Laboratory 4
Silicon Diodes and Their Applications

ECSE 331: Electronics

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Abstract – This laboratory investigates and discusses the results of several experiments performed with the NI Elvis-II+ Test Instrument. The purpose of the particular lab is to explore the i-v characteristics of a silicon diode as a function of diode voltage. In order to best understand these characteristics, multiple different diodes were analyzed. These include the signal, rectifier and Zener diodes. Furthermore, this lab quantifies the temperature dependence of diodes and its different regions as well as diodes applications in our world.

I. Introduction

Diodes are some of the most basic non-linear elements used in electronics. Diodes are essentially used to move current solely through one direction, although they can be combined to allow much more complex applications. Virtually all modern diodes are constructed using semiconductors, by having a crystalline piece of semiconductor material with a p-n junction connected to two electrical terminals. The most commonly used diodes today are silicon diodes. This is due to silicon's valence electrons which allow for semi-conductor properties, along with the fact that silicon is readily available and cheap. Silicon Diodes can be analyzed from a i-v perspective in order to explore the forward, reverse and breakdown regions. These regions are defined from a i-v graph and show key aspects of diodes. Different diodes have different breakdown regions which make them suitable for certain applications. In this lab we will investigate the breakdown regions of different diodes, as well as the temperature dependence and the different applications of the diodes as rectifiers, voltage regulators and limiters.

II. Project Report

For the first part of this lab, we built a curve-tracer in order to measure the i-v characteristic of a silicon diode. The circuit built uses the 741 op-amp and the 1N4148 signal diode (see Appendix A). We then applied a triangular waveform over a -2V to +2V signal range, with a 1kHz signal frequency. In order to test for the circuit, we placed a 100Ω resistor instead of the diode. As such, we were able to test how our circuit would behave with a resistor. Figure 1 shown below shows the input / output relationship of our circuit.

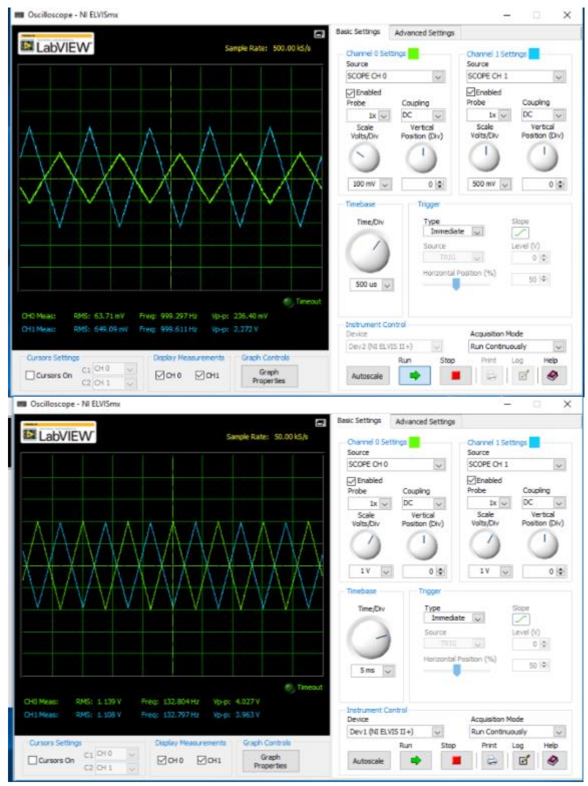


Figure 1: Input/Output of the circuit in Appendix A using a 100 Ω resistor instead of the diode

As can be seen from the figure above, the triangular input applied resulted in a triangular output. It can also be seen that the output graph (shown in blue) has a much higher amplitude than the input (shown in green).

The voltage is ten times larger than the current, thus we set the input scale to 50mV/sec and the output to 1V/sec. We then proceeded to use SPICE in order to simulate this circuit and verify our results. Our SPICE simulations helped us notice that the i-v characteristic corresponded indeed to a 10kΩ resistor (10kΩ being the equivalent resistance of the circuit).

