Electronic Devices and Circuits I 2EI4

# Design Project #1 - DC Power Supply

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Due Date: February 9th 2025

# Summary

A DC power supply that converts AC to DC consists of four main components: a transformer, rectifier, filter, and regulator as noted in *Figure 1* below. This project involves designing and building a DC power supply capable of delivering 10 mA at 3V ± 0.1V, utilizing a 120V RMS source operating at 1 kHz. The design must rectify all negative cycles of an AC signal, filter out any remaining fluctuations, and regulate the output to deliver a stable and smooth DC signal.

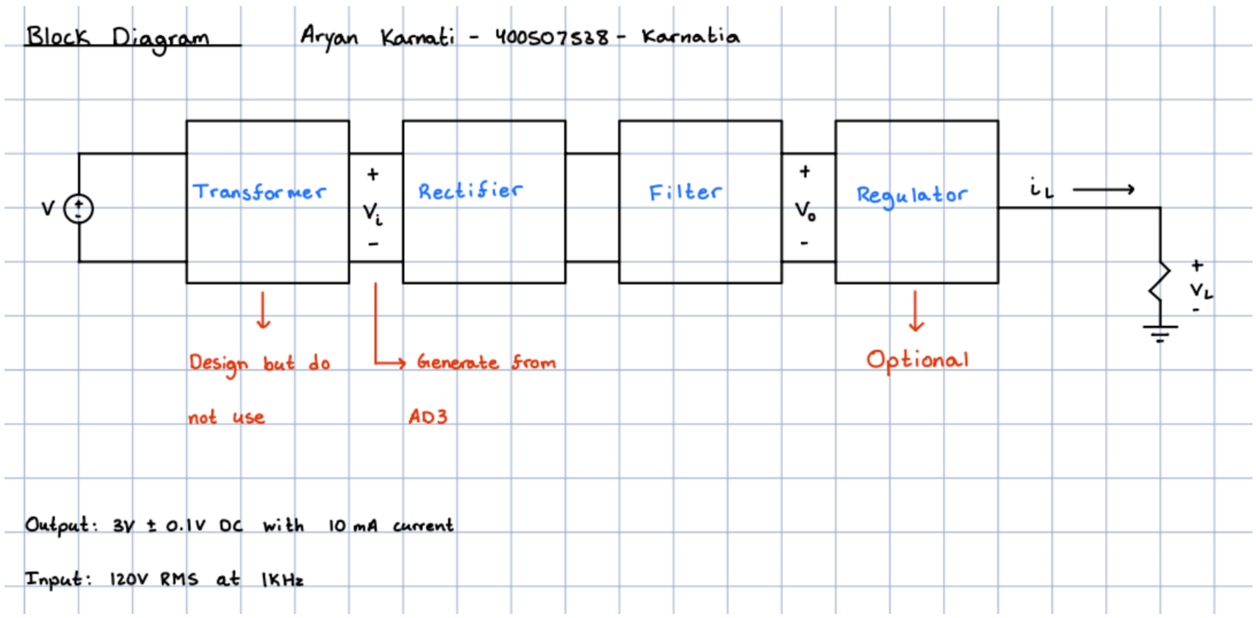


*Figure 1: Block Diagram*

# Design

## *i. Transformer*

This DC power supply design does not include a physical transformer but simulates the step-down process of the AC signal using the AD3. The needed voltage for the design after the transformer steps down the AC signal is approximately 5.5 volts. A transformer with a 22 to 1 turns ratio is assumed, which reduces the voltage from 120 volts RMS to 5.45 volts with a peak voltage of 7.71 volts. This input is generated using the AD3 integrated DC power supply. The transformer that would have been utilized is a center tapped transformer in combination with a full wave rectifier circuit. The justification of the turns ratio and rectifier topology will be explained in the subsequent section.

## *ii. Rectifier*

The rectifier topology that has been chosen is a full wave rectifier with a center tapped transformer. A full wave rectifier utilizes both halves of an AC cycle unlike a half wave rectifier which discards the negative half. This results in a higher power conversion efficiency. This topology also reduces ripple voltage when converting AC to DC. The frequency of the rectified signal is twice that of a signal rectified by a half wave rectifier, allowing for the use of a smaller capacitor to smooth out the DC output. A full wave rectifier can also utilize a center tapped transformer because both halves of the AC cycle are used.

Utilizing a center tapped transformer with a 22:1 turns ratio, the 120 volts RMS will be stepped down to 5.45 volts. The full wave rectifier will half the voltage from the transformer resulting in an output of approximately 3.85 volts. This is because the peak voltage output from the transformer is 7.71 volts and due to the topology of the full wave rectifier the voltage will be halved.

