NEXT-GENERATION OPEN-SOURCE BATTERY MANAGEMENT SYSTEM PLATFORM WITH FRAUNHOFER IISB & NXP

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Fraunhofer IISB and NXP are collaborating on the next generation of the foxBMS® open-source battery management system platform.

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EXECUTIVE SUMMARY

High-voltage recharging batteries are increasingly used in electric vehicles to provide a longer driving range and offer weight- and mass-saving advantages. In addition to automotive applications, high-voltage rechargeable batteries are increasingly being used in a wide variety of other applications, including industrial, airborne, waterborne, railways, and military deployments.

Many of these deployments are safety-critical and mission-critical. This means that, in addition to being robust and reliable, the systems used to manage high-voltage rechargeable batteries have to meet the highest levels of functional safety.

Fraunhofer IISB has launched an initiative called foxBMS® to offer an open-source battery management system (BMS) dedicated to the design of complex designs for a broad range of stationary and mobile applications areas.

The latest generation of foxBMS® platform, foxBMS® 2, features NXP's MC33775A 14-channel lithium-ion (Li-ion) battery cell controller integrated circuit.

HIGH-VOLTAGE RECHARGEABLE BATTERIES

The term "rechargeable battery" has been popularized by the low-voltage AA and AAA batteries often used in small flashlights and children's toys. Today, by comparison, much larger high-voltage battery packs are used in automotive applications in the form of electric vehicles (EVs). In fact, even larger and higher-voltage battery packs are increasingly being deployed.

Applications are diverse and wide-ranging, from providing emergency power to a hospital, or buffering the output from a power station. These rechargeable batteries may be presented in a form factor like that of a shipping container in the order of 8 feet wide, 9 feet tall, and anything up to 45 feet long.

Consider grid-scale battery storage, for example, which can be used to enhance power system flexibility and enable high levels of renewable energy integration. In August 2022, the US Energy Information Agency posted preliminary findings from its latest energy survey, which noted that grid-scale battery storage tripled in 2021 to more than 4.6 GW.[1]

Rechargeable batteries of this class are composed of hundreds, thousands, or tens of thousands of cells. Each cell can provide only a limited amount of potential energy (voltage). For example, Li-Ion which is a popular battery chemistry because of its high energy density by volume and weight, relatively low self-discharge, low maintenance, and its ability to sustain a large number of charge-discharge cycles—has a nominal cell voltage of 3.6 V. Higher voltages can be obtained by connecting multiple cells in series. Higher currents can be obtained by connecting multiple cells in parallel. Achieving the voltage and current desired by any particular application involves groups of parallel wired cells that are themselves wired in series (i.e., parallel-series wiring).

Consider EVs, which have traditionally used 400 V battery packs, for example. Designers are currently experimenting with new architectures to reduce charging times and obtain increased range from a single charge. One possibility is to use two independent 400 V batteries that can be connected in series when charging (800 V in total), consequently dramatically reducing the charging time, and in parallel when driving (400 V), thereby allowing designers to work with existing, competitively priced traction inverter modules. Other applications, such as large photovoltaic projects, use 1,500 V to increase efficiency and reduce costs. Although 1,500 V is the current high-end, it is possible that higher voltage systems like 2,000 V, 2,500 V, or more will start to be deployed in the not-so-distant future.

Of course, there is more to a rechargeable battery than the battery cells themselves. It is also necessary to manage the cells for safety purposes and to achieve optimal efficiency and performance.