Next, we replaced the resistor by the 1N4148 signal diode. The results shown by the oscilloscope are displayed below in Figures 2 and 3.

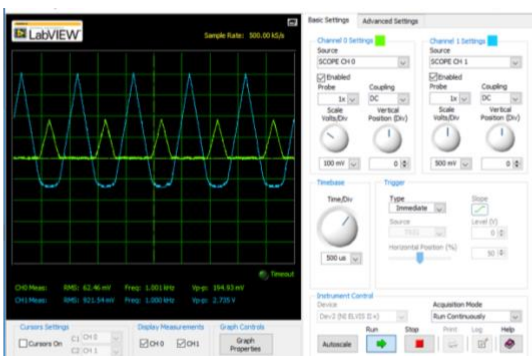


Figure 2: Screenshot of oscilloscope results with signal diode, Vin versus Vy

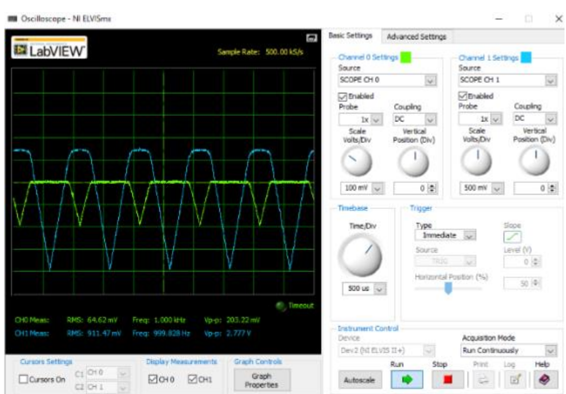


Figure 3: Screenshot of oscilloscope results with signal diode, Vx versus Vy

Next, we replaced the 1N4148 signal diode by the 1N5402 power rectifier diode. The oscilloscope results from this diode are shown in Figure 4 and 5.

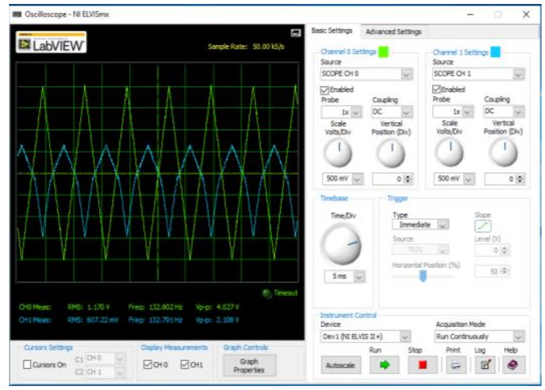


Figure 4: Screenshot of oscilloscope results with power rectifier diode, Vin versus Vy

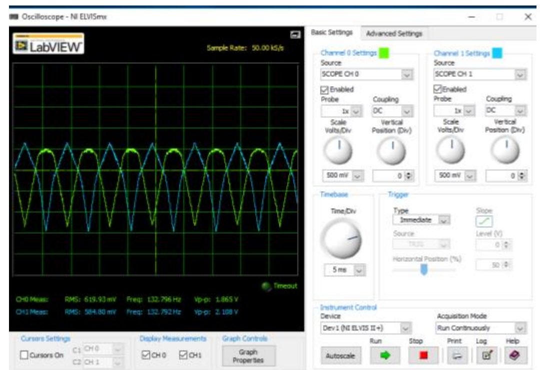


Figure 5: Screenshot of oscilloscope results with power rectifier diode, Vx versus Vy

Comparing the results for the signal and power rectifier shown above, it can be seen that the input and output characteristics are not too different in shape. It would seem however, that the power rectifier diode results in an output signal with a higher amplitude. Furthermore, when looking at the i-v characteristics, we can see that the power rectifier diode can handle more forward current and voltage than signal diodes. This signifies that small signal diodes have much lower power and current rating and would preferably be used in lower voltage and current circuits.

We then proceeded to reverse the direction of the diode while still using circuit from Appendix A. The results of doing this are shown in figures 6 and 7 below.

