Keywords: battery fuel gauge, battery protection, battery state of charge, authentication, TTM, runtime, battery shelf life, state of charge, time to market, battery charge

APPLICATION NOTE 7001

GET ENHANCED SAFETY, ACCURATE STATE-OF-CHARGE AND LONGER RUNTIME FOR YOUR PORTABLE DEVICE BATTERY

Abstract: Accurate battery state-of-charge (SOC), long runtime and shelf life, and safety are critical considerations when developing portable devices. A new, highly integrated family of fuel-gauge ICs addresses these battery challenges. By implementing the ModelGauge™ m5 EZ algorithm, the MAX17301 eliminates battery characterization, greatly improving time-to-market (TTM). The algorithm leads to an accurate prediction of SOC and enhanced safety. Furthermore, the low quiescent current of the IC allows for longer shelf life and longer run-time. Integration of fuel gauge and protection control enhances safety and minimizes the bill-of-materials (BOM) and PCB area.

Introduction

One of the big challenges for fuel gauges is that traditionally, getting the best battery SOC accuracy has required extensive characterization and analysis of each battery for specific application conditions (**Figure 1**). This makes it tough to meet fast TTM goals, since the customer either must perform complicated characterization on their own or ship the battery to a fuel gauge vendor. New updates to safety regulations for the transportation of lithium-ion batteries (such as UN 38.3) has turned this effort into a complicated logistics effort. Once the battery arrives, the fuel-gauge vendor can take two to three weeks to run the tests and analyze the results.

System designers must also properly address the safety risks associated with lithium-ion battery operation, as mistreatment can lead to catastrophic consequences. Compliance with safety standards such as IEC/UL 62368-1 is increasingly important. The protection of electronics is another necessary layer of complexity added to the battery management process.

For high-volume applications, the system designer must also mitigate the risk of unsafe aftermarket clone batteries, which affects system safety. Secure authentication can prevent such clones.

Finally, end users expect the system to run for long periods of time between charges (and to maintain a long shelf life). This is where low quiescent current, which minimizes wasted battery charge, comes into play.

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- Advanced Battery Management for the Rest of Us
- Choose the Right Battery Fuel Gauge for Fast Time-to-Market and Maximum Run-Time

This design solution reviews the challenges of powering an action camera (Figure 1) and introduces a novel, highly integrated fuel gauge and protection IC approach that overcomes them.

Figure 1. Action camera at work.

The SOC Accuracy Challenge

The battery SOC varies from zero (battery empty) to 100% (battery full) and determines the device's untethered runtime. One important consequence of a poorly modeled battery is an inaccurate SOC, and consequently, a poor estimate of runtime. A model of a typical action camera usage includes 70 minutes in an active state (including activities such as 4k video recording, WiFi, or GPS) and 90 days in a passive state (i.e., lying in a cabinet after the vacation). If the device consumes 1300mA in active mode and 0.1mA in passive mode over the course 90 days, it will consume a total of 1733mAhr, which is just about the battery capacity of a state-of-the-art action camera. Accurate prediction of the battery SOC is necessary to avoid unexpected or premature interruptions of the device operation. A 10% SOC error will rob the user of 173mAhr, which corresponds to 8 minutes of active usage or 2 months in passive state.

The I_Q Challenge

While it may seem like applications don't care about the quiescent current, many system designers are very conscious about keeping the battery drain low to ensure that the device doesn't drain the battery while in passive state or sitting on the shelf.

The Passive Runtime Duration Challenge

In addition to SOC and runtime accuracy, the runtime duration is equally important. In passive mode, the same battery can last up to 24.1 months. A typical fuel gauge that consumes 40μA will shorten the battery passive runtime by about 6.9 months, which is not a negligible amount of time.

The Shelf-Life Challenge

A 40μA quiescent current over 12 months will consume a hefty 346mAh. On the other hand, our camera battery is likely to be shipped with only 30% or 520mAh charge due to shipping safety regulations. The quiescent current uses 66% of the residual charge after about 12 months of shipping and while the camera sits on the warehouse or store shelf.

With such high quiescent current there are two choices.

One is to keep the fuel gauge “on” during shelf time, thereby preserving SOC accuracy but losing charge. This choice leads to a bad user experience as the customer is forced to charge the device first before using it.

