Electronic Devices & Circuits I 2EI4
Project 1

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1. Summary

The objective of the project is to design an AC to DC power supply that delivers a target current at a specified voltage, demonstrating the versatile applications of diodes. The design implements a full wave bridge rectifier with a capacitor filter to convert a 120 V AC input simulated with a function generator to a stable 3 V ± 0.1 V DC supply with a 10-mA current output at 1 kHz. Ensuring safety standards and power ratings, component values such as capacitors and resistors were calculated for the rectifier, as well as an AC source voltage that can be transformed from a 120 V source. Using PSpice simulations, circuit implementations, and measurement analysis, the report entails the systematic approach that is used to successfully generate a reliable DC power supply that meets the target specifications.

2. Design

i. Transformer

In the AC to DC power supply circuit, the transformer is required to convert a 120 V AC source to a 4.4 V AC source, which is the input of the rectifier. The 4.4 V source is approximately 3.11 V AC RMS, meaning the turns ratio is 38.6 in order for the transformer to perform a step down of the voltage.

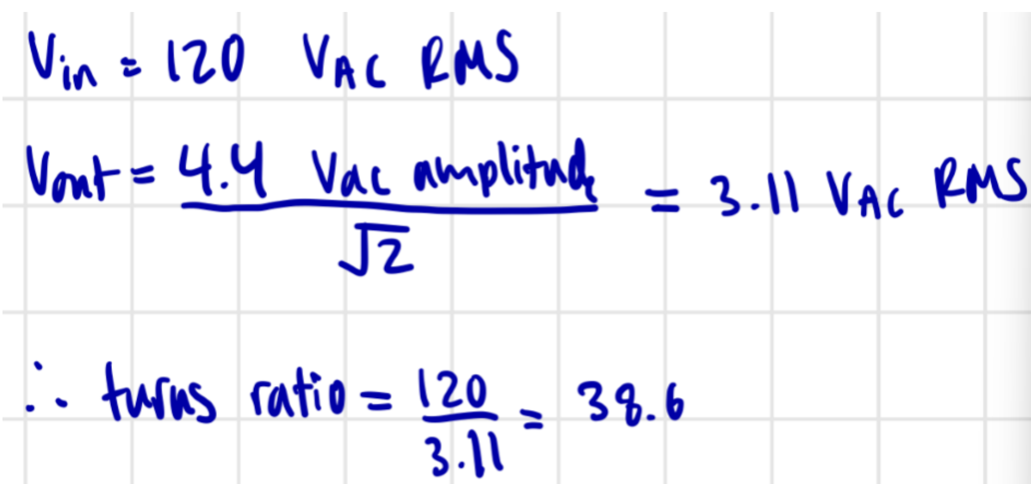


Figure 1. Transformer Ratio Calculations

ii. Rectifier

A full wave bridge rectifier is selected to design the AC to DC voltage converter due to its efficiency. Unlike other topologies like half-wave rectifiers which allows only half of an AC waveform, the full wave bridge rectifier can use both halves of the AC signal, resulting in a more stable output with a reduced ripple voltage that meets the ± 0.1 V requirement. Four 1N4148 diodes are incorporated in the rectifier based on their parameters, such as forward voltage drop and breakdown voltage. According to its datasheet, the diode’s maximum forward voltage is 1.0 V, where significant current begins to flow which plays a significant role in the converter DC voltage’s magnitude. Its breakdown voltage is 75 V, which adheres to the transformed AC voltage value of 4.4 V that is inputted in the rectifier circuit.

iii. Filter

A capacitor filter is implemented for simplicity and efficiency in stabilizing the rectified output and minimizing the ripple voltage. A component value of 25 uF is chosen as it is the lowest possible capacitance required to meet the voltage output requirement of 3 V ± 0.1 V DC. Due to the availability of components, three 10 uF capacitors are used instead to provide a total capacitance of 30 uF, exceeding the minimum capacitance and yielding more stable results although the difference is insignificant.

iv. Regulator

A regulator was not implemented in the AC to DC power supply circuit for simplicity.

