

ELECENG 2EI4

Design Project #1: DC Power Supply

Jasmine Dosanjh – dosanj5 – 400531879

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Summary

This project involves designing and building a DC power supply that delivers 10 mA at $3V \pm 0.1V$ from a 120V (rms), 1kHz AC source. A transformer was not used, instead the transformer's theoretical output voltage was determined to be 3.8V by working backward from the 120V (rms) input. The design utilizes a full-wave center-tapped rectifier with a low-pass filter, producing a stable DC output of $3V \pm 0.1V$. The implementation and performance of the circuit were analyzed through Pspice simulations and AD3 testing to verify that the design specifications were met.

Design

i. Transformer

The rectifier input voltages (transformer output) were theoretically determined to be $V_{in1} = V_{in2} = 3.8V$. Since a center-tapped transformer was used, the turns ratio is calculated as follows:

$$\frac{E_P}{2E_S} = \frac{N_P}{N_S} \quad \because E_P \rightarrow 2E_S \text{ (center tap)}$$

$$\frac{120\sqrt{2}}{2(3.8)} = \frac{N_P}{N_S}$$

$$\therefore \frac{N_P}{N_S} = 22.33$$

ii. Rectifier

A full-wave center-tapped transformer was chosen as it uses only two diodes instead of four, simplifying the circuit analysis. A full-wave rectifier was preferred over a half-wave rectifier since the latter requires a larger capacitance for filtering. Given the limited capacitor options in the components kit, the full-wave rectifier was the optimal choice.

iii. Filter

A 25 μF low-pass filter was used, connected in parallel with the load resistor. This capacitor minimizes ripple by storing charge during voltage peaks and discharging during troughs, thereby stabilizing the DC output and reducing voltage fluctuations.

iv. Regulator

A voltage regulator was not included in the design.

v. Complete Circuit Schematic

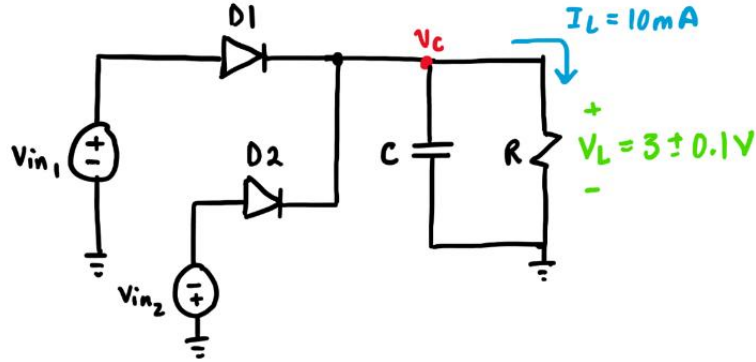


Figure 1. Circuit Schematic

vi. Calculations

Using Ohm's Law, the load resistance can be calculated as follows:

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

The ripple peak-to-peak voltage is determined using:

$$V_{rpp} = V_{max} - V_{min}$$

$$V_{rpp} = 3.1 \text{ V} - 2.9 \text{ V} = 0.2 \text{ V}$$

For a full wave rectifier, the output frequency is: $f_{out} = 2f_{in}$. Given an input frequency of 1kHz, the capacitance is calculated using the ripple voltage formula:

$$V_{rpp} = \frac{I_L}{f_{out} C}$$

$$C = \frac{I_L}{2f_{in} V_{rpp}}$$

$$C = \frac{10 \text{ mA}}{2(1 \text{ kHz})(0.2 \text{ V})}$$

$$C = 25 \mu\text{F}$$

Since the capacitor is in parallel with the load, we have: $V_L = V_C = 3 \text{ V}$.

However, the capacitor charges to the maximum voltage: $V_{C_{max}} = 3.1 \text{ V}$.

Using Kirchhoff's Voltage Law (KVL), the transformer's secondary (output) voltage can be found:

$$V_{in} = V_{D1} + V_{C,max} = 0.7V + 3.1V = 3.8V$$

vii. Expected Performance

The rectifier and filter should provide a DC output voltage with a peak-to-peak ripple of 0.2V, with V_{out} within the range of 2.9V to 3.1V

viii. Design Considerations

While designing the circuit, two main tradeoffs were made:

1. A half-wave rectifier uses a larger capacitor and thus would further reduce ripple, but the components kit only provided a capacitance of 1 μ F or 100 μ F, and thus a full wave rectifier was used.
2. Although a voltage regulator could have been used to further stabilize the output, the Zener diode in the kit has a $\pm 5\%$ tolerance. This tolerance would cause the output voltage to vary by $\pm 0.15V$ (5% of 3V), which exceeds the original input variation of $\pm 0.1V$. Therefore, using a regulator would not have improved stability and could have actually worsened it.

