How Smart Cells Will Help Unlock Future Vehicle Architectures

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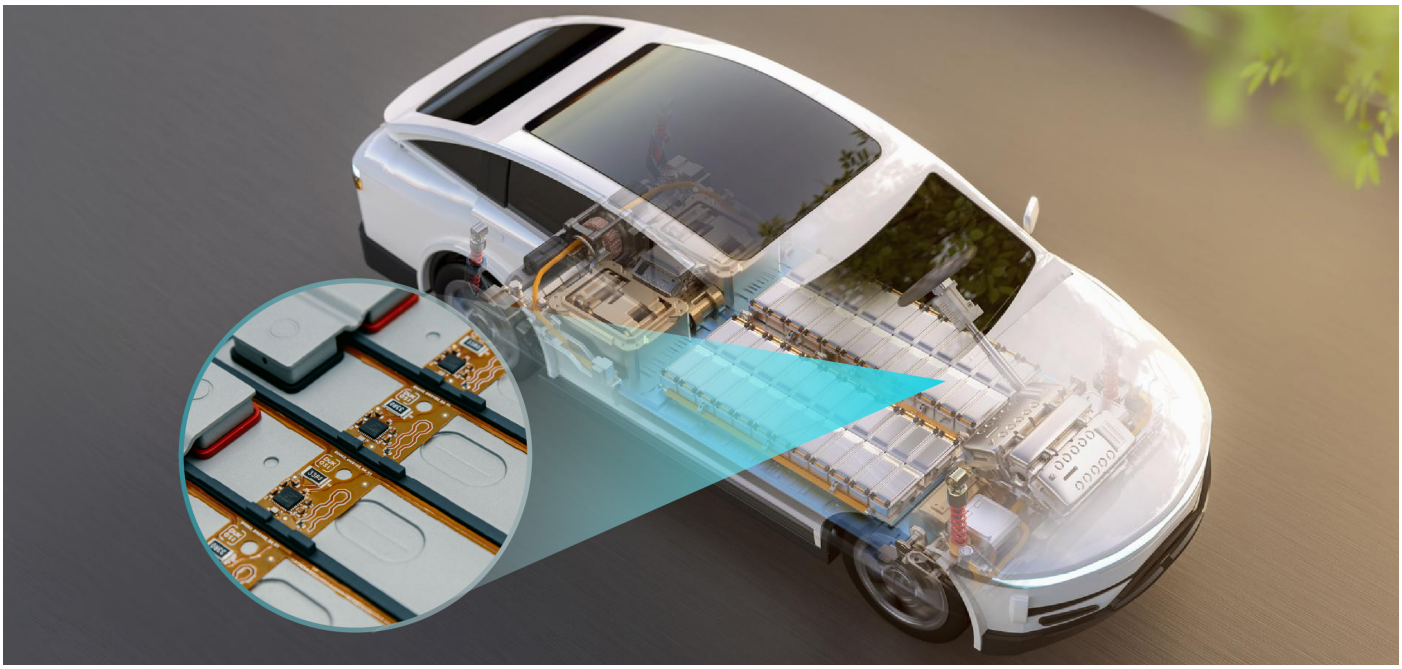
The development of electric drivetrains goes hand in hand with advanced electronics that power infotainment, connectivity, driver assistance systems, and the latest trend of software-defined, or even AI-defined vehicle experiences.

Zonal architectures are increasingly shaping these vehicles, with zonal controllers communicating directly with the vehicle's central processor to provide a holistic view of the system.

This capability is particularly important in AI-defined vehicles that use intelligent agents to sense, interpret and act autonomously, which requires visibility across multiple domains to operate safely and effectively.



An example of Dukosi Cell Monitors inside an EV battery.

This shift is already happening, with Volkswagen Group China having started production of its China Electronic Architecture (CEA), a zonal electronic architecture that reduces the number of ECUs by around 30%, shortens overall vehicle development cycles by up to 30%, and reduces development costs for new models by up to 50%.[1]

As these architectures consolidate vehicle functions around central compute and zonal control, battery systems are also likely to evolve and traditional battery management system (BMS) functions may also be disrupted. Some capabilities could be absorbed into the zone's power controller or even the vehicle's central processor to create a more unified approach to managing energy storage and power delivery vehicle-wide. This "zero-BMS" or virtualized BMS concept has already been proposed, but it cannot operate in isolation of high-quality raw data. This is where Smart Cells become essential.