v. Circuit Schematic

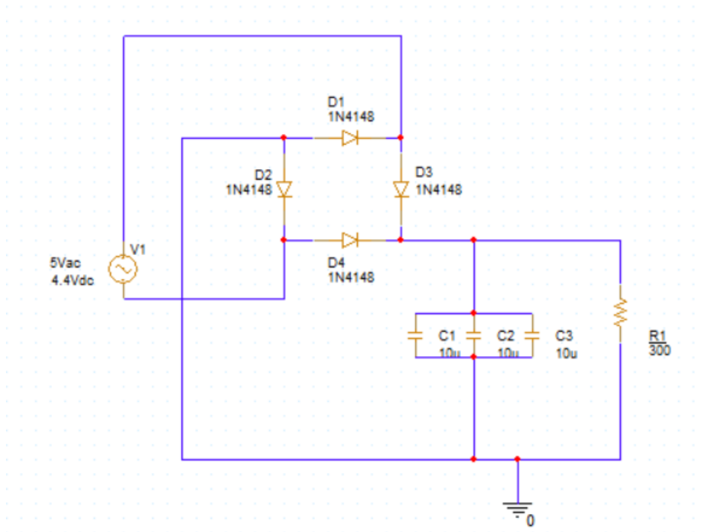


Figure 2. Circuit Schematic from PSpice

vi. Calculations

$$V_{ripple} = \frac{I_{out}}{2fC}$$

$$0.2 = \frac{10\times10^{-3}}{2(1\times10^{3})C}$$

$$C = \frac{10\times10^{-3}}{2(1\times10^{3})(0.2)}$$

$$C \geq 25\,mF$$

Figure 3. Minimum Capacitance Calculation

$$V_{rectifier} = V_s - V_{drop}$$

$$3 = V_s - (0.7 + 0.7)$$

$$V_s = 4.4V$$

Figure 4. AC Source Voltage Input Calculation

$$R = \frac{V}{I} = \frac{3}{10\times10^{-3}} = 300\Omega$$

Figure 5. Load Resistance Calculation

vii. Expected Performance

Based on the design calculations, the full wave bridge rectifier is expected to meet the requirement of a 3 V ± 0.1 V DC supply with a 10-mA current output at 1 kHz.

viii. Design Trade-offs and Safety

Several design trade-offs were made in the selection of the type of rectifier, where a full wave rectifier is chosen over topologies like half wave rectifiers due to its full AC signal waveform input and its minimal voltage ripple. However, the full wave rectifier requires more components such as diodes, which may lead to an increase in manufacturing costs and production time. A 30 uF capacitance was also used instead of the minimum capacitance of 25 uF, resulting in the use of three 10 uF diodes which also have higher costs. Similarly, three 100 Ω resistors were used to build an equivalent resistance of 300 Ω.

Safety was a high priority when implementing the rectifier circuit to ensure that there is no component damage, resulting in power rating and maximum voltage considerations. The resistors experience a power dissipation of 0.01 W in the rectifier circuit, upholding the power rating of 0.25 W. The voltage drop across the diodes are 4.4 V in the circuit, whereas its maximum voltage is 75 V. The capacitors also experience a voltage drop of 3 V, while its maximum voltage is 35 V based on its datasheet, adhering to its safety requirements.

$$P_{300\Omega} = \frac{V^2_{300\Omega,max}}{300\Omega} = \frac{3+0.1}{300} = 0.01\,W < 0.25W$$

