Portable Solar Panel Charging Station

A Senior Project

presented to

the Faculty of the Electrical Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

by

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TABLE OF CONTENTS

List of Figures and Tables

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Abstract

The portable solar powered charging station uses a solar powered mat that can be folded for portability. The device has the ability to charge small electronics during both day and night. When sunlight is available, the charger charges two C batteries in series and at the same time it charges any electronic device that can be connected via USB or cigarette lighter. At night the charger will charge the same electronic devices from the onboard batteries. The charging station must be able to interface with electronic devices using USB and a car cigarette lighter to charge the device's battery.

Introduction

The idea for a device that will charge portable consumer electronics came from Professor Samuel Agbo. The cause of this idea was due from the need for a well-built device to charge electronics in a reasonable amount of time. The initial thought for the senior project was to take a solar power mat that rolls up like a map or blueprints and the charging portion of the electronics would be stored in the middle of the rolled up cylinder. However, to keep the price of the project relatively low, a six watt panel took the place that folds over four times to a compact size. The charge management portion of the device now contains an attachment that disconnects from the solar panel itself.

Background

There is no shortage in solar powered chargers on the market today that are very cheap. However, these devices are either very low-powered, inefficient, or do not have the ability to charge devices at night. An example one of these devices is Solar Portable Battery Pack with Flashlight and Lantern by XTG Technology. The product is ultra-portable (fits in the palm of the hand), weighs 0.5 pounds, and includes an onboard battery. However, the battery holds only 1800mAh and the solar panel only outputs around 2.5 watts. The goal for this design is to create a charger that will include batteries that hold a greater charge and uses a solar panel with increased output power. The goal needs reach these qualitative goals without sacrificing much on the side of portability and cost. However, this project is constrained to the solar panels on the market today, and therefore, the majority of the cost will be due to the solar panel as the price dramatically increases with output power.

Requirements

The following requirements were set in order to set a goal and a focus to help form the basis of the project.

Portable Charging Station must fulfill the following requirements:

- Charging station must be reasonably portable when folded to allow travelers, hikers, etc. the ability to keep electronics fully charged on-the-go.
- Charges two C batteries when left in sunlight.
- Protects the battery from overcharging. When NiMH batteries are fully charged most of energy being transferred to the battery turns into heat, and will reduce the lifetime of the battery. A circuit will then be needed to detect temperature, voltage, or both in order to protect the battery.
- Protects the battery from over discharging. If the batteries are left to over-discharge, then the battery will eventually reverse its polarity causing irreversible damage. Therefore, a circuit will be needed to detect the voltage of the battery and disconnect itself before this damage happens.
- Follows USB specifications to charge devices.
- Follows cigarette lighter specifications to charge devices.
- Circuit must be able to charge both batteries and electronics devices concurrently in sunlight, and must be able to charge these same devices at night with onboard batteries.

Design

The diagram in figure 1 shows the initial block diagram used in the proposal for the senior project.

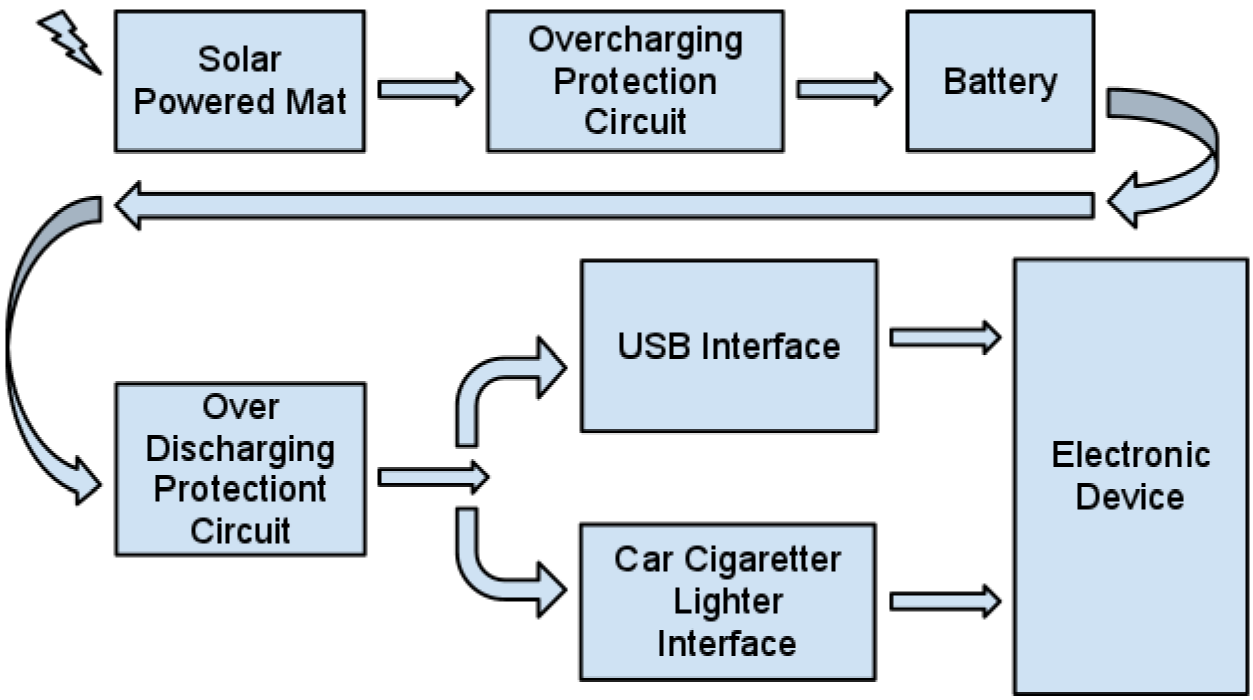

Figure 2: Block Diagram

The second block, "Overcharging Protection Circuit," will detect both the temperature and the voltage of the battery and will change the charging rate from full speed to a trickle charge at a rate of C/40, where C is the total charge of the battery, to keep the charge of the battery maintained. In block four, "Over Discharging Protection Circuit," it will detect the voltage of the battery and will stop the battery from discharging when the charge of the battery is too low. The next two parallel blocks are used to interface with an electronic device using USB and a cigarette lighter, which regulates the voltage at 5 Volts and 12 Volts, respectively.

