The City College of New York

School of Engineering
EE32200 Electrical Engineering Laboratory 2
Fall Semester

Lab Report Experiment #2
Diodes and Diode Circuits

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Remarks

1 Objective

The diode is quite useful when dealing with AC sources. Some notable uses of diodes in this case are signal rectification and voltage regulation. In this experiment, we will

1. Determine diode and Zener diode characteristics.
2. Test half-wave and full-wave rectifiers.
3. Design and test a non-regulated DC voltage supply.
4. Design and test a regulated DC voltage supply.

2 Procedure

The experiment will consist of six parts:

1. Diode I-V Characteristics
2. Half-wave Rectifier
3. Full-Wave Rectifier
4. DC Power Supply
5. Zener Diode Characteristics
6. Voltage Regulation

2.1 Pre-Lab

Here, we will design each circuit and simulate it.

2.1.1 Diode I-V Characteristics (Simulation)

Design the following circuit:

Figure 1: Simulated Diode Circuit

Sweep the current source in steps of $5\,\mu$A.

2.1.2 Half-Wave Rectifier (Simulation)

Design the following circuit:

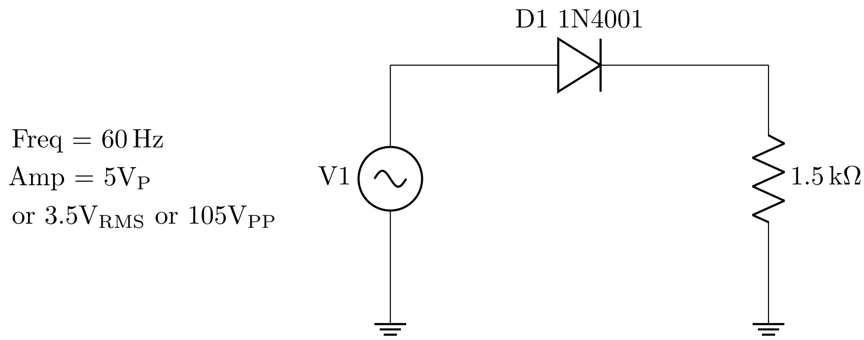

Figure 2: Simulated and Experimental Half-Wave Rectifier

Perform a transient analysis for 5 periods (about 83 ms), where the source and output voltages are on the same plot.

2.1.3 Full-Wave Rectifier (Simulation)

Consider the following design of a full-wave rectifier:

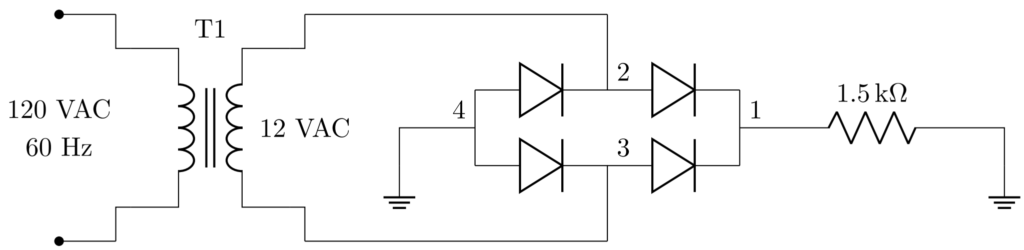

Figure 3: Experimental Full-Wave Rectifier

Now design the following circuit:

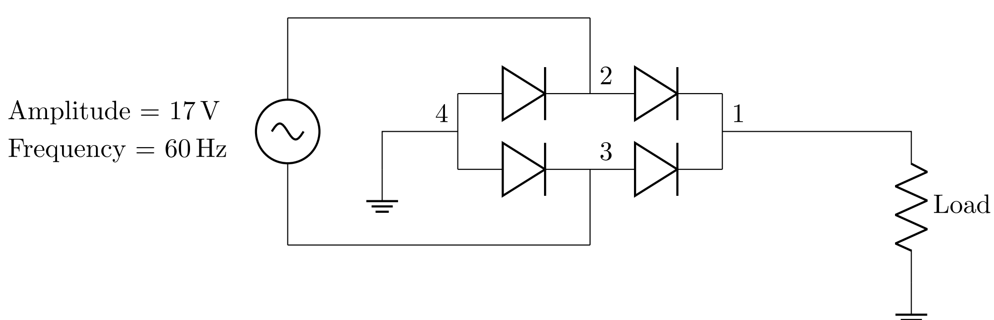

Figure 4: Simulated Full-Wave Rectifier

Perform a transient analysis from 0 to 50 ms (3 periods).

2.1.4 DC Power Supply (Simulation)

Consider the following circuit:

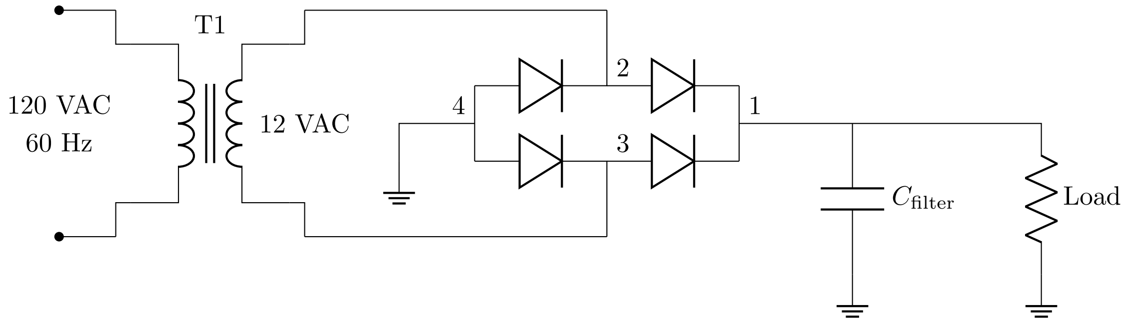

Figure 5: Experimental DC Power Supply

Then design the following circuit:

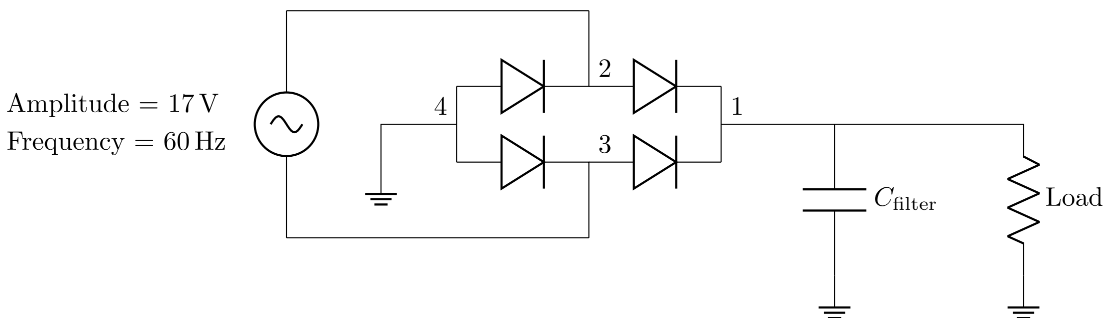

Figure 6: Simulated DC Power Supply

Remark 1 (Design Problen). For a DC power supply, the goal is usually to supply a current to the load, or a voltage across the load (think about Ohm's Law). Furthermore, given that we are converting an AC source to a DC source, there will be a "ripple" in the voltage (or current) supplied. Thus, you will need to calculate the filter capacitance C_{filter} and the load resistance R_L to not only supply a specified load current, but also a specified ripple. Usually, we specify the desired load voltage V_{DC} and the percent ripple (%Ripple) first. Then we calculate the ripple voltage V_{Ripple} using the following equation.

$$\%\text{Ripple} = \frac{V_{\text{Ripple}}}{V_{DC}}$$

If we specify a very low percent ripple, such as 1%, then we should expect a very small ripple voltage relative to the desired DC voltage. From this point, we then specify the desired load current I_L. Due to Ohm's Law, we can calculate the load resistance R_L from the desired DC voltage V_{DC} and load current I_L. Finally, we can use the following equation to calculate the filter capacitance C_{filter}.

$$V_{\text{Ripple}} = \frac{I_L \cdot T}{C_{\text{filter}}} = \left(\frac{V_{DC}}{R_L \cdot C_{\text{filter}}}\right) T$$

Note that what we call the desired load voltage V_{DC} is not determined by C_{filter} and R_L. Instead, V_{DC} is the root mean square voltage of the AC source that is rectified by the full-wave rectifier, thus if we have a AC source with amplitude V_p, then our desired voltage is given by

$$V_{DC} = \frac{V_p}{\sqrt{2}}$$

As for the pre-lab simulation, perform a transient analysis from 0 to 50 ms (3 periods), in which $C_{\text{filter}} = 100\,\mu\text{F}$ and $R_L = 1\,\text{k}\Omega$.

Then design a power supply that can deliver 100 mA of current to the load with only a 5% ripple. Note that while the amplitude of the AC source for the simulated full-wave is 17 volts as seen in Figure 4, the 12 VAC input shown in Figure 6 is actually the rms value of the 17 volt source.

$$V_{\text{rms}} = \frac{V_p}{\sqrt{2}} \longrightarrow \frac{17\,\text{V}}{\sqrt{2}} \approx 12\,V_{\text{rms}}$$

2.1.5 Zener Diode Characteristics (Simulation)

Figure 7: Simulated Zener Diode Circuit

Sweep the source current from -10 to 10 mA in increments of 0.01 mA.

2.1.6 Regulated Voltage (Simulation)

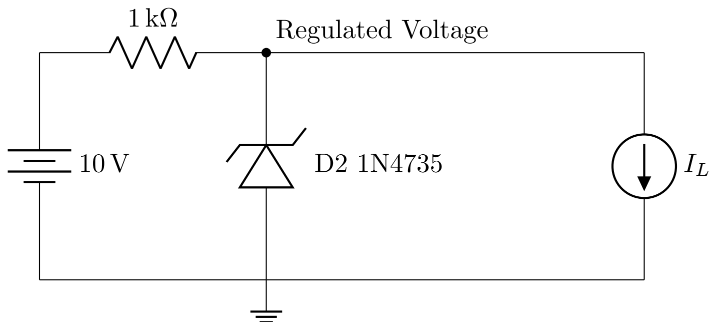

Figure 8: Simulated Voltage Regulation Circuit

Perform a DC Sweep with the load current from 0 to 5 mA in increments of 0.05 mA. Then redo the same DC Sweep with a 5 kΩ resister instead of the 1 kΩ resistor.

2.2 Experiments

Here, we will construct each circuit and test it.

2.2.1 Diode I-V Characteristics (Experiment)

Construct the following circuit:

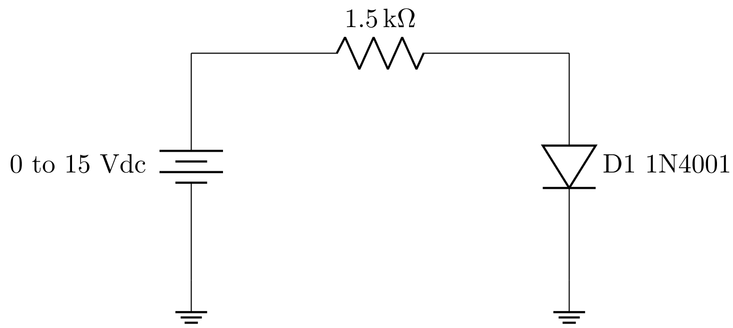

Figure 9: Experimental Diode Circuit

Attach the Digtal Multimeter across the diode and sweep the source voltage from 0 to 15 volts in increments of 0.1 volts.

2.2.2 Half-Wave Rectifier

Construct the circuit in Figure 2. The voltage across the resistor will be the output voltage. Wire the output voltage to channel 2 and the input voltage to channel 1 of the oscilloscope. Set the input coupling to DC for both channels. Then set the vertical scale to `2 volts/div`. Then set the DC level knobs so that the waveforms overlap in the middle of the screen. Then set the horizontal sweep to `5 ms/div`. Save a picture of the oscilloscope using "Save Oscilloscope Image" from LabVIEW VI.

2.2.3 Full-Wave Rectifier

Construct the circuit in Figure 3, then perform the following:

1. Connect the oscilloscope ground to node four.
2. Connect channel 1 to node 1 as the output of this circuit will be the voltage across the resistor.
3. Save a picture of the oscilloscope using "Save Oscilloscope Image" from LabVIEW VI.

2.2.4 DC Power Supply

Construct the circuit in Figure 5, in which you will calculate R_L and C_{filter} such that the load current is 100 mA with a ripple of 5%.

