The LiPo Crew
Dataforth Battery Charger

Final Report & User Manual

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1. Introduction

Dataforth Corporation, a world leader in designing, manufacturing, and marketing analog signal conditioning, data acquisition, and data communication product solutions. Their products provide industry-leading protection from the degrading effects associated with signal noise, experienced mainly in industrial applications. Their analog signal conditioners feature an enhanced modularity for ease of use with a variety of products such as current, position, strain, temperature and voltage measuring devices. With the ever-increasing need for sensor density in automotive, commercial and industrial applications, the inherent demand for accuracy is met by their 8B series isolated analog signal conditioners that have an accuracy rating of ±0.05% to ±0.50%. Dataforth is looking to showcase its product applications as a response to the increasing demands of the industry.

Mr. John Lehman, vice president of product development for Dataforth Corporation, has reached out to The LiPo Crew to develop a safe and efficient multi-cell lithium polymer (LiPo) battery charger with support for user-defined fault conditions. The battery charger is centered around a Texas Instruments MSP430 microcontroller, which will be responsible for the charging algorithm. The Texas Instruments MSP430 family of microcontrollers utilizes a 16-Bit reduced instruction set computer (RISC) architecture which provides an efficient, robust and versatile platform, capable of driving a multitude of sensors while simultaneously performing routine computational functions. These features, coupled with Dataforth's signal conditioning hardware, will prove to be the most effective route for preserving the signal integrity of the sensors.

The LiPo Crew's design incorporates Dataforth products to showcase their specialization and scalability in data acquisition and signal conditioning hardware. The LiPo Crew battery charger accentuates Dataforth's 8B series isolated analog signal conditioner features while also displaying their versatility in a low-energy application (LEA). Our design focuses on the manufacturability along with scalability for small LEAs to large, high-energy applications (HEA). Proper safety measures have been incorporated into our design including protective diodes for reverse current protection, and voltage regulators to ensure modularity for a safe circuit design.

The LiPo Crew completed all preliminary steps in the design process. The circuit design was fully functional during the prototyping phase, which allowed for full evaluation and testing to be conducted. Errors were incurred during the translation from the prototype schematic to the final Printed Circuit Board (PCB) layout. These errors were the demise of our entire project as The LiPo Crew did not account for possible failure during the final PCB integration. The following report outlines The LiPo Crew's design process, the final design, and testing results.

2. Design Process

The LiPo Crew's design process followed the ten-step design process outlined in our prior engineering classes. The first step was to identify the problem to establish a scope of work as well as the nature of the problem. With the problem identified, The LiPo Crew was then able to establish the requirements and constraints based upon both the client's, as well as the LiPo Crew's self-imposed requirements. With the proper guidance provided by the requirements and constraints, The LiPo Crew pursued different avenues within the realm of our requirements.The LiPo Crew's design process faced minor issues impart to our extensive research and elaboration from the client on specifications that were to remain open for interpretation or others that were strictly required to be as they were written on the project proposal. The thorough evaluation of the scope of the requirements and specifications enabled The LiPo Crew to conduct extensive preliminary research. The preliminary research unearthed valuable insight into how prior methods were employed to achieve similar outcomes. The knowledge attained through the research gave way to a multifaceted design that required various subsystems to function in a complementary fashion, to achieve the idealized LiPo battery charger.

Through the initial round of simulation and analysis, The LiPo Crew narrowed the design down to four fundamental subsystems including the charging algorithm, battery temperature, battery charging, and user interface subsystems. After a review of our specifications and requirements, The LiPo Crew decided to exclude the development of a discrete power supply and source a prebuilt power supply unit for the battery charger. Another example of democratic analysis was exhibited when The LiPo Crew chose to pursue a discrete implementation of the battery management system, rather than utilizing an integrated circuit (IC) for the battery management system. For one and a half months, our team deliberated amongst ourselves and ultimately asked the client for clarification on the proposed requirements in order to make the correct decision. Qualitative and quantitative analyses were executed over the winter break which proved vital in the success of our final design, specifically in the voltage and current regulators (charging subsystem and +5V rails). The risk reduction, provided through the use of Texas Instruments' Powerbench Software, allowed The LiPo Crew's hardware team to produce a stable 5V supply to peripherals by implementing a reputable voltage regulator in the form of the LM317.

The following step was to prototype our conceptual design into a physical design. Over the period of one month, The LiPo Crew prototyped the different subsystems starting with the voltage and current regulators. Challenges arose when the output voltage was greater than the desired output, which was solved by various tests that used different valued resistors that controlled the output of the LM317. This was done repetitively until the desired output voltage was achieved. Another issue posed during the prototyping phase was the cell balancing circuit, which consisted of MOSFETs and capacitors to allow for charge shuttling between higher and lower potential cells. This circuit was a safety feature to help reduce the risk of overcharging an individual cell and therefore causing an imbalance of the cells, conclusively deeming the battery unstable and dangerous. Our challenges for the cell balancing circuit occurred when one of the MOSFETs in our prototype kept overheating and ultimately melting the plastic dip packaging. After extensive analysis and careful consideration, The LiPo Crew chose to omit the cell balancing circuit due to multiple failed attempts to resolve this recurring issue. Prototyping proved to be an enlightening experience for the team, as our concepts did not prove to be entirely correct as they had appeared on paper. The software realm of the project was subjected to issues itself as it was littered with bugs unforeseen until the prototyping phase. The gravity of the issues encountered during the prototyping phase was the catalyst for The LiPo Crew's trend toward a minimalist design, as we had omitted various features that were not required.

2.1 Functional Decomposition

The LiPo Crew's battery charger consisted of four major subsystems coupled with independent components that were external to our design. The three independent components were the AC input of 115V at 60Hz supplied via a wall outlet, the power supply of the system and the 6-cell LiPo battery. The first subsystem was the charging algorithm, which was based upon the six cell voltages and implemented via the MSP430 microcontroller. If all cells were below 4.1V, the charger would provide the battery with constant current. Once a cell reached a voltage of 4.1V, the charger operated in constant voltage until the current fell below 125mA. Once the current had decreased to that point, the battery had completed its charging cycle. The second subsystem was the battery temperature to measure the temperature of the battery pack during its charging cycle to maintain a safe user experience. Our battery temperature subsystem consists of two Dataforth Corporation SensorLex 8B isolated analog signal conditioners to provide a noise free signal to the microcontroller for a highly accurate temperature measurement. The third subsystem was the battery charging system provided by the use of one voltage regulator and two current regulators. The control signals enable and disable the regulators based upon the cell voltages, as well as the current provided to the battery pack while it is being charged. The final subsystem was the user interface which was achieved through the use of a rotary encoder, to allow for the user to select a safe temperature threshold and timer limit. All information was displayed on a Liquid Crystal Display (LCD) in five second intervals. Data presented on the LCD includes the number of cells connected, individual cell voltages, battery current, battery pack temperature and the true charge time.

2.2 Prototype Findings

The LiPo Crew conducted rigorous testing on the prototype to gain a better understanding if our system is meeting both the self-imposed and client-defined requirements. The major takeaways from testing included the realizations that the output voltage from the regulators were not ideal and cell voltages were unstable. We were unable to vary the output current, meaning we could not support different battery capacities and the thermocouple system had to be calibrated.

Our solutions to these findings were derived through research and development after prototyping.

The solution to the issue of the voltage regulator not outputting the correct voltage, was due to an incorrect resistance value on the adjust pin of the regulator. The LiPo Crew had sourced the correct value for the resistor, therefore eliminating the harmful effects associated with overvoltage. The second problem that The LiPo Crew had encountered was the unstable cell voltages readings. To accommodate the variance in readings, our team employed the use of low pass filters for the analog inputs of the MSP430 to reduce the noise. Through further validation testing, the solution corrected the problem and allowed the system to accurately measure the individual cell voltages within a tenth of a millivolt.

The third hindrance in our prototyping was that the current supplied by the current regulators could not be varied according to the capacity of the attached battery. The limiting factor was the adjust resistor attached the adjust pin of the regulator. In order to facilitate the use of varying battery capacities, the design would have had to incorporate a digital potentiometer to vary the resistance according to the desired current output. The LiPo Crew did not allocate time for the redesign of the current regulators, which led to the redaction of a self-imposed requirement. The requirement that was redacted from our design was to accommodate varying battery capacities.

The final finding was that our code did not provide post-processing on the analog signals provided by the signal conditioners. Upon the first boot cycle, the system displayed a temperature reading that was significantly above the ambient temperature. To correct the issue, The LiPo Crew calculated the true temperature by dividing the hexadecimal value by the known ambient temperature in order to achieve the proper step size of the thermocouple readings. In doing so, The LiPo Crew streamlined the process by creating a function to divide the hexadecimal value by the step size and store the correct temperature value in a variable.