## *iii. Filter*

The filter chosen for this design is an RC filter, which is an effective way to smooth the output of a DC power supply by reducing ripple voltage. After rectification, the voltage is still pulsating, and the capacitor in the RC filter helps by storing and releasing charge to keep the voltage steady. The resistor controls the discharge rate of the capacitor, helping to smooth out fluctuations. This type of filter is easy to build, and works well for low-power applications. However, it is less effective for high-current circuits since the resistor causes some voltage drop and power loss. While an RC filter improves the quality of DC power, a voltage regulator or an LC filter may be needed for even better performance. With an ideal voltage ripple of 0.025V, the required capacitor value is approximately $200\mu F$. The 2EI4 and 2CJ4 electronics kits each contain capacitors with a maximum value of $100\mu F$. To achieve the needed $200\mu F$, capacitors from multiple kits are connected in parallel, effectively combining their capacitance to reach the desired value.

### *iv. Regulator*

For this design a voltage regulator was not used.

### *v. Circuit Schematic*

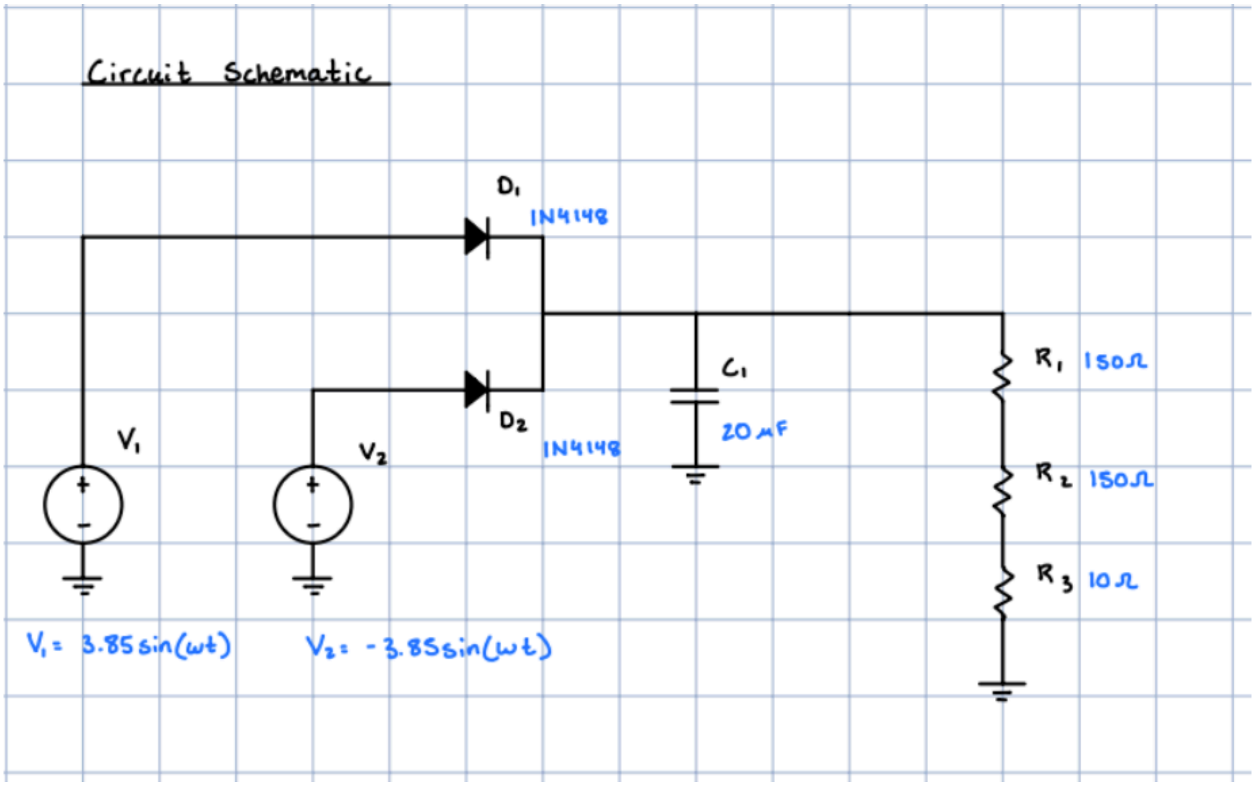


*Figure 2: Hand Drawn Circuit Schematic*

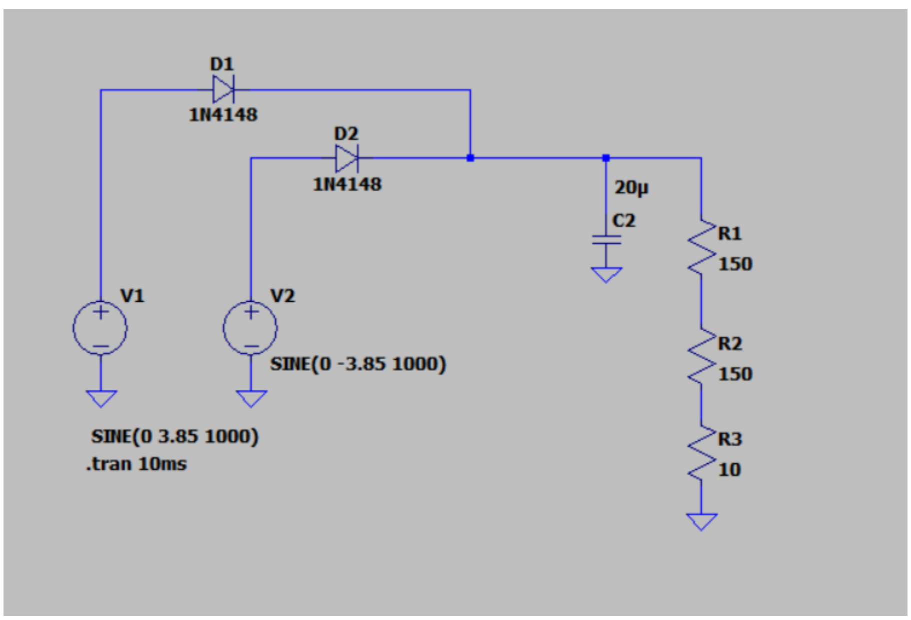


*Figure 3: LTSpice Circuit Schematic*

### *vi. Calculations*

| | Theoretical Calculations |
|---|---|
| Load Resistor | $R_L = \frac{V_L}{I_L} = \frac{3 \pm 0.1\,V}{10mA} = 300 \pm 10\Omega$<br>- Since the 2EI4 and 2CJ4 kits do not contain a $310\Omega$ resistor, two $150\Omega$ and one $10\Omega$ resistor will be used in series |
| Filter | $V_r = 0.3V$<br>(Due to the capacitors available a small ripple was chose to reduce the capacitor size)<br><br>$I_{out} = 10mA = 0.010\ A$<br>$f_{input} = 1kHz = 1000Hz$<br>$f_{output} = 2f_{input} = 2(1000Hz) = 2000Hz$<br>$C \geq \frac{I_{out}}{2kHz \times Vr} \geq \frac{0.010A}{2kHz \times 0.3} \geq \frac{0.010A}{600} \geq 16.67\,uF$<br><br>- Since the 2EI4 and 2CJ4 kits do not contain a $16.67\mu F$ capacitor, two $10\mu F$ capacitors will be used in parallel with each other<br>- At minimum a $16.67\mu F$ capacitor should be used but a higher capacitance will lead to a smoother output voltage with less ripple |
