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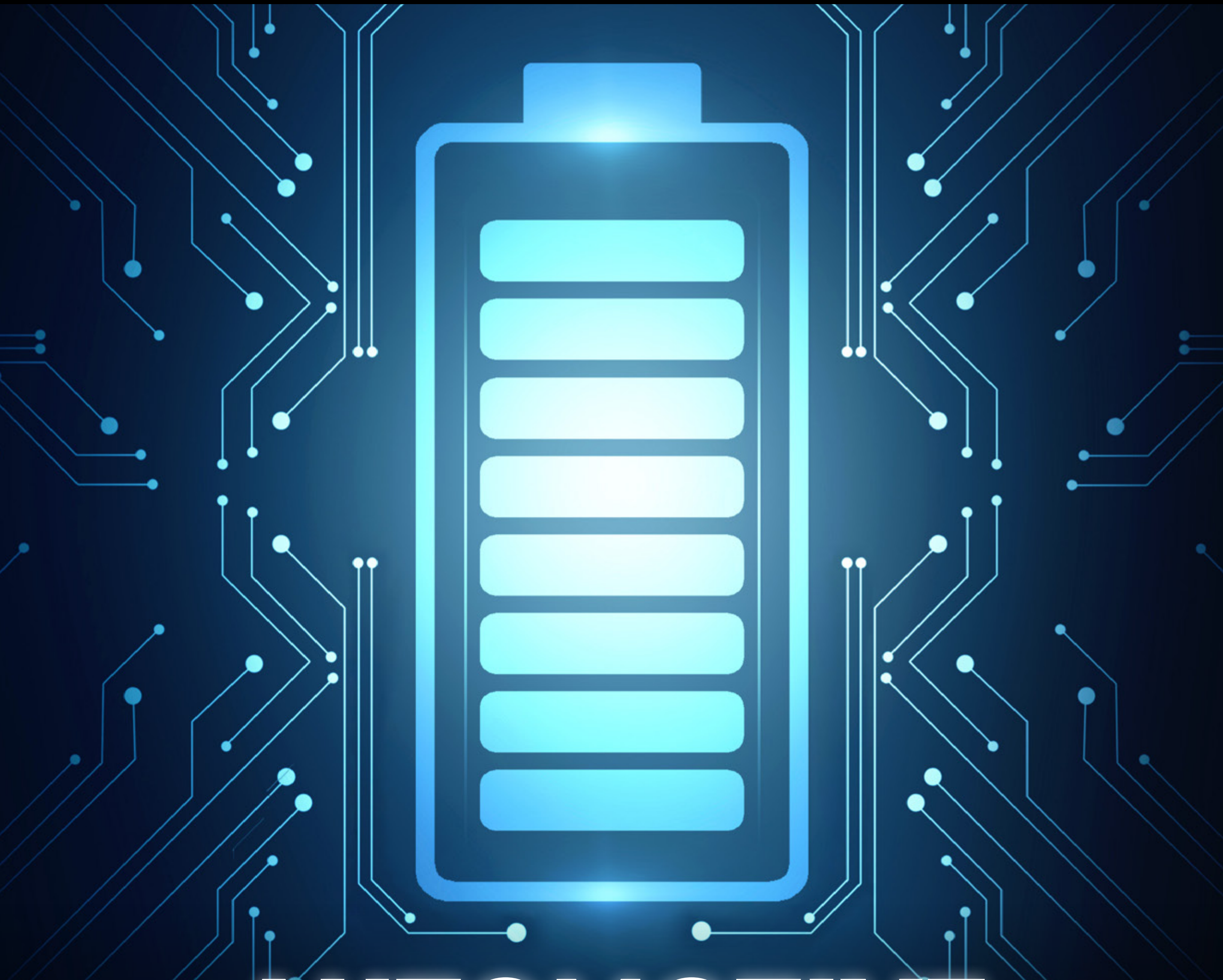

