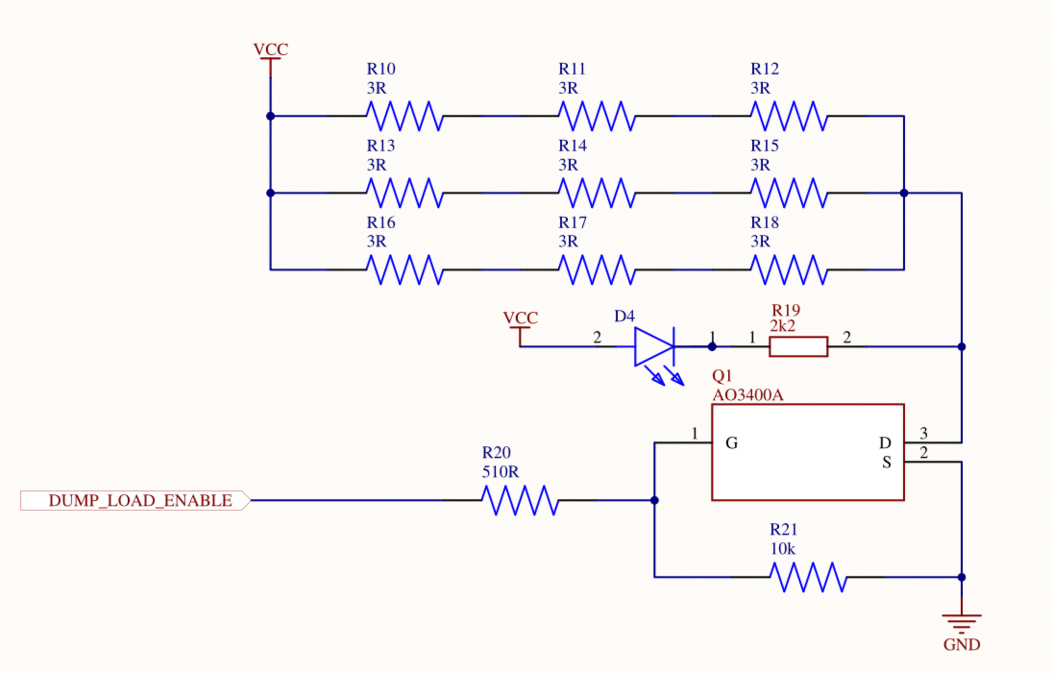
Comprehensive Design Details

Cell module

This module is an integral component designed for the real-time monitoring of individual battery cells within a pack, each with a nominal voltage of 3.7V. This module is specifically developed to ensure the optimal performance, safety, and longevity of battery packs used in various applications, ranging from portable electronic devices to electric vehicles. The detailed functionalities, including voltage and temperature monitoring, communication via UART, and protective measures, are outlined below:

1. Over-Voltage monitoring and voltage balancing circuit:



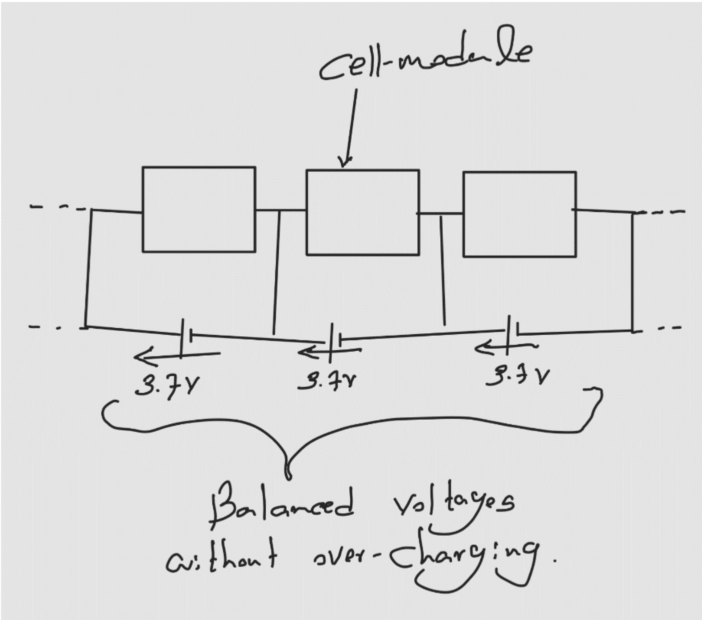
The battery monitoring system incorporates a sophisticated control strategy to prevent overcharging, which is critical for maintaining battery health and safety. The system utilizes a microcontroller unit (MCU) that continuously monitors the voltage levels of each battery cell within the pack. When the voltage of a cell exceeds the recommended threshold of 3.7V, indicative of potential overcharging, the MCU takes proactive measures to regulate the charge and maintain voltage stability.

