Solar Powered Backpack

Senior Project

by

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Abstract

One popular motto in electrical engineering today is “going green.” This project will convert the sun’s energy into reusable energy. The purpose of this senior project is to develop a solar powered backpack that can charge certain portable USB devices for students. Many students walk around campus with an iPod or cell phone, which has surely died or ran low on batteries at least once when needed most. This backpack will allow students to charge their devices “on the go.” When students walk or bike around campus, the solar panels attached to the backpack will allow recharging of their portable USB devices, while using a more “green” form of energy.

Introduction

This senior project idea came to us when we joined the Power & Energy Society (PES). PES offered us an opportunity to install solar panels for low-income families in order to reduce their electricity bill. This was done through PES with the support of Grid Alternatives, an organization which PES members volunteered with. This was the event that led us to decide that a solar powered backpack would not only offer an alternative greener solution to charging USB devices, but also come in handy when students are in need of a USB battery recharger while on campus. Society is looking for more environmental friendly ways to gather energy; so using renewable energy such as solar panels is becoming more and more popular. With the use of solar panels, the sun's energy can be easily collected and reused. Students and eventually consumers alike would love the idea of charging a USB device on the go. It can be seen everywhere that people need to recharge their batteries, whether they are on campus, in the library, at a coffee shop, biking, hiking, backpacking, traveling or even at airports. Just about everyone these days has some kind of electronic portable device, all of which can be charged through a USB port. Almost any type of portable device that charges via USB port can be charged using the solar powered backpack project. The use of the battery pack allows devices to be charged indoors and at night, when sunlight is unavailable. When outside, the solar panels are charging the battery. This project can very well help promote the use of a solar powered backpack throughout campus, especially at sunny Cal Poly San Luis Obispo and eventually all consumers with portable USB devices. This project is aimed to provide environmentally safe energy without spending a cent of electricity through the use of solar panels harvesting energy from the sun.

Background

There are many commercialized solar chargers out on the market already. An example of a solar charger is the portable solar charger shown in the figure below. These portable solar chargers are capable of charging various mobile phones, mp3 players, and other USB devices.

Figure 1: Front and back views of a portable solar charger with installed batteries

Solar chargers use crystalline solar panels to collect from the sun and generate it into electrical energy, which is then stored into a lead acid rechargeable battery. Solar panels are usually around 15-18% efficient. In addition, solar chargers typically have built-in batteries. The batteries are used to store energy generated from the solar panels and use the energy to charge devices when the sun is not available as a source. Solar chargers can charge loads directly without a battery, but the panels would require a circuit that would stabilize the current supplied by the solar panels.

The solar powered backpack project follows the same concepts as the portable solar charger. The sun's energy will be collected through the solar panels. The energy generated from the solar panels is then inputted into a circuit which stabilizes the current and voltage in order to

charge the battery. The battery outputs voltage to a DC-DC converter, which drops the voltage down to 5 volts for USB specifications.

Requirements

The goal of this project is to develop a solar powered backpack that is capable of charging portable USB devices, such as an iPod. There are six key components within the block diagram, as shown in Figure 2.

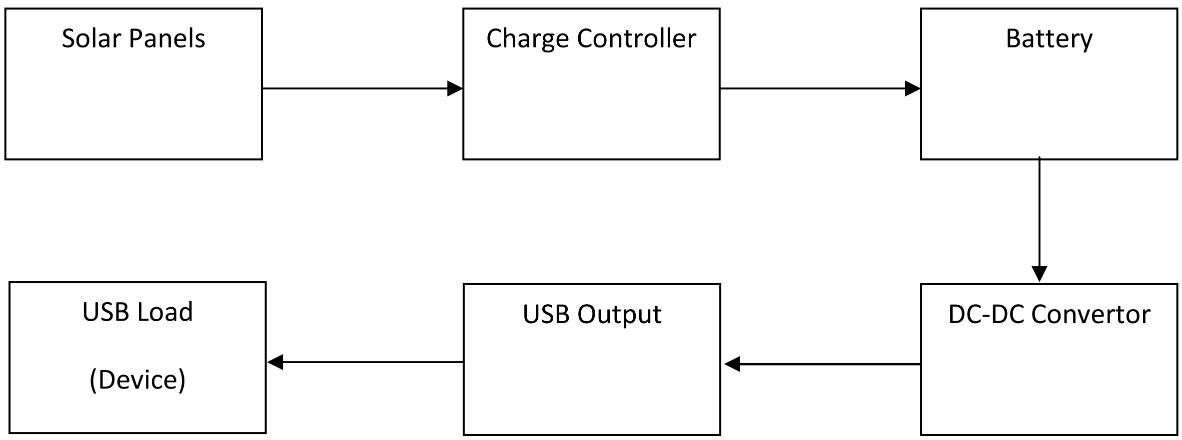


Figure 2: System Block Diagram for Solar Powered Backpack

After researching the requirements of charging iPods and most USB devices, it was found that iPods required an input voltage of 5V and a very low input current to begin charging.

The solar panels were rated at 6V, a maximum of 167mA, and provided 1W. The initial requirements are to input 12V and 334mA into the circuit (charge controller box). Therefore, a total of four solar panels were used. Two solar panels were connected in series to provide 12V and those two were connected in parallel with two more solar panels to provide 334mA, this is further explained in details in the *Solar Panel* section. The solar panels will be used to generate energy needed to drive the second box in the block diagram, which will be referred to as the "charge controller" as noted in Figure 2. The charge controller is where most of the electronic components will be used, such as resistors, diodes, a voltage regulator, and a BJT transistor. The charge controller will control the current running through the system and limit the current as

needed, as well as controlling any unwanted discharging and over charging. Once the voltage and current have been sent through the charge controller, the output voltage will be regulated to 6V in order to charge the battery. The battery component needed to be rechargeable; hence a 6V 4.5Ah sealed lead acid rechargeable battery was chosen. The battery was then inputted into a DC-DC convertor, which was needed to step down the 6V battery to the required 5V for USB specifications. The USB port was stripped and tied to the output of the DC-DC converter. Lastly, the iPod or USB device can now be connected.

Design

As shown in Figure 2, the block diagram provided an overview of the design. The solar panels would be used as the source, supplying power to the battery which is a load when it's uncharged and then becomes the source when charged. The fully charged battery supplies a USB load, such as an iPod or an iPhone.

Initial Design

The initial design was based on an experiment done in EE 449, the lab section of Senior Electronic Design (EE 409). The experiment was Design Project 8, *Automatic Light Controller.* In the experiment a voltage regulator was built and tested using the LM317. The voltage regulator was revisited and implemented into LTSpice. The voltage regulator was first constructed as a foundation of the charge controller and simulated in LTSpice, as shown in Figure 3.

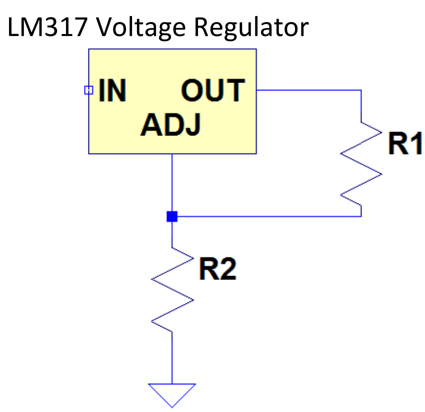


Figure 3: Initial Design using the LM317 Voltage Regulator

This generic voltage regulator was the starting point of the charging controller and it was used as a basis for the final charging controller. The generic LM 317 along with two resistors creates a great voltage regulator that can control the amount of voltage as required.

Final Design

After experimenting with the LM317 and simulating it with various resistors, calculations were done in order to obtain the correct resistor values to output a certain voltage. These calculations can be found in the *Charging Controller* section. Once the process of calculating the resistors to obtain a certain voltage was completed, the rest of the circuit was built in LTSpice and simulated. With advice and assistance from professors, classmates, pervious course work, and the Internet, a final design was constructed in LTSpice, shown in Figure 4.

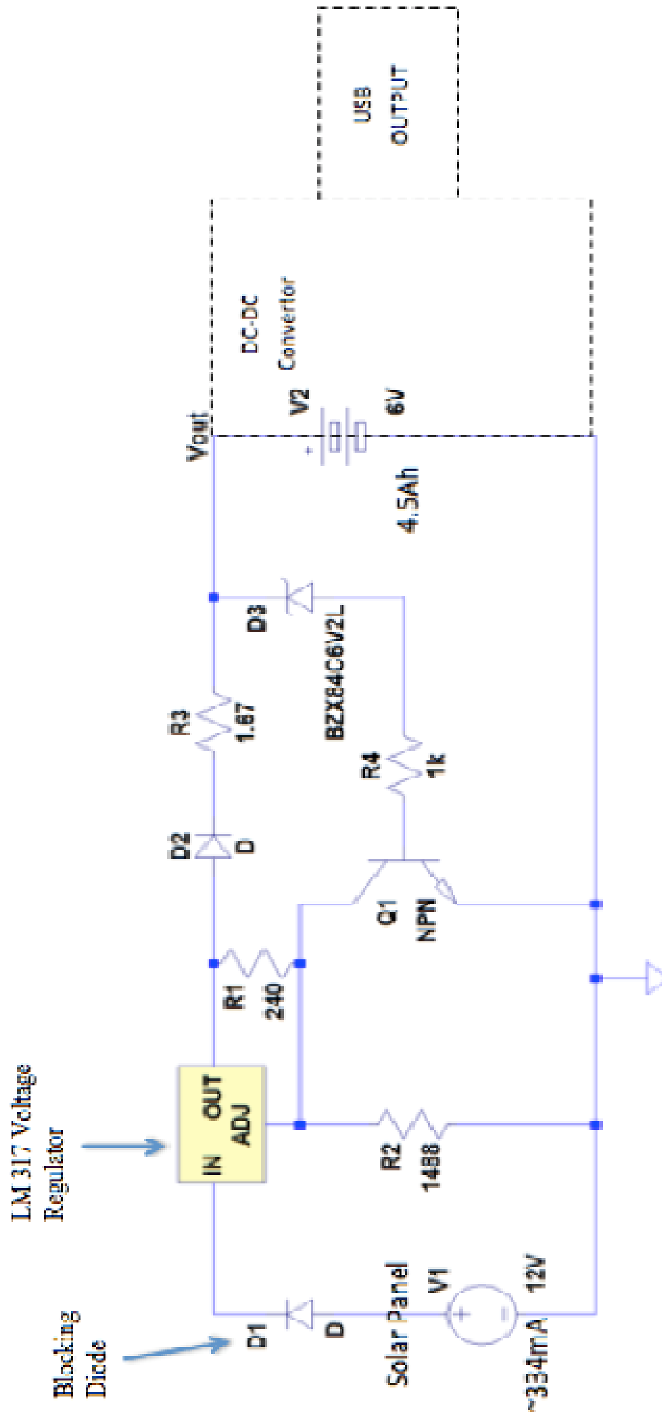


Figure 4: LTSpice Simulation of the Final Design

Solar Panels

The solar panels are the main source to the entire system as seen in Figure 4. As stated before in the requirements section, four solar panels were required in order to fulfill the specifications of charging USB devices such as an iPod. Each individual solar panel provided 6V and 167mA. Therefore, a set of two solar panels were placed in series to increase the voltage to 12V and then placed in parallel with two more solar panels, to increase the current to 334mA. An example of this series and parallel placement is shown below (Figure 5).

