Design Project 1 – DC Power Supply

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ELECENG 2EI4 – Electronic Devices and Circuits I

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Summary

Household power is generally delivered as a high-voltage AC signal, but many electronic devices used daily require a much lower DC voltage to operate. This makes AC to DC power conversion a crucial aspect of modern electrical systems. The purpose of this project is to build a power supply that converts a 120V (rms) AC source into a 3V $\pm$ 0.1V DC voltage source at 10mA.

This is accomplished by first using a transformer to lower the 120V (rms) at 1kHz AC supply to the required value. Next, a rectifier is used to remove the time when a negative voltage is delivered to the load. The filter is used to remove AC ripples, and a regulator (optional) can then be used to cap the voltage, providing the correct DC voltage to the load.

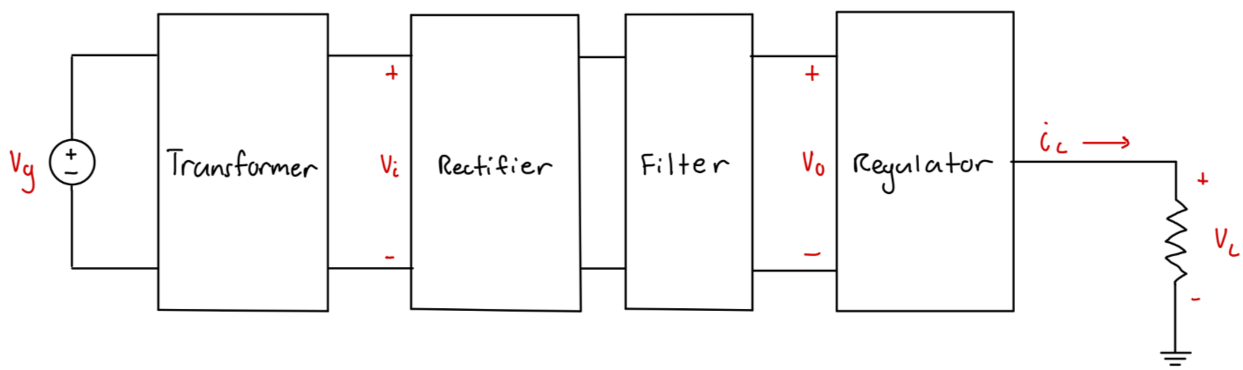

Figure 1: DC Power Supply Block Diagram

Design

Part I – Transformer:

A 120V source is not actually used for this project due to the dangers associated with high-voltage power sources. Instead, the AD3's function generator is used to produce a sinusoidal amplitude that the theoretical design would require at the output of a transformer. Even though there is no physical implementation of the transformer, the input voltage(s) needed for the design and the turns ratio of the theoretical transformer must be calculated.

The input voltage required for the design was calculated to be 7.64V, which is split into two mirrored 3.82V waves. The turns ratio of the theoretical transformer was found to be 22:1. See Figure 4 for calculations.

Part II – Rectifier:

The rectifier used in this circuit design is a center-tapped full-wave rectifier. A full-wave rectifier is ideal so that half of the wave isn't wasted as heat energy, making it more efficient than a half-wave rectifier. The center-tapped rectifier was chosen because it only uses 2 diodes instead of the bridge rectifiers 4, which improves efficiency because there is a lower voltage drop at each cycle and lowers the cost. See Figure 5 for diode parameters.

Part III – Filter:

A simple way to make a filter is to place a capacitor in parallel with the load (RC filter). The calculation required to find the minimum capacitance to produce an acceptable ripple can be derived from the formula given in "Project 1 guidelines" on A2L: $V_r = \frac{I_o}{f*C}$. This can be rearranged to solve for capacitance: $C_{min} = \frac{I_o}{f*V_r}$

Using this formula, I calculated that a minimum capacitance of 50uF would be required to smooth out the AC ripple enough so it stays within the accepted range of 2.9V – 3.1V. However, this doesn't leave much room for error and seeing as we have access to a 100uF capacitor (from the 2CI4 kit – CM107), I decided this would be better for my circuit. The higher the capacitance, the more stable my DC voltage becomes. See Figure 6 for capacitance calculations.

Part IV – Regulator:

Using a regulator for this project was optional. I didn't use one simply because it wasn't needed. The ripple voltage is already small enough, and the output voltage is within the accepted tolerance. Using one would make the circuit more complicated for no added benefit.

