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# a Modular Battery Management System for LFP Batteries

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Thesis presented in partial fulfilment of the requirements for the degree of Electrical Engineering in the Faculty of Engineering at Stellenbosch University.

Supervisor: Dr JM Strauss
Department of Electrical and Electronic Engineering

May 12, 2023

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forward together
sonke siya phambili
saam vorentoe

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| W. Viljoen<br>Voorletters en van / *Initials and surname* | May 12, 2023<br>Datum / *Date* |

# Executive Summary

This report presents a Modular Battery Management System (BMS) designed for Lithium Iron Phosphate (LFP) batteries. The report provides an introduction to the topic, followed by a system overview that outlines the key components and features of the BMS. The hardware design and implementation section details the circuitry and components used in the BMS, while the software development section describes the software architecture, algorithms, and functionality of the system. Measurements and results obtained from testing and evaluating the BMS are presented, highlighting its performance and efficiency. Finally, the report concludes with key findings and conclusions drawn from the development and testing of the Modular BMS for LFP batteries. The Modular BMS offers a flexible and scalable solution for managing LFP batteries, with potential applications in renewable energy systems, electric vehicles, and other energy storage applications.

Myself Mr. W Viljoen, the author of this report and the under-grade engineering student at the University of Stellenbosch will attempt the project proposed by Dr. JM Strauss as part of the BEng (Electr and Electron) N I102S ENERGY course and fulfilment of the Project(E) 448 module. The project (a Modular Battery Management System for LFP Batteries) is related to the ongoing innovation, design, and development of renewable energy.

Doen bedankinge

# Contents

# List of Figures

# Nomenclature

### Variables and functions

| | |
|---|---|
| $V$ | Voltage |
| $I$ | Current |
| $R$ | Resistance |

### Acronyms and abbreviations

| | |
|---|---|
| BMS | Battery Management System |
| Op-Amp | Operational Amplifier |
| LFP | Lithium Ferro-Phosphate |

# Introduction

## 1.1. Background and Motivation

In recent years, there has been a growing demand for large-scale energy storage solutions to support the integration of renewable energy sources, grid stabilization, and emergency backup power. High voltage battery banks have emerged as a promising technology for meeting these energy storage needs due to their high energy density, scalability, and flexibility in deployment. These battery banks can store excess energy during periods of low demand and discharge it during periods of high demand, thereby contributing to the efficient utilization of renewable energy sources and addressing the intermittency challenges associated with renewable energy. An example of such a system is the Tesla Megapack 1.1.

**Figure 1.1:** Tesla Megapack. [1]

However, while high voltage battery banks offer significant benefits, they also pose potential dangers if not managed properly. One critical aspect of managing high voltage battery banks is the implementation of an effective battery management system (BMS) to monitor, control, and protect the batteries. a BMS plays a crucial role in ensuring the safe and reliable operation of high voltage battery banks, as it monitors various parameters such as voltage, current, temperature, state of charge, and state of health of the batteries, and takes appropriate actions to prevent overcharging, over-discharging, overheating, and other critical events that can result in battery degradation, safety hazards, or even catastrophic failures.


**Figure 1.2:** Battery Balancing, Temperature runaway, State of Health

## 1.2. Conceptualization

A battery management system (BMS) is an electronic device that monitors and controls rechargeable batteries for safe and efficient operation. It manages charging, discharging, prevents overcharging/over-discharging, balances cell voltages, and provides real-time data on battery status. BMS is used in electric vehicles, renewable energy systems, and portable devices for battery optimization. in Figure1.3 on the right shows an example of a BMS with individual cell monitoring using a single controller, which is a common standard implementation.

