DESIGN OF BATTERY MANAGEMENT SYSTEM

Submitted in partial fulfillment of the requirements
of the degree of

Bachelor of Engineering

by

Saudamini Ghatge (60001160015)
Jonathan Nadar (60001160034)
Ratan Soni (60001160058)

Project Guide:
Prof. Rashmi Ravikumar

Electronics Engineering
Dwarkadas J. Sanghvi College of Engineering
Mumbai University
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Certificate

This is to certify that the project entitled **"Design of Battery Management System"** is a bonafide work of "**Saudamini Ghatge (60001160015), Jonathan Nadar (60001160034), Ratan Soni (60001160058)"** submitted to the University of Mumbai in partial fulfillment of the requirement for the award of the degree of **"Bachelor Of Engineering"** in Electronics Engineering.

Internal Guide   Internal Examiner

Prof. Rashmi Ravikumar   Prof.

Head of Department   External Examiner

Dr. Prasad S. Joshi

Principal

Dr. Hari Vasudevan

Project Report Approval for B. E.

This project report entitled *Design of Battery Management System* by *Saudamini Ghatge, Jonathan Nadar and Ratan Soni* is approved for the degree of **Electronics Engineering**.

Examiners

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Date:

Place: VileParle(west), Mumbai.

Abstract

The project reviews the necessity and design of battery management circuitry and also describes tests required for characterization of Li-ion cell. Design and analysis of cell balancing circuitry is discussed. Additionally, the text explains the design of electronic load which can also be used as a battery-charger. The effect of discharging rate on the capacity of a cell is analyzed. It is hoped this design would contribute to sustainable development.

Acknowledgments

The making of project involves teamwork, vision, patience and perseverance on the part of group members. But a team can achieve a greater height only by proper guidance from faculty members and friends. Hence we would like to express our gratitude to all those who in instrumental during the course of developing of the project.

First we would like to thank our internal guide **Prof Rashmi Ravikumar** for her valuable inputs and timely guidance. She always had very practical suggestions and sound knowledge.

We would like to thank our **Laboratory-Assistants** and **Laboratory-Attendants** for the help and co-operation offered by them along every stage of the project.

Lastly, we would like to thank our head of department, **Dr. Prasad S. Joshi** for extending his support towards the completion of this project and for the timely encouragement.

(Signature)

Contents

Chapter 1

Introduction

1.1. Need for Battery Monitoring and Management:

With the continual rise in average global temperatures, an alternative and eco-friendly source of transportation was required. Electric and hybrid-electric vehicles have proved to be efficient and environment friendly in the past decade. The most common power source for these vehicles are Lithium chemistry-based cells. Battery-packs made out of these cells needs continuous monitoring as they are hazardous and explosive in nature when subjected to a hostile environment. Maintenance of these batteries is thus proving to be of paramount importance. Selection of appropriate battery chemistry is a very important factor in deciding the overall performance of the system.

From today's perspective, Li-ion chemistry is the battery technology of choice due to its high energy density and power rating and charge/discharge efficiency in pulsed energy flow systems. A Li-ion fails if overcharged, over-discharged or operated outside their safe operating temperature window. For this reason, it requires a Battery Management System (BMS) which will maintain each cell of battery within the safe operating range. At present, numerous automobile firms have developed their BMS's. However, their designs are proprietary. Our goal is to develop a BMS which would serve the purpose of monitoring large battery-packs, with no compromise on the system and user's safety. The design would be open sourced so that the entire community is benefited.

Figure 1.1 18650 cell used in project

1.1.1. Requirements for Battery Monitoring and Management

Battery Monitoring is important for Li-ion chemistry for ensuring prolonged battery life as well as energy efficiency. The main parameters required for this task are voltage, current and temperature over time. Another important parameter to be taken into consideration is State-Of-Charge (SOC). The operational characteristics and cell life are a strong function of temperature. Abrupt cell temperature changes can indicate cell failure. The below figure illustrates a basic BMS used in a typical Electric Vehicle or a power generation station.
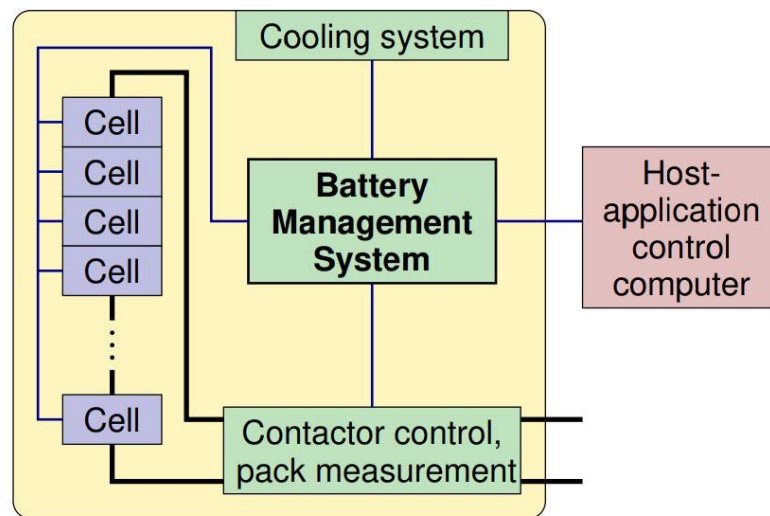

Figure 1.2 Typical BMS

1.1.2. Implementation

The project aims to implement a BMS based on a Master-Slave configuration. It would have multiple slaves each monitoring a fixed number of cells in a module. They would all be communicating the master board via a communication protocol.

The idea is to ensure the system is reliable and fail-proof. CAN would be used as it is the widely used protocol in the automobile sector. This allows flexibility in the number of slave boards connected in a system.

An additional functionality implemented is contactor control. Motor-drives, both AC and DC deploy high capacitance to reduce input ripples. Connecting the battery pack directly to the motor-drive would create an in-rush current, potentially damaging the contactors and the motor-drives. To prevent this, a pre-charge circuitry is implemented which charges the capacitors via a resistor.

Chapter 2

Review of Literature

Battery is an essential component as it's a very efficient and compact power source that helps to operate an electronic equipment on the go. According to the requirement of the equipment there are various cell chemistries available so that the relevant one is selected for a particular use. Since any battery is a power source, and any power source has to be constrained to provide the required necessary output or else it can damage the equipment. This task is performed by a Battery Management System, it is a combination hardware and software that controls the charging and discharging cycles of the battery, it even logs some important parameters that helps in determining the State of Charge as well as the battery life. Hence, nowadays battery management systems are used in almost every portable electric machine like laptops, cellphones, power-banks, portable hand drills, electric vehicles, etc.

BMS's are can be widely classified based on the number of cells they can handle. Higher number of cells pose a significant amount of risk if exposed to damaging conditions. Cells can trigger a chain reaction and possess enough energy to cause irreversible damage to a battery pack.

