Solar Powered Lithium Polymer Battery Charger

3312ENG – Electrical Design Project

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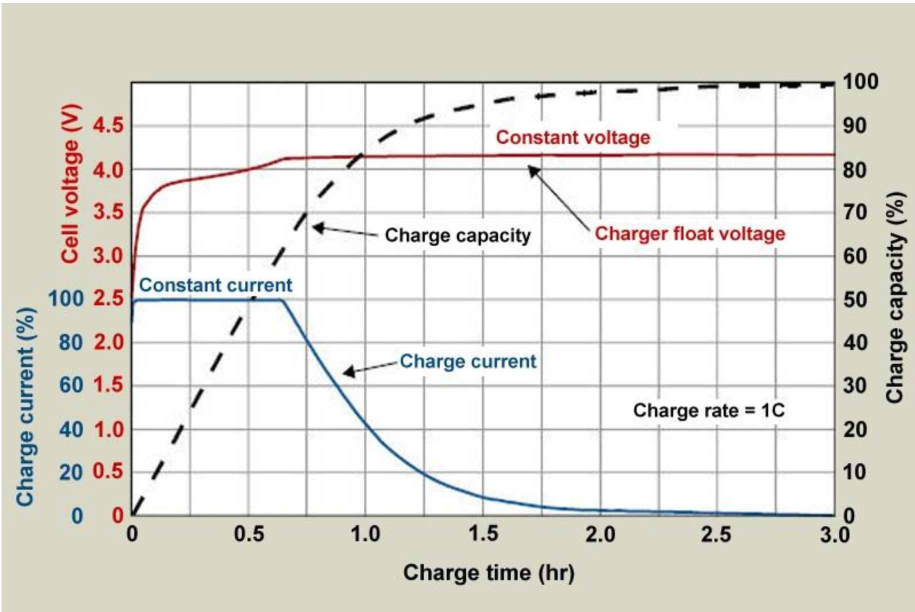
Contents

Section 1 – Introduction

The ability to power electronic devices anywhere with batteries has become crucial for many of the tasks that we used technology for today. However, these complex chemical structures are required to be recharged fairly regularly in order to keep up with the demand we place on them. With the world transitioning to greener forms of energy, designing a device that can recharge these electronics without burning fossil fuels is of great advantage. It also serves to pose an adequate design challenge, the project will involve many of the same concepts and theory that have been explored in earlier design projects however extended to a more complex purpose and requirements.

Lithium Polymer (Li-Po) batteries are a lower-cost version of traditional Lithium-Ion (Li-ion) Batteries. Their internal chemistry is similar to that of Li-ion in terms of energy density but instead uses a dry solid polymer electrolyte resembling a non-conductive plastic like film. The dry polymer is more cost effective during fabrication, also resulting in a design that is rugged, safe and thin. With cell thickness as small as 1mm, possible applications of these batteries are small communications devices, personal electronics, Electric Vehicles and Radio-Controlled Equipment. The voltage of a single LiPo cell can vary but ranges from about 4.2V(Fully Charged) to 2.7-3V (Fully Discharged) with a nominal voltage of 3.7V.

Li-Po Batteries require special current and voltage-limiting recharging devices, the typical safety threshold is set to 4.3V per cell with a current rating of 1-C, where the C rating is the capacity of the battery. E.g. a 5000MaH battery can be charged at 5A safely. Full Charge is attained when the voltage has reached the upper voltage threshold and the current has dropped to 5-10% of the nominal charge current. The typical charge time is approximately three hours with variance depending upon the charging current. The charging is conducted in two separate phases, the first being a constant current charge phase at 1C until the battery voltage is 4.2V per cell, followed then by a constant voltage charge phase where the current is slowly reduced until the full charge



current. Figure 1.1 shows the voltage and current levels over the charge phase.

Figure 1.1: Volts/capacity vs. time when charging [1]

Section 2 – Detailed Circuit Design

The circuit comprises of four individual sections as well as a supporting circuit that is required to test the design in all conditions. The five individual sections are:

- Solar Panel Voltage Regulation and Filter
- Constant Current
- Constant Voltage
- Battery Charge level indicators
- Overcharge Protection

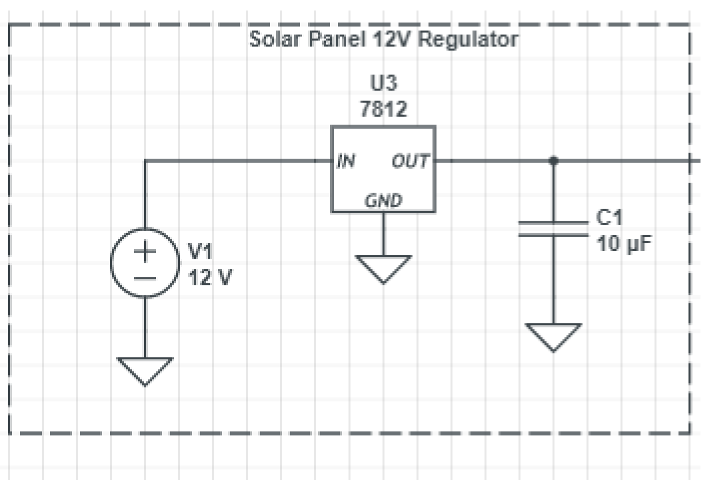
For the purpose of calculations, the battery charger is designed to charge a 2S 5200mAh Lithium Polymer battery, the 2S represents 2 cells in series. This means the nominal voltage is 7.4V and the fully charged voltage is 8.4V. A charging current of 500mA is targeted, this is due to the large amount of excess heat that will likely build up in the circuitry due to constant exposure from the sun. This should prevent the charging components from overheating during operation on hot days.

Section 2.1 – Solar Panel Voltage Regulation and Filter

A photovoltaic solar panel can be used to provide electricity from the sun, creating a sustainable source of energy to power the battery charger. The input from the Solar Panel has some variance depending on the available sunlight, the system is designed to run during peak sunlight hours.

A 20W Solar panel was selected for the cost/size efficiency, providing up to 1.16A at 12V during operation allows for a reasonable charging time with high efficiency. To compensate for the change in voltage and possible noise from the input, a 12V regulator and filter will be placed between the solar panel and charging circuitry.

The MC78T12 12V 3A Voltage Regulator was selected for this purpose, it requires no other components to regulate the voltage. A 10nF capacitor is also going to be used to eliminate any



noise from the regulator.

Figure 2.1.1: Solar Panel voltage Regulator

In the above schematic a 12V voltage source has been used to represent the solar panel input.