Activation of the Dump Load Enabler: Upon detection of an over-voltage condition, the MCU activates the Dump Load Enabler, which in turn controls a MOSFET. The MOSFET acts as a switch that reroutes the excess current away from the battery cell.

Current Diversion Through Resistors: The redirected current is passed through a predefined set of resistors. These resistors are specifically chosen for their ability to handle the excess current without overheating or damage. By flowing through these resistors, the overcurrent is safely dissipated as heat, and the voltage across the battery cell is effectively lowered and stabilized at the safe level of 3.7V.

Balancing Charge Across Series-Connected Battery Packs: This controlled method of handling overcharge conditions not only protects individual cells but also contributes to the overall balance of charge across series-connected battery packs. By ensuring that no single cell overcharges, the system promotes uniformity in the charge state across the entire battery pack, which is essential for optimal performance and longevity of the batteries.

System Benefits: This approach not only prevents the detrimental effects of overcharging, such as potential thermal runaway and reduced battery life but also enhances the reliability and efficiency of the battery management system. By maintaining each cell within its optimal voltage range, the system ensures that the battery pack delivers consistent performance and exhibits extended service life.



2. Temperature Sensing Circuit:

To ensure optimal performance and safety, the temperature of both the battery and the circuit within the battery management system (BMS) is meticulously monitored. This dual temperature monitoring is achieved using the CMFB103F3950FANT temperature sensor, a highly accurate and reliable component selected for its precision in thermal measurement.

Sensor Specifications and Functionality
The CMFB103F3950FANT sensor is utilized for its exceptional responsiveness and stability across a broad range of temperatures. It is designed to provide precise temperature readings, which are critical for preventing thermal runaway and enhancing the longevity of the battery system. The sensor's ability to operate under varying environmental conditions without degradation makes it an ideal choice for the demanding requirements of battery management.

Separate Monitoring of Circuit and Battery Temperatures
In our system, separate sensors are deployed to measure:

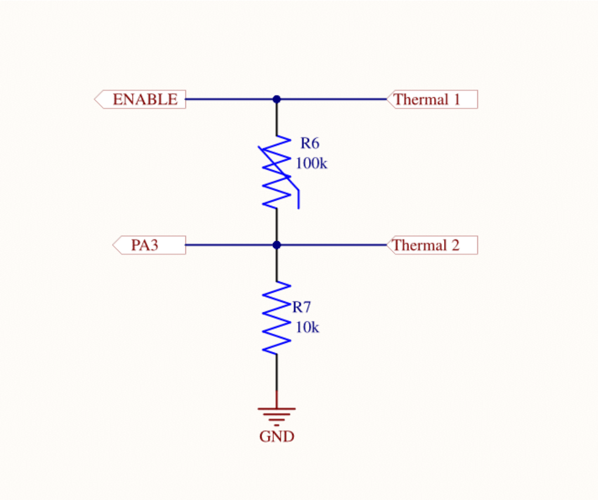
The Internal Circuit Temperature: Monitoring the temperature of the electronic circuitry is essential to prevent overheating and potential damage to the BMS components. Elevated temperatures within the circuit can indicate inefficiencies or malfunctions, which may require immediate intervention.

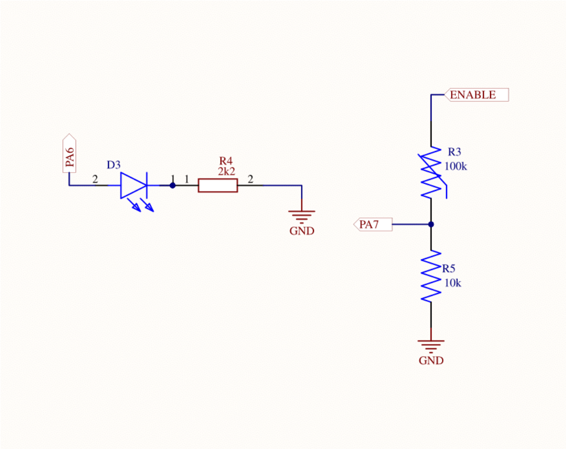
The Battery Temperature: Direct measurement of the battery's temperature provides data necessary to manage charging and discharging processes effectively. It helps in maintaining the battery within safe operational limits, thus safeguarding against hazards and prolonging battery life.

Both sets of data are critical for the BMS to execute real-time decisions regarding cooling measures, charge rate adjustments, and load balancing, which are dependent on temperature fluctuations.

Integration into BMS
Each CMFB103F3950FANT sensor is integrated into the system architecture via dedicated interfaces that relay temperature data to the central processing unit of the BMS. This integration allows for continuous monitoring and instant feedback, enabling dynamic adjustments to operational parameters in response to temperature changes detected by the sensors.