The LiPo Crew’s findings were attributed to the dedication and hard work put forth by each individual on the team. While the individual cell voltage issue was never realised in our final design, we tested our posed solution on an external test circuit with success. The second issue did not see full integration as stated above, due to time constraints. The posed solution is known to the electrical engineering community as a fail-safe solution to issues of that nature. As for solutions one and four, they were found to be efficient answers to the problems our team had faced after we tested them in a fully integrated prototype

3. Final Design

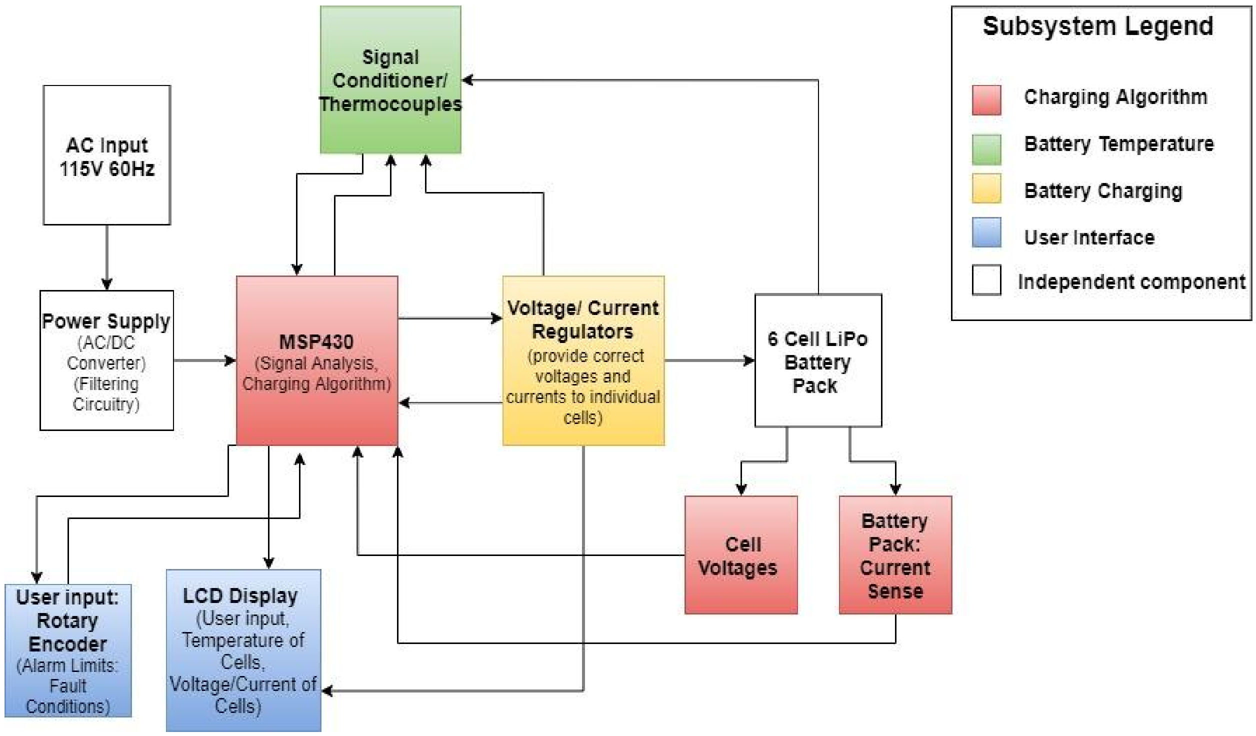


Figure 1. Full system architecture

The final design consisted of the four major subsystems outlined below in figure 1. The design operated with an input voltage of 115V AC provided by a wall outlet. The first major subsystem was the charging algorithm implemented by the MSP430, which was responsible for the signal analysis and corresponding charging algorithm. The analog inputs were provided by the cell voltages, the current sense and the battery temperature subsystem.

The signal conditioner/thermocouple block seen in figure 1, encompasses the entire battery temperature subsystem. It consists of the two, t-type thermocouples paired with two of Dataforth Corporation's SensorLex 8B isolated analog signal conditioners. The signal conditioners provide ±0.05% accuracy, ±0.02% linearity, 5-pole filtering and low output noise. The signal conditioners were mounted on a breakout board specially developed for prototyping. For our final design, The LiPo Crew used the breakout board, due to its ease of use, rather than having floating signal conditioners within the case. The battery temperature subsystem was responsible for providing the MSP430 with the analog representation of the battery temperature, to enable our team to code fault conditions that will terminate the charge cycle based upon the temperature. The upper limit temperature threshold was coded at a value of 45°C, with no lower limit set.

For the next subsystem seen in figure 1, highlighted in yellow, is the battery charging subsystem. The voltage and current regulators are the primary components supplemented by the passive components surrounding it, as depicted in the schematic seen in figure 2. The top two regulators were responsible for providing a stable 5V rail for the fan and LCD. The next voltage regulator solely provided the MSP430 development board with a 5V power supply. The next regulator below the two 5V voltage regulators is the constant voltage regulator that supplies the battery with a stable 25.2V. The two regulators below the constant voltage, are the constant current regulators whose purpose is to provide a constant 2.35A while the battery is below a 70% state of charge.

The charging algorithm was enabled by the MSP430 which took the analog inputs from the cells, along with the current and thermocouples, to provide the correct state of charge. The system first determined the number of cells connected by taking the measurement of the individual cells. If the cells were between 3.0V and 4.0V, the system then would proceed to charge in constant current mode. At which point the system enables the constant voltage until one of the cells reaches 4.2V. During the entire charging process, the MSP430 continually displayed: cell voltages, number of cells connected, the charge current, charge timer, battery temperature, and the average cell voltage. The user interface includes both the LCD along with the rotary encoder. The rotary encoder is used during the initial startup of the battery charger to select fault conditions, such as the charge time limit and the temperature limit ranging from 40-45°C. The user can also select to enable the default fault condition values, which are set at 45°C for the temperature upper limit and one hour for the charge timer.

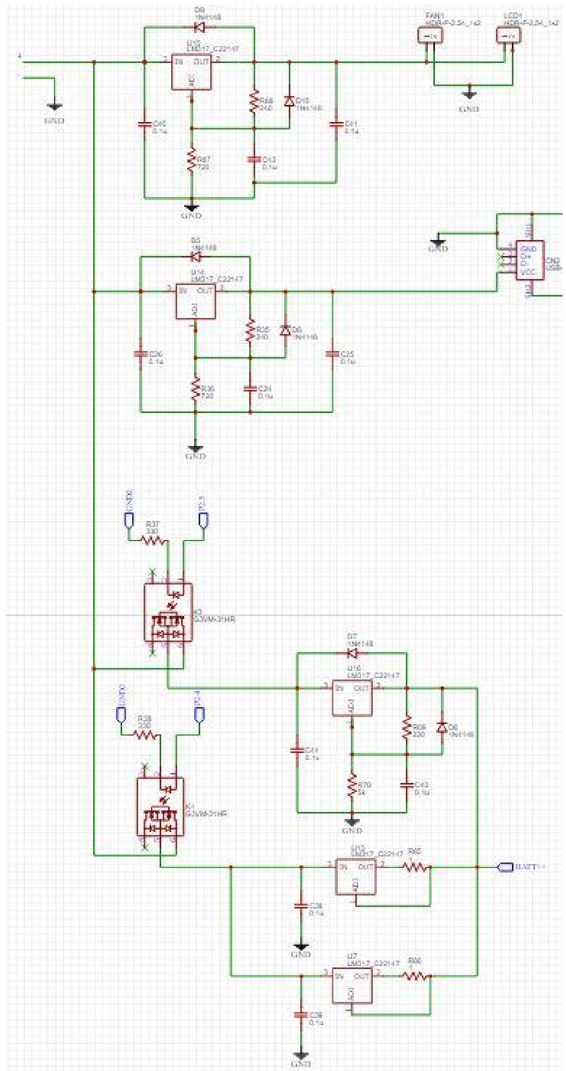


Figure 2. Voltage regulators & current regulators

The above image figure 2, is the schematic for the two individual 5V rails, one of the voltage regulators is for the constant voltage, and the two current regulators in parallel are for the constant current. The first voltage regulator supplied the fan and the LCD with a stable 5V while the second voltage regulator solely supplied the MSP430 development board with 5V via a universal serial bus (USB) port. Seen below the second 5V rail is the constant voltage regulator responsible for supplying the battery with the constant 25.2V. The regulator is controlled by the solid-state relay to the left of it which is ultimately controlled by the MSP430. The same layout was implemented for the constant current circuit with a solid-state relay to the left side of the regulator to enable and disable them based upon the charging algorithm. The output of the constant voltage and constant current circuits are tied to one another considering only one circuit will ever be enabled at any given time which then supplies the positive side of the battery pack.

