How Innovation in Battery Management Systems is Increasing EV Adoption
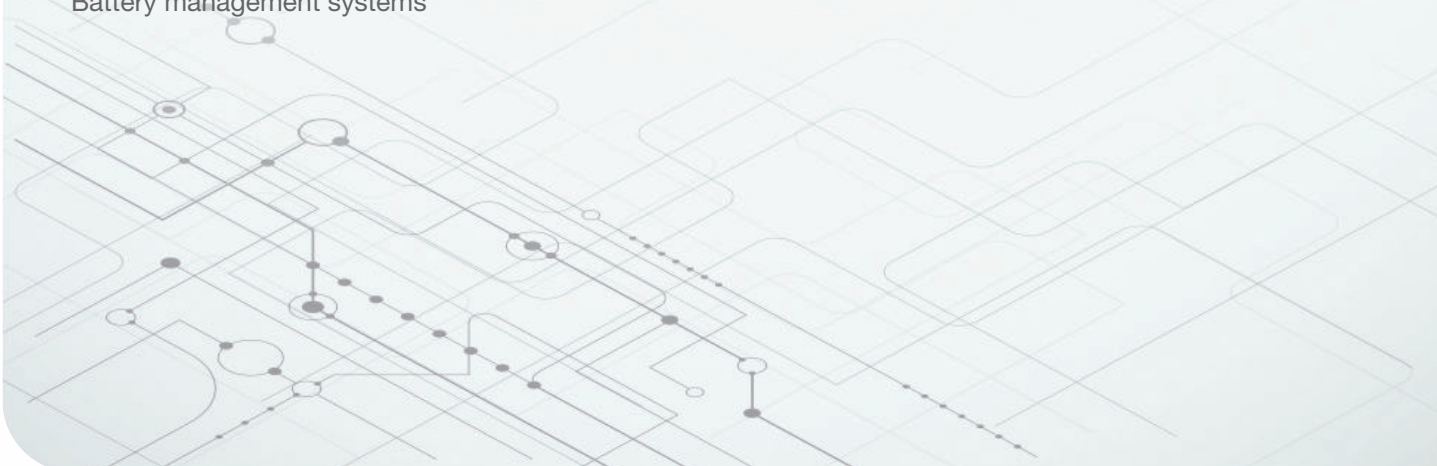
TEXAS INSTRUMENTS

Mark Ng
Sector general manager
HEV/EV powertrain

Issac Hsu
Marketing manager
Battery management systems

Taylor Vogt
Applications manager
Battery management systems

The reality of an all-electric future requires innovation in electric powertrain systems, which comprise BMS, onboard chargers and DC/DC converters, and traction inverters. At the heart of these systems are the semiconductor components that make electrification possible.

At a glance

Battery management systems (BMS) have evolved with the widespread adoption of hybrid electric vehicles (HEVs) and electric vehicles (EVs). This paper takes an in-depth look into the trends affecting BMS development, as well as how the major subsystems work together to improve safety and efficiency.

1 **The working principle of a BMS and industry trends**

Review how integrating the three major BMS subsystems enables safe, efficient battery packs, and explore new battery chemistries and BMS trends, including wireless BMS.

2 **Advanced estimations of battery capacity and battery health**

An accurate estimation of a battery's remaining charge has a direct effect on the remaining driving range. Take a detailed look at the cell supervisor unit (CSU) and how it provides increasingly detailed cell status measurements to maximize the battery pack benefits.

3 **Traditional vs. intelligent battery junction box (BJB)**

Discover how silicon innovations are enabling a shift toward a more modern architecture known as the intelligent BJB, and learn about the role of the battery control unit (BCU) as the communication interface.

The BMS protects the battery from damage, extends the life of the battery with intelligent charging and discharging algorithms, predicts how much battery life is left, and maintains the battery in an operational condition. Lithium-ion battery cells present significant challenges, demanding a sophisticated electronic control system. Plus, there is a significant risk of injury from fires and explosions. A BMS therefore requires cutting-edge silicon to meet all performance, safety and cost metrics.

In general, the three main BMS challenges that every designer strives to improve are maximizing driving range, improving cost and enhancing safety.

Solving one of these challenges may adversely impact the other. In this white paper, we'll discuss several emerging trends to address all three challenges.

