# ELECENG 2EI4
# **Project 1 – DC Power Supply**

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## Summary

An AC-to-DC converter converts alternating current from a power source into a direct current, which is needed for most electronic devices. An AC-to-DC converter consists of a transformer, rectifier, filter, and regulator [1]. This project aimed to determine the specifications of the parts needed to achieve the design requirements. The requirements were to design and build a DC power supply capable of delivering 10 mA at 3V ± 0.1V from a 120V (rms), 1 kHz source.

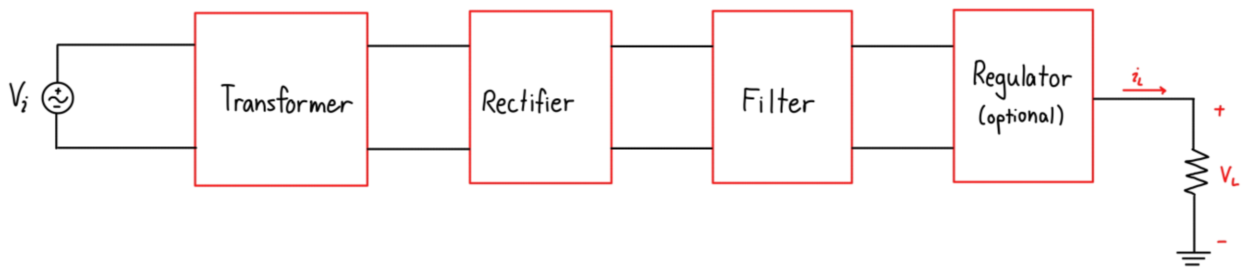


*Figure 1: Components of an AC to DC converter*

## Design

To achieve the analog-to-digital converter as per the required specifications, I decided to implement it using a center-tapped full-wave rectifier design. With the given requirements for this DC power supply, I designed an initial model of the circuit to later calculate the required values accordingly.

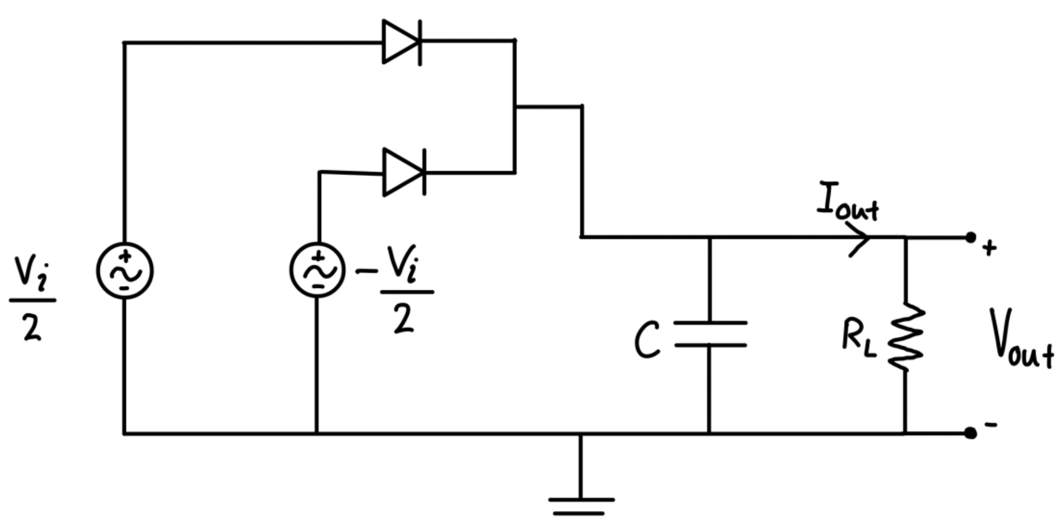


*Figure 2: Initial model of the circuit*

The first component is the load resistor, which can be determined easily as it is connected in parallel with the load. Using Ohm's law and the circuit's requirements, the resistance value can be calculated.

$$V_{out} = 3V \pm 0.1V$$

$$I_{out} = 10mA$$

$$V_{out} = I_{out} R_L$$

$$R_L = \frac{3V}{10mA} = 300\Omega$$

$$P_L = 3V * 10mA = 0.03w$$

The calculations suggest using a 300Ω resistor; however, since there are no 300Ω resistors provided in our list, I will be using a 330Ω resistor. This is also within the power rating of the resistor (0.25w), so it is safe to use for this circuit.

The next component that is involved is the filter. I chose to use a capacitor in this circuit to make a parallel RC filter. The addition of the capacitor smooths the output voltage as it slowly discharges when voltage is no longer applied, essentially shorting any noise to ground [2]. This reduces the peak-to-peak voltage output, leading to a more stable output current. Based on the properties of a capacitor and its times constant in a parallel RC circuit, the larger the capacitor, the more stable the output. However, I needed to determine its minimum value to keep the output within the desired amount. Additionally, the requirements specified that the input voltage has a frequency of 1000Hz, however, since I am using a full-wave center-tapped rectifier, the ripple frequency is doubled because it is rectifying both the positive and negative sides of the waveform.

$$V_{PP} = 0.2V$$

$$I_{out} = 10mA$$

$$f = 2000Hz$$

$$V_{PP} = \frac{I_{out}}{fC}$$

$$C = \frac{10mA}{(0.2V)(2000Hz)} = 25\mu F$$

This is the minimum value to achieve a ripple with the range of 2.9V-3.1V. While this value of the capacitor is not provided in our kits, I chose to combine three 10µF capacitors in parallel to achieve a total of 30µF.