This strategic approach to temperature monitoring underscores our commitment to system safety and efficiency, ensuring that all components operate within their thermal thresholds, thereby optimizing the performance and durability of the battery system.





3. *Micro-controller Unit*:

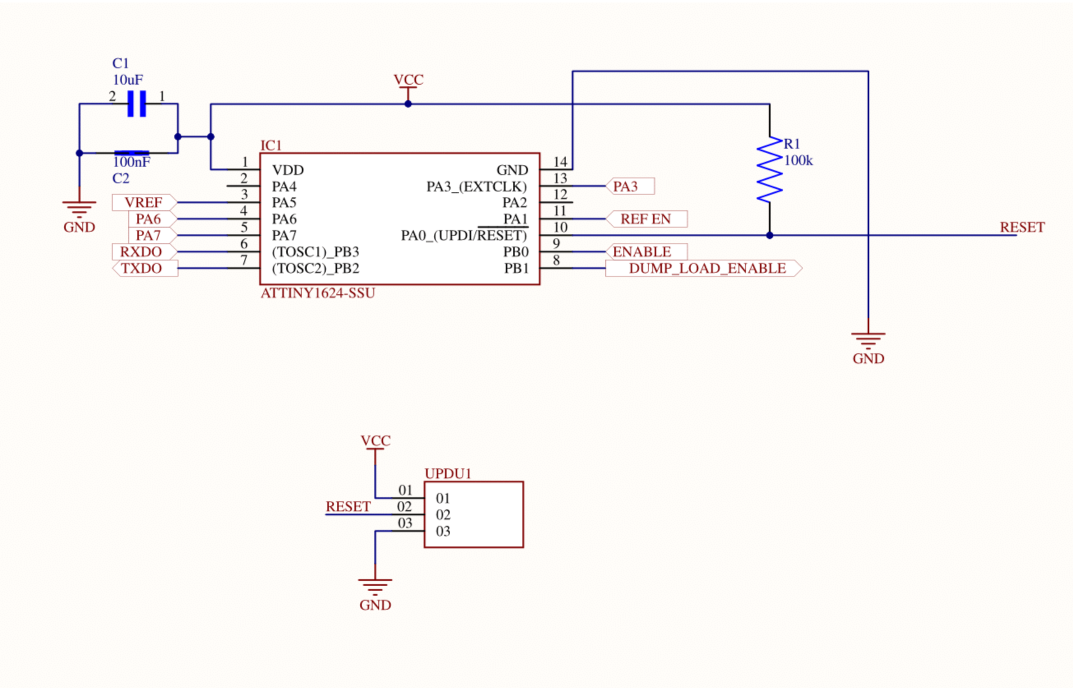
The battery management system employs a microcontroller to perform critical functions, including the measurement of battery cell voltages and the monitoring of temperatures using connected sensors. The microcontroller used in this system is the ATTINY1624-SSU, selected for its reliability, compact size, and capability to handle multiple inputs efficiently.

Voltage and Temperature Measurement:
The primary role of the microcontroller within the system is to continuously measure the voltage of each battery cell. This data is vital for assessing the state of charge and overall health of the battery. In parallel, the microcontroller reads inputs from temperature sensors strategically placed to monitor both the internal and ambient temperatures associated with the battery cells. These temperature readings help prevent conditions that could lead to overheating, thereby ensuring safe operation under various load conditions.

Programming the Microcontroller:

To facilitate precise control over these functions, the ATTINY1624-SSU microcontroller is programmed using a UPDI (Unified Program and Debug Interface) programmer. The UPDI programmer enables efficient uploading of necessary firmware into the microcontroller, which governs its operation. This programming method is advantageous for its simplicity and effectiveness, allowing for easy updates and debugging of the system software.

The utilization of the UPDI programmer with the ATTINY1624-SSU microcontroller ensures that the system can be finely tuned to respond appropriately to the complex dynamics of battery management. This setup not only guarantees precision in monitoring but also provides flexibility in system configuration to accommodate future enhancements or adjustments in operational protocols.



4. *UART transmitter and receiver:*

In the battery management system (BMS), communication and data interchange between individual battery cell modules and the main controller module are facilitated using the Universal Asynchronous Receiver/Transmitter (UART) protocol. This choice of communication standard is instrumental due to its reliability, simplicity, and effectiveness in systems requiring serial data exchange.