The other choice is to turn off the fuel gauge. Now the charge is preserved but the SOC at turn-on is inaccurate. It will take several hours of operation for the fuel gauge to relearn the battery capacity. The risk here is that the user could be left stranded in the middle of a task.

The Safety Challenge

Lithium-ion/polymer batteries are very common in a wide variety of portable electronic devices because they have very high energy density, minimal memory effect, and low self-discharge. However, care must be taken to avoid overheating or overcharging these batteries to prevent damage to the batteries. This helps avoid potentially dangerous outcomes or explosive events. Run-of-the-mill undervoltage (UV) protection utilized to stop discharge is inefficient as it may be triggered by discharge bursts that are too short to matter. Most discrete protectors do not monitor battery temperature either. A more sophisticated approach to protection is required.

The Solution

As an example, the application in **Figure 2** is a low-I stand-alone

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pack-side fuel gauge IC with protection and authentication for 1-cell lithium-ion/polymer batteries. The protector controls external high-side N-FETs (Figure 2). Authentication prevents battery pack cloning. The fuel gauge implements Maxim's ModelGauge m5 algorithm. The IC monitors the voltage, current, temperature, and state-of-battery to ensure that the lithium-ion/polymer battery operates under safe conditions to prolong the life of the battery. Integration of fuel gauge and protection control minimizes the BOM and PCB area occupation.

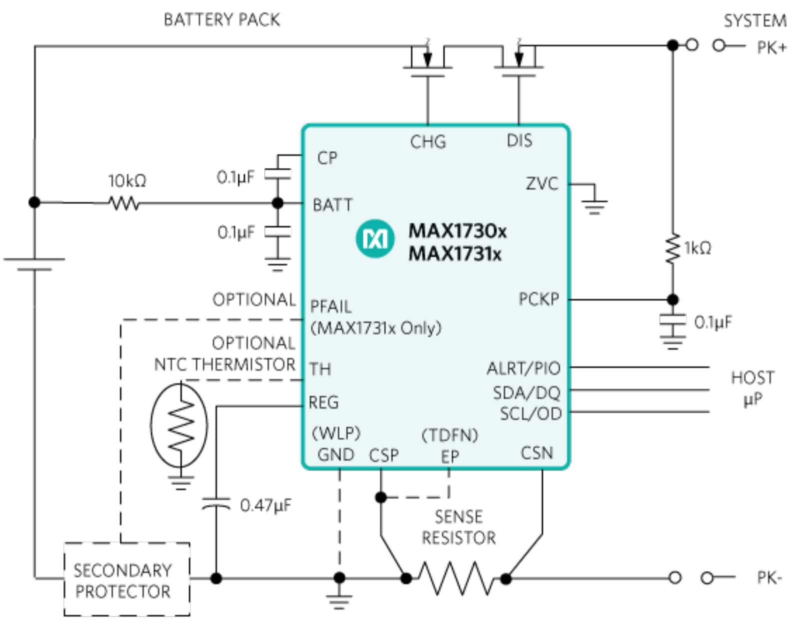

Figure 2. Fuel gauge and protection IC.

Nonvolatile memory allows the IC to store the cell’s fuel gauge and protection parameters. It also enables age forecasting to estimate the battery end-of-life. Life history logging provides comprehensive diagnostics for understanding usage patterns, failure analysis, and warranty returns.

A 1-Wire® (MAX17311) or 2-wire I^2C (MAX17301) interface provides access to data and control registers. The ICs are available in a lead-free, 3mm x 3mm 14-pin TDFN and 1.7mm x 2.5mm 15-bump 0.5mm pitch WLP packages.

The SOC Accuracy

The ModelGauge m5 algorithm combines the short-term accuracy and linearity of a coulomb counter with the long-term stability of a voltage-based fuel gauge. Along with temperature compensation, it provides industry-leading fuel gauge accuracy. The fuel gauge IC automatically compensates for cell aging, temperature, and discharge rate, and provides accurate SOC in milliampere-hours (mAhr) or percentage (%) over a wide range of operating conditions.

ModelGauge estimates the battery's open-circuit voltage (OCV) without the help of the sense resistor even when the battery is under load using battery characterization and real-time simulation. The ModelGauge algorithm uses the relationship between SOC and OCV to predict SOC (**Figure 3**).

