Understanding and overcoming the challenges of building high voltage automotive battery management systems

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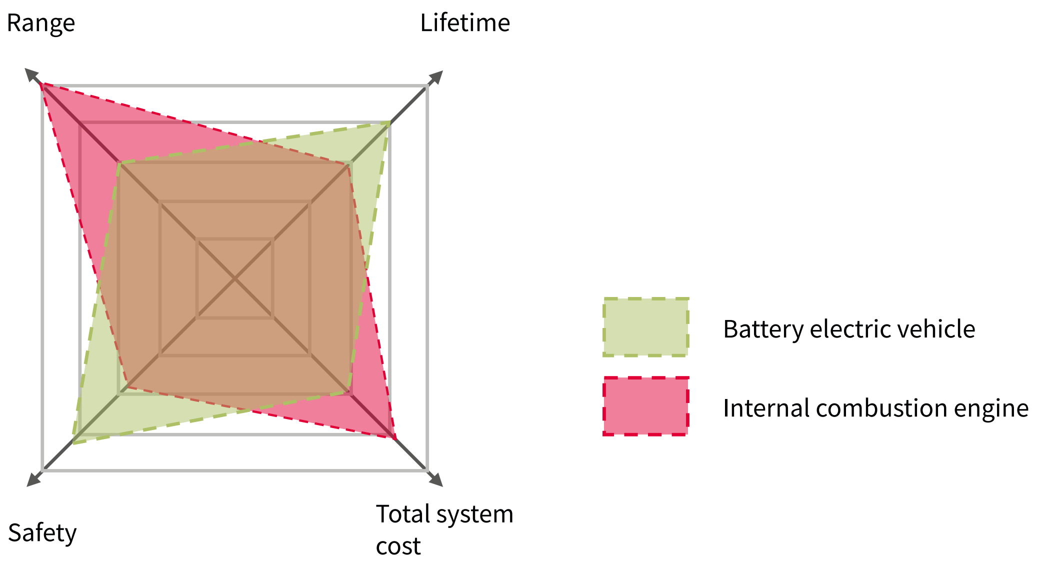
Introduction

In this paper we will discuss challenges associated with developing an automotive battery management system (BMS). We will start with a general introduction to Li-ion batteries, why they are the best choice for automotive applications, and why they need management. We then introduce BMS and their usage in high voltage automotive uses. Lastly, we will present Infineon's products and system approach towards offering a best-in-class BMS by addressing the four key criteria:

- Performance: reflecting the driving range per battery charge
- Battery lifetime: reflecting the battery yearly depreciation
- Safety: protecting the battery from critical events, that might risk the safety of the passengers
- Total system cost: reflecting the initial cost of the hybrid or electric vehicle

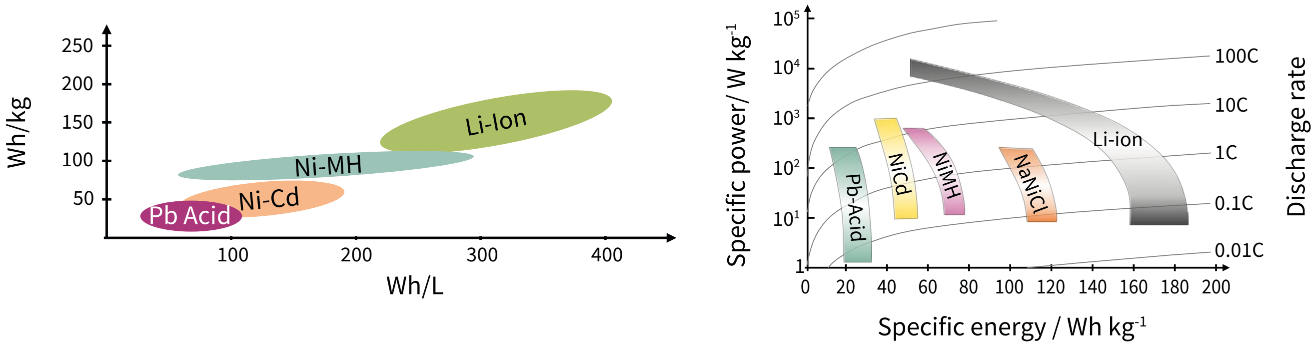
The diagram below shows how these criteria can be compared between a battery electric vehicle (BEV) and an internal combustion engine.



In this paper, we show what are key metrics to consider when building a BMS solution. We also show how small variations in the BMS solution can lead to dramatic improvements, enabling vendors to maximize the performance of the battery over its lifetime, while improving safety and minimizing cost.

What are lithium-ion batteries and why are they important?

The growth in electric mobility has been driven by multiple factors, but one of the most important has been the substantial advancement in the battery technologies.

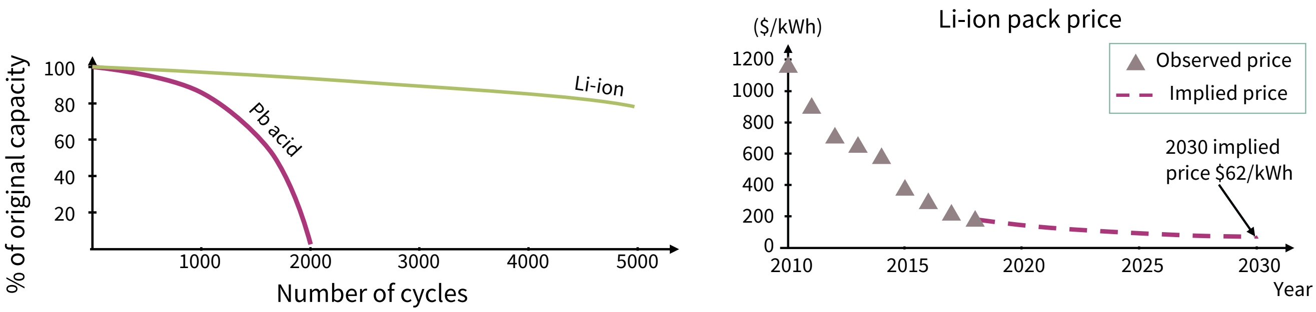


a) [1]

b) [2]

Figure 1 showing the gravimetric & volumetric specific energies of the different cell chemistries.

Figure 1 shows the first drastic achievement of Li-ion battery cells, by beating other forms of battery chemistries in volumetric and specific energy.



a)

b) [3]

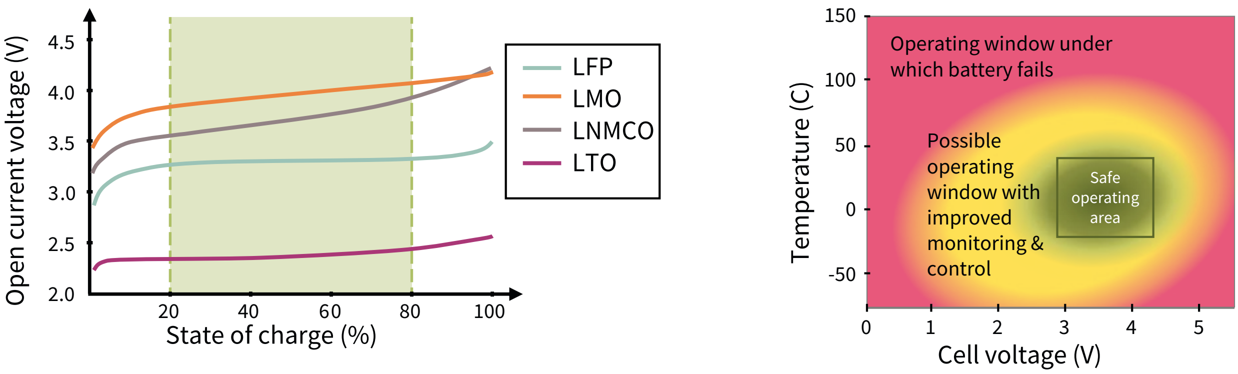
Figure 2. showing (a) the longevity of Li-ion chemistry compared to classical chemistries such as Pb-acid and (b) the cost reduction of the Li-ion chemistry.

