

Importance of Grounding in Battery Management Systems

This application note explores the crucial role of grounding in battery management systems (BMS). It starts with fundamental BMS concepts relevant to various applications, then discusses key design considerations. The document also discusses the function of isolators in battery-powered systems. Finally, it emphasizes the importance of proper connections between BMS evaluation boards, dongles, and overall system to prevent dangerous ground loop currents that can damage or destroy a circuit.

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1. Introduction

Grounding considerations for Battery Management Systems (BMS) in battery-operated environments are crucial for ensuring safety, functionality, and accurate battery monitoring. Key aspects include ensuring BMS circuits are electrically isolated from the chassis to prevent ground loops and interference, therefore, ensuring accurate measurements. Proper grounding provides a path for fault currents, reducing the risk of electric shock and should comply with relevant standards and regulations. Stable grounding is essential for accurate voltage and current readings, reflecting the true state of the batteries. Effective grounding practices also minimize common-mode noise, reducing electromagnetic interference (EMI), and ensuring precise BMS operation. Additionally, grounding should protect against both electromagnetic and radio-frequency interference, which is especially important in applications like electric vehicles that are sensitive to EMI.

For high-voltage systems, galvanic isolation can enhance safety by separating the BMS from high-voltage components. Proper grounding of communication interfaces such as CAN or LIN is also crucial, aligning with relevant standards to ensure reliable external communication. Grounding should address static discharge protection to safeguard sensitive BMS components. Compliance with industry standards, such as ISO 26262 for automotive functional safety, is essential for grounding practices. Grounding design should facilitate fault detection and isolation, helping to promptly address issues and prevent safety hazards. Finally, grounding strategies should consider thermal management to assist in heat dissipation, promoting optimal BMS performance and longevity.

2. Concepts of Isolation and Grounding Separation

Grounding for safety is crucial to protect personnel by connecting the metal body of devices to earth ground, ensuring that fault currents flow harmlessly to the ground. Safety grounding provides a low-impedance path for fault currents, reducing the risk of electric shock by preventing excessive current from flowing through the human body in case of faults such as insulation breakdowns or short circuits. Additionally, grounding prevents voltage buildup on exposed conductive parts, maintaining equipment at a safe potential, dissipating static charges, and protecting against transient events like lightning strikes.

Electromagnetic Compatibility (EMC) is another critical aspect of grounding. Proper grounding minimizes electromagnetic interference (EMI), ensuring that sensitive electronic devices operate without disturbances from external electromagnetic fields. Unlike safety grounding, EMC grounding does not always connect to earth ground; it often involves shielding or conductive planes to mitigate EMI. EMI arises when electronic circuits interact with external electromagnetic fields, disrupting normal operations and compromising power quality.

Isolation, in BMS circuits, refers to electrically separating two circuits to prevent unwanted interactions. This separation ensures that BMS measurements, such as voltage and current, remain accurate and unaffected by external factors. By isolating BMS circuits from the vehicle or system chassis, ground loops are minimized, reducing EMI risk. Isolation also protects against potential faults and transients, preventing conducted and radiated emissions. Techniques for isolation include optical isolation using optocouplers or photovoltaic cells, magnetic isolation with transformers or inductors, and capacitive isolation relying on capacitors to transmit AC signals while blocking DC components.

Galvanic isolation is a technique used to enhance safety by electrically separating various parts of a system while allowing signal transmission between them. This method prevents direct electrical contact and eliminates current flow through a conductive path, ensuring no common ground exists between the input and output sides. Isolation barriers such as optocouplers, transformers, capacitors, or digital isolators facilitate this separation. In high-voltage systems like electric vehicles (EVs) and energy storage systems, galvanic isolation is essential for protecting against electric shock hazards. During faults such as short circuits or insulation breakdowns, galvanic isolation prevents excessive current flow, reducing fire or injury risks and ensuring user safety during maintenance or repair.

