Ministry of Higher Education and Scientific Research
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Microelectronics Engineering First Year annual Project report:

Open-Source Advanced Battery Management System for Robotics & electric vehicles

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Abstract

This report outlines the development of an open-source battery management system (BMS) designed for use in electric vehicles and robotics platforms. The BMS was designed using Altium Designer for creating schematics and PCB layouts, while the software was developed using the Arduino IDE and deployed on an Arduino Nano MCU. The primary aim of this project was to explore the latest advancements in BMS technology and to gain experience using advanced Electronics CAD tools like Altium. This report provides a detailed overview of the BMS design and its various features, with an emphasis on its potential applications in the fields of electric vehicles and robotics.

Index Terms: BMS (Battery management System), CAD (computer aided design), Altium Designer, Arduino, electric vehicles, robotics.

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General introduction

I. Brief Overview:

Battery Management Systems (BMS) are electronic systems designed to manage and monitor batteries, ensuring their optimal performance and safety. BMS are widely used in various applications, including electric vehicles, renewable energy systems, and portable electronics, to name a few.

The primary functions of a BMS are to protect the battery from overcharging, over-discharging, and overheating, which can lead to a decrease in battery life and, in extreme cases, pose a safety hazard. A BMS achieves this by monitoring various battery parameters, such as voltage, and current, and taking appropriate actions based on the measured values.

BMSs come in various types, including passive, active, and hybrid. Passive BMSs rely on passive balancing techniques to balance the individual cells in a battery pack, while active BMSs use active balancing techniques. Hybrid BMSs combine the advantages of both passive and active balancing techniques.

In recent years, there has been a growing interest in open-source BMSs, as they offer greater transparency, flexibility, and cost-effectiveness compared to proprietary solutions. Open-source BMSs allow users to modify and customize the system according to their needs and provide a platform for collaboration and knowledge-sharing among the maker community.

The purpose of this report is to document the process of designing, developing, and testing the Open Source BMS System. The report will cover the various aspects of the project, including the design and development of the BMS PCB using Altium Design, and coding of the BMS using Arduino. The report will also provide a comparison of the Open Source BMS System with other commercial BMS systems, as well as its limitations and future improvements.

The report aims to serve as a guide for anyone interested in designing and developing their own BMS system, as well as to promote the use of Open Source hardware and software.

II. Design & Development:

1. Description of OpenBMS

The Open Source Battery Management System (OpenBMS) for Lithium Cells is a system designed to Monitor battery status and display it, charge the battery as required, and most importantly, balance the cells, insuring a longer lifespan, as well as protecting them from under-volting. The system can also prepare the cells for permanent storage.

OpenBMS is suitable for Lithium-ion, Lithium Iron Phosphate (Lifepo4), Nickel Cadmium (NiCd), Nickel-Metal Hydride (NiMH), Lead Acid (flooded, VRLA, SLA) batteries up to 12V, and other types such as NiZn, alkaline, etc., with a total voltage of up to 20V.A

The Open Source BMS System consists of several modules, including the Cell Module, containing the voltage measure, balance, and charge circuits, the Limiter, a display Module in the form of an i2c LCD display, and a control module in the form of a power regulator and MCU.

The Cell Module is responsible for monitoring the voltage of each cell in the battery pack, and the Control Unit processes this information and controls the operation of the Limiter and charging. The Limiter limits the charging current to 1A when a cell in the pack is balancing, and the Charging Module charges the battery pack according to the required battery parameters.

The PCB design was created using Altium Design, and is modular, allowing for the addition or removal of cells as required. The board is double-layered and uses CEM methods, making it suitable for use with a range of battery types.

The BMS system is powered by an Arduino Nano controller and is programmed using Arduino. The system constantly monitors battery parameters, and instantly cuts off the input or output from the battery as soon as any unusual behavior is detected. The system also includes warning LEDs and charge indicator LEDs for user convenience.

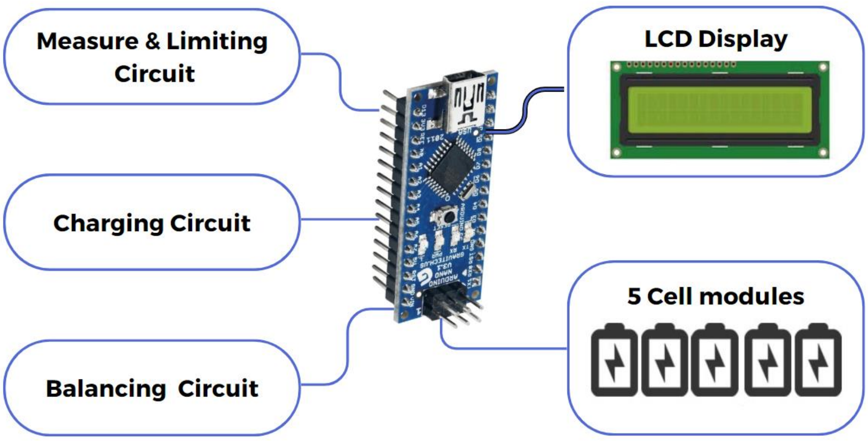

FIGURE 1. OPENBMS SYSTEM DIAGRAM

2. PCB Design

2.1. Schematics

We have used the Multi-sheet & Hierarchical approach [1] when it comes to organizing the different parts of this system, all the schematics are grouped and connected to the Top layer called OpenBms.SCHDOC, This is done via the “create sheet from sheet symbol tool.

The figure below showcases how the different modules are connected, on the left we can see a hypothetical indication showing how batteries must be connected to the system. Inspiration for tis approach was taken from the community [2].