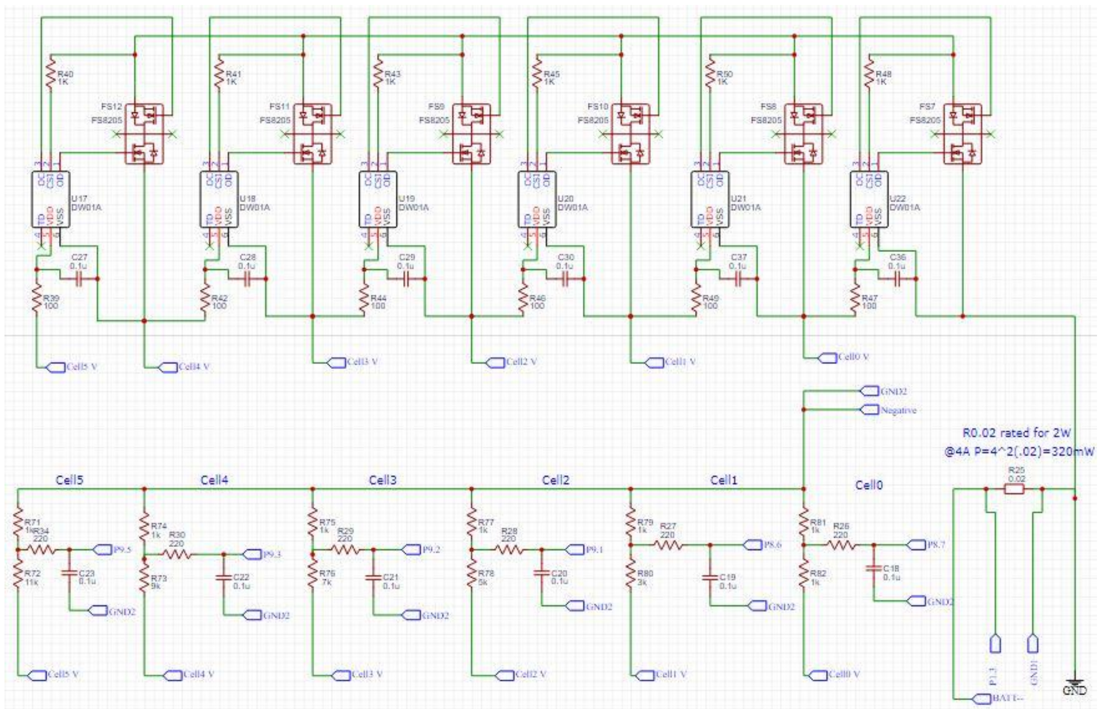


Figure 3. Cell voltage reading & protection circuits

Figure 3 represents the individual cell voltage reading circuit on the bottom and on the top is the cell protection circuit. Starting at the top of the schematic, the cell voltage protection circuit analyzed every cells' voltage for overcurrent and overvoltage. If any overcurrent or overvoltage were to occur the battery supply would be directly tied to the ground. On the bottom half of the figure, is the cell voltage reading circuit which is a series of voltage dividers with low pass filters attached to the analog inputs going to the analog to digital converter (ADC) of the MSP430. The low pass filters stabilized the voltage reading by eliminating the noise associated with our battery charger. To the right of the voltage dividers are the current sense resistor.

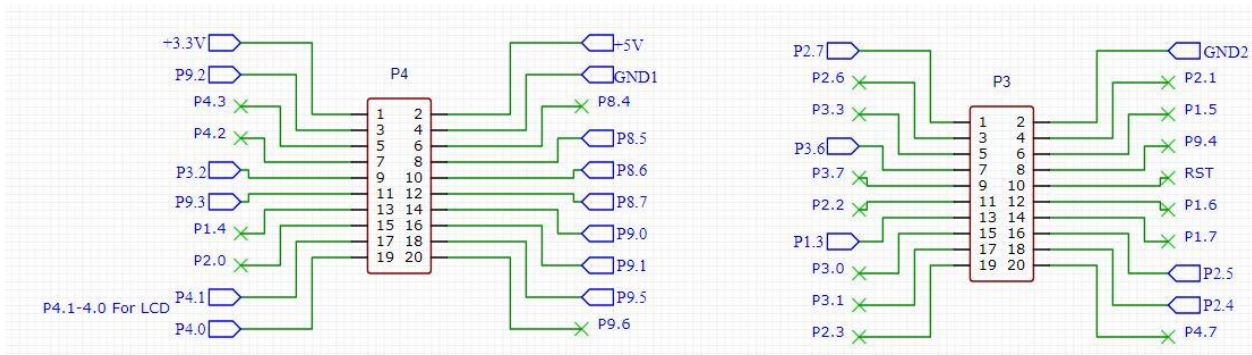


Figure 4. MSP430 header connections

Figure 4 shows the input headers for the MSP430.

The LiPo Crew's design was to make our PCB a "top-hat" for the MSP430 development board such that the MSP430 would plug into the bottom side of our PCB. each pin on the header is associated with the port number of the MSP430 pin it was connected to.

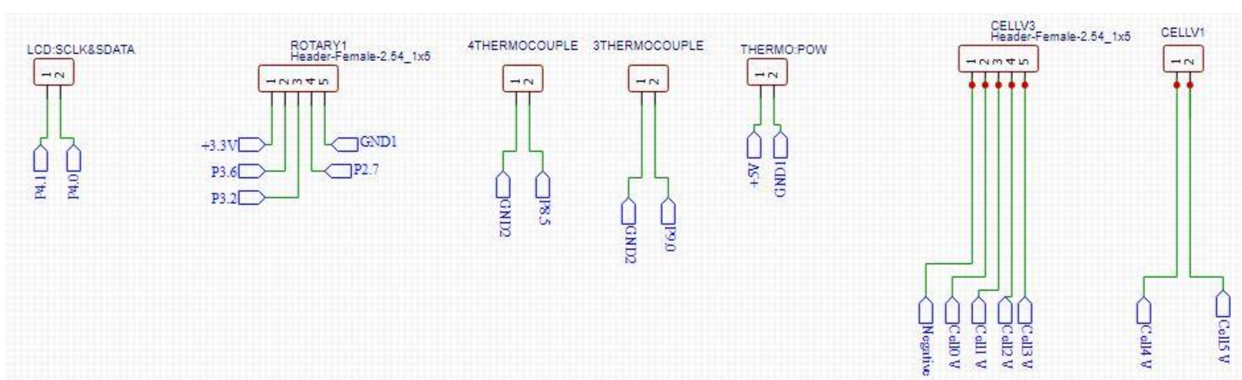


Figure 5. Peripheral connections

Figure 5 provides the headers for the: fan, rotary encoder, thermocouples, thermocouple power, and cell voltages.

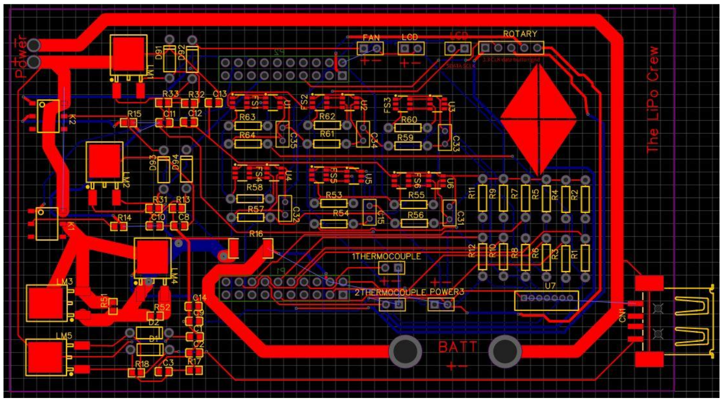


Figure 6. Final PCB layout

The image above shows the final layout for the traces of our design. There were multiple errors with the design. The first error was that our team used the incorrect footprints for the voltage and current regulators. Next, was that the ground of the cell voltages was tied directly to the neighboring positive voltage, therefore, shorting the cell. Another problem with the design was that the bottom row of the cell protection ICs were ground together while the top row was not properly grounded. Ultimately, grounded errors plagued The LiPo Crew's PCB design which resulted in the failure of our PCB. There were numerous mistakes that were overlooked during the layout phase primarily due to inexperience in conjunction with time constraints.

