Host-side gas-gauge-system design considerations for single-cell handheld applications

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Introduction

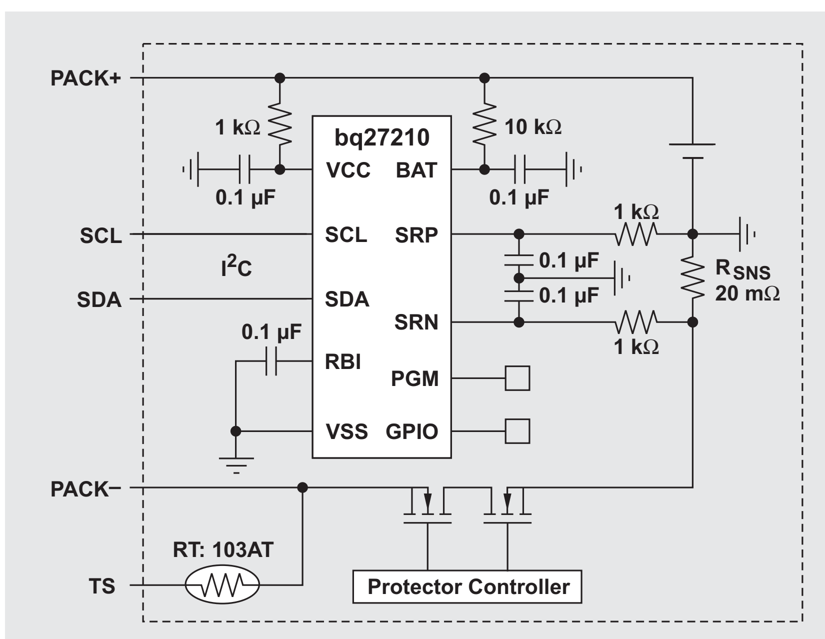
It is desirable to determine the remaining capacity of a battery for handheld devices such as smartphones, portable media players (PMPs), and personal digital assistants (PDAs). Many handheld portable devices have used voltage measurement alone to approximate the remaining battery capacity, but the need for a more accurate method has become critical in some applications. A host-side gas gauge has become more attractive than the traditional pack-side gas gauge since it can reduce the cost of a new battery pack when the life of the original battery is over. This article focuses on improving gas-gauge accuracy and on host-side battery-management design considerations such as high-accuracy Impedance Track™ gas gauges, battery insertion, and coordinating operation with the battery-charging system.

Problems of existing gas gauges

The traditional gas gauge is located in the battery pack as shown in Figure 1 and is always connected to the Li-ion cell. The gas gauge monitors the charging and discharging activity and uses an embedded algorithm to report the remaining battery capacity. When the battery life is over, the battery cell along with the pack electronics circuit will be thrown away, wasting the gas gauge that is still in good operation. The end user has to buy not only another battery pack but also another gas gauge. In the host-side gas-gauge system, the gas gauge is located in the motherboard, while the battery cell and pack-protection circuit are in the pack side. With this configuration, the user will not have to pay for a gas gauge when purchasing a new battery pack; but there are several design challenges, including battery-chemistry detection, battery-insertion detection, and coordinating operation with the battery charger.

A common erroneous belief is that the shrinking run time of a Li-ion battery is primarily due to depletion of the battery capacity. However, it is generally not the capacity loss but the increasing battery impedance that results in early system shutdown. The battery capacity actually drops by less than 5%, while the internal DC resistance of the battery increases by a factor of 2 after approximately 100 cycles. A direct effect of the higher resistance of an aging

Figure 1. Traditional battery pack



battery is a higher internal voltage drop in response to a load current. This voltage drop causes the aging battery to reach the minimum system operating voltage or battery cutoff voltage earlier than would a fresh battery.

Conventional gas-gauging technologies—mainly the voltage-based and coulomb-counting algorithms—have obvious performance limitations. The voltage-based scheme, widely adopted in handheld devices such as cellular phones due to its low cost and simplicity, suffers from changes in the battery resistance over time. The battery voltage is given by

$$V_{BAT} = OCV - I \times R_{BAT},$$

where OCV is the battery open-circuit voltage and R_{BAT} is the battery internal DC resistance. Figure 2 shows that the lower voltage of an aging battery causes the system to shut down earlier than it would with a fresh battery.

