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DEVELOPMENT AND OPTIMIZATION OF HARDWARE CIRCUITS FOR BATTERY MANAGEMENT SYSTEMS

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Abstract: *In recent years, the exponential proliferation of conventional vehicles has given rise to pressing concerns related to excessive energy consumption and environmental degradation. Consequently, there has been a substantial upswing in awareness regarding the detrimental impact of traditional vehicles on both energy resources and the environment. In response, there has been a concerted effort to promote the development of new energy vehicles that prioritize safety, cleanliness, and efficiency. Among the various technologies fueling the ascent of new energy vehicles, lithium batteries have garnered extensive adoption. Their allure stems from characteristics like high energy density, exceptional charge-discharge performance, lightweight construction, prolonged lifespan, and environmentally friendly attributes. This paradigm shift toward new energy vehicles has underscored the crucial role of the Battery Management System (BMS), as referenced in [3]. The BMS stands as a pivotal component charged with the continuous monitoring of a battery pack's voltage, current, and temperature, as elaborated in [1]. Its principal mission is to forestall potential issues, including overcharging, over-discharging, overcurrent, and overheating during the charging and discharging processes. The paramount objective is to ensure the secure operation of lithium batteries while optimizing the battery pack's efficiency and enhancing battery longevity.*

Keywords: *New energy vehicles, Lithium batteries, Battery Management System (BMS), Energy efficiency, Environmental protection*

1. Introduction

In recent years, the rapid growth in the number of conventional vehicles has triggered serious problems such as excessive energy consumption and environmental pollution. This has prompted the country to increase its awareness of the harm caused by traditional vehicles to energy and the environment in recent years, and to actively promote the development of safe, clean and efficient new energy vehicles. In new energy vehicles, lithium batteries are widely used for their high energy density, excellent charging and discharging performance, light weight, long life and green environmental protection, among many other advantages.

With the emergence of new energy vehicles, the significance of the Battery Management System (BMS)[3] has amplified as a critical component responsible for continuous monitoring of the battery pack's voltage, current, and temperature[1]. Its primary objective is to prevent potential issues such as overcharging, over-discharging, over-current, and over-temperature during the charging and discharging processes. It is of paramount importance to ensure the safe performance of lithium batteries while maximising the efficiency of the battery pack and extending the life of the battery.

The object of this paper is the lithium battery pack used in electric vehicles. Using the STM32F103C8T6 as the main control chip and the LTC6804[2] as the battery monitoring chip, this paper designs a complete battery management system. The system is capable of monitoring important parameters such as battery voltage, current and temperature in real time, and transmitting the monitored data to the vehicle controller via CAN bus[4]. At the same time, this paper incorporates SOC (State of Charge) [5]related algorithms to provide accurate battery life information to the vehicle driver and to achieve a balanced battery management function, thus improving the utilisation of the battery.

Through this research, the results of this paper will provide important technical support for the development and application of the new energy vehicle industry[6]. By optimising the hardware design and development of the battery management system, it can better cope with the energy and environmental problems caused by conventional vehicles and promote the reliability, performance and sustainability of new energy vehicles.

2. Functional requirements and hardware architecture

The primary function of the battery management system in an electric vehicle is to accurately detect and acquire voltage, current, and temperature data from the lithium battery pack.The detected voltage, current and temperature data will be sent to the main control chip for processing. The main control chip is responsible for processing and coding the data in order to number the battery voltage and temperature and to correspond them to the charge level of the battery pack. At the same time, in conjunction with the SOC[7] algorithm, the system is able to estimate the SOC parameters of the battery pack. The processed data is transmitted to the vehicle controller via the CAN bus and the estimated battery voltage, current and temperature information is displayed on the host computer via communication. The battery management hardware system must therefore be highly reliable, stable and safe.

The BMS controller consists of five main modules as follows:

Micro Control Module: This module is the core of the BMS controller and includes the main control chip and related peripheral circuits. It is responsible for calculating and processing data and sending out the processed data, and is a key component in the realisation of the BMS control strategy.

Power supply module: This module provides a powerful, stable and reliable power supply for each input and output module.

CAN communication module: This module implements the communication data forwarding between the BMS controller and the vehicle controller. As a commonly used multi-threaded communication network, the CAN communication module provides high speed data transmission and excellent fault detection capabilities.

