Design Project #1 – DC Power Supply

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Summary

This project aims to design a dc power supply that delivers 10mA at 3V ± 0.1V from a source that is 120V (rms) at 1kHz. To accomplish this, a function generator with amplitude 4.7V and 1kHz was used to imitate the output of a transformer, full wave bridge rectifier to convert the AC voltage to DC, and a 100uF capacitor to minimize the ripple across the load resistor.

Design

Transformer

A transformer of turns ratio 36:1 is used to step down the voltage from 120V (rms) to 4.65V.

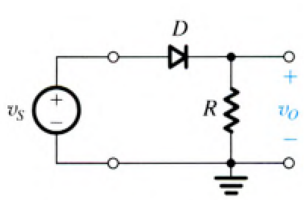
Rectifier

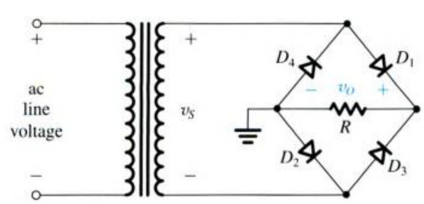
In order to convert the 4.7V peak AC output from the transformer, a few different rectifier topologies could be used including the half-wave rectifier, full-wave bridge rectifier, or center-tap full-wave rectifier.

The half wave rectifier utilizes a single diode to discard all of the negative signals. This topology leads to a very high ripple and low efficiency since half of the input signal is discarded.

A center-tap full-wave rectifier uses two diodes and a center-tapped transformer. Each diode conducts during alternate half-cycles, allowing for both halves of the AC waveform to be rectified. However, this approach is expensive due to the use of a center tap transformer.

A full-wave bridge rectifier uses four diodes arranged in a bridge circuit. During the positive half-cycle of the AC input, current flows through D1, the load resistor R, and D2. Similarly, during the negative half-cycle, current flows through D3, R, and D4, ensuring unidirectional current through the load. However, the bridge topology requires a higher input voltage to achieve the same peak output as other rectifier configurations due to the voltage drop across two conducting diodes in each cycle.





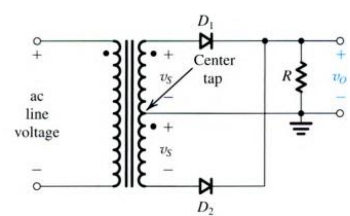


Figure 1 Half-wave rectifier (1) *Figure 2 Full-wave bridge rectifier(1)* *Figure 3 Full-wave center-tap rectifier(1)*

In this project, a full-wave bridge rectifier is used due to its efficiency and inexpensive cost. Four 1N4148 diodes are used to form the bridge configuration, allowing both halves of the AC waveform to be rectified. The 1N4148 diodes are fast switching and have a forward voltage drop between 0.6V and 0.75V (assumed V_F = 0.7).

Filter

The circuit uses a 100uF capacitor filter to smooth the rectified DC output by reducing the ripple voltage. The filter turns the rectified wave into a smooth voltage with a ripple of 0.05V.

Regulator

A regulator such as a Zener diode could be used to further minimize the variation in the DC output. However, this was not needed to meet the design specifications.

Circuit Schematic

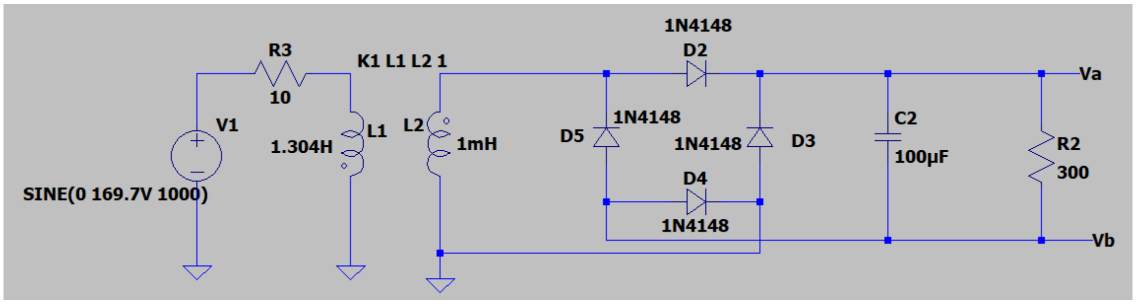


Figure 4 Circuit Diagram

Calculations for all components

Given that we must produce 10 mA at 3V ± 0.1V, find that our load resistor must be 3V/10mA = 300Ω.

The ripple voltage is defined by the Load current (I_L), output period from the rectifier (T_{out}) and the capacitance (C).

$$V_r \approx \frac{I_L T_{out}}{C} \qquad 0.05 \approx \frac{(10\text{mA})\times(1/2\text{kHz})}{100\text{uF}}$$

Note a 50 uF capacitor would yield a 0.1 ripple voltage.

Given that we need a 3V V_{avg} over the load: $V_{in} = 3V + 2*V_D + V_C$, 4.65V = 3V + 2(0.7V) + 0.25V.

