Design Project #1: DC Power Supply

Electronic Devices and Circuits - 2EI4

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Summary

The objective of this project is to design and build a DC Power Supply5 capable of converting a 120V (rms) at 1 kHz AC input to a DC output delivering 10 mA at 3V ± 0.1V across a load. The design process involves designing a transformer, rectifier, filter, and regulator.

Design

Transformer

For this project, a Transformer is to be designed but not physically implemented. Below are the calculations of the Turns Ratio required for the hypothetical Transformer. Specifically, the Center Tapped Transformer was designed based on the chosen rectifier topology. Justification for this decision will be discussed further below along with the rectifier. The parameters for the design of this Transformer are an AC input of 120V RMS and a total output voltage of $7.49 \sin \omega t$ volts across 2 lines.

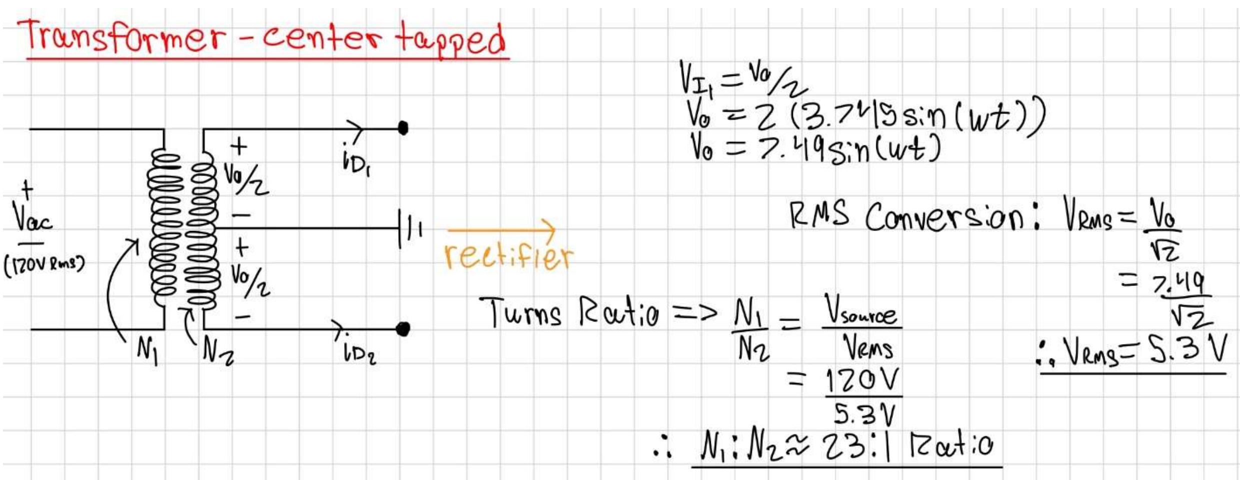

Figure 1: Transformer Calculations

Based on calculations, the hypothetical transformer would require an approximately 23:1 Turns Ratio to output the required voltage.

Rectifier

The design consisted of a Center Tapped Full-Wave Rectifier. This rectifier topology was chosen due to its advantages over the Half-Wave and Full-Wave Bridge topology. Advantages include high efficiency due to the utilization of positive and negative AC cycles, less power loss, and less ripple factor than the Half-Wave topology [1]. Another advantage specific to the details of this project is that I can create an efficient design using only 2 diodes through the Center Tapped Full-Wave topology while not needing to construct a Center Tapped Transformer. The parameters for this design include a peak voltage of 3.05V at the capacitor (in the filter) and a voltage ripple of 0.05 volts. The voltage ripple is allowed to be 0.1V according to project specifics, but 0.05V was chosen such that we can force a smaller variance of voltage which may offset any voltage discrepancies in the theoretical vs implemented circuit. Essentially, the bounds are being tightened to ensure success. The required voltage to turn on the diode is a forward drop of 0.72V as can be seen from the datasheet of the 1N4148 ABRA diode that will be used in the physical build [2]. One of the voltage sources is to be 180 degrees out of phase from the other to mimic the equal but opposite outputs of a Center Tapped Transformer.