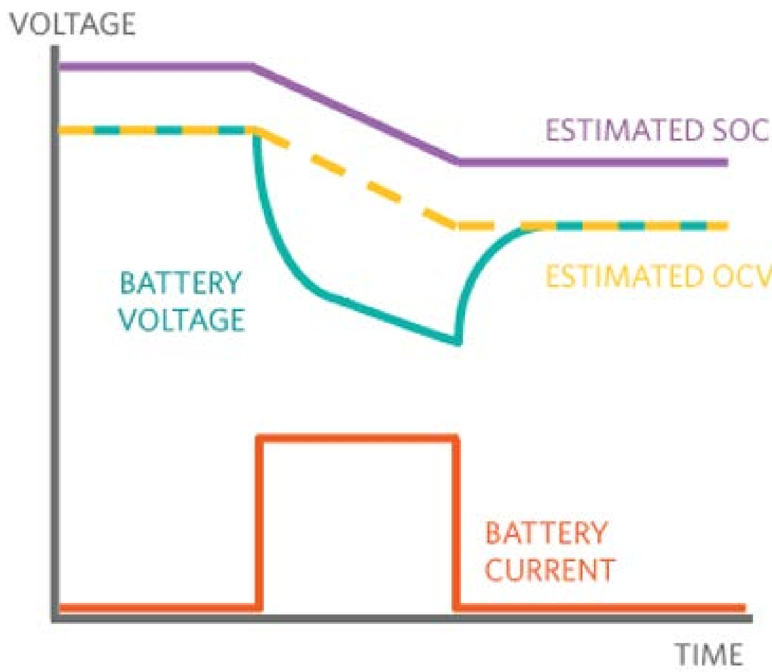

Figure 3. Voltage-based fuel gauge.

Coulomb Counter with ModelGauge m5

Because of coulomb-counter ADC offset errors, the SOC estimated by the fuel gauge deviates over time from the ideal SOC value. However, by using the internal OCV-based (or voltage-only based) estimation which runs in parallel to the coulomb counter, the fuel gauge IC compensates for these errors and brings the resulting SOC back on track. This happens every third of a second and the correction is a tiny fraction of a percent (nearly invisible) when the battery is under load, being charged, or even at no load. This is an improvement over other solutions, which need to wait until the battery is fully relaxed at no load for several hours before any correction can be made.

ModelGauge corrects the Coulomb counter error thrice per second, over 200,000 times per day, using ~0.00001% steps (**Figure 4**).

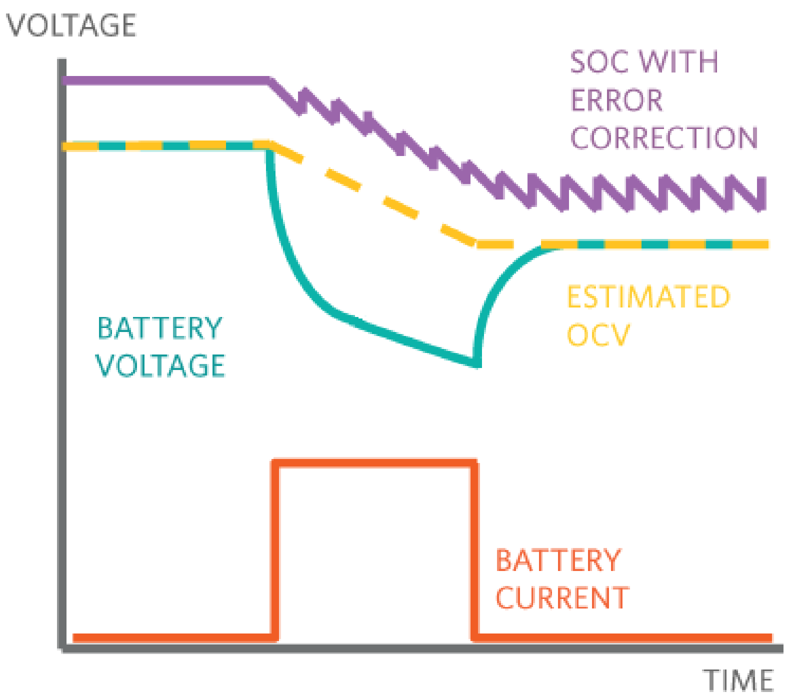

Figure 4. Accurate fuel gauging with ModelGauge M5.

