Electronic Devices and Circuits

Design Project 1 - DC Power Supply

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a. Summary

This project is aimed at creating a DC power supply that converts an AC input into a 3 volt DC output. A DC power supply is composed of a transformer, rectifier, filter, and a regulator. The purpose of this project is to calculate the parameters and specifications of these components to convert an AC 120V rms voltage at 1kHz into a 3V +-0.1 DC voltage at 10 amps at the load.

b. Design

I) Transformer:

For our purposes a transformer was not built, but it was designed. For this device we need an input voltage of 3.1 going out of a center tapped full wave rectifier, meaning we will experience a drop of ~0.8 volts due to the diodes. This results in needing ~3.85Vp (V peak) input into the rectifier from the transformer, which means we need an output peak voltage of 2*3.85 = 7.7, which is also an rms voltage of 7.7/(sqrt(2)) = 5.44 Volts. Using the turns ratio formula of VinRMS/VoRMS we get a 120/5.4 = ~22:1 turns ratio, which would be the ratio used if we were to build the transformer.

II) Rectifier:

For the rectifier there were multiple choices, first there are two types of rectifiers, full-wave and half-wave. A Full wave uses 2 or more diodes to convert the entire AC signal into DC, whereas a half-wave uses 1 diode to simply filter out half of the signal. For our purposes a Full-wave makes more sense so we can use all the power we can get. From researching, it seems like there are 2 main topologies for the full wave rectifiers: center tapped and bridge. For this design I went with the center tapped due to it being much simpler to build and only requiring 2 diodes compared to 4, although it requires 2 inputs with a 180 degree offset. For the parameters of the diode, it is mentioned above that the 1N4148 diodes have a forward drop of ~0.8 volts[1], and in a center tapped rectifier our input voltage goes through only 1 diode (2 diodes are in parallel) meaning it will experience a drop in voltage, which gives the input voltage required.

III) Filter:

The filter for this device is simply just a capacitor, this should help "fill in" the gaps between the signals coming out of the rectifier and make it behave more DC like. To determine the capacitance needed, we are given a ripple voltage of 0.2v, 2khz frequency (two 1khz inputs), and a load current of 10mA. Using the ripple voltage formula Vt >= I/(f*C) we can determine that a minimum capacitance of 25uF is needed for the circuit, for the purposes of this device I will use a 100uF capacitor to reduce ripple voltage further.

IV) Regulator:

For this device I ended up deciding to not use a regulator. After designing the circuit in Pspice with a regulator (A zener diode with a zener breakdown voltage of 3v in parallel with load) I realized that it would need an extremely large amount of current ~(200mA) which is way higher than the rated amount of 40mA that the AD3 can supply [2]

