Optimizing Run-Time for Devices Powered by Lithium-Ion Batteries

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Abstract

More of today's consumer devices are being powered by lithium-ion (Li-ion) batteries. While Li-ion technology continues to advance in longevity and safety, factors such as cycling and temperature may result in aging that hampers the battery's performance over time. This white paper examines how fuel-gauging technology can extend battery run-time and deliver accurate battery state-of-charge (SOC) information for a variety of Li-ion battery-powered products.

Introduction

How Fuel Gauges Can Help Maximize Device Run-Time

Compact, internet-enabled devices demand a lot from their small Li-ion batteries

A runner who's tracking heart rate and calories burned while competing in a marathon. A writer working in her home office, with background music playing from wireless speakers. A building manager who relies on the facility's automation system to control the lights, heating and ventilation equipment, and security system all day and all night. All of these scenarios involve small, connected devices powered by Li-ion batteries. And in each case, users expect an accurate assessment of the battery SOC at any given time, not to mention long battery run-time per charge. No one appreciates seeing 1% of battery life left for an extended period of time if the remaining battery capacity is underestimated, or facing an abrupt shutdown if the capacity that's left is overestimated.

When it comes to wearables and many internet of things (IoT) products, smaller size is preferred for these devices. However, the compact, sleek designs of these devices present a formidable challenge from a battery run-time perspective because engineers can accommodate only small batteries in them. Limited PCB space must, after all, primarily support components that deliver the unique features customers want. Of course, the catch is that all of these sophisticated features will draw more power. There are various techniques and technologies for extending battery life per charge in these types of connected devices. Using a fuel-gauge IC with the right capabilities is one approach that can make a big difference in whether end users are disappointed or delighted.

Fuel gauges indicate battery SOC and state-of-health and predict how much time a battery can continue to power the device, based on specific operating conditions. Traditional fuel gauges operate with great dependency on battery type, typically requiring designers to undergo time-consuming battery characterization in a lab in order to tailor the gauges to their batteries. The characterization work considers various load, temperature, and other application conditions in order to enable the fuel gauge to determine battery SOC. This testing and analysis work can take a few weeks.

Newer fuel-gauge ICs utilize algorithms that eliminate the characterization step without a sacrifice in accuracy. Figure 1 depicts a block diagram of a battery-powered application with a fuel-gauge IC integrated on the board. In this paper, we'll take a closer look at how these next-generation fuel-gauge ICs are ideally suited to address the challenges of Li-ion battery-powered products. First, let's understand the performance limitations of Li-ion batteries.

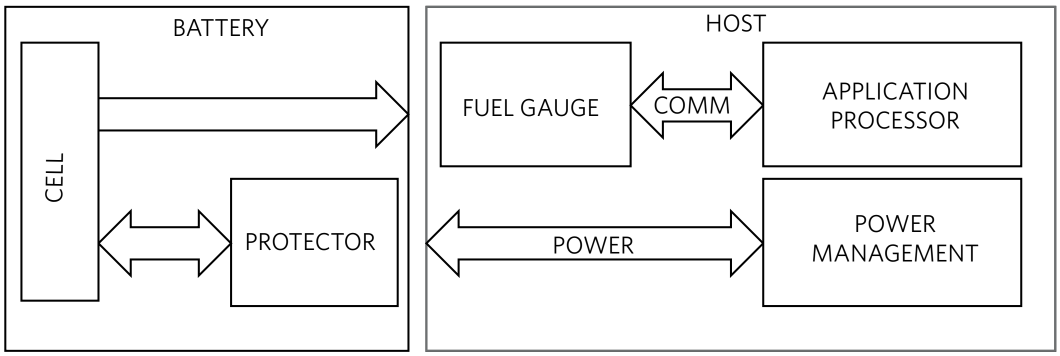

Figure 1. In this block diagram, the fuel-gauge IC monitors the battery by connecting to the power terminals and, in some cases, to the thermistor inside the battery pack.

What Degrades Li-Ion Battery Performance?

Applications that were once powered by lead acid and then NiMH batteries, including mobile phones and laptops, are now run on Li-ion batteries. Invented in the 1970s and introduced commercially in the 1990s, Li-ion batteries are based on ion movement between positive and negative electrodes. This battery type is notable for its low rates of self-discharge compared to other rechargeable batteries, high energy densities, efficiency, negligible memory effects, relatively constant voltage levels, and compact size.

For most consumer products, manufacturers estimate that the Li-ion battery will support 300 to 500 discharge/charge cycles[1].