No Battery Characterization Required

ModelGauge m5 EZ eliminates battery characterization. The system designer can use the EV kit software to step through a few application details and generate the model in just a few minutes, resulting in great improvement of TTM. Maxim has run simulations using more than 300 different batteries and 3000 discharges, demonstrating that this method results in less than 3% error in more than 97% of test cases.

Long Shelf Life

A 7µA I_Q (with protection FETs off) helps prevent the battery from draining during extended periods of standby and enables long shelf life and runtime. A 7µA quiescent current over 12 months will use only about 12% of the battery residual charge vs. 66% of the previous case.

Alternately, the IC can be put into a ship mode that draws just 0.5µA I_Q, resulting in even longer shelf life. It can resume normal operation using several options, including turning on when a pushbutton is pressed, or a charger is connected. On resuming normal operation, the fuel gauge can calculate the SOC right away and relearn the full capacity of the battery over the next 1 ½ cycles.

Long Runtime

With an I_Q of 18µA (FETs on), the battery passive runtime goes from 6.9 months down to only 3.7 months.

Enhanced Safety

The IC integrates a highly programmable protector control for lithium-ion batteries to prevent damage due to abnormal voltage, current, temperature conditions, and to ensure safe charging and discharging in a wide range of applications. Integration of protection and fuel gauging on the same IC allows for a more sophisticated approach to battery safety, while preventing nuisance-tripping of the protector. In particular, the ability to estimate SOC during a very short battery voltage dip allows the IC to determine if it is appropriate to shut down or continue operation.

Many battery makers are recommending that the system charger lower the charge voltage as the battery ages. To implement this, the system microcontroller can read the age and cycles register of the fuel gauge IC.

Since the system micro is controlling the charger, it is important to detect a crash that may cause the charger to operate in an unsafe manner. The fuel gauge IC has a watchdog and detects the microcontroller's abnormal system conditions and prevents a runaway charger from damaging the battery by going into protection mode.

In addition to the primary protector, if the battery capacity is large, many system makers implement a secondary protector for redundancy. But such protectors usually only act on voltage and current fault conditions. The fuel gauge can supplement this by triggering the 2nd level protector based on additional highly abnormal temperature and voltage conditions. This includes when it detects that the primary protector FETs have failed. Essentially, this results in the battery being permanently disabled for safety reasons.

All these enhanced features make it easier for system makers to meet updated product safety standards such as IEC 62368-1/UL62368-1.

Conclusion

We reviewed fuel gauge challenges related to battery SOC accuracy, runtime, shelf life, and safety and introduced a new, highly integrated family of ICs and a development protocol that address these challenges. By implementing the ModelGauge m5 EZ algorithm, the IC eliminates battery characterization, greatly improving TTM. The system designer can use the EV kit to generate the model in just a few minutes. The algorithm leads to an accurate prediction of SOC and enhanced safety. Finally, the fuel gauge IC's low quiescent current allows for longer shelf life and longer run time. Integration of the fuel gauge and protection control further enhances safety and minimizes the BOM and PCB area occupation.

Glossary

OCV: Open circuit voltage
SOC: State-of-charge. Varies from zero (battery empty) to 100%/mAhr (battery full).
Runtime: The operation time allowed by the SOC.

Related Parts		
MAX17301	1-Cell ModelGauge m5 EZ Fuel Gauge with Protector and SHA-256 Authentication	Samples
MAX17302	1-Cell ModelGauge m5 EZ Fuel Gauge with Protector and SHA-256 Authentication	Samples
MAX17303	1-Cell ModelGauge m5 EZ Fuel Gauge with Protector and SHA-256 Authentication	Samples
MAX17311	1-Cell ModelGauge m5 EZ Fuel Gauge with Protector and SHA-256 Authentication	Samples
MAX17312	1-Cell ModelGauge m5 EZ Fuel Gauge with Protector and SHA-256 Authentication	Samples
MAX17313	1-Cell ModelGauge m5 EZ Fuel Gauge with Protector and SHA-256 Authentication	Samples

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