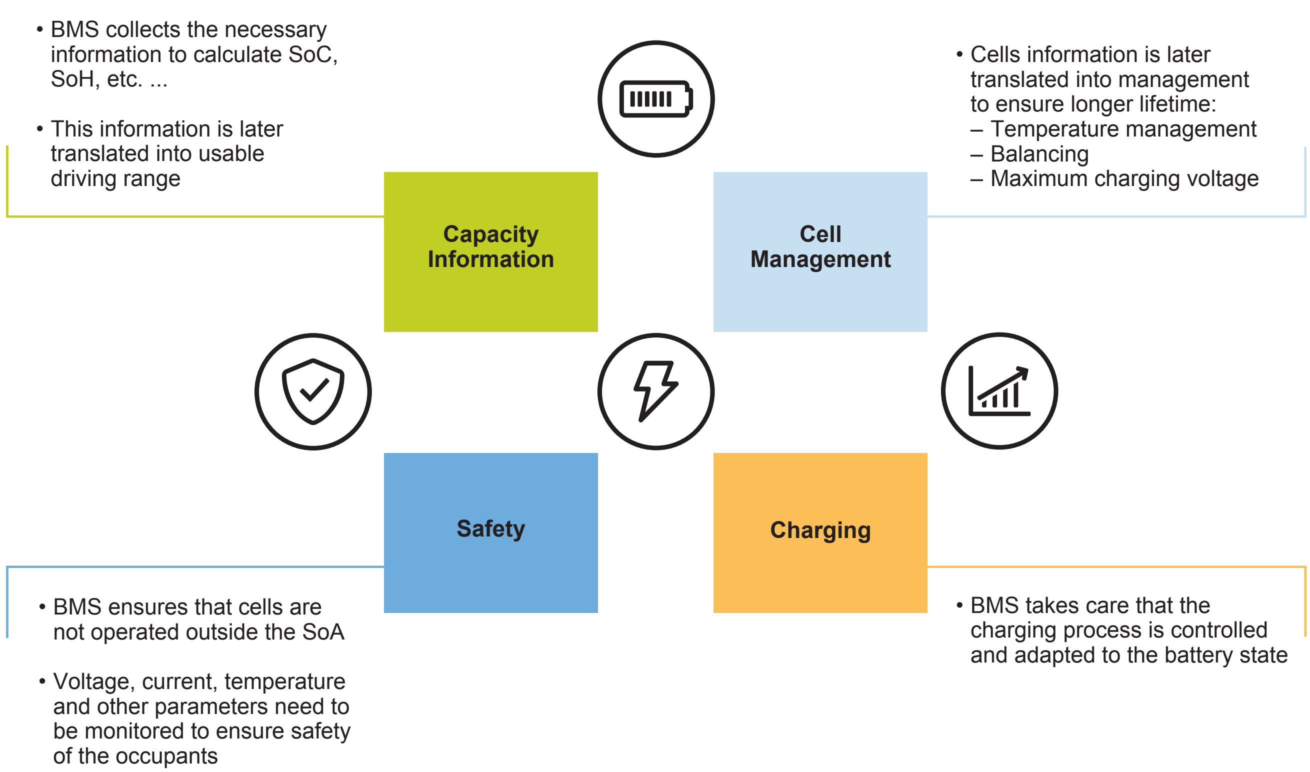

Figure 1: Key Functions of a BMS

HIGH-VOLTAGE BATTERY MANAGEMENT SYSTEMS

A BMS is an electronic system that manages a rechargeable battery comprising one or more cells while that battery is charging or discharging. The BMS monitors the state of the battery and protects it from operating outside its safe operating conditions. Items that may be monitored by the BMS include: voltage, temperature, current, health of individual cells, and state of balance of cells.

In addition to monitoring the state of balance of cells, the BMS is also in charge of battery balancing. This refers to techniques that are used to improve the available capacity of a battery pack with multiple cells and increase each cell's longevity. The individual cells in a battery pack naturally have somewhat different capacities. Variations in capacity are due to manufacturing and assembly variances (e.g., cells from one production run mixed with others), cell aging, impurities, or environmental exposure (e.g., some cells may be subject to additional heat from nearby sources like motors, electronics, etc.). As a result, over the course of multiple charge and discharge cycles, different cells may end up at a different state of charge (SoC).

Balancing a multi-cell battery pack helps to maximize the capacity and the service life of the pack by working to maintain equivalent SoC of every cell, to the degree possible given their different capacities, over the widest possible range. Balancing is only necessary for packs that contain more than one cell in series. Parallel cells will naturally balance since they are directly connected to each other, but groups of parallel wired cells, wired in series (parallel-series wiring) must be balanced between cell groups.