Galvanic isolation also improves noise immunity by minimizing the impact of external EMI on BMS signals and preventing ground loops, which can introduce noise and ensure accurate measurements. For battery monitoring accuracy, galvanic isolation ensures precise voltage and current measurements within the battery pack. Isolated

sensors, like current shunt resistors, provide reliable data for state of charge (SoC), state of health (SoH), and fault detection.

Techniques for galvanic isolation include the use of optocouplers, which transmit signals across an isolation barrier using light (photons), commonly for digital signals but with limited bandwidth and sensitivity to temperature variations. Transformers use inductive coupling to transfer signals without direct electrical contact, suitable for both analog and digital signals, providing high isolation voltage, and are widely used in power supplies and communication interfaces.

3. Electrostatic Discharge

Electrostatic discharge (ESD) occurs when static electricity builds up on surfaces due to friction or the separation of materials. When surfaces with different electrical potentials come into contact, a sudden discharge can transfer the stored energy. Proper grounding is essential for mitigating the risks associated with ESD.

Grounding for static discharge protection involves several key aspects. Firstly, grounding provides a low-resistance path for static charges to flow safely to the ground, preventing charge accumulation on surfaces and reducing the risk of sudden discharges. Secondly, grounding ensures that all components within the BMS share the same reference potential. This equalization of potentials minimizes static discharge between components. Additionally, grounding protects personnel handling the BMS during installation, maintenance, or repair by preventing electric shock hazards caused by accumulated static charges.

To effectively manage static discharge protection, various grounding strategies can be employed. Single-point grounding involves connecting all BMS components, such as sensors, microcontrollers, and connectors, to a common ground point, minimizing ground loops and avoiding interference. Grounding the BMS enclosures, such as control boxes, is also important. Metal enclosures can function as Faraday cages, shielding internal components from external static charges. Using grounding wires or straps to connect components to the ground plane ensures low-resistance connections, enhancing ESD protection.

Implementing antistatic measures during BMS assembly and handling is crucial. Using antistatic mats, wrist straps, and conductive bags can prevent static buildup and reduce the risk of ESD. These precautions ensure that the BMS components are protected from static electricity, maintaining their integrity and functionality.

4. BMS Grounding

Grounding in Battery Management Systems (BMS) is crucial for ensuring voltage and current measurement accuracy. Accurate voltage measurements depend on a stable ground reference. If the BMS ground is improperly connected or affected by noise, voltage readings can become distorted. Proper grounding also helps mitigate common-mode noise, such as electromagnetic interference, which can couple into voltage measurement circuits and compromise accuracy.

For current measurements, shunt resistors are often used. These resistors are placed in series with the battery, and the voltage drop across them provides a proportional current measurement. To ensure accurate readings, it is essential to use separate wires for current and voltage connections, minimizing the voltage drop across the shunt resistor. This approach reduces voltage measurement errors caused by shunt resistance, thereby enhancing the precision of current measurements within the BMS. Pin Filters (RC filters) are used for battery pack voltage measurement to reduce noise, smooth fluctuations, and protect against transients. They improve measurement accuracy by conditioning the signal, crucial for precise battery state monitoring and control.

Grounding strategies are crucial for accurate voltage measurement and effective battery management.

- **Single-Point Grounding** – This method involves connecting all voltage measurement points to a common ground point, minimizing ground loops and interference. By linking sensors, BMS circuitry, and battery cells to a single ground, it prevents multiple current paths that could introduce noise and ensures a consistent reference potential for sensors.

