Resistance Racing – Electrical

Battery Management System

Fall 2017 Technical Report

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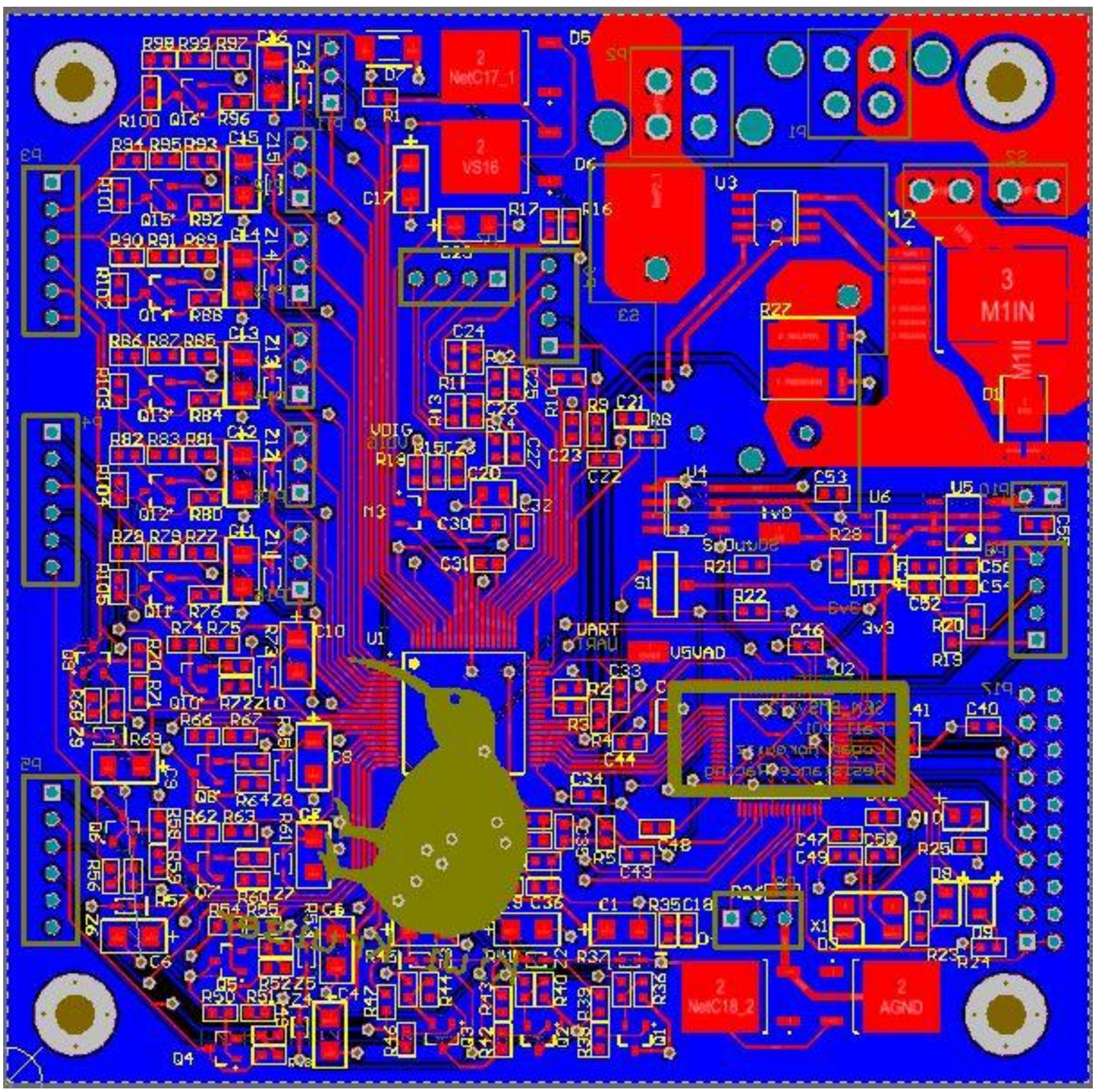
Summary

System Description

The battery management system acts as the overall safety monitor for the vehicle. It collects various data describing the operation of the vehicle and shuts down all power if it determines the conditions are unsafe. As the board has not been manufactured yet, the current version of the layout is shown below.



Terminology

IC: Integrated Circuit. A device designed for mounting on a PCB or in a breadboard, usually in a small black package, which performs some specific functionality (opamp, microcontroller)

PCB: Printed Circuit Board. A board of copper and fiberglass used for wiring small IC's and passives in a compact manner.

Trace: A connection of copper on a PCB; basically an integrated wire

Cell/Battery: These are sometimes interchangeable; I generally use battery to refer to the battery pack in the vehicle which is actually a series connection of 12 different batteries. I refer to each of these individual batteries as a cell.

Passive Device: Something with a linear IV relationship either directly or by first derivative. (resistor, cap, inductor)

Joulemeter: Device which measures current and voltage to determine the amount of instantaneous power consumption.

MC: Motor Controller. Delivers signals to the motor to control when and how fast it accelerates the vehicle. We are using a brushless DC motor and therefore a BLDC motor controller.

BMS: Battery Management System

DAQ: Data Acquisition System. Collects data and will provide visualization and analysis.

Research

Design Requirements

The battery management system collects voltage, current, temperature, and fault data and then analyzes it to determine if the vehicle is operating in an unsafe condition. If so, the BMS communicates the information to the data acquisition system and cuts electrical power to the rest of the vehicle. It must ensure that all electrical power is isolated from the front of the vehicle during a fault. If the vehicle is operating safely, it simply sends the data to the DAQ and then checks the vehicle again.

Design Requirements Derived from Rules

Article 37

d) The emergency shutdown switches must isolate the batteries from the propulsion system; relays must be normally open

f) There must be both an internal and an external shutdown mechanism.

g) The emergency mechanism must be a latching red pushbutton

Article 57

a) For safety reasons, the maximum voltage on board of any vehicle at any point must not exceed 48 Volts nominal and 60 Volts max

b) For all vehicles, only one on-board battery is allowed.

d) If Lithium-based batteries are used,

i. Battery Management Systems (BMS) must be tailored to the lithium chemistry

1. The BMS must provide cell balancing and overvoltage protection during off-track charging.

2. For battery electric vehicles, the additional requirement of cell level over-discharge, cell level overcurrent and battery over-temperature must be provided as part of the on-vehicle system. The BMS must AUTOMATICALLY isolate the battery, without operator intervention!

Article 57

d) iii. Charging of batteries must be done with the battery charger purchased together with the battery or a purpose-built charger specifically suited to the given battery chemistry.

vi. Any Lithium based battery must be equipped with a solid metal containment tray under the battery OR the battery must be enclosed in a battery charging bag. Either the tray or bag must be suitable to prevent the battery, in the event of a battery fire, from burning through the battery mounting or the vehicle body and dropping to the ground.

viii. Printed manufacturer's documentation for lithium-based batteries and the associated battery management system must be available for review during technical inspection for the battery and BMS to be acceptable (see Article 58:c)

Article 57

e) All batteries and Supercapacitors must be short circuit protected. Short circuit protection devices must be located on the positive conductor and as close as possible, or a maximum 300 mm from the positive terminal of the battery

g) All vehicle electrical circuits must be protected against electrical overload. This can be controlled electronically or by using fuse/circuit breaker.

k) No spaghetti wiring

Article 24

h) Effective equipment suitable to mitigate and/or control Lithium-based battery fires must be used during battery charging. The equipment must prevent or contain the spread of fire or battery even during charging. Equipment that may be used includes: battery charging bag or fire blanket

In summary, the battery management system must monitor over/undervoltage, overcurrent, and high-temperature conditions. It must respond to any unsafe condition or a pulling of the emergency switch by physically isolating the batteries from the rest of the vehicle's electrical system (via normally-open relay). It must be capable of cell-balancing and monitoring the batteries' condition during charging as well. Both the BMS and the charger must be capable of performing their functionality with batteries of the chosen chemistry (ours is lithium polymer). We must place a fuse near the battery pack and all wiring must be clearly constrained and labelled. The battery must be contained in a metal tray.

Key Specifications

Our primary specification is safety; it must be able to perform the above duties without fail. Some additional considerations include:

- Size and weight
- Communication with DAQ
- Robustness of safety protocols
- Modularity
- Power Consumption

Interfaces

The BMS must interface with every other electrical system on the vehicle because it controls the power flow; it must also communicate to data acquisition and heavily influences the design of the wiring harness. Its physical location relative to the batteries is very important, so it influences bulkhead electronics tray design as well.