AUTOMOTIVE BATTERY MANAGEMENT

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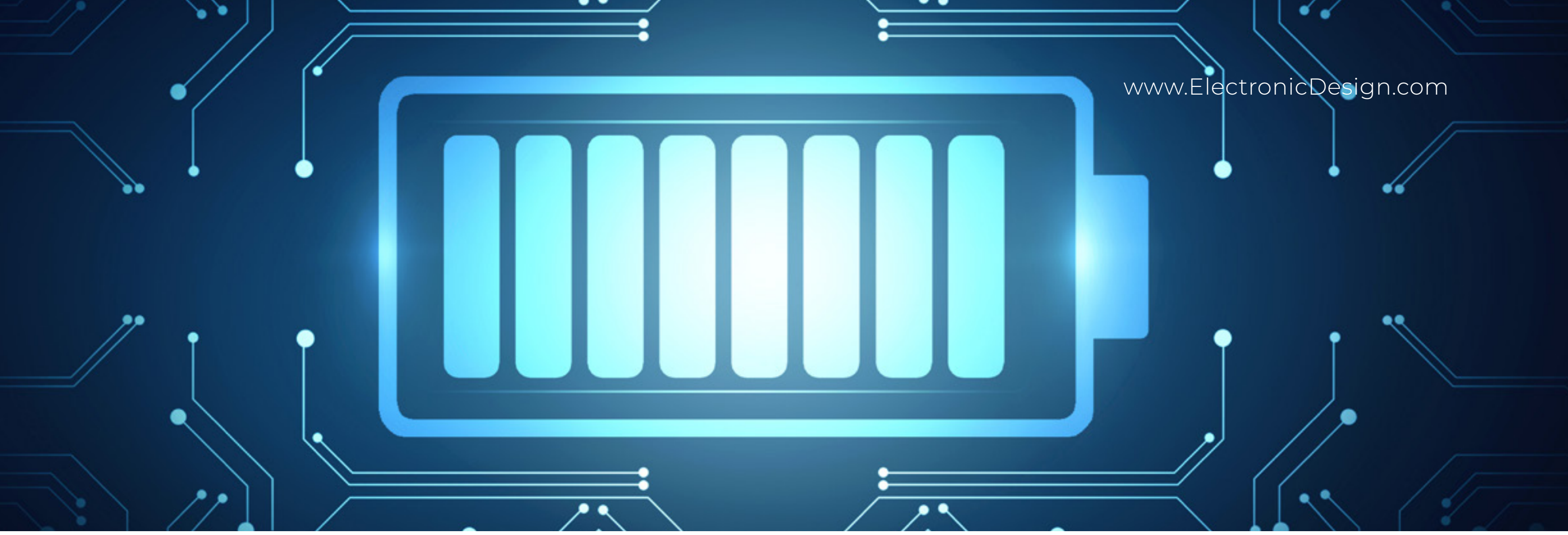

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A Look Inside Battery-Management Systems

Careful consideration of battery requirements and battery-life goals will help determine the right architecture, functional blocks, and related ICs to create an optimal battery-management system and charging scheme.

By Ryan Roderick

Today's electronic devices have higher mobility and are greener than ever before. Battery advances are fueling this progression in a wide range of products, from portable power tools to plug-in hybrid electric vehicles to wireless speakers. In recent years, battery efficiency—the amount of power a battery can output with respect to size and weight—has dramatically improved.

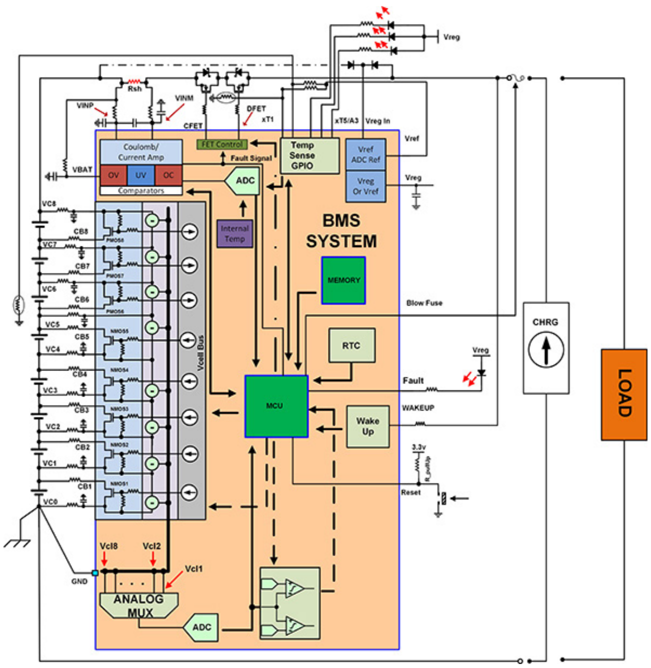
Ryan Roderick, Principal Electrical Engineer, Precision Products Group, Intersil Corp.

Think about the weight and bulkiness of a car battery. Its main purpose is to start the car. With recent advances, however, you can now jumpstart your car with a lithium-ion battery, which is the size of your hand and weighs only a couple of pounds.

Perpetually transforming battery technology has prompted many newcomers to become knowledgeable in battery-management system design. This article provides a beginner's guide to the battery-management-system (BMS) architecture, discusses the major functional blocks, and explains the importance of each block to the BMS system.

BATTERY-MANAGEMENT-SYSTEM ARCHITECTURE

A battery-management system (BMS) typically consists of several functional blocks, including cutoff field-effect transmitters (FETs), fuel-gauge monitor, cell-voltage monitor, cell-voltage balance, real-time clock, temperature monitors, and a state machine (*Fig. 1*). Several types of BMS ICs are available.



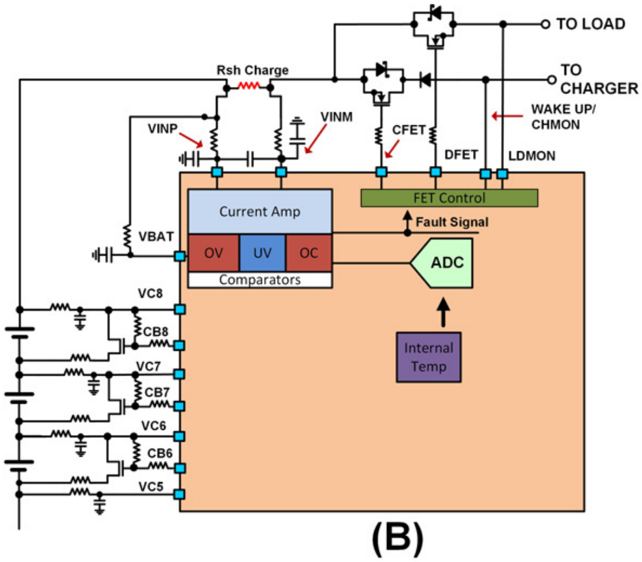
1. A battery-management system (BMS) includes multiple building blocks.

