ECSE 331 Electronics

Laboratory Report

McGill University

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Silicon Diodes and Their Applications*

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***Abstract*— The purpose of this laboratory experiment was to explore the current-voltage properties of diodes. The main concepts we investigated in this lab are the rectification, zener diodes, AC to DC conversion, and forward and reverse bias.**

I. INTRODUCTION

Silicon diodes are two-terminal devices that are composed of the p-n conjunction. They are used for rectification. Standard diodes allow current in only one direction and do not conduct in reverse bias. However, zener diodes can operate in reverse-breakdown. This lab explores the properties of different diodes. We use an operational amplifier to keep track both the voltage across and the current through the diode under test.

In this report, we will present the result we obtained during the experiment and analysis them using knowledge we learned from class.

II. EXPERIMENTS PROCEDURES AND RESULT

A. Part 1: I-V Characteristics Using a Curve Tracer

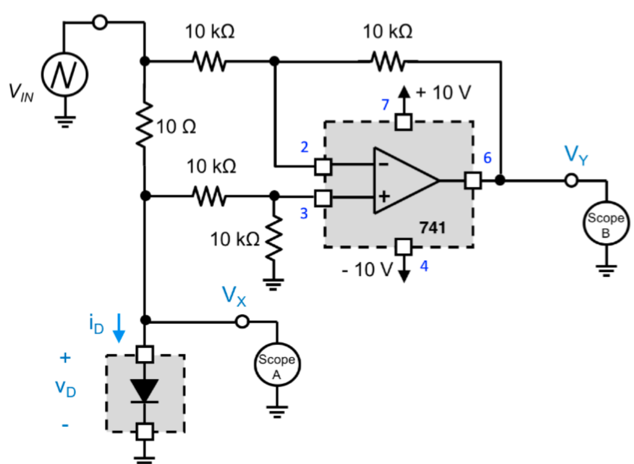

Fig. 1. Circuit for i-v diode measurement in Part 1

In the first part of the lab, before we construct the above circuit shown in Fig. 1 using the 1N4148 signal diode. We first verify that the voltage shown in scope B is 10 times greater than the current i_D by replacing the diode with a 100 Ω resistor. The input signal is a triangle wave with 4 V peak to peak voltage and zero offset. The experiment result is shown in Fig. 2; the black one is V_a and the grey one is V_b. V_b has an amplitude of 1.2645 V and V_a has an amplitude of 129.305 mV (258.61 mV peak-to-peak); by Ohm's law the amplitude of the current through the resistor is 12.645 mA, which is about 10 times less than V_b. Thus, the circuit works properly.

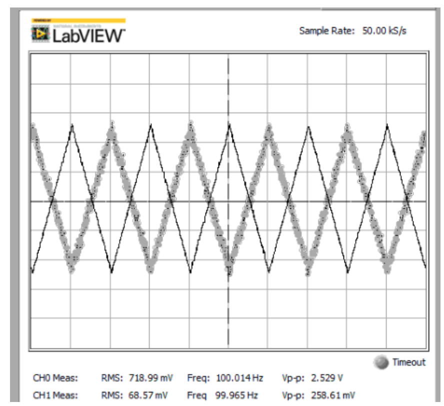

Fig. 2. Result for testing the op-amp; black is Va and grey is Vb

Next, we replace the resistor with the 1N4148 signal diode, while keep the input signal the same as before. Fig. 3 shows the simulation and the experiment result.