2.2.5 Zener Diode Characteristics

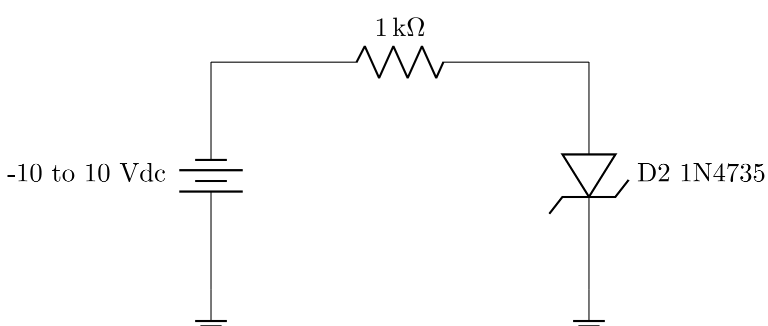

Figure 10: Experimental Zener Diode Circuit

First, measure the diode voltage when the source voltage is at -10, 0, and 10 V. Ideally, the diode voltage will be -6, 0, and 0.6 V respectively.

Then sweep the source voltage from -10 to 10 V by first sweeping the voltage from 0 to 10 V, then flipping the battery, and sweeping from 0 to 10 V again.

2.2.6 Voltage Regulation

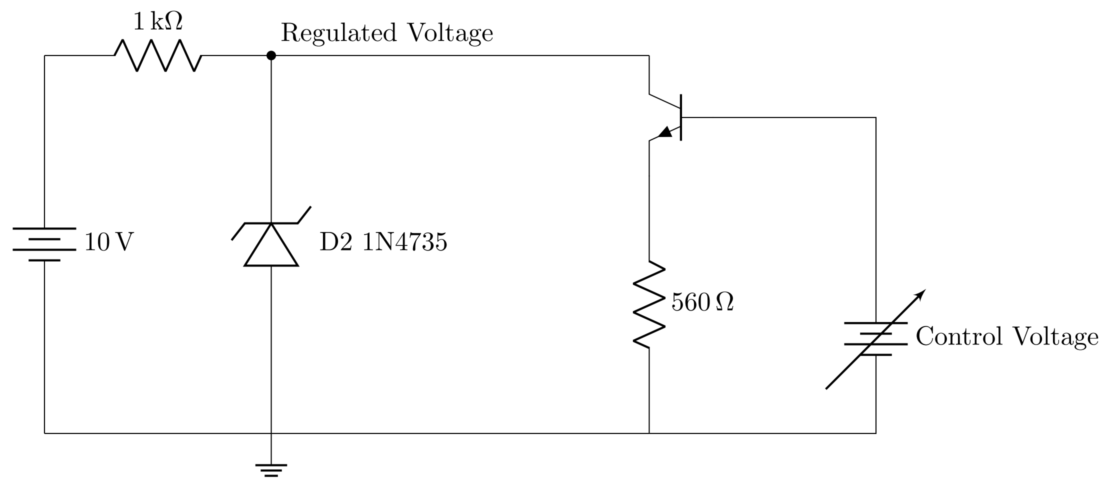

Figure 11: Experimental Voltage Regulator

The control voltage and 10 V source will be given by the 0-6 V and 0-30 V ports on the Regulated DC Power Supply. First, observe the regulated voltage as you change the control voltage from 0 to 4 V. As long as the control voltage is less than 3 V, you should expect to see a nearly constant regulated voltage. Then you will sweep the control voltage from 0.7 to 4 V in steps of 0.1 V.

3 Data Figures and Graphs

Here are a collection of experimental data, simulated data, and analytical figures.

3.1 Simulated Figures

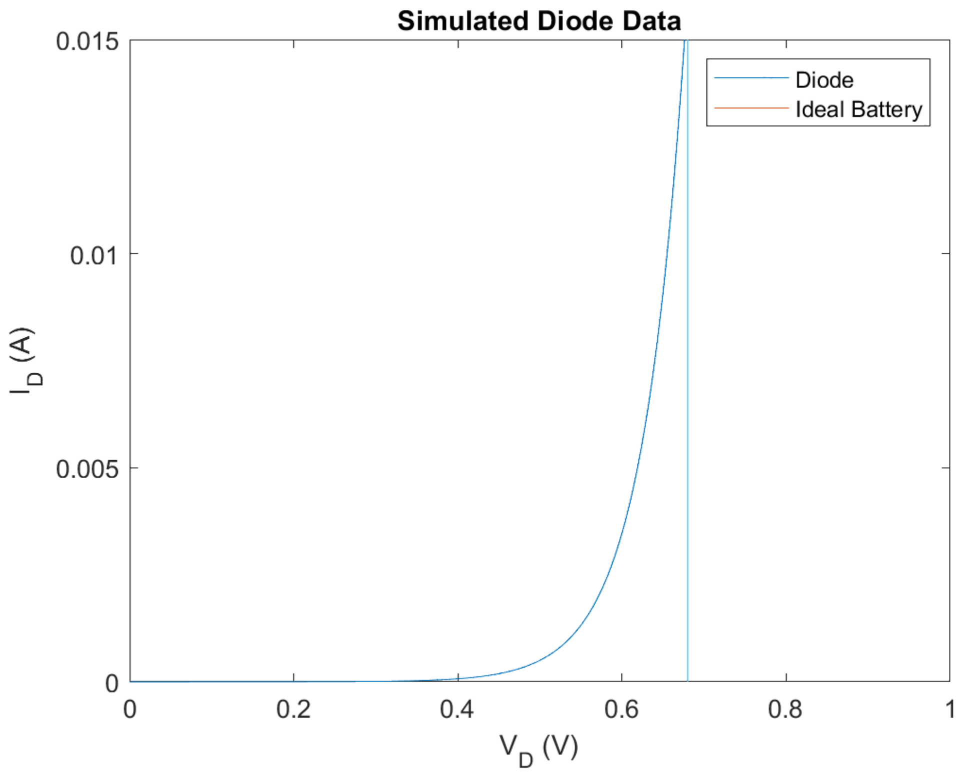

Figure 12: Simulated Diode I-V Characteristics (0 to 15 mA)

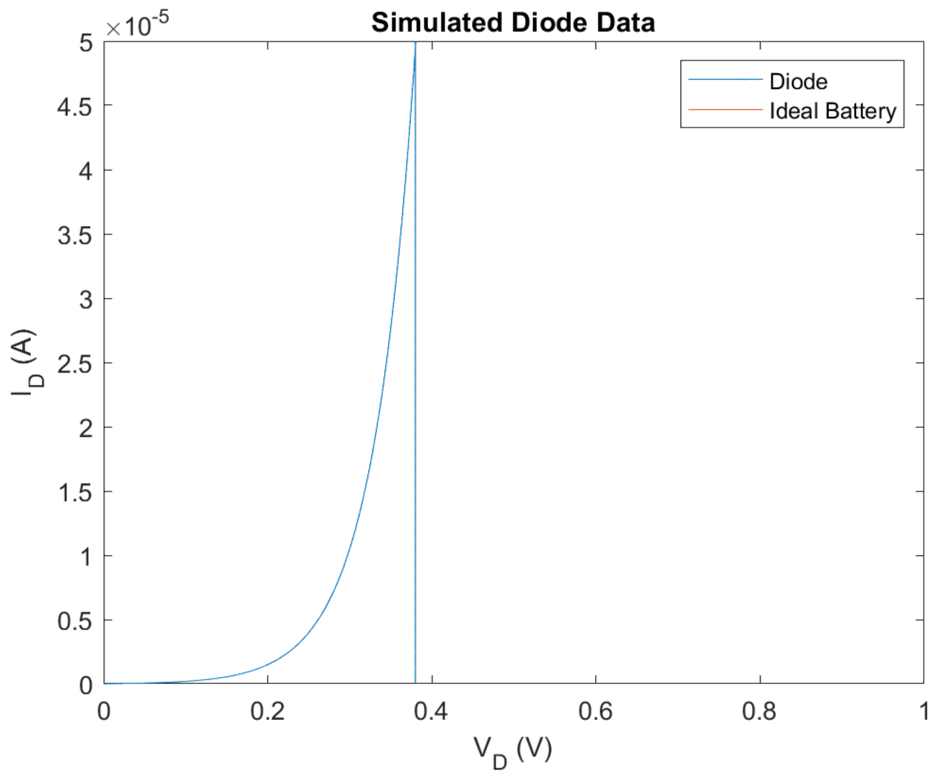

Figure 13: Simulated Diode I-V Characteristics (0 to 50 μA)

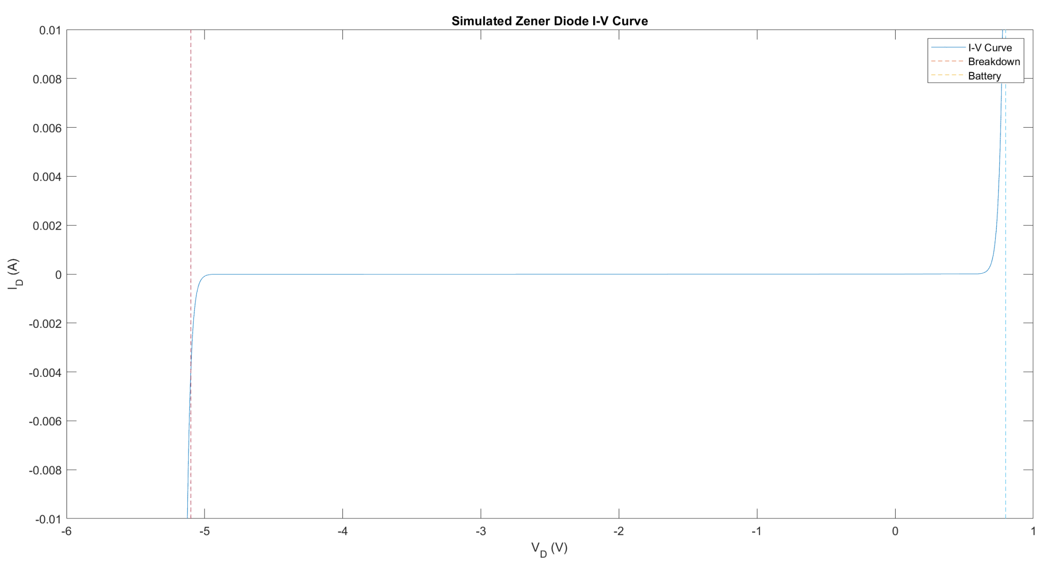

Figure 14: Simulated Zener Diode I-V Characteristics (-10 to 10 mA)