During our tenure at DJS Thunderbolt, we were exposed to design, manufacturing and testing of a 150V, 40Ah battery pack. The BMS used was an OEM part, designed by Elithion. Being an OEM part, it was very difficult to modify its features as per our needs. Below is a detailed report of the BMS.

2.1. Elithion Lithiumate HD:

It is one of the most widely used Li-Ion chemistry based battery management systems that monitors, balances (passive balancing), evaluates and protects a Li-Ion battery pack. It is a very compact and portable design enclosed with a rugged molded case with unique set of connectors for various extensions built for high voltage uses. It supports a total battery pack voltage value of around nine hundred voltages and for up-to sixteen banks in parallel. A cell board is mounted on each cell which is another hardware which is connected to the main Lithiumate HD module for exchange of parameters. A cell board measures cell voltage, temperature around it, and balances the cell.

This module supports all the cell form factors small and large cylinders, prismatic and pouch cells; and each of them in whichever Li-Ion chemistry they are available in like:

•LiFePO4 , LiFeYPO4 - Lithium iron phosphate (LFP)

•LiCoO2 - Lithium cobalt oxide (LCO)

•LiMn2O4 - Lithium manganese oxide (LMO)

•LiNiMnCoO2 - Lithium nickel manganese cobalt oxide (NMC)

•LiNiCoAlO2 - Lithium nickel cobalt aluminum oxide (NCA)

Figure 2.1 Elithion Lithiumate HD BMS

This also provides some very important features like protection from over/under voltage, over current, and over/under temperature. As it is a plug-and-play battery management system, it also has its own graphic user interface (GUI) that helps providing input for the necessary parameters which can be configured on the go just by connecting it to a computer via a USB cable. It also supports CAN and RS232 communications.

It also offers optical isolation between the pack and the low voltage circuit. This module is one of the safest to be used high voltage systems and due to its versatile functionality many people have recommended it.

Our motive was to overcome the issues faced while working with the above mentioned BMS along with providing all the necessary functionalities provided by the OEM BMS. We understood basic concepts like isolation and its necessity in high voltage, floating load systems and tried to implement the same in the project.

Chapter 3

System Model / Architecture

3.1. Design of Charger-Discharger Circuit:

In order to design a BMS, characteristics of the cell under use must be known. To obtain the cell characteristics, we have designed an electronic load which can discharge with different currents and profiles. The circuit uses a 1 ohm, 10 W equivalent resistor and FET's internal resistance to dissipate cell's energy in the form of heat. Current and cell voltage is monitored and stored.

The circuit uses a STM32F103C8T6 development board for control and monitoring the process. The threshold voltages are set using the keypad prior to the start of discharge cycle. A PID controller is implemented which adjusts the duty cycle to maintain constant discharge current. When the cell is fully discharged, the process is halted. The cell temperature is monitored continuously so that the effects of temperature on cell characteristics is minimal.

The same set-up is used to charge a battery. The designed circuit can be used to charge batteries rated up-to 50 V with a charging current limit of 10 A. A relay is used to switch the battery between charge and discharge modes. Charger circuit rated up-to 150 V, 20 A is being developed.

3.1.1. Components used:

Table 3.1 Components used in Charger-Discharger

| Component	Purpose
STM32F103C8T6 development board	Micro-controller
3.3V buck-converter	Provides power to micro-controller
DPDT Relay	Switch between discharge and charge modes
IRFZ44N	Switching FET
PC817	Used as MOSFET driver
10mΩ, 2W Resistor	Current Sense Resistor
10Ω, 2W Resistors (10 in parallel)	Power dissipation resistors
LM 324 Operational Amplifier	As current sense amplifier

3.1.2. BMS Master v1.0 PCB:
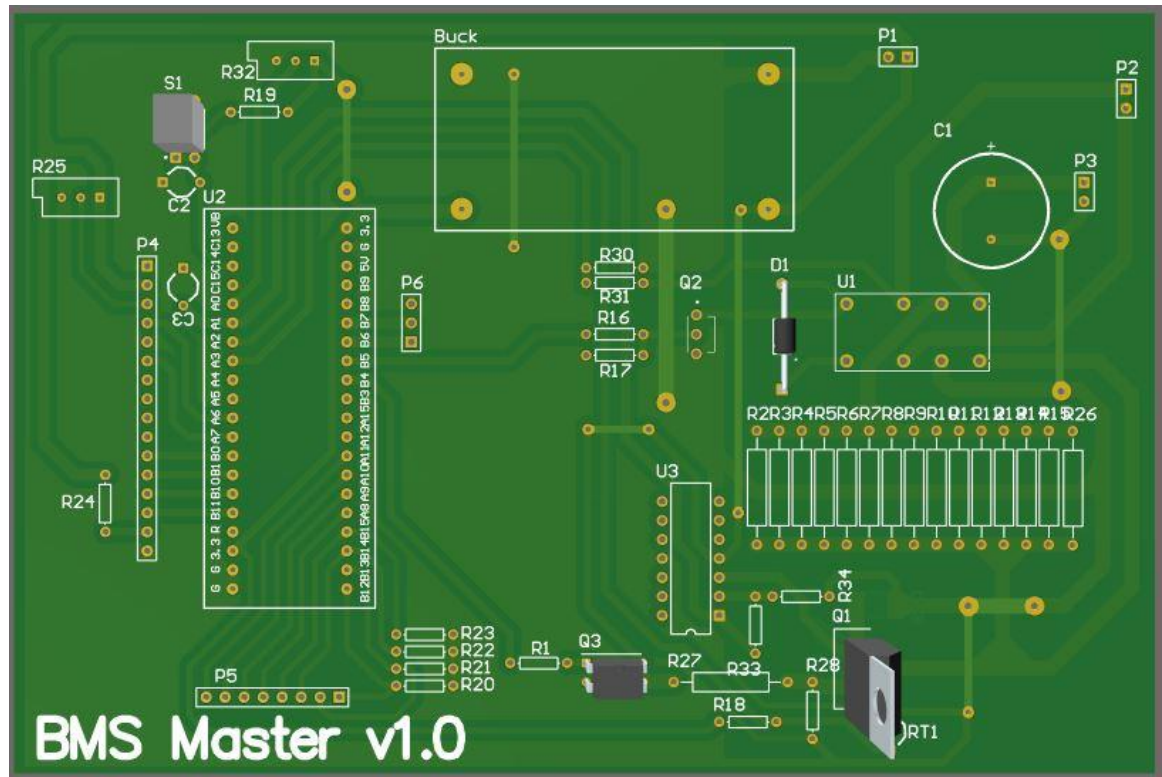
Figure 3.1 Charger-Discharger Circuit

3.1.3. Limitations:

The designed circuit had the following problems:

- Error while current and voltage sensing due to switching.
- Improper MOSFET switching.

