# bq27510-G3 System-Side Impedance Track™ Fuel Gauge With Integrated LDO

# Technical Reference Manual

![Texas Instruments]

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# Preface

This document is a detailed Technical Reference Manual (TRM) for using and configuring the bq27510-G3 battery fuel gauge. This TRM document is intended to complement but not supersede any information contained in the separate bq27510-G3 datasheet.

Refer to the *bq27510-G3 Datasheet (SLUSAT1)*.

## Formatting conventions used in this document:

| Information Type | Formatting Convention | Example |
|---|---|---|
| Commands | *Italics* with parentheses and no breaking spaces | *RemainingCapacity( )* command |
| Data Flash | *Italics*, **bold**, and breaking spaces | ***Design Capacity*** data |
| Register bits and flags | Brackets and *italics* | *[TDA]* bit |
| Data Flash bits | Brackets, *italics*, and **bold** | ***[LED1]*** bit |
| Modes and states | ALL CAPITALS | UNSEALED mode |

## Related Documentation from Texas Instruments

To obtain a copy of any of the following TI documents, call the Texas Instruments Literature Response Center at (800) 477-8924 or the Support Center at (512) 434-1560. When ordering, identify this document by its title and literature number. Updated documents also can be obtained through the TI Web site at www.ti.com.

1. *bq27510-G3, System-Side Impedance Track™ Fuel Gauge With Integrated LDO* Data Sheet (SLUSAT1)
2. *Going to Production with the bq275xx* Application Report (SLUA449)
3. *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* Application Report (SLUA450)
4. *Host System Calibration Method* Application Report (SLUA640)

## Revision History

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

# General Description

The bq27510-G3 fuel gauge accurately predicts the battery capacity and other operational characteristics of a single-series, Li-based, rechargeable cell. It can be interrogated by a system processor to provide cell information, such as time-to-empty (TTE), state-of-charge (SOC), and the SOC interrupt signal to the host.

Information is accessed through a series of commands, called *Standard Commands*. Further capabilities are provided by the additional *Extended Commands* set. Both sets of commands, indicated by the general format *Command( )*, read and write information contained within the device control and status registers, as well as its data flash locations. Commands are sent from system to gauge using the $I^2C$ serial communications engine, and can be executed during application development, system manufacture, or end-equipment operation.

Cell information is stored in the device in non-volatile flash memory. Many of these data flash locations are accessible during application development. They cannot, generally, be accessed directly during end-equipment operation. Access to these locations is achieved by either use of the companion evaluation software, through individual commands, or through a sequence of data-flash-access commands. To access a desired data flash location, the correct data flash subclass and offset must be known.

The key to the high-accuracy fuel gauging prediction is Texas Instruments proprietary Impedance Track™ algorithm. This algorithm uses cell measurements, characteristics, and properties to create state-of-charge predictions that can achieve less than 1% error across a wide variety of operating conditions and over the lifetime of the battery. See application report SLUA450, *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family*.

The fuel gauge measures charging and discharging of the battery by monitoring the voltage across a small-value series sense resistor (5 mΩ to 20 mΩ, typical) located between the system $V_{SS}$ and the battery PACK− terminal. When a cell is attached to the device, cell impedance is learned, based on cell current, cell open-circuit voltage (OCV), and cell voltage under loading conditions.

The external temperature sensing is optimized with the use of a high-accuracy, negative temperature coefficient (NTC) thermistor with R25 = 10.0 kΩ ±1%. B25/85 = 3435 kΩ ± 1% (such as Semitec NTC 103AT). Alternatively, the fuel gauge can also be configured to use its internal temperature sensor or receive temperature data from the host processor. When an external thermistor is used, an 18.2-kΩ pullup resistor between BI/TOUT and TS pins is also required. The fuel gauge uses temperature to monitor the battery-pack environment, which is used for fuel gauging and cell protection functionality.

To minimize power consumption, the device has different power modes: NORMAL, SNOOZE, SLEEP, HIBERNATE, and BAT INSERT CHECK. The fuel gauge passes automatically between these modes, depending upon the occurrence of specific events, though a system processor can initiate some of these modes directly. More details can be found in Section 5.6, *Power Modes*.

2C

# Standard Data Commands

The bq27510-G3 fuel gauge uses a series of 2-byte standard commands to enable system reading and writing of battery information. Each standard command has an associated command-code pair, as indicated in Table 2-1. Because each command consists of two bytes of data, two consecutive I²C transmissions must be executed both to initiate the command function and to read or write the corresponding two bytes of data. Additional options for transferring data are described in Chapter 3, *Extended Data Commands*. Read and write permissions depend on the active access mode, SEALED or UNSEALED. For details, see Section 4.3, *Device Access Modes*. See Chapter 6, *Communications*, for I²C details.

**Table 2-1. Standard Commands**

| Name | | Command Code | Unit | SEALED Access |
|---|---|---|---|---|
| Control( ) | CNTL | 0x00 and 0x01 | NA | RW |
| AtRate( ) | AR | 0x02 and 0x03 | mA | RW |
| AtRateTimeToEmpty( ) | ARTTE | 0x04 and 0x05 | Minutes | R |
| Temperature( ) | TEMP | 0x06 and 0x07 | 0.1°K | RW |
| Voltage( ) | VOLT | 0x08 and 0x09 | mV | R |
| Flags( ) | FLAGS | 0x0A and 0x0B | NA | R |
| NominalAvailableCapacity( ) | NAC | 0x0C and 0x0D | mAh | R |
| FullAvailableCapacity( ) | FAC | 0x0E and 0x0F | mAh | R |
| RemainingCapacity( ) | RM | 0x10 and 0x11 | mAh | R |
| FullChargeCapacity( ) | FCC | 0x12 and 0x13 | mAh | R |
| AverageCurrent( ) | AI | 0x14 and 0x15 | mA | R |
| TimeToEmpty( ) | TTE | 0x16 and 0x17 | Minutes | R |
| StandbyCurrent( ) | SI | 0x18 and 0x19 | mA | R |
| StandbyTimeToEmpty( ) | STTE | 0x1A and 0x1B | Minutes | R |
| StateOfHealth( ) | SOH | 0x1C and 0x1D | % / num | R |
| CycleCount( ) | CC | 0x1E and 0x1F | num | R |
| StateOfCharge( ) | SOC | 0x20 and 0x21 | % | R |
| InstantaneousCurrent( ) | | 0x22 and 0x23 | mA | R |
| InternalTemperature( ) | INTTEMP | 0x28 and 0x29 | 0.1°K | R |
| ResistanceScale( ) | | 0x2A and 0x2B | | R |
| OperationConfiguration( ) | Op Config | 0x2C and 0x2D | NA | R |
| DesignCapacity( ) | | 0x2E and 0x2F | mAh | R |
| UnfilteredRM( ) | UFRM | 0x6C and 0x6D | mAh | R |
| FilteredRM( ) | FRM | 0x6E and 0x6F | mAh | R |
| UnfilteredFCC( ) | UFFCC | 0x70 and 0x71 | mAh | R |
| FilteredFCC( ) | FFCC | 0x72 and 0x73 | mAh | R |
| TrueSOC( ) | UFSOC | 0x74 and 0x75 | % | R |

## 2.1 *Control( )*: 0x00 and 0x01

Issuing a *Control( )* command requires a subsequent 2-byte subcommand. These additional bytes specify the particular control function desired. The *Control( )* command allows the system to control specific features of the fuel gauge during normal operation and additional features when the device is in different access modes, as described in Table 2-2.

**Table 2-2. *Control( )* Subcommands**

| Control Function | Control Data | SEALED Access | Description |
|---|---|---|---|
| CONTROL_STATUS | 0x0000 | Yes | Reports the status of DF checksum, hibernate, Impedance Track™, etc. |
| DEVICE_TYPE | 0x0001 | Yes | Reports the device type (for example: 0x0520) |
| FW_VERSION | 0x0002 | Yes | Reports the firmware version on the device type |
| PREV_MACWRITE | 0x0007 | Yes | Returns previous *Control( )* subcommand code |
| CHEM_ID | 0x0008 | Yes | Reports the chemical identifier of the Impedance Track™ configuration |
| OCV_CMD | 0x000C | Yes | Requests the fuel gauge to take an OCV measurement |
| BAT_INSERT | 0x000D | Yes | Forces *Flags( ) [BAT_DET]* bit set when **OpConfig B [BIE]** bit = 0 |
| BAT_REMOVE | 0x000E | Yes | Forces *Flags( ) [BAT_DET]* bit clear when **OpConfig B [BIE]** bit = 0 |
| SET_HIBERNATE | 0x0011 | Yes | Forces *CONTROL_STATUS [HIBERNATE]* bit to 1 |
| CLEAR_HIBERNATE | 0x0012 | Yes | Forces *CONTROL_STATUS [HIBERNATE]* bit to 0 |
| SET_SNOOZE | 0x0013 | Yes | Forces *CONTROL_STATUS [SNOOZE]* bit to 1 |
| CLEAR_SNOOZE | 0x0014 | Yes | Forces *CONTROL_STATUS [SNOOZE]* bit to 0 |
| DF_VERSION | 0x001F | Yes | Returns the **Data Flash Version** code |
| SEALED | 0x0020 | No | Places the fuel gauge in SEALED access mode |
| IT_ENABLE | 0x0021 | No | Enables the Impedance Track™ (IT) algorithm |
| RESET | 0x0041 | No | Forces a full reset of the fuel gauge |

Example using *DEVICE_TYPE* subcommand:

• To device address 0xAA, starting at command 0x00, write two bytes of data: 0x01 and 0x00.

• Then read the response using an incremental read. To device address 0xAB, starting at command 0x00, read two bytes.

### 2.1.1 CONTROL_STATUS: 0x0000

Instructs the fuel gauge to return status information to *Control( )* addresses 0x00 and 0x01. The status word includes the following information:

**Table 2-3. CONTROL_STATUS Bit Definitions**

|  | bit7 | bit6 | bit5 | bit4 | bit3 | bit2 | bit1 | bit0 |
|---|---|---|---|---|---|---|---|---|
| **High Byte** | – | FAS | SS | – | CCA | BCA | OCVCMDCOMP | OCVFAIL |
| **Low Byte** | INITCOMP | HIBERNATE | SNOOZE | SLEEP | LDMD | RUP_DIS | VOK | QEN |

**High Byte**

FAS = Status bit indicating the fuel gauge is in FULL ACCESS SEALED state. Active when set.

SS = Status bit indicating the fuel gauge is in SEALED state. Active when set.

CCA = Status bit indicating the fuel gauge Coulomb Counter Calibration routine is active. The CCA routine takes place approximately 1 minute after the initialization and periodically as gauging conditions change. Active when set. (See Section 5.3.5, *Autocalibration*)

BCA = Status bit indicating the fuel gauge board calibration routine is active. Active when set.

OCVCMDCOMP = Status bit indicating the fuel gauge has executed the OCV command. This bit can only be set with the presence of a battery. True when set.

OCVFAIL = Status bit indicating an OCV reading failed due to the current. This bit can only be set with the presence of a battery. True when set.

**Low Byte**

INITCOMP = Initialization completion bit indicating the initialization completed. This bit can only be set with the presence of a battery and can be monitored to determine when fuel gauge values are valid. It is recommended to poll this bit at initialization or startup. True when set.

HIBERNATE = Status bit indicating a request for entry into the HIBERNATE mode from the SLEEP mode. True when set. Default is 0.

SNOOZE = Status bit indicating the SNOOZE mode is enabled. True when set.

SLEEP = Status bit indicating the gauge is in the SLEEP mode. True when set.

LDMD = Status bit indicating the Impedance Track™ algorithm is using constant-power model for predictions. True when set. Default is 0 (constant-current model).

RUP_DIS = When set, this status bit indicates resistance table updates are disabled. This bit is set on initialization or initial battery insertion, or if resistance updates exceed allowable values. This bit automatically clears after sufficient battery relaxation.

VOK = Status bit indicating *Voltage( )* is okay for Qmax updates and calculations. True when set.

QEN = Status bit indicating Qmax updates are enabled during end-equipment operation as long as Impedance Track™ is enabled. True when set.

### 2.1.2 DEVICE_TYPE: 0x0001

Instructs the fuel gauge to return the device type to addresses 0x00 and 0x01. The bq27510-G3 device type returned is 0x0520.

### 2.1.3 FW_VERSION: 0x0002

Instructs the fuel gauge to return the firmware version (0x0329) to addresses 0x00 and 0x01.

### 2.1.4 PREV_MACWRITE: 0x0007

Instructs the fuel gauge to return the previous subcommand written to addresses 0x00 and 0x01.

> **NOTE:** This subcommand is only supported for previous subcommand codes 0x0000 through 0x0014. For subcommand codes greater than 0x0009, a value of 0x0007 is returned.

### 2.1.5 CHEM_ID: 0x0008

Instructs the fuel gauge to return the chemical identifier value stored in data flash (see Table 4-6) for the Impedance Track™ configuration to addresses 0x00 and 0x01.

### 2.1.6 OCV_CMD: 0x000C

Requests the fuel gauge to take an open-circuit voltage (OCV) reading. This command can only be issued after the *CONTROL_STATUS [INITCOMP]* bit is set, indicating the initialization has been completed. The OCV measurement takes place at the beginning of the next repeated 1-second firmware synchronization clock. If the **OpConfig D [SOC_OCV]** bit is set, the SOC_INT pin pulses for approximately 165 ms to indicate the measurement window. (See also Table 5-10.) See Appendix A, *Open-Circuit Voltage Measurement Background*, for more details on OCV measurements and recommended usage of this command.

> **NOTE:** The *CONTROL_STATUS [OCVFAIL]* bit is set if the *OCV_CMD* subcommand is received when the *Flags( ) [CHG_INH]* bit is set.

### 2.1.7 BAT_INSERT: 0x000D

Instructs the fuel gauge to force the *Flags( ) [BAT_DET]* bit to be set and informs the gauge of the presence of a battery when the insertion detection feature is disabled (**OpConfig B [BIE]** bit = 0). Alternatively, battery presence detection can be enabled (**OpConfig B [BIE]** bit = 1) to monitor the external thermistor network. (See Section 5.3.3, *Battery Presence Detection Using the BI/TOUT Pin.*)

### 2.1.8 BAT_REMOVE: 0x000E

Instructs the fuel gauge to force the *Flags( ) [BAT_DET]* bit to clear when the battery insertion detection is disabled (**OpConfig B [BIE]** bit = 0). Alternatively, battery presence detection can be enabled (**OpConfig B [BIE]** bit = 1) to monitor the external thermistor network. (See Section 5.3.3, *Battery Presence Detection Using the BI/TOUT Pin.*)

### 2.1.9 SET_HIBERNATE: 0x0011

Instructs the fuel gauge to force the *CONTROL_STATUS [HIBERNATE]* bit to 1. This allows the gauge to enter the HIBERNATE power mode after the transition to the SLEEP power mode is detected and the required conditions are met. The *[HIBERNATE]* bit is automatically cleared upon exiting the HIBERNATE mode.

### 2.1.10 CLEAR_HIBERNATE: 0x0012

Instructs the fuel gauge to force the *CONTROL_STATUS [HIBERNATE]* bit to 0. This prevents the gauge from entering the HIBERNATE power mode after the transition to the SLEEP power mode is detected. It can also force the gauge out of the HIBERNATE mode.

### 2.1.11 SET_SNOOZE: 0x0013

Instructs the fuel gauge to set the *CONTROL_STATUS [SNOOZE]* bit to 1. This enables the SNOOZE power mode. The gauge enters the SNOOZE power mode after the following transition conditions are met.

- **Op Config [SLEEP]** = 1
- *CONTROL_STATUS [SNOOZE]* = 1
- | *AverageCurrent ( )* | ≤ **Sleep Current**

### 2.1.12 CLEAR_SNOOZE: 0x0014

Instructs the fuel gauge to set the *CONTROL_STATUS [SNOOZE]* bit to 0. This disables the SNOOZE power mode. The gauge exits from the SNOOZE power mode after the *[SNOOZE]* bit is cleared.

### 2.1.13 DF_VERSION: 0x001F

Instructs the fuel gauge to return the 16-bit data flash revision code to addresses 0x00 and 0x01. The code is stored in **Data Flash Version** and provides a simple method for the customer to control data flash revisions. The default *DF_VERSION* is 0x0000 as configured in data flash.

### 2.1.14 SEALED: 0x0020

Instructs the fuel gauge to transition from the UNSEALED state to the SEALED state. The fuel gauge must always be set to the SEALED state for use in end-equipment.

### 2.1.15 IT_ENABLE: 0x0021

Forces the fuel gauge to begin the Impedance Track™ algorithm, and sets **IT Enable** = 0x01 and both *CONTROL_STATUS [VOK, QEN]* bits = 1. The *[VOK]* bit is cleared if *Voltage( )* is not suitable for a Qmax update. This subcommand is only available when the fuel gauge is UNSEALED and is typically enabled at the last step of production after system test is completed. If it is not enabled, then Qmax and Ra cannot be learned.

### 2.1.16 RESET: 0x0041

Instructs the fuel gauge to perform a full reset. This subcommand is only available when the fuel gauge is UNSEALED.

## 2.2 AtRate( ): 0x02 and 0x03

The *AtRate( )* read- and write-word function is the first half of a two-function command set that sets the *AtRate( )* value used in calculations made by the *AtRateTimeToEmpty( )* function. The *AtRate( )* units are in mA.

The *AtRate( )* value is a signed integer, with negative values interpreted as a discharge current value. The *AtRateTimeToEmpty( )* function returns the predicted operating time at the *AtRate( )* value of discharge. The default value for *AtRate( )* is 0 and forces *AtRateTimeToEmpty( )* to return 65,535. Both the *AtRate( )* and *AtRateTimeToEmpty( )* commands must only be used in the NORMAL mode.

## 2.3 AtRateTimeToEmpty( ): 0x04 and 0x05

This read-word function returns an unsigned integer value of the predicted remaining operating time if the battery is discharged at the *AtRate( )* value in minutes with a range of 0 to 65,534. A value of 65,535 indicates *AtRate( )* = 0. The fuel gauge updates *AtRateTimeToEmpty( )* within 1 second after the system sets the *AtRate( )* value. The fuel gauge automatically updates *AtRateTimeToEmpty( )* based on the *AtRate( )* value every second. Both the *AtRate( )* and *AtRateTimeToEmpty( )* commands must only be used in the NORMAL mode.

## 2.4 Temperature( ): 0x06 and 0x07

This read- and write-word function returns an unsigned integer value of the temperature in units of 0.1°K measured by the fuel gauge. See Table 2-4, *Temperature Measurement Options,* and Section 5.4, *Temperature Measurement.*

### Table 2-4. Temperature Measurement Options

| OpConfig B [WRTEMP] | Op Config [TEMPS] | Temperature( ) Read Command | Temperature( ) Write Command |
|---|---|---|---|
| 0 | 0 | Returns internal temperature as read from an internal sensor. This data is also available using the *InternalTemperature( )* function. | The data is ignored. |
| 0 | 1 | Returns external temperature read from an external thermistor. | |
| 1 | X | Returns the *Temperature( )* value previously written. | Sets the *Temperature( )* value to be used for gauging calculations. |

## 2.5   *Voltage( )*: 0x08 and 0x09

This read-word function returns an unsigned integer value of the measured cell-pack voltage in mV with a range of 0 to 6000 mV.

## 2.6   *Flags( )*: 0x0A and 0x0B

This read-word function returns the contents of the fuel-gauge status register, depicting the current operating status.

### Table 2-5. Flags Bit Definitions

|           | bit7   | bit6 | bit5   | bit4    | bit3    | bit2  | bit1    | bit0 |
|-----------|--------|------|--------|---------|---------|-------|---------|------|
| High Byte | OTC    | OTD  | –      | CALMODE | CHG_INH | XCHG  | FC      | CHG  |
| Low Byte  | –      | –    | OCV_GD | WAIT_ID | BAT_DET | SOC1  | SYSDOWN | DSG  |

**High Byte**

OTC = Overtemperature in charge condition is detected. True when set. See Table 4-3, Safety Subclass parameters for threshold settings. If the **OpConfig D [SOC_OT]** bit = 1, SOC_INT pin toggles once the *[OTC]* bit is set.

OTD = Overtemperature in discharge condition is detected. True when set. If the **OpConfig D [SOC_OT]** bit = 1, SOC_INT pin toggles once the *[OTD]* bit is set.