Section 2.2 – Constant Current

The constant current section is based on the LM317 Adjustable voltage regulator Integrated Circuit. The regulator is a 3 terminal floating regulator, where it only sees the input-output differential voltage and can be programmed via two external resistors to set the output voltage. During operation, it sets a nominal 1.25V differential between the output and adjust terminals. In the below base schematic in Figure 2.2.1, the reference voltage would be across the program resistor R1 and since this is a constant voltage a constant current will flow through the output set resistor R2.

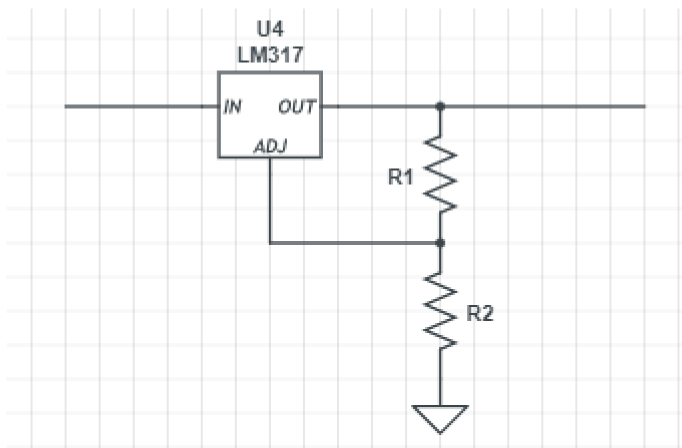


Figure 2.2.1: LM317 Base Schematic

The LM317 is designed to accept an unregulated voltage of up to 37V and can output a maximum current of 1.5A, making it ideal for this application. To set the constant current level and calculate the value of R1, ohms law can be used:

$$I = \frac{V}{R}$$

$$500mA = \frac{12}{R1}$$

$$R1 = \frac{12}{500mA}$$

$$R1 = 2.4\Omega$$

As R2 is used to set the voltage, which is unnecessary for a constant current source, it can be omitted from the circuit. From this calculated value the constant current circuit will set the charging current at 500mA, the circuit can be seen in the below figure.

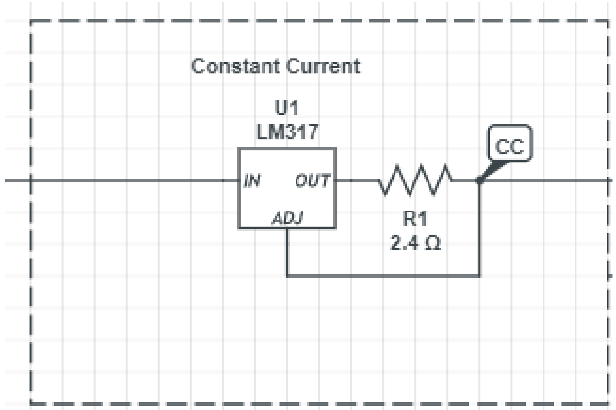


Figure 2.2.2: Constant Current Circuit

Section 2.3 – Constant Voltage

The constant voltage circuitry is also based on the LM317 Adjustable voltage regulator, an adjustable voltage regulator is required as during the first phase of the battery charging cycle the voltage increases up to the full charge voltage. Setting the voltage can be done by calculating the appropriate R1 and R2 values, the output of the voltage regulator can be seen as the following formula:

$$Vout = 1.25V_{in}\left(1 + \frac{R1}{R2}\right)$$

$Subbing\ in\ our\ known\ values$

$$8.4V = 1.25(12V)\left(1 + \frac{R1}{R2}\right)$$

$$0.56 = \left(1 + \frac{R1}{R2}\right)$$

$$1.56R1 = R2$$

$If\ an\ arbitrary\ value\ of\ R1\ is\ chosen$

$$R1 = 470K$$

$$1.56(470K) = 780K$$

With these calculate values and placing into the base schematic it will regulate the battery voltage up to 8.4V. A 10nF capacitor has also been placed on the output to further reduce any possible noise, the calculated values can be seen in the below schematic.

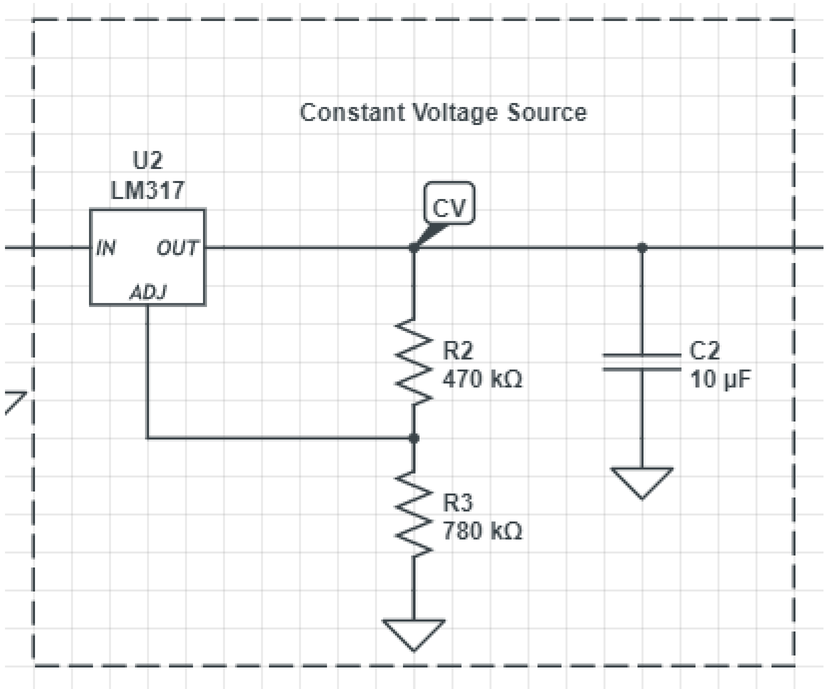


Figure 2.3.1: Constant Voltage Circuit

Section 2.4 – Overcharge Protection

The overcharge protection circuit comprises of one NPN transistor attached to the constant current circuitry, the base of the transistor is connected to the battery charging rail via a resistor and Zener diode. The design is intended that once the battery voltage is high enough for the voltage drop across the resistor, Zener diode breakdown voltage then turn on the transistor, it connects the constant current regulator to ground, turning off the charging of the battery. To prevent any dangerous overcharge, this limit has been set at 8.5V.