To prevent undesirable conditions, the BMS must monitor the condition of individual cells for operational characteristics such as temperature, voltage, and current. Under normal operation, discharging must stop when any cell runs out of charge even though other cells may still hold significant charge. Likewise, charging must stop when any cell reaches its maximum safe charging voltage. Failure to do either may cause permanent damage to the cells or—in extreme cases—may drive cells into reverse polarity, cause internal gassing, thermal runaway, or other catastrophic failures. If the cells are not balanced such that the high and low cut-off are at least aligned with the state of the lowest capacity cell, then the energy that can be taken from and returned to the battery as a whole will be limited.

FRAUNHOFER IISB AND THE foxBMS PLATFORM

As one of the 72 institutes and research units of the Fraunhofer-Gesellschaft, the Fraunhofer Institute for Integrated Systems and Device Technology (IISB)[2], which is based in Erlangen, Germany, conducts applied research and development in the field of electronic systems for a wide range of application areas, including electric mobility, aerospace, industry 4.0, power grids, and energy technology. In this respect, Fraunhofer IISB covers the entire value chain, from basic materials to entire electronic power systems.

In the case of high-voltage BMS (HVBMS), Fraunhofer IISB has been building a deep knowledge base since 2006 when work first started on electromobility projects. In 2015, Fraunhofer IISB launched an initiative called foxBMS® to offer an open-source BMS platform for a broad range of stationary and mobile applications areas, including industrial, airborne, waterborne, railways, and military applications.

The foxBMS® brand name and associated internet domain[3] were registered in 2016, and the design files for the first generation of the foxBMS® platform were made available online on GitHub a year later. Since that time, more than 150 customers and global players have ordered and used Fraunhofer IISB's BMS platform worldwide.

The designers from these organizations employ parts of the foxBMS® platform in their development processes and in their prototypes for end products. Since foxBMS® is made available under open-source hardware and software licenses, the foxBMS® platform can be used without contacting Fraunhofer IISB. As a result, the exact number of users is not known since no data is collected on them. However, retrieval rates from GitHub indicate that hundreds of users benefit from the opportunity to use foxBMS® technology to study the possibilities of their systems and as a basis for their own product developments.

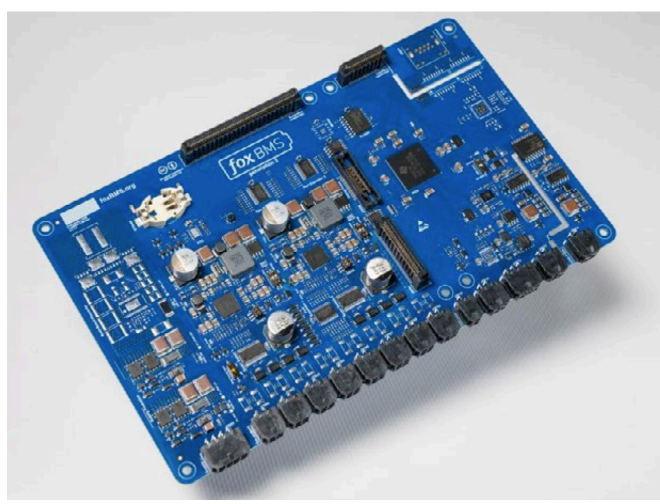

Figure 2: First Generation foxBMS Master Unit

The second generation of the foxBMS® platform, foxBMS® 2, was published in 2021. This new incarnation places the focus on a high level of functional safety provided by the hardware for stationary and mobile battery system applications up to 1,500 V. In addition to paving the way to fuel cell monitoring applications in systems combining fuel cells and batteries, the second generation platform is also of use with respect to managing flow batteries (rechargeable batteries in which electrolyte flows through one or more electrochemical cells from one or more tanks).

foxBMS® 2 is highly modular and provides the most complete set of interface options available on the market. In addition, the new platform addresses the functional safety requirements associated with a wide range of applications, from automotive, industrial, airborne, waterborne, railway, and military. It should be noted that this new generation is specifically optimized for functionality but not for costs. Any cost optimization or application-specific functional development is performed under bilateral research and development contracts between the customers and Fraunhofer IISB.