Motor Controller: The only interaction is through high-power wires. We have agreed on Molex Minifit Connectors for this.

Data Acquisition: These devices will communicate via I2C.

DC-DC Converter: The power for the DAQ comes from the BMS through a DC-DC converter. We have again chosen Molex Minifit connectors for the wires from the BMS to the converter.

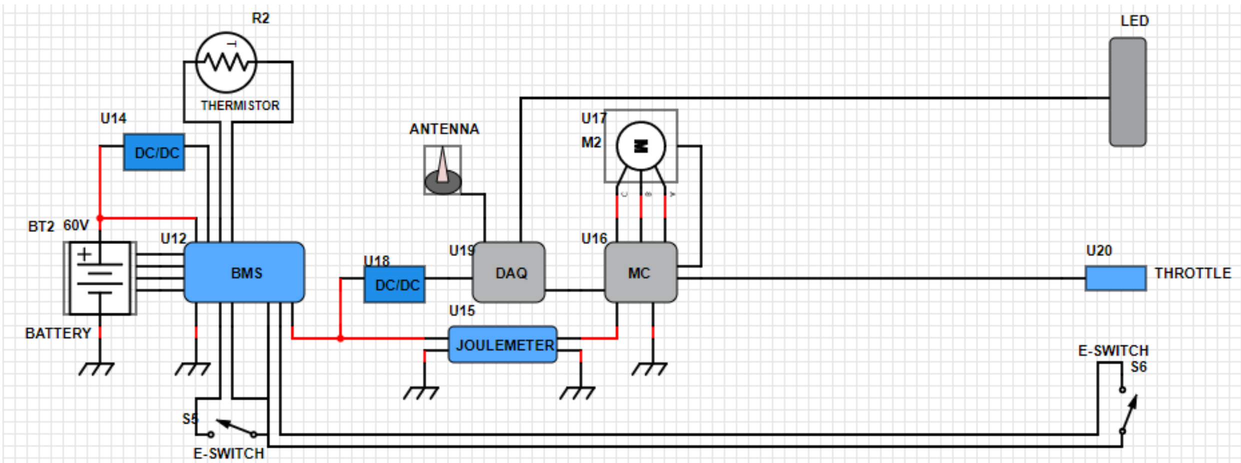
Wiring Harness: We will need to think carefully about where we place various connectors and how we route the wiring to ensure that we can attach and detach all of the electronics easily and safely as needed. The bulk of that design process has yet to be completed, but it will need to take many things into consideration such as:

- Length and location of high-power wires
- Distance between BMS and batteries
- Which aspects may need to be disconnected at comp and which should never be

Bulkhead Layout: The BMS must be situated very close to the batteries and should be as close as possible to the joulemeter to minimize high-power wire length.

System Diagram

The battery management system is integrated with the battery pack, and it controls all discharge from the pack to the rest of the vehicle. The figure below illustrates its position in the vehicle. Red wires are high-power (44V, up to 30A), black wires are low-power (5V, up to 2A).



The BMS takes all the cell voltages as inputs, as well as two emergency switches. It also receives 5V power from a DC-DC converter, and communicates to the data acquisition system via I2C.

Potential Designs

There were two main designs options: buy a commercial BMS or design a system around a BMS IC. There are tradeoffs for both; the advantages of building our own system are:

- Highly optimized in terms of functionality
- Small and lightweight
- Better design experience
- Lower power consumption
- We can understand and debug issues ourselves

while the disadvantages are:

- Less robust
- Much more difficult, time-consuming, and likely to fail

We currently own one of the best commercial battery management systems available, the Orion BMS. The other best commercial option which still fit Shell's stringent safety requirements was the iBMS. There were many options for BMS IC's, each with varying characteristics. In order to analyze their efficacy, I looked over their datasheets and looked at their robustness of safety protocol, what faults they can detect, how optimized they could be for our vehicle, how difficult they would be to implement, how much of a good learning experience they would be to work with, and how expensive the overall system would be. The chart below details my rough conclusions about the best options.

System	Design Opportunity	Difficulty	Effectiveness	Cost/Feasibility	Overall
TI	9	9	9.5	7	**9.5**
LT	9	7	8	7	**8**
Maxim	10	9.5	7	7	**7**
Intersil	9	8.5	9.5	6	**9**
Orion	1	1	5	10	**4**
iBMS	Low	?	High	Low	**5**

Green: Self-Designed Using IC's Yellow: Commercial BMS

Here are my notes for each of the systems:

TI: Very safe with extensive fault conditions and shutdown, very robust, a lot of extra passive components, uart communication, capable of 16 cells (BQ76PL455A)
I think we could build a great system; much more complex than others but also much safer.

LT: Extremely accurate, isolated communication protocol, power directly from stack, GPIO, built-in ADC, power from pack, requires external caps, 12 cells max. (LTC6811-2)
I think we could build a simple, effective system.

Maxim: High accuracy, fault detection and shutdown, requires external ADC, requires separate 5V power source, 16 cells max(MAX14921)
I think we would have issues with the multitude of external IC's required; there are issues in isolation and power source which would complicate things

Intersil: Very safe with fault conditions and shutdown, low power, isolation issues, 3.3V logic level, 12 cells max, lots of passive components (ISL94212)
I think we could build a great system; slightly more complex than others but also safer. Must use Li-Ion batteries!

Orion: Very easy to implement, but no design opportunity and far from optimized.

iBMS: Expensive with no design opportunity; fairly optimized

Selected Design and Justification

I have chosen to go with the TI BQ76PL455A-Q1 IC from the chart above. I chose it primarily because of its robust safety protocols, its ability to be highly modular and optimizable, for the extensive design process we will need to get it working, its extensive documentation, and compatibility with lithium polymer batteries. Out of all the BMS IC's, I think it will provide the safest system. Now that I have chosen the BMS IC, I need to design the system around it. The datasheet illustrates a recommended schematic (http://www.ti.com/lit/ds/symlink/bq76pl455a-q1.pdf). This IC is capable of communicating to a microcontroller via UART, and it requires many passive components around it. The datasheet also lists specifications for these passive components to aid in their selection process. I will explain some of the important design choices, and leave the more arbitrary ones to be viewed in the Bill of Materials. (https://docs.google.com/spreadsheets/d/1V2rgOF2B6c6Zu4EjqhKDZiHWLr7XadBr8fcrRA5lOM8/edit#gid=714885108).

It may be clearer to read this after going over the schematic and layout so that you have an idea of what these components are doing and where they are located in the design.

Microcontroller: I chose the STM32F4 because its architecture is similar to what we are learning in 3140; it is a robust IC with a small footprint; it is currently what Tim is using for his motor controller and he has experience with it. We want to ensure that the team uses the same architecture for all projects going forward so it becomes easier to learn and debug. In the past, we have had issues with fractured organization and poorly documented components. (http://www.st.com/content/ccc/resource/technical/document/datasheet/ef/92/76/6d/bb/c2/4f/f7/DM00037051.pdf/files/DM00037051.pdf/jcr:content/translations/en.DM00037051.pdf)

FET Driver: I needed a chip which could drive the power FET at the top of the battery stack, turning it on or off as the microcontroller dictates. I chose the Microchip HT0740. It is a high-voltage tolerant chip suited for driving MOSFETs as high-side switches, which works at 3v3. (http://ww1.microchip.com/downloads/en/DeviceDoc/20005628A.pdf)

Power Transistor: The main consideration here is On-resistance. I wanted the FET to provide as small a resistance as possible so that the power lost is minimal as high currents go through it. This is important not only for efficiency, but also because heat dissipation is a real problem on PCBs. Anything that burns power on the order of Watts requires a heat-sink and may cause problems to neighboring components or itself. I chose the Infineon IRFS7530 because it has the lowest R-on of any FET I found. (http://www.mouser.com/ds/2/196/irfs7530-7ppbf-937822.pdf)

High-Power Diode: Again, the goal was to minimize power loss because this is in the high-power path. It will only pass current during charging, though. Therefore, it must be able to withstand about 3A without heating excessively. I chose the SBRT20M80SP5 from Diodes Inc because it offered a very low forward voltage drop. (https://www.diodes.com/assets/Datasheets/SBRT20M80SP5.pdf)