| Diodes | $V_D = 0.7V$ (Assuming Constant Drop Model) |
| Rectifier | $V_p = 3.3V$<br>(Peak Capacitor Voltage)<br><br>$V_c = V_p - \frac{1}{2}V_r = 3.3 - \frac{1}{2}(0.30) = 3.15V$<br>$V = V_D + V_C = 0.7V + 3.15V = 3.85V$<br><br>Rectifier Circuit Input<br>$V_1 = 3.85\sin(wt)$<br>$V_2 = -3.85\sin(wt)$ |

| | |
|---|---|
| Transformer Turns Ratio | $V_o = 2V_1$<br>$V_o = 2(3.85\sin(wt)) = 7.7\sin(wt)$<br><br>RMS Conversion<br>$\frac{V_o}{\sqrt{2}} = \frac{7.7}{\sqrt{2}} = 5.44V\ (RMS)$<br><br>Turns Ratio<br>$\frac{N_1}{N_2} = \frac{V_s}{V_o} = \frac{120V}{5.44V} \approx 22:1\ Turns\ Ratio$ |

*Table 1: Theoretical Calculations*

## *vii. Expected Performance*

Using the calculations from *Table 1,* an input signal with an amplitude of 3.85V at 1kHz from the AD3 should be used. To supply both diodes according to the topology, two waveforms should be used, with one of the waveforms having a 180 degree phase shift. This is due to the rectifier being able to utilize both positive and negative cycles of the input signal. When D1 is conducting D2 will be reverse biased, and vice versa. A fully rectified wave should be produced with this design. The 0.7V drop has been taken into account due to the signal only going through one diode at a time. The filter should be able to produce minimal ripple resulting in a smooth DC output.

## *viii. Trade Offs*

Throughout this project not many trade offs were made for the construction of the circuit. Due to the limitation of components in the 2EI4 and 2CI4 laboratory kits, to achieve the values theoretically calculated many components were placed in series or parallel to one another. Although this was changed later on due to an inaccurate result and components such the capacitors and resistors were switched out for higher values. These higher value components led to a more accurate final result.

