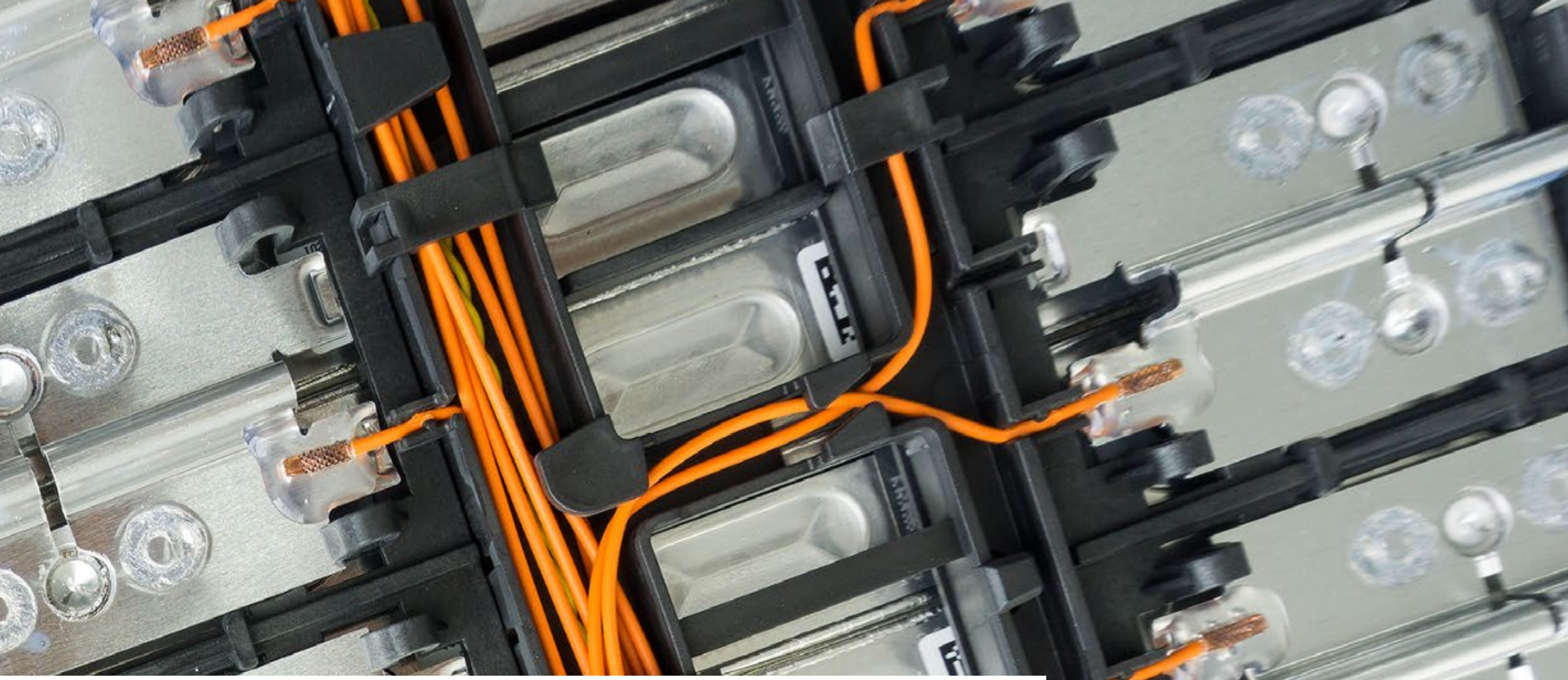


Battery Management Systems (BMS)