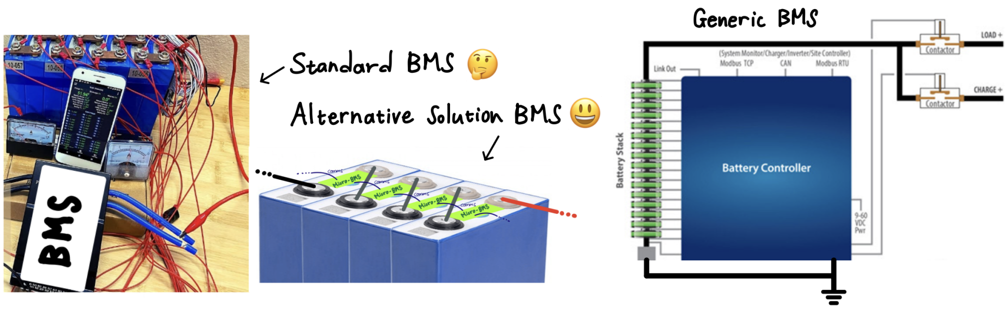


**Figure 1.3:** BMS Examples [2]

The focus is on high voltage battery banks (about 250 cells in series, achieving output voltages of around 800V). Connecting all these cells to a standard battery management system (on left in figure1.3) is a challenge due to the long cell strings, resulting in wire overload and inaccurate monitoring. To address this, an alternative design (middle of figure1.3) is proposed - a small module on top of each cell with monitoring components and its own micro-controller, essentially creating individual BMS for each cell. This design will be initially applied to four cells and can be scaled up by adding more cells with modules.

In conclusion, the Modular BMS designed and presented in this report offers a comprehensive solution for efficient and effective management of LFP cells. The report provides a detailed overview of the BMS, including its hardware design, software development, and performance testing. The measurements and results obtained from testing highlight the superior performance and scalability of the Modular BMS. With potential applications in energy storage applications, the Modular BMS presents a promising solution for the growing demand for advanced battery management systems. Overall, the development and testing of the Modular BMS for LFP batteries demonstrate its potential as a flexible and reliable solution for managing LFP batteries, paving the way for further research and development in this field.

# System Overview

The system design encompasses both hardware and software development, with a comprehensive overview provided in the setup description (see section 2.1). The hardware and software components of the system are meticulously developed through research and design, as detailed in the respective sections (see 3 and 4). While existing BMS topology has informed much of the system's functional blocks, the communication aspect poses a unique challenge as there is no standard or preexisting solution. This is due to the absence of a common ground or reference point for communication devices, as each module in the serial communication line operates with its own power supply. This unprecedented constraint requires a novel approach, which will be elaborated in the communication methodology section (see 2.2) where a design solution will be proposed.

## 2.1. Setup Description

Type something here about the whole system working...

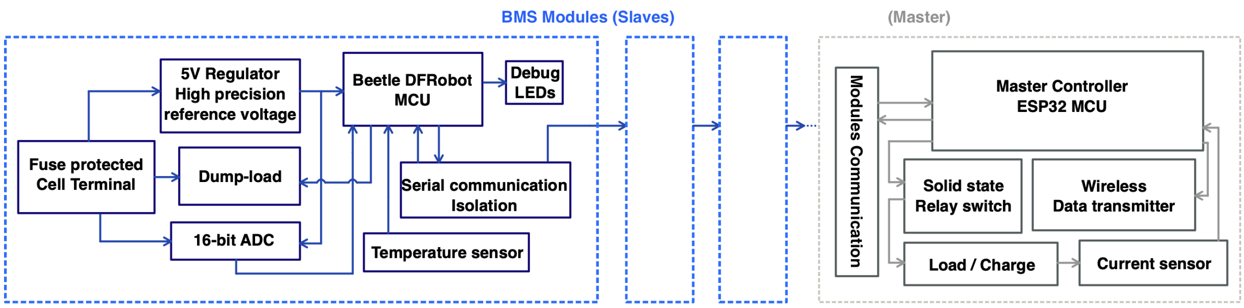


**Figure 2.1:** System overview.

Write about the spesific cell used in this project...

## 2.2. Module Communication Methodology

Communication plays a vital role in the system as it facilitates the data transfer of the monitoring system and enables individual cells to communicate with each other via the monitoring modules. To achieve a solution for the design, extensive research was carried out, beginning with exploring a canbus design by Stuart Pittaway [3] and the isoSPI design by Mark Wolf [4]. However, neither option proved feasible for the project. Eventually, a design utilizing isolated UART serial communication was discovered [5], which was found to be more compatible with the Beetle DFRobot microcontroller, and isolation between voltage levels was now achievable. Although hardware connection for UART communication between two microcontrollers is typically straightforward, in this project, communication is required between multiple modules in a stack. Consequently, a decision needed to be made on the type of connection configuration. Upon exploring various connection types, I was able to narrow down two options, the daisy-chain and all-call UART connection configurations, both of which are illustrated below.

