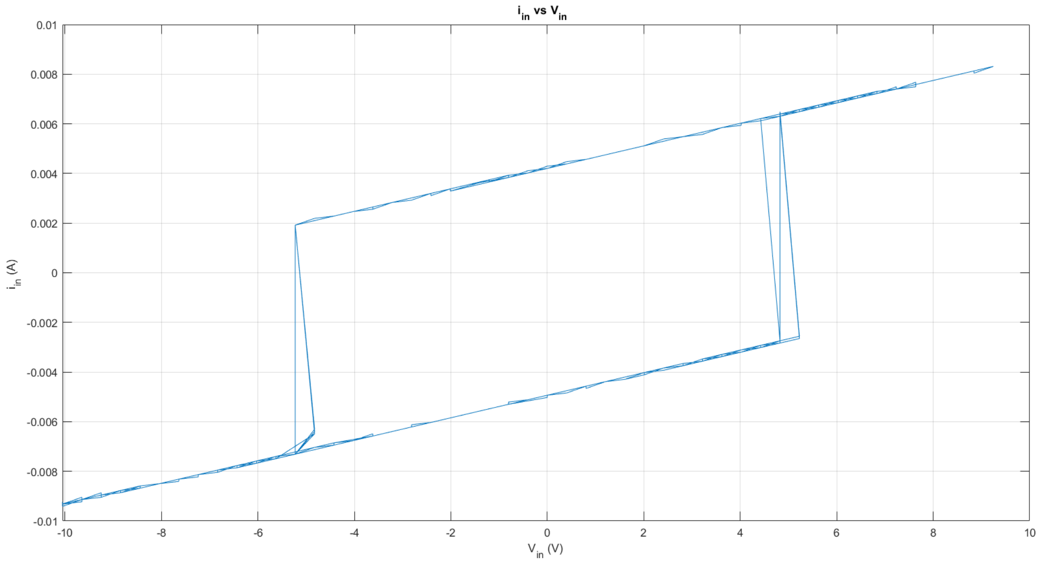

Figure 18: i_{in} vs V_{in}

In figure 19 the waveforms V_o , V_{in} plotted against time.

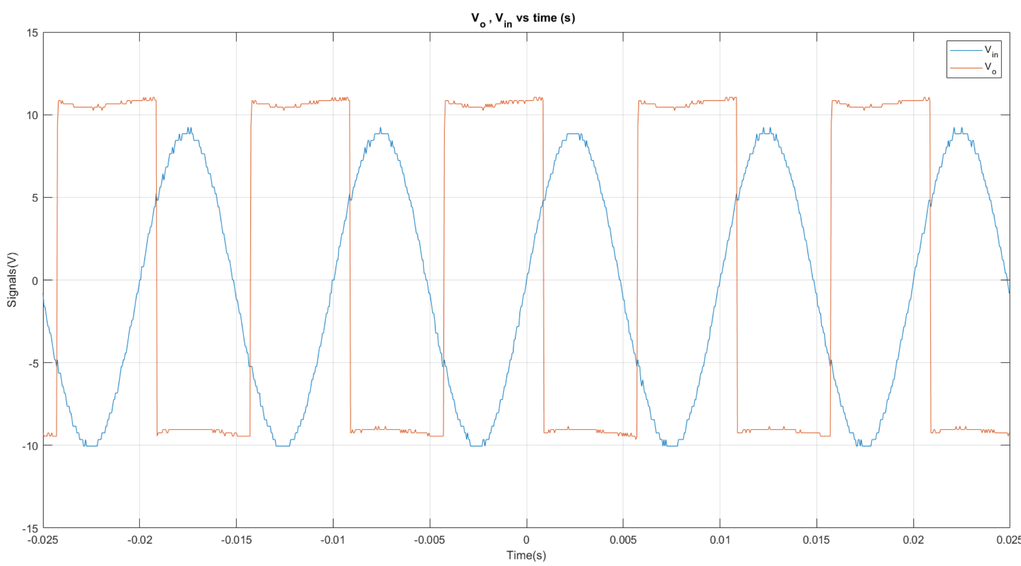

Figure 19: V_o , V_{in} vs time (s)

2.3.2 b)

In this part, the circuit setup is conserved except for signal generator input. A 1 μF capacitor is connected across the terminals a and b. The data of capacitor voltage V_c and output voltage V_o is obtained and plotted, which is shown in Figure 20.