I-Sense Resistor: I simply needed something which would be fairly accurate, easy to connect to, and provide the correct resistance. After some computation with the likely currents in the vehicle, I figured 5mohm would be an appropriate value. I chose a Vishay SMD resistor. (http://www.vishay.com/docs/30131/wsl2726.pdf)

Sense Amplifier: I needed an amplifier capable of monitoring the voltage across the sense resistor at the high side of the pack. This requires high-voltage isolation. Also, I wanted a bidirectional amplifier so that we could monitor current while charging or discharging. I chose to go with the MAX4081. I like MAX products because they generally have very high precision, making them a good choice for ADC's or precise regulators. I selected the 4081 because it offers bidirectional sensing. (https://datasheets.maximintegrated.com/en/ds/MAX4080-MAX4081.pdf)

Relay: The relay needs to be able to handle at least 60V and 30A and preferably higher. It should provide minimum on-resistance again to reduce power losses and heating. Finally, it needs to have a control voltage of 5V. I chose the only one I could find that met these specifications, the T90 series from TE connectivity. (http://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=1308242_T90&DocType=DS&DocLang=English)

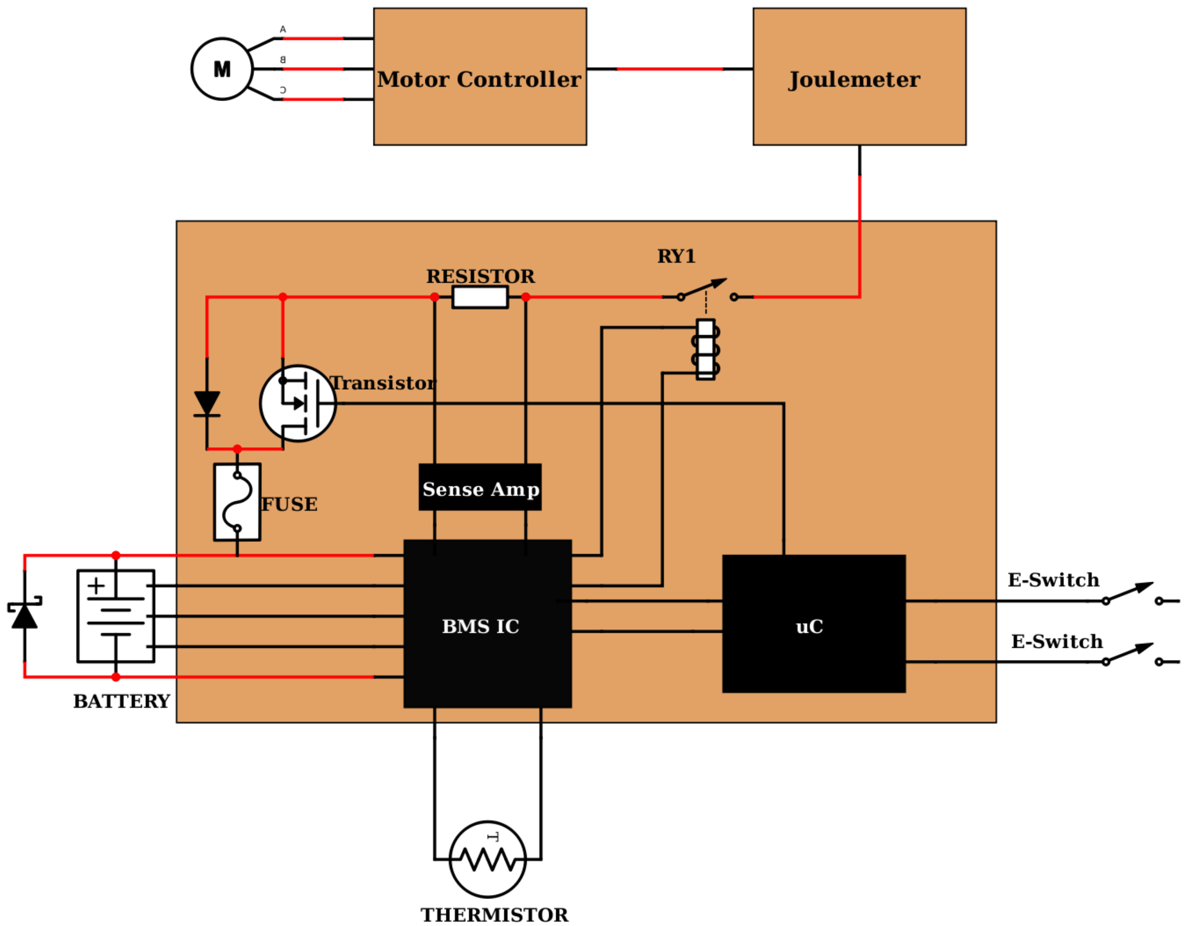
Capacitors: Anything that would be shown the full rail (~60V) was chosen to be a polarized electrolytic 1206 SMD capacitor. All others were ceramic 0603 capacitors.

The other component selections were either arbitrary or dictated by specifications in the recommended schematics for previous chips.

Detailed Design (CAD)

Design Overview

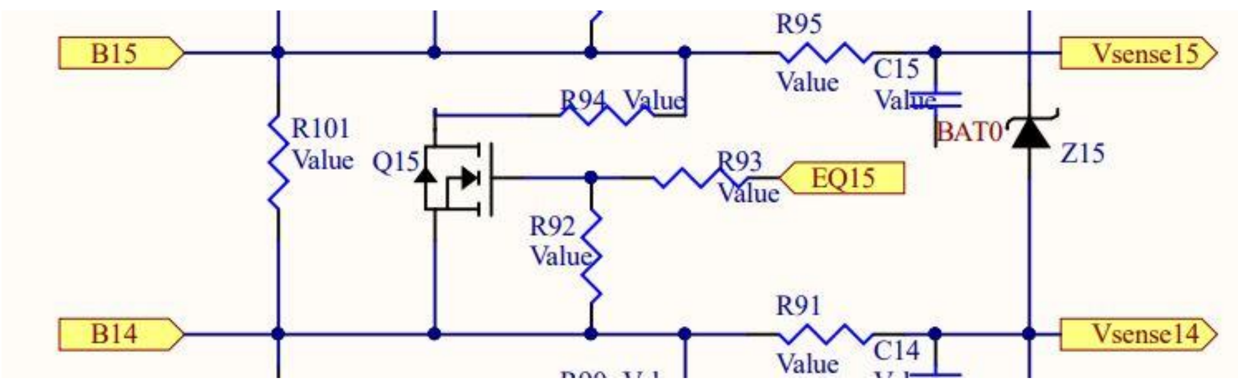
The figure below illustrates the high-level BMS design and illustrates its cut-off mechanisms



The BMS IC is connected to every cell in the battery stack and is capable of monitoring the voltage of each cell. The current will be determined using a sense resistor and amplifier. The temperature of the BMS IC is monitored internally, while the temperature of four locations in the battery pack will be monitored via Thermistors. The BMS IC also monitors communication faults between itself and the microcontroller (uC). The E-Switches will be connected to the microcontroller on the BMS through GPIO. The BMS IC will only close the relay if there are no fault conditions, while the microcontroller will only close the FET if there are no fault conditions or open E-switches.

We have four different safety mechanisms which ensure that the rest of the vehicle electrical system will not be subject to unsafe voltage or current conditions. First, we have a fuse positioned at the top of the battery stack which is rated to blow for sustained current above 30 amps. Second, we have a power MOSFET controlling discharge current which the microcontroller can open when a fault or E-switch condition dictates. Third, there is a normally open relay which the BMS IC will close only if it recognizes safe temperature, voltage, current, E-switch, and communication conditions. Fourth, we have various transient suppression diodes across the battery pack and BMS. All of the high-power wiring to the rest of the vehicle comes from the output of the relay, ensuring that the vehicle remains electrically active only when we are certain of the safety.