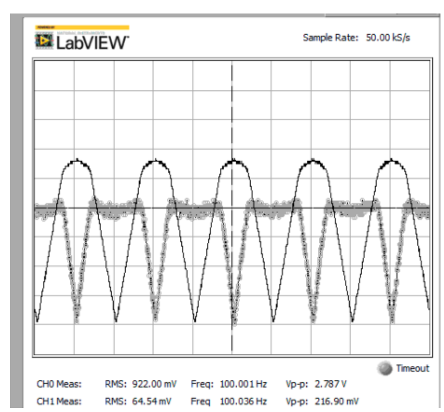

Fig. 3. Simulation result of the 1N4148 diode; black is Va and grey is Vb

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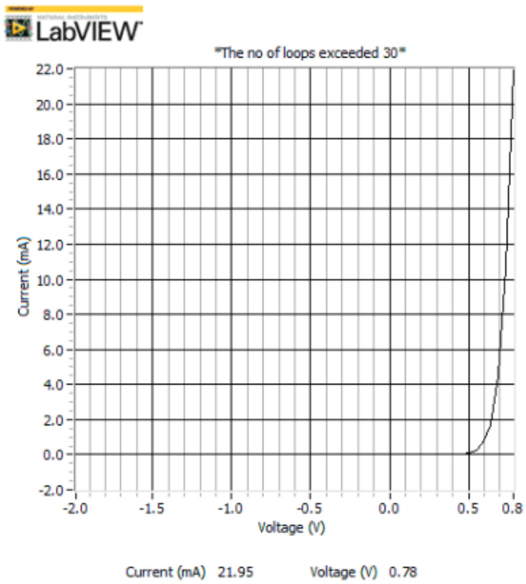


Fig. 4. The i-v curve of the 1N4148 diode

This simulation diagram by itself is not very valuable and nothing can really be generated of from this form; therefore, we plot the i-v diagram of this diode, and the result is shown above in Fig. 4. By observing the graph, we find that the cut-in voltage is 0.5 V. Also, by using the formula slope = deltaI/deltaV, and the two pairs of data points (circled in red) from the i-v diagram in Fig. 5, we calculate the slope at 0.7 V is 123.55 mA/V.

0.007	-0.005
0.061	-0.005
0.108	-0.003
0.160	-0.005
0.207	-0.005
0.261	-0.003
0.308	-0.003
0.361	0.000
0.408	0.009
0.460	0.035
0.504	0.095
0.550	0.263
0.595	0.681
0.638	1.689
0.688	4.531
0.737	10.585
0.785	21.949

Fig. 5. The data points from i-v curve of the 1N4148 diode; the first column represents the voltage in V; the second column represents the current in mA

The maximum voltage difference between the actual i-v curve and that predicted by the piecewise linear model over a voltage range from -2 to +2 V is very small (0.1V). The piecewise linear approximation is a reliable model.

Then, we replace the 1N4148 signal diode with an 1N4005 diode, Fig. 6 shows the simulation and the experiment results. The results are similar.

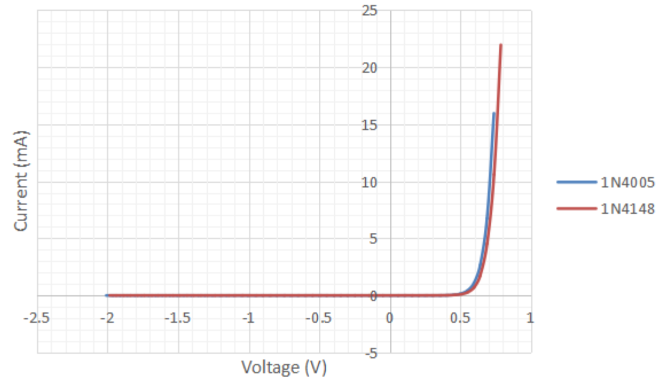


Fig. 6. Comparision of the i-v curves for 1N4005 diode and 1N4148 diode

Finally, we reverse the 1N4148 diode, we observe that the behavior is also reversed because the triangle wave is symmetric with respect to 0 V. Fig. 7 shows the i-v curve of the reversed 1N4148 diode.