Part V – Complete Circuit Schematic:

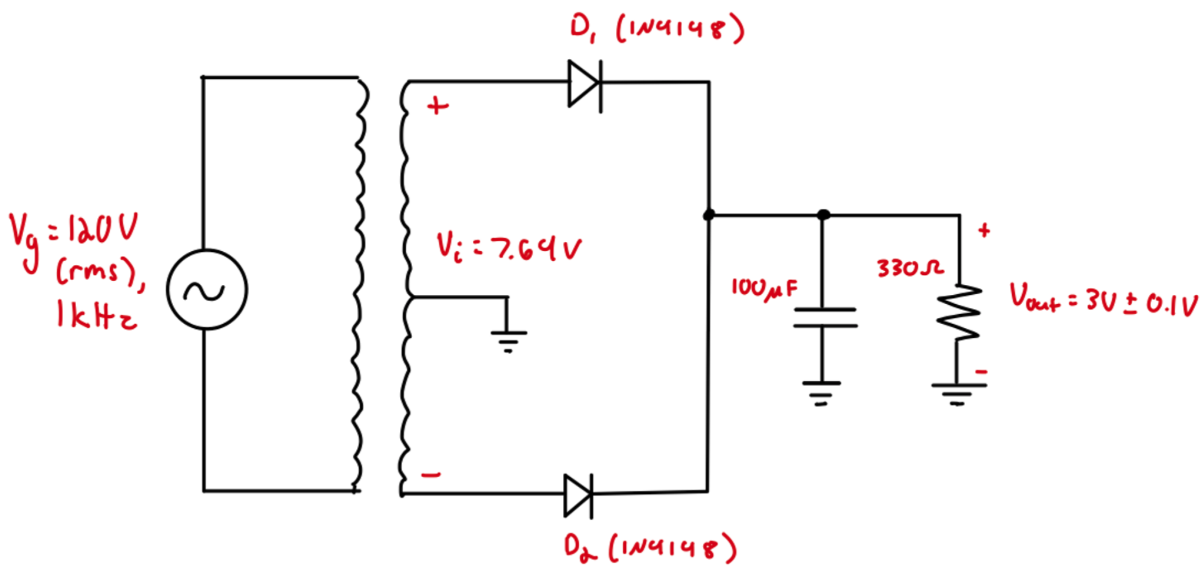

Figure 2: Complete Circuit Diagram – With Transformer

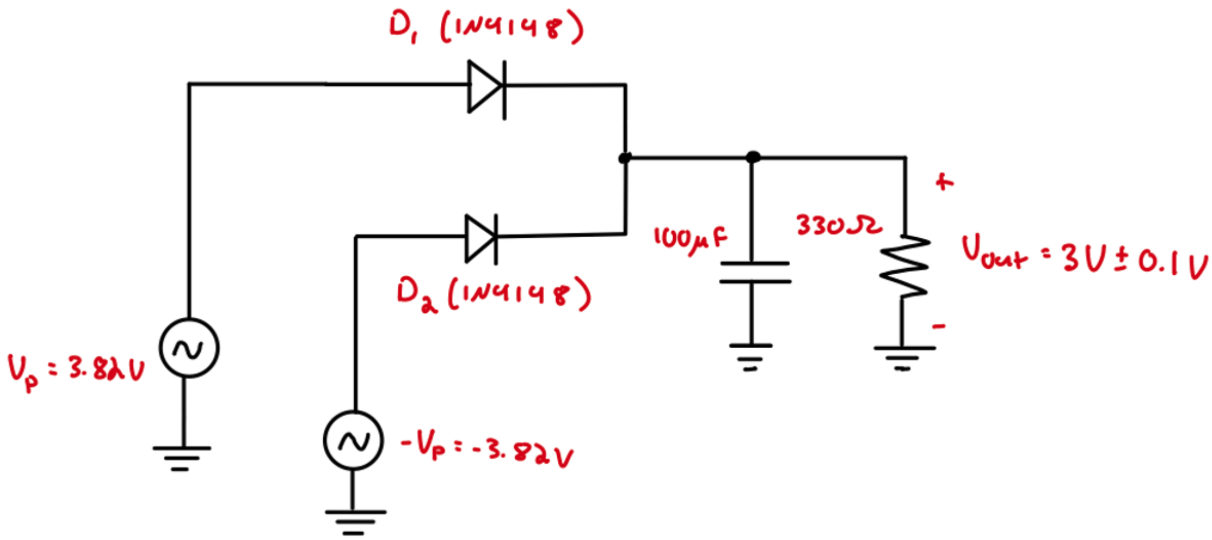

Figure 3: Complete Circuit Diagram - Without Transformer

Part VI – Calculations to Determine Component Values:

$V_o = 3V, V_D = 0.72V$

$V_p = V_o + V_D + 0.1\ (tolerance) = 3V + 0.8V = 3.72V + 0.1 = 3.82$

$V_i = 2 * V_p = 2 * 3.82V = 7.64V$

Convert V_o to RMS: $V_{i,RMS} = \frac{V_i}{\sqrt{2}} = \frac{7.64}{\sqrt{2}} =$ 5.40V (RMS)

Turns Ratio: a $= \frac{V_{primary}}{V_{secondary}} = \frac{V_{g,RMS}}{V_{i,RMS}} = \frac{120V}{5.40V} = 22{:}1\ Turns$