As a high current will be flowing through the auto cutoff, a durable NPN transistor will be used to avoid damaging the component and circuit. The TIP122 has been chosen as the 3A maximum current will be able to operate in all conditions. The turn on voltage of the TIP122 2.5V, with a turn off goal of 8.5V, this leaves a 6V drop remaining that is required to turn the transistor on at the correct voltage. To achieve this, a Zener diode in reverse bias with a breakdown voltage of 5.2V, followed by a 7kΩ resistor for the remaining 0.8V. These components have been placed into the schematic below:

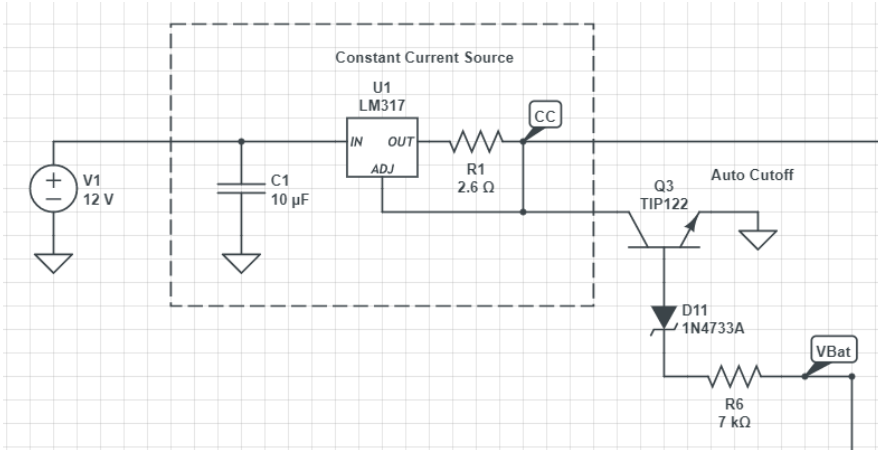


Figure 2.5.1: Overcharge protection

Section 2.5 – Battery Charge Level Indicators

The charge level indicators are required in order to indicate to the user how far along the charging process is and estimate how much longer is required. The charge percentage can be estimated from the battery voltage and the charging current, the following charge levels have been determined as an estimate

- **25% -** Slightly above the fully discharged voltage (6.8V)
- **50% -** Reaches the nominal charge voltage (7.4V)
- **75% -** Reaches the full charge voltage (8.4)
- **100% -** Charging current reaches 1/10th of the nominal current (50mA)

To represent the charge percentage, 4 LEDs will be used, red to represent the charging levels and green to show fully charged. As the requirement for the LED to turn on is the voltage, a Zener Diode can be used to serve this purpose. A Zener diode acts as a two-way gate for current flow, in the forward direction its easy to flow through, only 0.6V is required as the turn on voltage. However, in the reverse direction it requires a voltage at the Zener breakdown voltage in order to allow the current to flow. This breakdown voltage can vary between 1.8V and 200V depending on the model. Therefore, the required circuit can be created if the appropriate Zener diodes are selected for each charge level. Through research, the following Zener diodes have been selected based on their breakdown voltage, estimating a 2V voltage drop across the LED as well.

- **1N4731A** – 4.3V
- **1N4733A** – 4.7V
- **1N4735A** – 6.2V
- **1N4735A** – 6.2V

Using Zener diodes and then appropriately selected resistors to set the current flow for an LED will be the only circuitry required for the indicators. The circuit schematic can be seen below, the diodes are connected to the VBat line. The same value Zener diode has been used for the 75% and 100% indicator as a green LED will be used on the 100% indicator, green LEDS have a higher voltage drop then typical red LEDs, therefore it will activate at the correct voltage level.

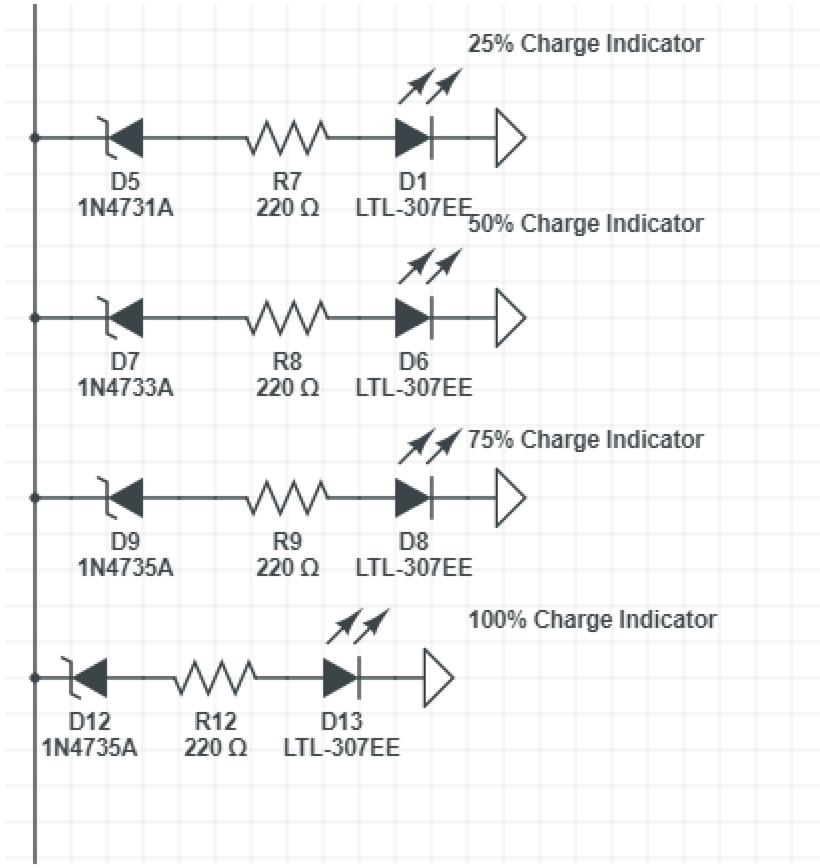


Figure 2.5.1: Charging Indicators

Section 2.6 – Combined Circuit

All of the designed sections are able to be combined together to form the final battery charger, each section connects together as can be seen in the below block diagram.

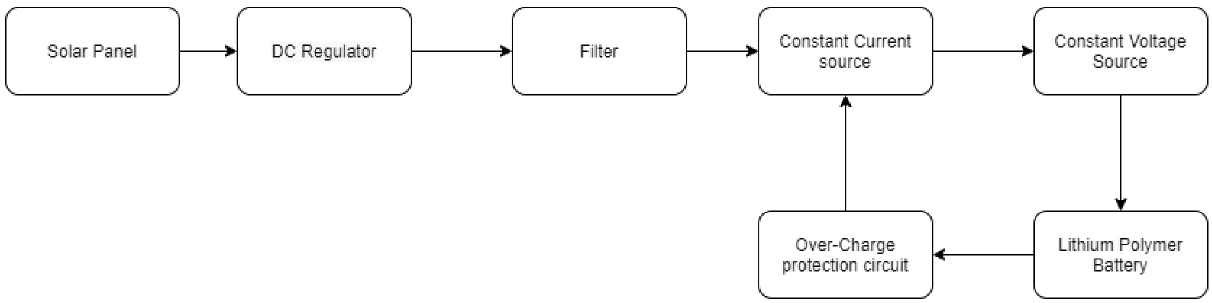


Figure 2.6.1: Block Diagram

Connecting each section together forms the final combined circuit diagram, the 12V voltage supply emulates the operation of the solar panel.

