5V DC POWER SUPPLY PROJECT

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ECEN 350 BYU-I

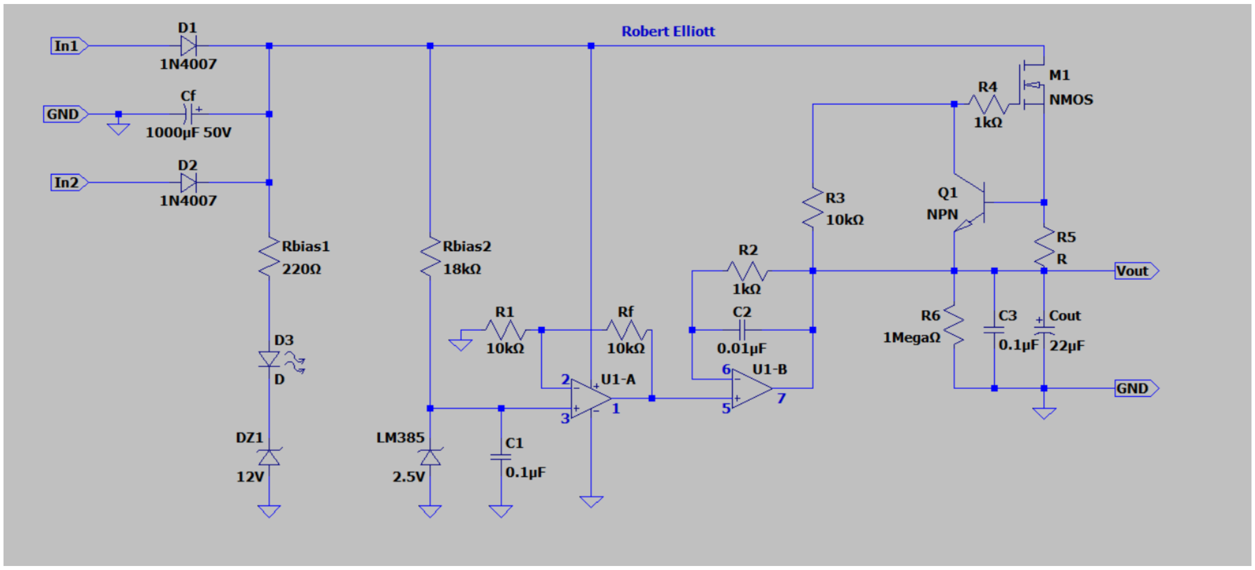
Introduction

Our ECEN 350 project is to design and construct a fixed **DC Output Power Supply** with a current limit that can be either AC or DC powered. The output voltage of this project will be 5V DC. The primary objective of this project is to create a regulated 5V DC power supply with the capability to deliver a consistent voltage output under varying load conditions. This involves the use of rectification, filtering, and voltage regulation techniques to convert an AC signal or DC signal greater than 5 volts to a smooth and constant direct current output of 5 volts. For this project many components are given. However we will calculate the required components for R5, R_{bias2}, R1, R_f and C_f as part of this report. The following are specification for our power supply:

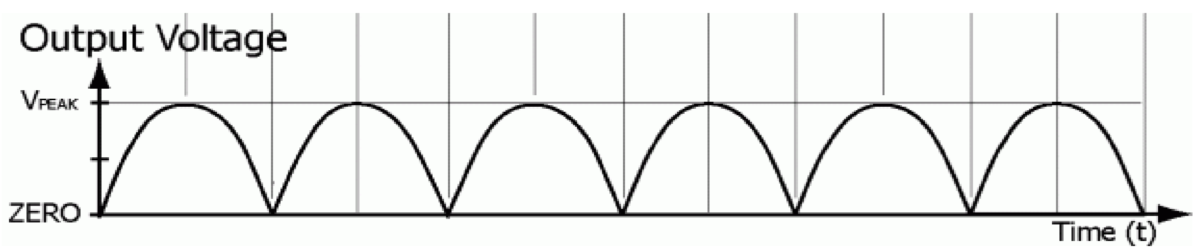
- **AC or DC powered.**
- **5V output voltage**
- **140mA current overload protection**
- **LED Power On indicator.**