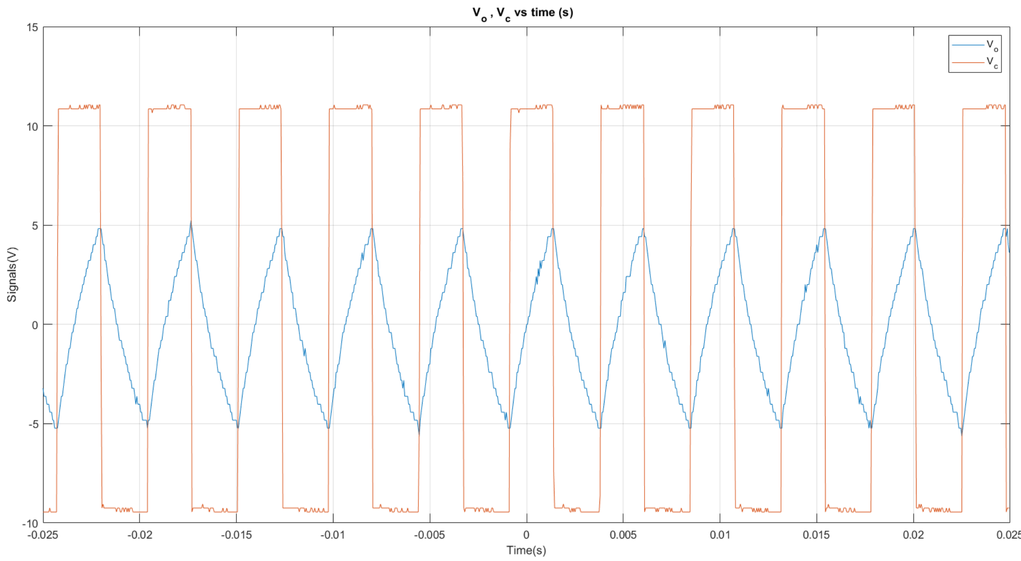

Figure 20: V_c , V_{in} vs time (s)

The result shows us that the capacitor behaves like a signal generator that supplies a sawtooth-like signal. When measured, the frequency is found as approximately "212 Hz". The signal supplied by the capacitor is amplified by the non-inverting operational amplifier configuration, and the output can be observed saturated.

2.3.3 c)

In this part, circuit setup is conserved except a parallel resistor of 2.2kΩ is connected to R_f. The data of capacitor voltage V_c and output voltage V_o is obtained and plotted which is shown in Figure 21.