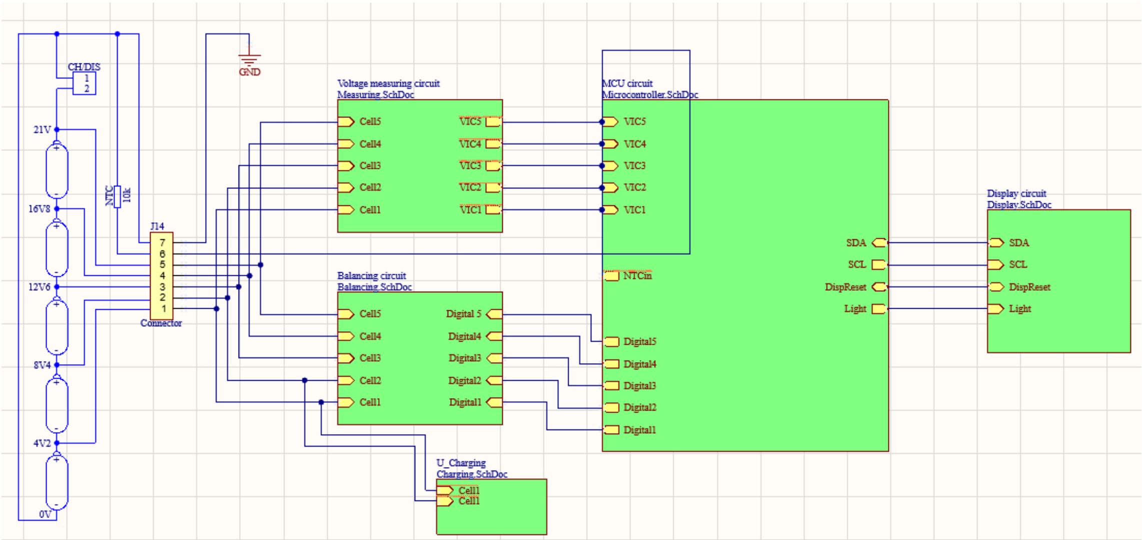

FIGURE 2. MAIN SYSTEM SCHEMATIC

2.1.1. MCU & Power management Schematic

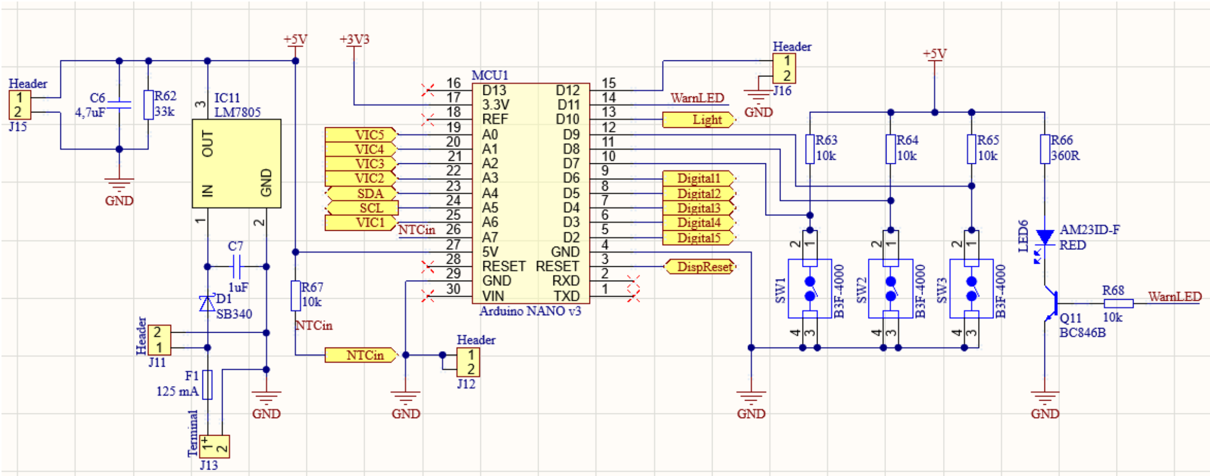

FIGURE 3. MCU & POWER MANAGEMENT SCHEMATIC

The Figure above highlights the first part of our system, here we are using a regular header, along with some regular input connectors to take the external power source, and then we take the power through a filtering & regulation stage, for it to finally be distributed to the whole system. The necessary MCU pins are also connected, and 3 buttons are provided in order to cycle between the different operating modes.

The regulation circuit design was taken from a reliable source online, as it is simple and non-expensive.