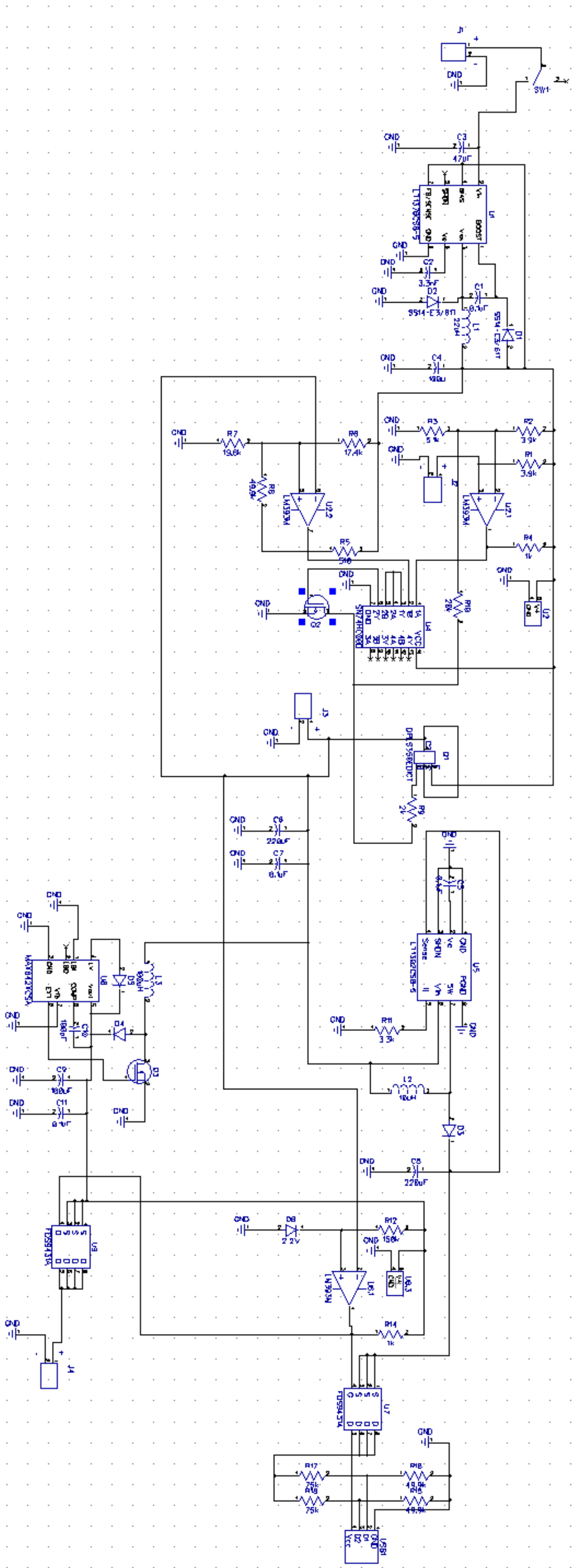

Figure 3: Schematic

Prototype Design

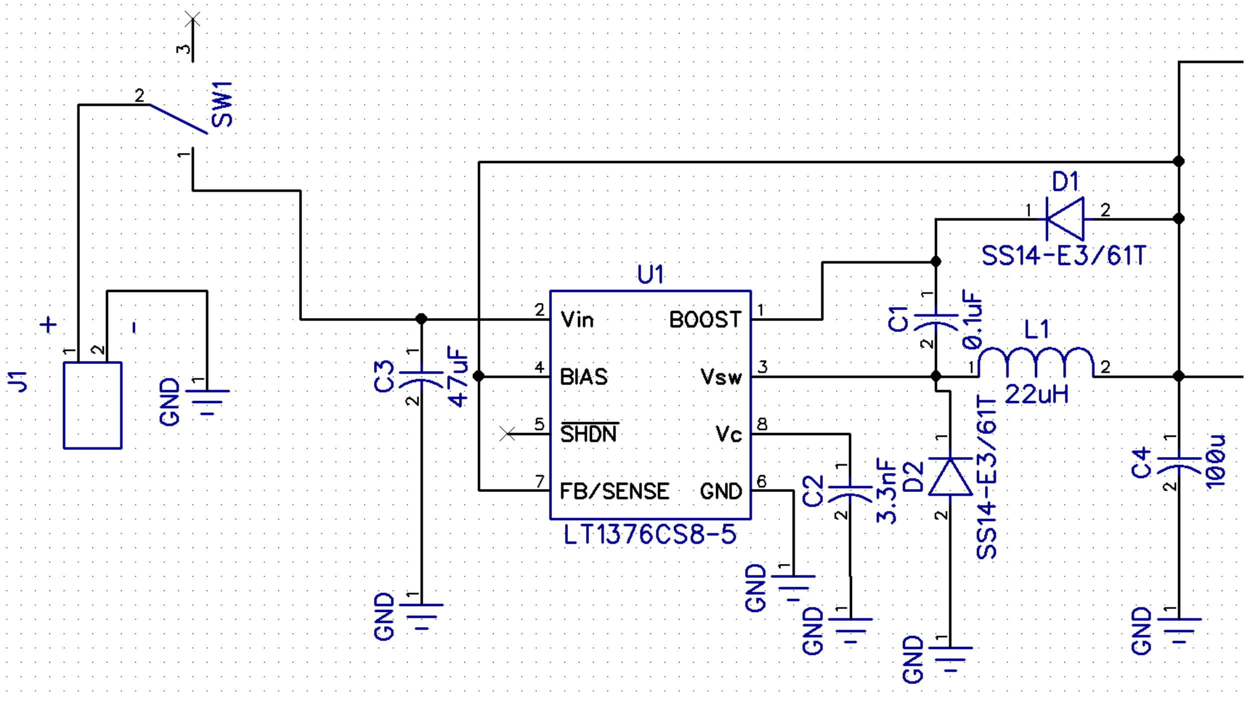

Figure 4: 12V to 5V Buck Converter

Figure 3 shows the portion of the circuit used to charge 2 NiMH C batteries. The voltage source labeled J1 represents the 15V unregulated DC output of the solar cell. The output of the solar panel uses a buck converter to change the voltage from the solar panel to a regulated 5V supply using Linear's LT1376. The output of the boost converter is taken at node 2 of L1.

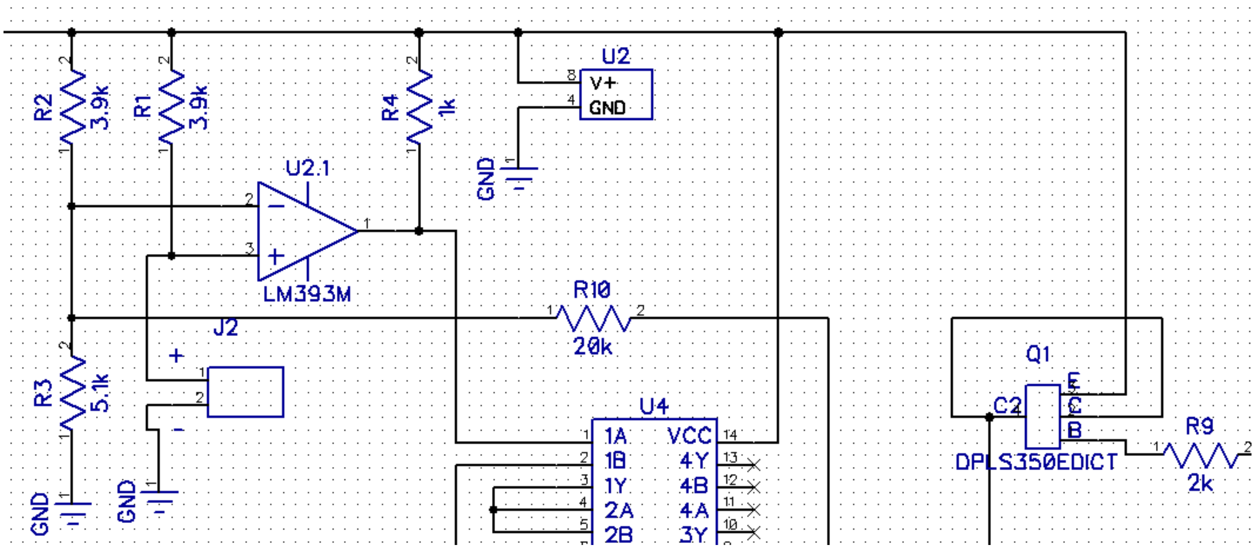

Figure 5: Temperature Sensor

In figure 4, the comparator, U2.1, uses a thermistor to gauge the temperature on the NiMH batteries. The nominal value at room temperature of the thermistor is 10k Ω as shown in figure 6.

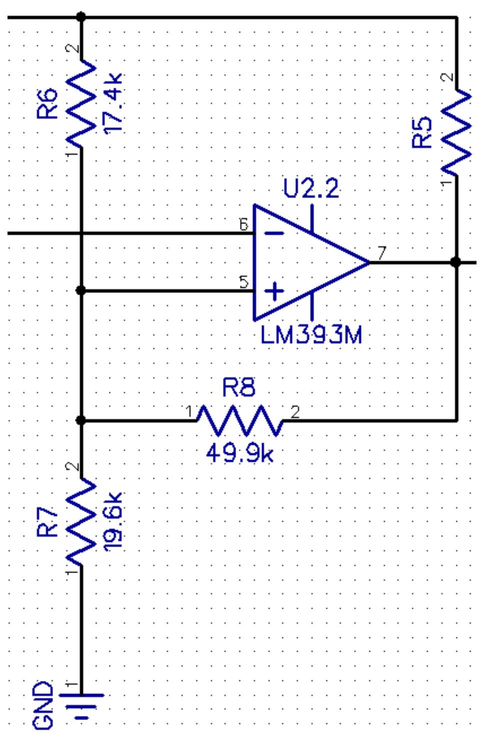

Figure 6: Voltage Sensor

When the temperature of the battery rises, the resistance of the thermistor will drop below 5k Ω at 45 °C, which will lower the output of the comparator to approximately 0V. J1 represents the junction where thermistor from Murata Electronics with part number: NTSD1XH103FPB40 will be attached. The LM393 is used for U2.1, U2.2, and U6.1.

U2.2 uses the offset inverting Schmitt trigger topology and the voltage of the battery to determine if the battery needs charging. The battery will charge until it reaches 3.1V and will not charge again until the voltage of the battery drops below 2.5V. The voltage of 3.1V is greater than the voltage when the battery is fully charged. However, due to the internal resistance

of the battery and a charge rate of approximately 500mA, U2.2 sees a voltage of 3.1V at full charge.

Part Number	NTS□□XM202	NTS□□XR502	NTS□□XH103	NTS□□XV103	NTS□□WB203	NTS□□WC303	NTS□□WD503	NTS□□WF104
Resistance	2.0kΩ	5.0kΩ	10kΩ	10kΩ	20kΩ	30kΩ	50kΩ	100kΩ
B-Constant	3500K	3700K	3380K	3900K	4050K	4100K	4150K	4250K
Temp. (°C)	Resistance (kΩ)	Resistance (kΩ)	Resistance (kΩ)	Resistance (kΩ)	Resistance (kΩ)	Resistance (kΩ)	Resistance (kΩ)	Resistance (kΩ)
−40	44.657	123.484	195.652	347.808	733.007	1149.500	1948.575	4256.752
−35	33.505	92.295	148.171	248.591	524.831	819.651	1387.289	3005.888
−30	25.388	69.614	113.347	179.973	380.184	591.391	999.456	2148.514
−25	19.402	52.860	87.559	131.832	277.845	430.529	728.895	1555.020
−20	14.961	40.480	68.237	97.679	205.260	316.870	537.039	1137.312
−15	11.644	31.275	53.650	73.119	153.642	236.337	399.167	839.314
−10	9.133	24.339	42.506	55.301	116.016	177.842	299.469	625.338
−5	7.198	19.154	33.892	42.257	88.125	134.630	226.186	469.127
0	5.716	15.148	27.219	32.582	67.522	102.816	172.393	355.224
5	4.571	11.964	22.021	25.324	52.168	79.183	132.857	272.045
10	3.682	9.520	17.926	19.847	40.617	61.460	103.089	209.803
15	2.987	7.624	14.674	15.679	31.847	48.045	80.430	162.713
20	2.437	6.160	12.081	12.478	25.151	37.834	63.201	127.117
25	2.000	5.000	10.000	10.000	20.000	30.000	50.000	100.000
30	1.651	4.082	8.315	8.068	16.014	23.955	39.825	79.215
35	1.371	3.354	6.948	6.552	12.902	19.249	31.918	63.150
40	1.143	2.773	5.834	5.353	10.457	15.560	25.733	50.649
45	0.958	2.299	4.917	4.399	8.527	12.657	20.877	40.885
50	0.807	1.914	4.161	3.635	6.993	10.354	17.034	33.195
55	0.683	1.607	3.535	3.020	5.771	8.525	13.929	27.014
60	0.582	1.356	3.014	2.521	4.789	7.058	11.439	22.079
65	0.497	1.149	2.586	2.115	3.992	5.869	9.485	18.226
70	0.426	0.978	2.228	1.783	3.343	4.905	7.906	15.124
75	0.367	0.834	1.925	1.510	2.809	4.113	6.614	2.598
80	0.318	0.714	1.669	1.284	2.371	3.463	5.558	10.542
85	0.276	0.612	1.452	1.096	2.020	2.945	4.686	8.852
90	0.240	0.527	1.268	0.939	1.729	2.516	3.967	7.463
95	0.210	0.456	1.110	0.808	1.476	2.143	3.373	6.321
100	0.183	0.396	0.974	0.698	1.264	1.832	2.878	5.374
105	0.161	0.345	0.858	0.605	1.085	1.571	2.465	4.585
110	0.142	0.302	0.758	0.527	0.935	1.350	2.118	3.925
115	0.125	0.264	0.671	0.460	0.812	1.171	1.828	3.376
120	0.111	0.232	0.596	0.403	0.708	1.019	1.583	2.913
125	0.099	0.205	0.531	0.354	0.617	0.886	1.374	2.520

Figure 7: Temperature vs. Resistance Characteristics of the NTSD1XH103FPB40 Thermistor

After voltage levels were chosen for the Schmitt trigger, the resistor values were calculated. The calculations for the resistors came from the EE 409 book, *Design with Operational Amplifiers and Analog Integrated Circuits* by Sergio Franco using the following equations:

$$\frac{1}{R_2} = \frac{V_{TL}}{V_{CC}-V_{TL}}\left(\frac{1}{R_1}+\frac{1}{R_3}\right)$$
$$\frac{1}{R_1} = \frac{V_{CC}-V_{TH}}{V_{TH}}\left(\frac{1}{R_2}+\frac{1}{R_3}\right)$$

with V_{CC} = 5V, V_{TL} = 2.5V, V_{TH} = 3.1V. Therefore, $R_1 = R_7$ = 19.6K Ω, $R_2 = R_6$ = 17.4K Ω, $R_3 = R_8$ = 49.9K Ω, and R_5 = 510 Ω, since R_8 needs to be much greater than R_5.