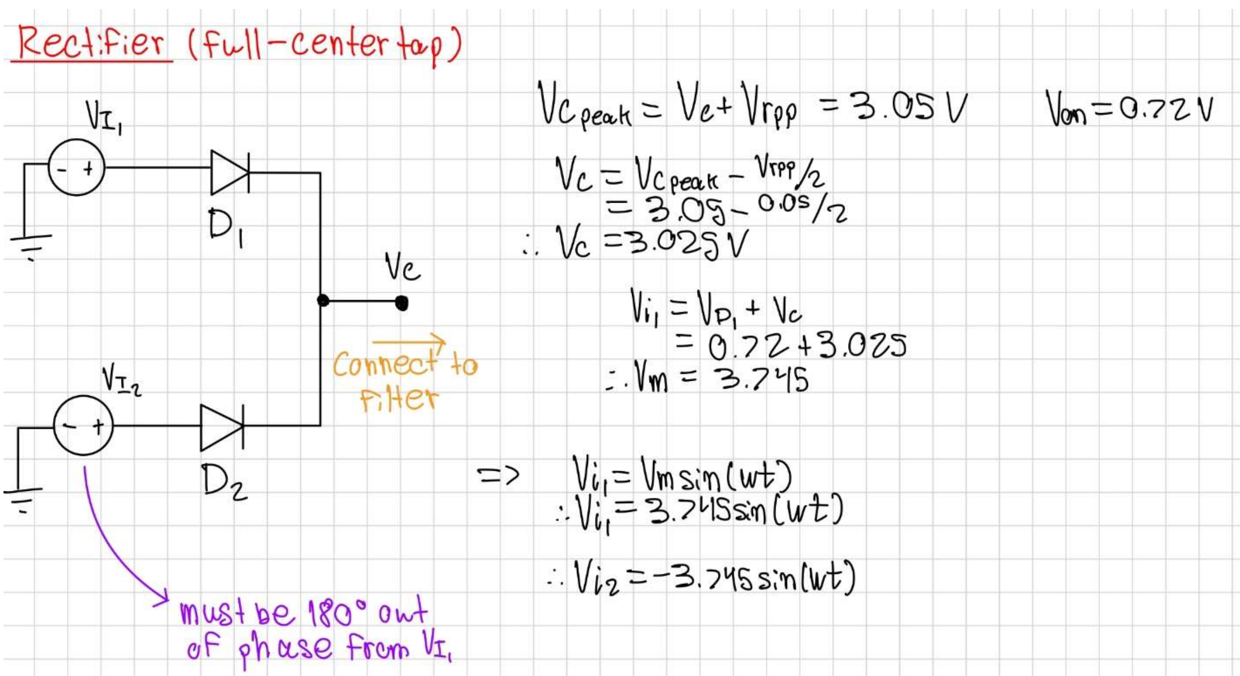

Figure 2: Rectifier Calculations

Based on calculations, we must construct a rectifier that connects to 2 equal but opposite sinusoidal input waveforms with a max voltage of 3.745 volts.

Filter

The filter chosen to be designed and implemented is the RC Filter. The RC Filter was chosen due to the availability of components. Other filter designs require an inductor(s) which weren't accessible. This is a significant design trade-off as the resister required for this filter topology increases series resistance. This is acceptable for the design as we require a load resistor regardless, but if the design was to be meant as a phone charger for example, or any design where a resistor is not required, then an increase in resistance can be unfavourable [3]. The inductor itself is also better at resisting changes in current compared to a capacitor which aids in blocking high-frequency signals. This design will utilize a $100\mu F$ capacitor, the ABRA CM107, and a 300Ω load resistor. The parameters for this design include a 3-volt drop across the capacitor and load resistor, a 10-milliamp current through the resistor, and a ripple voltage of 0.1 volts. Specifically, a 0.05V voltage ripple was utilized to ensure the variation in voltage at the load is strictly under 0.1 volts.