Figure 6. Component Rating Calculations

3. Measurement and Analysis

i. Physical Circuit

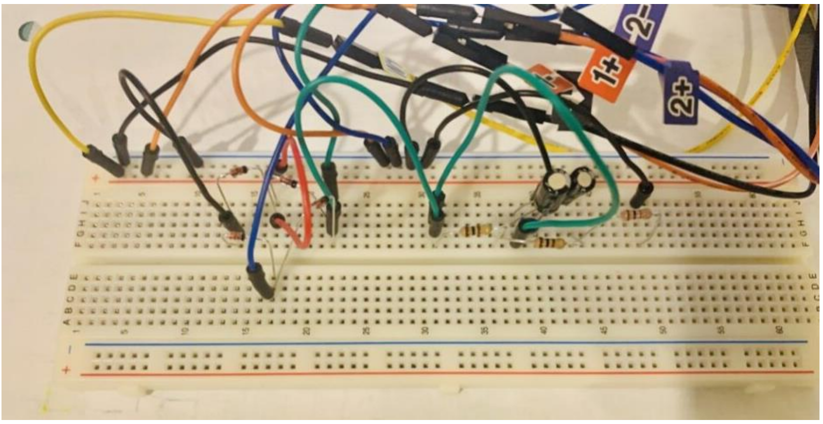


Figure 7. Side View of Circuit

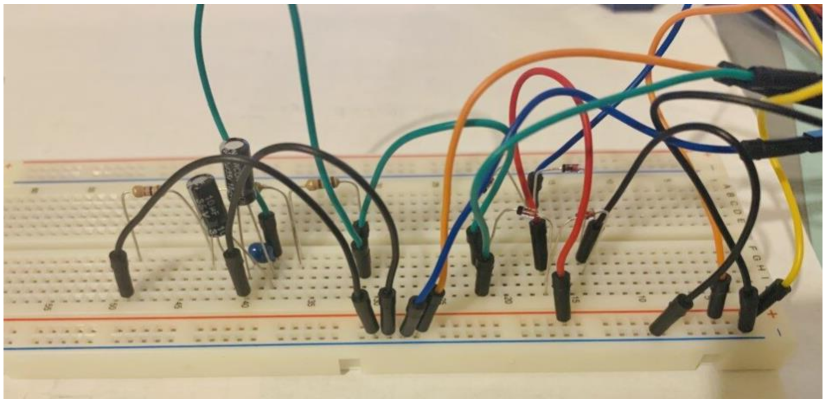


Figure 8. Alternate Side View of Circuit

ii. Measurement Procedure

To determine the performance of the circuit, the AD2's waveform generator was used to supply the 4.4 V AC source. The channel 1 probes were connected to measure the input AC voltage source, whereas the channel 2 probes were connected to measure the rectified voltage output. A custom math function channel was then defined to calculate the output current, where I = C2 / 300 Ω. Using the measurement feature on the WaveForms software, the average, maximum, and minimum output voltage, and average current was determined. Furthermore, the voltage ripple was determined to ensure that it met the requirement using the maximum and minimum voltage values and the cursors.

iii. Results

The average output voltage was determined to be 3.0154 V, where the maximum voltage is 3.1159 V, and the minimum voltage is 2.9311 V. The voltage ripple was calculated to be 184.8 mV and the average output current is 10.051 mA.