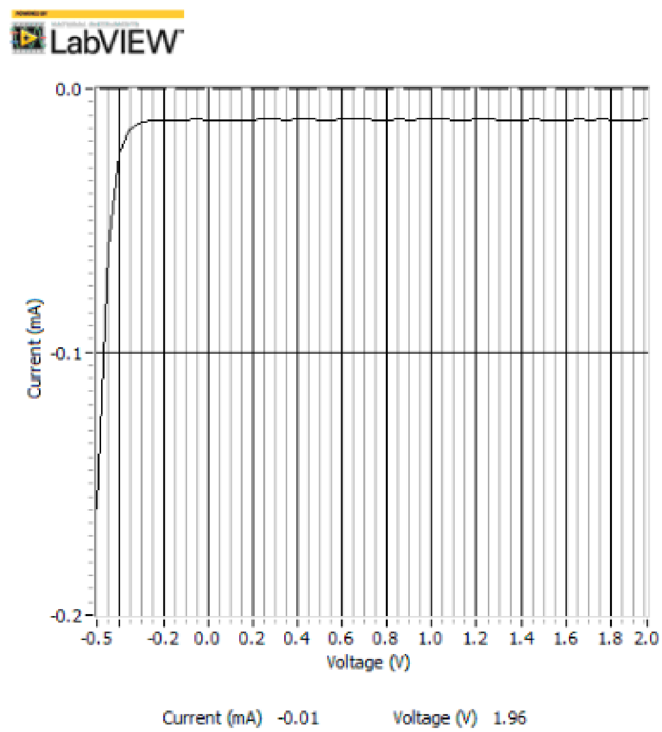


Fig. 7. The i-v curve of the reversed 1N4148 diode

B. Part 2: Diode Temperature Effect

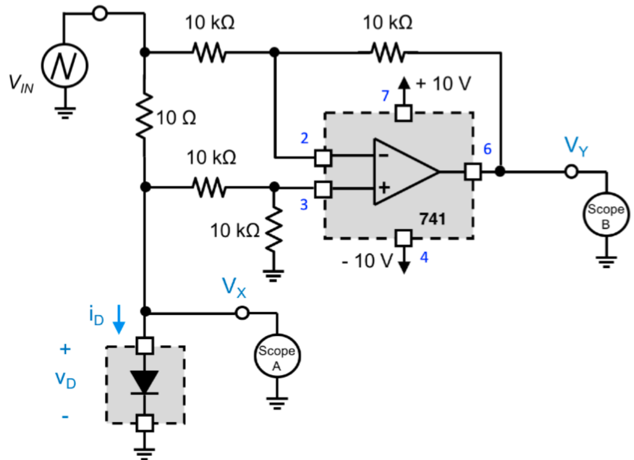


Fig. 8. Circuit for i-v diode measurement in Part 1

In part 2, we observe the behavior of a diode under different temperature conditions. The diode 1N4148 was tested first in room temperature, then in a lower temperature and a higher temperature by the above circuit in Fig. 8. We keep track of the temperature by the hand-held thermal imager.

By observing the results from in Fig. 9, we find that the increase in the temperature will lower the cut in voltage of the diode. This is expected because as the overall energy in the electrons of semi-conductors increases, the amount of extra energy need to be provided to make the diode conduct decreases.

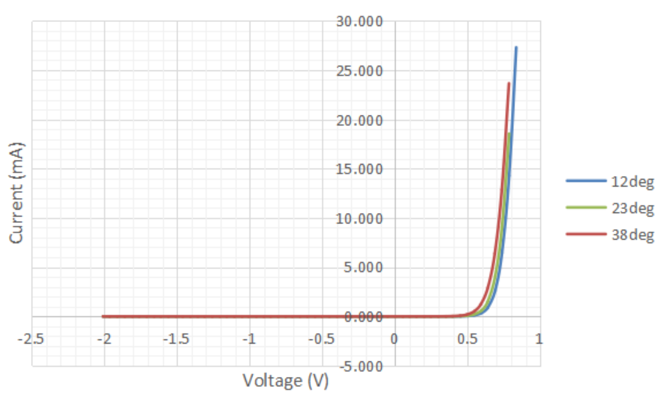


Fig. 9. The i-v measurement for 1N4148 diode at different temperatures

C. Part 3: Zener Diodes

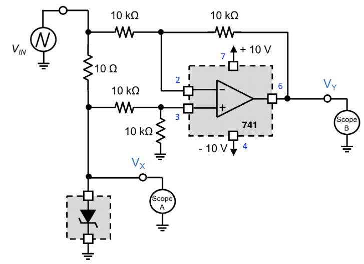


Fig. 10. Circuit for capturing the i-v characteristic of a 3.3 V Zener diode.

Fig. 10 shows the circuit that was applied to conclude the characteristics of a Zener diode. A sawtooth input signal and varied amplitude was applied to the circuit. The behavior of the Zener diode is shown below in Fig. 11 and Fig. 12.