In addition, the BMS must balance the cell voltages during charging. The basic idea is that throughout charge and discharge cycles, some of the batteries may be used more than others, and therefore they will have a different amount of charge than neighboring cells. This usually corresponds to having a different potential than other cells. Imbalances in cell charge can cause issues with the batteries' "health" and diminishes the number of cycles they can undergo before requiring replacement. Anyone who has owned an iPhone and notices that the battery capacity significantly degrades over time is experiencing a deterioration in their battery's health. It also causes safety concerns because some cells may be over or under-discharged. There are two types of cell-balancing: active and passive. Passive cell-balancing involves using a transistor to switch current through a resistor instead of through a cell, thereby reducing the amount it charges. Active cell-balancing is a similar process which uses inductors and capacitors instead of a resistor for higher efficiency. Shell mandates that we implement at least passive balancing, and we have chosen to do just that because active balancing is much more complex and unnecessary. The passive balancing is achieved using the following circuit:



The battery is connected between ports B15 and B14; Q15 and R94 provide the alternate path for current to flow.

Finally, the BMS must communicate with the data acquisition system. It does this via a 2-wire I2C connection. It will send temperature, voltage, current, and fault data for analysis.

Wiring Diagram

The schematics are split into 6 sheets and then connected by a top_level sheet.

https://drive.google.com/drive/folders/0BxsUkcy2L3JQdjBDNmVFc0tRX2s

The first schematic is for the BMS IC. The cell connections are wired to ports labelled Vsense0 – Vsense10. Then they continue with VS11 – VS16. The reason for the difference is that we wanted the BMS to be modular in terms of number of cells connected. We can have anywhere from 10-16 cells connected; depending on how many we choose, it will affect the connections of these top cells. This is explained more in the headers sheet. We also have connections EQ1 – EQ16 going to ports. These are the control signals for cell-balancing. There are diode connections to the bottom and top cells for transient suppression as well. All of the connections on the top side of the IC have low-pass filtering and then go to ports to the headers sheet, these are the temp sensor inputs. On the right side, there is a plethora of decoupling capacitors, and a BJT to regulate the 60V down to an internal 5V for the chip. There are 6 GPIO connections and two UART, all of which go the microcontroller. Much of this is based off the recommended schematic for the TI BMS chip on its datasheet.

The second schematic is for the cell connections. These receive inputs for each cell from the headers sheet and the outputs go the the BMS IC on the previous sheet. This sheet shows the cell-balancing circuits for the battery pack. R100 – R105 are 0ohm resistors which will only be soldered on to short the top cell connections down to whatever our top cell is. For example, if we are running with only 12 cells, then R100-R103 will be soldered on so that the top cell for the BMS IC is Vsense13. Q16 and R98 provide the alternate current path when we are balancing cell 16, and the corresponding transistors and resistors do the same for every cell. The capacitors provide decoupling and the Zener diodes provide transient suppression.

The third schematic is for the control path. The high-power path from the batteries flows through these components before exiting the BMS and going to other components on the vehicle. First, there is a fuse which is rated to blow at continuous 30A. Second, we have the power MOSFET and low-Vf diode in parallel. The MOSFET is controlled by the HT0740 because it requires a higher voltage/current than the microcontroller can supply. It will be turned on to allow discharge, while the diode allows charging (it has a lower Vf than the body diode of the MOSFET so it will cause less heating). Then current flows through the sense resistor. The voltage across that is amplified by the sense resistor and sent to the microcontroller. Finally, there is a relay which is controlled by the BMS IC.

The fourth schematic is for all of the connections to the board. It features 2 Molex Minifit connectors for the high-power path, 3 tension-clamping terminal blocks for the cell connections, 2 tension-clamping terminal blocks for the thermistor connections, 1 tension-clamping terminal block for the emergency switches, 1 tension-clamping terminal block for the I2C communication with DAQ, 1 two-pin header for the 5V input, a switch for setting the BMS in charge or discharge mode, 1 twenty-pin header for programming, and 6 two-pin headers so we can short whichever top cells we need, depending on how many cells we choose for the vehicle.

The fifth schematic is for low-voltage power. It consists of a 1V regulator to provide a reference voltage for the sense amplifier, a 3v3 regulator for the STM logic level, and an LED to indicate when the board is powered.

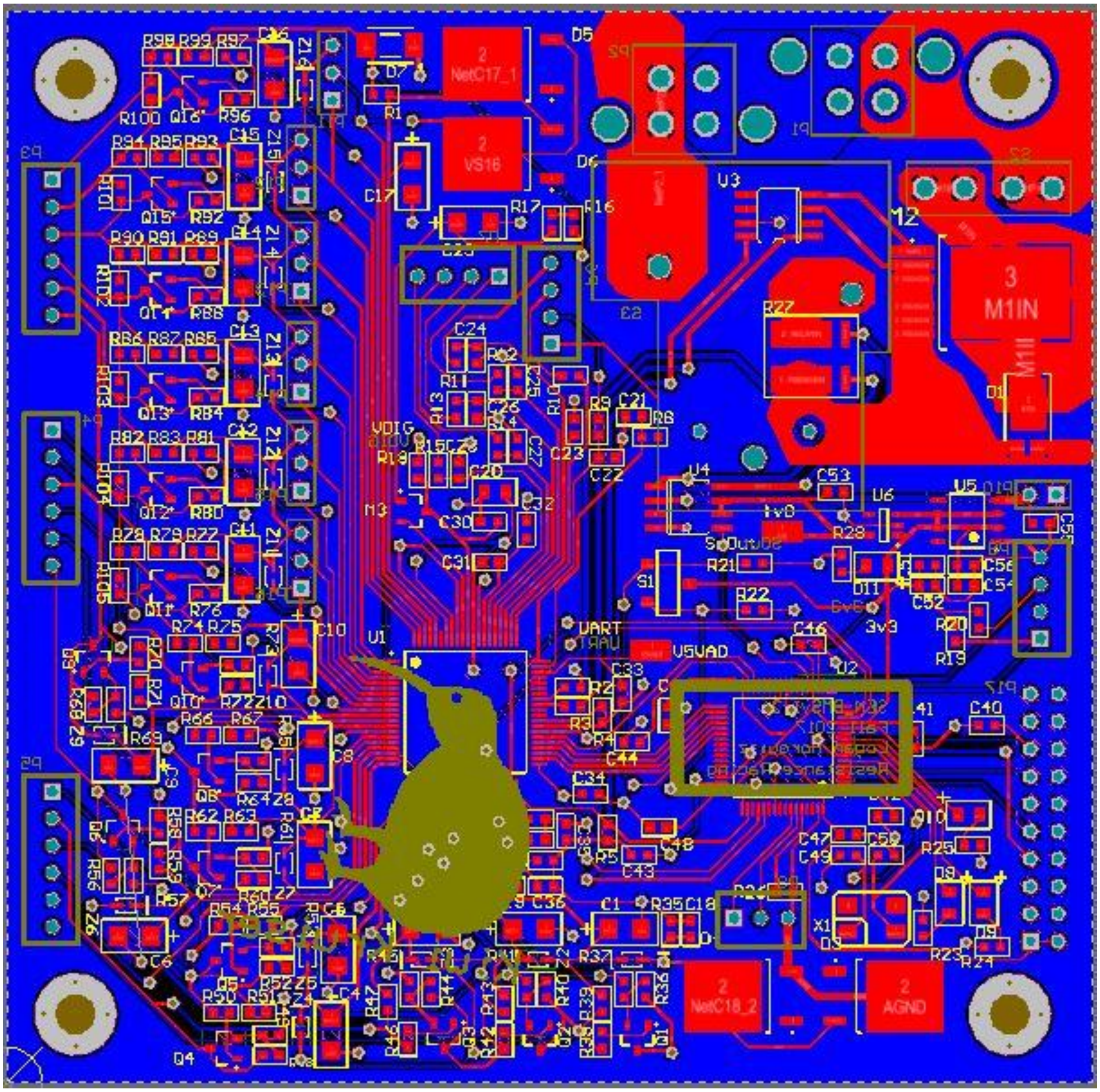
The sixth schematic is for the STM IC. There are many decoupling capacitors connected to the Part B. There are connections to all of the pins needed on the programming header including NRST, SWDIO, SWCLK, and SWO. A crystal is connected for the IC's clock. There are 3 different LEDs connected for signaling different things. There are GPIO connections to the BMS IC as well as GPIO inputs wired for the emergency switches and discharge/charge control signals. Finally, there are output controls to the FET driver.

The final schematic is the top level, which shows all of the connections between the sheets. We can see the cell and cell-balancing connections between the BMS_IC sheet and the Cell_Connections sheet, as well as the wiring for these from Cell_Connections to the Headers sheet. We can see the GPIOs between BMS_IC and STM_IC. All of the AUX inputs between Headers and BMS_IC are for the temperature sensors. Power has no connections because its outputs are specified as voltage rails.

