



The Smart Battery Survival Guide Series:  
**Design Considerations for Smart Battery Systems**

## Foreword

Planning for the battery system early in the design process maximizes performance, durability, reliability and safety.

Fueled by industry and consumers, marketplace demand is skyrocketing for high-power portable instruments and equipment. In the healthcare and field-service industries, for example, companies hope to increase productivity, competitiveness and customer service by implementing the use of portable electronic devices into many daily business operations.

To address this rising demand, electronics manufacturers are leveraging faster processors, enhanced color displays and backlighting, wireless networking, as well as voice and multimedia capabilities for next-generation portable devices. But the transition to highly sophisticated, power-hungry portable electronic systems in smaller, lighter, more ergonomic packages is creating new battery system-design challenges.

It is now crucial that battery system engineers avoid design problems and device failures by effectively planning, developing and implementing smart battery system solutions into their portable applications. Yet designing a power-management system for high-performance portable electronics applications can be difficult, even for the most experienced design engineer. Underestimating the complexity of the battery system and the interrelationship between battery and device circuitries can lead to setbacks during product development. Worse, the entire system may fail in the field.

These kinds of problems indicate that many original equipment manufacturers (OEMs) are facing battery-system design issues that they may not have the tools or internal expertise to solve. Fortunately, planning for the battery system early enough in the design process, along with proper implementation, can minimize or eliminate the possibility of battery problems.

This “Smart Battery Survival Guide” series helps battery system designers recognize and avoid challenges inherent in the battery system design process. It also helps designers develop intelligent designs that contribute significantly to the value of a product and its success in the marketplace.

## DESIGN CONSIDERATIONS OF A SMART BATTERY SYSTEM SOLUTION: POWER

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Applications that utilize Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (Ni-MH) battery packs with one or two cells, a few wires and a simple fuse are becoming increasingly rare. Battery technology has kept pace as portable electronic devices have become more sophisticated and demanding. Today, more designers are turning to smart battery pack solutions that offer advanced chemistries, such as Lithium-ion (Li-ion) and Lithium polymer (Li-polymer). These chemistries offer the highest energy densities currently available and, in the case of Li-ion, a very competitive cost-per-watt-hour for their weight.

With operating voltages ranging from 3.6V to 3.8V, only one rechargeable lithium chemistry cell is required for a 3V operating system. In contrast, yesterday's nickel-based technology, which operated at 1.2V, required three batteries for a 3V operating system. Today, some rechargeable lithium technologies offer improved energy densities of greater than 400Wh/l, and can handle 1C continuous discharge rates.

Available battery capacity depends on operating temperature and discharge current. Battery manufacturers rate their cells at an "ideal" performance level of standard C/5 constant current at 20 degrees Celsius (°C). Any deviation from this performance level may degrade battery performance. It is also important to note that some manufacturers rate their cells on typical performance, while some rate their cells based on nominal or minimum performance. The designer should always use nominal or minimum performance, never typical, when selecting cells, as it is at this level where cell manufacturers can guarantee performance. The exposure of the battery system to high temperatures or high discharge rates will impair its capacity and service life. In addition, when cells are put into a pack, the "weakest link" scenario will prevail, and the pack will only be as good as the worst cell in the pack.

Hence, the choice of the appropriate battery cell is crucial to the performance, reliability and cost of the battery system. Since the battery system is an integral part of the portable device, to determine which battery cells and circuitry perform best in the application, it is important to characterize and validate candidate cells using the portable system's "usage profile." This profile articulates the variables of voltage, current, operating temperature and charging methodology.

To ascertain a usage profile, device designers must first consider the operational voltage range, specifically the minimum and maximum operating voltages required by the system. Improper operating voltage ranges can undermine a battery system's performance and safety.

Secondly, the designer must determine the maximum current-drain rate that the pack will experience, the maximum inrush charge current, and nominal operating drains under various functions of the unit. For example, when the device is first powered on, the battery system may experience a high pulse current for a short time. During normal operation it may experience an entirely different current demand level if a special feature of the product is used, such as the print function.

The inexperienced design engineer often disregards the ambient, or operating temperature, range of the battery system within the host device. The designer may look at a battery system as merely a "sum of parts," not understanding the interplay of cell heating on the circuitry within the pack.