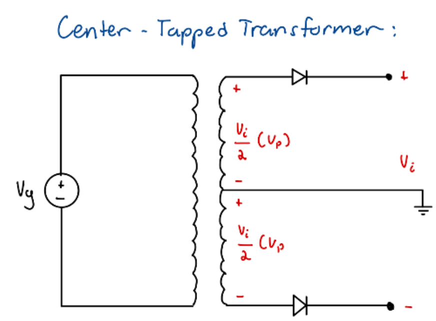

Figure 4: Transformer Calculations

$V_D = 0.72V$ (according to the data sheet for 1N4148 diodes)

Figure 5: Rectifier Diode Parameters

$$V_r = 3.1V - 2.9V = 0.2V, I_o = 0.01A, f = 1000Hz$$

$$C_{min} = \frac{I_o}{f * V_r} = \frac{0.01A}{1000Hz * 0.2V} = 50uF$$

Therefore, the minimum required capacitance to produce an acceptable ripple is 50uF.

Figure 6: Filter Capacitor Calculations

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

The load resistor was calculated to be 300 ohms. The closest we have to that value in our kits is 330 ohms, so we were instructed to use this resistor.

Figure 7: Load Resistor Calculations

Part VII – Expected Performances:

The circuit is expected to supply a stable 3V +- 0.1V output with a 10mA load current. The full-wave center-tapped rectifier circuit is configured with 1N4148 diodes and is expected to produce a peak voltage of 3.82V, which, after filtering with a 100uF capacitor, results in a voltage of approximately 3V with a ripple voltage of <0.2V. The function of the transistor is simulated by using two waveforms from our AD3, both of which are supplying an input signal of 3.82V at a frequency of 1kHz. These waves are opposite to each other, so that together they produce a fully rectified wave. This also means only one waveform is going through one diode at a time, which is why $V_d = 0.7$ is added to account for the voltage drop at all times. The circuit does not include a voltage regulator because the capacitor filtering is enough to maintain the voltage within the acceptable limit.

Part VIII – Desing Trade-Offs, Safety Considerations and Component Ratings:

Several design trade-offs were made to ensure a simple yet effective result. A full-wave center-tapped rectifier was used instead of a bridge rectifier so fewer diodes could be used, therefore minimizing the voltage drop. I used a 100uF capacitor to reduce ripple voltage when, theoretically, anything >= 50uF would have worked. This decision was made to improve DC stability, but it also increases capacitor charging time. I also decided not to use a voltage regulator in this circuit as the capacitor can keep the ripple voltage within the desired range. This helps keep the circuit simple, which makes understanding and troubleshooting much easier.

This project heavily prioritized safety. There are many risks when it comes to dealing with high-voltage AC power sources, so instead of converting 120V (rms) AC to 3V DC with a physical transformer, we use our AD3's function generator to provide the theoretically calculated AC input at a much lower voltage so its safe for testing. Another safety precaution was ensuring that the diodes I selected (the 1N4148 diodes) could handle the forward current without overheating. I also checked that the 100uF capacitor's voltage rating was not exceeded, and its polarity was correct before connecting any power.

To ensure safety and correct function, I checked all component ratings exceeded their operating conditions significantly and simulated the circuit extensively. The 1N4148 diodes have a forward current rating that is much higher than 10mA, which is the expected current. This means they won't overhead to fail. The capacitor I chose has a voltage rating which is much higher (6.3V DC) than the peak rectified voltage of 3.82V which ensures I don't accidentally blow it up. It was also a ceramic capacitor, so polarity was not of concern. The load resistor was calculated to be 300 ohms, but I used a 330 ohm one as that is what we have supplied in our kits. Although it would be easy enough to connect three 100 ohm resistors in series to get a 300 ohm effective resistance, the instructor made it clear that 330 ohm resistor was within an acceptable range to not affect the function of the circuit.

Measurements and Analysis

Part I – Photograph of Circuit:

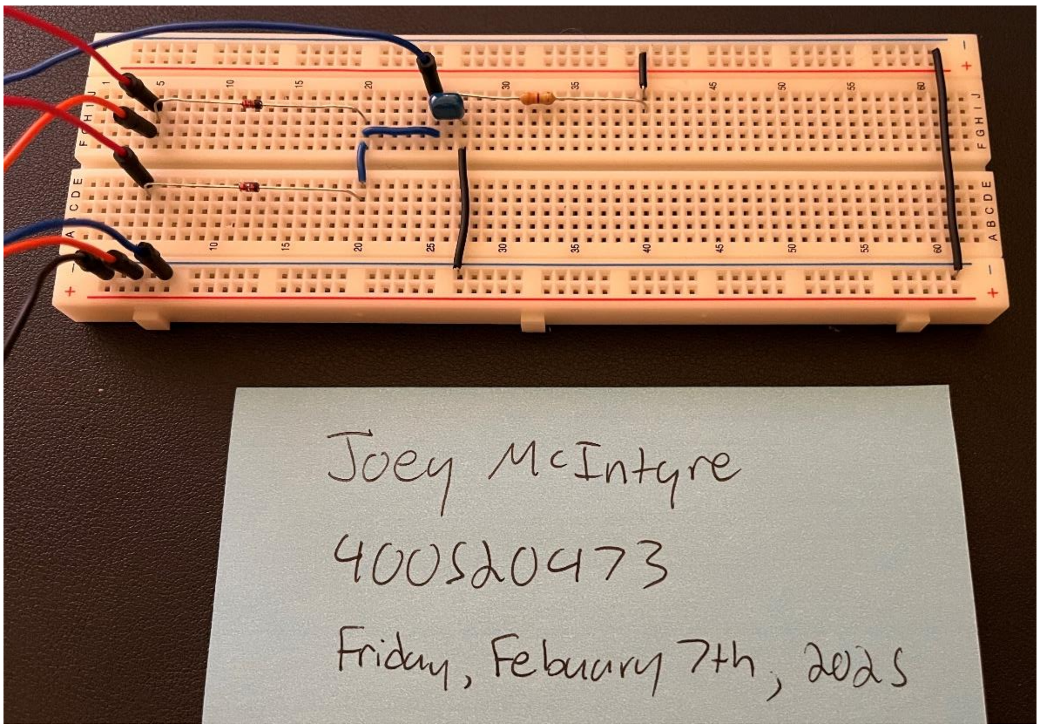

Figure 8: Photo of Circuit

Part II – Measurement Procedure Explanation and Performance Evaluation:

I built the circuit to compare the results from my physical circuit to my theoretical calculations. (as shown in Figure 8). I connected the two function generators from the AD3 to the input diodes, supplying two sine waves with amplitudes of 3.82V and -3.82V, respectively, with a frequency of 1kHz. The AD3 Wavegen settings can be observed in Figure 9.

To measure the input voltage, I connected channel 1 from the AD3 to the top node with the function generator W1 and the diode. I then connected the ground to the circuits ground.

To measure the resulting voltage across the load resistor, I connected channel 2 from the AD3 to both ends of the 330 ohm load resistor.

There is no way to measure current using the AD3 so to measure it I created my own math channel in the Wavegen software and divided the output voltage across the load resistor (channel 2) by 330 ohms. This gives me the current across the load resistor.

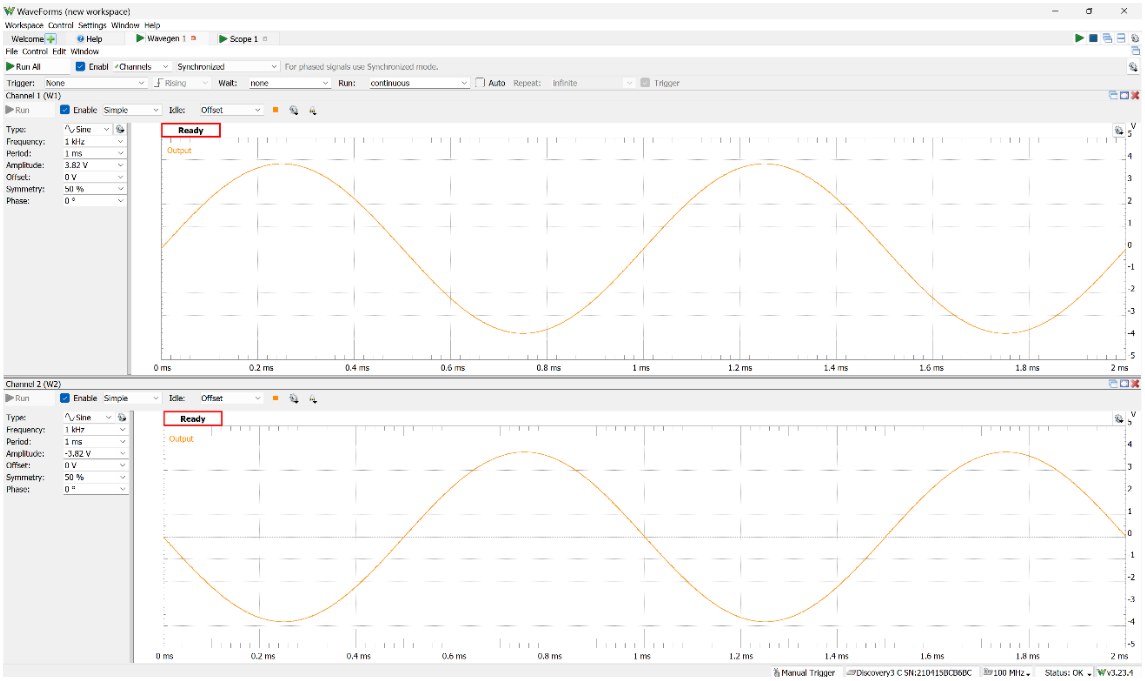

Figure 9: Function Generator Settings

Part III – Key Measurement Results:

As mentioned in part II, the key measurements are the input voltage, output voltage, and the current. Using the AD3's cursor feature, I can measure each of these key values to ensure they are within an acceptable range.