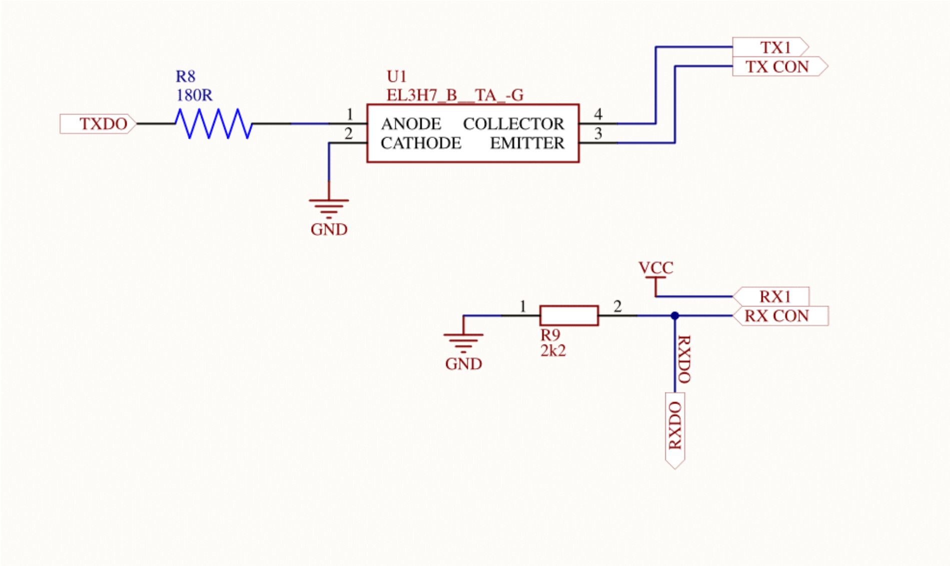
Implementation of UART Communication

UART protocol is utilized to establish a robust communication link within the BMS. Each battery cell module is equipped with UART capabilities, allowing it to transmit critical data such as voltage levels and temperature readings to the main controller module. This data is essential for real-time monitoring and management of the battery cells, enabling the main controller to make informed decisions regarding charge regulation, health assessment, and fault diagnostics.

Importance of Series Connectivity

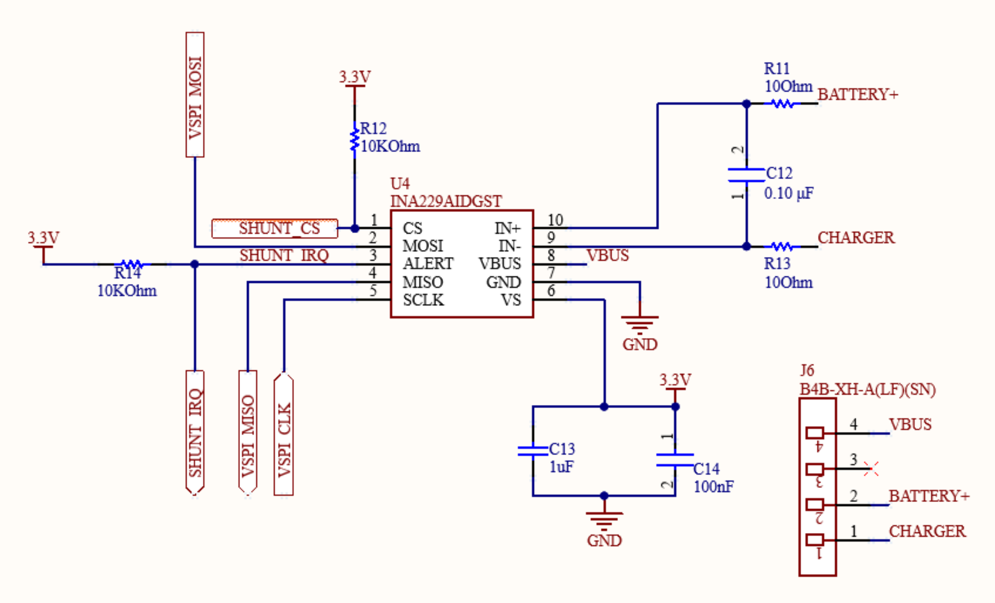
The battery system is designed to be series-expandable, allowing for scalability in energy capacity and voltage levels. In such configurations, maintaining coherent and synchronized operation among multiple serially connected battery cell modules becomes crucial. The interconnection of each module in series via UART ensures seamless data transmission across the system, preserving the integrity and timing of the communicated signals. This setup not only supports the current system architecture but also accommodates future expansions with minimal adjustments.

The strategic implementation of UART interconnectivity thereby enhances the overall efficiency and reliability of the BMS, ensuring that each component within the series-connected array can communicate effectively with the main controller. This capability is vital for maintaining balanced charge cycles, monitoring state-of-health across the battery array and executing coordinated responses to operational anomalies.



Controller module

1. Onboard current shunt monitor



The onboard current shunt monitor uses the INA219, a high-side current sensor from Texas Instruments.