The third component used is the rectifier. I chose to use a center-tapped full-wave rectifier. The full wave rectifier was selected over the half wave rectifier since it produces fewer ripples and takes into account both halves of the AC cycles and therefore has a higher average output voltage [3]. Additionally, with the full wave rectifiers, there are two variants, canter tapped and bridge rectifiers. I chose to use a centre-tapped rectifier since it is more efficient, cheaper and easier to implement since it only requires 2 diodes as opposed to 4 with the bridge rectifier, leading to a higher voltage drop from the diodes. A downside of using the centre-tapped rectifier is that it produces around half the output voltage compared to a bridge rectifier. However, for the use in this project, it will not have a significant impact. To calculate the voltage input for this rectifier, we can analyze the voltage drop at the capacitor and diodes. The diodes I am using are the 1N4148 diodes, which, according to their datasheet, have a forward voltage of 0.72V and a breakdown voltage of 100V. However, the diode can have up to a maximum of 1V forward voltage drop [5].

$$V_C = 3.1V$$

$$V_D = 0.72V$$

$$V_{peak} = V_C + V_D$$

$$V_{peak} = 3.1V + 0.7V$$

$$V_{peak} = 3.82V$$

$$V_1 = 3.82\sin(wt)\,V$$

$$V_2 = 3.82\cos(wt)\,V \; or \; V_2 = -3.82\,sin(wt)\,V$$

$V_1$ and $V_2$ are 180 degrees out of phase. $V_1 = -V_2$

I did not use a regulator in this project, as it is not needed, since altering the input voltage and filter keeps the output at the desired range. Although it is not needed, it can improve performance by preventing voltage spikes and drops.

The last component is the transformer. We are not designing or using the transformer for this project since we used the secondary voltage that would have come from the transformer directly from the AD3. Since a center-tapped transformer is being used, the secondary peak voltage of the transformer is double the magnitude of voltage $V_1$ or $V_2$. This is because the center-tapped rectifier uses both positive and negative cycles of the AC input signal. Additionally, the input voltage of 120V AV is assumed to be RMS voltage.

$$V_{in,RMS} = 120$$

$$V_{out,Peak} = 2 * 3.82$$

$$V_{out,RMS} = \frac{V_{out,Peak}}{\sqrt{2}}$$

$$V_{out,RMS} = \frac{7.64}{\sqrt{2}}$$

$$V_{out,RMS} = 5.40$$

$$a = \frac{N_1}{N_2} = \frac{V_{in,RMS}}{V_{out,RMS}} = \frac{120V}{5.40V} \approx 22{:}1\ Turns\ Ratio$$

With the calculations finished, I added them to my initial circuit schematic.

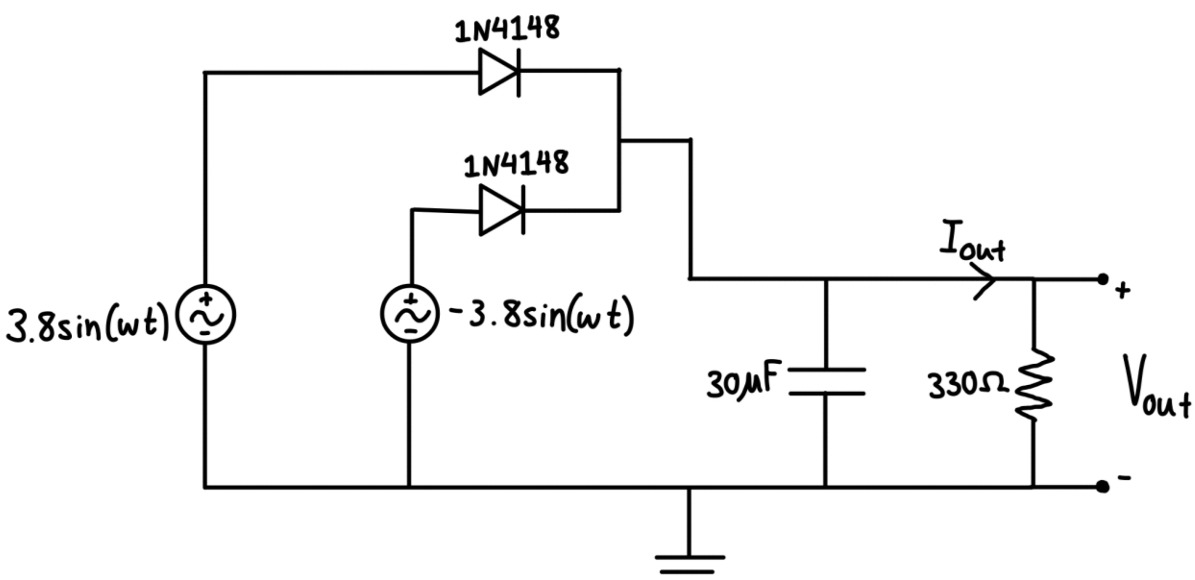


*Figure 3: Circuit schematic with specific component values*

## Measurement and Analysis

To test the results from the calculations, I built the circuit using parts from our kits. I am connecting the waveform generator for the AD3 to the circuit at the inputs where the transformer would have been connected. Setting the parameters for the wave generator the same as what was calculated of $3.82V_{pp}$, with one of the waveforms out of phase by $180^{o}$, the output voltage is slightly lower than what is expected.