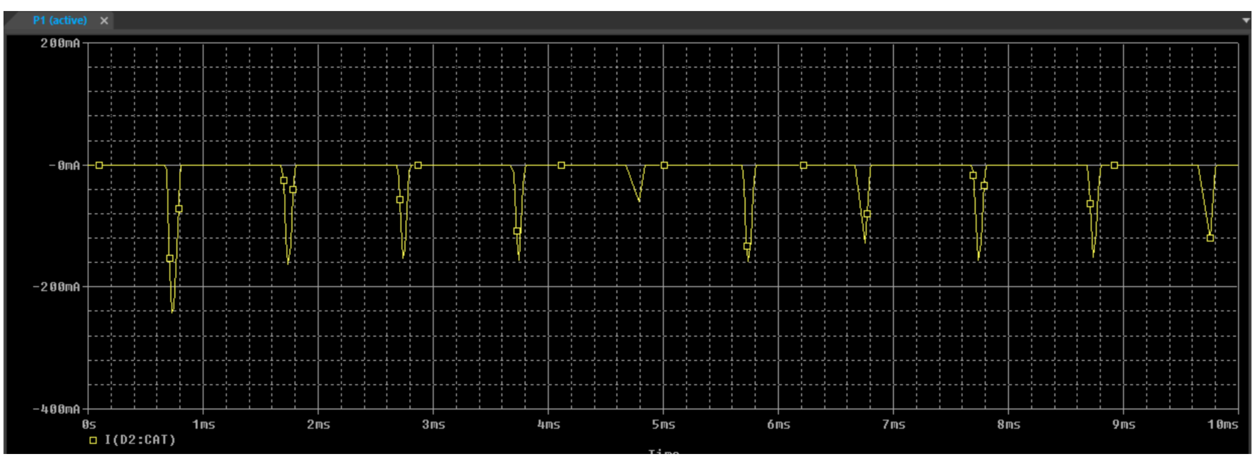
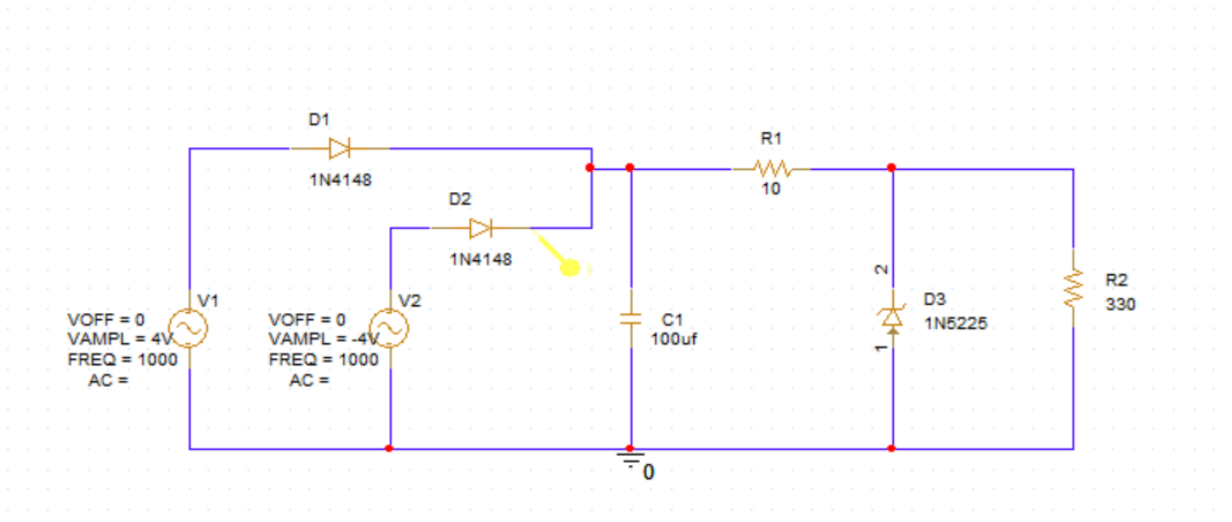


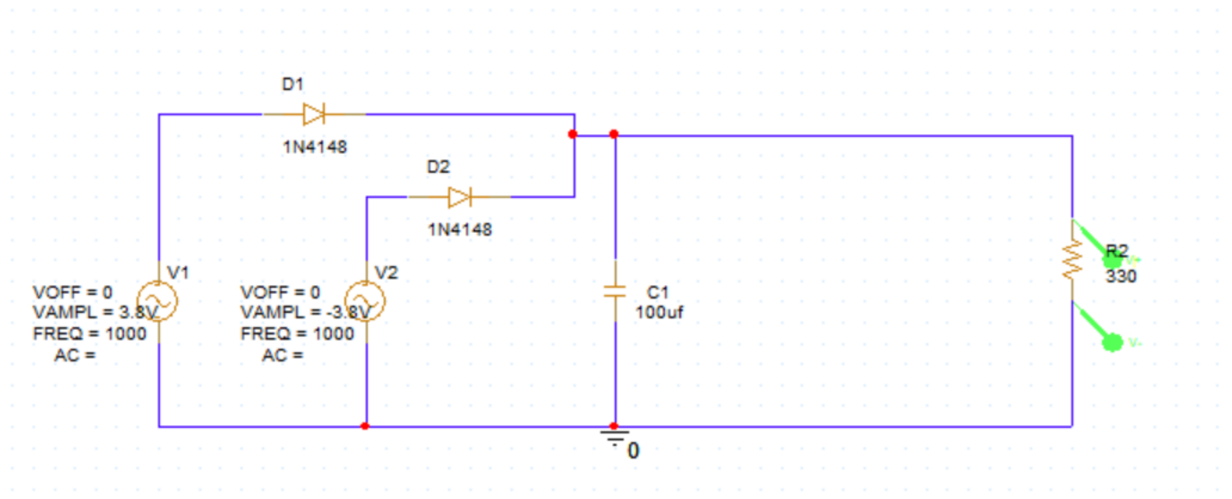
Figure 1: Pspice simulation of current at rectifier diodes.