When designing the circuit, it was crucial to consider safety and component ratings. The CM107 capacitor, rated for 6.3V (twice the expected 3V), was selected to prevent overvoltage damage. The resistor dissipates 33mW, which is well below its 250mW power rating, and the diode dissipates 7mW, which is well below its 500mW rating (calculations provided below). These ratings ensure safe operation of the components. To prevent electrical shock and component damage, the circuit was fully simulated before physical testing.

$$P_{330\Omega} = I^2 R = (10mA)^2 (330\Omega) = 33mW \text{ absorbed}$$

$$P_{D1} = V_{C,max} I = (0.7V)(10mA) = 7mW \text{ absorbed}$$

Simulation

i. Circuit Schematic

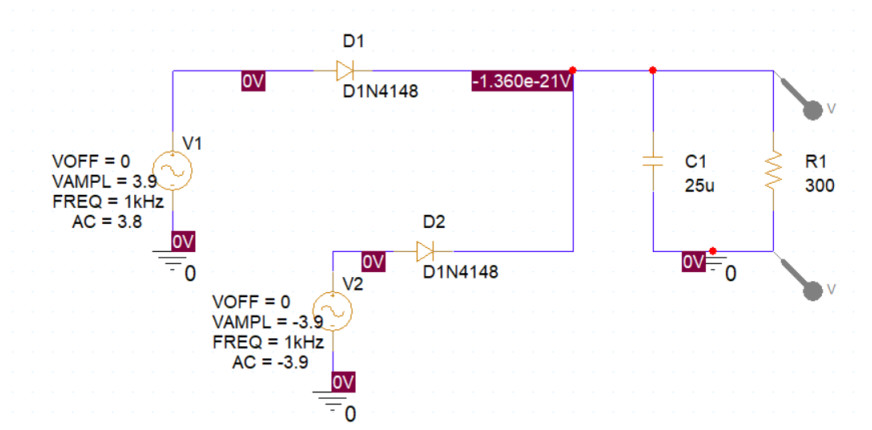


Figure 2. Simulation Circuit Schematic

ii. Netlist

```
1: * source PROJECT 1
2: D_D1      N00101 N00108 D1N4148
3: V_V1      N00101 0 AC 3.8
4: +SIN 0 3.9 1kHz 0 0 0
5: C_C1      0 N00108 25u TC=0,0
6: R_R1      0 N00108 300 TC=0,0
7: D_D2      N00512 N00108 D1N4148
8: V_V2      N00512 0 AC -3.9
9: +SIN 0 -3.9 1kHz 0 0 0
```