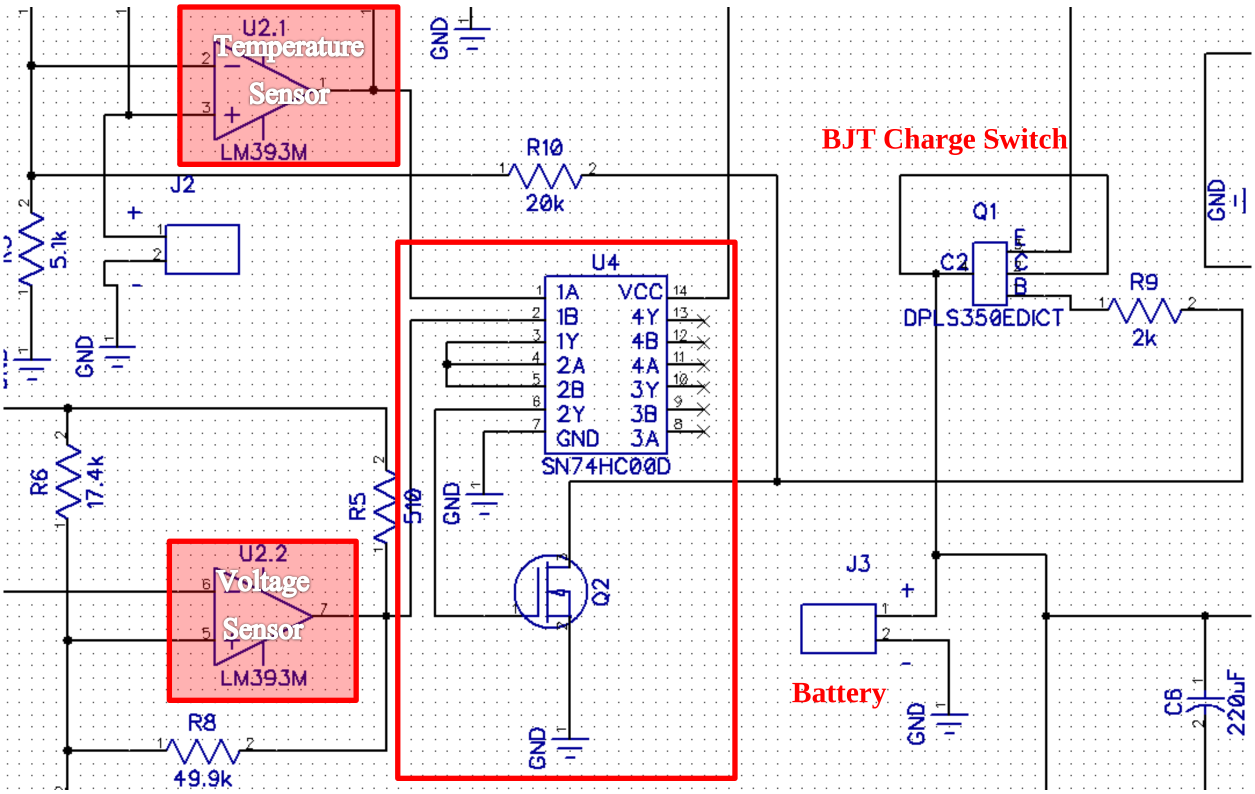

Figure 7: Overvoltage Protection Circuit

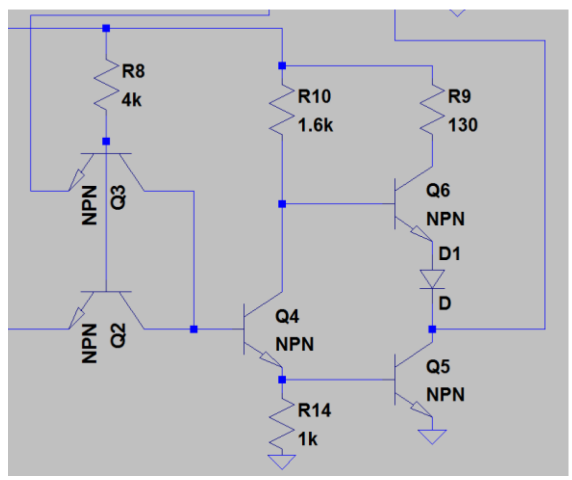

Figure 8: NAND Gate

The transistors, Q2 through Q6 in figure 8, form a TTL NAND gate used from the topology learned from the EE 307 book, *Introduction to Digital Microelectronic Circuits*, by K Gopal Gopalan. The NAND gate in figure 8 is used with LTspice for circuit simulation. During prototyping, the integrated circuit, SN74HC00N took the place of discrete BJTs as shown in figure 7. The NAND gate checks the state of both the voltage sensor and temperature sensor. When both the temperature and voltage are at acceptable levels, the sensors output a high logic level. During this state, the output of the NAND gate drops low to approximately 0V, and all of the base current from Q1 flows through the NAND gate Q5. This produces the following base current:

$$I_B = \frac{5V - .7V}{2K\Omega} = 2.15mA$$

The gain, h_{FE}, of the BJT, ZTX955, based on the datasheet is approximately 200. This provides a charge current that is approximately 450mA. When either of the sensors is at an unacceptable level, the sensor with bad input raises a flag that is represented by a low logic level on its output. This causes the output of the NAND gate to rise to a high level and all of the base current flows through R3, R9, and R10. This produces the following base current:

$$I_B = \frac{5V - .7V}{2K\Omega + 5K\Omega + 20K\Omega} = 160\mu A$$

This base current creates a charge current of approximately 30mA. The full charge of the C batteries used is 2.5Ah. This creates a trickle charge of C/80.

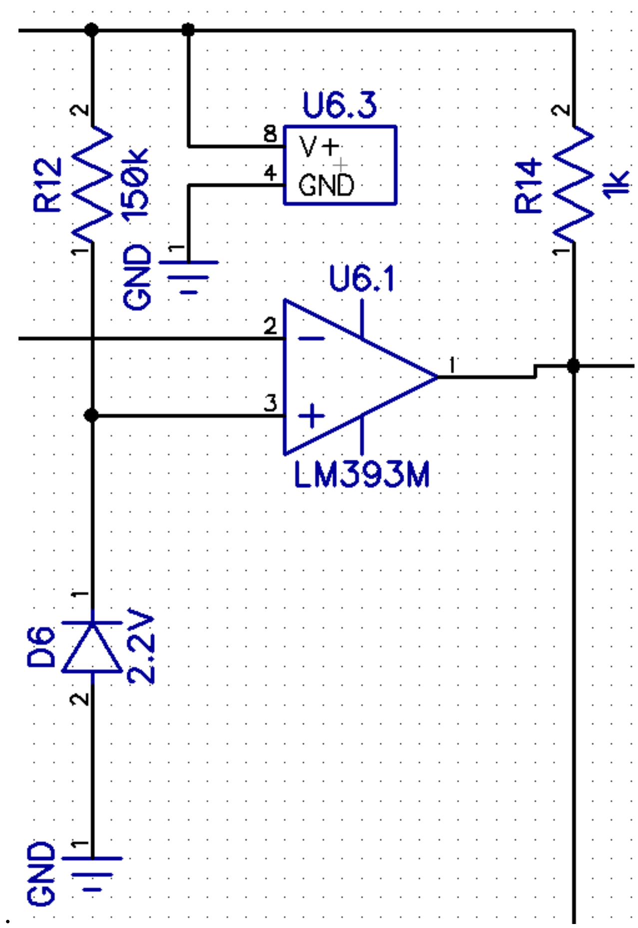

Figure 9: Under Voltage Protection

The last comparator, U6.1, shown in figure 9 on the previous page, checks the voltage of the battery to determine if the battery has enough charge left to charge an electronic load. Whenever the battery drops below the 2.2V, which is maintained by the 2.2V zener diode, it will send a flag to U7 and U9. On the schematic in figure 2, it shows U6.1 is powered by the 12V regulated output of U8.