CALMODE = Status bit indicating the calibration function is active. True when set. This bit must be cleared when the device is in NORMAL mode.

CHG_INH = Charge inhibit: If set, indicates that charging should not begin because *Temperature( )* is outside the range **[Chg Inhibit Temp Low, Chg Inhibit Temp High]**. True when set.

XCHG = Charge suspend alert (temperature outside the range **[Suspend Low Temp, Suspend High Temp]**). True when set.

FC = Full-charged is detected. If **FC Set%** = –1, the *[FC]* bit is set when the fuel gauge has detected charge termination.
Alternatively, if **FC Set%** is configured with a positive % threshold, the *[FC]* bit is set when the *StateOfCharge( )* is larger than the **FC Set%** threshold and cleared when the *StateOfCharge( )* is lower than the **FC Clear%** threshold. (See Section 5.5, *Charging and Charge Termination Indication*)

CHG = Indicates OK to charge. This bit is set if *StateOfCharge( )* is below **TCA Set %** and *Temperature( )* is within the ranges set by **[Chg Inhibit Temp Low, Chg Inhibit Temp High]** and **[Suspend Low Temp, Suspend High Temp]**.
This bit is cleared when *StateOfCharge( )* rises above **TCA Clear %**, unless **TCA Clear %** is set to –1.
If **TCA Clear %** = –1, then this bit is cleared when primary charge termination is detected.
If **FC Set %** = –1, then the *[CHG]* bit clears at the same moment as the *[FC]* bit is set when primary charge termination is detected.

**Low Byte**

OCV_GD = Good OCV measurement taken. True when set.

WAIT_ID = Waiting to identify inserted battery. True when set.

BAT_DET = Battery detected. True when set.

SOC1 = State-of-charge threshold 1 (**SOC1 Set Threshold**) is reached. SOC_INT pin toggles once when this bit is set or cleared if **OpConfig B [BL_INT]** bit = 1. True when set.

SYSDOWN = System down bit indicating the system should shut down. See Table 4-3, Discharge Subclass, **SysDown** parameters for threshold settings. True when set. SOC_INT pin toggles once if set.

DSG = Discharging detected. True when set.

## 2.7   *NominalAvailableCapacity( )*: 0x0C and 0x0D

This read-only command pair returns the uncompensated (less than C/20 load) battery capacity remaining. Units are mAh.

## 2.8   *FullAvailableCapacity( )*: 0x0E and 0x0F

This read-only command pair returns the uncompensated (less than C/20 load) capacity of the battery when fully charged. *FullAvailableCapacity( )* is updated at regular intervals, as specified by the Impedance Track™ algorithm. Units are mAh.

## 2.9   *RemainingCapacity( )*: 0x10 and 0x11

This read-only command pair returns the compensated battery capacity remaining (*UnfilteredRM( )*) when the **OpConfig D [SMTHEN]** bit is cleared or filtered compensated battery capacity remaining (*FilteredRM( )*) when the **[SMTHEN]** bit is set. Units are mAh.

## 2.10   *FullChargeCapacity( )*: 0x12 and 0x13

This read-only command pair returns the compensated capacity of fully charged battery (*UnfilteredFCC( )*) when the **OpConfig D [SMTHEN]** bit is cleared or filtered compensated capacity of fully charged battery (*FilteredFCC( )*) when the **[SMTHEN]** bit is set. Units are mAh. *FullChargeCapacity( )* is updated at regular intervals, as specified by the Impedance Track™ algorithm.

## 2.11   *AverageCurrent( )*: 0x14 and 0x15

This read-only command pair returns a signed integer value that is the average current flow through the sense resistor. In NORMAL mode, it is updated once per second and is calculated by dividing the 1-second change in coulomb counter data by 1 second. Large current spikes of short duration are averaged out in this measurement. Units are mA.

## 2.12   *TimeToEmpty( )*: 0x16 and 0x17

This read-only function returns an unsigned integer value of the predicted remaining battery life at the present rate of discharge, in minutes. A value of 65,535 indicates battery is not being discharged.

## 2.13   *StandbyCurrent( )*: 0x18 and 0x19

This read-only function returns a signed integer value of the measured standby current through the sense resistor. The *StandbyCurrent( )* is an adaptive measurement. Initially it reports the standby current programmed in **Initial Standby**, and after spending several seconds in standby, reports the measured standby current.

The register value is updated every second when the measured current is above the **Deadband** and is less than or equal to 2 × **Initial Standby**. The first and last values that meet this criteria are not included, because they may not be stable values. To approximate a 1-minute time constant, each new *StandbyCurrent( )* value is computed by taking approximately 93% weight of the last standby current and approximately 7% of the current measured average current.

## 2.14   *StandbyTimeToEmpty( )*: 0x1A and 0x1B

This read-only function returns an unsigned integer value of the predicted remaining battery life at the standby rate of discharge in minutes. The computation uses *NominalAvailableCapacity( )* (NAC), the uncompensated remaining capacity, for this computation. A value of 65,535 indicates battery is not being discharged.

## 2.15   *StateofHealth( )*: 0x1C and 0x1D

0x28 SOH percentage: this read-only function returns an unsigned integer value, expressed as a percentage of the ratio of predicted *FCC(25°C, SOH LoadI)* over the *DesignCapacity( )*. The *FCC(25°C, SOH LoadI)* is the calculated full-charge capacity at 25°C and the **SOH LoadI** which is specified in the data flash. The range of the returned SOH percentage is 0x00 to 0x64, indicating 0 to 100%, correspondingly.

0x29 SOH status: this read-only function returns an unsigned integer value, indicating the status of the SOH percentage. The meanings of the returned value are:

- 0x00: SOH not valid before initialization
- 0x01: Instant SOH value ready
- 0x02: Initial SOH value ready. The calculation is based on unlearned Qmax and is updated at the first grid point during discharge after cell insertion.
- 0x03: SOH value ready. The calculation is based on an updated learned Qmax value. The updated

Qmax value is measured after charge or relaxation conditions are met.

• 0x04 to 0xFF: Reserved

## 2.16 *CycleCount( )*: 0x1E and 0x1F

This read-only function returns an unsigned integer value of the number of cycles that the active cell has experienced with a range of 0 to 65535. One cycle occurs when accumulated discharge ≥ **CC Threshold**. The gauge maintains a separate cycle counter for both cell profiles and resets to 0 if the insertion of a new pack has been detected.

## 2.17 *StateOfCharge( )*: 0x20 and 0x21

This read-only function returns an unsigned integer value of the predicted remaining battery capacity expressed as a percentage of *FullChargeCapacity( )*, with a range of 0 to 100%. *StateOfCharge( )* = *RemainingCapacity( )* ÷ *FullChargeCapacity( )* rounded up to the nearest whole percentage point.

## 2.18 *InstantaneousCurrent( )*: 0x22 and 0x23

This read-only function returns a signed integer value that is the instantaneous current flow through the sense resistor. The conversion time is 125 ms. It is updated every second. Units are mA.

## 2.19 *InternalTemperature( )*: 0x28 and 0x29

This read-only function returns an unsigned integer value of the internal temperature sensor in units of 0.1°K, as measured by the fuel gauge. This function can be useful as an additional system-level temperature monitor if the main *Temperature( )* function is configured for external or host-reported temperature.

## 2.20 *ResistanceScale( )*: 0x2A and 0x2B

This read-only function returns the resistance scale value when the Fast Resistance Scaling feature is enabled via the **OpConfig B [FCE]** bit. (See Section 5.1.14, *Fast Resistance Scaling.*)

## 2.21 *OperationConfiguration( )*: 0x2C and 0x2D

This read-only function returns the contents of the data flash **Op Config** register and is most useful for system level debug to quickly determine device configuration.

## 2.22 *DesignCapacity( )*: 0x2E and 0x2F

This read-only function returns the value stored in **Design Capacity** and is expressed in mAh. This is intended to be the theoretical or nominal capacity of a new pack, and is used for the calculation of *StateOfHealth( )*.

## 2.23 *UnfilteredRM( )*: 0x6C and 0x6D

This read-only command pair returns the compensated battery capacity remaining. When the **OpConfig D [SMTHEN]** bit is cleared, this value is reported in the *RemainingCapacity( )* register. Units are mAh.

## 2.24 *FilteredRM( )*: 0x6E and 0x6F

This read-only command pair returns the filtered compensated battery capacity remaining. When the **OpConfig D [SMTHEN]** bit is set, this value is reported in the *RemainingCapacity( )* register. Units are mAh.

## 2.25  *UnfilteredFCC( )*: 0x70 and 0x71

This read-only command pair returns the compensated capacity of the battery when fully charged. When the **OpConfig D [SMTHEN]** bit is cleared, this value is reported in the *RemainingCapacity( )* register. *UnFilteredFCC( )* is updated at regular intervals, as specified by the Impedance Track™ algorithm. Units are mAh.

## 2.26  *FilteredFCC( )*: 0x72 and 0x73

This read-only command pair returns the filtered compensated capacity of the battery when fully charged. When the **OpConfig D [SMTHEN]** bit is set, this value is reported in the *RemainingCapacity( )* register. *FilteredFCC( )* is updated at regular intervals, as specified by the Impedance Track™ algorithm. Units are mAh.

## 2.27  *TrueSOC( )*: 0x74 and 0x75

This read-only function returns an unsigned integer value of the predicted remaining battery capacity expressed as a percentage of *UnfilteredFCC( )*, with a range of 0 to 100%. When the **OpConfig D [SMTHEN]** bit is cleared, this value is reported in the *StateOfCharge( )* register.

# Extended Data Commands

Extended commands offer additional functionality beyond the standard set of commands. They are used in the same manner; however, unlike standard commands, extended commands are not limited to 2-byte words. The number of command bytes for a given extended command range in size from single to multiple bytes is specified in Table 3-1. See Section 4.1 for details on accessing the data flash and Section 4.6 for an example to update a data flash parameter.

**Table 3-1. Extended Data Commands**

| Name | Command Code | Unit | SEALED Access[1] [2] | UNSEALED Access[1] [2] |
|---|---|---|---|---|
| Reserved | 0x34 to 0x3D | NA | R | R |
| DataFlashClass( ) [2] | 0x3E | NA | NA | RW |
| DataFlashBlock( ) [2] | 0x3F | NA | RW | RW |
| BlockData( ) | 0x40 to 0x5F | NA | R | RW |
| BlockDataCheckSum( ) | 0x60 | NA | RW | RW |
| BlockDataControl( ) | 0x61 | NA | NA | RW |
| ApplicationStatus( ) | 0x6A | NA | R | R |
| Reserved | 0x6B to 0x7F | NA | R | R |

[1] SEALED and UNSEALED states are entered via commands to Control( ) 0x00 and 0x01.
[2] In SEALED mode, data flash cannot be accessed through commands 0x3E and 0x3F.

## 3.1 DataFlashClass( ): 0x3E

**UNSEALED Access:** This command sets the data flash class to be accessed. The class to be accessed must be entered in hexadecimal.

**SEALED Access:** This command is not available in SEALED mode.

## 3.2 DataFlashBlock( ): 0x3F

**UNSEALED Access:** This command sets the data flash block to be accessed. When 0x00 is written to BlockDataControl( ), DataFlashBlock( ) holds the block number of the data flash to be read or written. Example: writing a 0x00 to DataFlashBlock( ) specifies access to the first 32-byte block, a 0x01 specifies access to the second 32-byte block, and so on.

**SEALED Access:** This command directs which data flash block is accessed by the BlockData( ) command. Writing a 0x01 or 0x02 instructs the BlockData( ) command to transfer the **Manufacturer Info Block**. All other DataFlashBlock( ) values are reserved.

## 3.3 BlockData( ): 0x40 to 0x5F

**UNSEALED Access:** This data block is the remainder of the 32-byte data block when accessing data flash.

**SEALED Access:** This data block is the remainder of the 32-byte data block when accessing **Manufacturer Info Block**.

## 3.4   *BlockDataChecksum( )*: 0x60

**UNSEALED Access:** This byte contains the checksum on the 32 bytes of block data read from or written to data flash. The least-significant byte of the sum of the data bytes written must be complemented ([255 – *x*], *x* is the least-significant byte) before being written to 0x60.

**SEALED Access:** This byte contains the checksum for the 32 bytes of block data written to **the Manufacturer Info Block**. The least-significant byte of the sum of the data bytes written must be complemented ([255 – *x*], *x* is the least-significant byte) before being written to 0x60.

## 3.5   *BlockDataControl( )*: 0x61

**UNSEALED Access:** This command controls the data flash access mode. Writing 0x00 to this command enables *BlockData( )* to access general data flash.

**SEALED Access:** This command is not available in SEALED mode.

## 3.6   *ApplicationStatus( )*: 0x6A

This byte function allows the system to read the **Application Status** data flash location. See Table 5-12, *ApplicationStatus( ) Bit Definitions*, for specific bit definitions.

# Data Flash Interface

## 4.1 Accessing The Data Flash

The bq27510-G3 data flash is a non-volatile memory that contains initialization, default, cell status, calibration, configuration, and user information. The data flash can be accessed in several different ways, depending in which mode the fuel gauge is operating and what data is being accessed.

Commonly accessed data flash memory locations, frequently read by a system, are conveniently accessed through specific instructions, already described in Chapter 3, *Extended Data Commands*. These commands are available when the fuel gauge is either in UNSEALED mode or SEALED mode.

Most data flash locations, however, are only accessible in UNSEALED mode by use of the evaluation software or by data flash block transfers. These locations should be optimized and/or fixed during the development and manufacture processes. They become part of a golden image file and can then be written to multiple systems. Once established, the values generally remain unchanged during end-equipment operation.

To access data flash locations individually, the block containing the desired data flash location(s) must be transferred to the command register locations, where they can be read to the system or changed directly. This is accomplished by sending the set-up command *BlockDataControl( )* (0x61) with data 0x00. Up to 32 bytes of data can be read directly from the *BlockData( )* (0x40 to 0x5F), externally altered, then rewritten to the *BlockData( )* command space. Alternatively, specific locations can be read, altered, and rewritten if their corresponding offsets are used to index into the *BlockData( )* command space. Finally, once the correct checksum for the whole block is written to *BlockDataChecksum( )* (0x60), the data residing in the command space is transferred to the data flash.

Occasionally, a data flash class is larger than the 32-byte block size. In this case, the *DataFlashBlock( )* command designates in which 32-byte block the desired locations reside. The correct command address is then given by 0x40 + offset *modulo* 32. For example, to access **Terminate Voltage** in the **Gas Gauging** class, *DataFlashClass( )* is issued 80 (0x50) to set the class. Because the offset is 55, it must reside in the second 32-byte block. Hence, *DataFlashBlock( )* is issued 0x01 to set the block offset, and the offset used to index into the *BlockData( )* memory area is 0x40 + 55 *modulo* 32 = 0x40 + 23 = 0x40 + 0x17 = 0x57.

Reading and writing subclass data are block operations up to 32 bytes in length. If, during a write, the data length exceeds the maximum block size, then the data is ignored.

None of the data written to memory are bounded by the bq27510-G3 fuel gauge – the values are not rejected by the fuel gauge. Writing an incorrect value may result in hardware failure due to firmware program interpretation of the invalid data. The written data is not persistent, so a power-on reset does resolve the fault.

## 4.2 Manufacturer Information Block

The fuel gauge contains 32 bytes of user programmable data flash storage called the **Manufacturer Info Block**. The method for accessing these memory locations is slightly different, depending on whether the device is in UNSEALED or SEALED mode.

When in UNSEALED mode and 0x00 has been written to *BlockDataControl( )*, accessing the manufacturer information blocks is identical to accessing general data flash locations. First, a *DataFlashClass( )* command sets the subclass, then a *DataFlashBlock( )* command sets the offset for the first data flash address within the subclass. The *BlockData( )* command codes contain the referenced data flash data. When writing to the data flash, a checksum is expected to be received by *BlockDataChecksum( )*. Only when the checksum is received and verified is the data actually written to data flash.

When in SEALED mode or when 0x01 *BlockDataControl( )* does not contain 0x00, the data flash is no longer available in the manner used in UNSEALED mode. Rather than issuing subclass information, a designated **Manufacturer Info Block** is selected with the *DataFlashBlock( )* command. Issuing a 0x01 or 0x02 with this command causes the corresponding information block to be transferred to the command space 0x40 to 0x5F for editing or reading by the system. Upon successful writing of checksum information to *BlockDataChecksum( )*, the modified block is returned to the data flash.

> **NOTE:** The **Manufacturer Info Block** is read-only when in SEALED mode.

## 4.3 Device Access Modes

The fuel gauge provides three security modes (FULL ACCESS, UNSEALED, and SEALED) that control data flash access permissions, according to Table 4-1.

**Table 4-1. Data Flash Access**

| Security Mode | Data Flash | Manufacturer Info Block |
|---|---|---|
| FULL ACCESS | RW | RW |
| UNSEALED | RW | RW |
| SEALED | None | R |

Although FULL ACCESS and UNSEALED modes appear identical, only FULL ACCESS allows the fuel gauge to read or write access-mode transition keys.

## 4.4 Sealing and Unsealing Data Flash

The fuel gauge implements a key-access scheme to transition between SEALED, UNSEALED, and FULL ACCESS modes. Each transition requires that a unique set of two keys be sent to the fuel gauge via the *Control( )* command. The keys must be sent consecutively, with no other data being written to the *Control( )* register in between. Do not set the two keys to identical values.

> **NOTE:** To avoid conflict, the keys must be different from the codes presented in the *Control Data* column of Table 2-2, *Control( ) Subcommands*.

When in the SEALED mode, the *CONTROL_STATUS [SS]* bit is set, but when the UNSEAL keys are correctly received by the fuel gauge, the *[SS]* bit is cleared. When the FULL ACCESS keys are correctly received, then the *CONTROL_STATUS [FAS]* bit is cleared.

Both sets of keys for each level are 2 bytes each in length and are stored in data flash. The UNSEAL key (stored at **Unseal Key 0** and **Unseal Key 1**) and the FULL ACCESS keys (stored at **Full-Access Key 0** and **Full-Access Key 1**) can only be updated when in FULL ACCESS mode. The order of the keys is **Key 1** followed by **Key 0**. The order of the bytes entered through the *Control( )* command is the reverse of what is read from the part. For example, if the **Key 1** and **Key** 0 of the **UNSEAL keys** returns 0x1234 and 0x5678, then the *Control( )* command should supply 0x3412 and 0x7856 to unseal the part.

## 4.5 Data Flash Summary

Table 4-3 through Table 4-10 summarize the data flash locations available to the user, including their default, minimum, and maximum values.