The grouping of functional blocks vary widely from a simple analog front end, such as the [ISL94208] that offers balancing and monitoring and requires a micro-controller, to a standalone integrated solution that runs autonomously (e.g., the [ISL94203]). Now let's examine the purpose and technology behind each block, as well as the pros and cons of each technology.

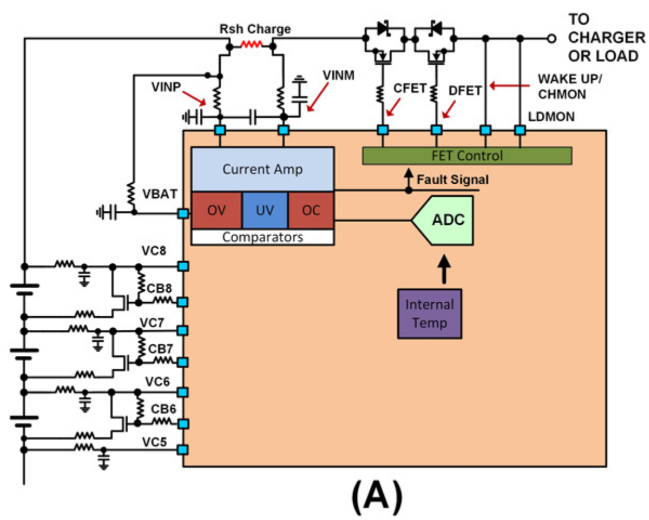
CUTOFF FETS AND FET DRIVER

A FET-driver functional block is responsible for the battery pack's connection and isolation between the load and charger. The FET driver's behavior is predicated on measurements from battery-cell voltages, current measurements, and real-time detection circuitry. Figure 2 illustrates two different types of FET connections between the load and charger, and the battery pack.

Figure 2A requires the fewest number of connections to the battery pack and limits the battery pack operating modes to either charge, discharge, or sleep. The current flow direction and the behavior of a specific real-time test determine the device's state.



2. Shown are cutoff FET schematics for single connection between the load and charger (A), and a two-terminal connection that allows for simultaneous charging and discharging (B).



For example, the ISL94203 has a channel monitor (CHMON) that monitors the voltage on the right side of the cutoff FETs. If a charger is connected and the battery pack is isolated from it, the current injected toward the battery pack will cause the voltage to rise to the charger's maximum supply voltage. The voltage level at CHMON is tripped, which lets the

BMS device know a charger is present. To determine a load connection, a current is injected into the load to determine if a load is present. If the voltage at the pin does not rise significantly when injecting current, the outcome determines that a load is present. The FET driver's DFET then turns on. The connection scheme in Figure 2B allows the battery pack to operate while charging.

FET drivers can be designed to connect to the high or low side of a battery pack. A high-side connection requires a charge-pump driver to activate the NMOS FETs. When using a high-side driver, it allows for a solid ground reference for the rest of the circuitry. Low-side FET driver connections are found in some integrated solutions to reduce cost, because they don't need a charge pump. They also don't require high-voltage devices, which consume a larger die area. Using the cutoff FETs on the low side floats the battery pack's ground connection, making it more susceptible to noise injected into the measurement. This affects the performance of some ICs.

FUEL-GAUGE/CURRENT MEASUREMENTS

The fuel-gauge functional block keeps track of the charge entering and exiting the battery pack. Charge is the product of current and time. Several different techniques can be used when designing a fuel gauge.

A current-sense amplifier and an MCU with an embedded low-resolution analog-to-digital converter (ADC) is one current-measurement method. The current-sense amplifier, which operates in high common-mode environments, amplifies the signal, enabling higher-resolution measurements. This design technique sacrifices dynamic range, though. Other techniques use a high-resolution ADC, or a costly fuel-gauge IC. Understanding the load behavior's current consumption versus time determines the best type of fuel-gauge design.

The most accurate and cost-efficient solution is to measure the voltage across a sense resistor using a 16-bit or higher ADC with low offset and high common-mode rating. A high-resolution ADC offers a large dynamic range at the expense of speed. If the battery is connected to an erratic load, such as an electric vehicle, the slow ADC may miss high-magnitude and high-frequency current spikes delivered to the load.

For erratic loads, a successive-approximate-register (SAR) ADC with perhaps a current-sense amplifier front end may be more desirable. Any offset error affects the overall error in the amount of battery charge. Measurement errors over time will cause significant charge status battery-pack errors. A measurement offset of 50 µV or less with 16-bit resolution is adequate when measuring charge.