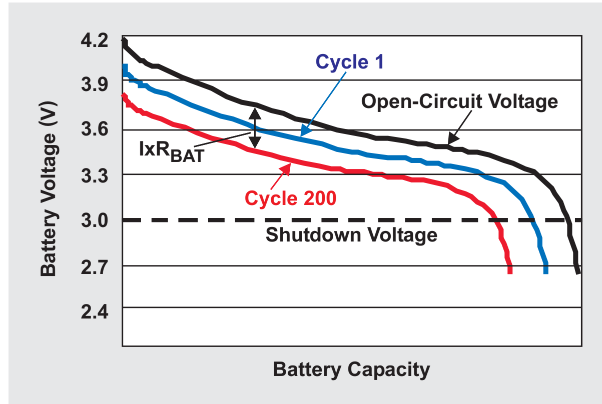
Load conditions and temperature variations can change the available battery capacity by up to 50%. Most end users have experienced early system shutdown in portable devices that lack a true gas gauge. The coulomb-counting scheme takes the alternative approach of continuously integrating coulombs going to and from the battery to compute the consumed charge and state-of-charge (SOC). With an established value for full capacity, coulomb counting allows the remaining capacity to be determined. The drawback of this approach is that self-discharge is difficult to model with accuracy, and without periodic full-cycle calibration the gauging error accrues over time. None of these algorithms addresses resistance variations of the battery. The designer must reserve more capacity by terminating system operation prematurely to avoid the unexpected shutdown, leaving a significant amount of energy unused.

Single-cell Impedance Track gas gauge

What makes Impedance Track technology unique and much more accurate than other solutions is a self-learning mechanism that accounts for the changes in chemical capacity (Q_{MAX}) and the increasing battery resistance that is due to aging. An Impedance Track gas gauge implements a dynamic modeling algorithm to learn and track the battery characteristics by first measuring and then tracking the impedance and capacity changes during battery use. With this algorithm, no periodic, full-cycle capacity calibration is required.

Impedance Track technology enables compensation for load and temperature to be modeled accurately. Most important, gas-gauging accuracy can be maintained during the whole lifetime of the battery. Because system design no longer requires a premature-shutdown scheme, the battery capacity can be fully utilized. Impedance Track gas gauges determine the remaining battery capacity more accurately than either coulomb counting or cell-voltage correlation. They actually use both techniques to overcome the effects of aging, self-discharge, and temperature variations.

Figure 2. Battery-discharge characteristics over cycle life



Impedance Track devices constantly maintain database tables to keep track of battery resistance (R_{BAT}) as a function of depth of discharge (DOD) and temperature. To understand when these tables are updated or utilized, it is helpful to know what operations occur during different states. Several current thresholds can be programmed into the gas gauge's nonvolatile memory to define a charge; a discharge; and "relaxation time," which allows the battery voltage to stabilize after ceasing charge or discharge.

When a handheld device is turned on, the gas gauge determines the exact SOC by measuring the battery open-circuit voltage (OCV) and correlating it with the OCV(DOD,T) table. After completing OCV measurement, the gas gauge applies the load, starts the integrating coulomb counter, and continuously calculates the SOC.

The total capacity, Q_{MAX}, is calculated through two OCV readings taken at fully relaxed states when the battery-voltage variation is small enough before and after the charge or discharge activity. As an example, before the battery is discharged, the SOC is given by

$$SOC_1 = \frac{Q_1}{Q_{MAX}}.$$

After the battery is discharged with a passed charge of ΔQ, the SOC is given by

$$SOC_2 = \frac{Q_2}{Q_{MAX}}.$$

Taking the difference of these two equations and solving for Q_{MAX} yields

$$Q_{MAX} = \frac{\Delta Q}{|SOC_1 - SOC_2|},$$

where $\Delta Q = Q_1 - Q_2$. This equation illustrates that it is not necessary to have a complete charge-and-discharge cycle to determine the battery's total capacity. The battery's time-consuming learning cycle during pack manufacturing can therefore be eliminated.