**Table 4-2. Data Type Decoder**

| Type | Min Value | Max Value |
|------|-----------|-----------|
| F4 | $\pm 9.8603 \times 10^{-39}$ | $\pm 5.707267 \times 10^{37}$ |
| H1 | 0x00 | 0xFF |
| H2 | 0x00 | 0xFFFF |
| H4 | 0x00 | 0xFFFF FFFF |
| I1 | −128 | 127 |
| I2 | −32768 | 32767 |
| I4 | −2,147,483,648 | 2,147,483,647 |
| Sx | 1-byte string | X-byte string |
| U1 | 0 | 255 |
| U2 | 0 | 65535 |
| U4 | 0 | 4,294,967,295 |

**Table 4-3. Data Flash Summary—Configuration Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value Min | Value Max | Value Default | Unit |
|-------------|----------|--------|------|-----------|-----|-----|---------|------|
| 2 | Safety | 0 | OT Chg | I2 | 0 | 1200 | 550 | 0.1°C |
| | | 2 | OT Chg Time | U1 | 0 | 60 | 2 | s |
| | | 3 | OT Chg Recovery | I2 | 0 | 1200 | 500 | 0.1°C |
| | | 5 | OT Dsg | I2 | 0 | 1200 | 600 | 0.1°C |
| | | 7 | OT Dsg Time | U1 | 0 | 60 | 2 | s |
| | | 8 | OT Dsg Recovery | I2 | 0 | 1200 | 550 | 0.1°C |
| 32 | Charge Inhibit Cfg | 0 | Chg Inhibit Temp Low | I2 | −400 | 1200 | 0 | 0.1°C |
| | | 2 | Chg Inhibit Temp High | I2 | −400 | 1200 | 450 | 0.1°C |
| | | 4 | Temp Hys | I2 | 0 | 100 | 50 | 0.1°C |
| 34 | Charge | 2 | Charging Voltage | I2 | 0 | 4600 | 4200 | mV |
| | | 4 | Delta Temp | I2 | 0 | 500 | 50 | 0.1°C |
| | | 6 | Suspend Low Temp | I2 | −400 | 1200 | −50 | 0.1°C |
| | | 8 | Suspend High Temp | I2 | −400 | 1200 | 550 | 0.1°C |
| 36 | Charge Termination | 2 | Taper Current | I2 | 0 | 1000 | 100 | mA |
| | | 6 | Taper Voltage | I2 | 0 | 1000 | 100 | mV |
| | | 9 | TCA Set % | I1 | −1 | 100 | 99 | Percent |
| | | 10 | TCA Clear % | I1 | −1 | 100 | 95 | Percent |
| | | 11 | FC Set % | I1 | −1 | 100 | −1 | Percent |
| | | 12 | FC Clear % | I1 | −1 | 100 | 98 | Percent |
| | | 13 | DODatEOC Delta T | I2 | 0 | 1000 | 50 | 0.1°C |

**Table 4-3. Data Flash Summary—Configuration Class (continued)**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 48 | Data | 4 | Initial Standby | I1 | −256 | 0 | −10 | mA |
| | | 7 | CC Threshold | I2 | 100 | 32767 | 900 | mAh |
| | | 10 | Design Capacity | I2 | 0 | 65535 | 1000 | mAh |
| | | 12 | Des Energy Scale | U1 | 0 | 65535 | 1 | num |
| | | 13 | SOH LoadI | I2 | −32767 | 0 | −400 | mA |
| | | 15 | Default Temperature | I2 | 2732 | 3732 | 2982 | 0.1°C |
| | | 17 | Device Name | S11 | x | x | bq27510-G3 | |
| | | 28 | Data Flash Version | H2 | 0x00 | 0xFFFF | 0x00 | num |
| 49 | Discharge | 0 | SOC1 Set Threshold | U1 | 0 | 5000 | 10 | Percent |
| | | 1 | SOC1 Clear Threshold | U1 | 0 | 5000 | 12 | Percent |
| | | 5 | SysDown Set Volt Threshold | I2 | 0 | 4200 | 3150 | mV |
| | | 7 | SysDown Set Volt Time | U1 | 0 | 60 | 2 | s |
| | | 8 | SysDown Clear Volt | I2 | 0 | 4200 | 3400 | mV |
| | | 14 | Def Avg I Last Run | I2 | −32768 | 32767 | −299 | mA |
| | | 16 | Def Avg P Last Run | I2 | −32768 | 32767 | −1131 | mW |
| 64 | Registers | 0 | Op Config | H2 | 0x00 | 0xFFFF | 0x0975 | flags |
| | | 7 | SOC Delta | U1 | 0 | 25 | 1 | percent |
| | | 8 | i2c Timeout | U1 | 0 | 7 | 4 | percent |
| | | 9 | DF Wr Ind Wait | U2 | 0 | 65535 | 0 | percent |
| | | 11 | OpConfig B | H1 | 0x00 | 0xFF | 0x4E | flags |
| | | 12 | OpConfig C | H1 | 0x00 | 0xFF | 0x0C | flags |
| | | 13 | OpConfig D | H1 | 0x00 | 0xFF | 0x5E | flags |
| | | 14 | OpConfig E | H1 | 0x00 | 0xFF | 0x02 | flags |
| 68 | Power | 0 | Flash Update OK Voltage | I2 | 0 | 4200 | 2800 | mV |
| | | 4 | Sleep Current | I2 | 0 | 100 | 10 | mA |
| | | 13 | Hibernate I | U2 | 0 | 700 | 8 | mA |
| | | 15 | Hibernate V | U2 | 2400 | 3000 | 2550 | mV |

**Table 4-4. Data Flash Summary—System Data Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 57 | Manufacturer Info | 0 through 31 | Block 0 through 31 | H1 | 0x00 | 0xFF | 0x00 | |

**Table 4-5. Data Flash Summary—Gas Gauging Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 80 | IT Cfg | 0 | Load Select | U1 | 0 | 255 | 1 | Number |
| | | 1 | Load Mode | U1 | 0 | 255 | 1 | Number |
| | | 21 | Max Res Factor | U1 | 0 | 255 | 15 | num |
| | | 22 | Min Res Factor | U1 | 0 | 255 | 7 | num |
| | | 24 | Ra Filter | U2 | 0 | 1000 | 800 | num |
| | | 40 | Min % Passed Chg for Qm | U1 | 1 | 100 | 37 | % |

**Table 4-5. Data Flash Summary—Gas Gauging Class (continued)**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 80 | IT Cfg | 44 | Qmax Filter | U1 | 0 | 255 | 96 | mAh |
| | | 45 | Max % Default Qmax | U1 | 0 | 255 | 110 | % |
| | | 46 | Terminate Voltage | I2 | −32768 | 32767 | 3200 | mV |
| | | 48 | Term V Delta | I2 | 0 | 4200 | 200 | mV |
| | | 51 | ResRelax Time | U2 | 0 | 65534 | 500 | s |
| | | 55 | User Rate-mA | I2 | −32000 | −100 | 0 | mA |
| | | 57 | User Rate-m/cW | I2 | −32000 | −350 | 0 | mW or cW |
| | | 59 | Reserve Cap-mAh | I2 | 0 | 32000 | 0 | mAh |
| | | 61 | Reserve Cap-m/cWh | I2 | 0 | 32000 | 0 | mWh or cWh |
| | | 66 | Min Delta Voltage | I2 | −32000 | 32000 | 0 | num |
| | | 68 | Max Sim Rate | U1 | 0 | 255 | 1 | C/rate |
| | | 69 | Min Sim Rate | U1 | 0 | 255 | 20 | C/rate |
| | | 70 | Ra Max Delta | U2 | 0 | 65535 | 44 | mΩ |
| | | 72 | Qmax Max Delta % | U1 | 0 | 65535 | 5 | % |
| | | 73 | DeltaV Max dV | U2 | 0 | 65535 | 10 | mV |
| | | 75 | Max Res Scale | U2 | 0 | 32767 | 5000 | Num |
| | | 77 | Min Res Scale | U2 | 0 | 32767 | 200 | Num |
| | | 79 | Fast Scale Start SOC | U1 | 0 | 100 | 10 | % |
| | | 80 | TermV Valid Time | U1 | 0 | 255 | 2 | s |
| 81 | Current Thresholds | 0 | Dsg Current Threshold | I2 | 0 | 2000 | 60 | mA |
| | | 2 | Chg Current Threshold | I2 | 0 | 2000 | 75 | mA |
| | | 4 | Quit Current | I2 | 0 | 1000 | 40 | mA |
| | | 6 | Dsg Relax Time | U2 | 0 | 8191 | 60 | s |
| | | 8 | Chg Relax Time | U1 | 0 | 255 | 60 | s |
| | | 9 | Quit Relax Time | U1 | 0 | 63 | 1 | s |
| | | 10 | Transient Factor Charge | U1 | 0 | 255 | 128 | num |
| | | 11 | Transient Factor Discharge | U1 | 0 | 255 | 128 | num |
| | | 12 | Max IR Correct | U2 | 0 | 1000 | 400 | mV |
| 82 | State | 0 | IT Enable | H1 | 0x0 | 0x3 | 0x0 | num |
| | | 1 | App Status | H1 | 0x00 | 0xFFFF | 0x00 | flags |
| | | 2 | Qmax Cell 0 | I2 | 0 | 32767 | 1000 | mAh |
| | | 4 | Cycle Count 0 | U2 | 0 | 65535 | 0 | Count |
| | | 6 | Update Status 0 | H1 | 0x0 | 0x3 | 0x0 | num |
| | | 7 | Qmax Cell 1 | I2 | 0 | 32767 | 1000 | mAh |
| | | 9 | Cycle Count 1 | U2 | 0 | 65535 | 0 | Count |
| | | 11 | Update Status 1 | H1 | 0x0 | 0x3 | 0x0 | num |
| | | 12 | Avg I Last Run | I2 | −32768 | 32767 | −299 | mA |
| | | 14 | Avg P Last Run | I2 | −32768 | 32767 | −1131 | cW or mW |
| | | 16 | Delta Voltage | I2 | −32768 | 32767 | 2 | mV |
| | | 20 | T Rise | U2 | 0 | 65535 | 20 | Num |
| | | 22 | T Time Constant | U2 | 0 | 65535 | 1000 | Num |
| | | 24 | Cell 0 V at Chg Term | I2 | 3800 | 4500 | 4200 | mV |
| | | 26 | Cell 1 V at Chg Term | I2 | 3800 | 4500 | 4200 | mV |

**Table 4-6. Data Flash Summary—OCV Tables Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | | Min | Max | Default | |
| 83 | OCVa0 Table | 0 | Chem ID | H2 | 0x00 | 0xFFFF | 0x100 | flags |
| | | 2 | Qmax Cell 0 | I2 | 0 | 32767 | 1000 | mAh |
| | | 4 | Update Status | H1 | 0x0 | 0x3 | 0x0 | num |
| 84 | OCVa1 Table | 0 | Chem ID | H2 | 0x00 | 0xFFFF | 0x100 | flags |
| | | 2 | Qmax Cell 1 | I2 | 0 | 32767 | 1000 | mAh |
| | | 4 | Update Status | H1 | 0x0 | 0x3 | 0x0 | num |

**Table 4-7. Data Flash Summary—Default Ra Tables Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | | Min | Max | Default | |
| 87 | Def0 Ra | 0 | Def0 Ra status | H1 | 0x0 | 0x0 | 0xFF | |
| | | 1 | Def0 Ra flag | H1 | 0x0 | 0x0 | 0x55 | |
| | | 2 | Def0 Ra Base R | I2 | −200 | 200 | 41 | |
| | | 4 | Def0 Ra Gain | H1 | 0x0 | 0x0 | 0x0 | |
| | | 5 | Def0 Ra 1 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 6 | Def0 Ra 2 | I1 | −128 | 127 | −4 | $2^{-10}$ Ω |
| | | 7 | Def0 Ra 3 | I1 | −128 | 127 | 0 | $2^{-10}$ Ω |
| | | 8 | Def0 Ra 4 | I1 | −128 | 127 | −2 | $2^{-10}$ Ω |
| | | 9 | Def0 Ra 5 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 10 | Def0 Ra 6 | I1 | −128 | 127 | 6 | $2^{-10}$ Ω |
| | | 11 | Def0 Ra 7 | I1 | −128 | 127 | 7 | $2^{-10}$ Ω |
| | | 12 | Def0 Ra 8 | I1 | −128 | 127 | 5 | $2^{-10}$ Ω |
| | | 13 | Def0 Ra 9 | I1 | −128 | 127 | 8 | $2^{-10}$ Ω |
| | | 14 | Def0 Ra 10 | I1 | −128 | 127 | 15 | $2^{-10}$ Ω |
| | | 15 | Def0 Ra 11 | I1 | −128 | 127 | 30 | $2^{-10}$ Ω |
| | | 16 | Def0 Ra 12 | I1 | −128 | 127 | 54 | $2^{-10}$ Ω |
| | | 17 | Def0 Ra 13 | I1 | −128 | 127 | 87 | $2^{-10}$ Ω |
| | | 18 | Def0 Ra 14 | I1 | −128 | 127 | 115 | $2^{-10}$ Ω |

**Table 4-7. Data Flash Summary—Default Ra Tables Class (continued)**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 88 | Def1 Ra | 0 | Def1 Ra status | H1 | 0x0 | 0x0 | 0xFF | |
| | | 1 | Def1 Ra flag | H1 | 0x0 | 0x0 | 0x55 | |
| | | 2 | Def1 Ra Base R | I2 | −200 | 200 | 41 | |
| | | 4 | Def1 Ra Gain | H1 | 0x0 | 0x0 | 0x0 | |
| | | 5 | Def1 Ra 1 | I1 | −128 | 127 | 2 | $2^{-10}\ \Omega$ |
| | | 6 | Def1 Ra 2 | I1 | −128 | 127 | −4 | $2^{-10}\ \Omega$ |
| | | 7 | Def1 Ra 3 | I1 | −128 | 127 | 0 | $2^{-10}\ \Omega$ |
| | | 8 | Def1 Ra 4 | I1 | −128 | 127 | −2 | $2^{-10}\ \Omega$ |
| | | 9 | Def1 Ra 5 | I1 | −128 | 127 | 2 | $2^{-10}\ \Omega$ |
| | | 10 | Def1 Ra 6 | I1 | −128 | 127 | 6 | $2^{-10}\ \Omega$ |
| | | 11 | Def1 Ra 7 | I1 | −128 | 127 | 7 | $2^{-10}\ \Omega$ |
| | | 12 | Def1 Ra 8 | I1 | −128 | 127 | 5 | $2^{-10}\ \Omega$ |
| | | 13 | Def1 Ra 9 | I1 | −128 | 127 | 8 | $2^{-10}\ \Omega$ |
| | | 14 | Def1 Ra 10 | I1 | −128 | 127 | 15 | $2^{-10}\ \Omega$ |
| | | 15 | Def1 Ra 11 | I1 | −128 | 127 | 30 | $2^{-10}\ \Omega$ |
| | | 16 | Def1 Ra 12 | I1 | −128 | 127 | 54 | $2^{-10}\ \Omega$ |
| | | 17 | Def1 Ra 13 | I1 | −128 | 127 | 87 | $2^{-10}\ \Omega$ |
| | | 18 | Def1 Ra 14 | I1 | −128 | 127 | 115 | $2^{-10}\ \Omega$ |

**Table 4-8. Data Flash Summary—Ra Tables Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 91 | Pack0 Ra | 0 | Pack0 Ra status | H1 | 0x0 | 0x0 | 0xFF | |
| | | 1 | Pack0 Ra flag | H1 | 0x0 | 0x0 | 0x55 | |
| | | 2 | Pack0 Ra Base R | I2 | −200 | 200 | 41 | |
| | | 4 | Pack0 Ra Gain | H1 | 0x0 | 0x0 | 0x0 | |
| | | 5 | Pack0 Ra 1 | I1 | −128 | 127 | 2 | $2^{-10}\ \Omega$ |
| | | 6 | Pack0 Ra 2 | I1 | −128 | 127 | −4 | $2^{-10}\ \Omega$ |
| | | 7 | Pack0 Ra 3 | I1 | −128 | 127 | 0 | $2^{-10}\ \Omega$ |
| | | 8 | Pack0 Ra 4 | I1 | −128 | 127 | −2 | $2^{-10}\ \Omega$ |
| | | 9 | Pack0 Ra 5 | I1 | −128 | 127 | 2 | $2^{-10}\ \Omega$ |
| | | 10 | Pack0 Ra 6 | I1 | −128 | 127 | 6 | $2^{-10}\ \Omega$ |
| | | 11 | Pack0 Ra 7 | I1 | −128 | 127 | 7 | $2^{-10}\ \Omega$ |
| | | 12 | Pack0 Ra 8 | I1 | −128 | 127 | 5 | $2^{-10}\ \Omega$ |
| | | 13 | Pack0 Ra 9 | I1 | −128 | 127 | 8 | $2^{-10}\ \Omega$ |
| | | 14 | Pack0 Ra 10 | I1 | −128 | 127 | 15 | $2^{-10}\ \Omega$ |
| | | 15 | Pack0 Ra 11 | I1 | −128 | 127 | 30 | $2^{-10}\ \Omega$ |
| | | 16 | Pack0 Ra 12 | I1 | −128 | 127 | 54 | $2^{-10}\ \Omega$ |
| | | 17 | Pack0 Ra 13 | I1 | −128 | 127 | 87 | $2^{-10}\ \Omega$ |
| | | 18 | Pack0 Ra 14 | I1 | −128 | 127 | 115 | $2^{-10}\ \Omega$ |

### Table 4-8. Data Flash Summary—Ra Tables Class (continued)

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | | | | Min | Max | Default | |
| 92 | Pack1 Ra | 0 | Pack1 Ra status | H1 | 0x0 | 0x0 | 0xFF | |
| | | 1 | Pack1 Ra flag | H1 | 0x0 | 0x0 | 0x55 | |
| | | 2 | Pack1 Ra Base R | I2 | −200 | 200 | 41 | |
| | | 4 | Pack1 Ra Gain | H1 | 0x0 | 0x0 | 0x0 | |
| | | 5 | Pack1 Ra 1 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 6 | Pack1 Ra 2 | I1 | −128 | 127 | −4 | $2^{-10}$ Ω |
| | | 7 | Pack1 Ra 3 | I1 | −128 | 127 | 0 | $2^{-10}$ Ω |
| | | 8 | Pack1 Ra 4 | I1 | −128 | 127 | −2 | $2^{-10}$ Ω |
| | | 9 | Pack1 Ra 5 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 10 | Pack1 Ra 6 | I1 | −128 | 127 | 6 | $2^{-10}$ Ω |
| | | 11 | Pack1 Ra 7 | I1 | −128 | 127 | 7 | $2^{-10}$ Ω |
| | | 12 | Pack1 Ra 8 | I1 | −128 | 127 | 5 | $2^{-10}$ Ω |
| | | 13 | Pack1 Ra 9 | I1 | −128 | 127 | 8 | $2^{-10}$ Ω |
| | | 14 | Pack1 Ra 10 | I1 | −128 | 127 | 15 | $2^{-10}$ Ω |
| | | 15 | Pack1 Ra 11 | I1 | −128 | 127 | 30 | $2^{-10}$ Ω |
| | | 16 | Pack1 Ra 12 | I1 | −128 | 127 | 54 | $2^{-10}$ Ω |
| | | 17 | Pack1 Ra 13 | I1 | −128 | 127 | 87 | $2^{-10}$ Ω |
| | | 18 | Pack1 Ra 14 | I1 | −128 | 127 | 115 | $2^{-10}$ Ω |
| 93 | Pack0 Rax | 0 | Pack0 Rax status | H1 | 0x0 | 0x0 | 0xFF | |
| | | 1 | Pack0 Rax flag | H1 | 0x0 | 0x0 | 0xFF | |
| | | 2 | Pack0 Rax Base R | I2 | −200 | 200 | 41 | |
| | | 4 | Pack0 Rax Gain | H1 | 0x0 | 0x0 | 0x0 | |
| | | 5 | Pack0 Rax 1 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 6 | Pack0 Rax 2 | I1 | −128 | 127 | −4 | $2^{-10}$ Ω |
| | | 7 | Pack0 Rax 3 | I1 | −128 | 127 | 0 | $2^{-10}$ Ω |
| | | 8 | Pack0 Rax 4 | I1 | −128 | 127 | −2 | $2^{-10}$ Ω |
| | | 9 | Pack0 Rax 5 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 10 | Pack0 Rax 6 | I1 | −128 | 127 | 6 | $2^{-10}$ Ω |
| | | 11 | Pack0 Rax 7 | I1 | −128 | 127 | 7 | $2^{-10}$ Ω |
| | | 12 | Pack0 Rax 8 | I1 | −128 | 127 | 5 | $2^{-10}$ Ω |
| | | 13 | Pack0 Rax 9 | I1 | −128 | 127 | 8 | $2^{-10}$ Ω |
| | | 14 | Pack0 Rax 10 | I1 | −128 | 127 | 15 | $2^{-10}$ Ω |
| | | 15 | Pack0 Rax11 | I1 | −128 | 127 | 30 | $2^{-10}$ Ω |
| | | 16 | Pack0 Rax 12 | I1 | −128 | 127 | 54 | $2^{-10}$ Ω |
| | | 17 | Pack0 Rax 13 | I1 | −128 | 127 | 87 | $2^{-10}$ Ω |
| | | 18 | Pack0 Rax 14 | I1 | −128 | 127 | 115 | $2^{-10}$ Ω |