2.1.2. Charging Circuit Schematic

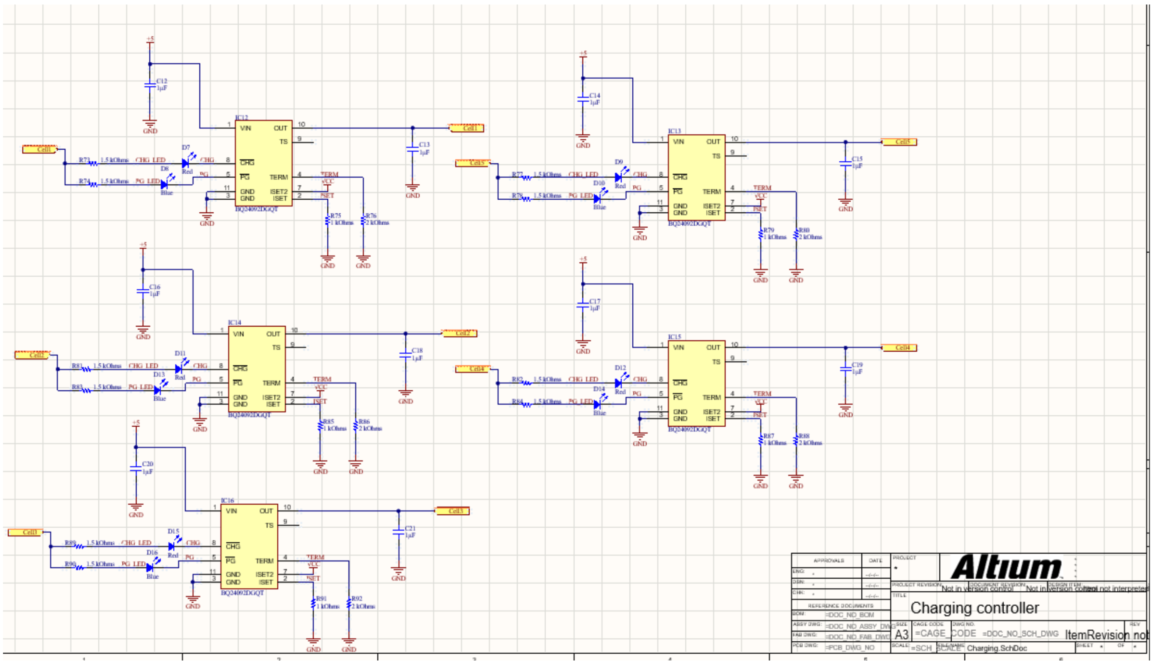

FIGURE 4. CHARGING CIRCUIT SCHEMATIC

In the figure above, you can see a simple charging & charge indication circuit, which is duplicated for each of the cells of our system(to be showcased later).

This will be a common theme in the rest of the project, since it's modular, meaning that you can keep on duplicating the modules for the number of requested total cells. In this case, the system can support five cells at once.

This circuit is based on the BQ24092DGQT IC, which takes our regulated input and makes sure to correctly charge the battery; it comes after the balancing & voltage measurement stages, assuring correct charging.

2.1.3. Balancing Circuit Schematic

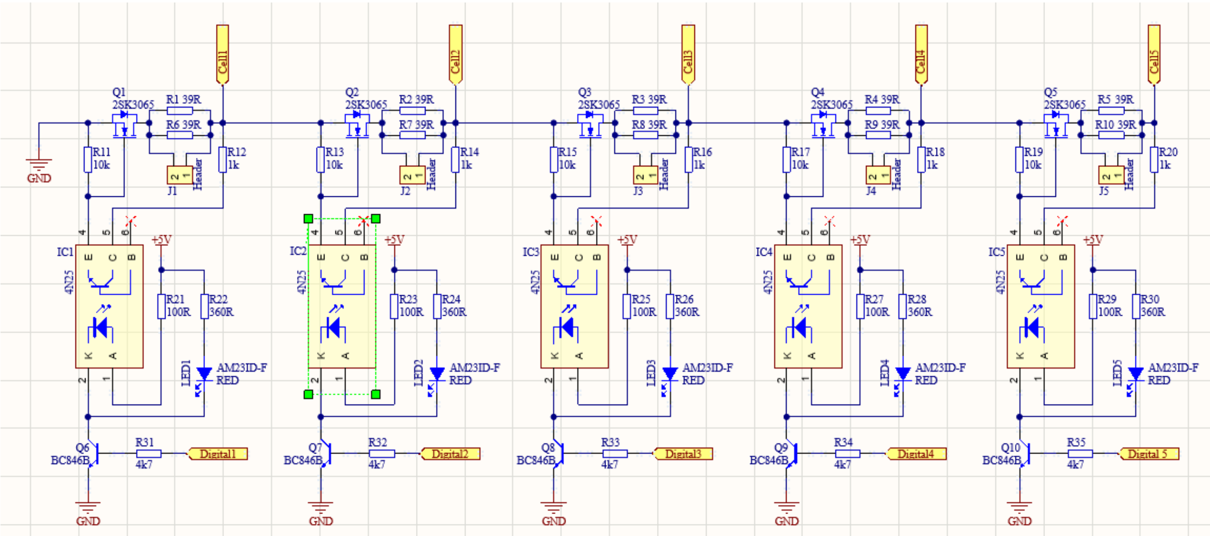

FIGURE 5. BALANCING CIRCUIT SCHEMATIC

Here, you can see the five duplicated modules, each them Is based on the 4N25 Optocoupler, which will help us reduce noise, and most importantly, isolate Low-voltage devised from high voltage circuits, allowing us to compare the cells and identity miss-balanced ones.

We used extra headers here to insure the functionality of probing, to facilitate testing and debugging the system when needed.