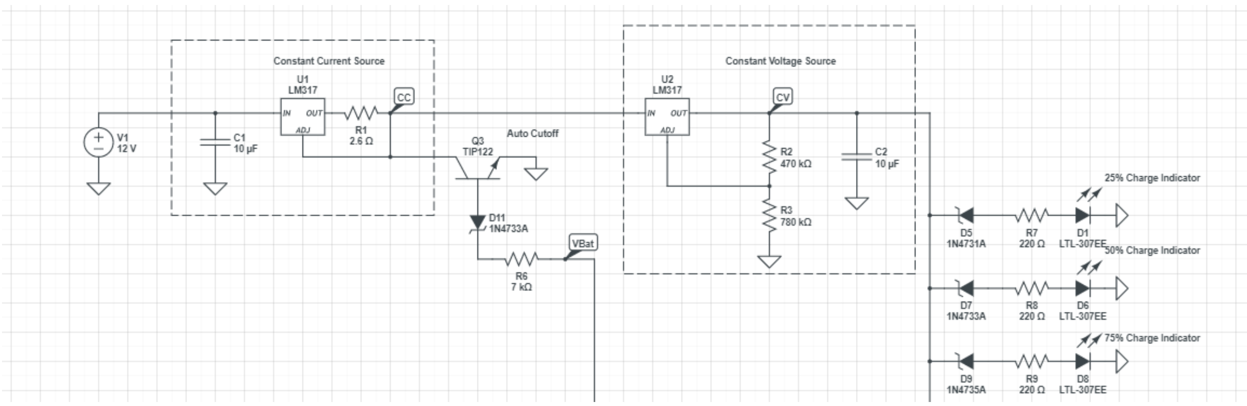


Figure 2.6.2: Combined Circuit Diagram

Section 2.7 – Battery Emulator

As the incorrect charging of lithium polymer batteries has the capability of causing serious harm to the battery, resulting a fire and explosive hazard. Before the designed chargeris able to be safely used on a lithium battery, it must be tested in all charging conditions to ensure it always operates in a safe manner that cannot compromise the internal chemistry of the battery. Real batteries obviously cannot be used for this purpose safely, therefore a battery emulator has been designed to simulate a batteries characteristic at different charge levels.

Comprising of an LM324 Operational amplifier, NPN Transistor, PNP Transistor and voltage source a battery emulator has been designed. The emulator can work in both sourcing and sinking current, however for charging only the current sink is required. To achieve this an operational amplifier is used in negative feedback with the output connected to the base of both transistors. The charge level the battery is emulating is then fed into the positive feedback terminal. This allows the circuit to sink current at the desired battery voltage. The schematic for the design can be seen below:

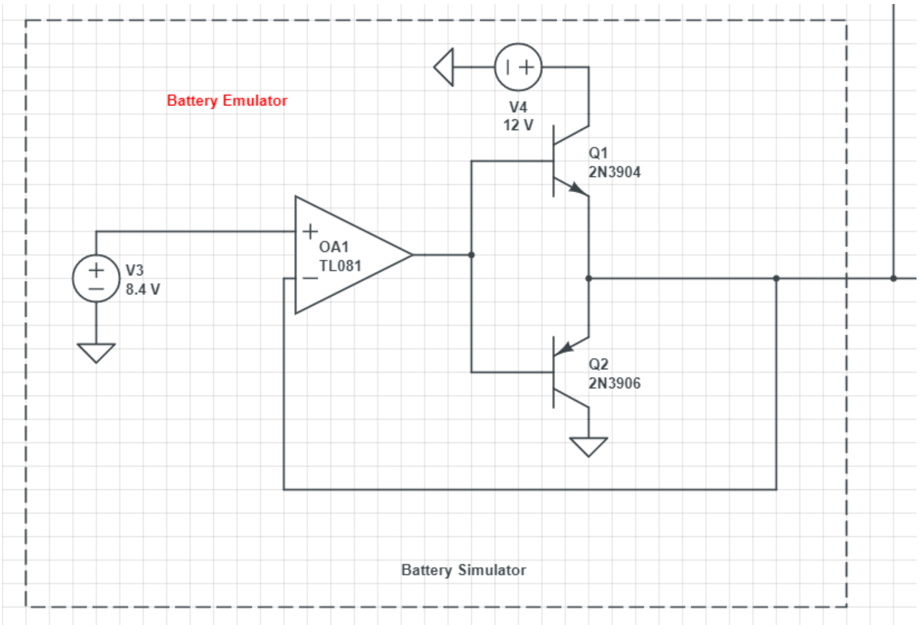


Figure 2.7.1: Battery Emulator

Due to the requirement of having to sink up to 500mA, conventional PNP transistors such as the 2N3906 would overheat extremely quickly, therefore a more heavy duty TIP32 transistor is required. Able to sink current of up to 3A, it will be able to achieve the desired task with ease. A heatsink will also be attached to the transistor to prevent any overheating for extended periods of testing.

Section 3 – Simulation Results and Waveform Analysis

The waveform analysis been completed within circuitlab on the final designed circuit. The two sections that need to be simulated is the constant current and constant voltage to ensure they work as intended and in a manner that can safely charge the lithium polymer battery. The simulations will be tested over a range of voltages from 7V to 9V to test the charging in full current until the battery charges the fully charge voltage and the auto-cutoff circuitry turns on. To simulate the battery, the battery emulator will be used.

Section 3.1 – Constant Current

The constant current section of the battery charger has been simulated using the combined circuit in figure 2.6.2. The simulation agrees with the calculated results and provides a high constant current charging until the battery level reaches 8V which the charging current gradually starts reducing in correlation with the voltage. There is a slight discrepancy of the auto cutoff circuitry not activating at the correct voltage level, this is due to the simulation software CircuitLab incorrectly modelling the turn on voltage of the TIP122 transistor.