**Table 4-8. Data Flash Summary—Ra Tables Class (continued)**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 94 | Pack1 Rax | 0 | Pack1 Rax status | H1 | 0x0 | 0x0 | 0xFF | |
| | | 1 | Pack1 Rax flag | H1 | 0x0 | 0x0 | 0xFF | |
| | | 2 | Pack1 Rax Base R | I2 | −200 | 200 | 41 | |
| | | 4 | Pack1 Rax Gain | H1 | 0x0 | 0x0 | 0x0 | |
| | | 5 | Pack1 Rax 1 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 6 | Pack1 Rax 2 | I1 | −128 | 127 | −4 | $2^{-10}$ Ω |
| | | 7 | Pack1 Rax 3 | I1 | −128 | 127 | 0 | $2^{-10}$ Ω |
| | | 8 | Pack1 Rax 4 | I1 | −128 | 127 | −2 | $2^{-10}$ Ω |
| | | 9 | Pack1 Rax 5 | I1 | −128 | 127 | 2 | $2^{-10}$ Ω |
| | | 10 | Pack1 Rax 6 | I1 | −128 | 127 | 6 | $2^{-10}$ Ω |
| | | 11 | Pack1 Rax 7 | I1 | −128 | 127 | 7 | $2^{-10}$ Ω |
| | | 12 | Pack1 Rax 8 | I1 | −128 | 127 | 5 | $2^{-10}$ Ω |
| | | 13 | Pack1 Rax 9 | I1 | −128 | 127 | 8 | $2^{-10}$ Ω |
| | | 14 | Pack1 Rax 10 | I1 | −128 | 127 | 15 | $2^{-10}$ Ω |
| | | 15 | Pack1 Rax 11 | I1 | −128 | 127 | 30 | $2^{-10}$ Ω |
| | | 16 | Pack1 Rax 12 | I1 | −128 | 127 | 54 | $2^{-10}$ Ω |
| | | 17 | Pack1 Rax 13 | I1 | −128 | 127 | 87 | $2^{-10}$ Ω |
| | | 18 | Pack1 Rax 14 | I1 | −128 | 127 | 115 | $2^{-10}$ Ω |

**Table 4-9. Data Flash Summary—Calibration Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | Default | |
| 104 | Data | 0 | CC Gain | F4 | 1.00E−01 | 4.00E+01 | 0.4768 | Number |
| | | 4 | CC Delta | F4 | 2.98E+04 | 1.19E+06 | 567744.56 | Number |
| | | 8 | CC Offset | I2 | −32768 | 32767 | −1200 | mA |
| | | 12 | Board Offset | I1 | −128 | 127 | 0 | µA |
| | | 13 | Int Temp Offset | I1 | −128 | 127 | 0 | Number |
| | | 14 | Ext Temp Offset | I1 | −128 | 127 | 0 | Number |
| | | 15 | Pack V Offset | I1 | −128 | 127 | 0 | Number |
| 106 | Temp Model | 0 | Ext a Coef 1 | I2 | −32768 | 32767 | −11130 | num |
| | | 2 | Ext a Coef 2 | I2 | −32768 | 32767 | 19142 | num |
| | | 4 | Ext a Coef 3 | I2 | −32768 | 32767 | −19262 | num |
| | | 6 | Ext a Coef 4 | I2 | −32768 | 32767 | 28203 | num |
| | | 8 | Ext a Coef 5 | I2 | −32768 | 32767 | 892 | num |
| | | 10 | Ext b Coef 1 | I2 | −32768 | 32767 | 328 | num |
| | | 12 | Ext b Coef 2 | I2 | −32768 | 32767 | −605 | num |
| | | 14 | Ext b Coef 3 | I2 | −32768 | 32767 | −2443 | num |
| | | 16 | Ext b Coef 4 | I2 | −32768 | 32767 | 4696 | num |
| | | 34 | Max Correction I | I2 | 0 | 32767 | 1500 | mA |
| | | 36 | I Correction Rate | U1 | 0 | 100 | 10 | % |
| | | 37 | Thermistor OR Hi | I1 | 0 | 120 | 100 | °C |
| | | 38 | Thermistor OR Low | I1 | −120 | 10 | −40 | °C |
| 107 | Current | 1 | Deadband | U1 | 0 | 255 | 5 | mA |

**Table 4-10. Data Flash Summary—Security Class**

| Subclass ID | Subclass | Offset | Name | Data Type | Value | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | **Min** | **Max** | **Default** | |
| 112 | Codes | 0 | Sealed to Unsealed | H4 | 0x00 | 0xFFFF FFFF | 0x00 | |
| | | 4 | Unsealed to Full | H4 | 0x00 | 0xFFFF FFFF | 0x00 | |

**Table 4-11. Data Flash to EVSW or GaugeStudio Conversion**

| Class | Subclass ID | Subclass | Offset | Name | Data Type | Data Flash Default | Data Flash Unit | EVSW Default | EVSW Unit | Data Flash to EVSW Conversion |
|---|---|---|---|---|---|---|---|---|---|---|
| Configuration | 48 | Data | 15 | Default Temperature | I2 | 2982 | °C | 250 | 0.1°C | DF − 2732 |
| | 64 | Registers | 9 | DF Wr Ind Wait | U2 | 0 | µs | 0 | % | DF × 5 |
| Calibration | 104 | Data | 0 | CC Gain | F4 | 0.4768 | Number | 10 | mΩ | 4.768 ÷ DF |
| | | | 4 | CC Delta | F4 | 567744.6 | Number | 10 | mΩ | 5677445 ÷ DF |
| | | | 8 | CC Offset | I2 | −1200 | mA | −5.76 | mA | DF × 0.0048 |
| | | | 12 | Board Offset | I1 | 0 | µA | 0 | µA | DF × 0.0075 |

## 4.6    Data Flash Parameter Update Example

This section shows an example of the command sequence that modifies a data flash parameter while device firmware is still running. It can update one or more parameters without going to ROM mode and loading a new data flash image (.dfi, .dmi, or .dffs file).

For this example, the **OpConfig B [WRTEMP]** bit of the fuel gauge is changed from 0 to 1.

Some bq27510-G3 pins are configured via the **OpConfig B** register. This register is programmed and read via the methods described in Section 4.1, *Accessing The Data Flash*. See Section 4.5, *Data Flash Summary*, for the location (subclass and offset) of these configuration registers.

### Table 4-12. OpConfig B Register Bit Definitions

|         | bit7   | bit6 | bit5   | bit4   | bit3 | bit2    | bit1     | bit0 |
|---------|--------|------|--------|--------|------|---------|----------|------|
| Byte    | WRTEMP | BIE  | BL_INT | GNDSEL | FCE  | RMC_IND | RFACTSTEP| RSVD |
| Default | 0      | 1    | 0      | 0      | 1    | 1       | 1        | 0    |
|         | 0x4E   |      |        |        |      |         |          |      |

WRTEMP =   Enables the temperature write. The temperature is expected to be written by the host and is used for gauging. Neither the external thermistor or internal temperature sensor is used. True when set.

Note that subclass ID and offset values in Table 4-13 are in decimal format. The example below has converted these to hexadecimal. For example, the **OpConfig B** subclass is d64 = 0x40.

### Table 4-13. Data Flash Summary—Configuration

| Subclass ID | Subclass  | Offset | Name      | Data Type | Value Min | Value Max | Value Default | Unit |
|-------------|-----------|--------|-----------|-----------|-----------|-----------|---------------|------|
| 64          | Registers | 11     | OpConfig B | H1       | 0x00      | 0xFF      | 0x4E          | hex  |

### 4.6.1    Modify WRTEMP of OpConfig B Register

1.  Unseal the device by using the *Control( )* (0x00 and 0x01) command if the device is SEALED.

    (a) Write the first 2 bytes of the UNSEAL key using the *Control(0x0414)* command.
        (*wr 0x00 0x14 0x04*)

    (b) Write the second 2 bytes of the UNSEAL key using the *Control(0x3672)* command.
        (*wr 0x00 0x72 0x36*)

2.  Write 0x00 using *BlockDataControl( )* command (0x61) to enable block data flash control.
    (*wr 0x61 0x00*)

3.  Write 0x40 (**OpConfig B** Subclass) using the *DataFlashClass( )* command (0x3E) to access the registers subclass.
    (*wr 0x3E 0x40*)

4.  Write the block offset location using *DataFlashClass( )* command (0x3F). To access data located at offset 0 to 31 use offset = 0x00. To access data located at offset 32 to 41 use offset = 0x01.
    For example, **OpConfig B** (offset = 11) is in the first block so use:
    (*wr 0x3F 0x00*)

5.  To read the data of a specific offset use address 0x40 + mod(offset, 32).
    For example **OpConfig B** (offset = 11) is located at 0x4B, read 1 byte starting at 0x4B address.
    (*rd 0x4B old_OP_CONF_B_BYTE*)
    In our example, assume *WRTEMP*(MSB) is cleared.

6.  To read the 1-byte checksum use the *BlockDataChecksum( )* command (0x60).
    (*rd 0x60 OLD_checksum*)

7.  Set *WRTEMP* by setting the most-significant bit of *OP_CONF_B_BYTE*.

8.  The new value for *OP_CONF_B_BYTE* can be written by writing to the specific offset location.
    For example to write 1-byte *OP_CONF_B_BYTE* new value with MSB set to **OpConfig B** (offset = 11)
    located at 0x4B, use command: (*wr 0x4B new_OP_CONF_B_BYTE*)

9.  The data is actually transferred to the data flash when the correct checksum for the whole block (0x40
    to 0x5F) is written to *BlockDataChecksum( )* (0x60).
    (*wr 0x60 NEW_checksum*)
    The checksum is (255 – x) where x is the 8-bit summation of the *BlockData( )* (0x40 to 0x5F) on a
    byte-by-byte basis. A quick way to calculate the new checksum is to make use of the old checksum:

    (a) temp = mod(255 – *OLD_checksum* – *old_OP_CONF_B_BYTE*, 256)

    (b) NEW_checksum = 255 – mod(temp + *new_OP_CONF_B_BYTE*, 256)

10. RESET the gauge to ensure the new data flash parameter goes into effect by using *Control(0x0041)*.
    (*wr 0x00 0x41 0x00*)
    If previously sealed, then the gauge automatically becomes sealed again after RESET.

11. If not previously sealed, then SEAL the gauge by using *Control(0x0020)*.
    (*wr 0x00 0x20 0x00*)

# Functional Description

## 5.1 Impedance Track™ Variables

The bq27510-G3 fuel gauge has a number of data flash variables that permit the user to customize the Impedance Track™ algorithm for optimal performance. These variables are dependent upon the power characteristics of the application as well as the cell itself.

### 5.1.1 Load Mode

**Load Mode** selects either the constant-current or constant-power model for the Impedance Track™ algorithm as used in **Load Select** (see Section 5.1.2). When **Load Mode** is 0, the constant-current model is used (default). When **Load Mode** is 1, the constant-power model is used. The *CONTROL_STATUS [LDMD]* bit shows the status of **Load Mode**.

### 5.1.2 Load Select

**Load Select** defines the type of power or current model that computes the load-compensated capacity in the Impedance Track™ algorithm.

If **Load Mode** = 0 (constant-current model), then the options presented in Table 5-1 are available.

**Table 5-1. Constant-Current Model Used When *Load Mode* = 0**

| Load Select Value | Current Model Used |
|---|---|
| 0 | The average discharge current from previous cycle, **Avg I Last Run**. (See Section 5.1.10) |
| 1 (default) | Present average discharge current: This is the average discharge current from the beginning of this discharge cycle until present time. |
| 2 | Average current: based on *AverageCurrent( )* |
| 3 | Current: based off of a low-pass-filtered version of *AverageCurrent( )* (τ = 14 s) |
| 4 | Design capacity / 5: C Rate based off of Design Capacity /5 or a C/5 rate in mA. |
| 5 | AtRate (mA): Use whatever current is in *AtRate( )* |
| 6 | User_Rate-mA: Use the value in *User_Rate-mA*. This mode provides a completely user-configurable method. |

If **Load Mode** = 1 (constant-power model), then the options shown in Table 5-2 are available.

**Table 5-2. Constant-Power Model Used When *Load Mode* = 1**

| Load Select Value | Power Model Used |
|---|---|
| 0 | The average discharge power from previous cycle, **Avg P Last Run**. (See Section 5.1.11) |
| 1 (default) | Present average discharge power: This is the average discharge power from the beginning of this discharge cycle until present time. |
| 2 | Average current × voltage: based off the *AverageCurrent( )* and *Voltage( )* |
| 3 | Current × voltage: based off of a low-pass-filtered version of *AverageCurrent( )* (τ = 14 s) and *Voltage( )* |
| 4 | Design energy / 5: C Rate based off of Design Energy /5 or a C/5 rate in mA. |
| 5 | AtRate (10 mW): Use the value is in *AtRate( )*. |
| 6 | User_Rate−10mW: Use the value in *User_Rate−10mW*. This mode provides a completely user-configurable method. |

### 5.1.3  Reserve Cap-mAh, Reserve Cap-mWh/cWh

**Reserve Cap-mAh** (**Load Mode** = 0) or **Reserve Cap-mWh/cWh** (**Load Mode** = 1) determines how much actual remaining capacity exists when the fuel gauge reports zero for *RemainingCapacity( )* before reaching the **Terminate Voltage**. This accommodates a controlled shutdown scheme based on battery capacity rather than a specific voltage. A loaded rate or no-load rate of compensation can be selected for **Reserve Cap-mAh** via the **Op Config [RESCAP]** bit.

### 5.1.4  Design Energy Scale

Design energy scaling accommodates large capacity battery packs greater than approximately 6000 mAh. **Des Energy Scale** selects the scale and unit of a set of data flash parameters. The value of **Des Energy Scale** can be either 1 or 10, only. For batteries less than 6000 mAh, a setting of 1 is recommended. For batteries greater than 6000 mAh, a setting of 10 is recommended.

**Table 5-3. Data Flash Parameter Scale and Unit Based on *Design Energy Scale***

| Data Flash | Design Energy Scale = 1 (default) | Design Energy Scale = 10 |
|---|---|---|
| *Design Energy* | mWh | cWh |
| *Reserve Capacity–mWh or cWh* | mWh | cWh |
| *Avg Power Last Run* | mW | cW |
| *User Rate–mW or cW* | mWh | cWh |
| *T Rise* | No Scale (example: default is 20) | Scaled by ×10 (example: default is 200) |

### 5.1.5  Dsg Current Threshold

This register is used as a threshold by many functions in the fuel gauge to determine if significant discharge current is flowing out of the cell. The default for this register is in Table 4-5, Current Thresholds Subclass, which should be sufficient for most applications. This threshold should be set low enough to be below any normal application load current but high enough to prevent noise or drift from affecting the measurement.

### 5.1.6  Chg Current Threshold

This register is used as a threshold by many functions in the fuel gauge to determine if significant charge current is flowing into the cell. The default for this register is in Table 4-5, Current Thresholds Subclass, which should be sufficient for most applications. This threshold should be set low enough to be below any normal charge current but high enough to prevent noise or drift from affecting the measurement.

### 5.1.7  Quit Current, Dsg Relax Time, Chg Relax Time, and Quit Relax Time

The **Quit Current** is used as part of the Impedance Track™ algorithm to determine when the fuel gauge enters the relaxation mode from a current-flowing mode in either the charge direction or the discharge direction. The value of **Quit Current** is set to a default value in Table 4-5, Current Thresholds Subclass, and should be above the standby current of the system.

Either of the following criteria must be met to enter the relaxation mode:

- | *AverageCurrent( )* | < | **Quit Current** | for **Dsg Relax Time**
- | *AverageCurrent( )* | < | **Quit Current** | for **Chg Relax Time**

After about 5 minutes in relaxation mode, the fuel gauge attempts to take accurate OCV readings. An additional requirement of dV/dt < 1 μV/s is required for the fuel gauge to perform Qmax updates. These updates are used in the Impedance Track™ algorithms. It is critical that the battery voltage be relaxed during OCV readings and that the current is not higher than C/20 when attempting to go into relaxation mode.

*Quit Relax Time* specifies the minimum time required for *AverageCurrent( )* to remain above the **Dsg Current Threshold** or **Chg Current Threshold** before exiting the relaxation mode. See Application Report [SLUA450](#), *Theory and Implementation of Impedance Track Battery Fuel-Gauging Algorithm*, for more information.

### 5.1.8 Qmax Cell 0 and Qmax Cell 1

Generically called **Qmax**, these dynamic variables contain the respective maximum chemical capacity of the active cell profiles, and are determined by comparing states of charge before and after applying the load with the amount of charge passed. They also correspond to capacity at a low rate of discharge, such as the C/20 rate. For high accuracy, this value is periodically updated by the fuel gauge during operation. Based on the battery cell capacity information, the initial value of chemical capacity should be entered in the **Qmax n** field for each default cell profile. The Impedance Track™ algorithm updates these values and maintains them in the associated cell profiles.

**Qmax Max Delta %** is the percent of *DesignCapacity( )* to limit how much Qmax may grow or shrink during any one Qmax update. The default is 5%.

**Min % Passed Chg for Qm** represents the approximate change in SOC that is required as part of the qualification for Qmax updates. It is not recommended to change this value.

**Qmax Filter**. Qmax updates are filtered to prevent corrupt values. It is not recommended to change this value.

Although there is variation between batteries, in general Qmax should only decrease over time and use. **Max % Default Qmax** prevents erroneous updates from being recorded if they are too high.

### 5.1.9 Update Status 0 and Update Status 1

The **Update Status n** registers are modified automatically by the fuel gauge and the TI evaluation software during the process of creating a golden Data Flash file. A golden file with optimized Qmax and resistance values should have the **Update Status** = 2.

### 5.1.10 Avg I Last Run

The fuel gauge computes average current from the beginning to the end of each discharge cycle and stores the average current from the previous discharge period in this register if the duration is > 500 seconds. This register should not be modified by the host as it is automatically updated by the fuel gauge when required. For a golden file, this register should be initially set to a typical system discharge current level.

### 5.1.11 Avg P Last Run

The fuel gauge computes average power from the beginning to the end of each discharge cycle and stores this average power from the previous discharge period in this register if the duration is > 500 seconds. Average Power is computed by continuously averaging the product of *InstantaneousCurrent( )* and *Voltage( )*. This register should not be modified by the host as it is automatically updated by the fuel gauge when required. For a golden file, this register should be initially set to a typical system discharge power level.

### 5.1.12 Delta Voltage

The fuel gauge stores the maximum difference of *Voltage( )* during short load spikes and normal load, so the Impedance Track™ algorithm can calculate remaining capacity for pulsed loads. It is not recommended to change this value.

**Min DeltaV** is the minimum **Delta Voltage** that is saved during discharge cycles. The default is 0 mV.

**DeltaV Max dV** limits on how far **Delta Voltage** grows or shrinks on one grid update (in mV). This register defaults to 10.

### 5.1.13 Default Ra and Ra Tables

These tables contain encoded data and, with the exception of the **Default Ra Tables**, are automatically updated during device operation. No user changes should be made except for reading or writing the values from a pre-learned pack (part of the process for creating golden image files).

During the update of Ra values a filtering process is performed to eliminate unexpected fluctuations in the updated Ra values. **Ra Max Delta** limits the change in Ra values to an absolute magnitude per Ra update. This value should be set to 15% of the Ra[4] value. Value needs to be manually adjusted after chemistry change.

**Min Res Scale** and **Max Res Scale** specify the allowed change in the Fast Ra Scaling algorithm. A value of 1000 corresponds to 1x and a value of 200 corresponds to 0.2x.

### 5.1.14 Fast Resistance Scaling

Fast resistance scaling improves convergency of remaining capacity and terminates the voltage at end of discharge. The feature is enabled via the **OpConfig B [FCE]** bit and operates when cell voltage is below (**Terminate Voltage** + **Term V Delta**) or *StateofCharge( )* is less than **Fast Scale Start SOC**. For most applications, the default values of **Term V Delta** and **Fast Scale Start SOC** are recommended. It is also recommended to keep (**Terminate Voltage** + **Term V Delta**) below 3.6 V for most battery applications.

**Fast Scale Start SOC** and **Term V Delta** specify voltage and SOC thresholds for fast Ra scaling activation. Fast Ra scaling is activated when either of the following conditions is true:

- SOC < **Fast Scale Start SOC**
- Voltage < (**Terminate Voltage** + **Term V Delta**)

### 5.1.15 SOC Smoothing

Rapid changes in operating conditions, such as temperature or discharge current, can lead to sudden changes in the immediate calculation of *RemainingCapacity( )*, *FullChargeCapacity( )*, and *StateOfCharge( )* by the algorithm. SOC smoothing provides filtered data to the host resulting in more gradual changes to SOC-related data when conditions vary and can provide a better end-user experience. The feature is enabled via the **OpConfig D [SMTHEN]** bit and has one configuration option available via the **OpConfig D [RCJUMPOK]** bit.