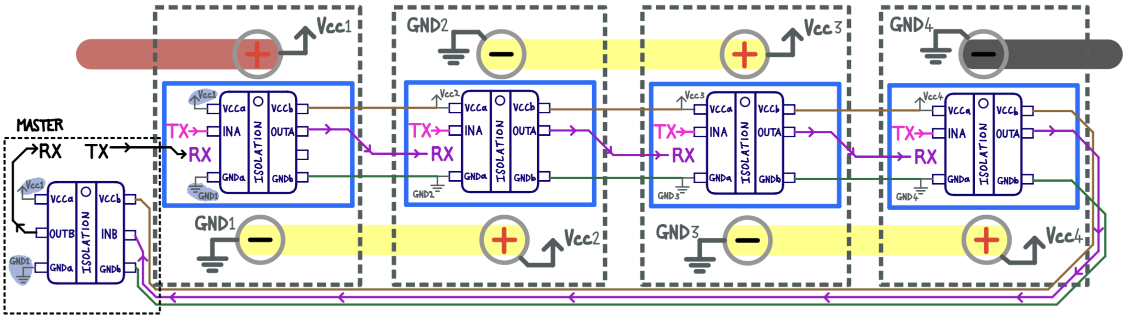


**Figure 2.2:** Daisy-chain configuration.

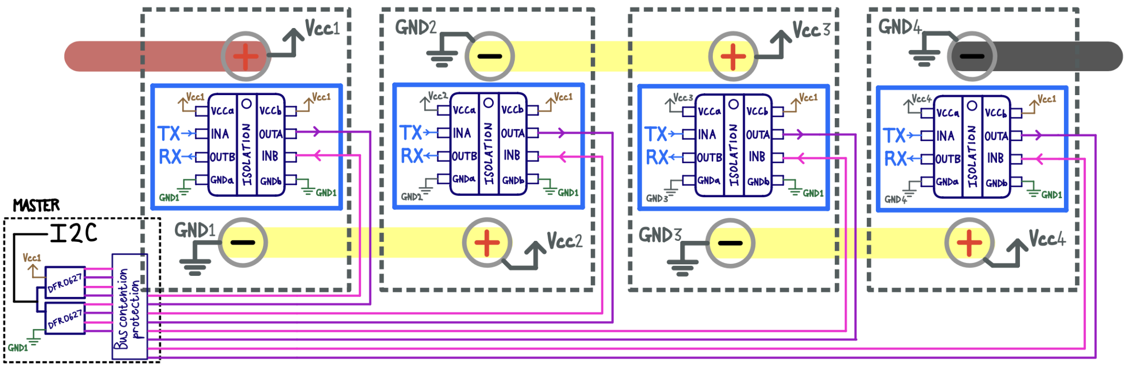


**Figure 2.3:** All-call configuration.

By analyzing the sketches presented above, it becomes evident that there are clear distinctions between the assorted options. For instance, one of the options is a series connection and the other parallel. However, to make the most suitable design selection, I delved into the specifics of each configuration to construct the comparison table below.

| Feature | Daisy-Chain Configuration | Bus Configuration |
|---|---|---|
| Definition | Devices are connected in a series, with each device connected to the next device's RX and TX pins, forming a closed loop | Devices are connected in parallel to a single communication line, with all devices connected to the same RX and TX pins of the master controller |
| Hardware complexity | Simple, each device requires only two connections for RX and TX | More complex, requires additional hardware components, such as pull-up resistors and line drivers, to ensure reliable communication |
| Wiring complexity | Increases with the number of devices in the chain, requires more connections between devices | Simplifies wiring, reduces number of connections required, all devices are connected to the same lines |
| Transmission delay | Each device must wait for the previous device to complete its transmission before transmitting data, limiting the data rate | Devices can transmit data at any time, without waiting for other devices, potentially increasing the data rate |
| Data rate | Limited by the transmission delay between devices, which increases with the number of devices in the chain | Potentially higher, depending on hardware and software design, can support higher data rates |
| Software complexity | Higher, requires time delay programming for each device to ensure data is transmitted in sequence | Simpler, devices can transmit data at any time, without waiting for other devices |
| Fault tolerance | Communication can be disrupted if any device fails, since it breaks the closed loop | Communication can continue as long as at least one device remains functional, since all devices are connected in parallel |
| Advantages | Simple hardware design, suitable for small-scale systems with a few devices | Simplifies wiring, can support higher data rates, suitable for larger systems with multiple devices |
| Disadvantages | Limited data rate, requires time delay programming for each device, may be disrupted if any device fails | More complex hardware design, requires additional components, may be more expensive, may require higher software complexity to manage communication |

**Figure 2.4:** Table of Daisy-chain and All Call UART Configuration.

$$Maximum\ data\ transfer\ rate = \frac{baudrate}{10 \times \#devices} \times \#databits\ per\ byte$$
$$Maximum\ data\ transfer\ rate = \frac{baudrate}{10 \times (\#databits + paritybits + stopbits)}$$