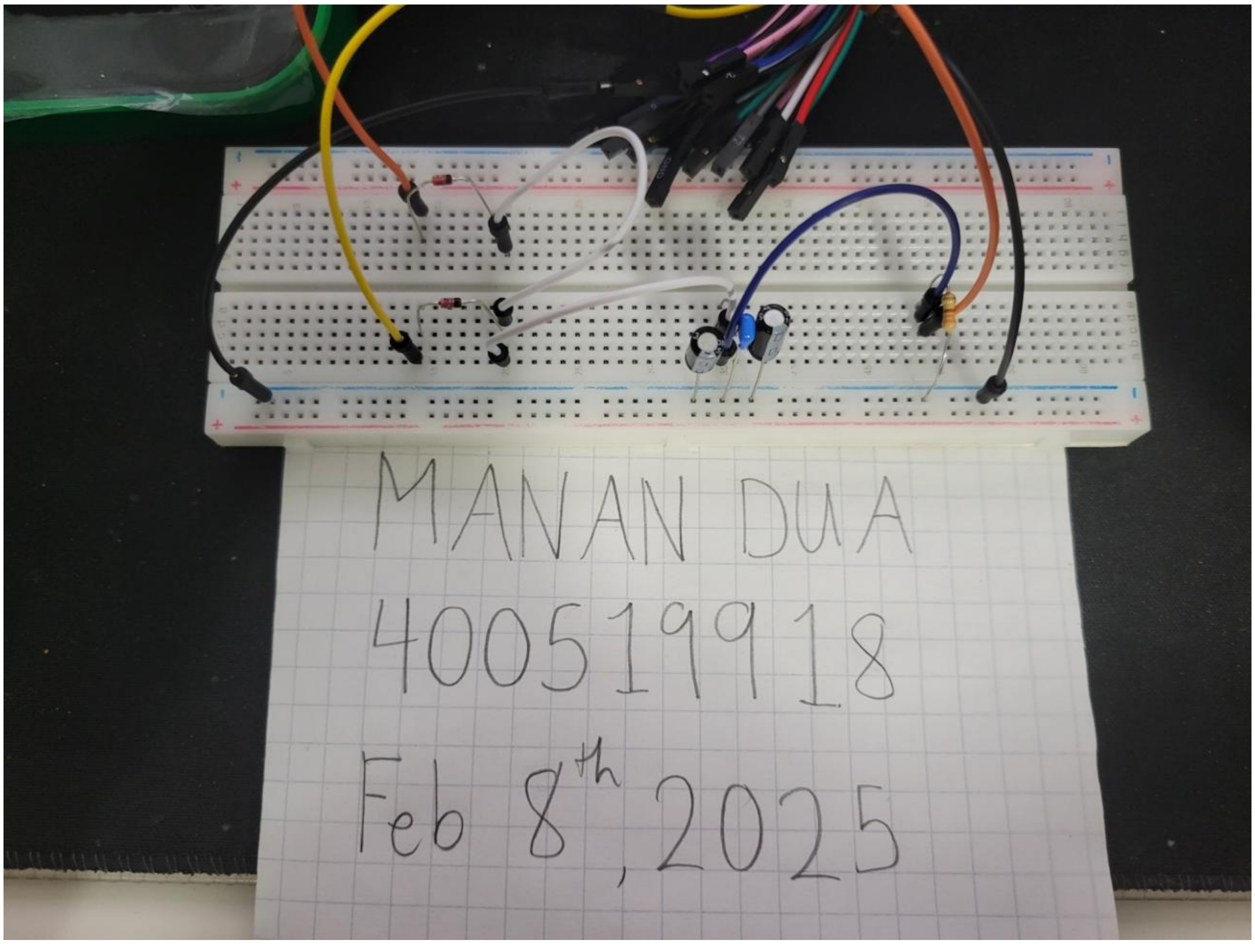


*Figure 4: Physical circuit using the values of components from calculations*

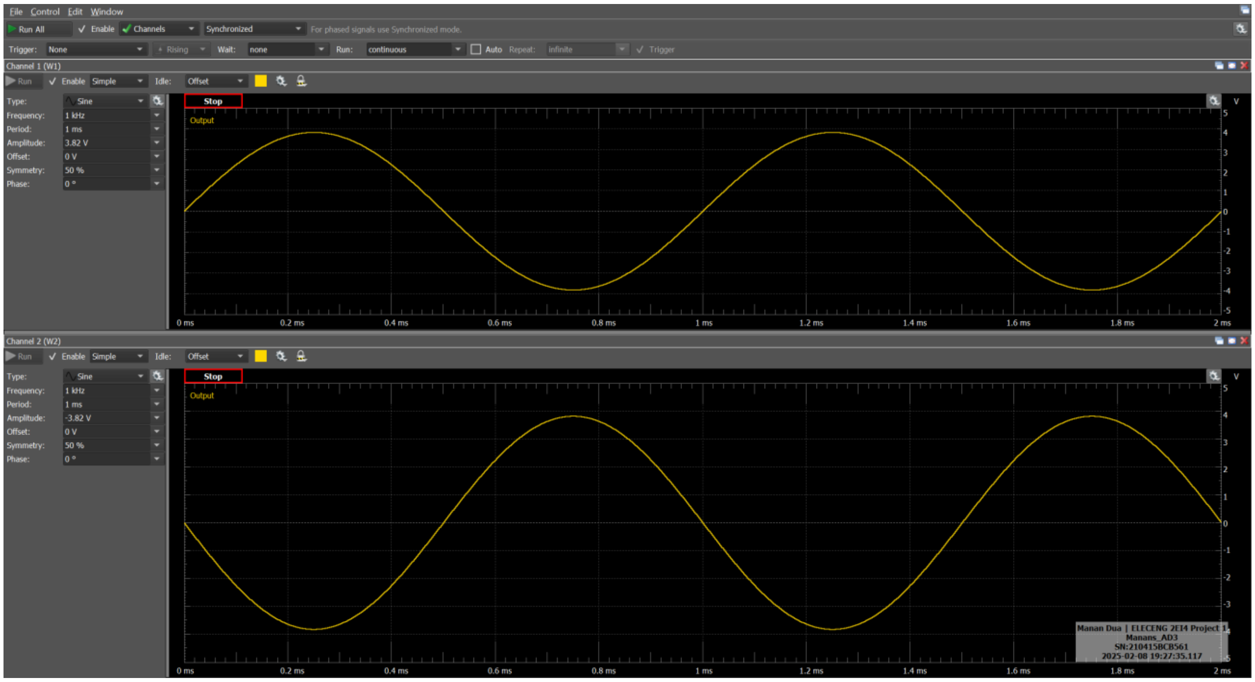


*Figure 5: Initial waveform generator settings*

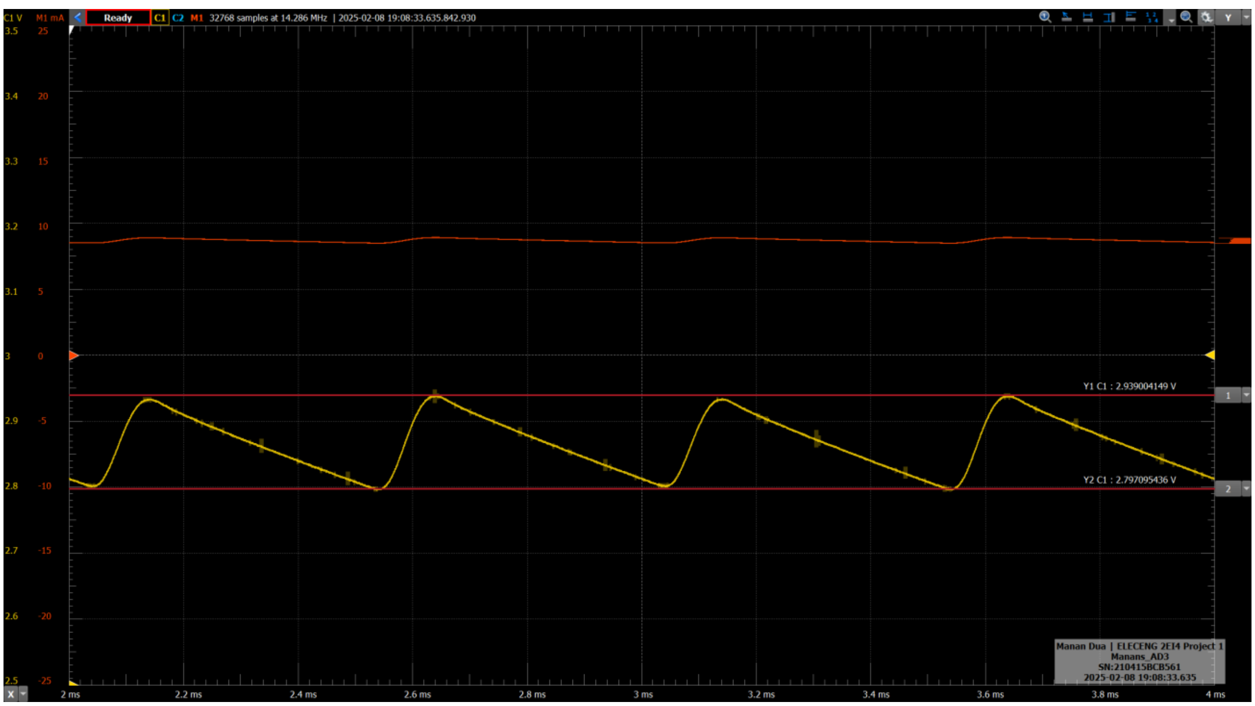


*Figure 6: Initial circuit output with cursors*

The output waveform ripples between 2.8V and 2.94V, which is too low for the requirements. Adjusting the input waveforms from $3.82V_{pp}$ to $3.95V_{pp}$ brings the output waveform into the correct range required. This may be due to the forward voltage of the diode not being exactly 0.72V since the peak-to-peak ripple voltage and current produced is what was expected.