Both smoothed and unsmoothed registers are available at the higher register addresses, but the **OpConfig D [SMTHEN]** bit determines which values get reported in the *RemainingCapacity( )*, *FullChargeCapacity( )*, and *StateOfCharge( )* registers.

### 5.1.16 Flash Updates

Data flash can only be updated if *Voltage( )* ≥ **Flash Update OK Voltage**. Flash programming current can cause an increase in LDO dropout. The value of **Flash Update OK Voltage** must be selected such that the $V_{CC}$ voltage does not fall below its minimum of 2.4 V during flash write operations. Data flash updates can occur at any time during gauge operation. During data flash updates, the gauge may stretch the I²C clock significantly. See Section 6.4, *I²C Clock Stretching*, for more information.

The SOC_INT pin can be configured to generate a pulse before and during data flash updates if desired. This is disabled by default. See Section 5.3.2.3, *SOC_INT Pin Behavior*, for details.

## 5.2   Device Configuration

The configuration options are configured via the following **Operation Configuration** data flash registers. These registers are programmed and read via the methods described in Section 4.1, *Accessing the Data Flash*. See Table 4-3, Registers Subclass, for the location (subclass and offset) of these configuration registers. A faster way to read the current value of the **Operation Configuration** register is to use the *OperationConfiguration( )* function.

### 5.2.1   Operation Configuration (Op Config) Register

**Table 5-4. Op Config Register Bit Definition**

|            | bit7 | bit6 | bit5 | bit4 | bit3 | bit2 | bit1 | bit0 |
|------------|------|------|------|------|------|------|------|------|
| **High Byte** | RESCAP | BATG_OVR | INT_BREM | PFC_CFG1 | PFC_CFG0 | IWAKE | RSNS1 | RSNS0 |
| **Default** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
|            | 0x09 | | | | | | | |
| **Low Byte** | INT_FOCV | IDSELEN | SLEEP | RMFCC | GPOUT_POL | GPOUT_INT | BAT_FN | TEMPS |
| **Default** | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
|            | 0x75 | | | | | | | |

**High Byte (0x09)**

RESCAP = Selects the rate of compensation method for the reserve capacity calculation. If clear (default), a loaded rate is used. If set, a no-load rate is used. (See Section 5.1.3, *Reserve Cap-mAh, Reserve Cap-mWh/cWh*)

BATG_OVR = GPOUT override bit. If the gauge enters HIBERNATE only due to the cell voltage, the GPOUT pin does not negate. This option may be useful if the GPOUT pin is interfaced with a charger IC. True when set. (See Section 5.3.2.2, *Power Path Control With the GPOUT Pin*)

INT_BERM = Battery removal interrupt bit. The SOC_INT pin pulses 1 ms when the battery removal interrupt is enabled. True when set. (See Table 5-10, *SOC_INT Pulse Conditions and Widths*)

PFC_CFG1, PFC_CFG0 = Pin function code (PFC) mode selection: PFC 0, 1, 2, or 3 selected by 00, 01, 10, or 11, respectively (see Section 5.3.1, *Pin Function Code (PFC) Descriptions*).

IWAKE, RSNS1, RSNS0 = These bits configure the current wake function (see Section 5.3.4, *Wake-Up Comparator*).

**Low Byte (0x75)**

INT_FOCV = Indication of the measurement of the OCV during the initialization. The SOC_INT pin pulses during the first measurement if this bit is set. True when set. This option may be useful if the SOC_INT pulse can trigger the system to enter a low-power state for the best possible OCV measurement. (See Table 5-10, *SOC_INT Pulse Conditions and Widths*)

IDSELEN = Enables cell profile identification feature. True when set. If the battery is embedded and will never be swapped by the user, then clear IDSELEN. Otherwise, leave it set. (See Section 5.7.1, *Battery Profile Storage and Selection.*)

SLEEP = The fuel gauge can enter SLEEP if operating conditions allow. True when set.

RMFCC = RM is updated with the value from FCC on valid charge termination. True when set. (See Section 5.5.1, *Detecting Charge Termination*)

GPOUT_POL = GPOUT pin polarity control. Active low is 0. Active high is 1.

GPOUT_INT = GPOUT pin function selection.
0 = Use GPOUT pin for BAT_LOW or BAT_GD functions. See BAT_FN description below.
1 = Use GPOUT pin for SOC_INT (interrupt) function. Ignore BAT_FN. (See Section 5.3.2, *GPOUT Pin*)

BAT_FN = GPOUT pin function if GPOUT_INT = 0.
0 = GPOUT used for BAT_LOW (battery low) function.
1 = GPOUT used for BAT_GD (battery good) function.
If GPOUT_INT = 1, then BAT_FN is ignored.

TEMPS = Selects external thermistor for *Temperature( )* measurements. True when set. (See Section 5.3.1, *Pin Function Code (PFC) Descriptions*, and Section 2.4, *Temperature( ): 0x06 and 0x07*)

## 5.2.2 Operation Configuration B (OpConfig B) Register

**Table 5-5. OpConfig B Register Bit Definitions**

|         | bit7   | bit6 | bit5   | bit4   | bit3 | bit2    | bit1     | bit0 |
|---------|--------|------|--------|--------|------|---------|----------|------|
| **Byte** | WRTEMP | BIE  | BL_INT | GNDSEL | FCE  | RMC_IND | RFACTSTEP | RSVD |
| **Default** | 0    | 1    | 0      | 0      | 1    | 1       | 1        | 0    |
|         | 0x4E |

| | |
|---|---|
| WRTEMP = | Enables the temperature write. The temperature is expected to be written by the host and is used for gauging. Neither the external thermistor or internal temperature sensor is used. True when set. (See Section 5.3.1, *Pin Function Code (PFC) Descriptions*, and Section 2.4, *Temperature( ): 0x06 and 0x07*) |
| BIE = | Battery Insertion Detection feature enable. When enabled, the gauge detects battery insertion using the TS pin. If disabled, the gauge relies on the host to set and clear the *Flags( ) [BAT_DET]* bit using the *BAT_INSERT* or *BAT_REMOVE* subcommand. True when set. (See Section 5.3.3, *Battery Presence Detection Using the BI/TOUT Pin*, and Section 5.6.1, *BAT INSERT CHECK Mode*) |
| BL_INT = | Enables toggle of SOC_INT pin upon the state change of *Flags( ) [SOC1]* in addition to the GPOUT pin's discrete output of the battery low condition. True when set. (See Table 5-10, *SOC_INT Pulse Conditions and Widths*) |
| GNDSEL = | The ADC ground select control. $V_{SS}$ (pin 6) is selected as ground reference when the bit is clear. Pin 7 (SRP) is selected when the bit is set. The default value is recommend for typical applications. |
| FCE = | Fast Convergence Enable for Resistance Scaling. Configures algorithm to use fast convergence method. The default value is recommend for typical applications. (See Section 5.1.14, *Fast Resistance Scaling*) |
| RMC_IND = | Remaining capacity indicator. If **[RMC_IND]** and **[GPOUT_INT]** are set, the GPOUT pin generates a series of 3 pulses as indicated below. The polarity of the pulses is determined by the selection of **[GPOUT_POL]**. |

|          | Enable Condition    | Pulse Width | Comment                                              |
|----------|---------------------|-------------|------------------------------------------------------|
| SOC1 Set | **RMC_IND** = 1     | 10 ms       | When RSOC reaches the **SOC1 Set Threshold** in the DF |
| SOCF Set | **RMC_IND** = 1     | 10 ms       | When RSOC reaches the SOCF Set Threshold in the DF   |

| | |
|---|---|
| RFACTSTEP = | Enables Ra step up or down to **Min/Max Res Factor** before disabling Ra updates. |
| RSVD = | Bit 0 is reserved. |

## 5.2.3 Operation Configuration C (OpConfig C) Register

**Table 5-6. OpConfig C Register Bit Definitions**

|         | bit7 | bit6 | bit5 | bit4 | bit3   | bit2    | bit1      | bit0      |
|---------|------|------|------|------|--------|---------|-----------|-----------|
| **Byte** | RSVD | RSVD | RSVD | RSVD | VconsEn | SlpWkChg | DeltaVOpt1 | DeltaVOpt0 |
| **Default** | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
|         | 0x0C |

| | |
|---|---|
| RSVD = | Bits 7:4 are reserved. |
| VconsEn = | Enables Voltage Consistency checking function. Use default value for proper operation. |
| SlpWkChg = | Enables compensation for the passed charge missed when waking from SLEEP mode. |
| DeltaVOpt[1:0] = | Configures options for determination of **Delta Voltage** which is defined as the maximum difference in *Voltage( )* during normal load and short load spikes. **Delta Voltage** is used as a compensation factor for calculating *RemainingCapacity( )* under pulsed loads.<br>00 = Standard DeltaV. Average variance from steady state voltage used to determine end-of-discharge voltage. (Default)<br>01 = No Averaging. The last instantaneous change in *Voltage( )* from steady state determines the end-of-discharge voltage.<br>10 = Use the value in **Min Delta Voltage**.<br>11 = Not used. |

### 5.2.4   Operation Configuration D (OpConfig D) Register

**Table 5-7. OpConfig D Register Bit Definitions**

|         | bit7 | bit6 | bit5 | bit4 | bit3 | bit2 | bit1 | bit0 |
|---------|------|------|------|------|------|------|------|------|
| Byte    | RCJUMPOK | SMTHEN | SOC_STATE | SOC_OCV | SOC_DFW | SOC_OT | CHGDODEOC | RSVD |
| Default | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 |
|         | 0x5E | | | | | | | |

RCJUMPOK = Allows SOC to change due to a temperature change during relaxation when the SOC smoothing algorithm is enabled. True when set. (See Section 5.1.15, *SOC Smoothing*)

SMTHEN = Enables SOC smoothing function. (See Section 5.1.15, *SOC Smoothing*)

SOC_STATE = Enables SOC_INT pin function to generate a pulse due to an Impedance Track™ algorithm state change. (See Table 5-10, *SOC_INT Pulse Conditions and Widths*)

SOC_OCV = Enables SOC_INT pin function to generate a pulse due to OCV command. (See Table 5-10, *SOC_INT Pulse Conditions and Widths*)

SOC_DFW = Enables SOC_INT pin function to generate a pulse due to data flash write. (See Table 5-10, *SOC_INT Pulse Conditions and Widths*)

SOC_OT = Enables SOC_INT pin function to generate a pulse due to overtemperature conditions in conjunction with the assertion of *Flags( ) [OTC or OTD]* . (See Table 5-10, *SOC_INT Pulse Conditions and Widths*)

CHGDODEOC = Enables DoD at End-of-Charge recalculation during charging only. True when set. The default setting is recommended. If cleared, the DoD at EoC can be recalculated at any time due to temperature changes greater than **DODatEOC Delta T**.

RSVD = Bit 0 is reserved.

### 5.2.5   Operation Configuration E (OpConfig E) Register

**Table 5-8. OpConfig E Register Bit Definitions**

|         | bit7 | bit6 | bit5 | bit4 | bit3 | bit2 | bit1 | bit0 |
|---------|------|------|------|------|------|------|------|------|
| Byte    | RSVD | RSVD | RSVD | RSVD | RSVD | CHGFASTQM | TOVERRD | RSVD |
| Default | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
|         | 0x02 | | | | | | | |

RSVD = Bits 7:3 are reserved.

CHGFASTQM = Ensures that DOD0 is updated on full charge detection. Default is 0 for backwards compatibility, but the recommended setting is 1.

TOVERRD = Thermistor override bit

RSVD = Bit 0 is reserved.

## 5.3 External Pin Functions

### 5.3.1 Pin Function Code (PFC) Descriptions

This fuel gauge has several pin-function configurations available for the end application. Each configuration is assigned a pin function code, or PFC, specified by the **Op Config [PFC_CFG1, PFC_CFG0]** bits (see Table 5-9). If the fuel gauge is configured to measure external temperature via the **Op Config [TEMPS]** bit, a voltage bias of approximately 125 ms is applied periodically to the external thermistor network to make a temperature measurement.

**Table 5-9. Pin Function Code Summary**

| PFC | PFC_CFG [1:0] | External Thermistor Bias Rate ([TEMPS] = 1 only) | | | GPOUT Pin Usage for PFC | Pin Function Description |
|---|---|---|---|---|---|---|
| | | Discharge | Charge | Sleep | | |
| 0 | 00 | 1 / s | 1 / s | 1 / 20 s | NA | A dedicated external thermistor is used for the fuel gauge to monitor battery temperature in all conditions. The GPOUT pin is not used to interface with a charger IC. |
| 1 | 01 | | | | Temperature-based Charge Inhibit | A dedicated external thermistor is used for the fuel gauge to monitor battery temperature in all conditions. If battery charging temperature falls outside of the preset range defined in data flash, a charger can be disabled via the GPOUT pin until cell temperature recovers. See Section 5.5.2, *Charge Inhibit and Suspend*, for additional details. |
| 2 | 10 | | None | | NA | A shared external thermistor is supported between the fuel gauge and a charger IC; however, the GPOUT pin is not used to interface with the charger IC. The fuel gauge biases the thermistor for battery temperature measurement and BAT INSERT CHECK mode (if **OpConfig B [BIE]** bit = 1) under discharge and relaxation conditions only so the charger IC can separately bias the thermistor during charge mode. Bias networks required by the fuel gauge and the charger for the thermistor must be identical. |
| 3 | 11 | | 1 / s | | Follows *Flags( ) [FC]* flags bit | Disables a battery charger IC when fuel gauge has determined the battery is fully charged. The GPOUT pin reflects the logical status of the *Flags( ) [FC]* bit and is typically connected directly to the charger Charge Enable/Disable (CE/CD) pin or via a network to drive the charger Temperature Sense (TS) pin. |

### 5.3.2 GPOUT Pin

The GPOUT pin is a general-purpose open-drain output which may be configured as battery low, battery good, or perform SOC interrupt functionality. When the gauge detects remaining capacity falling below both SOC1 and SOCF thresholds, the GPOUT pin is pulsed three times. Each pulse is 10 ms long, separated by a 10-ms delay.

The **Op Config [GPOUT_INT]** bit configures the GPOUT pin. If **[GPOUT_INT]** is 1, it performs SOC interrupt functionality. If **[GPOUT_INT]** is 0, the GPOUT pin is configured as either the battery low or battery good function. Default value of the **[GPOUT_INT]** bit is 1.

The **Op Config [BAT_FN]** bit determines the battery low or battery good function. If **[GPOUT_INT]** is 0 and **[BAT_FN]** is 0, then the battery low function is enabled. If **[GPOUT_INT]** is 0 and **[BAT_FN]** is 1, the battery good function is enabled. Default value of the **[BAT_FN]** bit is 0.

The remaining capacity indicator is the **OpConfig B [RMC_IND]** bit. If **[RMC_IND]** is 1 and **[GPOUT_INT]** is 1, the GPOUT pin generates a series of 3 pulses as indicated by the table below. The polarity of the pulses is determined by the selection of the GPOUT polarity by the **Op Config [GPOUT_POL] bit**.

| | Enable Condition | Pulse Width | Comment |
|---|---|---|---|
| SOC1 Set | **[RMC_IND]** = 1 | 10 ms | When RSOC reaches the **SOC1 Set Threshold** in the data flash |
| SOCF Set | **[RMC_IND]** = 1 | 10 ms | When RSOC reaches the **SOCF Set Threshold** in the data flash |

| GPOUT Function | GPOUT_INT State | BAT_FN State |
|---|---|---|
| BAT_LOW | 0 | 0 |
| BAT_GD | 0 | 0 |
| SOC_INT | 1 | Not applicable |

### 5.3.2.1 Battery Low Function

The battery low function provides a system processor with an external indicator of battery status. The signaling on the GPOUT pin follows the status of the *Flags( ) [SOC1]* bit. The battery low function is configured via the **Op Config [GPOUT_INT]** and [BAT_FN] bits as explained previously.

### 5.3.2.2 Power Path Control With the GPOUT Pin—REWRITE

The fuel gauge must operate in conjunction with other electronics in a system appliance, such as chargers or other ICs and application circuits that draw appreciable power. After a battery is inserted into the system, it is preferable that no charging current or discharging current higher than C/20 is present, so that an accurate OCV can be read. The OCV helps determine which battery profile to use, as it constitutes part of the battery impedance measurement and determines initial SOC. To disable these functions, the GPOUT pin can be connected to the Charger Enable/Disable (CE/CD) pin to disable the charging function. Once an OCV reading has been made, the GPOUT pin is asserted, thereby enabling battery charging and regular discharge of the battery. The **Op Config [GPOUT_POL]** bit can change the polarity of the GPOUT pin in case the default configuration needs to be changed for the system application.

Figure 5-1 and Figure 5-2 detail how the GPOUT pin functions in the context of battery insertion and removal, as well as NORMAL versus SLEEP modes.

In PFC 1, the GPOUT pin also disables battery charging when the fuel gauge reads battery temperatures outside the range defined by *[Chg Inhibit Temp Low, Chg Inhibit Temp High]*. The GPOUT line is asserted once temperature falls within the range *[Chg Inhibit Temp Low + Temp Hys, Chg Inhibit Temp High – Temp Hys]*.

### 5.3.2.3 SOC_INT Function Behavior

The SOC_INT function generates a pulse of different pulse widths under various conditions as indicated by Table 5-10. After initialization, only one SOC_INT pulse is generated within any given one-second time slot and, therefore, may indicate multiple event conditions.

**Table 5-10. SOC_INT Pulse Conditions and Widths**

| Pulse Condition | Enable Condition | Pulse Width | Comment |
|---|---|---|---|
| Change of *StateOfCharge( )* | (**SOC Delta**) ≠ 0 | 1 ms | During charge, when the SOC is greater than (>) the points: 100% – n × (**SOC Delta**) and 100%; During discharge, when the SOC reaches (≤) the points: 100% – n × (**SOC Delta**) and 0%; where n is an integer starting from 0 to the number generating SOC no less than 0% Examples: For **SOC Delta** = 1% (default), the SOC_INT intervals are 0%, 1%, 2%, …, 99%, and 100%. For **SOC Delta** = 10%, the SOC_INT intervals are 0%, 10%, 20%, …, 90%, and 100%. |
| Change of *Flags( ) [SOC1]* state (Set or Clear) | **OpConfig B [BL_INT]** = 1 | 1 ms | When SOC reached the **SOC1 Set** or **Clear Threshold** set in the Data Flash. |
| Change of *Flags( ) [SYSDOWN]* state (Set or Clear) | Always | 1 ms | When the *Voltage( )* has reached **SysDown Set Volt Threshold** or **SysDown Clear Volt** threshold. |
| Battery State Change | (**SOC Delta**) ≠ 0 and **OpConfig D [SOC_STATE]** = 1 | 1 ms | Upon detection of a state change in battery charging and discharging. Relaxation is not included. |
| Battery Removal | **OpConfig B [BIE]** = 1 and **Op Config [INT_BREM]** = 1 | 1 ms | |

**Table 5-10. SOC_INT Pulse Conditions and Widths (continued)**

| Pulse Condition | Enable Condition | Pulse Width | Comment |
|---|---|---|---|
| OCV measurement after initialization | *Op Config [INT_FOCV]* = 1 | Approximately 380 ms | Within 1.5 seconds after a POR event or the receipt of either *BAT_INSERT* or *RESET* subcommand, SOC_INT begins a pulse for the duration of the OCV measurement and initialization time period. |
| OCV measurement from *OCV_CMD* subcommand | *OpConfig D [SOC_OCV]* = 1 | Approximately 260 ms | Within 1 second after receipt of *OCV_CMD* subcommand, SOC_INT begins a pulse for the duration of the OCV measurement execution time period. |
| After initialization and *DF Wr Ind Wait* ≠ 0 | *OpConfig D [SOC_DFW]* = 1 | Programmable (see comment) | SOC_INT pin indicates the data flash update. The gauge waits *DF Wr Ind Wait* × 5 µs after the SOC_INT signal to start the data flash update. This function is disabled if *DF Wr Ind Wait* = 0. |
| *Flags( ) [OTC]* or *[OTD]* | *OpConfig D [SOC_OT]* = 1 | 1 ms | Upon first assertion of *Flags( ) [OTC]* or *[OTD]* overtemperature conditions. |
| Remaining capacity below SOC1 and SOCF thresholds | *[RMC_IND]* and *[GPOUT_INT]* are set | 10 ms, separated by 10 ms | If *[GPOUT_INT]* is set, it overrides any use of IO pin as either at BAT_LOW or BAT_GD if set. Default value is 1. |

### 5.3.3 Battery Presence Detection Using the BI/TOUT Pin

During power-up or hibernate activities, or any other activity where the fuel gauge needs to determine whether or not a battery is connected, the fuel gauge applies a test for battery presence when the *OpConfig B [BIE]* bit is set. First, the BI/TOUT pin is put into high-Z status. The weak 1.8-MΩ pullup resistor keeps the pin high while no battery is present. When a battery is inserted (or is already inserted) into the system device, the BI/TOUT pin is pulled low. This state is detected by the fuel gauge, which polls this pin every second when the gauge has power. A battery-disconnected status is assumed when the fuel gauge reads a thermistor voltage that is near 2.5 V.