# Hardware Design and Implementation

Explain that PCB design was done simultaneously with the design of circuit elements and component selection was also done with time consuming datasheet research, datasheets of every component can maybe be added as appendixes... Then do the report on circuit designs and component selection, after that, do a section on KiCad to emphasise how much design went into the PCB itself

## 3.1. Module Connection to Cell

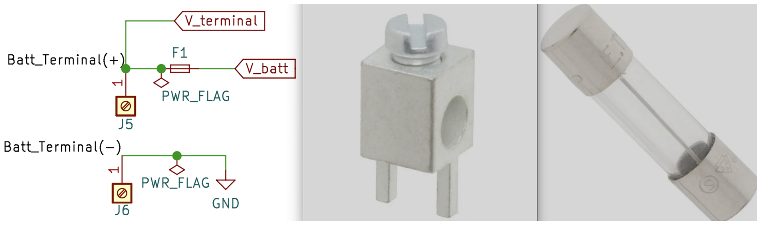


**Figure 3.1:** Module terminals and fuse protection.

The BMS modules are connected to each cell's positive and negative terminals to monitor the cell voltage, but the cell also supplies the module through the same connection (parasite power). The module was equipped with Metz screw connectors to allow for an easy and flexible installation. Power wires can be connected to any type of cell terminal and be connected or removed from the module without soldering.

For over-current protection a fuse was added to the design, connecting the positive terminal to the rest of the circuit. However, in the desired system where nearly 300 cells are in series, a glass fuse will not be a useful design since these fuses would not be accessible to replace and the system will not be self-sustainable. For version...

Insert normal fuse, the desire prototype will have a polyfuse and limp mode, because fuses will not be accesable, but for this testing prototype a normal fuse can be replaced faster than polyfuse can reset.

## 3.2. Power Supply

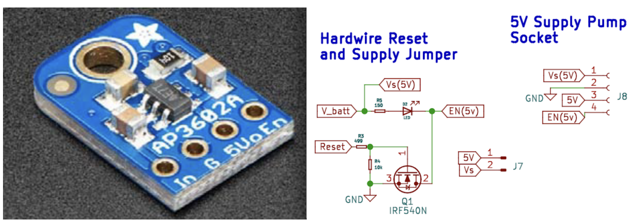


**Figure 3.2:** Adafruit MiniBoost 5V Charge Pump - AP3602A.

To ensure the high precision monitoring system functions optimally, it is crucial to guarantee a stable and accurate 5V power supply to the board. While the system can operate with voltage as low as 3V, it can't reach its full capacity. Hence, the voltage level of the 3.2V LFP cell is insufficient to power the board correctly. Therefore, a voltage regulator is necessary to step up the battery voltage to the required 5V. After considering various options, a mini-booster module utilizing a charge-pump topology was selected. This module is ideal for single Lithium batteries, and its compact size and affordability make it an excellent choice for the project. Equipped with an AP3602A chip that ensures low power dissipation and high efficiency, the module outputs a stable 5V on the OUT pin when provided with a 3-5VDC input on the IN and ground pins. This guarantees that the Arduino Beetle board functions correctly. Additionally, the module includes an enable pin that can be used as an emergency reset for the system. In conclusion, the mini-booster voltage regulator module is an optimal choice for the project because it provides a reliable and accurate 5V power supply to the Arduino Beetle board using a single Lithium battery. Its small size, affordability, and high efficiency make it a practical and dependable choice for this application.
This module that is used in the project mounts into a socket that is soldered and wired into monitoring module PCB. The 5V supply goes through a jumper which can be opened to allow the MCU to be programmed from a computer while installed on a battery cell (prevents short circuit between the regulator supply and computer port). The circuitry for the emergency reset uses the same design detailed in section 3.6.

## 3.3. Monitoring Controller

Type something here about the Beetle's work and the ADC and Vref... (use subsections!!!)

## 3.4. Communication / Data Transfer

Type something here about the final coms design...

## 3.5. Printed Circuit Boards

Show something here about the ALL KiCad work... Mention that the circuit boards were designed to fit the hardware designs metioned above

## 3.6. Dump-load Module

Mmm...