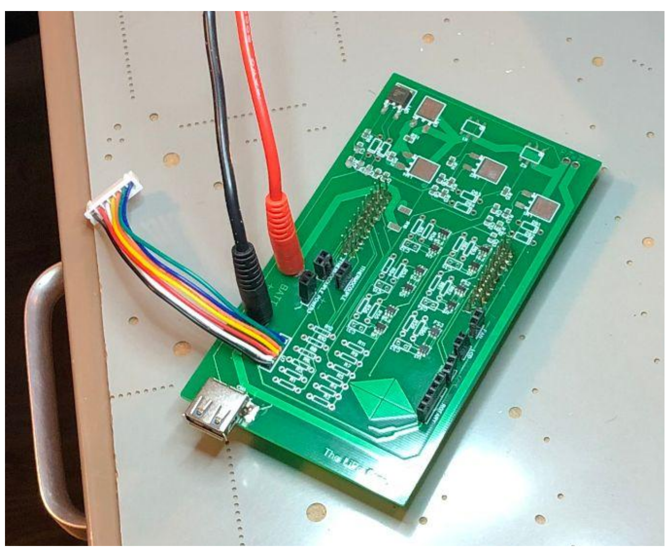


Figure 7. Final PCB by JLCPCB

Our final PCB with some of the headers soldering on along with the: USB, cell voltage connector, and the main power connection for the battery.

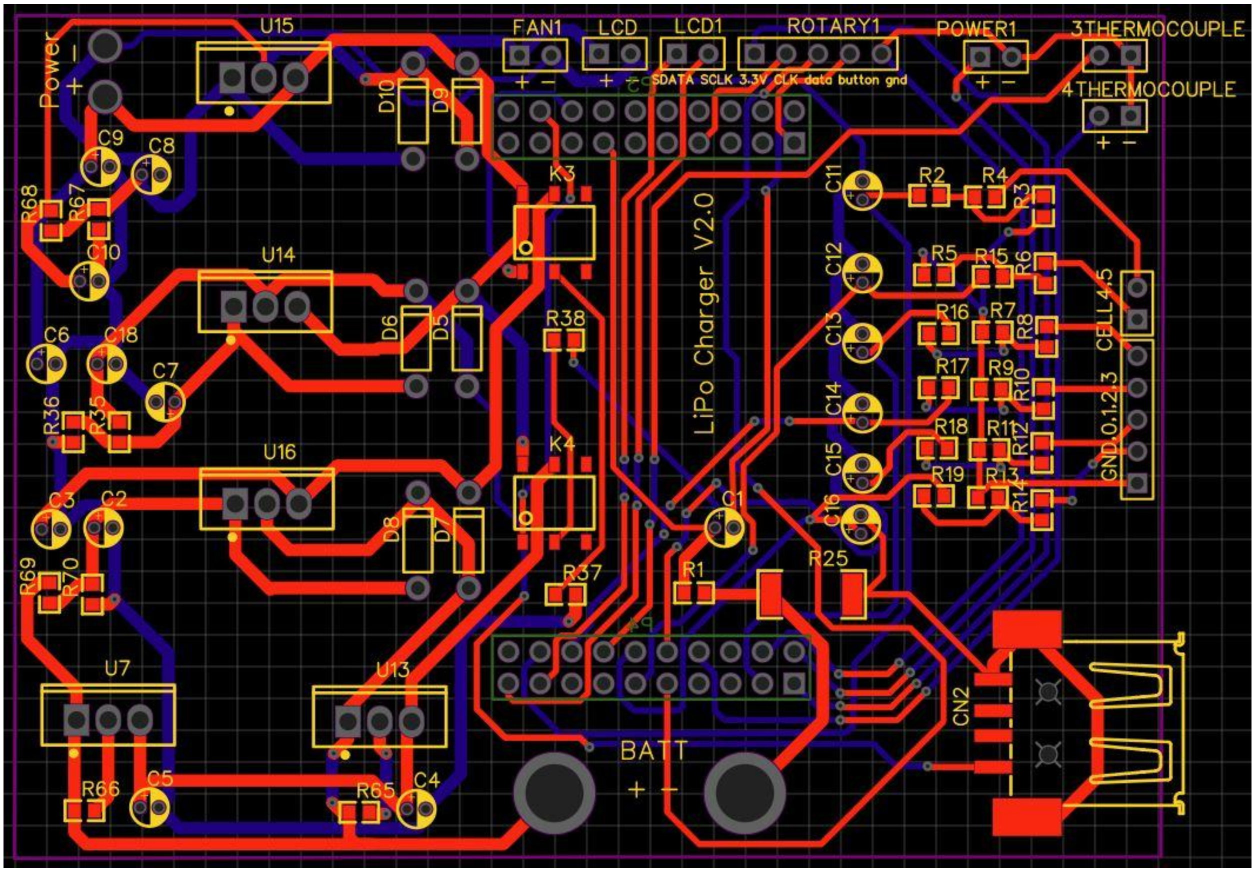


Figure 8. Revised PCB Layout (Version 2.0)

This is the revised PCB layout. Most of the errors were corrected from the first PCB to the second, but some errors remained. First, we had to eliminate the U15 LM317 due to instability issues. Our team then connected the top of D6 to the middle throughhole of U15 on the PCB to supply the fan and LCD with a stable 5V rail. In order to accommodate the extra load attached to the U14 LM317, we had to use an oversized heat sink such that the LM317 would not reach its thermal cutoff. We also had to connect a wire from the right side of R37 to the right side of R 38 to provide R37 with the MSP430 ground. Another alteration to the board was the resistor values for R6 and R8 had to be corrected to the correct values, 9k and 7k respectively. Our team was still unable to achieve a current measurement, other than that, our battery charger works according to our specifications.