All lithium batteries have a side reaction which accompanies the main redox reactions and always happens within the cell. The side reactions consume usable lithium ions, thus diminishing the battery's capacity. Exposure to higher temperature kinetically increases the rate of all reactions, including the side reaction, which causes higher degradation. Keeping batteries at full (4.2V or 4.35V-4.4V for some batteries) also significantly diminishes the battery's lifetime since higher voltages affect the stability of the electrolyte. Normal cycling also causes degradation as some of the active material gets lost in the process. Some active material may get lost due to passivation, meaning it becomes unusable. Usually, higher rates of charge result in built-up impedance, caused by passivation. Higher rates of charge as well as charging at low temperatures may also lead to dendrites, a metallic lithium build-up on the surface of the anode. This may trigger a severe failure mode, such as internal shorts, as the dendrite can puncture through the separator.

While fuel-gauging sealed lead acid batteries typically involves a simple voltage measurement, the process for Li-ion batteries typically calls for more sophisticated approaches. Shallow discharges pose a unique challenge for fuel gauges while learning the correct capacity. For example, many fuel gauges require more than 50% SOC change. The traditional approach for fuel-gauging

High accuracy, low quiescent current, and small size are some key fuel-gauge IC features

Li-ion batteries is to use coulomb-counting, which measures current going in and out of the battery at all times. Coulomb-counting provides excellent short-term accuracy, but this approach is hampered by offset accumulation drift. So, over extended periods of time, what might seem like a small error can actually result in a large over- or underestimation of battery capacity. To get good long-term accuracy with coulomb-counters, various compensation techniques to get rid of the offset accumulation drift have to be implemented in fuel-gauge ICs. In recent years, internally sophisticated, but simple on the outside, fuel-gauge ICs have also been introduced.

Managing Power to Meet Battery Performance Demands

Battery life is determined by the active, sleep, and hibernate currents of the device's microcontroller (or another central processing unit) and other system loads. Quiescent current, while nominal, cannot be overlooked when assessing techniques to maximize battery life. When a device is in sleep or hibernate mode, its power supply's quiescent current is the largest contributor to a system's standby power consumption. And most wearables, small IoT devices, and even larger smart systems like electric bikes and electric scooters spend the majority of their time in sleep mode, so low quiescent current of the ICs inside is necessary to prevent battery drain. Fuel-gauge ICs that consume mere microamperes of quiescent current contribute their part in this battery life equation.

Many high-performance devices are now designed with elaborate power management techniques to extend battery life. These techniques, however, typically require that the processor remain in a very low-power state until the end user takes some action that requires the processor to ramp up quickly, which draws huge peak loads. Proper power management here is critical; otherwise, there's the risk that the battery will get overwhelmed and be unable to deliver the currents needed, causing the device to crash.

It's common to find fast-charging capabilities in many of today's mobile devices. Various smartphone manufacturers, for example, have their own fast-charging methods, reducing the time required from hours to tens of minutes for a full charge. Because these techniques generally utilize larger amounts of current and higher voltages to charge the batteries faster, the techniques generally call for more careful battery monitoring. Fast charging can only proceed safely when the exact battery voltage is known. Fuel-gauge ICs that deliver high accuracy while monitoring voltage, temperature, and current can help here.

Supporting Small Solution Sizes

Fuel-gauge ICs that integrate as many essential functions as possible save valuable board space and also simplify the design process. Current sensing, for example, is an important capability used in coulomb counting. In this approach, all of the current that goes in and out of the battery is measured over time. The estimated charge used by a given device is subtracted from the total charge that can be held by the battery, compensated by operating temperature and load conditions, to indicate how much charge remains overall. Sense resistors are, however, rather large components, and adding them as discretes can add to the overall costs of a design. A fuel-gauge IC with internal current sensing solves this dilemma, particularly for applications featuring small batteries with modest loads. For higher current applications, an external sense resistor would be more suitable as it can withstand more power dissipation.

Some designs are so small or uniquely shaped or need a rugged exterior that they don't support an LCD screen or similar display, which would be the normal place to find battery SOC information. An alternative in these cases is an LED indicator, and an indicator based on a push button would avoid battery drain. A fuel-gauge IC that integrates LED control would be ideal for these types of applications and would alleviate the system microcontroller from having to handle this function.

See Figure 2 for a block diagram of a fuel-gauge IC with an integrated LED controller.

Fuel-Gauging Accuracy Without Characterization

Maxim's newest ModelGauge™ fuel-gauge ICs combine traditional coulomb-counting with a novel fuel-gauge algorithm that further improves accuracy. The ModelGauge m5 EZ enables design engineers to program the fuel-gauge IC in the field without factory characterization of the battery. The newest ICs in this portfolio are the:

- MAX17262 5.2μA 1-cell fuel gauge with the ModelGauge m5 EZ algorithm and internal current sensing, available in a 1.5mm x 1.5mm wafer-level package (WLP)
- MAX17263 single-/multi-cell fuel gauge with the ModelGauge m5 EZ algorithm and integrated LED control, available in a 3mm × 3mm thin dual flat no-lead (TDFN) package

ModelGauge m5 EZ fuel-gauge ICs deliver accuracy without battery characterization

