bq27741-G1
Pack-Side Impedance Track™ Battery Fuel Gauge With Integrated Protector and LDO

User's Guide

Literature Number: SLUUAA3
July 2013

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Preface

This document is a detailed Technical Reference Manual (TRM) for using and configuring the bq27741-G1 battery fuel gauge. This TRM document is intended to complement but not supersede any information contained in the separate bq27741-G1 datasheet.

Refer to the bq27741-G1 Datasheet (SLUSBF2).

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

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1. *bq27741-G1, Single Cell Li-Ion Battery Fuel Gauge with Integrated Protection* Data Sheet (SLUSBF2)
2. *HDQ Communication Basics* Application Report (SLUA408)
3. *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* Application Report (SLUA450)
4. *How to Generate Golden Image for Single-Cell Impedance Track™ Devices* Application Report (SLUA544)
5. *bq27741EVM Single Cell Impedance Track™ Technology Evaluation Module* User's Guide (SLUUAH1)

Revision History

Version	Change Date	Description
—	July 2013	Initial Release

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I²C is a trademark of NXP B.V. Corp Netherlands.

Chapter 1

SLUUAA3–July 2013

General Description

The bq27741-G1 fuel gauge accurately predicts the battery capacity and other operational characteristics of a single Li-based rechargeable cell. It can be interrogated by a system processor to provide cell information, such as state-of-charge (SOC) and time-to-empty (TTE).

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 control and status registers, as well as its data flash locations. Commands are sent from system to fuel gauge using the serial communications engine, and can be executed during application development, pack manufacture, or end-equipment operation.

Cell information is stored in the 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 fuel gauge provides 64 bytes of user-programmable data flash memory, partitioned into two 32-byte blocks: ***Manufacturer Info Block A*** and ***Manufacturer Info Block B***. This data space is accessed through a data flash interface. For specifics on accessing the data flash, see Section 5.1.2, *Manufacturer Information Blocks*.

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.

The fuel gauge measures charge and discharge activity by monitoring the voltage across a small-value series sense resistor (5 mΩ to 20 mΩ, typical) located between the CELL– and the battery PACK– terminal. When a cell is attached to the fuel gauge, cell impedance is computed 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 kΩ ± 1% and B25/85 = 3435 kΩ ± 1% (such as Semitec 103AT) for measurement. The fuel gauge can also be configured to use its internal temperature sensor. 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 fuel gauge has three different power modes: NORMAL, SLEEP, and FULLSLEEP. 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 2.9, *Power Modes*.

Functional Description

2.1 Fuel Gauging

The bq27741-G1 fuel gauge measures the cell voltage, temperature, and current to determine battery SOC based on Impedance Track™ algorithm (see Application Report SLUA450, *Theory and Implementation of Impedance Track Battery Fuel-Gauging Algorithm*, for more information). The fuel gauge monitors charge and discharge activity by sensing the voltage across a small-value resistor (5 mΩ to 20 mΩ, typical) between the SRP and SRN pins and in series with the cell. By integrating charge passing through the battery, the battery SOC is adjusted during battery charge or discharge.

The total battery capacity is found by comparing states of charge before and after applying the load with the amount of charge passed. When an application load is applied, the impedance of the cell is measured by comparing the OCV obtained from a predefined function for present SOC with the measured voltage under load. Measurements of OCV and charge integration determine chemical state of charge and chemical capacity (Qmax). The initial Qmax values are taken from a cell manufacturers' data sheet multiplied by the number of parallel cells. It is also used for the value in ***Design Capacity***. The fuel gauge acquires and updates the battery-impedance profile during normal battery usage. It uses this profile, along with SOC and the Qmax value, to determine *FullChargeCapacity( )* and *StateOfCharge( )*, specifically for the present load and temperature. *FullChargeCapacity( )* is reported as capacity available from a fully charged battery under the present load and temperature until *Voltage( )* reaches the ***Terminate Voltage***. *NominalAvailableCapacity( )* and *FullAvailableCapacity( )* are the uncompensated (no or light load) versions of *RemainingCapacity( )* and *FullChargeCapacity( )*, respectively.

The fuel gauge has two flags accessed by the *Flags( )* function that warns when the SOC of the battery has fallen to critical levels. When *RemainingCapacity( )* falls below the first capacity threshold, specified in ***SOC1 Set Threshold***, the *[SOC1] (State of Charge Initial)* flag is set. The flag is cleared once *RemainingCapacity( )* rises above ***SOC1 Clear Threshold***. All units are in mAh.

When *RemainingCapacity( )* falls below the second capacity threshold, ***SOCF Set Threshold***, the *[SOCF] (State of Charge Final)* flag is set, serving as a final discharge warning. If ***SOCF Set Threshold*** = –1, the flag is inoperative during discharge. Similarly, when *RemainingCapacity( )* rises above ***SOCF Clear Threshold*** and the *[SOCF] flag* has already been set, the *[SOCF]* flag is cleared. All units are in mAh.

The fuel gauge has two additional flags accessed by the *Flags()* function that warns of internal battery conditions. The fuel gauge monitors the cell voltage during relaxed conditions to determine if an internal short has been detected. When this condition occurs, *[ISD]* is set. The fuel gauge also has the capability of detecting when a tab has been disconnected in a 2-cell parallel system by actively monitoring the *SOH*. When this condition occurs, *[TDD]* is set.

2.2 Fast Resistance Scaling

When Fast Resistance Scaling is enabled by setting the ***[FConvEn]*** bit in ***Pack Configuration B***, the algorithm improves accuracy at the end of discharge. The *RemainingCapacity()* and *StateOfCharge()* should smoothly converge to 0. The algorithm starts convergence improvements when cell voltage goes below (***Terminate Voltage*** + ***Term V Delta***) or *StateofCharge()* goes below ***Fast Scale Start SOC***. For most applications, the default value of ***Term V Delta*** and ***Fast Scale Start SOC*** are recommended. Also it is recommended to keep (***Terminate Voltage*** + ***Term V Delta***) below 3.6 V for most battery applications.

2.3 StateOfCharge() Smoothing

When operating conditions change (such as temperature, discharge current, resistance, and so on), it can lead to large changes of compensated battery capacity and battery capacity remaining. These changes can result in large changes of *StateOfCharge()*. When the ***[SmoothEn]*** bit is enabled in ***Pack Configuration C***, the smoothing algorithm injects gradual changes of battery capacity when conditions vary. This results in a gradual change of *StateOfCharge()* and can provide a better end-user experience for *StateOfCharge()* reporting.

The *RemainingCapacity()*, *FullChargeCapacity()*, and *StateOfCharge()* are modified depending on the ***[SmoothEn]*** bit as shown below.

[SmoothEn]	*RemainingCapacity()*	*FullChargeCapacity()*	*StateOfCharge()*
0	*UnfilteredRM()*	*UnfilteredFCC()*	*UnfilteredRM()/UnfilteredFCC()*
1	*FilteredRM()*	*FilteredFCC()*	*FilteredRM()/FilteredFCC()*

2.4 Lifetime Data Logging Parameters

The Lifetime Data logging function helps development and diagnosis with the fuel gauge. The *IT_ENABLE* subcommand needs to be enabled (command 0x0021) for lifetime data logging functions to be active. The fuel gauge logs the lifetime data as specified in the ***Lifetime Data*** and ***Lifetime Temp Samples*** data flash subclasses. The data log recordings are controlled by the ***Lifetime Resolution*** data flash subclass.

The Lifetime Data Logging can be started by setting the *IT_ENABLE* subcommand and setting the Update Time register to a non-zero value.

Once the Lifetime Data Logging function is enabled, the measured values are compared to what is already stored in the data flash. If the measured value is higher than the maximum or lower than the minimum value stored in the data flash by more than the Resolution set for at least one parameter, the entire Data Flash Lifetime Registers are updated after at least LTUpdateTime.

LTUpdateTime sets the minimum update time between DF writes. When a new maximum or minimum is detected, a LT Update window of [update time] seconds is enabled and the DF writes occur at the end of this window. Any additional maximum or minimum value detected within this window is also updated. The first new maximum or minimum value detected after this window triggers the next LT Update window.

Internal to the fuel gauge, there exists a RAM maximum/minimum table in addition to the DF maximum/minimum table. The RAM table is updated independent of the resolution parameters. The DF table is updated only if at least one of the RAM parameters exceeds the DF value by more than resolution associated with it. When DF is updated, the entire RAM table is written to DF. Consequently, it is possible to see a new maximum/minimum value for a certain parameter even if the value of this parameter never exceeds the maximum or minimum value stored in the data flash for this parameter value by the resolution amount.

The Life Time Data Logging of one or more parameters can be reset or restarted by writing new default (or starting) values to the corresponding data flash registers through SEALED or UNSEALED access as described below. However, when using UNSEALED access, new values take effect only if the device is reset within ***LT Update Time*** after the DF is loaded with new values.

The logged data in ***Lifetime Data*** subclass (subclass ID = 59) can be read and written in both SEALED and UNSEALED modes. However, in SEALED mode, access to this subclass is using a process identical to accessing ***Manufacturer Info Block B***. The *DataFlashBlock()* command code is 4. See Section 5.1.2, *Manufacturer Information Blocks*, for details of this sequence.

The subclasses ***Lifetime Resolution*** (subclass ID = 66) and ***Lifetime Temp Samples*** (subclass ID = 60) that contain settings for lifetime data logging can be configured only in UNSEALED mode using the regular DF access method.

The Lifetime resolution registers contain the parameters which set the limits related to how much a data parameter must exceed the previously logged maximum/minimum value to be updated in the lifetime log. For example, V must exceed MaxV by more than Voltage Resolution to update MaxV in the data flash.

2.5 System Control Function

The fuel gauge provides system control functions which allow the fuel gauge to enter shutdown mode in order to power-off with the assistance of an external circuit or provides an interrupt function to the system. Table 2-1 shows the configurations for the HDQ pin.

Table 2-1. HDQ Pin Function

[INTSEL]	**Communication Mode**	**HDQ Pin Function**
0 (default)	I^2C	Not Used
	HDQ	HDQ Mode[1]
1	I^2C	Interrupt Mode
	HDQ	HDQ Mode[1]

[1] HDQ pin is used for communication and HDQ Host Interrupt Feature is available.

2.5.1 Shutdown Mode

This is the mode in which the gauge and protector are completely shutdown. The device spontaneously enters SHUTDOWN mode when the following conditions are satisfied:

- *Current()* < SleepCurrent
- *Voltage()* < ShutdownVoltage
- Device is in SLEEP mode

The device can also be forced to enter SHUTDOWN mode by sending the *SET_SHUTDOWN* command. On sending *SET_SHUTDOWN* command the firmware sets the *CONTROL_STATUS[SHUTDWN]* bit and initiates the shutdown sequence. The gauge opens both charge and discharge FETs and waits for charger removal. As soon as the charger is removed, the gauge and protector will shut down leaving both charge and discharge FETs open. The only way to recover from this SHUTDOWN mode is to connect a charger. If the *CLEAR_SHUTDOWN* command is sent during the wait for charger disconnection phase, it aborts the SHUTDOWN sequence and clears the *[SHUTDWN]* bit.

2.5.2 Host Interrupt

The fuel gauge has the capability to interrupt the host system when one or more of a predefined set of events occur in the gauge. The actual mechanism used for interrupting the host depends on the communication mode. In HDQ mode, the HDQ bus is used to interrupt the host whereas in I^2C mode RC2, one of the GPIO pins is used for this purpose. The events that result in an interrupt and the mechanism to enable or disable interrupts are also different between the two communication modes. The following sections give a detailed account of host interrupt feature in both cases.

2.5.2.1 HDQ Mode

In HDQ mode interrupts are enabled when the gauge receives a *SET_HDQINTEN* command from the host. On receiving *SET_HDQINTEN* the gauge sets *CONTROL_STATUS [HDQIntEn]* bit to 1 and becomes the HDQ master. If one or more of the events in Table 2-2 occur when *CONTROL_STATUS [HDQIntEn]* is 1, the gauge interrupts the host by generating a pattern on the HDQ line as shown in Figure 2-1. Gauge repeats this sequence three times at 1-second intervals.

Table 2-2. Host Interrupt Events in HDQ Mode

Interrupt Condition	**Flags() Status Bit**	**Enable Condition**	**Comment**
SOC1 Set	*[SOC1]*	Always	This interrupt is raised when the *[SOC1]* flag is set.
Over-Temperature Charge	*[OTC]*	***OT Chg Time*** ≠ 0	This interrupt is raised when the *[OTC]* flag is set.
Over-Temperature Discharge	*[OTD]*	***OT Dsg Time*** ≠ 0	This interrupt is raised when the *[OTD]* flag is set.

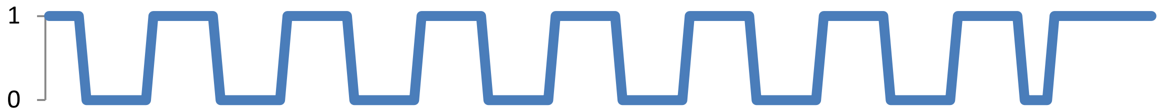


Figure 2-1. HDQ Mode Interrupt Sequence

The host can clear the *CONTROL_STATUS [HDQIntEn]* bit asynchronously by sending *CLEAR_HDQINTEN* command. To make sure that a *CLEAR_HDQINTEN* is not lost in a collision with an interrupt raised by the gauge it is advised that the host send the *CLEAR_HDQINTEN* two times back to back. Figure 2-2 shows typical interrupt related hand-shake between host and fuel gauge in HDQ mode. Figure 2-3 demonstrates the collision issue and the solution for it.

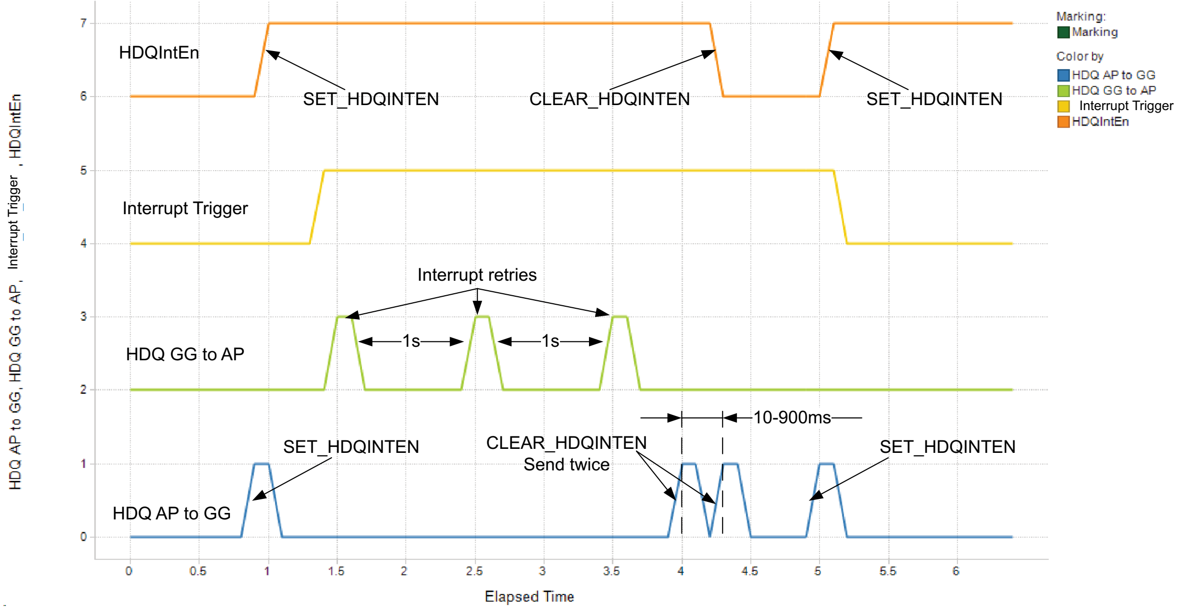


Figure 2-2. Interrupt Handling in HDQ Mode

Figure 2-3. Possibility of HDQ Collision When Gauge Is in Master Mode

2.5.2.2 I²C Mode

When the gauge is in I²C mode, it uses the GPIO pin RC2 to interrupt the host. The ***[HOSTIE]*** bit in the ***Pack Configuration*** register enables and disables the interrupt and the ***[HOSTPOL]*** bit can select the polarity of the interrupt signal (active low or active high). The interrupt is raised when one or more of the events mentioned in Table 2-3 occur.

Table 2-3. Host Interrupt Events in I²C Mode

Interrupt Condition	Flags() Status Bit	Enable Condition	Comment
SOC1 Set	*[SOC1]*	Always	This interrupt is raised when the *[SOC1]* flag is set.
Over-Temperature Charge	*[OTC]*	***OT Chg Time*** ≠ 0	This interrupt is raised when the *[OTC]* flag is set.
Over-Temperature Discharge	*[OTD]*	***OT Dsg Time*** ≠ 0	This interrupt is raised when the *[OTD]* flag is set.
Battery High	*[BATHI]*	Always	This interrupt is raised when the *[BATHI]* flag is set.
Battery Low	*[BATLOW]*	Always	This interrupt is raised when the *[BATLOW]* flag is set.
Internal Short Detection	*[ISD]*	***[SE_ISD]*** = 1 in ***Pack Configuration B***	This interrupt is raised when the *[ISD]* is set.
Tab Disconnection Detection	*[TDD]*	***[SE_TDD]*** = 1 in ***Pack Configuration B***	The *[TDD]* Flag is set or cleared based on conditions specified in Section 2.5.5, *Tab Disconnection Detection*.

2.5.3 Battery Level Indication

The fuel gauge can indicate when battery voltage has fallen below or risen above predefined thresholds. The *[BATHI]* of *Flags()* is set high to indicate *Voltage()* is above the ***BH Set Volt Threshold*** for a predefined duration set in the ***BH Volt Time***. This flag returns to low once battery voltage is below or equal the ***BH Clear Volt threshold***. It is recommended that the ***BH Set Volt Threshold*** is configured higher than the ***BH Clear Volt threshold*** to provide proper voltage hysteresis.

The *[BATLOW]* of *Flags()* is set high to indicate *Voltage()* is below the ***BL Set Volt Threshold*** for predefined duration set in the ***BL Volt Time***. This flag returns to low once battery voltage is above or equal the ***BL Clear Volt threshold***. It is recommended that the ***BL Set Volt Threshold*** is configured lower than the ***BL Clear Volt threshold*** to provide proper voltage hysteresis.