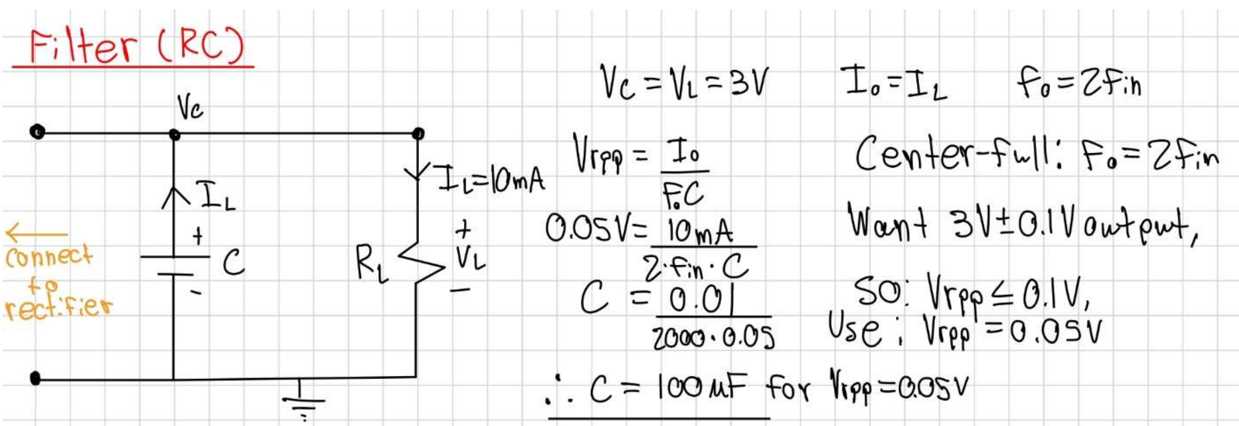

Figure 3: Filter Calculations

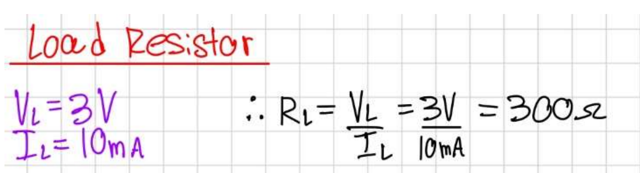

Figure 4: Load Resistor Calculations

Based on calculations, I must implement a filter using a 100 microfarad or greater capacitor to ensure the required output at the 300Ω load resistor.

Regulator

A regulator was not used for this design.