Figure 2 shows the second drastic advancement of Li-ion battery cells cost and lifetime. All this has made Li-ion the preferred chemistry for automotive battery cells.

To put this in perspective, in 2019 the average range of a BEV was 336 km [4]. With Li-ion cells packing up to 4000 charging cycles per lifetime, a well-managed car battery could exceed a million kilometers lifetime range.

However, despite all this impressive advancement, the lithium-ion batteries are still the most expensive component in a car. In 2019 the average capacity of a BEV battery pack was 42 kWh [5] and the average cost of a battery cell was just under $150/kWh [6]. This makes the cell cost of an average pack in the range of $6,300. Knowing that the cells make on average 70% of the pack price [7], an average battery pack in 2019 cost just under $9,000.

This all means that utilizing a battery pack to its maximum is essential. This is of particular importance, since Li-ion chemistry is a complex chemistry that requires management. Incorrect management of the cells can not only reduce the efficiency, lifetime and performance of the battery but also lead to catastrophic events such as thermal runaway.



a) [8]

b)

Figure 3 showing (a) the state of charge characteristics and (b) the operating window of a Li-ion battery cell.

Figure 3 shows some of the complexities associated with lithium-ion chemistries. Figure 3a shows the flat characteristic of the state of charge (SoC) curve. This means that small measuring errors in cell voltage can lead to inaccurate estimates of the cell state of charge. Figure 3b shows that a Li-ion cell must never be operated beyond the safe operating zone (the region in green). However, if the cell is properly managed, it is possible to extend the operational zone (the yellow region), thus utilizing a battery cell to its maximum potential.

Introduction to battery management systems

To address the challenges mentioned in the previous chapter, a battery management system (BMS) is used. As the name implies, a BMS is a system that monitors and regulates the charging and discharging of the battery, making the battery more intelligent by enabling the following key functionalities:

- Monitor the pack and cells parameters (including voltages, currents, temperature)
- Calculate and estimate the battery & cell states (SoX: states of charge, health, power, safety, and more)
- Optimize the battery performance/operation (including balance cells, request for cooling/heating battery pack)
- Protect the battery from being operated outside the safe operating regions (for example, during events like over current, over/under charge)

The individual BMS sub-functions are always OEM-specific and can therefore differ considerably depending on the system design. The tasks of the BMS discussed in this article are therefore not necessarily comprehensive for a particular BMS, and are implemented in different ways depending on the electric vehicle manufacturer.

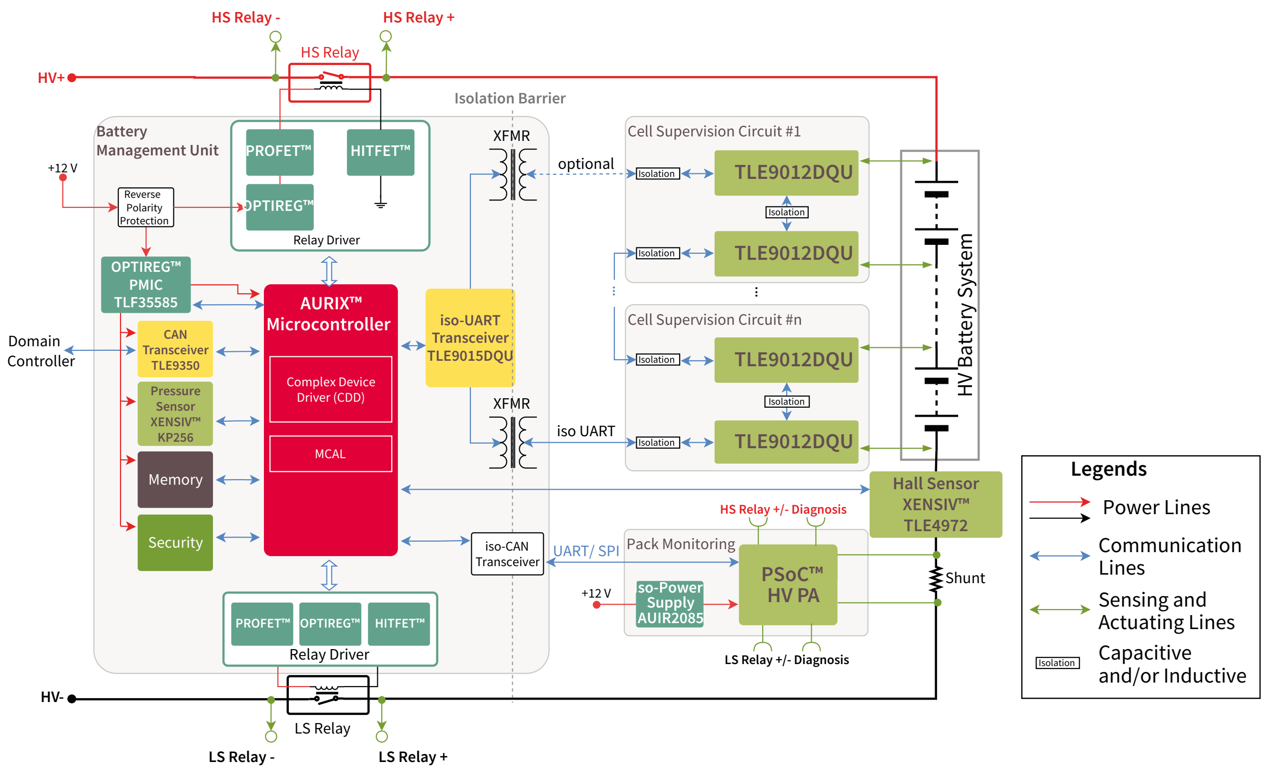


Figure 4 showing an example block diagram of high voltage automotive BMS.

Figure 4 shows the BMS schematics in the overall context of the high-voltage battery in the electric vehicle.

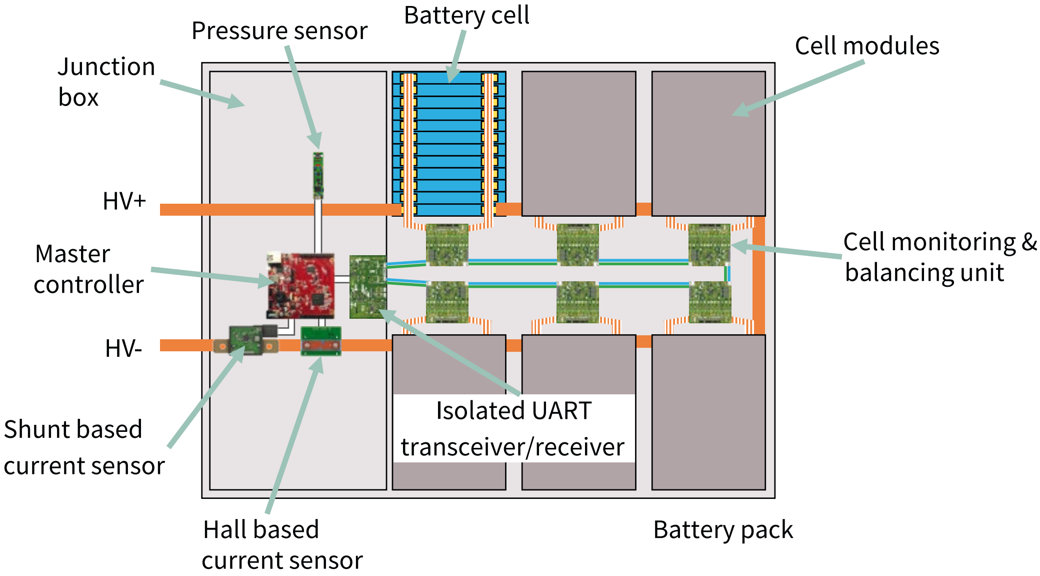


Figure 5 showing the different BMS components inside a high voltage cell-to-module battery pack.