3.2. Design of BMS Master:

To overcome these issues, a new version was developed. It incorporated the necessary functions of a BMS Master board as well.
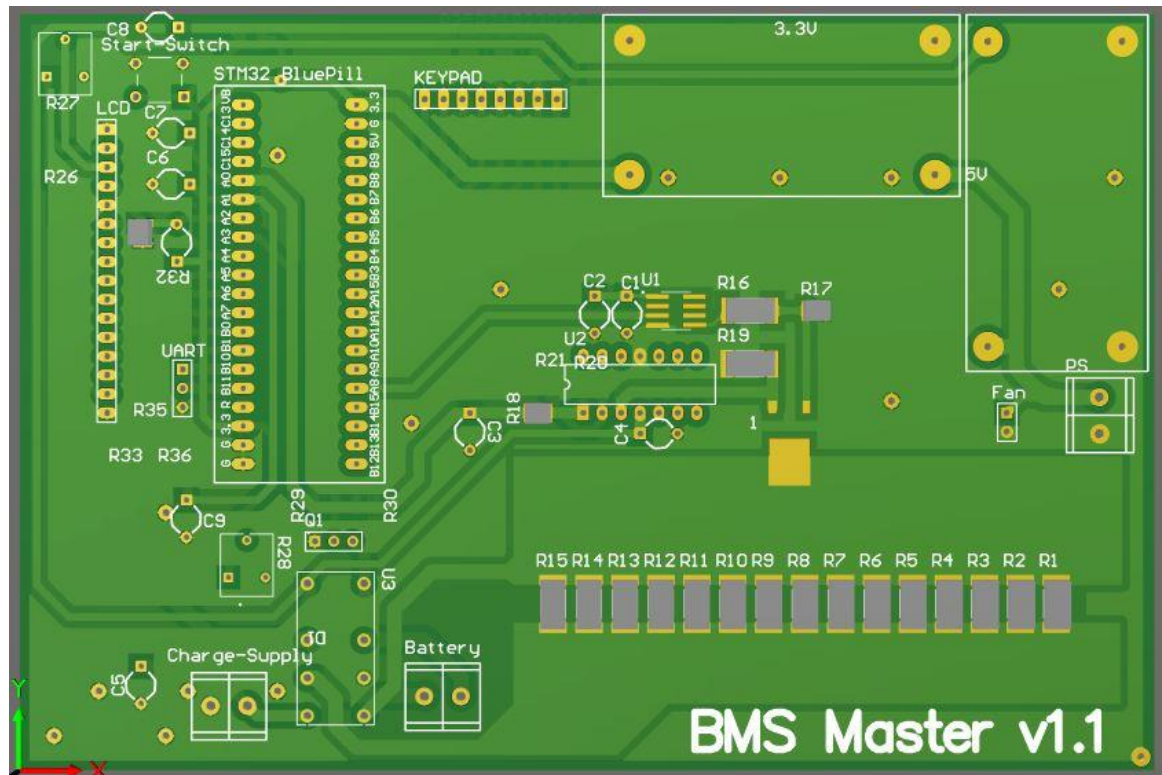
3.2.1. BMS Master v1.1 PCB:

Figure 3.2 BMS Master v1.1

3.2.2. Modifications:

The switching harmonics which affected current and voltage measurement were eliminated using low pass filters with cut-off frequency as 10 kHz, which is half of the switching frequency. The IRFZ44N was replaced with an IRFR024N MOSFET. It was driven by an IRS2003STRPBF half-bridge driver. This significantly improved the performance.

3.3. Design of BMS Slave:

To understand the basic requirements of a slave board, we reverse engineered the Elithion Lithiumate BMS. After analyzing the boards, we found out it comprises of the following circuit blocks:

- Voltage sensing
- Temperature sensing
- Passive balancing circuit
- Isolated communication
- PIC micro-controller

3.3.1. BMS Slave v1.0:

Necessary components for isolated communication were not readily available. So we implemented the other four features in our first version of slave board. The circuits were first tested on LTSpice and Proteus. A prototype PCB was designed and manufactured in the labs for preliminary testing. The prototype board had a provision of monitoring and balancing three cells. The circuits were tested multiple times to ensure the design is fail-proof.

3.3.1.1. Components Used:

Table 3.2 Components used in BMS Slave v1.0

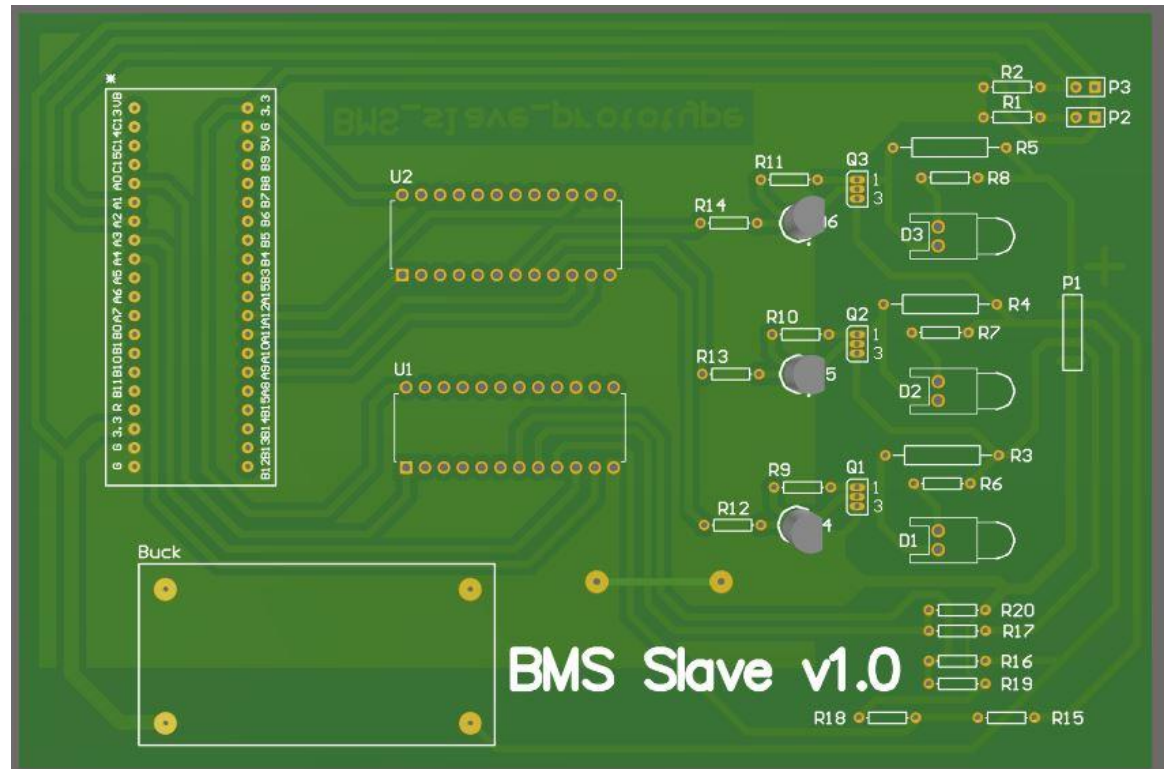| Component	Purpose
STM32F103C8T6 development board	Micro-controller
3.3V buck-converter	Provides power to micro-controller
BC 556	Balancing Transistor
33Ω, 2W Resistors	Bleeder resistors
CD74HC4067	Analog Multiplexer
10kΩ NTC Thermistor	Temperature Sensing