- Kelvin Sensing – This method enhances measurement accuracy by separating current and voltage paths. Three main lines are involved:
 - High-Side Load line – Connects the battery pack's positive terminal (Node B) to the BMS PCB (Node A), passing through FETs to reach PACK +.
 - VPACK Bat Pin Sensing Line – Separates voltage sensing from the load current line within the PCB, connecting Node A to the VBAT Pin of the BMS IC.
 - Top Cell Sense – The top cell measurement input filter, VC16 in this example, is routed with its own wire to the top of the battery pack (Node B) to avoid measurement errors caused by load current induced IR drops in the load line.
 - Bottom Cell Sense – The bottom cell measurement negative terminal input filter for VC0 is routed with its own wire to the bottom of the battery pack (Node C) to avoid measurement errors caused by load current induced IR drops in the low-side load line.
 - Low-Side Load line – Connects the battery pack's negative terminal (Node C) to the BMS PCB and the low-side current sense resistor. In this example, the PACK-side of the current sense resistor is the BMS ground node. In some systems, ground is on the Node C side of the low-side current sense resistor.
- Low-Resistance Grounding – Reducing ground resistance helps minimize voltage drop across the shunt resistor, which is crucial for accurate current measurement. By ensuring low-resistance grounding, the integrity of voltage measurements is maintained, leading to more reliable battery monitoring and management.

