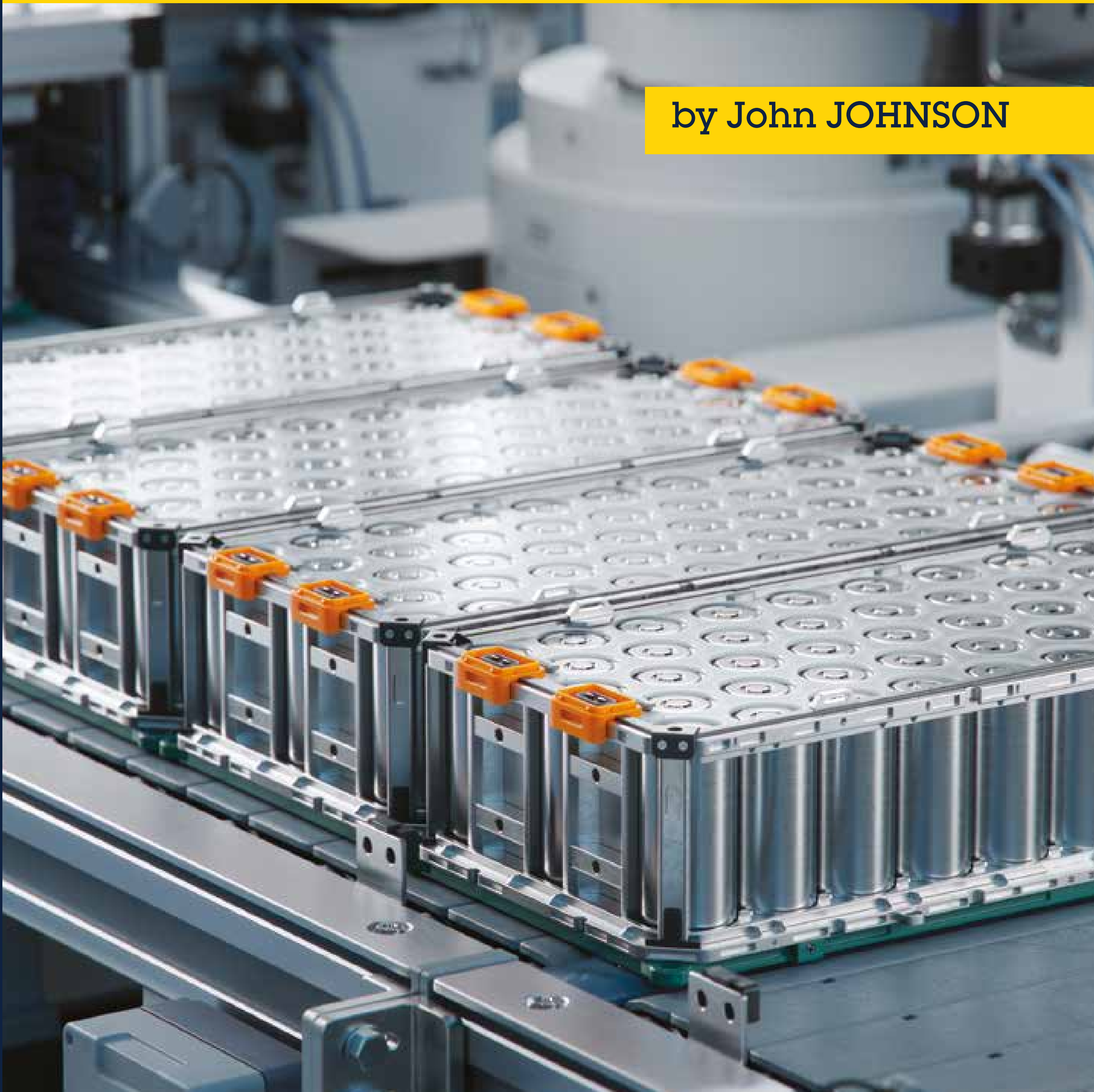
Battery Management Systems
A Key to e-Mobility Applications



by John JOHNSON

Battery management considerations in e-mobility applications

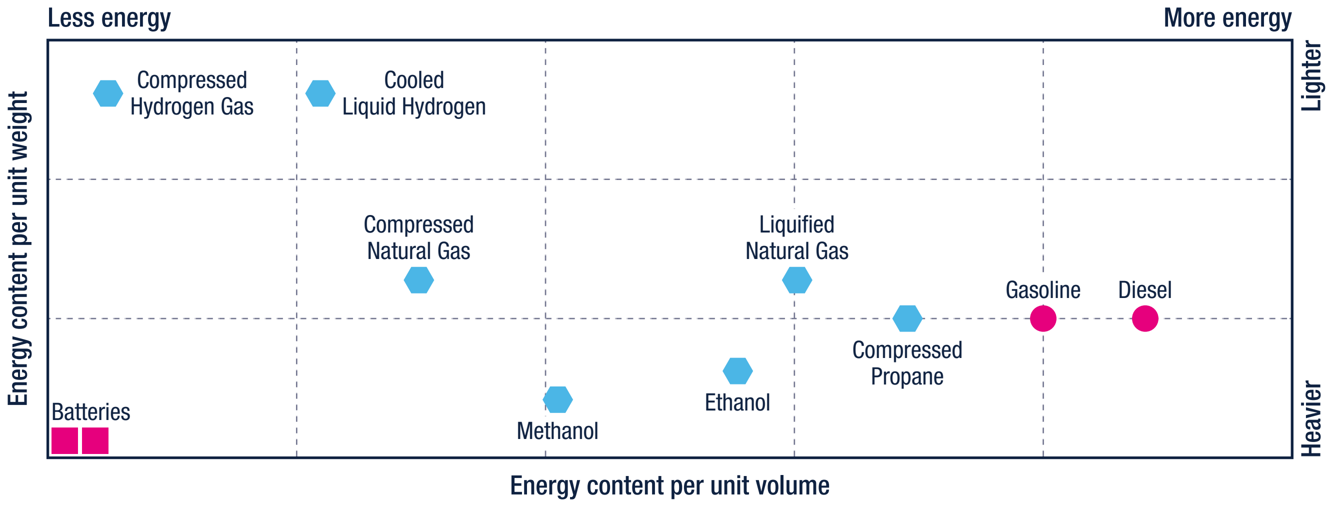
RANGE ANXIETY AND MARKET ACCEPTANCE

The tsunami of new products incorporating ‘electrification’ is not without controversy. Aside from economic and even political debate, there are a myriad of technical challenges that must be addressed. Many of the more prevalent and well publicized issues involve a series of compromises entailing technical, commercial, and even political aspects; and industry leaders, policy makers, and consumers are all participants in these debates to some extent. Even so, the consensus is that electrification must ultimately produce a positive impact on the environment and do so in such a way that is both sustainable and financially viable. Ultimately, few, if any of the perceived barriers and challenges associated with electrification (e-mobility in particular) are unsolvable; political, and monetary considerations notwithstanding.

According to an article published by Forbes[1], 79% of consumers who have not yet purchased an electric vehicle have been hesitant to do so due to so-called “range anxiety”. At the root of this phenomenon is that consumers have life-long experience using fossil fuels as energy storage for transportation. Fossil fuels are an amazing way to transport energy.

As Figure 1 illustrates, batteries are significantly heavier and require much more space to store energy than gasoline and diesel fuel. Not only do fossil fuels transport more energy, but the process of refilling the fuel tank is a matter of minutes (compared to hours to recharge a battery). In the past, drivers rarely pondered questions like, ‘can I get there?’ or ‘what do I do if I run out of gas?’ In the e-mobility world, these questions foster so called “range anxiety” among those contemplating an EV purchase.

Figure 1: Energy Storage Mechanisms



Note: 1. David Roberts, Forbes Technology Council, August 30, 2023

Range anxiety factors

The primary factors that influence electric vehicle range anxiety include:

- **Drivetrain efficiency** – the drivetrain is the primary user of energy in an EV, so it is no surprise that efficiency is a critical parameter. The introduction of wide bandgap technologies has addressed this aspect, with impressive results achieved.
- **Power distribution** – how power is routed throughout the vehicle is becoming an increasingly important design concern. As electronic systems continue to proliferate and require more power, a move from legacy power buses like 12 V to 48 V is gradually taking place.
- **Vehicle charging** – both on-board and external charging are important ingredients in the range anxiety stew. Quickly and safely restoring energy to the battery pack is driving vehicle designs toward elevated on-board charger (OBC) power ratings as well as moving to even higher battery pack voltage to accommodate high-voltage DC chargers by reducing the requirement to carry excessive amounts of electrical current from the charger to the car.
- **Battery pack** – obviously, the battery is the primary medium to store energy in an electric vehicle; however, it is also typically the most expensive sub-system comprising an electric vehicle's architecture. For this reason, designers are keenly focused on addressing certain key performance indicators (KPIs) ascribed to the battery pack. The balance of this article discusses these KPIs and how engineers can address them.

BATTERY PACK KEY PERFORMANCE INDICATORS

The battery pack should meet certain design targets including energy storage capacity and cost; however, additional factors help define how well a design performs its intended function. Some of these are listed in Table 1.