CELL VOLTAGE AND MAXIMIZING BATTERY LIFETIME

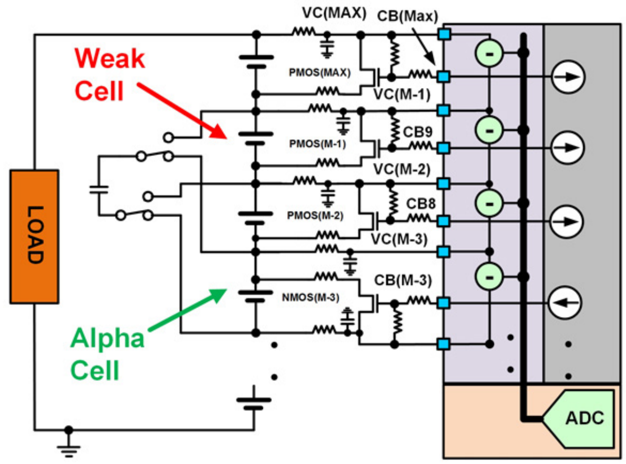
Monitoring the cell voltage of each cell in a battery pack is essential to determine its overall health. All cells have an operating voltage window where charging/discharging should occur to ensure proper operation and battery life. If an application is using a battery with a lithium chemistry, the operating voltage typically ranges between 2.5 and 4.2 V. Voltage range is chemistry-dependent. Operating the battery outside the voltage range significantly reduces the lifetime of the cell and can render it useless.

Cells are connected in series and parallel to form a battery pack. A parallel connection increases the battery pack's current drive, while a series connection increases the overall voltage. A cell's performance has a distribution: At time equal zero, the battery-pack cell's charge and discharge rates are the same. As each cell cycles between charge and discharge, each cell's charge and discharge rates change. This results in a spread distribution across a battery pack.

A simple way to determine if a battery pack is charged is to monitor each cell's voltage to a set voltage level. The first cell voltage to reach the voltage limit trips the battery-pack charged limit. A weaker-than-average cell battery pack results in the weakest cell reaching the limit first, keeping the rest of the cells from fully charging.

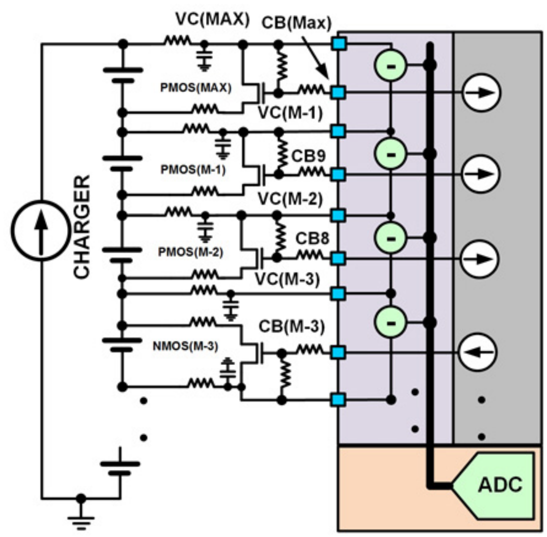
A charging scheme, as described, doesn't maximize the battery-pack ON time per charge. The charging scheme reduces the battery pack's lifetime because it needs more charge and discharge cycles. A weaker cell discharges faster. The also occurs on the discharge cycle; the weaker cell trips the discharge limit first, leaving the rest of the cells with charge remaining.

There are two ways to improve the ON time per battery pack charge. The first is to slow the charge to the weakest cell during the charge cycle. This is achieved by connecting a bypass FET with a current limiting resistor across the cell (Fig. 3A). It takes current from the cell with the highest current, resulting in a slowing cell charge. As a result, the other battery pack cells are able to catch up. The ultimate goal is to maximize the battery pack's charge capacity by having all of the cells simultaneously reach the fully charged limit.



(B)

3. Bypass cell balancing FETs help slow the charge rate of a cell during the charge cycle (A). Active balancing is used during the discharge cycle to steal charge from a strong cell and give the charge to a weak cell (B).



(A)

The second method is to balance the battery pack on the discharge cycle by implementing a charge-displacement scheme. It's achieved by taking charge via inductive coupling or capacitive storage from the alpha cell and injecting the stored charge into the weakest cell. This slows the time it takes the weakest cell to reach the discharge limit, otherwise known as active balancing (*Fig. 3B*).

TEMPERATURE MONITORING

Today's batteries deliver lots of current while maintaining a constant voltage. This can lead to a runaway condition that causes the battery to catch fire. The chemicals used to construct a battery are highly volatile—a battery impaled with the right object can also make the battery catch fire. Temperature measurements aren't just used for safety, they also can determine if it's desirable to charge or discharge a battery.

Temperature sensors monitor each cell for energy-storage-system (ESS) applications or a grouping of cells for smaller and more portable applications. Thermistors powered by an internal ADC voltage reference are commonly used to monitor each circuit's temperature. In addition, an internal voltage reference helps reduce inaccuracies of the temperature reading versus environmental temperature changes.