The working principle of a BMS and industry trends

A distributed BMS architecture (Figure 1) has a modular structure and typically comprises three major subsystems: the cell supervision unit (CSU), the battery control unit (BCU) and the battery disconnect unit (BDU).
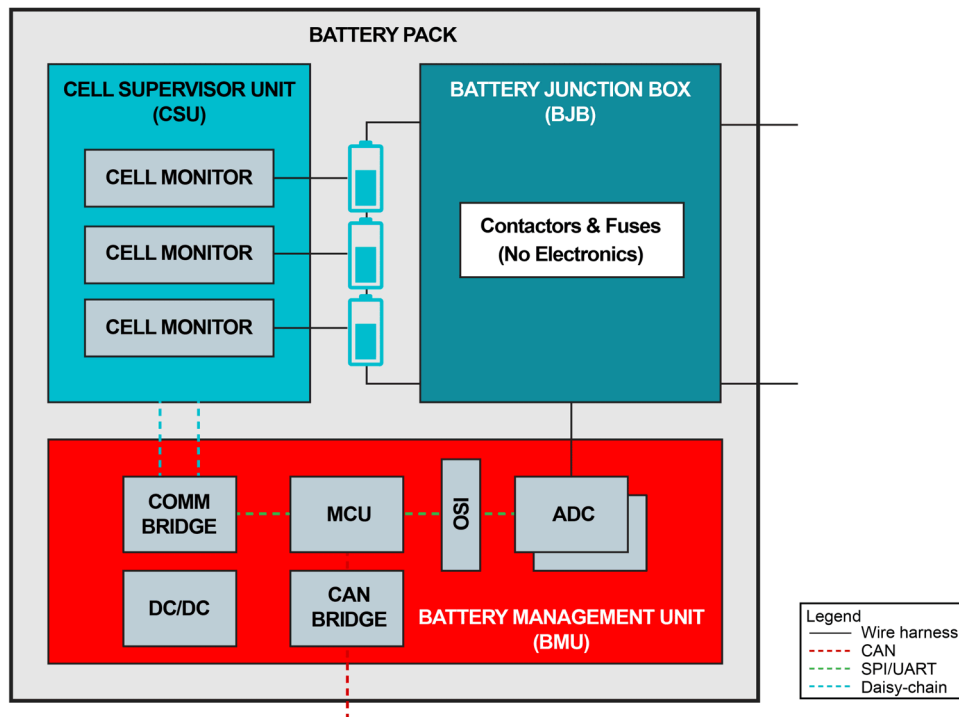
Figure 1. *A typical BMS architecture.*

The industry has different names for these subsystems, listed in **Table 1**, so it can be helpful to set a baseline for the various names and acronyms.

Subsystem Name	Also Referred to as:	Acronyms
Cell supervisor unit	Cell supervision circuit Cell monitor unit	CSU CSC CMU
Battery control unit	Battery electrical controller Battery energy control module Battery management unit	BCU BEC BECM BMU
Battery disconnect unit	Battery junction box	BDU BJB

Table 1. *Common industry acronyms for BMS subsystems.*

The CSU collects parametric information from all battery cells by sensing the voltage and temperature of each cell. The CSU helps compensate for inconsistencies between battery cells by performing cell balancing. The BCU must incorporate the parametric information from the CSUs and must also detect the voltage and current of the battery pack to perform pack management. According to all collected voltage, current and temperature data, the BCU is responsible for allocating how to charge and discharge the battery according to the overall condition of each and every battery cell. Continuous monitoring of the condition of the batteries occurs through calculations of state of charge, state of power and state of health. Intelligent protection control is also an important feature of the BCU, as it must perform insulation monitoring, control the contactors in the event of a crash or short circuit, continuously monitor the temperature sensors, and perform diagnostics to check that all incoming parameters are indeed valid. The information is transmitted to the automobile vehicle control unit or electronic control unit through Controller Area Network (CAN) communication.

New battery chemistries

Lithium-ion can refer to a wide array of chemistries; however, it ultimately consists of a battery based on charge and discharge reactions from a metal-oxide cathode and a graphite anode. Two of the more popular lithium-ion chemistries are nickel manganese cobalt (NMC) and lithium-iron phosphate (LFP).

NMC is the dominant chemistry given its superior energy density, which has a direct impact on drive range. However, demand for nickel and cobalt has surged in recent years, and automakers are adopting strategies to hedge against the turbulent market. Nickel and cobalt are also rare and difficult to extract from the earth.