3.3.1.2. BMS Slave v1.0 PCB:

Figure 3.3 BMS Slave v1.0

3.3.1.3. Limitations:

The balancing circuit worked perfectly fine, however, at high voltages, the base-emitter voltage exceeded the threshold, causing the transistor to fail. To overcome this, we used an opto-coupler to drive individual transistors with their gate-drain voltage restricted to the maximum cell voltage.

The above board could monitor only three cells. We designed a new PCB with the ability to monitor up-to 16 cells and got it manufactured from JLC.

3.3.2. BMS Slave v1.1:

3.3.2.1. Components Used:

Table 3.3 Components used in BMS Slave v1.1

Component	Purpose
STM32F103C8T6	Micro-controller
TLP290(SE	Balancing FET opto-coupler
MCH3382	Balancing Transistor
10Ω, 3W Resistors	Bleeder resistors
MCP1623T-I_CHY	5V switching IC
MIC5504-3.3YM5-TR	3.3V LDO Regulator
CD74HC4067M96	Analog Multiplexer
ATA6560-GAQW-N	CAN Transreceiver

Instead of using an existing STM32F103C8T6 development board, a minimum system using the same IC was developed. SWD was enabled for programming as well as for debugging.

Additionally, CAN transreceiver was set-up with necessary filters. USB CDC was enabled along with a UART port.
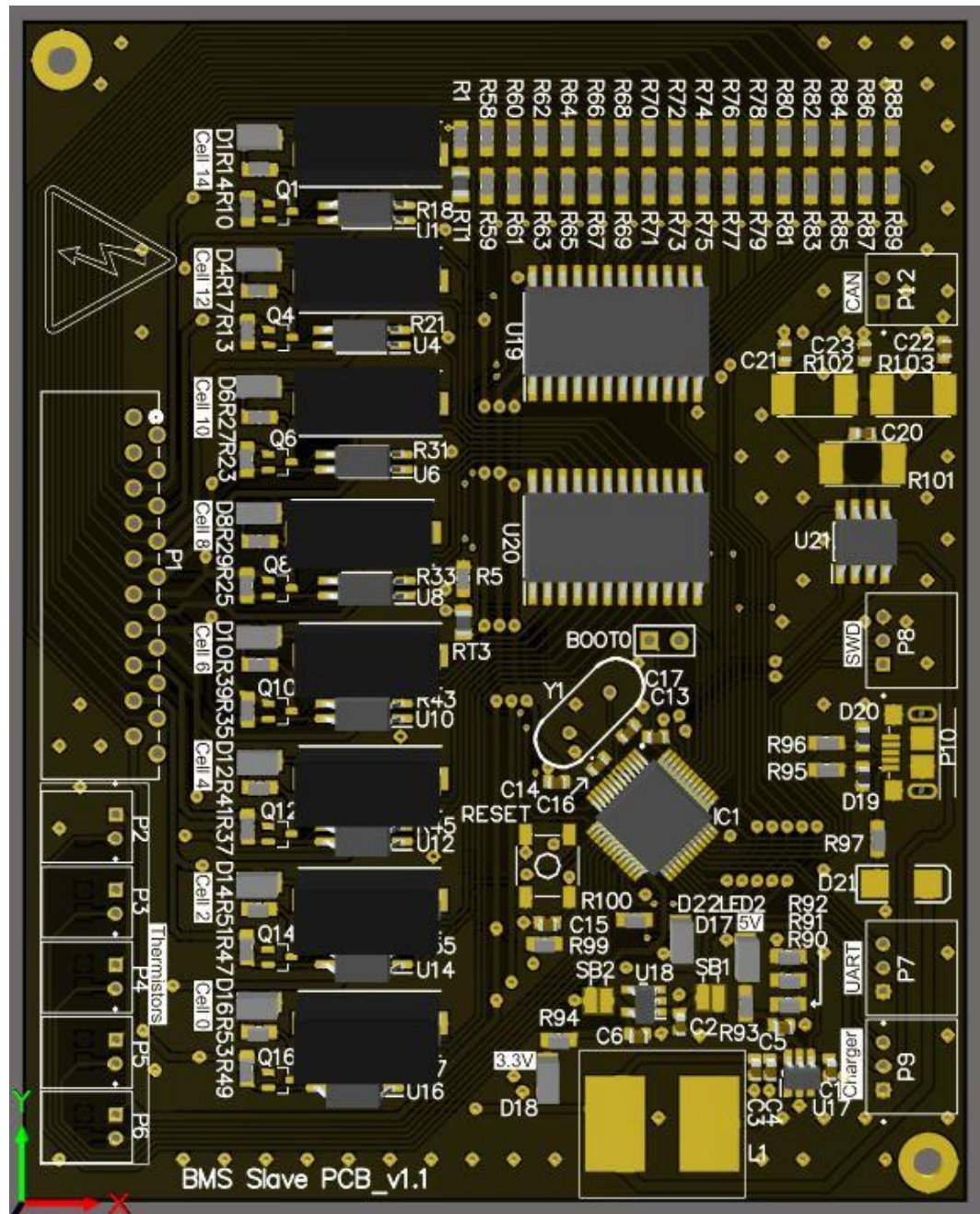
3.3.2.2. BMS Slave v1.1 PCB:

Figure 3.4 BMS Slave v1.1

3.3.2.3. Issues encountered:

This being our first experience with STM32 micro-controllers, we were aware of possible issues we might face. However, setting up the micro-controller was extremely difficult. SWD, UART and USB failed to detect the micro-controller on the debugger.

As we had utilized all our micro-controllers, we did not have any other option but to use the development board itself. Another board was developed, with the same architecture, however, used the development board.