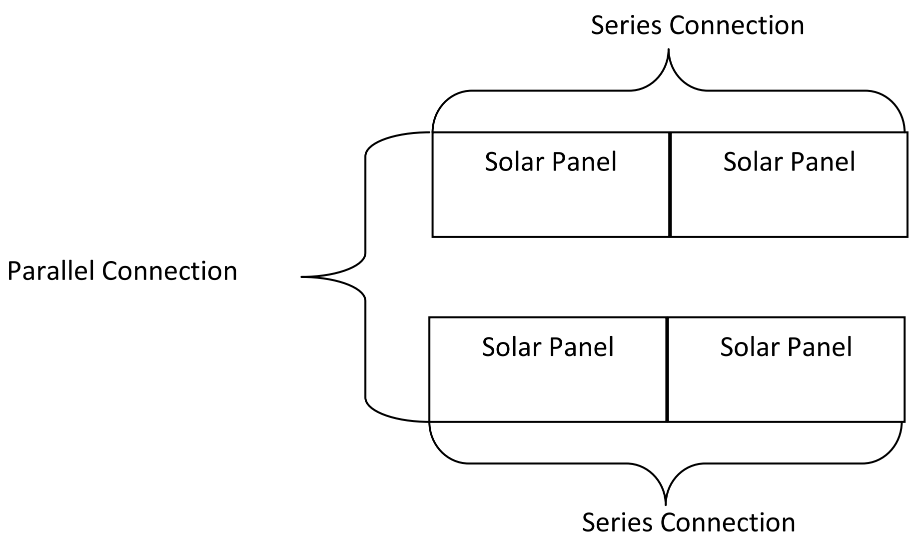


Figure 5: Configuration of the Series and Parallel Connection Combination

Charging Controller

The “charging controller” is where the design portion of this project was completed. The charging controller is used to control the current and voltage from the solar panels to the 6V rechargeable lead-acid battery. The charging controller portion of the final design (Figure 5) is shown below in Figure 6.

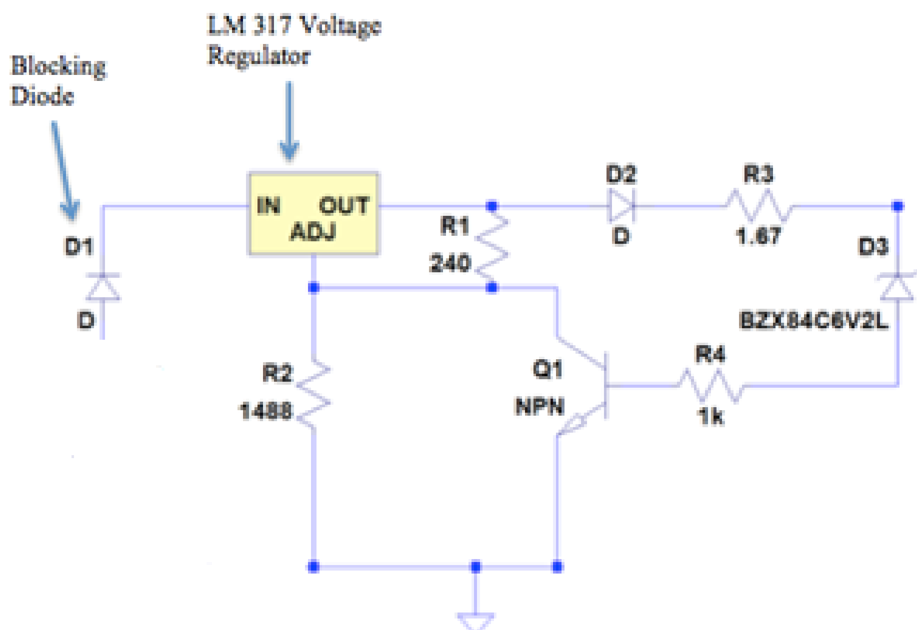


Figure 6: Schematic Portion of the Charging Controller

The initial design with the LM317 voltage regulator was experimented with using LTSpice and this is the final charging controller circuit. The first step to this process was to obtain the resistors values in order for the voltage regulator to output the desired voltage, which was determined to be 9V. The output of the voltage regulator was chosen to be 9V because the circuit required the voltage regulator to have a higher output voltage than the battery, which is 6V. The resistor calculations and the charging controller simulations are provided below.

Calculations:

Step 1: Calculate Resistors 1 & 2

$$V_{out} = 1.25\left(1 + \frac{R_2}{R_1}\right)$$

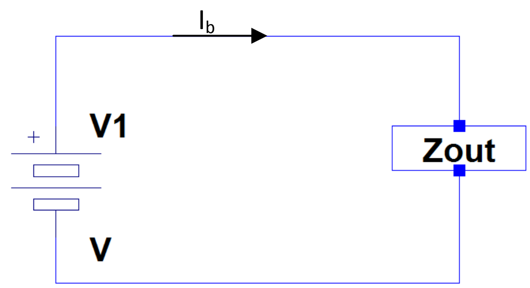
$$\boxed{R_1 = 240\Omega}$$

$$V_{out} = 9V$$

$$9 = 1.25V\left(1 + \frac{R_2}{240\Omega}\right)$$

$$\boxed{R_2 = 1488\Omega}$$

Step 2: Calculate Resistor 3 through Z_{out} and I_b



$$Z_{out} = R_3\left(1 + \frac{R_2}{R_1}\right)$$

$$I_b = \frac{V_b}{Z_{out}}$$

$$set\ \ 500mA = \frac{6}{Z_{out}}$$

$$Z_{out} = 12$$

$$12 = R_3\left(1 + \frac{1488}{240}\right)$$

$$\boxed{R_3 = 1.67\Omega}$$

Step 3: Pick Resistor 4 to be 1k in order to limit the current

$$R_4 = 1k\Omega$$

The next step was to simulate the voltage regulator portion of final design and find the output voltage at R1(240Ω) of Figure 6 using LTSpice probes. The output is displayed in Figure 7 and shows that the simulation is similar to our desired value.

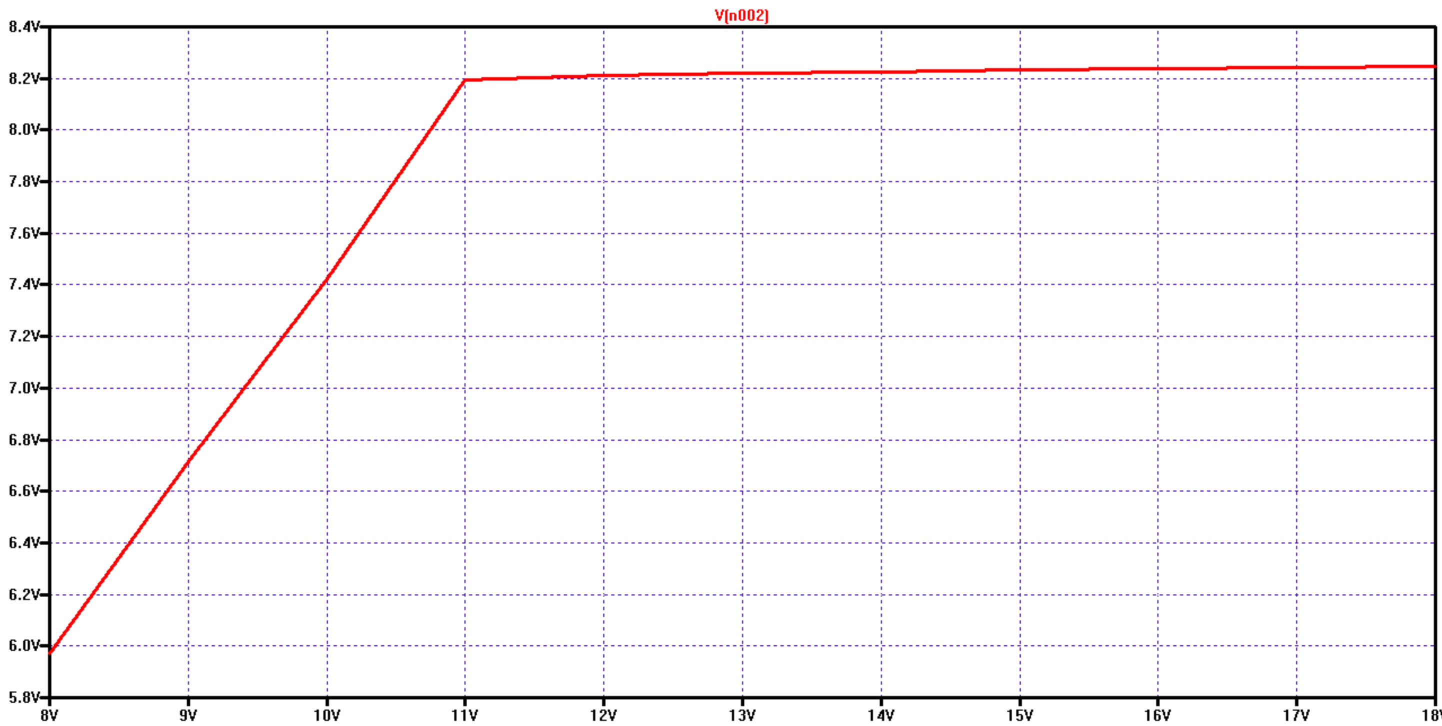


Figure 7: LTSpice Simulation of the Output Voltage at the Output of the Voltage Regulator

The simulation in Figure 7 shows the output voltage is about ~8.25. The simulated value is not quite 9V because the theoretical calculations were based on the voltage regulator by itself. Figure 7 shows the output of the voltage regulator with the rest of the charging controller circuit. Some voltage may be lost in the transistor, diodes, and resistors. Although 8.25V is not quite 9V, it is acceptable because 8.25V is still higher than 6V, hence the design along with the calculations of the resistors are still valid.