V) Complete Circuit Schematic

1) With regulator



2) Without regulator (final design)



VI) Calculations:

For the amplitude of the Voltage source:

Vout from rectifier = 3V

Vout = Vamp - VDiode = 3V

3V = Vamp - 0.8

Vamp = 3.8V

For Capacitor:

C >= I/(f*Vr)

C >= 10ma/(2Khz*0.2)

C >= 25uF

100uF >= 25uF.

For Resistor:

V = IR

3 = 10*(10^-3)*R

R = 300 Ohms

(For the purposes of this device a 330 ohm resistor was good enough)

VII) Expected Performance:

The expected performance of this device is a 3V DC signal outputting with a ripple voltage of around 0.05 due to the Capacitor being 4x bigger than it needs to be.

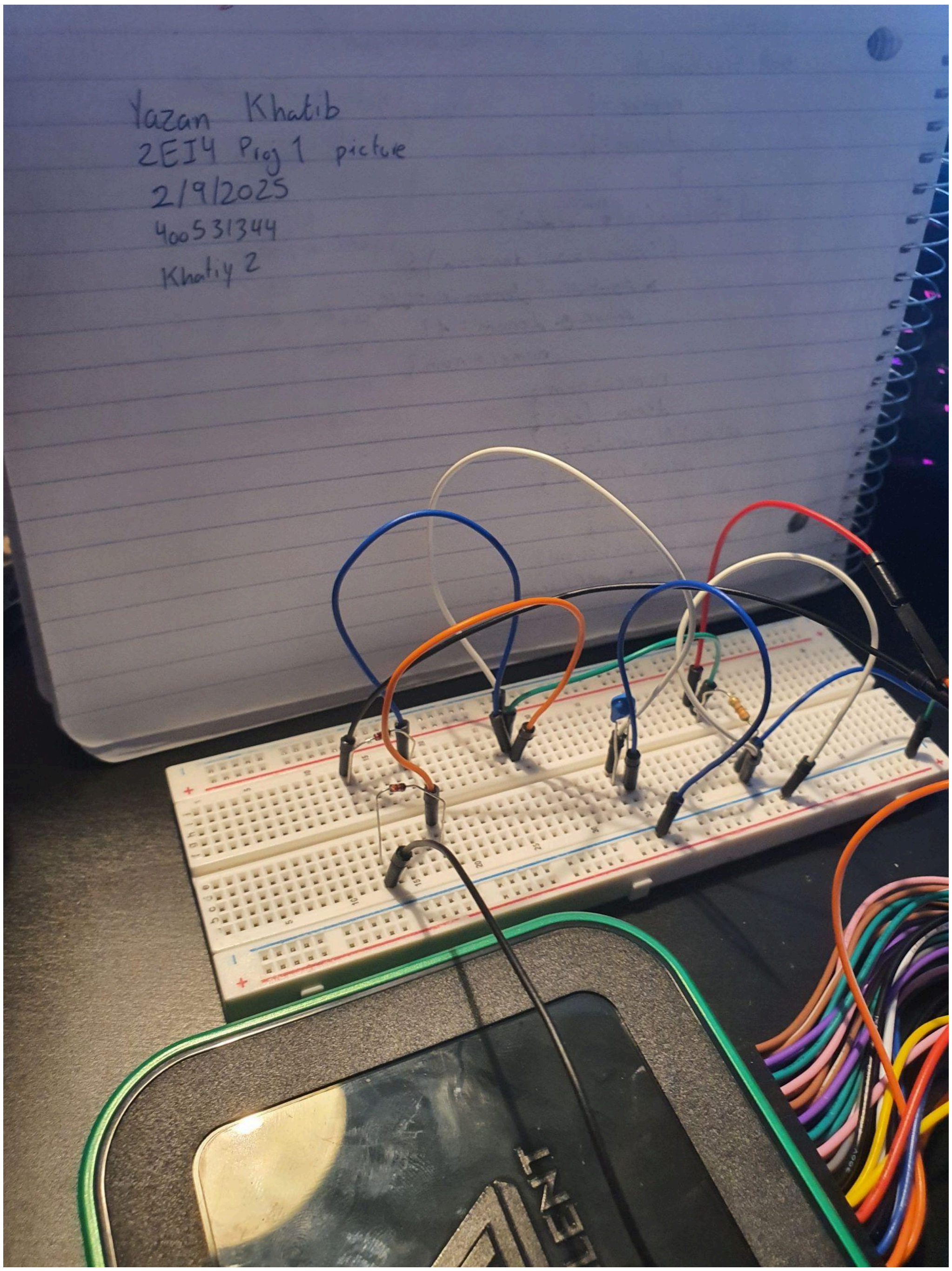
The expected Current is slightly below 10mA at the load due to a slightly bigger resistor being used. It is also expected that none of the currents in the circuit exceed the device specifications of the components/