Figure 3: NXP's MC33775A 14-Channel Li-Ion Battery Cell Control IC

NXP AND THE MC33775A

For the latest generation of foxBMS®, Fraunhofer IISB is working in collaboration with NXP. Existing generations of foxBMS® already make use of various devices from NXP. However, the next generation will also feature NXP's MC33775A 14-channel Li-Ion battery cell controller integrated circuit (IC)[5].

The MC33775A is typically located on cell monitoring unit of the BMS system. Its duty is to monitor and balance battery cells, to monitor the cell temperatures and finally to communicate the data to the battery management unit, as illustrated in figure 4.

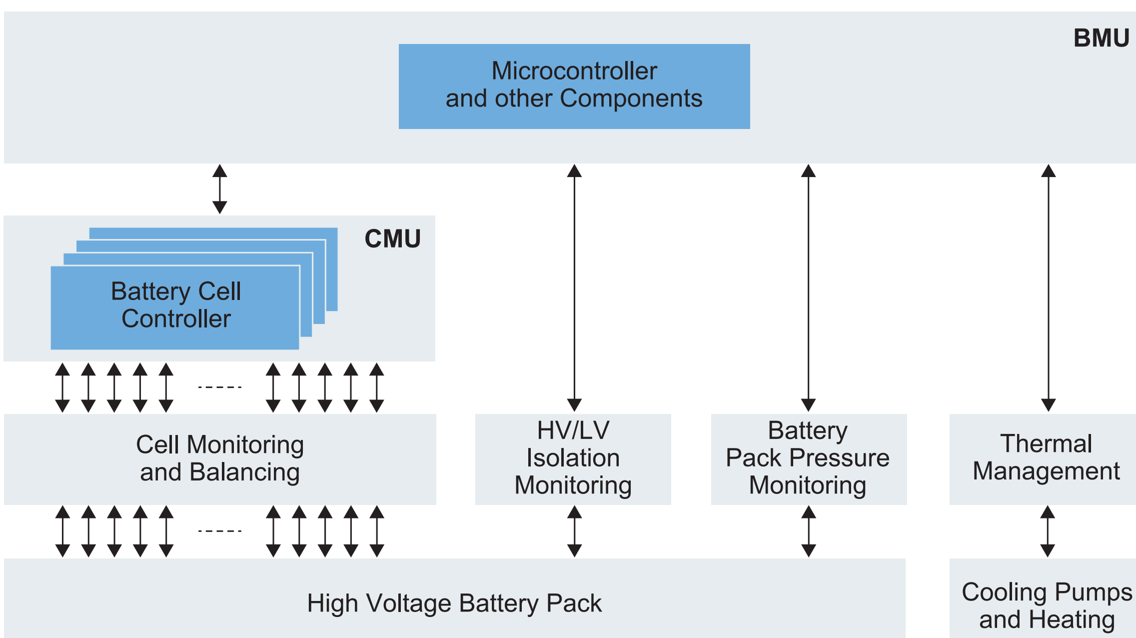

Figure 4: Simplified Block Diagram of the BMU & CMU Portions of a BMS

The MC33775A has been designed from the ground up for use in safety-critical HVBMS for a wide range of deployments, including automotive applications, such as hybrid (HEVs) and electric vehicles (EVs) and industrial applications, such as energy storage system (ESS) units, LFP batteries, and increasing battery voltages from 400 V to 800 V and above. NXP developed the MC33775A, with several innovations:

- Accuracy & measurement system
- Bill of material (BOM) reduction
- Balancing concept
- Functional safety concept designed for 800 V+ batteries

ACCURACY AND MEASUREMENT SYSTEM

OCV prediction algorithms require a very accurate cell voltage measurement. Compared to NMC batteries LFP batteries have very flat discharge curves and hysteresis, where 1.75 mV corresponds appr. 1% of the SOC (see Figure 5). As a consequence high accuracy voltage measurements are needed.