## 3.7. Temperature monitor

Type something about why you need an internal and external temp sensor...
Mmm... Talk about external temperature sensor

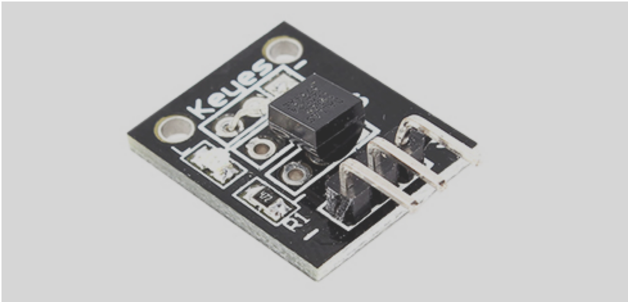


**Figure 3.3:** External temperature sensor.

Mmm... Talk about INTERNAL temperature sensor

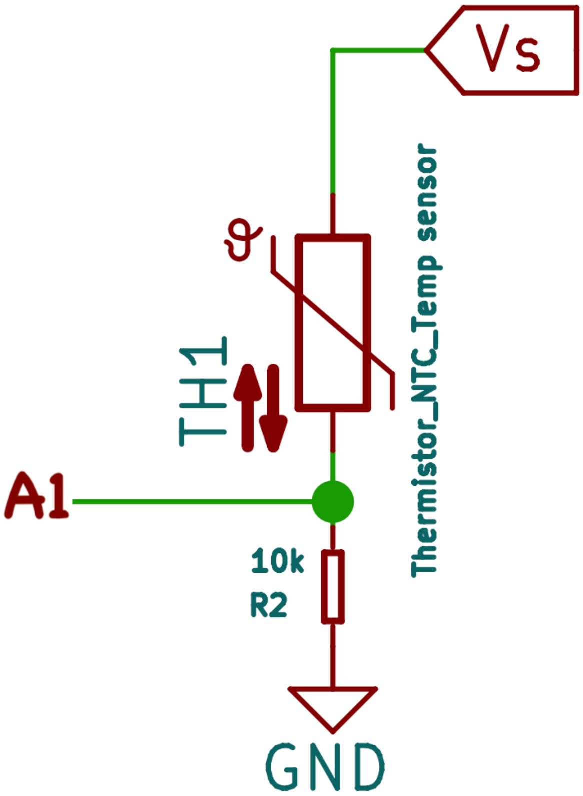


**Figure 3.4:** Circuit to measure module internal temperature.

# Software Development

The beetles will do everything, master will only collect...

## 4.1. Firmware Pseudo Code

Show something here about the program flow...

# Measurements and Results

Create a draft for this section...

Do an Experimental procedure section...

# Bibliography


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[3] Stuart Pittaway, "diybms," 2019. [Online]. Available: https://github.com/stuartpittaway/diyBMS

[4] Mark Wolf, "Mlt isolated spi module," 2017. [Online]. Available: https://www.open-electronics.org/guest_projects/mlt-isolated-spi-module/

[5] Texas Instruments, "Isolated rs-232 to uart converter reference design," 2014. [Online]. Available: https://www.ti.com/tool/TIDA-00163

# Project Risk Assessment

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E-design 344 Social Contract

2022

The purpose of this document is to establish commitment between the student and the organisers of E344. Beyond the commitment made here, it is not binding.

In the months preceeding the term, the lecturer (Thinus Booysen) and a few paid helpers (Rita van der Walt, Keegan Hull, and Michael Ritchie) spent countless hours to prepare for E344 to ensure that you get your money's worth, that you are enabled to learn from the module, and demonstrate and be assessed on your skills. We commit to prepare the assignments, to set the assessments fairly, to be reasonably available, and to provide feedback and support as best and fast we can. We will work hard to give you the best opportunity to learn from and pass analogue electronic design E344.

I, ..........Willem Viljoen.......... have registered for E344 of my own volition with the intention to learn of and be assessed on the principals of analogue electronic design. Despite the potential publication online of supplementary videos on specific topics, I acknowledge that I am expected to attend the scheduled lectures to make the most of these appointments and learning opportunities. Moreover, I realise I am expected to spend the additional requisite number of hours on E344 as specified in the yearbook.

I acknowledge that E344 is an important part of my journey to becoming a professional engineer, and that my conduct should be reflective thereof. This includes doing and submitting my own work, working hard, starting on time, and assimilating as much information as possible. It also includes showing respect towards the University's equipment, staff, and their time.

| | |
|---|---|
| Prof. MJ (Thinus) Booysen | Student number: 22877169 |
| Signature: .......... | Signature: .......... |
| Date: .......... | Date: 22/07/2022 |

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# Estimated Time and Cost Details