Auto Power-SOI: Shaping the Future of Battery Monitoring Technology

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Abstract

Cell-to-pack (CTP) is the prevailing method for EV battery assembly due to its compact size, cost-effectiveness, streamlined assembly with fewer connections, and enhanced reliability. The primary challenges in Battery Monitoring ICs (BMIC) for CTP lie in supporting more series-connected monitoring cells and achieving greater measurement precision. This presentation outlines how Auto Power-SOI technology facilitates the development of advanced BMICs that excel in precision, integrate high and low voltage components on a single die, and meet stringent functional safety demands, addressing the evolving needs of CTP technology in EV batteries.

1 Introduction

The automotive industry's shift towards electric vehicles (EVs) has accelerated the demand for high-performance, reliable, and safe battery systems. As EVs gain mainstream adoption, automakers and battery manufacturers are under pressure to develop advanced battery technologies that offer longer driving ranges, faster charging times, and enhanced safety features.

At the forefront of innovation are next-generation Battery Monitoring ICs (BMICs) supporting cell-to-pack (CTP) battery pack configurations. BMICs monitor and manage individual battery cells' performance, ensuring safe and efficient operation of EV battery systems.

CTP configurations integrate battery monitoring, battery management and other functions directly into the battery pack, eliminating the need for separate modules. This approach offers several advantages:

A. Smaller size: Compact battery pack designs crucial for space-constrained EVs.
B. Reduced bill of materials: Fewer components lead to cost savings and improved manufacturing efficiency.
C. Simplified assembly: Streamlined process with fewer interconnections and potential failure points.
D. Heightened reliability: Minimized interconnections reduce the risk of failures associated with module-to-module connections.

Automakers like BYD, SAIC and others are leading the way in adopting CTP configurations, which are vital for ensuring the functional safety and reliability of next-generation EV battery systems. This adoption has accelerated further, with CTP-equipped vehicles capturing a remarkable 48.6% market share from January to October 2023. Projections indicate that by the end of 2023, CTP configurations will surpass the 50% mark, becoming the predominant choice for new energy vehicle battery systems. [1]

2 Cell-To-Pack Battery Monitoring IC Trends and Challenges

2.1 CTP BMIC Trends

With the evolution of CTP technology, the trends of BMICs are summarized below.

2.1.1 Compact and Efficient Design

CTP technology demands BMICs to be capable of monitoring a higher number of cells in series and to provide smaller solution size. Traditional battery pack configurations often have a limited number of cells connected in series within a

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module, typically up to 18 cells. However, CTP architectures eliminate the modular approach, allowing for a higher number of cells to be connected in series within a single pack, often exceeding 100 cells or more.

This increase in the number of cells in series poses a significant challenge for BMICs, as they need to be designed to handle higher voltage levels and more complex monitoring requirements. As a result, each BMICs need to be capable of monitoring a higher number of cells in series (up to 30 cells). This next generation BMICs must be able to withstand these higher voltage levels while maintaining accurate cell monitoring and management capabilities.

BMIC designs are trending towards integration and miniaturization. Semiconductor manufacturers are developing highly integrated BMICs that combine multiple functionalities, such as cell voltage monitoring, temperature monitoring, cell balancing, and communication interfaces, into a single chip. This integration helps reduce the overall component count, board space, and wiring complexity, enabling more compact and streamlined battery pack designs. Additionally, miniaturization efforts are focused on reducing the package size and footprint of BMICs through advanced packaging technologies and die shrinks.

2.1.2 High Measurement Precision

As CTP configurations integrate a larger number of cells in series, precise and accurate cell monitoring over wide temperature ranges and harsh environments becomes crucial. Even minute measurement errors can accumulate, impacting battery performance, safety, and driving range. Consequently, BMICs are prioritizing achieving the highest measurement precision by minimizing error sources.

Advanced analog-to-digital converter (ADC) architectures, calibration techniques, and error compensation algorithms are employed to reduce measurement inaccuracies. High-resolution ADCs, up to 16-bit or higher, enable precise voltage monitoring, while on-chip temperature sensors and signal conditioning circuits compensate for thermal and environmental effects.