The MC33775A measurement system supports

- Primary cell voltage measurement
  - Supports bus bars with ±5 V input voltage
  - 16 bit resolution and ±1 mV typical measurement accuracy with ultra-low long-term drift
  - Integrated configurable digital filter
- External temperature and auxiliary voltage measurements
  - eight analog inputs
  - 5 V input range; configurable as absolute or ratiometric
  - 16 bit resolution and ±5 mV typical measurement accuracy
  - Integrated configurable digital filter
- Module voltage measurement
  - 9.6 V to 65 V input range
  - 16 bit resolution and 0.3 % measurement accuracy
  - Integrated configurable digital filter

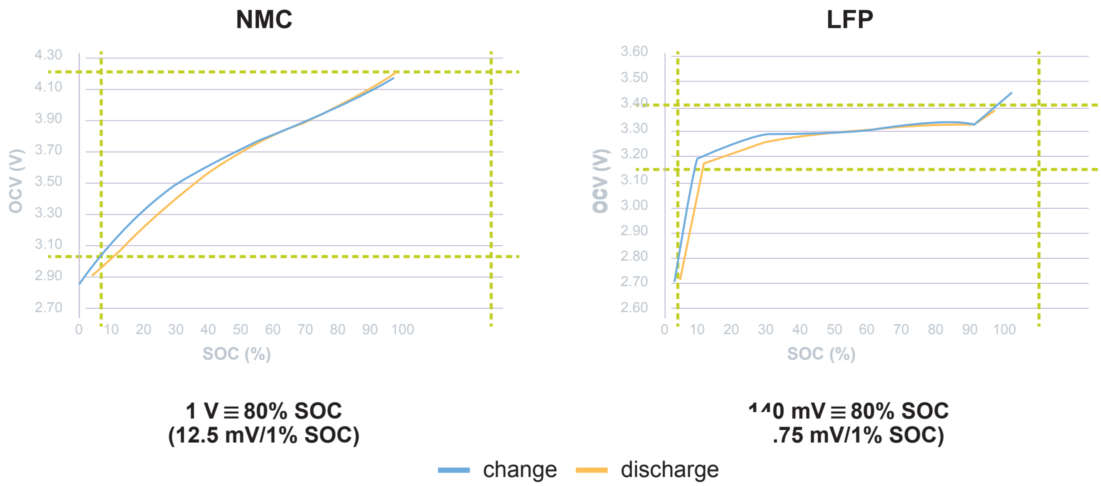

Figure 5: LFP flat discharge curve require high measurement accuracy for SOC estimation

BILL OF MATERIAL REDUCTION

The new measurement concept of MC33775A, enabled significant external BOM reduction, mainly driven by reducing, simplifying and optimizing filters and CAPs values for cell measurements, cell balancing, and GPIOs (see Figure 6).

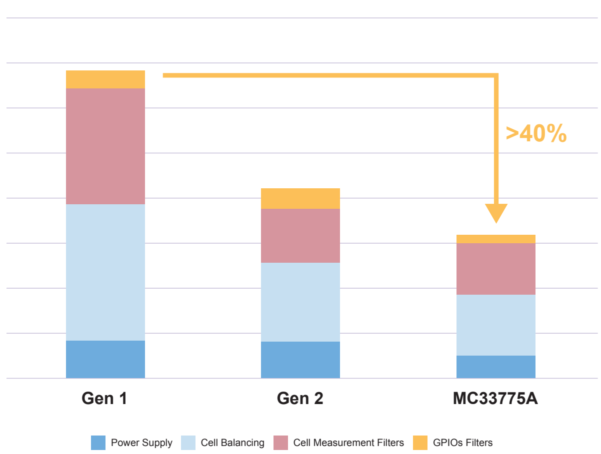

Figure 6: External BOM Reduction

BALANCING CONCEPT

The cell voltage balancing function allows discharging individual cells based on a current defined by external resistors. Different PWM duty cycle can be used to define the average current. The internal switches are controlled by individual balancing timers and/ or by the cell voltage. Additionally, the balancing process can be interrupted based on an external temperature in order to manage the power dissipation of the balancing resistors.