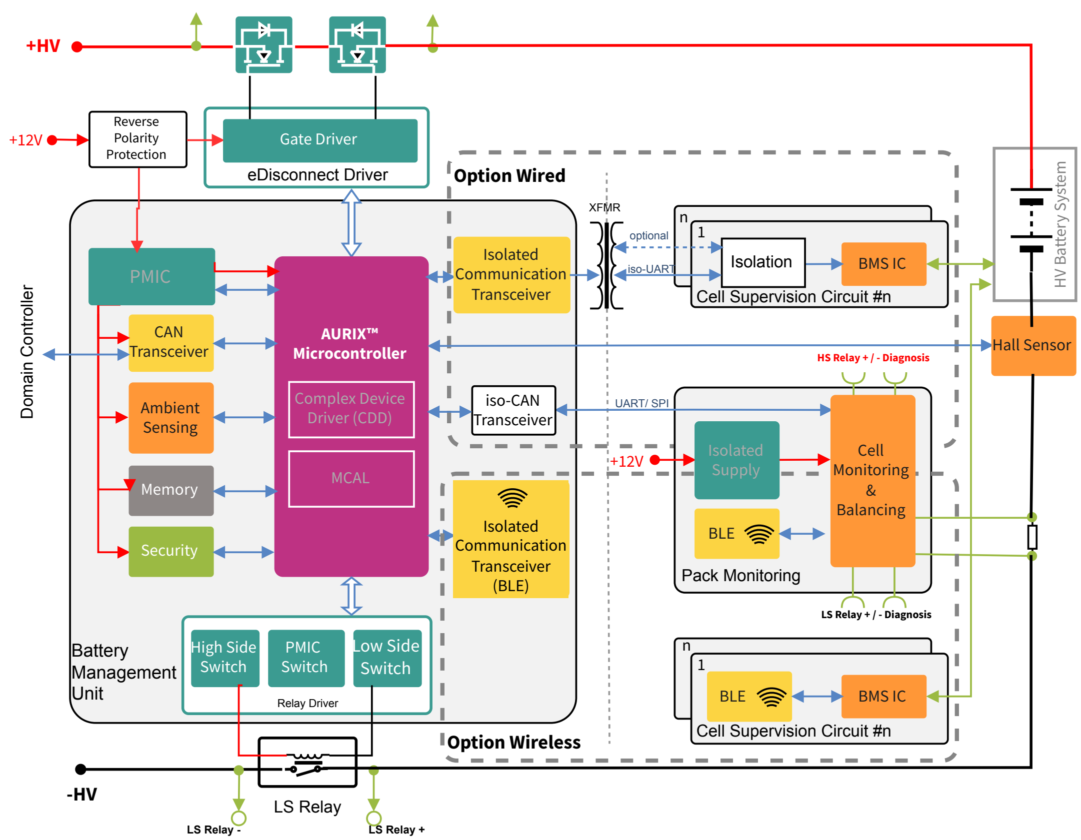
What is a battery?

An electric battery is a device that stores and releases electrical energy through chemical/ physical reactions. They are composed of multiple individual cells connected in series to increase voltage or in parallel to increase current and capacity. These cells can be made from various chemistries such as lead acid, nickel metal hydride, lithium-ion, and others.

What is a BMS?

A Battery Management System (BMS) is an electronic system that manages and monitors rechargeable batteries, ensuring their safe and efficient operation. It consists of hardware and software components that work together to control the charging and discharging of the battery, monitor its state of charge and health, and provide alerts or shut down the system in case of any faults. Overall, a BMS is crucial to ensure the safe and reliable operation of a rechargeable battery, extending its lifespan and reducing the risk of accidents or failures. Besides providing a safe operating environment, a good BMS design can reduce the cost of the pack itself by enabling the maximum use of the energy available.

An example block diagram of a BMS is shown below which includes a microcontroller, sensors, both solid-state and electromechanical disconnects (switches), voltage regulators, communication interfaces, and protection circuits.



Why is a Battery Management System (BMS) needed?

Safety: Certain types of cell chemistries can be damaged or cause a safety issue when operated outside of chemistry-specific operation conditions. Some such conditions include over-discharging, overcharging, temperature too high or low, and too much energy too quickly into or out of the battery. The BMS continuously monitors the battery for any faults or abnormal conditions.

Extended range: The BMS accurately estimates the remaining capacity of the battery. This information enables the vehicle's powertrain system to provide more accurate range predictions and helps drivers plan their trips accordingly. By having this reliable data, the drivers can optimize their patterns and make informed decisions to maximize the available range.

Battery life: The BMS ensures that all cells within the battery pack are balanced, meaning they have similar voltage levels. Balanced cells operate more efficiently and have a longer lifespan.