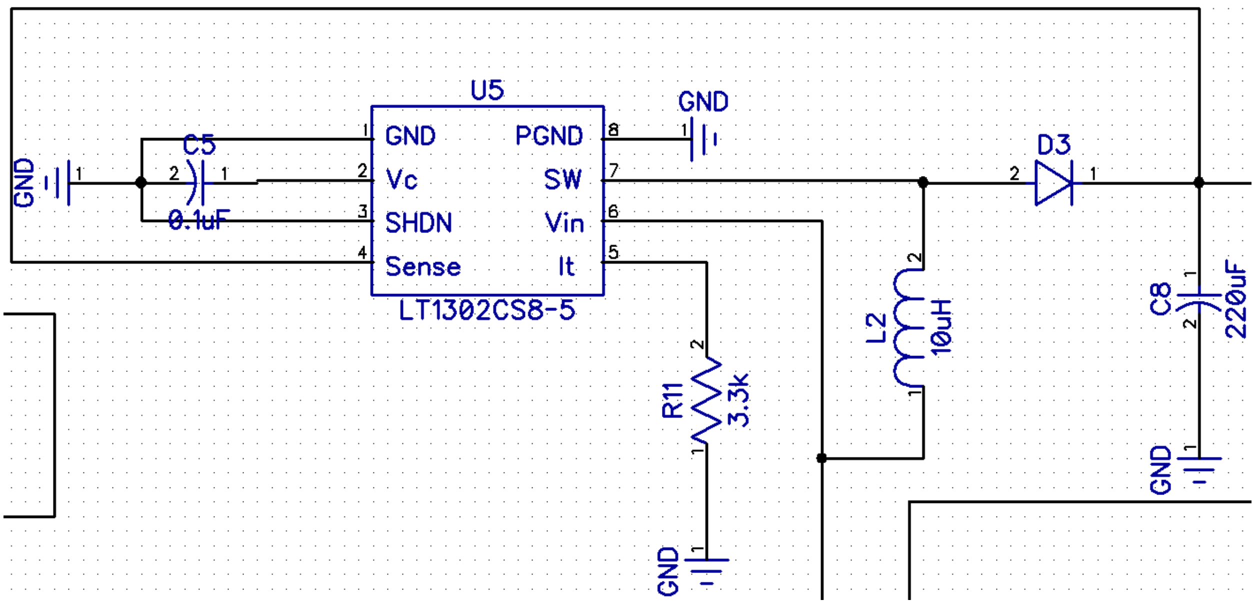

Figure 10: 2.5V to 5V Boost Converter

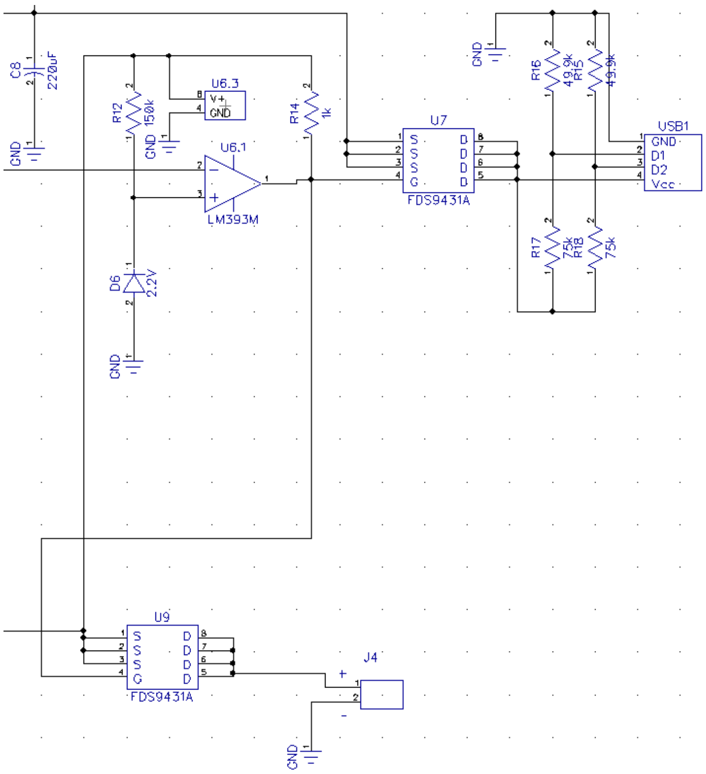

Figure 11: MOSFET Switches Controlled by U6.1

When the voltage of the battery is greater than 2.2V, the output of U6.1 in figure 11 drops to a low voltage to turn on the PMOS switch, U7, to allow a device to be charged though USB, shown if figure 11. A similar circuit controlled by U6.1 will control when the cigarette lighter will be able to charge. As before, when the voltage of the battery is greater than 2.2V, the output of U6.1 will drop to a low voltage allowing the PMOS, U9, to turn on and allow current to flow to the cigarette lighter. Since cigarette lighters use a constant 12V DC supply to charge devices, Maxim's MAX642 boost converter

converts the 2.5V from the battery to a regulated 12V supply. The switching regulator that does this is shown below in figure 12.

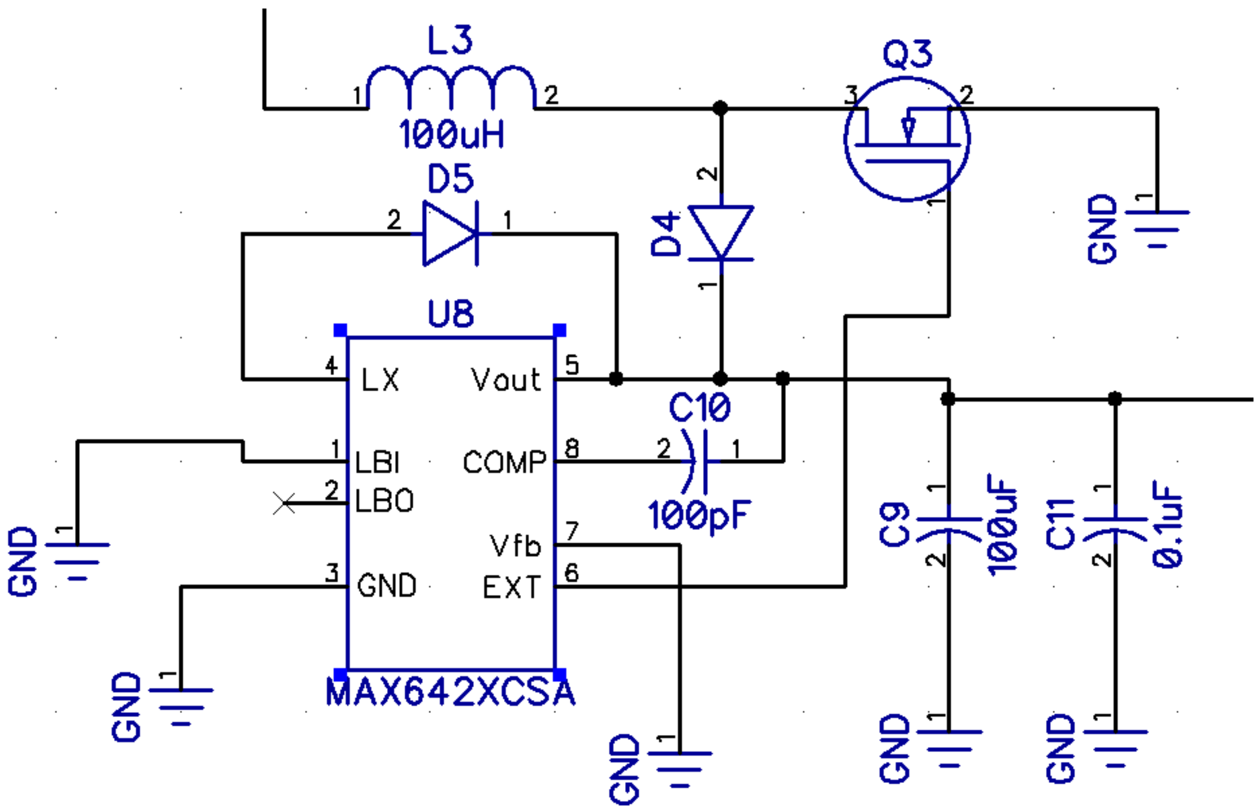

Figure 12: 2.5V to 12V Boost Converter

Construction

Construction for the prototype of the portable solar powered charger was made on a prototyping board. The first portion of the project built was the temperature sensor and the voltage sensor using two comparators. The next addition included adding on the TTL NAND gate and the transistor that controls current flow to the battery. Once the charge management circuit for the NiMH batteries was completed, a buck converter to convert the input source of the solar panel to 5V was constructed. After this was successfully completed, the first phase of the circuit was completed which charges two C batteries. Afterwards, the boost converters to convert from 2.5V to 5V and 12V were added to be used for the USB and cigarette lighter attachments. Then the comparator, U6.1, was added to control when the USB and cigarette lighter can charge an external load. Dual inline packaging was chosen for all the ICs for ease of use except for the LT1376 chip where a small outline package was the only package available to order.

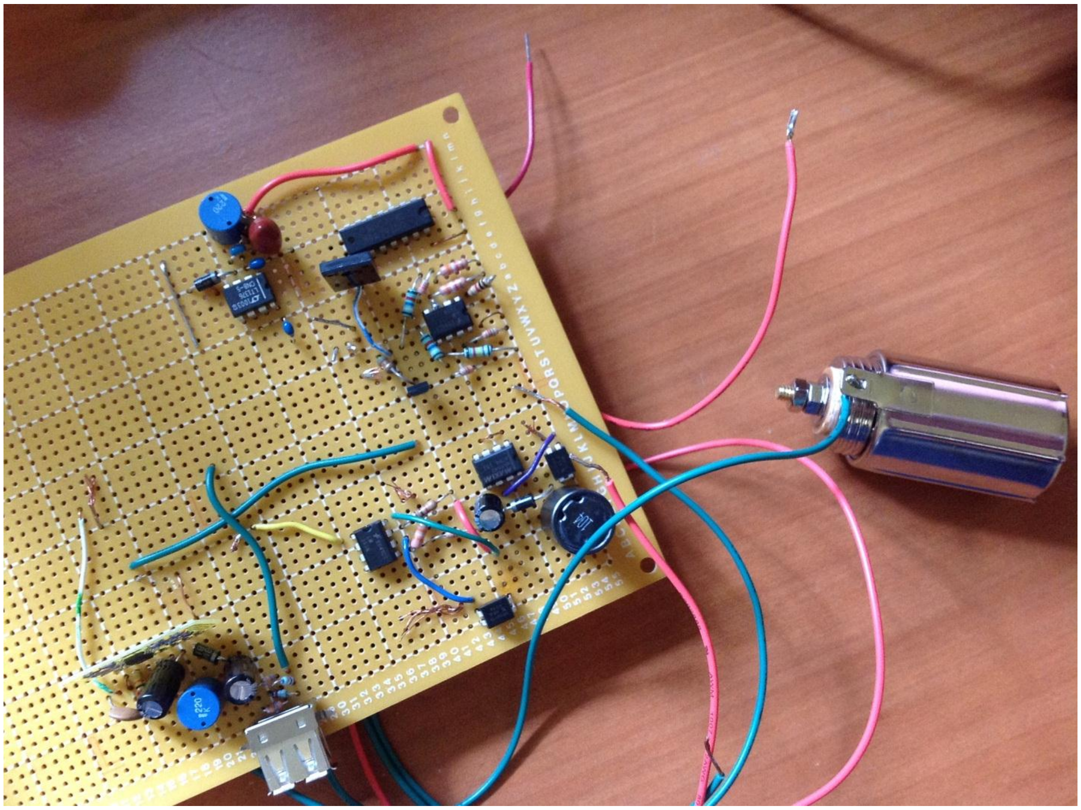

Figure 13: Prototype of Circuit

Design and construction for the final circuit took place in IME 458, Microelectronics Packaging. Diptrace software was used to draw the schematic and layout the components of the circuit board. Figure 14 shows the layout used for the charging circuit. Afterwards, the gerber file was sent off by Professor Pan to a professional PCB fabricator, and they built and manufactured the board.

