# Low-Power, Long Runtime Battery Fuel Gauging Scheme

**ABSTRACT**

Many battery-powered applications exist which require weeks or months of run time between charging. Average current draw from the battery may be in the µA range, and it can be desirable to minimize current consumption by the battery fuel gauge to maximize run time. This application report presents a method to adapt a single-cell Impedance Track™ fuel gauge for this purpose. In essence, the gauge is placed in a SHUTDOWN mode for a majority of the time where it will typically consume 600 nA of current. When an accurate update of the battery SOC (state of charge) is required, the gauge can be awoken, the registers initialized and read, then restored to the SHUTDOWN mode. The capacity fade of the battery can still be learned by the fuel gauge upon a charge event, so accurate fuel gauging can still be maintained as the battery ages. For this report, specific examples using the bq27520-G4 and bq27421-G1 fuel gauges are used.

## 1 System Characteristics

For this example, we will use a hypothetical system with the following characteristics:

- 100-mAh, rechargeable, single-cell, Li-ion or Li-polymer battery
- Average system current is on the order of 500 µA which corresponds to a C/200 average discharge rate.
- Spikes of greater than 100 mA lasting for several microseconds are allowed (perhaps from a radio).
- Low power mode is 1 to 10 µA.
- The bq27421-G1 power modes are:
  - 93 µA typical in NORMAL mode. In this mode, the coulomb counter is active and updates occur every second.
  - 21 µA typical in SLEEP mode. In this mode, the coulomb counter and oscillators are off, waking for 1 second every 20 seconds.
  - 9 µA typical in HIBERNATE mode. In this mode, the gauge is completely shutdown until communication wakes it, and then it must be reinitialized just as if it was coming from a power-on reset (POR).
  - 600 nA typical in SHUTDOWN mode if the SHUTDOWN command is sent. In this mode, the internal low drop-out oscillator (LDO) is off.
- The bq27520-G4 power modes are:
  - 118 µA typical in NORMAL mode. In this mode, the coulomb counter is active and updates occur every second.
  - 23 µA typical in SLEEP mode. In this mode, the coulomb counter and oscillators are off, waking for 1 second every 20 seconds.
  - 8 µA typical in HIBERNATE mode. In this mode, the gauge is completely shutdown until communication wakes it. Upon exiting the HIBERNATE mode, the gauge will reinitialize itself just as if it was coming from a POR.
  - Less than 1 µA in SHUTDOWN mode if the CE pin is held low. In this mode, the internal LDO is off.

## 2 Low-Power Scheme During Discharge

System discharge current is typically too low for the gauge to accurately coulomb count. Instead, the gauge will rely on open-circuit voltage (OCV) measurements to update the state of charge (SOC). There is no need to waste power by keeping the gauge awake (NORMAL or SLEEP modes) during battery discharge. The SOC changes <1% per hour. Gauge resolution of the SOC is 1%. Remaining capacity resolution is 1 mAh.

### *2.1 bq27421-G1 Low-Power Scheme*

The bq27421-G1 low-power scheme is the following:

1. Send the SHUTDOWN command and wait until the SOC update is needed.
2. When the bq27421 gauge is enabled, it needs to be initialized. The ITPOR bit is set to 1 at power up and the configuration defaults are read from ROM.
3. The host uses the CONFIG UPDATE mode to restore the configuration options and any previously learned values.
4. The host uses the SOFT_RESET command to exit the CONFIG UPDATE mode. It takes approximately 4 seconds to initialize and report the SOC. To minimize overall power, the host may return to the low-power mode during this 4-second period.
5. Typically, no more than once per hour, the host can:
   (a) Enable and initialize the gauge.
   (b) Return to sleep for 4 seconds while the gauge initializes.
   (c) Wake again to read the SOC from the gauge.
   (d) Shutdown the gauge and return the system to low-power mode.

### *2.2 bq27520-G4 Low-Power Scheme*

The bq27520-G4 low-power scheme is the following:

1. Use the general-purpose IO pin of the host to hold the gauge CE pin low until an SOC update is needed.
2. When the gauge is enabled, it will take approximately 4 seconds to initialize and report the SOC.
3. Check the INITCOMP bit to know when gauge initialization is complete.
4. Typically, no more than once per hour, the host can:
   (a) Enable the gauge.
   (b) Return to sleep for 4 seconds while the gauge initializes.
   (c) Wake again to read the SOC from the gauge.
   (d) Shutdown the gauge and return the system to low-power mode.

## 3 Qmax Learning Scheme During Charge

Qmax represents the maximum theoretical chemical capacity of the battery that fades over time. Battery aging depends on temperature, cycling, calendar time, storage voltage, and other unpredictable factors. To learn the capacity fade of the battery over time, the gauge can measure a relaxed battery voltage near empty, coulomb count during the charge, and then measure the relaxed battery voltage after reaching full charge. Alternatively, the Fast Qmax method allows Qmax learning without the wait periods.