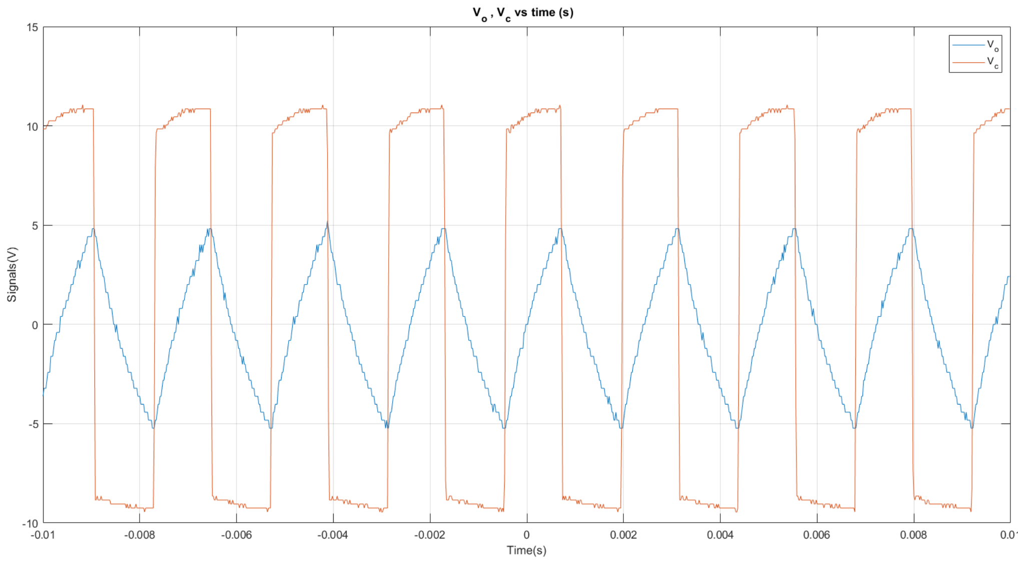

Figure 21: V_c , V_{in} vs time (s)

The result shows that the capacitor behaves like a signal generator that supplies a sawtooth-like signal. Different than the previous part, the measured frequency is found as approximately "413 Hz". The non-inverting operational amplifier configuration amplifies the signal supplied by the capacitor, and the output can be observed saturated. We can observe that the frequency of the signal supplied by the capacitor depends on the resistance connected to it.

2.4 Step 4

In this step, the darkness sensor circuit given in Figure 22 is constructed.

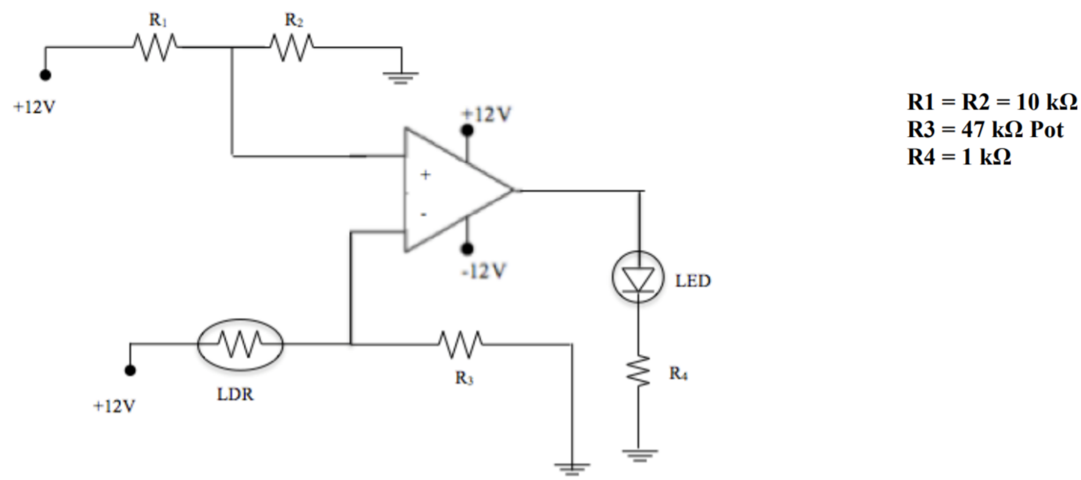

Figure 22: Circuit schematic for Step 4

2.4.1 a)

The circuit is an example of a comparator; the opamp compares the voltage between its inverting and non-inverting terminals. At the non-inverting terminal, 6 Volts is supplied with a voltage divider setup. A voltage divider setup is constructed via an LDR and pot at the inverting terminal. When the LDR is in the dark, the led is on, so the system senses the darkness.

2.4.2 b)

For the , the lightness sensor proposed circuit given in Figure 23 is set.