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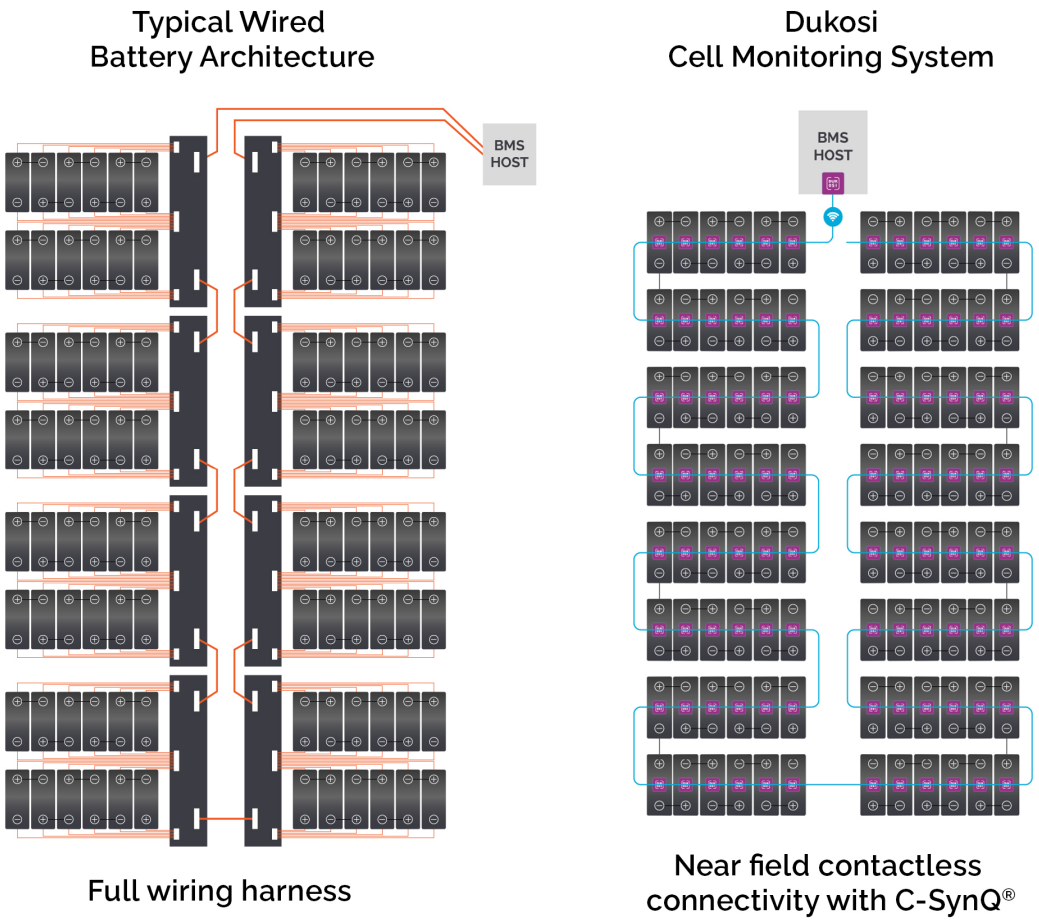
Why Battery Intelligence Must Move Closer to the Cell

In a traditional BMS, cells are grouped into modules and monitored through multi-cell electronics connected by extensive wiring. This approach has served the industry well, but it also introduces compromises. Cell measurements can be affected by wiring parasitics, busbar impedance, electrical noise, and differences in communication paths across the pack. Data is often collected and interpreted at module level, which can limit visibility into the behavior of individual cells and reduce the fidelity of the information available to higher-level vehicle systems.



Dukosi DKCMS versus a typical wired battery architecture.