Circuit Components:
1. INA219 (U4): This is a current shunt and power monitor with an I2C interface.
2. Shunt Resistor (R11): Placed between the load (battery) and the ground to measure the voltage drop caused by the load current.
3. Pull-up Resistors (R12, R13): Connected to the I2C lines to pull them up to 3.3V.
4. Bypass Capacitors (C11, C12, C13, C14): Used to filter noise and stabilize the power supply.
5. Connector (J6): For interfacing with the battery and charger.

Circuit Description:
1. Current Measurement:
   - The INA219 monitors the current flowing through the shunt resistor (R11).
   - The voltage drop across R11 is proportional to the current passing through it.
   - INA219 measures this voltage drop and, using the known resistance value of R11, calculates the current using Ohm's Law (I = V/R).

2. Power and Bus Voltage Measurement:
   - INA219 also measures the bus voltage (VBUS), which is the voltage at the load side of the shunt resistor.
   - By measuring both the current and the bus voltage, the INA219 can calculate the power consumed by the load.

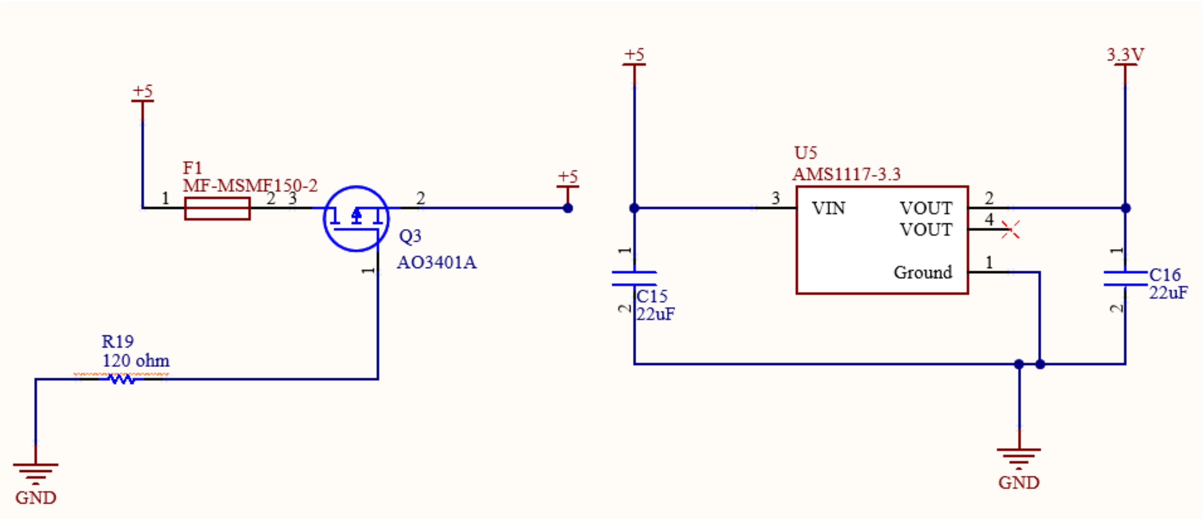
3. I2C Communication:
   - The INA219 communicates with a microcontroller (not shown in the diagram) through the I2C interface.
   - The SCL (clock) and SDA (data) lines are connected to the microcontroller’s I2C bus.
   - Pull-up resistors (R12, R13) are used to pull these lines up to 3.3V, ensuring proper logic levels for I2C communication.

4. Power Supply and Grounding:
   - The circuit is powered by a 3.3V supply.
   - Bypass capacitors (C11, C12, C13, C14) are placed near the power pins to filter out any high-frequency noise and stabilize the power supply to the INA219 and the I2C bus.

Operation:
- When the system is powered on, the INA219 continuously monitors the voltage drop across the shunt resistor and the bus voltage.
- These measurements are sent to the microcontroller via the I2C interface.
- The microcontroller can then use these readings to monitor the current, voltage, and power consumption of the connected load, which in this case is a battery and charger system.

This circuit is designed to provide real-time monitoring of current and voltage, which is crucial for applications such as battery management systems. By integrating the INA219, the circuit offers precise measurement and easy interfacing with a microcontroller via I2C, making it suitable for the project.

2. *Reverse polarity protection*



This circuit is designed to provide reverse polarity protection and voltage regulation for the battery management system

Reverse Polarity Protection:
1. MOSFET (Q3 - AO3401A):
   - The P-channel MOSFET (Q3) is used for reverse polarity protection.
   - When the correct polarity is applied (+5V at the source, ground at the gate through R19):
   - The MOSFET turns on, allowing current to flow from the source to the drain, thus providing +5V to the rest of the circuit.
   - If the polarity is reversed (ground at the source, +5V at the gate through R19):
   - The MOSFET remains off, preventing current from flowing and protecting the circuit from damage.