While still the minority chemistry, LFP has a lower energy density, but significant advantages. LFP does not have costly and rare nickel and cobalt elements and will cost less. It also lends itself to a high cycle life and thus longer lifetimes. LFP batteries are also more stable and less likely to catch fire than batteries with nickel and cobalt, requiring fewer protections.

LFP will therefore likely be the predominant chemistry in the high-volume vehicle segment where the driving range is not as important as affordability, safety or being earth-friendly (not using cobalt and nickel). LFP will require extremely accurate battery-monitoring technology, as it exhibits a very flat discharge curve. Read how advanced semiconductors are enabling BMS architectures for new and emerging battery chemistries in the article, **What's next in BMS? Safer, more affordable electric vehicles**.

In the meantime, some vendors are investigating the use of even lower cost sodium-ion cells to compete with LFP.

Unlike traditional lithium-ion batteries that use a liquid electrolyte, solid-state batteries use a solid electrolyte consisting of glass, ceramics, solid polymers or sulfites – hence the name. Multiple automotive manufacturers are studying solid-state batteries given their inherent performance advantages: better energy density; increased reliability and aging characteristics; significantly faster charging; and perhaps most importantly, improved safety. At high temperature, liquid electrolytes become flammable. Solid electrolytes offer higher thermal stability, which in turn can limit the risk of fires or explosions.

Wireless BMS

Wires are the de facto method of implementing a BMS today. In many cases, it is the most reliable way to achieve Automotive Safety Integrity Level D (ASIL D) compliance because functional safety capabilities are built into the daisy-chained wired communication protocol. Wires have their disadvantages, however: cable failures, warranty repairs and battery cell replacements are expensive.

One advantage of a wireless BMS, shown in **Figure 2**, is the simplicity associated with assembly and production of the battery pack – which can save costs and increase efficiency during production. Production line technicians can simply assemble the battery pack and get instant readings, whereas a wired BMS requires technicians to plug cables into every battery module.

Another advantage of a wireless BMS is that cable harnesses and connectors can be one of the leading causes of failure in a battery pack. A wireless BMS reduces low-voltage cabling and has the potential to save original equipment manufacturers (OEM) from significant warranty claims.

A wireless BMS helps reduce weight, and perhaps more importantly, there is now more space in the battery pack. With the increased space, a battery manufacturer or OEM can add more battery cells to the pack. Increased cells plus lower weight can lead to extended driving ranges.

A wireless BMS can also help save component costs because of its inherent isolation, so automotive manufacturers can save money by not having to use transformers, capacitors or common-mode chokes to achieve isolation.

TI's automotive-qualified **CC2662R-Q1** SimpleLink™ wireless microcontroller (MCU) includes a 48-MHz Arm® Cortex®-M4 processor and is capable of running a 2.4-GHz **proprietary wireless BMS protocol**.
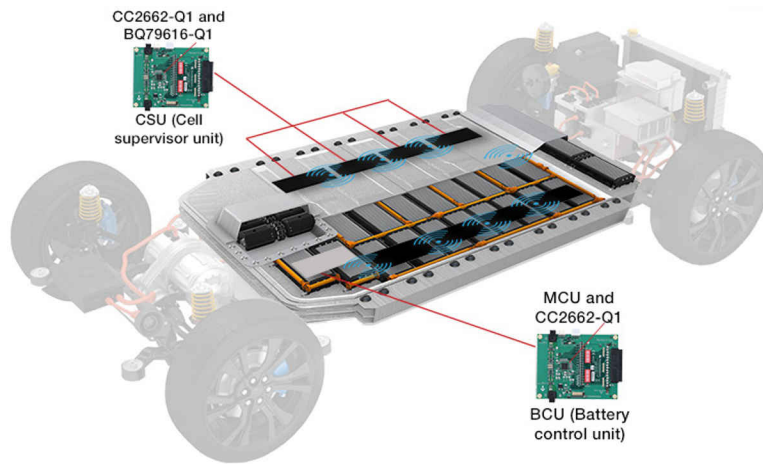
Figure 2. TI's wireless BMS technology.