Table 1: Battery pack key performance indicators

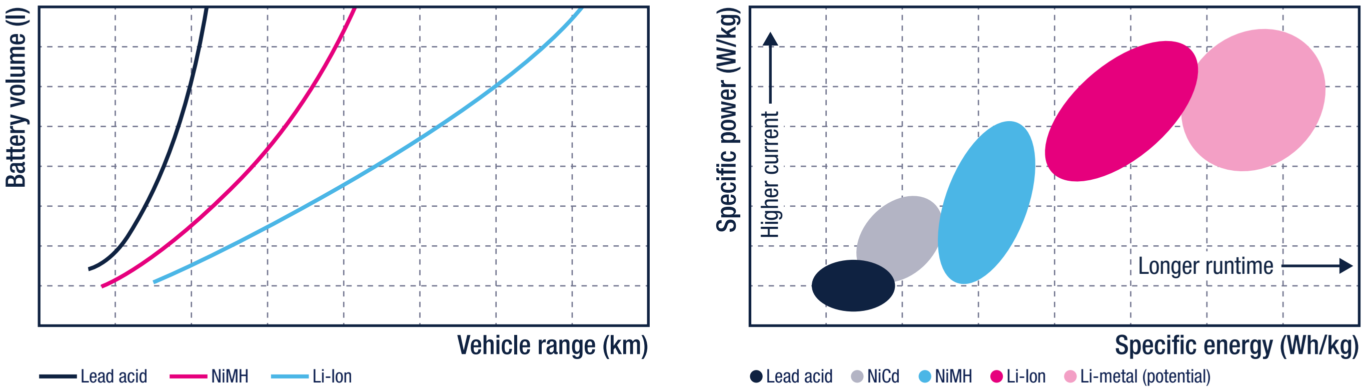
Factor	Unit	Significance	Range Anxiety
Energy capacity	W-h	Battery capacity	Yes
Energy density	W-h/l	Battery size	Yes
Specific power	W/kg	Battery weight	Yes
Charge time	Miles (capacity)/hour	Range anxiety	Yes
Service life	Cycles, years	Reliability	---
Safety	MTBF	Safety	---
Cost	$/kWh	Cost	---

Choosing targets for these factors often introduces interesting compromises and optimizations. For instance, expansion of battery pack capacity obviously increases vehicle range, but it also means that the pack will take longer to charge and add incremental cost. Furthermore, governmental agencies in Europe and the U.S. have published targets for many of these factors and have set expectations that performance should ideally improve over time. The choice of battery chemistry also plays a role. The battery pack is typically the most expensive vehicle system and is a key variable in the range anxiety equation. For these reasons, the 'care and feeding' of the battery pack and the type(s) of battery cells employed is fueling product development as well as advanced research and innovation.

BATTERY CELL CHEMISTRY

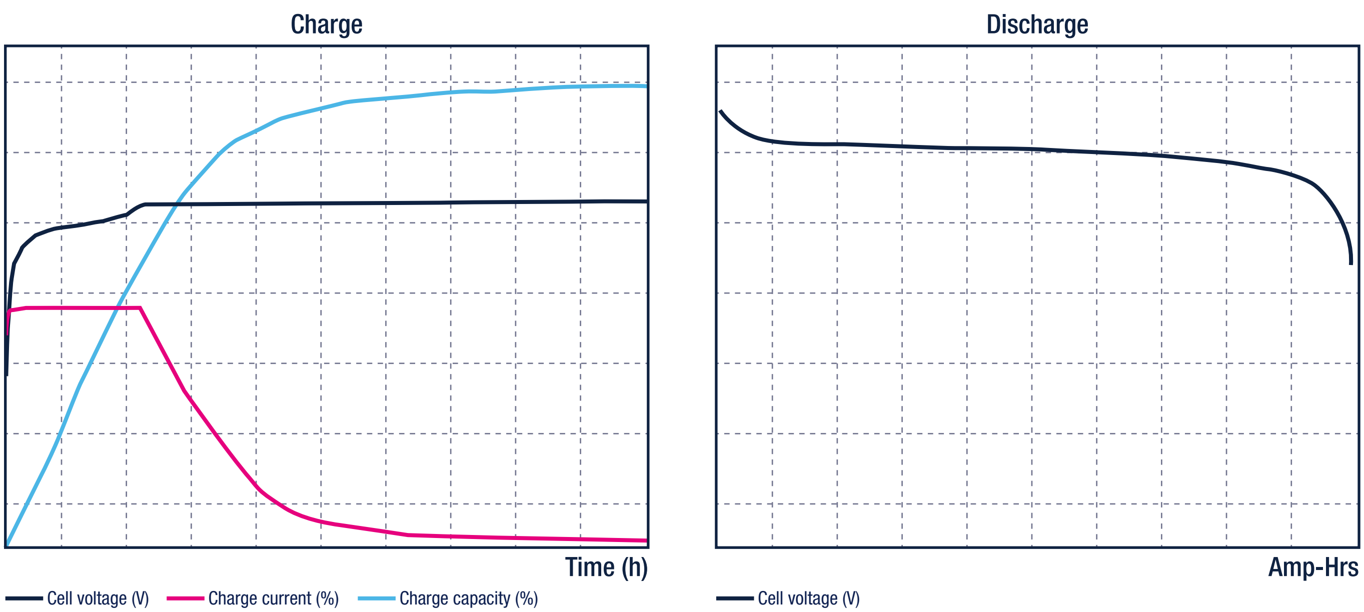
Electric vehicles convert energy that is stored in a battery pack into motion. The term 'secondary' battery refers to cells that are rechargeable. Figure 2 depicts several secondary battery chemistries. Given some of the KPIs listed in Table 1, it is clear that lithium-ion chemistry demonstrates specific qualities necessary to maximize vehicle range due to its performance characteristics, particularly the capacity to deliver high currents for a sustained period of time; therefore, it is not surprising that different variants of lithium-ion cells are incorporated in EV designs today.

Figure 2: Secondary battery chemistry comparison



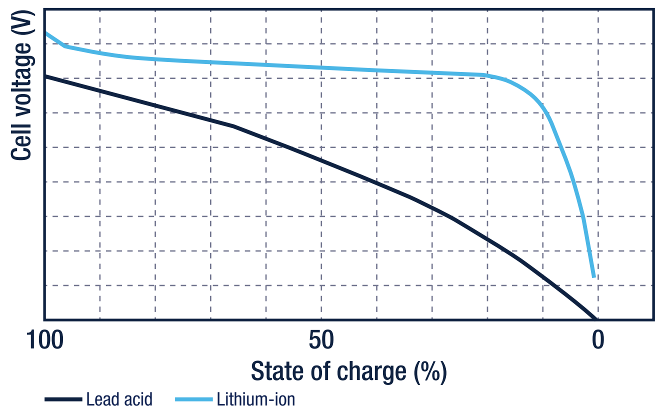
Lithium-ion cells demonstrate qualities that make it a good energy source, particularly the fact that cell voltage remains virtually constant over a wide envelope of state of charge as shown in Figure 3.

Figure 3: Lithium-ion charge and discharge characteristics



Contrast this behavior with a lead acid cell as illustrated in Figure 4. On the positive side of the ledger, reading the voltage of a lead-acid cell renders a clear indication of the state of charge; however, cell voltage quickly diminishes and the cell's ability to deliver power tails off accordingly. By contrast, the 'flatness' of the lithium-ion curve introduces some challenges. For instance, it is more difficult to ascertain the **state of charge** by measuring the cell voltage due to a lack of slope of the voltage curve over the operational envelope of the cell. State of charge (SOC) is perhaps the most important parameter that a **battery management system** (BMS) must estimate as it is essentially the fuel gauge for the vehicle. Moreover, continuous, and accurate SOC estimation plays a key role in ensuring the long-term reliability of the battery stack as well.

Figure 4: Lithium-ion vs. lead acid cell characteristics



A possible solution to estimating SOC on a lithium-ion cell by sampling the cell voltage is to employ a highly accurate measurement apparatus, and while it is usually more costly to deliver accurate voltage measurements (particularly in the presence of noise), incorporating higher degrees of resolution and filtering to the signal path does not solve the problem entirely. This is for two reasons:

1. Typically, cell voltage provides a reasonable indication of the state of charge **if the cell is unloaded and is allowed to be at rest (unloaded) for a significant period.** This is hardly a practical approach for a vehicle used for transportation.
2. As Figure 5 and Figure 6 clearly show, the curves associated with cell voltage vs. state of charge vary widely when the cells are exposed to changes in temperature and loading over a certain sampling window. While it is true that it is unlikely that temperature would change significantly, it is conceivable that the loading on the cell will change given the driving profiles of the vehicle.