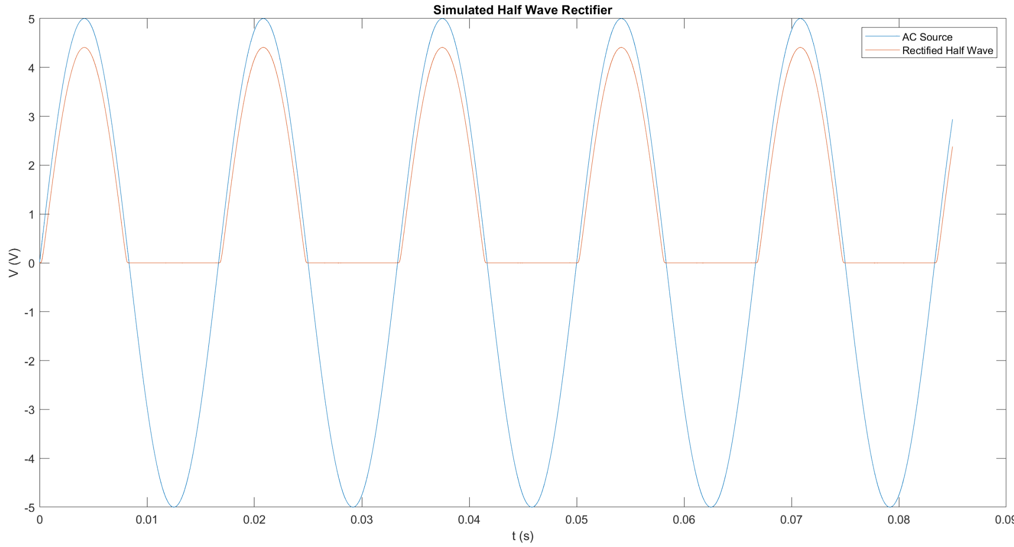

Figure 15: Simulated Half Wave Rectifier

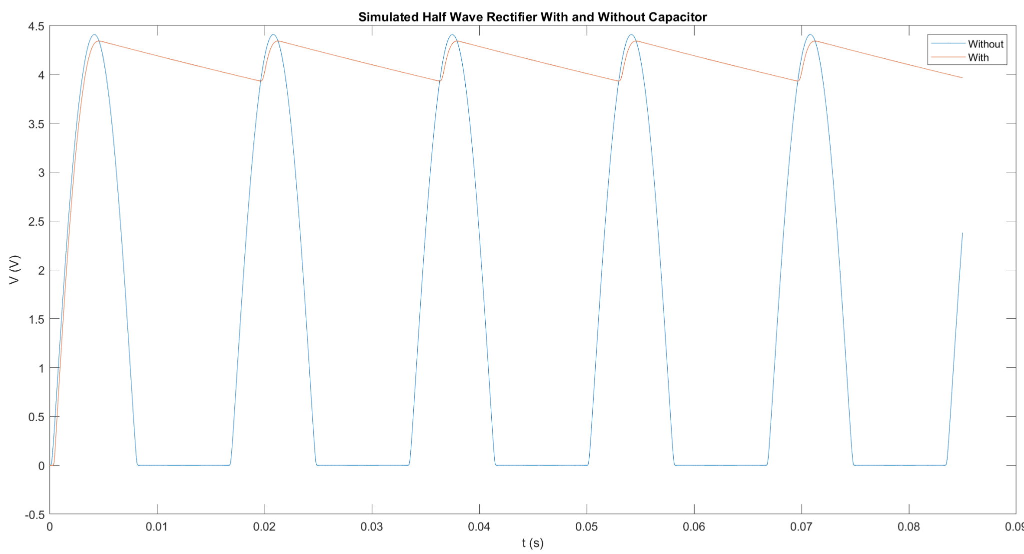

Figure 16: Simulated Half Wave Rectifier With and Without Capacitor

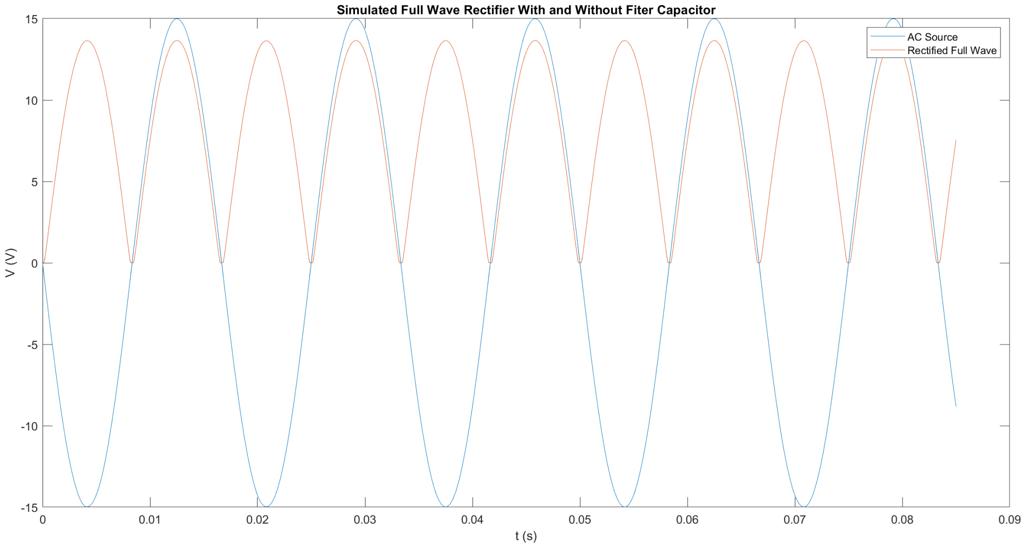

Figure 17: Simulated Full Wave Rectifier

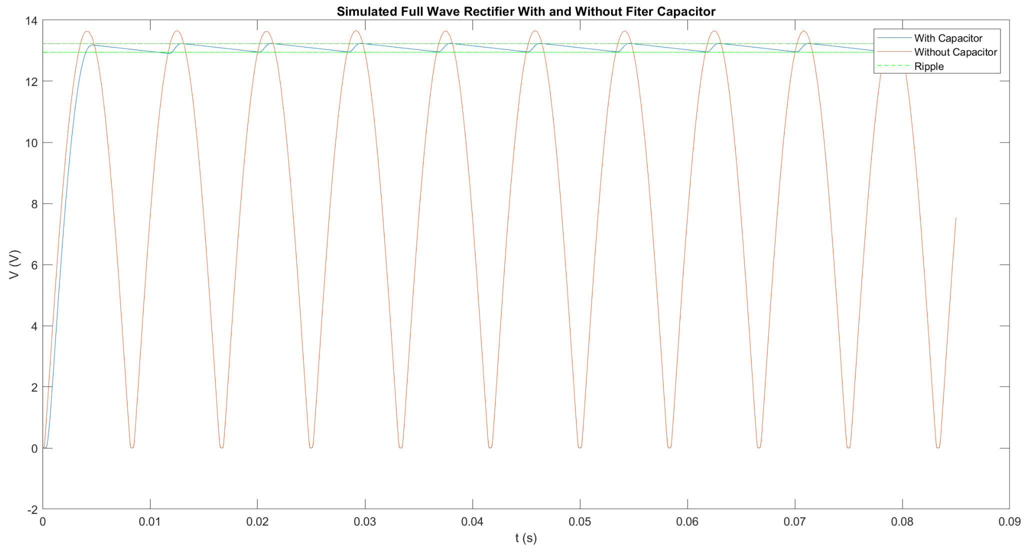

Figure 18: Simulated Full Wave Rectifier With and Without Filter Capacitor

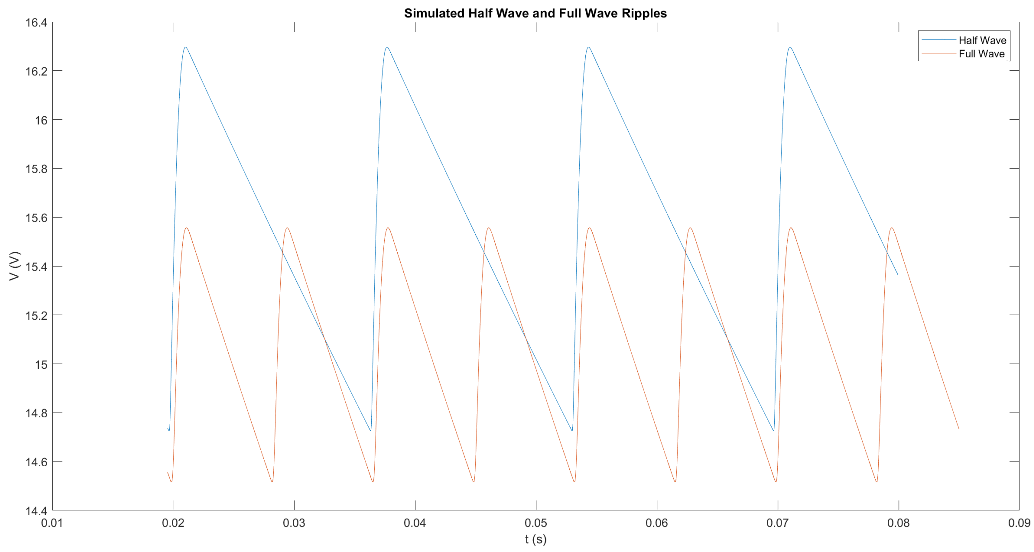

Figure 19: Simulated Half Wave and Full Wave Ripples

3.2 Experimental Figures

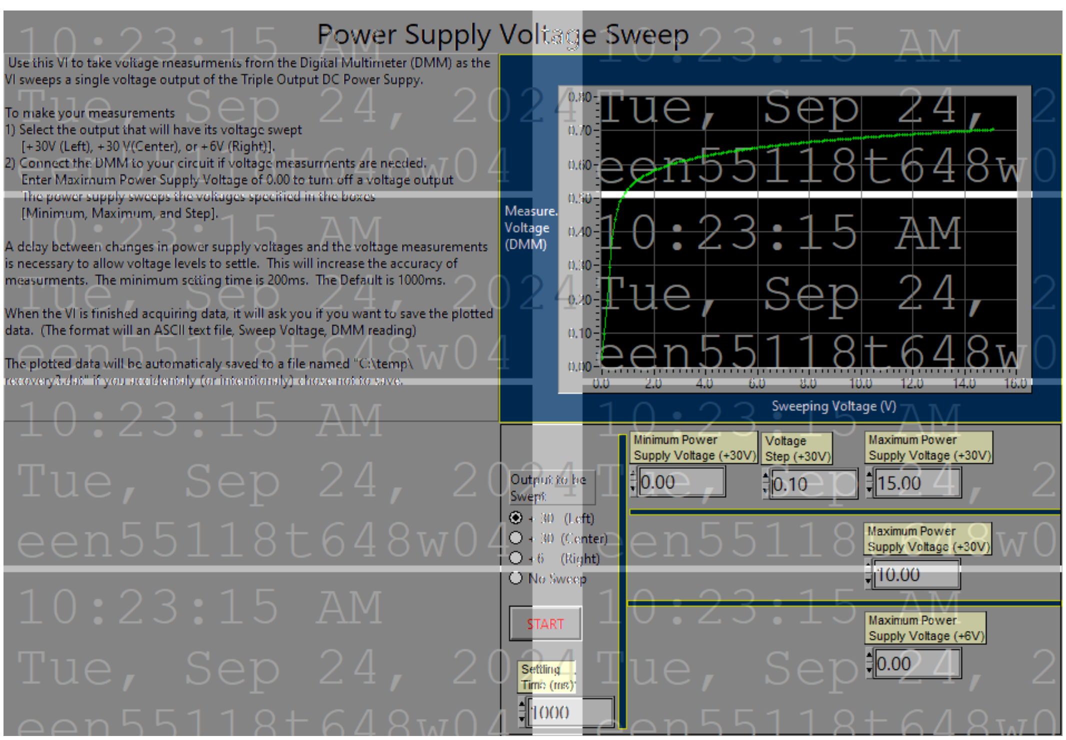

Figure 20: Diode I-V Characteristics

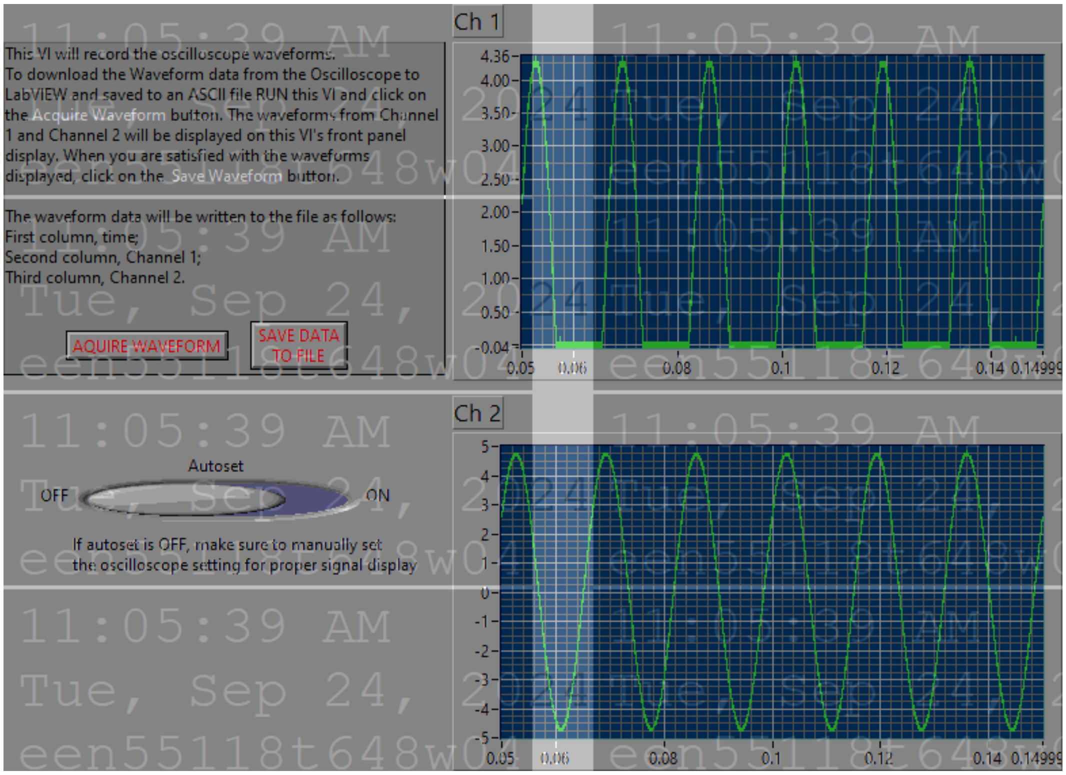

Figure 21: Half-Wave Rectifier Waveform

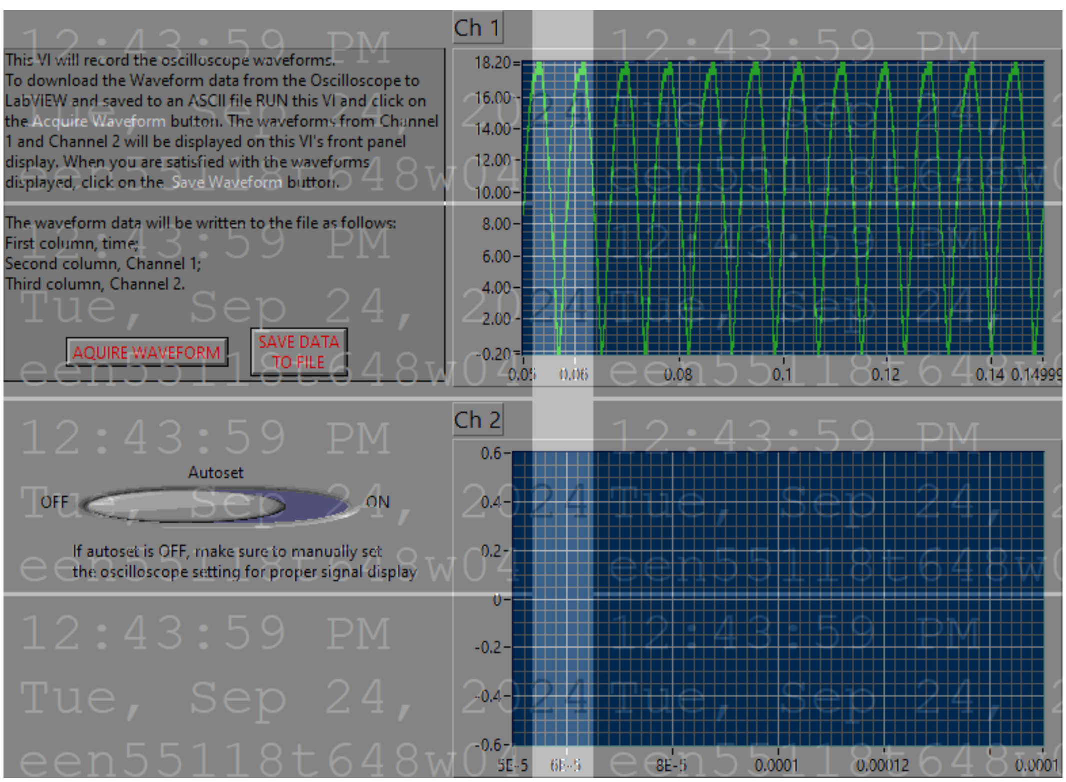

Figure 22: Full-Wave Rectifier Waveform

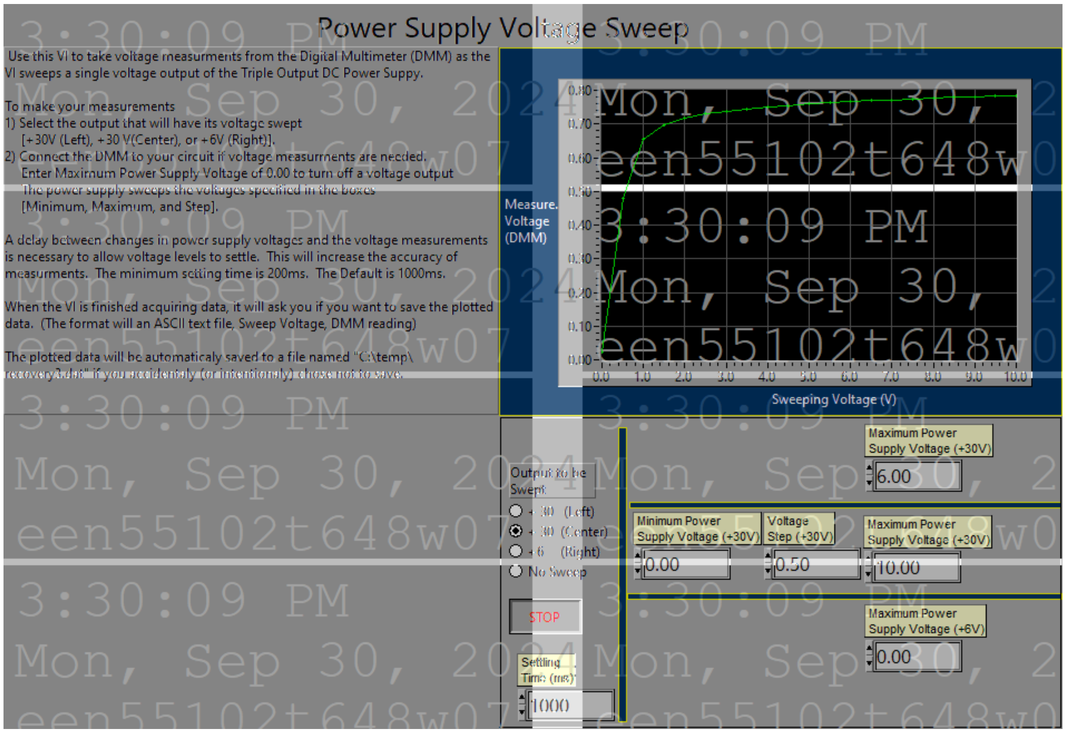