Figure 5 shows an example on different BMS components and their location inside a high voltage cell-to-module battery pack.

In the upcoming sections, we will show how the BMS can impact the key battery features and how Infineon's solutions can improve them:

› Performance: how performance is improved by maintaining the high accuracy of the analog front ends (AFEs) and the appropriate thermals and conditions of the battery cells. We will show how the accuracy of the AFE must be considered beyond the individual components and how the entire system can impact their performance significantly. We will also explain ,some of the key conditions under which the cells must be operated and how the cell monitoring devices can achieve that
› Battery lifetime: how robustness, quality and performance of the individual BMS components can impact the lifetime of the battery, and how the weakest component in the battery pack decides the lifetime of the entire pack
› Safety: why high safety requirements such as ASIL-D are necessary and how a BMS plays a role in achieving them
› Total system cost: how the cost of the entire system is more important the cost of the individual components

We will do that by reviewing the following individual functional blocks of the BMS:

› Cell monitoring and balancing (CMB)
› Current sensing
› Pack monitoring
› Isolated communication
› Battery control unit (BCU)
› Battery disconnect unit (BDU)

Cell monitoring and balancing

When designing a BMS, the designer often starts with the cell monitoring device. This is also known as the BMS IC, Analog Front End (AFE), or Cell Monitoring and Balancing (CMB) device. Often located on a Cell Management Controller (CMC) unit, the CMB's function is to measure the voltages and temperatures for cells and communicate this information to a main controller. Additionally, the CMB can undertake diagnostics of cells and their surrounding (for example, detecting connections failures in the circuit surround a cell such as open or short circuits). The values monitored by the CMB are then used to:

- Check if the cells are always operating within their safe operating area (SOA) and report if they reach the SOA limits
- Measure the voltages of the cells for the state of charge (SoC)
- Report the cell temperatures for the thermal management of the pack

Furthermore, a CMB device is responsible for balancing the cells. Cell imbalance comes from the fact that high voltage batteries are built out of many single cells in series (see figure 7a), which inevitably have production variances, for example in battery capacity. In fact, a 400 V or 800 V battery can have up to 120 or 240 cells in series, respectively.

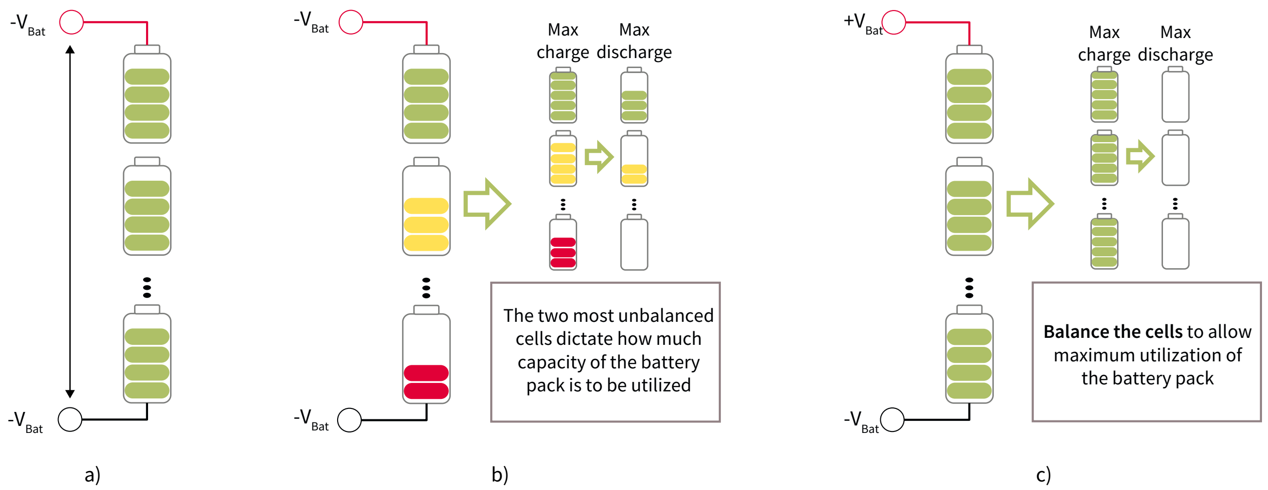
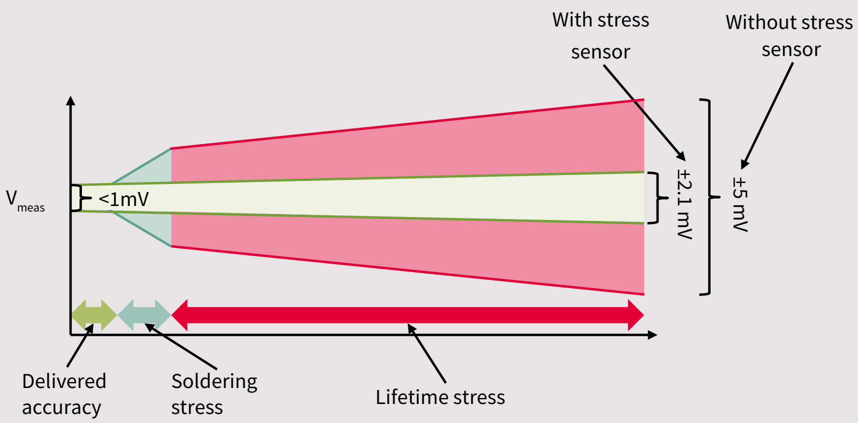


Fig 6. Showing the charging and discharging behavior of (a) cells in series when (b) unbalanced and (c) balanced.

Figure 6b shows how unbalanced cells prevent the full utilization of the battery pack. In fact, the two most unbalanced cells define how much of the battery pack can be utilized. Figure 7c shows how balanced cells allow for full charging and discharging of the pack.

Critical points to consider when selecting a CMB device include:

- Accuracy: while the accuracy of the CMB's analog to digital converters (ADCs) is important, the impact of the surround is just as significant. For example, the CMB accuracy can be impacted by the stresses resulting from CMC production, operational conditions, and lifetime aging. Additionally, drifting in the values of surrounding components (such as external filters and protection circuitry) can affect the accuracy of the CMB



- The capability of the CMB to balance cells simultaneously. Many CMBs can only balance one set of cells at a time, which makes the balancing process long and inefficient
- CMBs should have as similar as possible properties. Variation in the properties, such as current consumption of the CMB, will unbalance the cells attached to it. Furthermore, the relative accuracy between the different CMBs is also important to balance all the cells and modules
- Since the CMB must be connected to all parallel cells in a set, multiple CMBs would be required. In fact, depending on the battery voltage class, up to 24 CMBs might be required to monitor a battery pack. As such, to reduce failure probabilities and maintain the total system accuracy, the CMB PPM rates and the errors between the CMBs must be kept low
- The CMB is permanently supplied from the cells it is monitoring, and encounters a much higher voltage than the conventional vehicle architecture, as well as experiencing much higher stress during transient conditions like hot plugging. This is where a superior device and technology quality are important, with special precautions considered during device design and test

In the following chapter we will show how Infineon differentiates in achieving End of Life accuracy and optimum balancing features.