Figure 5: Lithium-ion cell behavior vs temperature

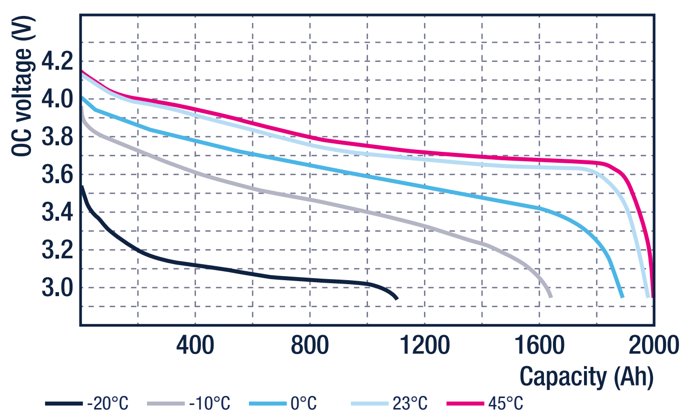
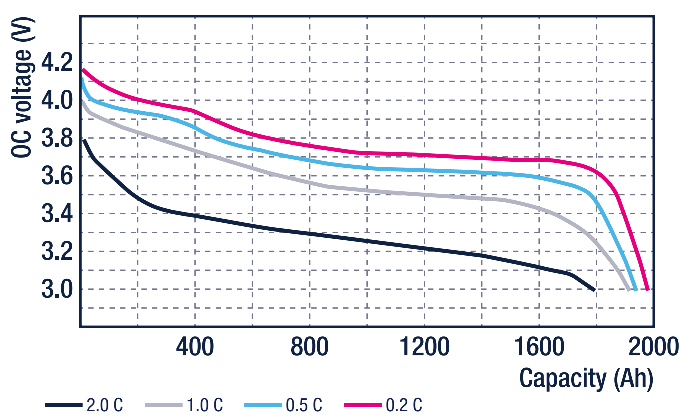
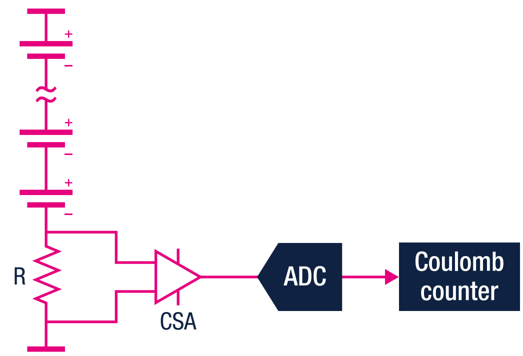


Figure 6: Lithium-ion cell behavior vs load (C-rate)



Another state of charge estimation method is to implement a coulomb counter. Coulombs are ampere-seconds (As). A coulomb counter accumulates ampere-seconds (As) flowing in and out of the battery pack. This could be implemented by inserting a shunt resistor in line with the battery pack and determining the current by measuring the voltage drop across the shunt (Figure 7). This circuit measures the current flow in and out of the entire stack (the SOC for individual cells comprising the stack cannot be measured using a coulomb counter). The equation shown is used to calculate SOC based on the coulomb counter. One important aspect to consider is that any gain or offset errors present in the signal path (including the CSA and the ADC) will have a cumulative effect on the error of the estimate. Therefore, these errors must have compensation, otherwise the estimate will become increasingly useless.

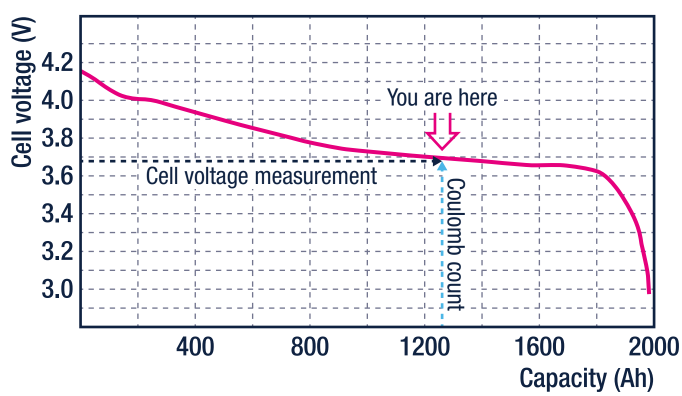
Figure 7: Battery stack coulomb counter



$$SOC = SOC(t0) + \frac{1}{C_{total}} \int_{t0}^{t0+\tau} (I_b - I_{loss})dt$$

Some implementations combine both measurements (i.e. measuring cell voltage and counting coulombs together) to estimate state of charge (Figure 8). Obviously, this approach does not overcome the limitations enumerated above.

Figure 8: Battery stack coulomb counting



BATTERY PACK CONFIGURATIONS

Figure 9 provides some definitions that are helpful to understand how an entire battery pack is constructed. A battery pack comprises several battery modules. A module is a grouping of cells connected in a particular way to deliver specific characteristics. Cells can be connected in series in a 'stack' and the voltage of the stack is the sum of the individual cell voltages. Cells are also sometimes connected in parallel to increase the amount of current that the parallel combination can deliver. A typical module incorporates a combination of both serial and parallel cells; and the modules are also combined to form the battery pack. Consider Figure 10 which depicts a battery pack for an electric vehicle that is in production today. It incorporates 16 modules connected in series. Each module comprises 444 cells connected in a 6S74P configuration (i.e. six sets of 74 parallel cells connected in series). This battery pack provides up to 90 kWh of capacity at 364.8 V and comprises 7,104 individual cells.

Figure 9: Battery cell configurations

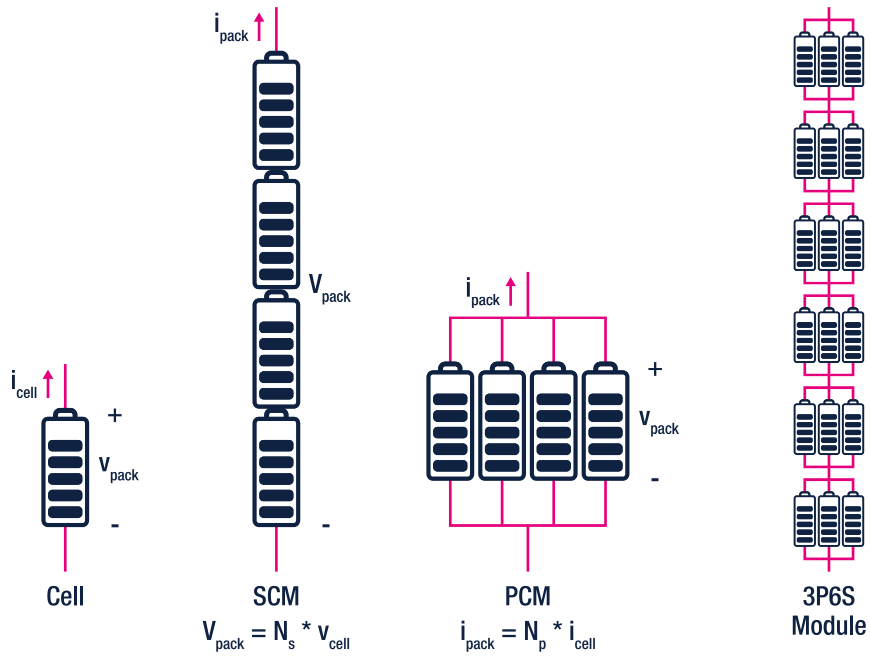
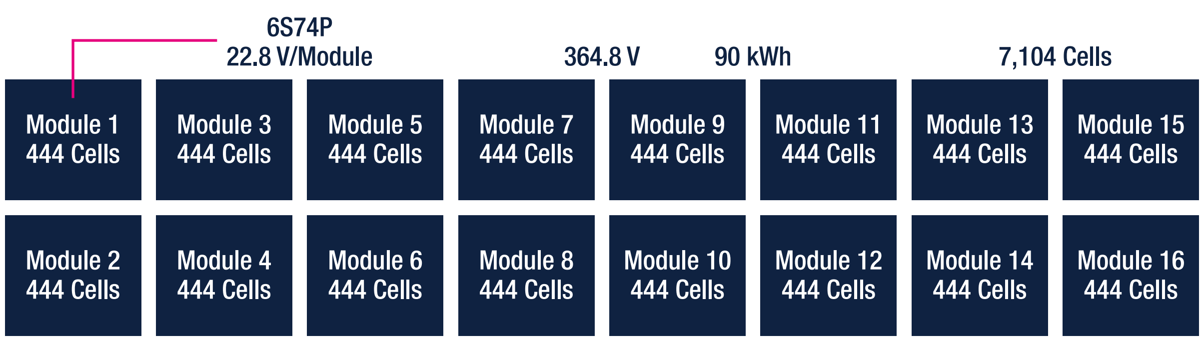


Figure 10: Electric vehicle battery pack configuration

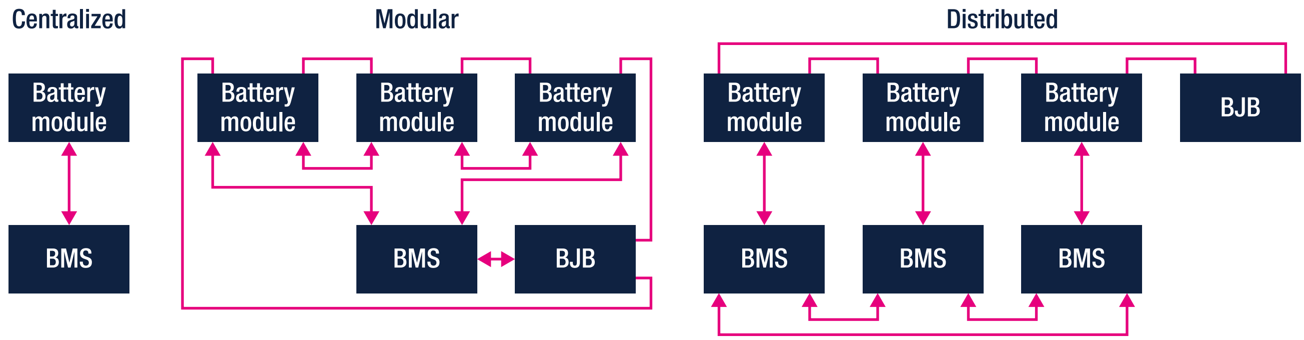


Consider the discussion regarding Figure 8 while also studying the configuration shown in Figure 10. If the BMS measures the voltage drop across a parallel combination of cells (in this case 74 cells), a measurement of **individual** cell voltages no longer applies as it is not possible to measure them directly. The implication is that for most production EV battery packs, accurately estimating SOC can be far more complex than a voltage measurement and coulomb counting. Even so, these parameters do play an important role in SOC estimation as will be discussed later.