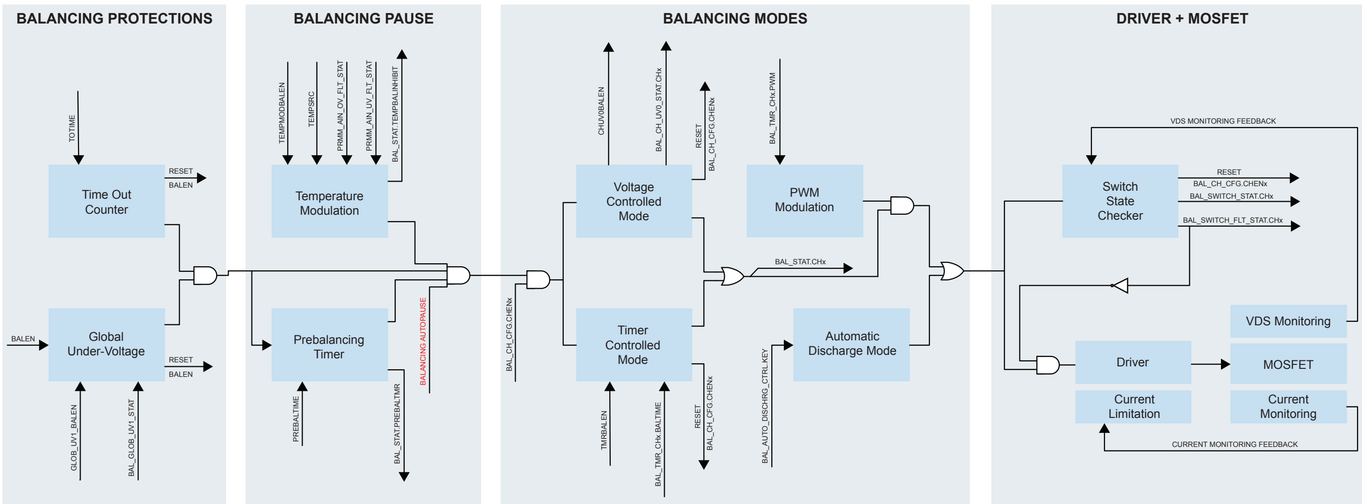

Figure 7: Functional diagram of the balancing functionality

BALANCING FEATURES REUSED FROM PREVIOUS PRODUCT GENERATIONS

- Timer controlled balancing mode is used to balance the cells during an individual configurable time
- Current limitation of the balancing MOSFETs
- Switch state checker of the balancing MOSFETs
- Auto pause to exclude effect of balancing current on the measurement
- Simultaneous cell balancing up to 300 mA

NEW BALANCING PROTECTIONS MECHANISMS TO AVOID DEEP DISCHARGE OF BATTERY CELLS

- Global balancing timeout timer is used to make sure all balancing process are stopped after the configured time
- Global under-voltage protection is used to make sure all balancing process are stopped if a configured minimum cell voltage has been reached by any cell.

NEW BALANCING PAUSE FUNCTIONS TO DELAY OR INTERRUPT THE BALANCING PROCESS

- Pre-balancing timer is used to delay the balancing process after the BMS went to sleep to allow the battery to cool down
- Temperature-controlled balancing is used to interrupt the balancing process based on the temperature of the external balancing resistors.

NEW BALANCING MODES TO OPTIMIZE THE BALANCING PROCESS

- Voltage-controlled mode is used to balance all cells down to a configurable voltage threshold
- PWM modulation is used to adapt the RMS balancing current / heat in the external balancing resistors in case less discharge current is needed
- Automatic discharge allows an emergency discharge of the cells to reduce the stored energy in the battery to a minimum voltage which allow the device still to operate for diagnostics (~12 V).