Component Operations (Figure 6)

- Diode 1 (D1): D1 is acting as a blocking diode to keep the battery from discharging across the solar panel.
- LM317, Resistor 1 and Resistor 2 (LM317, R1, R2): LM317, R1 and R2 of this circuit are controlling the output voltage, together acting as a voltage regulator as mentioned above.
- Diode 2 and Resistor 3 (D2, R3): D2 prevents discharge from the battery and R3 is restricting the charging current.
- BJT Transistor (NPN), Zener Diode, and R4 (Q1, D3, R4): Q1, D3, and R4 are acting as a protective system to make sure the battery isn't overcharged. Furthermore, Q1 and D3 are acting as a cut off switch once the battery is full. When the battery is fully charged, D3 will conduct because it is approaching the zener diode voltage. As soon as the zener conducts, current will stop flowing to the battery and instead will flow to the base of the transistor. This will ground the current, so the battery is not damaged.

Lead-Acid Battery

The sealed lead-acid rechargeable battery is attached between the charging controller circuit and the DC-DC convertor. The battery is rated at 6V and 4.5 Ah. The battery will be used as the voltage source when it is fully charged. When the battery needs to be recharged, the power will be supplied from the solar panels through the charging circuit. The battery is acting as a storage device so the backpack can be used at any time during the day. The LTSpice simulation also provides some clarification that the system will provide the battery with 6V, enough to

charge it, as seen in Figure 8. Additional battery details can also be found in the *Requirement* section as well as the *Conclusion* section.

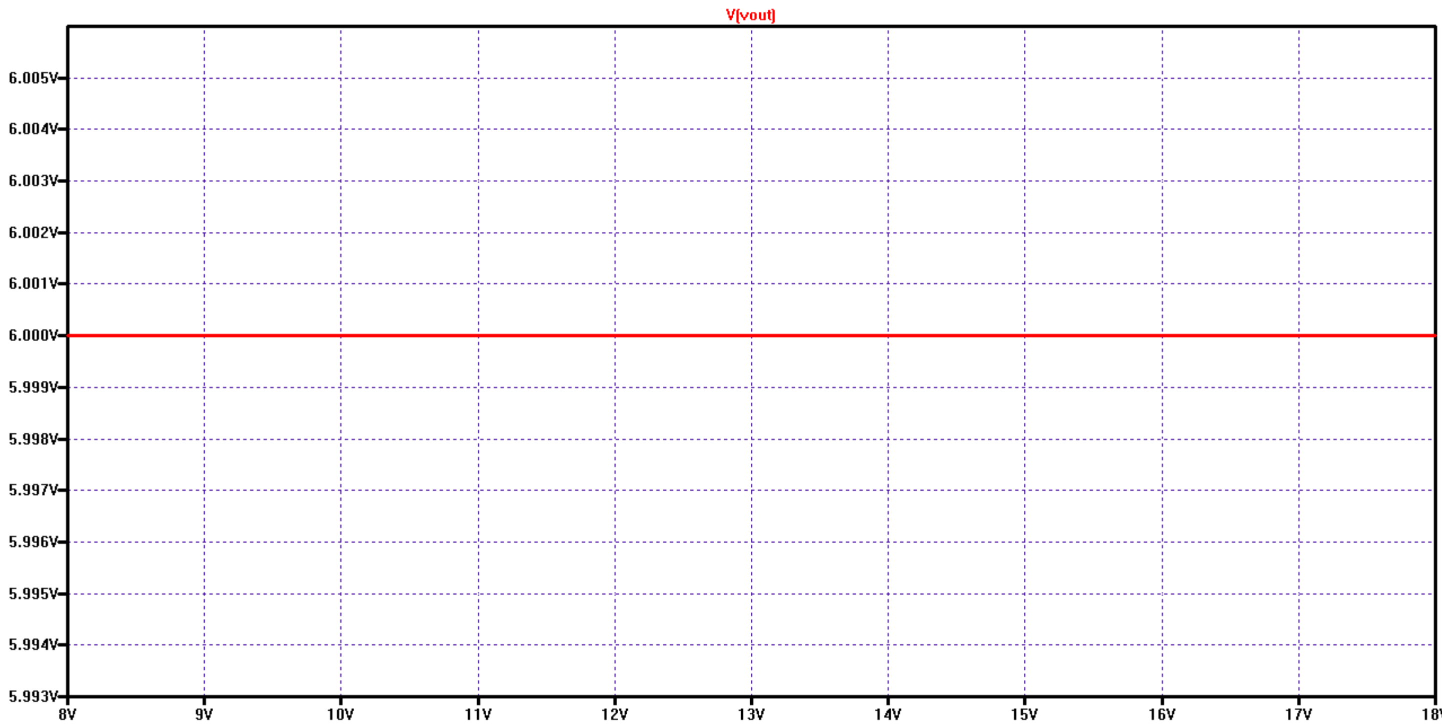


Figure 8: LTSpice Simulation of the Output Voltage

DC-DC Convertor

The DC-DC convertor is connected in parallel with the battery. The main purpose of the DC-DC convertor is to step down the voltage of the battery, which is 6V to a more suitable 5V. Apple specifications for iPods, iPhones, and most USB devices require 5V; hence the DC-DC convertor must be used step down the battery output voltage from 6V to 5V. This is to prevent any damages to the iPod or USB device.

USB Output Port

A USB cable was stripped and the USB data sheet was accessed in order to have the correct wires tied for the USB port. The male end of the USB wire was cut off and then the wires

were stripped inserting the high and data+ wires into the positive terminal of the DC-DC convertor, while the negative wire was inserted into the ground of the convertor. The data- wire was left unconnected. The female part of the USB is now attached to the convertor and is capable of charging various USB portable devices with 5V charging specifications. This process will be explained in detail in the next section called *Development and Testing*.

Development and Testing

Once the final design was complete, the parts were ordered online or bought from the local Radio Shack in San Luis Obispo. A step-by-step approach was taken when building the prototype circuit. First, a power supply was connected to provide 12V instead of using the solar panels. The initial design was tested first (Figure 3), so only R1 and R2 were attached to the output of the LM317 to verify that the output voltage was correct, please refer to Figure 9 on the next page. This was done by placing the components onto a breadboard as a temporary circuit, shown below. Figure 9 shows that the calculations for the charging controller are correct and valid. The voltage regulator did indeed give the correct output voltage, 9V just as calculated; hence the assumptions of the results for the voltage regulator simulations are correct and prove the validity of the hand calculations from the *Charging Controller* section.

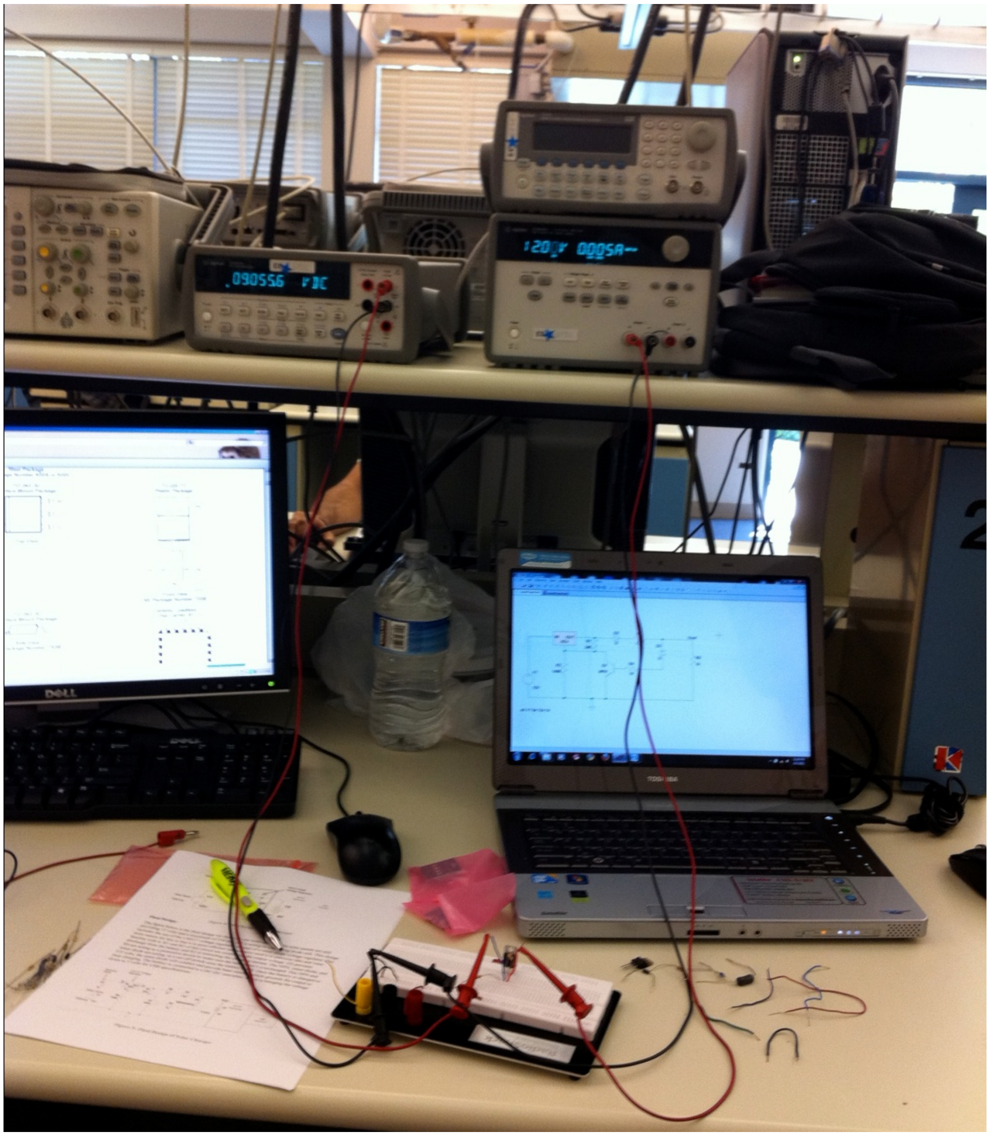


Figure 9: Development and Verification of the Initial Design the Voltage Regulator

In the next step, the rest of the remaining parts were connected as shown in the final design (Figure 5). Figure 5 was although altered by replacing the battery with a 1kΩ resistor instead, for testing purposes. Leaving the battery in would only prove that the battery would charge the iPod. With the 1kΩ resistor in place the voltage at the load was tested. Figure 10 below shows that the final design (Figure 5) has an output of 6.437V, which was more than enough to charge the battery. This verifies the final design is valid and that it works.

