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Adopting the Battery Gas Gauge in Handheld Devices

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Integrated functionality and shrinking form factors are driving demand for handheld devices, but the power source has quickly become a bottleneck for advancing technology. Improvement of battery power density can not keep up with demand, and the dynamic load profile makes tracking battery status a complex task. More and more system designers are casting their eyes on the battery gas gauge to improve run time prediction, capacity measurement and overall battery management. Integrated circuit (IC) manufacturers are responding to the market need by exploring ways to equip future batteries with gas gauge technology. The focus is to develop the hardware to accurately measure coulomb charge passing in and out of batteries and, more importantly, the firmware to model the batteries and accommodate a variety of load profiles. The Lithium-Ion (Li-ion) battery is widely adopted for its high capacity and light weight. However, questions remain concerning how the gains from gas gauges justify the added cost, how to configure the gas gauge for optimum performance, and how to integrate the gas gauge test into the existing development and production test for battery packs.

The Need for Gas Gauging

Most handheld devices are still using only voltage measurement for battery capacity reports, since batteries always exhibit certain voltage versus capacity characteristics. This is further justified for Li-Ion batteries, whose cell voltage drops sharply near the end of battery life.

Although simple and low in hardware cost, the voltage-based scheme compromises on accuracy by failing to account for the elusive battery impedance. On one hand, the open circuit voltage (OCV) of the Li-Ion battery is closely linked to battery capacity and the characteristics hardly change for temperature, aging and cell variations. However, the good news stops there, because it is hard to count on capturing OCV when needed in a dynamic load environment. Therefore, the voltage measurement is always compounded by battery impedance effect, and the I*R portion can easily make voltage measurement invalid for capacity prediction. Hard facts about battery impedance include the following:

- It is highly sensitive to temperature, typically increasing 1.5 times for every 10°C in temperature drop.
- Its initial tolerance can be +/-20 percent, and can double after 70 cycles. The aging rate is highly dependent on cell vendors and battery usage conditions.
- It varies largely with battery capacity, increasing significantly at the end of capacity.

To extend the voltage-based solution, some designers work on the firmware to cover compensate for the battery impedance. However, success has been limited without direct capacity measurement because of the variability of impedance and relaxation effects related to variable load. Low confidence in gauging capacity often results in over conservation of battery usage. System designers tend to cut off the load prematurely in order to avoid surprises resulting from battery depletion.

An alternative to voltage-based monitoring is to measure coulomb in addition to voltage. Coulomb Charge, computed by integrating battery current over time, is a real representation of battery capacity. At the beginning of each discharge cycle, the coulomb counter remaining capacity is initialized to full capacity value if the charge termination is detected, and reset to zero when the battery reaches minimum voltage. Charge and discharge current would add and subtract the coulomb counter charge from the remaining capacity for anywhere in between. In a very simple form, dividing coulomb counter remaining capacity by load current yields the time to empty, and coulomb counter remaining capacity divided by full capacity yields the relative state of charge. Battery full capacity under typical usage is detected if a full discharge cycle is captured when the battery is discharged from full to empty under typical load and temperature without interruption of the charge current.

Configure Gas Gauges

There are two types of gas gauges, with and without a CPU. The one without a CPU, known as a battery monitor, provides coulomb data to the host along with battery voltage and temperature readings. The gas gauge and host communicate by I2C or by one wire like HDQ and SDQ. The host processes the data and computes capacity. The gas gauge with a CPU provides a stand-alone solution for battery management. All measurement and computation are transparent to end users, and key battery parameters, such as remaining capacity and relative state of charge, are directly accessible through the communication port. This eliminates the need to develop gas gauge code, which is often unfamiliar to electronics engineers.

No matter where the gas gauge code resides, it is always necessary to gather battery characteristics and system power requirements. These numbers are programmed into the gas gauge for different battery sources and applications. Battery end of discharge voltage (EDV) is a parameter commonly used by gas gauges to reset the battery capacity to zero. On the other hand, the system will always have a requirement for minimum operating voltage (MOV), which could be the undervoltage lockout threshold of power conversion ICs connected to the battery. It could also be the battery voltage the system required for reserved capacity, below which the system automatically goes into low power mode. In many cases, people simply use these voltages as EDV, which often results in surprising system shutdown because the battery discharge curve varies with load current due to battery impedance, as shown in Figure 1. Setting EDV to MOV is fine as long as the load current keeps pretty constant. However, this is the last thing the designer can count on in today's portable devices. For instance, if the battery reaches point A in the typical load discharge curve and the system turns into high gear, the battery voltage immediately drops below the MOV and causes an unexpected system shutdown. To avoid this experience, estimate the total battery capacity based on the heavy load, and use the typical load voltage corresponding to this capacity as the EDV. Although there's unused capacity in light load discharge, the user will not get any unpleasant surprises.