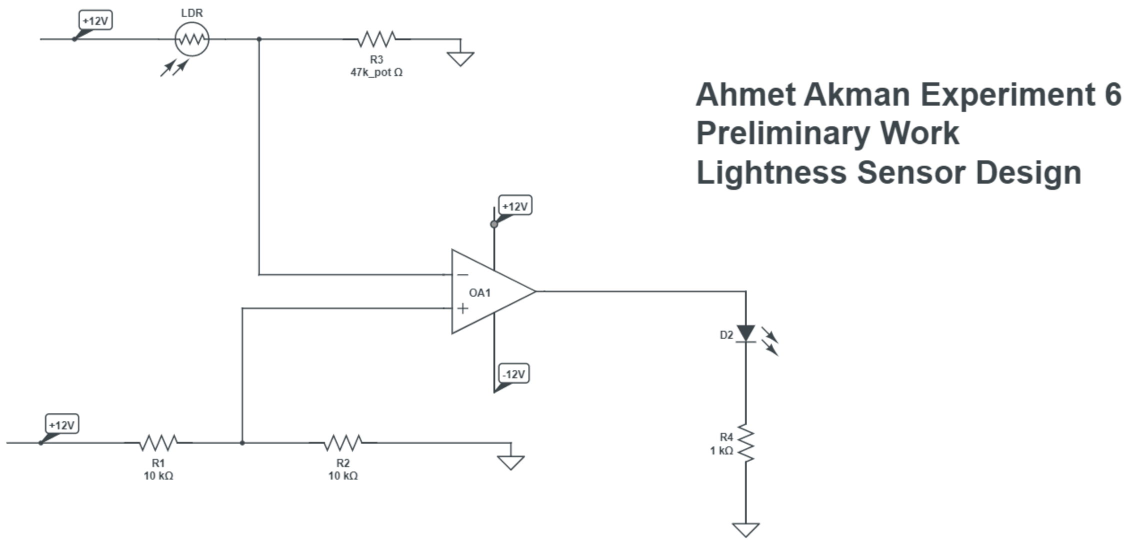

Figure 23: Lightness sensor circuit schematic for Step 4 part b

The circuit is an example of a comparator; the opamp compares the voltage between its inverting and non-inverting terminals. At the inverting terminal, 6 Volts is supplied with a voltage divider setup. At the non-inverting terminal, a voltage divider setup is constructed via an LDR and pot. When the LDR is getting sufficient light, the led is on, so the system senses the lightness. The system can be tuned by adjusting the pot.

2.4.3 c)

The only difference between darkness and the lightness sensor is the terminals of the opamp are swapped. So the result of the comparison also swapped. This means the comparison reference is the only difference, and the polarity of the output determines whether led is on or off.

2.5 Step 5

In this step the circuit in Figure 24 is constructed.

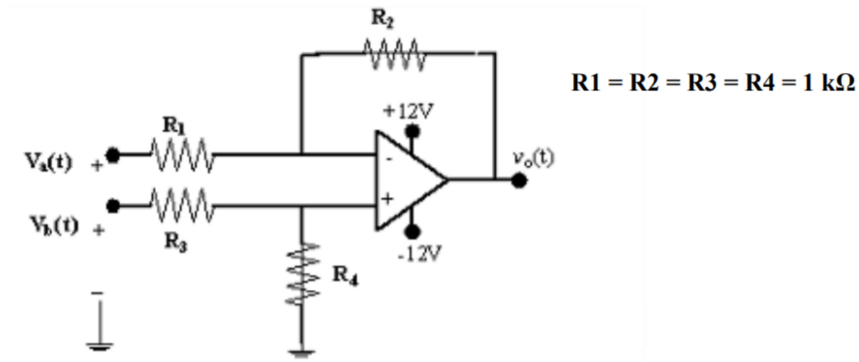

Figure 24: Difference amplifier circuit schematic for Step 5

In order to supply two different signals with one signal generator, voltage is divided with three 1kΩ resistors. Then to prevent voltage drop and let the voltage divider work properly, a buffer circuit is used, as given in Figure 25.