These limitations become more significant as electric vehicles become more software-defined. Advanced control strategies depend on synchronized, repeatable, and trustworthy data. More accurate State of Charge (SoC)[2] and State of Health (SoH)[3] estimation can help reduce conservative design margins, improve usable energy, support faster diagnostics, and enable more confident safety decisions. However, these gains depend on the BMS having access to high-quality information from every cell in the pack.

Battery architecture is also changing due to manufacturing and platform pressures. Automakers are slowly moving toward more advanced pack designs, including cell-to-pack and cell-to-chassis, as they seek to improve power density, reduce wiring and assembly complexity, as well as needing to simplify validation across multiple vehicle platforms. Fixed module groupings can restrict this flexibility, particularly where vehicle architectures need to evolve quickly or support different pack shapes or capacity requirements.

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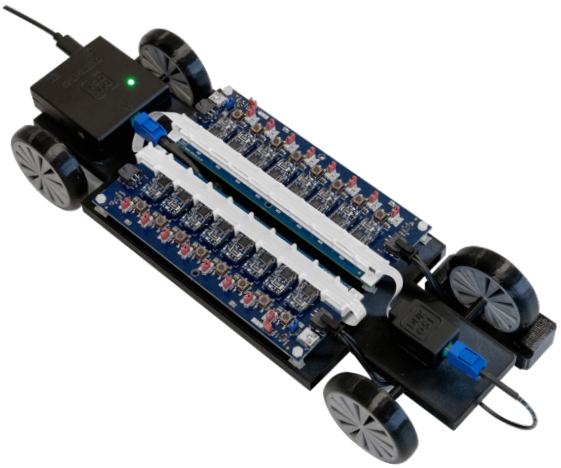
From Better Battery Data to Cell-Level Intelligence

In many applications, lifecycle expectations are changing as well. Batteries are increasingly expected to carry critical information that supports regulatory compliance, warranty analysis, service decisions, second-life assessment, and recycling[4]. This can be achieved with data captured at the module or pack level. However extending this approac to each cell represents an opportunity to unlock the full sustainability potential of the circular economy[5].



Dukosi DKCMS Automotive Demonstrator.

Smart Cells address this shift by making each cell a more active participant in the battery system. Compared with conventional multi-cell monitoring, they place sensing, processing, and critically, data storage closer to the electrochemical source. This enables a wider range of parameters to be captured at the cell, including voltage, temperature[6], current, pressure, and even gas indicators, while supporting greater measurement accuracy through shorter, uniform wiring and low-voltage circuitry.

Because the measurement path can be consistent from cell to cell, Smart Cells also improve repeatability across the pack, helping ensure cell-to-cell comparisons reflect real differences in cell behavior rather than variation introduced by the monitoring architecture.

Local processing further enables multiple data sources to be interpreted directly at the cell, reducing communication load and latency while creating the opportunity to retain manufacturing and operational history with each cell. This opens the door to improved diagnostics, lifecycle management, serviceability, and regulatory traceability.

Therefore, the key question is not whether cell-level intelligence is useful, it is how that intelligence can be implemented at scale without adding unacceptable complexity, cost, wiring, or reliability risk.

Smart Cells: Accuracy and Simplicity

Dukosi Cell Monitors, Smart Cell ICs[7], are an integral part of the Dukosi Cell Monitoring System (DKCMS®)[8]. Each Cell Monitor is dedicated to a single cell, enabling voltage measurement to be optimized for maximum accuracy while also providing highly accurate temperature monitoring and long-term data storage capability.

In conventional battery architectures, interconnect inductance and busbar impedance can create large voltage spikes when contactors open or close, requiring TVS diodes to protect the analog front end. This issue becomes more severe as pack voltages increase. By contrast, a Smart Cell IC is connected only to, and powered by, its own cell, making it inherently immune to high-voltage transients while eliminating the need for additional voltage suppression components.