Theory of Operation

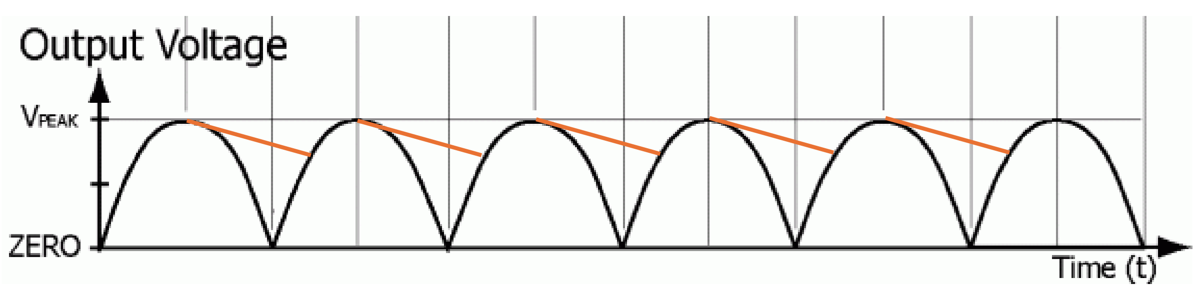
To understand the operation of our power supply we will look at the circuit diagram below:



From the diagram we can see that D1, D2, and C_f act to create a full wave rectifier from a center tap transformer. Both the D1 and D2 diodes work together to create a full wave rectified signal.



The capacitor C_f acts as a filter capacitor that helps to fill the gaps of the signal as it charges and discharges, creating a ripple voltage that is more akin to a steady DC voltage, represented by the red line.



The purpose of the Red LED, R_{bias1}, and the Zener Diode with 12V breakdown voltage is to supply a visual confirmation that the voltage supply is sufficient to turn on the power supply. R_{bias1} acts as a current limiter to prevent an overdraw of current that will burn out the LED, and the 12V breakdown zener diode acts as a voltage regulator for the same purpose.

The LM382 voltage regulator provides a constant 2.5V input to the non-inverting op amp. U1-A is a non inverting amplifier with negative feedback. The output gain of this type of op amp is calculated using $\frac{V_{out}}{V_{in}} = \left(1 + \frac{R_f}{R1}\right)$. Using this formula we can calulate the required R_f and R1 values to achieve a voltage of 5 volts.

$$\frac{5V}{2.5V} = 1 + \frac{R_f}{R1} => 1 = \frac{R_f}{R1} => R1 = R_f$$

Since we want a gain of two, R_f and R1 must be equal to eachother. We also want to be sure that the current through these resistors is greater than 10µA and less than 1mA. To calculate this range we can simply use Ohm's Law.

$$\frac{2.5}{10\mu A} = 250k\Omega, \qquad \frac{2.5}{1mA} = 2.5k\Omega$$

$$thus,$$

$$2.5k\Omega < R1 < 250k\Omega$$

For this project I chose R1 and R_f to both equal 10kΩ. This allows U1-A to create a voltage gain of 2, which amplifies our 2.5V signal to 5V.