The frequency and methodology of pack charging can greatly influence its available capacity and cycle life. Many cell manufacturers place more restrictions on the charging of their cells than on the discharging of them.

Understanding the usage profile is critical in determining what cell to use. The usage profile indicates the quantity and type of cells to use. Because battery cells have different impedance levels, current demands may exclude some types of cells from consideration. The designer can then further narrow the cell options, based on size and weight constraints.

By carefully evaluating the demands that the portable device places on the battery system during real-world use, and quantifying how those demands will affect capacity, cycle life, reliability, safety and durability, the battery system designer can choose the optimal cell for the application.

As an illustration of this point, a leading medical devices company was looking to match a battery with the power requirements of its new portable ultrasound device. To determine how many ultrasound procedures a battery system could support based on a full charge, the designer verified the performance of multiple battery cell candidates by cycling prototype battery packs with their usage profile. By applying real-world usage patterns, rather than cell manufacturer data, the designer was able to select the battery cell that could support a satisfactory number of medical procedures between charges for its entire cycle life.

Without these tests, the battery system designer would have relied on published data or extrapolation, which may have led to an incorrect choice of battery cell, possibly resulting in lackluster battery system performance.

## DESIGN CONSIDERATIONS FOR A SMART BATTERY SYSTEM SOLUTION: SAFETY

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The development of leading-edge battery technologies does present several design challenges. Because Li-ion and Li-polymer technologies can be hazardous when over-stressed, extra caution must be taken during the design process to ensure that the cells are being utilized in a manner appropriate to their technology. Voltages must stay within strict operating ranges. Additionally, the use of a safety circuit, separate in function and purpose from any fuel-gauging capability within the battery pack, should be utilized to protect the pack from external stressors, such as overcharging, over-discharging, short-circuiting and excessively high or low operating temperatures.

The introduction of complex printed circuit assemblies (PCAs) within a battery pack introduces a number of considerations to be addressed during the design and assembly of a smart battery system. Because most battery packs are encased in plastic that requires ultra-sonic welding (USW), the PCA may be damaged during the assembly process. The importance of proper PCA location and connection within the battery system cannot be overstated.

The PCA's physical configuration and method of connectivity to the rest of the battery system directly influences the reliability, quality and cost-effectiveness of the battery system. Mistakes made by the less-experienced design engineer in this area are among the most common and expensive in the development of battery systems. For example, high current and temperature extremes can cause internal heating within the pack and the pack's electronics. Even though cells may be specified at 1C discharge currents, large packs—for example, three or more cells in parallel—constantly drained at this level may experience internal heating of 15°C to 20°C above ambient. This can harm the battery system's electronics, damaging key components, destroying traces on the circuit board and melting the wires. It can also degrade the performance of the safety circuitry, battery management electronics and system communications.

## DESIGN CONSIDERATIONS OF A SMART BATTERY SYSTEM SOLUTION: ACCURACY

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All fuel gauging is not the same. Fuel gauging can be based on voltage monitoring, via one-wire protocol, or on coulomb counting, via two-wire protocol.

External, voltage-based fuel gauging is the simplest and least expensive to perform. It relies on the periodic voltage measurements of the battery pack, and works best on a cell technology with a sloping discharge curve. However, this method only enables a relative capacity estimation and provides capacity information outside of product use.

The voltage-based, one-wire method (also known as DQ or HDQ) can determine battery capacity by monitoring the amount of current input to, or removed from, a rechargeable battery. The IC monitors a voltage drop across a sense resistor connected in series between the negative battery terminal and the ground. This determines the charge and discharge activity of the battery.

Two-wire, or coulomb counting is the most common form of fuel gauging. It allows absolute capacity estimation while giving capacity information during use. The most common protocols for two-wire counting are either I2C or SMBus.

While fuel gauging can make the end-user's job easier, poor fuel-gauge accuracy can limit the performance of the battery system. If temperature, discharge rate and age of the battery are not compensated for, an inaccurate fuel gauge can leave up to 30 percent of available battery capacity unused. Poor accuracy of the fuel gauge may also cause inefficient charging. Further, if the battery is left undercharged or if it overcharges, run time or service life can be shortened.