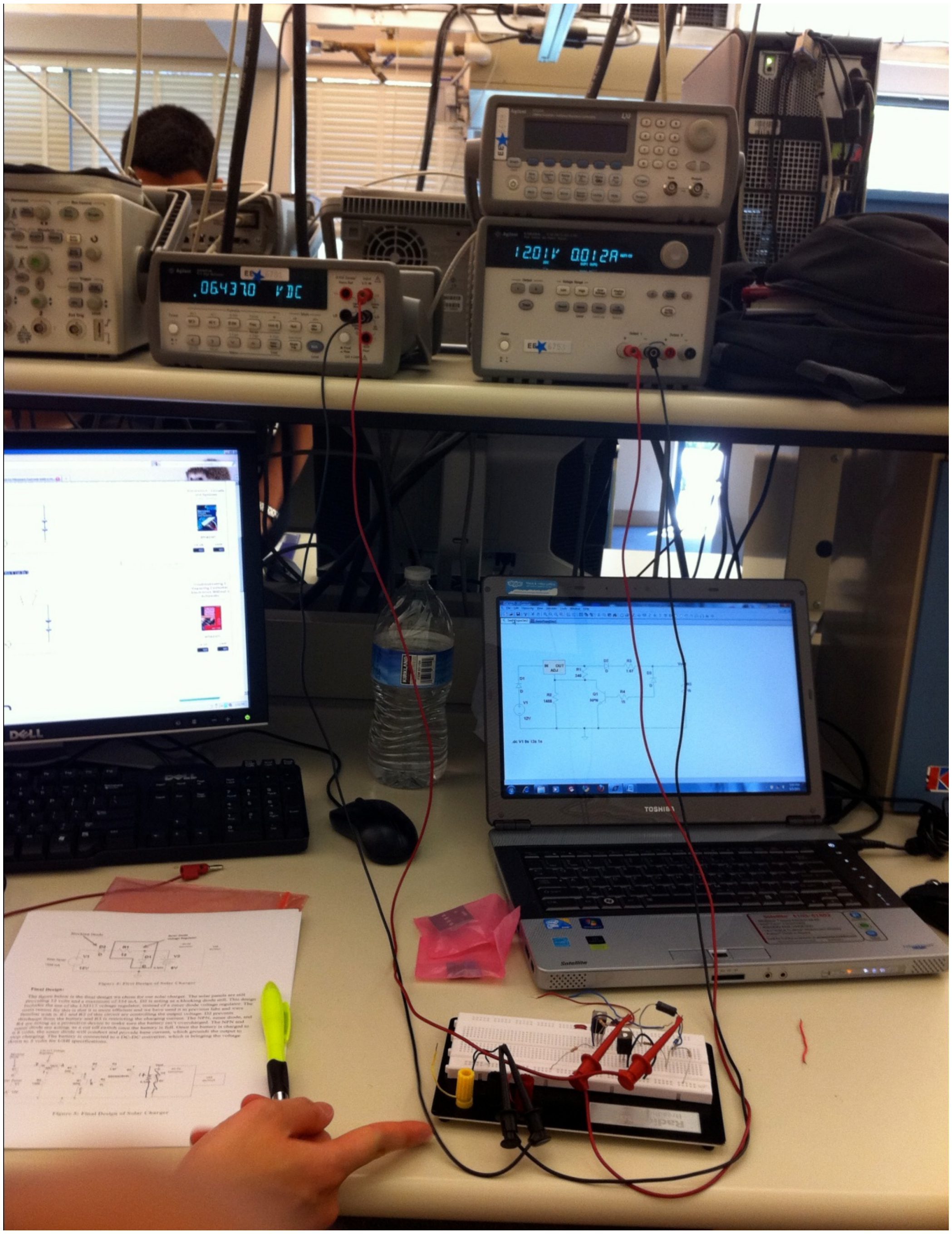


Figure 10: Development and Verification of the Final Design Output

The next step in the development process was to cut the male end and strip the USB cable. The USB data sheet was researched in order to make connections from the stripped USB cable to the DC-DC convertor. The V_{CC} and Data+ ends were tied together and inserted into the positive terminal of the output section of the DC-DC convertor. The V_{EE} end was inserted into negative terminal of the output section of the DC-DC convertor. The data- end was left unconnected. To test this, 5V was supplied through the power supply into the female USB end and outputted to the iPhone for verification, shown in Figure 11.

Figure 11: Verification of the Correct USB Connections

Finally, the circuit was hooked up with the solar panels along with the battery to complete the solar powered backpack prototype. The system was taken outside on a nice bright sunny day to verify the charging of the iPhone. Figures 12, 13, and 14 will verify that the system works and provide close-ups of the iPhone charging. The prototype is now ready to be tested for data and measurements.

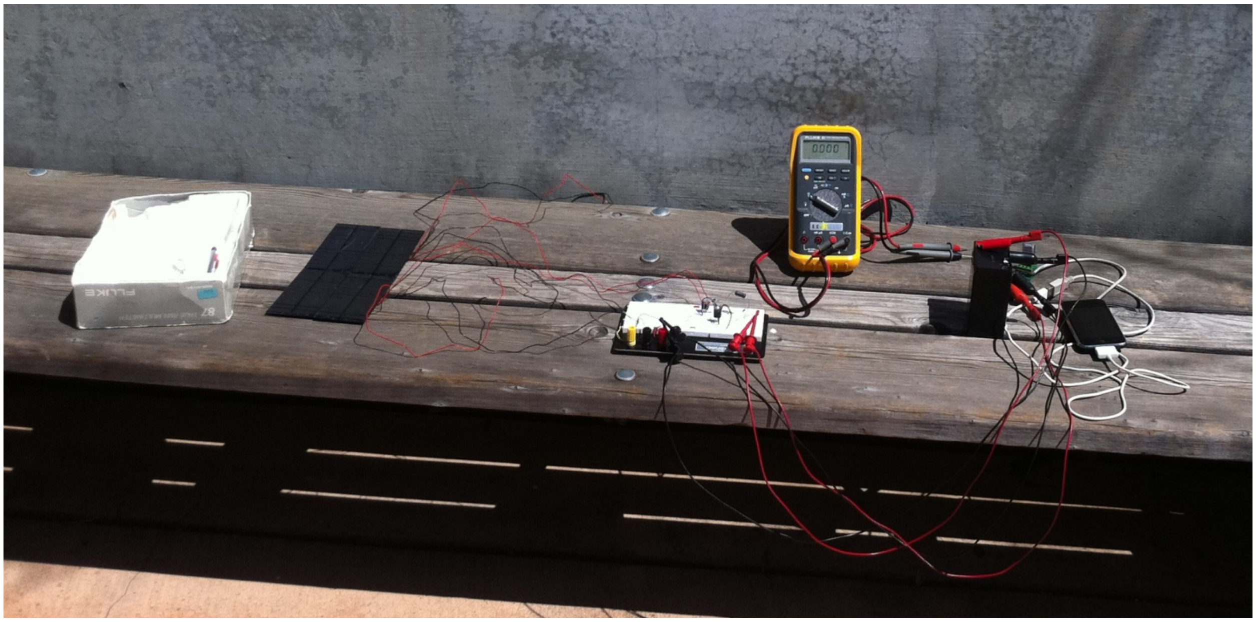


Figure 12: Solar Panel and Battery Connected while Charging the iPhone

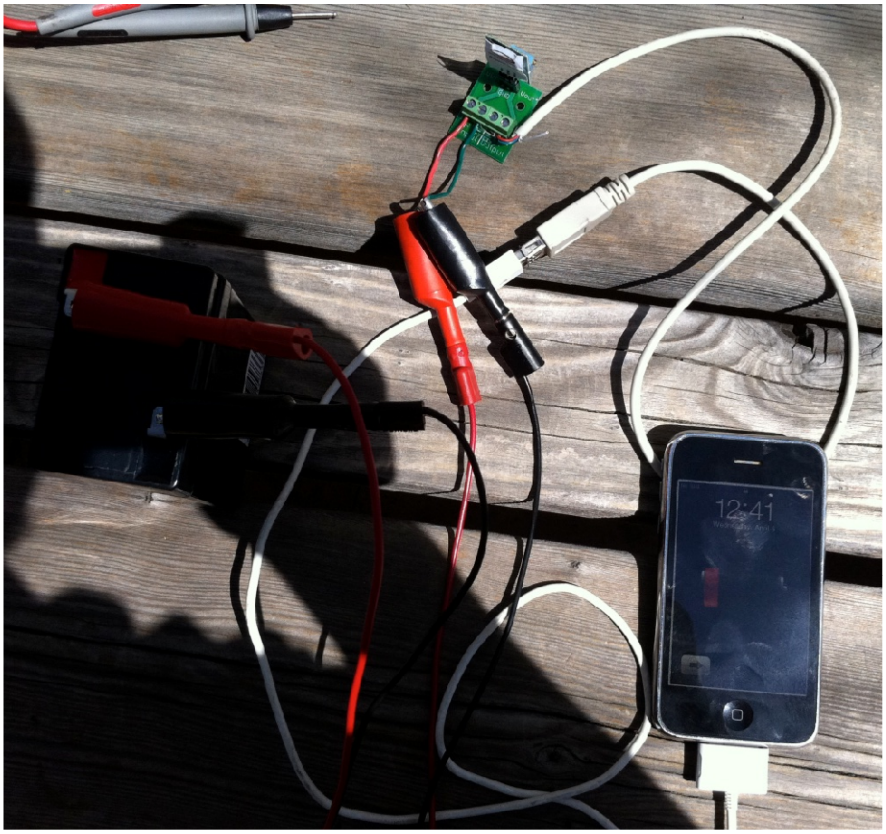


Figure 13: Connections between the Battery, DC-DC Convertor, and iPhone

Figure 14: Close-Up of the Charging iPhone

Furthermore, the battery was removed and the DC-DC convertor was directly connected to the charging circuit, which verified that the solar panels gathered enough energy to charge the iPhone.

Data Testing Results

The prototype was set-up and ready for testing, this time using an iPod instead of an iPhone to check the charging of other USB devices. The first set of data recorded included the voltage and current out of the solar panels with no load connected. Shaded transparencies were used to shade the solar panels. The transparencies ranged from 0-100% in increments of 10%, which were made with a tool in Microsoft Word 2011. As shown in Table 1, the voltage only drops slightly, while the current drops much quicker. The maximum current that was expected was about 334 mA, which was received.