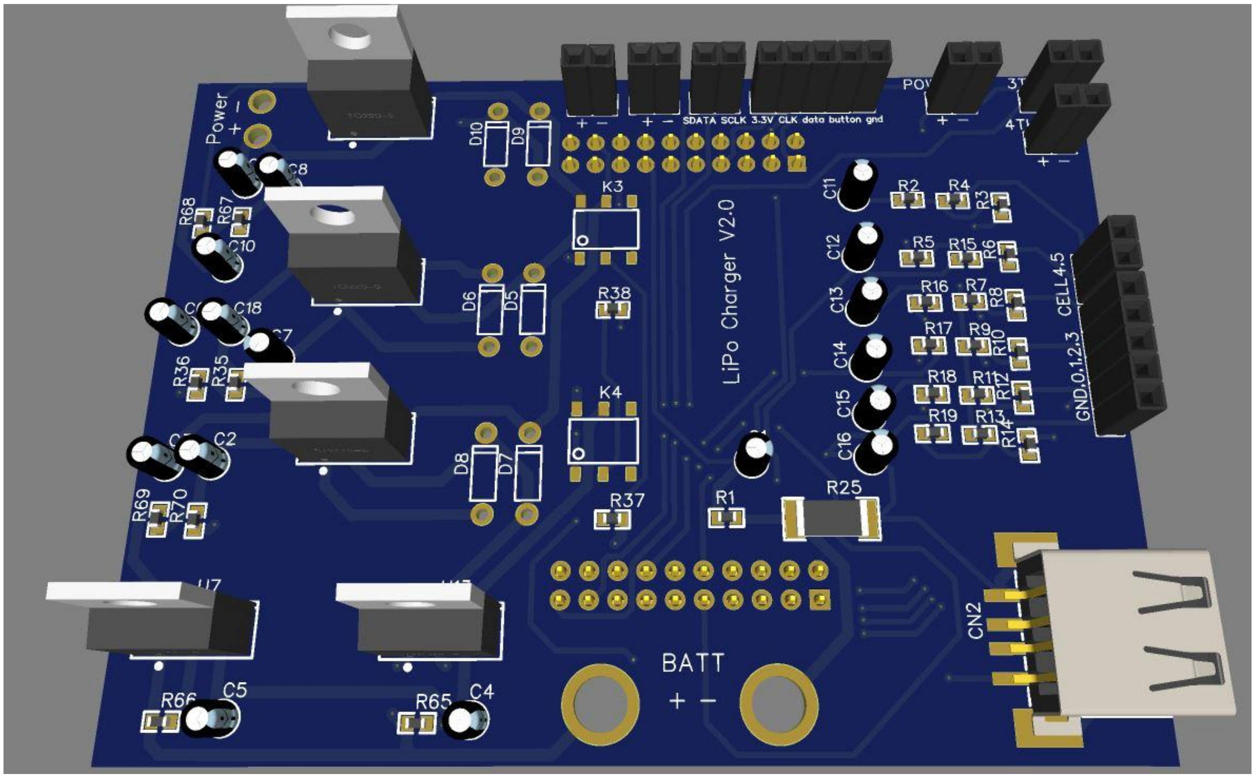


Figure 9. 3D Model of the PCB V2.0

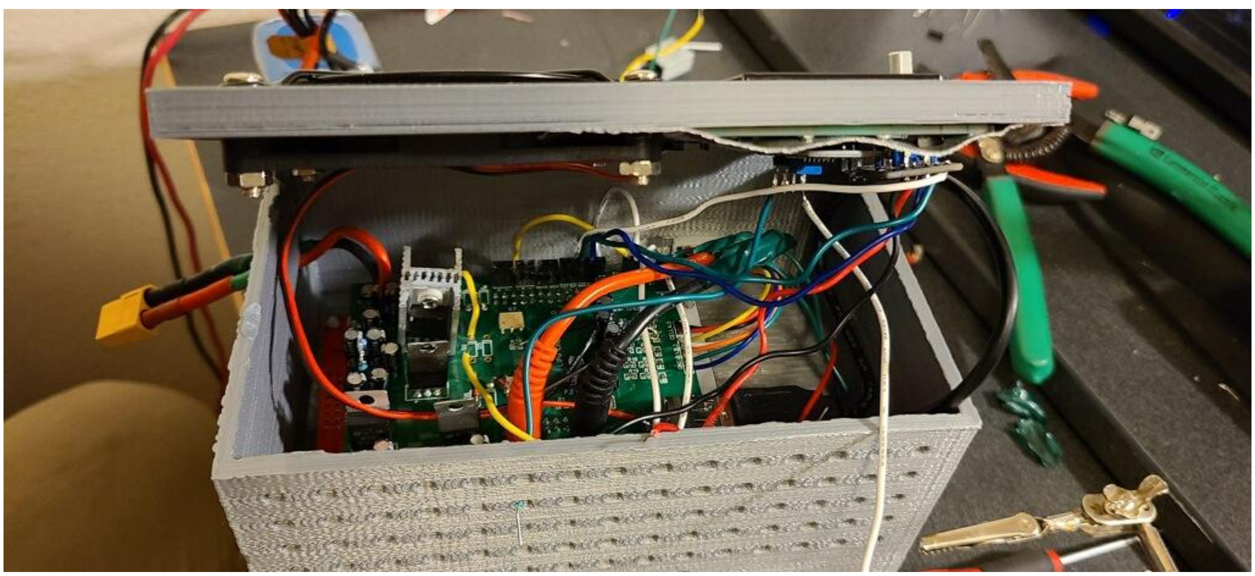


Figure 9. Final System

Full system integration with the LCD fan rotary encoder attached to the lid of the case. The holes in the side of our case were strictly for ventilation.

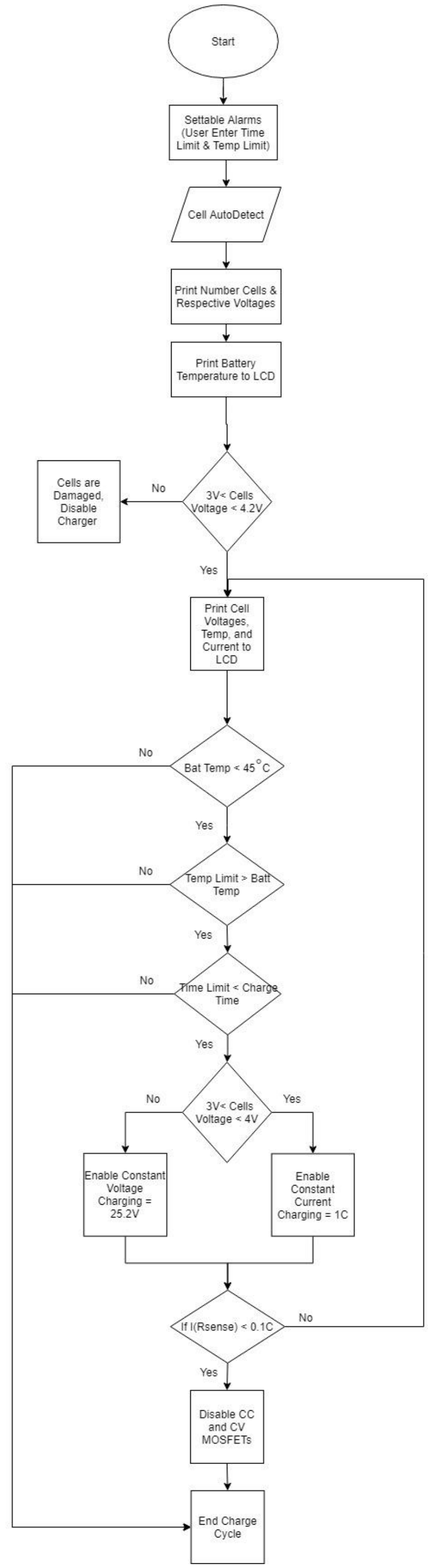


Figure 9. Flowchart of our system

The system prompts the user to enter if they would like to enter in a manual value for the fault conditions of the temperature and timer limits or to use the default limits which are set at 45°C and 60 minutes respectfully. After the user inputs whether or not they would like to enter fault conditions, the system would then auto-detect the number of cells connected to the system. Next, the program would verify if all cells connected were within the tolerated voltage range which was 3-4.2V. If this criterion was meant, the system would then commence the charging cycle and either enter the constant voltage or constant current phase based upon the cell voltages. If any of the cells reached 4.0V the system would enter the constant voltage phase while simultaneously disabling the constant current regulators. Throughout the entire period of the charging cycle, the program is continually checking the time and temperature limit set forth by the user or the default limits if the user had chosen so. The charging cycle is completed if and only if the charge current has reached less than 125mA. At which point, the LCD would display that the battery had finished charging.

4. Results

Instructions: List all of your requirements, and use a numbering system.

Type of Test	Status	Req #	Requirement
		1	Abide by IEC safety standards, efficiency rating of 90-95% charger/monitor for a multi-cell LiPo battery
		1.1	State of charge monitoring
Integrate		1.1.1	Presets must be predetermined for the LiPo battery being charged, this will automatically set the voltage and
Inspect		1.1.2	Must display to LCD
		1.2	PCB thermals and components must not exceed 85 ° C, battery cells thermals must not exceed 70 ° C while c
UTM	*	1.3	Display thermals of individual cells and the overall average of the six cells to LCD.
Inspect		1.3.1	Requires sufficient active cooling for Solid State Relays in the form of an individual 5V fan
		1.4	Cell Protection
Integrate		1.4.1	Ensures all batteries are protected during charging from over charge, over discharge, and over current.
		1.4.1.1	Cells can charge safely even if one cell of the battery pack is fully charged compared to the rest of the pack.
Integrate	*	1.5	User settable alarms limits via physical buttons and for fault conditions detection for defective cells within th
		1.5.1	User ability to set fault conditions
	*	1.5.1.1	Fault conditions: Battery over or under charging(±100mV) , battery reached one hundred percent charge cap faulty battery connection, wrong user input for battery type, battery over or under current(±50mA), faulty ce
		1.5.2	Fault detection alarms
UTS	*	2.4	To maximize productivity the battery charger will need to incorporate a preset in terms of voltage and current as well as an overall "time of charge" in present time to allow users to effectively charge a LiPo battery with minimal wasted effort
		4.1	Display will provide exact data in real time
Integrate		4.2.3	1-2 buttons to control scrolling options through the user interface

Figure 10. Requirements that were tested

4.1 Important Test Results

To ensure that the requirements of our project were met by our design, we performed several tests that each focused on different subsystems of our system architecture. One of our major tests was a unit step-by-step test that assessed the constant current and the constant voltage regulators. The constant current and constant voltage phases are required to safely and effectively charge a lithium polymer battery. The system initiates with the constant current phase till the battery reaches 70% fully charged when then it disables the constant current and enables the constant voltage for the remainder of the charging cycle. Solid-state relays were implemented as switches for turning on power to either the constant voltage or constant current regulator. The constant voltage continues until one of the battery cells reaches 4.2 volts. Once a cell voltage exceeds this limit, the charger will display a notification for the user on the LCD and cut off the constant voltage being supplied to the battery pack.

Our first step in the test was to ensure the solid-state relays did enable and disable the constant current and constant voltage (CC/CV) system. This step was a success considering that when the enable signal was sent to the solid-state relay for either regulator, we measured the correct output being supplied to the battery. Next, our team tested the output from the constant current regulator. This test was a success and the current output from the regulator was measured at 2.354A when the expected result was about 2.3A. The following test was to test the endurance of the constant current system in terms of heat dissipation. Our team measured the amount of time the regulator could be on before it would reach its thermal cutoff. Our test was a failure because the constant current system turned off at forty seconds when the expected result was one minute. The fourth step was to connect the CC/CV system to the MSP430 and set the user-defined fault conditions. This step in the test was necessary to confirm that the user can successfully set the fault conditions to allow the cell count, cell voltages, and pack temperature to be displayed on the screen. The fifth step tested the functionality of the constant current phase of charging. The system passed the test and the current measured going into the input of the battery was 2.3A which was the expected value. The sixth step was to allow the constant current phase to be enabled for ten minutes with a load connected to verify that the thermal cutoff was not reached to assure that the attached heatsinks worked as intended.