When a thermistor is not used by the system for the gauge to detect battery insertion, there are two options. First, the BI/TOUT pin can be tied to $V_{SS}$ with a resistor so the gauge always considers a battery to be present if it has power. Second, the *OpConfig B [BIE]* bit can be cleared so host can inform the gauge of the battery status via the *BAT_INSERT* and *BAT_REMOVE* subcommands.

### 5.3.4 Wake-Up Comparator

The wake-up comparator indicates a change in cell current while the fuel gauge is in SLEEP mode. The *Op Config [RSNS1:RSNS0]* bits select the appropriate comparator threshold for the sense resistor value used. The *Op Config [IWAKE]* bit selects one of two possible voltage threshold ranges for the given sense resistor selection. An internal interrupt is generated when the threshold is reached in either the charge or discharge direction. Setting both *[RSNS1]* and *[RSNS0]* bits to 0 disables this feature.

**Table 5-11. $I_{WAKE}$ Threshold Settings[1]**

| RSNS1 | RSNS0 | IWAKE | Vth (SRP – SRN) |
|---|---|---|---|
| 0 | 0 | 0 | Disabled |
| 0 | 0 | 1 | Disabled |
| 0 | 1 | 0 | 1.0 mV or –1.0 mV |
| 0 | 1 | 1 | 2.2 mV or –2.2 mV |
| 1 | 0 | 0 | 2.2 mV or –2.2 mV |
| 1 | 0 | 1 | 4.6 mV or –4.6 mV |
| 1 | 1 | 0 | 4.6 mV or –4.6 mV |
| 1 | 1 | 1 | 9.8 mV or –9.8 mV |

[1] The actual resistance value versus the setting of the sense resistor is not important, only the actual voltage threshold when calculating the configuration. The voltage thresholds are typical values under room temperature.

### 5.3.5  Autocalibration

The fuel gauge provides an autocalibration feature that measures the voltage offset error across SRP and SRN as operating conditions change. It subtracts the resulting offset error from normal sense resistor voltage, $V_{SR}$, for maximum measurement accuracy.

Autocalibration of the coulomb counter begins on entry to SLEEP mode, except if *Temperature( )* is ≤ 5°C or *Temperature(  )* ≥ 45°C.

The fuel gauge also performs a single offset when:

- The condition of *AverageCurrent( )* ≤ 100 mA
- {voltage change since last offset calibration ≥ 256 mV} or {temperature change since last offset calibration is greater than 8°C for ≥ 60 s}.

Capacity and current measurements continue at the last measured rate during the offset calibration when these measurements cannot be performed. If the battery voltage drops more than 32 mV during the offset calibration, the load current has likely increased; hence, the offset calibration is aborted. The *CONTROL_STATUS [CCA]* bit is set during coulomb counter autocalibration.

## 5.4 Temperature Measurement

The fuel gauge typically measures battery temperature via its TS input to supply battery temperature status information to the fuel gauging algorithm and charger-control sections of the gauge. Alternatively, it can be configured to use an internal on-chip temperature sensor or receive temperature data from the host processor. See Section 2.4, *Temperature( ): 0x06 and 0x07*, for specific information on configuration options. Regardless of which temperature configuration is used, the host processor can request the current battery temperature by reading the *Temperature( )*, and for internal temperature, *InternalTemperature( )*.

The external thermistor circuit requires the use of an 10K NTC 103AT-type thermistor. Additional circuit information for connecting this thermistor to the fuel gauge is shown in Chapter 7, *Reference Schematic*.

### 5.4.1 Overtemperature Indication

#### 5.4.1.1 Overtemperature: Charge

If during charging, *Temperature( )* reaches the threshold of **OT Chg** for a period of **OT Chg Time**, and *AverageCurrent( )* > **Chg Current Threshold**, then the *Flags( ) [OTC]* bit is set. When *Temperature( )* falls to **OT Chg Recovery**, the *Flags( ) [OTC]* bit is cleared.

If **OT Chg Time** = 0, then the feature is completely disabled.

#### 5.4.1.2 Overtemperature: Discharge

If during discharging, *Temperature( )* reaches the threshold of **OT Dsg** for a period of **OT Dsg Time**, and *AverageCurrent( )* ≤ −**Dsg Current Threshold**, then the *Flags( ) [OTD]* bit is set. When *Temperature( )* falls to **OT Dsg Recovery**, the *Flags( ) [OTD]* bit is cleared.

If **OT Dsg Time** = 0, then the feature is completely disabled.

### 5.4.2 Thermistor Override Detection, Maximum Correction Current, and Current Correction Rate

In some system designs, the thermistor used by the fuel gauge may not be inside the battery pack or may be placed close to hot components that might cause the gauge to read temperatures that don't reflect the true battery temperature. Because accurate battery temperature readings are important for optimized gauging, several parameters are introduced to allow for compensation of the temperature readings in certain non-ideal cases. For most system designs where the gauge is accurately measuring the battery cell temperature, these features are not necessary, so **I Correction Rate** should be set to 0.

This feature overrides the thermistor reading by the internal temperature sensor reading if the thermistor reading is outside the preset temperature limit in the Data Flash. The *[T_OR]* flag is triggered if the **OpconfigB [TOVERRD]** bit is set and temperature is greater than the **Thermistor OR Hi** or lower than the **Thermistor OR Low** range. The ranges are:

- **Thermistor OR Hi** range is 0°C to 120°C; default 100°C
- **Thermistor OR Low** range is −120°C to 10°C; default −40°C

### 5.4.3 Maximum Correction Current and Current Correction Rate

**Max Correction I** and **I Correction Rate** correct the internal thermistor sensor based on amount of discharge current. This feature is disabled if the battery is charging.

Compensation temperature formula:

T = T_measured + T_correction
where T_correction = **I Correction Rate** × (abs(Average Current) / **Max Correction I**)

To avoid excessive correction:

If abs(Average Current) > **Max Correction I**, then T_correction = **I Correction Rate**
If Average Current > 0, set T_correction = 0

## 5.5    Charging and Charge—Termination Indication

### 5.5.1   Detecting Charge Termination

For proper fuel gauge operation, the cell **Charging Voltage** must be specified by the user. The default value is specified in Table 4-3, *Data Flash Summary—Configuration Class*.

The fuel gauge detects charge termination when:

- During two consecutive periods of 40 seconds, *the AverageCurrent( ) <* **Taper Current**.
- During the same two periods, the accumulated change in capacity must be > 0.
- *Voltage( ) >* **Charging Voltage – Taper Voltage**.

When this occurs, the *Flags( ) [CHG]* bit is cleared and the *Flags( ) [FC]* bit is set. Also, if the **Op Config [RMFCC]** bit is set, then *RemainingCapacity( )* is set equal to *FullChargeCapacity( )*. This will cause *StateOfCharge( )* to jump to 100%, if not already there.

### 5.5.2   Charge Inhibit and Suspend

The fuel gauge can indicate when battery temperature has fallen below or risen above predefined thresholds **Chg Inhibit Temp Low** or **Chg Inhibit Temp High**, respectively. In this mode, the *Flags( ) [CHG_INH]* bit is set and the GPOUT pin is deasserted to indicate this condition. The *[CHG_INH]* bit is cleared and the GPOUT pin is asserted once the battery temperature returns to the range **[Chg Inhibit Temp Low + Temp Hys, Chg Inhibit Temp High – Temp Hys]**.

When PFC = 1, the fuel gauge indicates when battery temperature has fallen below or risen above predefined thresholds **Suspend Low Temp** or **Suspend High Temp**, respectively. In this mode, the *Flags( ) [XCHG]* bit is set to indicate this condition. The *[XCHG]* bit is cleared once the battery temperature returns to the range **[Chg Inhibit Temp Low + Temp Hys, Chg Inhibit Temp High – Temp Hys]**.

The charging should not start when the temperature is below the **Chg Inhibit Temp Low** or above the **Chg Inhibit Temp High**. The charging can continue if the charging starts inside the window [**Chg Inhibit Temp Low**, **Chg Inhibit Temp High**] until the temperature is either below **Suspend Low Temp** or above the **Suspend High Temp**. Therefore, the window [**Chg Inhibit Temp Low**, **Chg Inhibit Temp High**] must be inside the window of [**Suspend Low Temp**, **Suspend High Temp**].

## 5.6 Power Modes

The fuel gauge has different power modes: BAT INSERT CHECK, NORMAL, SNOOZE, SLEEP, and HIBERNATE. In NORMAL mode, the fuel gauge is fully powered and can execute any allowable task. In SNOOZE mode, both low-frequency and high-frequency oscillators are active. Although the SNOOZE mode has higher current consumption than the SLEEP mode, it is also a reduced-power mode. In SLEEP mode, the fuel gauge turns off the high-frequency oscillator and exists in a reduced-power state, periodically taking measurements and performing calculations. In HIBERNATE mode, the fuel gauge is in a low-power state, but can be woken up by communication or certain IO activity. Finally, the BAT INSERT CHECK mode is a powered up, but low-power halted, state, where the fuel gauge resides when no battery is inserted into the system.

Figure 5-1 and Figure 5-2 show the relationship between these modes.
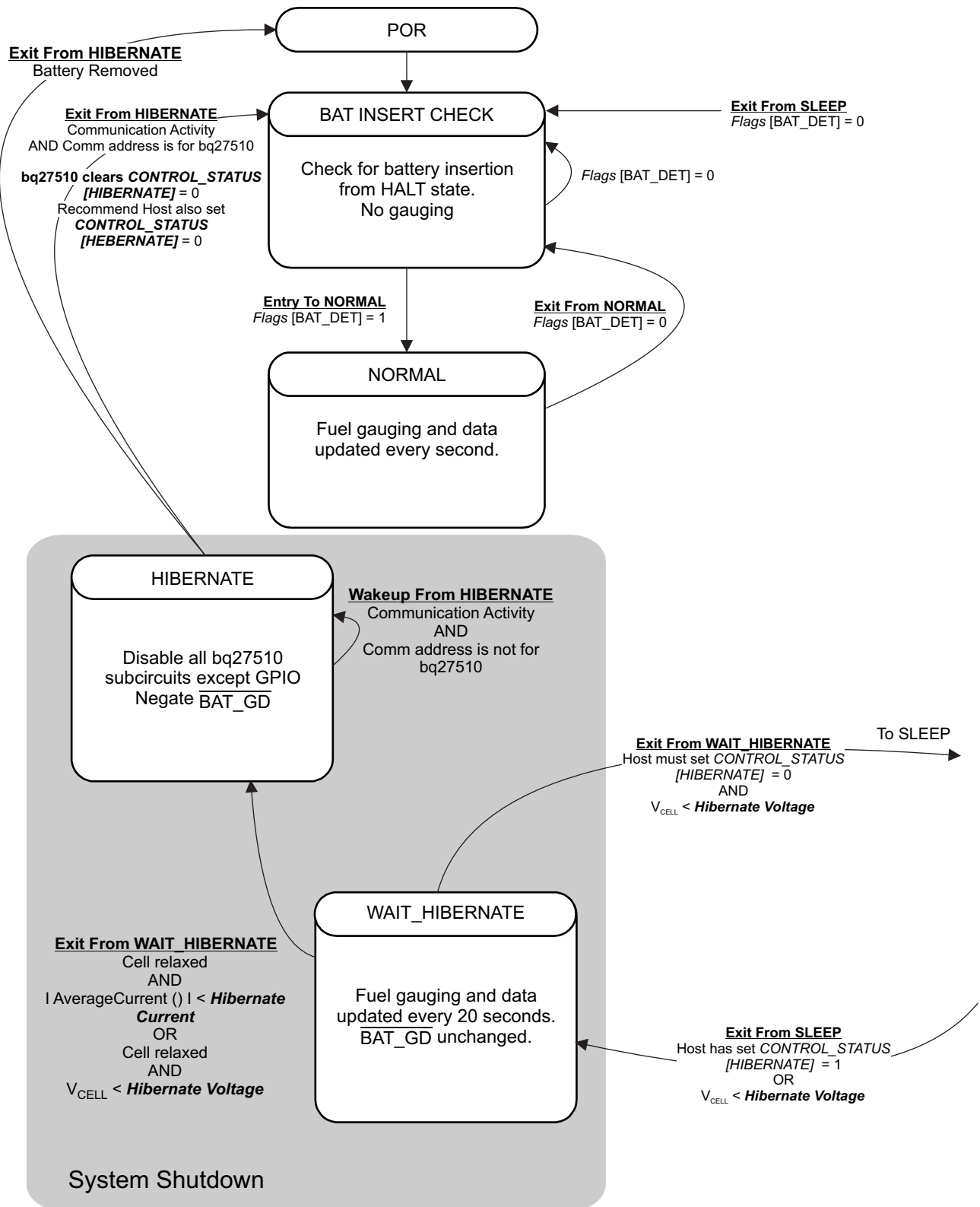
**Figure 5-1. Power Mode Diagram for System Shutdown**
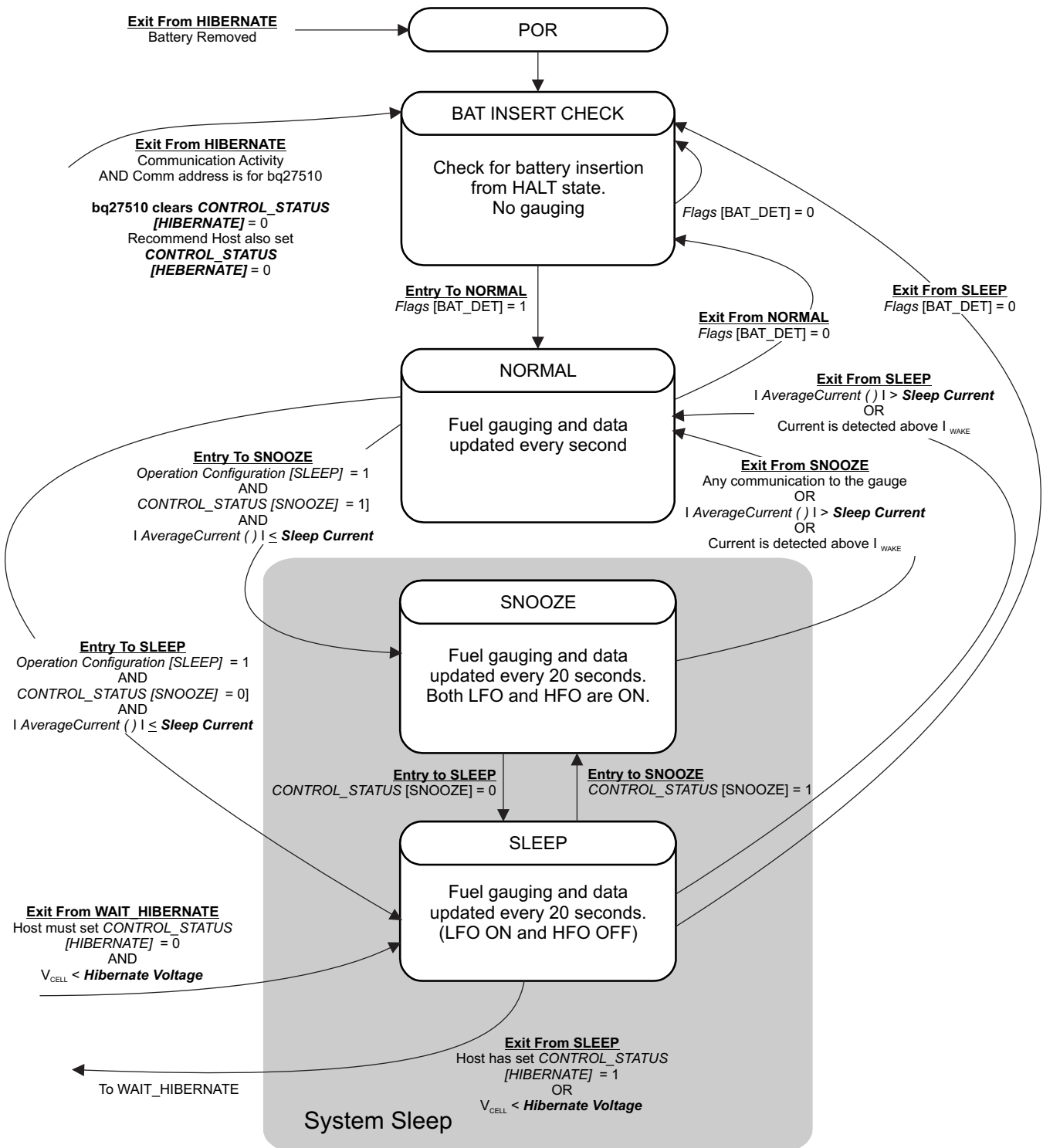
**Figure 5-2. Power Mode Diagram for System Sleep**

### 5.6.1 BAT INSERT CHECK Mode

This mode is a halted-CPU state that occurs when an adapter, or other power source, is present to power the fuel gauge (and system), yet no battery has been detected. If enabled via the **OpConfig B [BIE]** bit, the fuel gauge detects battery insertion either through use of the thermistor network or the BI/TOUT pin. Alternatively, the host can use the *BAT_INSERT* or *BAT_REMOVE* subcommand to inform the battery presence or removal status, if **OpConfig B [BIE]** is cleared. When battery insertion is detected, a series of initialization activities begin which include: OCV measurement, setting the GPOUT pin, and selecting the appropriate battery profiles.

Some commands, issued by a system processor, can be processed while the fuel gauge is halted in this mode. The gauge wakes up to process the command, then returns to the halted state awaiting battery insertion.

### 5.6.2 NORMAL Mode

The fuel gauge is in NORMAL mode when not in any other power mode. During this mode, *AverageCurrent( )*, *Voltage( )*, and *Temperature( )* measurements are taken, and the interface data set is updated. Decisions to change states are also made. This mode is exited by activating a different power mode.

Because the gauge consumes the most power in the NORMAL mode, the Impedance Track™ algorithm minimizes the time the fuel gauge remains in this mode.

### 5.6.3 SLEEP Mode

SLEEP mode is entered automatically if the feature is enabled (**Op Config [SLEEP]** bit = 1) and *AverageCurrent( )* is below the programmable level **Sleep Current**. Once entry into SLEEP mode has been qualified, but before entering it, the fuel gauge performs a coulomb counter autocalibration to minimize offset.

During SLEEP mode, the fuel gauge periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The fuel gauge exits the SLEEP mode if any entry condition is broken, specifically when either:

- *AverageCurrent( )* rises above **Sleep Current**.
- A current in excess of $I_{WAKE}$ through $R_{SENSE}$ is detected.

In the event that a battery is removed from the system while a charger is present (and powering the gauge), Impedance Track™ updates are not necessary. Hence, the fuel gauge enters a state that checks for battery insertion and does not continue executing the Impedance Track™ algorithm.

### 5.6.4 SNOOZE Mode

Compared to the SLEEP mode, the SNOOZE mode has the high-frequency oscillator in operation, hence the communication delay associated with waking up from SLEEP mode can be eliminated. The SNOOZE mode is entered automatically if the feature is enabled (*CONTROL_STATUS [SNOOZE]* bit = 1) and *AverageCurrent( )* is below the programmable level **Sleep Current**.

During SNOOZE mode, the fuel gauge periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The fuel gauge exits the SNOOZE mode if any entry condition is broken, specifically when:

- Any communication activity with the gauge.
- *AverageCurrent( )* rises above **Sleep Current**.
- A current in excess of $I_{WAKE}$ through $R_{SENSE}$ is detected.