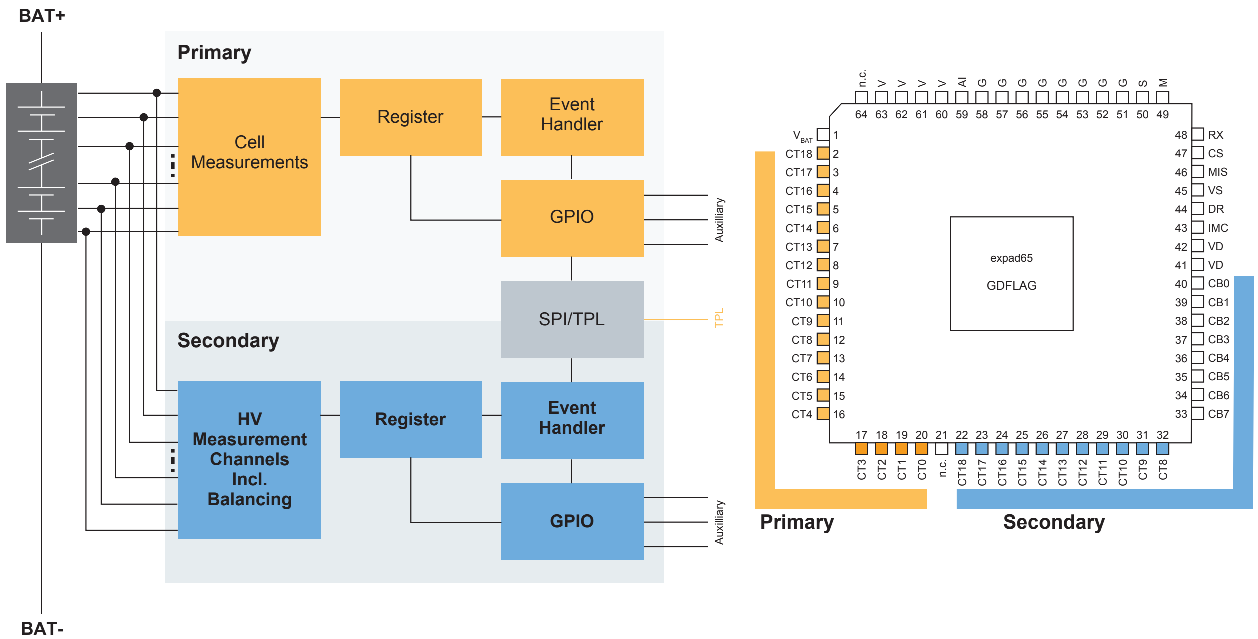

Figure 8: Fully redundant device architecture

FUNCTIONAL SAFETY CONCEPT DESIGNED FOR 800 V+ BATTERIES

As battery voltages are moving from 400 V to 800 V and beyond, challenges are arising on the functional safety side. Increasing the battery voltages comes with the unavoidable fact of having more cell-sensing devices in the system. This increment of devices is translated into a functional safety challenge since the total failure-in-time (FIT) probability is increased. On the other side, the maximum residual FIT allowed by the ISO 26262:2018 standard does not change. For systems with ASIL D safety goals, the ISO standard allows a maximum of 10 residual FIT to be shared between all subsystems (BMU, BJB and CMU).

NXP tackles this challenge by using fully independent redundant measurement paths as well as independent pin-out architectures to avoid common cause failures.

Cell voltage and temperature measurement faults become latent faults due to the fully independent measurement paths, reducing the Single-Point-Failure metrics and, consequently, device residual FIT. The measurement availability is drastically increased since there is no dependency on the reliable safety concept that can be easily justified at the system level.

The MC33775A offers ASIL D support for high-precision cell voltage, module voltage, and temperature measurements. Additionally, the device provides an extensive set of passive cell voltage balancing features to equalize the individual cell voltages across the battery stack.

SUMMARY

For close to two decades, Fraunhofer IISB has been building a deep knowledge base with respect to high-voltage battery management. Fraunhofer IISB's foxBMS® initiative offers an open-source BMS platform dedicated to the design of complex BMS for a broad kind of stationary and mobile applications areas, including industrial, airborne, waterborne, railways, and military applications.

The latest generation of foxBMS® platform features NXP's MC33775A 14-channel Li-Ion battery cell controller integrated circuit.

The MC33775A has been designed from the ground up for use in safety-critical high-voltage battery management systems for a wide range of deployments. In addition to handling all of the BMS topologies that are used today to implement today's 400 V, 800 V, and 1,500 V systems, a next-generation BMS employing MC33775A battery cell controller ICs can, in principle, support voltages up to 2,800 V.

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