After we had confirmed that every component was working properly, we needed to start testing the actual charging of our battery. The seventh step was to test the effectiveness of our constant voltage phase of charging while the battery pack was connected. Our team conducted a test with a two-cell, 7.75V battery pack with the cells reading at 3.88V and 3.87V before charging. The constant charging voltage was 9.2V and after ten minutes of charging, cell one was measured at 3.89V, and cell two was measured at 3.89V for a total pack voltage of 7.78V. From this test, we concluded that the battery cells would increase around 10mV every ten minutes during the constant voltage phase. The next step was to allow the constant current to charge the two-cell battery for ten minutes. Before charging, the battery pack was measured at 7.78V and after ten minutes of charging the battery pack reached a total voltage of 7.89V. We concluded that the rate of charge during the CC charging cycle was 25mV per 10 minutes. We finished our CC/CV test by disabling both the CC and CV regulators, which worked properly.

Another major test of ours was to examine the accuracy of our two thermocouple sensors. Testing the accuracy of our thermocouples is important because if a LiPo battery exceeds its temperature limit, the battery could be permanently damaged or catch on fire. For our final product to be safe for the user, our temperature readings must be accurate within a certain range, which is being checked in this unit matrix test. To perform the test, we started by taking the ambient temperature of the room which will be the temperature that one of the two thermocouple sensors is kept at constantly. Then, we heated a cup of water in the microwave and measured the temperature of the water using a thermometer. We waited until the temperature of the water-cooled down to our desired temperature, and then inserted one of our thermocouple sensors into the water and recorded the temperature that was displayed on the LCD. For example, if one thermocouple was at room temperature and the other was at 3 degrees Celsius (℃) above room temperature, we expected the LCD to show a temperature of 1.5 ℃ above room temperature due to our calculated temperature being the average of the two thermocouples. We set a range of +/-1.5 ℃ for comparing our actual results with our expected results to determine whether that trial failed or passed. After each trial we switched thermocouples, let them cool back down to room temperature, and recorded the room temperature again in case it changed from the last trial. We switched the thermocouples every time to ensure that both thermocouples are indeed accurate. We repeated these steps many times over and tested our readings at four temperatures above 50 ℃ and four temperatures below 50 ℃.

Overall, we were satisfied with our results of this test and we consider our thermocouple's accuracy to be suitable for our application. For our first three trials, the room temperature was at 22 ℃ and we heated our cup of water to 31 ℃, 36 ℃, and 40 ℃. Our expected result for the first trial was 26.5 ℃, which comes from the average room temperature of 22 ℃ and the temperature of the heated water which was 31℃. Our actual results came out to be 28.5℃ which exceeded our range of +/-1.5 ℃, so we considered that trial to be a failure. For the second trial, we were within 1.2 ℃ of our expected result, so we considered that trial to be a success. For the third trial, we read 1.8 ℃ above our expected temperature so that was also considered a failure. The next five trials were all within 1.5 ℃ and they were all counted as successes, but our final trial was over the expected temperature by 1.9 ℃ and was counted as a failure. As you can see from our results, our thermocouples are not perfectly accurate but they are sufficient enough to be used in our design. The least accurate reading we had was only two degrees above the expected temperature and our most accurate trial resulted in only a difference of 0.3 ℃. Our thermocouple system was highly accurate with a correlation coefficient of 0.9975, confirming that the sensors were currently ready for full system integration.

The single most important test of ours was the full system integration test that encompassed all our subsystems and components. This was chosen to be executed last due to its dependencies on the success of all subsystem testing. The integration test consisted of the LCD, fan, thermocouple, voltage and current regulator, rotary encoder, and cell voltage reading subsystems. This was white box testing considering our team required the knowledge and workings of the systems that were to be implemented. The first step in our test was to allow the user to determine whether or not they wanted to select a customizable fault condition or to use the default settings. Step one passed as it worked correctly for all user input cases. Step two, was to ensure the cell autodetection was accurate and displayed the correct number of cells, with their respective voltages. After those steps had passed, it was time to start charging our six-cell battery pack.

Step three in our test was to allow the battery to commence the charging phase for five minutes in constant current mode. The cell voltages before charging were 3.95 V, 3.83 V, 3.83 V, 3.85 V, 3.92 V, and 4.00 V for cells one through six respectively. This resulted in a total pack voltage of 23.23 V and an average cell voltage of 3.850 V. After charging, the cell voltage average was 3.905 V with individual cell voltages reading 3.99 V, 3.85 V, 3.85 V, 3.88 V, 3.98 V, and 4.03 V for cells one through six. The total pack voltage was 23.43 V after a recorded charge time of five minutes and nine seconds. The next step in the testing was to reconnect the battery and remeasure the individual cell voltages after ten minutes of charging. The cell voltages after ten minutes and eight seconds were 4.02 V, 3.88 V, 3.88 V, 3.91 V, 4.01 V, and 4.12 V for all six cells, resulting in a total pack voltage of 23.66 V and a cell average of 3.943 V. The sixth test was to verify that after any cell reached a voltage of 4.0V, the system would acknowledge that the battery is fully charged and cut off the voltage and current that is being supplied to the battery. The last step in the test was to remeasure the cell voltages. This test was successful and verified that we were actually increasing the charge capacity of the battery without damaging the battery pack or any part of our circuit.

4.2 Analysis of Results

Once our unit tests and system integration test were complete, it was time to implement our printed circuit board (PCB) before doing a final evaluation of our design and its performance. Our design performed almost exactly how we had hoped with our protoboards and we were hoping that nothing would change once we started using our PCB. Unfortunately, that was not the case for our team as we quickly ran into several problems related to the PCB. After soldering all the needed components to the PCB, we integrated the circuit board into our design with everything connected except the battery, for safety reasons. As soon as the power was turned on, a trace on the PCB immediately started smoking. We went back to our design files and thoroughly reviewed our PCB layout which led to multiple findings. We quickly found out that there were improper traces in our layout. The first problem we found was that the trace was connected somewhere it should not have been and to fix that we drilled a hole through the trace. We repeated this process multiple times and each time we tried to retest the circuit board, another component or trace would heat up too much and cause damage to the board. After drilling multiple holes into the PCB to break traces and soldering wires on the top of the board to create traces, we were not making any progress. We continued to work on the PCB, but sadly we were unable to fix the PCB before our deadline. Having a dysfunctional PCB was very upsetting for our team, but it was the first attempt at designing a PCB for everyone on our team and we also had to rush our design in order to satisfy our deadline. Even though our attempt at implementing the PCB failed, we still consider our total project a success. When actualizing our circuit using protoboards, our team was able to satisfy the requirements specified by our client and we were able to successfully charge the battery pack. It would have been amazing if our PCB worked as expected, but the PCB was not a requirement given to us by our client and we originally were not planning on doing a PCB layout. Charging the battery sufficiently and safely was our main goal of this project and we were able to do just that. Although many mistakes were made and even more lessons were learned throughout the duration of this project, our team is proud of the work that resulted from all the time and effort we put in over the course of this last year.

5. Conclusion

In order to appropriately showcase Dataforth Corperation's products, our team had to make a variety of strict requirements that would properly uphold the same level of quality that Datafotrth ensures in its products. The team's self-imposed requirements along with the concrete ones given on the project proposal made that feat possible for us. One of the most important requirements crucial to the success of our project was the fault conditions. This requirement was important because ultimately it was the requirement that could prevent a safety hazard from occurring and is the reason why the user's safety is ensured. Another example of a vital requirement would be the user interface, without one the whole project would be pointless and unusable. The goal of the user interface was to give the user all the information that would be desired to know about the charging process. Included in the user selectable values such as the battery pack temperature, cell voltages, and the current going into the pack. The LiPo Crew incorporated a rotary encoder which made navigating through the menu effortless to satisfy the ease-of-use requirements. Lately, the charging algorithm was essential to the success of the project. Although the charging algorithm was not specifically a requirement, the project would not have been possible without being able to control the amount of charge the battery would receive. Without the algorithm, the high energy density of LiPo batteries would create a very unsafe situation for anyone trying to charge a battery of this chemistry. As noted in the testing analysis, these requirements all played their role successfully and allowed for the user to charge the battery with their own settable fault limits or the default ones, safely. This concludes a review of the requirements paramount to the success of The LiPo Crew's 6-cell LiPo battery charger.