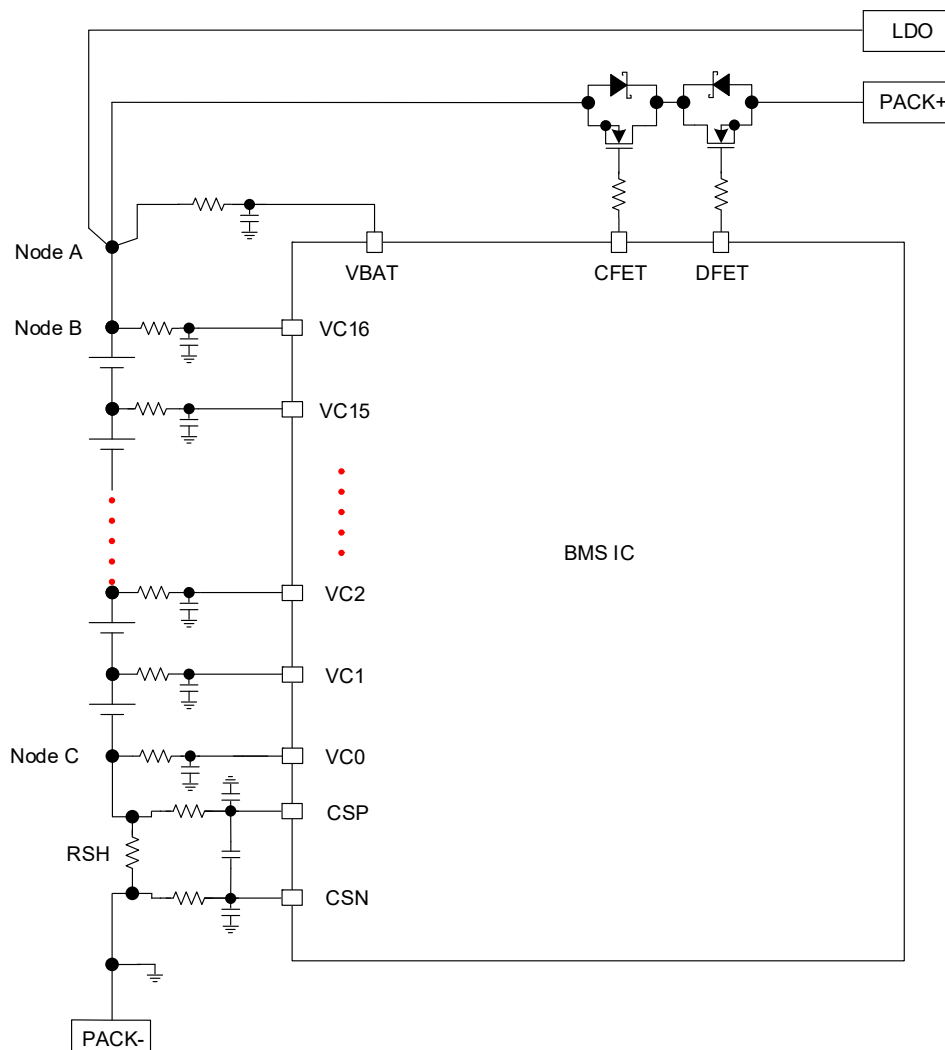


Figure 1. Simplified 16-Cell Battery Pack Block Diagram

5. Importance of Communication Interfaces

Communication interfaces are vital in Battery Management Systems (BMS) for several reasons. Firstly, they enable data exchange. A BMS continuously collects data from battery cells, sensors, and other components, including voltage, current, temperature, state of charge (SoC), and state of health (SoH). Communication interfaces facilitate the transfer of this data to external systems for analysis, control, and decision-making.

Secondly, communication interfaces are crucial for transmitting safety alerts. A BMS uses these channels to send warnings about low SoC levels, excessive temperatures, or abnormal currents. External systems can then respond appropriately to prevent damage or unsafe conditions.

Proper grounding is essential for effective communication in BMS, especially for protocols like CAN and LIN. For CAN (Controller Area Network), which is widely used in automotive and industrial applications, it allows multiple devices to communicate over a shared two-wire bus. It is crucial that all CAN nodes connect to a single ground point and avoid daisy-chaining ground connections to maintain signal integrity and prevent ground loops.

For LIN (Local Interconnect Network), a low-cost, low-speed communication protocol used for simple tasks like sensor data transmission, all LIN nodes should share a common ground reference. Ensuring that LIN slave nodes, such as sensors, have a stable ground connection is vital for reliable communication and accurate data transmission.

In summary, proper isolation and grounding are essential for accurate BMS measurements, EMI prevention, and overall system safety. By understanding these concepts and implementing effective techniques, BMS designers can optimize performance and ensure reliable operation in electric vehicles and energy storage systems. Proper grounding is a foundational aspect of electrical systems, ensuring protection against electric shock, equipment safety, and EMC compliance. By adhering to relevant standards and implementing proper grounding practices, engineers can create reliable and safe electrical installations.

6. Different Types of Electrical Systems

The examples mentioned in [Table 1](#) shows that the choice between grounded and floating systems depends on the specific requirements of the application, emphasizing factors such as safety, stability, and the need for isolation.

IMPORTANT: Carefully consider the design implications and adhere to relevant standards when selecting the grounding approach for a particular system.

Table 1. Examples of Grounded and Floating Systems

Grounded Systems	Floating Systems
Residential Electrical Wiring – In residential electrical systems, the neutral wire is typically grounded at the service entrance. This grounding provides a reference point for the entire electrical system and helps ensure safety by providing a path for fault currents.	Isolated Power Supplies – Some power supplies, especially those used in sensitive electronic equipment or medical devices, operate in a floating mode. Isolation from ground helps prevent ground loops and minimizes the risk of electrical interference.
Power Distribution Systems – Power distribution networks commonly use grounded systems to stabilize voltage and facilitate the detection and isolation of faults. Grounding helps protect equipment and ensures the safety of personnel.	Medical Devices – Many medical devices, such as patient monitors or diagnostic equipment, use floating systems to ensure patient safety. Isolation from ground reduces the risk of electrical shocks and allows the medical device to operate independently of other connected equipment. Floating systems also allow equipment to travel with the patient as they are moved around.

Table 1. Examples of Grounded and Floating Systems

Automotive Electrical Systems – In automotive systems, the negative terminal of the battery is often grounded to the vehicle chassis. This grounding helps maintain a stable electrical reference for various components and contributes to safety.	High Voltage Test Equipment – High voltage testing equipment may employ floating configurations to isolate the test circuit from ground. This is done to prevent unintended ground connections and ensure the safety of the testing environment.
Laboratory Equipment – Certain laboratory setups and experiments require grounded systems to maintain a stable reference potential. This is essential in precision measurements and experiments where accurate voltage levels are crucial.	Telecommunications Equipment – Certain telecommunications systems, especially those in remote or critical locations, may use floating systems to minimize the impact of ground potential differences and to enhance overall system reliability.