R5 acts as a current limitor along with Q1 to create a current limiting circuit to protect our power supply and anything that may be connected to it. To calculate the value of R5 we need to consider the thermal resistance of our MOSFET, which is 62.5 °C/W, we can assume an ambient temperature of 50 °C, and a maximum junction temperature of 175 °C. Looking at our schematice, we can use the 2^{nd} approximation for the forward voltage of D1 and D2 of 0.7V, and assume that R5 drops 0.66V. If we have a voltage input of 21V, the source to drain voltage of M1 would be equal to 21-0.7-0.66-5 = 14.64V. We can then use the junction temperature formula for transistors to calculate the maximum current and then the correct R5 value.

$$\mathrm{TJ} = \mathrm{TA} + \mathrm{PTOT} * \mathrm{R_{thja}} => 175 = 50 + 14.6 * I_{limit} * 62.5$$

$$\frac{125}{915} = I_{limit} = 136.6mA \quad R5 = \frac{0.66}{0.1366} = 4.83$$

The closest standard resistor value to our calculated R5 is 4.7Ω. R5 and Q1 work together to create a current limiting circuit. When a load current is sufficient enough to induce a 0.66V voltage drop across the R5 resistor the transistor Q1 turns on and decrease the voltage going to the gate of M1. This effectively increases the resistance of M1 disallowing the current to increase past 140mA. So the maximum load current this power supply can provide is 140mA.

U1-B is a simple voltage follower op amp. This acts as a buffer in the circuit because it draws very little current from the voltage source, due to its high input impedance. This eliminates the loading effects of connecting something to our power supple, while still providing a constant voltage. The M1 MOSFET when in the saturation region acts as a voltage controlled current source. The threshold voltage of our MOSFET is 4V, with the input voltage being 5V, and the gate to source voltage V_{GS} being greater than this, roughly 14.6V with 21V input voltage, the MOSFET meets the criteria for being in the saturation region. $V_{DS} \geq \mathrm{V_{GS}} - \mathrm{V_T} => 14.6 \geq 1$. Because of this we know that M1 is in saturation, which creates a steady and stable current for our load device. Both U1-B and M1 work together to create a stable voltage and current for our load.

Measured Performance

To measure the efficiency and effectiveness of our power supply we will first take a look at the output voltage (V_{out}) vs the load current (I_{load}).

Table 1: Output Voltage Regulation and Current Limit Data.

Measured V_{out}(V)	R_{load} (Ω)	$I_{load}= V_{out}/R_{load}$ (mA)
5.00V	∞ (Open-Circuit)	0A
5.02V	(30%) 120Ω(calc) 122(tested)	41.8mA
5.02V	(60%) 60Ω(calc) 55Ω(tested)	91.3mA
5.01V	(90%) 40Ω(calc) 44Ω(tested)	114mA
4.81V	(100%) 36Ω(calc) 33Ω(tested)	145mA
3.21V	Power Resistor: 22 Ω.	145mA
1.60V	Power Resistors: 22 Ω‖22 Ω=11 Ω.	149mA

To calculate the R_{load} resistance we took our maximum current value of 140mA, then found 30%, 60%, 90%, and 100% of that value to find the desired resistance for each respective load.

$$0.140 * 0.30 = 42mA = 30\% => \frac{5}{0.042} = 120\Omega$$

$$0.140 * 0.60 = 84mA = 60\% => \frac{5}{.084} = 60\Omega$$

$$0.140 * 0.90 = 126mA = 90\% => \frac{5}{.126} = 40\Omega$$

$$140mA = 100\% => \frac{5}{.140} = 36\Omega$$

These exact resistor values were not available, and since most standard resistors are only rated for 0.25W, power resistors were used. The only power resistors available to me were in the form of 100Ω, 33Ω, and 22Ω. As seen on the table combinations of these resistors were used to test the calculated values within 15%. We can see from the table below and the graph above the power supply and its current limiter is behaiving as expected. When the load current is at or below our maximum current, the power supply gives a steady and stable 5V, however as the load current starts to draw more than the current limit, we lose voltage drastically.