VIII) Design Tradeoffs/Limitations

When consulting the datasheets for the components, the above calculations were used to prove that none of the currents exceed the design specifications. The decision to not use a regulator was done with safety issues/component ratings in mind as to guarantee all components operate within their rated specifications. This decision is considered a tradeoff as a regulator does provide a much smoother DC output signal.

c. Measurement and Analysis:

I) Photograph of built circuit



II) Measurements and Performance

Performance was determined by measuring all the voltages/currents in the circuit and comparing them to the expected values in the simulation. When measuring the output Voltage given an input of 3.8 and -3.8 to the rectifiers, we can see in figure 3 that the voltage is significantly lower than expected. This turns out to be due to the diodes having a higher forward voltage than previously thought. When measuring the voltage across the diode we can see in figure 2 it is around 1v. Upon inspection it seems that there are 2 conflicting datasheets for the 1N4148 Diode, one says its max is 1v the other is 0.8. Regardless of the issue it can be mitigated by simply raising the AD3 output voltages to 4v (Diode voltage is 0.2v higher than expected, so raise input voltage by 0.2). When doing so we can see in Figure 4 we are achieving an about ~3V DC output with ~0.3V ripple. This result is very identical to what we expected from the simulation. This also means the currents are also behaving as expected. With a ~9.2mA current being output due to the 330 ohm resistor (10% less current due to a 10% bigger resistor).

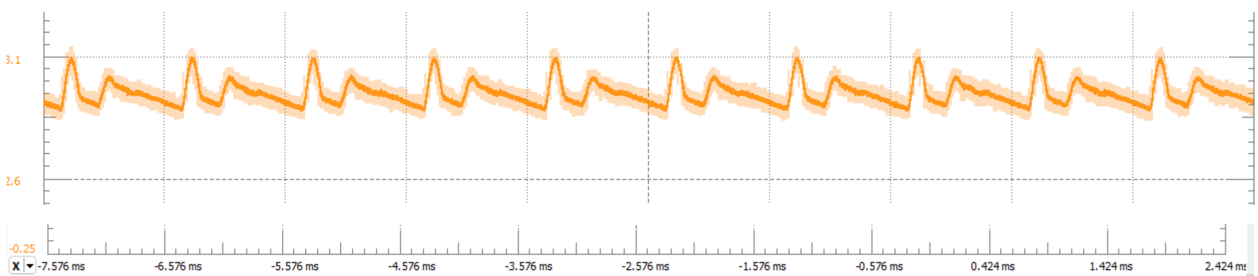


Figure 2: Output voltage from rectifier given 4.1V (we can see a 1v voltage drop due to the diode)