Layout

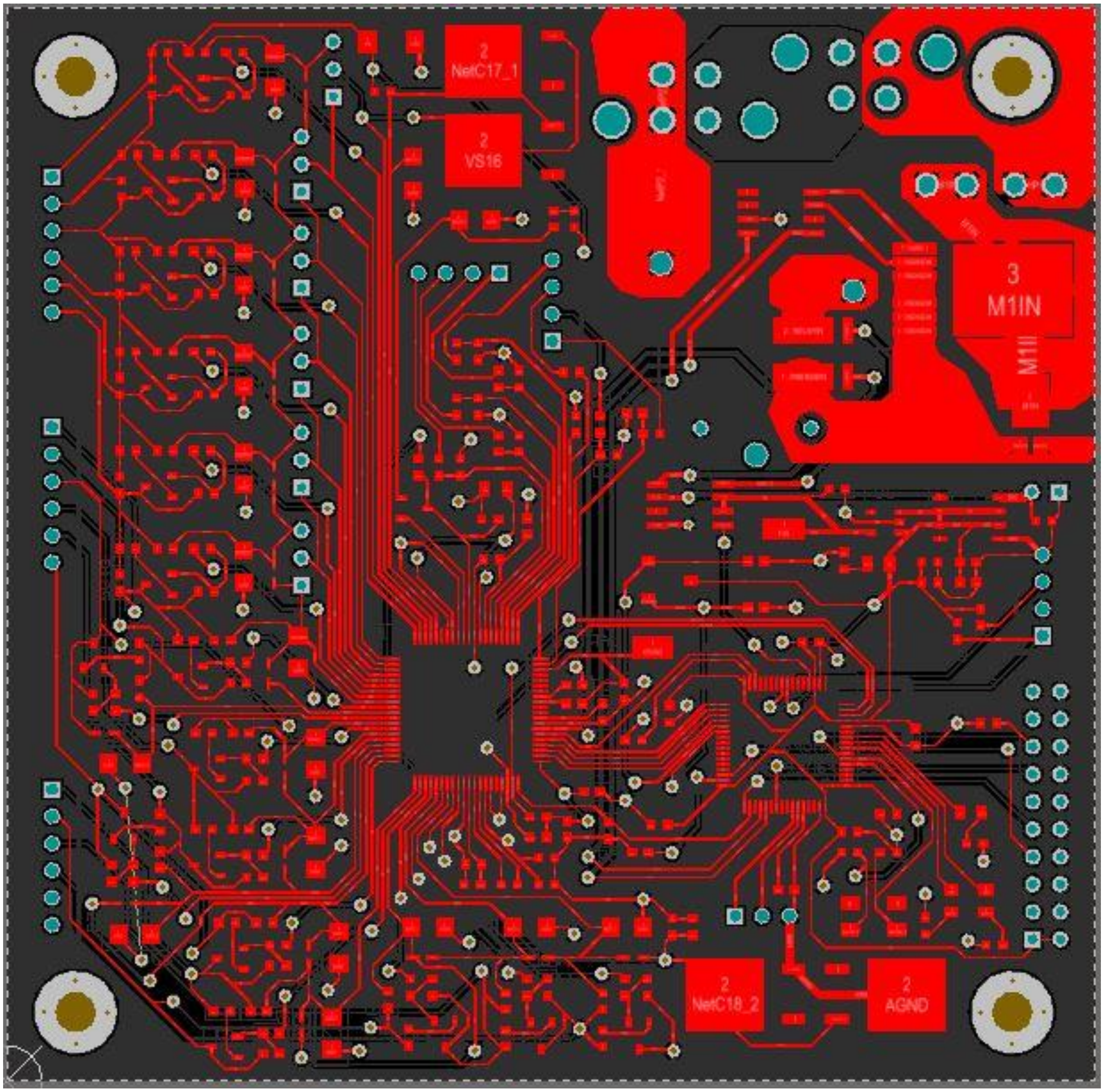
This has gone through multiple revisions and may go through a couple more before ordering the board, so for the latest version check github: https://github.coecis.cornell.edu/Resistance-Racing/SEM-BMS

Complete Picture:



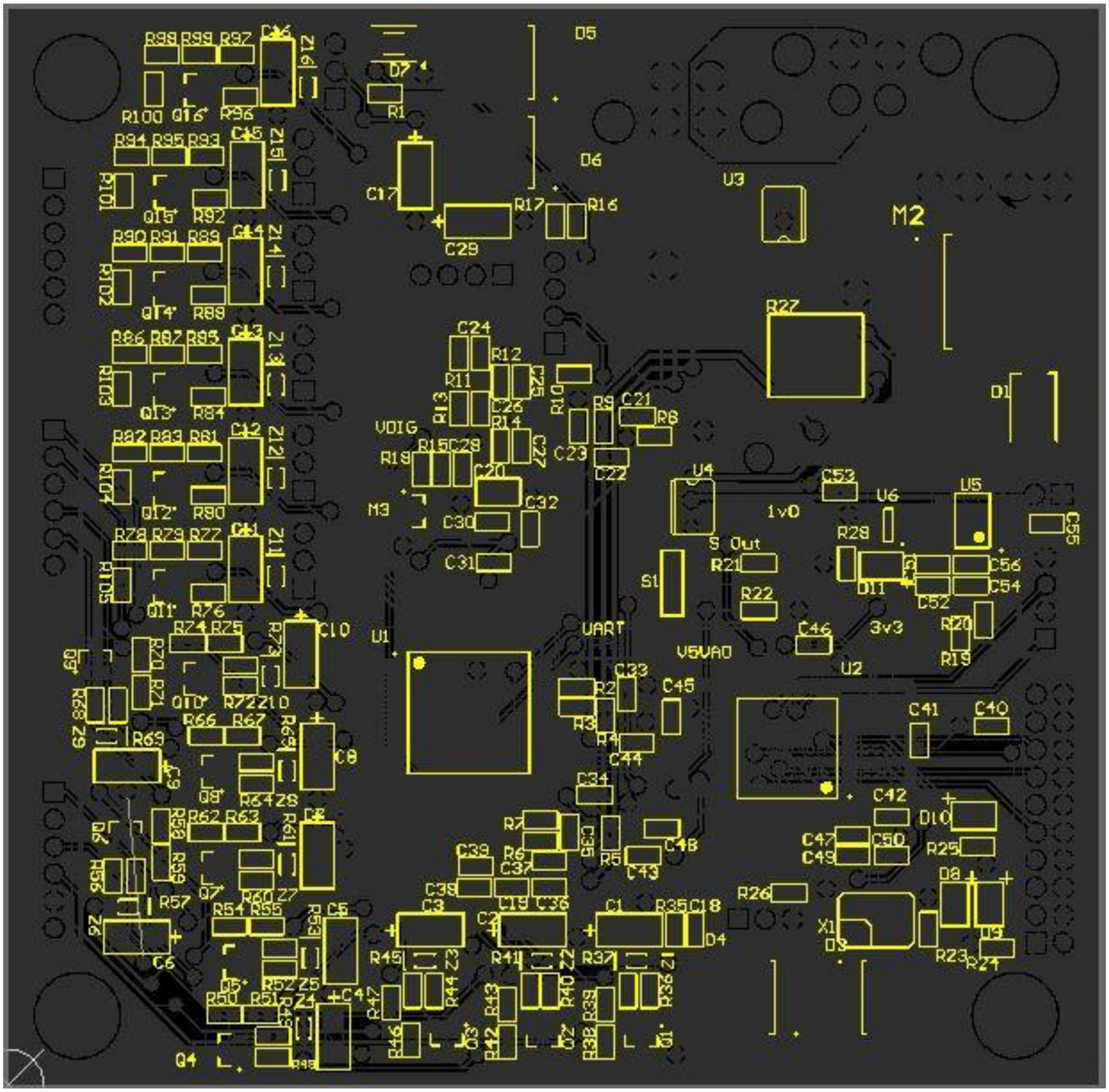
All of the SMD components are placed on the top layer. These consist of all the IC's as well as the active and passive devices around them. All of the through-hole components are placed on the bottom. These consist of all the headers and the relay. I chose to organize it this way because there was not enough room to place everything on the same layer, and this allowed for the most compact layout.