Error sources like offset, gain, and non-linearity errors are minimized through trimming, auto-calibration, and digital compensation. Robust design practices, like isolating analog and digital domains, mitigate noise and interference.

Stringent accuracy specifications, such as ±1mV cell voltage measurement error over -40°C to +125°C, ensure optimal battery management and extended driving ranges.

2.1.3 Functional Safety

Functional safety (FuSa) is a top priority in the automotive industry, particularly for electric vehicles (EVs), where battery systems are critical components. Ensuring the safe operation of these systems is paramount to prevent hazards that could lead to injuries or fatalities. To address this, BMICs are integrating advanced safety features and redundancy measures to meet the strictest safety requirements, such as Automotive Safety Integrity Level D (ASIL D), the highest level defined by ISO 26262 for automotive functional safety.

ASIL D certification mandates rigorous safety measures, including hardware and software redundancy, fault detection and mitigation mechanisms, and stringent design processes. BMICs designed for ASIL D compliance incorporate redundant voltage measurement channels, error-correcting codes for communication interfaces, and built-in self-test (BIST) capabilities to detect and recover from faults.

2.1.4 Communication Protocol

BMICs are incorporating advanced communication protocols, such as Controller Area Network (CAN), Local Interconnect Network (LIN), and Serial Peripheral Interface (SPI), to enable seamless and efficient interaction with the vehicle's Battery Management System (BMS) and other critical control systems.

Additionally, advanced communication protocols in BMICs facilitate Over-the-Air (OTA) firmware updates, allowing manufacturers to remotely update the chip's software and introduce new features or performance enhancements without the need for physical intervention. This capability enhances the overall flexibility and longevity of the vehicle's battery management system, contributing to improved safety, efficiency, and user experience throughout the vehicle's lifespan.

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2.1.5 Advanced Diagnostics

BMICs are incorporating advanced diagnostic capabilities to detect and report battery faults, anomalies, and degradation at an early stage. Some of these diagnostic features include voltage monitoring, temperature sensing, cell balancing, impedance tracking algorithms etc. By continuously analyzing battery data, BMICs can identify potential issues like cell imbalances, thermal runaway risks, or capacity fade. Upon detecting anomalies, BMICs can promptly report these conditions to the Battery Management System (BMS) and vehicle control units. This early detection enables timely maintenance interventions, preventing further damage and enhancing overall battery pack safety and longevity in electric vehicles.

2.2 CTP BMIC Challenges

As CTP technology evolves, the challenges faced by BMICs can be summarized as follows.

2.2.1 Increased Complexity

Monitoring an increasing number of series-connected cells in CTP significantly complicates the design of BMICs. Engineers face the challenge of balancing simplicity in BMIC architecture while ensuring robust functionality for accurate cell monitoring, balancing, fault detection, thermal management, and communication with vehicle systems. Achieving this balance is crucial for cost-effective and reliable battery management solutions in electric vehicles.

2.2.2 Cost Considerations

Although CTP technology has the potential to reduce the bill of materials (BOM), BMICs must strike a balance between cost-effectiveness and incorporating advanced features. This trade-off presents a significant challenge. CTP architectures provide a cost-reduction pathway by integrating critical functions. However, the inclusion of sophisticated capabilities within BMICs, such as comprehensive diagnostics, precision monitoring, and advanced balancing algorithms, inevitably increases complexity and associated expenses. Therefore, designers of BMICs must navigate a complex trade-off between reducing manufacturing costs and delivering durable and feature-rich battery management solutions that meet the strict requirements of electric vehicle applications.

2.2.3 Redundancy and Fail-Safe Systems

Designing BMICs that balance functional safety, redundancy, and cost is a challenging task. To meet strict safety standards, these circuits must include fault detection and mitigation mechanisms, as well as redundant architectures to prevent single-point failures. Concurrently, the exigency of curtailing manufacturing expenditures imposes constraints on the complexity and resource footprint of the BMIC. Reconciling these seemingly antithetical objectives demands a judicious optimization of the system's intricate tradespace, necessitating a delicate balance between safety assurances, reliability enhancements, and economic viability to forge cost-effective yet uncompromising battery management solutions.