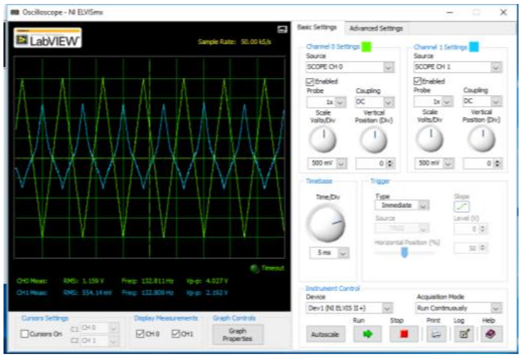


Figure 6: Screenshot of the results for the inversed signal diode

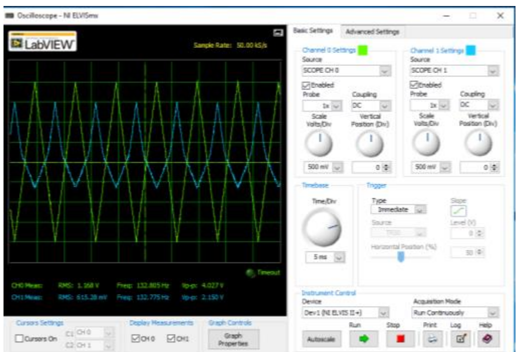


Figure 7: Screenshot of the results for the reversed rectifier diode

By looking at the results above it can be seen that when the diode direction is changed, the output signal is reversed. This seems to be the case when either the rectifier diode or the signal diode is placed backwards.

For the second part of this lab, our goal was to investigate the affect of temperatures on diodes. In order to do so, We displayed the i-v characteristics of diodes at different temperatures. This was done by measuring i-v characteristics at room temperature, at high temperatures (with a hair dryer) and at low temperatures (with a spray cooler). We began by using the signal diode connected to the circuit shown in Appendix A and measured the i-v characteristics at room temperature. The room temperature measured was measured using heat infrared gun and was found to be approximately 21.3°C when this data was taken. The i-v characteristics are shown in Figure 8.

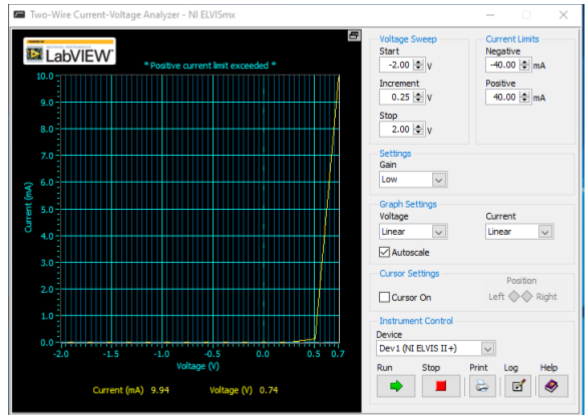


Figure 8: I-V characteristics of diode at room temperature (21.3C)

From this plot, it can be seen that the current limit is approximately 9.74mA at voltage 0.71V.

We then proceeded to use a can of freeze spray in order we cooled the diode to a temperature of 15°C, and plotted its i-v characteristic shown in Figure 9.

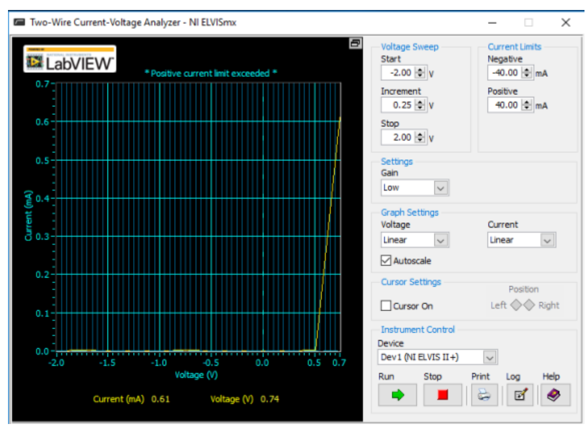


Figure 9: I-V characteristic of diode at colder temperatures (~13C)

As can be seen from above, the current limit for the same voltage (0.71V) is approximately 0.62mA. This is a huge decrease from the 9.74mA measured at room temperature. Hence, it can be concluded that for the signal diode, decreasing the temperature results in a decrease in forward current limit.