2. Resettable Fuse (F1 - MF-MSMF150-2):
   - F1 is a resettable fuse that provides overcurrent protection.

   - If the current exceeds the fuse's rating (1.5A), the fuse will trip and open the circuit, preventing damage to the components.
   - Once the fault condition is removed, the fuse will reset automatically.

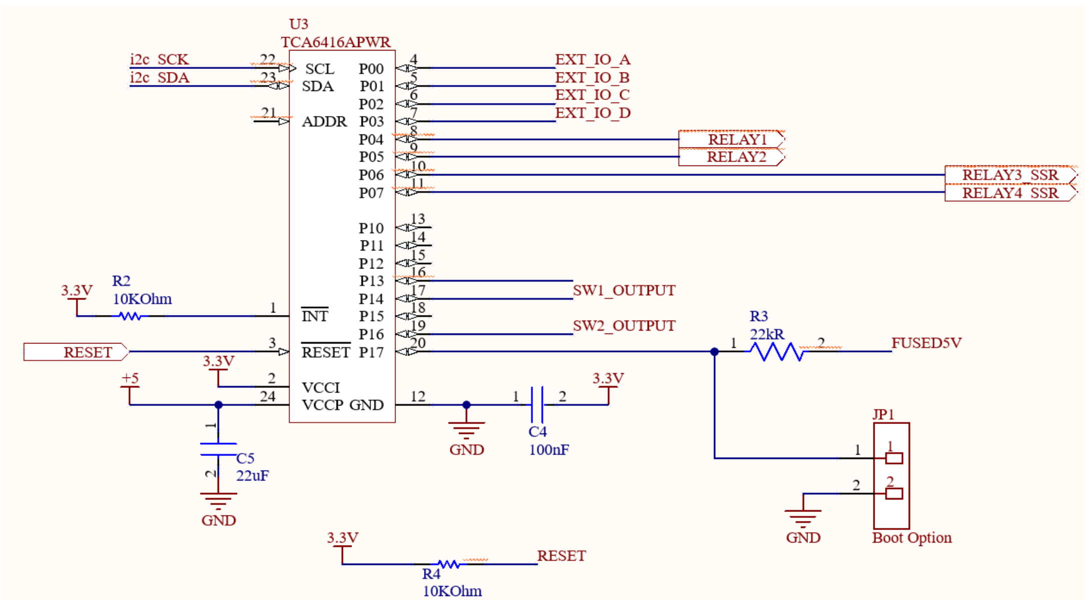
Voltage Regulation:
1. Voltage Regulator (U5 - AMS1117-3.3):
   - U5 is a linear voltage regulator that converts the +5V input to a stable +3.3V output.
   - The VIN pin (pin 3) receives the +5V input.
   - The VOUT pin (pin 2) provides the regulated +3.3V output.
   - The GND pin (pin 1) is connected to ground.

2. Capacitors (C15 and C16 - 22uF):
   - C15 and C16 are decoupling capacitors that stabilize the input and output voltages by filtering out noise and providing a smooth voltage supply.
   - C15 is connected between the VIN pin and ground.
   - C16 is connected between the VOUT pin and ground.

Overall Functionality:
- The circuit ensures that power is only delivered to the battery management system if the input voltage is correctly polarized.
- It protects the system from reverse polarity and overcurrent conditions.
- It provides a stable +3.3V output from a +5V input, suitable for powering components that require a lower voltage.

By incorporating these components, the circuit enhances the reliability and safety of the battery management system.

3. *IO Expander*



This schematic illustrates the integration of TCA6416A I/O expander within the battery management system (BMS).

Functional Overview:

1. I2C Communication:
   - Pins 22 (SCL) and 23 (SDA): These pins facilitate communication with the microcontroller via the I2C bus, allowing the microcontroller to control and monitor the states of the GPIO pins on the I/O expander.

2. General Purpose Input/Output (GPIO) Expansion:
   - Pins P00 – P17 The TCA6416A provides 16 GPIO pins, which can be configured individually as either inputs or outputs. These pins are connected to various external components:
     - EXT_IO_A to EXT_IO_D (Pins 4-7): General-purpose external I/O lines.
     - RELAY1 and RELAY2 (Pins 8 and 9): Control signals for mechanical relays, used to switch high power loads or other circuits.
     - RELAY3_SSR and RELAY4_SSR (Pins 10 and 11): Control signals for solid-state relays (SSR), offering faster switching and longer life compared to mechanical relays.
     - SW1_OUTPUT and SW2_OUTPUT (Pins 18 and 19): Output signals to control or indicate the status of switches, for user inputs or control signals for other devices.