### 5.6.5 HIBERNATE Mode

The HIBERNATE mode should be used when the system equipment needs to enter a low-power state, and minimal gauge power consumption is required. This mode is ideal when system equipment is set to its own HIBERNATE, SHUTDOWN, or OFF mode.

For normal entry to the HIBERNATE mode, the system must set the *CONTROL_STATUS [HIBERNATE]* bit by issuing a *SET_HIBERNATE* subcommand. The gauge does not enter the HIBERNATE mode until a valid OCV measurement is made and the magnitude of the average cell current has fallen below **Hibernate I**. Regardless of the *CONTROL_STATUS [HIBERNATE]* bit status, the gauge can also enter the HIBERNATE mode if *Voltage( )* falls below **Hibernate V** and a valid OCV measurement has been taken. The gauge remains in the HIBERNATE mode until the system issues a direct I$^2$C command to the gauge or a POR occurs. I$^2$C communication that is not directed to the gauge does not wake the gauge.

For proper system-level coordination of the HIBERNATE mode with the use of a charger IC, see Table 5-9, *Pin Function Code Descriptions.* It is important to prevent a charger from inadvertently charging the battery before an OCV reading can be taken. It is the responsibility of the system to wake the fuel gauge after it has gone into the HIBERNATE mode. After waking, the gauge can proceed with the initialization of the battery information (OCV, profile selection, and so forth).

## 5.7 Application-Specific Information

### 5.7.1 Battery Profile Storage and Selection

The fuel gauge supports only one type of battery profile. This profile is stored in both the **Def0** and **Def1** profiles. When a battery pack is inserted for the first time, the default profile is copied into the **Packn** profiles. Then the Impedance Track™ algorithm begins gas gauging, regularly updating **Packn** as the battery is used.

In addition to the default profiles, the fuel gauge maintains two profiles: PACK0 and PACK1. These tables hold dynamic battery data, and keep track of the status for up to two of the most recent batteries used. In most cases, the fuel gauge can manage the information on two removable battery packs. When a battery pack is removed from host equipment, the fuel gauge maintains some of the battery information in case the battery is re-inserted. This way, the Impedance Track™ algorithm has a means of recovering battery-status information, thereby maintaining good state-of-charge (SOC) estimates.

When an existing pack is removed from the fuel gauge and a different (or same) pack is inserted, cell impedance is measured immediately after battery detection (see Section 5.7.2, *First OCV and Impedance Measurement*). The fuel gauge chooses the profile which is closest to the measured impedance, starting with the **Packn** profiles. That is, if the measured impedance matches **Pack0**, then the **Pack0** profile is used. If the measured impedance matches **Pack1**, then the **Pack1** profile is used. If the measured impedance does not match the impedance stored in either **Pack0** or **Pack1**, the battery pack is deemed new (none of the previously used packs). Either **Def0 or Def1** profile is copied into either the **Pack0** or **Pack1** profile, overwriting the oldest **Packn** profile.

#### 5.7.1.1 Reading Application Status

The **Application Status** data flash location contains cell profile status information, and can be read using the *ApplicationStatus( )* extended command (0x6A). The bit configuration of this function or location is shown in Table 5-12.

**Table 5-12. ApplicationStatus( ) Bit Definitions**

| Application Configuration | bit7 | bit6 | bit5 | bit4 | bit3 | bit2 | bit1 | bit0 |
|---|---|---|---|---|---|---|---|---|
| Byte | — | — | — | — | — | — | UNSUPBAT | LU_ PROF |

UNSUPBAT = Indicating inserted battery is not supported in the current cell profiles.

LU_PROF = Last profile used by fuel gauge. *Cell0* last used when cleared. *Cell1* last used when set. Default is 0.

### 5.7.2 First OCV and Impedance Measurement

Upon power-up or pack insertion, an open-circuit voltage (OCV) measurement of the battery is made via the BAT pin. For best gauging results, the system load during the OCV measurement should not exceed a C/20 discharge rate of the battery. For this first critical measurement, the GPOUT pin is available for system synchronization. (See Section 5.3.2.2, *Power Path Control With the GPOUT Pin*, Section 5.3.2.3, *SOC_INT Function Behavior*, and Section 2.1.6, *OCV_CMD: 0x000C*.)

Upon completion of the OCV voltage measurement, the *CONTROL_STATUS [OCVCMDCOMP]* is set. Table 4-6, *Data Flash Summary—OCV Table*, and the first OCV voltage measurement determine the initial SOC of the inserted battery, while impedance is computed from subsequent voltage and current samples under load using:

$$Z(SOC) = ( OCV(SOC) - V ) / I.$$

This impedance is compared with the impedance of the dynamic profiles, **Packn**, and the default profiles, **Defn**, for the same SOC. Following all initialization functions, the *CONTROL_STATUS [INITCOMP]* bit is set.

## 5.8 Additional Data Flash Parameter Descriptions

### 5.8.1 TCA Set %

**TCA Set %** is the Terminate Charge Alarm Set Percentage threshold. **TCA Set %** sets a *StateOfCharge( )* percentage threshold at which the *Flags( ) [CHG]* bit is cleared. When **TCA Set %** is set to −1, it disables the use of the charge alarm threshold. When **TCA Set %** is set to −1 and the taper condition is detected, the *[CHG]* bit is cleared.

**TCA Set %** only affects the *[CHG]* bit but does not affect the charge termination process nor the gauging function. The default value is set to 99%.

### 5.8.2 TCA Clear %

**TCA Clear %** is the Terminate Charge Alarm Clear Percentage threshold. **TCA Clear %** sets a *StateOfCharge( )* percentage level at which the *Flags( ) [CHG]* bit is set.

**TCA Clear %** only affects the *[CHG]* bit but does not affect the charge termination process nor the gauging function. The default value is set to 95%.

### 5.8.3 FC Set %

**FC Set %** is the Full Charge Set Percentage threshold. **FC Set %** sets a *StateOfCharge( )* percentage threshold at which the *Flags( ) [FC]* bit is set. When **FC Set %** is a value other than −1, the *[FC]* bit is set based on the amount of passed charge detected by the gauge and not charge termination detection. If **FC Set %** is set to −1, the *[FC]* bit is set based on charge termination detection (see **Taper Current** and **Taper Voltage** in Section 5.5.1).

**FC Set %** only affects the *[FC]* bit which does not affect the charge termination process. The default value is set to 100%.

### 5.8.4 FC Clear %

**FC Clear %** is the Full Charge Clear Percentage threshold. **FC Clear %** sets a *StateOfCharge( )* percentage threshold at which the *Flags( ) [FC]* bit is cleared.

**FC Clear %** only affects the *[FC]* bit register which does not affect the charge termination process. The default value is set to 98%.

### 5.8.5 DOD at EOC Delta Temperature

This represents the temperature change threshold to update $Q_{start}$ and *RemainingCapacity( )* due to temperature changes. During relaxation and at the start of charging, the remaining capacity is calculated as *RemainingCapacity( ) = FullChargeCapacity( ) –* $Q_{start}$. As temperature decreases, $Q_{start}$ can become much smaller than that of the old *FullChargeCapacity( )* value, resulting in overestimation of *RemainingCapacity( )*. To improve accuracy, *FullChargeCapacity( )* is updated whenever the temperature change since the last *FullChargeCapacity( )* update is greater than **DODatEOC Delta T** × 0.1ºC.

The default value is 50. Note that the units are a tenth of a °C which means a value of 50 corresponds to 5ºC.

### 5.8.6 Default Temperature

This is the temperature used to initialize the *Temperature( )* register until the host writes a different value if the **OpConfig B [WRTEMP]** bit is set. If **OpConfig B [WRTEMP]** is not set, then **Default Temperature** is not used.

### 5.8.7 Device Name

This is string data that can be a maximum of 7 characters. This field does not affect the operation, nor is it used by the part. It is read by using the extended data command: *DeviceName( )* (0x63 through 0x69).

### 5.8.8 Data Flash Version

This location can be used to store the data flash configuration version. Version control of golden flash files used in production is recommended. It is read without having to unseal the gauge by using the *Control( )* subcommand, *DF_VERSION*. This is accomplished by writing 0x001F to registers 0x00 through 0x01 and then reading the result from 0x00 through 0x01. The default value is 0x0000.

### 5.8.9 SOC1 Set Threshold

**SOC1 Set Threshold** sets a *StateOfCharge( )* percentage threshold used to indicate when *StateOfCharge( )* falls to or below a defined *StateOfCharge( )*. The **SOC1 Set Threshold** is typically used as an initial low *StateOfCharge( )* warning. When *StateOfCharge( )* falls below the **SOC1 Set Threshold**, the State of Charge Initial *[SOC1]* bit in the *Flags( )* register is set. The *[SOC1]* bit is cleared once *StateOfCharge( )* rises above the **SOC1 Clear Threshold**. If **SOC1 Set Threshold** is set to –1, then the *[SOC1]* bit becomes inoperative.

The default value is set to 10%.

### 5.8.10 SOC1 Clear Threshold

**SOC1 Clear Threshold** sets a *StateOfCharge( )* percentage threshold used to indicate when *StateOfCharge( )* rises above a defined *StateOfCharge( )*. When *StateOfCharge( )* rises above the **SOC1 Clear Threshold**, the State of Charge Initial *[SOC1]* bit in the *Flags( )* register is cleared.

**SOC1 Clear Threshold** is normally set to 5% above the **SOC1 Set Threshold**. The default value is set to 15%.

### 5.8.11 Final Voltage and Final Volt Time

If *Voltage( )* is below **Terminate Voltage** for at least **TermV Valid Time** (in seconds), then *RemainingCapacity( )* and *StateOfCharge( )* are forced to 0. **Final Voltage** is usually set to the same value as **Terminate Voltage**.

### 5.8.12 Def Avg I Last Run and Def Avg P Last Run

These parameters are not used in the fuel gauge.

### 5.8.13   Max Res Factor

Maximum percentage (ratio) that an impedance value stored in the Ra table is allowed to change in a single update in the positive direction.

The default setting is 15. The algorithm divides the value of this parameter by 10. The upper bound is determined by multiplying (*Max Res Factor* / 10) by the impedance value stored in the Ra table. Therefore, a value of 15 indicates resistance can only change by 50% from the current resistance value in the positive direction.

### 5.8.14   Min Res Factor

Maximum percentage (ratio) that an impedance value stored in the Ra table is allowed to change in a single update in the negative direction.

The default setting is 5. The algorithm divides the value of this parameter by 10. The lower bound is determined by multiplying (*Min Res Factor* / 10) by the impedance value stored in the Ra table. Therefore, a value of 5 indicates resistance can only change by 50% from the current resistance value in the negative direction.

### 5.8.15   Ra Filter

Ra table updates are filtered. This is a weighting factor which takes a certain percentage of the previous Ra table value and the remaining percentage comes from the newest calculated Ra value. This is to prevent resistances in the Ra table from changing quickly. After this filter has been applied, there is a final check to make sure that the new resistances satisfy both *Max Res Factor* and *Min Res Factor*.

It is normally set to 800 (80% previous Ra value plus 20% learned Ra value to form new Ra value).

### 5.8.16   ResRelax Time

This value is used for Impedance Track™ transient modeling of effective resistance. The resistance increases from zero to final value determined by the Ra table as defined by the exponent with time constant *ResRelax Time* during discharge simulation. Default value has been optimized for typical cell behavior, but could be increased if the gauge is being too conservative at low temperature.

### 5.8.17   Max Sim Rate, Min Sim Rate

Maximum and minimum limits for current used in simulation runs. The parameters are functions of *DesignCapacity( )* (that is, C/*Max Sim Rate* or C/*Min Sim Rate*).

### 5.8.18   Transient Factor Charge and Discharge

When a battery is inserted and the system is powering up, it is possible that current may be flowing at the same time the gauge is initializing the SOC based on a voltage measurement. The gauge compensates for this current flow but the amount of compensation can be adjusted by changing the values of these data flash parameters. For most cases, the default values are recommended.

### 5.8.19   Max IR Correct

The *Max IR Correct* is a maximum IR correction applied to OCV lookup under load. It only applies to OCV lookup after wakeup with detected charge current when gauge needs to establish capacity baseline, but the current is already flowing.

### 5.8.20   Thermal Modeling

At low temperatures the gauge could be overly conservative if it assumes the low temperature will persist. In fact, most systems will self-heat during operation. These thermal modeling parameters can be adjusted to predict the self-heating.

The *T Rise* constant reflects the level of system heating due to self-heating of the cell during discharge. This number can be measured empirically. It can be adjusted also through experimentation. In general, it can be increased if the gauge is too conservative at low temperature.

*T Time Constant* reflects the time constant of system heating due to self-heating of the cell during discharge. This number can be measured empirically. It can be adjusted also through experimentation. In general, it can be decreased if the gauge is too conservative at low temperature.

## 5.8.21 Cell 0 and 1 V at Chg Term

Records the voltage reading at the full charge taper termination. This voltage is used to calculate DODatEOC. Essentially this register is updated automatically to learn the true full level of the system or charger.

## 5.8.22 Calibration Parameters

Most of the following values never require direct modification by the user. They are usually only modified by using the calibration plug-ins in the graphical user interface (GUI). For details about how to perform calibration using a host system, see *Host System Calibration Method* (SLUA640).

The recommended flow for production calibration is to use the GUI to perform voltage and current calibration on a representative sample of production boards, then use the average values for *Pack V Offset*, *Board Offset*, *CC Gain*, and *CC Delta* in the golden file that is programmed into all ICs during production. This way, individual calibration is not required for every system during production. Calibration of *CC Offset* and *Board Offset* should be performed before calibrating *CC Gain* and *CC Delta*.

### CC Gain and CC Delta

This is the gain factor for calibrating sense resistor, trace, and internal Coulomb Counter (integrating ADC delta-sigma) errors. It is used in the algorithm that reports charge in and discharge out of the battery through the *RemainingCapacity( )* register. The difference between *CC Gain* and *CC Delta* is that the algorithm that reports *AverageCurrent( )* cancels out the time base because *AverageCurrent( )* does not have a time component (it reports in mA) and *CC Delta* requires a time base for reporting *RemainingCapacity( )* (it reports in mAh).

### CC Offset

Two offsets are used for calibrating the offset of the internal Coulomb Counter, board layout, sense resistor, copper traces, and other offsets from the Coulomb Counter readings. *CC Offset* is the calibration value that primarily corrects for the offset error of the Coulomb Counter circuitry. The other offset calibration is *Board Offset* and is described next. To minimize external influences when doing *CC Offset* calibration by automatic *CC Offset* calibration or *CC Offset* calibration function in Calibration Mode, an internal short is placed across the SRP and SRN pins inside the fuel gauge. *CC Offset* is a correction for small noise and errors; therefore, to maximize accuracy, it takes about 20 seconds to calibrate the offset. Because it is impractical to do a 20-second offset during production, two different methods have been selected for calibrating *CC Offset*.

(A) The first method is to calibrate *CC Offset* by putting the fuel gauge in Calibration mode and initiating the *CC Offset* function as part of the entire calibration suite. See the application note: *Going to Production with the bq275xx* (SLUA449) for more information on the Calibration mode. This is a short calibration that is not as accurate as the second method, *Board Offset*. Its primary purpose is to calibrate *CC Offset* enough so that it does not affect any other Coulomb Counter calibrations. This is only intended as a temporary calibration because the automatic calibration, *Board Offset*, is done the first time the I$^2$C data and clock lines are low for more than 20 seconds, which is a much more accurate calibration.

(B) During normal Gas Gauge Operation when the I$^2$C clock and data lines are low for more than 5 seconds and *AverageCurrent( )* is less than *Sleep Current* in mA, then an automatic *CC Offset* calibration is performed. This takes approximately 16 seconds and is much more accurate than the method in Calibration mode.

### Board Offset

*Board Offset* is the second offset register. Its primary purpose is to calibrate everything the *CC Offset* does not calibrate. This includes board layout, sense resistor, copper trace, and other offsets which are external to the fuel gauge chip.

### Int Temp Offset

The fuel gauge has a temperature sensor built into the IC. The **Int Temp Offset** is used for calibrating offset errors in the measurement reported in the *InternalTemperature( )* register, as well as in the *Temperature( )* register if the gauge is configured to use the internal temperature sensor for gauging. The gain of the internal temperature sensor is accurate enough that a calibration for gain is not required.

### Ext Temp Offset

**Ext Temp Offset** is for calibrating the offset of the thermistor connected to the TS pin as reported by *Temperature( )*. The gain of the thermistor is accurate enough that a calibration for gain is not required.

### Pack V Offset

**Pack V Offset** is a calibration value that is used to correct for any offset relating to the analog-to-digital converter (ADC) cell voltage measurement.

# Communications

## 6.1 I²C Interface

The bq27510-G3 fuel gauge supports the standard I²C read, incremental read, quick read, one byte write, and incremental write functions. The 7-bit device address (ADDR) is the most significant 7 bits of the hex address and is fixed as 1010101. The first 8-bits of the I²C protocol is, therefore, 0xAA or 0xAB for write or read, respectively.



(S = Start, Sr = Repeated Start, A = Acknowledge, N = No Acknowledge, and P = Stop).

The "quick read" returns data at the address indicated by the address pointer. The address pointer, a register internal to the I²C communication engine, increments whenever data is acknowledged by the fuel gauge or the I²C master. "Quick writes" function in the same manner and are a convenient means of sending multiple bytes to consecutive command locations (such as two-byte commands that require two bytes of data)

The following command sequences are not supported:

Attempt to write a read-only address (NACK after data sent by master):
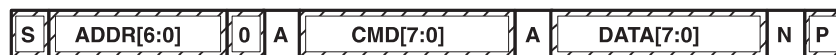


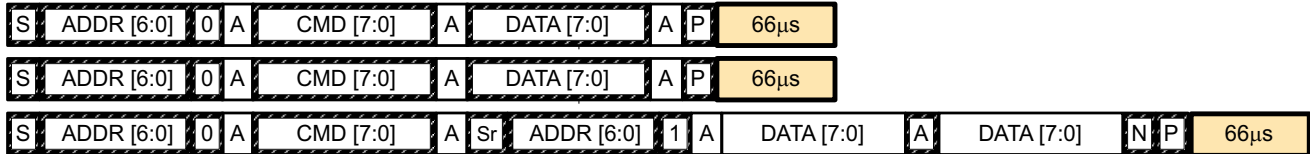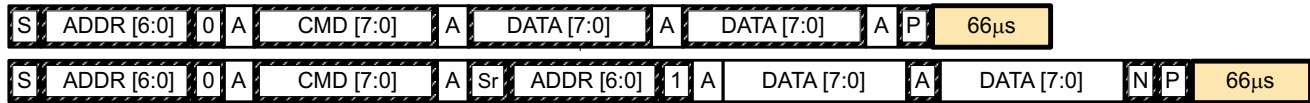Attempt to read an address above 0x6B (NACK command):



## 6.2 I²C Time Out

The I²C engine releases both SDA and SCL if the I²C bus is held low for 2 seconds. If the fuel gauge was holding the lines, releasing them frees them for the master to drive the lines. If an external condition is holding either of the lines low, the I²C engine enters the low-power sleep mode.

## 6.3 I²C Command Waiting Time

To ensure proper operation at 400 kHz, a $t_{(BUF)} \geq 66$ µs bus free waiting time must be inserted between all packets addressed to the fuel gauge. In addition, if the SCL clock frequency ($f_{SCL}$) is > 100 kHz, use individual 1-byte write commands for proper data flow control. The following diagram shows the standard waiting time required between issuing the control subcommand and the reading the status result. An *OCV_CMD* subcommand requires 1.2 seconds before reading the result. For read-write standard command, a minimum of 2 seconds is required to get the result updated. For read-only standard commands, there is no waiting time required, but the host should not issue all standard commands more than two times per second. Otherwise, the fuel gauge could result in a reset issue due to the expiration of the watchdog timer.