Current sensing

Looking again at Figure 3, we can see the flat nature of the State of Charge (SoC) curve. Additionally, the SoC curve is highly sensitive to factors such temperature, aging and operation conditions (see the following figure).

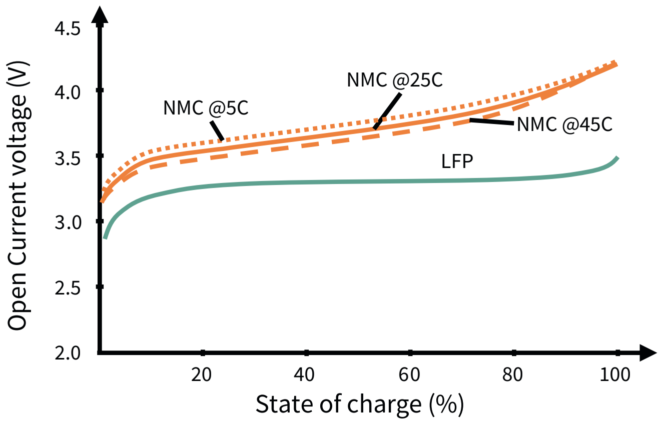


Figure 7 showing the sensitivity of Li-ion's SoC curve to temperature [8].

This means that deducing the SoC accurately from the cell voltage alone would not be possible. Therefore, a Coulomb counting current sensor is used, which measures the charges that enter or leave a battery cell. The most common ways to measure current are with shunt resistors and/or hall sensors.

Additionally, the current sensor can also detect over current events (OCD). An OCD event implies that the cells and the load need to be protected by disconnecting the battery.

Critical points to consider when selecting a current sensor:

- Accuracy: The accuracy of a current sensor must be high over a very wide range of current. This is because a car consumes anywhere from a few mA of current during parking to a few hundred amps during driving
- Speed: Over current events happen extremely fast (between 50 ns and 10 µs). In that time, the current might exceed thousands of amps, which could damage the pack and the load, and become hazardous to the passengers
- Connectivity/communication: Synchronizing the voltage and current measurements has many benefits. The current sensing device must be able to measure current synchronously with the packs and AFEs voltages

Pack monitoring

Pack monitoring is composed of four main functionalities:

- Insulation and arcing monitoring
- Over current detection (OCD)
- Thermal runaway detection
- Battery disconnect monitoring

The high voltage battery must be insulated from the rest of the car, so constant monitoring of the pack insulation is necessary. This is performed by using high-impedance faulty shunts to sense the variation in impedance between the different poles of the pack.

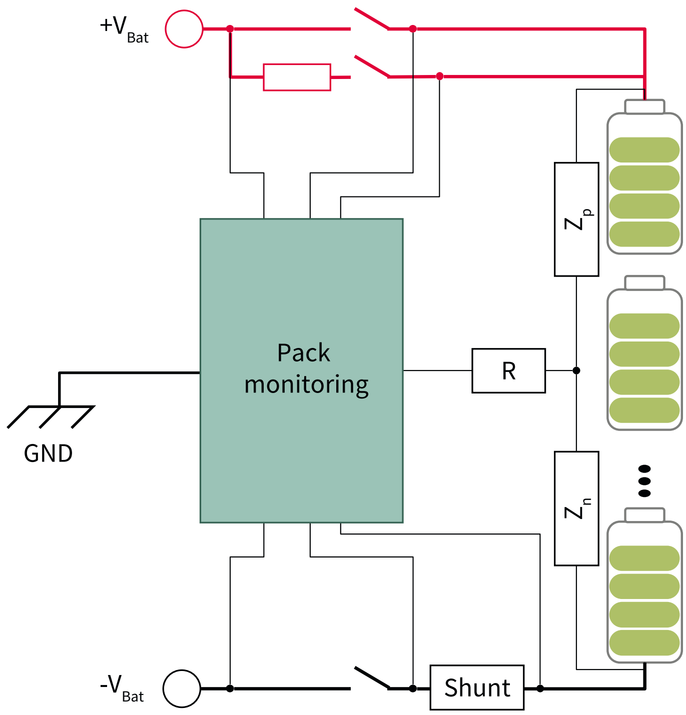


Figure 8 showing a simplified schematic of a pack monitoring circuit

Critical points to consider when selecting a pack monitoring device:

- Speed of OCD and reaction: In the event of a short circuit, the DC bus bar current can spike to a few thousand amps in just a few hundred microseconds. Since the disconnect might need time to switch off (less than 10 µs for solid state disconnects and a few milliseconds for relays), the pack monitoring must have a very fast OCD and trigger the disconnect to switch off
- Signature recognition: The pack monitoring device must have intelligence that can identify signatures, which in turn can identify:
  - Insulation detection
  - Arcing detection
  - Relay aging
  - Relay armature motion
- Failing to identify the signatures mentioned above could magnify any OCD events, and lead to damage to the vehicle and even risking the safety of the passengers

Isolated communication

All monitored values (such as the various voltages, temperatures, and currents) need to be transmitted to a main controller, that takes care of the state calculations and housekeeping. However, as can be seen in Figure 9, the different monitoring units sit in different voltage islands. This means that isolated communication is required, to transmit the monitored information without damaging the monitoring units.

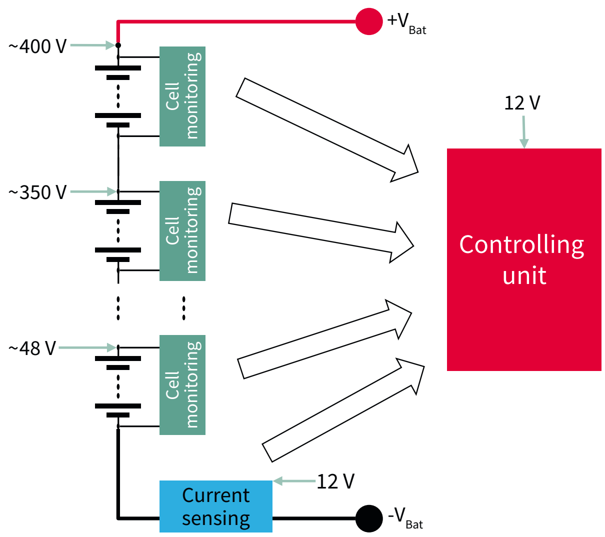


Figure 9 showing the different monitoring devices, the controlling unit and their different voltage islands.

Critical points to consider when selecting an isolated communication device:

- Robustness of the isolation: The battery pack operates under very electrically noisy conditions, so the stability and quality of the transmitted information can be drastically impacted by the isolation
- Bandwidth and latency: This must be sufficient to handle synchronizing and getting simultaneous measurements from all AFEs
- Booting the system via the communication links is required, with no power consumption
- To meet the appropriate ASIL level, a fail operational state of the communication needs to be achieved. Otherwise, if the communication with the AFEs breaks, the entire pack will need to be disconnected
- Cost of isolation: there are many ways to isolate the communication, but the cost of isolating can become very expensive

Battery control unit

The battery control unit (BCU) consists mainly of the master controller and all the supplementary interfaces:

- Power management IC
- Communication interface to the domain controller
- Isolated communication transceivers/receivers with the monitoring units
- Memory for storing all the battery logs and history

The BMS software runs on the BCU and is responsible for:

- Driving all the monitoring units
- Collecting all the monitored values
- Calculating the various states of the battery (SoX), such as State of Charge (SoC), State of Health (SoH), State of Power (SoP), and State of Safety (SoS)
- Performing housekeeping
- Updating the BMS firmware

Critical points to consider when developing a BCU:

- Performance: The cell chemistry models are complex and must be run on the BCU while constantly monitoring the safe condition of the cells. This means that the BCU needs multiple cores to manage this. Additionally, cell chemistry and models are constantly changing, which means the BMS algorithms must be constantly updatable on the fly. This means a BCU must offer software over the air updates (SOTA), without interrupting the battery monitoring and controlling
- Safety: Since the BCU is the main component that disconnects and connects the battery and communicates with the domain controller about the different states of the pack, the ASIL D requirement is crucial. Just imagine if a car is driving at high speed and suddenly the pack gets switched off, or if while charging the pack is full, yet the BCU is saying that it is not

Battery disconnect units

A battery disconnect unit (BDU) is responsible for disconnecting and connecting the DC bus of the high voltage (HV) battery.