Solar Panel with No Load

Table 1: Data Collection of Voltage and Current out of Solar Panels (Case 1)

Case 1: Voltage and Current out of Solar Panels			
Shaded (%)	**Voltage (V)**	**Current (mA)**	**Power (mW)**
0	13.21	335.00	4425.35
10	13.18	292.00	3848.56
20	13.17	277.00	3648.09
30	13.15	202.00	2656.30
40	13.12	152.00	1994.24
50	12.93	136.00	1758.48
60	12.71	119.00	1512.49
70	12.49	97.00	1211.53
80	12.17	70.00	851.90
90	11.78	48.00	565.44
100	11.19	27.00	302.13

The next set of data included gathering the voltage and current at the output of the iPod. Table 2 shows that the current dropped heavily when the solar panels were shaded at 40%. In addition, the voltage stayed steady until shaded at 90%. When the solar panels were shaded at 90%, the voltage dropped and the current increased. It seemed as if the iPod was trying to maintain a constant power when shaded at 90%, so the current jumped up as the voltage decreased. Interestingly, the iPod did not stop charging until shaded at 100%.

Solar Panel Charging iPod as Load

Table 2: Data Collection of Solar Panels charging iPod (Case 2)

Case 2: Solar Panels charging iPod (about 60% charged already)			
Shaded (%)	**Voltage (V)**	**Current (mA)**	**Power (mW)**
0	6.32	116.10	733.75
10	6.32	116.00	733.12
20	6.32	116.00	733.12
30	6.32	116.00	733.12
40	6.32	13.10	82.79
50	6.32	12.23	77.29
60	6.34	11.88	75.32
70	6.32	11.65	73.63
80	6.29	11.53	72.52
90	2.20	36.13	79.49
100*	2.17	20.95	45.46

*Note: iPod stopped charging at 100% shaded.

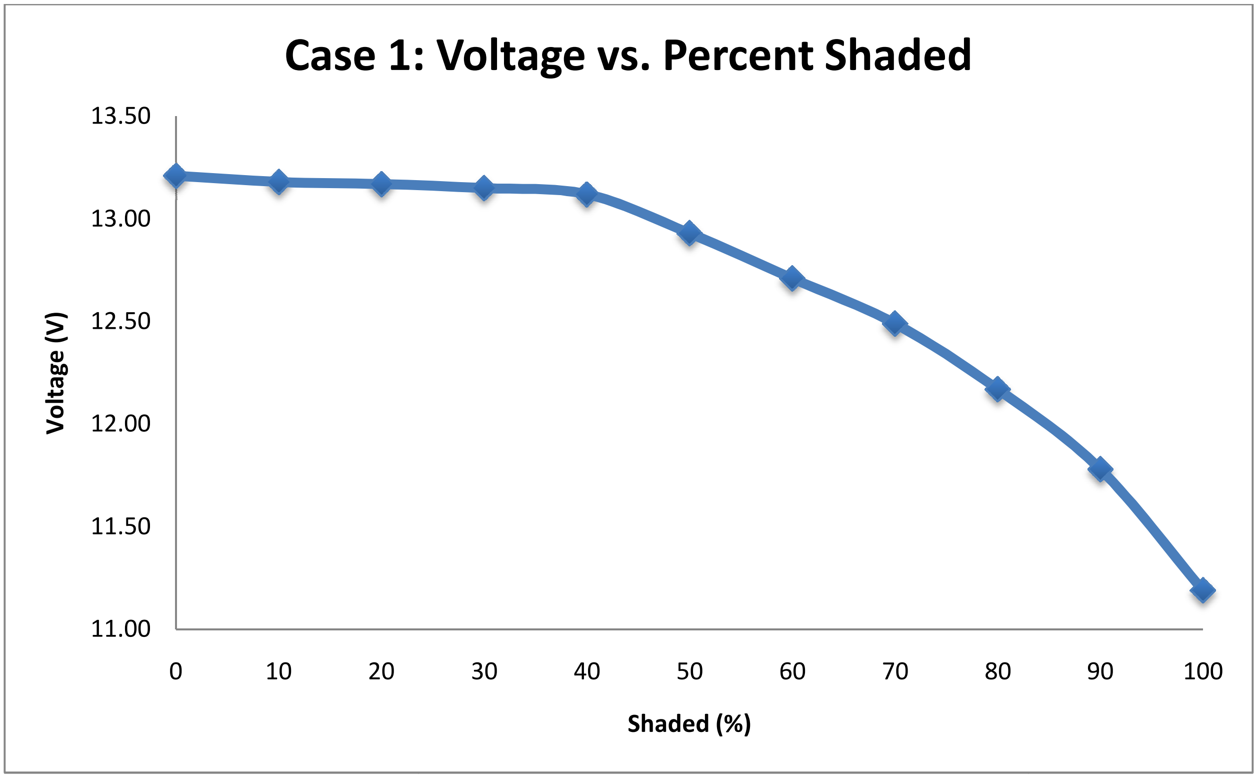


Figure 15: Voltage vs. Percent Shaded (Case 1)

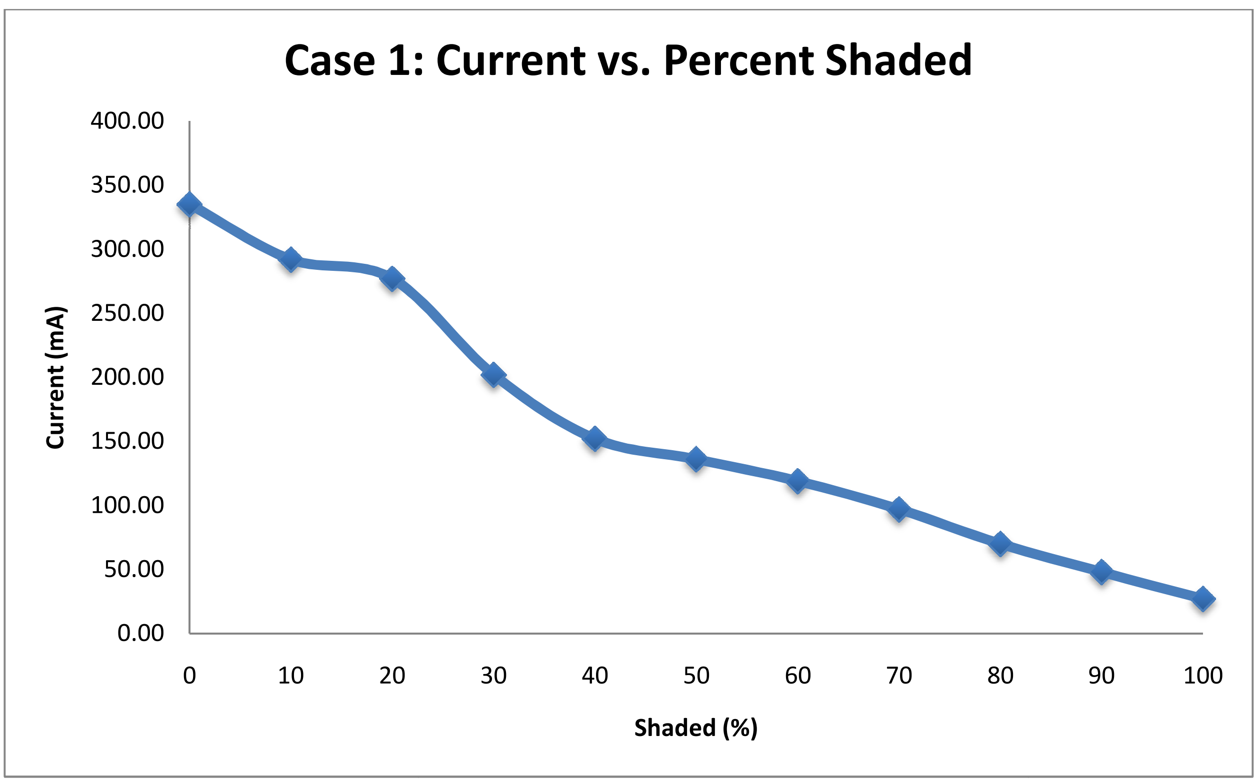


Figure 16: Current vs. Percent Shaded (Case 1)

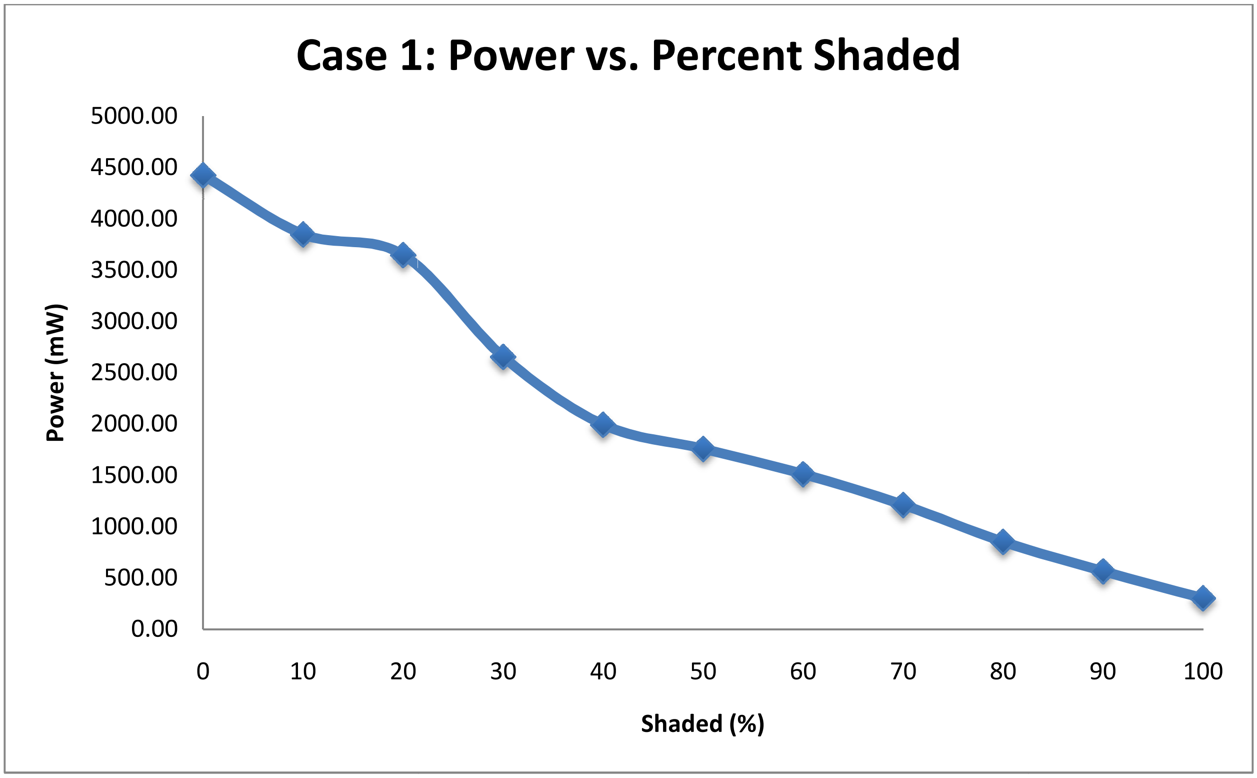


Figure 17: Power vs. Percent Shaded (Case 1)