Relevant Standards:

- IEC 60335-1:2020 deals with the safety of electrical appliances for household and similar purposes, their rated voltage being not more than 250V for single-phase appliances and 480V for other appliances including direct current (DC) supplied appliances and battery-operated appliances.
- IEC 60086-4:2019 specifies tests and requirements for primary lithium batteries to ensure their safe operation under intended use and foreseeable misuse.
Note: Primary lithium batteries that are standardized in IEC 60086-2 are expected to meet all applicable requirements herein. It is understood that consideration of this part of IEC 60086 might also be given to measuring and/or ensuring the safety of non-standardized primary lithium batteries.
- IEC 63370:2022 contains a subset of requirements from IEC 62841-1:2014 that are applicable for battery charging systems.

7. GND Pin Connections and the Role of an Isolator

Connecting the GND pin between the PCB and communications dongle has several implications. Firstly, this connection directly ties the ground reference of the PCB and dongle, meaning they share a common reference point for communications and voltage measurements. However, this also creates a pathway for ground noise from the BMS PCB to potentially transfer to the dongle and the USB interface of the laptop. Similarly, noise from the laptop can affect the BMS PCB. Additionally, if the laptop is connected to a different power outlet or device with its own ground, a ground loop may form, introducing noise and causing communication errors.

8. Determining the Need for an Isolator

Deciding whether to include an isolator between the USB port and the communication line to the PCB depends on several factors. The sensitivity of the communication line to noise and voltage fluctuations is crucial, especially for high-speed or precision data lines where noise is a significant concern. The operating environment is another factor; systems in noisy environments, such as near motors or industrial machinery, are more likely to encounter elevated levels of electrical noise. Reliability requirements are also important; in critical applications, communication must be dependable without errors or disturbances. Additionally, ground potential differences matter, as BMS node voltages, including BMS ground, are likely to be at different potentials relative to earth ground when isolated.

9. Advantages and Disadvantages of an Isolator

Using an isolator has several advantages. It prevents ground loops, which eliminates a significant source of noise. It also protects against large potential differences between the laptop and system grounds, safeguarding the USB port and dongle. Moreover, by minimizing noise entering the communication line from the USB side, it enhances

signal quality. However, isolators also have drawbacks. They add cost to the dongle design and introduce additional components and design considerations. Some types of isolators may also have limitations on maximum data transfer speeds.

An isolator is strongly recommended for systems operating in electrically noisy environments, applications where data reliability is paramount, and situations with significant voltage differences between the laptop and PCB grounds.

10. Alternative to Full Isolation

Instead of full isolation, other strategies can be employed. Careful grounding practices, such as good PCB layout and grounding techniques, can minimize ground loop potentials. Adding filters on communication lines can suppress high-frequency noise. Additionally, connecting the isolated battery pack ground to earth ground before making other connections between the pack and the test system or external communications interface can help equalize grounds.

11. Connection Scenarios

The following describes BMS grounding issues in different connection scenarios. The power supply is assumed to be powering the evaluation kit resistor ladder, but the earth ground connection is critical in all cases.

- **Scenario 1: A ground-referenced power supply** – This approach is recommended when using non-floating power supplies. Here, the negative terminal of the bench power supply is internally connected to earth ground through the power cord and acts as the reference point for the system. The negative terminal should be connected first to establish the BMS ground reference. Consequently, all voltage measurements on the PCB are relative to this negative terminal.
- **Scenario 2: A floating power supply** – In this case, the power supply's negative terminal is electrically isolated from earth ground. Use the GND terminal of the power supply as the new reference point for the BMS by connecting it to the PCB ground node first. Connecting the negative terminal to the BMS PCB without referencing it to earth ground can result in an unknown voltage level as the reference point.