The ICs must also be calibrated to ensure that they are functioning and communicating properly with the battery pack. Finally, once the battery pack is assembled, a "learn cycle" must be completed. This cycle helps the battery to remember where "empty" and "full" are, so that the fuel gauge will be set correctly.

Battery cell manufacturers publish their specifications based on a common operating point (C/5 constant drain at 20°C). However, in real-world applications, portable systems rarely operate at this ideal point. The greater a device's usage profile differs from this ideal operating point, the greater the cell's behavior and performance is likely to differ from the specification.

Because every portable device has a unique set of power drain and temperature profiles, it is impossible to develop a fixed algorithm that can predict the impact that these features will have on the performance of the battery system. As a result, it is becoming important to focus on the design of the battery system, and not just the assembly. Every battery system must be characterized and validated using the unique profiles of the device, to determine the battery's usage profile.

## CONCLUSION

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Today's sophisticated portable electronic systems have created new challenges for battery system designers. A good design will take into consideration numerous factors, particularly those related to power, safety and accuracy.

The choice of battery chemistry is critical for performance, reliability and cost issues. For these reasons, more designers are turning to advanced formulations, such as Li-ion and Li-polymer. These chemistries deliver high energy densities and competitive cost-per-output for their weight. Characterizing and validating cells to fit their usage profile define chemistry choice and circuitry further.

Advanced battery chemistries demand extra attention for safety considerations. Voltages must be kept within strict operating limits. Safety circuits are mandatory to protect against hazards caused by external stresses. Placement of PCAs is a more critical safety issue in smart battery systems as well.

Additionally, smart battery systems require extra attention to highly accurate fuel gauging. Inaccurate fuel gauges may fail to optimize all of a cell's available power, as well as cause inefficient charging.

By recognizing and considering these design challenges, battery system designers can avoid or minimize problems early on. And they can maximize performance, durability, reliability and safety.

## REQUIRED CAPABILITIES FOR TODAY'S SMART BATTERY MANUFACTURERS

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The rise in industry battery defects is directly related to a competency gap between the capabilities of battery assemblers and the skills required to produce the next generation of high-performance battery systems.

Technical competence is a key requirement for designers of high-performance battery systems. A battery system supplier that does not possess the technical skills and application experience needed to understand the requirements of the application, interpret the specifications or speak intelligently about the latest battery cells and battery management technologies is likely to fail.

Driven by the requirements of the marketplace and today's portable applications, manufacturers must:

- develop a unique, systems-focused development approach
- possess extensive application knowledge and expertise
- provide lean, flexible and state-of-the-art manufacturing capabilities
- maintain close relationships with technology leaders, including the top-tier cell vendors
- offer exceptional customer service through quality, delivery, responsiveness and flexibility

High-performance battery systems require greater levels of sophistication and talent to develop than yesterday's battery packs, which were simple enough for anyone with a soldering iron, a garage and a few developers. Today's manufacturers must offer advanced technical skills, tightly controlled development processes, complex testing and manufacturing equipment, as well as many years of experience in the development of battery systems. These are capabilities that most battery pack assemblers currently lack.

## ABOUT MICRO POWER ELECTRONICS INCORPORATED

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With a proven track record of technical excellence, quality solutions and award-winning service, Micro Power Electronics Incorporated has become the fastest growing supplier of custom battery systems in North America.

Micro Power is an ISO 9001 certified and FDA-registered supplier of custom battery systems for the portable healthcare, field-service and handheld computing

markets. As a pioneer in the development of Lithium battery systems and smart battery packs, Micro Power is capable of meeting the most challenging power requirements. We have more than 15 years experience developing battery solutions for the world's most demanding customers.

Offering state-of-the-art cell chemistries, accurate fuel gauging technologies and the latest in smart battery options, Micro Power battery systems are optimized to deliver maximum performance in the customer's application. And our battery systems are verified extensively to perform reliably and safely in challenging work environments.

Micro Power's mission is to develop the world's most dependable power sources for portable equipment. Our solutions enable manufacturers to free their technologies from the power sockets that confine them—making them mobile and more accessible to people who critically need them.

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