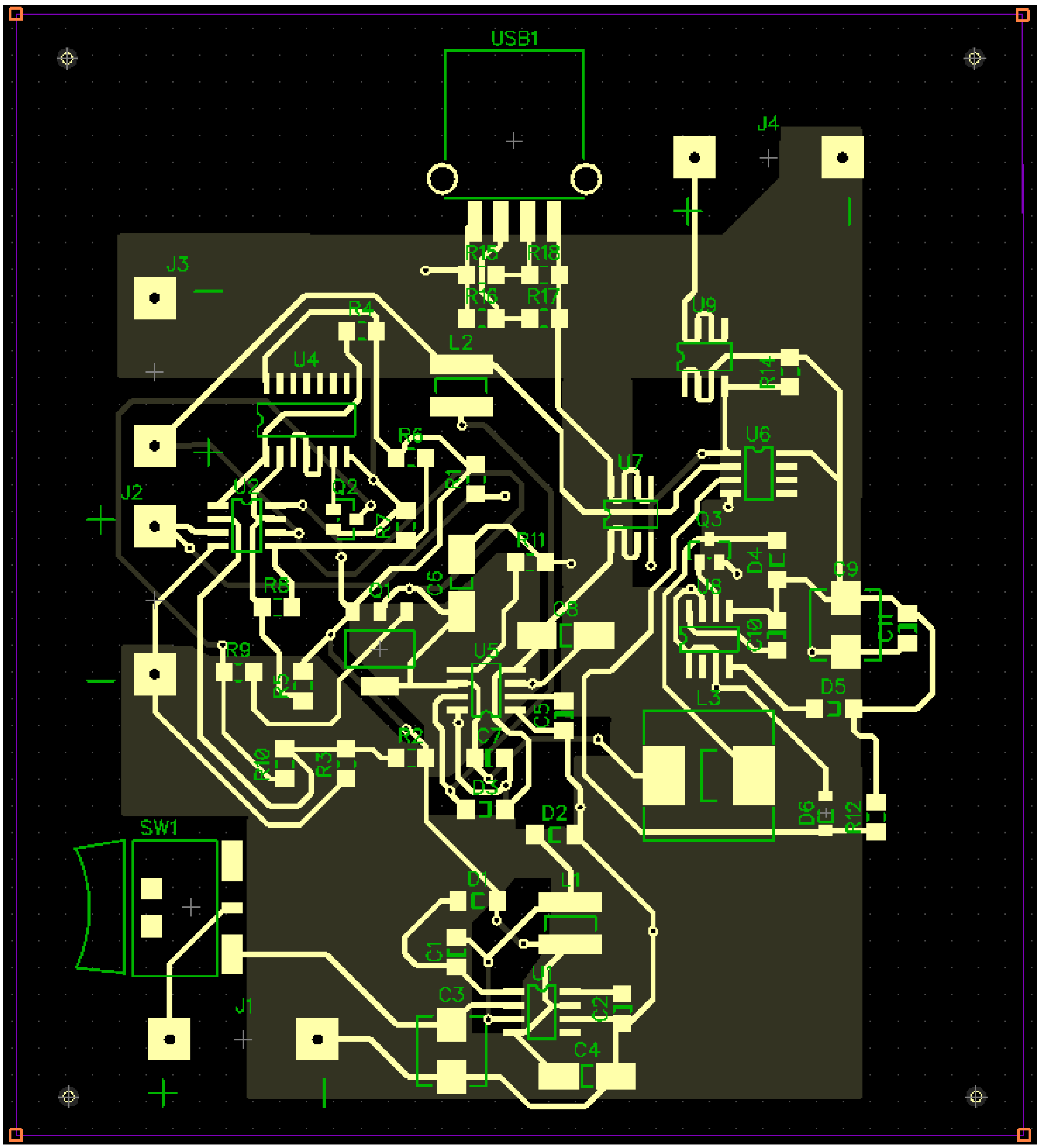

Figure 14: PCB Design

Once the circuit board arrived from the manufacturer, the board was inspected for breaks in the copper traces and short circuit connections between two adjacent traces. The same gerber file was also sent to Pololu Robotics and Electronics to order a stencil. The stencil was used to add solder paste only to the surface mount pads. The stencil was cut to the width and length of the PCB and taped to prevent the stencil from moving. A glob of lead-free solder was set onto the stencil and a squeegee used to spread the paste to the holes on the stencil. Afterwards, surface mount components ordered from Digikey were placed by hand and were held down by the surface tension brought by the solder paste. The PCB was then placed through a reflow oven in order to melt the solder to make a solid connection between the components and the board itself. The assembled printed circuit board is shown below.

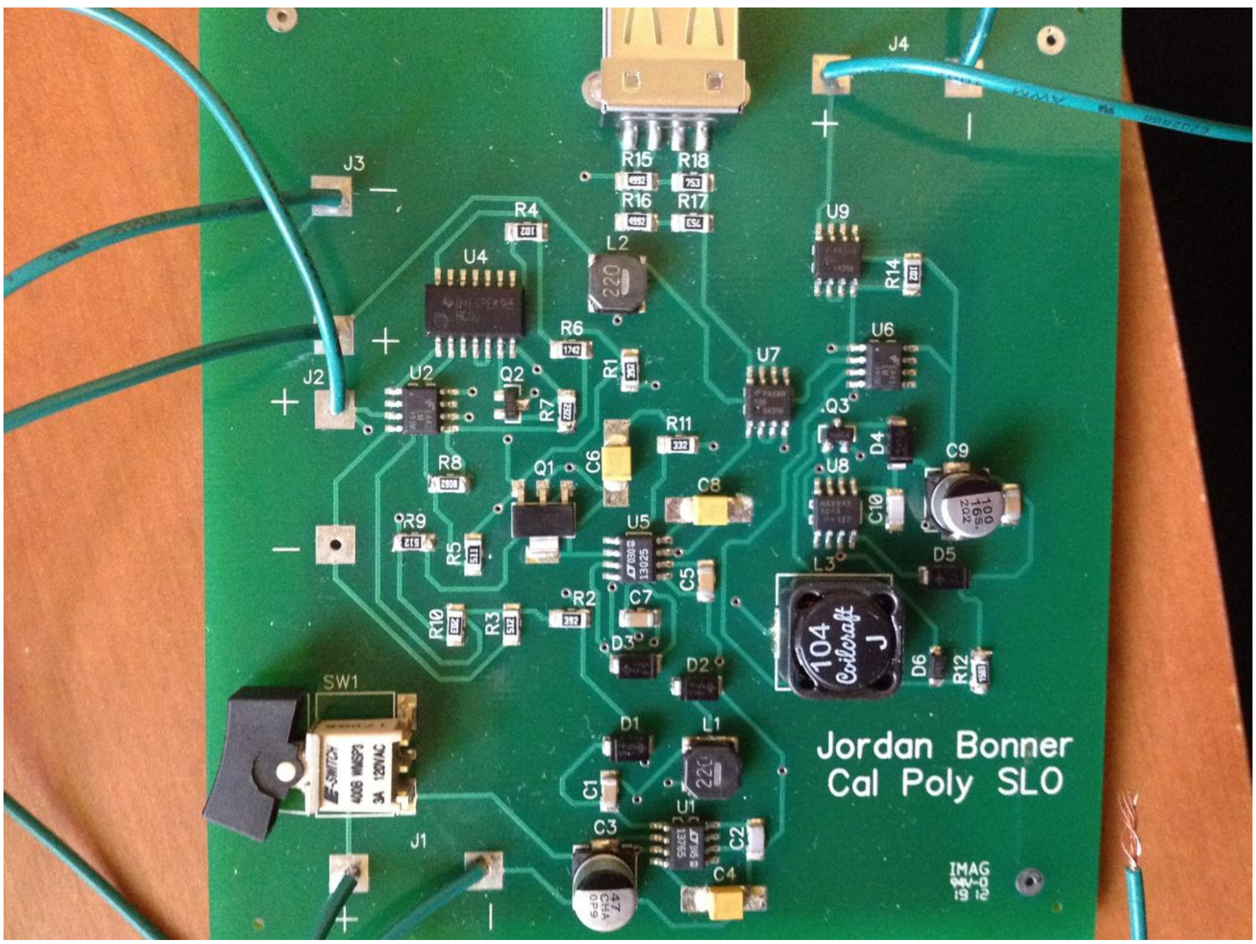

Figure 15: Assembled Printed Circuit Board

The project enclosure for the printed circuit board was purchased from Jameco. The board was mounted inside the enclosure and holes were drilled into the side of the boxed enclosure to allow for the external connections of the solar panel, USB, and cigarette lighter shown in the next figure. Lastly, hook-and-loop fasteners were added to the bottom of the enclosure and to the folded up solar panel.

Figure 16: Finished Assembly of the Charger

Testing

Prototype

Testing the project involved breaking down the circuit into sections. Testing followed the same order as construction was completed. The first section of testing involved checking to see if the temperature sensor performed as expected. Testing the temperature sensor could not be performed in a temperature controlled environment. However, a potentiometer replaced the thermistor in order to confirm the output of the sensor changed states when the resistance passed the 5KΩ threshold, and this in fact checked out with no troubles.

The next task involved testing the performance of the offset inverting Schmitt trigger. Again the Schmitt trigger checks the voltage of the battery and will only let the battery charge if it is below a certain point. Testing the Schmitt trigger found the following threshold voltages in table 1.

Table 1: Schmitt Trigger Thresholds

	Design Voltage(V)	Voltage(V)
V_{TL}	2.1	2.6
V_{TH}	3.4	3.03

This data conveys the battery will always charge when the voltage is below 2.6V, and will continue to charge until the voltage is 3.03V. This causes the output of the Schmitt trigger to change states which in turn, shuts off the BJT, Q5 of figure 8, to prevent any base current to flow through the transistor. The Schmitt trigger will remain in the no-charge state until the voltage drops below 2.6V, which turns back to the charge state.

Following completion of the two sensors, the next step involves testing the two sensors together by adding the TTL NAND gate. The NAND gate checks that both the temperature

sensor and the voltage sensor are both in the charge state. While testing, it was confirmed that the NAND gate reads the states correctly and outputted the correct voltage. When both the sensors are in the charge state, the output of the NAND gate drops to a voltage close to 0V, which allows all of the base current from the Q1 to drain through the transistor. This creates a charge current close to 500mA. Once either of the sensor sends a flag to the NAND gate, the NAND gate shuts off Q5 of figure 8 and all of the base current should be directed through the R3, R9, and R10 resistor branch, which then creates a charge current approximately equal to C/80.

This last section ends the front end of the project. The back end involves manipulating the voltage to charge a phone using USB or cigarette lighter. This section involves testing the 5V boost converter, LT1302, and 12V boost converter, MAX642. To test the switching converters, the line regulation and load regulation needs to be measured. Full load for the both converters is 500mA, and the nominal input voltage for both is 2.4V. The equation for line regulation is:

$$LineRegulation = \frac{V_{O(high-input)} - V_{O(low-input)}}{V_{O(nominal)}}$$

The equation for load regulation is:

$$Load\ Regulation = \frac{V_{O(low-load)} - V_{O(high-load)}}{V_{O(high-load)}}$$

Table 2: Switching Converter Regulation

	Line Regulation	Load Regulation
LT1302	0%	4.4%
MAX642	0%	46.6%
LT1376	1.2%	.8%

The last part to test is to confirm that U6.1 only allows the NiMH battery to charge a phone at an acceptable voltage. The voltage at which charging occurs is when the voltage is greater than 2.2V.