The battery's $R_{BAT}(DOD,T)$ table is updated constantly during discharges, and the resistance is calculated as

$$R_{BAT}(DOD,T) = \frac{OCV(DOD,T) - \text{Battery Voltage Under Load}}{\text{Average Load Current}}.$$

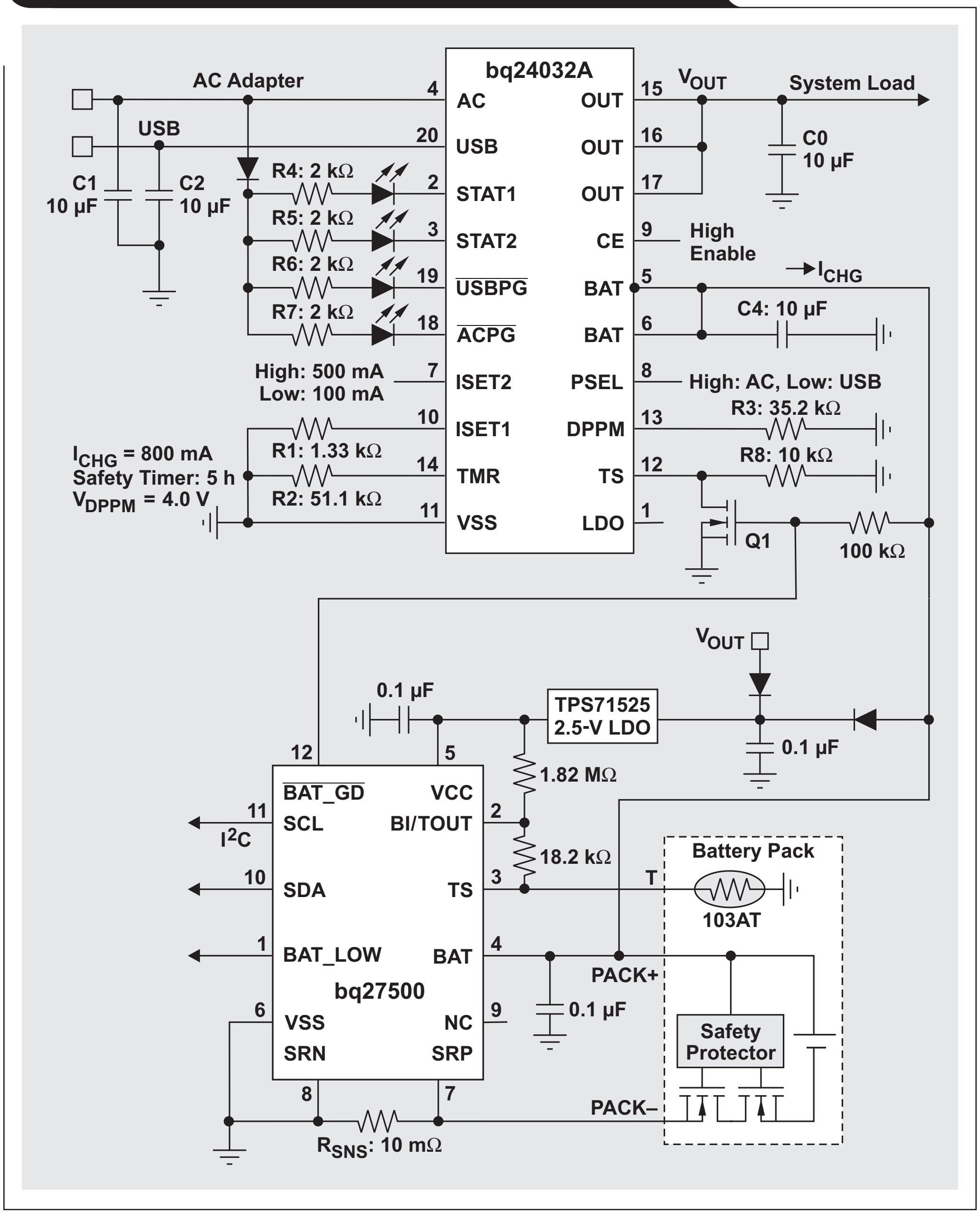
The gas gauge uses R_{BAT} to compute when the termination voltage will be reached at the present load and temperature. It also uses R_{BAT} to determine the remaining capacity (RM) by using a voltage-simulation method in the firmware. The simulation starts from the present SOC_{START} and calculates the future battery-voltage profile under the same load currents with consecutive SOC decrements. When the simulated battery voltage, $V_{BAT}(SOC_I,T)$, reaches the battery termination voltage (typically 3.0 V), the SOC corresponding to this voltage is captured as SOC_{FINAL}. The remaining capacity, RM, is calculated as

$$RM = (SOC_{START} - SOC_{FINAL}) \times Q_{MAX}.$$

Design considerations for host-side gas-gauge and battery-charging system

Figure 3 is a circuit diagram of a host-side battery-management system including the battery charger and gas gauge. The bq24032A is a power-path-management battery charger that can simultaneously power the system while charging the battery.