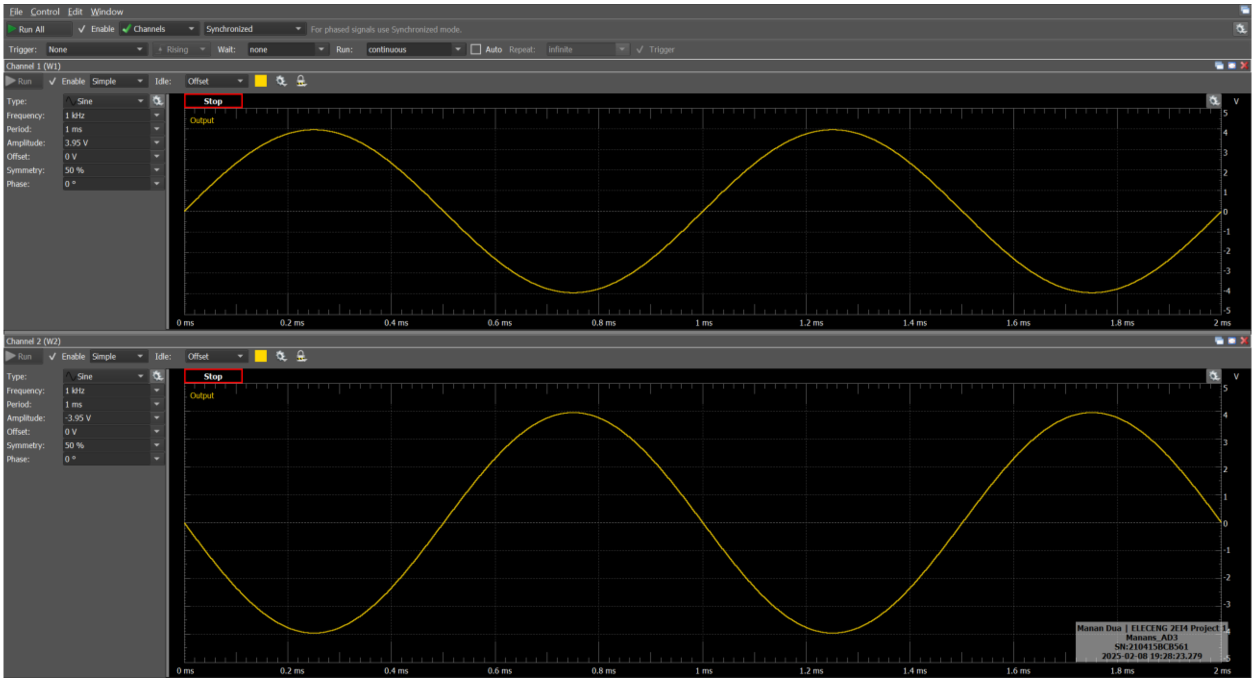

*Figure 7: Modified waveform generator settings to correct for the low voltage*

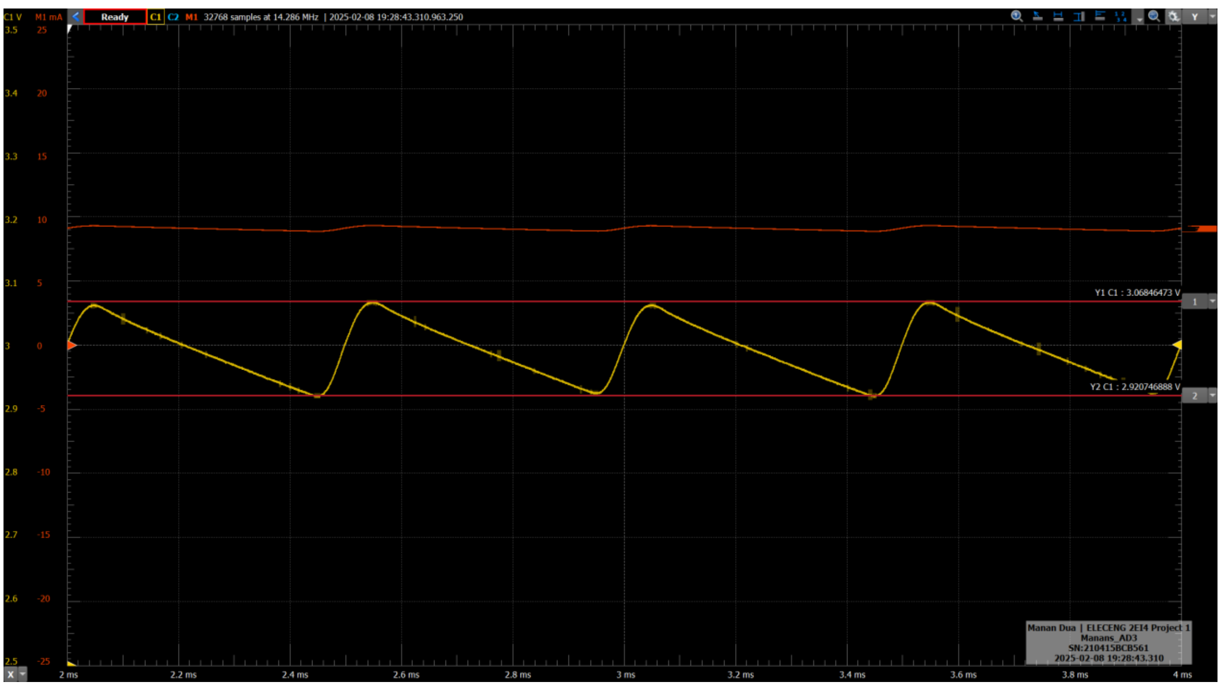


*Figure 8: Output of circuit with modified input values with cursors*

With this new adjusted input, the output waveform now ripples between 3.07V and 2.92V, which is now in the range of the requirements. Additionally, the current can be calculated by dividing the voltage by the resistance. As seen on the graph, the current outputted is roughly 8.7mA to 9.3mA. This is expected since the resistor being used, 330Ω, is slightly higher than the one that was calculated, 300Ω.