## Advanced estimations of battery capacity and battery health

An accurate estimation of a battery's remaining charge has a direct effect on the remaining driving range. Even though battery cell manufacturers provide the nominal capacity of the battery, it changes over time. Some important factors that cause battery capacity to fade include elevated temperature, cycling (usage), depth of discharge patterns and aging. These factors require continuous estimation of the battery capacity for an accurate estimation of the state of charge.

Accurate measurement of a battery's health determines whether the drivers will have to replace the battery or wait until an explicit and hazardous cell failure event occurs.

Effective synchronization of voltages and currents helps enable precise state-of-charge, state-of-health and electrical impedance spectroscopy (EIS) calculations that results in optimal utilization of the battery. For more information, see the technical article How to design an intelligent battery junction box for advanced EV battery management systems.

A detailed look at the cell supervisor unit (CSU)

Figure 3 shows a simplified CSU. The CSU operates closely within the actual cells of the pack, connecting the cell monitor device wiring harnesses and ensuring efficient transmission of the essential pack data back to the host BCU.
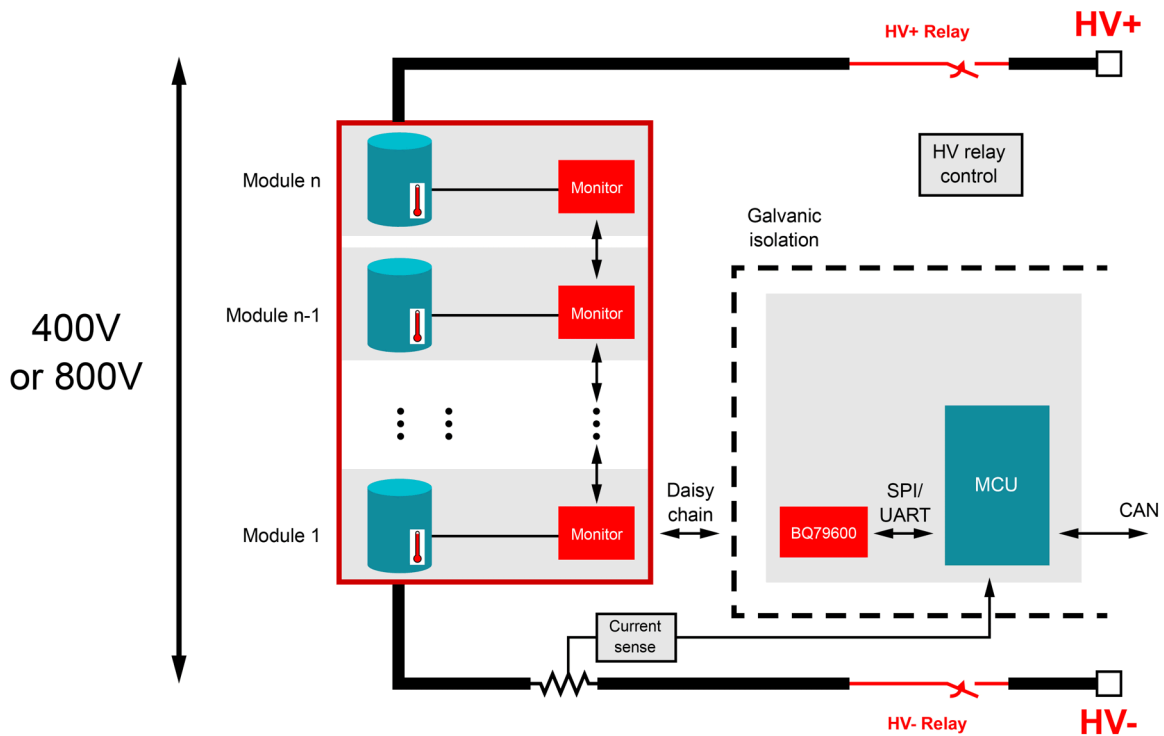
Figure 3. *Simplified CSU system block diagram.*

Without the CSU, there would be little information available regarding the status of the battery pack. The diagnostic data output from the CSU enables state-of-health and state-of-charge estimations, which directly impact the safety goals of the system. With highly precise monitors, these algorithms can provide extremely accurate estimations to the driver and maximize the most utility from each charge. This action is typically done passively, and at high enough currents where thermal management becomes challenging to maintain and measure. Overall, implementing a sophisticated CSU into the pack benefits the lifetime charge cycles of the vehicle, offering a safer and more improved overall experience.