3 Auto Power-SOI Technology: A Game-Changer

Auto Power-SOI is emerging as an important enabler in addressing the evolving trends and challenges associated with BMICs for the latest CTP battery configuration in EVs.

3.1 Auto Power-SOI for Compact and Efficient Design

3.1.1 Higher Monolithic Integration of High-Voltage and Low-Voltage Blocks on the Same Die

Auto Power-SOI technology facilitates the monolithic integration of high-voltage and low-voltage functional blocks on the same die, while enabling a reduced die area footprint. This is achieved through the deployment of Silicon-on-Insulator (SOI) substrates in conjunction with Deep Trench Isolation (DTI) techniques. The buried oxide layer of SOI wafers provides robust dielectric isolation between the high-voltage and low-voltage domains, mitigating latch up and minimizing parasitic coupling. Complementarily, DTI structures form effective vertical isolation barriers, allowing high-voltage and low-voltage devices to coexist within close proximity on the die. This integration approach yields compact BMIC implementations with reduced form factors, benefiting CTP battery configurations in EVs where board area constraints are critical. Figure 1 illustrates the comparison of required device-to-device isolation spacing based on currently available technologies in the market.

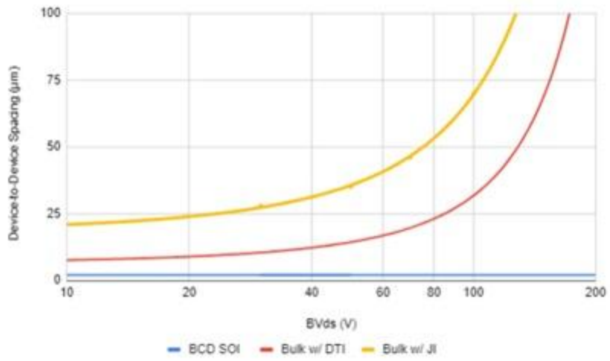

Fig. 1 Device-to-device isolation spacing based on BCD with Auto Power-SOI and DTI, BCD with bulk and DTI and BCD with bulk and junction isolation

3.1.2 High Integration of Main Functions and Redundancy on the Same Die

For high functional safety systems, redundancy blocks are required to prevent failures in main function blocks. Conventionally, two separate ICs were needed to ensure redundancy and meet stringent FuSa requirements like ASIL D. However, this approach increases system size, cost, and failure-in-time (FIT) rate due to higher bill-of-materials (BOM).

As shown in Fig. 2, Automotive Power-SOI enables monolithic integration of main and redundant blocks on a single die by leveraging deep trench isolation (DTI) and buried oxide (BOX) layers for full electrical isolation. Main and redundant blocks reside on separate silicon islands, meeting FuSa redundancy mandates.

This monolithic BMIC solution approach significantly reduces system size and cost compared to multi-chip approaches. Lower BOM count also optimizes system FIT rates, facilitating compliance with stringent automotive safety integrity levels like ASIL D.

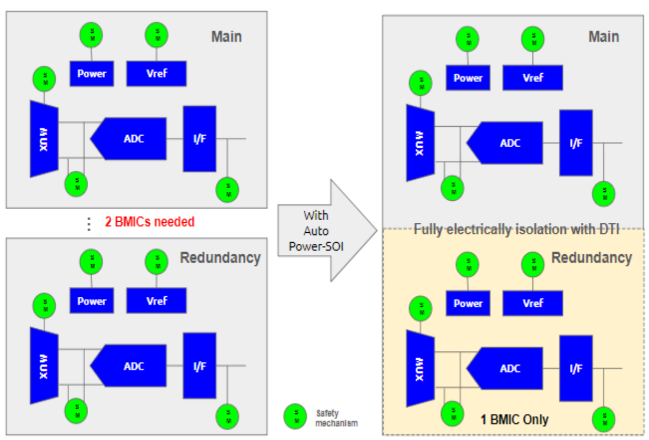

Fig. 2 Monolithic integration of main and redundancy blocks on the same die with DTI and BOX

3.2 Auto Power-SOI for Higher Measurement Precision

3.2.1 Low Leakage Current for High Measurement Accuracy

Auto Power-SOI structure, comprising a BOX layer, minimizes leakage currents at elevated temperatures (e.g. 125°C) compared to conventional bulk silicon substrates. The BOX acts as an insulator, suppressing substrate leakage paths that increase exponentially with temperature in bulk devices. Figure 3 shows the comparison of leakage currents for both Auto Power-SOI with DTI and bulk substrate with junction isolation [2].