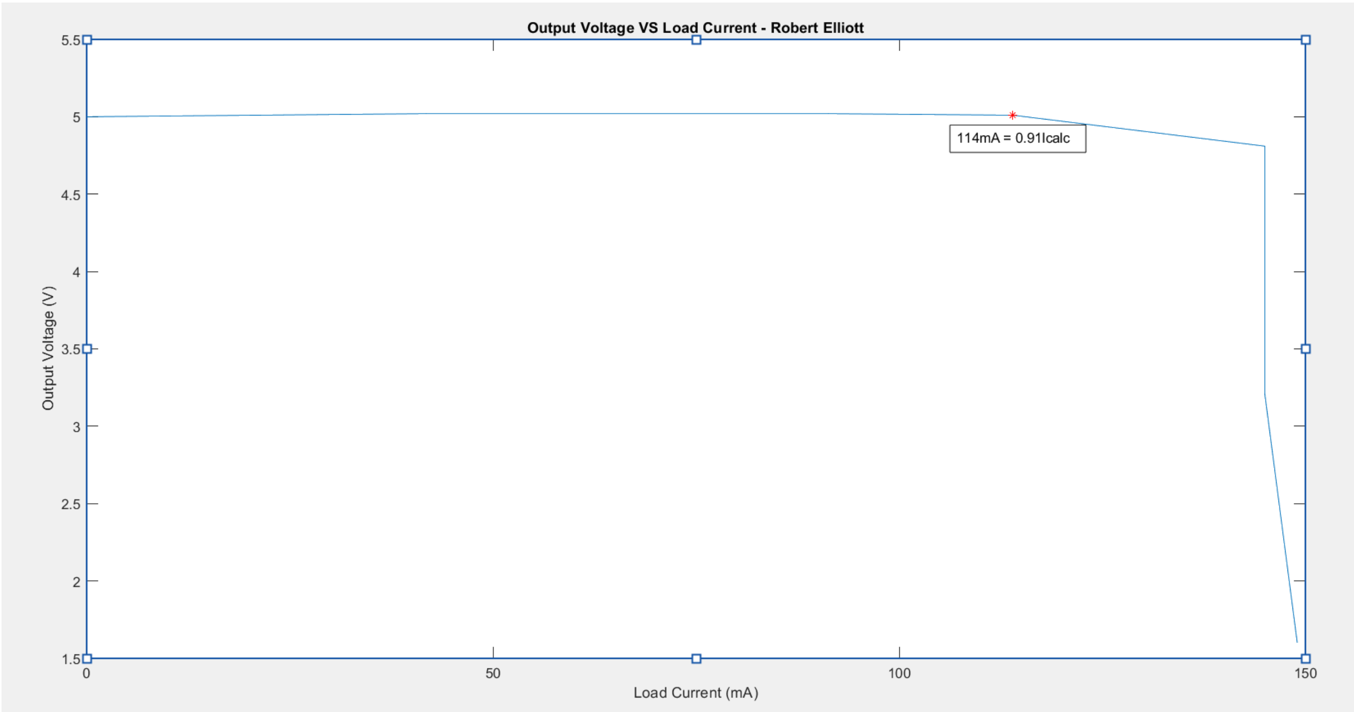


Figure 1: Plot of Output Voltage VS Load Current

Table 2: Measured Voltage regulator Performance Parameters.

Parameter	Measured Values
Minimum DC Input Voltage that turns on the LED Indicator (V).	13.9V
Measured Current Limit Value I_{meas} (mA).	145mA
Percent error between measured and calculated current limit value, with % Error = (100)(.145 – .14)/(.14).	3.6%
Calculated input voltage ripple for $I_{Load} = 0.9I_{calc}$.	1.05V
Measured input voltage ripple (ΔVfiltered) for $I_{Load} \approx 0.9I_{calc}$. (Vpk-pk).	863mV
Measured output voltage for no external load. (V).	5.03V
Measured output voltage for $I_{Load} = 0.9I_{calc}$. (V)	5.03V
120 Hz Ripple Rejection in dB for $I_{Load} = 0.9I_{calc}$.	51.0dB