iv. Oscilloscope Output

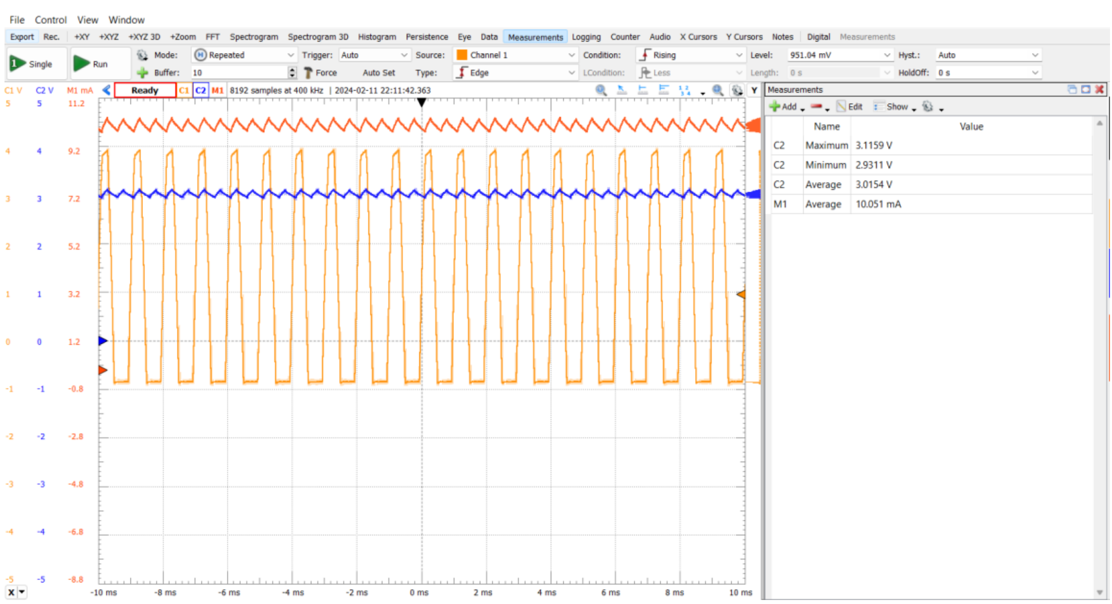


Figure 9. The Oscilloscope Results with Output Voltage and Current Values

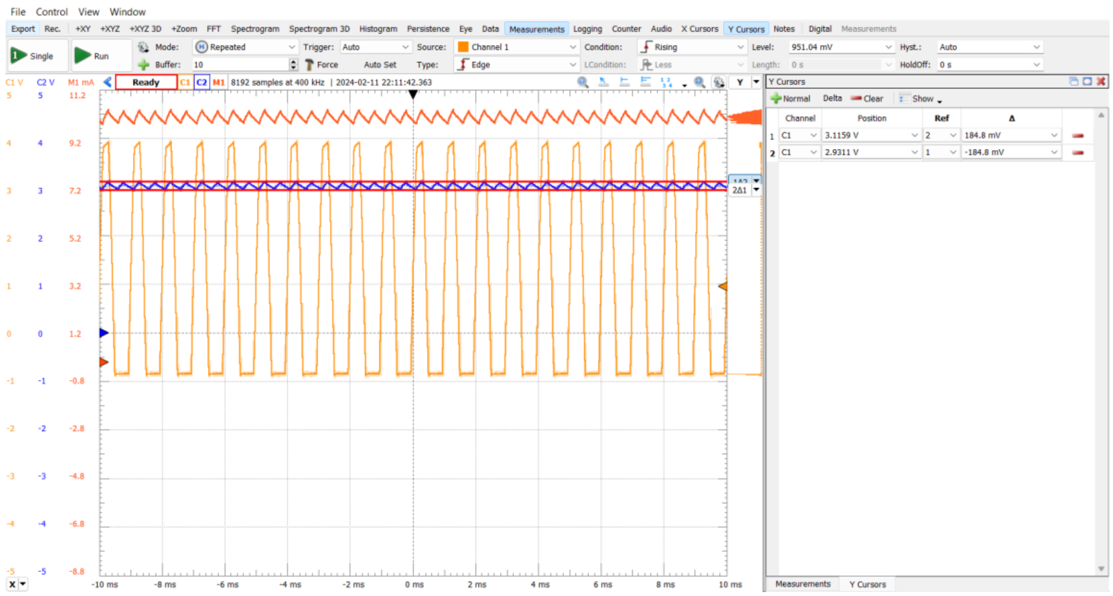


Figure 10. Voltage Ripple Results on the Oscilloscope

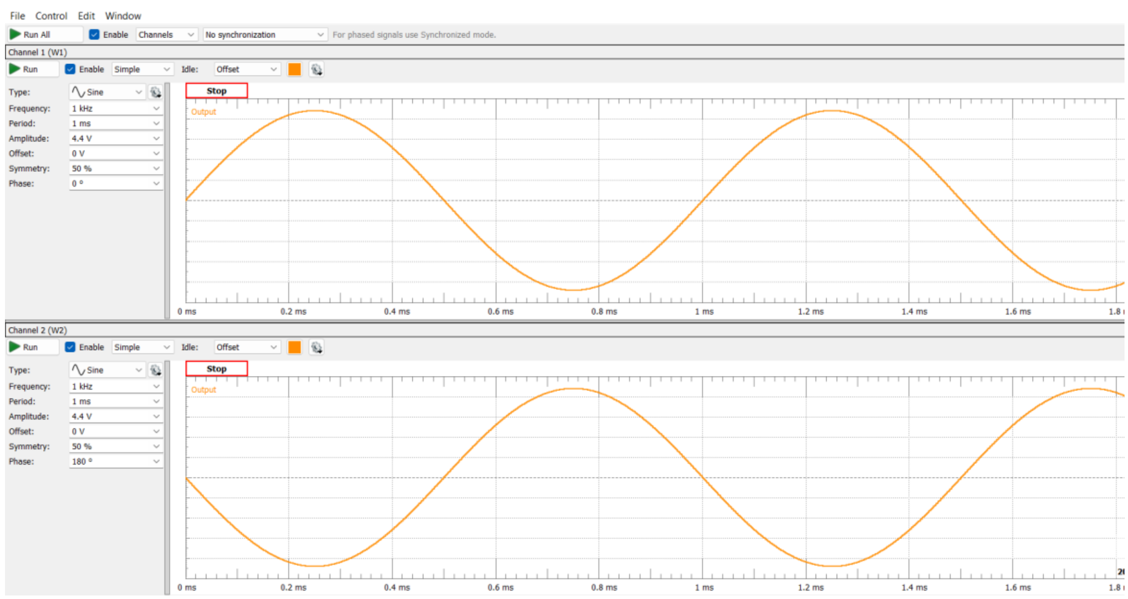


Figure 11. Waveform Generator Configurations

4. Simulation

i. Circuit Schematic

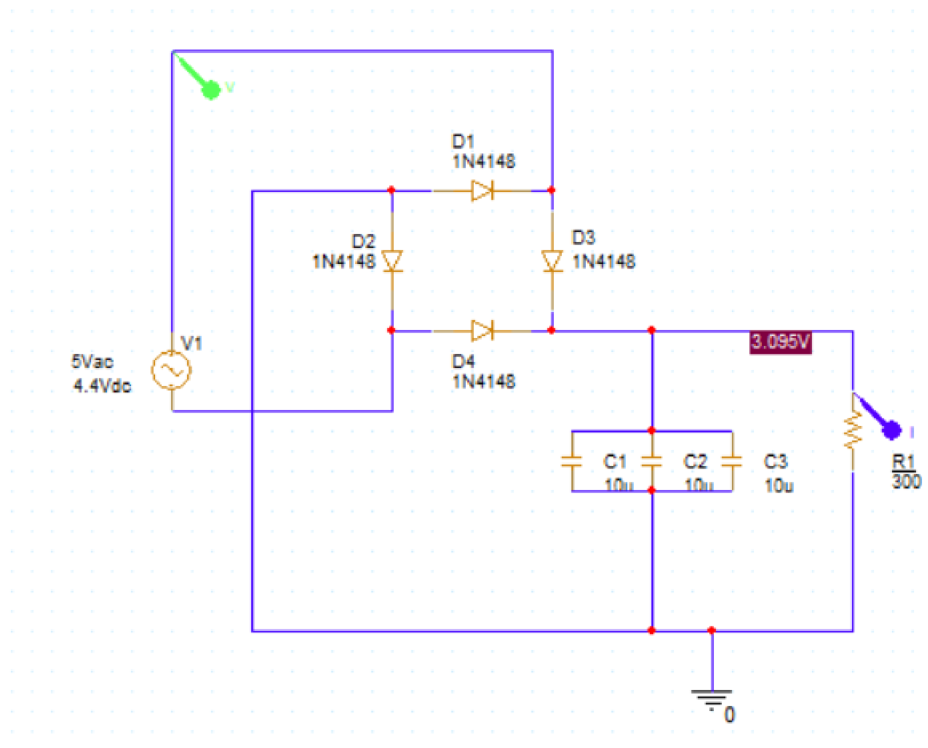


Figure 12. Circuit Schematic from PSpice

ii. Netlist.

```
1: * source PROJECT1_CIRCUIT2
2: X_D1          0 N00480 awbln4148 PARAMS:
3: X_D2          0 N00469 awbln4148 PARAMS:
4: X_D3          N00480 N00487 awbln4148 PARAMS:
5: X_D4          N00469 N00487 awbln4148 PARAMS:
6: C_C1          0 N00487  25u  TC=0,0
7: R_R1          0 N00487  300 TC=0,0
8: V_V1          N00480 N00469 DC 4.4Vdc AC 5Vac
9:
```

Figure 13. Netlist for the Circuit Schematic from PSpice

iii. Simulation conditions.