## Simulation

To test the values I calculated, I designed a circuit using LTSpice. I simulated the circuit with the values of the components that were available to me, but keeping the calculated input voltage to be the same. I simulated a transient analysis on the circuit, with the simulation time stopping at 4ms with 1N4148 diodes from the software's presets. The outputs of the simulation can be seen in Figure 10 and Figure 11 with the cursors at the bottom of the graphs.

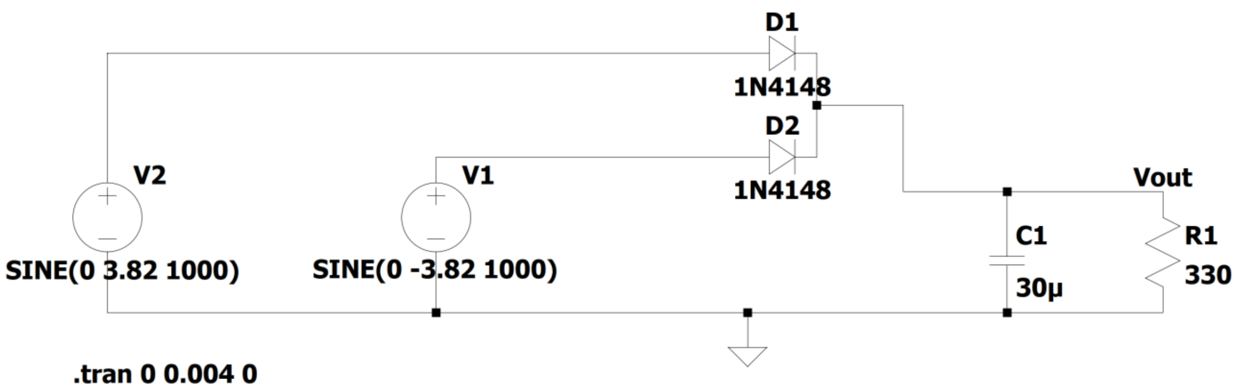


*Figure 9: Simulation schematic of the circuit using available component values*

Netlist:

D1 N001 Vout 1N4148
D2 N002 Vout 1N4148
V1 N002 0 SINE(0 -3.82 1000)
V2 N001 0 SINE(0 3.82 1000)
C1 Vout 0 30µ
R1 Vout 0 330
.model D D
.lib C:\Users\duama\AppData\Local\LTspice\lib\cmp\standard.dio
.tran 0 0.004 0
.backanno
.end