BMS ARCHITECTURES

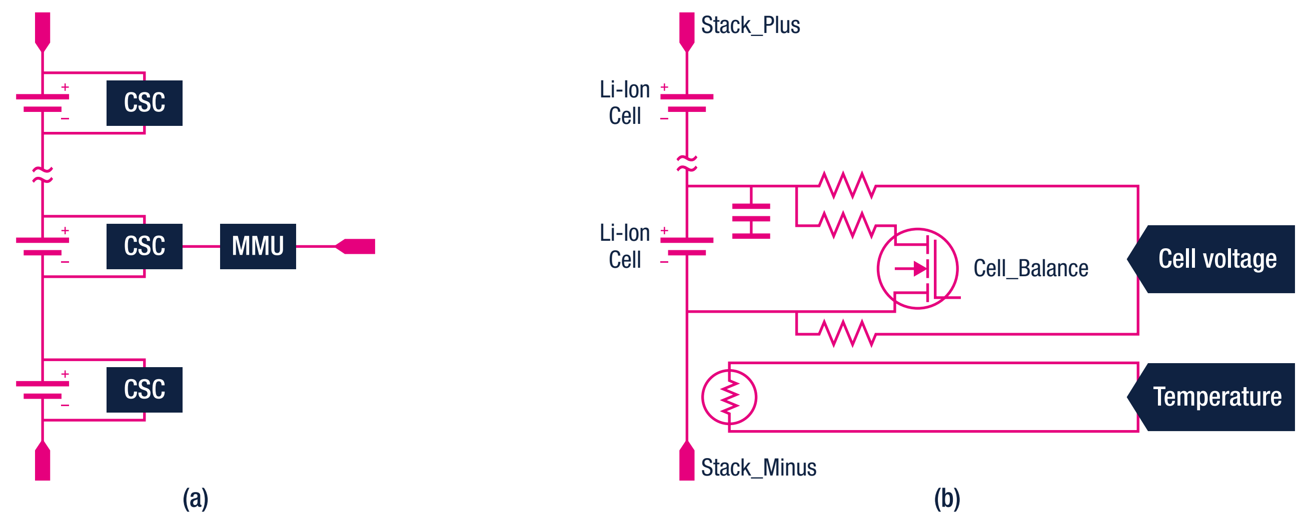
Figure 10 shows a high-level view of a battery pack for an electric vehicle. The battery pack comprises one or more battery modules, one or more battery management systems (BMS), and sometimes a junction box (BJB). Depending on the number of modules and the physical dimensions of the pack, one of three different architectures are often used in the design (Figure 11).

Figure 11: Battery pack architecture



The battery modules shown in Figure 11 could be broken down into elements as shown in Figure 12a. A module typically includes several Cell Supervisory Circuits (CSC) and a Module Management Unit (MMU). Figure 12b shows a breakdown of a CSC. It includes provisions to read the voltage of a cell(s). Sometimes, **cell balancing** circuitry is provided. Finally, there are typically a few temperature sensor inputs, although there are not the same number of temperature sensor inputs as there are cell voltage sensor inputs. A collection of several CSCs are connected to an MMU, and this comprises a battery module.

Figure 12: Battery module elements



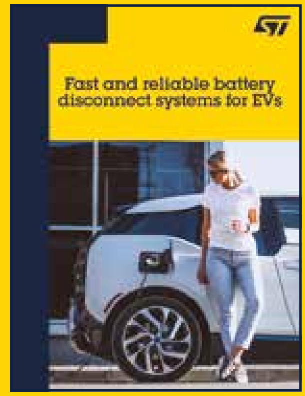
A centralized architecture is used for battery packs that have less capacity and are comparably smaller than other implementations. This approach is common for e-bikes, tools, mowers, and some hybrid vehicles. The modular architecture is the most common approach employed in EV designs. The communication between modules, the BMS, and the BJB could be either wired (usually isolated) or wireless. The distributed architecture is sometimes called a 'smart' battery architecture because each module has its own BMS.

BATTERY MANAGEMENT SYSTEM FUNCTIONS

The primary functions of a BMS include:

- **Accurate fuel gauging** – a continuous and accurate estimate of the state of charge (SOC) of the battery pack.
- Ensuring reliable operation and long **service life**. This entails estimating state of health (SOH), cell balancing/equalization, and charge management. Overcharging and over-discharging cells may result in damage and a loss of energy storage capacity.
- Battery pack **thermal management**. The battery must be protected from high temperatures. In addition, the battery pack should be heated in periods of extreme cold in preparation for battery charging. Lithium-ion cells do not readily accept a charge when exposed to cold temperatures.
- Battery pack **safety** – the BMS needs to detect faults and have mechanisms to protect occupants, service personnel, and first responders. For example, the battery must be disconnected from the vehicle if a crash is detected. The battery must also disconnect if a wiring fault is detected between the battery elements and the chassis of the vehicle. From a functional safety perspective, the battery pack (and associated BMS) should ideally comply with ASIL-D requirements.
- Vehicle **communication** – the BMS must communicate with other vehicle systems including the charging system and the vehicle control unit. For example, the BMS must provide SOH and SOC estimates for purposes of service and instrumentation. The power level and available energy in the pack must be reported to the vehicle control unit so that the VCU can control the vehicle traction system effectively and continuously report estimated remaining distance until charging is required. The BMS must also coordinate the charging process with either the OBC or an external charger by relaying information about the status of the stack.
- **Traceability** – new regulations have emerged that require that certain data related to the value chain associated with a specific battery including its manufacturing information, usage history, performance history, and chemical makeup to name a few. This is known in the industry as a **battery passport**. The objective is to support sustainability, reduce waste, and minimize disruptions in the value chain. This data must be stored in a secure, non-volatile medium.

Download our whitepaper to find out more about our battery disconnect and fire-off solutions.



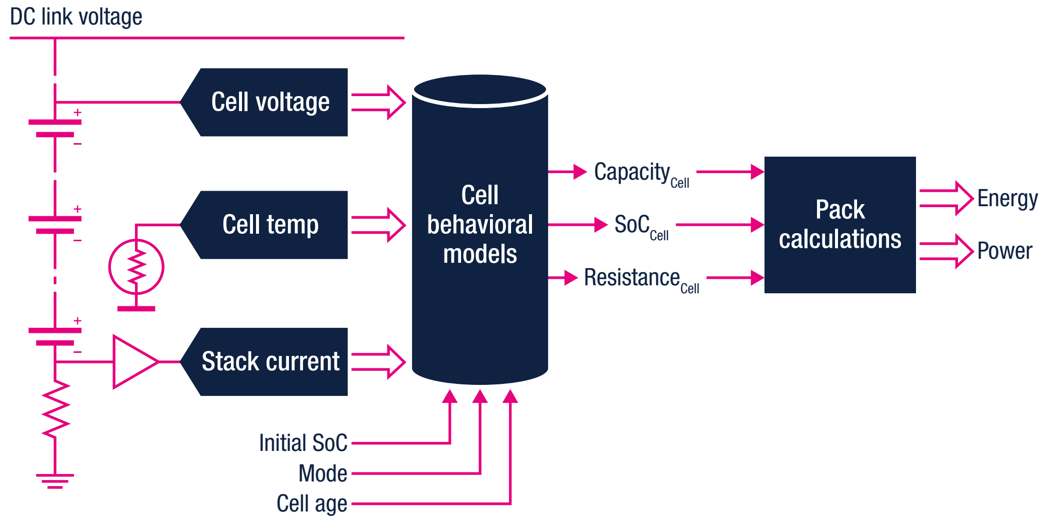
STATE OF CHARGE ESTIMATION – KEY INGREDIENTS

As already discussed, estimating state of charge (SOC) is perhaps the most important function a BMS provides; and depending on the needed accuracy and reliability of the estimate different approaches are implemented. SOC estimation techniques are subject to significant research, and dozens of papers are published each year addressing the topic. Low-cost approaches often employ cell voltage measurements. Coulomb counting, or a combination of the two to implement SOC estimation algorithms. SOC is defined as follows:

$$SOC_{CELL}\,(\%) = \frac{SOC_{est} - SOC_{0\%}}{SOC_{100\%} - SOC_{0\%}}$$

The driver needs to know how far the vehicle can travel which is derived from how much energy remains in the battery pack. Also, the vehicle needs to know how much power is available in the pack to meet demands to produce torque due driver input via the accelerator. There are no sensors available to measure SOC directly, however, there are ‘workarounds’ available. One such approach is to employ model-based estimation techniques. In this instance, a database of information about the cells employed is kept in the BMS. This includes the behaviors of the cells over temperature and at different loads and this is necessitated based on the family of curves shown in Figure 5 and Figure 6. Other aspects include usage history, the age of the cells (as well as the behavior of the cells as they age), etc. In model-based SOC estimation, certain measurements (cell voltage, cell temperature, and stack current) provide inputs to the algorithms that estimate the capacity of each cell to store charge, the SOC for each cell, and the impedance of each cell based on the behavioral models contained in the database. From these estimates, SOC, the available energy, and power in the stack are estimated based on calculations. Figure 13 illustrates this process.