BMS modules:

Current and voltage detection module: This module collects the total current and total voltage of the battery pack.

Battery System Management Module: This module collects voltage and temperature data from the battery pack and monitors the voltage of each cell. The collected data is sent to the main control chip for processing.

Clock module: This module provides accurate time information to the master chip for marking the time of voltage data collection.

By optimising the design and development of the hardware system for the BMS controller, we are able to better address the energy and environmental issues facing electric vehicles and improve the reliability, performance and sustainability of the system. The overall framework of the system is shown in Fig.1

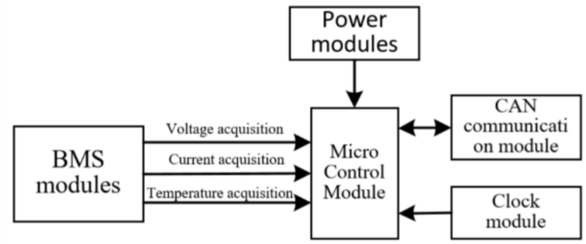

Figure 1: Overall system framework

3. Circuit design of main functional modules

3.1. Micro-control module

The micro-control module is the core part of the BMS controller, which consists of the STM32F103C8T6 micro-controller as the main control chip, and is equipped with the necessary peripheral circuits. The microcontroller has excellent cost performance, low power consumption, powerful computing capability, sufficient storage space and CAN communication function, which fully meets the requirements of the BMS controller, as shown in Figure 2. The micro-control module undertakes the key tasks of signal acquisition, processing and control implementation.

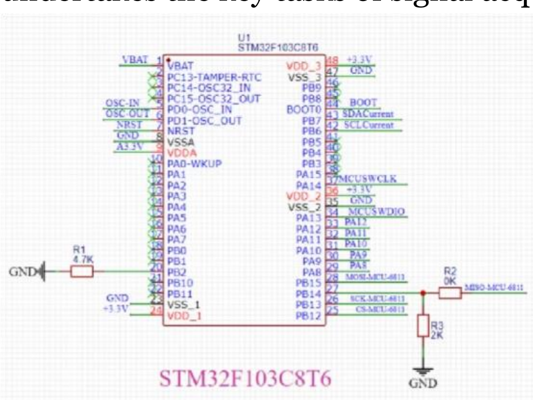

Figure 2: STM32F103C8T6 Schematic

The microcontroller module mainly includes: reset circuit, crystal oscillator circuit, decoupling filter circuit, etc.

3.1.1. Reset circuit

In order to facilitate debugging, a reset button is added to the design in this paper. When the reset button is pressed, a low-level pulse will be generated and fed to the reset pin of the main control chip. The purpose of this reset circuit is to restore the master chip to its initial state in order to reboot the system or perform debugging operations. By pressing the reset button, this document allows for a quick and easy reset of the master chip and ensures proper system operation , as shown in Figure 3.

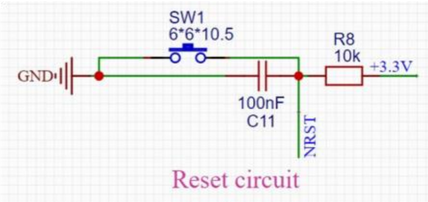

Figure 3: Reset circuit schematic

3.1.2. Crystal circuit

An 8MHz passive crystal is used as the crystal oscillator circuit in this microcontroller minimum system. The crystal circuit provides a stable and accurate clock signal for the system. The purpose of the crystal circuit is to generate a precise frequency signal through the oscillation characteristics of the crystal for timing and clock synchronisation by the microcontroller. By using an 8MHz passive crystal, the system's clock signal is guaranteed to be stable and accurate. This crystal circuit is designed to provide a reliable clock source for the microcontroller to ensure proper operation and accurate timing of the system , as shown in Figure 4.

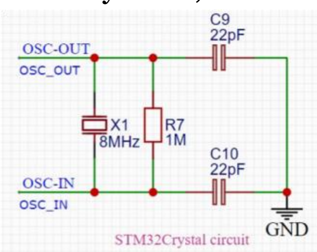

Figure 4: STM32Crystal circuit schematic

3.1.3. Decoupling filter circuit

The main control chip has multiple sets of power-up pins for providing power to the different modules. The stability of the power supply pins is crucial to the stable operation of the software. In order to ensure the stable and reliable operation of the integrated controller, we have configured the corresponding decoupling and filtering circuits on the power supply pins.