Complete Schematic

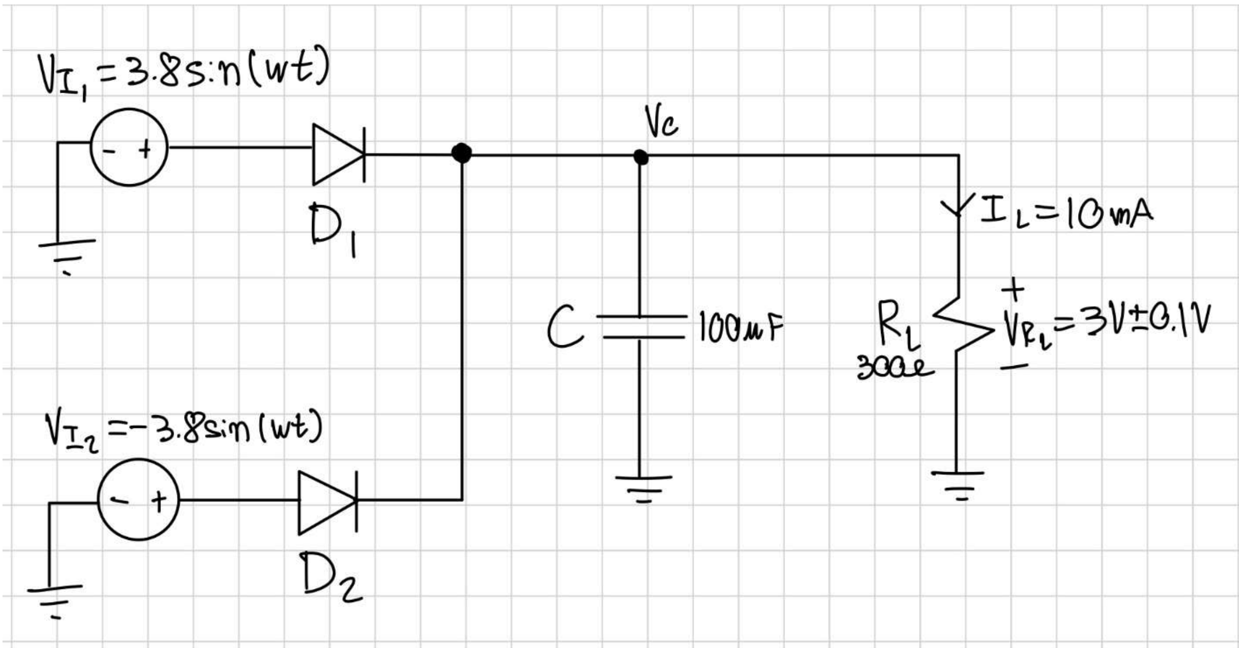

Figure 5: Complete Circuit Schematic

Simulation

Details and Result

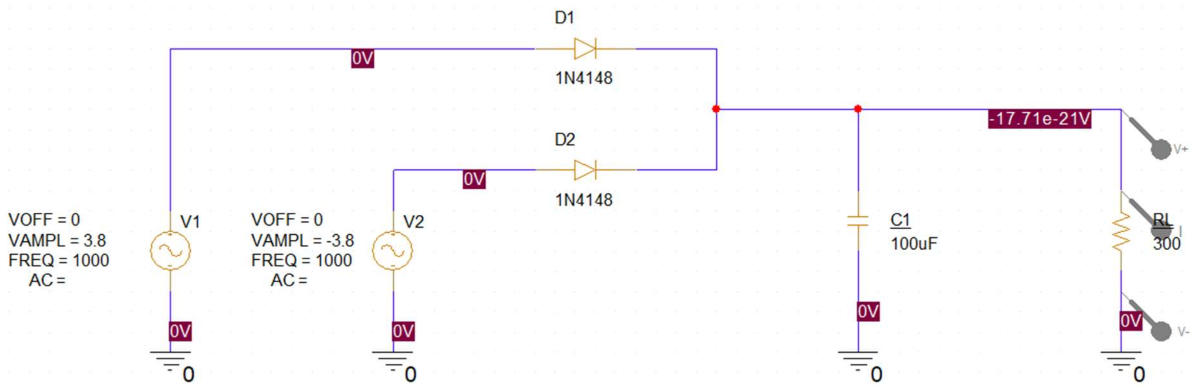

Figure 6: Simulation Circuit Setup

Before physical implementation, the design was simulated in OrCAD PSpice. The software performed a transient sweep simulation of the proposed circuit for 6000us. The graph in pink represents the measurement of voltage drop across the load resistor. As per design specifications, this must measure at 3V ± 0.1V. we can observe from the graph that the voltage ranges from 2.99V to 3.03V, which meets the required output of the design. The design also specifies a current of 10 milliamps at the load resistor. As voltage and current are proportional, it makes sense that current ranges along with voltage. We can observe that the current at the load ranges from 9.95mA to 10.12mA. Overall, the simulation verifies a design that theoretically meets the requirements of the project.