Figure 23: Zener Diode I-V Characteristics for -10 to 0 V

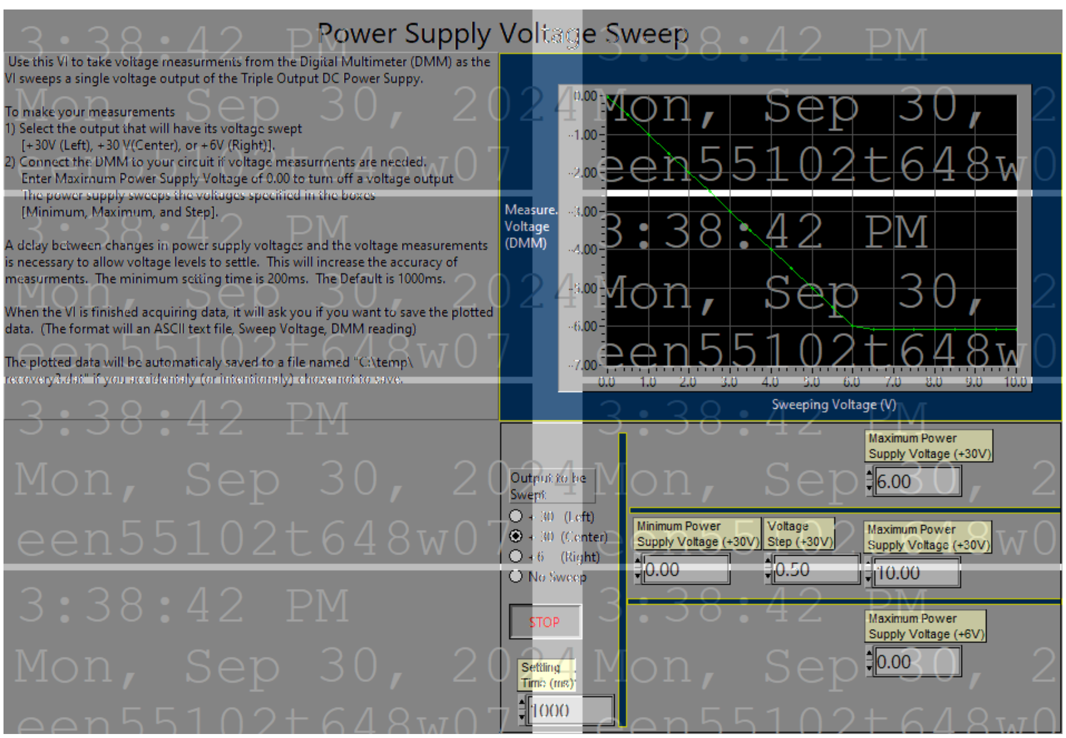

Figure 24: Zener Diode I-V Characteristics for 0 to 10 V

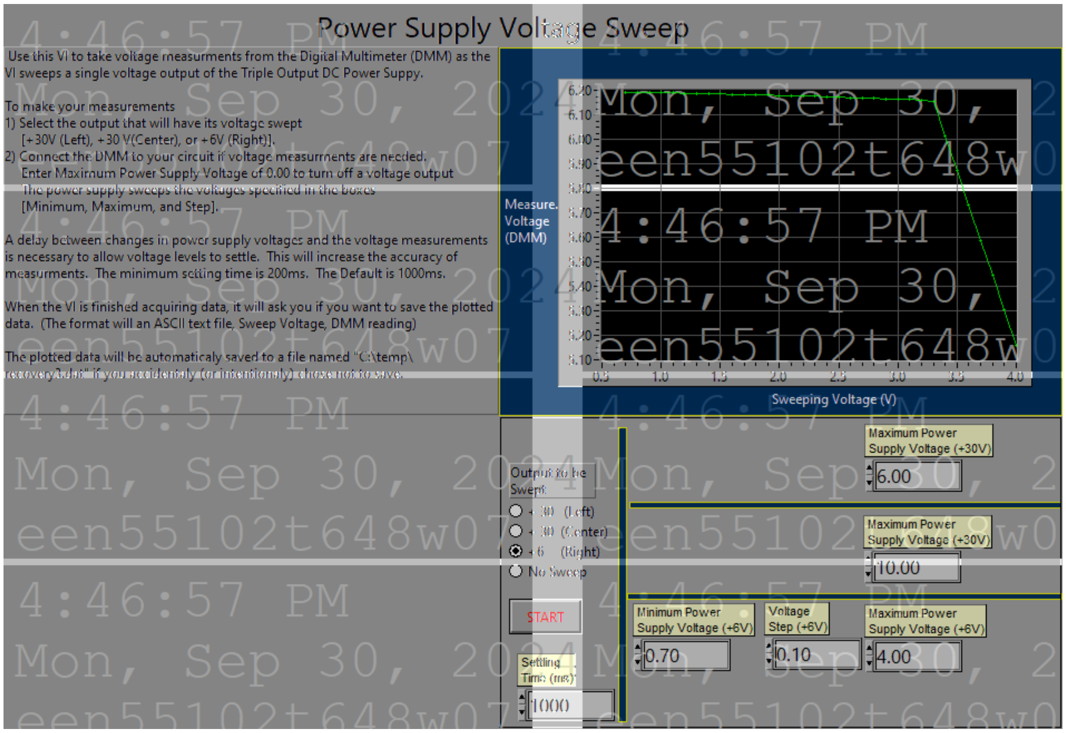

Figure 25: Voltage Regulator from 0.7 to 4 V

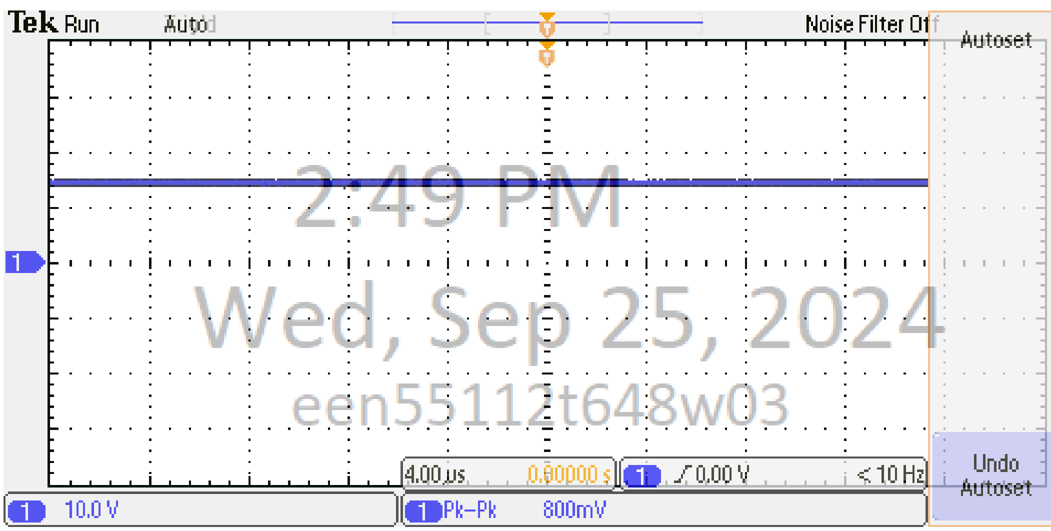

Figure 26: DC Power Supply Oscilloscope Image

3.3 Analytical Figures

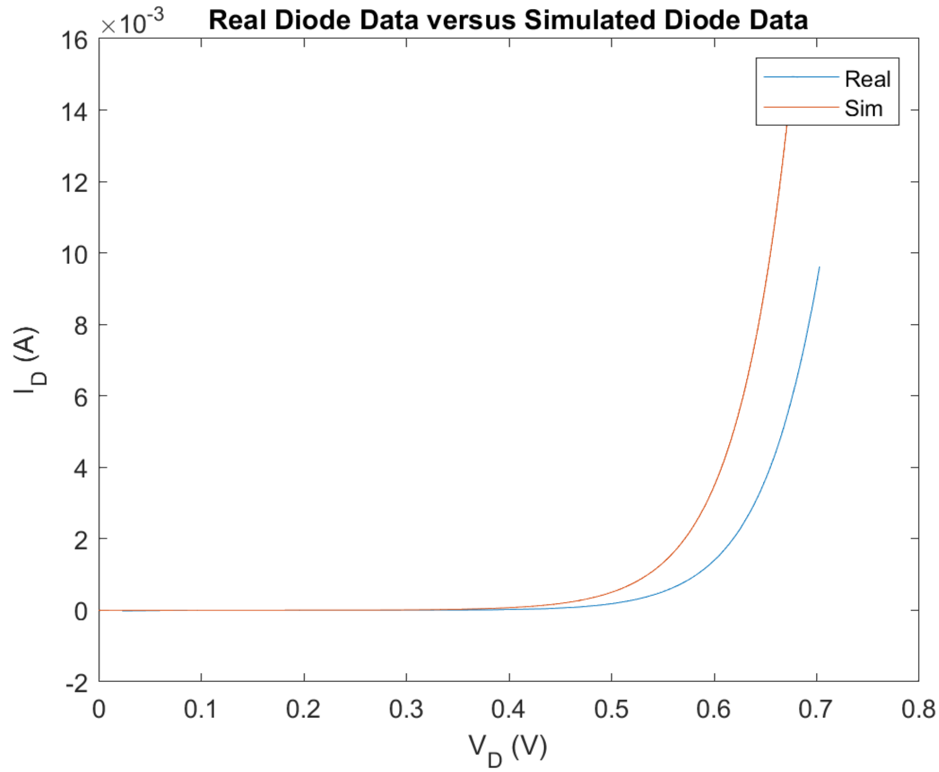

Figure 27: Real versus Simulated Diode

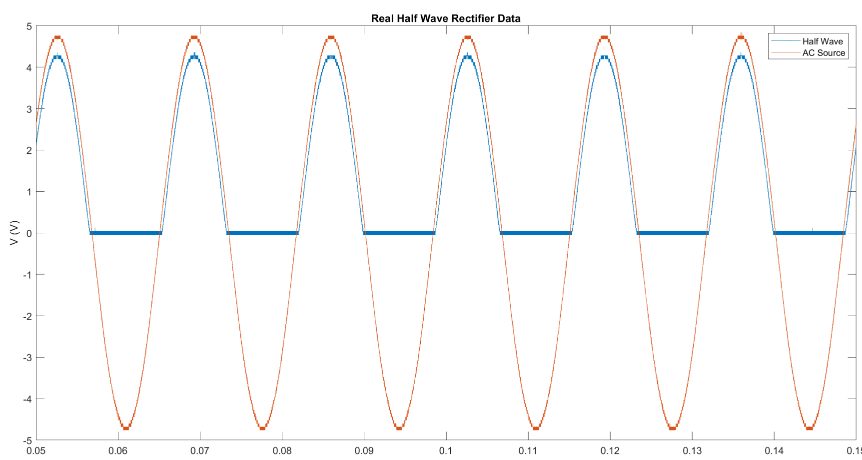

Figure 28: Real Half Wave

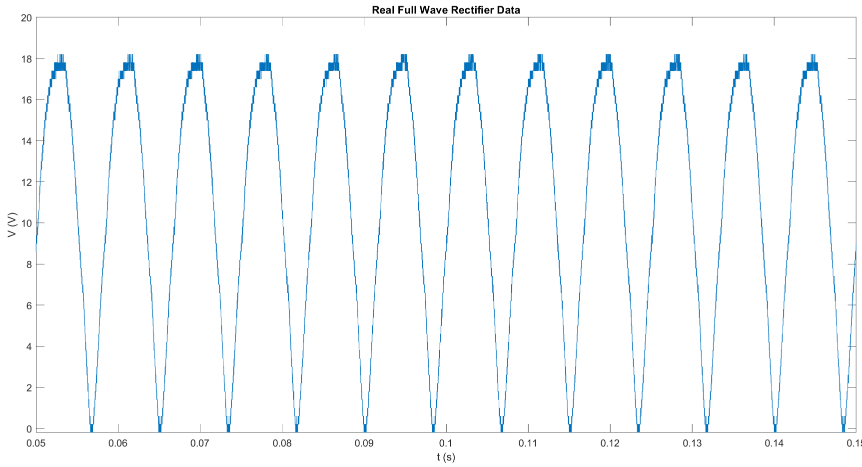

Figure 29: Real Full Wave

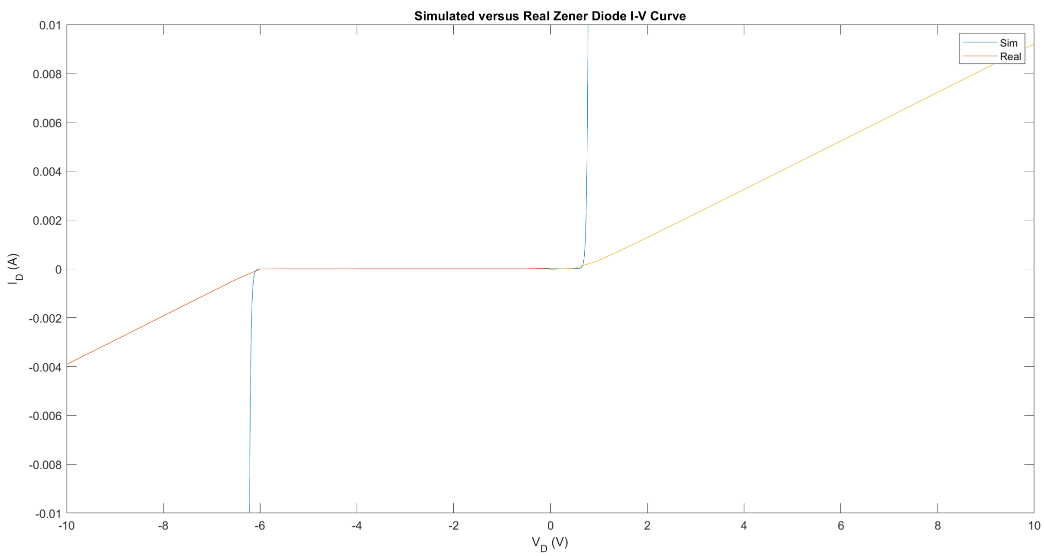

Figure 30: Real versus Simulated Zener Diode

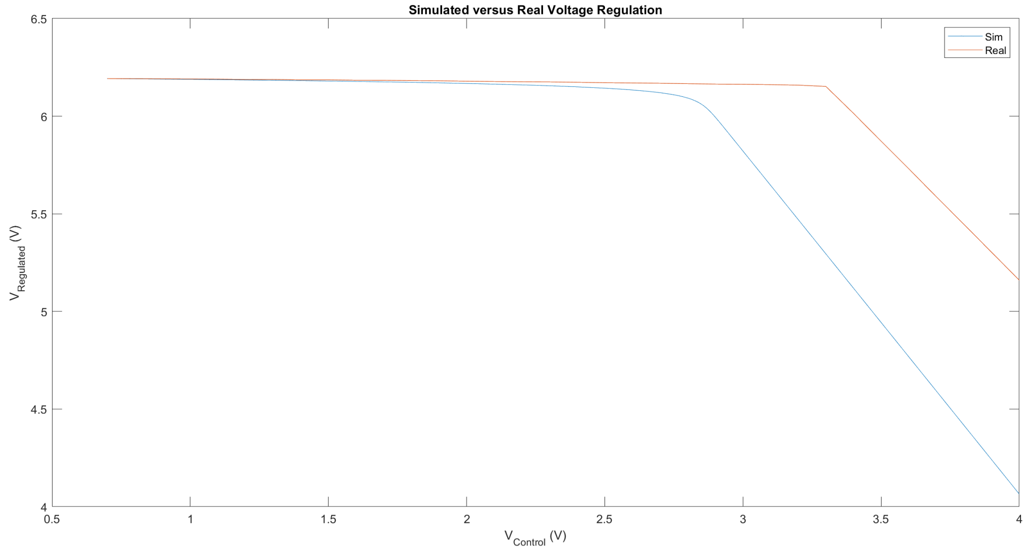

Figure 31: Real versus Simulated Voltage Regulation

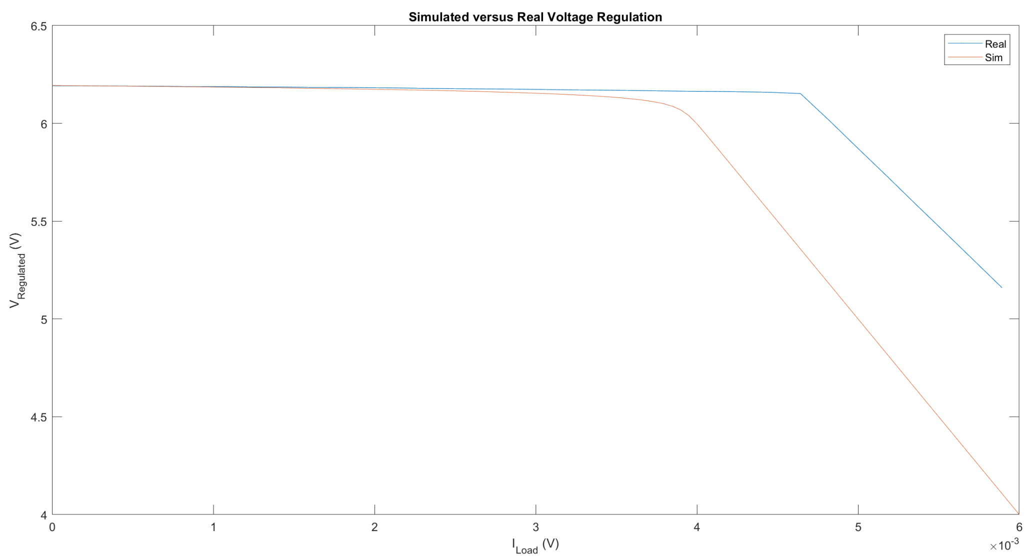

Figure 32: Real versus Simulated V-I Curves of Voltage Regulator

4 Tables and Measurements

In addition to figures, there are tables and manual measruements collected during the experiment.

4.1 Tables

Table 1: Manually Measured Zener Diode Voltages Using the DMM

V_i	V_D
-9.998 V	-6.095 V
0.000 V	0.0 V
9.998 V	0.783 V

4.2 Measurements

For the DC Power Supply, the load current I_L was measured to be about 109 mA and the output voltage V_L was measured to be about 14.2 V. Of course, due to the voltage ripple, the singular measurements taken by the DMM were not exactly stable, with the load current varying by about ± 1 mA and the output voltage varying by about ± 400 mV.

$$I_L = 109 \pm 0.1\,\text{mA} \quad V_L = 14.2 \pm 0.4\,\text{V}$$

5 Circuit Designs and Implementations

Below are the circuit designs and implementations constructed for the experiment.