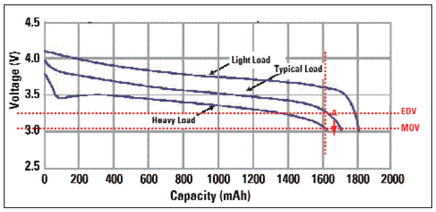

Figure 1. Discharge curves from different load currents.

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Figure 1 also shows that remaining capacity is highly dependent on discharge current. Data from the coulomb counter often needs to be compensated for load current when computing remaining capacity. One simple but effective way is to linearly compensate battery capacity for discharge current. Figure 2 shows that computation reduces battery capacity for load current when the current is above a certain threshold. The 1C rate is normally the current in mA that equals the cell capacity in mAh. Cell capacity is typically measured at about a C/5 discharge rate.

A similar approach can cover the effect of temperature on remaining capacity. For any given load, low temperature increases the battery impedance, altering the discharge curve. Discharge curves for different loads and temperatures should be available from the battery data sheet. The compensation threshold and slope should be extracted from these curves to best fit the linear compensation for the operating conditions required for the applications.

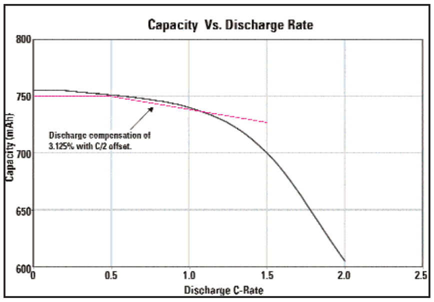

Figure 2. Compensation for discharge current. The black line measures remaining capacity, while the red line estimates remaining capacity.

Design and Test Gas Gauges

Battery charge and discharge current is measured across a sense resistor in series with battery cells. To avoid unnecessary power loss, the value of the sense resistor is often in the range of 10 mΩ to 20 mΩ. This puts a large burden on the accuracy of the coulomb and current measurement circuit, because to measure 5 mA current, the 50 uV signal has to be interpreted correctly. Gas gauges all require some form of calibration to measure and compensate for offset, and some devices need to execute a command to put the part into a calibration mode to capture a snapshot of the offset. Gas gauge function ceases to operate during the calibration mode, so the gas gauge can only be calibrated at the manufacture site, and the offset is only good for one operation condition defined by battery voltage, temperature, etc. More advanced devices implement auto calibration, which continually carries out the calibration procedure even when devices are in the field. It provides "live" calibration data and reduces test time for the devices.

When a gas gauge is installed in a detachable battery pack, passing a system level electrostatic discharge (ESD) test can be a major task to accomplish. Without a gas gauge, electronic devices inside battery packs are only analog components. Passing a pack-level ESD test often simply means the components have no physical damage. Therefore, if there's adequate component-level ESD protection, it is hard to fail a system-level ESD test. With the gas gauge, the system has embedded memory and CPU. ESD failure is now the result of memory loss or corruption, CPU reset or mis-execution. In a single cell Li-ion application, the gas gauge is often powered directly from the battery, which is connected to the pack+ and pack- terminal of the battery pack. ESD energy released onto those terminals can be easily coupled into the power supply pin of the gas gauge. Therefore, improving the decoupling circuit is the first step to fend off ESD disturbance.

Since layout doesn't add to the bill of materials, the designer should make every effort to optimize the layout, understanding that traces and vias can easily turn into unwanted "components" at a certain frequency. One common oversight is that the power supply decoupling capacitor is only placed close to the supply pin but not to the ground pin, even though they are equally important. Sometimes it is useful to parallel a small ceramic capacitor, such as 68 pF, with a large capacitor for its lower high-frequency impedance.

Some gas gauges are equipped with a backup power supply pin, which is simply a capacitor charged up during normal operation. When the main power supply fails, the capacitor serves as temporary power source for memories. After power recovers, there has to be an integrity check for memory data before the execution resumes.

Overall, today's portable devices are accepting gas gauge technology at a very fast pace. Although the benefit is well understood, maximizing the performance often leads designers to unfamiliar territory, battery characteristics. IC vendors are creating solutions to integrate the CPU with a gas gauge algorithm. However, system engineers still need a basic grasp on how the battery behaves in an application and the ability to configure the gas gauge for optimum performance. A gas gauge in the battery pack adds complexity, which requires heightened design and layout experience. Device manufacturers are continuously working to make gas gauges easier for system designers to use and to improve the devices' robustness.

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