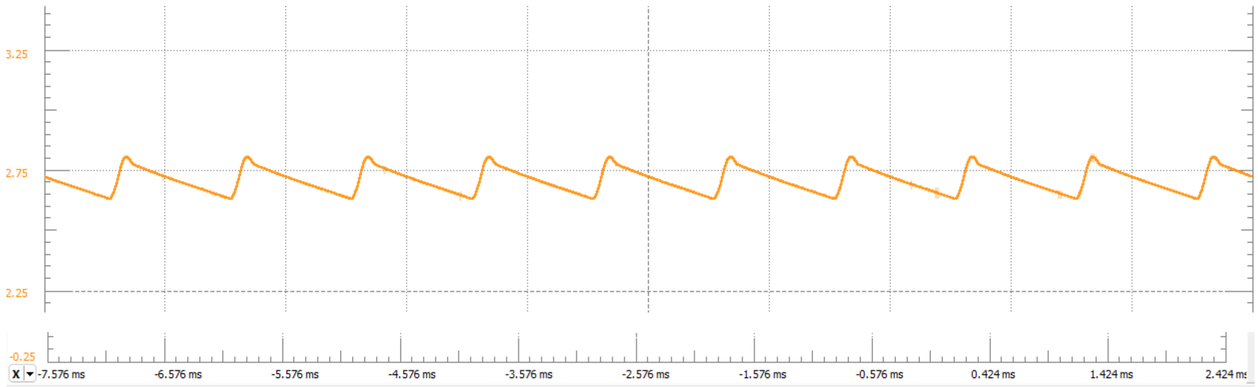


Figure 3: Output Voltage from DC supply given 3.8 input voltage.