The CSU provides increasingly detailed cell status measurements to maximize the aforementioned battery pack benefits. For state-of-health and state-of-charge calculations, synchronizing these measurements at the highest possible data rates safely and reliably offers

the best estimations. As the trend toward >400-V high-voltage packs rises, an intelligent CSU design facilitates the growing number of cell data transmissions across the pack. To enable the most affordable HEV/EVs, the challenge is how to accomplish these benefits with the lowest possible power consumption and external printed circuit board components.

With LFP becoming more popular, the flat discharge curve compared to NMC (as depicted in **Figure 4**) requires even more accurate cell voltage measurements to determine the usable mileage of an EV. The Texas Instruments (TI) **BQ79718-Q1** stackable battery monitor and cell balancer measures 18 cells in series. It provides cell voltage measurements to ±1-mV accuracy, with passive cell balancing featuring 300-mA current capability. The device also supports voltage and current synchronized measurements together with the **BQ79731-Q1** battery monitor to provide more accurate state-of-health and state-of-charge calculations.
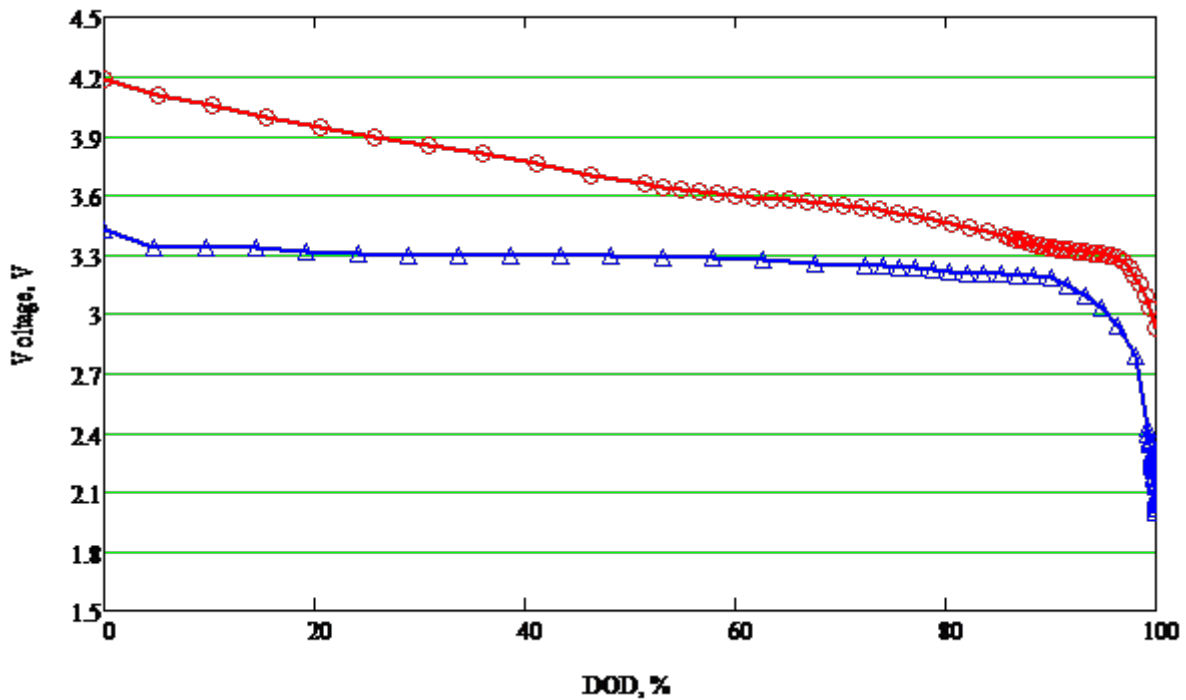
Figure 4. *Battery chemistry discharge curve (red = NMC, blue = LFP).*

Traditional vs. intelligent battery junction box (BJB)

BMS architectures are continuously evolving. Silicon innovations (spurred by the arrival of a so-called pack monitor) are enabling a shift toward a more modern architecture known as the intelligent battery junction box (BJB). Whereas a traditional BJB contains only mechanical components, an intelligent BJB introduces active silicon devices into the BJB itself, performing high-voltage monitoring, current sensing and insulation detection (functions traditionally performed by the BCU).