Figure 3. Schematic Netlist

iii. Simulation Conditions

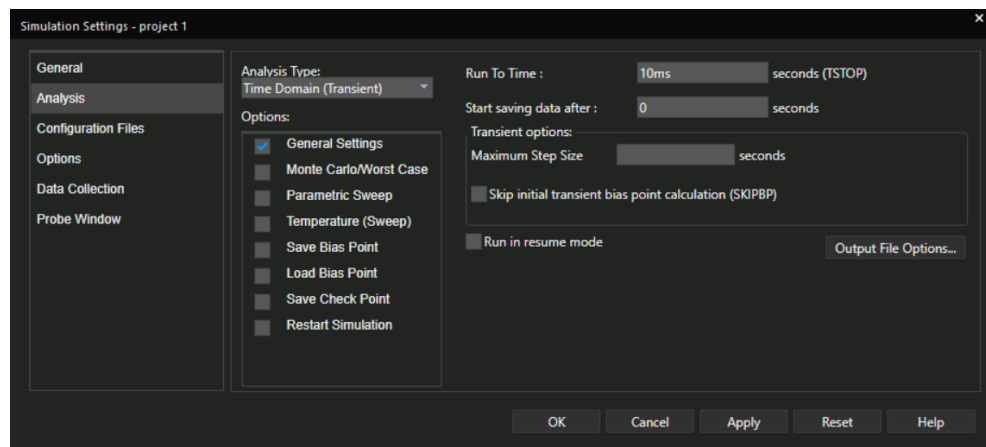


Figure 4. Simulation Conditions

iv. Simulation Output

The simulation of the voltage output produced a waveform in the range of 2.9V to 3.1V, which meets the design requirements (see Figures 5 and 6). However, the theoretical input voltage had to be increased from 3.8V to 3.9V. The initial input of 3.8V resulted in an output range of only 2.7V to 2.9V. With this adjustment, the transformer provides an output voltage of approximately 3.9V, ensuring that the circuit delivers a final output of $3V \pm 0.1V$.