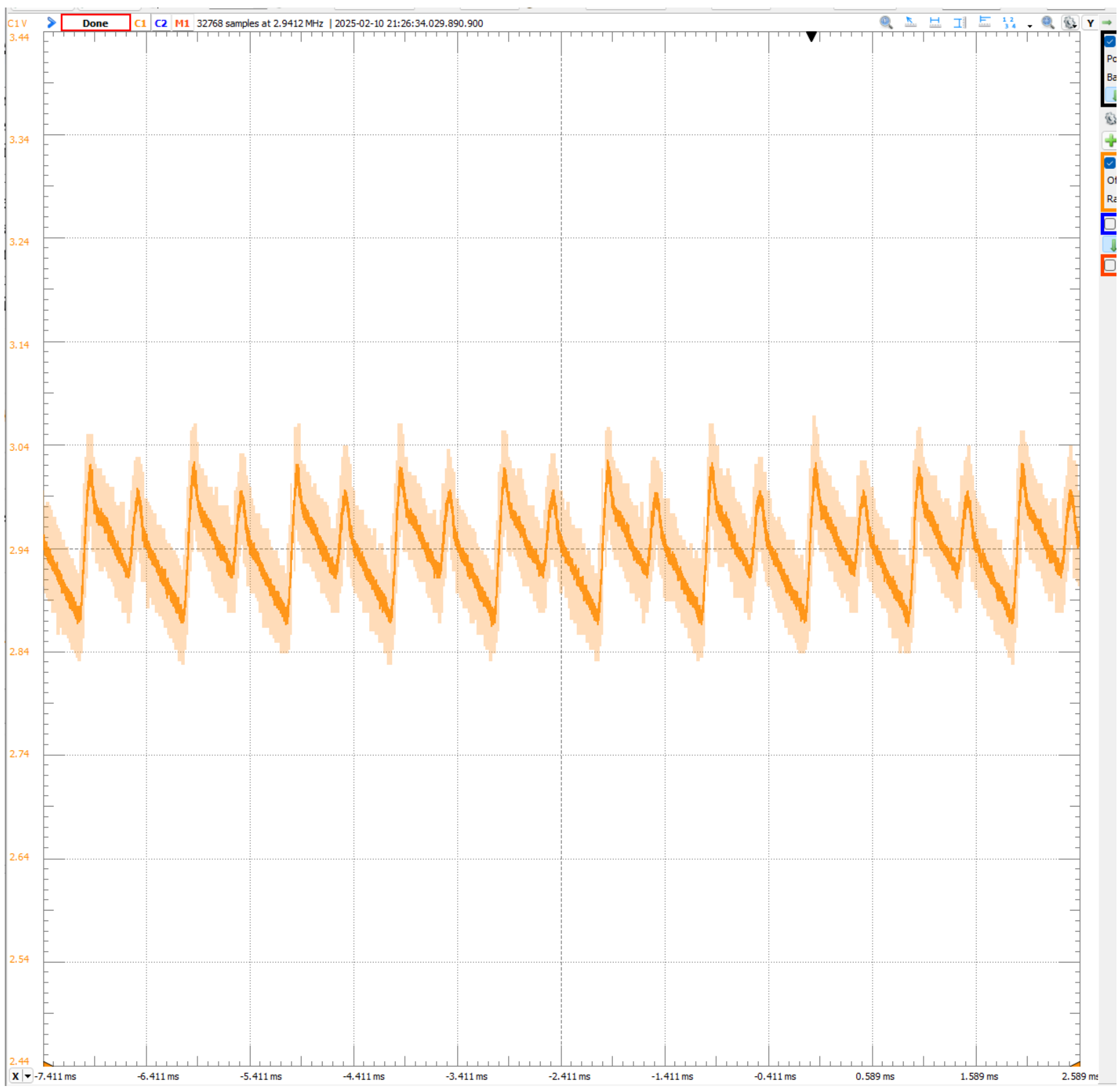
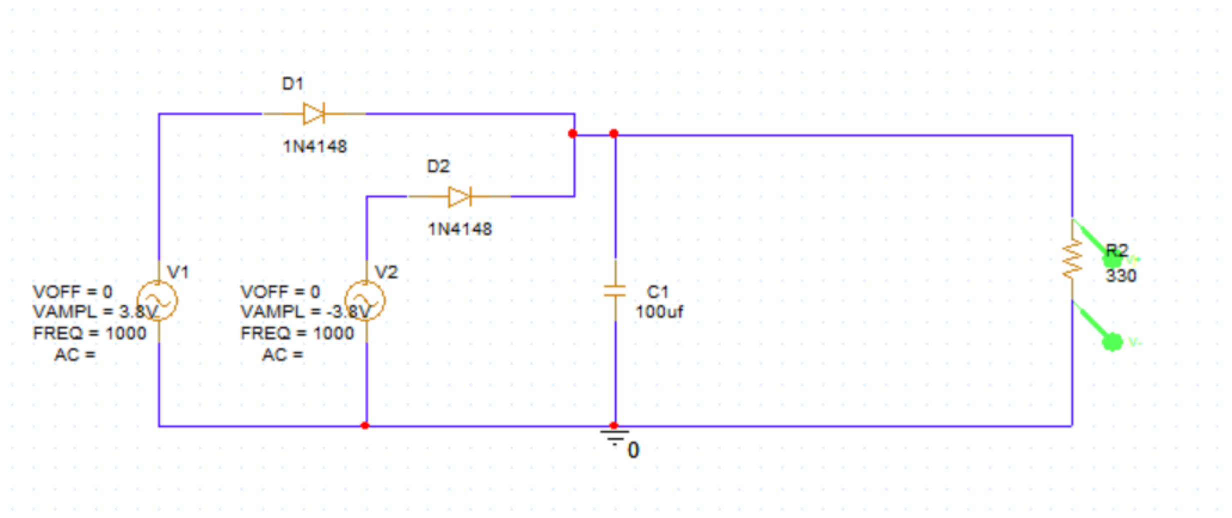


Figure 4: Output voltage from DC supply given a 4V input. Voltage ranges are within 2.9v - 3.03v (zoomed in to show values).