5.1 Lessons Learned

Throughout the semester our team learned an immense amount of valuable lessons and information that we will all take with us for future projects and challenges we face in our careers. One of the first and most important lessons we learned was that theory doesn't always translate to practice. For example, when deciding the topology of the charging process we would ultimately incorporate into our design, the charge shuttling method proved to be the most efficient based on the research we did on other peoples prior work. Unknowingly, the mosfets that were being used as switches for the charge shuttling proved to be much more difficult to use in practice and we had a very difficult time controlling them. We could not get them to turn on when wanted or off when needed, based on the articles we read online they behaved as normal switches but was not the case for us when we actually used them in our circuit. After burning out more than what was planned we switched to solid state relays that did the same thing and worked for us with a lot more ease. Another valuable and useful lesson we learned had to do with signal integrity. An issue with the amount of noise that the signals carrying the individual cell voltages to the MSP430 microcontroller. Intense fluctuations occurred at the input to the MSP430 for each of the cells due to many noisy signals being passed into the MSP's inputs. To get rid of that noise, the team decided to add a resistor, capacitor (RC) filter right before the signal entered the MSP430. This reduced the fluctuation of the signals being read by the MSP significantly enough to where we could get an accurate measurement of each cell without doubt. With these valuable lessons, the team can now pass on this vital information to friends and colleagues that have not yet been exposed to situations in which those skills and knowledge are needed.

6. Manual

6.1 Introduction

We are pleased that you have chosen The Lipo Crew for your business needs. There is a strong need for lithium polymer battery chargers, as evidenced by the increasing demand for high voltage output applications in Electric vehicles. Our team provides you with a powerful system for managing the charging process that has been custom-designed to meet your needs. Some of the key highlights include Dataforth's signal conditioning unit paired with their thermocouple to provide the most accurate temperature measuring of the pack to ensure safety, user-settable fault conditions to allow you to determine when the charging will begin, how long it will charge for, and under what conditions should the charging stop. The purpose of this user manual is to help you, the customer, successfully use and maintain The LiPo battery charging product in your business context going forward. We aim to make sure that you can benefit from our product for many years to come!

As the demand for high output voltage applications in portable situations increases, so will the need for the maintenance of the most effective battery chemistry type. In the case of EV's the most popular type of battery chemistry is the lithium polymer, this is due to their high energy density and have a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge. Although that chemistry performs the best, it comes with dangers that require special attention to the instability of the battery cells themselves. To maintain the stability and longevity of the battery, our team chose to have multiple checks around the system to maintain the safety of the user. For example, specific lines of code in the charging algorithm were made to implement and ensure we could control when the battery charges in the constant voltage phase or when it should enter the constant current phase. Another way in which we check for a safety hazard is by checking the temperature of the battery pack itself using Dataforth's signal conditioning unit along with their thermocouple to ensure accuracy of temperature. These were both made possible through the use of the MSP430 in which handles all of the communication between the temperature sensors and will cut off or reduce voltage and current as necessary.

Our team broke up the project into four main subsystems in which we worked on in pairs. The first subsystem covered the charging algorithm which was strictly software orientated. This system was crucial for the success of the project because it controlled when the battery would receive a charge, the rate of charge, and the time of charge. Due to safety concerns, we took the average of all the cells, and if the average was over 4.0V the charging algorithm would stop the constant current phase and switch to constant voltage for the last stage of charging. The second subsystem consisted of a thermal system in which two thermocouples, along with the signal conditioning unit provided by our client, communicate to the MSP430 their individual temperature reading of the battery pack. This information is then taken and used to generate the average of the two individual temperature readings in order to account for any fluctuations in their respective readings. Conveniently the average temperature of the battery pack is then displayed onto the LCD on a timed interval and displayed for five seconds every other 5 seconds. The third subsystem is the battery charging circuit which utilized LM317T voltage regulators to provide the constant current and constant voltage charge to the battery. By using 2 regulators our system can output a current of 2.35A for our constant current charge. The system's constant voltage output utilized a single regulator to output a total of 25.2V of charge voltage to the battery. The final subsystem references the user interfacing software and hardware as described in the user manual under "Configuration and use." In terms of hardware, an LCD and rotary encoder are used for the user interface. AS the LCD displays the information the rotary encoder is used to navigate the screens options. For the software portion of this subsystem, it allows for user-settable fault conditions and alarms as well as a battery status indicator for user coherence.

6.2 Product Features

- 6S battery balance port plug
- Main charging port plug
- 5 V DC regulated fan
- LCD w/ rotary encoder
- Battery Discharge Port
- Alclorol 30V 10A power supply
- MSP430FR6989 Microcontroller for charge control/algorithms
- LM317 voltage/current regulation
- 2 x Thermocouples with signal conditioning unit
- DW01A battery protection IC

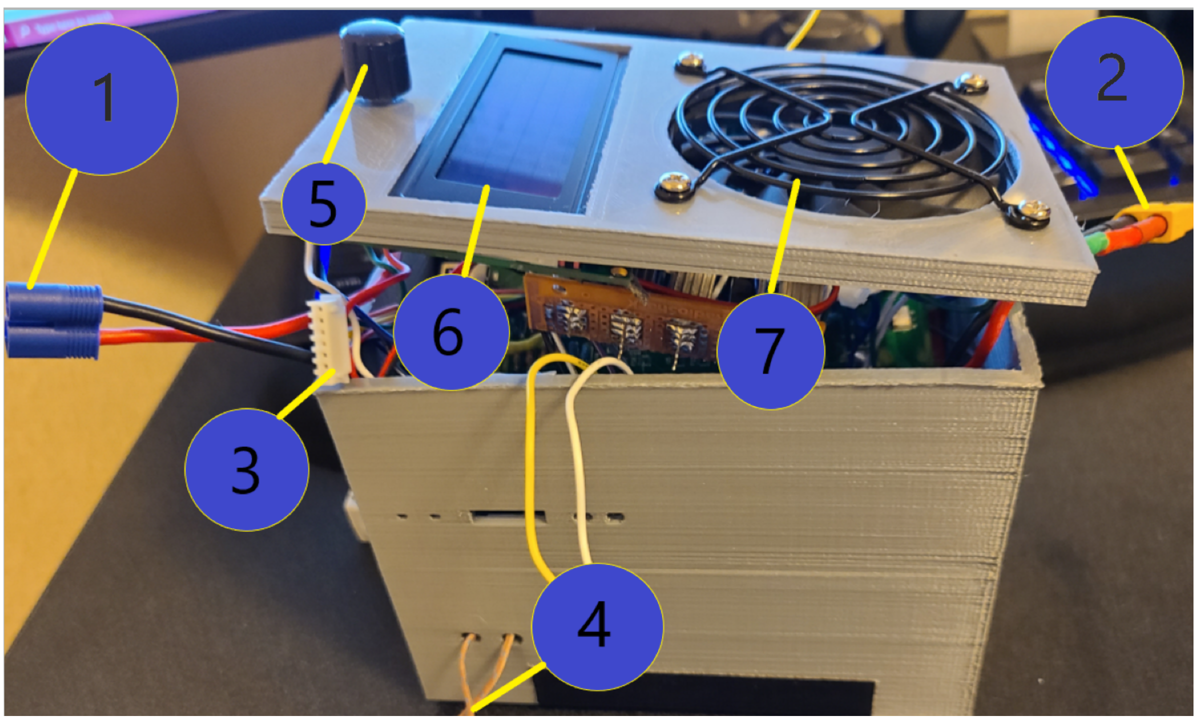
6.3 Specifications

Size: 160 x 109 x 110mm
Battery Chemistry: Lithium Polymer (LiPo) ONLY
Battery Cells: Constructed for 6S batteries ONLY
Power supply input: 115V AC
Power supply output: 25.8V DC
Output Wattage: 38.7W
Charging Voltage: 25.2V
Charging Current: 2.35A (1250 - 1300mAh batteries)

6.4 Safety Instructions

1. For indoor use only.
2. Do not use any power source that does not have a legal manufacturing license.
3. Use only 6S Lithium Polymer Batteries. No other battery chemistry or cell count will be compatible with this device.
4. Be sure to plug the battery into the charge ports before applying the power supply.
5. Recommended use of a LiPo battery fireproof safe bag while using this product.

Components



[1] Main battery plug **[2] Power supply connector** **[3] Battery Balance Port**

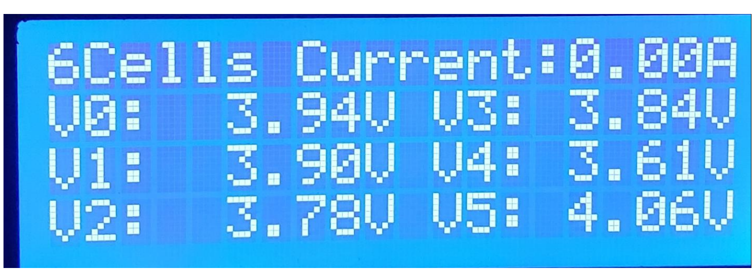
[4] 2 x Thermocouples **[5] Rotary Encoder** **[6] LCD** **[7] 5V DC Fan**

6.5 Installation

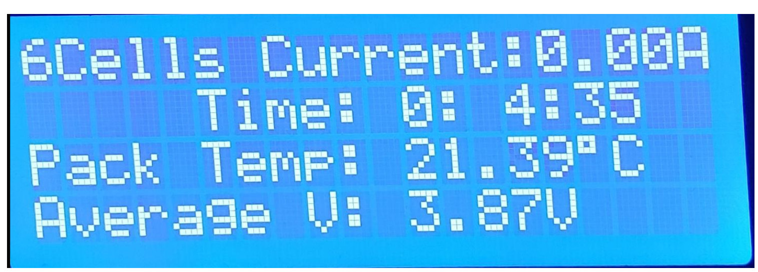
1. Before starting, verify that the power supply [2] is not connected to the product.
2. Connect a healthy 6S LiPo battery to the balance port [3] and the main battery plug [1].
3. Connect your power supply output coms to the power supply connectors [2].
4. Plugin the 25.8V power supply to a US 115V AC outlet.
5. Upon startup, the LCD [6] will flash on and the device is ready to be used.