2.1.4. Measuring Circuit Schematic

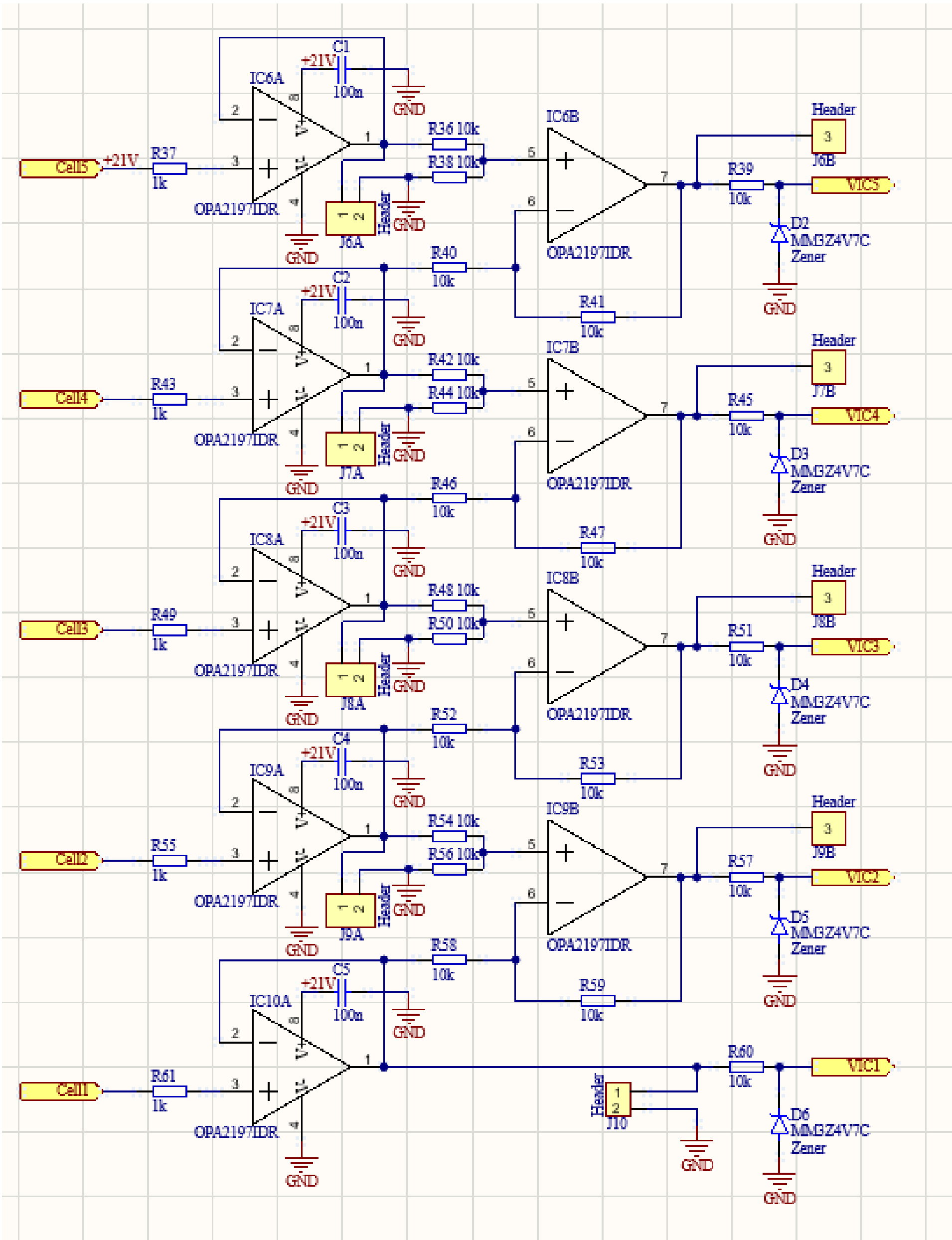

FIGURE 6. MEASURING CIRCUIT SCHEMATIC

This circuit is used to sense voltage and current, thus making sure the batteries are safe and protected, is uses two OPAx197 Dual 36-V, precision, rail-to-rail input output, low offset voltage op amps [3].

The Unique features of this amp, such as the differential input-voltage range to the supply rail, high output current (±65 mA), high capacitive load drive of up to 1 nF, and high slew rate (20 V/µs) make the OPA197 a robust, high-performance operational amplifier for high-voltage, industrial applications.