# Measurement and Analysis

### *i. Photograph Of Built Circuit*

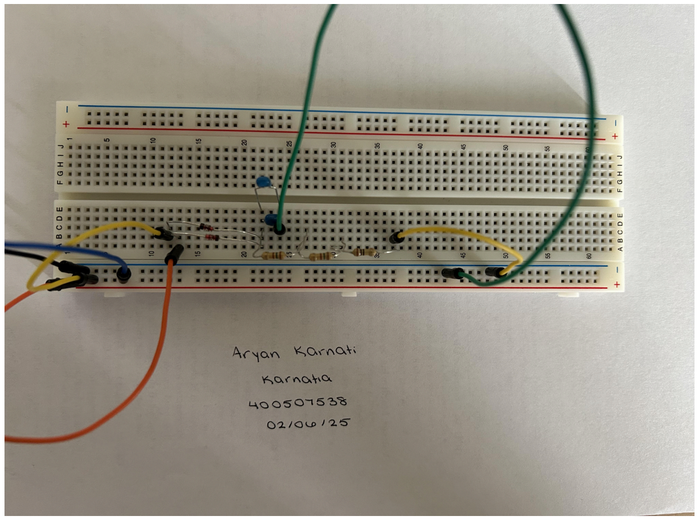


*Figure 4: Physical Circuit of Original Schematic*

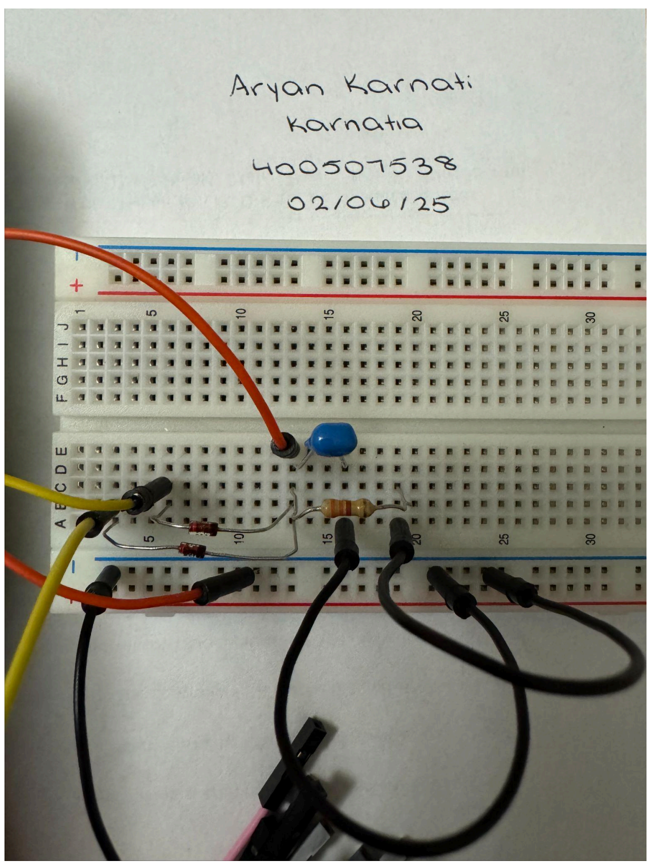


*Figure 5: Physical Circuit after 3 Iterations*

## *ii. Measurement Procedure*

To determine the performance of the circuit, the oscilloscope of the AD3 was used to show the output voltage waveform. The rectified wave was also shown to troubleshoot any errors. Using the scope function the output voltage was measured at the specific node where diodes, capacitors, and resistors were all connected. To measure current a math function was created on the AD3 due to the device not being able to accurately measure current.

## *iii. Measurement Results*

As seen in the "Oscilloscope Output" section three iterations of the circuit were created to get the most accurate result for the specified requirements. The first iteration was an accurate representation of the calculations conducted in *Table 1*. There were many unaccounted errors that created an output voltage not in the range of the specified requirements. The first improvement that was made was an increase in the input voltage as the peak voltage was not in the desired range. This can be a result of internal resistance from the wires and a loss of energy in the form of heat. For the second iteration a greater capacitance was used to better smooth out the output voltage as 20uF was not sufficient. For the third iteration a higher resistance was used to reduce current draw to show a higher output voltage. The resistance was increased from 310 ohms to 330 ohms. The third iteration accurately displays the voltage within the required range of 3 ± 0.1V.