Types of BMS based on chemistry

There are various types of BMS, depending on the application and battery chemistry. Some of the common types include:

Lithium-ion BMS: Used in applications like electric vehicles, energy storage systems (ESS) for the grid and home, and multiple portable electronics. They always include individual cell voltage monitoring and typically include cell balancing, temperature monitoring, overcharge/over-discharge protection, and communication capabilities.

Lead-acid BMS: used in applications like backup power systems, UPS, and electric forklifts that use lead-acid batteries. They typically include charge control, voltage monitoring, temperature compensation, and low-voltage disconnect.

Automotive: In the context of automotive, Lead-acid batteries generally does not require a BMS. Lead Acid cells do not exceed 100% SoC (State of Charge) when overcharged but will outgas hydrogen at this point. Battery cells at lower SoC will continue to charge until they also reach 100% SoC. All cells will stop charging (and begin outgassing) at 100% SoC. This same feature is why lead acid batteries do not require cell balancing (see below).

Nickel-cadmium BMS: For applications like aircraft, marine, and telecommunications that use nickel-cadmium batteries. They typically include voltage monitoring, temperature sensing, and charge control.

Flow battery BMS: Used in large-scale energy storage applications that use flow batteries. They typically include monitoring the electrolyte levels, temperature, flow rates, and control of the charge/discharge cycles.

What is SOC?

SOC stands for, State of Charge, which is a measurement of the amount of energy stored in a battery relative to its maximum capacity. It is expressed as a percentage and can range from 0% (empty) to 100% (fully charged).

There are various techniques used by the BMS to determine the SOC of a battery, including:

- **Coulomb counting** is a method used by the BMS to estimate the SOC of a battery. It involves measuring the flow of electrical charge into and out of the battery over time. Coulomb counting requires a current sensor to measure the current flowing into or out of the battery, and the BMS calculates the SOC by integrating the current measurements over time.

  By continuously monitoring the current flowing in and out of the battery, the BMS can accurately estimate the SOC of the battery and provide information about the battery's remaining capacity.

  Coulomb counting is a reliable and accurate method for estimating the SOC of a battery when used in conjunction with other methods such as cell voltage measurement and temperature sensing. The BMS may use a combination of methods to calculate the SOC of the battery to improve the accuracy and reliability of the estimation.

- **Open-circuit voltage (OCV)** measurement: The BMS measures the voltage of the battery and each individual cell when it is at rest and not under load to eliminate voltage transients generated during operation. The OCV indicates the SoC of the cell.

  Example: A Lithium-Ion NCA (Nickel Cobalt Aluminum) cell may have a voltage range from 3.3V to 4.0V which respectively indicates 0% SoC to 100% SoC. An OCV of 3.75V on a cell of this type would indicate an SoC of 64.3%.

- **Cell Charge and Discharge Limits**

  If cells in a battery pack become overcharged, they may become damaged, and their capacity may decrease, which can lead to an imbalance in the battery pack. Similarly, if some cells become undercharged, they may not be able to recharge to their full capacity, which can also result in an imbalance. In addition to capacity and lifetime reductions, overcharging and over-discharging cells can lead to safety hazards such as thermal runaway, which can result in a fire or explosion. At a minimum, an imbalanced battery pack will reduce the overall performance of the battery relative to the energy available to the application.

  Cells connected in a series all have the same charging and discharging current. Cells with higher SoC will reach 100% SoC more quickly compared to those with lower SoC. Charging MUST stop at this point to avoid overcharging them. However, the cells with lower SoC will not yet be fully charged. Conversely, the pack can only provide energy until the cell(s) with the lowest SoC reach 0% SoC at which point discharge must be halted. However, the cells with a higher SoC still have usable energy that cannot be utilized by the application.

  Using the NCA cell example from above: An OCV of 3.3V is the absolute minimum voltage to which this cell should be discharged to avoid damage (example: lithium plating). Conversely, charging the cell past the absolute maximum of 4.0V causes irreversible damage to the cell's capacity and can result in safety hazards such as overheating, fire, or explosion.

  These imbalances between the cells are corrected via Cell Balancing.