The *[BATHI]* and *[BATLOW]* flags can be configured to control the interrupt pin (RC2 or HDQ) by enabling interrupt mode. See Section 2.5.2, *Interrupt Mode*, for details.

2.5.4 Internal Short Detection

The fuel gauge can indicate detection of an internal battery short by setting the *[SE_ISD*] bit in ***Pack Configuraton B***. The device compares the self-discharge current calculated based *StateOfCharge()* in relaxation mode and AverageCurrent() measured in the system. The self-discharge rate is measured at 1-hour intervals. When battery *SelfDischargeCurrent()* is less than the predefined (***–Design Capacity / ISD Current*** threshold), the *[ISD]* of *Flags()* is set high. The *[ISD]* of *Flags()* can be configured to control interrupt pin (SE or HDQ) by enabling interrupt mode. See Section 2.5.2, *Interrupt Mode*, for details.

2.5.5 Tab Disconnection Detection

The fuel gauge can indicate tab disconnection by detecting change of *StateOfHealth()*. This feature is enabled by setting *[SE_TDD]* bit in ***Pack Configuraton B***. The *[TDD]* of *Flags()* is set when the ratio of current *StateOfHealth()* divided by the previous *StateOfHealth()* reported is less than ***TDD SOH Percent***. The *[TDD]* of *Flags()* can be configured to control an interrupt pin (SE or HDQ) by enabling interrupt mode. See Section 2.5.2, *Interrupt Mode*, for details.

2.6 Temperature Measurement and the TS Input

The fuel gauge measures battery temperature via the TS input to supply battery temperature status information to the fuel gauging algorithm and charger-control sections of the gauge. Alternatively, the gauge can also measure internal temperature via its on-chip temperature sensor, but only if the ***[TEMPS]*** bit of ***Pack Configuration*** register is cleared.

Regardless of which sensor is used for measurement, a system processor can request the current battery temperature by calling the *Temperature( )* function (see Section 4.1, *Standard Data Commands*, for specific information).

The thermistor circuit requires the use of an external 10-kΩ thermistor with negative temperature coefficient (NTC) thermistor with R25 = 10 kΩ ± 1% and B25/85 = 3435 kΩ ± 1% (such as Semitec 103AT) that connects between the V_{CC} and TS pins. Additional circuit information for connecting the thermistor to the fuel gauge is shown in Chapter 6, *Reference Schematics*.

2.7 Over-Temperature Indication

2.7.1 Over-Temperature: Charge

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

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

2.7.2 Over-Temperature: 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 *[OTD]* bit of *Flags( )* is set. When *Temperature( )* falls to ***OT Dsg Recovery***, then the *[OTD]* bit of *Flags( )* is reset.

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

2.8 Charging and Charge Termination Indication

2.8.1 Charge Termination Detection

For proper operation, the cell charging voltage must be specified by the user. The default value for this variable is in the data flash ***Charging Voltage***.

The fuel gauge detects charge termination when:

1. During 2 consecutive periods of ***Current Taper Window***, the *AverageCurrent( )* is ***< Taper Current***,
2. During the same periods, the accumulated change in capacity > 0.25 mAh / ***Current Taper Window***, and
3. *Voltage( )* ***> Charging Voltage – Taper Voltage***.

When this occurs, the *[CHG]* bit of *Flags( )* is cleared. Also, if the ***[RMFCC]*** bit of ***Pack Configuration*** is set, *RemainingCapacity( )* is set equal to *FullChargeCapacity( )*. When ***TCA_Set*** is set to –1, it disables the use of the charger alarm threshold. In that case, TerminateCharge is set when the taper condition is detected. When ***FC_Set*** is set to –1, it disables the use of the full charge detection threshold. In that case, the *[FC]* bit is not set until the taper condition is met.

2.8.2 Charge Inhibit

The fuel gauge can indicate when battery temperature has fallen below or risen above predefined thresholds (***Charge Inhibit Temp Low*** and ***Charge Inhibit Temp High***, respectively). In this mode, the *[CHG_INH]* of *Flags( )* is made high to indicate this condition, and is returned to its low state, once battery temperature returns to the range ***[Charge Inhibit Temp Low + Temp Hys***, ***Charge Inhibit Temp High – Temp Hys]***.

2.9 Power Modes

The fuel gauge has three power modes: NORMAL, SLEEP, and FULLSLEEP. In NORMAL mode, the fuel gauge is fully powered and can execute any allowable task. In SLEEP mode the fuel gauge exists in a reduced-power state, periodically taking measurements and performing calculations. The FULLSLEEP mode is a deeper low-power state. The FULLSLEEP mode turns off the high-frequency oscillator in addition to reduced frequency of measurements; this results in a power consumption that is lower than that of the SLEEP mode.

The relationship between these modes is shown in Figure 2-4. Details are described in Section 2.9.1 through Section 2.9.3.

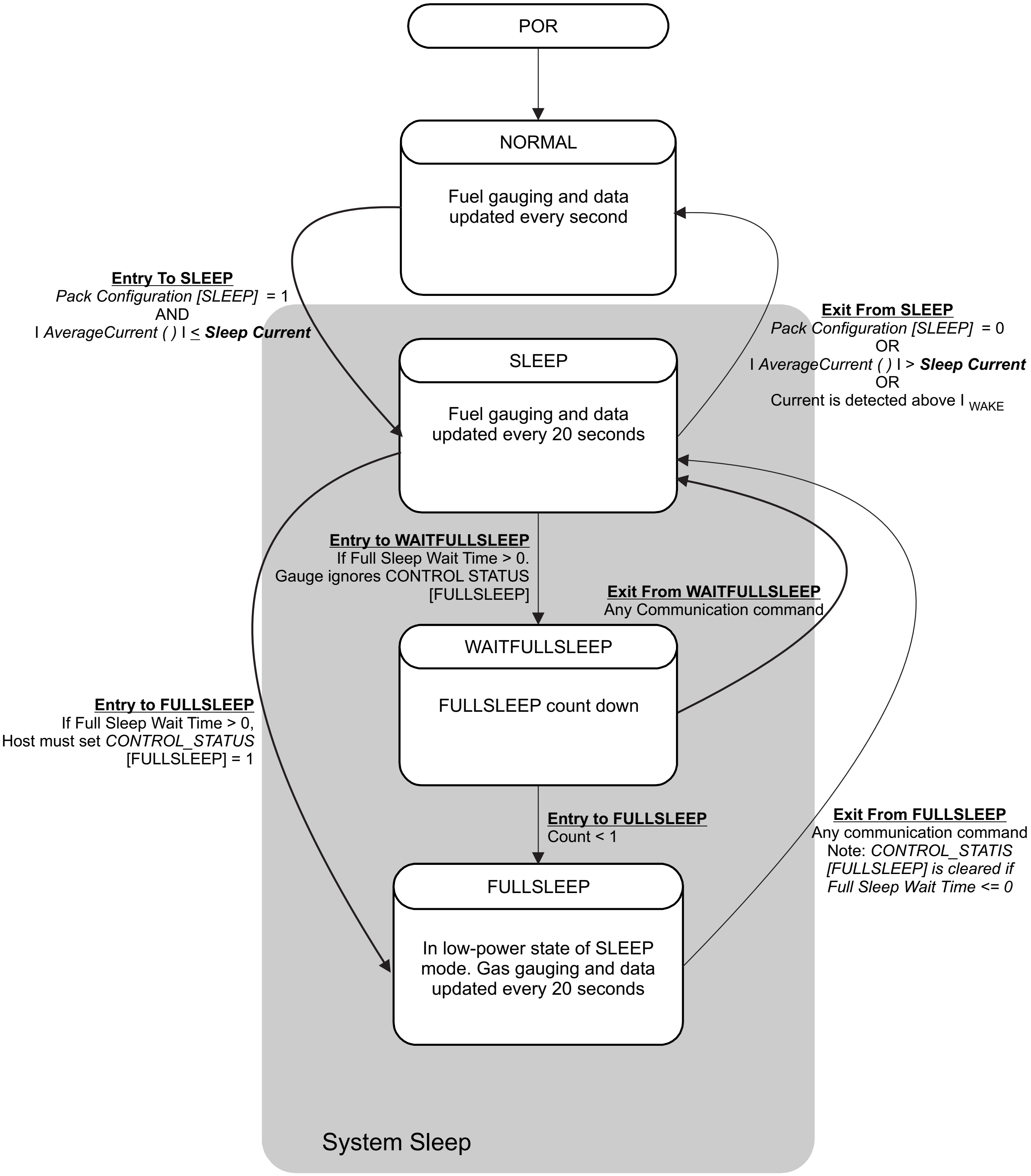


Figure 2-4. Power Mode Diagram–System Sleep

2.9.1 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 NORMAL mode, the Impedance Track™ algorithm minimizes the time the fuel gauge remains in this mode.

2.9.2 SLEEP Mode

SLEEP mode is entered automatically if the feature is enabled (***Pack Configuration [SLEEP]***) = 1) and *AverageCurrent( )* is below the programmable level ***Sleep Current***. Once entry into SLEEP mode has been qualified, but prior to entering it, the fuel gauge performs an ADC autocalibration to minimize offset.

During the 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 SLEEP if any entry condition is broken, specifically when:

- *AverageCurrent( )* rises above ***Sleep Current***, or
- A current in excess of I_{WAKE} through R_{SENSE} is detected when the I_{WAKE} comparator is enabled.

2.9.3 FULLSLEEP Mode

FULLSLEEP mode is entered automatically when the fuel gauge is in SLEEP mode and the timer counts down to 0 (***Full Sleep Wait Time*** > 0). FULLSLEEP mode is entered immediately after entry to SLEEP if ***Full Sleep Wait Time*** is set to 0 and the host sets the *CONTROL_STATUS [FULLSLEEP]* bit using the *SET_FULLSLEEP* subcommand.

During FULLSLEEP 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 gauge exits the FULLSLEEP mode when there is any communication activity. The *[FULLSLEEP]* bit can remain set (***Full Sleep Wait Time*** > 0) or be cleared (***Full Sleep Wait Time*** ≤ 0) after exit of FULLSLEEP mode. Therefore, EVSW communication activity might cause the gauge to exit FULLSLEEP mode and display the *[FULLSLEEP]* bit as cleared. The execution of *SET_FULLSLEEP* to set the *[FULLSLEEP]* bit is required when ***Full Sleep Wait Time*** ≤ 0 in order to re-enter FULLSLEEP mode.

While in FULLSLEEP mode, the fuel gauge can suspend serial communications as much as 4 ms by holding the communication line(s) low. This delay is necessary to turn the high-frequency oscillator back ON while moving out of FULLSLEEP mode.

The fuel gauge exits FULLSLEEP if any entry condition is broken, specifically when:

- *AverageCurrent( )* rises above ***Sleep Current***, or
- A current in excess of I_{WAKE} through R_{SENSE} is detected when the I_{WAKE} comparator is enabled.

2.10 Power Control

2.10.1 Reset Functions

When the fuel gauge detects a software reset by sending *Control( ) [RESET]* subcommand, it resets the firmware and increments the reset counter. This counter is accessible by issuing the command *Control( )* function with the *RESET_DATA* subcommand.

2.10.2 Wake-Up Comparator

The wake-up comparator indicates a change in cell current while the fuel gauge is in SLEEP modes. ***Pack Configuration*** uses bits ***[RSNS1, RSNS0]*** to set the sense resistor selection. ***Pack Configuration*** also uses the ***[IWAKE]*** bit to select one of two possible voltage threshold ranges for the given sense resistor selection. An internal interrupt is generated when the threshold is breached in either charge or discharge directions. Setting both ***[RSNS1]*** and ***[RSNS0]*** to 0 disables this feature.

Table 2-4. I_{WAKE} Threshold Settings[1]

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

(1) The actual resistance value vs the setting of the sense resistor is not important just the actual voltage threshold when calculating the configuration. The voltage thresholds are typical values under room temperature.

2.10.3 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.

2.11 Autocalibration

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

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

The fuel gauge also performs a single offset calibration when:

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

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 considerably; hence, the offset calibration is aborted.

2.12 Battery Pack Protection

This gas gauge integrates complete battery protection. Protection features in this device can be divided in HW-based or FW-based protections.

FW-based protection:

- Overtemperature - gas gauge opens both charger and discharge FETs when measured temperature exceeds the threshold (for details, see Section 5.3.1.3).

HW-based protection (see details of HW protector behavior in the bq27741-G1 data sheet (SLUSBF2)):

- OVP - overvoltage protection
- UVP - undervoltage protection
- OCD - overcurrent in discharge protection
- OCC - overcurrent in charger protection
- SCD - short-circuit protection

Communications

3.1 Authentication

The fuel gauge can act as a SHA-1/HMAC authentication slave by using its internal engine. Sending a 160-bit SHA-1 challenge message to the fuel gauge causes the gauge to return a 160-bit digest, based upon the challenge message and a hidden, 128-bit plain-text authentication key. If this digest matches an identical one generated by a host or dedicated authentication master, and when operating on the same challenge message and using the same plain text keys, the authentication process is successful.

3.2 Key Programming (Data Flash Key)

By default, the fuel gauge contains a default plain-text authentication key of 0x0123456789ABCDEFFEDCBA9876543210. This default key is intended for development purposes. It must be changed to a secret key and the part immediately SEALED, before putting a pack into operation. Once written, a new plain-text key cannot be read again from the fuel gauge while in SEALED mode.

Once the fuel gauge is UNSEALED, the authentication key can be changed from its default value by writing to the *Authenticate( )* Extended Data Command locations. A 0x00 is written to *BlockDataControl( )* to enable the authentication data commands. The *DataFlashClass( )* is issued 112 (0x70) to set the Security class. Up to 32 bytes of data can be read directly from the *BlockData( )* (0x40 through 0x5F) and the authentication key is located at 0x48 (0x40 + 0x08 offset) to 0x57 (0x40 + 0x17 offset). The new authentication key can be written to the corresponding locations (0x48 through 0x57) using the *BlockData( )* command. The data is transferred to the data flash when the correct checksum for the whole block (0x40 through 0x5F) is written to *BlockDataChecksum( )* (0x60). The checksum is (255 – x) where x is the 8-bit summation of the *BlockData( )* (0x40 through 0x5F) on a byte-by-byte basis. Once the authentication key is written, the gauge can then be SEALED again.

3.3 Executing an Authentication Query

To execute an authentication query in UNSEALED mode, a host must first write 0x01 to the *BlockDataControl( )* command, to enable the authentication data commands. If in SEALED mode, 0x00 must be written to *DataFlashBlock( )*, instead.

Next, the host writes a 20-byte authentication challenge to the *Authenticate( )* address locations (0x40 through 0x53). After a valid checksum for the challenge is written to *AuthenticateChecksum( )*, the fuel gauge uses the challenge to perform the SHA-1/HMAC computation, in conjunction with the programmed key. The fuel gauge completes the SHA-1/HMAC computation and writes the resulting digest to *Authenticate( )*, overwriting the pre-existing challenge. The host must wait at least 45 ms to read the resulting digest. The host may then read this response and compare it against the result created by its own parallel computation.

3.4 HDQ Single-Pin Serial Interface

The HDQ interface is an asynchronous return-to-one protocol where a processor sends the command code to the fuel gauge. With HDQ, the least significant bit (LSB) of a data byte (command) or word (data) is transmitted first. The DATA signal on pin 12 is open-drain and requires an external pullup resistor. The 8-bit command code consists of two fields:

- The 7-bit HDQ command code (bits 0 to 6)
- The 1-bit RW field (MSB bit 7)

The RW field directs the fuel gauge either to:

- Store the next 8 or 16 bits of data to a specified register or

- Output 8 bits of data from the specified register

The HDQ peripheral can transmit and receive data as either an HDQ master or slave.

HDQ serial communication is normally initiated by the host processor sending a break command to the fuel gauge. A break is detected when the DATA pin is driven to a logic-low state for a time $t_{(B)}$ or greater. Then the DATA pin must be returned to its normal ready high logic state for a time $t_{(BR)}$. The fuel gauge is now ready to receive information from the host processor.

The fuel gauge is shipped in the I^2C mode. TI provides tools to enable the HDQ peripheral. The SLUA408 application report provides details of HDQ communication basics.

3.5 HDQ Host Interruption Feature

The default fuel gauge behaves as an HDQ slave-only device when HDQ mode is enabled. If the HDQ interrupt function is enabled, the fuel gauge is capable of mastering and also communicating with an HDQ device. There is no mechanism for negotiating who is to function as the HDQ master and care must be taken to avoid message collisions. The interrupt is signaled to the host processor with the fuel gauge mastering an HDQ message. This message is a fixed message that signals the interrupt condition. The message itself is 0x80 (slave write to register 0x00) with no data byte being sent as the command is not intended to convey any status of the interrupt condition. The HDQ interrupt function is disabled by default and needs to be enabled by command.

When the *SET_HDQINTEN* subcommand is received, the fuel gauge detects any of the interrupt conditions and asserts the interrupt at one-second intervals until either:

- The *CLEAR_HDQINTEN* subcommand is received, or
- The number of tries for interrupting the host has exceeded a predetermined limit (default is 3).

3.5.1 Low Battery Capacity

This feature works identically to SOC1. It uses the same data flash entries as SOC1 and triggers interrupts as long as SOC1 = 1 and the *CONTROL_STATUS [HDQIntEn]* bit = 1.

3.5.2 Temperature

This feature triggers an interrupt based on the OTC (Over-Temperature in Charge) or OTD (Over-Temperature in Discharge) condition being met. It uses the same data flash entries as OTC or OTD and triggers interrupts as long as either the OTD or OTC condition is met and the *CONTROL_STATUS [HDQIntEn]* bit = 1.

3.6 I^2C Interface

The fuel gauge supports the standard I^2C read, incremental read, one-byte write quick read, and functions. The 7-bit device address (ADDR) is the most significant 7 bits of the hex address and is fixed as 1010101. The 8-bit device address is therefore 0xAA or 0xAB for write or read, respectively.