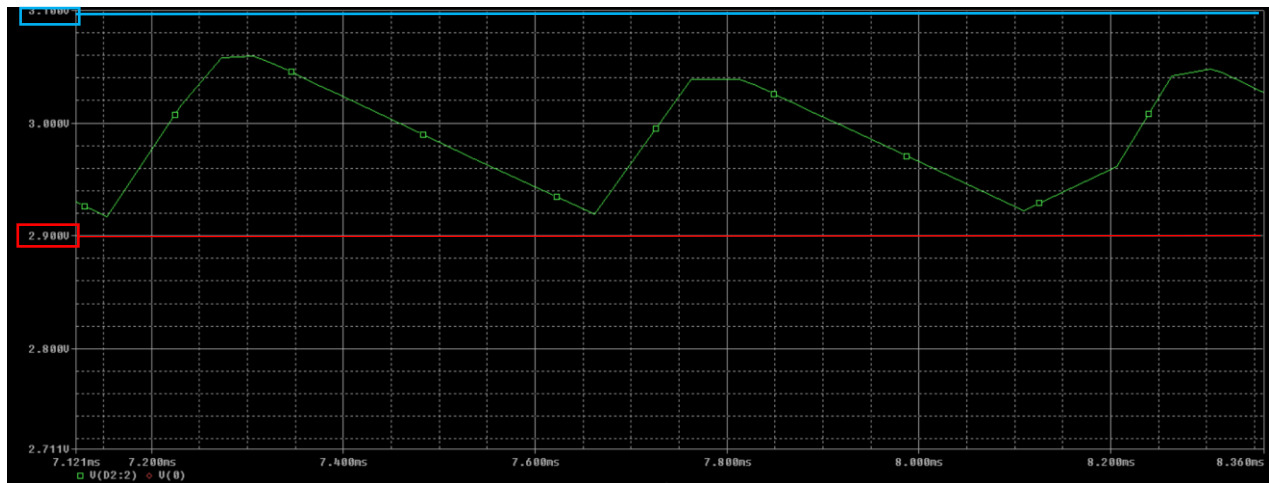


Figure 5. Simulation Voltage Output Zoomed in



Figure 6. Simulation Voltage Output

Measurement and Analysis

i. Photograph of Circuit

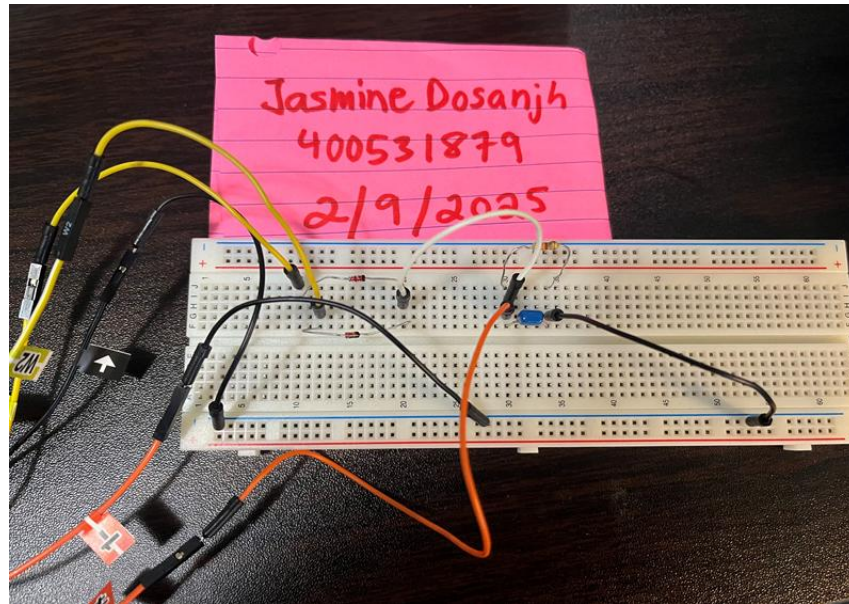


Figure 7. Physical Circuit Implementation

ii. Measurement Procedure + Key Measurement Results

The physical circuit is shown in Figure 7. It was created using a $330\ \Omega$ resistor, a CM107 capacitor and two 1N4148 diodes. An AC voltage of 3.8V was supplied by two sine wave signals that were generated with a peak amplitude of 3.8V and a frequency of 1 kHz (see Figure 8). One signal was used for the positive portion of the full-wave rectifier, while the second signal, with a 180° phase shift, was used for the negative portion. This provided an output between 2.7V to 2.9V which falls short. The input voltage had to be significantly increased to 4.25V. The resulting waveform, shown in Figure 9, falls within the desired output range of 2.9V to 3.1V.