STATE MACHINES OR ALGORITHMS

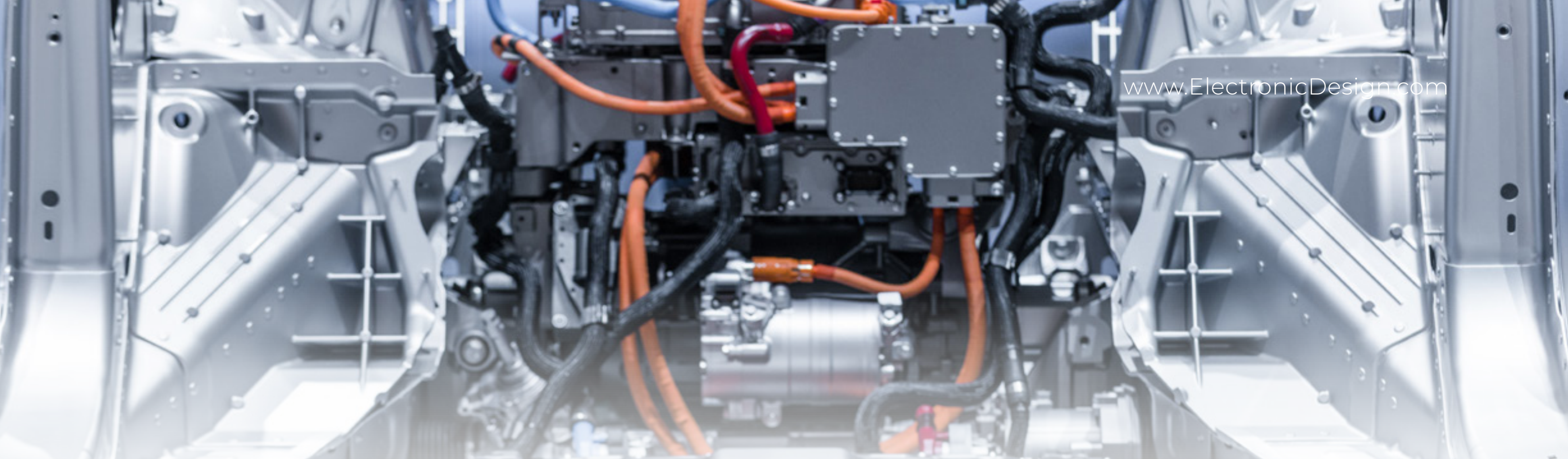
Most BMS systems require a microcontroller (MCU) or a field-programmable gate array (FPGA) to manage information from the sensing circuitry, and then make decisions with the received information. In certain devices, such as the ISL94203, an algorithm that is digitally encoded enables a standalone solution with one chip. Standalone solutions are also valuable when mated to an MCU, because the standalone's state machine can be used to free up MCU clock cycles and memory space.

OTHER BMS BUILDING BLOCKS

Other functional BMS blocks may include battery authentication, real-time clock (RTC), memory, and daisy chain. The RTC and memory are used for black-box applications—the RTC is used as a time stamp and memory is used for storing data. This lets the user know the behavior of battery pack prior to a catastrophic event. The battery authentication block prevents the BMS electronics from being connected to a third-party battery pack. The voltage reference/regulator is used to power peripheral circuitry around the BMS system. Finally, daisy-chain circuitry is used to simplify the connection between stacked devices. The daisy-chain block replaces the need for optical couplers or other level-shifting circuitry.

CONCLUSION

Battery-management systems can be built using a plethora of functional blocks and design techniques. Careful consideration of battery requirements and battery-life goals will help determine the right architecture, functional blocks, and related ICs to create a battery-management system and charging scheme that optimizes battery life. For more information about battery-management solutions, go here.



EMI Reduction in Automotive Power Converters

Designers of automotive power systems must consider mitigation techniques needed to reign in EMI disturbances to the overall electronic system in the automotive vehicle. This effort is crucial to a safe, reliable, and stable system design.

By Steve Taranovich

This article will discuss electromagnetic-interference (EMI) mitigation techniques as they relate to the optimum performance of vehicle system architectures. Critical areas in vehicles can be highly affected by EMI and lead to subpar electronic circuit performance, especially in automotive power supplies, which are at the heart of an overall vehicle electrical/electronic system.

Covered here will be EMI filtering and other system techniques that can be integrated into the system architecture to minimize RF EMI interference, both conducted and radiated. These should help designers pass EMI standards testing in their respective regions.

EMISSIONS STANDARDS

The automotive industry and individual automobile manufacturers must meet a variety of electromagnetic-compatibility (EMC) requirements. Regulatory compliance to EMC standards, CISPR 25 for automotive applications, is critical in a product design. For example, two requirements are to ensure that electronic systems don't emit excessive EMI or noise, and be immune to the noise emitted by other systems.

The efforts required to achieve compliance affect both product development costs and time to market. CISPR 25 is one of the most stringent international emission standards for vehicles and devices targeting radio disturbance characteristics. The limits and methods of measurements are intended to protect onboard receivers from disturbances produced by components, such as a switching regulator in a power-supply design.

Designers need to fully understand CISPR and other emission standards before they begin their power designs (*see References 2 and 3*).

TYPES OF EMI

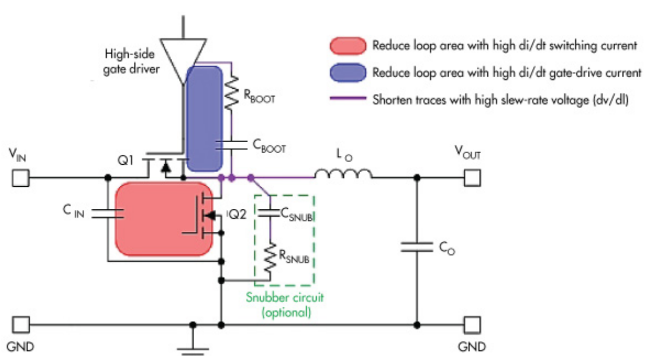
To reduce EMI in a design, engineers first must understand how EMI propagates into a design. EMI has two main classes—conducted and radiated—that can lead to longer design time to market and added cost. The design efforts, to lower EMI to a level that will pass EMI standards for areas or countries in which a product would be used, are crucial in creating a successful functioning design.