Cell balancing

Cell balancing is a process of equalizing the state of charge (SOC) and voltage of each cell within a battery pack to ensure optimal performance, prolong the battery's lifespan, and prevent any potential safety hazards. Cell balancing is required because even though the cells within a battery pack are manufactured to have similar characteristics, their internal resistance, and chemical reactions all vary slightly causing them to have slightly different static and dynamic characteristics which over time cause different SOC and voltage levels. Left uncorrected, these drifting SoCs will impact the overall performance of the battery pack. Equalizing the SoC on the cells corrects this drift and restores maximum pack performance.

Cell balancing can be achieved using various methods such as passive balancing, active balancing, and hybrid balancing.

a. Passive balancing involves the use of resistors to discharge the cells with the highest SoC to reach the SoC of the lowest cells. Being inexpensive and easy to implement are two advantages of passive balancing. A disadvantage is that the energy in higher SoC cells is simply dissipated as heat during balancing, thus, having an impact on system efficiency.

b. Active balancing involves the use of dedicated circuitry to transfer charge between cells. One advantage of active balancing is energy in cells with a higher SoC can be moved to cells with a lower SoC and not wasted as heat. The disadvantages: it is harder to implement, requires significantly higher component cost, and efficiency losses when transferring energy across numerous cells or module boundaries negate the theoretical benefit.

c. Hybrid balancing combines both passive and active balancing methods to achieve the desired cell balance.

In summary, cell balancing is an essential function of the BMS, and it ensures that the battery pack operates safely, efficiently, and optimally.

What is SOH?

SOH stands for State of Health, which is a measurement of the overall condition and performance of a battery relative to its original state when it was first manufactured. It is expressed as a percentage and reflects the battery's ability to deliver its rated capacity and power compared to when it was new.

The SOH of a battery is affected by various factors such as the number of charge and discharge cycles, operating conditions such as temperature and humidity, and the depth of discharge. Over time, these factors can cause degradation of the battery, resulting in a decrease in its capacity and performance.

The State of Health is often expressed as a percentage, where 100% indicates the battery is operating at its original or new condition, and lower percentages reflect the degree of degradation or loss in capacity. For example, if a battery has a SOH of 80%, it means it can deliver 80% of its original capacity and performance.

There are various techniques used by the BMS to determine the SOH of a battery, including:

Resistance measurement: The BMS measures the internal resistance of the battery, which will increase as the battery ages and degrades. An increase in internal resistance indicates a decrease in the battery's capacity and SOH. It also leads to reduced current capability and increased internal heating.

Impedance spectroscopy: The BMS uses a small AC signal to measure the battery's impedance, which can provide information about the battery's state of charge, state of health, and internal resistance. This can be performed at the pack or individual cell levels. Spectroscopy at the cell level is more difficult to implement but yields a better assessment of SoH.

Capacity testing: The BMS performs a discharge test on the battery to measure its capacity and compare it to the new battery's capacity. A decrease in capacity compared to the new battery indicates a decrease in the battery's SOH.

Model-based estimation: The BMS uses mathematical models to estimate the battery's SOH based on its performance and operating conditions. These can be very accurate but computationally intensive. The models take into account factors such as chemistry, temperature, discharge rate, and cycle life. Future generations of microcontrollers, such as the Infineon TC4x, enable processing of model-based-estimation and impedance spectroscopy by including dedicated peripherals for parallel processing of information within the microcontroller.

By using one or more of these techniques, the BMS can accurately estimate the SOH of the battery and provide information about its remaining useful life, allowing for proactive maintenance or replacement of the battery to ensure reliable and safe operation.

Safety

a. Isolation: Isolation is an important safety feature in electrical systems, including battery systems. It involves physically and galvanically separating the battery pack from other components or systems to prevent electrical contact and potential hazards such as electric shock or short circuits. Isolation can be achieved using physical barriers, insulation materials, or air gaps to provide a safe operating environment.