3. Power and Ground Connections:
   - VCCI (Pin 24): 3.3V supply voltage for the device's logic.
   - VCCP (Pin 2): 5V supply voltage, likely used for driving the external components connected to the GPIOs.
   - GND (Pin 1 and others): Common ground reference for the circuit.
   - Capacitors:
   - C4 (100nF): Provides noise filtering and stabilization for the power supply.
   - C5 (22uF): Larger decoupling capacitor to smooth out voltage variations and provide stable power.

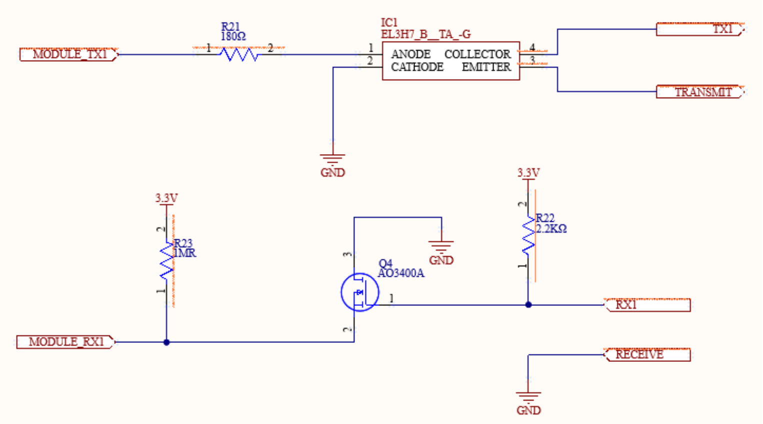
4. Control and Configuration:
   - RESET (Pin 3): This pin is used to reset the I/O expander. The reset circuit includes a 10kΩ pull-up resistor (R2) and a RESET switch, allowing manual reset of the device.
   - INT (Pin 15): The interrupt pin can be used to alert the microcontroller of any changes in the state of the input pins, enabling efficient event-driven programming.

5. Boot Option (JP1):
   - JP1 Connector: Provides a jumper configuration for boot options, which might be used to select different operational modes or configurations for the system.
   - R3 (22kΩ resistor): Pull-up resistor associated with the boot option selection, ensuring a defined logic level when the jumper is not connected.

Overall Functionality:

The TCA6416A I/O expander significantly increases the I/O capacity of the BMS, enabling it to interface with a variety of external components such as relays, switches, and other digital inputs/outputs. This extension of I/O capability allows the BMS to monitor and control more aspects of the battery system, enhancing its functionality and flexibility. Through the I2C interface, the microcontroller can easily manage these additional I/O points, making the system more scalable and adaptable to complex requirements.

4. *Standard module communication circuit*



This schematic illustrates the standard module communication circuit in the BMS. The circuit facilitates the communication between the BMS and external modules, enabling data transmission and reception.

Key Components and Their Functionality:

1. Optocoupler (IC1 - EL3H7):
   - Pins 1 (Anode) and 2 (Cathode): The input side of the optocoupler, where the signal from the BMS is applied. The optocoupler isolates the transmitting circuit electrically from the receiving circuit.
   - Pins 3 (Collector) and 4 (Emitter): The output side of the optocoupler, where the isolated signal is transmitted to the external module.
   - Function: The optocoupler provides galvanic isolation, protecting the BMS from voltage spikes and noise that might originate from the external modules. It ensures that the signal integrity is maintained across the isolation barrier.

2. Resistors:
   - R21 (180Ω): Limits the current through the optocoupler when transmitting data from the BMS (TXI).
   - R22 (22kΩ): Pull-down resistor ensuring that the RXI line remains at a known logic level when the transistor is not conducting.
   - R23 (1MΩ): Pull-up resistor for the gate of the MOSFET, ensuring it remains off when not driven by the optocoupler.
   - Function: These resistors are critical for current limiting, pulling voltages to defined levels, and ensuring stable operation of the circuit components.

3. MOSFET (Q4 - AO3400A):
Acts as a switch that is controlled by the optocoupler. When the optocoupler is activated by the BMS transmit signal, the MOSFET allows current to flow, transmitting the signal to the receiving module.

4. Communication Lines:
   - MODULE TXI: Input from the BMS transmitting module.
   - TXI: Transmit line to the external module after passing through the optocoupler.
   - MODULE RXI: Input from the receiving module to the BMS.
   - RXI: Receive line from the external module, controlled by the MOSFET.
   - TRANSMIT and RECEIVE: External connectors for communication with external modules.

This circuit provides a robust and isolated communication interface for the battery management system, ensuring safe and reliable data exchange between the BMS and external modules. The use of an optocoupler ensures electrical isolation, protecting the BMS from potential electrical disturbances, while the MOSFET facilitates controlled signal reception. The resistors ensure proper current flow and voltage levels for stable operation.