Conducted EMI is typically coupled via cables and physical conductors such as power connections, parasitic impedances, as well as ground connections. Radiated EMI gets coupled via radio transmission sources through the air due to electric fields (capacitive coupling) or magnetic fields (magnetic coupling).

Switching voltage regulators will usually be one of the main culprits of EMI generated within an automotive system or generated externally.

ORIGINS OF EMI

Electronic circuitry usually has current flowing from a source to a load and returning back to the source in a loop. Loops have inductance and a varying current through components, wires, or PCB traces. When current varies within the loop, it will generate a proportional voltage. The loop has a self-inductance and the rate of current change will be di/dt due to current demand in the load. When the current changes quickly in the loop, it will generate a voltage spike.



1. This schematic shows a simplified synchronous buck converter with critical loops and traces identified for EMI (image from Reference 5).

To minimize a spike, designers can shrink the loop area, which will reduce the loop inductance. The power IC can use two input loops in parallel that result in effectively half the parasitic loop inductance[5] (*Fig. 1*). Designers can employ bypass capacitors strategically located close to ICs and other devices to minimize EMI as well.

Good ground planes will provide low-impedance paths for such components as bypass capacitors. Designers can keep noisy switching nodes or oscillators as far away as possible from sensitive nodes on the PCB. Good ground areas or planes also may serve as shielding or physical separation from noisy areas or components like switch nodes/power transistors, high di/dt capacitors, and inductors.

Some other methods will help reduce radiation in the loop, too. One example would be a design using a discrete buck regulator with switching power FETs. The drive signal to the FET can be slowed down by adding a gate resistor, which may help meet the tough radiated emissions standards for automobiles. The downside to this method is that the design now loses some efficiency, adds a component, and increases board footprint.

EMI IN AUTOMOTIVE WIRING HARNESSES

Advanced automotive electronic-control technology has led to added electronic equipment in the vehicle. Frequencies and power have gradually increased in the vehicle, creating a denser atmosphere of electromagnetic waves. This will greatly contribute to EMI in the vehicle, thus disturbing electrical/electronic equipment and possibly damaging electrical/electronic components.

Automotive wiring harnesses, one of the highest contributors of EMI in the automobile, also may be affected by EMI.

Designers can take some measures to minimize EMI effects by shielding source equipment and their respective wiring harnesses. Conducted and radiated EMI can be minimized in longer harnesses by adding an improved filter. Careful planning of the wiring harness also will help by arranging lower power circuitry closer to the signal source and higher power interfering circuitry closer to the load.

Improved grounding techniques will also help reduce EMI in automotive harnesses. Shielding harnesses and connecting to the car body is a good means of reducing EMI interference.

REDUCTION OF RADIATED AND CONDUCTED EMI IN THE AUTOMOBILE

Figure 2 shows EMI bands of interest and mitigation techniques.[7]

Radiated EMI in non-isolated power converters in the automobile

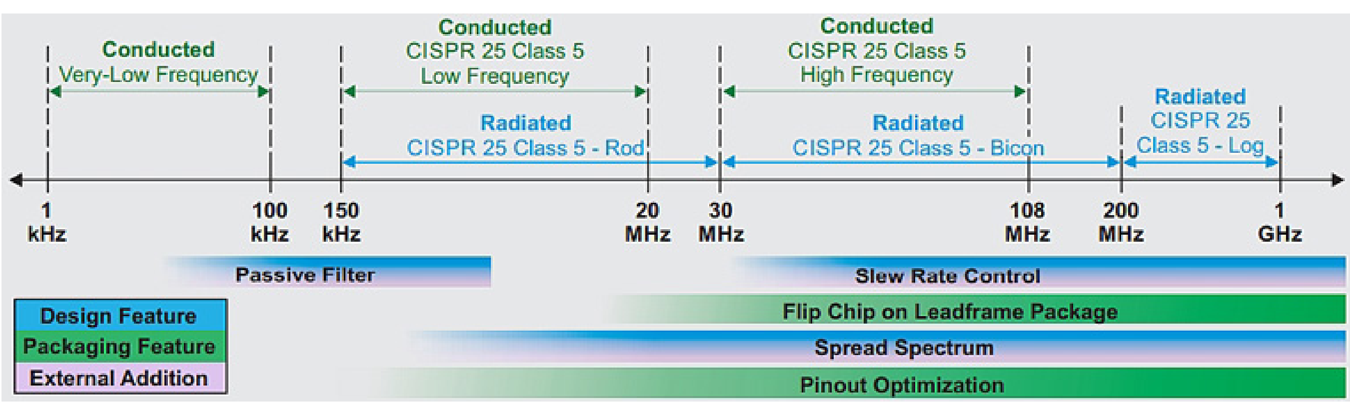
Radiated EMI is caused by common-mode noise in the vehicle power cables, which radiates into the vehicle space. This noise is mostly radiated by non-isolated power converters via the switching power devices within that power converter. Higher switching frequencies in modern power supplies and efforts to reduce power converter physical sizes are the main contributors to EMI in the automobile (*Fig. 2, again*).