The function of the decoupling circuit is to eliminate high frequency noise and fluctuations on the supply pins in order to maintain a stable voltage supply to the main control chip. It absorbs and smoothes out noise on the power supply lines by means of capacitors connected in parallel, and provides transient response capability to make the supply voltage more stable.

Filter circuits are used to filter out high frequency noise and interference signals on the power lines to ensure a clean, stable power supply to the supply pins. These filter circuits, usually consisting of capacitors and inductors, are effective in filtering out high frequency noise and fluctuations to maintain the supply voltage at the desired stable level.

With the appropriate decoupling and filtering circuits, a stable and reliable power supply can be provided to the main controller chip, ensuring the proper functioning of the integrated controller and the stable operation of the software. This effectively protects against noise and interference on the supply pins, provides a good working environment and improves the reliability and performance of the system , as shown in Figure 5.

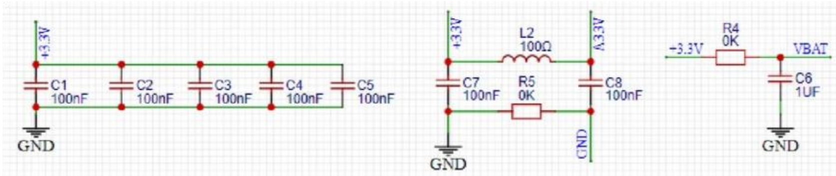

Figure 5: Decoupling filter circuit schematic

3.2. Power supply module

The power supply module in the BMS controller uses two step-down circuits to convert the 12V voltage to 5V. One 5V power supply is supplied to the relay circuit and CAN communication circuit, while the other 5V voltage is then converted to 3.3V required by the main controller chip through the step-down circuit.

The GODSEND power supply module is used in this paper for the 12V to 5V circuit and is used in conjunction with peripheral devices. This power supply module can effectively suppress disturbing signals such as voltage glitches, fluctuations and group pulse interference. This design enables the BMS controller to operate in a relatively stable electromagnetic environment, thus ensuring its stability and reliability.

With such a power supply module, a stable and reliable power supply is provided to the relay circuits, CAN communication circuits and the main control chip to ensure their normal operation. At the same time, the suppression of interference signals also helps to reduce electromagnetic interference in the system, improving overall performance and reliability , as shown in Figure 6.

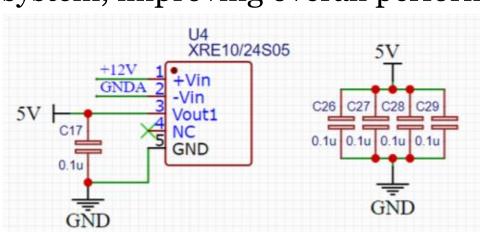

Figure 6:12V to 5V schematic

In the 5V to 3.3V circuit, the AMS1117-3.3V power supply regulator chip low dropout linear regulator is selected. The AMS1117 is a three-terminal regulator with a PNP-driven NPN tube regulator, with two versions available, fixed and adjustable. Suitable for high efficiency linear regulators , as shown in Figure 7.

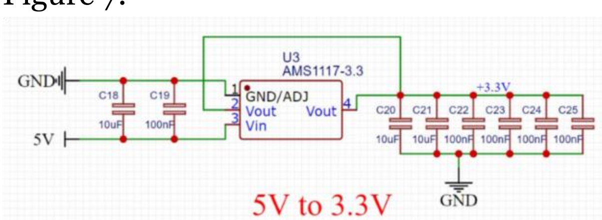

Figure 7: 5V to 3.3V schematic

3.3. CAN communication module

The CAN communication module employs the TJA1050T chip as the CAN transceiver, serving as the interface between the Controller Area Network (CAN) protocol controller and the physical bus. The TJA1050T chip facilitates differential transmit and differential receive functions, enabling reliable data transmission. It supports data transmission speeds of up to 1000kbps, fully satisfying the requirements of BMS controllers.