Printed Circuit Board

Testing the printed circuit board followed most of the same procedures as testing the prototyped board. The major difference on testing the PCB is the inability to disconnect and isolate sections of the circuit from each other. The temperature sensor of the project performed as expected; however, the voltage sensor needed to be calibrated. The lower threshold voltage on the sensor was found to be below 2.4V, preventing the batteries from charging when it is not fully discharged. Using LTspice, R7 was changed from 19.6KΩ to 23.2kΩ and R8 was changed from 49.9kΩ to 80.6kΩ, creating the following threshold voltages for the sensor:

Table 3: PCB Threshold Voltage for Schmitt Trigger

	Design Voltage(V)	Prototype Voltage(V)	PCB Voltage(V)
V_{TL}	2.1	2.6	2.53
V_{TH}	3.4	3.03	3.1

The switching regulators were tested after the sensors were confirmed to be working. Both the LT1302 buck converter and the LT1376 boost converter were found to output a correct 5V output. The output voltage while testing the MAX642 boost converter was found to output a voltage of 6.4V at full load. This voltage is approximately the same found in the prototype board, meaning the problem was unsuccessfully fixed when designing the chip for the PCB. Table 4 shows the load regulation for the final circuit.

Table 4: Line and Load Regulation for Switching Regulators on the PCB

	Line Regulation	Load Regulation
LT1302	0%	3.4%
MAX642	0%	46.6%
LT1376	1.2%	.8%

For testing purposes, R9 was temporarily changed from 2kΩ to 5.1kΩ to examine the characteristics of the charging BJT, Q1. With R9 at 5.1kΩ, the full charge current sent to the battery is 300mA. To find the DC gain of Q1, the following equations were used:

$$I_{Base} = \frac{5V - 0.7V}{5.1k\Omega} = .84mA$$

$$\beta = \frac{300mA}{.84mA} \approx 350\frac{V}{V}$$

The rest of the final circuit used the same testing procedure as the prototyped board, and the other portions of the circuit performed in the same way as the prototype.

Figure 17: Testing the Completed Circuit

Solar Cell Characteristics

The data collected below in table 5 determined the voltage and current characteristics of the solar panel purchased for the project. The open circuit voltage was first measured by not shading the solar panel, then shading 1/8, 1/4, 3/8, and so on until the entire panel was entirely shaded. The same procedure was used to determine the current when the panel is shorted through a multimeter. After finding both the voltages and the currents, the values were multiplied together to determine the power the panel is able to deliver. When testing the solar panel, solar radiation when testing the panel was at 900W/m^2 according to sloweather.com.

Table 5: Voltage and Current Characteristics of the Solar Panel

Percent Shaded	Voltage(V)	Current(mA)	Power(W)
0%	14.91	420	6.262
12.50%	14.91	310	4.622
25%	14.91	57	0.850
37.50%	14.91	33	0.492
50%	14.91	25	0.373
62.50%	13.65	22	0.300
75%	14.2	18	0.256
87.50%	12.6	14	0.176
100%	9.6	9	0.086