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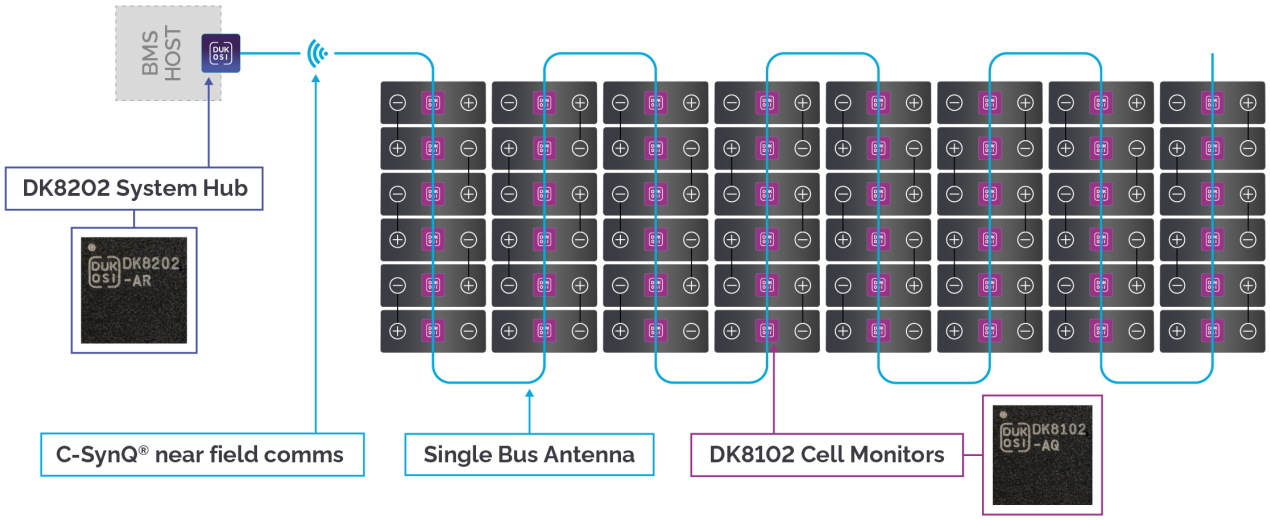
The challenge, however, lies in making Smart Cells practical at the pack level. Traditional battery communication systems were not designed for this model, and conventional wiring cannot realistically support hundreds of Smart Cell ICs that must capture voltage and temperature data simultaneously and deliver it with deterministic latency.

In other words, the benefits of cell-level intelligence are clear, but unlocking them depends on a communications architecture capable of meeting the scale, timing, and reliability requirements of next-generation battery systems.



DKCMS-based Smart Cell battery design.

Smart Cell Enabler: Communications

Making Smart Cells practical at the pack level and scalable requires a battery communications architecture designed specifically for dense, electrically noisy environments. Far field wireless networks can appear attractive for reducing battery pack wiring, but communication reliability depends on conditions that are difficult to guarantee inside a pack, where metal structures, shielding, cell density, and electromagnetic interference (EMI) all co-exist, affecting signal integrity.

DKCMS takes a different approach, using near field RF technology[9] and only a small air-gap interface between each Cell Monitor and the antenna, which serves as the principal communication bus. Unlike far field wireless systems, this approach does not depend on long distance line-of-sight transmission, making it better suited to densely packed battery assemblies. This scalability has been demonstrated with a single 10-meter bus antenna successfully communicating with all Cell Monitors. For applications requiring larger packs or higher cell counts, DKCMS® can be extended into a hierarchical multi-hub tree architecture that allows very large networks to be managed efficiently while preserving synchronous data capture.

Combined with Dukosi's proprietary C-SynQ®[10,11] communications protocol, which was designed expressly for battery networks, the protocol triggers simultaneous data acquisition across all cells, creating a unified snapshot of the entire battery before delivering that data to the BMS processor with deterministic latency. The system achieves effectively zero data loss, with reliability exceeding 99.999999%, even in systems heavily exposed to localized and focused interference sources.