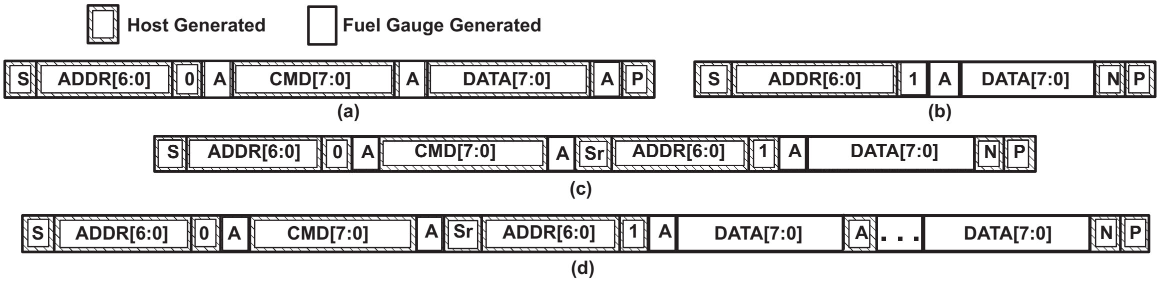


Figure 3-1. Supported I^2C Formats

(a) 1-byte write
(b) Quick read
(c) 1-byte read

(d) Incremental read (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 I^{2}C communication engine, increments whenever data is acknowledged by the fuel gauge or the I^{2}C 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).

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

Attempt to read an address above 0x7F (NACK command):

Attempt at incremental writes (NACK all extra data bytes sent):

Incremental read at the maximum allowed read address:

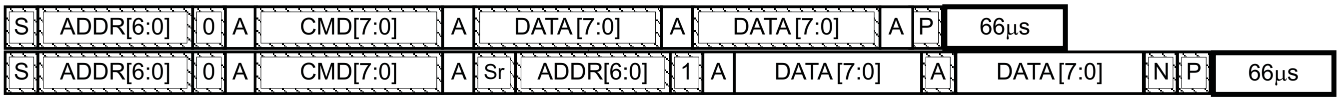
The I^{2}C engine releases both SDA and SCL if the I^{2}C bus is held low for $t_{(BUSERR)}$. If the fuel gauge was holding the lines, releasing them frees the master to drive the lines. If an external condition is holding either of the lines low, the I^{2}C engine enters the low-power SLEEP mode.

3.6.1 I^{2}C Time Out

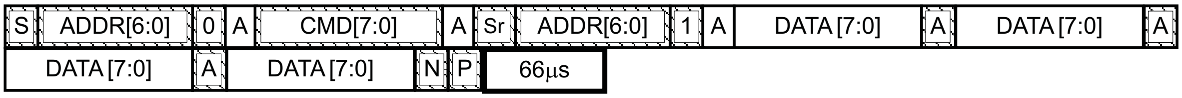
The I^{2}C engine releases both SDA and SCL if the I^{2}C bus is held low for about 2 seconds. If the fuel gauge was holding the lines, releasing them frees the master to drive the lines.

3.6.2 I^{2}C Command Waiting Time

To make sure the correct results of a command with the 400-kHz I^{2}C operation, a proper waiting time must be added between issuing command and reading results. For subcommands, the following diagram shows the waiting time required between issuing the control command the reading the status with the exception of the checksum command. A 100-ms waiting time is required between the checksum command and reading result. For read-write standard commands, 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 must not issue all standard commands more than two times per second. Otherwise, the gauge could result in a reset issue due to the expiration of the watchdog timer.



Waiting time between control subcommand and reading results



Waiting time between continuous reading results

3.6.3 *I^2C Clock Stretching*

I^2C clock stretches can occur during all modes of fuel gauge operation. In the SLEEP mode, a short clock stretch occurs on all I^2C traffic as the device must wake-up to process the packet. In NORMAL and SLEEP modes, clock stretching only occurs for packets addressed for the fuel gauge. The timing of stretches varies as interactions between the communicating host and the gauge are asynchronous. The I^2C clock stretches may occur after start bits, the ACK/NAK bit and first data bit transmit on a host read cycle. The majority of clock stretch periods are small (≤ 4 ms) as the I^2C interface peripheral and CPU firmware perform normal data flow control. However, less frequent but more significant clock stretch periods may occur when data flash (DF) is being written by the CPU to update the resistance (Ra) tables and other DF parameters such as Qmax. Due to the organization of DF, updates need to be written in data blocks consisting of multiple data bytes.

An Ra table update requires erasing a single page of DF, programming the updated Ra table and a flag. The potential I^2C clock stretching time is 24 ms maximum. This includes 20-ms page erase and 2-ms row programming time (×2 rows). The Ra table updates occur during the discharge cycle and at up to 15 resistance grid points that occur during the discharge cycle.

A DF block write typically requires a maximum of 72 ms. This includes copying data to a temporary buffer and updating DF. This temporary buffer mechanism protects from power failure during a DF update. The first part of the update requires 20 ms to erase the copy buffer page, 6 ms to write the data into the copy buffer and the program progress indicator (2 ms for each individual write). The second part of the update is writing to the DF and requires 44-ms DF block update time. This includes a 20-ms each page erase for two pages and 2 ms each row write for two rows.

In the event that a previous DF write was interrupted by a power failure or reset during the DF write, an additional 44-ms maximum DF restore time is required to recover the data from a previously interrupted DF write. In this power failure recovery case, the total I^2C clock stretching is 116 ms maximum.

Another case where I^2C clock stretches is at the end of discharge. The update to the last discharge data goes through the DF block update twice because two pages are used for the data storage. The clock stretching in this case is 144 ms maximum. This occurs if there has been a Ra table update during the discharge.

Chapter 4

Data Commands

4.1 Standard Data Commands

The bq27741-G1 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 4-1. Each protocol has specific means to access the data at each Command Code. Data RAM is updated and read by the gauge only once per second. Standard commands are accessible in the NORMAL operation mode.

Table 4-1. Standard Commands

Name		Command Code	Unit	SEALED Access
Control( )	CNTL	0x00 and 0x01	NA	RW
AtRate( )	AR	0x02 and 0x03	mA	RW
UnfilteredSOC()	UFSOC	0x04 and 0x05	%	R
Temperature( )	TEMP	0x06 and 0x07	0.1°K	R
Voltage( )	VOLT	0x08 and 0x09	mV	R
Flags( )	FLAGS	0x0A and 0x0B	NA	R
NomAvailableCapacity( )	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
FilteredFCC()	FFCC	0x18 and 0x19	mAh	R
StandbyCurrent( )	SI	0x1A and 0x1B	mA	R
UnfilteredFCC()	UFFCC	0x1C and 0x1D	mAh	R
MaxLoadCurrent( )	MLI	0x1E and 0x1F	mA	R
UnfilteredRM()	UFRM	0x20 and 0x21	mAh	R
FilteredRM()	FRM	0x22 and 0x23	mAh	R
AveragePower( )	AP	0x24 and 0x25	mW or cW	R
InternalTemperature( )	INTTEMP	0x28 and 0x29	0.1°K	R
CycleCount( )	CC	0x2A and 0x2B	counts	R
StateOfCharge( )	SOC	0x2C and 0x2D	%	R
StateOfHealth( )	SOH	0x2E and 0x2F	% / num	R
PassedCharge( )	PCHG	0x34 and 0x35	mAh	R
DOD0( )	DOD0	0x36 and 0x37	hex#	R
SelfDischargeCurrent()	SDSG	0x38 and 0x39	mA	R

4.1.1 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 fuel gauge is in different access modes, as described in Table 4-2.

Table 4-2. Control( ) Subcommands

CNTL Function	CNTL Data	SEALED Access	Description
CONTROL_STATUS	0x0000	Yes	Reports the status of DF Checksum, Impedance Track™, etc.
DEVICE_TYPE	0x0001	Yes	Reports the device type of 0x0741 (indicating bq27741-G1)
FW_VERSION	0x0002	Yes	Reports the firmware version on the device type
HW_VERSION	0x0003	Yes	Reports the hardware version of the device type
PROTECTOR_VERSION	0x0004	Yes	Reports the hardware version of the protector portion of the device
RESET_DATA	0x0005	Yes	Returns reset data
Reserved	0x0006	No	Not to be used
PREV_MACWRITE	0x0007	Yes	Returns previous *Control( )* subcommand code
CHEM_ID	0x0008	Yes	Reports the chemical identifier of the Impedance Track™ configuration
BOARD_OFFSET	0x0009	No	Forces the device to measure and store the board offset
CC_OFFSET	0x000A	No	Forces the device to measure internal CC offset
CC_OFFSET_SAVE	0x000B	No	Forces the device to store the internal CC offset
DF_VERSION	0x000C	Yes	Reports the data flash version on the device
SET_FULLSLEEP	0x0010	Yes	Sets the *CONTROL_STATUS [FULLSLEEP]* bit to 1
SET_SHUTDOWN	0x0013	Yes	Sets the *CONTROL_STATUS [SHUTDN_EN]* bit to 1
CLEAR_SHUTDOWN	0x0014	Yes	Clears the *CONTROL_STATUS [SHUTDN_EN]* bit to 0
SET_HDQINTEN	0x0015	Yes	Forces the *CONTROL_STATUS [HDQIntEn]* bit to 1
CLEAR_HDQINTEN	0x0016	Yes	Forces the *CONTROL_STATUS [HDQIntEn]* bit to 0
STATIC_CHEM_CHKSUM	0x0017	Yes	Calculates chemistry checksum
ALL_DF_CHKSUM	0x0018	Yes	Reports checksum for all data flash excluding device specific variables
STATIC_DF_CHKSUM	0x0019	Yes	Reports checksum for static data flash excluding device specific variables
SEALED	0x0020	No	Places the fuel gauge in SEALED access mode
IT_ENABLE	0x0021	No	Enables the Impedance Track™ algorithm
START_FET_TEST	0x0024	No	Starts FET Test based on data entered in FET Test register. Sets and clears the *[FETTST]* bit in the *CONTROL_STATUS* register
CAL_ENABLE	0x002D	No	Toggle calibration mode
RESET	0x0041	No	Forces a full reset of the fuel gauge
EXIT_CAL	0x0080	No	Exit calibration mode
ENTER_CAL	0x0081	No	Enter calibration mode
OFFSET_CAL	0x0082	No	Reports internal CC offset in calibration mode

4.1.1.1 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 4-3. CONTROL_STATUS Flags

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High Byte	RSVD	FAS	SS	CALMODE	CCA	BCA	RSVD	HDQHOSTIN
Low Byte	SHUTDWN	FETTST	FULLSLEEP	SLEEP	LDMD	RUP_DIS	VOK	QEN

High Byte

RSVD = Reserved

FAS = Status bit indicating the fuel gauge is in FULL ACCESS SEALED state. Active when set (no data flash access).

SS = Status bit indicating the fuel gauge is in the SEALED state. Active when set (no ROM access).

CALMODE = Status bit indicating the calibration function is active. True when set. Default is 0.

CCA = Status bit indicating the 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.

BCA = Status bit indicating the Board Calibration routine is active. Active when set.

RSVD = Reserved

HDQHOSTIN = Status bit indicating the HDQ interrupt function is active. True when set. Default is 0.

Low Byte

SHUTDN_EN = Control bit indicating that the *SET_SHUTDOWN* subcommand has been sent and signals an external shutdown of the fuel gauge when conditions permit. See Section 2.5.1, *Shutdown Mode*.

FETTST = Status bit indicating the state of the FET test. True when set. Default is 0.

FULLSLEEP = Status bit indicating the fuel gauge is in FULLSLEEP mode. True when set. The state can be detected by monitoring the power used by the fuel gauge because any communication automatically clears it.

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

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

RUP_DIS = Status bit indicating the Ra table updates are disabled. True when set.

VOK = Status bit indicating cell voltages are OK for Qmax updates. True when set.

QEN = Status bit indicating the Qmax updates are enabled. True when set.

4.1.1.2 DEVICE_TYPE: 0x0001

Instructs the fuel gauge to return the device type to addresses 0x00 and 0x01. The bq27741-G1 device type returns 0x0741.

4.1.1.3 FW_VERSION: 0x0002

Instructs the fuel gauge to return the firmware version to addresses 0x00 and 0x01. The firmware version returned is 0x0105.

4.1.1.4 HW_VERSION: 0x0003

Instructs the fuel gauge to return the hardware version to addresses 0x00 and 0x01. For bq27741-G1, 0x0000 or 0x0060 is returned.

4.1.1.5 PROTECTOR_VERSION: 0x0004

Instructs the fuel gauge to return the hardware version of the protector portion of the device to addresses 0x00 and 0x01.

4.1.1.6 RESET_DATA: 0x0005

Instructs the fuel gauge to return the number of resets performed to addresses 0x00 and 0x01.

4.1.1.7 PREV_MACWRITE: 0x0007

Instructs the fuel gauge to return the previous *Control()* subcommand written to addresses 0x00 and 0x01. The value returned is limited to less than 0x0020.

4.1.1.8 CHEM_ID: 0x0008

Instructs the fuel gauge to return the chemical identifier for the Impedance Track™ configuration to addresses 0x00 and 0x01.

4.1.1.9 BOARD_OFFSET: 0x0009

Instructs the fuel gauge to perform the board offset calibration. During board offset calibration the *CONTROL_STATUS [BCA]* bit is set.

4.1.1.10 CC_OFFSET: 0x000A

Instructs the fuel gauge to perform the coulomb counter offset calibration. During calibration the *CONTROL_STATUS [CCA]* bit is set.

4.1.1.11 CC_OFFSET_SAVE: 0x000B

Instructs the fuel gauge to save the calibration coulomb counter offset after calibration.

4.1.1.12 DF_VERSION: 0x000C

Instructs the fuel gauge to return the data flash version stored in ***DF Config Version*** to addresses 0x00 and 0x01.

4.1.1.13 SET_FULLSLEEP: 0x0010

Instructs the fuel gauge to set the *CONTROL_STATUS [FULLSLEEP]* bit to 1. The gauge enters the FULLSLEEP power mode after the transition to the SLEEP power state is detected. In FULLSLEEP mode less power is consumed by disabling an oscillator circuit used by the communication engines. For HDQ communication one host message is dropped. For I^2C™ communications the first I^2C message incurs a 6- to 8-ms clock stretch while the oscillator is started and stabilized. A communication to the device in FULLSLEEP forces the part back to the SLEEP mode.

4.1.1.14 SET_SHUTDOWN: 0x0013

Sets the *CONTROL_STATUS [SHUTDN_EN]* bit to 1, thereby enabling the fuel gauge to shutdown if conditions are met.

When the *[SHUTDWN]* bit is set, the gas gauge opens both charge and discharge FETs and waits for charger removal. As soon as charger is removed, the gas gauge and protector will shutdown leaving both charger and discharge FETs open. The only way to recover from this Shutdown Mode is to connect a charger.

4.1.1.15 CLEAR_SHUTDOWN: 0x0014

Clears the *CONTROL_STATUS [SHUTDN_EN]* bit to 0. The gas gauge closes the charge and discharge FETs and aborts the shutdown sequence.

4.1.1.16 SET_HDQINTEN: 0x0015

Instructs the fuel gauge to set the *CONTROL_STATUS [HDQIntEn]* bit to 1. This enables the HDQ interrupt function. When this subcommand is received, the device detects any of the interrupt conditions and asserts the interrupt at one-second intervals until:

- The *CLEAR_HDQINTEN* subcommand is received, or
- The number of tries for interrupting the host has exceeded a predetermined limit (default 3).

4.1.1.17 CLEAR_HDQINTEN: 0x0016

Instructs the fuel gauge to set the *CONTROL_STATUS [HDQIntEn]* bit to 0. This disables the HDQ interrupt function.

4.1.1.18 STATIC_CHEM_CHKSUM: 0x0017

Instructs the fuel gauge to calculate chemistry checksum as a 16-bit unsigned integer sum of all static chemistry data. The most significant bit (MSB) of the checksum is masked yielding a 15-bit checksum. This checksum is compared with value stored in the data flash ***Static Chem DF Checksum***. If the value matches, the MSB is cleared to indicate pass. If it does not match, the MSB is set to indicate failure. The checksum can verify the integrity of the chemistry data stored internally.

NOTE: The ***Static Chem DF Checksum*** is programmed by the Chemistry programming tool.

4.1.1.19 ALL_DF_CHKSUM: 0x0018

Instructs the fuel gauge to calculate data flash checksum as a 16-bit unsigned integer sum of all data flash excluding device specific variables. The most significant bit (MSB) of the checksum is masked yielding a 15-bit checksum. This checksum is compared with value stored in the data flash ***ALL_DF_Checksum***. If the value matches, the MSB is cleared to indicate pass. If it does not match, the MSB is set to indicate failure. The checksum can verify the integrity of the data flash stored internally.

4.1.1.20 STATIC_DF_CHKSUM: 0x0019

Instructs the fuel gauge to calculate static data flash checksum as a 16-bit unsigned integer sum of static data flash excluding device specific variables. The most significant bit (MSB) of the checksum is masked yielding a 15-bit checksum. This checksum is compared with value stored in the data flash ***Static_DF_Checksum***. If the value matches, the MSB is cleared to indicate pass. If it does not match, the MSB is set to indicate failure. The checksum can verify the integrity of the static data flash stored internally.

4.1.1.21 SEALED: 0x0020

Instructs the fuel gauge to transition from UNSEALED state to SEALED state. The fuel gauge should always be set to SEALED state for use in customer’s end equipment as it prevents spurious writes to most standard commands and blocks access to most data flash.

4.1.1.22 IT ENABLE: 0x0021

Forces the fuel gauge to begin the Impedance Track™ algorithm, sets bit 2 of ***UpdateStatus*** and causes the *[VOK]* and *[QEN]* flags to be set in the *CONTROL_STATUS* register. *[VOK]* is cleared if the voltages are not suitable for a Qmax update. Once set, *[QEN]* cannot be cleared. This command is only available when the fuel gauge is UNSEALED and is typically enabled at the last step of production after system test is completed.

4.1.1.23 START_FET_TEST: 0x0024

In UNSEALED mode and when IT is not enabled, this command starts the FET Test based on data entered in the *FETTest()* register. On a write to this register, the *FETTest()* register is evaluated for checksum correctness (see Section 4.2.14 for details). If checksum is correct, then the *[FETTST]* bit in the *CONTROL_STATUS* register is set and the FETs selected in the *FETTest()* register are opened by using FW override of the FETs. If the *[RECEN]* bit in *FETTest()* is set, then the FW override is removed and *[FETTST]* bit is cleared after 2 seconds. If *[RECEN]* is 0, then FW override of the selected FETs is never removed unless the device is reset or a fresh *START_FET_TEST* command is sent which allows the override to be removed.

4.1.1.24 RESET: 0x0041

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

4.1.1.25 EXIT_CAL: 0x0080

Instructs the fuel gauge to exit calibration mode.

4.1.1.26 ENTER_CAL: 0x0081

Instructs the fuel gauge to enter calibration mode.