An intelligent BJB architecture (illustrated in **Figure 5**) has several clear advantages. It clearly separates the high- and low-voltage domains – all high-voltage signals are measured directly in the BJB, allowing the BCU to become a fully low-voltage design. The pack monitor's use of a proprietary daisy-chain interface eliminates costly digital isolator devices because the daisy chain enables discrete capacitor isolation. Daisy-chain communication also comes with the added advantage of not requiring any other components such as transceivers (like CAN), nor do they require an additional MCU to control and drive the communication protocol. Placing the pack monitor in or around the BJB makes high-voltage signals immediately accessible, and there is no longer a need to run multiple long wires back to the BCU. It is possible to measure currents and to perform shunt current sensing.

Traditional BMS → Intelligent battery junction box (BJB)
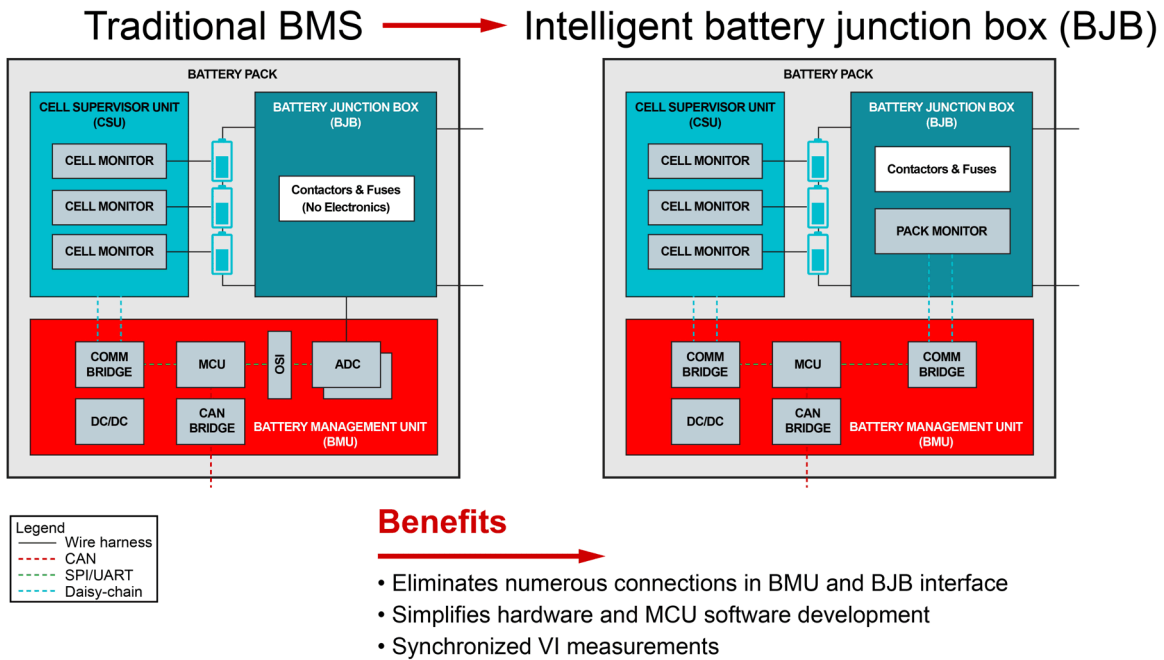
Figure 5. *A traditional BMS architecture vs. a modern intelligent BJB architecture.*