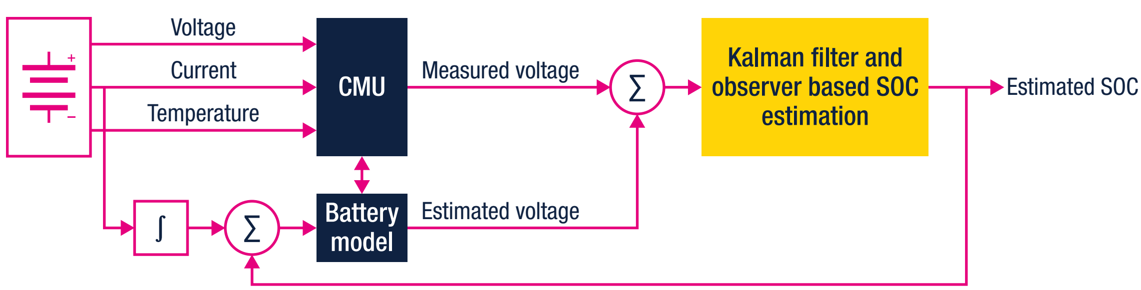
Figure 13: Model-based SOC estimation



For model-based SOC estimation to work properly, certain parameters must be measured accurately to provide inputs to the model so that it can render the values desired. These include cell voltage, cell temperature, and stack current as shown in Figure 13. It is imperative that these measurements that index the database of cell behavioral models be **aligned in time**. Why and what does this mean? Consider Figure 6, which pictures the behavior of a cell as the load on the cell changes. Also, consider the fact that the modules/BMS must sample voltages and temperatures of hundreds of cells. If the load changes during the **sampling window**, samples will be taken at different loads. The resultant SOC estimation is virtually useless. It is also apparent that this sampling must be coordinated across dozens of battery modules.

Figure 14 depicts an alternate model-based estimator that employs a Kalman filter/observer. As with the other model-based estimator shown in Figure 13, this implementation must be provided with time-aligned highly accurate samples of voltage and temperature across the cells throughout the entire stack that are synchronized with a measurement of the stack current. Fundamentally this approach combines estimates of an unknown value to improve future approximations. The compute throughput necessary to implement a **Kalman filter** is high; therefore, most implementations implement Kalman filters over a subset of the cells comprising the stack; and rely on each of the cells behaving very similarly given they are exposed to identical loads and temperatures.

Figure 14: Kalman filter-based SOC estimator



Why is state of charge important?

As discussed already, SOC represents the fuel gauge for the vehicle and as such is an important factor in addressing range anxiety. However, there are other aspects associated with SOC estimation that need to be understood. First, Figure 15 shows the effect that charging a cell to different voltage levels has on the number of charge/discharge cycles that a cell can encounter before it loses its capacity to store energy. As can be observed, the higher charge levels can have a negative impact on cell capacity if performed on an ongoing/continuous basis. This factors into warranty as well as battery pack reliability and service life.

Another aspect is shown in Figure 16. Some designs control the perceived capacity of the pack by managing how much of the capacity is used over the life of the vehicle/product. When a product is brand new, a subset of the actual capacity is employed to store energy. As the pack and the product is used over time, an increasingly larger amount of the capacity is utilized to store energy. Thus, while the actual capacity of the battery pack degrades over time, the range/operating time of the product remains constant. Accurate SOC estimation on a cell-by-cell basis is required to implement this method.

Figure 15: The effects of overcharging on capacity

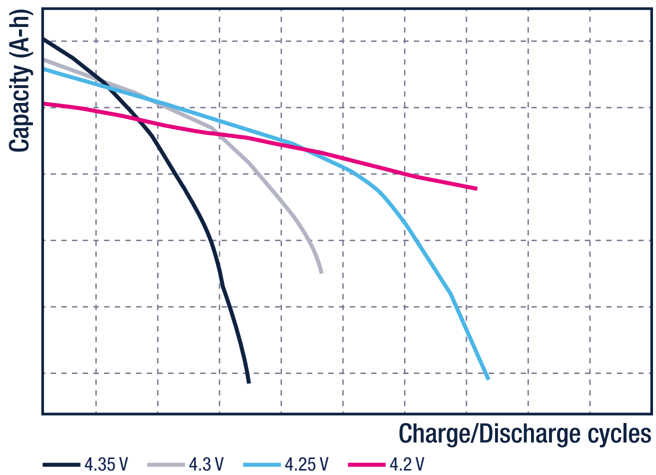
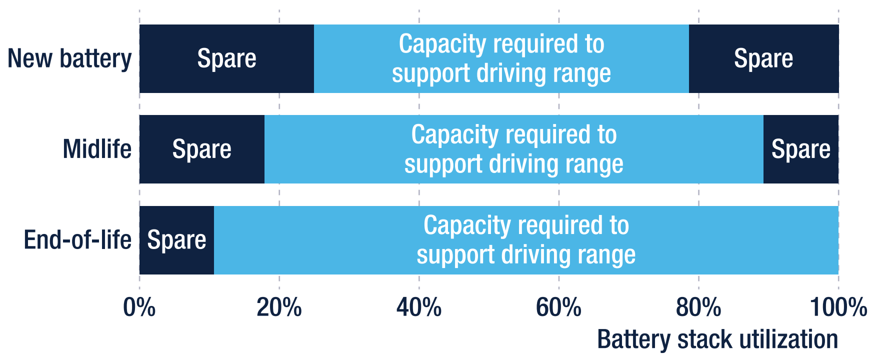


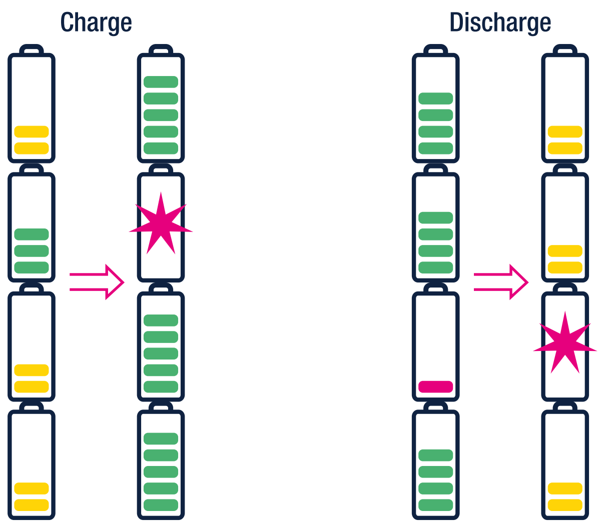
Figure 16: Battery capacity management in an EV



EQUALIZATION

Obviously, cells comprising the pack are usually connected in combinations of both parallel and series configurations. Consider Figure 17, which depicts a charge and a discharge scenario for a group of cells connected in series. In the charging instance, if one of the cells is at a significantly higher SOC than all the other cells, and the stack undergoes a charging operation, then that individual cell could be overcharged and its capacity to store energy will be degraded. The converse of this scenario for the discharge example is also pictured in the figure. The process of levelling the SOC of the cells is called cell balancing or cell equalization. This requires that the BMS have accurate estimates of SOC of the cells and that a mechanism exists to remedy the unbalanced stack.

Figure 17: Cell equalization scenarios



ESTIMATING AND MAINTAINING STATE OF HEALTH

There is no universally agreed upon definition of battery state of health (SOH). Basically, certain cell parameters are estimated, recorded, and tracked. Even so, cell total capacity and series resistance are key parameters that give the best indication of the ability of the pack to store and deliver energy. The BMS records these estimates as well as considering how these parameters change over time. Since these parameters are estimated in the process of calculating pack energy and instantaneous power available (Figure 13), SOH estimates represent incremental calculations and data recording. Essentially, SOH is an indicator of the capacity a cell to store charge compared to the cell's rating:

$$\text{SOH (\%)} = \frac{Q_{max}}{Q_{rated}} * 100\%$$

Figure 18 shows an enhanced self-correcting equivalent-circuit model of a single cell. The model includes a dependent voltage source, a non-linear hysteresis element and some resistors and a capacitor. The source represents the open circuit voltage and is dependent on the state-of-charge of the cell. R0 represents the Ohmic resistance of the cell while the resistor/capacitor model the cell model's diffusion voltages. These parameters depend on both SOC as well as cell temperature. The hysteresis element is dependent on the SOC of the cell as well.