2.1.5. Display Circuit Schematic

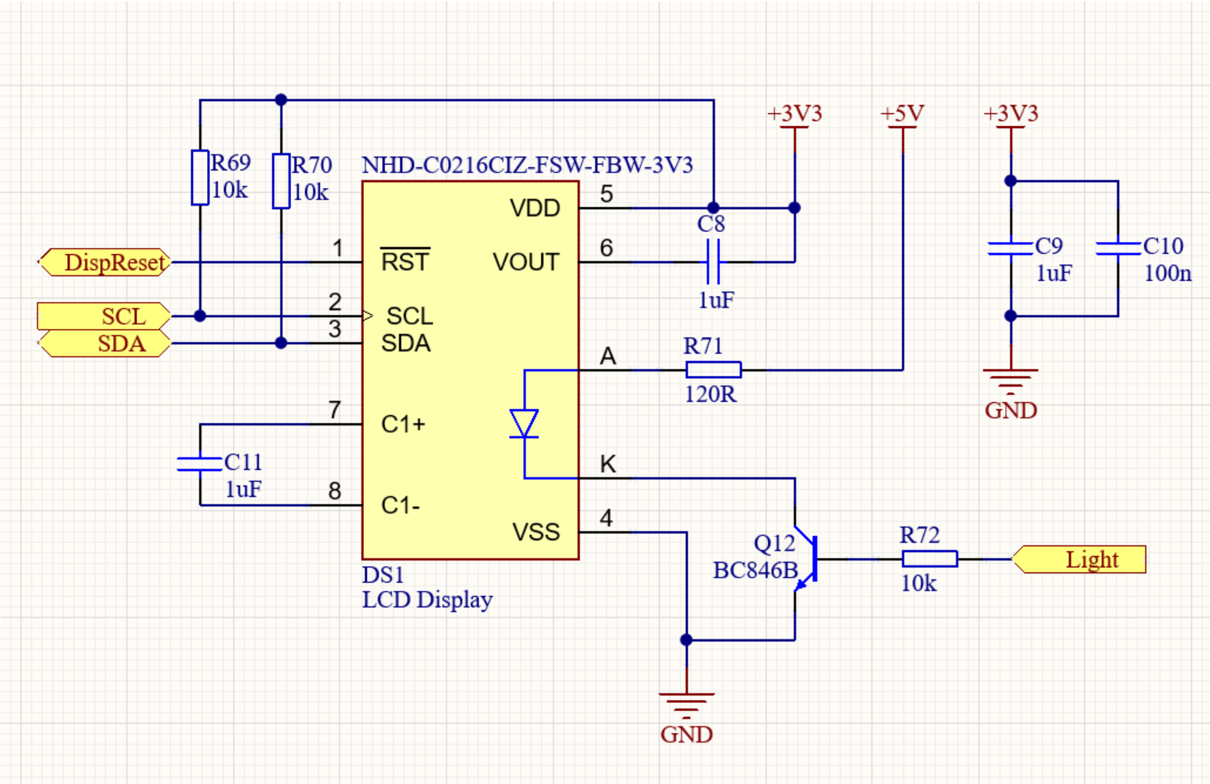

FIGURE 7. DISPLAY CIRCUIT SCHEMATIC

Here, we have the final schematic of our system, which is the simple connection to the LCD Display, with resistors and capacitors added in order to clean the signals, and a connection to the light indicator. The multi-layer approach allowed us to facilitate the feat of creating schematics, by giving us breathable space, and a clear visual experience; also, it improves readability and thus rendering the project more suitable for collaborations.

2.2. PCB

2.2.1. Specifications and Design rules

The final board size is 133.0000mm x 136.5000mm, with 155 total components.

We used a two-layer design, one top and one bottom, with all components on the top layer, also ground area was left on both in order to improve the quality of the design and make it resilient towards outside noise, thus respecting the laws of electromagnetic compatibility.

The toal Copper Area is 16428 Sq Mms, with 63 drill pairs.

Our track width was a consistent 0.0254mm, with some exceptions when needed.

The dominant technology used is SMD, as it reduces space and improves the overall quality.

2.2.2. PCB Design

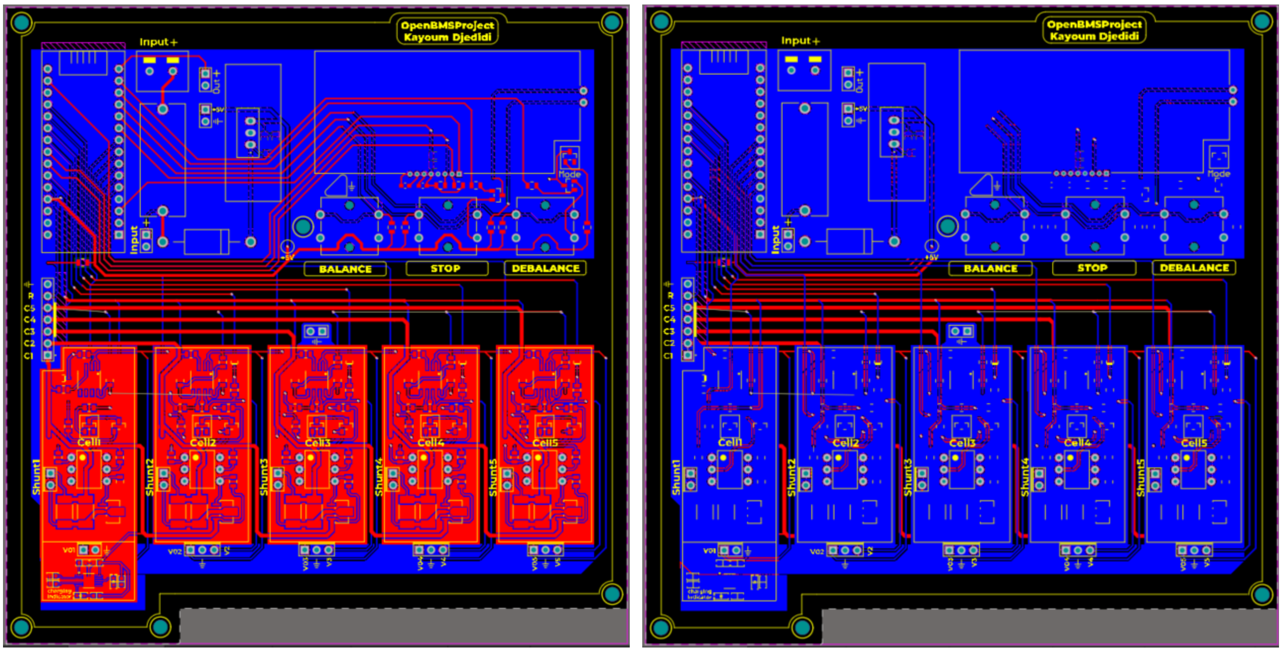

FIGURE 8. FINAL ASSEMBLY PCB IN 2D TOP VIEW

The figure above showcases the final design, as you can see, ground planes where used on both the top and bottom layers to provide shielding, also, the design is mostly duplicated in order to increase the number of supported cells.