### 3.1 bq27421-G1 Qmax Learning Scheme

The following sequence is recommended for the bq27421-G1 fuel gauge:

1. The host detects that the adapter is plugged in and disallows charging immediately.

**NOTE:** It is important to minimize any current flow during the next step.

2. The host then:
   (a) Wakes the gauge.
   (b) Waits approximately 4 seconds for initialization (the INITCOMP bit is set).
   (c) Sends the IT_ENABLE command.
   (d) Waits for the RUP_DIS bit to clear. This indicates the gauge has taken an OCV measurement to be used for Qmax updates.
   (e) Sends the SEALED command.
3. The gauge remains active and charging is allowed. Gauge coulomb counts throughout battery charging.
4. After charge termination is reached, there will be two methods to allow a Qmax update:
   - Traditional Qmax update: Leave the gauge awake until the VOK bit clears. This indicates the second OCV measurement was taken. If all Qmax update conditions were met, then Qmax has been learned. This typically takes 30 to 60 minutes, but could take as long as 2 hours.
   - Fast Qmax update: This method does not require waiting until the VOK bit clears, but does require the gauge to remain awake until Qmax is updated. If the previous steps were followed and a discharge is started after charge termination, but before VOK clears, then Qmax will be updated.
5. The host stores this learned ***Qmax Cell 0*** value before putting the gauge in SHUTDOWN mode and then restores it along with the other configuration parameters every time it exits the SHUTDOWN mode.

### 3.2 bq27520-G4 Qmax Learning Scheme

The following sequence is recommended for the bq27520-G4 fuel gauge:

1. The host detects that the adapter is plugged in and disallows charging immediately.

**NOTE:** It is important to minimize any current flow during the next step.

2. The host then:
   (a) Wakes the gauge.
   (b) Waits approximately 4 seconds for initialization (the INITCOMP bit is set).
   (c) Unseals the gauge.
   (d) Sends the IT_ENABLE command.
   (e) Waits for the RUP_DIS bit to clear. This indicates the gauge has taken an OCV measurement to be used for Qmax updates.
   (f) Sends the SEALED command.
3. The gauge remains active and charging is allowed. Gauge coulomb counts throughout battery charging.
4. After charge termination is reached, there will be two methods to allow a Qmax update:
   - Traditional Qmax update: Leave the gauge awake until the VOK bit clears. This indicates the second OCV measurement was taken. If all Qmax update conditions were met, then Qmax has been learned. This typically takes 30 to 60 minutes, but could take as long as 2 hours.
   - Fast Qmax update: For this method, the CHGFASTQM bit in the OpConfig E dataflash register must be set in the gauge configuration. This method does not require waiting until the VOK bit clears, but does require the gauge to remain awake until Qmax is updated. If the previous steps were followed and a discharge is started after charge termination, but before VOK clears, then

Qmax will be updated.

### 3.3 Notes About SEALED Mode

It is recommended that the fuel gauge be placed in the SEALED mode during normal operation. This blocks accidental writes to the gauge DataRAM values. Also, the SEALED mode blocks reading and writing of learned and configuration data memory parameters including ***Qmax Cell 0***. Furthermore, the SEALED mode blocks certain commands, such as IT_ENABLE, SHUTDOWN, and RESET.

Because the schemes presented in this document require use of the SHUTDOWN subcommand (bq27421-G1 only) and the IT_ENABLE subcommand, the gauge must either be unsealed before sending these commands or else never put in the SEALED mode in the first place. For the bq27421-G1, the gauge will always power up in an UNSEALED state, and for this scheme it will be only briefly used before powering down, so there is no use in putting it in the SEALED mode unless it will be used for normal gauge operation for an extended period. Flash-based gauges such as the bq27520-G4, once put in the SEALED mode, will always power up in the SEALED state, even if unsealed before shutdown. It is recommended to put these gauges in the SEALED mode after production programming of the flash, and then include the unseal command sequence before the IT_ENABLE subcommand is used.

## 4 Qmax Learning Notes

Qmax does not need to be learned every cycle since it changes slowly over time. Once a month or even every few months will be sufficient for this application.

The Qmax update qualifications are:

- At least approximately 37% change in the SOC is required between the first and second OCV.
- Neither OCV measurement can be taken in the flat region of the voltage curve. The exact voltage region depends on the battery profile but could roughly correspond to the region between 50% and 25%, as an example.
- Both OCV measurements must be taken when the temperature is 10°C < T < 40°C.
- The gauge must not be reset between OCV measurements.

**NOTE:** For gauges that do not have NVM, such as the bq27421-G1, the host must store the learned Qmax and then restore it along with the other configuration parameters whenever the ITPOR bit is 1; that is, when it is re-enabled.

## 5 Rsense Values for bq27520-G4

The gauge will probably not be useful for measuring submilliampere currents. An enormous sense resistor could be used, but then the insertion loss will be high and power will be wasted during peak currents.

The gauge reports current with a 1-mA resolution. The maximum measurable input voltage across the SRP and SRN pins of the gauge is ±125 mV. Assuming maximum system current peak of 200 mA, the sense resistor should be no larger than 125 mV / 200 mA = 625 mΩ. Because the gauge coulomb counter input offset could be as high as 10 µV:

- With a 10-mΩ sense resistor, this corresponds to 1-mA offset.
- With a 20-mΩ sense resistor, this corresponds to 500-µA offset.
- With a 400-mΩ sense resistor, this corresponds to 25-µA offset.

The smallest current to measure should be >10× the minimum offset for reasonable accuracy. Therefore, measuring µA-current levels is not practical.

A 10-mΩ or 20-mΩ sense resistor is typically used with bq27520-G4 and would be sufficient for this example to learn Qmax.

**NOTE:** The bq27421-G1 gauge has an integrated sense resistor of approximately 7 mΩ which will work fine for this example.

# 6 Revision History

| Version | Change Date | Description |
| --- | --- | --- |
| — | January 2014 | Initial Release |
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