## *iii. Oscilloscope Output*

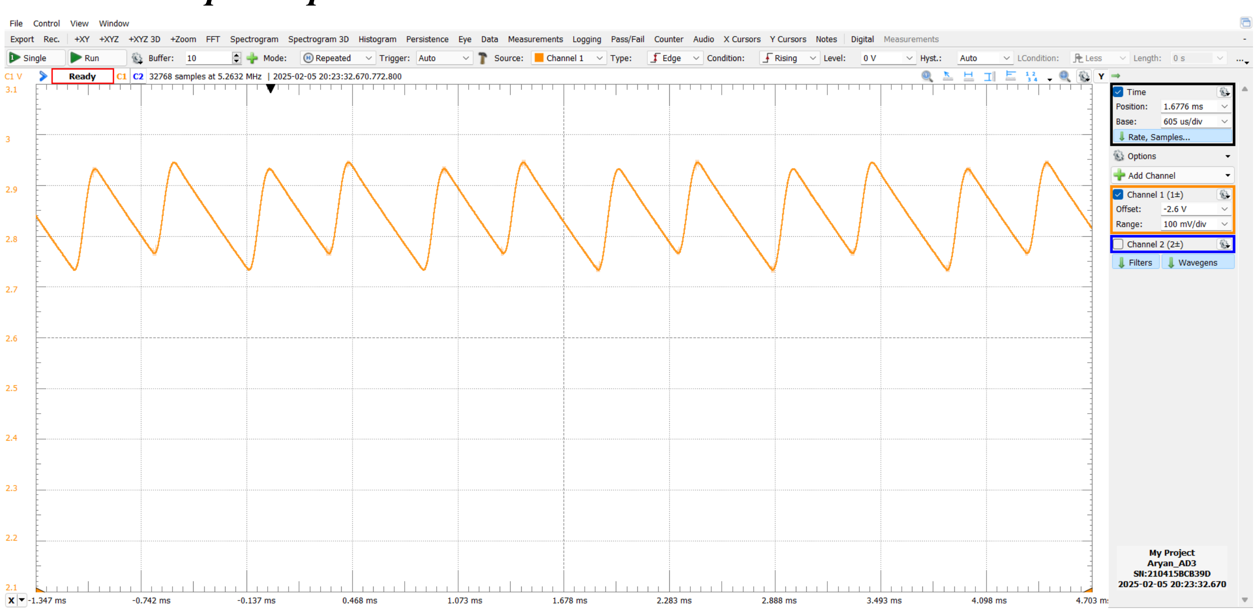


*Figure 6: Circuit Output of First Iteration*

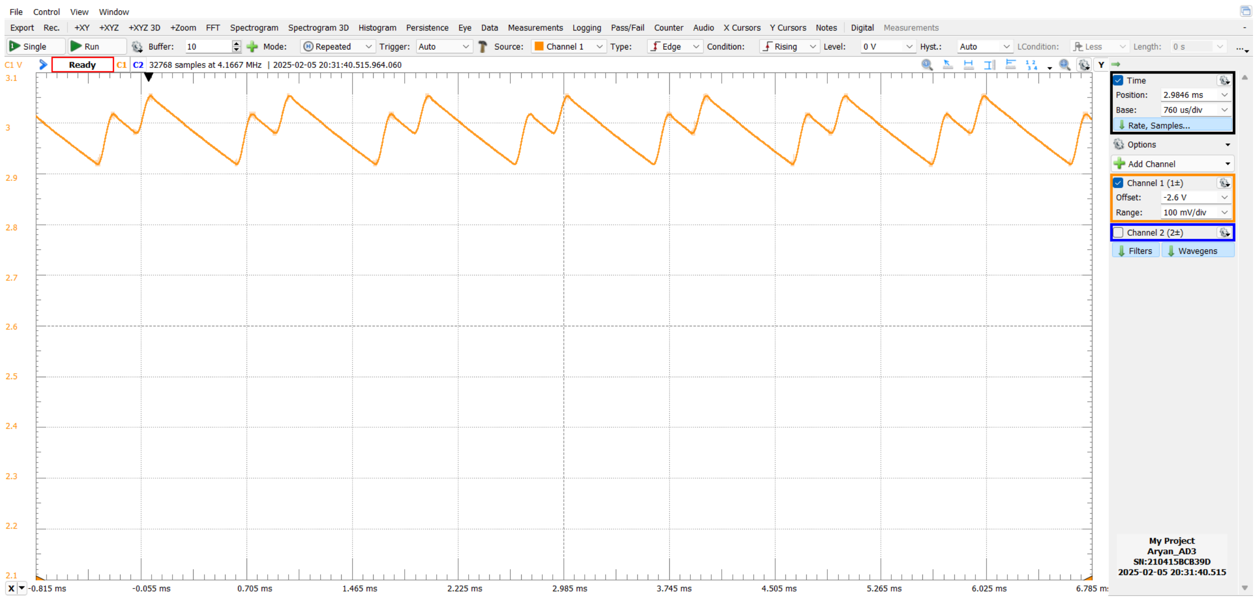


*Figure 7: Circuit Output of Second Iteration*


*Figure 8: Circuit Output of Third Iteration*

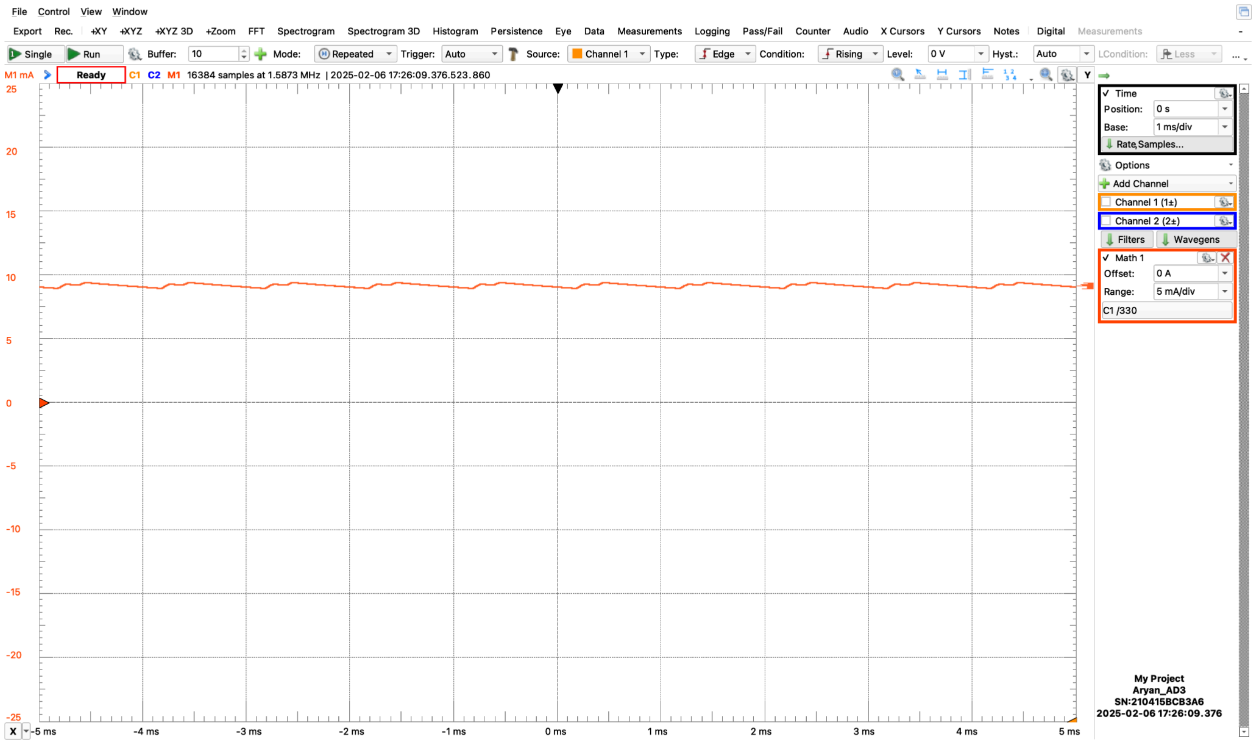

*Figure 9: Circuit Output of Current after 3rd Iteration*

# Simulation

## *i. Circuit Schematic From Simulator*

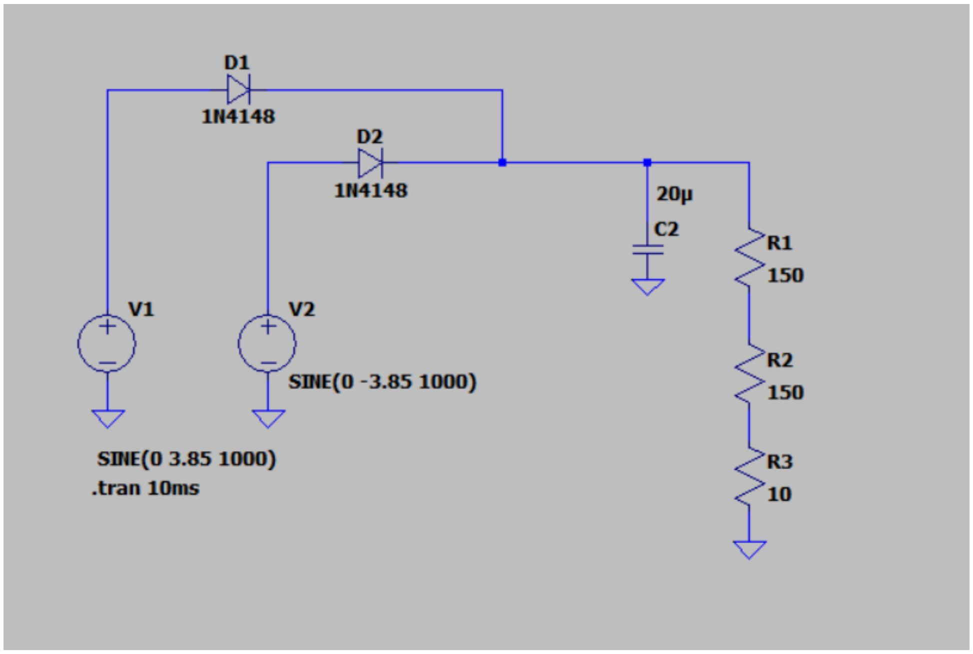


*Figure 10: LTSpice Circuit Schematic*

### *ii. Netlist*

SPICE Netlist: C:\Users\19ary\AppData\Local\LTspice\Draft1.net

```
* C:\Users\19ary\AppData\Local\LTspice\Draft1.asc
V1 N001 0 SINE(0 3.85 1000)
V2 N003 0 SINE(0 -3.85 1000)
D1 N001 N002 1N4148
D2 N003 N002 1N4148
R1 N002 N004 150
C2 N002 0 20µ
R2 N004 N005 150
R3 N005 0 10
.model D D
.lib C:\Users\19ary\AppData\Local\LTspice\lib\cmp\standard.dio
.tran 10ms
.backanno
.end
```

*Figure 11: LTSpice Netlist*

### *iii. Simulation Conditions*

The simulation was performed as a transient simulation, and data was recorded from 0s to 10ms.