Next, analyze two more scenarios focusing on PC grounding and the use of a desktop versus a laptop. Consider the ground path to the power outlet and determine the USB ground reference. It is assumed the recommended earth ground connections previously mentioned are made.

- **Scenario 3: Grounded PC** – This represents a common scenario. Both the BMS and the PC have a separate path to earth ground for reference. This configuration can create ground loops that can lead to noise on the communication lines, making USB communication between the dongle and the laptop unreliable. In this scenario, an isolated dongle between the BMS and the PC ensures each has its own path to earth ground by breaking the ground loop.
- **Scenario 4: Ungrounded PC** – Given an ungrounded laptop, its chassis and USB ground are not connected to the earth ground of the building's electrical system; this occurs when the laptop charging supply is not connected. While the BMS circuit has a proper ground reference from the bench power supply, a small voltage difference can exist between the BMS ground and the laptop ground, potentially introducing some noise on the communication lines. The laptop acquires its ground reference through the USB to BMS path. Although communication might function, there is a risk of data errors due to this potential ground difference. Handling the ungrounded laptop requires caution to avoid electrostatic discharge (ESD) that can damage the BMS circuit. In this scenario, an isolated dongle between the BMS and the PC ensures the BMS does not pass PC ground currents.
- **Scenario 5: Floating BMS grounded PC** – This is a common situation at final test for battery packs as they may not have an accessible ground node. When connecting a communications dongle between the test system PC and pack, this can provide the pack's path to earth ground if the connection is not isolated. This situation often leads to damage of the dongle and loss of communications. In this scenario, an isolated dongle between the BMS and the PC ensures the PC does not pass BMS ground currents and the dongle functions reliably.

The worst-case scenario involves a floating BMS being connected to a floating laptop (Or Test System). In this case, neither assembly has a ground reference, and they may be at very different potentials that are suddenly reconciled when they are first connected.

If using batteries instead of the resistor ladder, the evaluation board should still have a known path to earth ground. Grounding the system through an oscilloscope probe ground or the USB port of a PC can be problematic.

Whether working with an evaluation board on the bench or using fully Automated Test Equipment (ATE), it is beneficial to all components to provide a ground reference first. Potential damage can be avoided if connections are made between nodes with the same ground reference.

12. Avoidable Situations

To ensure proper functioning and safety:

- **Prioritize Standard Powering** – Always use the positive and negative terminals of the bench power supply to power the BMS circuit if using a resistor ladder. Connect the power supply earth ground terminal to the BMS ground terminal first to ensure a proper ground reference and avoid risks associated with a shifted ground reference.
- **Ground the Laptop** – Whenever possible, ensure the laptop is grounded using its power cable to minimize noise and communication issues.
- **Consider Isolation** – If certain scenarios are unavoidable due to testing requirements, adding an isolation circuit to the dongle can significantly improve communication reliability by breaking the ground loop and reducing noise. This is why Renesas provides isolation in the dongle, which is provided in the evaluation kit.

13. Additional Tips

- **Safety First** – When working with the BMS circuit, prioritize safety and avoid situations that could compromise its ability to accurately monitor and protect the battery.
- **ESD Precautions** – Handle ungrounded equipment with care to prevent ESD damage to the BMS circuit. Renesas recommends connecting the BMS PCB to the power supply and power it up before connecting the dongle to the desktop or laptop using a USB cable.
- **Consult Datasheets** – Refer to the datasheets of the BMS components and dongle to understand their grounding requirements and potential limitations.

14. References

Related References Links:

- [AN1681](#) - Grounding Techniques
- [AN1975](#) - Use of Optocouplers in Battery Management Systems
- [AN1684](#) - Nonideality of Ground

15. Revision History

Revision	Date	Description
1.00	Jul 2, 2024	Initial release.

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