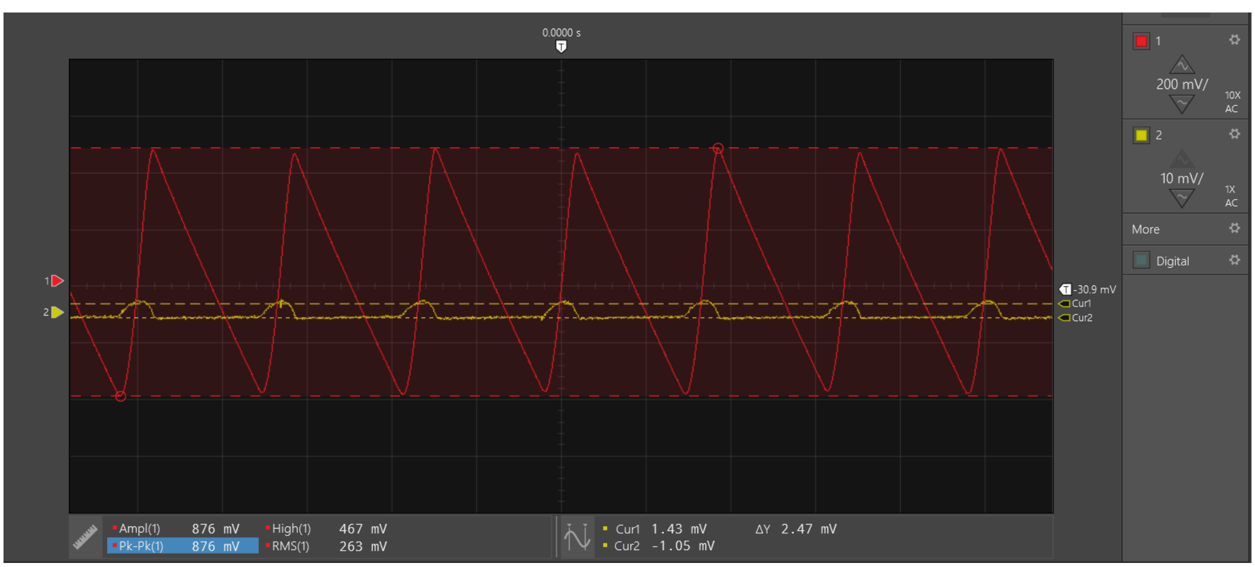


Figure 2: Oscilloscope Measurement of Output Ripple Voltage.

Table 2 and figure 2 display more key data points from our project. Table 2 shows that each measured value is within expected values for each data point, and illustrates how effective and efficient our power supply is. Figure 2 shows the output ripple voltage, as well as the input ripple voltage of our power supply when at 0.91 of our measured current limit. The pk-to-pk voltages from the graph shows a ripple rejection number of $20\log_{10}\left(\frac{.876}{.00247}\right) = 51dB$. This indicates that the op-amp greatly rejects the ripple.

Discussion and Conclusions

Completion of this project was both rewarding and instructive. The use of diodes, a capacitor, and a center tap transformer allowed me to create a full wave rectifier. Using this rectified signal I was able to create a 5V signal through the use of a 2.5V voltage regulator, and an op-amp with a gain of 2. This along with the MOSFET and current limiter allowed me to create a stable voltage and current signal for my power supply.

Figure 3: Front and Back of Completed Power Supply

I do believe that some improvements can be made. My original calculated value for the C_f capacitor was above the 1000μF value that we ended up using. This was due to hardware limitations, as the PCB board was not able to accommodate a larger capacitor. An additional improvement would be to include the ability to switch the power supply on its own. We are already using MOSFETs in this project so it would be simple to implement.

By creating this DC voltage source, I was able to become more comfortable working with MOSFET transistors and combine that knowledge with previous knowledge of op-amps. As my first project working with AC voltage, I was able to apply my knowledge of rectifiers and center tap transformers to create a functional and stable 5 DC voltage supply.