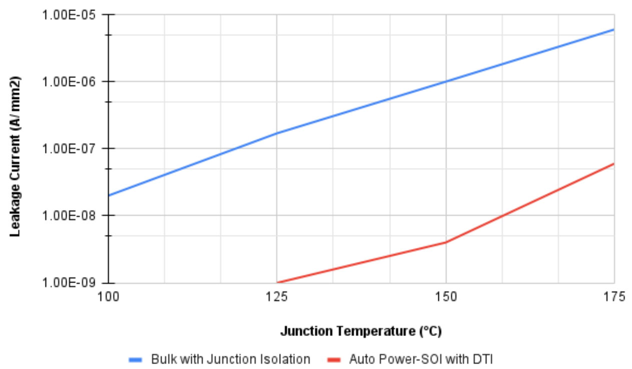

Fig. 3 Comparison of leakage currents for Auto Power-SOI with DTI and bulk substrate with junction isolation [2]

Auto Power-SOI's remarkable low leakage current, even at elevated junction temperatures exceeding 125º, simplifies the design of high-precision analog circuits. Auto Power-SOI's suppressed leakage currents at high temperatures, eliminating need for temperature compensation circuitry, facilitate design of precision reference circuits with reduced drifts over temperature (voltage, gain, etc.). This enhances measurement accuracy of analog-to-digital converters (ADCs) by minimizing temperature-induced errors, critical for reliable high-temperature automotive BMICs.

3.2.2 High Noise Immunity and Less Cross-talk for High Measurement Accuracy

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Leveraging BOX and DTI in Auto Power-SOI, the technology mitigates noise coupling and crosstalk issues prevalent in highly integrated BMICs with multiple measurement channels. The intrinsic isolation provided by the BOX/DTI stack significantly reduces capacitive and substrate noise coupling between adjacent channels. This enhances measurement accuracy for ADCs by minimizing inter-channel interference as channel counts scale higher in next generation BMICs.

3.3 Auto Power-SOI for Higher FuSa

3.3.1 Low FIT with High Integration

Auto Power-SOI enables higher monolithic integration, reducing the chip count per system. Fewer components decrease the overall system failure-in-time (FIT) rate by minimizing interconnect and other failure points. This chip-level integration enhances system reliability, a critical requirement for achieving automotive functional safety targets. The monolithic integration facilitated by Auto Power-SOI's DTI & BOX isolations directly improve the mean time between failures (MTBF) for safety-critical applications such as BMICs.

3.3.2 High Robustness & Reliability

Auto Power-SOI's intrinsic robustness against latch-up, electrostatic discharge (ESD), electromagnetic compatibility (EMC) issues and electromagnetic interference (EMI) minimizes systematic faults stemming from the manufacturing process technology. The SOI structure with BOX and DTI layers mitigates these reliability concerns. This robust process reduces the burden of implementing design techniques to tolerate process-induced faults, simplifying the development of high functional safety (FuSa) compliant systems adhering to stringent automotive standards like ISO 26262.

4 Conclusion

In summary, Auto Power-SOI is a pivotal enabling technology for advanced BMIC designs targeting CTP battery architectures in EVs. The technology's monolithic integration capabilities, facilitated by DTI and BOX layers, allow more compact, power-efficient and reliable BMIC implementations.

Auto Power-SOI's inherent robustness against latch-up, ESD, EMC/EMI issues enhances systematic reliability. Reduced chip counts decrease overall system FIT rates, while integrated redundancy provisions assist in achieving stringent automotive functional safety requirements like ISO 26262 ASIL-D.

As CTP configurations proliferate and BMIC complexity increases, Automotive Power-SOI remains a key driver enabling next-generation EV battery management solutions to meet evolving performance, safety and efficiency demands.

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