Top Layer:



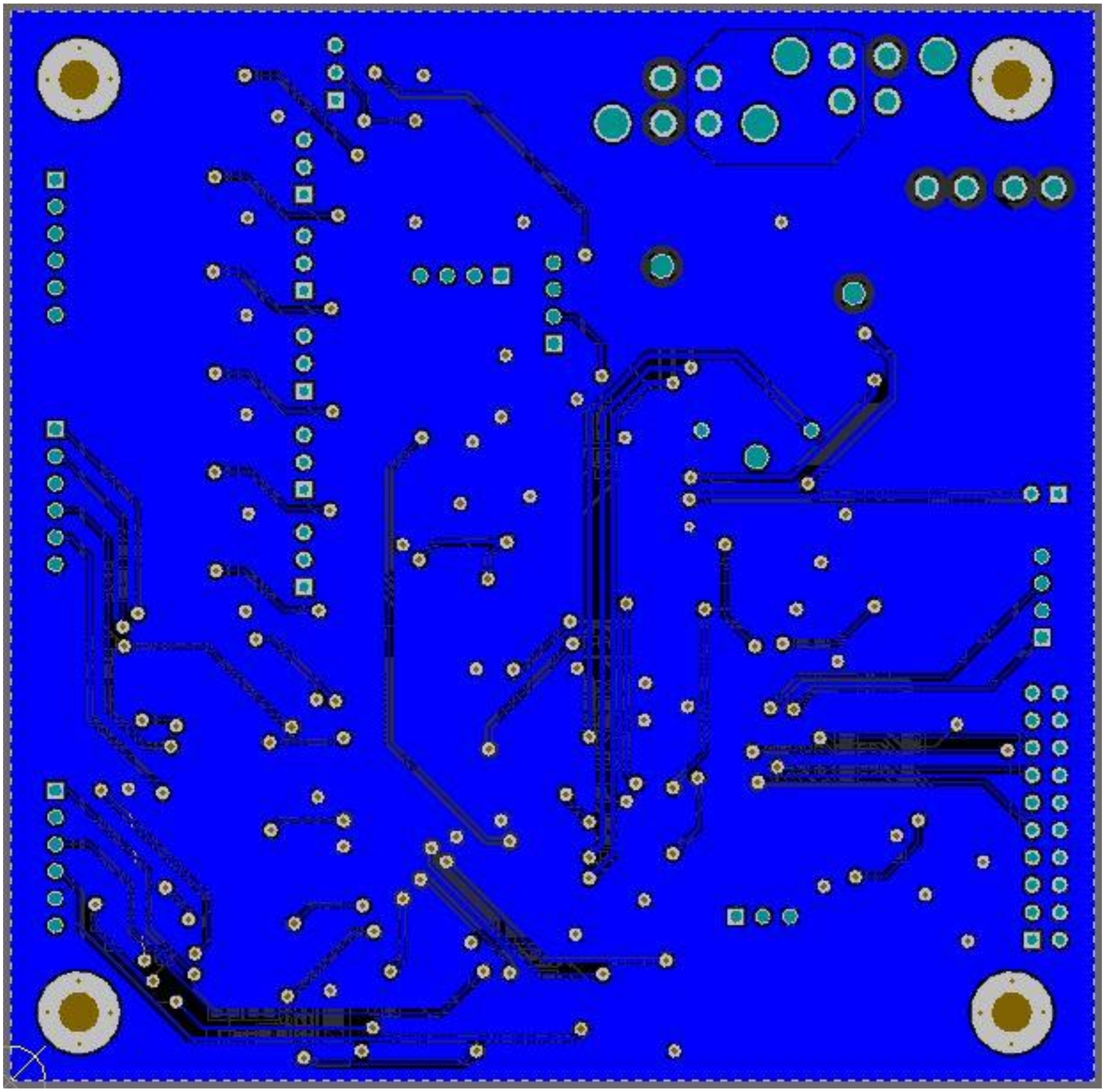
Here we can see all of the SMD component footprints as well as the routing between them and to vias. In the top right corner there are multiple pours for high-current connections. I will go into more detail on this later. The important thing is to make all high-power traces as wide as possible to minimize the amount they heat up.

Top Components:



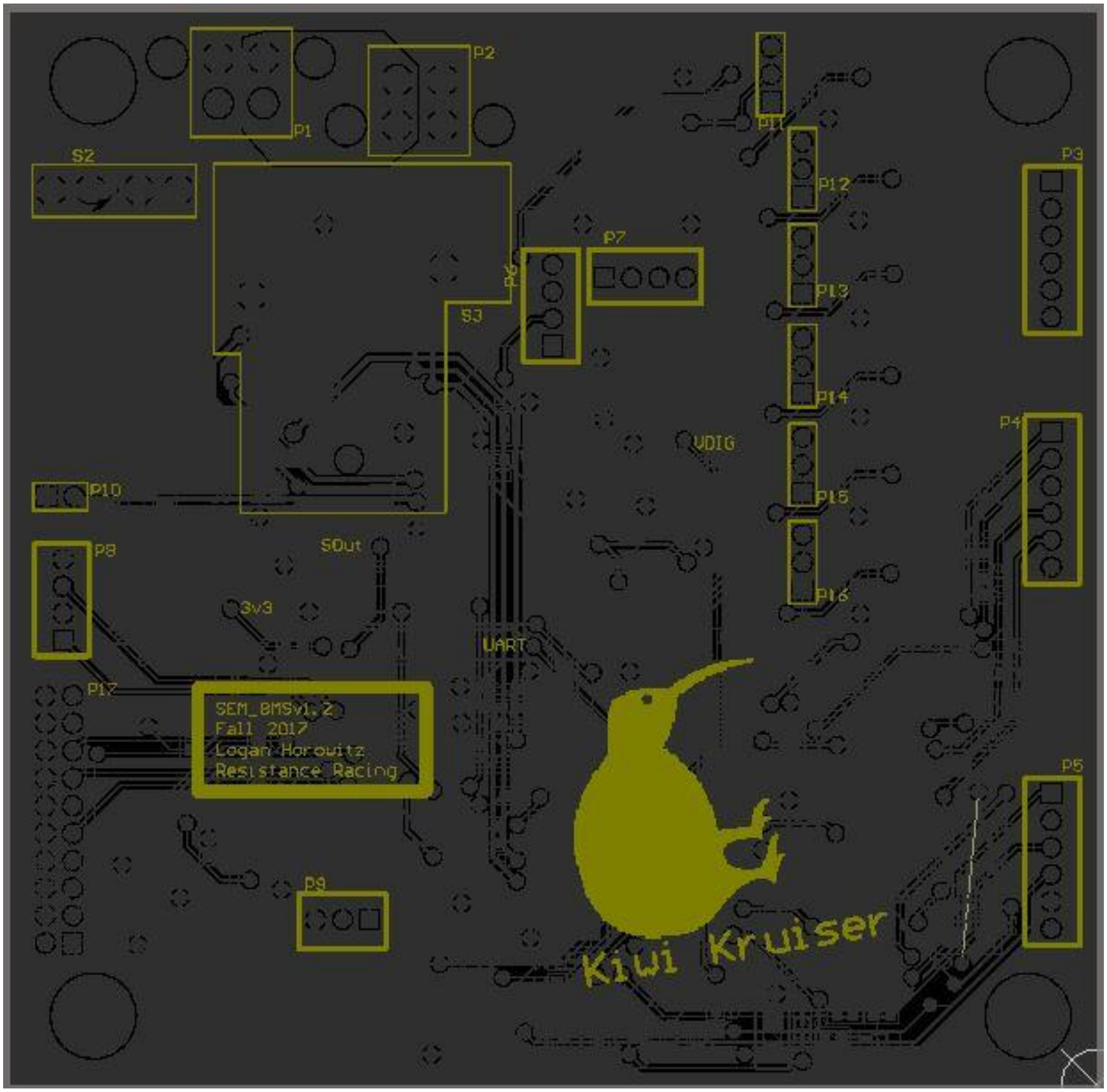
This shows the component outlines for the top of the board.