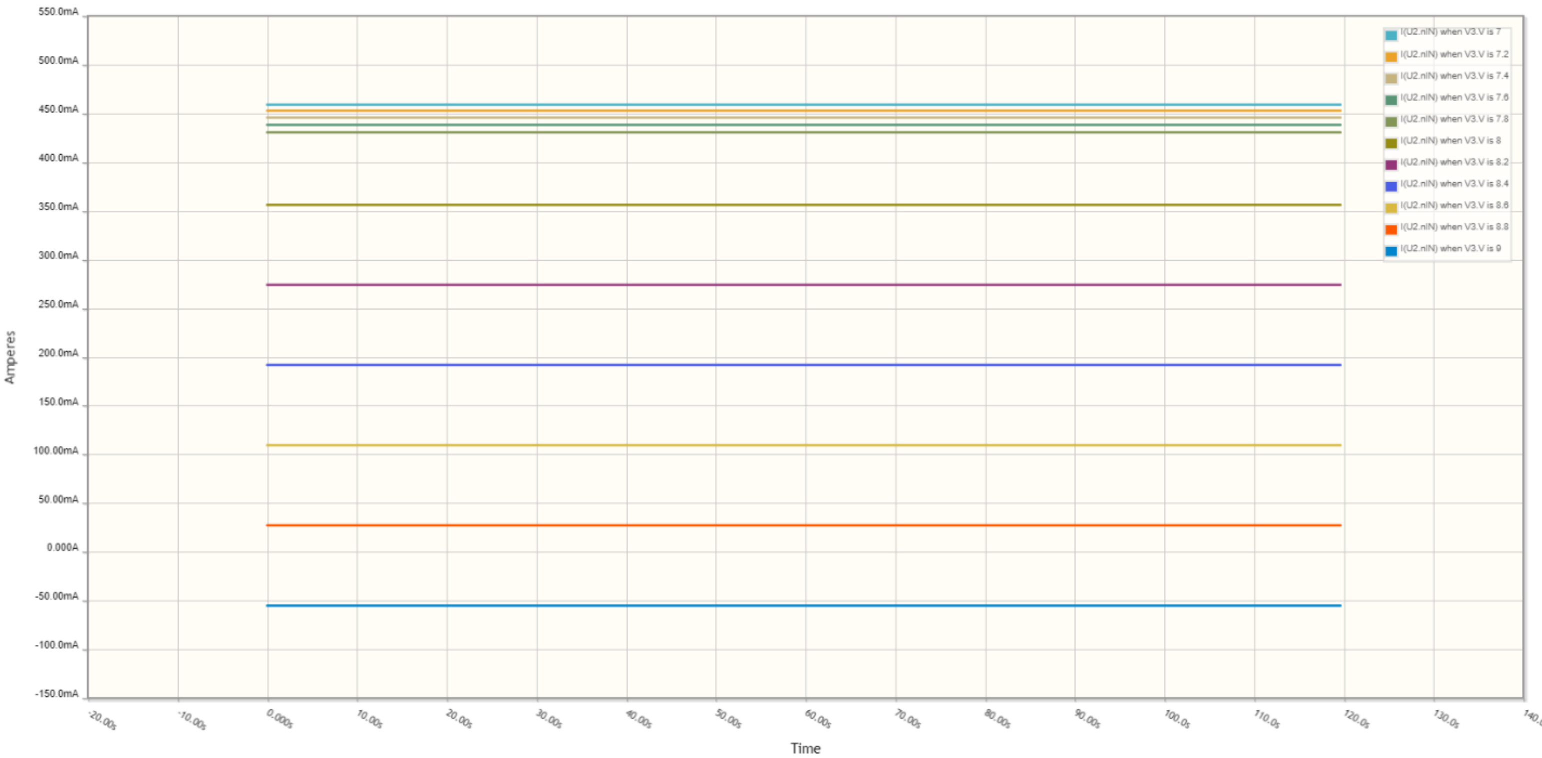


Figure 3.1.1: Constant Current Simulation

Each horizontal line represents the charging current at each voltage level of the battery, starting from 7V up to 9V in 0.2V increments. As can be seen, the charging current operates as designed.

Section 2.2 – Constant Voltage

The constant voltage section of the battery charger has been simulated using the combined circuit in figure 2.6.2. The simulation operates as designed, regulating the voltage to the target charging voltage at all times. Even when the overcharge protection circuitry activates, it does not disrupt the voltage regulation as the battery is still connected to the charger. The simulation results can be seen below:

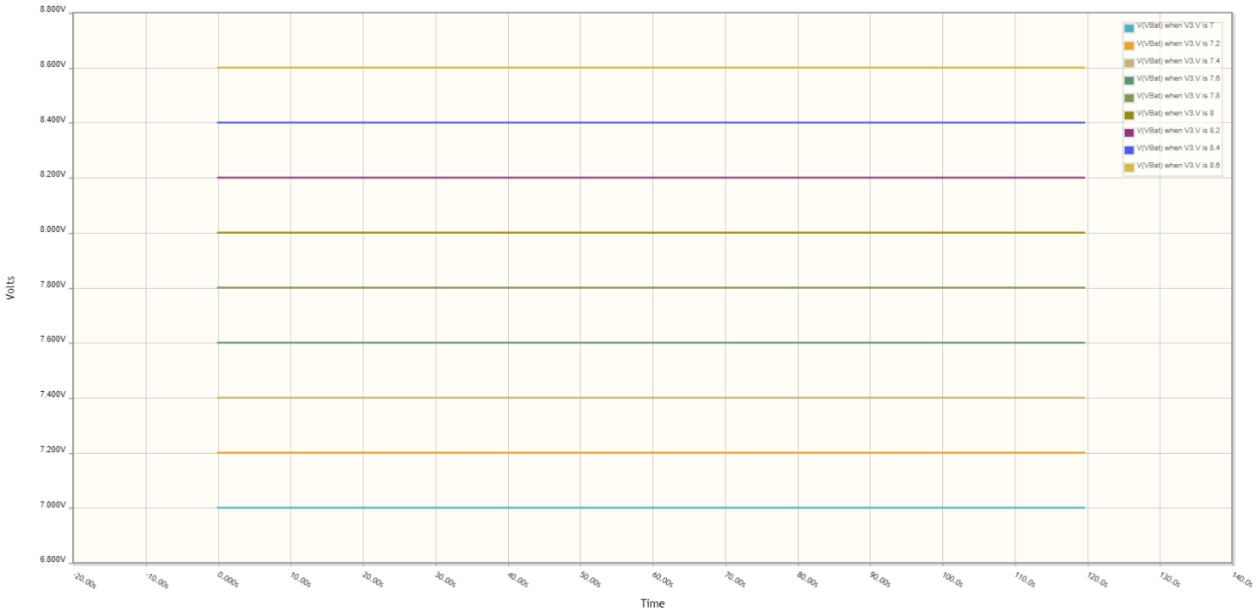


Figure 3.1.2: Constant Voltage Simulation

Section 4 – Full Circuit Implementation

With the simulation results demonstrating the designed characteristics, the circuit has been prototyped on a breadboard and then transferred onto a Veroboard and soldered for a more robust prototype. The Veroboard design is in the same layout as a breadboard, this has been chosen to simplify the transition process. As some resistor values are not available in typical packaging, multiple resistors have been used in series to achieve the desired resistance value. Each component was tested on a multimeter to ensure that it matched the