As the cell ages, the capacity of the cell to store energy is diminished as the equivalent series resistance (ESR) increases (Figure 19). This not only reduces the range per charge of the pack (cell) but also dramatically degrades thermal performance as ESR degrades (increases) over time. An estimate of ESR could be used to estimate SOH. **Electrochemical Impedance Spectroscopy** (EIS) is one method to measure cell impedance, and thus SOH can be estimated. This method is somewhat impractical in all but the laboratory. Other methods of measuring cell impedance directly by modulating a higher frequency signal onto the stack and taking subsequent measurements is also a cell impedance measurement method being explored.

With respect to cell impedance, an additional issue is the fact that cell overheating significantly reduces battery life; and as the battery ages, the cell expels more thermal energy due to higher intrinsic resistances. In the extreme case, a battery pack can undergo a **thermal meltdown**. In this case, the polymer separator is compromised, and the anode and cathode are no longer isolated. This results in an exothermic reaction that degrades the separators in adjacent cells. Thus, a chain reaction starts, and a thermal meltdown will occur. It is imperative that the BMS incorporate thermal sensing, thermal management, and safety mechanisms to mitigate the hazards associated with this phenomenon as well as other catastrophic events.

Figure 18: Battery cell behavioral model

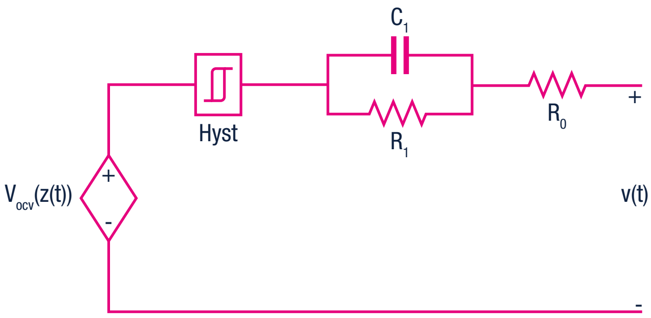
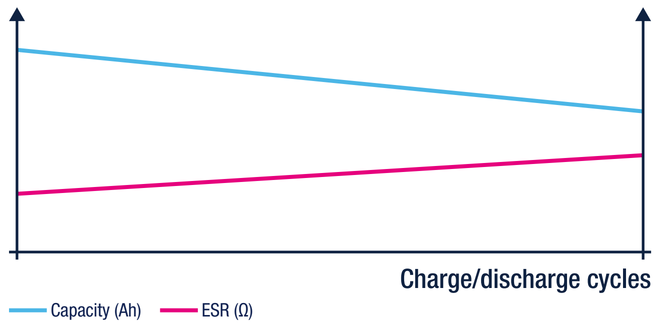


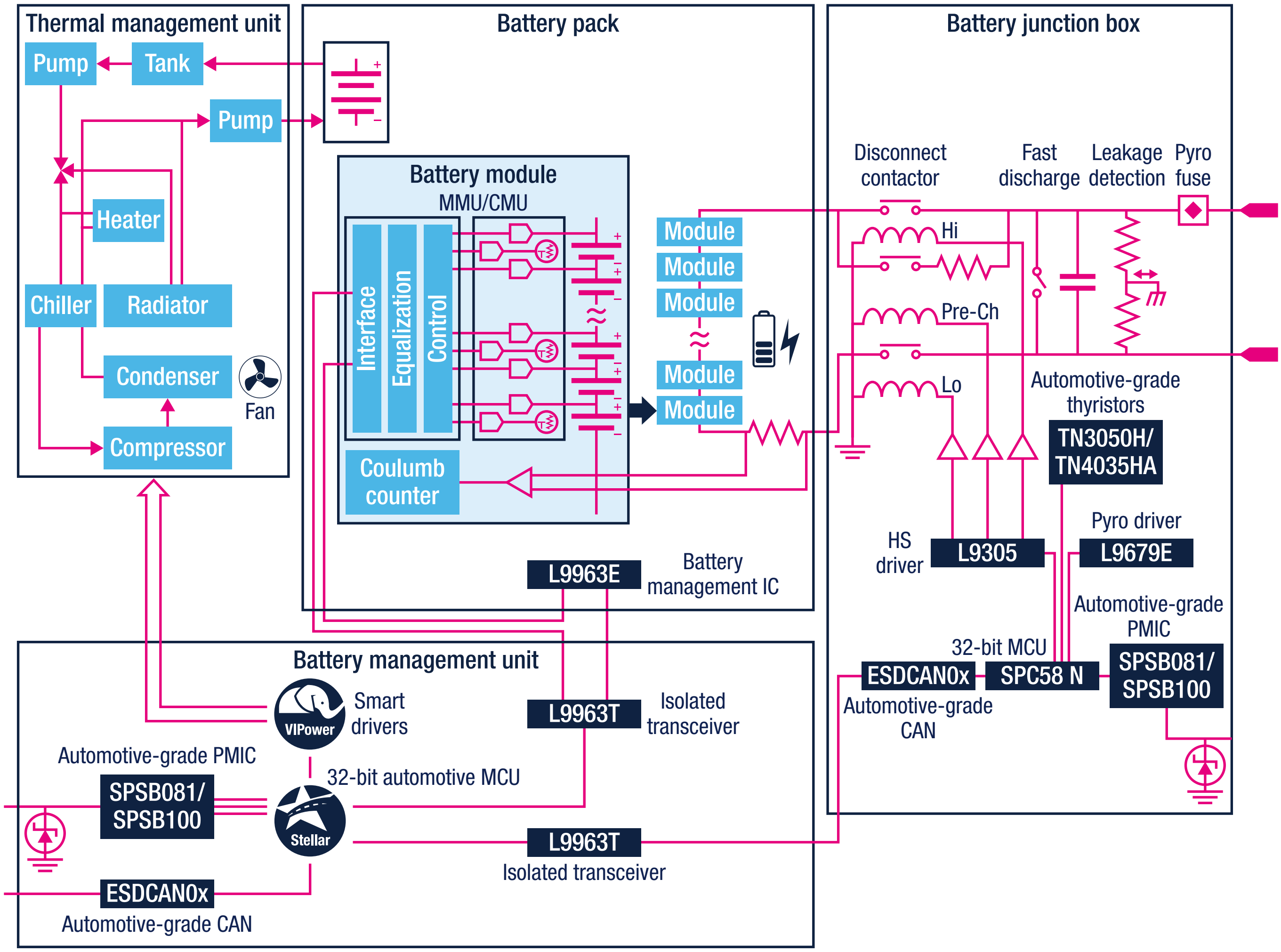
Figure 19: Battery cell degradation over charge/discharge cycles



BMS SUBSYSTEMS

The previous sections discussed factors associated with battery management without much analysis covering implementation. The purpose was to establish groundwork regarding what the BMS must perform and the underlying reasons why it must operate in a certain way. The balance of this paper will focus on how the system could be implemented with a focus on functional and system partitioning, and specific component details. Figure 20 shows some of the systems that comprise the entire battery management system including some of the products tailored for BMS offered by STMicroelectronics. Subsystems include the battery management unit (BMU), the battery pack (comprising one or more battery modules), a battery junction box (BJB), and sometimes a thermal management unit.

Figure 20: BMS sub-systems



Thermal management unit

A thermal management unit is often included in vehicles that employ larger battery packs and it is usually incorporated in luxury vehicles. A thermal management unit can provide pre-heating of the pack to facilitate charging in cold climates and battery pack cooling when appropriate. As depicted in Figure 20, the thermal management unit can be a complex system that often warrants its own dedicated control independent of the BMU.

Battery junction box

The battery junction box provides several BMS functions:

- Measure stack current for purposes of safety and instrumentation.
- Provide and control contactors/switches that connect/disconnect the battery pack from the vehicle. This includes a mechanism to pre-charge and discharge the DC link capacitor.
- Implement an emergency disconnect fuse using a pyro-based disconnect with an associated driver. This device is activated in the event of a vehicle collision and its operation is like an airbag system.
- Incorporate leakage detection circuits that are used to sense wiring faults between the high voltage cables/busses and other vehicle systems (including the chassis).
- Communicate with BMU and other vehicle systems.

Battery management unit

Computationally intensive tasks (e.g. SOC and SOH estimation) take place within the BMU. The BMU serves as an information collection hub where all sensor data is collected and processed; therefore, it also serves as a communication hub. Communication between the BMU and the battery pack is accomplished via an isolated wired communications link or through a wireless implementation. For wired communication with the battery pack/modules, a special isolated transceiver is usually needed. For communications with other vehicle systems, CAN (controller area network) is the interface of choice. A significant amount of non-volatile memory must be present to save information for behavioral models of the cells as well as the history of each cell in the stack. Other data must be saved, including that which is associated with battery passport functionality. The processor must comply with ASIL-D requirements and must also have intrinsic security features, especially if battery passport features are needed.

Battery pack

The battery pack (battery modules) is where all cell voltages and temperatures are sampled; and these values must be sent back to the BMU for processing. Devices that are dedicated to battery management have been developed to implement this functionality. For electric vehicles, battery pack management ICs must typically be ASIL-D compliant; however, other e-mobility applications (e.g. e-bikes, scooters, etc.) may have less stringent functional safety requirements.