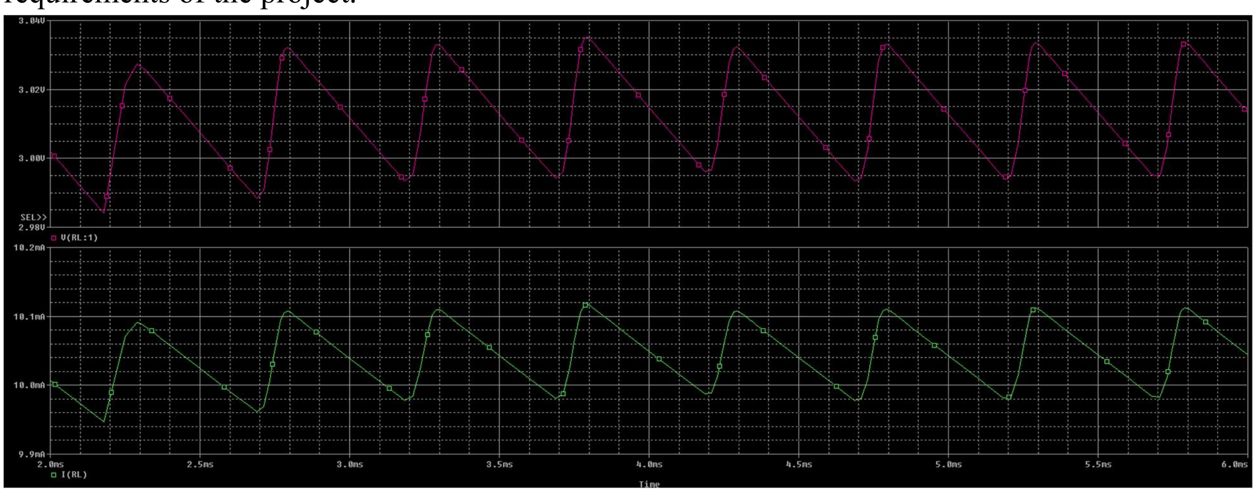

Figure 7: Voltage (pink) and current (green) simulated measurements

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/ - (SCHEMATIC1 : PAGE1)   Component Explorer
1: * source 2EI4 PROJECT 1
2: V_V1         N14541 0
3: +SIN 0 3.8 1000 0 0 0
4: V_V2         N14534 0
5: +SIN 0 -3.8 1000 0 0 0
6: X_D1         N14541 N14587 awb1n4148 PARAMS:
7: X_D2         N14534 N14587 awb1n4148 PARAMS:
8: C_C1         0 N14587  100uF
9: R_RL         N14587 0  300
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Figure 8: Simulation Netlist

Measurement and Analysis

Procedure

After a successful simulation, the circuit was created on a breadboard. A voltmeter was placed in parallel with the load resistor to measure the voltage drop across. Note that the load resistor being used here is 330Ω. This decision was not optimal but is explicitly permitted if needed as per the guidelines of this project. The voltmeter readings were observed to determine the performance of the DC power supply. Recall that the design is required to output 3V ± 0.1V at 10mA through the load resistor (the increase in resistance from the chosen resistor is expected to reduce current).