3.3.3. BMS Slave v1.2:

3.3.3.1.   Components Used:

Table 3.4 Components used in BMS Slave v1.2

Component	Purpose
STM32F103C8T6	Micro-controller
TLP290(SE	Balancing FET opto-coupler
MCH3382	Balancing Transistor
10Ω, 3W Resistors	Bleeder resistors
CD74HC4067M96	Analog Multiplexer

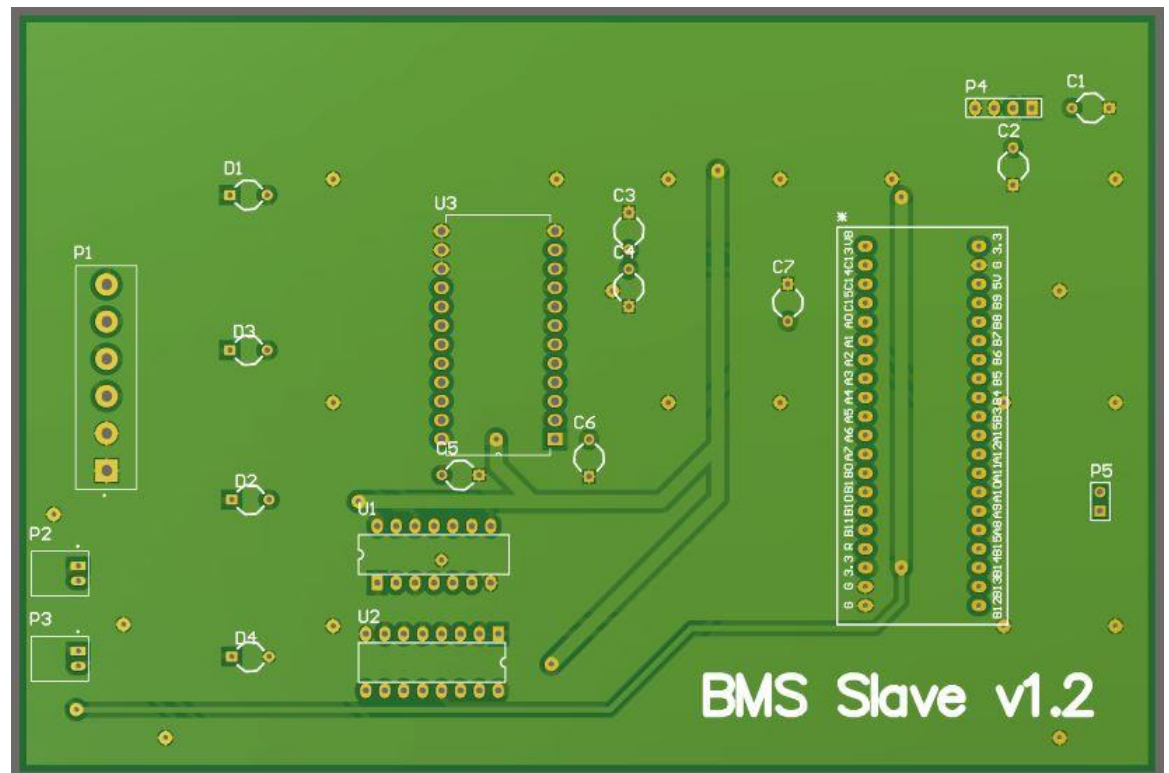#### 3.3.3.2.   BMS Slave v1.1 PCB:

Figure 3.5 BMS Slave v1.2

3.3.3.3. Further development:

Owing to the current scenario, BMS Slave v1.2 could not be tested. However, it definitely provides a good scaled down version of the 16-cell BMS Slave v1.1. Instead of CAN, the board uses an SPI interface to communicate with the BMS Maser.

Implementation of STM32 minimum system is possible, however requires some additional pull-up resistors on SWDIO and SWDCLK. Pulling up BOOT1 pin might help. We could not do the latter due to space constraints.

Chapter 4

System Implementation

4.1. Development of Battery-Pack:

4.1.1. Cell Selection:

A battery pack is required for testing that the system is working correctly or not. As we mentioned there are various cell chemistries available to choose from to make the battery pack. We had to choose a type that has a Lithium based chemistry, so we decided to use Li-Ion batteries as they widely used in the electronics sector. Even the Li-Ion batteries are available in different form factors but 18650s are the best fit as they have a compact body structure in a cylindrical shape so that they can be stacked in various different ways which makes the battery pack assembly easy for us.

When we were thorough with what type of a cell to select, we had to select which one to use as there are many companies producing this particular type. Due to the availability Samsung's product line around our location, it was an easy choice for us.

Hence, we chose Samsung's Li-Ion 18650s to be used in our battery pack for testing the BMS system circuit.

Figure 4.1 Samsung Li-Ion 18650

4.1.2. Assembly:

The battery pack we were making was for the testing pourposes so the configuration we went ahead with 8s2p. This means a pair of cells in parallel was one module and eight such modules connected in series to form a bank of 8s2p.

We used the cell holders for 18650s to mount the cell in a fixed position. First we made eight module of two cells in parallel in which we connected both the cells with an aluminium strip. We heated the aluminium strips and used flux to solder them with the cell ends. After the eight modules were ready in their cell holders we used multistranded wires to provide a series connection. Then we just glued the holders together using a hot glue-gun.

One of the risks was the cells getting damaged while soldering the ends with aluminium strip but we took care that tempareture at cell end was below a certain point and the connections were made sure to be proper. With this we completed our DIY test battery pack.
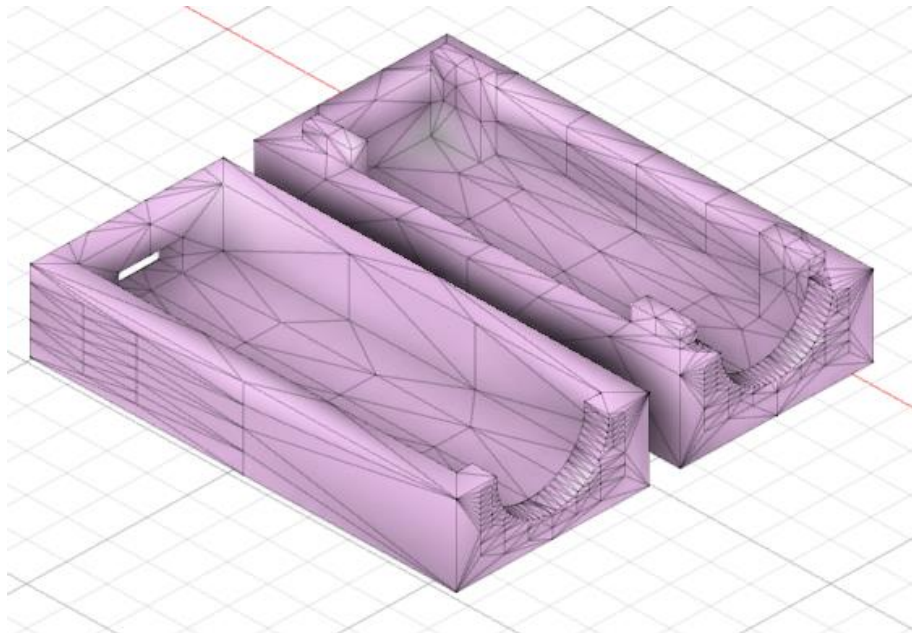

Figure 4.1 Cell Holders designed using Fusion360

4.2. Cell Characterization:

Cell characterization is the process of identifying the distinguishing parameters, which are unique to a particular cell type and chemistry. They are have high dependencies on external environment, load dynamics and the cell chemistry itself. We used a Samsung ICR 18650-26J 2600mAh Lithium-ion cell for characterization. The following are the important cell parameters required:

4.2.1. State of Charge(SOC):

State-Of-Charge (SOC) determines the energy capacity of battery, i.e. knowing the amount of energy left in battery compared with the energy it had when it was full. SOC estimates whether the cell is charged or discharged and let us know the present state of the battery.