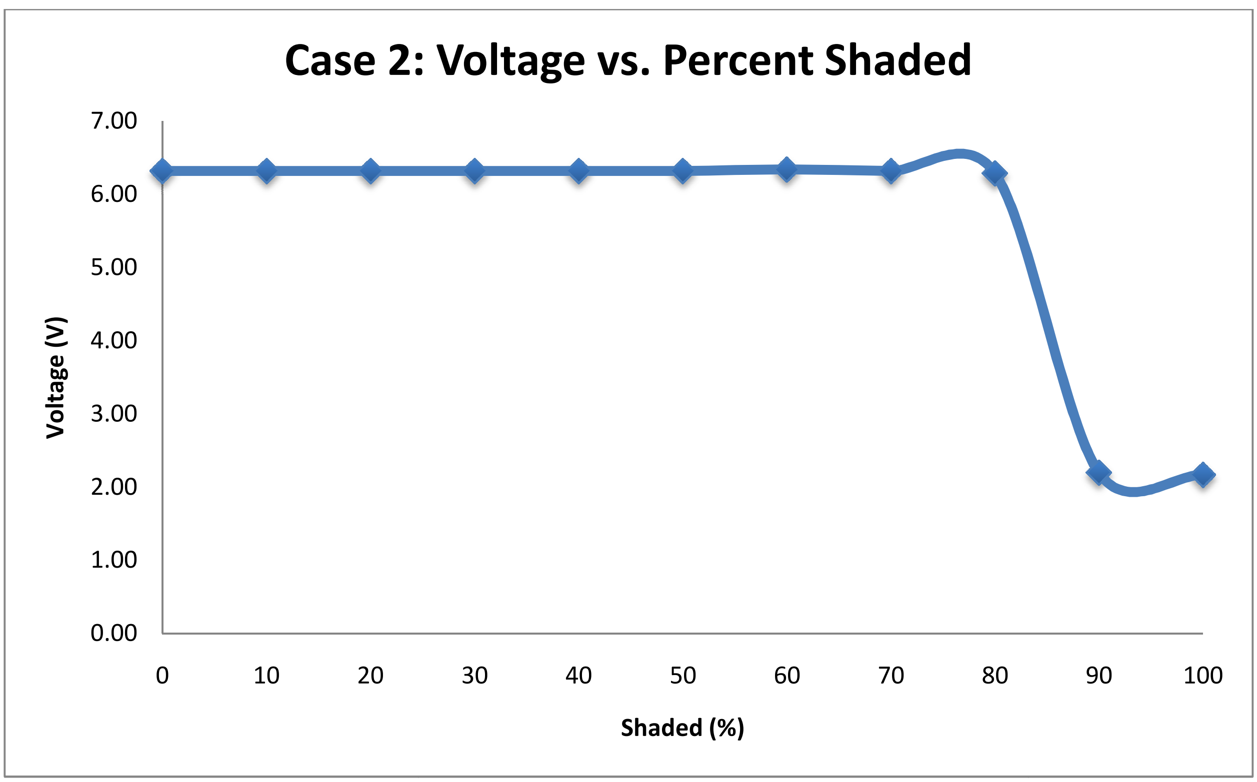


Figure 18: Voltage vs. Percent Shaded (Case 2)

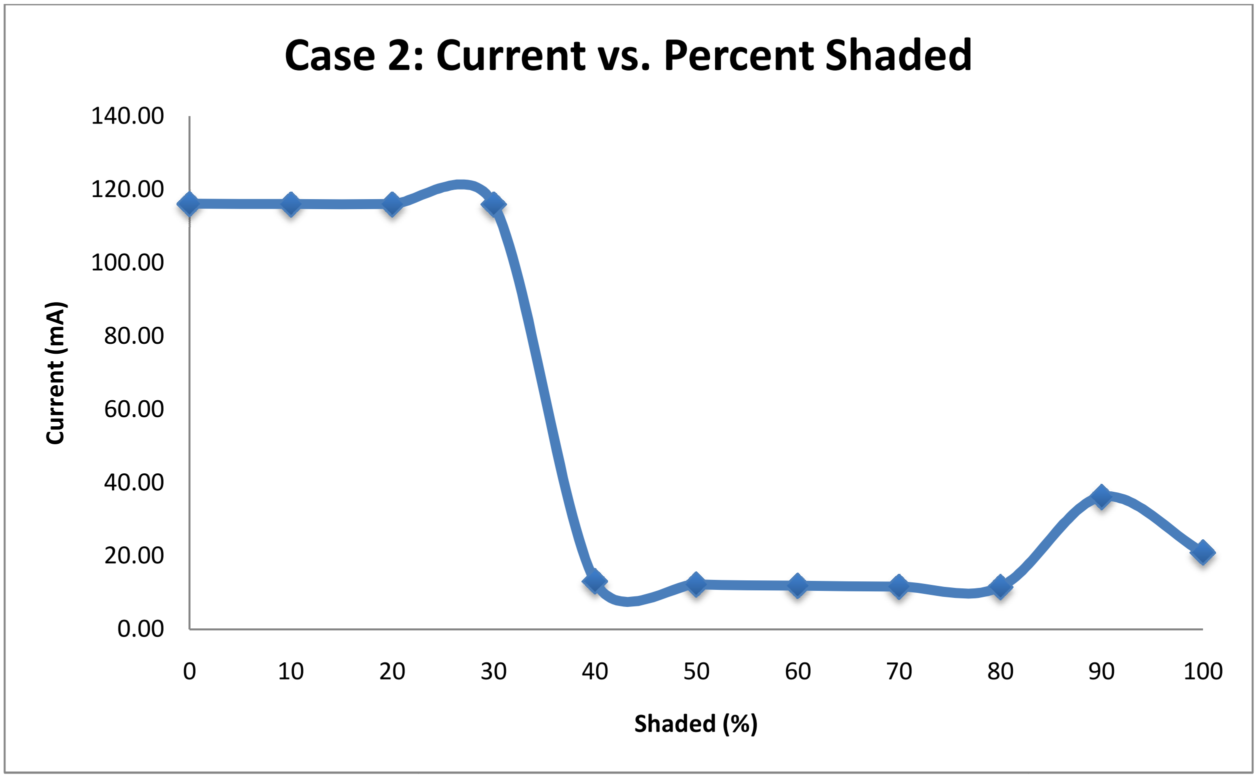


Figure 19: Current vs. Percent Shaded (Case 2)

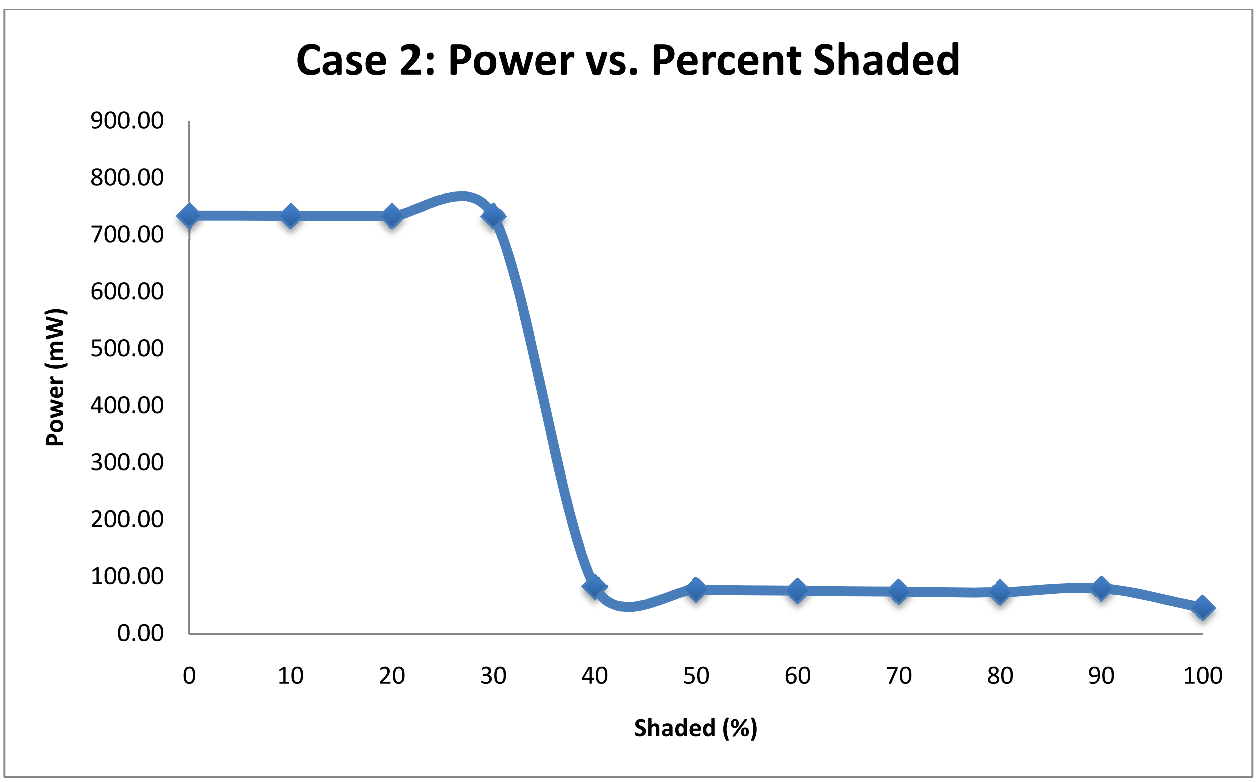


Figure 20: Power vs. Percent Shaded (Case 2)

The last set of data taken consisted of gathering the voltage and current out of the solar panels with no load at two different angles, 180° and 90°. As Table 3 shows, the voltages and currents were higher when the solar panels were placed at 180°. This set of data helped when deciding the placement of the solar panels on the backpack. The solar panels were placed as close to the desired 180° as possible, which is also further explained in the *Construction* section.