4.1.1.27 OFFSET_CAL: 0x0082

Instructs the fuel gauge to perform offset calibration.

4.1.2 AtRate( ): 0x02 and 0x03

The *AtRate( )* is a read-write function that reads or sets the load value used in computing load-compensated capacity in the Impedance Track™ algorithm when ***Load Mode*** = 0 and ***Load Select*** = 5. *AtRate( )* is not supported when ***Load Mode*** = 1. The *AtRate( )* value is a signed integer, with negative values interpreted as a discharge current value. *AtRate( )* commands should only be used in NORMAL mode.

The unit of *AtRate( )* is mA and the default value is 0.

4.1.3 UnfilteredSOC( ): 0x04 and 0x05

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%.

4.1.4 Temperature( ): 0x06 and 0x07

This read-only function returns an unsigned integer value of the battery temperature in units of 0.1°K measured by the fuel gauge and is used for fuel gauging algorithm. It reports either the *InternalTemperature()* or the external thermistor temperature depending on the setting of the ***[TEMPS]*** bit in ***Pack Configuration***.

4.1.5 Voltage( ): 0x08 and 0x09

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

4.1.6 Flags( ): 0x0A and 0x0B

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

Table 4-4. Flags Bit Definitions

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High Byte	OTC	OTD	BATHI	BATLOW	CHG_INH	OT_FET	FC	CHG
Low Byte	OCVTAKEN	ISD	TDD	RSVD	RSVD	SOC1	SOCF	DSG

High Byte

OTC = Over-Temperature in Charge condition is detected. True when set. See the parameters in Section 5.3.1, *Safety Subclass*, for threshold settings.

OTD = Over-Temperature in Discharge condition is detected. True when set. See the parameters in Section 5.3.1, *Safety Subclass*, for threshold settings.

BATHI = Battery High bit indicating a high battery voltage condition. See the parameters in Section 5.3.5.4, *Battery High Set Voltage Threshold, Time, and Clear,* for threshold settings.

BATLOW = Battery Low bit indicating a low battery voltage condition. See the parameters in Section 5.3.5.3, *Battery Low Set Voltage Threshold, Time, and Clear,* for threshold settings.

CHG_INH = Charge Inhibit indicates the temperature is outside the range ***[Charge Inhibit Temp Low, Charge Inhibit Temp High]***. True when set.

OT_FET = Indicates when overtemperature condition has been reached. True when set.

FC = Full-charged is detected. FC is set when charge termination is reached and ***FC Set %*** = –1 (see Section 2.8, *Charging and Charge Termination Indication*, for details) or State of Charge is larger than ***FC Set %*** and ***FC Set %*** is not –1. True when set.

CHG = (Fast) charging allowed. True when set.

Low Byte

OCVTAKEN = Cleared on entry to relax mode and set to 1 when OCV measurement is performed in relax mode.

ISD = Internal Short is detected. True when set.

TDD = Tab Disconnect is detected. True when set.

RSVD = Bits 3 and 4 are reserved.

SOC1 = State-of-Charge Threshold 1 ***(SOC1 Set)*** reached. True when set.

SOCF = State-of-Charge Threshold Final ***(SOCF Set %)*** reached. True when set.

DSG = Discharging detected. True when set.

4.1.7 NominalAvailableCapacity( ): 0x0C and 0x0D

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

4.1.8 FullAvailableCapacity( ): 0x0E and 0x0F

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

4.1.9 RemainingCapacity( ): 0x10 and 0x11

This read-only command pair returns the compensated battery capacity remaining (*UnfilteredRM()*) when the ***[SmoothEn]*** bit in ***Pack Configuration C*** is cleared or filtered compensated battery capacity remaining (*FilteredRM()*) when ***[SmoothEn]*** bit is set. Units are mAh.

4.1.10 FullChargeCapacity( ): 0x12 and 0x13

This read-only command pair returns the compensated capacity of fully charged battery (*UnfilteredFCC()*) when the ***[SmoothEn]*** bit in ***Pack Configuration C*** is cleared or filtered compensated capacity of fully charged battery (*FilteredFCC()*) when ***[SmoothEn]*** bit is set. Units are mAh. *FullChargeCapacity()* is updated at regular intervals, as specified by the IT algorithm.

4.1.11 AverageCurrent( ): 0x14 and 0x15

This read-only command pair returns a signed integer value that is the average current flow through the sense resistor. It is updated every second in NORMAL mode and every 20 seconds in SLEEP and FULLSLEEP modes. Units are mA.

4.1.12 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.

4.1.13 FilteredFCC( ): 0x18 and 0x19

This read-only command pair returns the filtered, compensated capacity of the battery when fully charged. Units are mAh. *FilteredFCC()* is updated at regular intervals, as specified by the IT algorithm.

4.1.14 StandbyCurrent( ): 0x1A and 0x1B

This read-only function returns a signed integer value of the measured system 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 some time in standby, reports the measured standby current.

The register value is updated every second when the measured discharge current is between 0 and 2 × ***Initial Standby*** for 3 consecutive seconds. The first and last values that meet this criteria are not averaged in, because they may not be stable values. To approximate a 1-minute time constant, each new *StandbyCurrent( )* value is computed by taking approximately 93% of the last standby current and approximately 7% of the current measured average current. *StandbyCurrent( )* averaging filter constant is set by ***Filter***.

4.1.15 UnfilteredFCC( ): 0x1C and 0x1D

This read-only command pair returns the compensated capacity of the battery when fully charged. Units are mAh. *UnFilteredFCC()* is updated at regular intervals, as specified by the IT algorithm.

4.1.16 MaxLoadCurrent( ): 0x1E and 0x1F

This read-only function returns a signed integer value, in units of mA, of the maximum load conditions of the system. The *MaxLoadCurrent( )* is an adaptive measurement which is initially reported as the maximum load current programmed in ***Initial Max Load Current***. If the measured current is ever greater than ***Initial Max Load Current***, then *MaxLoadCurrent( )* updates to the new current. *MaxLoadCurrent( )* is reduced to the average of the previous value and ***Initial Max Load Current*** whenever the battery is charged to full after a previous discharge to an SOC less than 50%. This prevents the reported value from maintaining an unusually high value.

4.1.17 UnfilteredRM( ): 0x20 and 0x21

This read-only command pair returns the compensated battery capacity remaining. Units are mAh.

4.1.18 FilteredRM( ): 0x22 and 0x23

This read-only command pair returns the filtered, compensated battery capacity remaining. Units are mAh.

4.1.19 AveragePower( ): 0x24 and 0x25

This read-word function returns an unsigned integer value of the average power of the current discharge. It is negative during discharge and positive during charge. A value of 0 indicates that the battery is not being discharged. The value is reported in units of mW (***Design Energy Scale*** = 1) or cW (***Design Energy Scale*** = 10).

4.1.20 InternalTemperature( ): 0x28 and 0x29

This read-only function returns an unsigned integer value of the measured internal temperature of the device in units of 0.1°K as measured by the fuel gauge.

4.1.21 CycleCount( ): 0x2A and 0x2B

This read-only function returns an unsigned integer value of the number of cycles the battery has experienced with a range of 0 to 65,535. One cycle occurs when accumulated discharge ≥ ***CC Threshold***.

4.1.22 StateOfCharge( ): 0x2C and 0x2D

This read-only function returns an unsigned integer value of the predicted *RemainingCapacity( )* expressed as a percentage of *FullChargeCapacity( )*, with a range of 0 to 100%. The *StateOfCharge()* can be filtered or unfiltered since *RemainingCapacity( )* and *FullChargeCapacity( )* can be filtered or unfiltered based on ***[SmoothEn]*** bit selection in ***Pack Configuration C***.

4.1.23 StateOfHealth( ): 0x2E and 0x2F

0x2E SOH percentage: this read-only function returns an unsigned integer value, expressed as a percentage of the ratio of predicted *FCC(25°C, SOH Load I)* over the *DesignCapacity()*. The *FCC(25°C, SOH Load I)* is the calculated full charge capacity at 25°C and the SOH current rate which is specified by *SOH Load I*. The range of the returned SOH percentage is 0x00 to 0x64, indicating 0 to 100%, correspondingly.

4.1.24 PassedCharge( ): 0x34 and 0x35

This signed integer indicates the amount of charge passed through the sense resistor since the last IT simulation in mAh.

4.1.25 DOD0( ): 0x36 and 0x37

This unsigned integer indicates the depth of discharge during the most recent OCV reading.

4.1.26 SelfDischargeCurrent( ): 0x38 and 0x39

This read-only command pair returns the signed integer value that estimates the battery self-discharge current.

4.2 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 ranges in size from single to multiple bytes, as specified in Table 4-5. For details on the SEALED and UNSEALED states, see Section 5.1.3, *Access Modes*.

Table 4-5. Extended Commands

Name		Command Code	Unit	SEALED Access[(1)] [(2)]	UNSEALED Access[(1)] [(2)]
PackConfig( )	PCR	0x3A and 0x3B	hex#	R	R
DesignCapacity( )	DCAP	0x3C and 0x3D	mAh	R	R
DataFlashClass( ) [(2)]	DFCLS	0x3E	NA	NA	RW
DataFlashBlock( ) [(2)]	DFBLK	0x3F	NA	RW	RW
BlockData( ) / Authenticate( )[(3)]	A/DF	0x40 to 0x53	NA	RW	RW
BlockData( ) / AuthenticateCheckSum( ) [(3)]	ACKS/DFD	0x54	NA	RW	RW
BlockData( )	DFD	0x55 to 0x5F	NA	R	RW
BlockDataCheckSum( )	DFDCKS	0x60	NA	RW	RW
BlockDataControl( )	DFDCNTL	0x61	NA	NA	RW
DeviceNameLength( )	DNAMELEN	0x62	NA	R	R
DeviceName( )	DNAME	0x63 to 0x6C	NA	R	R
Protector Status	AFESTAT1	0x6D	hex	R	R
Reserved	RSVD	0x6E and 0x6F	NA	R	R
Simultaneous Current		0x70 and 0x71	NA	R	R
Reserved	RSVD	0x72 and 0x73	NA	R	R
FETTest( )		0x74 and 0x75	NA	NA	RW
Reserved	RSVD	0x76 and 0x77	NA	R	R
Protector State	AFESTATE	0x78	hex	R	R
Reserved[(4)]	RSVD	0x79	NA	R	R
DODatEOC( )[(4)]		0x7A and 0x7B	NA	R	R
QStart( )[(4)]		0x7C and 0x7D	mA	R	R
FastQmax( )[(4)]		0x7E and 0x7F	mAh	R	R
AN_COUNTER[(5)]		0x79			
AN_CURRENT_LSB[(5)]		0x7A			
AN_CURRENT_MSB[(5)]		0x7B			
AN_VCELL_LSB[(5)]		0x7C			
AN_VCELL_MSB[(5)]		0x7D			
AN_TEMP_LSB[(5)]		0x7E			
AN_TEMP_MSB [(5)]		0x7F			

[(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)] The *BlockData( )* command area shares functionality for accessing general data flash and for using Authentication. See Section 3.1, *Authentication*, for more details.

[(4)] If *CONTROL_STATUS [CALMODE]* bit = 0, then this address or command is valid.

[(5)] If *CONTROL_STATUS [CALMODE]* bit = 1, then this address or command is valid.

4.2.1 PackConfig( ): 0x3A and 0x3B

SEALED and UNSEALED Access: This command returns the value stored in ***Pack Configuration*** and is expressed in hex value.

4.2.2 DesignCapacity( ): 0x3C and 0x3D

SEALED and UNSEALED Access: This command 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, but has no bearing on the operation of the fuel gauge functionality.

4.2.3 DataFlashClass( ): 0x3E

This command sets the data flash class to be accessed. The subclass ID to be accessed must be entered in hexadecimal.

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

4.2.4 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 and 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 0x00 to *DataFlashBlock( )* specifies the *BlockData( )* command transfers authentication data. Issuing a 0x01 or 0x02 instructs the *BlockData( )* command to transfer ***Manufacturer Info Block A or B***, respectively.

4.2.5 BlockData( ): 0x40 Through 0x5F

This command range is used to transfer data for data flash class access. This command range is the 32-byte data block used to access ***Manufacturer Info Block A*** or ***B***. ***Manufacturer Info Block A*** is read-only for the SEALED access. UNSEALED access is read-write.

4.2.6 BlockDataChecksum( ): 0x60

The host system must write this value to inform the device that new data is ready for programming into the specified data flash class and block.

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] , for x the 8-bit summation of the *BlockData()* (0x40 to 0x5F) on a byte-by-byte basis) before being written to 0x60.

SEALED Access: This byte contains the checksum for the 32 bytes of block data written to ***Manufacturer Info Block A***. The least-significant byte of the sum of the data bytes written must be complemented ([255 – x] , for x the 8-bit summation of the *BlockData()* (0x40 to 0x5F) on a byte-by-byte basis) before being written to 0x60.

4.2.7 BlockDataControl( ): 0x61

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

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

4.2.8 DeviceNameLength( ): 0x62

UNSEALED and SEALED Access: This byte contains the length of the ***Device Name***.

4.2.9 DeviceName( ): 0x63 Through 0x6C

UNSEALED and SEALED Access: This block contains the device name that is programmed in ***Device Name***.

4.2.10 Protector Status: 0x6D

UNSEALED and SEALED Access: This block returns protector status register AFESTAT1.

Table 4-6. Protector Status Register

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
CHG_OFF	DSG_OFF	CVM	UVP	OVP	SCD	OCD	OCC

CHG_OFF = Firmware override to disable charge FET:
1 = Charge FET Off
0 = Charge FET On

DSG_OFF = Firmware override to disable discharge FET:
1 = Discharge FET Off
0 = Discharge FET On

CVM = Cell voltage monitor threshold:
1 = Cell voltage monitor threshold detected
0 = Cell voltage monitor threshold not detected

UVP = Undervoltage protection fault:
1 = Undervoltage protection fault detected
0 = Undervoltage protection fault not detected

OVP = Overvoltage protection fault:
1 = Overvoltage protection fault detected
0 = Overvoltage protection fault not detected

SCD = Short-circuit discharge fault:
1 = Short-circuit discharge fault detected
0 = Short-circuit discharge fault not detected

OCD = Overcurrent discharge fault:
1 = Overcurrent discharge fault detected
0 = Overcurrent discharge fault not detected

OCC = Overcurrent charge fault:
1 = Overcurrent charge fault detected
0 = Overcurrent charge fault not detected

4.2.11 Reserved – 0x6E and 0x6F

4.2.12 Simultaneous Current: 0x70 and 0x71

UNSEALED and SEALED Access: This is the Current (in mA) measured simultaneously with Voltage.

4.2.13 Reserved – 0x72 and 0x73

4.2.14 FETTest( ): 0x74 and 0x75

UNSEALED Access: This command sets up the data for the START_FET_TEST command and provides FET test status.

Table 4-7. FETTest() Register

<table>
<tr><th>bit7</th><th>bit6</th><th>bit5</th><th>bit4</th><th>bit3</th><th>bit2</th><th>bit1</th><th>bit0</th></tr>
<tr><td colspan="8">STATUS</td></tr>
<tr><td colspan="2">CHKSUM</td><td>RSVD</td><td>RSVD</td><td>RSVD</td><td>RECEN</td><td>CHG</td><td>DSG</td></tr>
</table>

High Byte

STATUS = The STATUS field indicates the status of the FET Test:
0xFF = Checksum error, the *START_FET_TEST* command was unsuccessful.
2-3 = *START_FET_TEST* command was successful with RECEN = 1.
FW is currently waiting for 2 seconds to elapse to remove the FW override applied to the selected FETs. This field works like a countdown timer. It starts at 3 and counts down by 1 each second. When it reaches 1, the FW override is removed and the selected FETs return to hardware control again.
1 = Either *START_FET_TEST* command was executed with RECEN = 1 and the selected FETs return to hardware control,
or
START_FET_TEST command was executed with RECEN = 0 (selected FETs are in FW override state and are opened).

Low Byte

CHG = If set, this results in the CHG FET being opened on executing the *START_FET_TEST* command.

DSG = If set, this results in the DSG FET being opened on executing the *START_FET_TEST* command.

RECEN = Recovery Enable. Enables recovery of the FETs 2 seconds after the *START_FET_TEST* command is executed.
If this bit is set, the selected FETs are left under hardware control after 2 seconds.
If this bit is not set, the selected FETs will remain in FW override state and remain opened.

CHKSUM = Checksum should be set to CHG + DSG + RECEN.
If the checksum does not match this value, the *START_FET_TEST* command will not have any effect and this will be indicated by setting STATUS = 0xFF.

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

4.2.15 Reserved – 0x76 and 0x77

4.2.16 Protector State: 0x78

UNSEALED and SEALED Access: This block returns protector state machine register AFESTATE.

Table 4-8. Protector State Register

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
RSVD	RSVD	SHUTDWNW	OVP	OCD_SCD	OCC	NORMAL	HOLD

RSVD = Bits 6 and 7 are reserved.

SHUTDWNW = Protector State Machine in Shutdown Wait state
1 = Shutdown Wait State
0 = Not in Shutdown Wait State

OVP = Protector State Machine in OVP state
1 = OVP State
0 = Not in OVP State

OCD_SCD = Protector State Machine in OCD or SCD state
1 = OCD or SCD State
0 = Not in OCD or SCD State

OCC = Protector State Machine in OCC state
1 = OCC State
0 = Not in OCC State

NORMAL = Protector State Machine in NORMAL state
1 = NORMAL state
0 = Not in NORMAL state

HOLD = Protector State Machine in HOLD state
1 = HOLD state
0 = Not in HOLD state

4.2.17 Reserved – 0x79

If *CONTROL_STATUS [CALMODE]* bit = 0, then this address is reserved.

4.2.18 DOD at EOC: 0x7A and 0x7B

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 0, then this command reports DOD at the end of charge (EOC).

4.2.19 QStart: 0x7C and 0x7D

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 0, then this command reports Qstart.

4.2.20 Fast Qmax: 0x7E and 0x7F

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 0, then this command reports Fast Qmax.

4.2.21 AN_COUNTER: 0x79

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_COUNTER.

4.2.22 AN_CURRENT_LSB: 0x7A

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_CURRENT_LSB.

4.2.23 AN_CURRENT_MSB: 0x7B

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_CURRENT_MSB.

4.2.24 AN_VCELL_LSB: 0x7C

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_VCELL_LSB.

4.2.25 AN_VCELL_MSB: 0x7D

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_VCELL_MSB.