BMS solutions from STMicroelectronics

Table 2 lists some of the products offered by STMicroelectronics to support BMS system design. Some of these offerings are highlighted in Figure 20. Products must typically be automotive grade and support functional safety requirements up to ASIL-D. Many line items tabulated here were specially designed for BMS applications (the L9963x products in particular).

Table 2: Recommended ST components for BMS

Part Number	Description	BMS System	Quantity/System
L9963E	Battery management IC for automotive/high-capacity battery packs	Battery pack, BJB	1 per each series of 14 connected cells
L9963T	Isolated transceiver	BMU	One for single-ended topology or two for dual access ring topology
Stellar MCUs	Arm®-based 32-bit automotive microcontrollers	Module, BMS, BJB*	Varies depending on architecture
SPC58 MCUs	Power Architecture-based 32-bit automotive microcontrollers	Module, BMS, BJB*	Varies depending on architecture
SPSB081 **SPSB100**	Automotive-grade power management IC	All	As required
L9396 **L4995** **L99PM62**	Power supply/SBC	All	As required
L9305	High-side driver	BJB	1
TSC21x	Current sense amplifier	BJB	1
TN3050H-12V	Thyristor, 1200 V, 30 A	BJB	3
TN4035HA-8GY	Thyristor, 800 V, 40 A	BJB	As required
L9679E	Squib driver/pyrofuse driver	BJB	1
ESDCAN01/03/05	Transient protection – CAN	All	As required
L9907 **L9908**	3-phase BLDC FET pre-driver	Thermal management unit	1 per fan/pump
STripFET Power MOSFETs	N-channel MOSFET	Thermal management unit	6 per fan/pump

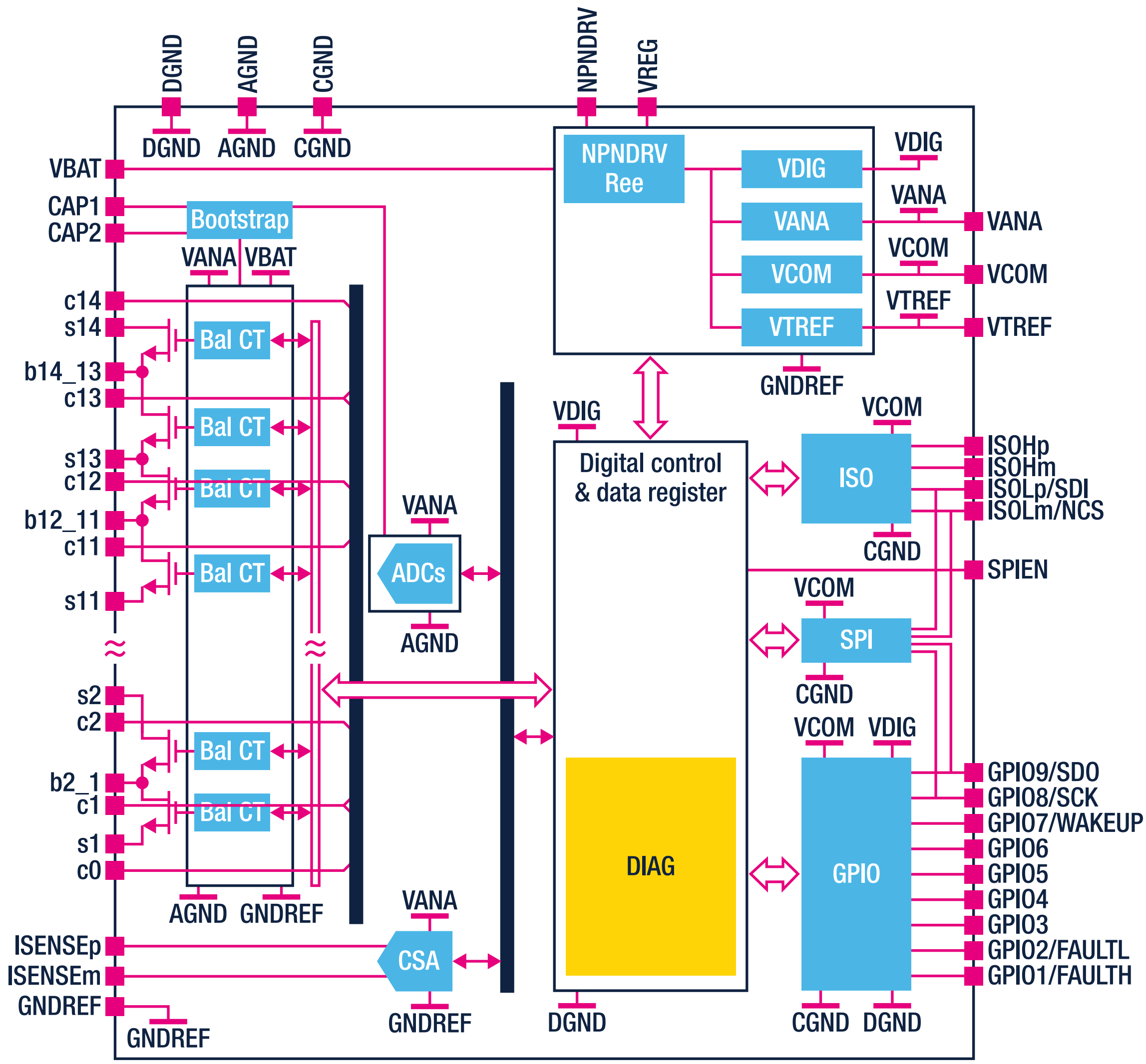
Note: * processor family applicability is dependent on battery system architecture

Product spotlight: L9963E

The L9963E is a Li-ion battery monitoring and protecting chip for high-reliability automotive applications and energy storage systems. Up to 14 stacked battery cells can be monitored to meet the requirements of 48 V and higher voltage systems. Each cell voltage is measured with high accuracy (±2 mV), as well as the current for the on-chip coulomb counting. The device can monitor up to seven negative-temperature-coefficient (NTC) thermistors. The information is transmitted through SPI communication or an isolated interface. Multiple L9963E can be connected in a daisy chain and communicate with one host processor via the transformer isolated interfaces, featuring high-speed, low EMI, long distance, and reliable data transmission. The interface facilitates time-aligned sampling throughout the entire stack (within an 8 ms window). Passive balancing with programmable channel selection is offered in both normal and low-power mode (silent balance). The balancing can be terminated automatically based on internal timer interrupt. Nine GPIOs are integrated for external monitoring and control. The L9963E features a comprehensive set of fault detection and notification functions to meet the safety standard requirements.

To help developers, a ready-to-use solution is available based on boards that allow to simulate an **Automotive Battery Management System (BMS)** solution setup (hardware and software).