d. Simulation

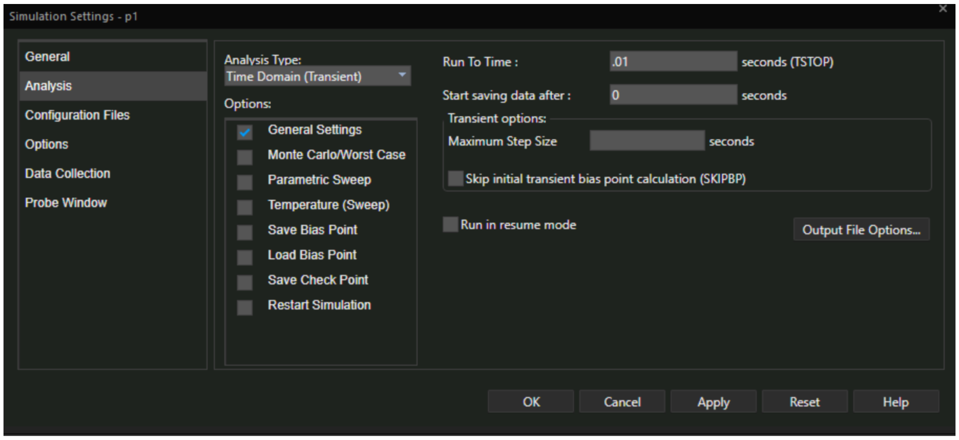
i) Circuit schematic from simulator



ii) Pspice Netlist:

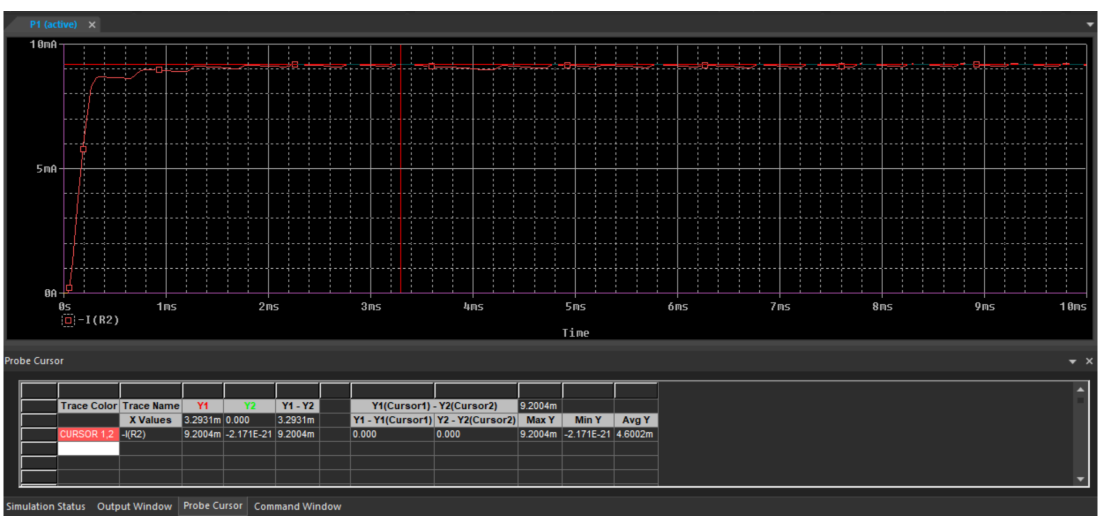
```
* source 2EI4PROJECT1
V_V1         N00276 0
+SIN 0 3.8V 1000 0 0 0
V_V2         N00285 0
+SIN 0 -3.8V 1000 0 0 0
R_R2         0 N00294  330 TC=0,0
C_C1         0 N00294  100uf  TC=0,0
X_D1         N00276 N00294 awb1n4148 PARAMS:
X_D2         N00285 N00294 awb1n4148 PARAMS:
```

iii) Simulation Conditions:

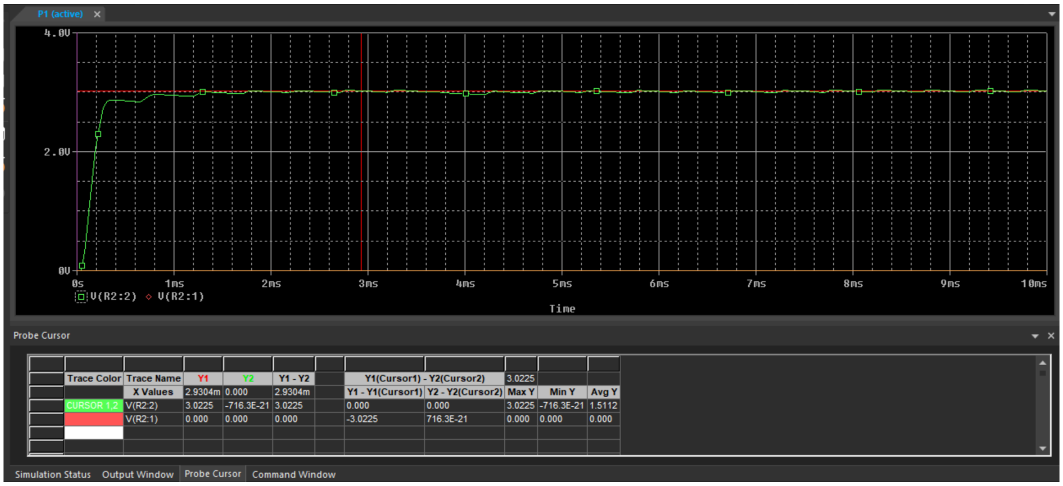


iv) Simulation Output:

The figures and numbers used for the simulation are exactly like the ones used in the circuit. Pspice has the exact same components as the ones in the 2EI4 kit, the only difference is that the diode in PSpice contains a 0.8v drop compared to 1v in the 2EI4 kit. This was mitigated by using 3.8v as our input voltage in the simulation. When done so we can see below that the current/voltage matches the one found in the real circuit.



Load current output from simulation



Load Voltage output from simulation

e. Discussion:

The final measured results closely matched the design objectives, producing a DC signal of 3V with a peak voltage of 3.1V and a minimum of 2.9V. However, there were several discrepancies between the design, simulation, and actual measurements. One major issue was with the voltage regulator, which initially failed to operate on the AD3 power supply because it required more current than the AD3 could provide. Additionally, discrepancies in diode voltages were observed—while the simulation and datasheet specified a 0.8V forward voltage, actual testing showed it to be 1V, requiring an increase in the initial voltage by 0.2V to compensate.

The design itself has inherent limitations. The use of a center-tapped rectifier, while requiring only two diodes, results in lower efficiency because only half of the transformer winding is utilized during each half-cycle. In contrast, a bridge rectifier would have improved efficiency by using the full winding. Another limitation stems from the capacitor filter—despite using a 100µF capacitor to reduce ripple, it was not entirely sufficient to achieve a perfectly stable DC output. This residual ripple, combined with the efficiency losses from the rectifier, prevented the output from being completely flat.

During the measurement process, additional challenges arose. The AD3 power supply constraints required re-evaluating the regulator's operation, and unexpected diode voltage drops led to necessary voltage adjustments. Troubleshooting involved verifying component specifications, adjusting input voltages, and testing under different load conditions to confirm findings. These challenges highlight the importance of accounting for real-world variations in component performance when designing circuits

Sources Cited:

[1] Fpsupdate, "1N4148 datasheet – Vishay's small fast switching diode," Free Online PCB CAD Library, https://www.ultralibrarian.com/2022/09/13/1n4148-datasheet-vishays-small-fast-switching-diode-ulc#:~:text=Electrical%20Characteristics,junction%20voltage%20of%200.7V. (accessed Feb. 10, 2025).

[2] J. Colvin, "Analog Discovery 3 specifications," Analog Discovery 3 Specifications - Digilent Reference, https://digilent.com/reference/test-and-measurement/analog-discovery-3/specifications (accessed Feb. 10, 2025).