Given the initial voltage of 120V RMS, the required turns ratio is calculated as:

$$\frac{120 \cdot \sqrt{2}}{4.65} = 36.49583387 = \sqrt{\frac{L_1}{L_2}}, L_1 = 1296mH, L_2 = 1mH$$

Thus, a transformer with a turn ratio of 36:1 is required to generate an output of 4.7V.

Specify the expected performance according to your design calculations

The expected performance is a dc power supply that delivers 10mA at 3V ± 0.05V.

Discuss design tradeoffs, design margins, component ratings, safety, and other issues that you considered in your design?

This DC power supply design optimizes efficiency and cost by selecting a full-wave bridge rectifier over a half wave to improve performance and being cheaper than a center-tap design. Four 1N4148 diodes are used for their low forward voltage drop of 1V at 10mA, and fast switching capabilities. A 100uF capacitor minimizes ripple to 0.05V, ensuring a stable 3V ± 0.1V output. However, a smaller capacitor of 50uF could also be used to create a maximum ripple of 0.1V. The 300Ω load resistor dissipates only 0.03W, well below its 0.25W rating, ensuring safe operation. The 1N4148 diodes handle 10mA forward current and a maximum simulated reverse voltage of 3.8V which is well below the threshold limits for reliable performance.

Measurement and Analysis

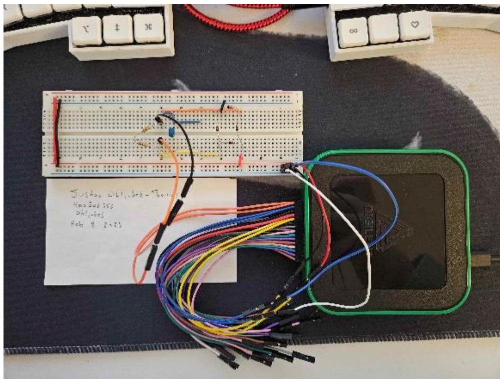


Figure 5 physical circuit

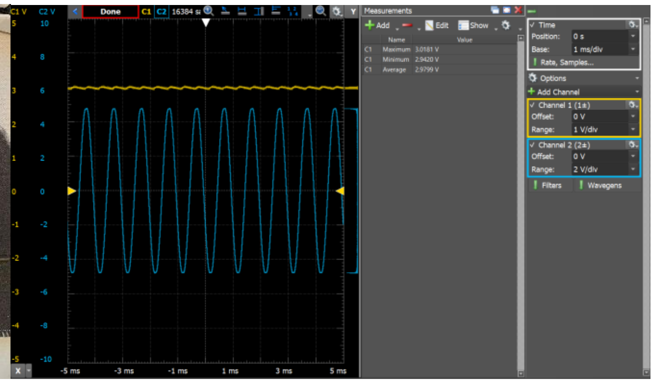


Figure 6 measured results

Measurement Procedure

The measurements were taken by replacing the 36:1 transformer and 120V rms source with a function generator to produce a sine wave of magnitude 4.65 and frequency of 1kHz. Two 150Ω resistors are connected in series to achieve a total resistance of 300Ω. The sine wave magnitude is increased to 5V as mentioned in discussion.

Channel 1 describes the voltage across the load resistance while channel two describes the function generator output from the AD3. Measurements were added to analyze the maximum, minimum, and average load voltages across the resistor. Furthermore, the resistance across the two 150Ω resistors was taken to decrease sources of error. The maximum, minimum, and average currents were calculated with ohms law.

Measurement Results

Measured resistance with multimeter: 297.1Ω

$$V_{max} = 3.0181V \qquad I_{max} = \frac{3.0181\text{V}}{297.1\Omega} = 10.16mA$$

$$V_{min} = 2.9420V \qquad I_{min} = \frac{2.9420\text{V}}{297.1\Omega} = 9.90mA$$

$$V_{\text{avg}} = 2.9799\text{V} \qquad I_{\text{avg}} = \frac{2.9799\text{V}}{297.1\Omega} = 10.03\text{mA}$$