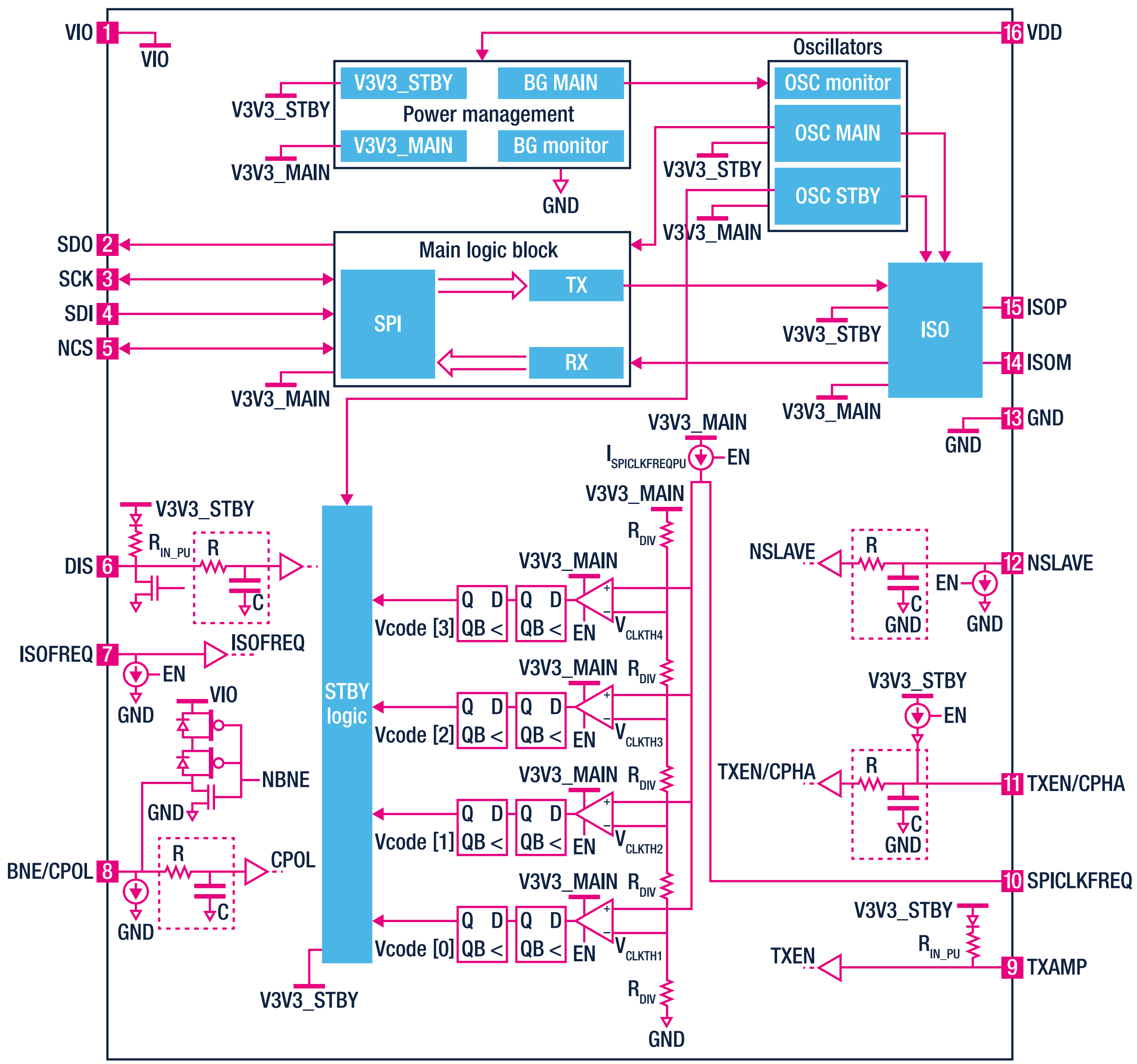
L9963E block diagram



Product spotlight: L9963T

The **L9963T** is a general-purpose SPI to isolated SPI transceiver intended to create a communication bridge between devices located in different voltage domains. The L9963T can transfer communication data incoming from a classical 4-wire based SPI interface to a 2-wire isolated interface (and vice versa). The transceiver supports both transformer and capacitive isolation, since the isolated signal generated according to a proprietary protocol is suitable to be transmitted over both decoupling circuitries. The device can be configured either as Peripheral or as Controller of the SPI bus and supports any protocol made of SPI frames 8 to 64 bits long. The transceiver manages the transfer of the information without performing any protocol check. The SPI peripheral can work up to 10 MHz when configured as Peripheral. The SPI clock frequency can be programmed among (250 kHz; 1 MHz; 4 MHz; 8 MHz) when configured as Controller. The isolated SPI peripheral features two different operating modes: slow @333 kbps and fast @2.66 Mbps. The asynchronous nature between the two sides is internally managed, allowing all possible configuration frequencies on both peripherals to be used in application. The L9963T features an internal queue of 3 slots for the frames received on the SPI port and a queue of 20 slots for the ones received on the isolated SPI side. This allows buffering and decoupling the two different clock domains. The device is natively compatible with the L9963 isolated SPI, allowing its usage in BMS applications. The L9963T is compatible with both 3.3 V and 5 V logic.

L9963T block diagram



BMS SOLUTION EVALUATION/DEVELOPMENT TOOLS

AutoDevKit Introduction

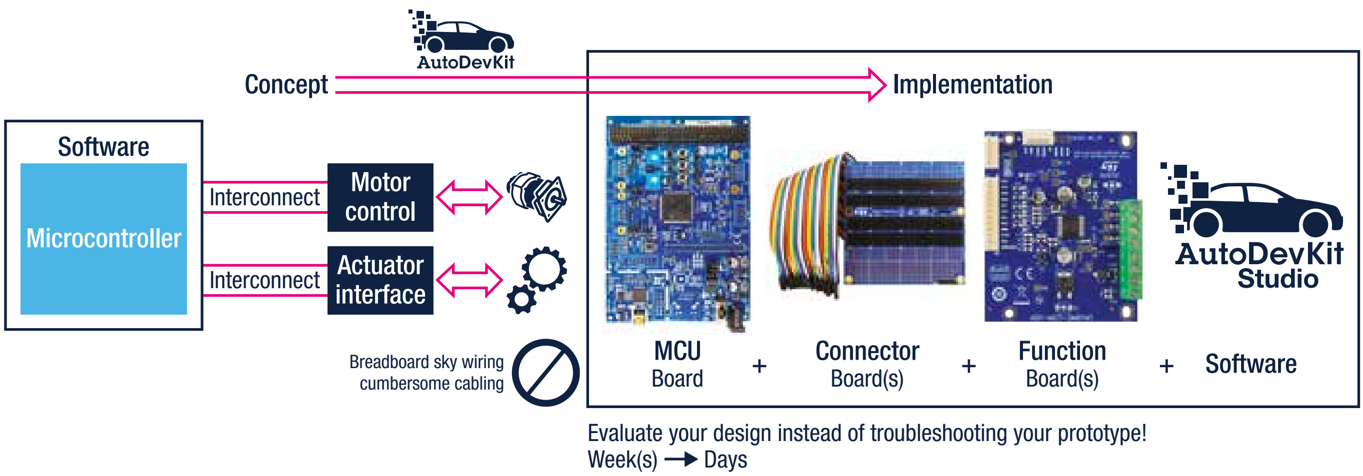
AutoDevKit™ is the shortened term for Automotive Development Kit.

This ecosystem addresses Automotive as well as Transportation and Mobile Robotics markets.

It offers expert and junior engineers the best and easiest way for rapid evaluation and prototyping using a common, integrated, unique, and flexible environment that supports complete ECU development, leveraging on the widest ST automotive-grade product portfolio.

To learn more about **AutoDevKit ecosystem** visit our website.

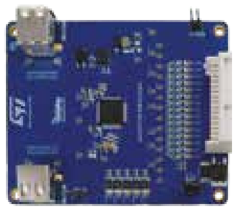
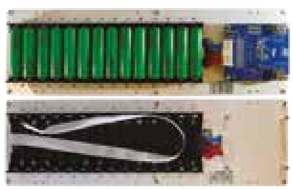
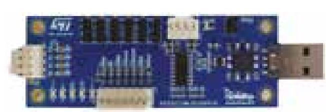
Figure 21: AutoDevKit™ Concept



BMS Evaluation using the AutoDevKit ecosystem

A platform and environment for BMS evaluation and development based on the L9963E is available and is now part of the **AutoDevKit™ ecosystem**.

Table 3: AutoDevKit ecosystem for BMS evaluation

 **AEK-POW-BMS63EN**	Based on the L9963E, this board monitors cells and battery node status through stack voltage measurement, cell voltage measurement, temperature measurement, and coulomb counting. It provides a full-function monitoring network to sense the voltage, current, and temperature of up to 31 Li-ion battery nodes. Each battery node manages from 4 to 14 battery cells, for a voltage range between 48 V and 800 V.
 **AEK-POW-BMSHOLD**	This practical battery holder kit can contain up to 14 cells connected in series and includes a dedicated connector for the L9963E BMS module (AEK-POW-BMS63EN). You can stack up to three or four holder kits together and easily estimate SoC and SoH values using an extended Kalman filter and AutoDevKit Studio. Developers can quickly create a battery pack to evaluate BMS solutions based on the L9963E analog front-end node (AEK-POW-BMS63EN) and the SPI to isolated SPI dongle (AEK-COM-ISOSPI1) built around the L9963T transceiver.
 **AEK-COM-ISOSPI1**	Based on the L9963T transceiver, this dongle converts SPI signals into isolated SPI signals, reducing the number of required wires from 4 to 2. Used to create a communication bridge between the MCU and the BMS chain belonging to different voltage domains, it also ensures higher noise immunity and robustness for long-distance communications.
 **AEK-MCU-C4MLIT1**	This SPC58 C-line discovery board with CAN transceivers can be used as cell monitoring controller (CMC) when prototyping BMS modules. Designed for applications requiring automotive safety and security levels, it is compliant with the EVITA Medium standard thanks to the Hardware Secure Module (HSM) embedded in the SPC58 MCU.

Our **automotive battery management system (BMS) solution page** provides developers with a complete description of our recommended solution and the necessary hardware tools and software resources based on our AutoDevKit Studio development environment to quickly create prototypes and evaluate your designs.

SUMMARY

Electric Vehicle systems are a key area of investment for STMicroelectronics; and our product portfolio and roadmaps reflect this level of commitment. EV system designers can take advantage of ST's broad technology portfolio including semiconductor processes, packaging technologies, and design/systems know-how. So much of an EV design encompasses power conversion, so power semiconductors (including wide bandgap technologies) are key to efficiency and power density. Furthermore, most EV systems have stringent functional safety requirements; and ST offers a comprehensive portfolio of automotive-grade products that are ASIL compliant. The BMS has its own unique challenges including the need for HV isolation, the ability to accurately take time-aligned measurements of certain parameters that are dispersed throughout the system, and the ability to store and process large amounts of data.

ADDITIONAL RESOURCES

L9963E Li-ion battery monitoring and protecting chip [Product page]

L9963T general-purpose SPI to isolated SPI transceiver [Product page]

Automotive battery management system (BMS) [Solution page]

AutDevKit battery management system module (AEK-POW-BMS63EN) based on L9963E [Evaluation board]

Battery holder (AEK-POW-BMSHOLD) for cylindrical batteries and battery management system node for automotive applications [Evaluation page]

Overcoming design challenges for battery management systems [On-demand webinar]

L9963: Battery management - monitoring and protection - for automotive and energy storage systems [YouTube video] [YouTube video]

L9963E: 5 things to watch out for in a battery management solution [Blog post]

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