4.2.26 AN_TEMP_LSB: 0x7E

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_TEMP_LSB.

4.2.27 AN_TEMP_MSB: 0x7F

UNSEALED and SEALED Access: If *CONTROL_STATUS [CALMODE]* bit = 1, then this command reports AN_TEMP_MSB.

Data Flash Summary

5.1 Data Flash Interface

5.1.1 Accessing The Data Flash

The 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 bq27741-G1 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 4 *Data Commands*. These commands are available when the fuel gauge is either in UNSEALED or SEALED modes.

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 must 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 battery packs. 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, the data residing in the command space is transferred to data flash, once the correct checksum for the whole block is written to *BlockDataChecksum( )* (0x60).

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 67, it must reside in the third 32-byte block. Hence, *DataFlashBlock( )* is issued 0x02 to set the block offset, and the offset used to index into the *BlockData( )* memory area is 0x40 + 67 *modulo* 32 = 0x40 + 16 = 0x40 + 0x03 = 0x43.

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 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 persistent, so a power-on reset does not resolve the fault.

5.1.2 Manufacturer Information Blocks

The fuel gauge contains 64 bytes of user programmable data flash storage: ***Manufacturer Info Block A*** and ***Manufacturer Info Block B***. The method for accessing these memory locations is slightly different, depending on whether the device is in UNSEALED or SEALED modes.

When in UNSEALED mode and when 0x00 has been written to *BlockDataControl( )*, accessing the Manufacturer Info 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 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.

As an example, the data flash location for ***Manufacturer Info Block B*** is defined as having a Subclass = 58 and an Offset = 32 through 63 (32-byte block). The specification of Class = System Data is not needed to address ***Manufacturer Info Block B***, but is used instead for grouping purposes when viewing data flash info in the evaluation software.

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

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

5.1.3 Access Modes

The fuel gauge provides three security modes (FULL ACCESS, UNSEALED, and SEALED) that control data flash access permissions according to Table 5-1. Data Flash column refers to those data flash locations that are accessible to the user. Manufacturer Information column refers to the two 32-byte blocks.

Table 5-1. Data Flash Access

Security Mode	Data Flash	Manufacturer Information
FULL ACCESS	RW	RW
UNSEALED	RW	RW
SEALED	None	R (A); RW (B)

Although FULL ACCESS and UNSEALED modes appear identical, only the FULL ACCESS mode allows the fuel gauge to write access-mode transition keys stored in the Security class.

5.1.4 Sealing or 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. To avoid conflict, the keys must be different from the codes presented in the CNTL DATA column of Table 4-2, *Control( ) Subcommands*.

When in 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, the *CONTROL_STATUS [FAS]* bit is cleared.

Both ***Unseal Key*** and ***Full-Access Key*** have two words and are stored in data flash. The first word is Key 0 and the second word is Key 1. The order of the keys sent to fuel gauge are Key 1 followed by Key 0. The order of the bytes for each key entered through the *Control( )* command is the reverse of what is read from the part. For an example, if the Unseal Key is 0x56781234, key 1 is 0x1234 and key 0 is 0x5678. Then *Control( )* must supply 0x3412 and 0x7856 to unseal the part. The ***Unseal Key*** and the ***Full-Access Key*** can only be updated when in FULL-ACCESS mode.

5.2 Data Flash Summary Tables

Table 5-3 through Table 5-9 summarize the data flash locations available to the user, including their default, minimum, and maximum values.

Table 5-2. Data Type Decoder

Type	Min Value	Max Value
I1	–128	127
I2	–32768	32767
I4	−2,147,483,648	2,147,483,647
U1	0	255
U2	0	65535
U4	0	4,294,967,295
H1	0x00	0xFF
H2	0x00	0xFFFF
H4	0x00	0xFFFF FFFF
Sx	1-byte string	X-byte string

Table 5-3. Data Flash Summary—Configuration Class

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
2	Safety	0	OT Chg	I2	0	1200	550	0.1°C
		2	OT Chg Time	U1	0	60	5	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	5	s
		8	OT Dsg Recovery	I2	0	1200	550	0.1°C
		10	OT Prot Threshold	I2	0	1200	600	0.1°C
		12	OT Prot Delay	U1	0	60	3	s
		13	OT Prot Recovery	I2	0	1200	550	0.1°C
34	Charge	0	Charging Voltage	I2	0	4600	4200	mV
36	Charge Termination	0	Taper Current	I2	0	1000	100	mA
		2	Min Taper Capacity	I2	0	1000	25	mAh
		4	Taper Voltage	I2	0	1000	100	mV
		6	Current Taper Window	U1	0	60	40	s
		7	TCA Set %	I1	–1	100	99	%
		8	TCA Clear %	I1	–1	100	95	%
		9	FC Set %	I1	–1	100	–1	%
		10	FC Clear %	I1	–1	100	98	%
		11	DODatEOC Delta T	I2	0	1000	50	0.1°C

Table 5-3. Data Flash Summary—Configuration Class (continued)

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	8	Initial Standby	I1	–256	0	–10	mA
		9	Initial MaxLoad	I2	–32767	0	–500	mA
		17	Cycle Count	U2	0	65535	0	Count
		19	CC Threshold	I2	100	32767	900	mAh
		23	Design Capacity	I2	0	32767	1000	mAh
		25	Design Energy	I2	0	32767	5400	mWh
		27	SOH Load I	I2	–32767	0	-400	mA
		29	TDD SOH Percent	I1	0	100	80	%
		40	ISD Current	I2	0	32767	10	Hour Rate
		42	ISD I Filter	U1	0	255	127	Count
		43	Min ISD Time	U1	0	255	7	Hour
		44	Design Energy Scale	U1	1	10	1	number
		45	Device Name	S11	x	x	bq27741-G1	
49	Discharge	0	SOC1 Set Threshold	U2	0	65535	150	mAh
		2	SOC1 Clear Threshold	U2	0	65535	175	mAh
		4	SOCF Set Threshold	U2	0	65535	75	mAh
		6	SOCF Clear Threshold	U2	0	65535	100	mAh
		9	BL Set Volt Threshold	I2	0	16800	2500	mV
		11	BL Set Volt Time	U1	0	60	2	s
		12	BL Clear Volt Threshold	I2	0	16800	2600	mV
		14	BH Set Volt Threshold	I2	0	16800	4500	mV
		16	BH Volt Time	U1	0	60	2	s
		17	BH Clear Volt Threshold	I2	0	16800	4400	mV
56	Manufacturer Data	0	Pack Lot Code	H2	0x0000	0xFFFF	0x0000	hex
		2	PCB Lot Code	H2	0x0000	0xFFFF	0x0000	hex
		4	Firmware Version	H2	0x0000	0xFFFF	0x0000	hex
		6	Hardware Revision	H2	0x0000	0xFFFF	0x0000	hex
		8	Cell Revision	H2	0x0000	0xFFFF	0x0000	hex
		10	DF Config Version	H2	0x0000	0xFFFF	0x0000	hex
57	Integrity Data	6	All DF Checksum	H2	0x0000	0x7FFF	0x0000	hex
		8	Static Chem DF Checksum	H2	0x0000	0x7FFF	0x0000	hex
		10	Static DF Checksum	H2	0x0000	0x7FFF	0x0000	hex
59	Lifetime Data	0	Lifetime Max Temp	I2	0	1400	0	0.1°C
		2	Lifetime Min Temp	I2	–600	1400	500	0.1°C
		4	Lifetime Max Pack Voltage	I2	0	32767	2800	mV
		6	Lifetime Min Pack Voltage	I2	0	32767	4200	mV
		8	Lifetime Max Chg Current	I2	–32767	32767	0	mA
		10	Lifetime Max Dsg Current	I2	–32767	32767	0	mA
60	Lifetime Temp Samples	0	LT Flash Cnt	I2	0	32767	0	Count
		2	LT AFE Status	H1	0x00	0xFF	0x00	hex

Table 5-3. Data Flash Summary—Configuration Class (continued)

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
64	Registers	0	Pack Configuration	H2	0x0000	0xFFFF	0x1171	flags
		2	Pack Configuration B	H1	0x00	0xFF	0xA7	flags
		3	Pack Configuration C	H1	0x00	0xFF	0x1C	flags
66	Lifetime Resolution	0	LT Temp Res	U1	0	255	10	°C
		1	LT V Res	U1	0	255	25	mV
		2	LT Cur Res	U1	0	255	100	mA
		3	LT Update Time	U2	0	65535	60	s
68	Power	0	Flash Update OK Voltage	I2	0	4200	2800	mV
		2	Sleep Current	I2	0	100	10	mA
		11	Shutdown V	I2	0	2600	0	mV
		13	FS Wait	U1	0	255	0	s

Table 5-4. Data Flash Summary—System Data Class

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
58	Manufacturer Info	0	Block A 0 through 31	H1	0x00	0xFF	0x00	hex
		32	Block B 0 through 31	H1	0x00	0xFF	0x00	hex

Table 5-5. Data Flash Summary—Gas (Fuel) 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	0	number
		21	Max Res Factor	U1	0	255	15	number
		22	Min Res Factor	U1	0	255	5	number
		25	Ra Filter	U2	0	1000	800	number
		42	Fast Qmax Start DOD %	U1	0	255	92	%
		43	Fast Qmax End DOD %	U1	0	255	96	%
		44	Fast Qmax Start Volt Delta	I2	0	4200	200	mV
		46	Fast Qmax Current Threshold	I2	0	1000	4	C/rate
		64	Qmax Capacity Err	U1	0	100	15	0.10%
		65	Max Qmax Change	U1	0	255	30	%
		67	Terminate Voltage	I2	2800	3700	3000	mV
		69	Term V Delta	I2	0	4200	200	mV
		72	ResRelax Time	U2	0	65534	500	s
		78	User Rate-Pwr	I2	3000	14000	0	cW
		80	Reserve Cap-mAh	I2	0	9000	0	mAh
		82	Reserve Energy	I2	0	14000	0	cWh
		87	Max DeltaV	U2	0	65535	200	mV
		89	Min DeltaV	U2	0	65535	0	mV
		91	Max Sim Rate	U1	0	255	1	C/rate
		92	Min Sim Rate	U1	0	255	20	C/rate
		93	Ra Max Delta	U2	0	65535	43	mΩ
		95	Qmax Max Delta %	U1	0	100	5	%
		96	Qmax Bound %	U1	0	255	130	%
		97	DeltaV Max Delta	U2	0	65535	10	mV
		99	Max Res Scale	U2	0	32767	5000	number
		101	Min Res Scale	U2	0	32767	200	number
		103	Fast Scale Start SOC	U1	0	100	10	%
		104	Charge Hys V Shift	I2	0	2000	40	mV
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	Max IR Correct	U2	0	1000	400	mV
82	State	0	Qmax Cell 0	I2	0	32767	1000	mAh
		2	Update Status	H1	0x0	0x6	0x0	hex
		3	V at Chg Term	I2	0	5000	4200	mV
		5	Avg I Last Run	I2	–32768	32767	–299	mA
		7	Avg P Last Run	I2	–32768	32767	–1131	Power (mA)
		9	Delta Voltage	I2	–32768	32767	2	mV
		13	T Rise	I2	0	32767	20	number
		15	T Time Constant	I2	0	32767	1000	number

Table 5-6. Data Flash Summary—OCV Table Class

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
83	OCVa Table	0	Chem ID	H2	0x0000	0xFFFF	0x128	flags

Table 5-7. Data Flash Summary—Ra Table Class

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
88	R_a0	0	Cell0 R_a flag	H2	0x0000	0x0000	0xFF55	hex
		2	Cell0 R_a 0	I2	183	183	407	2^{-10} Ω
		4	Cell0 R_a 1	I2	181	181	407	2^{-10} Ω
		6	Cell0 R_a 2	I2	198	198	396	2^{-10} Ω
		8	Cell0 R_a 3	I2	244	244	429	2^{-10} Ω
		10	Cell0 R_a 4	I2	254	254	287	2^{-10} Ω
		12	Cell0 R_a 5	I2	261	261	236	2^{-10} Ω
		14	Cell0 R_a 6	I2	333	333	249	2^{-10} Ω
		16	Cell0 R_a 7	I2	338	338	252	2^{-10} Ω
		18	Cell0 R_a 8	I2	345	345	211	2^{-10} Ω
		20	Cell0 R_a 9	I2	350	350	189	2^{-10} Ω
		22	Cell0 R_a 10	I2	382	382	238	2^{-10} Ω
		24	Cell0 R_a 11	I2	429	429	281	2^{-10} Ω
		26	Cell0 R_a 12	I2	502	502	560	2^{-10} Ω
		28	Cell0 R_a 13	I2	545	545	1475	2^{-10} Ω
		30	Cell0 R_a 14	I2	366	366	2350	2^{-10} Ω
89	R_a0x	0	xCell0 R_a flag	H2	0xFFFF	0xFFFF	0xFFFF	hex
		2	xCell0 R_a 0	I2	183	183	407	2^{-10} Ω
		4	xCell0 R_a 1	I2	181	181	407	2^{-10} Ω
		6	xCell0 R_a 2	I2	198	198	396	2^{-10} Ω
		8	xCell0 R_a 3	I2	244	244	429	2^{-10} Ω
		10	xCell0 R_a 4	I2	254	254	287	2^{-10} Ω
		12	xCell0 R_a 5	I2	261	261	236	2^{-10} Ω
		14	xCell0 R_a 6	I2	333	333	249	2^{-10} Ω
		16	xCell0 R_a 7	I2	338	338	252	2^{-10} Ω
		18	xCell0 R_a 8	I2	345	345	211	2^{-10} Ω
		20	xCell0 R_a 9	I2	350	350	189	2^{-10} Ω
		22	xCell0 R_a 10	I2	382	382	238	2^{-10} Ω
		24	xCell0 R_a 11	I2	429	429	281	2^{-10} Ω
		26	xCell0 R_a 12	I2	502	502	560	2^{-10} Ω
		28	xCell0 R_a 13	I2	545	545	1475	2^{-10} Ω
		30	xCell0 R_a 14	I2	366	366	2350	2^{-10} Ω

Table 5-8. Data Flash Summary—Calibration

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
104	Data	0	CC Gain	F4	0.100	40.00	0.9536	mΩ
		4	CC Delta	F4	29800	1190000	1119000	mΩ
		8	CC Offset	I2	–32768	32767	–1500	mA
		10	Board Offset	I1	–128	127	0	µA
		11	Int Temp Offset	I1	–128	127	0	°C
		12	Ext Temp Offset	I1	–128	127	0	°C
		13	Pack V Offset	I1	–128	127	0	mV
107	Current	0	Filter	U1	0	255	239	number
		1	Deadband	U1	0	255	5	mA

Table 5-9. Data Flash Summary—Security

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
112	Codes	0	Sealed to Unsealed	H4	0	0xFFFF FFFF	0x3672 0414	hex
		4	Unsealed to Full	H4	0	0xFFFF FFFF	0xFFFF FFFF	hex
		8	Authen Key3	H4	0	0xFFFF FFFF	0x123 4567	hex
		12	Authen Key2	H4	0	0xFFFF FFFF	0x89AB CDEF	hex
		16	Authen Key1	H4	0	0xFFFF FFFF	0xFEDC BA98	hex
		20	Authen Key0	H4	0	0xFFFF FFFF	0x7654 3210	hex

Table 5-10. Data Flash to EVSW Conversion

Class	Subclass ID	Subclass	Offset	Name	Data Type	Data Flash Default	Data Flash Unit	EVSW Default	EVSW Unit	Data Flash to EVSW Conversion
Gas Gauging	80	IT Cfg	78	User Rate-Pwr	I2	0	cW or 10W	0	mW or cW	DF × 10
Gas Gauging	80	IT Cfg	82	Reserve Energy	I2	0	cWh or 10cWh	0	mWh or cWh	DF × 10
Calibration	104	Data	0	CC Gain	F4	0.47095	number	10.124	mΩ	4.768/DF
Calibration	104	Data	4	CC Delta	F4	5.595e5	number	10.147	mΩ	5677445/DF
Calibration	104	Data	8	CC Offset	I2	–1200	number	–0.576	mV	DF × 0.0048
Calibration	104	Data	10	Board Offset	I1	0	number	0	µV	DF × 0.0075

5.3 Configuration Class

5.3.1 Safety Subclass

5.3.1.1 Charging Overtemperature Threshold, Delay Time, and Recovery

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
2	Safety	0	OT Chg	I2	0	1200	550	0.1°C
		2	OT Chg Time	U1	0	60	5	s
		3	OT Chg Recovery	I2	0	1200	500	0.1°C

OT Chg:

When the pack temperature measured by *Temperature( )* rises to or above the overtemperature charge (***OT Chg***) threshold while charging (***Current*** > ***Chg Current Threshold***), then the *Flags( ) [OTC]* bit is set after ***OT Chg Time***. If the OTC condition clears prior to the expiration of the ***OT Chg Time*** timer, then the *Flags( ) [OTC]* bit is not set.

This setting depends on the environment temperature and the battery specification. Verify battery specification allows temperatures up to this setting during a charge and that this setting is sufficient for the application. The default is 55°C, sufficient for most Li-Ion applications.

OT Chg Time:

See ***OT Chg***. This is a buffer time allotted for overtemperature in the charge direction condition. The timer starts every time that *Temperature( )* is greater than ***OT Chg*** and during a charge. When the timer expires, the fuel gauge forces an *[OTC]* in *Flags( )*. Setting the ***OT Chg Time*** to 0 disables this function.

Default is set to 2 seconds, sufficient for most applications. Temperature is normally a slow-varying condition that does not need high-speed triggering. It must be set long enough to prevent false triggering of the *Flags( ) [OTC]* bit, but short enough to prevent damage to the battery pack.

OT Chg Recovery:

OT Chg Recovery is the temperature when the battery recovers from an ***OT Chg*** fault. This is the only recovery method for an ***OT Chg*** fault.

The default is 50°C which is 5°C lower than ***OT Chg***.

5.3.1.2 Discharging Overtemperature Threshold, Delay Time, and Recovery

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
2	Safety	5	OT Dsg	I2	0	1200	600	0.1°C
		7	OT Dsg Time	U1	0	60	5	s
		8	OT Dsg Recovery	I2	0	1200	550	0.1°C

OT Dsg:

When the pack temperature measured by *Temperature( )* rises to or above this threshold while discharging (***Current*** < (–)***Dsg Current Threshold***), then the *Flags( ) [OTD]* bit is set after ***OT Dsg Time***. If the OTD condition clears prior to the expiration of the ***OT Dsg Time*** timer, then the *[OTD]* bit is not set. If the condition does not clear, then the *[OTD]* bit is set.