A detailed look at the BJB

An intelligent BJB helps measure high voltages in the battery directly through a voltage, current and insulation resistance pack monitor. There are multiple voltage and current measurement channels available in a typical pack monitor, which can measure voltage across fuses and contractors and check the isolation voltage in the BJB. **Figure 6** is a simplified system diagram.
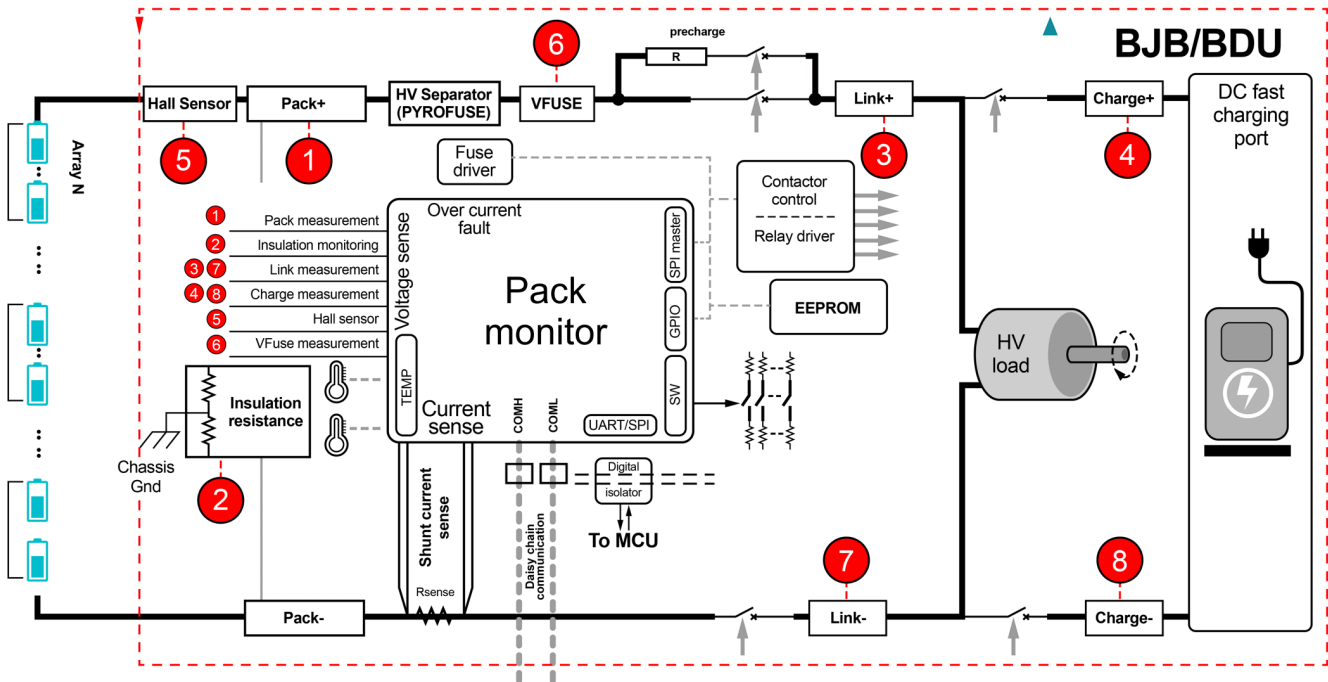
Figure 6. *Simplified BJB system block diagram.*

Since the pack monitor can measure the battery pack current, overcurrent protection is incorporated in the system. Some pack monitors such as the **BQ79731-Q1** include a Coulomb counting feature for state-of-charge calculations, too.

Voltage and current synchronization implemented in the BQ79731-Q1 enables the measurement of battery pack current and voltage at the same moment as the battery cell voltages are measured in the CSU. It is possible to poll all information captured through either one of the daisy-chained communication interfaces to the BCU.

Differentiation between the intelligent BJB and the traditional BJB is the digital control of contactor drivers and pyrofuses to disconnect the battery pack to the EV system during a crash. The BQ79731-Q1 includes Serial Peripheral Interface (SPI) controller channels that can control contactor drivers and pyrofuses, reducing the need for extra SPI resources from the BCU.

The battery pack uses mechanical contactors controlled by the pack monitor to connect or disconnect subsystems throughout the vehicle. It's important to prevent any potential failure of these contactors or exposure to high-voltage connections to protect drivers from life-threatening injuries.

Mechanical high-voltage contactors can weld or be damaged through arcing and pitting in the event of uncontrolled inrush current. *Why Pre-Charge Circuits are Necessary in High-Voltage Systems* explains the use of the **TPSI3050-Q1** isolated switch driver to form a reliable solid-state relay for pre-charging in an automotive BJB.

With no moving parts, the TPSI3050-Q1 can improve system-level reliability or failure-in-time rates when replacing mechanical pre-charge contactors.

Both the positive and negative terminals of the high-voltage battery pack must be sufficiently separated from the chassis of the vehicle in order to protect the driver or a technician from potential electrical shock. Periodic monitoring of this separation is known as isolation check or insulation resistance monitoring. Solid-state relays such as the **TPSI2140-Q1** connect and disconnect a known resistance value (such as 1 MΩ) in parallel to the unknown resistance value (between a battery terminal and chassis ground). By measuring the combined resistance using a pack monitor such as the BQ79731-Q1, you can determine whether the battery separation is within tolerance (at least 500 Ω/V per the Federal Motor Vehicle Safety Standards No. 305 specification) or potentially harmful.