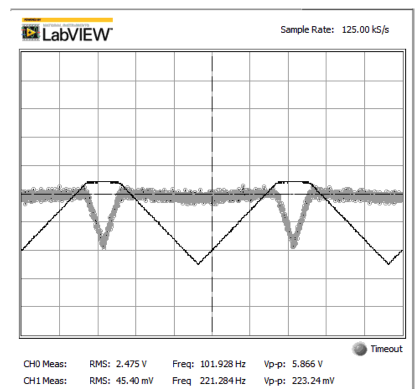


Fig. 11. Simulation results of the Zener diode.

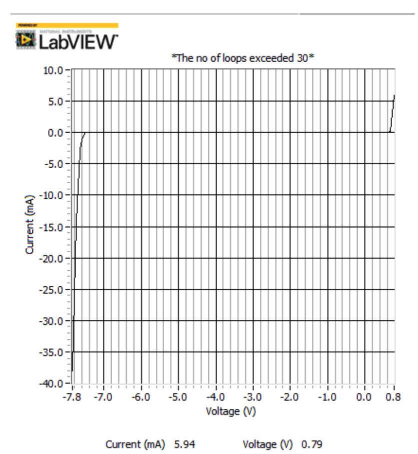


Fig. 12. I-V curve of the Zener diode.

This I-V curve clearly shows that the Zener diode is operating in the breakdown region. The Zener diode starts conducting large current when the voltage across it is below a certain value, in this case that seems to be around -7.5 V. Thus, the Zener diode breakdown happens around a voltage of -7.5 V.

The AC resistance inside the breakdown region is $\frac{1}{slope}$ of the breakdown region, estimated from the graph to be about 15.3 Ω.

D. Part 4: Rectifiers

This part of the lab focused on the rectifying of diodes. The circuit shown in Fig. 13 was configured.

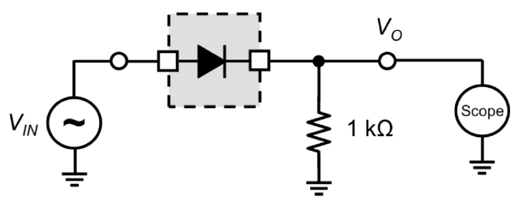


Fig. 13. Half-wave rectifier circuit.

In a half-wave rectifier circuit, only the signal in the positive domain of the wave is allowed to pass. In the experiment, the input signal is 60 Hz sine wave with 5 V amplitude. The simulation result is shown below in Fig. 14.

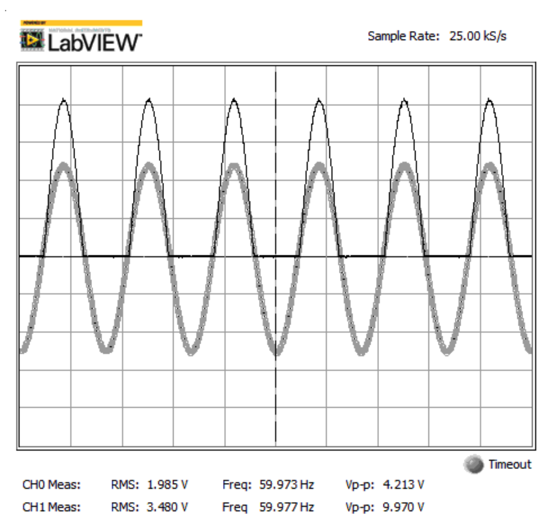


Fig. 14. Simulation of the half-wave-rectifier

It can be observed that only half the wave is going through the load and the diode triggers the voltage drop.

For the circuit with capacitor in Fig. 15, a 1 μF capacitor was placed in parallel with the load resistor.

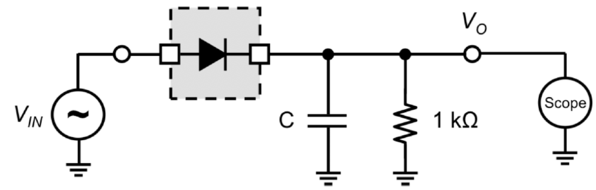


Fig. 15. Circuit diagram of the rectifier with a 1 μF capacitor.