In order to investigate this phenomena in more depth, we proceeded to increase the temperature of the same diode using a hair dryer. The temperature was increased to approximately 40°C. The i-v plot of the signal diode at this temperature is shown below in figure 10.

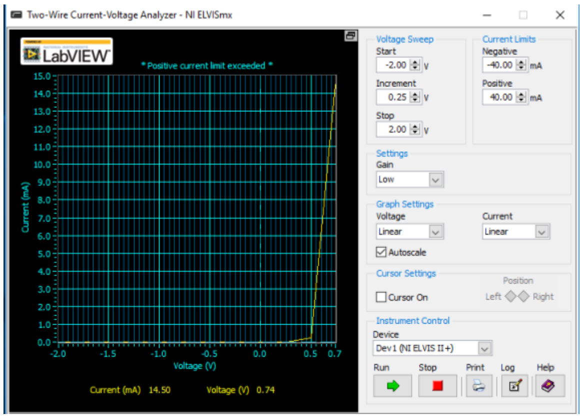


Figure 10: I-V characteristic of diode at hotter temperatures (~29C)

As can be seen from the graph above, the current limit is now higher at 14.5mA for a voltage of 0.71V. Thus, we can say that the behavior of a diode is largely determined by the temperature, in which temperature and current limit seem to be proportional.

The next step of this lab was to investigate Zener diodes. Zener diodes are diodes designed specifically to operate in the breakdown region. As such, in theory, Zener didoes allow a large reverse current to flow at a critical reverse voltage. The circuit constructed for this experiment is shown in Appendix B, with the Zener diode placed in the test port. A triangular waveform was applied in order to get as output a new triangular waveform that varies between -5V and +2V. The results are shown in the figures 11 and 12 below.

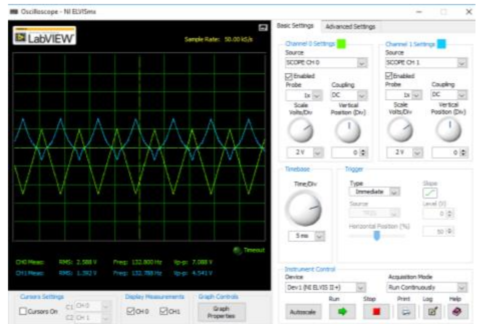


Figure 11: Screenshot of the oscilloscope Vin versus Vy for the Zener diode circuit (AppendixB)

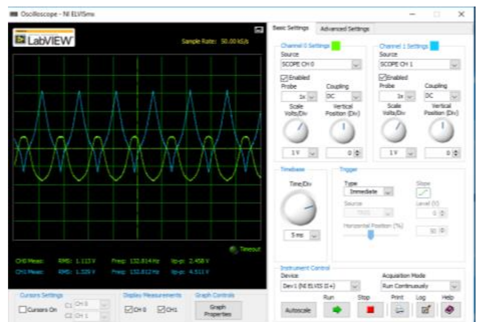


Figure 12: Screenshot of the oscilloscope Vx versus Vy for the Zener diode circuit (AppendixB)

In both the plots above, the input is shown in green and the output Vy is shown in blue. It can be seen quantitatively that the Zener diode breaks down at approximately 1.29V.

Diodes play an essential role in electronics, most notably in rectifiers that allow the conversion of an AC current to a DC current. During our lab, we designed two rectifier circuits. The first one, shown in Appendix C, is a half wave rectifier. We used the 1N5402 power rectifier diode at a 1-kΩ load, with an sinusoidal input of 5V amplitude and 60Hz frequency. The input and output of this circuit were observed using the oscilloscope and the results are shown in Figure 13.