5.1 Circuit Designs

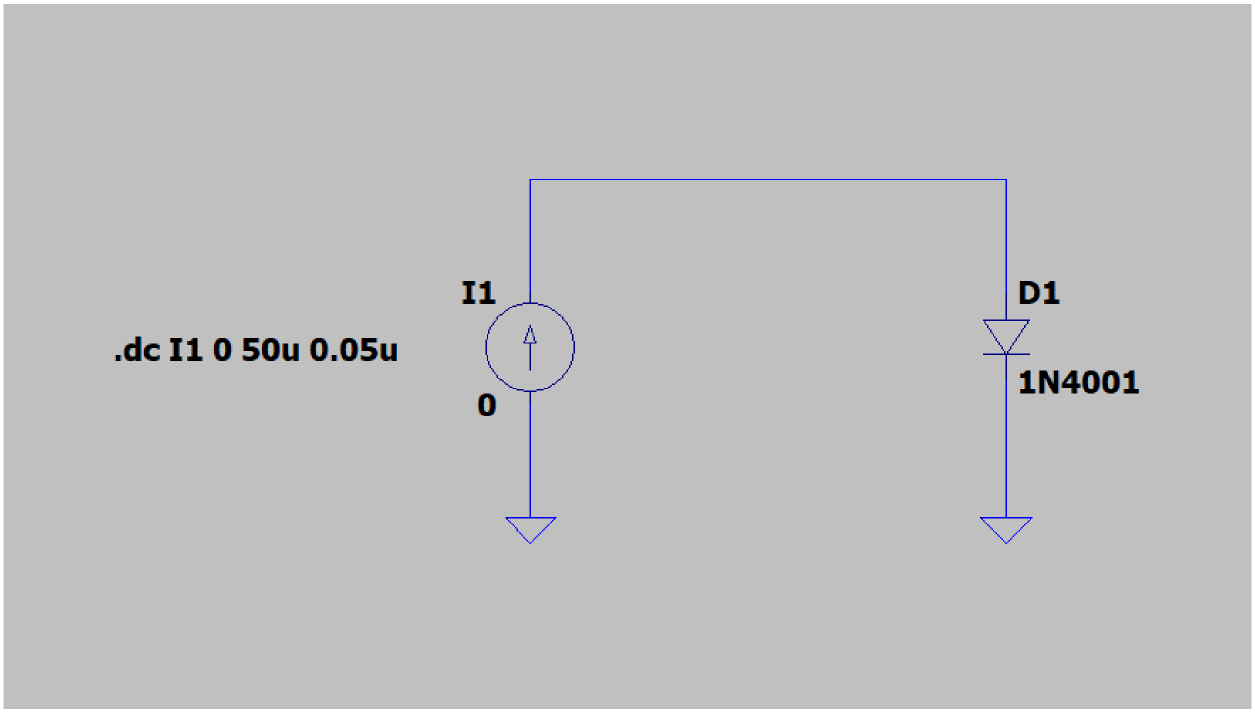

Figure 33: Diode Circuit Design

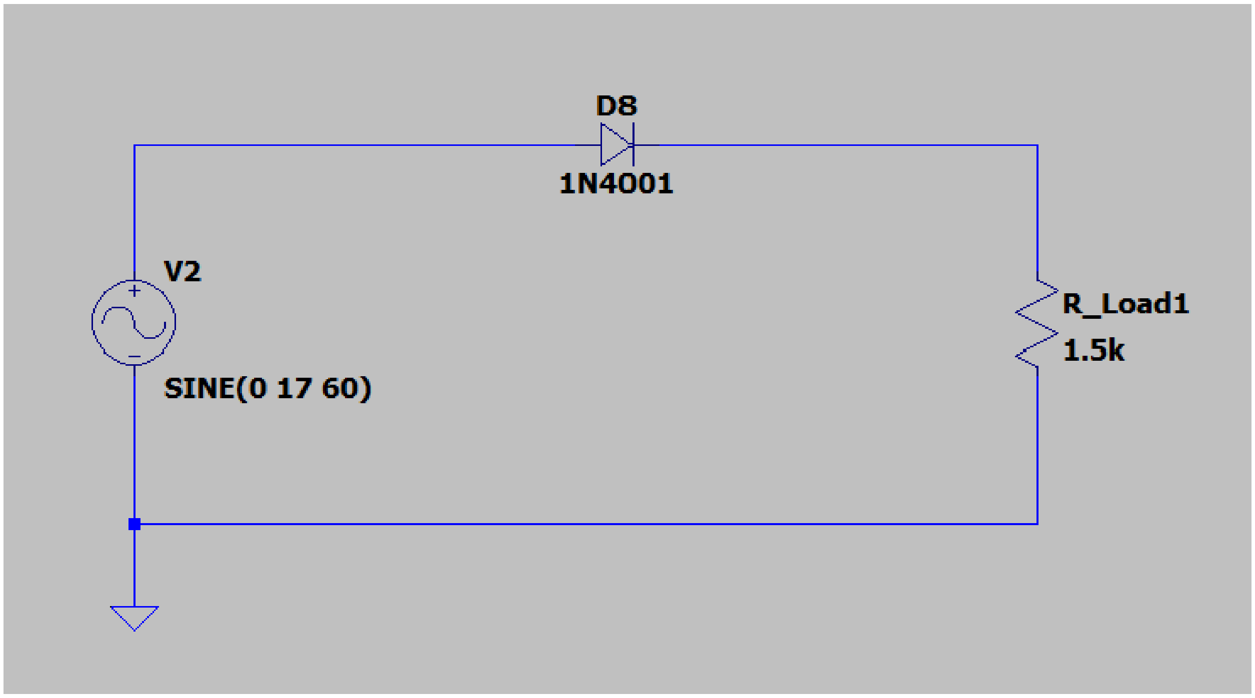

Figure 34: Half Wave Rectifier Design

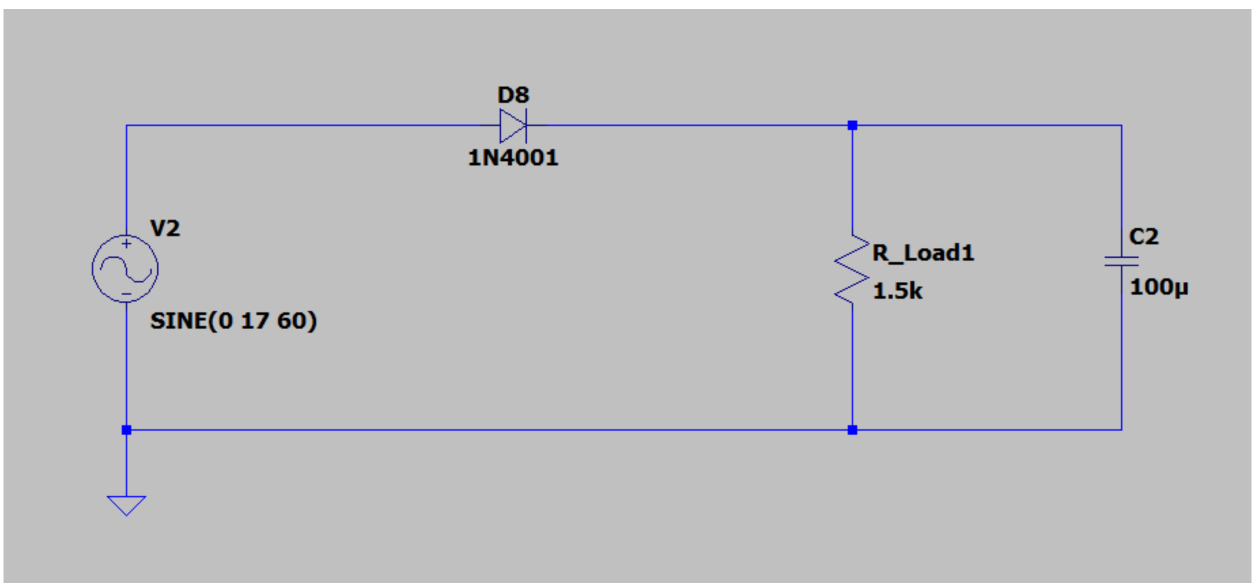

Figure 35: Half Wave Rectifier DC Supply Design

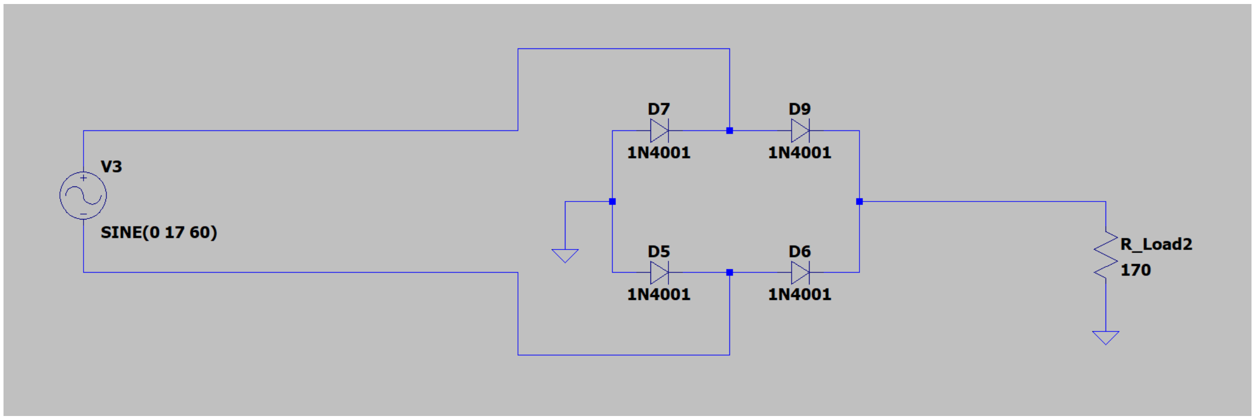

Figure 36: Full Wave Rectifier Design

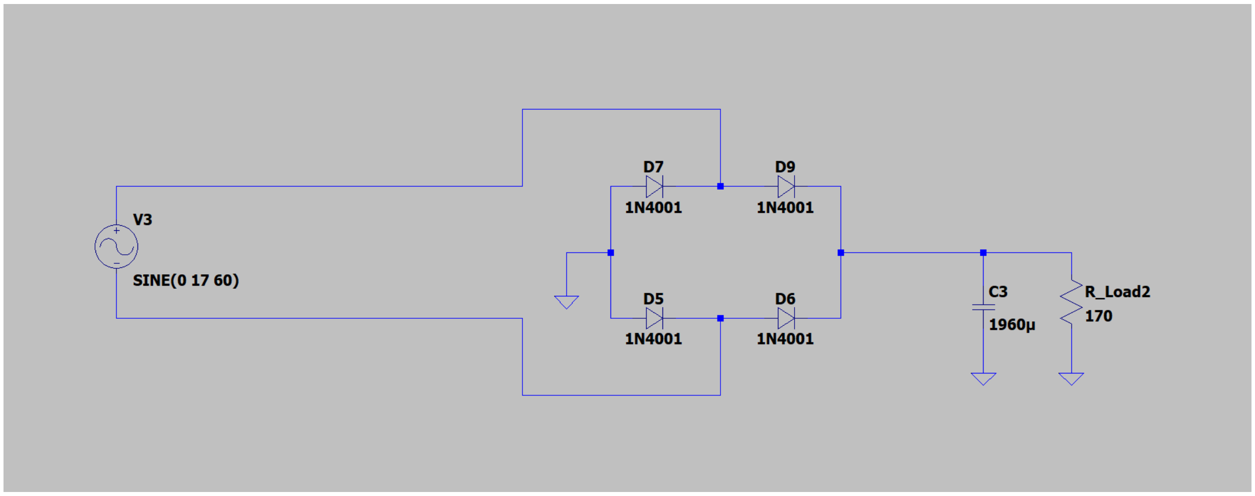

Figure 37: Solution to Design Problem

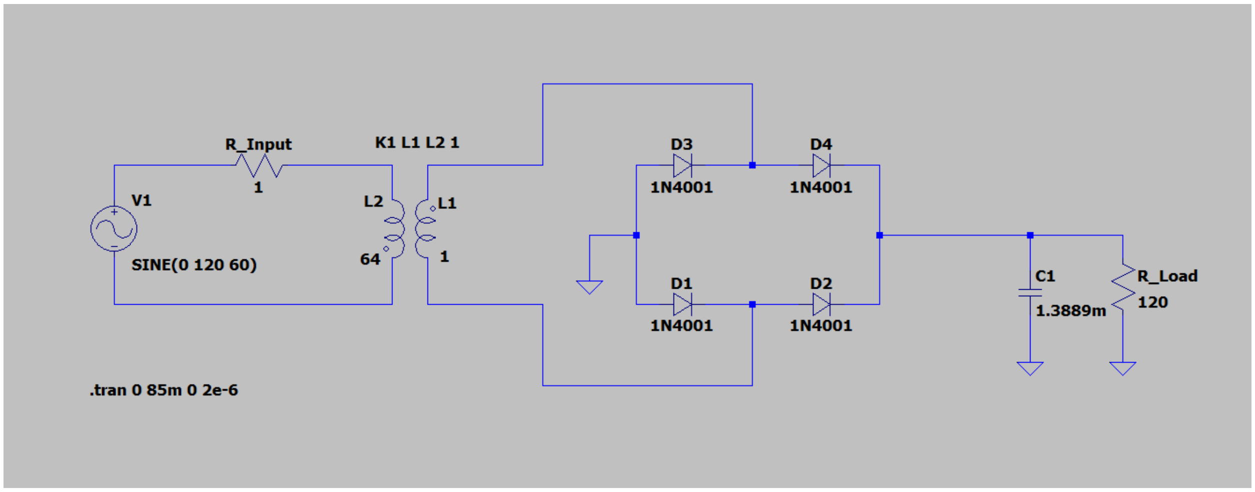

Figure 38: DC Power Supply Design

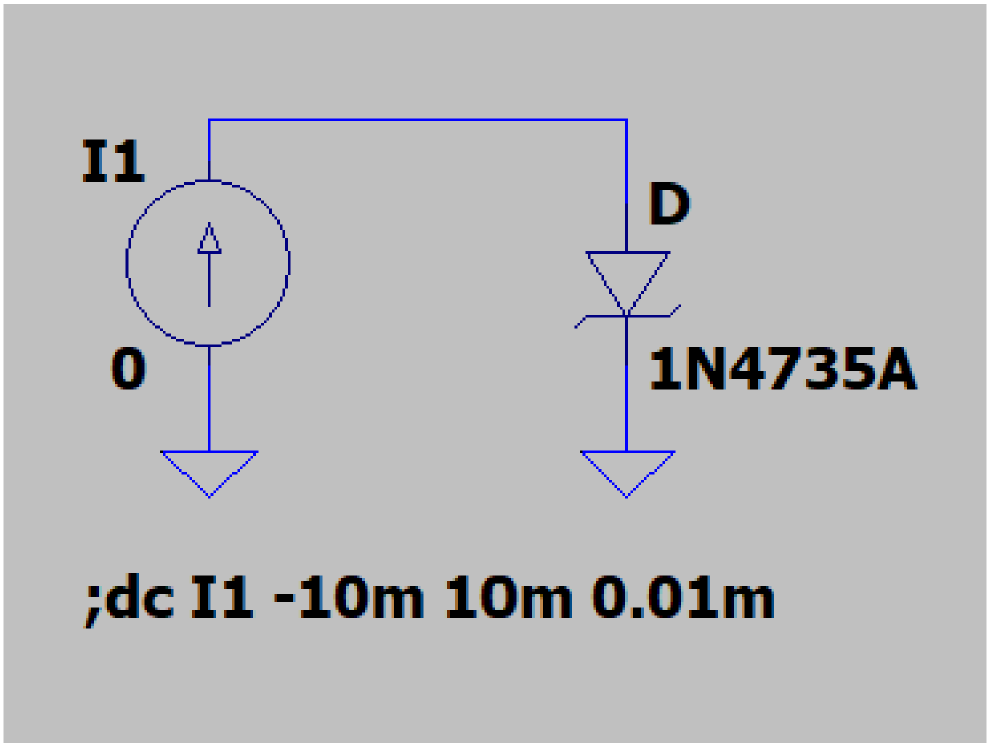

Figure 39: Zener Diode Design

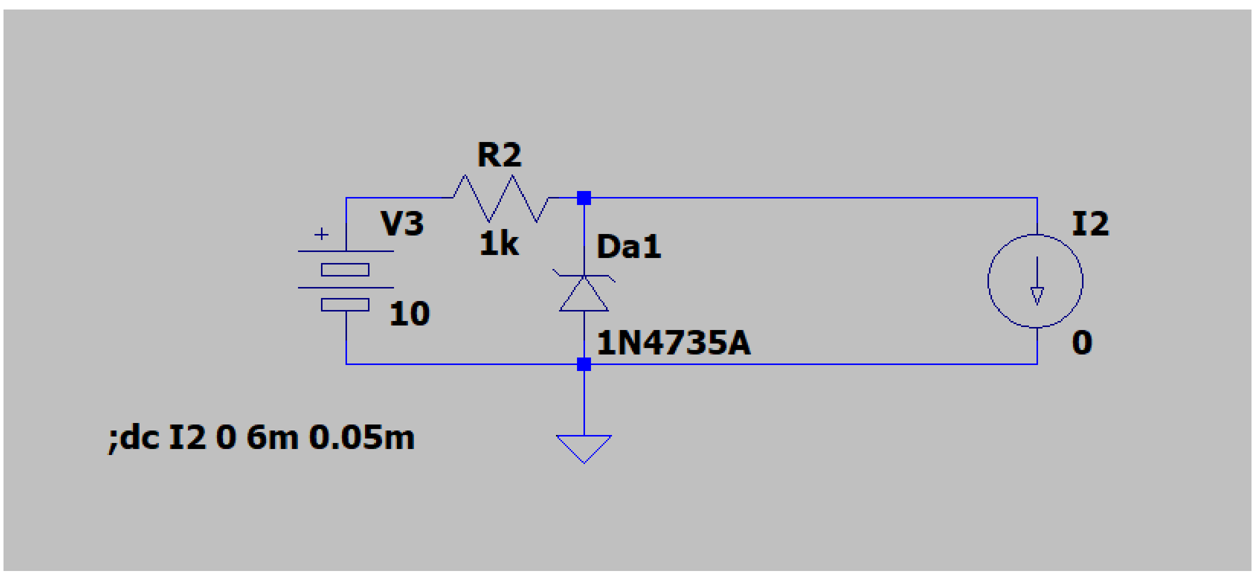

Figure 40: Voltage Regulator Design with Ideal Current Source

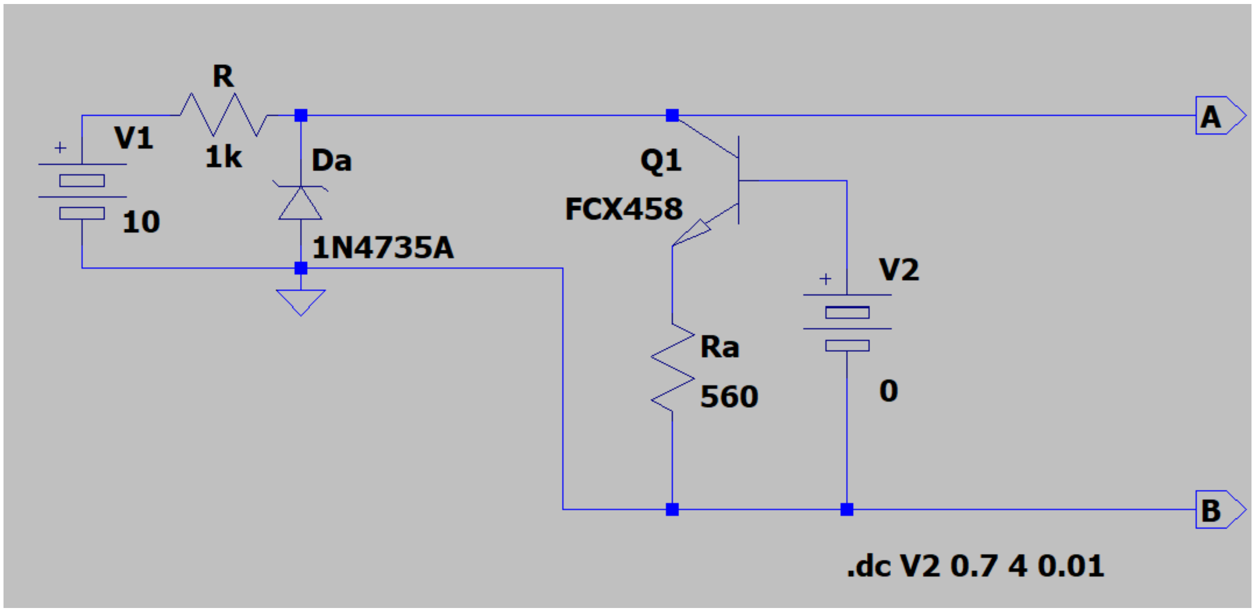

Figure 41: Voltage Regulator Design

5.2 Circuit Implementations

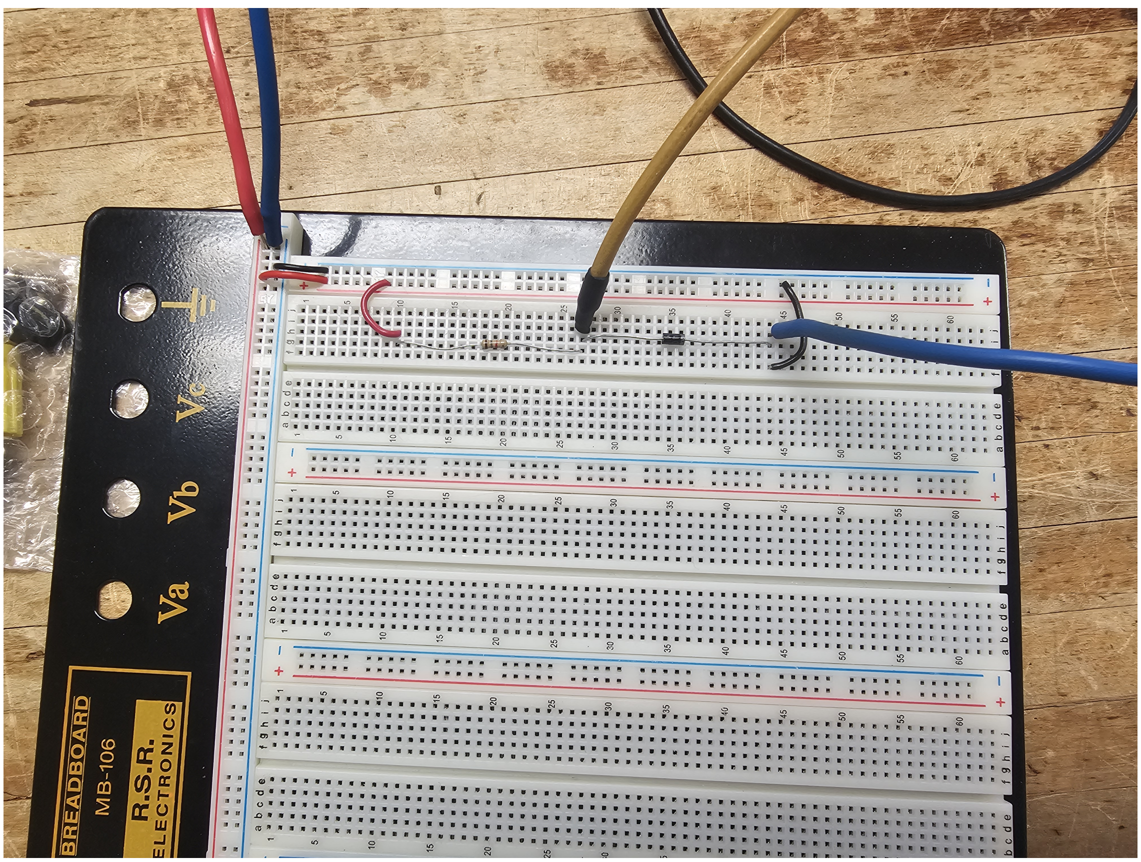

Figure 42: Diode Circuit and Half-Wave Rectifier Implement

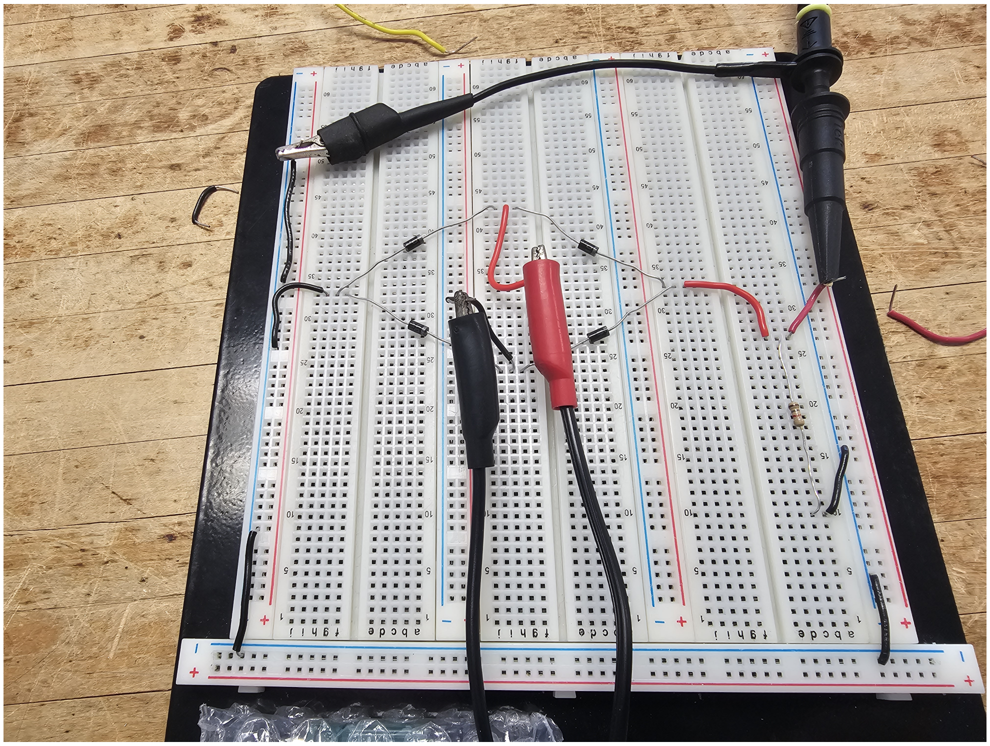

Figure 43: Full-Wave Rectifier Implement

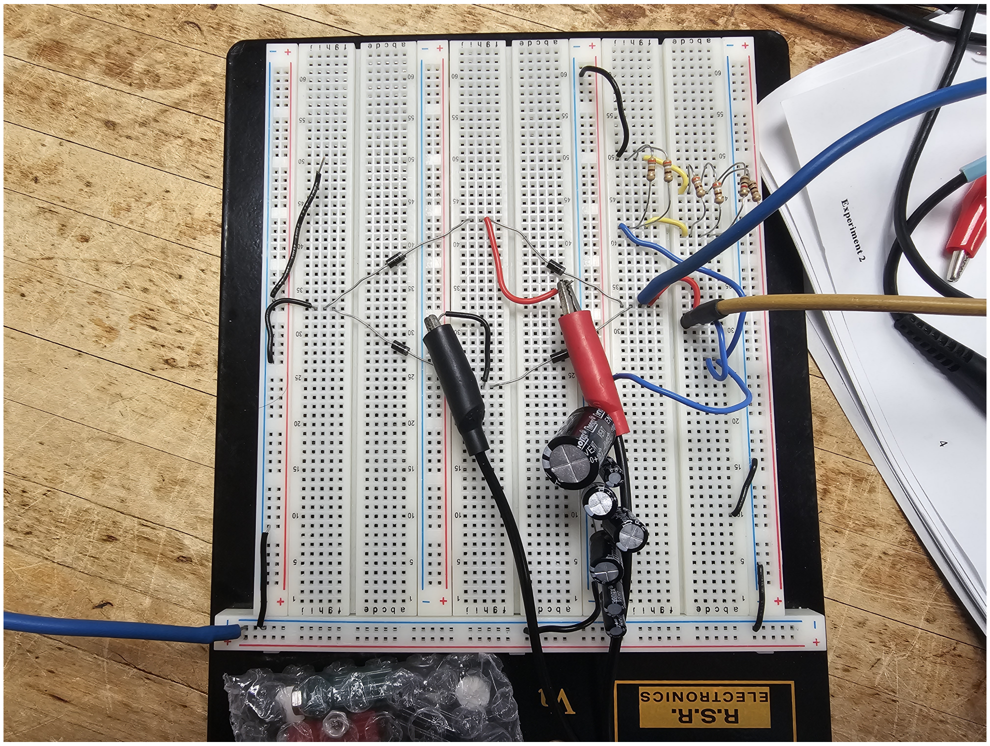

Figure 44: Implemented DC Power Supply

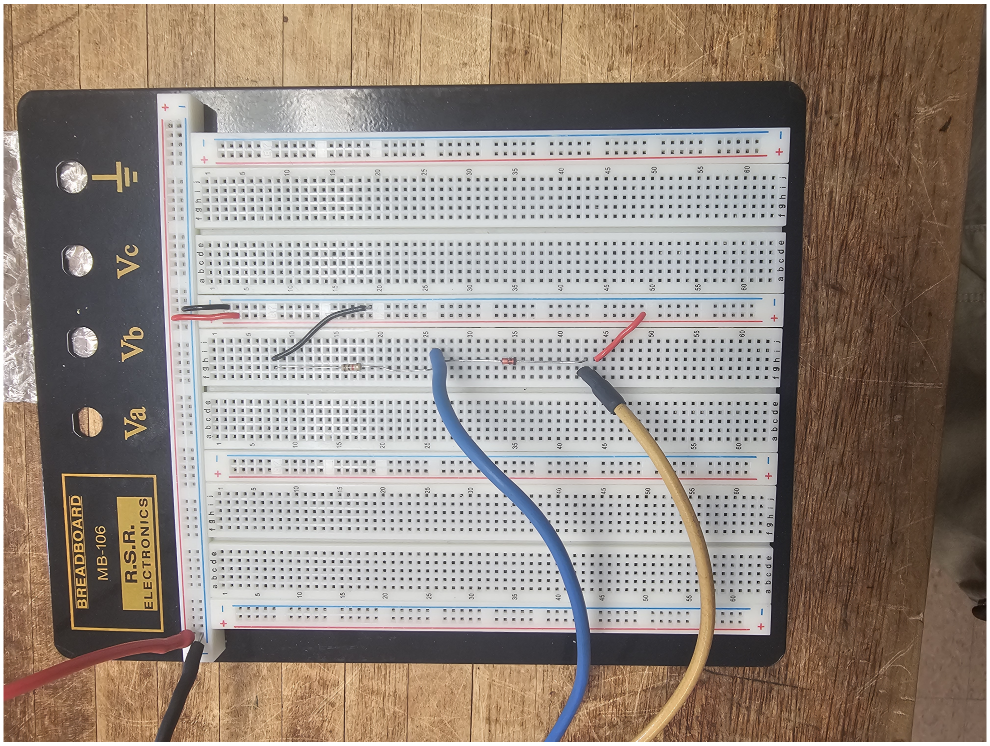

Figure 45: Implemented Zener Diode Circuit

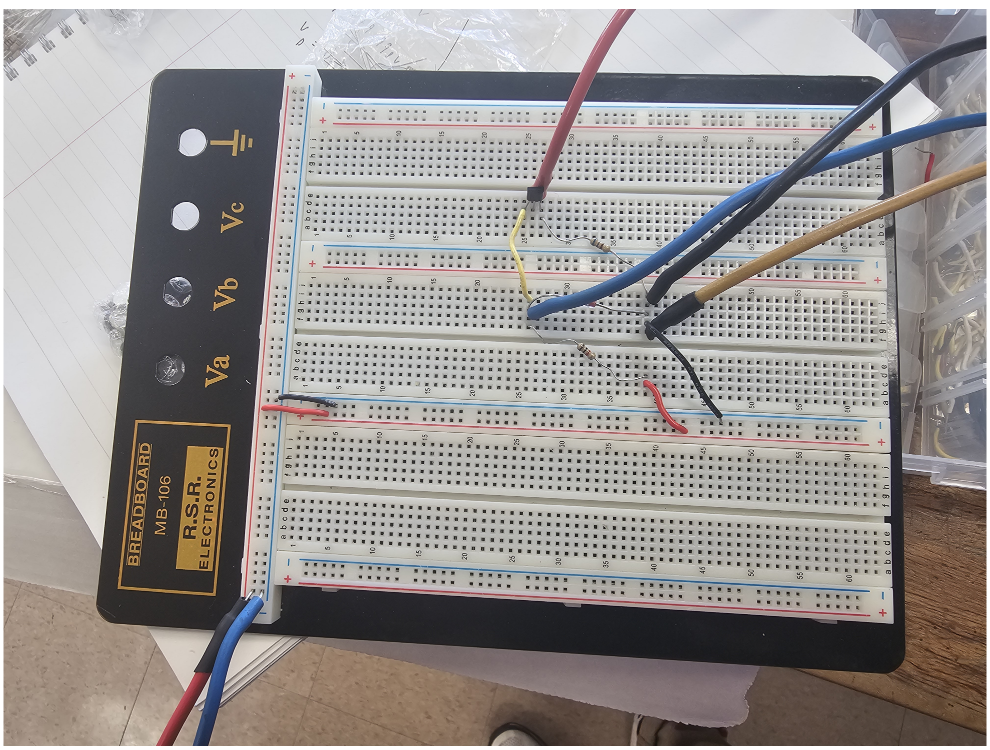

Figure 46: Implemented Voltage Regulator

6 Analysis

Each section of the lab will be analyzed separately.

6.1 Diode Characterization

Referring to Figure 12, the "knee" voltages of the real and simulated diode are within 100 mV of each other, but they are not the same. That said, the simulation did accurately predict the I-V characteristics of the diode.

6.2 Half-Wave Rectifier

Referring the recorded signals from the experimental half-wave rectifier circuit (Figure 28) and the simulated results (Figure 15), the results agree. Naturally, the recorded signals have some noise, but the noise is not significant enough to distort the signal and thus cause disagreement.

6.3 Full-Wave Rectifier