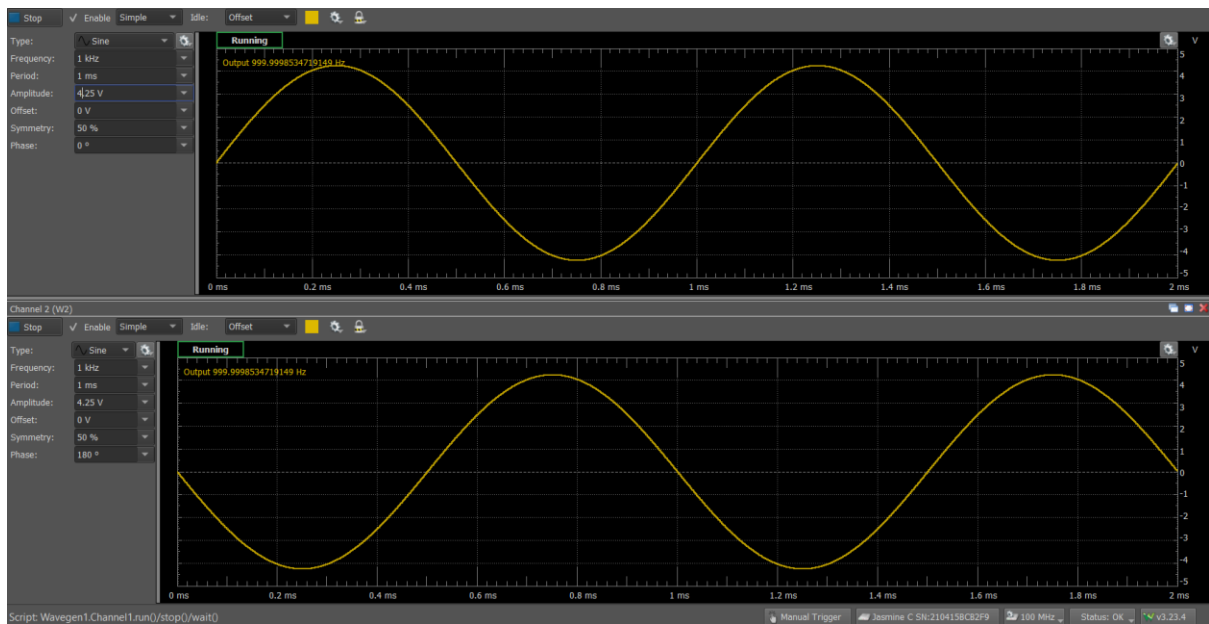


Figure 8. Wave Generator Setup for AC Voltage Supply

iii. Oscilloscope Output

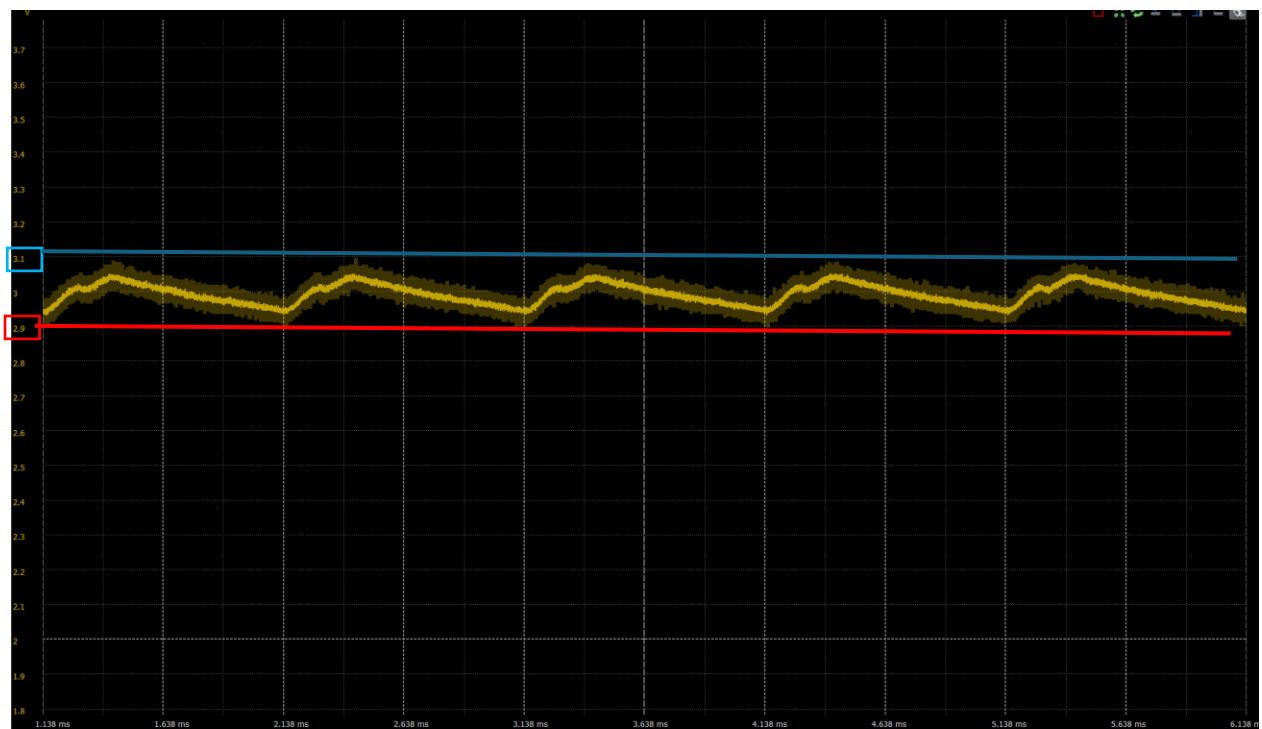


Figure 9. Voltage Output for Physical Circuit

Measurement and Analysis

i. Comparing Results

In this project, the DC power supply was evaluated through design, simulation, and physical implementation. Each phase aimed to meet the same output requirements of $3V \pm 0.1V$ at 10 mA, and the results were compared as follows:

1. Theoretical Results:

- A 3.8V AC input, 300 Ω resistor and 25 μF capacitor were expected to produce a stable DC output, within the 2.9V to 3.1V range.

2. Simulation Results:

- The simulation on PSpice showed an output voltage within the desired range of 2.9V to 3.1V with a 3.9V AC input.

3. Measurement Results:

- The physical circuit performed similarly to the simulation, but a 100 μF capacitor and 330 Ω resistor were used. The AC input voltage had to be increased further to 4.25V to achieve the desired output range of 2.9V to 3.1V.

ii. Discrepancies + Design Limitations

The most discrepancies were observed in the measurements due to real-world factors such as component tolerances and other variables that cause deviations from theoretical assumptions. Since a 25 μF capacitor was unavailable in the kit, a 100 μF capacitor was used instead, which was larger than expected.

Additionally, a 330 Ω resistor was chosen to simplify the circuit, resulting in a current of approximately 9mA flowing through the load, instead of the intended 10mA. These variations in component values may have led to performance outcomes in the physical circuit that differed from the design expectations.

iii. Problems Encountered

When simulating the circuit on PSpice, an AC source of 3.8V resulted in an output range lower than 2.9V, which was insufficient. As a result, the input voltage was gradually increased. After testing different values, a voltage of 3.9V was found to provide the desired output range of 2.9V to 3.1V. Similarly, when building the physical circuit, generating an AC voltage of 3.8V produced a similar outcome, so the input voltage had to be increased to 4.25V to achieve the desired output range.