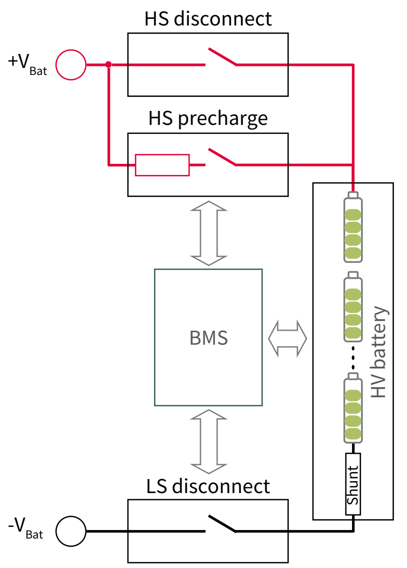


Figure 10. A simplified schematics of a battery disconnect unit.

As can be seen from the Figure 10, the BDU is composed of 3 major components:

- The low side disconnect that connects/disconnects the negative pole of the HV battery pack
- The high side disconnect that connects/disconnects the positive pole of the HV battery pack
- The precharge, which manages the turn-on inrush currents

Critical points to consider when designing the BDU:

- Detecting the aging and arcing of the mechanical disconnects
- The speed of disconnection during an OCD event
- Not to fail during disconnection. If the relays do not disconnect, a melting- or pyro-fuse must be triggered

Infineon BMS solutions

In this chapter we will present how Infineon addresses all the critical points mentioned previously. We will focus on four key metrics: accuracy, quality, application robustness and total system cost.

In the important areas that need consideration, we will explain:

- How Infineon BMS products improve performance by addressing:
  - The end-of-life accuracy of the CMBs
  - The robustness of the CMB
  - The accuracy of current sensing
- How Infineon BMS products reduce total system cost by reducing the bill of materials
- How Infineon BMS products increase battery safety with individual components, that enable ASIL D safety on a system level
- How Infineon BMS products increase battery lifetime with their exceptionally low PPM rates and high robustness

End of life accuracy of the CMB

We have addressed in the introductory chapter the flat characteristic of the SoC curve (see also Figure 6a). The flatness of the curve means the pack SoC is highly dependent on the accuracy of the cells' measured voltages. Any drifts in this accuracy will lead to a large perceived drift in the pack's SoC. For example, battery chemistries such as LTO and LFP show up to 5% error in SoC for every 1mV error in the CMB measurement.

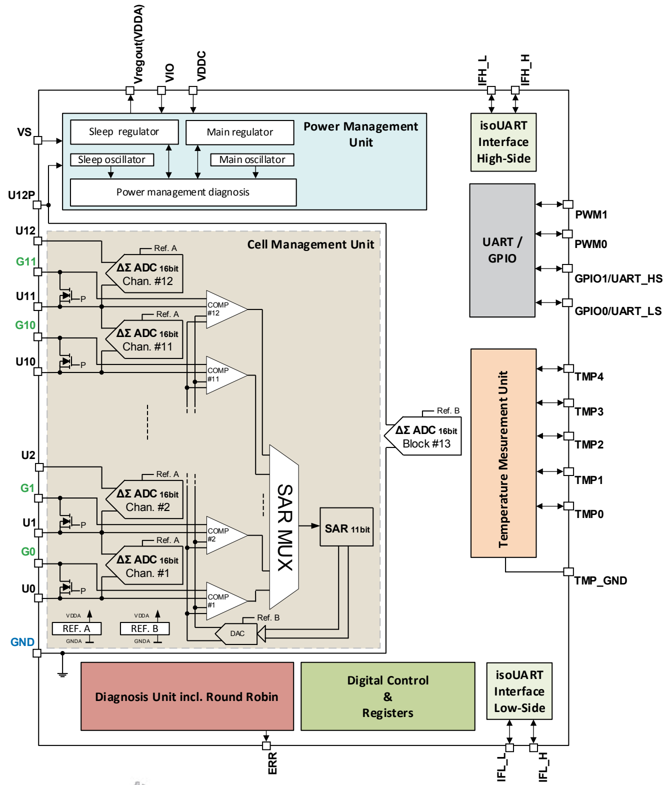
The accuracy of the CMD doesn't only depend on the BMS IC, but also on everything around it – from passives such as filters, to the cables and welding spots that connect the AFE to the cells. To make things more complicated the accuracy of all these components drift over the lifetime of the battery pack. That is why, when designing a CMB, not only the Beginning of Life (BoL) accuracy must be considered but also the End of Life (EoL) accuracy – including degradation of external components.

To address these issues, we have developed **TLE9012DQU**, a 12-channel balancing and monitoring IC, with the following key features:

- One ADC per channel with integrated digital filtering. These ADCs operate with a very high sampling frequency, thus allowing the use of smaller capacitance values and sizes. The measurement quality is not affected by these high frequencies, as the external filter is only required to avoid aliasing effects in the higher frequency bands and not used to filter noise from other parts of the vehicle, which is achieved via the digital filter
- No requirement for external TVS diodes to protect it from hot plug events. This eliminates any EoL aging effects they would cause
- A proprietary integrated stress sensor that compensates for mechanical stresses, thus automatically recalibrating the ADCs from any drifts. The stress sensor can therefore compensate board level stress reflecting back on the chip
- To measure the temperature of the cells, negative temperature coefficient (NTC) sensors are directly connected to **TLE9012DQU**. No external components are required as internal current sources can power the NTC. This reduces thermal measurement drifts and makes its thermal measurement accuracy best in class

- Stable current consumption throughout the whole operating range, with minimal variance from device to device to avoid introducing additional imbalances between cells
- High absolute cell voltage measurement accuracy including all errors over the device lifetime of ±2.1 mV (End-of-Life @3.6 V and 25°C)
- Less than ±1.0 mV relative accuracy over all devices against each other at any given point in the device lifetime (under similar conditions), for superior relative accuracies within one battery pack

TLE9012DQU - a 12 channel balancing and monitoring IC supporting ASIL D systems



Key benefits

- Balancing & monitoring for up to 12 cells in series
- Robust Infineon 90 V/130 nm automotive technology supports hot plugging and enables digital features
- Dedicated 16-bit delta-sigma ADC per cell enabling synced & filtered measurements
  - Several built-in digital filtering (down to 70 Hz cut-off)
  - Long running ADC mode with adaptive sample times for up to ~92 ms (<10 Hz cut-off) averaging
- Secondary ADC with same filter characteristics for a synced cell voltage plausibility as advanced End-to-End safety mechanism
- 13th DS-ADC with the same filter characteristics for synced block voltage measurements
- Compatible with Infineon complex device driver for TC3xx
- 5 NTC channels + additionally 4 GPIOs to connect e.g. an external EEPROM
- UART & robust capacitive coupled interface for daisy chain & ring mode communication
- Supporting up to ASIL-D BMS safety applications
- Small package (TQFP-48) & high feature integration for a lean external BOM