Daily Log Entries

No	Date	Log Entry
1		Planning & Initial Research - Held a project kickoff meeting. - Conducted initial research on existing battery management systems and documented key features and functionalities. - Created a preliminary project plan outlining phases, tasks, and timeline. - Discussed potential design approaches and technical challenges.
2		Requirements Gathering & Design Strategy - Developed detailed requirements for the BMS, including voltage, current, and temperature monitoring, as well as communication protocol. - Drafted a list of required components and decided on the type of microcontroller to be used. - Identified possible power sources and constraints to address in the design.
3		Circuit Design - Part 1 - Began designing the circuit layout, focusing on organizing key components such as voltage and current sensors. - Sketched initial circuit layouts on paper, outlining potential pathways for power and signal flow. - Discussed the use of protection circuits and considered possible safety mechanisms.
4		Circuit Design - Part 2 - Continued refining the circuit design, incorporating

		microcontroller and communication interfaces. - Drew rough schematics of the circuit layout, ensuring proper connections between components. - Explored different options for balancing circuits and discussed trade-offs.
5		Schematic Design - Part 1 - Started creating digital schematics. - Focused on organizing the schematics logically, ensuring clarity and ease of understanding.
6		Schematic Design - Part 2 - Continued building and refining the schematic design, making sure all key components and connections are represented. - Conducted a design review with the team to check for consistency and completeness. - Made necessary adjustments based on team feedback and simulation results.
7		PCB Layout - Part 1 - Transitioned from schematic design to PCB layout, starting with component placement on the board. - Focused on optimal placement for signal integrity and power management. - Considered size constraints and the placement of key interfaces.
8		PCB Layout - Part 2 - Continued routing connections between components, ensuring proper trace widths and clearance for power handling and signal lines. - Paid close attention to potential noise sources and their impact on sensitive circuits. - Created and simulated power and ground planes for efficient distribution.
9		PCB Layout - Part 3 - Conducted a detailed design review, checking the PCB layout against the schematic and requirements.

		- Worked on optimizing the layout for manufacturability and assembly ease. - Made final adjustments based on review feedback.
10		Enclosure Design - Part 1 - Discussed requirements for the enclosure, including size, material, and protection level. - Created initial design sketches of the enclosure, considering mounting options and access points. - Explored different materials for the enclosure, weighing factors such as cost and durability.
11		Enclosure Design - Part 2 - Developed models of the enclosure, incorporating the finalized PCB layout. - Made design adjustments to accommodate connectors, vents, and mounting features.
12		Enclosure Design - Part 3 - Held a design review meeting to assess the enclosure's compatibility with the PCB and overall system. - Finalized the enclosure design and created manufacturing files for production. - Submitted the files for 3D printing or manufacturing.
13		PCB Production & Component Ordering - Submitted finalized PCB design files to a manufacturer for production. - Ordered necessary components, including resistors, capacitors, ICs, connectors, and other parts. - Double-checked the component list for accuracy and completeness.
14		Component Arrival & Preparation - Received the fabricated PCBs and all ordered components. - Inspected the PCBs for quality and compliance with design specifications. - Organized and sorted the components for easy assembly.

15		PCB Assembly & Soldering - Part 1 - Began assembling components on the PCB according to the design. - Carefully placed and soldered each component, starting with smaller ones and progressing to larger ones. - Used a microscope to inspect solder joints and connections.
16		PCB Assembly & Soldering - Part 2 - Continued assembly and soldering, ensuring proper component orientation and polarity. - Conducted intermediate visual inspections.
17		PCB Assembly & Soldering - Part 3 - Completed the PCB assembly and soldering. - Cleaned the assembled PCBs to remove flux residue and inspected them for any remaining issues.
18		Initial Power-Up & Testing - Conducted the initial power-up tests for the BMS. - Checked for any short circuits, incorrect connections, and component functionality. - Monitored power supply and regulated output to avoid damage.
19		Testing & Troubleshooting - Part 1 - Performed functional tests, including voltage, current, and temperature measurements. - Verified communication between the BMS and external systems. - Detected minor issues in readings and adjusted as necessary.
20		Testing & Troubleshooting - Part 2 - Continued functional testing. - Monitored stability and accuracy of the BMS.

21		Testing & Troubleshooting - Part 3 - Made final adjustments to software and hardware based on testing results. - Conducted thorough debugging and verification to ensure all issues were resolved.
22		Enclosure Integration & Final Testing - Integrated the assembled PCB into the enclosure, ensuring a proper fit and secure mounting. - Double-checked all connections and interfaces for potential interference or damage. - Conducted final system tests with the BMS enclosed.
		Project Wrap-Up & Documentation - Completed all final testing and verification of the BMS, confirming it meets project requirements. - Created comprehensive documentation, including schematics, PCB layout, assembly instructions, and test results. - Conducted a project wrap-up meeting to discuss lessons learned, potential improvements, and future project ideas.