6.6 Configuration & Use

1. Power On
    - 1.1. The LCD [6] will turn on and asks to "Enable Fault Conditions:"
        - 1.1.1. Using the Rotary encoder [5], twist clockwise or counterclockwise to navigate through the two available options; "Yes" or "No." Press the rotary encoder firmly to select the desired option.
        - 1.1.2. If "Yes" is selected: On the next display, temperature limits on the battery can be set between 40 - 45℃.
            - 1.1.2.1. The last display will allow for the total charging time to be set between 5 - 60 minutes.
        - 1.1.3. If "No" is selected: On the next display, "Temperature" will be set at a default temperature of 45℃ with a default charge time of 60 minutes.
2. Charging
    - 2.1. As soon as the fault conditions have been set the charging process will activate.
    - 2.2. During the charge, the LCD will display the two screens shown below [1] and [2].
        - 2.2.1. Display 1, will show the voltages of each cell, how many cells are connected, and the *current (non-functional). This screen will be displayed for 6 seconds before switching to [2].
        - 2.2.2. Display 2, will show the overall time of charge, the pack temperature, the number of cells connected, the average voltages of the cells, and the *current (non-functional). This screen will be displayed for 6 seconds before switching to [1].



[1] Display 1



[2] Display 2

3. Fault Conditions, Battery Fully charged, and Extra Displays.
    3.1. The "Connect Battery" [3] fault condition will trigger for circumstances where the battery is disconnected, not connected properly, or if a cell voltage is detected to be ≤ 3.0V.
    3.2. The battery fully charged display shown in [4] will trigger when the battery is determined to be fully charged. This will occur when one cell reaches 4.2V.
        3.2.1. This screen can also be triggered if the battery charge time limit has been met even if the battery is not fully charged.
        3.2.2. If this screen [4] is shown you may now safely remove the battery from the charger.
    3.3. The "Temp Limit Reach, CC & CV Disabled" will be displayed when the temperature falls outside the temperature range limits of 40 - 45℃.

[3] Connect Battery [4] Battery Fully Charged

6.7 Maintenance

Please read the user manual carefully before operating this device. This product is only intended to be used as a 6S LiPo battery charger. Any other battery cell counts or battery chemistries can and will result in multiple safety hazards such as battery explosions, fires, destruction of the product, user harm, dismemberment, and even death. Furthermore, to preserve the integrity of the device, avoid damage to the product's external and internal features. This product must also be dry at all times and be kept in a room-temperature environment. The LiPo Crew also recommends the use of the Alclorol 30V 10A power supply when using this product.

6.8 Troubleshooting

1. If a system reset is needed, a simple disconnection of the power supply from the outlet or the product will reset the entire charger.
2. If any errors still persist, disassemble the top cover from the main product and check that all of the metal contacts on the wires are not touching.

3. For charging and display errors use the MSP430 Code provided and reconfigure the code using Code Composer studio software.

6.9 User Manual Conclusion

The presented 6S LiPo battery charger was designed and manufactured by The LiPo Crew. Overall, our product uses high end parts, of which the majority was provided by Dataforth Corporation's in house inventory. With Dataforth being a world leading data acquisition and signal conditioning unit, their products allow for high accuracy, great efficiency, and true reliability within our own battery charging design.

Again, the purpose of this user manual is to help you, the client successfully use and maintain The LiPo battery charging product in your business context going forward. The LiPo crew's goal is to provide a safe and efficient 6S LiPo Battery charging system and this product accomplishes that goal. In the end, please read each section of this user manual carefully before operation for your safety and satisfaction is our top priority.

7. Appendix A

Github Code address
https://github.com/lc833/LiPo-Battery-Charger.git

7.1 Appendix B

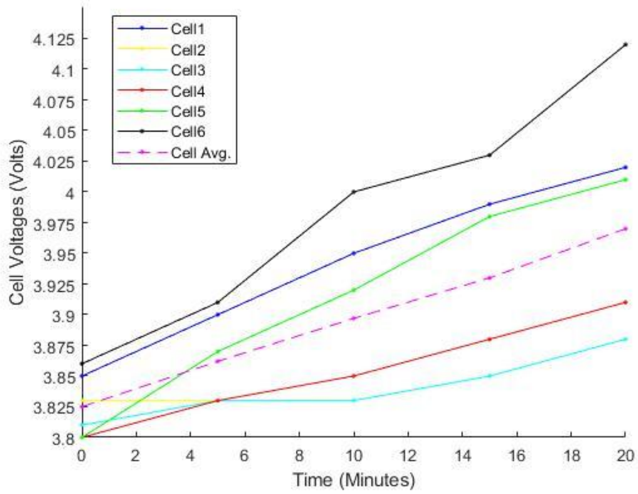


Figure 11. Cell voltages during 20 minute test

The cell voltages increased on average by 35.75mV per 5 minutes.

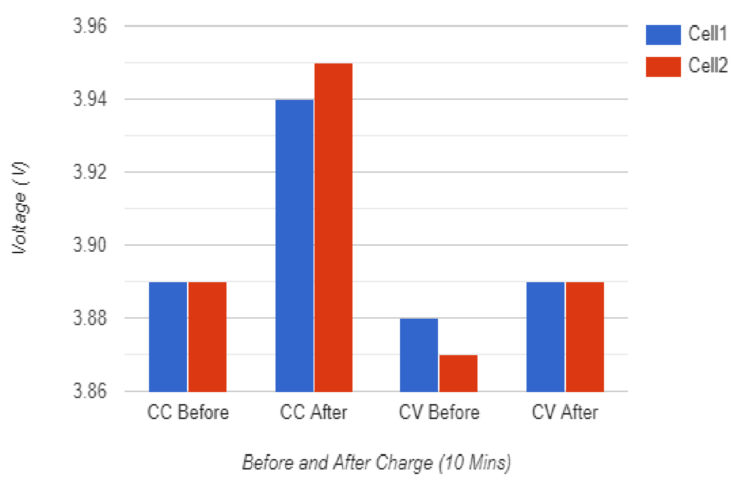


Figure 12. Cell voltages prior to and after CC & CV tests.

This test was conducted using a two cell battery for safety reasons therefore, only two cells are represented in this figure.

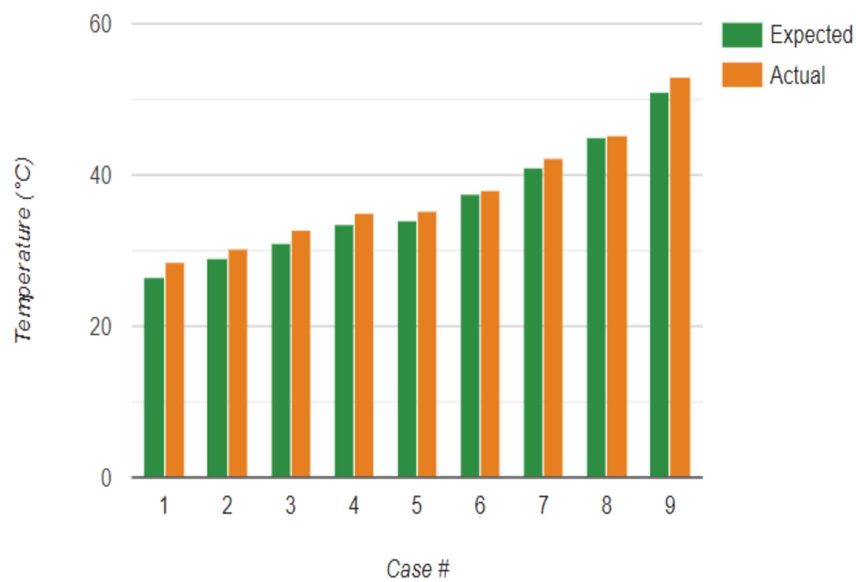


Figure 13. Average temperature measurement vs. expected temperature.

Tests were conducted by increasing one thermocouple over time and leaving the other at a constant 22.0°C. 66% of our test cases were successful, and the remaining unsuccessful test cases failed to fall within 1.5° of the expected temperature.