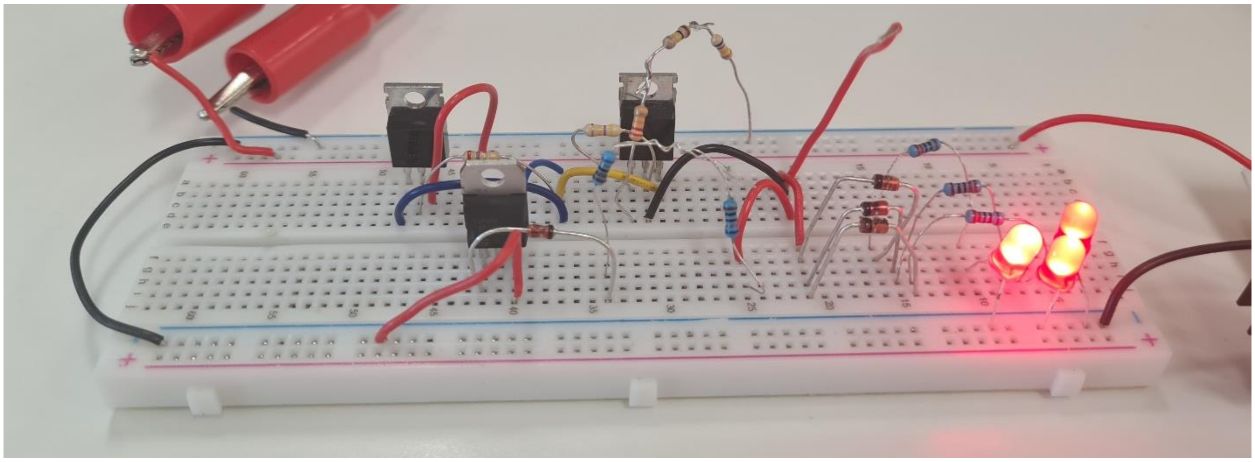


Figure 4.1.1: Full Circuit Breadboard Implementation

The battery emulator was also prototyped on a smaller form factor breadboard, it will be required for the physical testing of the charging circuity. The 12V rail is powered from the full circuit implementation, while the battery voltage level is set using a 2nd independent power supply.

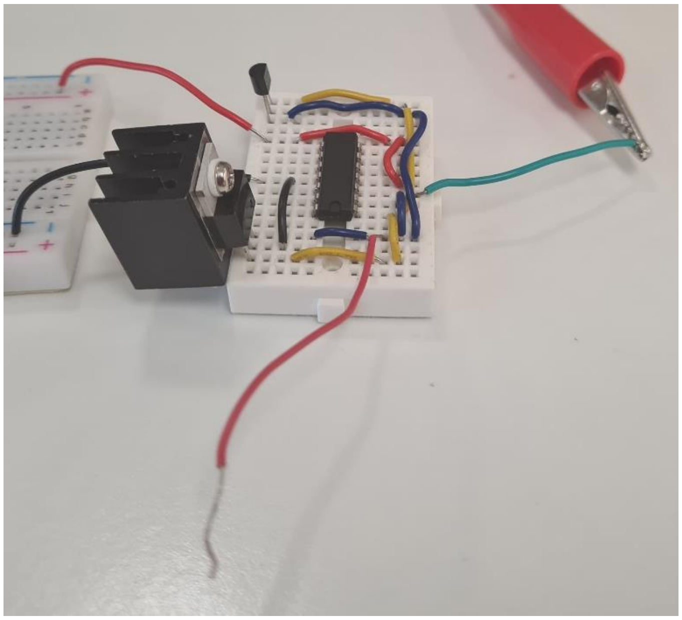


Figure 4.1.2: Battery Emulator Breadboard Implementation

The breadboard implementation was tested using the testing procedure in Section 5, the results agreed with the simulations and the design was ready to proceed to the Veroboard implementation.