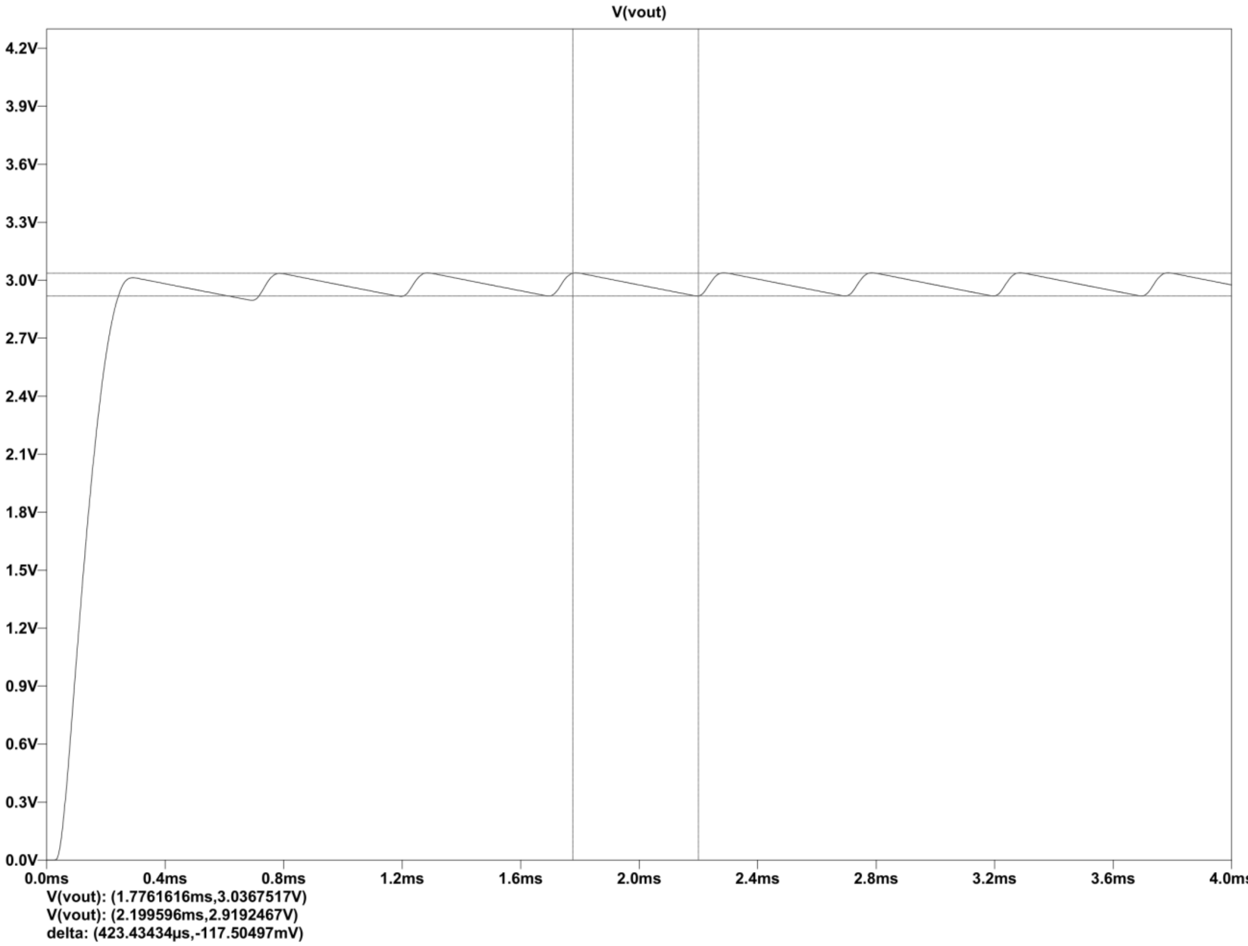


*Figure 10: Voltage output from the simulation with cursors*

From the peaks that are formed in the output voltage, this is where either one of the diodes is in forward bias. In the section where the voltage ripples down, this is when both are in cutoff and the capacitor is discharging. This pattern cycles with the diodes alternating in forward bias. Although it is noted that the peak output voltage is 3.03V when the calculated value would suggest that it is 3.1V. But it is still within the range of the specifications, so the circuit is functional. This could be due to the software having different parameters for the diodes.