This is estimated by relating the open circuit voltage of the cell to the specific value that is provided by the manufacturer of the cell. Comparing the maximum and minimum voltage value, the present open circuit voltage of the battery gives us the SOC. The open circuit voltage varies with change in temperature, so accordingly after calculating it while considering the temperature variation we can determine the SOC.

4.2.2. Internal Resistance:

Internal resistance is a variable quantity which determines the health of a cell. Temperature changes might cause temporary change in the cell resistance value. Permanent changes in the cell resistance occurs due to internal corrosion which increases gradually as the cell ages. But all these changes are minimal because Li-ion chemistry has new and better electrolyte additives.

4.2.3. State of Health(SOH):

State of Health refers to the overall degradation of a cell. With every charge-discharge cycle, the total capacity of a cell goes on reducing. SOH assists in the calculation of range of a battery pack along with providing a prediction of maintenance or replacement needs.

4.2.4. Cell Characterization using Electronic Load:

A Li-ion cell was fully charged and allowed to stabilize for one hour. The cell was subjected to constant current discharge of 0.4 C and 0.75 C. The terminal voltage and charge discharged Ah were monitored until the cell reached the lower voltage threshold.

Table 4.1 Cell threshold parameters

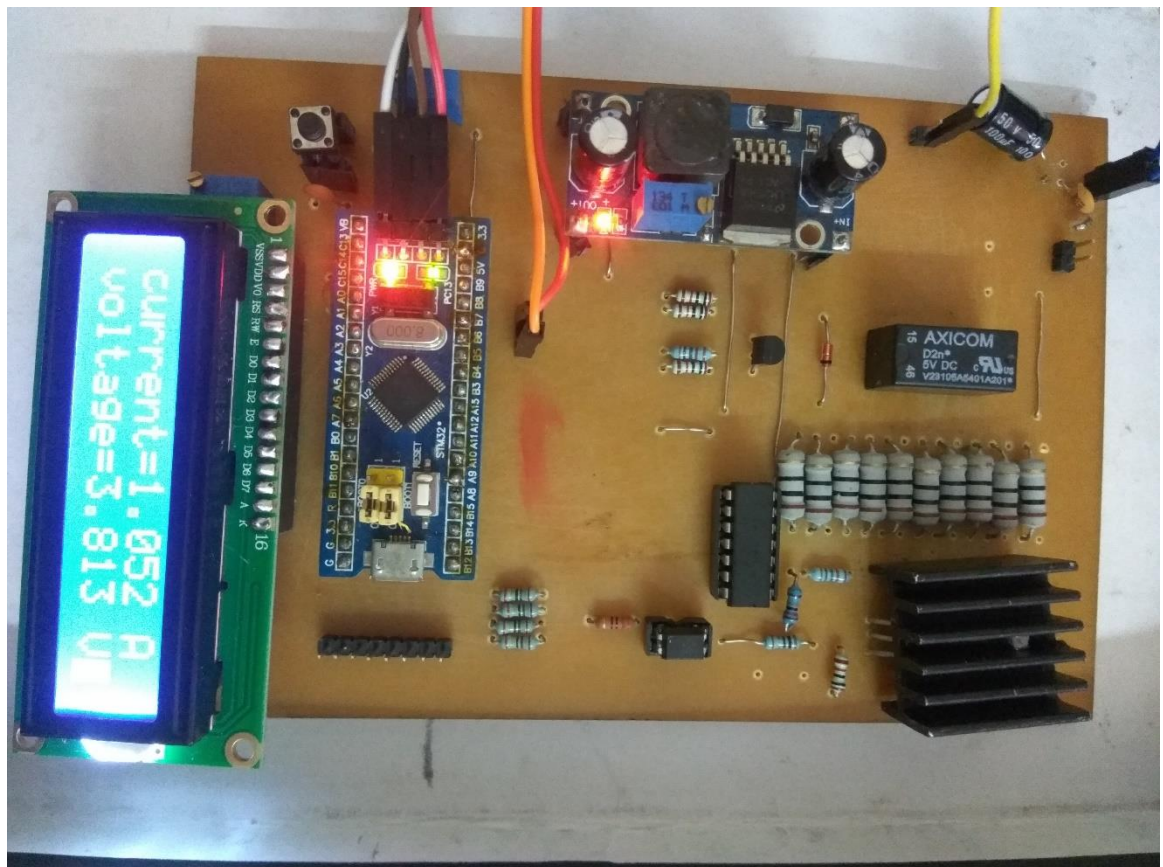| PARAMETERS	VALUES
Cell Temperature	25
Maximum terminal voltage	4.2 V
Minimum terminal voltage	2.8 V
Maximum discharge current	2.5 A