Galvanic isolation can be employed to enhance safety, protect sensitive components, and ensure reliable operation. Here are some specific scenarios where galvanic isolation is commonly used in a BMS:

i. **The primary purpose of galvanic isolation** is for safety. It reduces the potential for shock hazards to the operator under standard operating conditions.

ii. **Isolation between the battery's cells (High voltage domain) and control circuitry (Low voltage domain):** In a BMS, the control circuitry that monitors and manages the battery pack's parameters (voltage, current, temperature) needs to be isolated from the high-voltage battery pack itself. Galvanic isolation is implemented using isolation techniques such as optocouplers, transformers, etc. This isolation helps prevent voltage spikes, ground potential differences, or fault conditions in the battery pack from affecting the control circuitry and vice versa.

iii. **Isolation between communication interfaces:** BMS may incorporate communication interfaces, such as CAN bus, or Ethernet, to exchange data with external systems or devices. Galvanic isolation can be applied to these interfaces to prevent ground loops, electromagnetic interference, or transient events from affecting the communication signals. It ensures reliable and noise-free data transmission between the BMS and external systems.

iv. **Isolation for safety and fault protection:** Galvanic isolation can be utilized to provide safety and fault protection measures within the BMS. For example, isolation barriers can be employed to protect against high-voltage transients, short circuits, or faults in the battery cells or pack. By isolating these fault conditions, the BMS can prevent the propagation of dangerous currents or voltages to other parts of the system, ensuring the safety of the operator, battery pack, and the surrounding components.

By incorporating galvanic isolation in these different aspects, a BMS can enhance safety, protect sensitive electronics, isolate communication interfaces, and provide reliable operation and data integrity within the battery system.

b. Thermal Runaway: Thermal runaway is a condition in which a battery cell or pack experiences an uncontrolled increase in temperature, leading to a self-sustaining and escalating chemical reaction. Thermal runaway can result in a fire or explosion and can be caused by various factors such as overcharging, internal short circuits, or mechanical damage to the battery. To prevent thermal runaway, battery systems are designed with thermal management systems that monitor and control the temperature of the battery cells and pack.

Advanced sensing mechanism like gas concentration and pressure might also be required to early detect possible thermal runaway events. Pressure sensors like KP467, specially designed for BMS, enable a wide range of pressure sensing and implements internal mechanisms to save current consumption yet being able to detect possible risky situations during while driving, parking and charging.

c. FuSa: FuSa stands for Functional Safety, which is a concept that addresses the safety of a system or device in its intended function by defining safety goals at the system level. In the case of battery systems, functional safety includes measures to ensure the safe and reliable operation of the system under normal and abnormal conditions, including measures to prevent overcharging, over-discharging, short circuits, and other potential hazards. FuSa is achieved through a combination of hardware and software design, testing, and validation processes to ensure that the system operates safely and reliably in all conditions. The BMS is a critical component of the battery system that plays a key role in ensuring the functional safety of the system.

Communication

a. Wired vs. wireless communication: BMS can communicate with external systems and devices through wired or wireless connections.

i. Wired communication typically involves physical connections such as CAN bus, or Ethernet cables, while wireless communication uses radio frequency (RF) signals such as Bluetooth, or Wi-Fi. Wired communication can provide higher data rates and more reliable connections but require more complex wiring.

ii. Wireless communication is often more convenient and flexible but can be subject to interference and range limitations. The battery pack's internal physical design and shape must incorporate space or channels to allow Radio Frequency (RF) energy a path between the remote modules and the central processor for robust communications. Higher costs are also a factor but may be offset by savings in: wiring, weight, service, and warranty savings. Communications security is also a concern.

b. Communication methods: There are various communication methodologies used in BMS to enable communication with external systems and devices. Some of the commonly used communication chips are:

UART Transceiver IC: This IC is used for serial communication from the host microcontroller and other BMS ICs. The TLE9015DQU IC translates communications from the standard UART port of the host microcontroller to Isolated UART communications used by the galvanically isolated TLE9012DQU devices in a daisy chain inside a Li-Ion battery.

CAN (Controller Area Network) bus: CAN is a widely used communication protocol in automotive and industrial applications. Its differential outputs and twisted pair wiring provide high immunity to noise in the rugged automotive environment. CAN chips enable high-speed communication between devices and systems, allowing for real-time monitoring and control. Infineon high-speed CAN transceivers such as TLE9351VSJ and TLE9251VLE can be used to support CAN FD data frames up to 5 MBit/s.