The simulation result in Fig. 16 shows that since the capacitance is too small, it discharges very quickly.

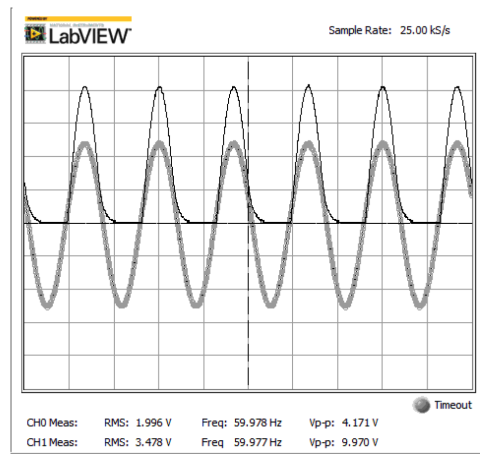


Fig. 16. Simulation of the rectifier with a 1 μF capacitor.

When the capacitance is increased to 100 μF, which decreases the time constant and increases the discharging time, the output amplitude shows the appearance similar to a DC voltage. Fig. 17 shows such behavior in the simulation.

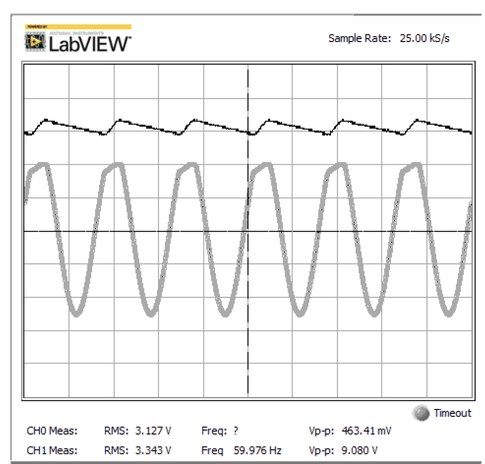
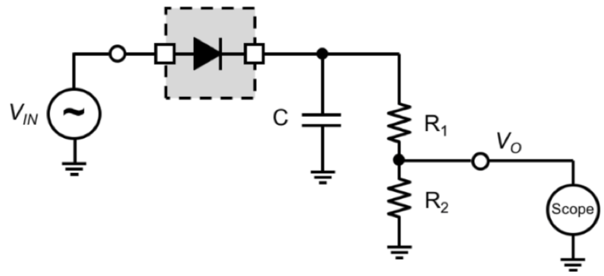


Fig. 17. Simulation of the rectifier with a 100 μF capacitor.

For the half-rectifier with 100 μF capacitor, the peak amplitude of the output function decreases to around 0.46 V. Given by $V_{p-p} = \frac{1}{f \cdot C}$, using this formula, we obtained a ripple frequency of 240 kHz when a 1 μF capacitor is used and 22 kHz when a 100 μF capacitor is applied.

E. Part 5: Voltage Regulation Using Zener Diode



(a)

Fig. 18. circuit diagram of the rectifier with a voltage divider at its output.

By using the basic format structure of the circuit from the previous section, we replaced the 1 kΩ resistor to R_1 and attaching an addition R_2 in series with R_1 to form a voltage divider (see Fig. 18). We constructed R_1 as two 100 Ω resistors in series with two 100 Ω resistor in parallel which would have an equivalent resistance of 250 Ω, on the other hand we used two 1 kΩ resistors in parallel and in series with Two 100 Ω in series which is in series of two 100 Ω resistor in parallel, in such a way we have R_2 = 750 Ω.

The output voltage is measured in Fig. 19.