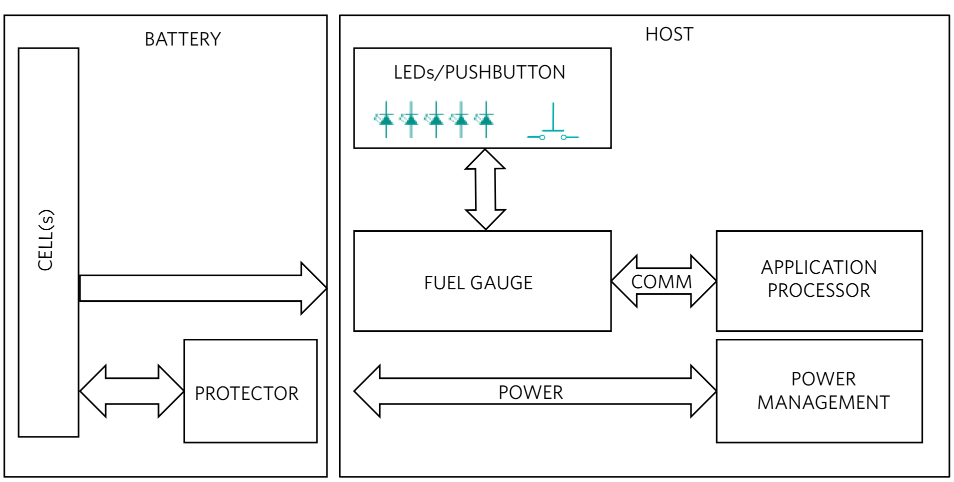

Figure 2. This block diagram shows a fuel-gauge IC with an integrated LED controller. The IC drives the LEDs based on push-button input or an I²C command by the application processor.

The MAX17262 is ideal for 100mAhr-6Ahr batteries used in compact mobile devices. Its low quiescent current extends battery run-time, while the integrated current sense resistor eliminates the need to use a typically larger and costlier discrete component. The MAX17263 is suited for extending run-time of Li-ion/polymer batteries of all sizes in mobile devices that require LED indication for battery status. The fuel-gauge IC drives 3-12 LEDs with push-button or I²C control. Over various load conditions with effective run-times of 3+ hours and temperatures of 0 degrees Celsius and higher, MAX17262 and MAX17263 have an SOC error of less than 3%. Both ICs also incorporate dynamic battery power technology that helps throttle the CPU and other system loads intelligently—just enough to prevent the system from crashing, ensuring that battery voltage is maintained above a safe threshold to maximize performance and extend run-time. This prevents the emergence of user experience problems due to abrupt changes in system performance that stem from brute-force throttling implemented in systems that do not have this battery intelligence. Both devices can be embedded in the captive battery pack to carefully monitor voltage, current, and temperature (a useful capability in mobile devices with fast charging). The ICs are also able to learn the correct capacity even in applications that involve very shallow discharges—as small as 10% SOC change from cycle to cycle. Figure 3 shows battery SOC accuracy levels provided by the ModelGauge m5 algorithm under different load and temperature conditions.

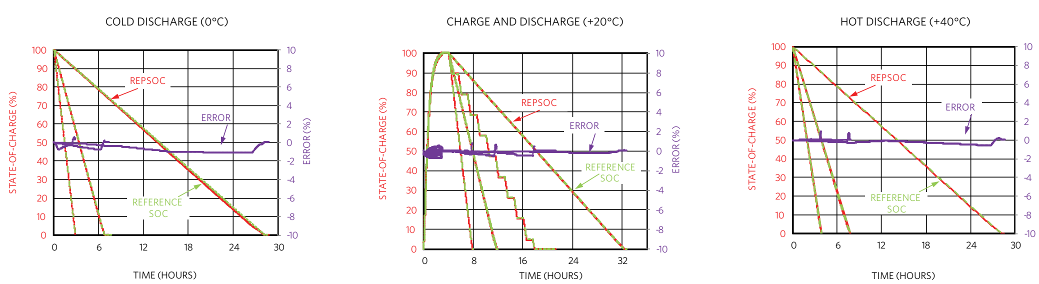

Figure 3. Battery SOC accuracy levels under different load and temperature conditions, provided by the ModelGauge m5 algorithm.

Summary

Li-ion battery technology continues to advance, providing a reliable source of energy for an array of products, portable and otherwise. Performance of these battery types is sensitive to the effects of factors such as cycling, aging, and temperature. This paper explained how fuel-gauging ICs with low quiescent current and integrated functions can extend battery run-time while delivering accurate battery SOC for a better user experience.

Learn More

Read the data sheet, user guide, and other technical resources from the MAX17262 and MAX17263 product pages.

Sources

1. Battery University/BU-808: How to Prolong Lithium-based Batteries

For more information, visit:
www.maximintegrated.com