Bottom Layer:



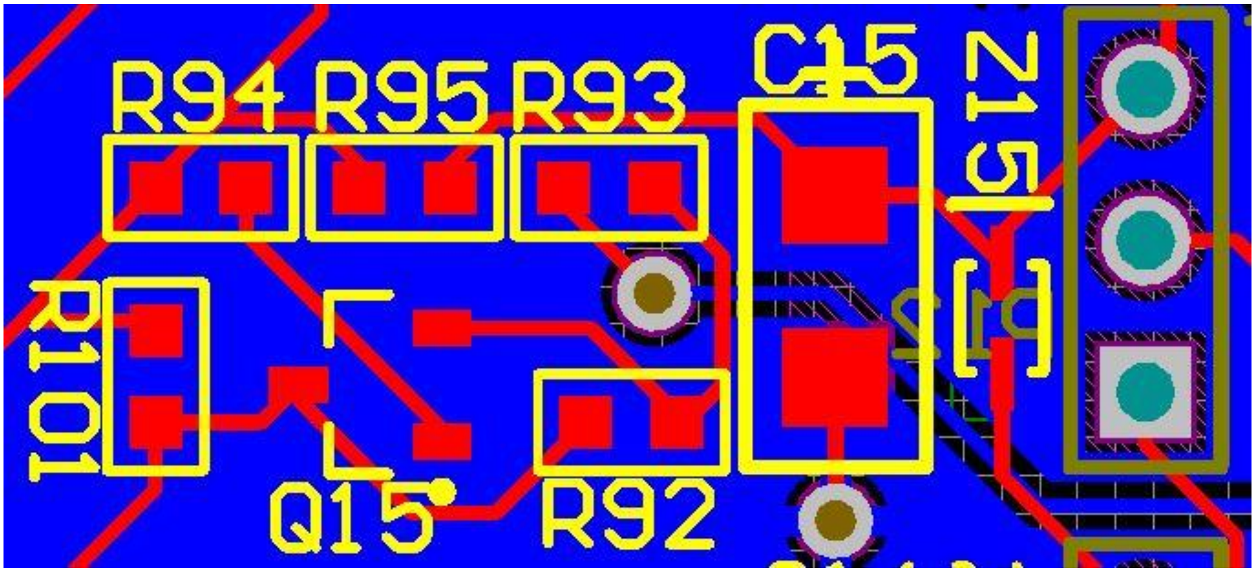
We can see that almost the entire bottom layer is full of copper; this is because it is a ground layer. All ground connections are made directly to vias, and any other routing on this layer is isolated on either side from the ground pour.

Bottom Components:



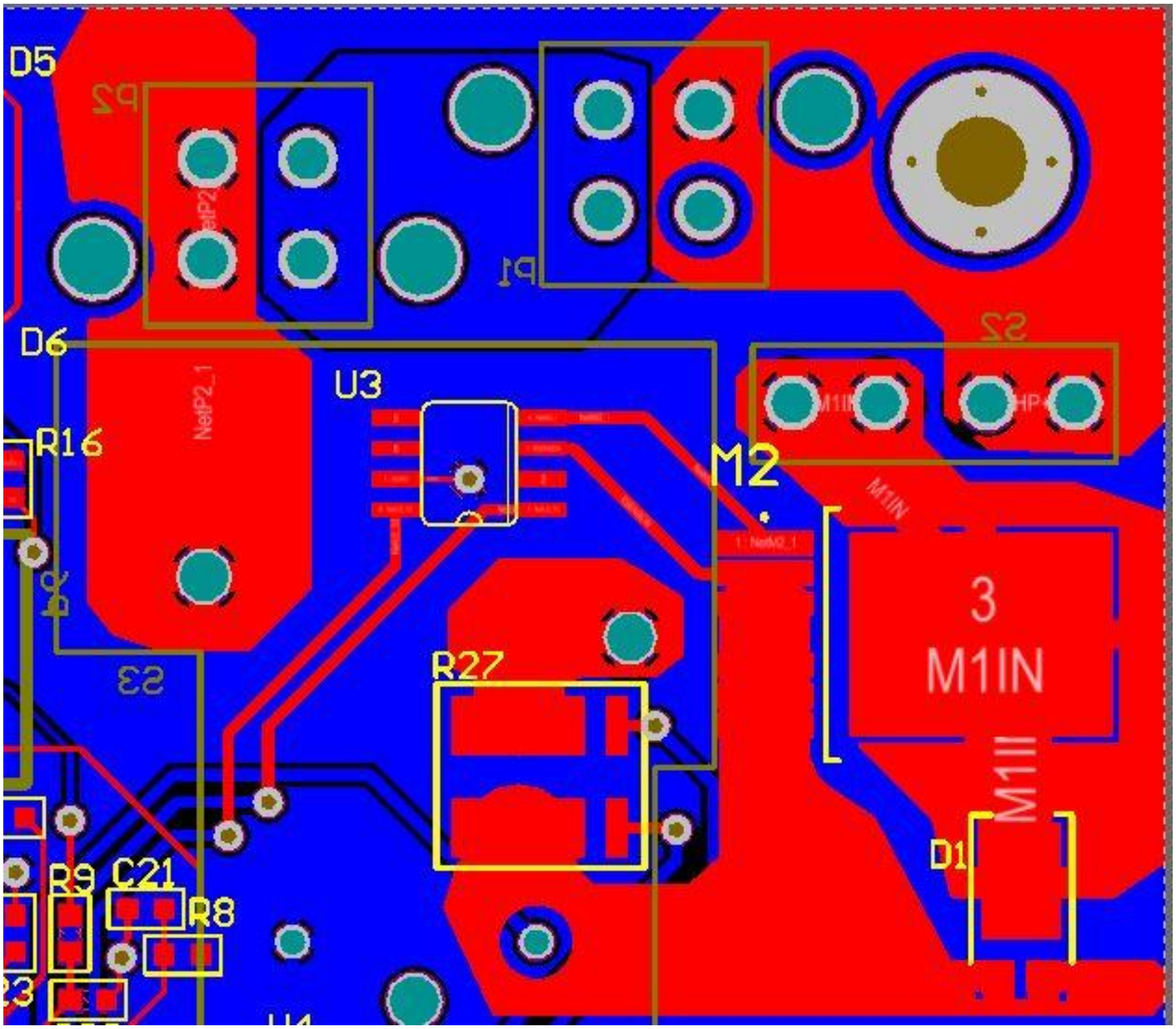
This shows the component outlines for the top of the board as well as a logo and board identifier.

Cell Connection:



This is a close-up on one cell-balancing circuit, which I showed for the schematic as well. It matches up somewhat closely to the schematic placement of components. Q15 and R94 are providing the alternative current path here.

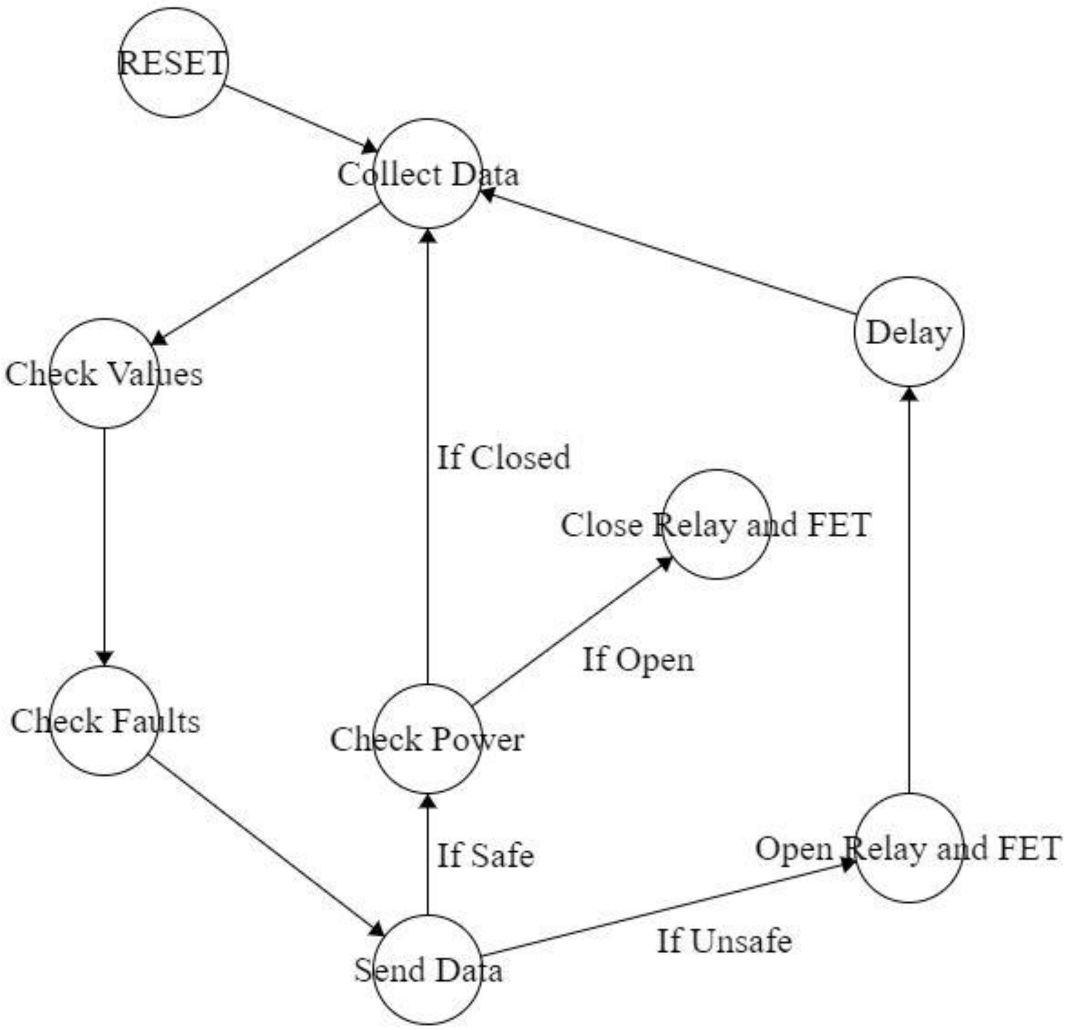
High-Power:



This is a close-up on the high-power path for the board. This layout is extremely important in terms of board heating, power loss, and potential electrical arcing. Power comes into the Molex connector P1 and goes through the fuse S2. Then through the diode D1 and power MOSFET M2 in parallel before going through the sense resistor and into one relay input. It comes out at the other end of relay and connects to the Molex P2 which the MC and DAQ receive power from.

Software Structure

There is no software written for the board yet, but that will be the primary focus of next semester and it will be included in that technical report. The basic structure will be simple:



Mounting and Packaging

The headers on the layout illustrate all of the electrical interfaces and there are four mounting holes each of 150mil diameter and located 3400mils apart which define the mechanical interface. The board requires at least 2 inches of clearance on top of it and at least a half-inch below it.

Analysis

Fault Handling

Voltage: The BMS IC is rated up to 16 cells and 88V. We are only planning on connecting 12 cells at around 44V so this should not be an issue. The other high-side IC's are each rated to over 400V. The main concern is the transients which can occur during cell connection. Therefore, we must be extremely careful during this first portion of wiring, and not change the cell connections after they have been made.

Current: The fuse and relay are currently rated to 30A. Anything above that will cause the fuse to blow, and would additionally cause heating in the pours of the board conducting this current. We must ensure that our motor can power the vehicle while consuming less than 30A, or a significant redesign will be necessary.

Communication: There are two communication protocols being used by the BMS. The microcontroller is communicating to the BMS IC via UART and also communicating to the DAQ by I2C. While neither is absolutely necessary, it is very important for the UART communication to function properly. It will allow the microcontroller to communicate current or temperature faults to the BMS IC and to receive voltage faults from it. If UART were to fail, we could theoretically still race with the BMS IC opening the relay in case of a voltage fault and the microcontroller opening the power MOSFET if there is overcurrent or overtemperature. The I2C communication is entirely nonessential; moreover, a lot of the data the BMS provides can come from the motor controller with the exceptions being battery temperature and faults.

Temperature: Many of the IC's can withstand very high temperatures and the BMS IC is actually rated to throw a fault if it gets above 105*C. The bigger concern is the batteries, which should not heat above 125*F to prevent health damage and above 140*F for serious safety concerns. Power dissipation on board may be an issue when currents are high; this will require more testing and potentially heat-sinks.

Vibration: This will test the viability of the solder joints. As long as careful visual inspections is done to ensure proper fillets, there should not be a concern. Batteries are sensitive to vibration, though, so it will be important to have dampening for their mounting.

Transients: There are transient suppression diodes all over the design. The only two concerns are the initial wiring of the batteries to the board and the back-EMF which would result if there was a sudden emergency and high-current needed to be cut immediately.

Failure Cases and Fixes

In terms of hardware, I am most concerned with the functionality of the cell-balancing network. That will require extensive testing. Also just the sheer number of components which must be placed and soldered correctly. This will require extensive verification before powering electronics. Otherwise, the design should be fairly robust and any possible failures will come as a result of software challenges.

Bill of Materials

It is located in the references below. It consists of 236 components and will cost a total of approximately $250. The per-board cost will be significantly lower because we will order 10 copies of the PCB as well as many extra passive components.

Manufacturing Plan

The manufacturing of the board itself will be handled by a fab house, likely easyEDA. That is really the only option because the board is too complex and requires too small of tolerances for us to mill it in the Maker Lab.

Once we get the boars, we will solder all of the components on. It is possible to outsource this, but is extremely expensive and unnecessary. There are certainly risks in us soldering it such as shorts or poor connections, but this can be alleviated with proper testing.

Testing Plan

At each step, I will need to verify the solder connections in terms of continuity and shorts both with visual test and multimeter (if possible) before powering anything.

- Solder the microcontroller and BMS IC first
  - Verify the connection visually
- Solder regulators and 5V power header
  - Supply power and test voltage rails
- Solder programming header
  - Test communication with STM IC using LEDs
- Test communication between STM IC and BMS IC via GPIO
- Solder all top-layer components
- Solder high-power connectors and all other headers
  - Test sense amp's accuracy
  - Test relay functionality
- Wire cells to the board
  - Test if BMS IC can read their voltages accurately
  - Test lighting LED's based on BMS IC fault conditions; test each kind of fault
- Test UART and I2C communication

This should verify all hardware.

Project Reflection and Future Work

It is hard to know what problems this design will incur because it has not been built yet. We will likely have a lot more for this section after next semester. There is not much that can be optimized in terms of passive components because the cell-balancing circuits must always be external. There may be difficulties in soldering the fine-pitch ICs', but that is a necessary learning experience when using high-performance SMD components. It appears to be a robust design but time will tell.

I have learned a lot about PCB design and will continue to teach new members because it has been a very valuable experience. I have also learned about the design process itself as I've narrowed down all of the components I intend to use.

References

BMS Design:
https://www.intersil.com/content/dam/Intersil/whitepapers/battery-management/battery-management-system-tutorial.pdf

TI BQ76 Documentation:

PDF:	**http://www.ti.com/lit/ds/symlink/bq76pl455a-q1.pdf**
User Guide:	**http://www.ti.com/lit/ug/sluuba7a/sluuba7a.pdf**
Software Reference:	**http://www.ti.com/lit/an/slva617a/slva617a.pdf**
Thermal Metrics:	**http://www.ti.com/lit/an/spra953c/spra953c.pdf**
Forum Help:	**http://e2e.ti.com/tags/battery%2bmonitor** **http://e2e.ti.com/tags/current%2bsensing**

Reference Designs:

Schematic:	http://www.ti.com/lit/df/tidrhk0/tidrhk0.pdf
BOM:	http://www.ti.com/lit/df/tidrhk2/tidrhk2.pdf
Software:	http://www.ti.com/general/docs/lit/getliterature.tsp?baseLiteratureNumber=tidcb23&fileType=zip
Test Reports:	http://www.ti.com/lit/ug/tiduas4/tiduas4.pdf
Layer Plot:	http://www.ti.com/lit/df/tidrhk4/tidrhk4.pdf
Assembly Drawings:	http://www.ti.com/lit/df/tidrhk3/tidrhk3.pdf
CAD Files:	http://www.ti.com/general/docs/lit/getliterature.tsp?baseLiteratureNumber=tidrhk5&fileType=zip
Gerber Files:	http://www.ti.com/general/docs/lit/getliterature.tsp?baseLiteratureNumber=tidcb22&fileType=zip

Look at the other reference designs! http://www.ti.com/product/BQ76PL455A-Q1/toolssoftware

BMS BOM:
https://docs.google.com/a/cornell.edu/spreadsheets/d/1V2rgOF2B6c6Zu4EjqhKDZiHWLr7XadBr8fcrRA5lOM8/edit?usp=drive_web

BMS Design Doc:
https://drive.google.com/drive/folders/0BxsUkcy2L3JQdjBDNmVFc0tRX2s

The BOM has links to datasheets for all of the components I am using, including the batteries.