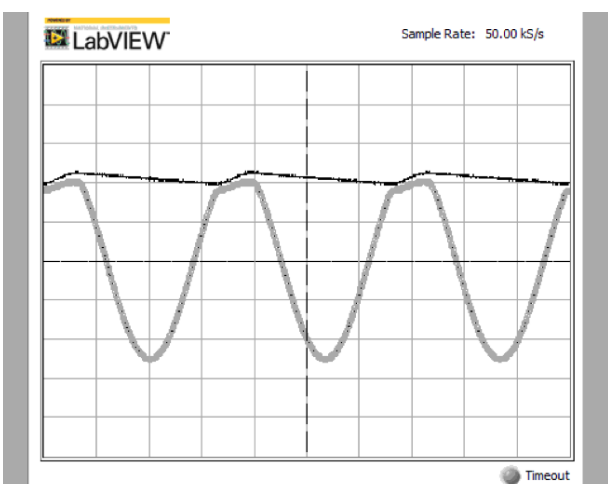
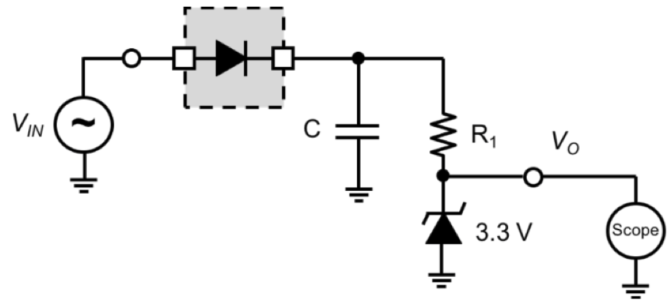


Fig. 19. output voltage with voltage divider (input is grey and output is in black)

The average output voltage is at 3.3V. The ripple is similar to the one in part IV, however, its amplitude has been divided, which makes this approach to have the smallest AC ripple.

We modified the circuit furthermore, by adding a zener diode in series with R_2 and replace the oscilloscope to the node where the Zener diode and R_2 attached as shown in Fig. 20.



(b)

Fig. 20. circuit diagram of the rectifier with a regulating Zener diode

The output measurement and the input measurement is as shown below in Fig. 21.

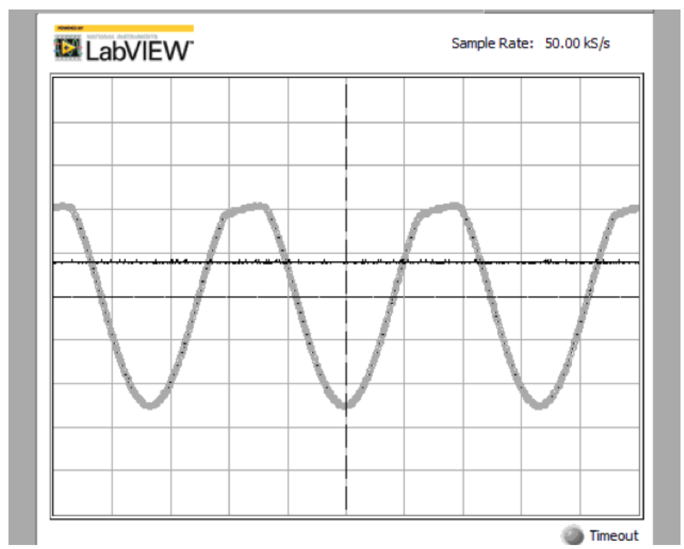


Fig. 21. output voltage signal with a regulating zener diode

The average output signal is at around 2.3 V, however the signal itself is smooth and have now visually detectable ripples. This circuit obviously provides the least AC ripple among every other method we have tried previously (including the resistor divider format).

F. Part 6: Limiter Circuit Using Diodes

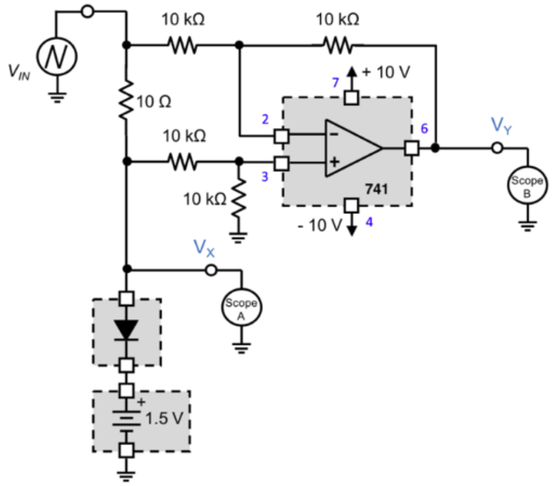


Fig. 22. circuit diagram of the voltage limiter with 1.5 V cell attached

We constructed the circuit as in Fig. 22 suggested, in which this circuit is induced by using a signal with $V_{p-p} = 5V$ and 0.5 V DC offset. The V_x and V_y is measured by using oscilloscope A and B. The result is as shown in Fig. 23 below where V_x is in grey and V_y is in black.