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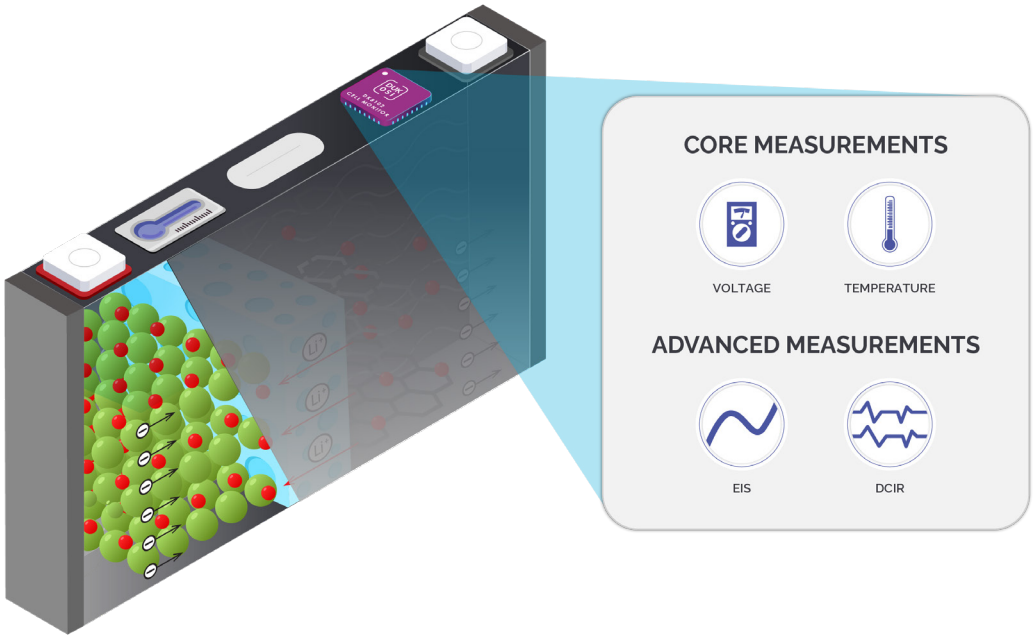
Powerful Analytics Through Advanced Measurements

For centralized and software-defined vehicle architectures, the value of Smart Cells extends beyond real-time monitoring. If more battery management functions are interpreted by a zonal controller, central processor, or higher-level software layer, the system needs data that can support deeper diagnostics and more predictive decision-making.

What makes DKCMS especially powerful is its ability to enable deeper analytics through advanced measurements, such as DCIR (Direct Current Internal Resistance)[12,13] and EIS (Electrochemical Impedance Spectroscopy).



Dukosi brings Core Measurements and Advanced Measurements directly to the cell.

These new analytical techniques provide insight into cell condition and behavior, giving another layer of data towards the assessment of each cell's state, performance, degradation, and long-term health. Unlike alternative approaches, the Cell Monitors are a self-contained solution, so measurements can be performed while the battery is in a quiet state, enabling the use of low-current stimulus signals. This creates repeatable, low-noise conditions that produce results comparable to those achieved using high-performance laboratory equipment.

The resulting data can feed into more accurate State of Health estimation, diagnostics, and long-term trend monitoring. For OEMs, this creates an opportunity to move beyond traditional monitoring toward battery systems that can be managed more intelligently and effectively throughout their operational life.

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Conclusion

Smart Cells represent the most effective approach to battery monitoring, but they must combine the right networking technologies to deliver a reliable and scalable solution. As Dukosi has demonstrated, Smart Cells are becoming both technically practical and commercially compelling, driving improvements across the battery value chain, including cell manufacturing, pack assembly, operational performance, safety, traceability, maintainability, and sustainability.

As vehicle architectures continue to centralize compute the need for Smart Cells will only increase. Dukosi is showing that the technology is ready, the economics are proven, and the regulatory landscape is evolving in its favor. Smart Cells are set to lead the next generation of battery innovation while creating a significant market opportunity.

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Dukosi Ltd develops revolutionary technologies that dramatically improve the performance, safety, and efficiency of battery systems, and enable a more sustainable battery value chain. The company provides a unique cell monitoring solution based on chip-on-cell technology and C-SynQ® communication protocol for electric vehicles (EV), industrial transportation and stationary battery energy storage markets.

For more information, email info@dukosi.com or visit www.dukosi.com.

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