Figure 3. Host-side gas-gauge and battery-charging system



There are several host-side gauging-system design considerations. The first one is to get a new battery's initial capacity when it is inserted. Since there is a solid correlation between the battery OCV and SOC, the OCV must be measured before the battery charging or discharging starts. For accurate OCV measurement, the bq27500 does not allow the battery to be charged or discharged after it is inserted. It first determines if the battery is present or not by putting the BI/TOUT pin in high-impedance mode and detecting battery insertion when the BI/TOUT pin voltage is pulled down. Battery charging is disabled when the temperature-monitoring pin is pulled to ground by turning on MOSFET Q1. After the OCV reading is finished and the initial battery capacity is accurately learned, $\overline{\text{BAT\_GD}}$ is pulled low, which turns off MOSFET Q1. When the battery is inserted without an adapter, the gauging system should wait for a few milliseconds to measure the OCV before applying power to the system load.

The second design challenge is how to monitor the battery temperature for charging qualification and for adjusting the battery capacity. To minimize battery degradation, the gas gauge prohibits battery charging, typically when the cell temperature is out of the 0 to 45°C range. The gas gauge also has to monitor the cell temperature to adjust the battery impedance and capacity. The bq27500 can be configured to monitor the cell temperature through its TS pin, while the temperature threshold to qualify charging can be set through the data flash constants. To minimize power consumption, the gas gauge measures cell temperature every 1 second by internally pulling BI/TOUT high and measuring the voltage across the TS pin. If the cell temperature falls outside of the preset range, $\overline{\text{BAT\_GD}}$ is pulled high and turns on the MOSFET Q1 so that the battery charger is disabled until the cell temperature recovers. In the meantime, the temperature information is used to normalize cell impedance and adjust the capacity.

Another design consideration is how to minimize the gas gauge's total power consumption, since the gas gauge is always connected to the battery as long as the battery is inserted. There are four operation modes: NORMAL, SLEEP, HIBERNATE, and BAT INSERT CHECK. In NORMAL mode, the gas gauge measures current, voltage, and temperature and periodically updates the interface data set. Decisions to change states are also made. The most power consumed is typically 80 µA. When the SLEEP-mode bit is set and the average current is below a programmable sleep current, the bq27500 enters the SLEEP mode. It periodically wakes to take data measurements and update the data set, then returns to sleep to minimize current consumption, typically down to 15 µA. To further reduce current consumption, the gas gauge enters HIBERNATE mode and consumes only 4 µA if the average current is less than the HIBERNATE current value programmed in the flash memory and if the HIBERNATE-mode bit is set. A cell voltage measured lower than the HIBERNATE voltage value programmed in the flash memory can replace the HIBERNATE bit requirement. The BAT INSERT CHECK mode manages when charging and discharging are allowed so that OCV measurements can be taken when a battery pack is inserted into the system. No gauging occurs in this mode. Once battery insertion is detected and OCV readings are complete, the gauge proceeds to NORMAL mode.

Another important design consideration is how to safely and accurately indicate low battery capacity so that data can be saved and the system can be safely shut down. Traditionally, the low-battery indication has been based purely on the battery voltage because of simple hardware implementations and cheap solutions. When the battery voltage is below the preset threshold, the BAT_LOW pin changes the state and can be used to control the system for possibly reducing functionality and providing a warning signal to the end user. However, this method may not be accurate, since the battery voltage is a function of the load current, aging, and temperature. The status indicator may flicker for a pulsating load in handheld applications. Another method by which BAT_LOW could be configured is based on the relative SOC, which is more accurate than the pure voltage measurement. With this method, BAT_LOW will change its state when either the battery voltage or the relative SOC reaches the preset threshold. Therefore, the microprocessor can safely prepare for data saving and system shutdown in advance.

Conclusion

The host-side Impedance Track gas-gauging system provides high-accuracy gauging and a low system cost. The bq27500 is an ideal solution for handheld devices such as smartphones, PMPs, and PDAs. Understanding the Impedance Track technology and host-side design challenges is critical.

Related Web sites

power.ti.com
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Replace *partnumber* with bq24032A, bq27210, bq27500, or TPS71525

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