Conducted EMI in an automotive buck converter

Designers may find that passing the FM band limit in CISPR 25 Class 5 is quite challenging.6 That's because the EMI filter worsens at high frequencies. Near-field coupling also will degrade EMI filter performance because high-frequency noise generates powerful magnetic and electric fields that will couple into the input of an EMI filter.

Some solutions that designers may want to try include:

- Reducing the noise source by adding a boot resistor or snubber, or decreasing the switching frequency (this will decrease the high-frequency harmonics of the noise source).
- Reducing the power-switch (SW) capacitive parasitics by placing as little PCB SW copper as possible, while also considering the thermal dissipation.
- Adding a shielding case will reduce electrical-field coupling.
- Adding filter components—a common-mode choke can be incorporated, but this will increase system cost.



2. This image illustrates the EMI bands of interest along with possible mitigation techniques (image from Reference 7).

Employing an EMI filter at the input of the buck converter, as well as a careful layout, will help, too. And an iron shielding box can be a last resort (*see Reference 6*).

COMPONENTS TO HELP MINIMIZE EMI

Often, the simplest components turn out to be the most important. Chip ferrite beads can be designed into the electronic system, enabling full current handling up to 85°C. The small size of ferrite beads allows them to provide EMI protection in even the most densely populated PCBs.

EMI-suppression film capacitors, qualified to the AEC-Q200 (rev. D) and IEC 60384-14: 2013/AMD1: 2016 grade IIB quality standards, can act as EMC filters for automotive power inverters.

EMI IN THE EV

Electric powertrains (EPTs) are major contributors to wideband, high-level EMI. It will intrude upon susceptible electronic and RF systems like those in connected vehicles, infotainment, advanced driver-assistance systems (ADAS), and autonomous-driving systems. EMI management is especially critical in these systems.

EMI IN VEHICLE-TO-EVERYTHING (V2X)

With wireless networking using 5G and V2X technologies, future EVs will transmit, communicate, and process far more data, over low-voltage networks, than today's vehicles. The automotive industry is pushing the envelope regarding battery capacity, range, engine power, and fast-charging technologies, all of which use high current and power levels. These high power/current levels will emanate strong electromagnetic fields that need to be addressed in the architecture of all electrical components.

EMI mitigation is critical to the reliable and safe operation of low-voltage networks with potentially susceptible electronic and RF units due to the presence of the power inverter in the EPT. The inverter, operating at high power and fast switching frequencies, generates rapid voltage and current transients that are the major source of conducted and radiated EMI.

In V2X automotive communication applications, passive components also play an important role. No matter how complex the semiconductors, without EMC components, transient protection, high-frequency connectors and antennas, V2X would not be possible.

SUMMARY

Switching power supplies in automobiles will need some form of input filtering to pass EMI standards such as CISPR 25 or other regions' EMI regulations. Other forms of minimizing EMI in the automobile were discussed in this article as well, and most likely will need to be incorporated in many design architectures to achieve standards approval.

So many methods are available to help tame EMI encroachment into automotive electronics. Most designers will use more than one method, and some will use multiple or all methods. Time-to-market is critical for these automotive power designs and the EMI testing must be done when the overall design is fully complete.

As we move forward from gasoline-powered vehicles to electric vehicles, and on to the autonomous vehicle, we will need to modify, as well as add, new and innovative EMI-mitigating techniques to pass compliance testing in a timely manner. More creative techniques will emerge as we venture into the future of automotive electronics.

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7. Advanced EMI mitigation techniques for automotive converters

Advancing BMS Testing with Accurate Emulation for EVs

Precise emulation is transforming BMS testing by eliminating the inefficiencies of traditional methods, enabling engineers to simulate charge and discharge cycles rapidly and safely.

By Ken Sieber

The electric-vehicle (EV) industry is expanding at an unprecedented pace, driven by innovations in battery technology and the growing global demand for sustainable transportation. At the heart of EVs lies the battery-management system (BMS), a critical component ensuring the battery's safety, reliability, and performance.

As EV adoption scales, so does the complexity of testing and validating BMS designs. This is where precise emulation, enabled by advanced tools such as the xMove platform, is revolutionizing the landscape of BMS testing.

UNDERSTANDING THE ROLE OF A BMS IN EVS

A BMS is responsible for monitoring and managing an EV's battery to ensure optimal performance and longevity. It safeguards the battery pack against hazards such as overcharging, over-discharging, overheating, and short circuits.

The system continuously monitors and measures voltage, current, and temperature across individual cells, calculates critical metrics such as state of charge (SOC) and state of health (SOH), and controls cooling and heating mechanisms to maintain safe operating temperatures. It also detects faults and triggers appropriate safety protocols when necessary.

On top of that, a BMS performs cell balancing to maintain optimal battery efficiency. Unbalanced cells can reduce the overall effectiveness of the battery by limiting its capacity and power delivery. The BMS uses relays and switches to redirect current and adjust voltage levels across individual cells, ensuring uniform performance across the battery pack.