A transient time domain analysis was performed with a run time of 20 ms, resulting in 20 cycles due to its period of 1 ms at 1 kHz. A larger run time was selected to have sufficient data to determine accurate simulated output values.

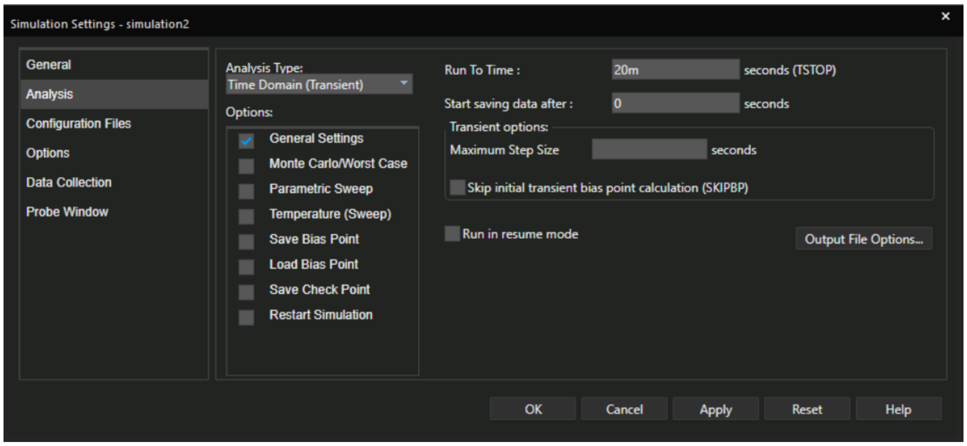


Figure 14. Circuit Simulation Settings on PSpice

iv. Simulation Output

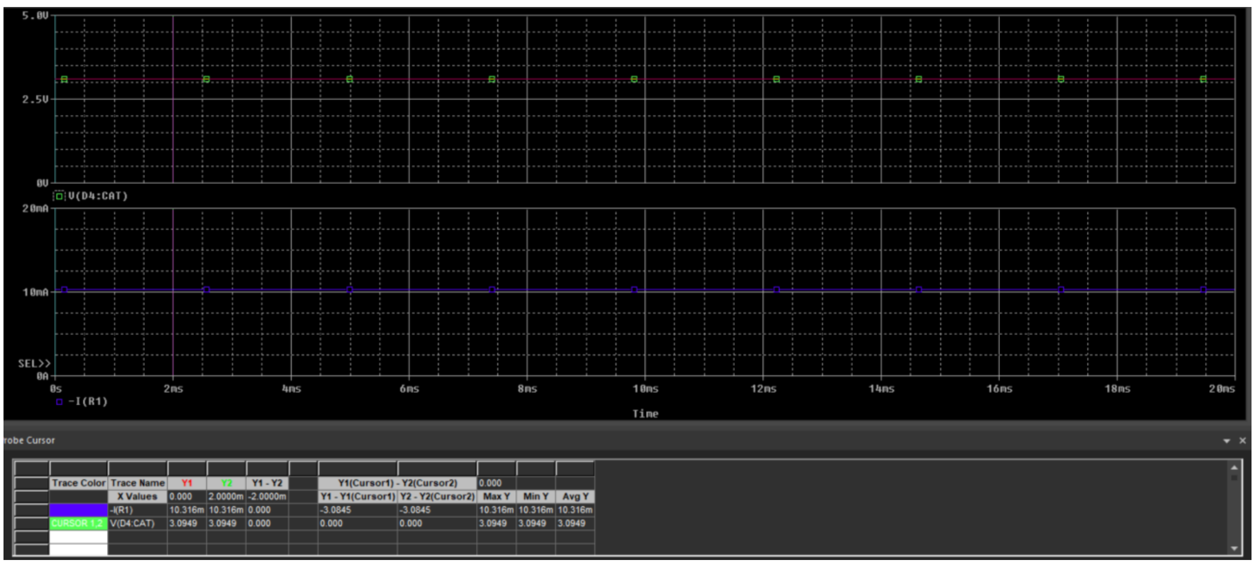
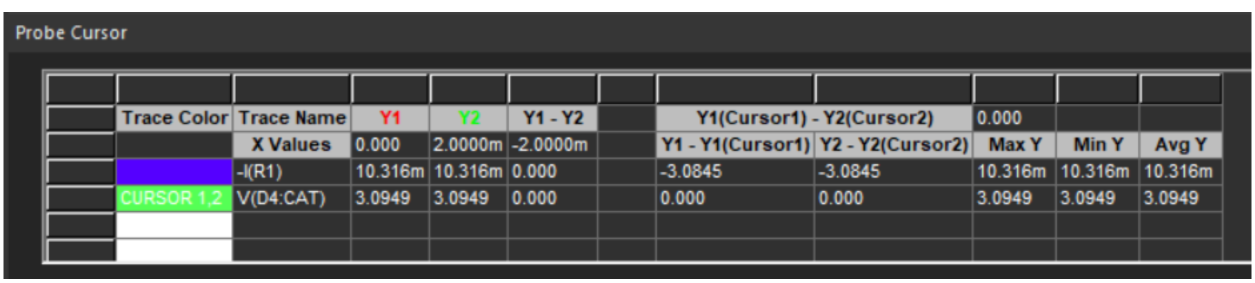