This setting depends on the environment temperature and the battery specification. Verify that the battery specification allows temperatures up to this setting while discharging, and verify that these setting are sufficient for the application temperature. The default is 60°C which is sufficient for most Li-Ion applications. The default ***OT Dsg*** is higher than the default ***OT Chg*** because Li-Ion can handle a higher temperature in the discharge direction than in the charge direction.

OT Dsg Time:

See ***OT Dsg***. This is a buffer time allotted for overtemperature in the discharge direction condition. The timer starts every time that *Temperature( )* measured is greater than ***OT Dsg*** during a discharge. When the timer expires, then the fuel gauge forces the *Flags( ) [OTD]* bit to be set. Setting the ***OT Dsg Time*** to 0 disables this feature.

This is normally set to 2 seconds which is sufficient for most applications. Temperature is normally a slow-acting condition that does not need high-speed triggering. Set ***OT Dsg Time*** long enough to prevent false triggering of the *[OTD]* bit in *Flags( )*, but short enough to prevent damage to the battery pack.

OT Dsg Recovery:

OT Dsg Recovery is the temperature at which the battery recovers from an ***OT Dsg*** fault. This is the only recovery method for an ***OT Dsg*** fault.

The default is 55°C which is 5°C lower than ***OT Dsg***.

5.3.1.3 Overtemperature Protection Threshold, Delay Time, and Recovery

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
2	Safety	10	OT Prot Threshold	I2	0	1200	600	0.1°C
		12	OT Prot Delay	U1	0	60	3	s
		13	OT Prot Recovery	I2	0	1200	550	0.1°C

The fuel gauge provides a feature by which firmware will force open the FETs when temperature exceeds a certain threshold for a predefined amount of time. There is no option to open FETs individually and also the firmware cannot force the FETs to close.

- When *Temperature()* > ***OT Prot Threshold*** for at least ***OT Prot Delay*** firmware forces open both the CFET and DFET and sets *[OT_FET]* bit in the *Flags()* register.
- When *Temperature()* < ***OT Prot Recovery*** firmware lets hardware protection take control of the FETs and clears the *[OT_FET]* bit.

5.3.2 Charge Subclass

5.3.2.1 Charging Voltage

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
34	Charge	0	Charging Voltage	I2	0	4600	4200	mV

The fuel gauge uses this value along with ***Taper Voltage*** to detect charge termination. During Primary Charge Termination detection, one of the three requirements is that ***Voltage*** must be above (***Charging Voltage*** – ***Taper Voltage***) for the gauge to start trying to qualify a termination. This value depends on the charger that is expected to be used for the battery pack. The default is 4.2 V.

5.3.3 *Charge Termination Subclass*

5.3.3.1 Taper Current, Minimum Taper Capacity, Taper Voltage, and Current Taper Window

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
36	Charge Termination	0	Taper Current	I2	0	1000	100	mA
		2	Min Taper Capacity	I2	0	1000	25	mAh
		4	Taper Voltage	I2	0	1000	100	mV
		6	Current Taper Window	U1	0	60	40	s

Taper Current is used in the Primary Charge Termination Algorithm. *AverageCurrent( )* is integrated over each of the two ***Current Taper Window*** periods separately, and then they are averaged separately to give two averages (Iavg1, Iavg2). Three requirements must be met to qualify for Primary Charge Termination:

- During two consecutive periods of ***Current Taper Windows***:
  Iavg1 < ***Taper Current*** and Iavg2 < ***Taper Current***
- During the same periods: Accumulated change in capacity < ***Min Taper Capacity*** per ***Current Taper Window***
- ***Voltage*** > ***Charging Voltage*** – ***Taper Voltage***

When Primary Charge Termination conditions are met, the *Flags( ) [FC]* bit is set and *[CHG]* bit is cleared. Also, if the ***Pack Configuration [RMFCC]*** bit is set, then *RemainingCapacity( )* is set equal to *FullChargeCapacity( )*.

This register depends on battery characteristics and charger specifications, but typical values are C/10 to C/20. *AverageCurrent( )* is not used for the qualification because its time constant is not the same as the ***Current Taper Window***. The reason for making two current taper qualifications is to prevent false current taper qualifications. False primary charge terminations happen with pulse charging and with random starting and stopping of the charge current. This is particularly critical at the beginning or end of the qualification period. It is important to note that as the ***Current Taper Window*** value is increased, the current range in the second requirement for primary charge termination is lowered. If the ***Current Taper Window*** is increased, then the current used to integrate to the ***Min Taper Capacity*** is decreased and this threshold becomes more sensitive.

5.3.3.2 Terminate Charge Alarm Set and Clear %

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
36	Charge Termination	7	TCA Set %	I1	–1	100	99	%
		8	TCA Clear %	I1	–1	100	95	%

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, the *[CHG]* bit is cleared when the taper condition is detected.

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.

[CHG] bit is cleared:

- At taper termination if ***TCA Set %*** is –1.
- When *StateOfCharge( )* ≥ ***TCA Set %*** and if ***TCA Set %*** is not –1.
- If *Flags( ) [OTC]*, *[CHG_INH]*, or *[OT_FET]* is set.

[CHG] bit is set:

- When any of the conditions for *[CHG]* bit to be cleared does not exist and *StateOfCharge( )* ≤ ***TCA Clear %***.

NOTE: ***TCA Set %*** and ***TCA Clear %*** only affect the *Flags( ) [CHG]* bit but does not affect the charge termination process or the gauging function.

5.3.3.3 Full Charge Set and Clear %

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
36	Charge Termination	9	FC Set %	I1	–1	100	–1	%
		10	FC Clear %	I1	–1	100	98	%

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 ***Min Taper Capacity***, ***Taper Current,*** and ***Taper Voltage*** in Section 5.3.3.1).

NOTE: ***FC Set %*** only affects the *Flags( ) [FC]* bit which does not affect the charge termination process.

The default value is set to –1%.

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.

NOTE: ***FC Clear %*** only affects the *Flags( ) [FC]* bit which does not affect the charge termination process.

The default value is set to 98%.

5.3.3.4 DOD at EOC Delta Temperature

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
36	Charge Termination	11	DODatEOC Delta T	I2	0	1000	50	0.1°C

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.

5.3.4 Data Subclass

5.3.4.1 Initial Standby Current

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	8	Initial Standby	I1	–256	0	–10	mA

This is the initial value that is reported in *StandbyCurrent( )* and is also used in Standby Current detection subsequently. Please see Section 4.1.14 for details.

5.3.4.2 Initial Maximum Load Current

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	9	Initial MaxLoad	I2	–32767	0	–500	mA

This is the initial value that is reported in *MaxLoadCurrent( )*. The *MaxLoadCurrent( )* is updated to the new current when *Current()* < ***Initial MaxLoad***. *MaxLoadCurrent( )* is reduced to the average of the previous value and ***Initial MaxLoad*** whenever the battery is charged to full after a previous discharge to an SOC less than 50%. This prevents the reported value from maintaining an unusually high value. Default value depends on the system.

5.3.4.3 Cycle Count

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	17	Cycle Count	U2	0	65535	0	Count

This register records the number of cycles the battery has experienced. One cycle occurs when accumulated discharge ≥ ***CC Threshold***. The value is reported in *CycleCount( )*.

5.3.4.4 Cycle Count Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	19	CC Threshold	I2	100	32767	900	mAh

This value increments *CycleCount( )*. When the gauge accumulates enough discharge capacity equal to ***CC Threshold***, then it increments *CycleCount( )* by 1. This discharge capacity does not have to be consecutive. The internal register that accumulates the discharge is not cleared at any time except when the internal accumulating register equals the ***CC Threshold***, and increments *CycleCount( )*.

This is normally set to about 90% of the ***Design Capacity***.

5.3.4.5 Design Capacity

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	23	Design Capacity	I2	0	32767	1000	mAh

This is the original chemical capacity of the pack as specified by the battery vendor. This is used in Impedance Track™ algorithm in remaining and full charge capacity (RM and FCC) calculations. The value should be set based on the battery specification.

5.3.4.6 Design Energy

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	25	Design Energy	I2	0	32767	5400	mWh or cWh

Design Energy is similar to ***Design Capacity*** but represented in energy units.

Design Energy = ***Design Capacity*** × 3.6 V

The actual unit of this parameter is dependent on ***Design Energy Scale***. The default value is 5400 mWh.

5.3.4.7 State of Health Load I

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	27	SOH Load I	I2	–32767	0	-400	mA

StateOfHealth( ) is calculated using the ratio of *FullChargeCapacity( )* (FCC) and *DesignCapacity( )*. The FCC used in the SOH calculation is simulated using a fixed temperature (25ºC) and load (defined by ***SOH Load I***). The FCC value used is not necessarily the same as the *FullChargeCapacity( )* data RAM register since the value reported in data RAM register changes based on current system load and temperature.

The default is –400 mA. It is recommended to set this value to a typical system current.

5.3.4.8 TDD State Of Health Percent

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	29	TDD SOH Percent	I1	0	100	80	%

The fuel gauge can indicate tab disconnection by detecting change of *StateOfHealth( )*. This feature is enabled by setting ***[SE_TDD]*** bit in ***Pack Configuration B***. The *[TDD]* of *Flags( )* is set when the ratio of current *StateOfHealth( )* divided by the previous *StateOfHealth( )* reported is less than ***TDD SOH Percent***. The *[TDD]* of *Flags( )* can be configured to control an interrupt pin (SE or HDQ) by enabling the interrupt mode. See Section 2.5.2, *Interrupt Mode*, for details.

The default is 80%.

5.3.4.9 ISD Current Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	40	ISD Current	I2	0	32767	10	Hour Rate

The fuel gauge can indicate detection of an internal battery short if the ***[SE_ISD]*** bit in ***Pack Configuration B*** is set. The gauge compares the self-discharge current calculated based on relaxation mode to the *AverageCurrent( )* measured in the system. The self-discharge rate is measured at 1 hour intervals. When battery *SelfDischargeCurrent( )* is less than the predefined –***Design Capacity*** / ***ISD Current*** threshold, the *[ISD]* of *Flags( )* is set high. The *[ISD]* of *Flags( )* can be configured to control interrupt pin (SE or HDQ) by enabling the interrupt mode. See Section 2.5.2, *Interrupt Mode*, for details.

The default is 10 HourRate. The HourRate unit is defined as *DesignCapacity( )* / [HourRate]. It is recommended to test this feature and tune this parameter to obtain the optimal value in order to avoid both false positives and false negatives.

5.3.4.10 ISD Current Filter

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	42	ISD I Filter	U1	0	255	127	Count

The ISD I Filter filters the amount of change allowed in the *SelfDischargeCurrent( )* register. A large value of ***ISD I Filter*** restricts large fluctuations in the value of *SelfDischargeCurrent( )* if the most recent current value read by the gauge is significantly different from the previous readings. A small value of ***ISD I Filter*** allows the value of *SelfDischargeCurrent( )* to update to a value that is closer to the most recent value read by the gauge.

The default is 127.

5.3.4.11 Minimum ISD Detection Time

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	43	Min ISD Time	U1	0	255	7	Hour

This parameter defines the amount of time the gauge needs to wait after the initial DOD measurement is made in relaxation mode before an attempt is made to detect an internal short in the battery pack.

The default is 7 hours.

5.3.4.12 Design Energy Scale

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	44	Design Energy Scale	U1	1	10	1	number

Design Energy Scale selects the scale and units of a set of data flash parameters. The value of ***Design Energy Scale*** can be either 1 or 10. For battery capacities larger than 6 Ahr, ***Design Energy Scale*** = 10 is recommended.

Table 5-11. Data Flash Parameter Unit/Scale Based on Design Energy Scale

Data Flash	Design Energy Scale = 1 (default)	Design Energy Scale = 10
Design Energy	mWh	cWh
Reserve Capacity (mWh)	mWh	cWh
Avg Power Last Run	mW	cW
User Rate-Pwr	mWh	cWh
T Rise	No Scale	Scaled by ×10

5.3.4.13 Device Name

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
48	Data	45	Device Name	S11	x	x	bq27741-G1	

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).

5.3.5 Discharge Subclass

5.3.5.1 State of Charge 1 Set and Clear Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
49	Discharge	0	SOC1 Set Threshold	U2	0	65535	150	mAh
		2	SOC1 Clear Threshold	U2	0	65535	175	mAh

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 *Flags( ) [SOC1]* bit 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.

SOC1 Set Threshold is normally set to 10% of ***Design Capacity***.

SOC1 Clear Threshold is normally set to 5% above the ***SOC1 Set Threshold***; that is, 15% of ***Design Capacity***.

5.3.5.2 State of Charge Final Set and Clear Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
49	Discharge	4	SOCF Set Threshold	U2	0	65535	75	mAh
		6	SOCF Clear Threshold	U2	0	65535	100	mAh

The ***SOCF Set Threshold*** is the *StateOfCharge( )* percentage threshold used to indicate when *StateOfCharge( )* falls to or below a defined *StateOfCharge( )*. The ***SOCF Set Threshold*** is typically used as a final low *StateOfCharge( )* warning. When *StateOfCharge( )* falls below the ***SOCF Set Threshold***, the *Flags( ) [SOCF]* bit is set. The *[SOCF]* bit is cleared once *StateOfCharge( )* rises above the ***SOCF Clear Threshold***. If ***SOCF Set Threshold*** is set to (–)1, then the *[SOCF]* bit becomes inoperative.

SOCF Set Threshold is normally set to 2% of ***Design Capacity***.

SOCF Clear Threshold is normally set to 3% above the ***SOCF Set Threshold***, that is 5% of ***Design Capacity***.

5.3.5.3 Battery Low Set Voltage Threshold, Time, and Clear

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
49	Discharge	9	BL Set Volt Threshold	I2	0	16800	2500	mV
		11	BL Set Volt Time	U1	0	60	2	s
		12	BL Clear Volt Threshold	I2	0	16800	2600	mV

BL Set Volt Threshold

BL Set Volt Threshold provides a threshold for the *Voltage( )* register. Once the *Voltage( )* register falls below this value for a specific time defined by ***BL Set Volt Time***, the battery low *Flags( ) [BATLOW]* bit is set. Fuel gauge must not be in SLEEP mode.

BL Set Volt Time

When *Voltage( )* < ***BL Set Volt Threshold*** is true, ***BL Set Volt Time*** provides the time to wait before the *Flags( ) [BATLOW]* bit gets set. Fuel gauge must not be in SLEEP mode.

BL Clear Volt Threshold

BL Clear Volt Threshold provides a threshold for the *Voltage( )* register. Once the *Voltage( )* register rises above this value, the *Flags( ) [BATLOW]* bit is cleared immediately. The fuel gauge must not be in SLEEP mode.

5.3.5.4 Battery High Set Voltage Threshold, Time, and Clear

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
49	Discharge	14	BH Set Volt Threshold	I2	0	16800	4500	mV
		16	BH Volt Time	U1	0	60	2	s
		17	BH Clear Volt Threshold	I2	0	16800	4400	mV

BH Set Volt Threshold

BH Set Volt Threshold provides a threshold for the *Voltage( )* register. Once the *Voltage( )* register rises above this value for a specific time defined by ***BH Volt Time***, the battery high *Flags( ) [BATHI]* bit is set. The fuel gauge must not be in SLEEP mode.

BH Volt Time

When *Voltage( )* < ***BH Set Volt Threshold*** is true, ***BH Volt Time*** provides the time to wait before the *Flags( ) [BATHI]* bit gets set. Fuel gauge must not be in SLEEP mode.

BH Clear Volt Threshold

BH Clear Volt Threshold provides a threshold for the *Voltage( )* register. Once the *Voltage( )* register falls above this value, the *Flags( ) [BATHI]* bit is cleared immediately. Fuel gauge must not be in SLEEP mode.

5.3.6 *Manufacturer Data Subclass*

5.3.6.1 Pack Lot Code

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
56	Manufacturer Data	0	Pack Lot Code	H2	0x0000	0xFFFF	0x0000	hex

The pack manufacturer can use this location to store the pack lot code.

5.3.6.2 PCB Lot Code

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
56	Manufacturer Data	2	PCB Lot Code	H2	0x0000	0xFFFF	0x0000	hex

The pack manufacturer can use this location to store the PCB lot code.

5.3.6.3 Firmware Version

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
56	Manufacturer Data	4	Firmware Version	H2	0x0000	0xFFFF	0x0000	hex

The pack manufacturer can use this location to store a firmware version number for their system or pack. This value is user-defined and is not related to the gauge's *Control(FW_VERSION)*.

5.3.6.4 Hardware Revision

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
56	Manufacturer Data	6	Hardware Revision	H2	0x0000	0xFFFF	0x0000	hex

The pack manufacturer can use this location to store a hardware version number for their system or pack. This value is user-defined and is not related to the gauge's *Control(HW_VERSION)*.

5.3.6.5 Cell Revision

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
56	Manufacturer Data	8	Cell Revision	H2	0x0000	0xFFFF	0x0000	hex

The pack manufacturer can use this location to store the version of their cell.

5.3.6.6 Data Flash Configuration Version

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
56	Manufacturer Data	10	DF Config Version	H2	0x0000	0xFFFF	0x0000	hex

The pack manufacturer can use this location to store the data flash configuration version. Version control of DFI files used in production is recommended.

5.3.7 Integrity Data Subclass

5.3.7.1 All Data Flash Checksum

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
57	Integrity Data	6	All DF Checksum	H2	0x0000	0x7FFF	0x0000	hex

This value is a 16-bit unsigned integer sum of each byte in the data flash. The sum is calculated on a byte-by-byte basis. The most significant bit of the checksum is masked yielding a 15-bit checksum. This checksum is compared with the value generated by command 0x1A. This checksum is intended to validate all parameters that are not pack specific. Table 5-12 shows the data flash that are excluded.

Table 5-12. All Data Flash Checksum Exclusions

Class	Subclass ID	Subclass	Comment
Configuration	57	Integrity Data	Reset Counter – Full (private) Reset Counter – Watch Dog (private)
Configuration	57	Integrity Data	All DF Checksum
System Data	58	Manufacturer Info	Block A Block B
Calibration	104	Data	CC Gain CC Delta CC Offset Board offset Int Temp Offset Ext Temp Offset Pack V offset

5.3.7.2 Static Chem Data Flash Checksum

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
57	Integrity Data	8	Static Chem DF Checksum	H2	0x0000	0x7FFF	0x0000	hex

This value is a 16-bit unsigned integer sum of each byte in the chemistry data flash. The sum is calculated on a byte-by-byte basis. The most significant bit of the checksum is masked yielding a 15-bit checksum. This checksum is intended to validate chemistry specific data. Table 5-13 shows the data flash that are included. This checksum is executed in conjunction with the *IT_ENABLE* subcommand. If this checksum fails, Impedance Track™ is not enabled.