Solar Panel Measurements at Different Angles

Table 3: Data Collection of Voltage and Current out of Solar Panels at an Angle

Voltage and Current out of solar panels						
	180°			90°		
Shaded (%)	**Voltage (V)**	**Current (mA)**	**Power (mW)**	**Voltage (V)**	**Current (mA)**	**Power (mW)**
0	13.01	323.00	4202.23	11.60	55.00	638
10	12.85	281.00	3610.85	11.50	50.00	575
20	12.79	265.00	3389.35	11.65	46.00	535.9
30	12.72	240.00	3052.80	11.65	43.00	500.95
40	12.54	210.00	2633.40	11.59	39.00	452.01
50	12.46	184.00	2292.64	11.54	33.00	380.82
60	12.25	141.00	1727.25	11.50	26.00	299
70	11.99	115.00	1378.85	11.25	19.00	213.75
80	11.70	83.00	971.10	10.56	15.00	158.4
90	11.34	56.00	635.04	10.43	11.00	114.73
100	10.84	31.00	336.04	9.88	7.00	69.16

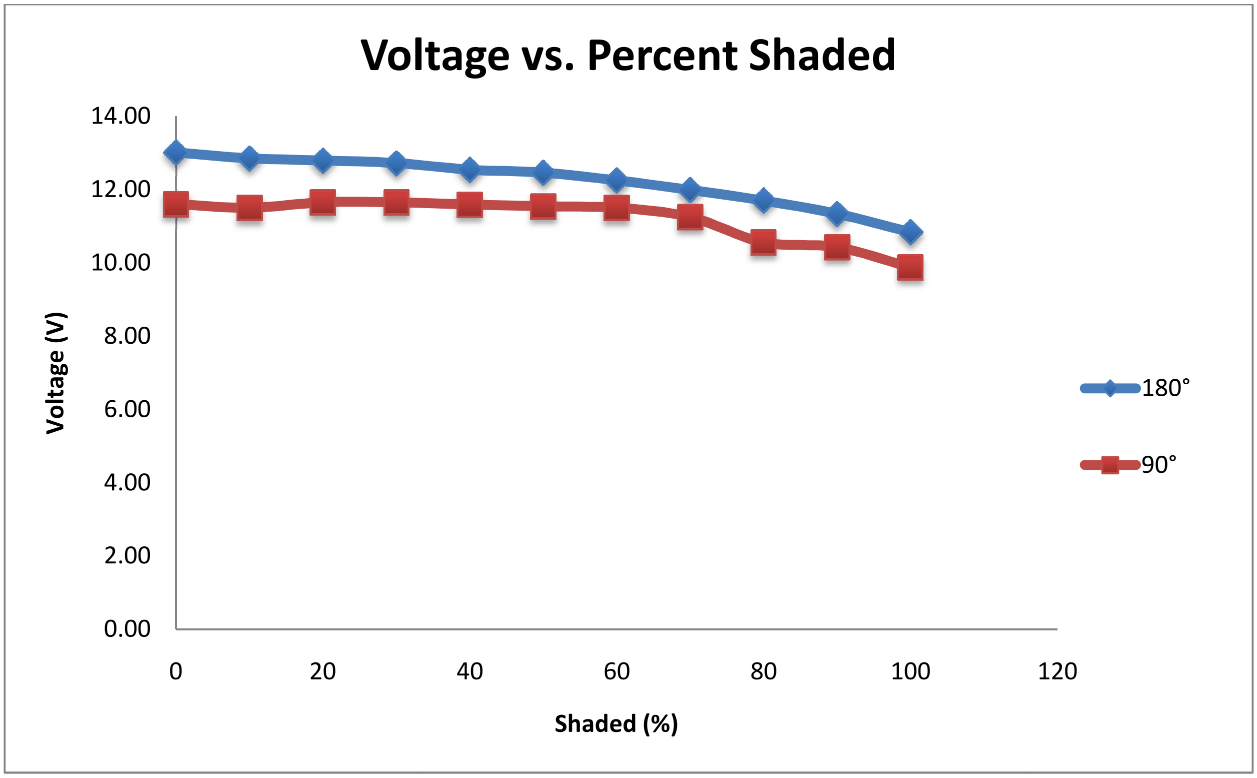


Figure 21: Voltage vs. Percent Shaded

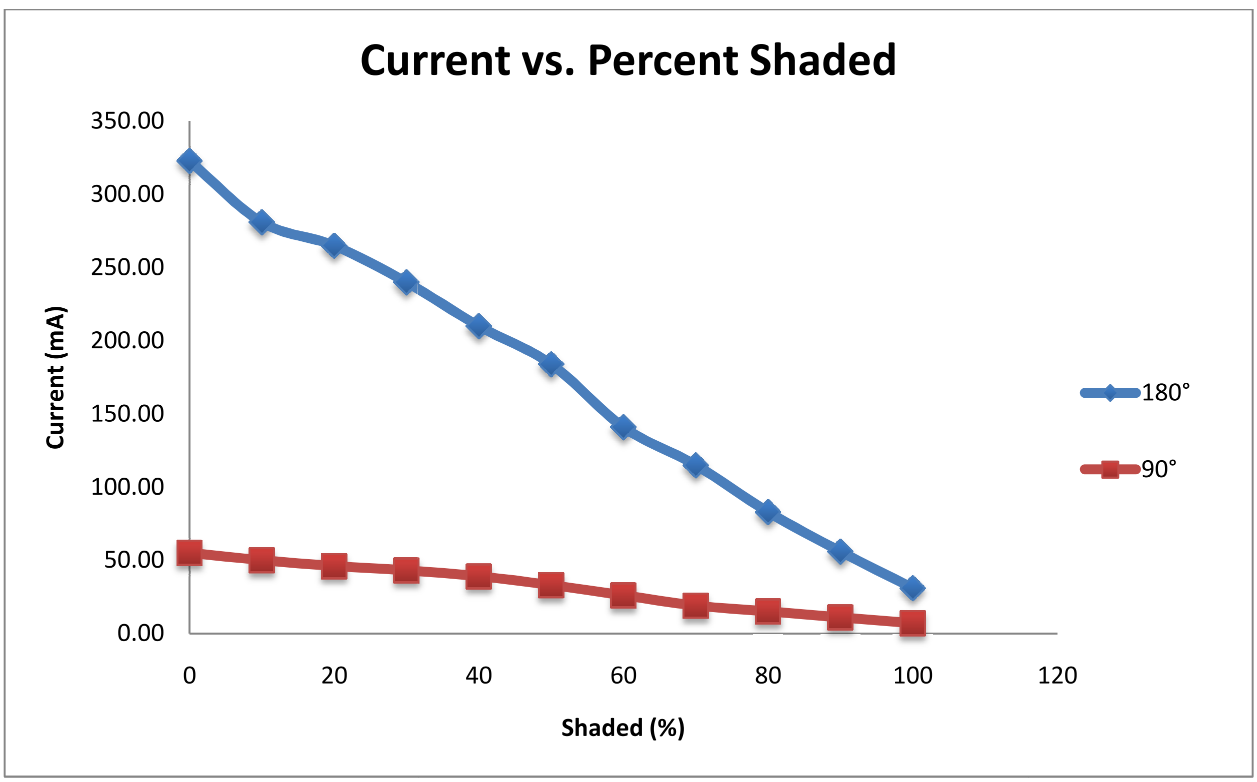


Figure 22: Current vs. Percent Shaded

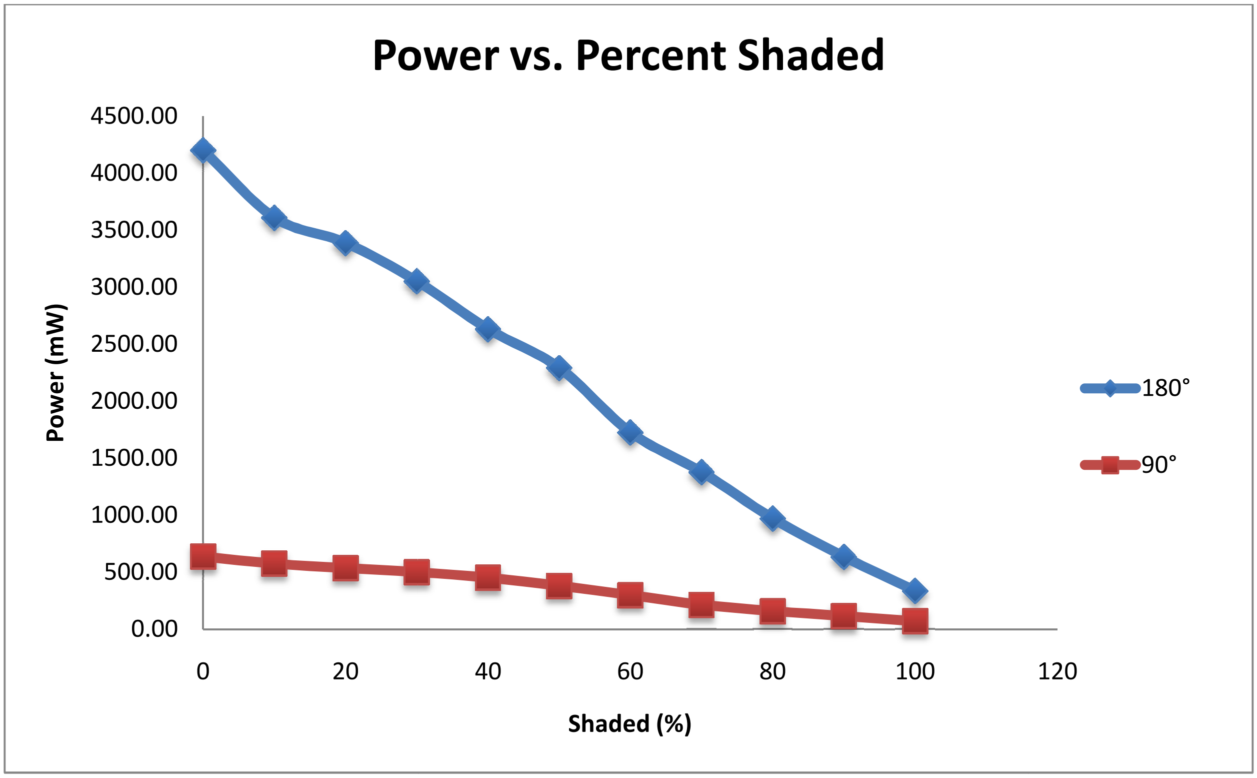


Figure 23: Power vs. Percent Shaded

Construction

Constructing the project was done last and after testing because in order to test the current, the circuit must be "broken." The circuit was broken and an ammeter had to be inserted between the Zener Diode (D3) and the 1kΩ resistor which was used in replacement of the battery. Therefore, construction had to be done afterwards. The soldering of the components would not allow the circuit to be "broken" and measured.