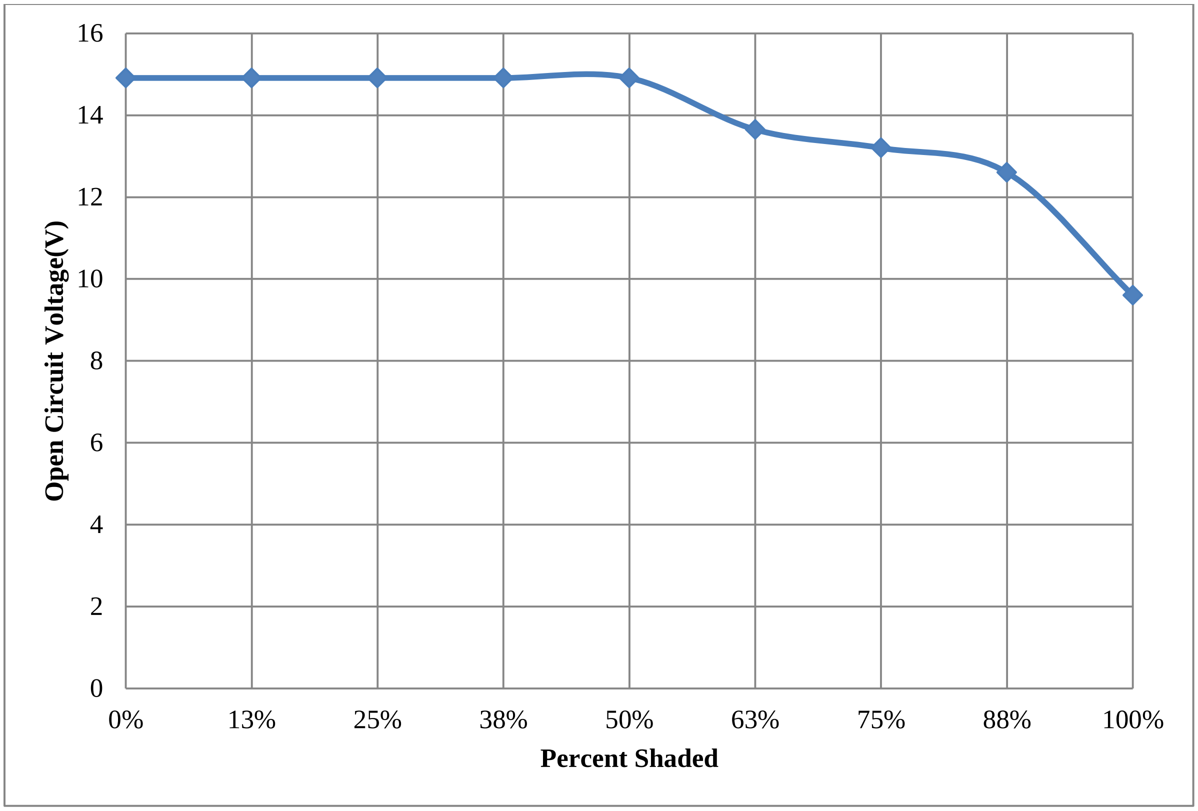

Figure 18: Open circuit voltage of the Solar Cell when shaded

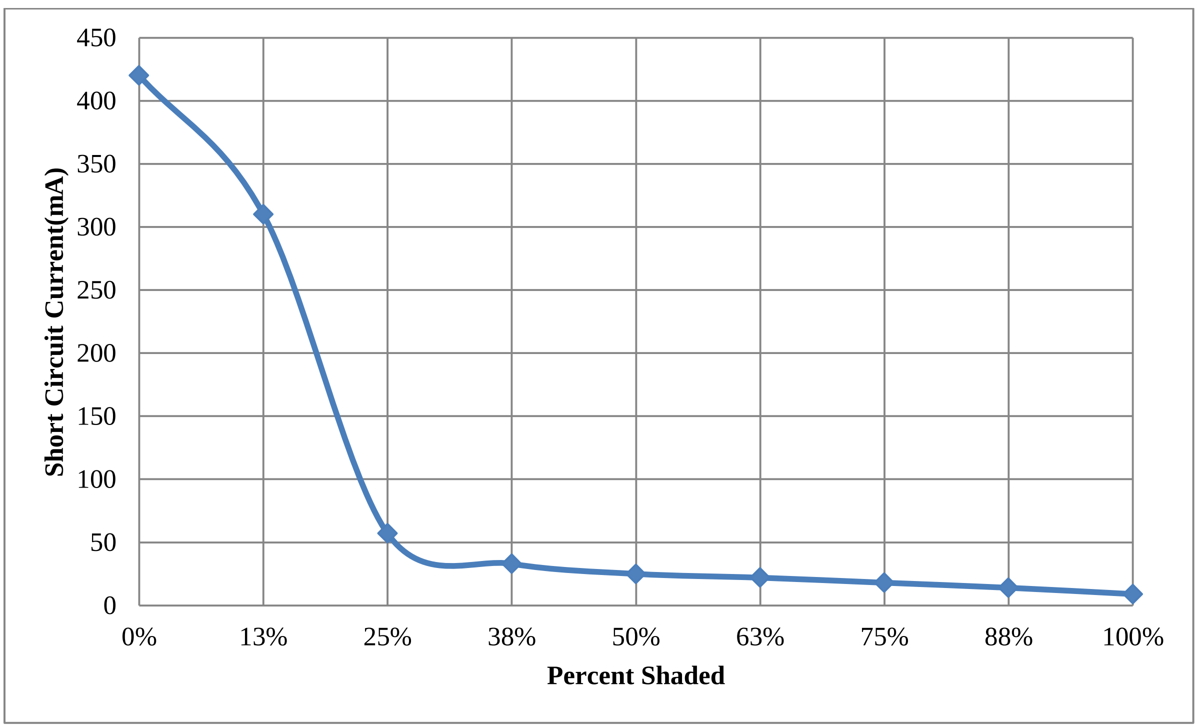

Figure 19: Short circuit current of the solar cell when shaded

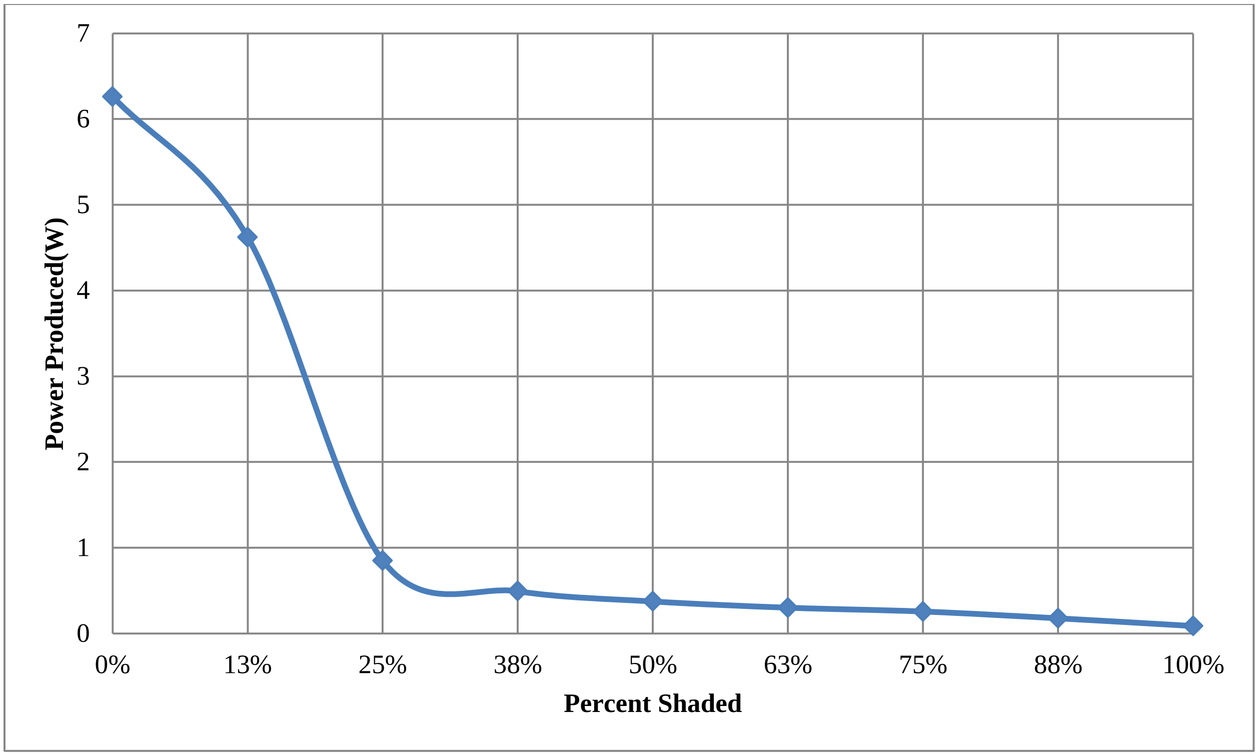

Figure 20: Power produced from the solar cell when shaded

Conclusion and Recommendations

After looking back, reviewing the requirements and comparing the finished product to the requirements, the project was able to fulfill all of the requirements. One area that barely passed was having the cigarette lighter attachment meeting the specification to charge electronics. The output of the lighter needs to regulate the output voltage needed for charging to be at 12V. However, the MAX642 did not have the correct inductor placed or the integrated circuit had poor load regulation, causing the output of cigarette lighter to be between 6-7V when charging. To overcome this challenge, different topologies or different boost converters need to be explored to find the regulator for this application; preferably, an ideal converter would have a MOSFET switch integrated into the chip instead of requiring an external MOSFET for the switch.

Another design consideration that needs to be looked is choosing a portable solar panel that fits this charger better. The solar panel chosen for this project was Sunforce 22005 12-Volt MotoMaster Eliminator Folding Solar Panel. The panel supplied more power than what this project required. To charge a cell phone at 5V and 500mA, only 2.5W is needed. A solar panel that supplies 3W should be adequate, and the Sunforce supplied approximately 6-7 watts in full sunlight. Therefore, a 3W panel would not only work, but would be lighter, have more portability, and cost cheaper for anyone needing a solar panel to charge their equipment.

The last thing this project needs to be a well-rounded product is a good casing to mount the circuit board, cigarette lighter, and battery to protect the project from damage from outdoor activity and to make it less troublesome to haul around. It would also include indicator LED to display ON/OFF status and charge status.

Bibliography

"Batteries." *Which Online*. 5 July 2004. Web. Jan. 2012. <http://homepages.which.net/~paul.hills/Batteries/BatteriesBody.html>.

"Current Weather Conditions." *SLOweather.com*. Web. 8 Apr. 2012. <http://wx.sloweather.com/>.

Franco, Sergio. *Design with Operational Amplifiers and Analog Integrated Circuits*. 3rd ed. McGraw-Hill, 2001.

Fried, Limor. "Minty Boost." *Lady Ada*. 17 May 2011. Web. Jan. 2012. <http://www.ladyada.net/make/mintyboost/icharge.html>.

Gopalan, K. *Introduction To Digital Microelectronic Circuits*. Richard D. Irwin, 1996.

Hayles, Peter. "Intelligent NiCd/NiMH Battery Charger." *Electronics & Computing Home Page*. 7 Dec. 2011. Web. 23 Apr. 2012. <http://www.angelfire.com/electronic/hayles/>.

Kidder, Chad. "The Dirty Truth About USB Device Charging." *Things Learned Along the Way*. Curious System Solutions, 18 Aug. 2010. Web. Feb. 2012. <http://blog.curioussystem.com/2010/08/the-dirty-truth-about-usb-device-charging/>.

"Nickel Metal Hydride (NiMH)." *Energizer*. Web. Jan. 2012. <http://data.energizer.com/PDFs/nickelmetalhydride_appman.pdf>.

Sabharwal, Sagar, and Tom Poonsopin. "Solar Powered Backpack." *Digital Commons @ Cal Poly*. California Polytechnic State University, San Luis Obispo, June 2011. Web. Feb. 2012. <http://digitalcommons.calpoly.edu/eesp/95/>.

Shannon, Trevor J. "Solar Charger Build." *Trevor's Home Page*. Web. Jan. 2012. <http://www.trevorshp.com/creations/solarcharger.htm>.

Sherman, Len. "Charging Batteries Using USB Power." *Maxim*. 24 June 2004. Web. Winter 2012. <http://www.maxim-ic.com/app-notes/index.mvp/id/3241>.

Vorkoetter, Stefan. "Build a USB Powered AA NiMH and NiCd Battery Charger."*Stefanv.com*. Web. Jan. 2012. <http://www.stefanv.com/electronics/usb_charger.html>.

Appendices

Parts List, Cost, and Time Schedule Allocation

Table 6: Bill of Materials

Item	Quantity	Reference	Description	Part #	Package	Cost($)
1	5	R1, R2	Resistor	3.9K Ω, 1/4W, ±5%	1206	0.50
2	10	R3	Resistor	5.1K Ω, 1/4W, ±5%	1206	1.00
3	10	R4, R14	Resistor	1K Ω, 1/4W, ±5%	1206	1.00
4	10	R5	Resistor	510 Ω, 1/4W, ±5%	1206	1.00
5	5	R6	Resistor	17.4K Ω, 1/4W, ±1%	1206	0.50
6	5	R7	Resistor	19.6K Ω, 1/4W, ±1%	1206	0.50
7	10	R8, R15, R16	Resistor	49.9K Ω, 1/4W, ±1%	1206	1.00
8	10	R9	Resistor	2K Ω, 1/4W, ±5%	1206	1.00
9	5	R10	Resistor	20KΩ, 1/4W, ±5%	1206	0.50
10	5	R11	Resistor	3.3KΩ, 1/4W, ±5%	1206	0.50
11	5	R12	Resistor	51KΩ, 1/4W, ±5%	1206	0.50
12	5	R13	Resistor	39KΩ, 1/4W, ±5%	1206	0.50
13	5	R17, R18	Resistor	75KΩ, 1/4W, ±5%	1206	0.50
14	3	C2	Capacitor	3.3nF, 250V, Ceramic	1206	0.84
15	2	C3	Capacitor	47uF, 16V, Aluminum	Radial	1.04
16	2	C4	Capacitor	100uF, 6.3V, Tantalum	1411	1.82
17	2	C6, C8	Capacitor	220uF, 6.3V, Tantalum	1411	3.60
18	2	C9	Capacitor	100uF, 16V, Aluminum	Radial	1.10
19	4	C10	Capacitor	100pF, 630V, Ceramic	1206	.96
20	10	C1, C5, C7, C11	Capacitor	0.1uF, 50V, Ceramic	1206	1.01
21	6	D1, D2, D3, D4, D5	Diode	SS14-E3/61T	DO-214AC	2.94

22	5	L1, L2	Inductor	NR6028T220M	6.00mm x 6.00mm x 2.80mm	1.70
23	2	L3	Inductor	NR6028T100M	6.00mm x 6.00mm x 2.80mm	0.68
24	2	Q1	PNP BJT	DPLS350EDICT	TO-261-4	1.08
25	4	Q2	N-type MOSFET	2N7002K-T1-E3	TO-236-3, SC-59, SOT-23-3	1.52
26	2	Q3	N-type MOSFET	SI2304BDS-T1-E3	TO-236-3, SC-59, SOT-23-3	1.16
27	1	U1	5V Buck Converter	LT1376CS8-5	8-SOP	6.78
28	5	U2, U6	Comparator	LM393M	8-SOP	2.00
29	3	U4	TTL NAND Gate	SN74HC00NSR	14-SOP	1.29
30	1	U5	5V Boost Converter	LT1302CS8-5	8-SOP	6.41
31	4	U7, U9	P-type MOSFET	FDS9431A	8-SOP	2.60
32	1	U8	12V Boost Converter	MAX642XCSA	8-SOP	6.99
33	2	USB1	USB Receptacle	896-43-004-00-000000	Irregular	3.34
34	1	N/A	Project Enclosure	H2852-R		7.50
35	1	N/A	Cigarette Socket	ZA2060		3.23
36	1	N/A	Solar Panel	B000C1Z2LY		95.00

Portable Solar Panel Charging Station

Cal Poly San Luis Obispo

Today's Date: 6/2/2012 Saturday
(vertical red line)

Project Lead: Jordan Bonner
Start Date: 10/3/2011 Monday

First Day of Week (Mon=2): 2

WBS	Tasks	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	**Preperation**	10/03/11	1/02/12	92	100%	66	92	0
1.1	Proposal	10/03/11	11/06/11	35	100%	25	35	0
1.2	Planning	11/07/11	11/13/11	7	100%	5	7	0
1.3	Research	11/14/11	1/02/12	50	100%	36	50	0
2	**Design**	1/03/12	4/15/12	104	100%	74	104	0
2.1	Schematic	1/03/12	1/23/12	21	100%	15	21	0
2.2	Simulate Circuit	1/19/12	1/23/12	5	100%	3	5	0
2.3	PCB Layout	4/02/12	4/15/12	14	100%	10	14	0
3	**Construction**	1/24/12	5/18/12	116	100%	84	116	0
3.1	Order Parts	1/24/12	1/30/12	7	100%	5	7	0
3.2	Prototype	1/30/12	2/05/12	7	100%	5	7	0
3.3	Order PCB and Parts	4/26/12	5/09/12	14	100%	10	14	0
3.4	Solder PCB	5/11/12	5/18/12	8	100%	6	8	0
4	**Testing**	2/06/12	5/23/12	108	100%	78	108	0
4.1	Test and Debug Prototype	2/06/12	2/25/12	20	100%	15	20	0
4.2	Test and Debug PCB	5/14/12	5/23/12	10	100%	8	10	0
5	**Report**	2/06/12	6/01/12	117	100%	85	117	0
5.1	Write Report	2/06/12	5/30/12	115	100%		115	0
5.2	Edit and Submit Report	5/15/12	6/01/12	18	100%		18	0