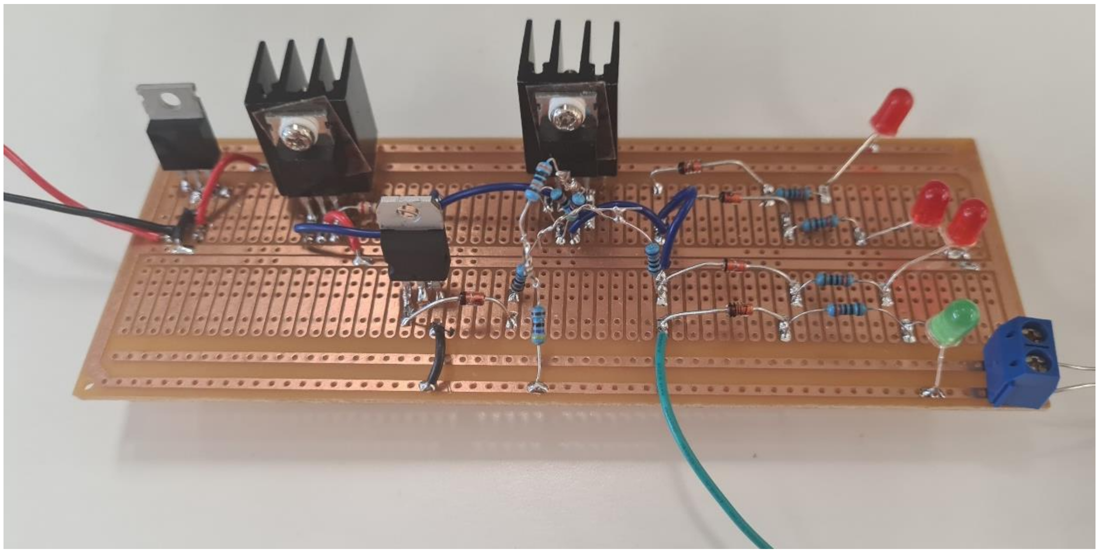


Figure 4.1.3: Full Circuit Veroboard Implementation

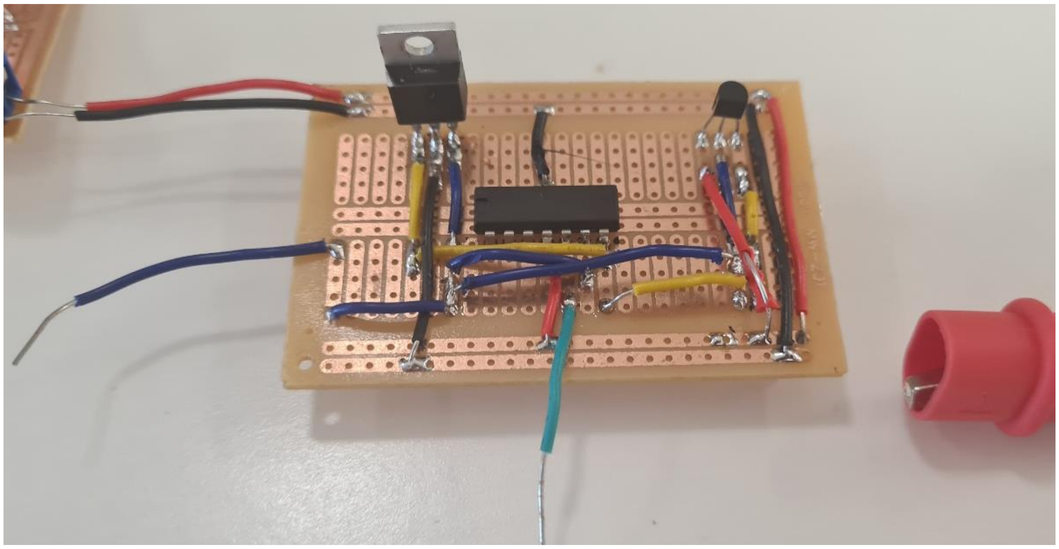


Figure 4.1.4: Battery Emulator Veroboard Implementation

The Veroboard implementation also works as designed, meaning that no modifications to the designed circuit is required.

Section 5 – Test Procedure

The testing procedure involves utilizing the battery simulator and battery charger at various charge levels to verify that it behaves as designed, followed by a real-life battery charge cycle using solar power. The test procedure requires the following equipment:

- Digital Multimeter – To measure charging current
- Dual Power Supply – To supply charger power source and battery emulation voltage
- 2S Lithium Polymer Battery
- Designed Charging Circuit Prototype
- Designed Battery Emulator Prototype

The procedure for testing is based on the layout of the Veroboard implementation.

1. Connect the Charging circuitry to the first power supply source, to emulate the solar panel set the power supply to 14V 500mA.
2. Connect the Battery Emulator circuit to the power rails of the charging circuit, screw terminals have been provided to ensure they connect securely.
3. Connect the multimeter to the charging leads of the Charging Circuit and the Battery Emulator, the positive lead connects to the charger and ground to the battery emulator. This ensures that a positive current is read on the multimeter, also check that it is connected to the higher amperage connector on the multimeter.
4. Connect the second power supply to the battery emulator green wire, set the power supply to 6V and 0A.
5. Turn on both power supplies

6. The charging current can now be seen on the multimeter, adjust the voltage on the second power supply to emulate different battery voltage levels

Section 6 – Test Results

The testing was completed on the Veroboard implementation using the testing procedure outlined in Section 5. The test was completed individually using both the battery emulator and the battery itself, the Solar panel was also used for real battery testing. The charging setup can be seen in below image 6.1.1.

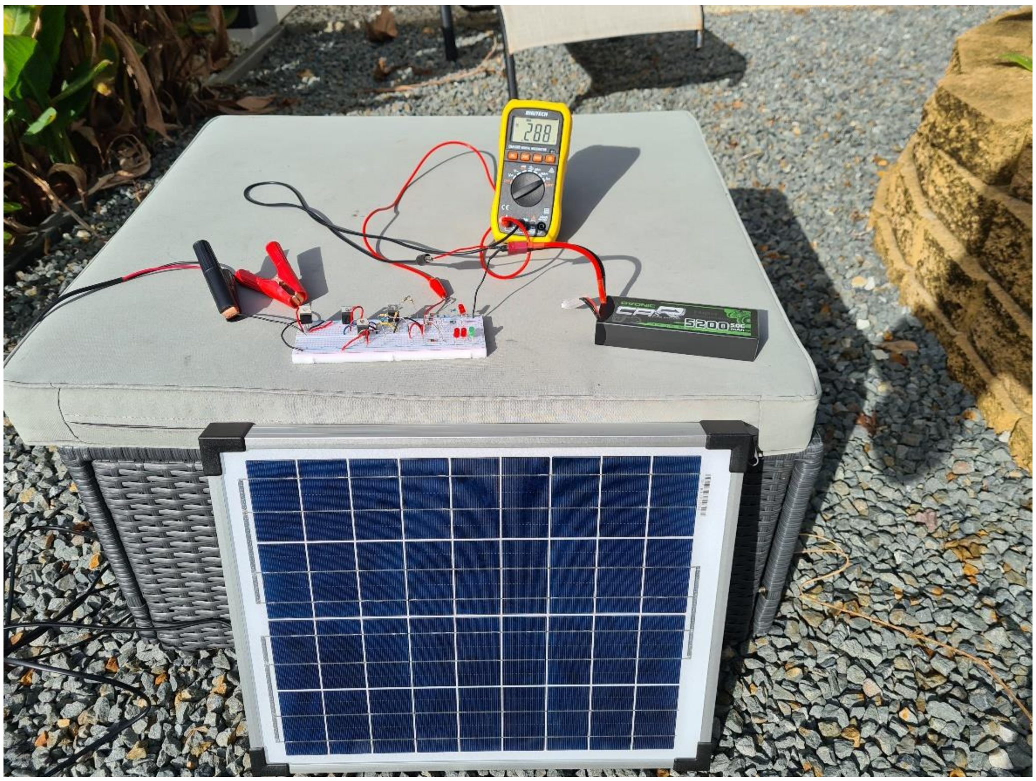


Image 6.1.1: Testing Procedure Setup

The first testing completed was the Veroboard implementation of the charging circuitry and battery emulator, this was done to ensure the prototyped charger operates safely before it can be used on the physical battery. Unfortunately, as the emulator requires a secondary power source and therefore must be tested inside, a DC power supply will be used instead of the solar panel. A reading for the charging current was taken at 0.2V increments from 6V to 9V, as well as limit testing to test the charger in extreme conditions.