Table 5-13. All Chemistry Data Checksum Inclusions

Class	Subclass ID	Subclass	Comment
OCV Table	83	OCV Table	ChemID (public) OCVa Table (private)
OCVb Table	84	OCVb Table	OCVb Table (private)
Rb_Hi Table	85	Rb_Hi Table	Rb Hi Table (private)
Rb_Lo Table	108	Rb_Lo Table	Rb Lo Table (private)
Gas Gauging	80	IT Cfg	Q Invalid Max V Q Invalid Min V

5.3.7.3 Static Data Flash Checksum

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
57	Integrity Data	10	Static DF Checksum	H2	0x0000	0x7FFF	0x0000	hex

This value is a 16-bit unsigned integer sum of each byte in the data flash. The sum is calculated on a byte-by-byte basis. The most significant bit of the checksum is masked yielding a 15-bit checksum. This checksum is compared with the value generated by command 0x1A. This checksum is intended to validate all parameters that are static. Table 5-14 shows the data flash that are excluded. The checksum execution takes approximately 5 ms and during this time, the fuel gauge does not communicate.

Table 5-14. All Static Data Flash Checksum Exclusions

Class	Subclass ID	Subclass	Comment
Configuration	48	Data	Cycle Count
Configuration	57	Integrity Data	Reset Counter – Full (private) Reset Counter – Watch Dog (private)
Configuration	57	Integrity Data	All DF Checksum
Configuration	57	Integrity Data	Static DF Checksum
System Data	58	Manufacturer Info	Block A Block B
LT Data	59	Lifetime Data	All Lifetime Data
LT Data	60	Lifetime Temp Samples	All Lifetime Temp Samples
Gas Gauging	82	State	Qmax Cell 0 Cycle Count Update_Status V at Chg Term Avg I Last Run Avg P Last Run Delta Voltage Max Discharge Duration (private)
Ra Tables	88	Data	Ra Table
Ra Tables	89	Data	Rax Table
Calibration	104	Data	CC Gain CC Delta CC Offset Board offset Int Temp Offset Ext Temp Offset Pack V offset

5.3.8 Lifetime Data Subclass, Lifetime Resolution Subclass

Lifetime data subclass contains black box data that records various data over the life of the pack. This data can be very useful for performing failure analysis on the returned packs. Lifetime data is enabled if the *CONTROL_STATUS [QEN]* bit is 1. The *[QEN]* bit is set by sending *IT_ENABLE* subcommand.

The lifetime update for the values below is throttled to not happen more than once per 60 seconds to avoid data flash wear out. The frequency of the updates will naturally slow down once pack updates the minimum and maximum values over several packs,

- ***Lifetime Max Temp***: Maximum temperature observed by the gauge. It is initialized to 300. The unit is 0.1ºC.
- ***Lifetime Min Temp***: Minimum temperature observed by the gauge. It is initialized to 200. The unit is 0.1ºC.
- ***Lifetime Max Pack Voltage***: Maximum battery voltage observed by the gauge. It is initialized to 3200. The unit is mV.
- ***Lifetime Min Pack Voltage***: Minimum battery voltage observed by the gauge. It is initialized to 4200. The unit is mV.
- ***Lifetime Max Chg Current***: Maximum charge current observed by the gauge. It is initialized to 0. The unit is mA.
- ***Lifetime Max Dsg Current***: Maximum discharge current observed by the gauge. It is initialized to 0. The unit is mA.
- ***LT Flash Cnt***: Lifetime flash page update counter keeps track of total number of updates. It is initialized to 0. The unit is counts.

5.3.8.1 Maximum Temperature, Minimum Temperature, Temperature Resolution

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
59	Lifetime Data	0	Lifetime Max Temp	I2	0	1400	0	0.1°C
		2	Lifetime Min Temp	I2	–600	1400	500	0.1°C
66	Lifetime Resolution	0	LT Temp Res	U1	0	255	10	°C

Lifetime Max Temp value is updated if one of the following conditions is met:

- *Temperature( )* – ***Lifetime Max Temp*** > ***LT Temp Res***
- *Temperature( )* > ***Lifetime Max Temp*** and any other lifetime value is updated.

Lifetime Min Temp value is updated if one of the following conditions is met:

- ***Lifetime Min Temp*** – *Temperature( )* > ***LT Temp Res***
- *Temperature( )* < ***Lifetime Min Temp*** and any other lifetime value is updated.

5.3.8.2 Maximum Pack Voltage, Minimum Pack Voltage, Voltage Resolution

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
59	Lifetime Data	4	Lifetime Max Pack Voltage	I2	0	32767	2800	mV
		6	Lifetime Min Pack Voltage	I2	0	32767	4200	mV
66	Lifetime Resolution	1	LT V Res	U1	0	255	25	mV

Lifetime Max Pack Voltage value is updated if one of the following conditions is met:

- *Voltage( )* – ***Lifetime Max Pack Voltage*** > ***LT V Res***
- *Voltage( )* > ***Lifetime Max Pack Voltage*** and any other lifetime value is updated.

Lifetime Min Pack Voltage value is updated if one of the following conditions is met:

- ***Lifetime Min Pack Voltage*** – *Voltage( )* > ***LT V Res***
- *Voltage( )* < ***Lifetime Min Pack Voltage*** and any other lifetime value is updated.

5.3.8.3 Maximum Charge Current, Maximum Discharge Current, Current Resolution

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
59	Lifetime Data	8	Lifetime Max Chg Current	I2	–32767	32767	0	mA
		10	Lifetime Max Dsg Current	I2	–32767	32767	0	mA
66	Lifetime Resolution	2	LT Cur Res	U1	0	255	100	mA

Lifetime Max Chg Current value is updated if one of the following conditions is met:

- *Current( )* – ***Lifetime Max Chg Current*** > ***LT Cur Res***
- *Current( )* > ***Lifetime Max Chg Current*** and any other lifetime value is updated.

Lifetime Max Dsg Current value is updated if one of the following conditions is met:

- ***Lifetime Max Dsg Current*** – *Current( )* > ***LT Cur Res***
- ***Lifetime Max Dsg Current*** > *Current( )* and any other lifetime value is updated.

NOTE: During discharge, current is negative.

5.3.9 Lifetime Temp Samples Subclass

5.3.9.1 Flash Write Count

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
60	Lifetime Temp Samples	0	LT Flash Cnt	I2	0	32767	0	Count

LT Flash Cnt tracks the number of lifetime data flash updates.

5.3.9.2 AFE Status

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
60	Lifetime Temp Samples	2	LT AFE Status	H1	0x00	0xFF	0x00	hex

LT AFE Status polls *Protector Status* every 1 second and records new protector events. This register shows the cumulative status of the protector over the lifetime of the gauge. Bitmap for this register:

Table 5-15. LT AFE Status Bit Definition

bit7 (MSB)	bit6	bit5	bit4	bit3	bit2	bit1	bit0
RSVD	RSVD	CVM	UVP	OVP	SCD	OCD	OCC

RSVD = Bits 6 and 7 are reserved. Do not use.

CVM = Cell voltage monitor threshold
1 = Cell voltage monitor threshold detected
0 = Cell voltage monitor threshold not detected

UVP = Undervoltage protection fault
1 = Undervoltage protection fault detected
0 = Undervoltage protection fault not detected

OVP = Overvoltage protection fault
1 = Overvoltage protection fault detected
0 = Overvoltage protection fault not detected

SCD = Short circuit discharge fault
1 = Short-circuit discharge fault detected
0 = Short-circuit discharge fault not detected

OCD = Overcurrent discharge fault
1 = Overcurrent discharge fault detected
0 = Overcurrent discharge fault not detected

OCC = Overcurrent charge fault
1 = Overcurrent charge fault detected
0 = Overcurrent charge fault not detected

5.3.10 Registers Subclass

5.3.10.1 Pack Configuration Register

Some pin configurations and algorithm settings are configured via the ***Pack Configuration*** data flash register, as indicated in Table 5-16. This register is programmed and read via the methods described in Section 5.1.1, *Accessing the Data Flash*. The register is located at subclass = 64, offset = 0.

Table 5-16. Pack Configuration Bit Definition

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High Byte	RESCAP	RSVD	HOSTIPol	HOSTIE	RSVD	IWAKE	RSNS1	RSNS0
	0	0	0	1	0	0	0	1
	0x11							
Low Byte	GNDSEL	RFACTSTEP	SLEEP	RMFCC	RSVD	RSVD	RSVD	TEMPS
	0	1	1	1	0	1	1	1
	0x71							

High Byte

RESCAP = No-load rate of compensation is applied to the reserve capacity calculation. True when set.

RSVD = Bit 6 is reserved. Must be 0.

HOSTIPol = Polarity for Interrupt pin.
0 = active low
1 = active high

HOSTIE = Enables host interrupt in I^2C mode

RSVD = Bit 3 is reserved. Must be 0.

IWAKE/RSNS1/RSNS0 = These bits configure the current wake function (See Section 2.10.2, *Wake-Up Comparator*).

Low Byte

GNDSEL = The ADC ground select control. The V_{SS} (pins C1 and C2) is selected as ground reference when the bit is clear. Pin A1 is selected when the bit is set.

RFACTSTEP = Enables Ra step up/down to Max/Min Res Factor before disabling Ra updates.

SLEEP = The fuel gauge can enter sleep, if operating conditions allow. True when set. (See Section 2.9.2, *SLEEP Mode*)

RMFCC = RM is updated with the value from FCC, on valid charge termination. True when set. (See Section 2.8.1, *Charge Termination Detection*)

RSVD = Bits 1, 2, and 3 are reserved. Must be 0.

TEMPS = Selects external thermistor for Temperature( ) measurements. True when set. (See Section 2.6, *Temperature Measurement and The TS Input*)

5.3.10.2 Pack Configuration B Register

Some pin configurations and algorithm settings are configured via the ***Pack Configuration B*** data flash register, as indicated in Table 5-17. This register is programmed and read via the methods described in Section 5.1.1, *Accessing the Data Flash*. The register is located at subclass = 64, offset = 2.

Table 5-17. Pack Configuration B Bit Definition

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
ChgDoDEoC	SE_TDD	VconsEN	SE_ISD	RSVD	LFPRelax	DoDWT	FConvEn
1	0	1	0	0	1	1	1
0xA7							

ChgDoDEoC = Enable DoD at EoC recalculation during charging only. True when set. Default setting is recommended.

SE_TDD = Enable Tab Disconnection Detection. True when set. (See Section 2.5.5, *Tab Disconnection Detection*)

VconsEN = Enable voltage consistency check. True when set. Default setting is recommended.

SE_ISD = Enable Internal Short Detection. True when set. (See Section 2.5.4, *Internal Short Detection*)

RSVD = Bit 3 is reserved. Must be 0.

LFPRelax = Enable $LiFePO_4$ long relaxation mode. True when set.

DoDWT = Enable DoD weighting feature of gauging algorithm. This feature can improve accuracy during relaxation in a flat portion of the voltage profile, especially when using $LiFePO_4$ chemistry. True when set.

FConvEn = Enable fast convergence algorithm. Default setting is recommended. (See Section 2.2, *Fast Resistance Scaling*)

5.3.10.3 Pack Configuration C Register

Some algorithm settings are configured via the ***Pack Configuration C*** data flash register, as indicated in Table 5-18. This register is programmed and read via the methods described in Section 5.1.1, *Accessing the Data Flash*. The register is located at subclass = 64, offset = 3.

Table 5-18. Pack Configuration C Bit Definition

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
FastQmax	RSVD	RelaxRCJumpOK	SmoothEn	SleepWkChg	RSVD	RSVD	RSVD
0	0	0	1	1	0	0	0
0x1C							

FastQmax = Fast Qmax feature is enabled.

RSVD = Bit 6 is reserved. Must be 0.

RelaxRCJumpOK = Allow SOC to change due to temperature change during relaxation when SOC smoothing algorithm is enabled. True when set.

SmoothEn = Enable SOC smoothing algorithm. True when set. (See Section 2.3, *StateOfCharge() Smoothing*)

SleepWkChg = Enables compensation for the passed charge missed when waking from SLEEP mode.

RSVD = Bits 0, 1, and 2 are reserved. Must be 0.

5.3.11 Lifetime Resolution Subclass

5.3.11.1 Lifetime Update Time

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
66	Lifetime Resolution	3	LT Update Time	U2	0	65535	60	s

This parameter sets the minimum time between data flash writes to update the Lifetime Parameters. The default for this register is 60.

5.3.12 Power Subclass

5.3.12.1 Valid Update Voltage

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
68	Power	0	Flash Update OK Voltage	I2	0	4200	2800	mV

This register controls one of the several data flash protection features. It is critical that data flash is not updated when the battery voltage is too low. Data flash programming takes much more current than normal operation of the gauge, and with a depleted battery, this current can cause the battery voltage to drop dramatically, forcing the gauge into reset before completing a data flash write. The effects of an incomplete data flash write can corrupt the memory, resulting in unpredictable and extremely undesirable results. The voltage setting in ***Flash Update OK Voltage*** prevents any writes to the data flash below this value. If a charger is detected, then this register is ignored.

The default for this register is 2800 mV. Ensure that this register is set to a voltage where the battery has plenty of capacity to support data flash writes but below any normal battery operation conditions.

5.3.12.2 Sleep Current Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
68	Power	2	Sleep Current	I2	0	100	10	mA

When *AverageCurrent( )* is less than ***Sleep Current*** or greater than (–)***Sleep Current***, the gauge enters SLEEP mode if the feature is enable by setting the ***Pack Configuration [SLEEP]*** bit.

This setting should be below any normal application currents.

5.3.12.3 Shutdown Voltage

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
68	Power	11	Shutdown V	I2	0	2600	0	mV

When voltage drops below the ***Shutdown V*** threshold and current is below ***Sleep Current***, then the device attempts to shutdown. If ***Shutdown V*** is set to 0 then this portion of shutdown operation is disabled. The *CLEAR_SHUTDOWN* subcommand can be used to interrupt the shutdown procedure if the charger was attached right after the conditions for automated shutdown occur.

The default value is set to 0 mV.

5.3.12.4 Full Sleep Wait Time

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
68	Power	13	FS Wait	U1	0	255	0	s

FS Wait provides the time to wait for the fuel gauge to go from SLEEP mode to FULLSLEEP mode. When the ***FS Wait*** value is 0, the gauge waits for the *SET_FULLSLEEP* subcommand, once the gauge receives this command while in SLEEP mode, it immediately goes to FULLSLEEP mode. If ***FS Wait*** is non-zero, the gauge switches to FULLSLEEP from SLEEP, once the timer expires. During the wait time, *SET_FULLSLEEP* subcommand is ignored. Note that when the gauge is in FULLSLEEP mode, any communication with the gauge triggers it to get out of FULLSLEEP mode. The best way to check the mode of the gauge is to monitor the drawn current out of the gauge.

Default value is 0 seconds.

5.4 System Data Class

5.4.1 Manufacturer Information Subclass

5.4.1.1 Block A and Block B

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
58	Manufacturer Info	0	Block A 0 through 31	H1	0x00	0xFF	0x00	hex
		32	Block B 0 through 31	H1	0x00	0xFF	0x00	hex

Each block can hold a maximum of 8 characters or 32 bytes of user-programmable data.

The method for accessing these memory locations is different, depending on whether the device is in UNSEALED or SEALED mode.

When in UNSEALED mode and when an 0x00 has been written to *BlockDataControl( )*, accessing the ***Manufacturer Info 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 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.

As an example, the data flash location for ***Manufacturer Info Block B*** is defined as having a Subclass = 58 and an Offset = 32 through 63 (32-byte block). The specification of Class = System Data is not needed to address ***Manufacturer Info Block B***, but is used instead for grouping purposes when viewing data flash info in the evaluation software.

When in SEALED mode or when *BlockDataControl( )* does not contain 0x00, data flash is no longer available in the manner used in UNSEALED mode. Rather than issuing subclass information, a designated ***Manufacturer Information Block*** is selected with the *DataFlashBlock( )* command. Issuing a 0x01, 0x02, or 0x03 with this command causes the corresponding information block (A or B, respectively) to be transferred to the command space 0x40 through 0x5F for editing or reading by the system. Upon successful writing of checksum information to *BlockDataCheckSum( )*, the modified block is returned to data flash.

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

5.5 Gas (Fuel) Gauging Class

5.5.1 IT Cfg Subclass

5.5.1.1 Load Select

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	0	Load Select	U1	0	255	1	number

Load Select defines the type of power or current model to be used to compute load-compensated capacity in the Impedance Track™ algorithm.

If ***Load Mode*** = 0 (constant-current model), then the options presented in Table 5-19 are available.

Table 5-19. Constant-Current Model Used When Load Mode = 0

Load Select Value	Current Model Used
0	Average discharge current from previous cycle: There is an internal register that records the average discharge current through each entire discharge cycle. The previous average is stored in this register.
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 off the *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	Use the value specified by *AtRate( )*
6	Use the value in ***User_Rate-mA.*** This gives a completely user-configurable method.

If ***Load Mode*** = 1 (constant-power model) then the following options are available:

Table 5-20. Constant-Power Model Used When Load Mode = 1

Load Select Value	Power Model Used
0	Average discharge power from previous cycle: There is an internal register that records the average discharge power through each entire discharge cycle. The previous average is stored in this register.
1	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 mW or cW.
5	Unsupported.
6	Use the value in User_Rate-Pwr. This gives a completely user-configurable method.

5.5.1.2 Load Mode

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	1	Load Mode	U1	0	255	0	number

Load Mode selects either the constant-current or constant-power model for the Impedance Track™ algorithm as used in ***Load Select*** (see Section 5.5.1.1, *Load Select*). 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 reflects the status of ***Load Mode***.

This is normally set to 0 (constant-current model) but it is application specific. If the application load profile more closely matches a constant-power model, then set to 1. This provides a better estimation of remaining run time, especially close to the end of discharge where current increases to compensate for decreasing battery voltage.