Referring to the recorded signals from the experimental full-wave rectifier circuit (Figure 29) and the simulated results (Figure 17), the results somewhat agree. Viewing the simulated results, the rectified full wave has a peak of around 14 volts, however the real results present what looks likes a rectified full wave with a peak of around 18 volts. Furthermore, the real results have a minimum voltage of around -0.2 volts, but as we know theoretically and from the simulation, the rectified wave should be strictly positive or negative (for our design, a strictly positive rectified full wave).

6.4 DC Power Supply

For the real DC power supply, the voltage ripple was recorded to be around 800 mV according to the oscilloscope image (Figure 26). Also, using the DMM, the output voltage V_L was recorded to be about 14.2 V and the load current I_L at about 109 mA. From the 14.2 V measurement, the 5% ripple should be 0.71 volts. With the measured ripple of 0.8 volts, the real DC power supply achieved about a 5.63% ripple.

6.4.1 Combinations and Error

In order to achieve the desired load current with the 5% ripple, the calculations were as followed

$$
\begin{aligned}
0.05 &= \frac{V_{\text{ripple}}}{12} \implies V_{\text{ripple}} = 0.6\,V \\
0.6 &= \frac{100\,\text{mA} \cdot \frac{1}{2\times 60\,\text{s}}}{C_{\text{filter}}} \implies C_{\text{ripple}} = \frac{1}{720}\,\text{F} \approx 1.3889\,\text{mF} \\
100\,\text{mA} &= 12 R_L \implies R_L = 120\,\Omega
\end{aligned}
$$

However, a capacitor with exactly 1.3889 mF was not available and a single 120 Ω can only withstand 0.25 watts of power, thus each design element needed to be constructed as a combination of different elements.

Remark 2 (The Capacitor Combination). We had access to a 1000 μF (1 mF) capacitor, which leaves us with a remaining capacitance of 0.3889 mF. From this, wiring three 100 μF (0.100 mF) capacitors in parallel with the 1000 μF capacitor with give us 1.300 mF. Then wiring wiring two 33 μF and two 10 μF capacitors in parallel with one another, and wiring this in parallel to the other combination was enough to achieve a capacitance of 1.3860 mF. Thus, we achieved about 99.79% of the 1.3889 mF capacitance, which in turn was about 100.0008% of the design capacitance of $\frac{1}{720}$ F.