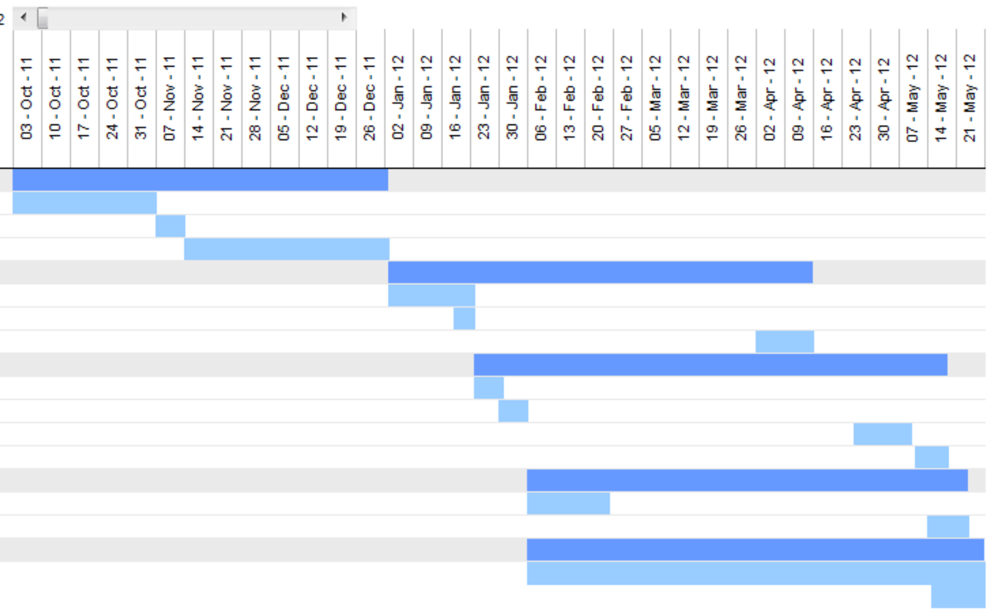

Figure 21: Time Schedule Allocation

Analysis of Senior Project Design

Project Title: Portable Solar Powered Charging Station
Student's Name: Jordan Bonner
Advisor's Name: Samuel Agbo

Summary of Functional Requirements

- Charging station must be reasonably portable when folded to allow travelers, hikers, etc. the ability to keep electronics fully charged on-the-go.
- Charges two C batteries when left in sunlight.
- Protects the battery from overcharging. When NiMH batteries are fully charged most of energy being transferred to the battery turns into heat, and will reduce the lifetime of the battery. A circuit will then be needed to detect temperature, voltage, or both in order to protect the battery.
- Protects the battery from over discharging. If the batteries are left to over-discharge, then the battery will eventually reverse its polarity causing irreversible damage. Therefore, a circuit will be needed to detect the voltage of the battery and disconnect itself before this damage happens.
- Follows USB specifications to charge devices.
- Follows cigarette lighter specifications to charge devices.
- Circuit must be able to charge both batteries and electronics devices concurrently in sunlight, and must be able to charge these same devices at night with onboard batteries.

Primary Constraints

The first constraint encountered was choosing a pre-existing solar panel on the market today. There are only so many panels to choose from and the panel needed to fit portability, cost, and power requirements. The solar panel that was chosen ending up having a power rating that was more than what was needed and the price was on the steep side costing from between $90-100.

But in the end, the solar panel folded into a compact size for the needed portability. One other constraint encountered was finding a project enclosure that fits the circuit and battery and an enclosure that was not any bigger than needed. The enclosure chosen for the charger fit the circuit well in the width and length dimensions, but the box was about ½" to ¾" too tall which decreases the portability of the project.

Economic

Examining the economic impacts of my project on the manufacturing side, the assembly of the circuit will be the simplest and will have an automatic process. The printed circuit board will be manufactured by a professional company and sent back to be assembled. Since the circuit is mostly surface mounted components, a pick and place machine and reflow oven will be used to automate the process of placing components on the PCB. As is, the only manual process and the process that will take the most human capital will be the wiring the external components and machining the holes in the project enclosure. If this project were to be mass produced, a custom plastic mold will be used to reduce the human capital to wiring and placing the external components. The price of the project if produced in mass quantities would drastically reduce; the only component keeping the price of the product up is the cost of the solar panel. If this project was marketed, the best way to sell the device would be to sell the project with only the charging portion and leave the customer to choose a solar panel of their liking. The cost to manufacture one charging station is located in the table below.

Table 7: Bill of Materials for Analysis

Item	Quantity	Reference	Description	Part #	Package	Cost($)
1	5	R1, R2	Resistor	3.9K Ω, 1/4W, ±5%	1206	0.50
2	10	R3	Resistor	5.1K Ω, 1/4W, ±5%	1206	1.00
3	10	R4, R14	Resistor	1K Ω, 1/4W, ±5%	1206	1.00

4	10	R5	Resistor	510 Ω, 1/4W, ±5%	1206	1.00
5	5	R6	Resistor	17.4K Ω, 1/4W, ±1%	1206	0.50
6	5	R7	Resistor	19.6K Ω, 1/4W, ±1%	1206	0.50
7	10	R8, R15, R16	Resistor	49.9K Ω, 1/4W, ±1%	1206	1.00
8	10	R9	Resistor	2K Ω, 1/4W, ±5%	1206	1.00
9	5	R10	Resistor	20KΩ, 1/4W, ±5%	1206	0.50
10	5	R11	Resistor	3.3KΩ, 1/4W, ±5%	1206	0.50
11	5	R12	Resistor	51KΩ, 1/4W, ±5%	1206	0.50
12	5	R13	Resistor	39KΩ, 1/4W, ±5%	1206	0.50
13	5	R17, R18	Resistor	75KΩ, 1/4W, ±5%	1206	0.50
14	3	C2	Capacitor	3.3nF, 250V, Ceramic	1206	0.84
15	2	C3	Capacitor	47uF, 16V, Aluminum	Radial	1.04
16	2	C4	Capacitor	100uF, 6.3V, Tantalum	1411	1.82
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19	4	C10	Capacitor	100pF, 630V, Ceramic	1206	.96
20	10	C1, C5, C7, C11	Capacitor	0.1uF, 50V, Ceramic	1206	1.01
21	6	D1, D2, D3, D4, D5	Diode	SS14-E3/61T	DO-214AC	2.94
22	5	L1, L2	Inductor	NR6028T220M	6.00mm x 6.00mm x 2.80mm	1.70
23	2	L3	Inductor	NR6028T100M	6.00mm x 6.00mm x 2.80mm	0.68
24	2	Q1	PNP BJT	DPLS350EDICT	TO-261-4	1.08
25	4	Q2	N-type MOSFET	2N7002K-T1-E3	TO-236-3, SC-59, SOT-23-3	1.52
26	2	Q3	N-type MOSFET	SI2304BDS-T1-E3	TO-236-3, SC-59, SOT-23-3	1.16

27	1	U1	5V Buck Converter	LT1376CS8-5	8-SOP	6.78
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30	1	U5	5V Boost Converter	LT1302CS8-5	8-SOP	6.41
31	4	U7, U9	P-type MOSFET	FDS9431A	8-SOP	2.60
32	1	U8	12V Boost Converter	MAX642XCSA	8-SOP	6.99
33	2	USB1	USB Receptacle	896-43-004-00-000000	Irregular	3.34
34	1	N/A	Project Enclosure	H2852-R		7.50
35	1	N/A	Cigarette Socket	ZA2060		3.23
36	1	N/A	Solar Panel	B000C1Z2LY		95.00
					Total	162.85

In the table above, multiple components were purchased for the resistors and capacitors, but due to the how inexpensive those components were the price does not affect the total price much. Thanks to Cisco Systems, the PCB did not have to be purchased, but if the price was included in the total, the total price to make the project is approximately $200. If the price of the solar panel is subtracted, then the project will cost approximately $100. Lastly, if it was mass produced, the project would definitely drop below $50 for each one produced.

If manufactured on a commercial basis and each product cost $100 to make, the sell price would be approximately $150. At this price, only outdoor enthusiasts would purchase this device and this would drastically cut down the number of customers who would purchase the device. A conservative estimate of 5,000 units could be sold each year, creating revenue of $750,000 and a profit of $250,000 not including the price of labor. However, if produced at this quantity, the price of each unit could be as low as $30/unit and could be sold at $50/unit. This could potentially open the market to 20,000 customers a year, creating revenue of $1 million and a profit of $400,000 not including the price of labor.

Environmental

Overall, this project has a net positive effect on the environment, as it promotes the use of clean and renewable energy. All solder joints used lead-free solder to reduce the toxicity of the circuit whenever it is disposed of. The least environmentally friendly component in charger is the NiMH batteries, but they are indeed less toxic than its counterpart, Ni-Cd batteries.

Manufacturability

Most of the circuit can be manufactured fairly easily. The components can be placed in an automatic process that involves adding solder paste, using a pick-and-place machine, and running the PCB through a reflow oven. A plastic mold can be easily manufactured if produced in high quantities. The only bottleneck in the manufacturing process will manually placing the PCB, batteries, wires, and cigarette lighter socket to the plastic mold.

Sustainability

The portable solar panel charger can easily sustain itself. Once purchased, the product will be ready to use out of the box. No maintenance will be required until after many uses whenever the NiMH batteries are past their lifetime and need to be replaced. A design to make the project more sustainable will be to change from NiMH batteries to lithium ion batteries. Lithium ion batteries have more charge cycles, thus having a greater lifetime. Changing to lithium ion batteries is also expected to increase performance of the charger due to the fact that the batteries hold more charge and have a higher voltage of 3.7V, which will help the performance of the 12V boost converter.

Ethical

No ethical implications are expected as the device cannot be misused and as long as the device is manufactured in a factory where humans are not exploited

Health and Safety

Considering all solder used in soldering the components was lead-free solder, it is a big step to ensure the project is safe to use and handle. All voltages on board the circuit are relativity low so the chance of shock is minimal to any user. Fire resistant material is used for the printed circuit board to prevent any fires an overheated component can cause. Overall, the charger should be safe to use and no written warning should be necessary before using.

Social and Political

The primary use for this project is that it will be used as a back-up power source to charge cell phones, cameras, etc. for when people are travelling. Therefore, this project will primarily affect those who use it. The only way this will affect the users is if they are in an emergency with a dead cell phone and they need a power source to power their phone to be able to make a phone call and the charger has failed. However, it will more likely benefit people in that situation and people will be able to use the device as a power source to be able to make a phone call if that issue were to ever occur. The project has the potential to help developing countries with limited power sources, where people in these nations can use it to charge a cell phone or any other devices they are able to get a hold of that uses USB or cigarette lighter to charge.

Development

Thanks to the course IME 458, I was able to use that class to help me understand the design process of what it would take to manufacture my project in mass quantities. I was able to learn how stencil machines, pick-and-place machines, and reflow ovens work to automate manufacturing printed circuit boards. Also, I picked up how a hot air gun is used to do solder rework on components. It is a handy device to remove small components such as resistors from a circuit board when mounted on the surface.