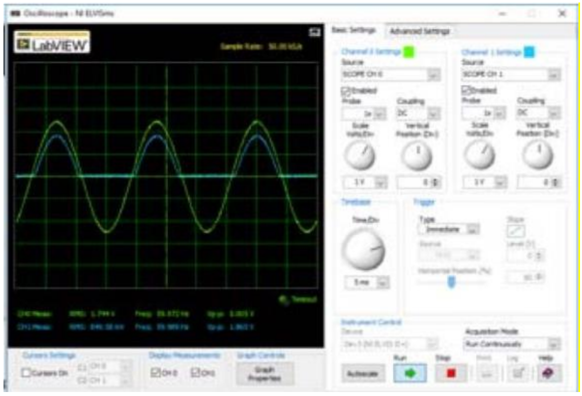


Figure 13: Input/Output of half-wave rectifier circuit of Appendix C

The second circuit we designed was a half-wave rectifier circuit with peak detector, as shown in Appendix D. We used a 1μF capacitor and we observed the output voltage across the load resistor, as shown in Figure 14.

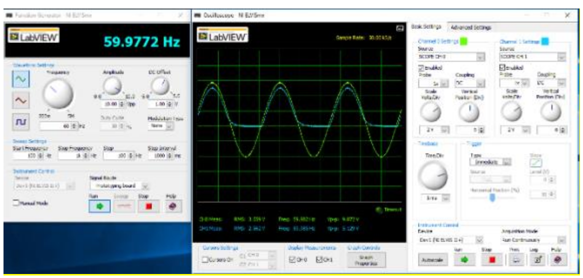


Figure 14: Input/Output of half-wave rectifier circuit with peak detector using 1μF capacitor

The ripples happen with a voltage equal to 5.129V and a frequency of 60Hz. The amplitude of the ripples is 2.56V. We then increased the capacitance to 100μF and observed the output voltage across the load (Figure 15). We note that the new amplitude of the ripples is 252.21mV, about 100 times less that their amplitude with the 1μF capacitor. It seems like there is a inverse linear relationship between the capacitance and the amplitude of the ripples.

In the next part, the goal was to compare two different ways to reduce a DC level from a fixed DC supply, which is done using voltage regulators. We first implemented the circuit shown in Appendix E using a 100μF capacitor and a voltage divider circuit. The voltage divider is supposed to produce an output voltage level of 3.3V, so we used R1 = 1kΩ and R2 = 2.2kΩ. The output voltage at the voltage divider is shown in the figure below.

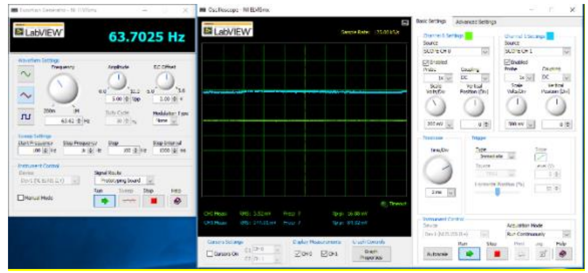


Figure 15: Input/Output of voltage regulator using rectifier diode

We notice that the ripples are at 90mV in this case.

We then replaced the diode by a Zener diode, as well as a series resistor of approximately 1kΩ as shown in Appendix F. The results are shown below.

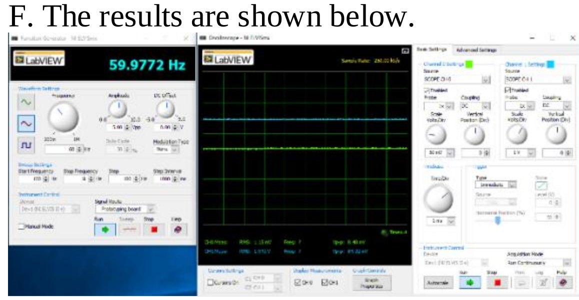


Figure 16: Input/Output of voltage regulator using Zener diode

We noticed that the ripples are reduced to 84mV, relative to the 90mV when we were using the voltage divider. However, the difference is minimal, and we do not believe that our equipment is accurate enough to give any significance to this difference. As expected, the circuit maintains a constant voltage at approximately 3.3V.