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | DATA [7:0] | A | P | 66µs |

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | DATA [7:0] | A | P | 66µs |

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | Sr | ADDR [6:0] | 1 | A | DATA [7:0] | A | DATA [7:0] | N | P | 66µs |

Waiting time inserted between two 1-byte write packets for a subcommand and reading results
(required for 100 kHz < $f_{SCL} \leq$ 400 kHz)

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | DATA [7:0] | A | DATA [7:0] | A | P | 66µs |

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | Sr | ADDR [6:0] | 1 | A | DATA [7:0] | A | DATA [7:0] | N | P | 66µs |

Waiting time inserted between incremental 2-byte write packet for a subcommand and reading results
(acceptable for $f_{SCL} \leq$ 100 kHz)

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | Sr | ADDR [6:0] | 1 | A | DATA [7:0] | A | DATA [7:0] | A |
| DATA [7:0] | A | DATA [7:0] | N | P | 66µs |

Waiting time inserted after incremental read

## 6.4 I²C Clock Stretching

A clock stretch can occur during all modes of fuel gauge operation. In SLEEP and HIBERNATE modes, a short clock stretch occurs on all I²C traffic as the device must wake-up to process the packet. In the other modes (BAT INSERT CHECK, NORMAL, SNOOZE) clock stretching only occurs for packets addressed for the fuel gauge. The majority of clock stretch periods are small as the I²C interface performs normal data flow control. However, less frequent yet more significant clock stretch periods may occur as blocks of Data Flash are updated. The following table summarizes the approximate clock stretch duration for various fuel gauge operating conditions.

| Gauging Mode | Operating Condition or Comment | Approximate Duration |
|---|---|---|
| SLEEP HIBERNATE | Clock stretch occurs at the beginning of all traffic as the device wakes up. | 5 ms |
| BAT INSERT CHECK, NORMAL, SNOOZE | Clock stretch occurs within the packet for flow control (after a start bit, ACK or first data bit). | 100 µs |
| | Normal Ra table Data Flash updates. | 24 ms |
| | Data Flash block writes. | 72 ms |
| | Restored Data Flash block write after loss of power. | 116 ms |
| | End of discharge Ra table Data Flash update. | 144 ms |

# Reference Schematic
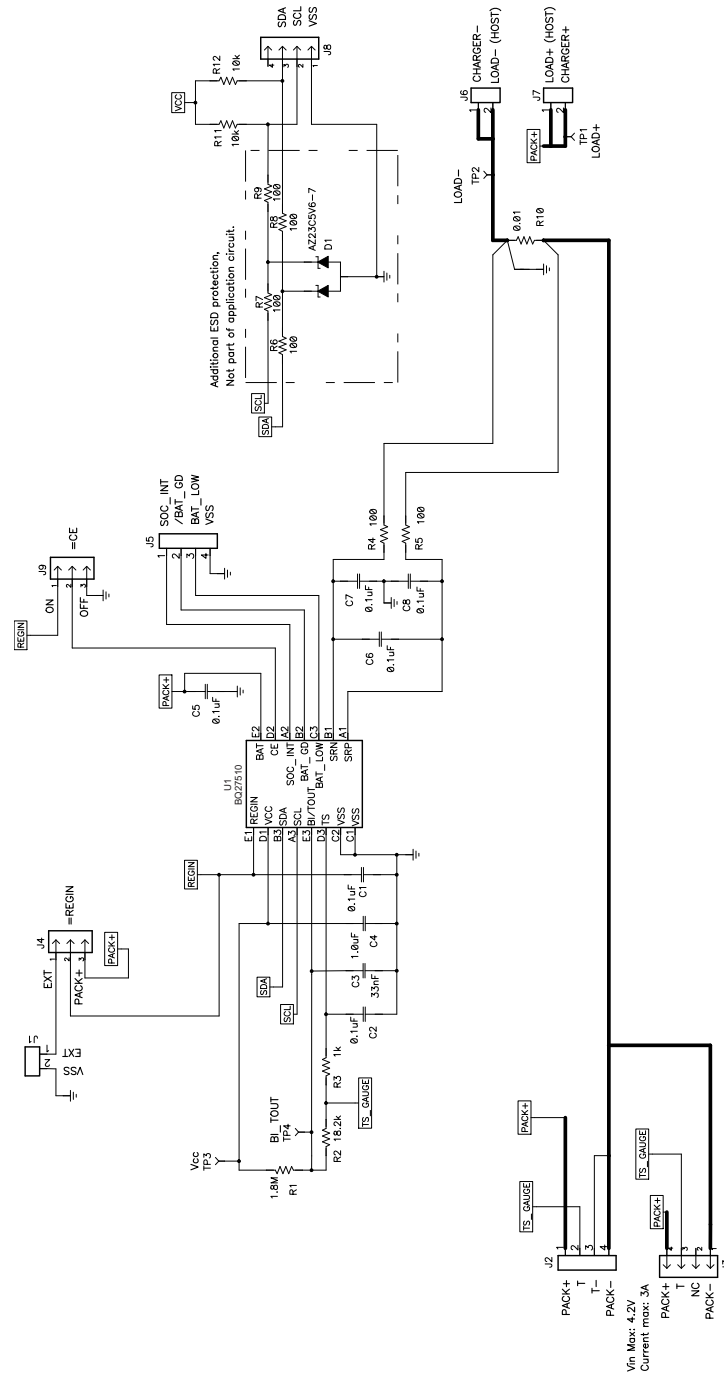


**Figure 7-1. Reference Schematic**

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# *Open-Circuit Voltage Measurement Background*

The accuracy of the Impedance Track™ (IT) algorithm strongly depends on the accuracy and validity of the open-circuit voltage (OCV) measurement taken by fuel gauges that are based on IT technology. This appendix describes the process of taking OCV measurements during different events.

## A.1 Background

- **OCV Calculation:** OCV (open-circuit voltage) is normally a calculated value because a true measurement of OCV requires an unloaded and relaxed condition on the battery. Because such an unloaded and completely relaxed condition is not always possible in a real system, the fuel gauge uses measured voltage, current, and temperature (VIT) to compute the OCV and as a result of this calculation, the state of charge (SOC) of the battery is established or reestablished.

- **OCV Qualification Time (QT):** The time in which SOC_INT is asserted during an OCV measurement is approximately 165 ms. This is the timeframe in which we test if the VIT measurement is qualified for an OCV calculation. This is not the timeframe in which the actual VIT measurement is taken. During this time, the instantaneous current (adci) is measured. If abs(adci) ≥ DesignCapacity/18, then the OCVFail bit is set. Otherwise, the VIT that we have just measured is qualified and the gauge proceeds with OCV calculation.

- **Current Measurement Time (CMT):** The time of current is measured – 1 s.

- **Voltage Measurement Time (VMT):** The time of voltage is measured – 125 ms.

- **Temperature Measurement Time (TMT):** The time of temperature is measured – 125 ms.

### A.1.1 OCV Qualification and Calculation

OCV qualification and calculation (**QC**) happens under two conditions:

- OCV_CMD is sent by the host.
- Battery Insert (**BI**) event is detected.

> **NOTE:** POR causes an immediate BI.

### A.1.2 OCV Calculation Assumption

The current, voltage, and temperature must remain stable during QT, CMT, VMT, and TMT. In every case that stable VIT is mentioned, the desired stable condition for current is <C/20. If this is not true, error can be introduced into the OCV Calculation.

### A.1.3 OCV Timing

The timing of each step in the OCV sequence is shown in Figure A-1.

1. After a POR, voltage, current, and temperature are measured before updating the fuel gauge parameters.
2. Quick voltage and current measurements are taken to qualify OCV VIT conditions.
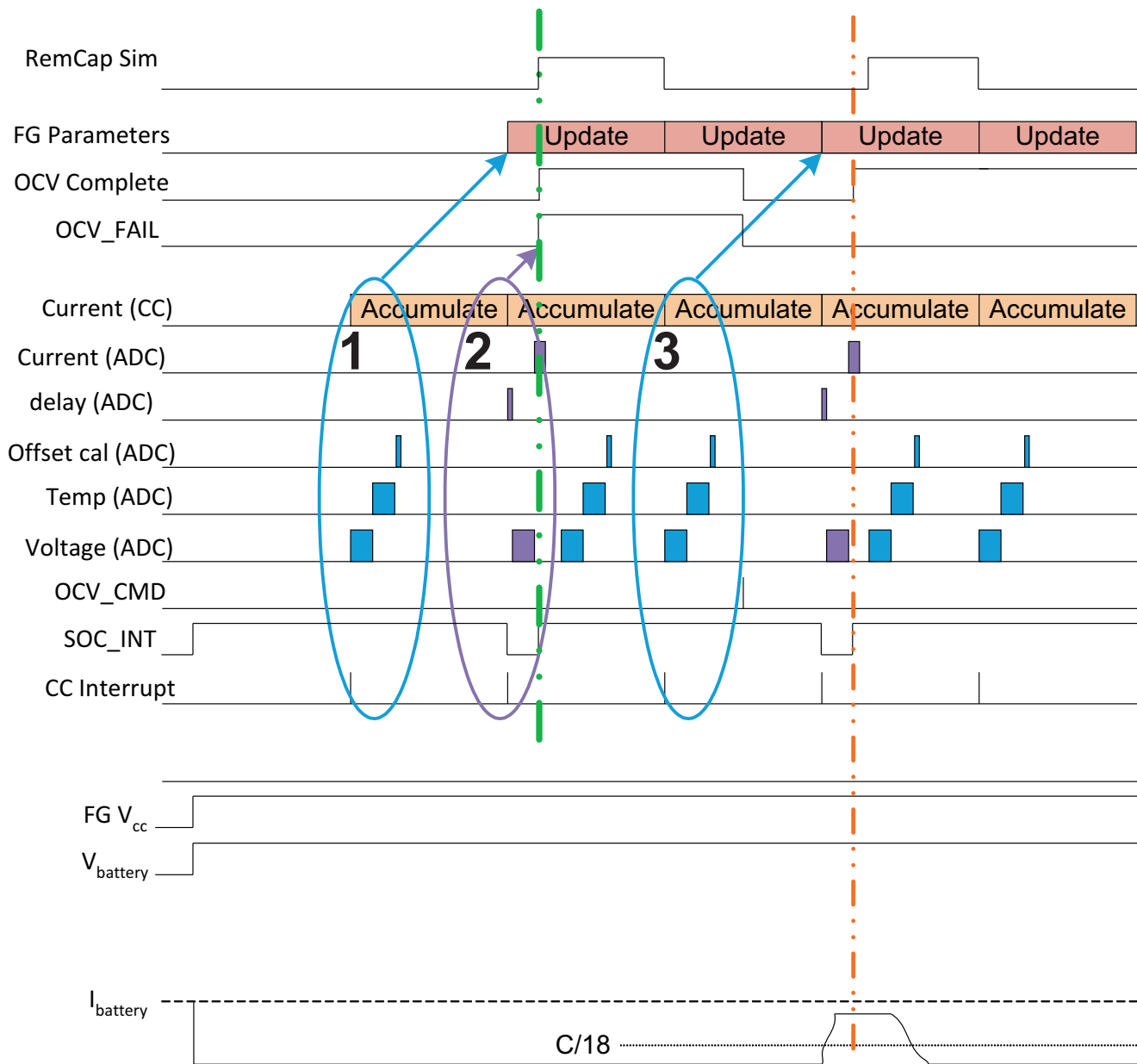3. Voltage, current, and temperature are measured for subsequent fuel gauge parameters updates.

**Figure A-1. OCV Timing Sequences**

The green dashed lines indicate the completion of an OCV measurement that has failed due to high load detected in current (ADC) measurement, whereas the orange dashed lines indicate the completion of a successful OCV measurement, given that the load at the time of measurement was below C/18 rate.

The second OCV measurement (orange line) is a success by qualification standard. However, this is not the recommended-use case because the current is only lowered during the OCV_INT time (the qualification time). This makes the fuel gauge respond as if this were a pass condition; however, the actual result is not good because the actual VIT measurement used for OCV was taken under high load.

## A.2  OCV Timing and OCV_CMD Use Recommendations

### A.2.1  ACTIVE Mode (Fuel Gauge is not in SLEEP Mode)

The VIT measurement used for the OCV calculation is the last VIT measured before the OCV_CMD was received. The VIT value used for the OCV calculation needs to be a stable, not transient value. Before sending the OCV_CMD, the current must be stable and <C/20 for at least one second. The recommendations for the OCV_CMD used for active mode is that the VIT remains stable from two seconds before the OCV_CMD is sent until the end of SOC_INT (see Figure A-2).
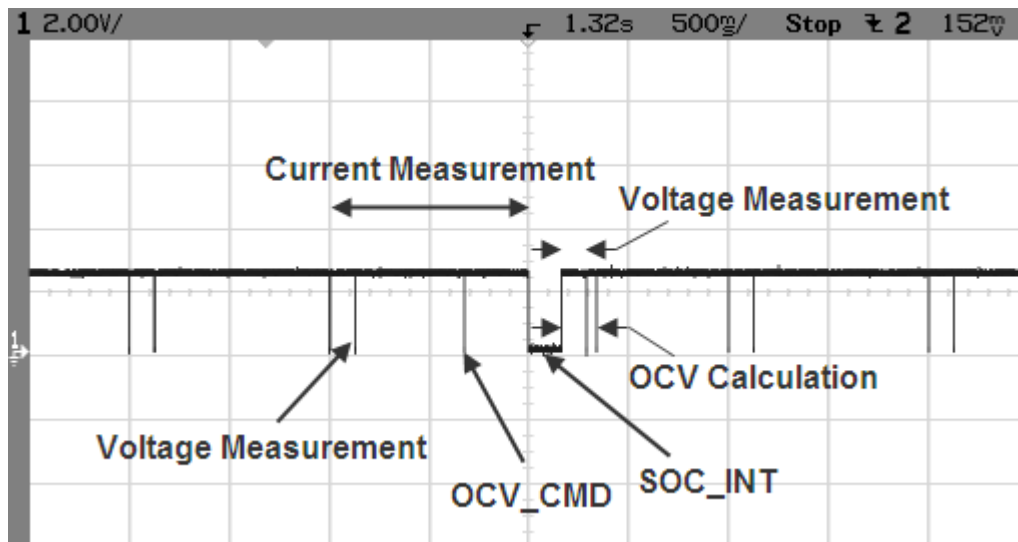


**Figure A-2. OCV Calculation Based on OCV Command**

### A.2.2  SLEEP Mode

In SLEEP mode, the fuel gauge measures VIT every 20 s, instead of 1 s. The VIT measurement used for the OCV calculation is the last VIT measured before the OCV_CMD was received. Sleep current is usually below the OCV current-fail threshold. So, the recommendations for the OCV_CMD sent during SLEEP mode is that the VIT remains stable and below the sleep threshold from the time OCV_CMD is sent until the end of SOC_INT.

### A.2.3  Initial OCV – POR

During POR, the VIT measurement used for the OCV calculation and qualification takes place between about 300 ms after POR until the end of SOC_INT. To achieve a good initial OCV measurement after POR, the recommendation is to keep VIT stable from POR until the end of SOC_INT (see Figure A-3).
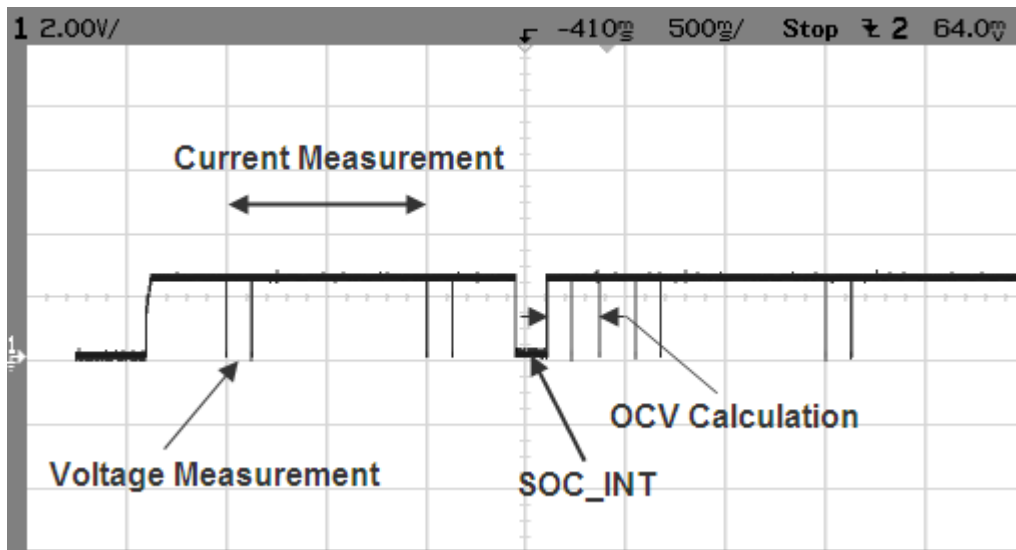
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**Figure A-3. Initial OCV Taken After POR**

# *Glossary*

| | |
|---|---|
| ACK | Acknowledge character |
| ADC | Analog-to-digital converter |
| BCA | Board calibration |
| BI | Battery insert |
| C Rate | C rate corresponds to discharge current that will discharge the battery in one hour, which is equal to full capacity of the battery in mAh. |
| CC | Coulomb counter |
| CCA | Coulomb counter calibration |
| CE | Chip enable |
| Charge Mode | Refers to a mode to where the gauge read *AverageCurrent( )* > **Chg Current Threshold** for at least 1 second. |
| Clear | Refers to a bit in a register becoming a logic LOW or 0. The bqEvaluation software (EVSW) represents a clear bit with the color green. |
| cWh | Centiwatt-hour |
| DF | Data flash |
| Discharge Mode | Refers to a mode where the gauge read *AverageCurrent( )* < (–)**Dsg Current Threshold** for at least 1 second. |
| DOD | Depth of discharge in percent as related to Qmax. 100% corresponds to empty battery. |
| DOD0 | Depth of discharge that was looked up in the DOD (OCV) table based on OCV measurement in relaxed state. |
| EOC | End-of-charge |
| FC | Fully charged |
| FCC | Full charge capacity. Total capacity of the battery compensated for present load current, temperature, and aging effects (reduction in chemical capacity and increase in internal impedance). |
| FIFO | First in, first out |
| Flag | This word usually represents a read-only status bit that indicates some action has occurred or is occurring. This bit typically cannot be modified. The flags are set and cleared automatically by the fuel gauge. |
| FVCA | Fast voltage and current acquisition |
| GPIO | General-purpose input output |
| HDQ | High-speed data queue |
| IC | Integrated circuit |
| ID | Identification |
| IO | Input or output |
| IT | Impedance Track™ |
| $I^2C$ | Inter-integrated circuit. The $I^2C$ interface is composed of a programmable serial clock (SCL) and a serial data bus (SDA). |
| LDO | Low dropout |
| LSB | Least significant bit |
| LT | Lifetime |
| MAC | Manufacturer access command or control command |
| mAh | Milliamp-hour |
| MSB | Most significant bit |
| mWh | Milliwatt-hour |
| NACK | Negative acknowledge character |
| NTC | Negative temperature coefficient |
| OCV | Open-circuit voltage. Voltage measured on fully-relaxed battery with no load applied. |
| OTC | Overtemperature in charge |
| OTD | Overtemperature in discharge |
| PFC | Pin function code |
| POR | Power-on reset |

| | |
|---|---|
| Qmax | Maximum absolute chemical capacity |
| Qpass | Qmax Passed Charge (Qpass). The amount of charge passed between two DOD0 points required for learning Qmax |
| QC | Qualification and calculation |
| QT | Qualification time |
| Relaxation Mode | Refers to a mode to where the gauge read *AverageCurrent( )* < **Quit Current** for at least 60 seconds. |
| RM | Remaining capacity in the battery compensated for present load current, temperature, and aging effects (reduction in chemical capacity and increase in internal impedance). |
| RW | Read or write |
| SCL | Serial clock: programmable serial clock used in the I²C interface |
| SDA | Serial data: serial data bus in the I²C interface |
| SE | Shutdown enable |
| Set | Refers to a bit in a register becoming a logic HIGH or 1. The bqEvaluation software (EVSW) represents a set bit with the color red. |
| SOC | State-of-charge in percent related to FCC |
| SOC1 | State-of-charge initial |
| SOCF | State-of-charge final |
| System | The word system is sometimes used in this document. When used, it always means a host system that is consuming current from the battery pack. |
| TCA | Terminate charge alarm |
| TS | Temperature status |
| TTE | Time-to-empty |
| TTF | Time-to-full |
| VIT | Voltage, current, temperature |
| VOK | Indicates that Qmax has been saved to data flash. This bit is located on *CONTROL_STATUS* register bit 1. |

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