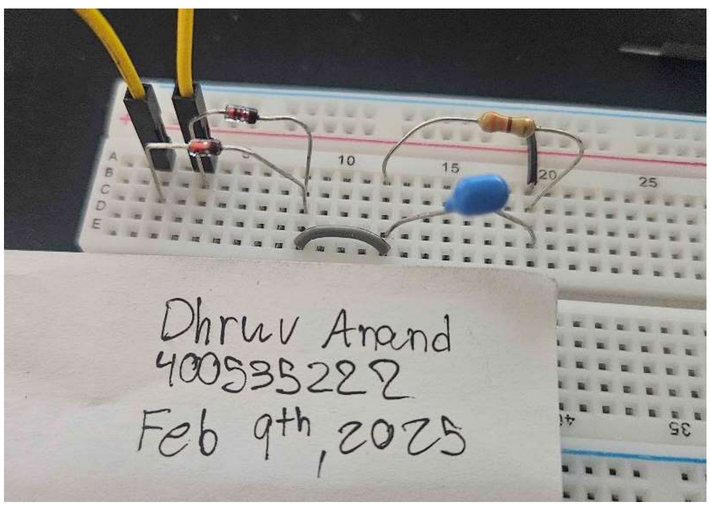

Figure 9: Physical design implementation

Results

Measurement confirmed that at the load, there is a 3V± 0.09V drop, which meets the project specifications. Through Ohms law, it is determined that the current at the load ranges from 8.8mA to 9.4mA. This decrease in current from simulated and theoretical values is explained using a 330Ω resistor versus the designed 300Ω. Applying Ohms law, it is determined that if the load was 300Ω, based on the measured voltages we would observe a 9.7mA to 10.0mA current at the load, meeting project specifications.