### *iv. Simulation Output*

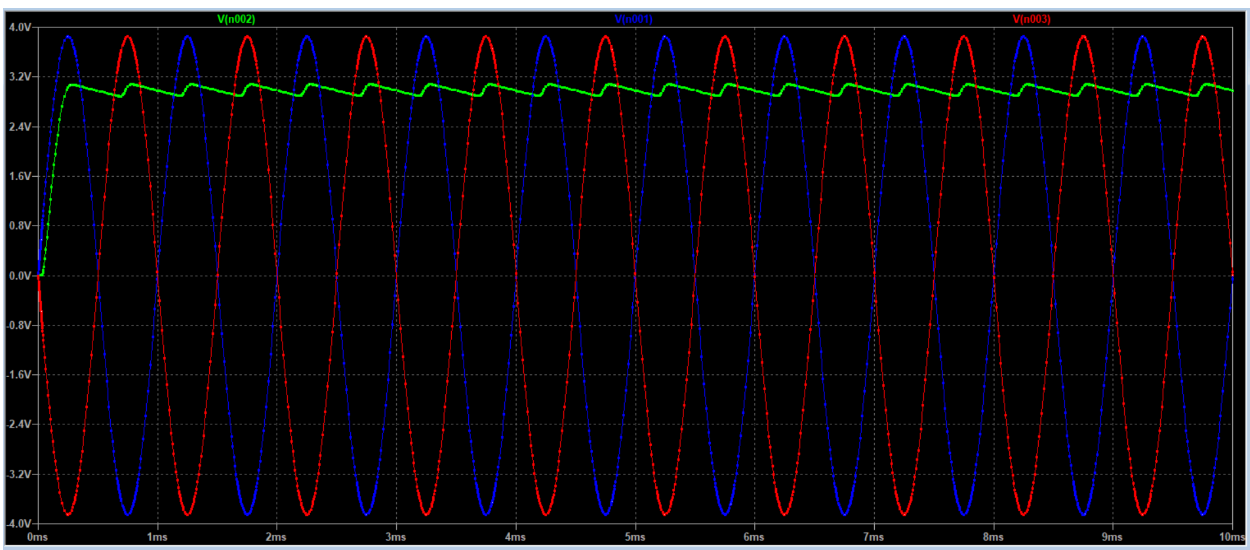


*Figure 12: Graph Of Input and Output Voltage*

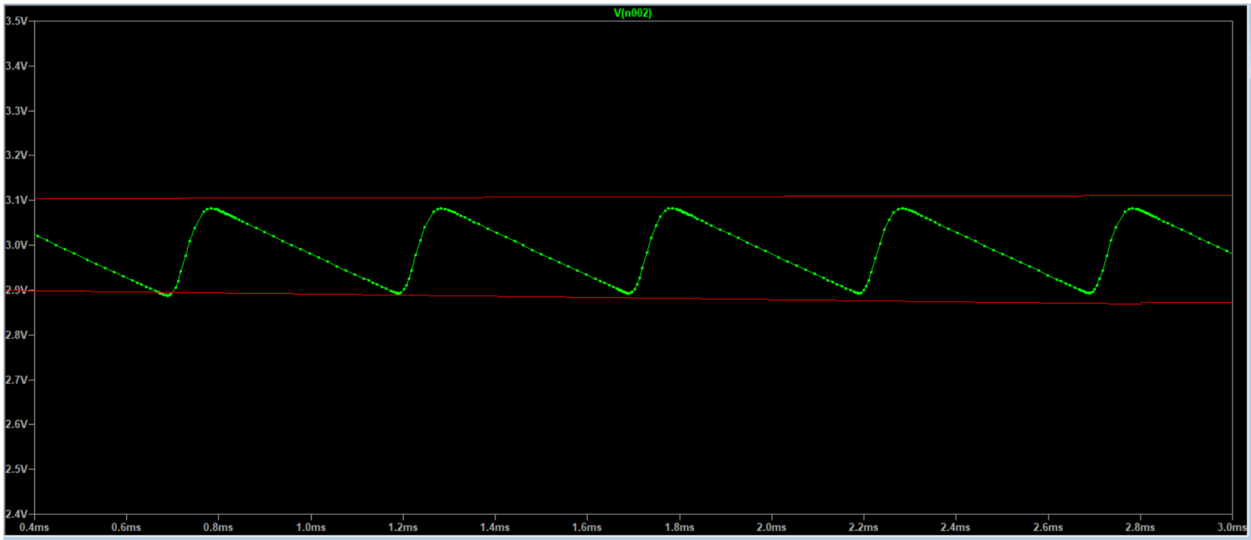


*Figure 13: Range of Output Voltage*

After running the simulation the output voltage seems to be oscillating within the desired range of 2.9V to 3.1V. The input wave with an amplitude of 3.85V worked effectively. However, as seen in the image above, the ripple was greater than anticipated. For a second run a larger capacitance should yield a smoother output voltage, decreasing the ripple.

# Discussion

### *i & ii. Results and Discrepancies*

Comparing the results with the theoretical calculations, the physical circuit's output measurements show slight variations from the expected values. Many adjustments had to be made for the physical circuit to meet the design requirements.

Obtained from *Table 1* the theoretical calculator for the input waveform was determined to be 3.85V. In reality the voltage needed to be increased to 4V due to internal resistance from the wire, components, and the breadboard itself. This unaccounted resistance caused the output waveform from 3.85V to be less than what was required.

When the circuit was simulated a minimum capacitance of $20\mu F$ was used and showed minimal voltage ripple. However, during the physical circuit's output measurements the $20\mu F$capacitance was not enough to smooth out the voltage output from the rectifier (as seen in *Figure 6*). A higher capacitance of $100\mu F$ was used to better manage the voltage ripple. The $100\mu F$ capacitor minimized the ripple enough to be closer to the desired range.

For the final iteration of the circuit the resistors were changed to a greater value to increase current draw which would result in a greater voltage output. The three resistors in series were all swapped out for one $330\Omega$ resistor. As shown in *Figure 7*, once the resistors have been swapped the final output waveform was within the desired range of 3 ± 0.1V. The ripple of the waveform was also minimized using the available parts from the 2EI4 and 2CI4 laboratory kits.