Bluetooth: Bluetooth chips enable wireless communication between devices, allowing for remote monitoring and control of the battery system using a smartphone or other Bluetooth-enabled devices. Infineon Bluetooth devices such as CYW89820 and CYW89829 support wireless BMS communication and are AEC-Q qualified.

Wi-Fi: Wi-Fi enables wireless communication between devices over a local area network (LAN), allowing for remote monitoring and control of the battery system using a web-based interface.

The choice of communication chip depends on the specific application requirements such as data rate, range, reliability, and cost. The

BMS may use one or more communication methodologies to enable communication with external systems and devices to provide information about the battery system's state and performance and to enable remote monitoring and control.

Development ecosystem

The development ecosystem for battery management systems (BMS) includes various tools, software, and hardware components that are used to design, develop, test, and deploy BMS for different applications. Here are some of the key components of the BMS development ecosystem:

Development tools: These include software tools that are used to design and simulate BMS circuits and systems, such as simulation software, schematic capture software, and PCB design software. These tools allow engineers to model and test the BMS design before it is built, reducing the time and cost of development.

Microcontrollers: A BMS typically uses microcontrollers to manage the battery cells and pack, and to communicate with external systems and devices. Infineon AURIX microcontrollers such as TC3xxx and Traveo T2G family of microcontrollers can be used to develop and deploy BMS. These microcontrollers offer advanced safety features such as hardware-based self-tests, redundant architecture, and comprehensive diagnostic coverage. AURIX microcontrollers coupled with safety PMICs can support FuSa levels up to and including ASIL-D, the highest Automotive safety rating.

Future microcontroller Families like AURIX TC4xxx will enable additional peripherals for electrochemical modeling processing and advance EIS computation.

Sensors: BMS relies on various sensors to monitor the state and performance of the battery cells and pack. Examples include: voltage monitoring, current sensors, temperature sensors, and impedance sensors. These sensors are typically integrated with the BMS circuitry and communicate with the microcontroller to provide real-time information about the battery system.

Cell Sensing: Infineon Li-Ion battery monitoring and balancing ICs, such as the TLE9012DQU, can be used to monitor voltages on up to 12 cells connected in series and 5 temperature sensors. Infineon is also developing devices to support higher number of cells per IC as well as to continuously improve the accuracy of the voltage measurements.

Current sensor: Current sensing is used for accurate SOC calculation and overcurrent detection. TLE4972 is a High precision Core-less current sensor that can be used for contactless sensing. The benefit of Contactless sensing is, it does not require an isolation barrier between low and high voltage domains other than the physical spacing provided by air or other non-conductive material placed between the sensor and the HV conductor. The PSoC 4 HV (high voltage) PA is a fully integrated programmable embedded system for battery monitoring and management that can also be used for current sensing.

Testing and validation tools: BMS development also requires testing and validation to ensure that the system meets the performance and safety requirements. Testing tools may include hardware-in-the-loop (HIL) simulators, automated test equipment (ATE), and diagnostic tools that allow engineers to test and debug the BMS during development and deployment.

Overall, the BMS development ecosystem includes a wide range of tools, hardware, and software components that are used to design, develop, test, and deploy BMS for various applications, ranging from small consumer electronics to large-scale energy storage systems. Robust BMS design is essential to maintaining a safe environment for the operator, maximizing pack reliability, and minimizing warranty costs.

Support:

Arrow has the BEVOP demo kit from Neutron Controls available, it serves as a **Battery Management System in a nutshell** using Infineon components.

This kit showcases the Infineon product portfolio and provides a platform for know-how transfer.

System Features:

- Infineon **TLE9012** for each of the 12 x 18650 cell voltages and 5 temperature measurements
- Infineon **TLE9015 for iso UART translator** for isolated high voltage pack use
- Infineon **AURIX TC399** running simple BMS
- Integrated charger and variable load to demo variation in current draw
- **High voltage Contactors** for load and discharge to demo I/O
- Infineon **PSoC HVPA** for pack current monitoring
- **Demo GUI** to display BMS data and activate funcations via CAN bus

For questions or further information on any of the above please email the author:

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