In the last part of the lab, we were to design limiter circuits using diodes. We first implemented the circuit shown in

Appendix G. The input/output plots are shown in the figure below.

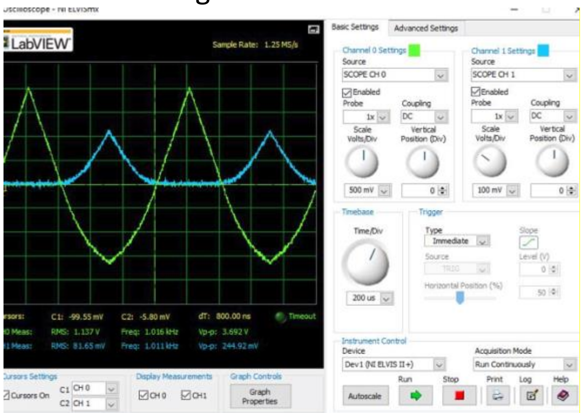


Figure 17: Input/Output for limiter circuit using 1.5V battery

We then implemented the circuit shown in Appendix H, using two diodes in parallel placed back-to-back. The measurement results are shown below.

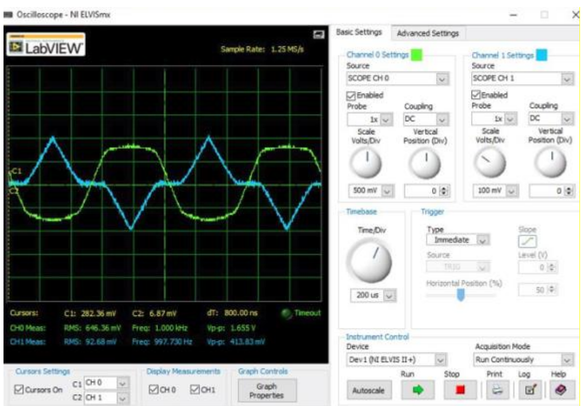


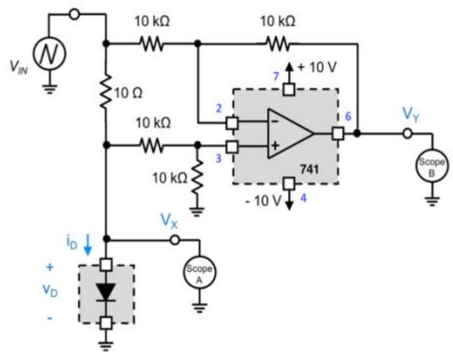
Figure 18: Input/Output for limiter circuit using two back-to-back diodes

We note that this limiter circuit is used to allow signals below a specific amplitude to pass unaffected, and to attenuate stronger signals that exceed the cutoff. Admittedly, this circuit acts as a Low-Pass filter. This circuit is not useful for small signals since they will pass through unaffected. It is however useful for signals with varying amplitudes since it attenuates large signals.

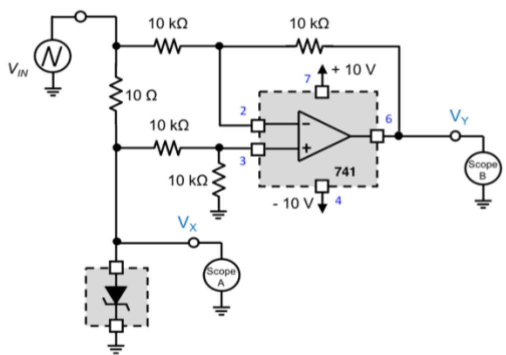
III. Conclusions

In conclusion, we can say that the different types of diodes (signal, rectifier, Zener) behave differently depending on the voltages and currents applied to them. It was seen that signal diodes function better in high frequency applications whereas rectifier diodes function better in situation with high current and high voltage. We also learned that the temperature also has a significant effect on the behavior of the diodes, as we can see very clearly on the i-v characteristics. Increasing the temperature of a diode tends on increase the cut off current, whereas decreasing the temperature decreases the cut off current. Finally, we investigated different circuits with special specifications that can be designed using diodes and that have very important roles in electronics, such as voltage regulators, rectifiers and limiter circuits. It can be seen that these circuits can perform extremely specific outputs depending on which diodes were issued.