Given its importance, the BMS must undergo rigorous testing to verify that it meets stringent performance and safety standards. Traditional testing methods, however, often fall short in replicating real-world conditions and scaling to the demands of modern EVs.

CHALLENGES IN BMS TESTING

BMS testing involves evaluating its functionality under a wide range of scenarios, including normal operation, edge cases, and fault conditions. One of the major challenges is the complexity of battery packs. EV batteries consist of hundreds of interconnected cells, making it difficult to simulate their behavior at scale.

Testing under fault conditions, such as thermal runaway or overvoltage scenarios, can pose significant safety hazards, further complicating the validation process. In addition, real-world operating conditions, such as varying temperatures and fluctuating loads, are difficult to replicate consistently in a laboratory setting. And physical prototyping and testing can be time-consuming and expensive, delaying product development and adding significant costs to the process.

To address these challenges, engineers are turning to advanced emulation platforms that replicate real-world conditions with unprecedented accuracy.

BMS EMULATION

BMS emulation involves using hardware and software tools to simulate the behavior of a battery pack and its environment. Unlike traditional methods, which rely on physical battery packs, emulation platforms create virtual test environments that can mimic various aspects of battery operation. These platforms can simulate voltage and current fluctuations, replicate thermal gradients across the battery pack, and test communication between the BMS and other vehicle systems (e.g., the thermal-management system and motor controller).

Emulation offers several advantages, including enhanced safety, flexibility, and cost-efficiency. It enables engineers to test scenarios that would be too risky or impractical with physical batteries, reducing reliance on costly prototypes and minimizing safety risks.

THE XMOVE PLATFORM: A NEW ERA IN BMS TESTING

One advanced tool for BMS emulation is the xMove platform, which works with other hardware and software products to deliver accurate, real-time simulations. The platform supports both cell monitoring unit (CMU) emulation and hybrid emulation modes, enabling comprehensive testing of BMS designs. With its scalable architecture, xMove can emulate battery packs ranging from a few cells to 216 cells, suiting it for all types of EVs, from e-bikes to commercial vehicles.

The platform provides real-time feedback on BMS responses, making it possible for engineers to fine-tune algorithms and settings. It also includes fault-injection capabilities, enabling engineers to introduce faults such as short-circuits, open-circuits, and polarity reversal to validate the BMS's safety mechanisms. The software's ability to work with battery models, file playback, test automation tools, and its modular hardware systems ensures compatibility with various BMS designs, supporting a wide range of communication protocols and configurations.

CMU EMULATION: SIMULATING REAL-WORLD CONDITIONS

Emulating the CMU is an alternative method of BMS testing. The CMU is responsible for measuring and reporting cell voltages, currents, and temperatures. The CMUs and the BMS communicate the cell voltage, current, and temperature information through the iso-SPI protocol. FPGAs help to emulate the CMU iso-SPI protocol that contains the target voltage, current, and temperature information. As a result, engineers can eliminate the need for real voltage emulation, reducing the number of channels being emulated.

This capability minimizes the hardware required for testing, effectively lowering the overall cost, and it increases repeatability due to it being a digital protocol. Instead of simulating the entire battery system, engineers can focus on a single component, improving efficiency and flexibility. When implementing emulation in a testing system, it's essential to evaluate which chip is being used to ensure compatibility with the BMS under test.

THE BENEFITS OF EMULATION IN BMS TESTING

Precise emulation is transforming BMS testing by addressing the limitations of traditional methods. Heating a battery to the desired temperature for testing takes time, consumes energy, and presents potential hazards. Similarly, charging and discharging a battery so that it's ready for testing can take an entire day to reach the desired state.

Emulation eliminates those inefficiencies, allowing engineers to simulate charge and discharge cycles rapidly and safely. Battery chemistry has also evolved, with new types such as solid-state, lithium-iron-phosphate (LFP), and fluoride-based batteries, to name a few, gaining traction. These advances impact testing strategies, particularly in relation to the SOC curve.

Some new chemistries exhibit a very flat SOC curve, meaning that a small change in cell voltage significantly impacts SOC readings. Emulators must be more precise than ever to accommodate these changes and provide accurate testing results.

THE FUTURE OF BMS TESTING AND EV SCALABILITY

As the EV industry evolves, the demand for robust and scalable BMS testing solutions will only grow. Emulation platforms like xMove are paving the way for higher reliability, ensuring that BMS designs meet the highest standards of safety and performance. These platforms also support the development of innovative features, such as predictive maintenance and adaptive thermal management.

By enabling comprehensive testing, emulation helps manufacturers create BMS solutions that are more intelligent and responsive to dynamic operating conditions.

BETTER BMS TEST WITH HIGH-ACCURACY EMULATION

Battery-management systems are the cornerstone of EV performance, safety, and efficiency. Accurate emulation is redefining how BMS testing is conducted, providing engineers with powerful tools to tackle the challenges of scaling EV technology.

Modular software-connected platforms like xMove exemplify the potential of this approach, combining precision, flexibility, and scalability to drive innovation in the EV industry. As emulation technology continues to advance, it will play a pivotal role in accelerating the transition to a sustainable, electrified future.

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