Remark 3 (The Resistor Combination). In order to prevent a resistor from burning out, we needed to distribute the load to multiple resistors. Theoretically, the power delivered to the load should be

$$P_L = I_L^2 R_L = (100\,\text{mA})^2 (120\,\Omega) = 1.2\,\text{W}$$

Since each resistor can only handle 0.25 W, we can determine a minimum number of resistors such that each resistor in the combination doesn't handle more than 0.25 W, in which we will call the 0.25 W limit for each resistor R_P.

$$\frac{P_L}{R_P} = \frac{1.2}{0.25} = 4.8 \approx 5$$

Thus we require a minimum of five resistors to prevent the circuit from burning.

6.5 Zener Diode Characterization

Referring to Figure 30 and Table 1, the forward knee voltages and the breakdown voltages agree. However, the simulation did not accurately predict the linear trend the real Zener diode exhibited when $V_D \notin [-6.2, 0.7]$.

6.6 Voltage Regulation

Referring to Figure 31 and Figure 32, the results are very similar. Also, the simulation was able to predict the same load current versus regulated voltage trend that we measured with the real voltage regulator.

7 Conclusion

Remark 4 (Findings). From the experiments, we found that diodes are indeed useful for AC to DC conversions and voltage regulation. We also found that we can characterize each diode by observing it's I-V characteristics, which can also just mean the diode voltage versus the source voltage. If two diodes share the same I-V characteristics, then we can say that these two diodes are functionally equivalent. Naturally, there are many sources of error that arise when implementing diode circuits; such as non-ideal wires, resistor tolerances, and leakage current.