There was an extremely large discrepancy when comparing the simulation results to the physical circuit's results. In the LTSpice simulation, the output voltage consistently remained within the expected range with minimal ripple. In the physical circuit, additional adjustments were required to achieve the same performance. The simulation did not account for real-world factors such as internal resistance from wiring, component tolerances, and energy losses due to heat dissipation. Additionally, while the simulated circuit performed well with a $20\mu F$ capacitor, the physical circuit required a $100\mu F$ capacitor to adequately reduce ripple and stabilize the output voltage. These discrepancies show that real-world circuits don't always match simulations exactly, so testing and adjustments are needed to get the expected results.

### *iii. Design Limitations*

The largest limitation on my design was the availability of components used for this project. Being restricted to only using the 2EI4 and 2CI4 laboratory kits limited the specific components required to match the theoretical calculations. Multiple components were either put in parallel or series to match the calculated theoretical values. Another major limitation was the accuracy of the available measurement tools. The AD3 oscilloscope and math functions provided useful data, but their precision was limited, especially when measuring small voltage ripples and current values. This could have introduced minor inaccuracies in the recorded measurements.

### *iv. Problems Encountered*

Many of the issues encountered in this project were due to the AD3 and the challenges of building the physical circuit. During the initial test of the first iteration (*Figure 4*), the AD3 failed to correctly read the waveform at the node where the oscilloscope probe was placed. To resolve this, the probe was first repositioned at the voltage source nodes to verify that the correct waveform was being supplied. After confirming the input voltage was correct, the probe was moved back to the output node, which then displayed the expected waveform. Other problems that were encountered include not accounting for internal resistance, not connecting to ground, and flipping the polarities of the diodes. All these issues were fixed with different troubleshooting techniques.

# References


[1] A. S. Sedra, K. C. Smith, T. C. Carusone, and V. Gaudet, Microelectronic circuits, 8th ed. New York, NY: Oxford University Press, 2019.

[2] YouTube, https://www.youtube.com/watch?v=GU5W-1o2v-E&t=68s (accessed Feb. 9, 2025).

[3] YouTube, https://www.youtube.com/watch?v=quyqtaKIr78 (accessed Feb. 9, 2025).

[4] YouTube, https://www.youtube.com/watch?v=wgP1zdp-yQc (accessed Feb. 9, 2025).

[5] YouTube, https://www.youtube.com/watch?v=jsBn2r94BDA (accessed Feb. 9, 2025).