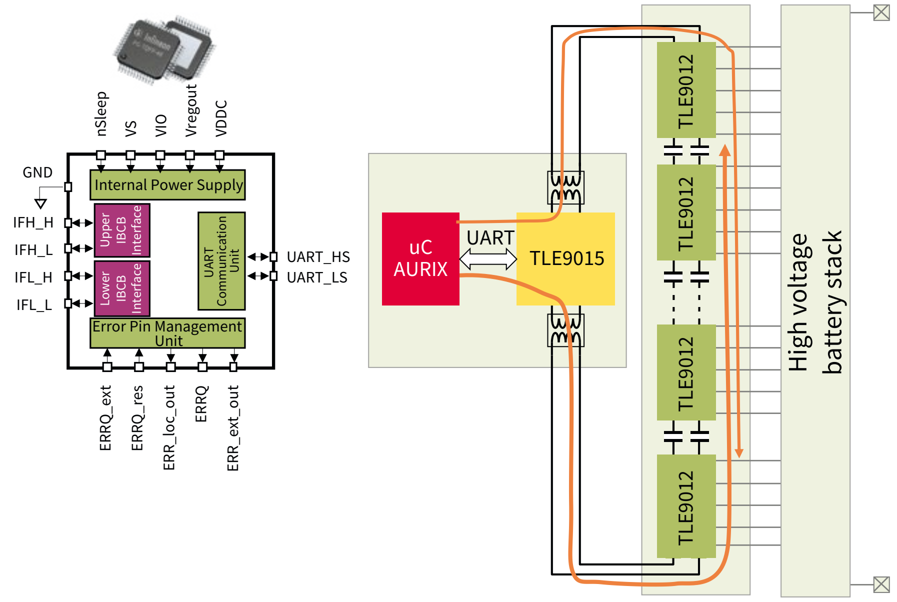
Robustness of the CMB

Since the CMB is the component that is directly connected to the cells, it must maintain its robustness. The TLE9012DQU achieves this with the following features:

- Proven hot plug robustness (no single additional external component needed) tested in cooperation with customers around the world using worst case assumptions
- Proven BCI robustness (with no ADC or communication interference at all) under harshest conditions (200 mA injected in sensing and daisy chain wires). All purely capacitive coupled (no choke needed) with a cost-effective 1 nF capacitor
- Proven board-level ESD robustness supporting 8kV gun testing without any additional external components
- Parallel ADC structure combined with high ADC sampling (14 MHz) and super large OSR (up to 131072) for stable voltage readings even under heavy noise without any large external RC filter

› Additionally, communication with the CMBs must be available at all times, which means that the communication path must be redundant to allow fail operational mode. To achieve this, Infineon has developed the **TLE9015DQU** transceiver IC. This can be stably operated with capacitive and inductive isolation, and enables a daisy chain architecture. The advantage of this architecture is that it achieves lowest cost of isolated communication while offering functional redundancy

TLE9015DQU a UART to iso UART transceiver IC



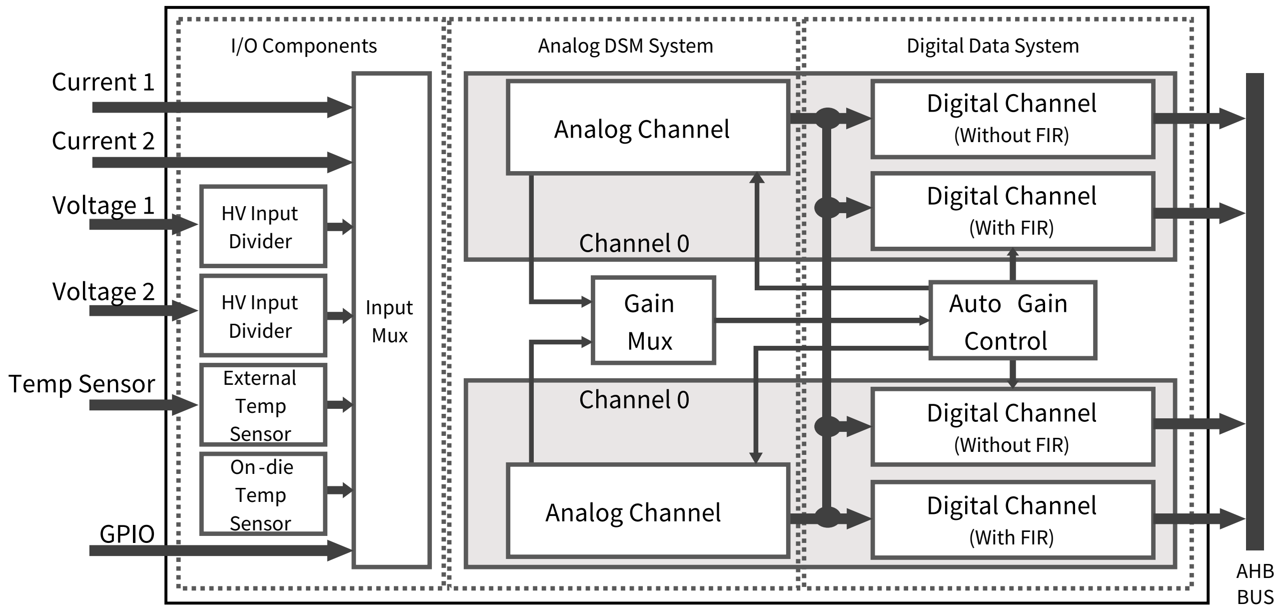
Key benefits

- › Two UART ports for serial communication to host microcontroller
- › Two iso UART ports for daisy chain communication inside battery pack
- › Fully transparent communication scheme from µC to sensing IC (**TLE9012DQU**)
- › Ring mode topology compatible (only 1 device needed)
- › Supporting up to 2 Mbit/s
- › High robustness against external noise
- › General purpose error pin
- › Two external fault inputs with internal latching
- › Error output pin to trigger external microcontroller
- › Internal supply monitoring
- › AEC-Q100 qualified

Accuracy of the current sensor

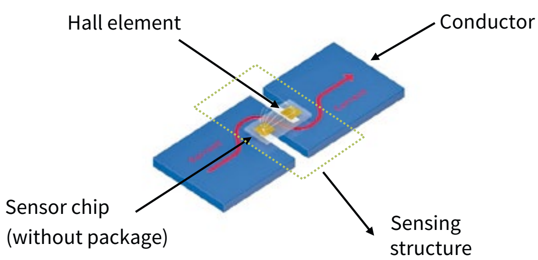
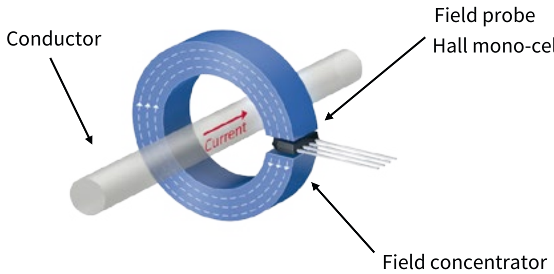
For high precision sensing, Infineon has developed the PSoC™ HV PA which features:

- › Shunt-based current measurement with up to 0.3% accuracy
- › Dual shunt sensor support for redundant measurements
- › Unique dual ADC (two precision sigma-delta ADCs with 16-20+ bits) and four digital processing channels (two including FIR filters) to provide effective four channels analog front-end (as shown in the figure below)
- › Automatic gain control enabling measurement of large starting currents or small battery-off currents accurately
- › Pack voltage monitoring using external voltage divider with up to 0.15% accuracy
- › Additional channels for temperature sensing with up to 1°C accuracy
- › Open shunt detection capability
- › Arm Cortex-M0+ controller available for running system diagnostics, signature recognition and Coulomb count algorithms
- › Additional analog inputs to monitor the relays



Speed of response to OCD

The current sensor **TLE4972** has an independent signal path for overcurrent detection and two separate output pins (OCD) to signal an overcurrent event. The typical response time of the OCD pins is 700 ns. The sensor is based on Hall technology, and due to its differential sensing principle, an iron core is not needed. This means that TLE4972 can measure currents with minimal footprint and can be easily mounted under the DC bus bar.