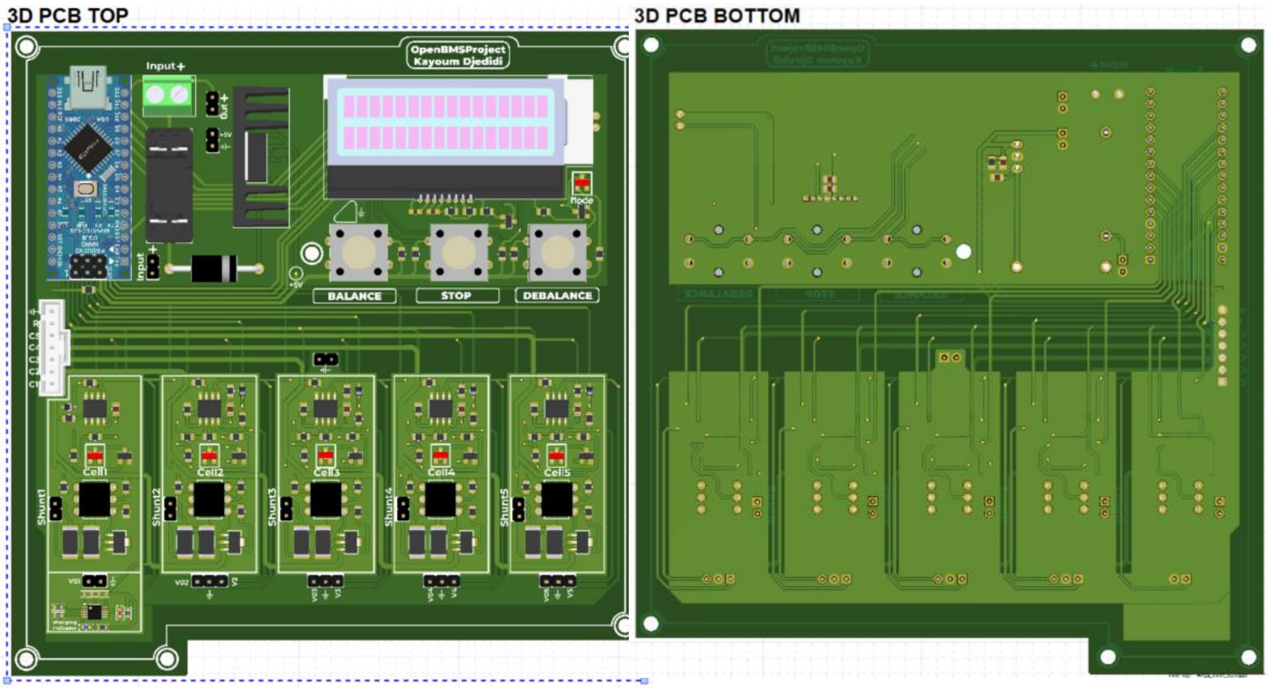

FIGURE 9. PCB 3D TOP & BOTTOM VIEWS

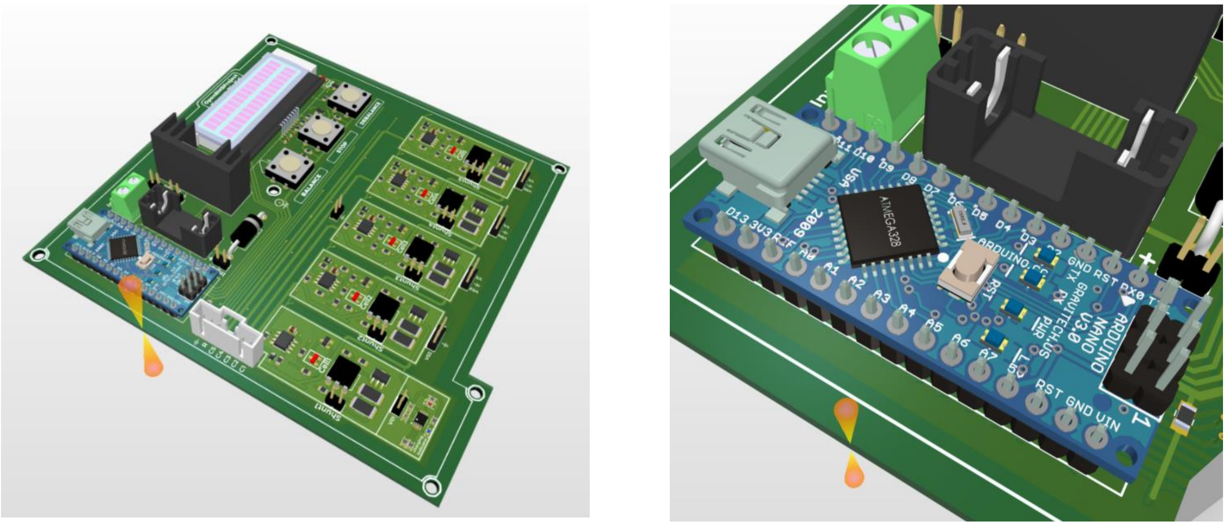

FIGURE 10. PCB HIGHLIGHTS

Jumper pins where left across the design to provide probes, and the routing was 50% automated, and 50% manual for the more tricky parts that couldn't be done by the auto-route feature, also the ground planes were added in later manually after the routing step was complete.

Footprints and 3D models were provided via the free open-source Celestial Altium library, which can be downloaded from the official website, some parts where manually added from various internet sources.