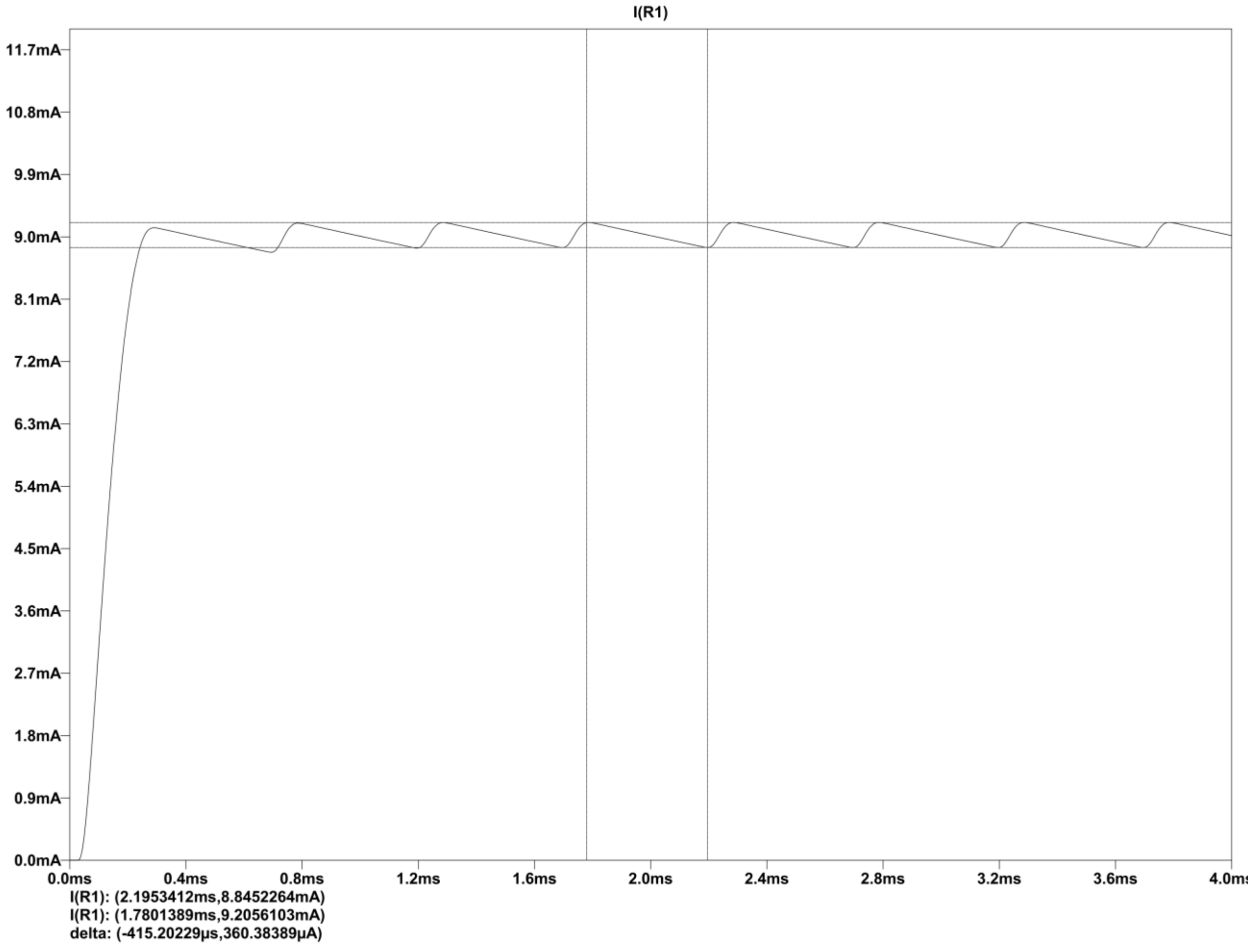


*Figure 11: Current output from the simulation with cursors*

# Discussion

Comparing the results from the calculations, simulation, and measurements, it is clear there are many discrepancies and inconsistencies between them. The results produced by the simulation yielded similar results to the calculations. Although the output voltage was the desired range, the maximum ripple voltage used in the calculations was 3.1V, and the simulation yielded a maximum ripple voltage of 3.03V. Comparing the calculations to the actual measurements showed even more discrepancies. With the voltage value calculated at 3.8V, the actual measurements obtained were lower than the specification. However, the ripples produced were in the correct range, so increasing the input voltage to 3.95V corrected for the low output voltage. One of the reasons this may have happened is because of the tolerances of each component. While each component individually has a small tolerance of ±5%, they can all add up, making the total tolerance possibly quite large. To troubleshoot this, I measured the potential of each component using a voltmeter on the AD3 to ensure their values are what should be expected and to ensure current flow in the correct direction. Through this, it was discovered that the diodes actually had a forward voltage of around 0.9V. This indicated a voltage difference of 0.18V. However, the input voltage was not increased by this amount because I tried to center the ripples around 3V, rather than having it peak at 3.1V, since the capacitor used was slightly larger than calculated, the ripples that were produced were smaller. This would explain why the voltage needed to be increased in the actual measurement. Moreover, the current seemed to be consistent between the results. The simulation yielded results rippling from 8.8mA to 9.2mA. The actual measurement produced a current from 8.7mA to 9.3mA. The current ripples due to the voltage ripples and since a larger resistance value is being used than the one calculated, it is expected for the current to be slightly lower than calculated. One of the limitations of this design is the RC filter that is used, as an LC filter would have been more efficient. By introducing an inductor, it wastes less energy than the resistor at any frequency. However, an LC filter would be more expensive and harder to implement since you would have to analyze its frequency response to ensure there are no irregular oscillations and is not commonly used in ADCs. Another limitation is the capabilities of the AD3. The AD3 has a maximum voltage output of ±5V at 800mA [4]. Assuming a maximum voltage of $5V_{PP}$, the maximum load this power supply could handle is 4W with the center-tapped full bridge rectifier. Additionally, depending on the load connected to this power supply, the current may not be the full 10mA, due to the resistor in parallel with the load. Connecting a high-power device to this power supply could damage the AD3. As a final check, I ensured there were no faulty wires used, and everything was conducting as expected. In the end, the power supply circuit was fully functional and operated with respect to the specification.

## 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] "Components—Part 1: The Capacitor is the Simplest Noise Filter," *Learn about Technology with TDK*, 2024. https://www.tdk.com/en/tech-mag/noise/04#:~:text=When%20noise%20enters%20a%20DC,while%20allowing%20noise%20to%20pass. (accessed Feb. 09, 2025).

[3] Electrical Technology, "What is a Rectifier? Types of Rectifiers and their Operation," *ELECTRICAL TECHNOLOGY*, Jan. 15, 2019. https://www.electricaltechnology.org/2019/01/what-is-rectifier-types-of-rectifiers-their-operation.html#center-tap-rectifier (accessed Feb. 09, 2025).

[4] J. Colvin, "Analog Discovery 3 Reference Manual - Digilent Reference," *Digilent.com*, 2023. https://digilent.com/reference/test-and-measurement/analog-discovery-3/reference-manual?srsltid=AfmBOoo5_b30x7lp-EPpax6uieCW1lx5A6bsgo2FwmNCyGSIDth8hHGE (accessed Feb. 09, 2025).

[5] "1N4148 / 1N4448," 2008. Available: https://www.diodes.com/assets/Datasheets/ds12019.pdf