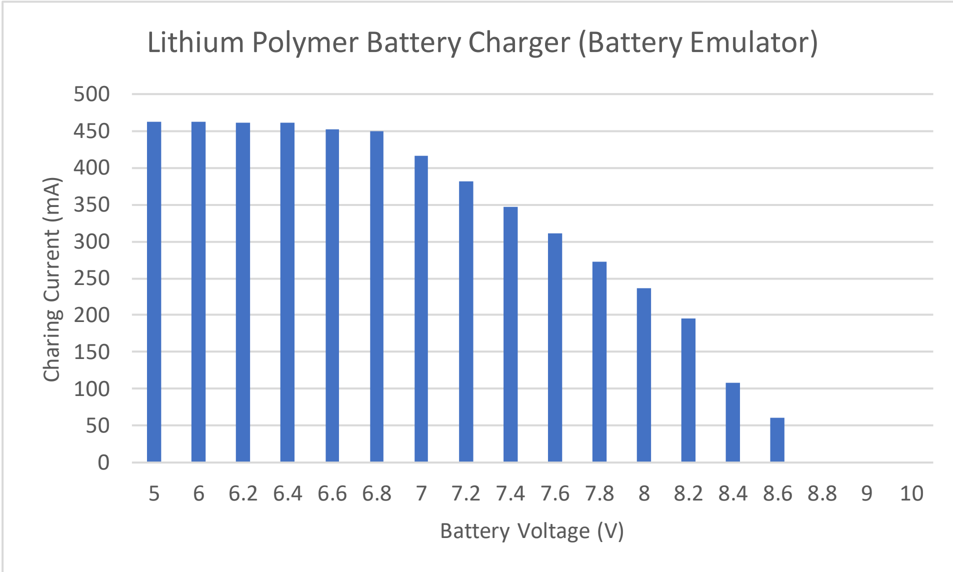


Figure 6.1.2: Prototyped circuit charging currents

As can be seen from the above figure, the charging circuit works as designed, charging with constant current until the battery voltage approaches the full charge voltage and then begins decrease the current. The Overcharge protection circuitry can also be seen to turn on as after the battery voltage reaches 8.6V, while slightly higher then the designed 8.5V, it can be explained by discrepancies in the Zener diode breakdown voltage being slightly higher. This is still however within an acceptable margin of error. Observationally, the charging level indicators also successfully represented the charging cycle, each turning on at the correct time and brightness to correlate with the level.

The final test was completing the same testing however now using a solar panel as the power source for the charging circuitry and a physical battery instead of the battery emulator. Using the setup in image 6.1.1, the following charging currents was observed.

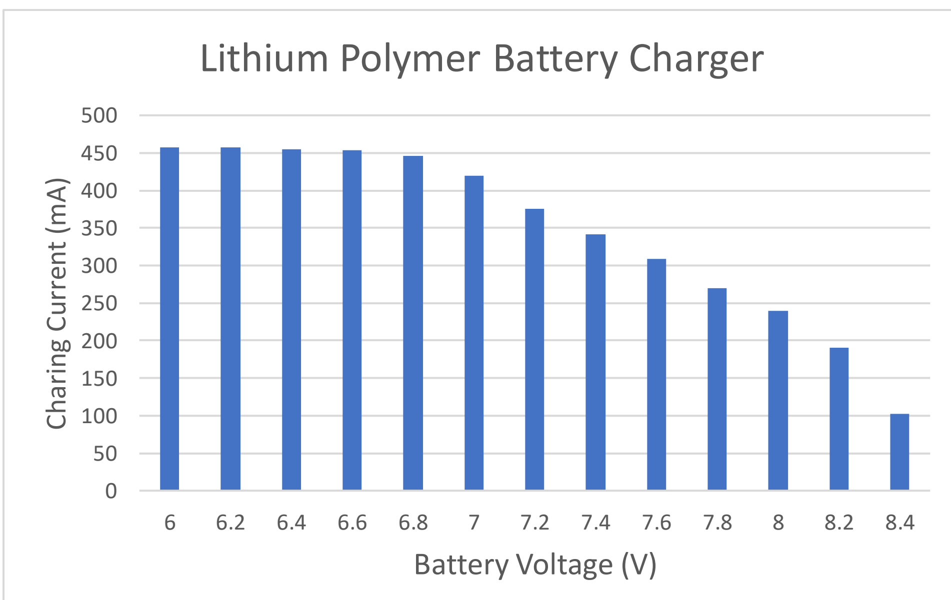


Figure 6.1.3: Real Implementation Testing Charging Currents

From the above figure it is evident that the real implementation follows the simulated results and works as designed.

Section 7 – Bill of Materials

The following bill of materials reflects all components required to construct the charging circuit on a breadboard. A separate bill of materials has been created if the battery simulator must also be constructed.

Table 7.1.1: Charging Circuit BOM

Component Designator	Value	Description	Supplier	Manufacturer	Quantity	Cost
LM317	-	Adjustable Voltage Regulator	Jaycar	Texas Instruments	2	2.95
MC78T12	12V	Fixed 12V regulator	Jaycar	Fairchild Semiconductor	1	4.95
TIP122	-	NPN Transistor	Jaycar	Motorola	1	2.45
Resistor	2.2	Resistor	Jaycar	Rohm	1	0.68
Resistor	470k	Resistor	Jaycar	Rohm	1	0.68
Resistor	800k	Resistor	Jaycar	Rohm	1	0.68
Resistor	220	Resistor	Jaycar	Rohm	4	0.68
Resistor	7k	Resistor	Jaycar	Rohm	1	0.68
1N4735A	6.2	Zener Diode	Jaycar	Fairchild Semiconductor	2	0.68
1N4733A	5.1	Zener Diode	Jaycar	Fairchild Semiconductor	1	0.68
1N4731A	4.3	Zener Diode	Jaycar	Fairchild Semiconductor	1	0.68
1N4736A	6.8	Zener Diode	Jaycar	Fairchild Semiconductor	1	0.68
Solar Panel	20W	Solar panel as a power source	Jaycar	Powertech	1	0.68
Capacitor	10nF	Electrolytic Capacitor	Jaycar	Rohm	2	0.3
Total						17.45

The below table then lists the bill of materials required to construct the battery simulator circuitry.

Table 7.1.2: Battery Simulator BOM

Component Designator	Value	Description	Supplier	Manufacturer	Quantity	Cost
LM324	-	Operational Amplifier	Jaycar	Texas Instruments	1	2.95
2N3904	-	NPN Transistor	Jaycar	Texas Instruments	1	2.95
TIP32	-	PNP Transistor	Jaycar	Texas Instruments	1	2.95
Total						8.85

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