Below is a full bill of materials:

Comment	Description	Designator	Footprint	LibRef	Quantity
100nF_35V	Capacitor [SMD]	C1, C2, C3, C4, C5, C10	C_0805	C_100nF_0805	6
4,7uF_35V	Capacitor [SMD]	C6	C_0805	C_4,7uF_0805	1
1uF_35V	Capacitor [SMD]	C7, C9	C_0805	C_1uF_0805	2
1uF_35V	Capacitor [SMD]	C8, C11	C_0603	C_1uF_0603	2
1µF	CAP CER 1UF 25V X5R 0603	C12, C13, C14, C15, C16, C17, C18, C19, C20, C21	CAP 0603_1608	CC0603KRX5R8BB105	10
SB340_DO-201AD	Diode Schottky 40V 3A [TH]	D1	DO-201AD	SB340_DO-201AD	1
MM3Z4V7C_SOD-323F	Zener Single Diode, 4.7 V, 200 mW [SMD]	D2, D3, D4, D5, D6	SODFL2512X90N	MM3Z4V7C_SOD-323F	5
Red	LED RED CLEAR 2SMD	D7, D9, D11, D12, D15	LED 0603_1608 RED	19-213USRC/S259/TR8	5
Blue	LED BLUE CLEAR 2SMD	D8, D10, D13, D14, D16	LED 0603_1608 BLUE	EAST16084BA8	5
LCD_FSTN_Display	NHD-C0216CIZ-FSW-FBW-3V3 LCD Display	DS1	LCD_NHD-C0216CIZ-FSW-FBW-3V3	LCD_FSTN_Display	1
PTF0078P	Fuse holder [TH]	F1	FUSE_5x20	PTF0078P	1
4N25_DIP6	Optocoupler [TH]	IC1, IC2, IC3, IC4, IC5	DIP6	4N25_DIP6	5
OPA2197IDR_8-SOIC	Dual OP AMP [TH]	IC6, IC7, IC8, IC9, IC10	SOIC8	OPA2197IDR_8-SOIC	5

LM7805_TO220	Linear Voltage Regulator 5V [TH] with thermal pad mounted to Fischer elektronik SK09 - 20mm heatsink with a screw and nut	IC11	TO220	LM7805_TO220	1
BQ24092DGQT	IC BATT CHARGER LI-ION 10MSOP	IC12, IC13, IC14, IC15, IC16	TI PDSO-10 DCQ	BQ24092DGQT	5
2.54mm pitch	Header, 2-Pin [TH]	J1, J2, J3, J4, J5, J10, J11, J12, J15, J16	HDR_1x2_2.54mm-MALE	Header 1x2	10
2.54mm pitch	Header, 3-Pin [TH]	J6, J7, J8, J9	HDR_1X3_2.54mm-MALE	Header 1x3AB	4
5mm pitch	PCB connector, 2-Pin [TH]	J13	TERMINAL_90_5MM	Terminal 1x2	1
Header connector 1x7	Header, 7-Pin [TH]	J14	HDR_1x7_2.54mm-MALE	Header connector 1x7	1
LED_SOT23	Red LED [SMD]	LED1, LED2, LED3, LED4, LED5, LED6	LED_SOT23	LED_SOT23	6
Arduino NANO v 3.0	Microcontroller [TH]	MCU1	Arduino_Nano_V3.0	Arduino NANO v 3.0	1
2SK3065_SOT89	N Channel MOSFET [SMD]	Q1, Q2, Q3, Q4, Q5	N_MOSFET	2SK3065_SOT89	5
BC846B_SOT23	NPN transistor [SMD]	Q6, Q7, Q8, Q9, Q10, Q11, Q12	NPN_BJT_SOT23	BC846B_SOT23	7
39R_2W	Resistor [SMD]	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10	R_2512	R_39R_2512	10
10k_125mW	Resistor [SMD]	R11, R13, R15, R17, R19, R36, R38, R39, R40, R41, R42, R44, R45, R46, R47, R48, R50, R51, R52, R53, R54, R56, R57, R58, R59, R60, R63, R64, R65, R67, R68, R69, R70, R72	R_0805	R_10k_0805	34
1k_125mW	Resistor [SMD]	R12, R14, R16, R18, R20, R37, R43, R49, R55, R61	R_0805	R_1k_0805	10
100R_500mW	Resistor [SMD]	R21, R23, R25, R27, R29	R_0805	R_100R_0805	5
360R_125mW	Resistor [SMD]	R22, R24, R26, R28, R30, R66	R_0805	R_360R_0805	6
4k7_125mW	Resistor [SMD]	R31, R32, R33, R34, R35	R_0805	R_4k7_0805	5
33k_125mW	Resistor [SMD]	R62	R_0805	R_33k_0805	1
120R_125mW	Resistor [SMD]	R71	R_0805	R_120R_0805	1
1.5 kOhms	RES SMD 1.5K OHM 1% 1/10W 0603	R73, R74, R77, R78, R81, R82, R83, R84, R89, R90	RES 0603_1608	ERJ-3EKF1501V	10
1 kOhms	RES SMD 1K OHM 5% 1/4W 0603	R75, R79, R85, R87, R91	RES 0603_1608	ERJ-PA3J102V	5
2 kOhms	RES SMD 2K OHM 5% 1/4W 0603	R76, R80, R86, R88, R92	RES 0603_1608	ERJ-PA3J202V	5
B3F-4000	SPST Push button [TH]	SW1, SW2, SW3	PUSH_BUTTON	B3F-4000	3

FIGURE 11. BOM

Draftsman document and an Output project PDF file generated using Altium with further details can be found in the project source files.

3. Programming

The code was developed using C++ with the Arduino IDE, We took a lot of inspiration from other resources found online [4], especially for necessary calculations and methods used, such as the usage of the MCU timers in order to do most functions.

Note that while it is functional and serves all the basic needs, it is still very not well optimized since we could not test it in a real world scenario. Future versions will focus on reducing unnecessary clutter and improving precision.