Figure 4.2 Cell under test

4.2.5. Results:

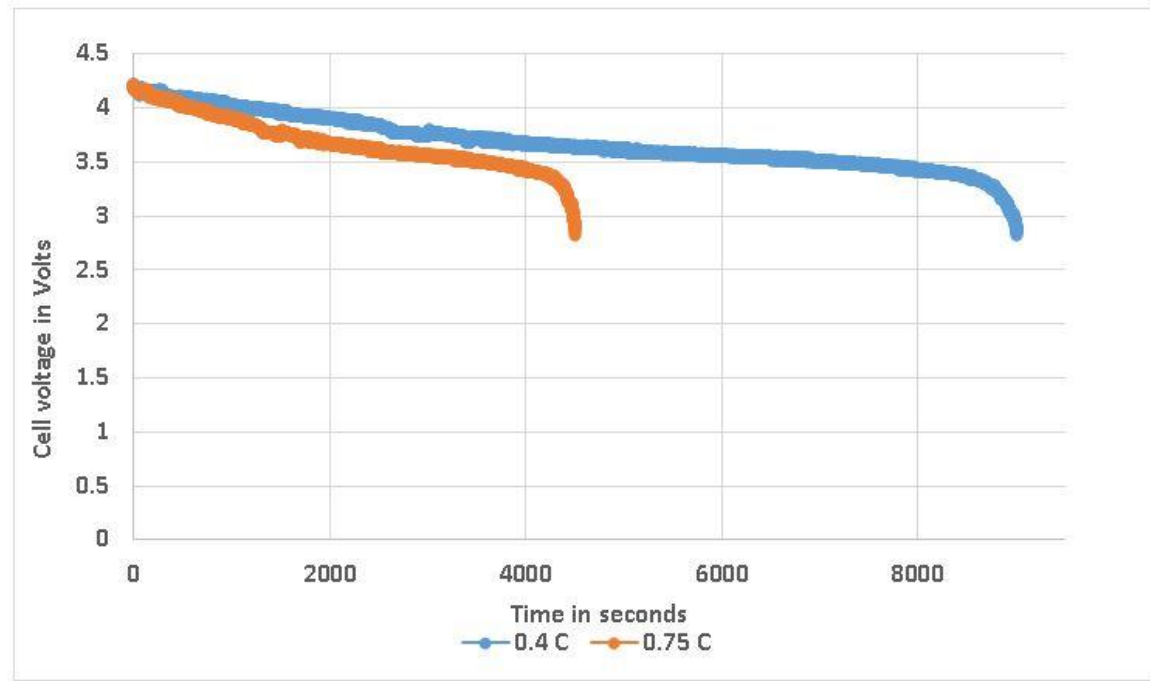The following are the outcomes of the tests performed:

Figure 4.3 Discharge curves

Table 4.2 Calculation of Relative Capacities

Discharge Rate	Ah Discharged	Relative Capacity
0.4 C (1 A)	2.494 Ah	96 %
0.75 C (2 A)	2.421 Ah	93 %

It is evident from the tests that the capacity of a cell is a function of discharge rate. The total capacity of 2.6 Ah as specified in the datasheet.

4.3. Slave Circuit Design and Testing:

During charging and discharging cycles of batteries, the voltage values for individual cells may vary. This leads to unequal voltage levels in cells all around the battery pack, which may further degrade the battery life. Hence, cell balancing is an important factor that helps us use the battery efficiently.

The balancing circuit involves three major components: a 10-ohm bleeder resistor, a P-channel MOSFET and an opto-coupler to drive the P-channel MOSFET. The circuit is tested to ensure that the FET is operated within its capabilities. The 100k-ohm pull-up resistor ensures that the FET is not turned on due to noise. When an imbalance is detected, the opto-coupler turns on the FET by pulling the gate low.
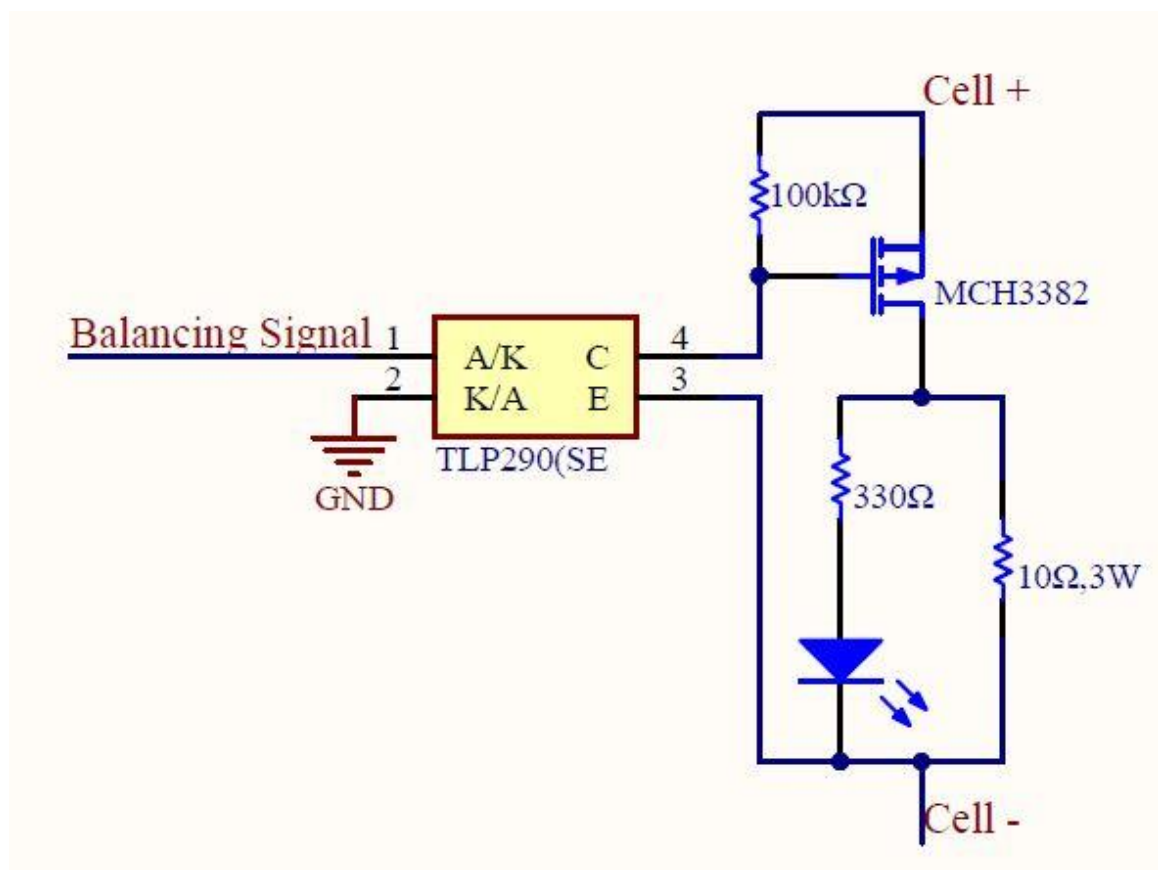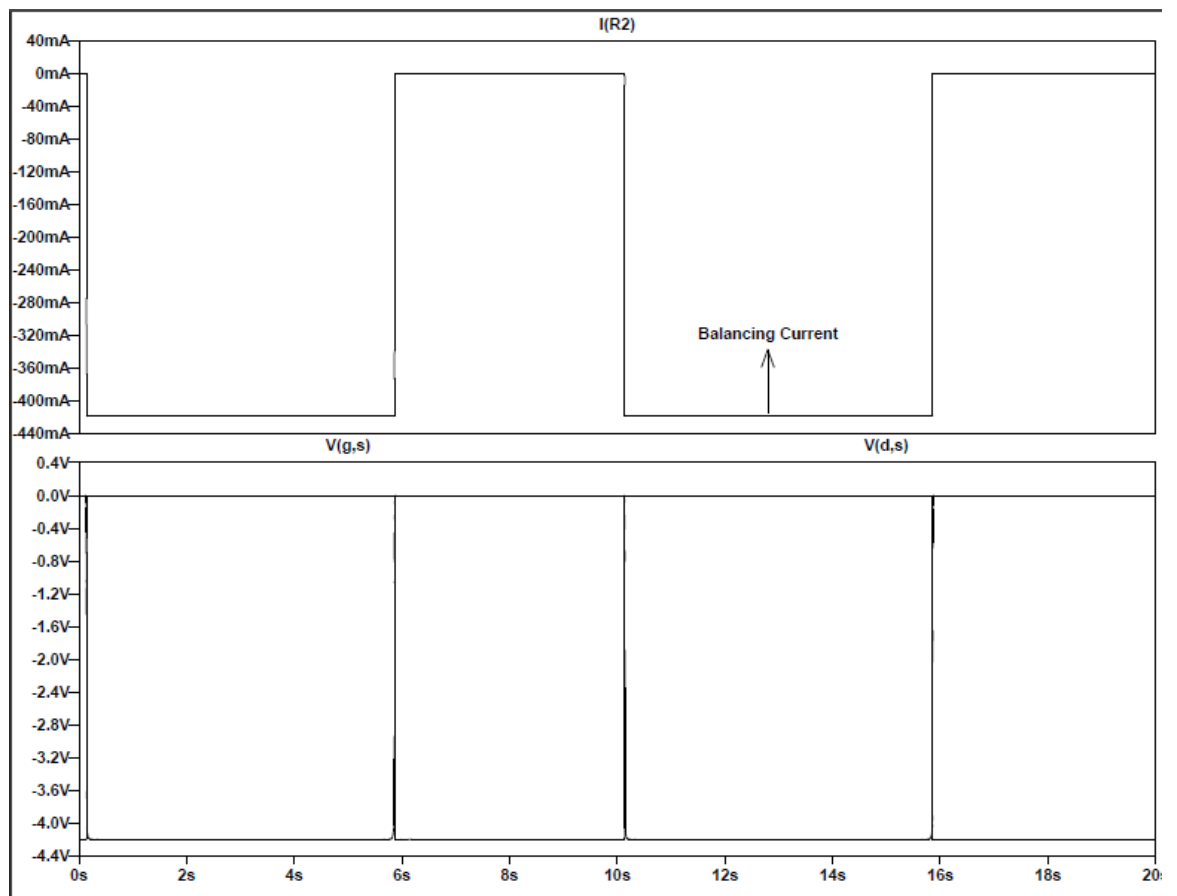