The TJA1050T is fully compatible with the "ISO 11898" standard, and the level of electromagnetic radiation is effectively reduced by optimising the fit between CANH and CANL. The chip is passive in the non-power-on state and outperforms previous CAN bus transceivers. In the hardware design, 120 Ω resistors are incorporated at both ends of the CAN bus, which is essential for matching the bus impedance and significantly improves the immunity and reliability of data communication. In addition, two small capacitors of 30pF are connected in parallel between CANH and CANL and ground to filter out high frequency interference on the bus and provide some protection against electromagnetic radiation.

By selecting the TJA1050T as the CAN transceiver and carefully configuring the resistors and capacitors in the hardware design, the BMS controller is able to achieve stable and reliable data transmission during the CAN communication process. This is essential to ensure the normal operation of the battery management system and effective communication with the vehicle controller , as shown in Figure 8.

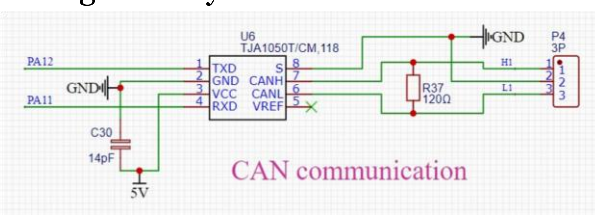

Figure 8: CAN communication schematic

3.4. Current and voltage detection module

For the current and voltage detection module, the INA226 chip, which is widely used in battery management systems, has been selected as a shunt/power monitor with an or SMBUS-compatible interface. The chip monitors current, bus supply voltage and power and provides programmable calibration values, conversion times and averaging. With its internal multiplier, it can directly read current values in amps and power values in watts. The INA226 chip senses current over a common-mode bus voltage range of 0V to 36V and is independent of the supply voltage. In addition, it supports up to 16 programmable addresses to meet the needs of different application scenarios. The diagram below shows the schematic of the INA226 chip , as shown in Figure 9.

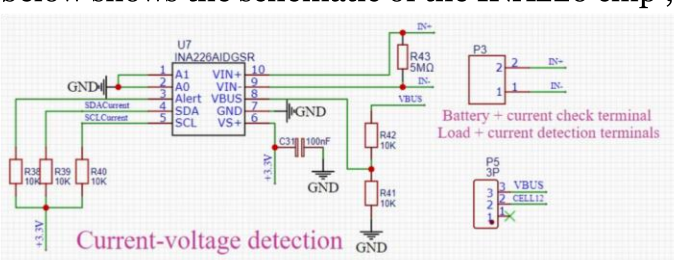

Figure 9: Current-voltage detection schematic

3.5. Battery management system module

The battery monitoring module utilizes the LTC6804[3] chip, a widely adopted component in battery management systems. As a third-generation multi-cell battery pack monitor, the LTC6804 is capable of accurately monitoring the voltage of up to 12 series-connected cells with a measurement error of less than 1.2mV. It offers a cell measurement range of 0V to 5V, making it compatible with a variety of battery chemistries. The LTC6804 achieves rapid voltage measurements for 12 cells in just 290us, and it also provides optional lower data acquisition rates to enhance noise rejection capabilities.

The LTC6804 chip incorporates an isoSPI interface, ensuring fast and reliable local area communication while mitigating the effects of RF interference. Its operation consists of two distinct sections: the core circuit and the isoSPI circuit. Specifically, the LTC6804-1 variant features two isoSPI ports (A and B) to facilitate daisy-chain communication. It is important to note that when monitoring fewer than 12 cells, the sum of the cell voltages should exceed 11V to ensure the LTC6804 is appropriately biased.

In circuit design, the LTC6804 chip is powered through two pins: V+ and VREG. V+ receives the necessary high voltage, equal to or greater than the highest battery voltage, and supplies power to the high voltage components of the core circuit. V+ and VREG can be directly powered from the top cell of the battery pack or an external power supply. To safeguard against transients, it is advisable to establish a permanent connection between V+ and the highest battery potential using a decoupling resistor capacitor (recommended values: 100Ω or 100nF) , as shown in Figure 10.