The diagrams below explain the code functionality in detail:

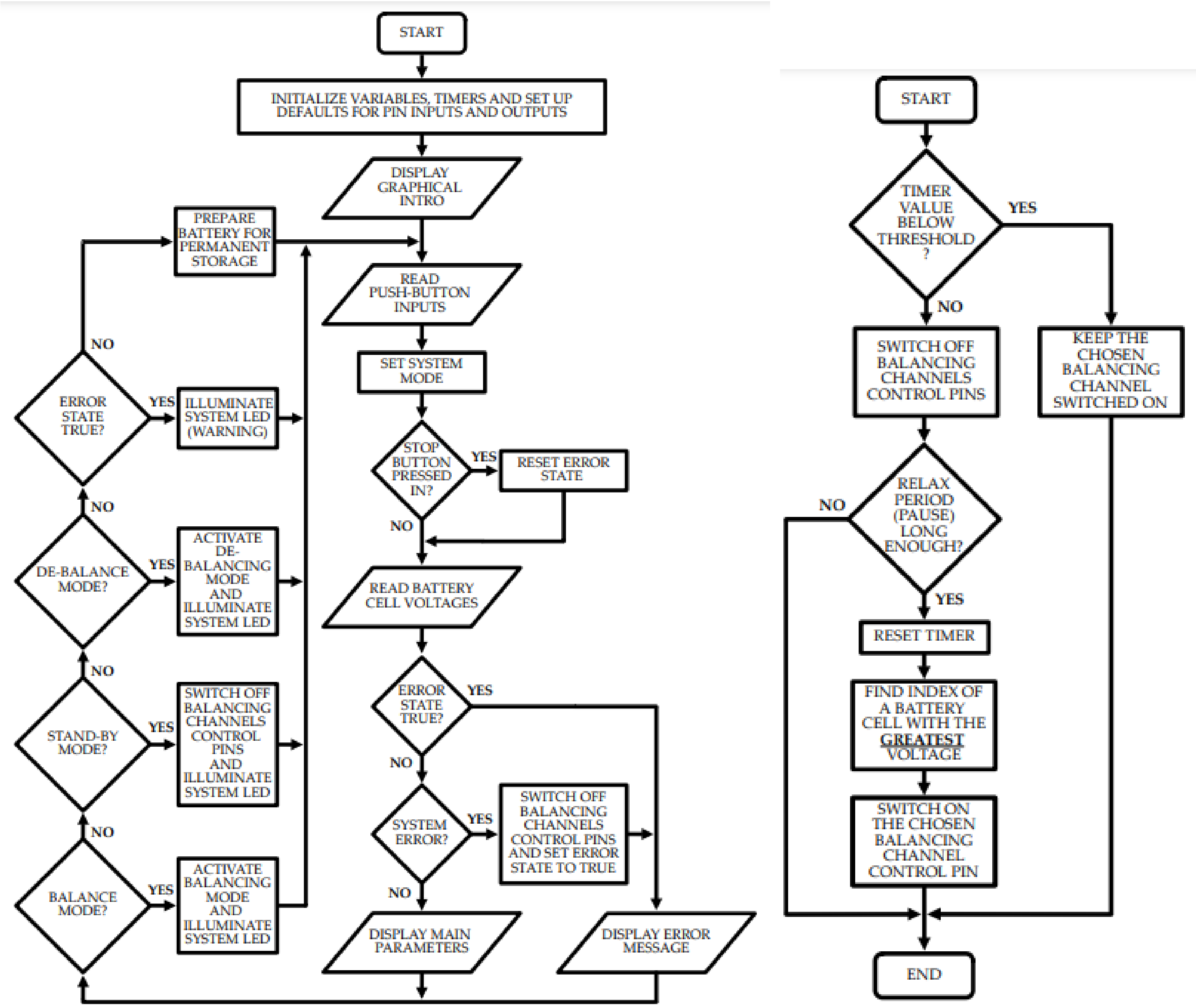

FIGURE 12. MAIN CODE & BALANCING MODE FLOWCHARTS

III. Conclusions

Compared to existing [5] [6] commercial BMS systems, this open-source BMS offers a more flexible and customizable solution, as well as a lower cost. While commercial BMS systems typically have a fixed set of features and may not be suitable for all applications, this open-source BMS allows users to modify and adapt the system to their specific needs. Additionally, commercial BMS systems can be expensive, while this open-source BMS offers a cost-effective solution for makers and hobbyists. However, there are also some disadvantages to this BMS system. One potential disadvantage is the level of technical expertise required to modify and adapt the system, which may be challenging for some users. Additionally, the open-source nature of the system means that there may be limited technical support available, although the community can provide assistance and guidance.

One limitation of this BMS system is that it is designed to work with specific types of batteries, including Li-ion, Li-Po, LiFePO4, NiCd, NiMH, and lead-acid batteries, with a maximum voltage of 20V. This may limit its use in certain applications that require other types of batteries or higher voltages.

Areas for improvement include expanding the range of compatible battery types and voltages, improving the documentation and technical support for the system, and further optimizing the software for better performance and reliability. Additionally, adding features such as wireless communication and remote monitoring could enhance the usability and flexibility of the BMS system.

In conclusion, the open-source advanced battery management system designed in this project provides an affordable and efficient solution for the management and protection of batteries used in electric vehicles and robotics platforms.

The system was designed using the Altium Designer tool set, with the software developed on an Arduino Nano MCU, and it features a number of important functions such as overvoltage protection, under voltage protection, cell balancing, and charging current limitation.

Through a comparison with existing BMS systems [7], it was found that the open-source BMS system offers similar performance at a much lower cost, making it a viable option for makers and DIY enthusiasts.

Overall, this project serves as a valuable exploration of BMS systems and a useful tool for learning about electronics CAD tools such as Altium, as well as providing a low-cost and effective solution for battery management and protection.

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