Simulation

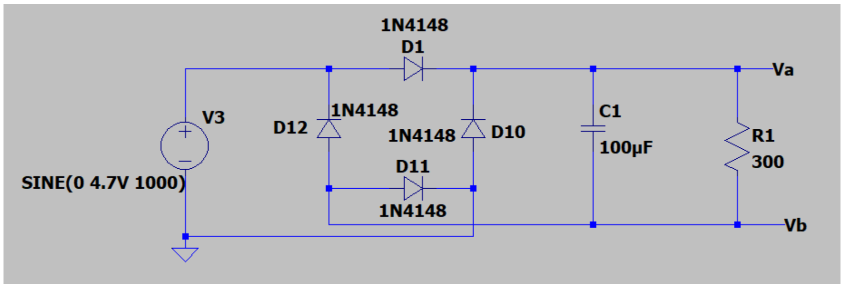


Figure 7 circuit diagram

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* C:\Users\Josh\Documents\COMPENG\Y2S2\2EI\DP1\DCPowerSupply.asc
D1 N001 Va 1N4148
D10 0 Va 1N4148
D11 Vb 0 1N4148
D12 Vb N001 1N4148
V3 N001 0 SINE(0 4.65V 1000)
R1 Va Vb 300
C1 Va Vb 100µF
.model D D
.lib C:\Users\Josh\AppData\Local\LTspice\lib\cmp\standard.dio
.tran 0 0.1 0
.backanno
.end
```

Simulation Conditions

Simulation time: 20ms Type of simulation: transient Diode model used: 1N4148

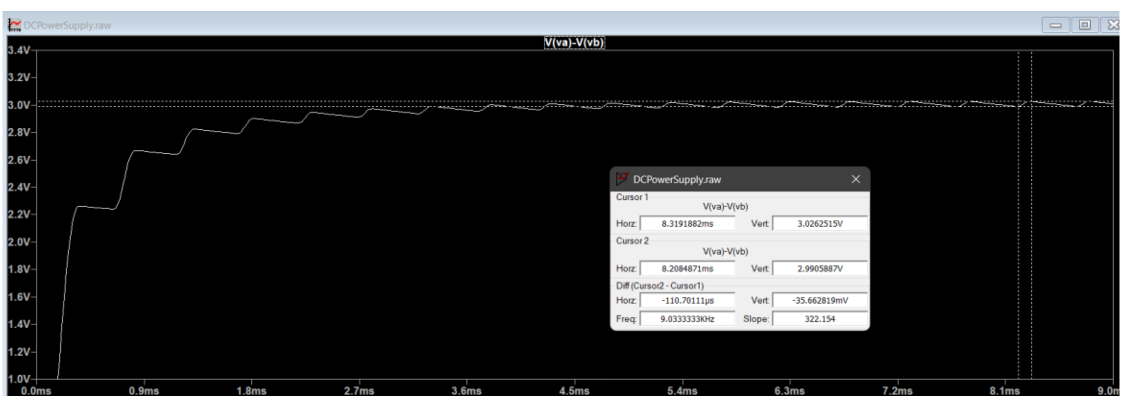

Figure 8 circuit simulation with cursors

Measurements:

$$V_{max} = 3.026V$$

$$I_{max} = \frac{3.026\text{V}}{300\Omega} = 10.09mA$$

$$V_{min} = 2.990V$$

$$I_{min} = \frac{2.990\text{V}}{300\Omega} = 9.97mA$$

$$V_{\text{avg}} = 3.008\text{V}$$

$$I_{\text{avg}} = \frac{3.008\text{V}}{300\Omega} = 10.03\text{mA}$$

Discussion

Compare the results from design, simulation, and measurement

	Theoretical	Simulation	Measured (5V)
V_{max}	3.05V	3.026V	3.018V
V_{min}	2.95V	2.990V	2.9420V
V_{avg}	3.00V	3.008V	2.9799V
V_{ripple}	0.05V	0.018V	0.0379V
I_{max}	10.17mA	10.09mA	10.16mA
I_{min}	9.83mA	9.97mA	9.90mA
I_{avg}	10mA	10.03mA	10.03mA

The theoretical values obtained from design calculations were slightly different from the simulation results but within a 0.27% error. While measuring on the physical model, the measured results were significantly lower, and the input voltage needed to be increased to 5V to achieve 3V ± 0.05V.

Discuss any discrepancies observed

Several discrepancies were observed with the theoretical and simulation values that should be exact. The theoretical values differ slightly from the simulation due to approximations in the ripple voltage formulas.

Furthermore, the initial physical model had a much lower load voltage than expected at 2.7V average. To test possible answers for this discrepancy, the voltage across the diodes was measured in a separate environment to be 0.85V, much higher than expected. This changes our calculations of $V_{in} = 3V + 2*V_D + V_C$: $V_{in} = 3V + 2*V_D + V_C$, $3V + 2(0.85V) + 0.25V = 4.95V$. This differs from the simulation results since ltspice assumes ideal components without considering variance.

Finally, on the physical model the load resistance was measured to be 297.1Ω rather than 300 causing minor voltage deviation.

Discuss the limitations of the design and the limitation of the measurements you performed

The design assumes ideal conditions and does not consider component tolerances as seen above. There is no maximum load resistor value since it does not affect the node voltages Va and Vb. However, as the load resistor is increased, the current I_L will fall leading to a decrease in ripple voltage. With no load resistor (open load circuit), the simulation has no ripple voltage and is stable at 3V. Decreasing the size of the resistor leads to a higher current draw and the same voltage at Va and Vb. However, the 1N4148 diodes have a maximum current rating of 300mA. Calculating the minimum resistor required:

$$V_L = 3V, \qquad \frac{300mA}{3V} < R, \qquad R > 0.1\Omega$$

Thus, the minimum resistance required is 0.1Ω.

Describe any problems encountered in measurements and the troubleshooting steps you took

One main issue when taking measurements occurred when the load voltage was significantly lower than expected. To troubleshoot this, several measurements were taken across the four diodes in a separate environment to test the forward voltage drop. This was measured to be 0.85V which is different from the assumed theoretical of 0.7V.

References

[1] “4.6 Rectifier Circuits,” in *SEDRA/SMITH Microelectronic Circuits*, 8th ed