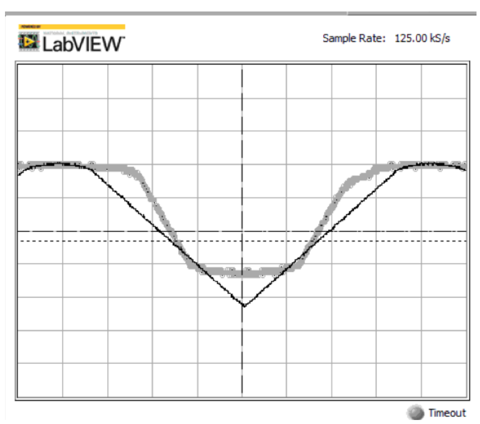


Fig. 23. V_x and V_y signal measured with 1.5 V cell battery in the circuit

We can see that after the as the input is passing 2 V, the battery-diode arrangement will turn on.

Now we remove the 1.5 V battery pack and replacing it with an opposite headed diode in parallel with existing diode in the circuit as shown in Fig. 24.

We re-adjust the input signal by using the function generator to generate a 4 V peak to peak and 0 V DC offset signal. The measured V_x and V_y is as shown below in Fig. 25.

This kind of circuit arrangement can be used in noise cancellation and small signal applications, since the reversed direction diode can limited voltage signal in both too high and too low, because if the nature of the diode too high reversed bias would cause reverse breakdown, thus this kind of circuit does not capable high voltage application.

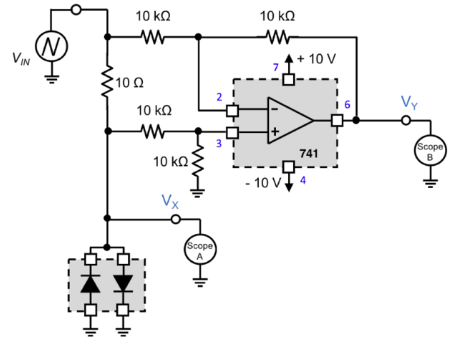


Fig. 24. circuit diagram with reverse direction diodes

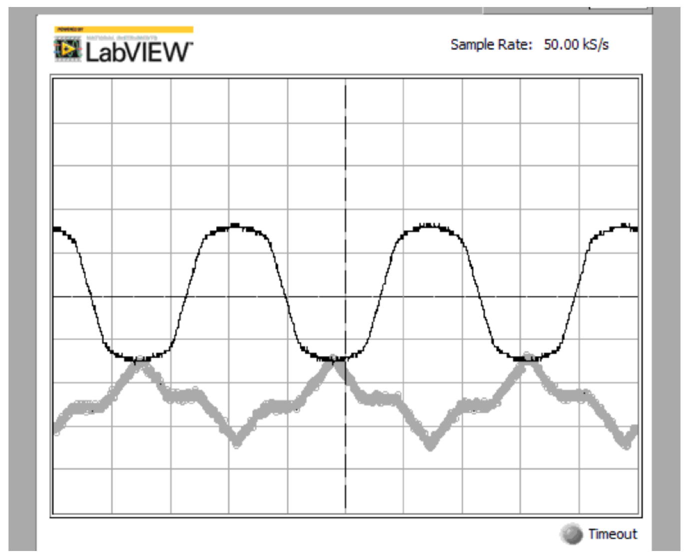


Fig. 25. V_x and V_y signal with reverse direction diodes

III. CONCLUSIONS

To conclude, in this lab, various Op-Amp circuits were built and their behaviors were observed. We saw in this lab that an op-amp contrary to its ideal model has an offset voltage, and small currents entering its inputs. So we found experimentally that op-amps have biased input currents and offset currents.

In this lab, the experiments also showed that the gain of amplifiers is dependent on frequency. It was also observed that if the input is frequency is too high, the output will be disturbed and distorted.