<table>
<tr><th colspan="2">Current sensing based on HALL effect
Differential sensing key for core-less sensing</th></tr>
<tr><th>Core-less sensing</th><th>Core-based sensing</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>› Stray field suppression through differential voltage measurement of 2 Hall probes/cell
› No saturation, no hysteresis, high linearity
› Low dependency on temperature and lifetime
› Sensor comes in small SMD packages</td><td>› Risk of saturation in case of over currents
› Hysteresis in case of PWM
› Non-linearity due to iron core
› Bulky package</td></tr>
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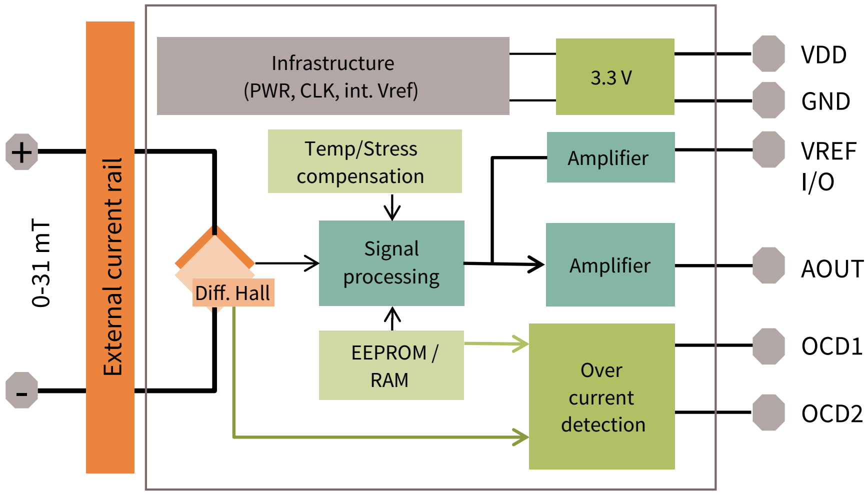
Product summary TLE4972 - Infineon current sensor optimized for drives

Product features

- Measurement range **0 to 31 mT** (0 A to >1 kA) enabling large measurement range
- Fast overcurrent detection output OCD
- Analog output
- High bandwidth (typ. 210 kHz) for fast measurement
- 3.3 V supply voltage
- High accuracy over temperature & lifetime
- Intrinsic stray-field robustness through differential measurement
- Automotive grade qualified
- ISO26262 complaint development
  – Component rating: ASIL B



Performance of the BCU

The main switch (or main relay) has a central function within the BMS for accident prevention and for adequate fault reaction of the BMS electronics. In most cases, this is opened by the BMS module as a fault reaction within an appropriate fault reaction time, for example, less than 10 ms (Break after Make).

The non-critical ‘Fail Safe’ state is always characterized by the fact that even in the event of failure of the BMS microcontroller, the external ‘saving element’ in the power supply module (for example, a window watchdog) ensures that the main switch relay safely opens both high-voltage contacts to the inverter (plus/minus) even in the event of total failure of the controller logic.

In addition to this important ASIL relevant safety functions, the following functions can also be integrated in a BMS system:

Leakage current monitoring to the chassis:
Here, even relatively high-impedance faulty shunts of the high-voltage circuit to the chassis are sensed and evaluated in the BMS system.

Main switch relay monitoring:
The voltage before and after the main switch is measured, and it is calculated whether the main switch can still fully perform its low-impedance closing function on both contacts.

Main battery management:
The classic function of the BMS is initially to control as well as care for and maintain the expensive high-voltage battery in the electric vehicle.

The synchronous measurement of the total current of all high-voltage battery cells through the main switch as well as the simultaneous cell-precise monitoring of all individual cell voltages via the slave ICs enables the BMS-MCU to evaluate battery parameters such as 'State of Health' or 'State of Charge' with the aid of battery chemistry-specific algorithms (for example. based on Matlab simulation models).

With the help of calibration parameters (look-up tables), corresponding charging and discharging strategies are calculated, which contribute significantly to guaranteeing the service life of the high-voltage battery and to avoiding critical over/under-charging conditions. In the future, AI-based neural networks (NN) will also be increasingly used in this area.

The BCU is usually not installed in the high-voltage battery itself, but is connected to the electronic balancing slaves via mostly redundant galvanically decoupled bus systems, and draws its supply voltage from the normal vehicle voltage (12 V battery). This improves safety, as the BCU will remain functional in the event of a chemical or mechanical defect within the HV battery (and can therefore open the main switch safely).

Due to increasingly complex battery-specific chemical-electrical algorithms, microcontrollers of 6-12 MB embedded FLASH with sample space for extensive calibration parameters or neural network parameters and with powerful multi-core processor architecture are used today for this purpose.

Standby function for parking situations:
In non-active driving situations (for example in parking garages), manufacturers of electric vehicles sometimes want to monitor the state of charge of the battery as well as the individual cells at regular intervals. For this purpose, it is essential that the BCU has functions which, on the one hand, enable very low current consumption of the microcontroller (in the µA range), and on the other hand, for example, via a timer, briefly wake up the system in order to then record the battery data in the active mode of the BMS via balancing ICs. For this purpose, in addition to the powerful TriCore multiprocessor architecture monolithically (on the same silicon), the TC3xx Infineon **AURIX™** variants also integrate an 8-bit standby microcontroller in a separate low-power domain, which can take over the task of cyclic wake-up with the aid of a wake-up timer within the BMS.

Battery thermal management:
Due to their construction, the high-voltage battery modules still partially contain an active thermal management – a heating system for winter or a cooling system for summer based on air cooling or water cooling. Here, the BMS is used to acquire the corresponding temperature data from the battery and either actively control and regulate the actuators (such as fan motors or water pumps) or pass the corresponding temperature parameters to an external thermal management ECU via CANFD. In case of a local BMS control of the electric actuators, this is easily possible via the built-in digital/analog converters and the various timer functions in the **AURIX™** microcontroller.

Crypto algorithms for securing the original OEM battery:
By securing the original OEM battery in the electric vehicle against unauthorized tampering by third parties, the chance of explosions or fire is reduced – where replacing of individual cells or assembling used batteries from 'cannibalized' individual parts would create unacceptable risks. In addition to the installation of appropriate protection components directly in the individual cell clusters (for example by the **OPTIGA™** IC from Infineon), a cost-effective integrated logical protection in the form of an HSM (Hardware Security Module) in the microcontroller is also possible.

The HSM module in the **AURIX™** from Infineon can effectively contribute to being able to recognize the scenarios described above as a battery master and store them in a 'secure' data memory. Authorized workshops can then read this information when servicing the vehicle and thus determine the authenticity of the battery. Another field of application would be the charging control: the comparison of the charged amount from the external provider and the actual measured amount via the BMS.