Figure 15. Voltage (V) vs Time (ms) [above] and Current (mA) vs Time (ms) [below]



Probe Cursor

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		0.000		
	X Values	0.000	2.0000m	-2.0000m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	-I(R1)	10.316m	10.316m	0.000		-3.0845	-3.0845	10.316m	10.316m	10.316m
CURSOR 1,2	V(D4:CAT)	3.0949	3.0949	0.000		0.000	0.000	3.0949	3.0949	3.0949

Figure 16. Close-up of Probe Cursor Simulation Results

Discussion

i. Results

The results from design, simulation, and measurement yields similar performance levels with an approximate 3 V ± 0.1 V DC supply with a 10-mA current. The simulation exhibits a 3.16% error from the theoretical current of 10-mA, as well as a 3.16% error from the theoretical DC voltage of 3 V. In contrast, the average voltage physical circuit exhibits a 0.5133% error from that of the theoretical and a 0.51% error for the average current. There are some discrepancies in the simulated and physical values which can be attributed to limitations of the devices and experimental errors.

ii. Discrepancies

While the simulation and physical revealed similarities, some minor discrepancies in the results can be observed. In the simulation, the final voltage and current plots appear to be more stable than that of the physical circuits due to the lack of voltage ripple. In reality, the capacitor filter does not eliminate the voltage ripple and the performance of the capacitor is dependent on factors such as manufacturing tolerance and material types. Due to limited availability of capacitors, two 10 uF electrolytic capacitors were used alongside a 10uF ceramic capacitor in the physical circuits, whereas three electrolytic capacitors were used in the simulation, causing minor discrepancies. Additionally, the forward voltage of the diodes is assumed to be 0.7 V in the circuit design, but in both the simulation and the physical circuit, the diodes exhibit a slightly different voltage drop. The results of the physical circuit yield lower values than the simulation, likely due to a different diode forward voltage. Tolerances and internal resistance of circuit components also skewer the results.

iii. Limitations

There are minor limitations in the measurements that may have resulted in discrepancies. The AD2 is not capable of measuring the current directly, meaning the current must be calculated using the voltage probe readings. The average output current that was determined by the custom math channel may differ from the actual current flow in the physical circuit. The current is also reliant on the resistor value, as a resistance value higher than 300 Ω may limit the current flow and a resistance value lower than 300 Ω may damage the resistors. In real life, the resistors exhibit a tolerance which is not reflected in the equation defined for the custom math channel function.

iv. Challenges

When designing the physical circuit with a 330 Ω resistor, the DC voltage supply was lower than expected, falling around 2.7 v - 2.8 V instead of 2.9 V – 3.1 V. I had originally used the 330 Ω resistor due to convenience and the availability of components. I then realized that the 330Ω resistor exceeded the 300Ω requirement and likely requires a higher voltage source to allow current to flow. Upon switching it with three 100Ω resistors, the output voltage matched the target specifications, signifying that the resistance value plays a vital role in the circuit design.