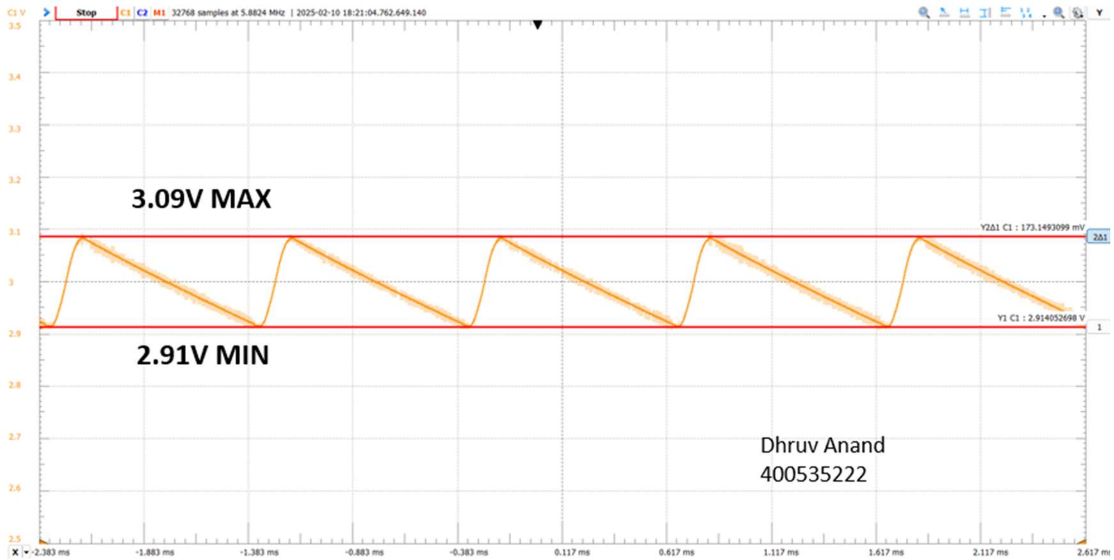

Figure 10: Voltage measured across load resistor

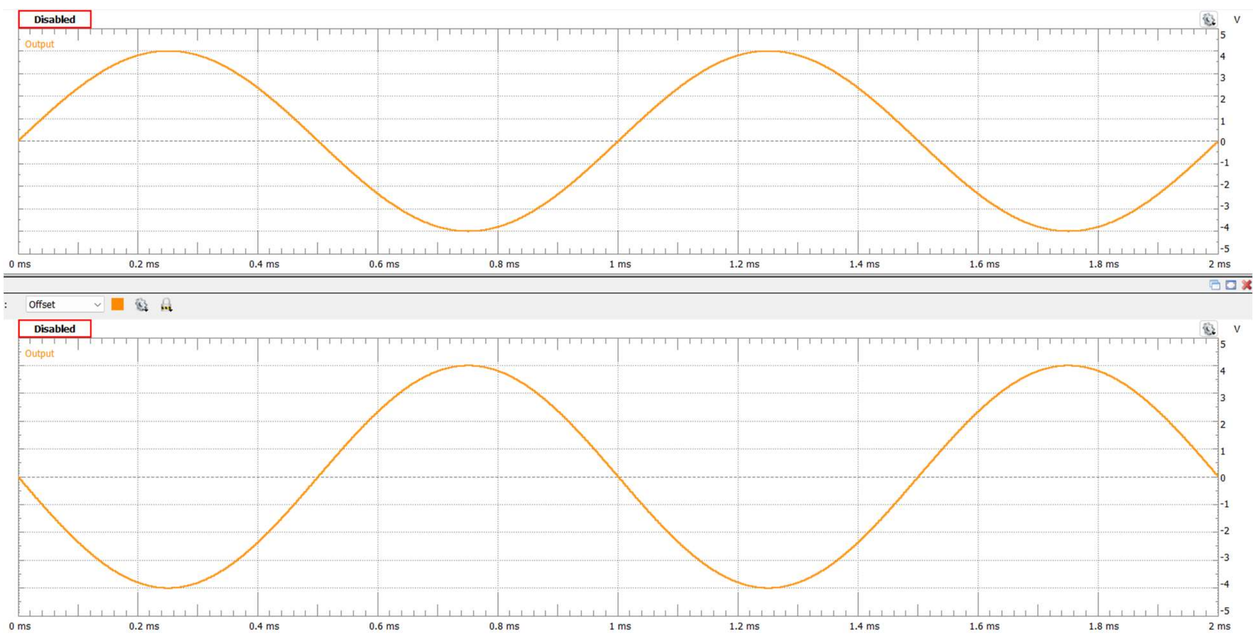

Figure 11: Input voltages

Discussion

The objective of the designed DC Power Supply was to output 3V ± 0.05V at 10mA at a load using 2 equal yet opposite sinusoidal input waveforms with a 3.8V amplitude. The simulation of this designed circuit yielded successful data, indicating that the design was sound. When moving to the physical implementation, there were some key problems in measurement compared to the simulated circuit. The first discrepancy was that when using 2 input waveforms with a max of 3.8V, the output voltage was found to be approximately 2.9V ± 0.1V, which was out of specifications for the design. This error was solved by increasing the amplitude of the input waveforms to 4.0V which then delivered the desired 3V ± 0.09V output. The reason this discrepancy arises is most likely due to the internal resistance and voltage/current tolerance of the physical components and the effectiveness of the connections between nodes on the breadboard. A second discrepancy that was found is the ± 0.09V ripple measured on the physical implementation versus the approximately ± 0.02V ripple in the simulation. This is also a result of internal resistance and voltage/current tolerance of components which are not accounted for in a simulated environment.

The main limitations of this design are the aforementioned internal resistance and voltage/current tolerance of physical components. To achieve the exact desired output, this design relies heavily on component values. Problems arise when components do not operate at their exact values due to internal factors, which are random and cannot be accounted for directly in design calculations. However, the choice of designing the filter with a 0.05V target voltage ripple (or any value less than the required) rather than the maximum allowed 0.1V is one way to mitigate the effect of any discrepancies. Similarly, discrepancies in measurement can be a result of the tolerance and resistance of the AD3, and the stability of wire connections from the circuit to the AD3.

References

1. Elprocus. “Center-Tapped Full-Wave Rectifier,” Elprocus, Available: https://www.elprocus.com/center-tapped-full-wave-rectifier/#:~:text=The%20advantages%20of%20center%2Dtapped,factor%20as%20compared%20to%20HWR. [Accessed: Feb. 9, 2025].

2. Diodes Incorporated. “Datasheet: DS12019,” Diodes Inc., Available: https://www.diodes.com/assets/Datasheets/ds12019.pdf. [Accessed: Feb. 9, 2025].

3. S. Xu. “Filters: Use RC, RL, or RLC Circuits?,” Simon Xu’s Blog, Mar. 10, 2015. Available: https://simonxu.wordpress.com/2015/03/10/filters-use-rc-rl-or-rlc-circuits/. [Accessed: Feb. 9, 2025].

4. Physics and Radio Electronics. “Full Wave Rectifier,” Physics and Radio Electronics, Available: https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/rectifier/fullwaverectifier.html. [Accessed: Feb. 9, 2025].