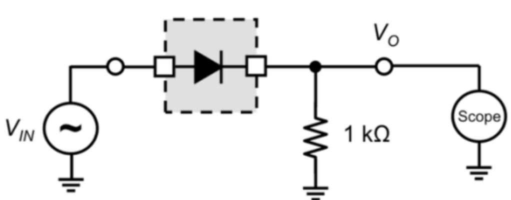
IV. Appendices



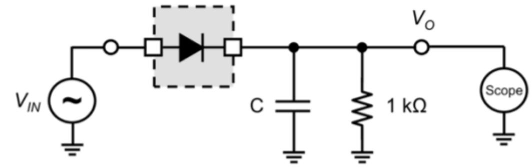
Appendix A: Curve-trace set-up for measuring the diode i-v characteristic



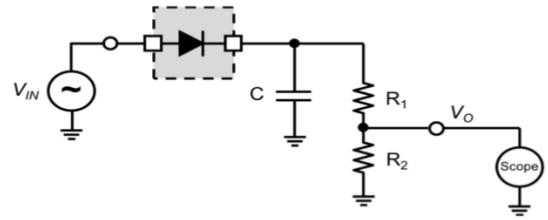
Appendix B: Capturing the i-v characteristic of a 3.3V Zener diode



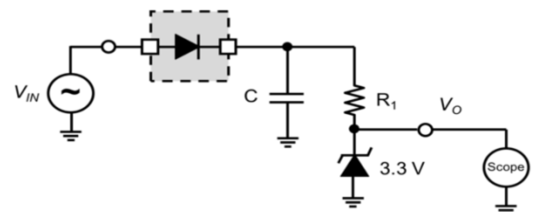
Appendix C: Half-wave rectifier circuit



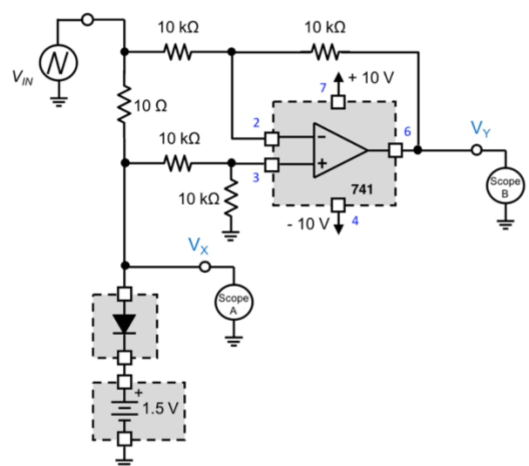
Appendix D: Half-wave rectifier circuit with peak-detector



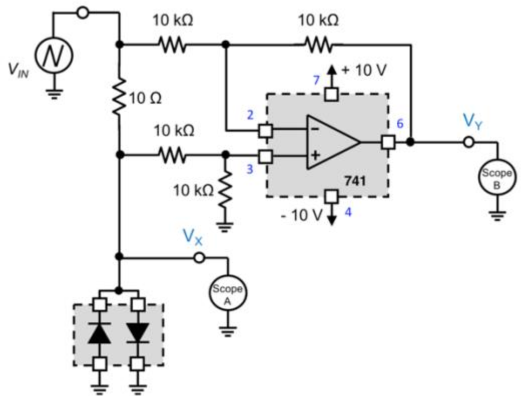
Appendix E: Voltage reference using resistor divider



Appendix F: Voltage reference using Zener diode



Appendix G: Capturing the i-v characteristic of a diode and a 1.5V voltage source called a limiter circuit



Appendix H: Capturing the i-v characteristic of two back-to-back diodes forming another type of limiter circuit