The construction began as the development did, starting with the charging controller circuit. The electronic components were all soldered onto a PC board. Once those were stable, the PC board was incased with a project box. Holes were drilled into the side of the box for wires to run from the circuit to the battery. The wires were then soldered onto the board and to the battery, which is all pictured in Figure 24.

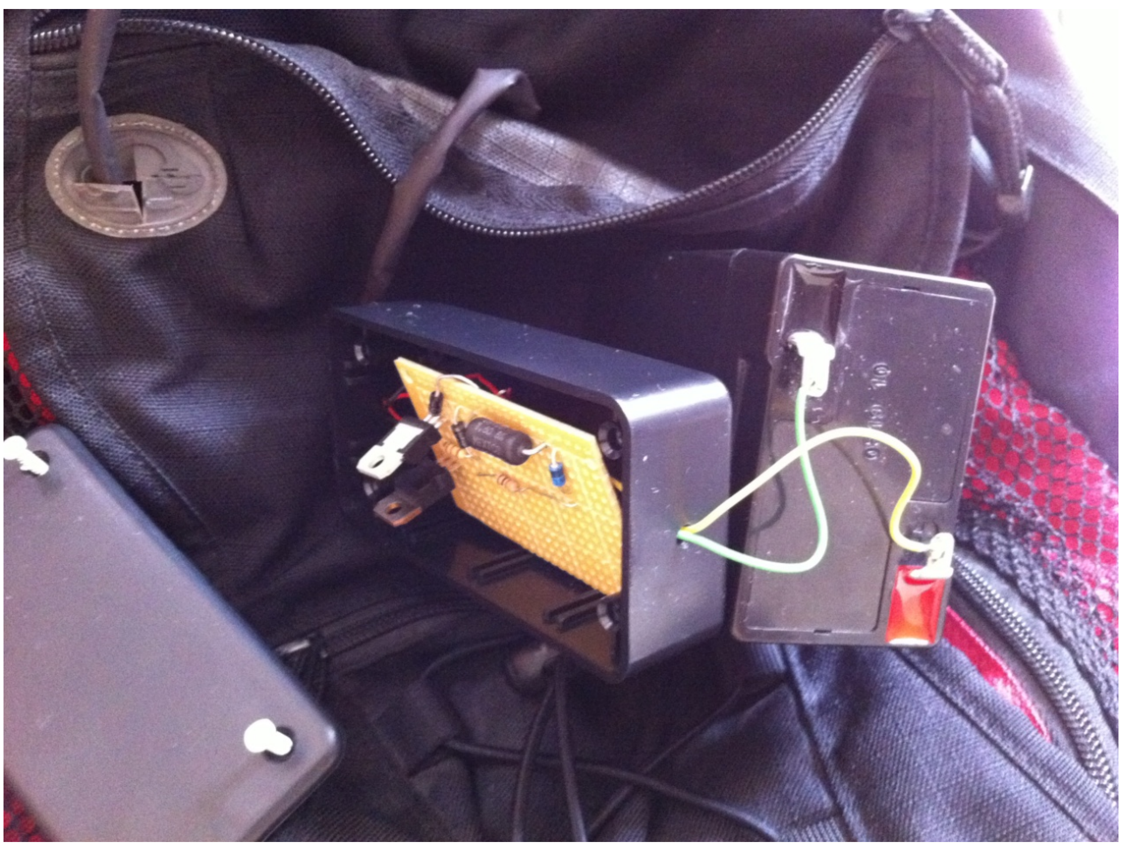


Figure 24: Soldered Electrical Components onto PC Board and Soldered to Battery

Construction was continued with soldering the DC-DC convertor from the battery to the USB cable, shown below. Then all the parts were put into the top pouch of the backpack and zipped up. The black protective rubber tubes seen coming out of the earphone hole of the backpack were heated with a blow dryer to tighten the tube. The construction of the solar panels was a bit different. It was found during testing that the solar panels worked best at angels close to 0° or 180°. Therefore, the original idea of having the solar panel vertically attached to the backpack on the lower pouch was not a good idea. It was tested and the solar panels just could not collect enough energy to charge the battery or the iPod as proved in the data contained in Table 3. So improvising was done and it was decided that the solar panels would be attached to the top of the backpack at an angle closer 180°. The way the solar panels were attached was using Velcro. The top of the solar panels have Velcro straps that can be removed so the owner of the backpack can zip and unzip the main pockets of the backpack. This is all presented in Figure 25 on the next page. Figure 26 shows the final product charging the iPod, which completes the Solar Powered Backpack.

Figure 25: Backpack Construction with Mounted Solar Panels

Figure 26: Final Product "Solar Powered Backpack"

Conclusion and Recommendations

Overall the project was a success. The objective of this project was to design a solar charger that is capable of charging a 6V lead-acid battery. The solar charger charged the lead-acid battery and also was used to charge the iPod directly. The 6V, 4.5Ah lead-acid battery can hold 97,200 joules of energy (27 joules/second *3600 seconds). Most USB devices have a battery that corresponds to an energy capacity of fewer than 15,000 joules of energy, which is the primary reason we used a lead-acid battery. Each step of the block diagram worked which lead to the accomplishment of the final product. All the data taken and observed served a purpose in one form or another in completing this project. Case 2 (Table 2) revealed that the solar panels would charge the battery until it is completely covered at 100%. Table 3 showed us that the solar panels could not possibly be mounted with our original idea, proving to us that we must mount them close to a 180° angle.

In the future, we can make the solar panels weatherproof so the backpack can be used in any season, instead of having to detach the solar panels when it is raining. In addition, the design can be altered to charge laptops instead of only USB devices. Another useful improvement can be to add a detector to know when the battery is fully charged. It can also be useful to find out why the current increased at 90% shaded, when the voltage dropped, according to the data in Table 2. Lastly, it can be helpful to place the solar panels in a better position so they do not need to be detached when unzipping the backpack, while still generating the max current possible.

Bibilography

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Appendices

Parts Lists

Quantity	Description	Cost
4	Solar Panels	$25
1	AnyVolt Micro Universal DC-DC Converter	$19.99
1	Voltage Regulator Breakout Board	$9.99
1	LM317 Voltage Regulator	$1.79
20	Zener Diodes	$3
1	6 V Lead-Acid Battery	$15.99
4	Various Resistors	Donated
1	BJT Transistor	$1.79
2	Diodes	Donated
1	Backpack	Donated
2	Project Box	$3.99
1	PC Board	$1.99
1	USB Cable	$4.99
1	Tubing	$1.95
4	Velcro	$3.46
2	Cable Ties	$3.49
1	Electric Tape	$0.70
	Total Cost	**$98.12**

Pert Chart Schedule

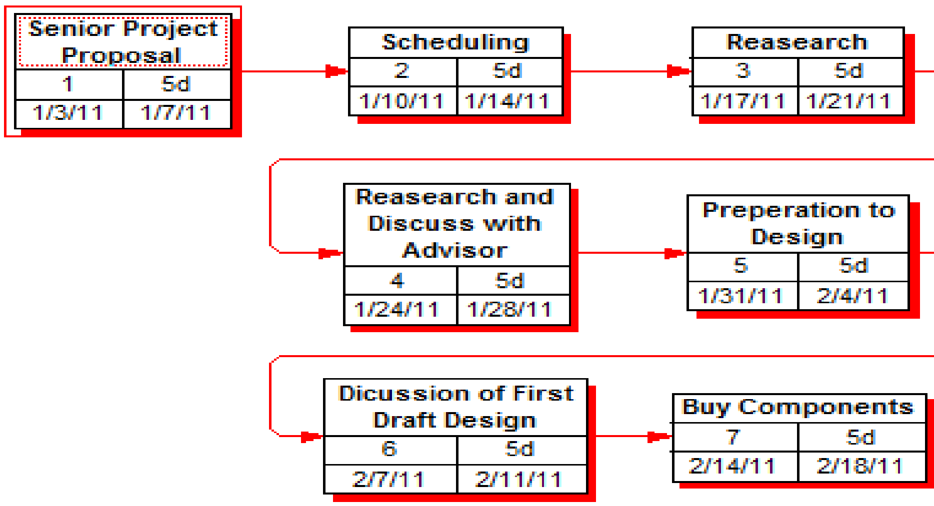

Figure 27: Pert Chart Winter Quarter 2011

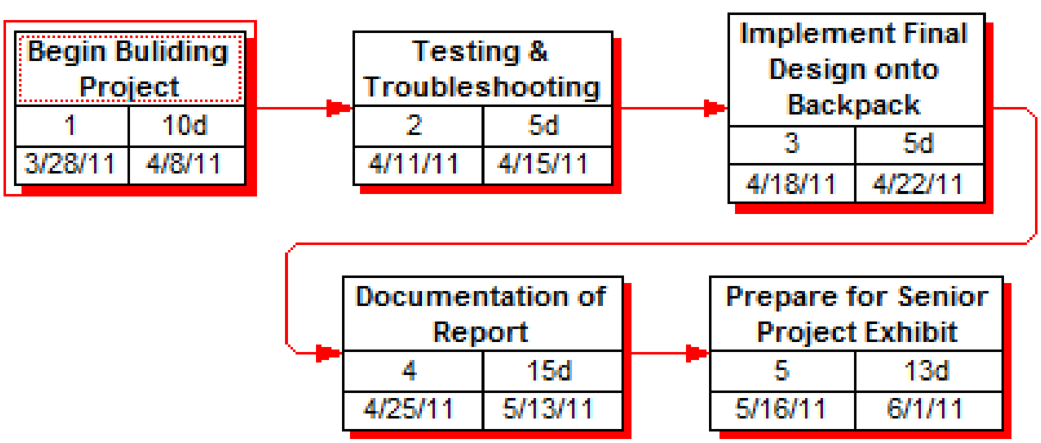

Figure 28: Pert Chart Spring Quarter 2011