The input voltage oscillates between a maximum of approximately 3.82V and a minimum of approximately -3.82V. This is correct as this is equivalent to what the function generator is supposed to supply. This can be observed in Figure 10.

The output voltage could be the most important result of this project. It was made clear in the project guidelines that the output must be 3V +- 0.1V DC. The output voltage is oscillating between a maximum of 2.98V and a minimum of 2.92V. This falls within the acceptable threshold, meaning it meets the project requirements. This confirms that the AC to DC voltage converter circuit was designed and executed correctly. This can be observed in Figure 11.

The current is oscillating between a maximum of 9.03A and a minimum of 8.83A. This is slightly lower than the desired 10A, however this can likely be attributed to using a 330 ohm resistor in place the ideal 300 ohm load resistor. This can be observed in Figure 12.

Part IV – Oscilloscope Output:

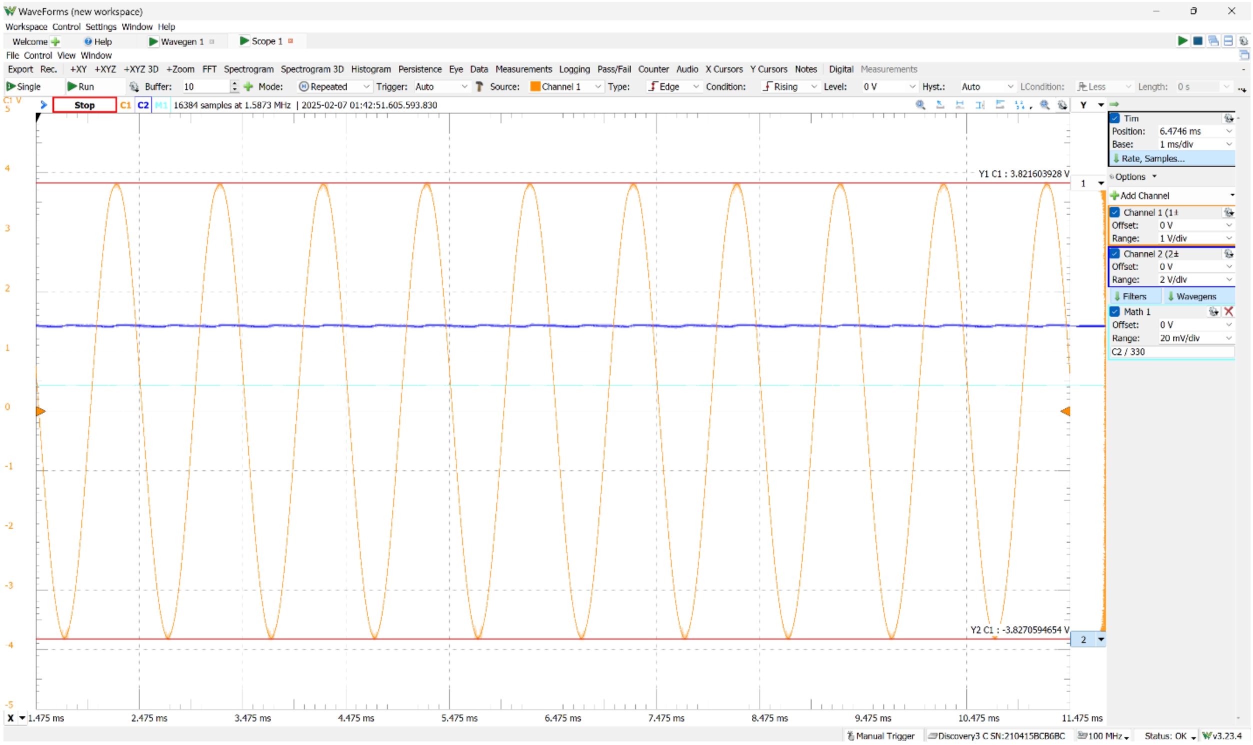

Figure 10: V in Measurement

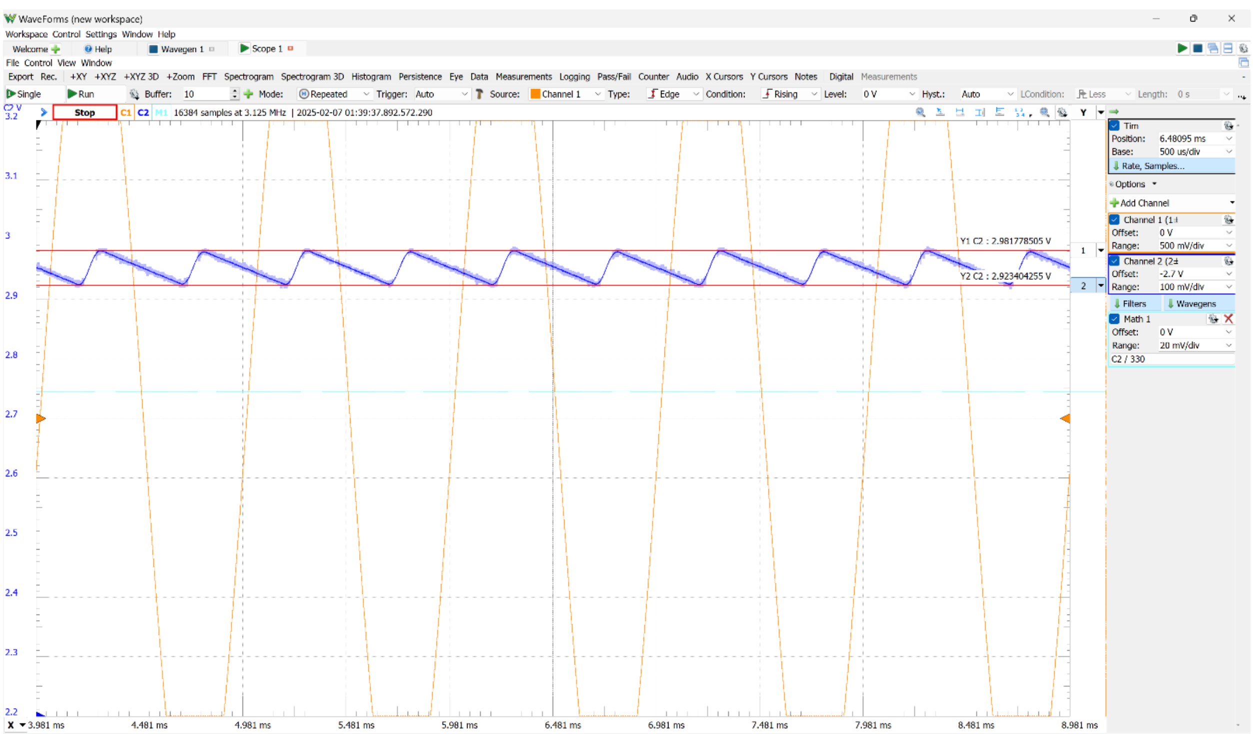

Figure 11: V out Measurement

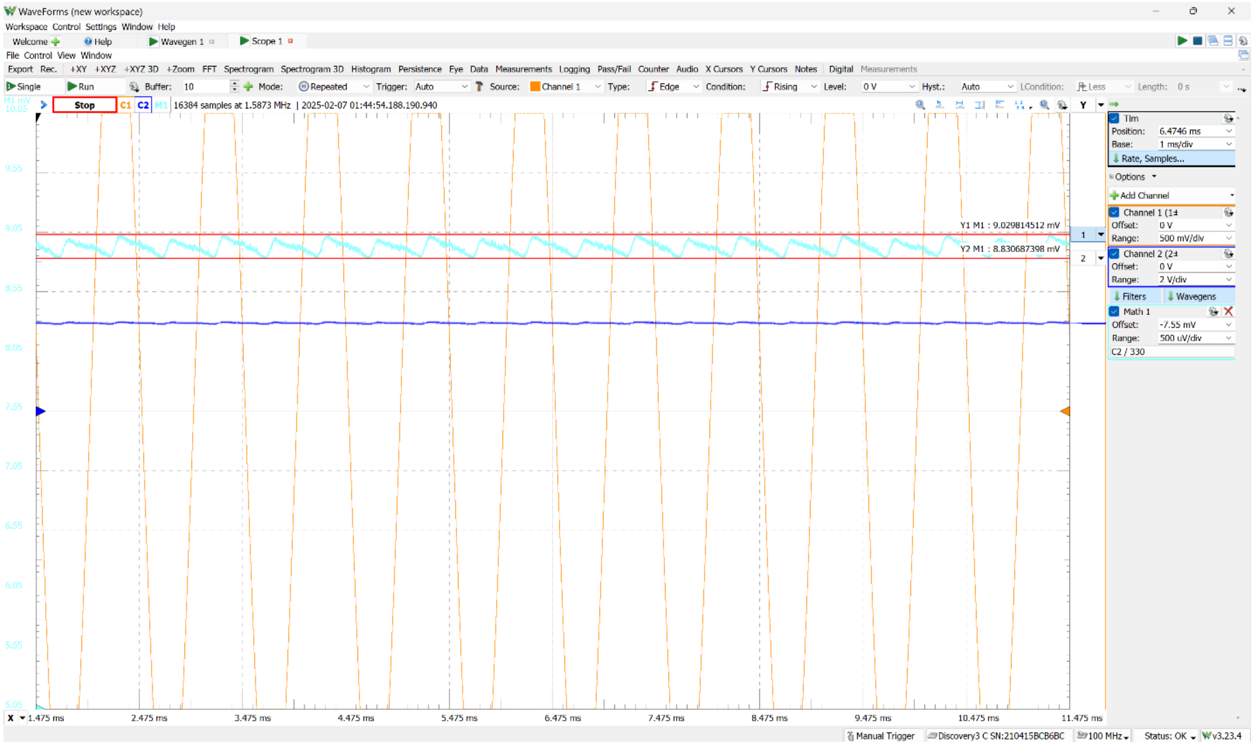

Figure 12: Current (I out) Measurement

Simulation

Part I – Simulation Schematic:

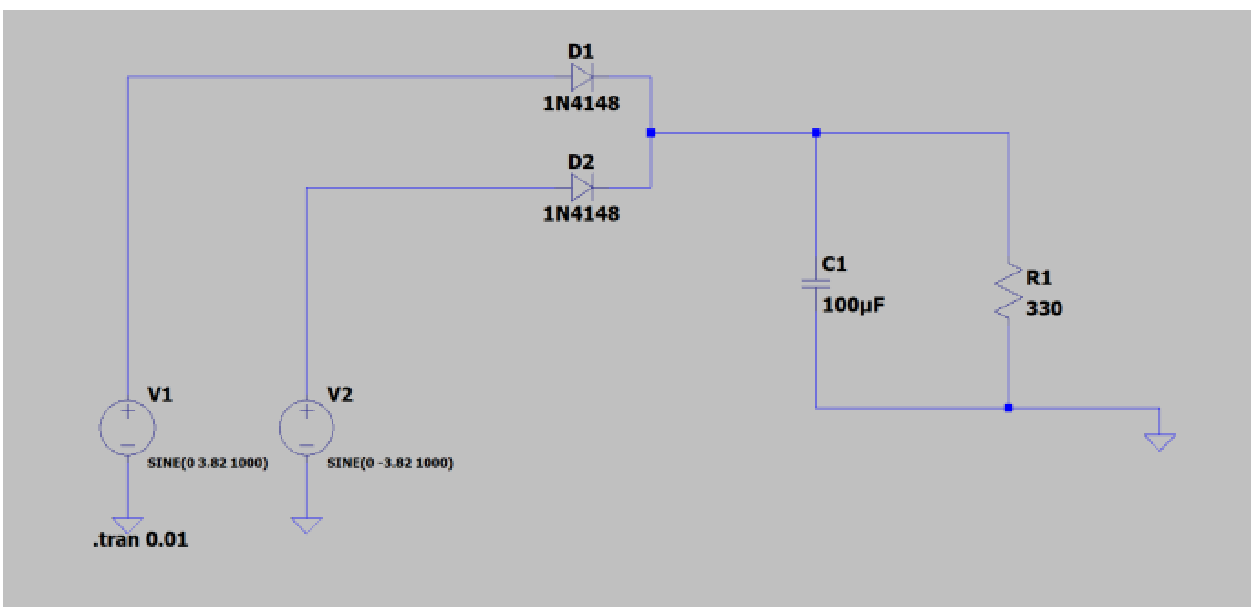

Figure 13: LTspice Circuit Schematic

Part II – Netlist:

```
V1 N001 0 SINE(0 3.82 1000)
V2 N003 0 SINE(0 -3.82 1000)
D1 N001 N002 1N4148
D2 N003 N002 1N4148
C1 N002 0 100µF
R1 N002 0 330
.model D D
.lib C:\Users\josep\AppData\Local\LTspice\lib\cmp\standard.dio
.tran 0.01
.backanno
.end
```

Figure 14: LTspice Netlist

Part III – Simulation Conditions:

This simulation was a transient sweep. It recorded data from 0 to 10 milliseconds.

Part IV – Simulation Output:

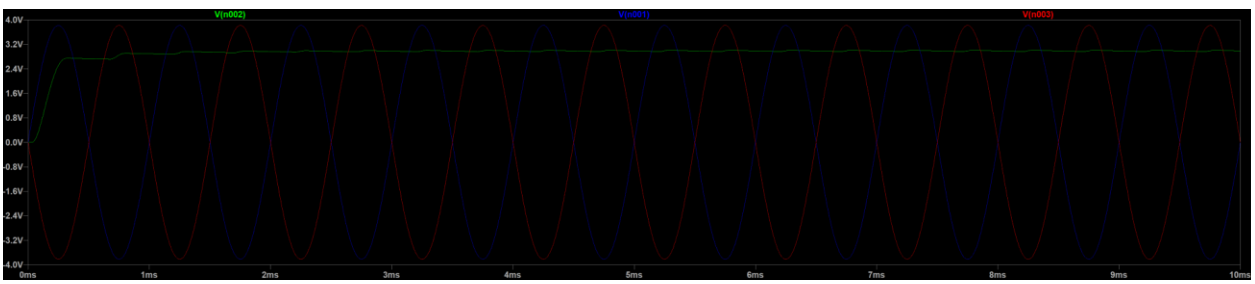

Figure 15: Simulation Output - Full View

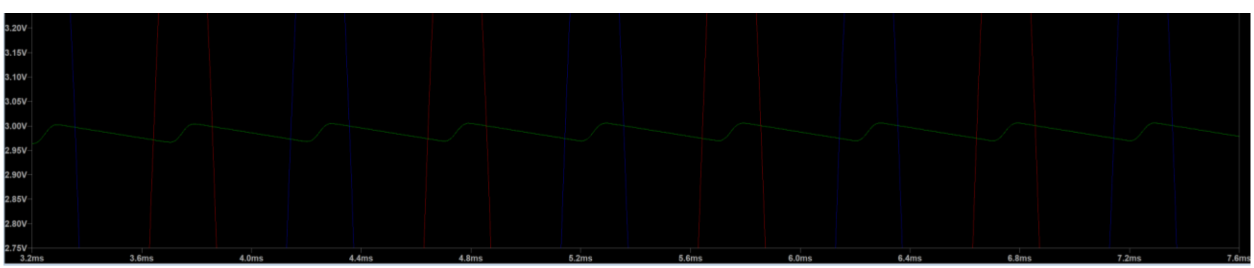

Figure 16: Simulation Output - Zoomed In

As observed in Figures 15 and 16, the output voltage (in green) is clearly within the 3V +- 0.1V threshold.

Discussion

Part I – Comparison of Results:

The results across the theoretical calculations, physical measurements and simulation were generally consistent. The calculated expected input voltage of +-3.82V was observed in LTspice, and with the AD3's oscilloscope. The output voltage of both the physical and simulated circuit were within the 3V +-0.1V accepted range, which confirms the accuracy of my design, calculations and measurements. However, the measured current through the load was slightly lower than the 10mA value we were looking for. However, this was expected due to the design trade-off of using a 330 ohm resistor as the load instead of a 300 ohm one. Overall, the physical circuit performed as predicted by the theoretical calculations and the simulation.

Part II – Observed Discrepancies:

While results were mostly comparable, some minor discrepancies were observed. The first of which is the variation in output voltage. I measured the output voltage to be 2.92V-2.98V, which is in the acceptable range, but it falls slightly lower than what would theoretically be expected. This is likely due to a higher voltage drop caused by the physical diodes than what is theoretically expected. Another discrepancy was the current being slightly lower than its theoretical value. This slight reduction in current is due to my load resistor being 330 ohms instead of 300 ohms which would be the ideal resistance.

Part III – Limitations of the Design and Measurements:

There were a few limitations that impacted my circuits design. For example, the highest capacitor I have access to is 100uF. A higher capacitance could have been used for the filter, which would have further reduced the voltage ripple and made the output voltage steadier. Another limitation was the fact that my design assumed ideal diode behaviour, when in reality a diodes forward voltage varies slightly with temperature and current. If the threshold had been smaller for an acceptable voltage range, I might have had to adjust my input voltages to account for these discrepancies. Another design limitation was the choice I made to not include a voltage regulator. This means the capacitor filter is entirely responsible for stabilizing the output voltage.

There are always going to be some limitations surrounding measurements because the AD3 is a great tool, but it is not perfect. Its function generator has a limited output current which could slightly affect the measured voltages. Its oscilloscope probes have a small amount of resistance and capacitance, which will slightly affect the readings. The main limitation however is the AD3 has no feature to measure current. To plot the current in the scope, I had to make a custom math channel that divides the voltage by the resistance to plot the calculated current. This introduces the possibility of some slight computational errors.

Part IV – Problems encountered and troubleshooting steps:

I was lucky to face very few problems during this project, likely due to the planning and simulating I did before even starting to build the circuit. One minor issue I faced when first collecting measurements was inconstant oscilloscope readings. I resolved this issue by using a multimeter to check connections, and verifying all components and wires were secure. Another minor problem was the output voltage being slightly lower than expected. The voltage was within the accepted range, so it was okay for this project, however the voltage wasn't oscillating around 3V, it was closer to 2.95. I was able to explain this by measuring the actual forward voltage drop across the diodes, which was slightly higher than an ideal model.

Conclusion

In conclusion, this project successfully met the design requirements. The AC to DC power converter outputted a voltage that stayed within the 3V +- 0.1V range. All of the design choices proved to be effective for the circumstances of this project. My measured data was very similar to the simulated and theoretical values, validating the design and measurement process. A way this project could be improved in the future would be by slightly increasing the input voltage to account for the forward voltage drop of real diodes, increasing the capacitance of the filter to further reduce the voltage ripple, and implementing a voltage regulator to cap the output voltage. All of these steps would result in a voltage much closer to the desired output.