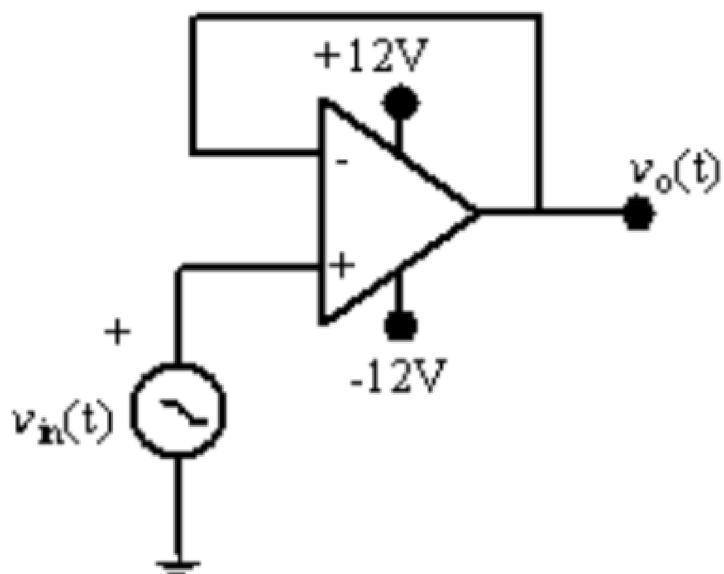

Figure 25: Buffer circuit schematic for Step 5

So the $V_a(t) = 3V_b(t) = 4.5sin(1000\pi t)$ signals are supplied to the circuit succesfully. As a result, the input and output waveforms are plotted in MATLAB, given in Figure 26.

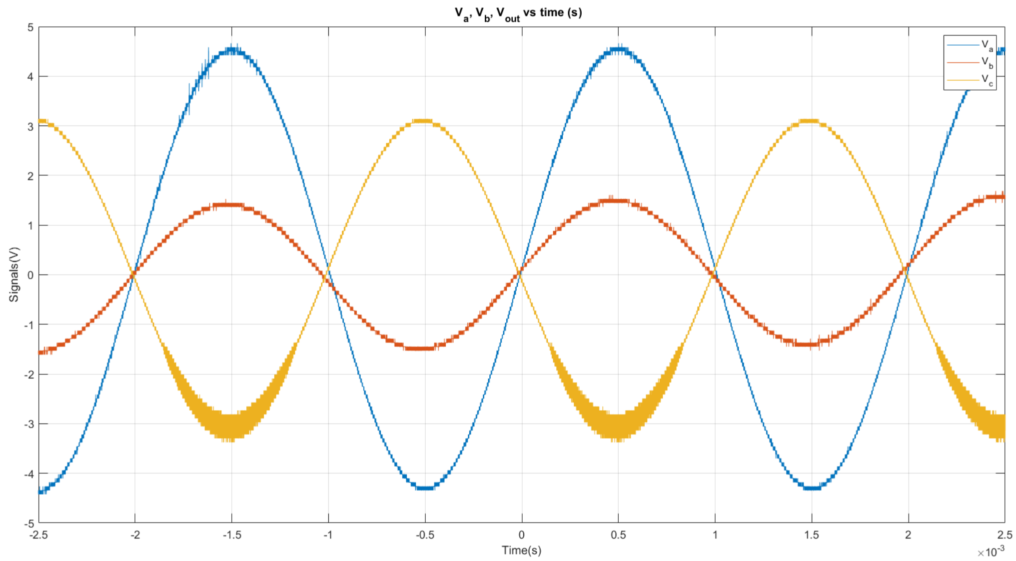

Figure 26: V_a, V_b , V_o vs time (s)

It can be stated that the resulting signal is the inverted version of the difference of the V_a and V_b, whose amplitude is equal to approximately "3 Volts". Also, since the amplifier is set to invert, the resulting signal has the phase difference of π radians with respect to the V_a and V_b.

3 Conclusion

In conclusion, in experiment 6, "Operational Amplifiers-II," as students, we have learned how various functional circuit setups of Op-Amps can be constructed. Preliminary laboratory work is done via simulations of the Op-Amp circuits in an LTSpice environment and by hand calculations. As students, we have observed how the amplifying job can be done in two-stage and its advantages. We have seen the effect of non-linear feedback on the Op-Amp setup. The characteristics of the negative resistance converter are observed. Also, implementing darkness and lightness sensors has experienced a real-life design approach. Lastly, a difference amplifier circuit is set, and the characteristics are observed with measurements. To sum up, in this experiment, as students, we have experimented with how different kinds of operational amplifier circuits operate.

Appendix I

Total time spent on/during:

- Pre-lab preparation: 6.5 hours (including the preliminary work and simulations)
- Experimental work: 2 hours (hours spent in lab)
- Report writing: 6 hours

Appendix II

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