Figure 4.4 Balancing Circuitry

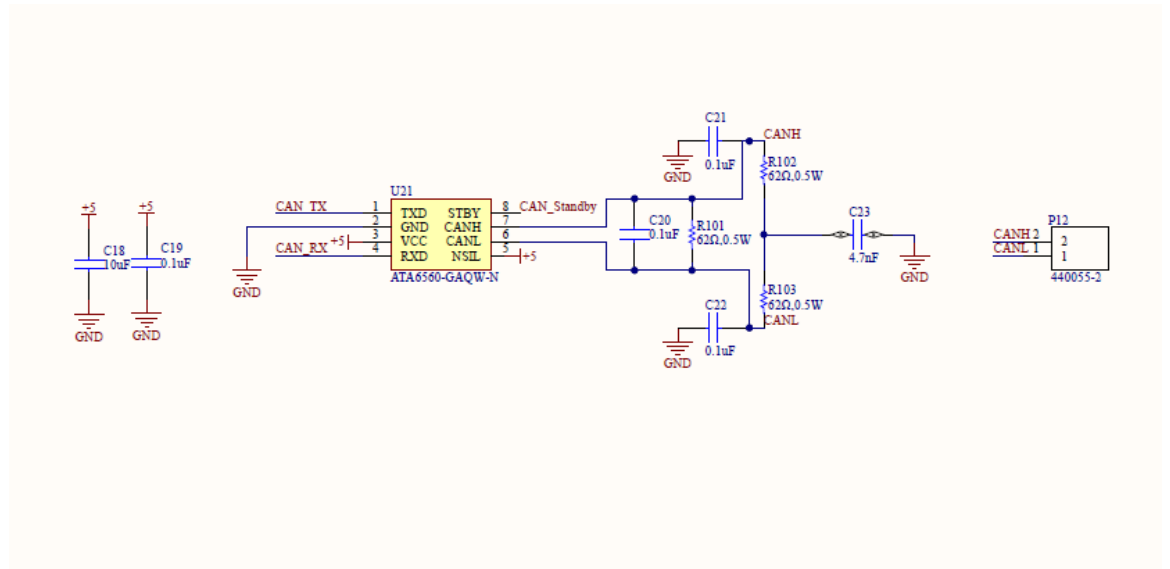**Figure 4.5 LTSpice Simulation Results**

Figure 4.6 CAN Implementation

CAN is the widely used communication protocol, especially in Automobile sector. However, its realization requires some additional measures like adding noise immunity on as well as off the PCB. Use of twisted wires and industrial grade connectors were suggested.

Figure 4.7 Voltage Dividers for Terminal Voltage Sensing

Chapter 5

Results

Amidst the Covid-19 pandemic, we could not finish our project. However, over the course of our project, we obtained the following results:

- Li-ion cells can be modelled using the above mentioned methods and circuits. It is the foremost step to design a battery pack.
- The cell data can be extrapolated to obtain a battery pack data. This is being used in the Slave board for battery monitoring.
- The designed Master board can be used as a charger by replacing the DPDT relay with a N-channel MOSFET. This FET is used while charging mode.
- Development of double-sided PCB with SMD components were manufactured at DJSCE labs. SMD components provide accurate measurement results when compared to their counterpart THT components.

Chapter 6

Conclusion & Scope

A Battery Management System (BMS) can be developed with various different configurations. However, a master- slave configuration suits well with 18650 or 21650 cylindrical cells owing to their limited capacity and higher number of cells in a battery pack.

A BMS must possess functionality to control charger, contactors, cooling systems and ground isolation protection. CAN or MODBUS work well with master- slave configuration BMS's and can be easily added into an automobile's electrical system.

Characterizing a cell is an integral part of BMS development. The project involves a PWM based closed loop discharge circuit for this purpose. The test conveys an important result that the capacity of a cell is a function of the discharge rate. This is an important parameter which effects SOC estimation in a dynamic condition like an Electric Vehicle.

Additionally, the same discharge circuit can be further modified into a charger circuit by using a half-bridge configuration. The high-side transistor would be operational while charging and the low-side transistor while discharging.

Chapter 7

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[2] P. Savanth and Shailesh K.R., "Reduction of parameters in a Lithium ion cell model by experimental validation of relationship between OCV and SOC," 2016 Online International Conference on Green Engineering and Technologies (IC-GET), Coimbatore, 2016, pp. 1-5.

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