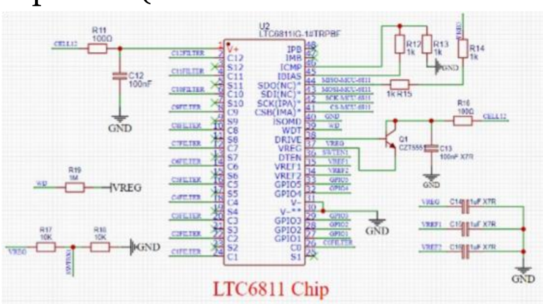

Figure 10: LTC6811 Chip schematic

For the LTC6804 chip, a low current 5.6V output is available at the DRIVE output pin, which can be buffered using a discrete NPN transistor. To protect the NPN from transient damage, it is recommended to connect the NPN collector supply via a decoupling network (100Ω resistor or 100nF capacitor recommended), while the emitter of the NPN should be bypassed via a 1uF capacitor. The use of larger capacitance values should be avoided to prevent an increase in the wake-up time of the LTC6804. A schematic of the LTC6804 chip is provided for reference.

In addition, the LTC6804 chip has the ability to measure temperature. The temperature of the battery can be monitored in real time by simply adding a thermistor near the battery. The temperature measurement circuit only requires the typical bias circuitry of a negative temperature coefficient thermistor. Temperature measurement is easily achieved by using the VREF2 pin of the LTC6804 to provide the required current bias.

In addition, the LTC6804 provides five general purpose input/output (GPIO) pins which can be used as analogue input channels. For these pins, a 10KΩ resistor and 1uF capacitor can be used for bypassing, which is a common sensor connection.

The following is the schematic of the LTC6804 chip for temperature measurement and general purpose input/output (GPIO) , as shown in Figure 11:

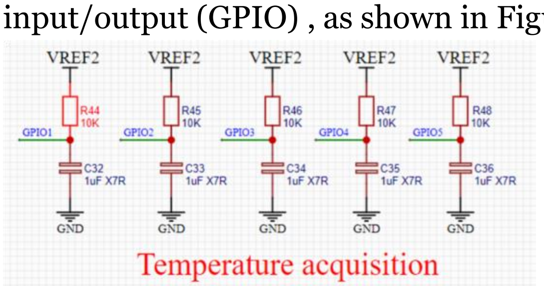

Figure 11: Temperature acquisition schematic

3.6. Clock module

The PCF8563 is a low-power CMOS real-time clock and calendar chip featuring a programmable clock output, interrupt output, and power-down monitor. It utilizes a bus interface for serial transmission of addresses and data. The chip supports a maximum bus speed of 400Kbits/s, and its embedded word address register is automatically incremented after each data read or write operation. The schematic diagram of the PCF8563 is presented below for reference , as shown in Figure 12.

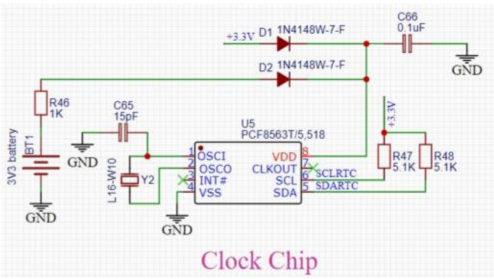

Figure 12: Clock Chip schematic

4. Conclusions

This study is dedicated to the design and development of the hardware circuit of the BMS controller for electric vehicles. Through the discussion of hardware design and component selection, the STM32F103C8T6 microcontroller and the LTC6804 chip are used as the core to successfully implement the functions of real-time battery status monitoring and communication, providing a significant improvement in the safety, stability and accuracy of the BMS system.

The STM32F103C8T6 microcontroller was chosen as the main control chip, and its efficient and stable performance provides powerful calculation and control capabilities for the BMS controller. At the same time, the selection of the LTC6804 chip as the battery monitoring chip makes the real-time monitoring of the battery status reliable and accurate, helping to detect battery abnormalities in advance and ensuring the safe operation of the battery system.

However, there is still room for further improvement in this study. For example, the hardware circuitry can be optimised to reduce power consumption and size and improve overall performance and reliability. In addition, the introduction of more advanced communication protocols and algorithms can be considered to further improve the intelligence and fault detection capability of the BMS system.

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