A detailed look at the battery control unit (BCU)

A BCU consists of a communication chip and an MCU. The communication chip is the interface between the MCU and the CSU and BJB, translating signals from the daisy chain of the CSU and the BJB into a decoded bitstream to send to the MCU. The MCU polls all of the information measured by the CSU and BJB, calculates the battery status, and responds to faults or diagnostics from the CSU and BJB. **Figure 7** shows a typical BCU block diagram.
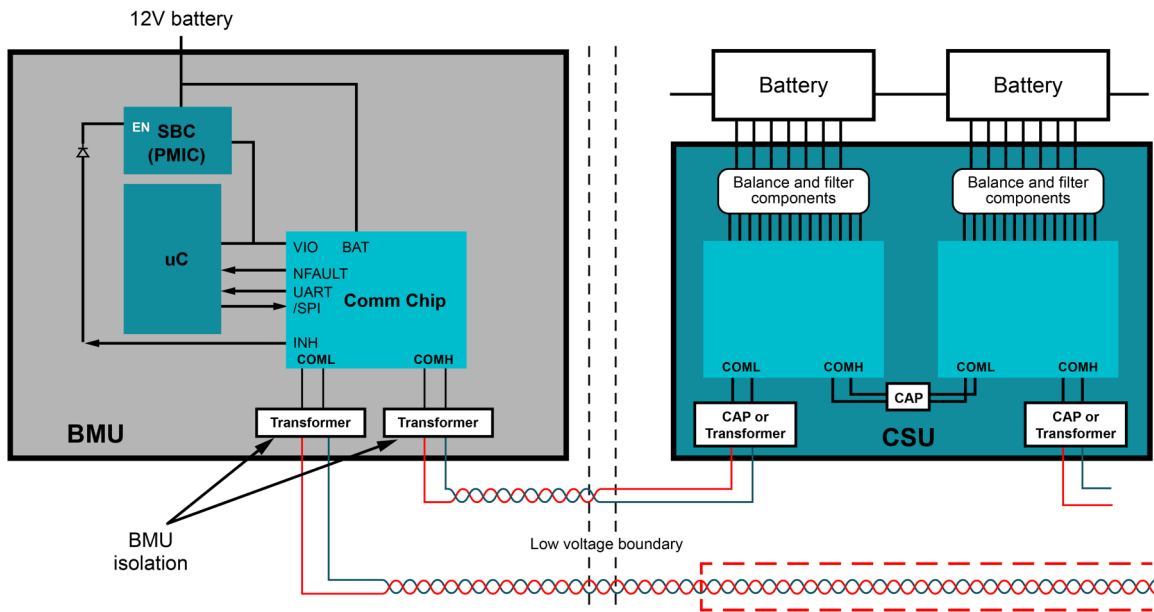
Figure 7. *Typical BCU block diagram.*

Creating a complete battery test environment ecosystem

In order to validate and test a BMS, automotive manufacturers use a hardware-in-the-loop (HiL) system, which creates a safe environment to test all functionality before connecting to real, potentially dangerous battery cells.

TI has worked with Comemso, whose battery cell simulator offers a mix of modules for BMS testing with scalable variants and different functions. The flexibility of this simulator has enabled TI to implement systems in different sizes to help meet design engineers' needs.

Conclusion

BMS architectures are continuously evolving as technical innovations are considered alongside commercial tradeoffs. New battery chemistries and new silicon devices combined with ever-increasing safety requirements create a divergent and dynamic design landscape. TI's goal is to enable the market to move nimbly in any design direction. Explore all of TI's **HEV/EV**

BMS design resources to help automakers maximize safety, reliability and drive range and advance the adoption of electric vehicles worldwide.

Additional resource

- Texas Instruments: *Wired vs. Wireless Communications in EV Battery Management*.

- Watch the webinar, **Battery Management Systems Seminar – Intelligent Battery Junction Box for Voltage and Current Synchronization**.

- Texas Instruments: *Functional Safety Considerations in Battery Management for Vehicle Electrification*.

- Read the technical article, **How to design an intelligent battery junction box for advanced EV battery management systems**.

TEXAS INSTRUMENTS

IMPORTANT NOTICE AND DISCLAIMER