The following block diagram shows the TC3xx AURIX™ MultiCore architecture in generic form:

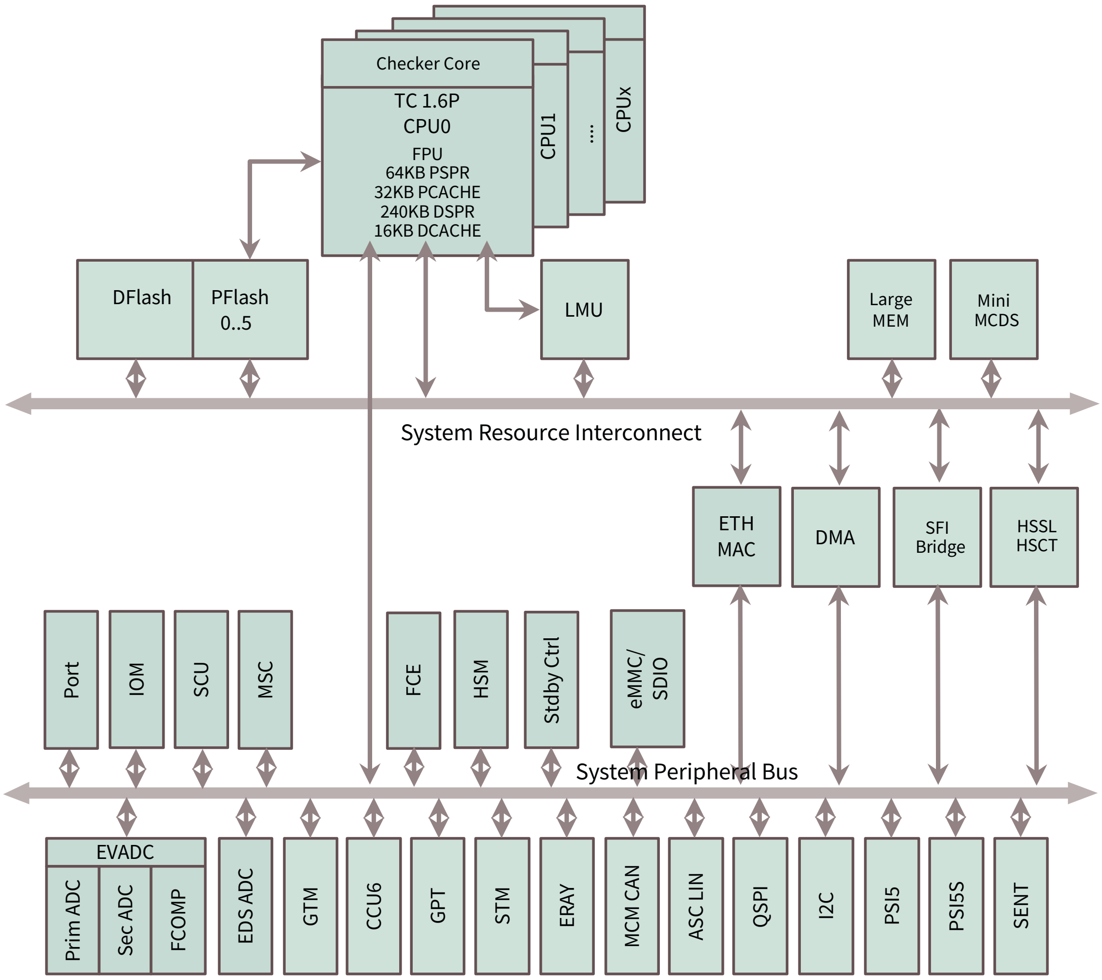


Figure 11 : TC3xx AURIX ™ Block diagram with TriCore Multicore Architecture.

The new 40 nm µC generation TC3xx AURIX™ from Infineon Technologies ideally fulfills all requirements for the required processor of the BMS and thus, in addition to a scalable family concept with different FLASH sizes as well as package variants, also offers all ASIL C-D relevant prerequisites (for example lockstep core, ECC in FLASH, SRAM as well as on the SRI crossbar) in order to be able to develop an ISO 26262 compliant E/E system in a certifiable manner.

In addition, Infineon offers with its ISO 26262 compliant and TÜV certified AURIX™ development as well as the special Safety SW driver SafeTcore together with documentation (Safety Case, Safety Manual, FMEDA & Safety Concept) an extensive further ISO 26262 supporting portfolio to keep the development effort at the customer's site within manageable limits.

ASIL D safety level

From today's perspective, specific E/E systems such as the BMS will be classified at the high safety level ASIL C to ASIL D (with at least 97% to 99% fault detection rate) by all OEMs within the scope of the ISO 26262 safety standard. This standard is, for example, mandatory in the European Union.

This highest hazard analysis is based on the following fault scenarios, which could endanger the life and safety of the electric vehicle passengers, if the fail-safe reaction of the system is not correct:

- Danger due to undetected faulty high voltage at the vehicle chassis
  - by means of changed cables
  - or accidental damage
- Danger due to fire or explosion of the high voltage battery
  - by overcharging the battery (for example on the public grid or by recuperation)
  - by (premature) aging of the battery (for example leakage of explosive gases)
  - by faulty liquid ingress and short circuit (for example by rainwater)
  - by misuse (for example faulty repair)
  - by faulty thermal management (for example failed cooling)
  - or by accidental impact

Our devices have been designed to fulfill such safety requirements:

Device	Safety level
TLE9012DQU	ASIL-D
TLE9015DQU	Automotive grade device enabling fail safe daisy chain communication
PSoC™ HV PA	ASIL-B
TLE4972	ASIL-B
AURIX™	When combined with OPTIREG™, AURIX™ achieves ASIL D

System cost

System cost reductions are enabled by the key features of the individual components:

Device	Cost benefits
TLE9012DQU	› True stable capacitive isolated communication, which is lower cost than inductive isolation › Requires no additional TVS diodes due to the hot-plug protection feature by design › Less dependency on the external passive filters due to the integrated digital filter › Requires lower cost external passive filters due to the one ADC per channel feature
TLE9015DQU	› True stable capacitive isolated communication, which is lower cost than inductive isolation › Enables daisy chain, which is the cheapest functionally redundant communication topology
PSoC™ HV PA	› Highly integrated solution with multiple analog interfaces and M0 core
TLE4972	› Does not require a core
AURIX™	› Features an ASIL-D functionality when combined with OPTIREG™ › Features a large ecosystem of partners delivering high quality, hardware-optimized software to enable fast time to market for our customers

System-level approaches

All the components mentioned in the previous chapters and shown in Figure 4 have been developed and designed to work seamlessly together, thus easing integration complexity and speeding time to market. For example:

- Integrating the OPTIREG™ with AURIX™ enable ASIL-D safety
- AURIX™ offers a wide ecosystem that helps the BMS makers to quickly and efficiently develop their BMS solutions.
- The TLE9015DQU and TLE9012DQU are built to complement each other for maximizing performance
- Infineon offers a set of complex drivers for the various BMS components which can be integrated in an AUTOSAR compliant application with or without an OS

Conclusion

In this white paper, we have discussed the use of Li-ion batteries in high voltage electric vehicle systems, and the challenges this raises for battery management systems (BMS). We have also looked at various components that can solve these challenges for the core functions of a BMS.

To ensure safety, performance and accuracy over the full system lifetime, it is essential to choose the right BMS components. This can also maximize the range and lifetime obtainable from the Li-ion battery, which is a vital differentiator for carmakers.

Infineon has a complete range of components and solutions for electric vehicle BMS, that enable customers to reduce risk and cut time to market, while optimizing performance, reliability and features.

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