5.5.1.3 Maximum and Minimum Resistance Factor

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	21	Max Res Factor	U1	0	255	15	number
		22	Min Res Factor	U1	0	255	5	number

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.

For Ra_new > Ra_old,
New Ra = min(Ra_new, Ra_old × ***Max Res Factor*** ÷ 10)

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.

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.

For Ra_new < Ra_old
New Ra = max(Ra_new, Ra_old × ***Min Res Factor*** ÷ 10)

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.

5.5.1.4 Ra Filter

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	25	Ra Filter	U2	0	1000	800	number

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***.

Ra Filter is a filter constant used to calculate the filtered Ra value that is stored into data flash from the old Ra value.

Ra = (Ra_old × ***Ra Filter*** + Ra_new × (1000 – ***Ra Filter***)) ÷ 1000

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

5.5.1.5 Fast Qmax Start DOD %, Fast Qmax Start Voltage Delta, Fast Qmax Current Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	42	Fast Qmax Start DOD %	U1	0	255	92	%
		44	Fast Qmax Start Volt Delta	I2	0	4200	200	mV
		46	Fast Qmax Current Threshold	I2	0	1000	4	C/rate

Fast Qmax measurement starts when the following conditions are met:

- DOD > ***Fast Qmax Start DOD%*** or
  Voltage < ***Terminate Voltage*** + ***Fast Qmax Start Volt Delta***
- Current < C / ***Fast Qmax Current Threshold***

5.5.1.6 Fast Qmax End DOD %

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	43	Fast Qmax End DOD %	U1	0%	255%	96%	mV

Fast Qmax measurement is performed at the end of discharge when the following conditions are met:

- Number of Fast Qmax measurements > 3
- DOD > ***Fast Qmax End DOD%*** or
  Voltage < ***Terminate Voltage*** + 50 mV

5.5.1.7 Qmax Capacity Error

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	64	Qmax Capacity Err	U1	0	100	15	0.10%

Qmax Capacity Err specifies maximum capacity error allowed during Qmax update. Capacity error is estimated based on the time spent for Qmax measurement.

5.5.1.8 Maximum Qmax Change

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	65	Max Qmax Change	U1	0	255	30	%

Max Qmax Change specifies maximum allowed change in Qmax value during Qmax update. Qmax update is disqualified if change from previous Qmax value is greater than ***Max Qmax Change***.

5.5.1.9 Termination Voltage

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	67	Terminate Voltage	I2	2800	3700	3000	mV

Terminate Voltage is used in the Impedance Track™ algorithm to compute *RemainingCapacity( )*. This is the absolute minimum voltage for end of discharge, where the remaining chemical capacity is assumed to be zero.

Terminate Voltage stores the voltage for the end of discharge where *RemainingCapacity( )* is set to 0 mAh.

Set ***Terminate Voltage*** based on battery cell specifications to prevent damage to the cell or set to the absolute minimum system voltage, taking into account impedance drop from the PCB traces, FETs, and wires. The default value is set to 3000 mV.

5.5.1.10 Termination Voltage Delta and Fast Scale Start SOC

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	69	Term V Delta	I2	0	4200	200	mV
		103	Fast Scale Start SOC	U1	0	100	10	%

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***)

The default value for ***Term V Delta*** is 200 mV. For most battery applications, it is recommended to keep (***Terminate Voltage*** + ***Term V Delta***) below 3.4 volts.

5.5.1.11 Simulation Res Relax Time

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	72	ResRelax Time	U2	0	65534	500	s

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 ***Res Relax Time*** during discharge simulation. Default value has been optimized for typical cell behavior.

ResRelax Time or resistance relaxation time is used for transient modeling. It represents the time it takes for the internal resistance to be fully saturated. This way the gauge will not simulate immediate large IR drops when it calculates the instantaneous voltage from the battery under load.

The default value is 500 seconds, which is sufficient for most applications.

5.5.1.12 User-Defined Rate-Power

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	78	User Rate-Pwr	I2	3000	14000	0	mWh or cWh

This is the discharge rate used for Impedance Track™ simulation of voltage profile to determine discharge capacity. It is only used when ***Load Mode*** = 1 (constant-power) and ***Load Select*** = 6 (user-defined rate).

User Rate-Pwr is only used if Load Select is set to 6 and ***Load Mode*** = 1. If these criteria are met, then the power stored in this register is used for the *RemainingCapacity( )* computation in the Impedance Track algorithm. This is the only function that uses this register.

It is unlikely that this register is used. An example application that requires this register is one that has increased predefined power at the end of discharge. With this application, it is logical to adjust the rate compensation to this period because the IR drop during this end period is affected the moment ***Terminate Voltage*** is reached. The actual unit of this parameter is dependent on ***Design Energy Scale***. The default value is 0.

5.5.1.13 Reserve Capacity

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	80	Reserve Cap-mAh	I2	0	9000	0	mAh

Reserve Cap-mAh determines how much actual remaining capacity exists after reaching 0 *RemainingCapacity( )*, before ***Terminate Voltage*** is reached when ***Load Mode*** = 0 is selected. A loaded rate or no-load rate of compensation can be selected for *Reserve Cap* by setting the ***[RESCAP]*** bit in the ***Pack Configuration*** data flash register. This is a specialized function to allow time for a controlled shutdown after 0 *RemainingCapacity( )* is reached.

Carefully select ***Reserve Cap-mAh*** based upon the system requirements. The default value is set to 0 mAh.

5.5.1.14 Reserve Energy

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	82	Reserve Energy	I2	0	14000	0	mWh or cWh

Reserve Energy determines how much actual remaining capacity exists after reaching 0 *RemainingCapacity( )* which is equivalent to 0 remaining power, before ***Terminate Voltage*** is reached when ***Load Mode*** = 1 is selected. A loaded rate or no-load rate of compensation can be selected for *Reserve Cap* by setting the ***[RESCAP]*** bit in the ***Pack Configuration*** data flash register. This is a specialized function to allow time for a controlled shutdown after 0 *RemainingCapacity( )* is reached.

The unit of this parameter depends on ***Design Energy Scale***. Please see Section 5.3.4.12, *Design Energy Scale*, for details. The default value is 0.

5.5.1.15 Maximum and Minimum Delta Voltage

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	87	Max DeltaV	U2	0	65535	200	mV
		89	Min DeltaV	U2	0	65535	0	mV

Max DeltaV:

This is the maximum ***Delta Voltage*** that is saved during discharge cycles. See Section 5.5.3.6 for the description of ***Delta Voltage***. The default is 200 mV.

Min DeltaV:

This is the minimum ***Delta Voltage*** that is saved during discharge cycles. See Section 5.5.3.6 for the description of ***Delta Voltage***. The default is 0 mV.

5.5.1.16 Maximum and Minimum Simulation Rate

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	91	Max Sim Rate	U1	0	255	1	C/rate
		92	Min Sim Rate	U1	0	255	20	C/rate

Max Sim Rate:

Maximum IT simulation rate (inversed). 2 implies C / 2. This is the maximum load used in IT simulations in terms of C-rate.

This register defaults to 1.

Min Sim Rate:

Minimum IT simulation rate (inversed). 20 implies C / 20. This is the minimum load used in IT simulations in terms of C-rate.

This register defaults to 20.

5.5.1.17 Ra Maximum Delta

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	93	Ra Max Delta	U2	0	65535	43	mΩ

The maximum jump allowed during updates of a Ra table grid point.

Calculate and modify ***Ra Max Delta*** when creating the golden file, set this to 15% of the grid 4 Ra value after optimization cycle is completed, the default is 43.

5.5.1.18 Qmax Maximum Delta %

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	95	Qmax Max Delta %	U1	0	100	5	%

This is the percent of *DesignCapacity( )* to limit how much Qmax may grow or shrink during any one Qmax update

The default is 5%.

5.5.1.19 Qmax Upper Bound %

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	96	Qmax Bound %	U1	0	255	130	%

Maximum allowed Qmax increase over lifetime of the pack. It is calculated as a fraction of ***Design Capacity***.

5.5.1.20 Delta V Maximum Delta

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	97	DeltaV Max Delta	U2	0	65535	10	mV

Limits on how far ***Delta Voltage*** grows or shrinks on one grid update (in mV).

This register defaults to 10.

5.5.1.21 Maximum and Minimum Resistance Scale

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	99	Max Res Scale	U2	0	32767	5000	number
		101	Min Res Scale	U2	0	32767	200	number

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

5.5.1.22 Charge Hysteresis Voltage Shift

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
80	IT Cfg	104	Charge Hys V Shift	I2	0	2000	40	mV

Charge Hys V Shift is a flash parameter that helps the gauge to avoid Qmax update in the flat region after a charge to avoid OCV hysteresis effects. If OCV (in mV) < Flat region upper bound (typically ~3800 mV) + ***Charge Hys V Shift***, then Qmax update is not allowed.

It is recommended to keep this value at the default setting of 40 mV.

5.5.2 Current Thresholds Subclass

5.5.2.1 Discharge and Charge Detection Threshold

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
81	Current Thresholds	0	Dsg Current Threshold	I2	0	2000	60	mA
		2	Chg Current Threshold	I2	0	2000	75	mA

Dsg Current Threshold:

This register is used as a threshold by many functions in the fuel gauge to determine if actual discharge current is flowing out of the battery. The *[DSG]* flag in *Flags( )* is the method for determining charging or discharging. If the fuel gauge detects discharge *[DSG]* is set to 1 and any other time (charging or relaxation), the *[DSG]* flag is set to 0. Discharge is detected if *AverageCurrent()* < –***Dsg Current Threshold***. Please note that current is negative while discharging.

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 (please note that ***Dsg Current Threshold*** is a positive value). The default is 60 mA.

Chg Current Threshold:

This register is used as a threshold by many functions in the fuel gauge to determine if actual charge current is flowing out of the battery. It is independent from the *[CHG]* bit which is used to determine charge termination. This threshold also has no effect on the *[DSG]* bit in the *Flags( )* register.

Many algorithms in the fuel gauge require more definitive information about whether current is flowing in the charge or discharge direction. This is what ***Chg Current Threshold*** is used for. The default for this register is 75 mA which is sufficient for most applications.

5.5.2.2 Quit Current

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
81	Current Thresholds	4	Quit Current	I2	0	1000	40	mA

Quit Current sets a current threshold to determine when the fuel gauge goes into relaxation mode from charge or discharge mode. The ***Quit Current*** parameter has units of mA. Either of the following criteria must be met to enter relaxation mode:

1. *AverageCurrent( )* is **less than** (–)***Quit Current*** and then goes within (±)***Quit Current*** for ***Dsg Relax Time***.
2. *AverageCurrent( )* is **greater than *Quit Current*** and then goes within (±)***Quit Current*** for ***Chg Relax Time***.

After 30 minutes in relaxation mode, the fuel gauge starts checking if the dV / dt < 1 µV/s requirement for OCV readings is satisfied. When the battery relaxes sufficiently to satisfy this criterion, the fuel gauge takes an OCV reading for updating Q_{max}. These updates are used by the Impedance Track™ algorithm.

It is critical that the battery voltage be relaxed during OCV readings to get the most accurate results. The quit current threshold must not be higher than ***Design Capacity*** / 20 when attempting to go into relaxation mode; however, it should not be so low as to prevent going into relaxation mode due to noise. The current threshold that the ***Quit Current*** parameter sets should always be less than the magnitude of the current threshold the ***Chg Current Threshold*** sets and less than the magnitude of the current threshold the ***Dsg Current Threshold*** sets. The default value is set to 40 mA.

5.5.2.3 Discharge and Charge Relax Time

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
81	Current Thresholds	6	Dsg Relax Time	U2	0	8191	60	s
		8	Chg Relax Time	U1	0	255	60	s

Dsg Relax Time:

The ***Dsg Relax Time*** is used in the function to determine when to go into relaxation mode after discharge current ceases. When *AverageCurrent( )* is less than (–)***Quit Current*** and then goes within (±)***Quit Current***, the ***Dsg Relax Time*** timer is initiated. If the current stays within (±)***Quit Current*** until the ***Dsg Relax Time*** timer expires, then the fuel gauge goes into relaxation mode. After 30 minutes in relaxation mode, the fuel gauge starts checking if the dV / dt < 4 µV/s requirement for OCV readings is satisfied. When the battery relaxes sufficiently to satisfy these criteria, the fuel gauge takes OCV reading for updating Qmax and for accounting for self-discharge. These updates are used in the Impedance Track algorithms.

Be careful when interpreting discharge descriptions in this document while determining the direction and magnitude of the currents, because they are in the negative direction. This is application specific, the default is 60 seconds.

Chg Relax Time:

The ***Chg Relax Time*** is used in the function to determine when to go into relaxation mode after charge current ceases. When *AverageCurrent( )* is greater than ***Quit Current*** and then goes within (±)***Quit Current***, the ***Chg Relax Time*** timer is initiated. If the current stays within (±)***Quit Current*** until the ***Chg Relax Time*** timer expires, then the fuel gauge goes into relaxation mode. After approximately 30 minutes in relaxation mode, the fuel gauge attempts to take accurate OCV readings. An additional requirement of dV / dt < 4 µV/s (delta voltage over delta time) is required for the fuel gauge to perform Qmax updates. These updates are used in the Impedance Track algorithms.

This is application specific. Default is 60 seconds.

5.5.2.4 Quit Relax Time

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
81	Current Thresholds	9	Quit Relax Time	U1	0	63	1	s

The ***Quit Relax Time*** is a delay time to exit relaxation. If current is greater than ***Chg Current Threshold*** or less than ***Dsg Current Threshold*** and this condition is maintained during ***Quit Relax Time***, then exiting relaxation is permitted.

This is particular to handheld applications in which low duty cycle dynamic loads are possible. Default is 1 second. For very short duration loads, it is permissible to consider the battery to have remained in relaxation mode if the loads were not extreme.

5.5.2.5 Maximum IR Correct

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
81	Current Thresholds	10	Max IR Correct	U2	0	1000	400	mV

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.

If current is flowing during a voltage measurement that is used for finding initial DOD, IR correction eliminates the effect of the IR drop across the cell impedance and obtain true OCV. ***Max IR Correct*** is the maximum value of IR correction that is used. It is to avoid artifacts due to very high resistance at low DOD values during charge.

This is particular to handheld applications. Default is 400 mV.

5.5.3 State Subclass

5.5.3.1 Qmax Cell 0

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
82	State	0	Qmax Cell 0	I2	0	32767	1000	mAh

Qmax contains the maximum chemical capacity of the cell profiles, and is determined by comparing states of charge before and after applying the load with the amount of charge passed. They also correspond to capacity at low rate of discharge, such as C/20 rate. For high accuracy, this value is periodically updated by the gauge during operation. Based on the battery cell capacity information, the initial value of the chemical capacity should be entered in Qmax filed. The Impedance Track™ algorithm updates this value and maintains it.

Before an optimization cycle is run, set this value to the battery cell datasheet capacity. After the optimization cycle is run and for creation of the golden settings, set it to the learned value. The default is 1000 mAh.

5.5.3.2 Update Status

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
82	State	2	Update Status	H1	0x0	0x6	0x0	hex

Since this is a pack-side gauge, the Update Status register can be represented by the bits below:

x	x	x	x	x	Bit 2	Bit 1	Bit 0

Three bits in this register are important:

- Bit 2 (0x04) indicates whether the Impedance Track™ algorithm is enabled.
- Bit 1 (0x02) indicates that the fuel gauge learned optimized values for Qmax and the Ra tables during a learning cycle.
- Bit 0 (0x01) indicates that the fuel gauge learned an initial value for Qmax after the charging portion of a learning cycle.

At the beginning of a learning cycle when creating a golden file, Update Status starts at 0x00. When IT is enabled with the *IT_ENABLE* subcommand being sent to *Control( )*, Update Status automatically changes to 0x04. After the charge and relaxation portion of the learning cycle are complete, Update Status should have become 0x05. Finally, after the discharge and relaxation portion of the learning cycle, Update Status becomes 0x06 if the learning cycle was successfully completed. A golden file can then be generated if Update Status was successfully set to 0x06 by the gauge. When the golden file is created, bit 2 is cleared, leaving Update Status = 0x02.

Do not change any of these bits manually. IT must be enabled only by sending the *IT_ENABLE* subcommand to the *Control( )* register.

Bit 1 is a status flag that can be set by the fuel gauge as needed. This bit should never be modified except when creating a golden file.

See for a detailed description of the learning cycle.

5.5.3.3 Voltage at Charge Termination

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
82	State	3	V at Chg Term	I2	0	5000	4200	mV

This is the gauge recorded voltage at charge termination. It is used by the gauge to learn the depth of discharge (DoD) of a full battery for a given system. This is updated by the gauge after every charge termination to account for variations between systems and different temperatures.

V at Chg Term defaults to 4200 mV but can be initialized to the nominal charging voltage of the system.

5.5.3.4 Average Current Last Run

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
82	State	5	Avg I Last Run	I2	–32768	32767	–299	mA

The fuel gauge logs the *AverageCurrent( )* averaged from the beginning to the end of each discharge. It stores this average current from the previous discharge period in this register provided that the previous discharge lasted at least 500 seconds.

This register should never need to be modified, it is only updated by the fuel gauge when the gauge exits discharge mode.

5.5.3.5 Average Power Last Run

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
82	State	7	Avg P Last Run	I2	–32768	32767	–1131	Power (mA)

The fuel gauge logs the power averaged from the beginning to the end of each discharge. It stores this average power from the previous discharge period in this register provided the previous discharge lasted at least 500 seconds. To get a correct average power reading, the fuel gauge continuously multiplies instantaneous current with *Voltage( )* to get power. It then logs this data to derive the average power.

This register should never need to be modified. It is only updated by the fuel gauge when the gauge exits discharge mode.

5.5.3.6 Pulse Delta Voltage

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
82	State	9	Delta Voltage	I2	–32768	32767	2	mV

The maximum difference of *Voltage( )* during short load spikes and normal load, so the Impedance Track™ algorithm can calculate remaining capacity for pulse loads. The ***Delta Voltage*** value is automatically updated by the gauge during operation as voltage spikes are detected. It can be initialized to a higher value if large spikes are typical for the system. Allowable values are limited by *Max Delta V* and *Min Delta V*. During the IT simulations, the target voltage of the empty battery is ***(Terminate Voltage*** + ***Delta Voltage***). This feature allows ***Terminate Voltage*** to be set at the minimum operating voltage of the system with confidence that the 0% point will be reached at a sufficiently high voltage to prevent voltage spikes from crashing the system while still extracting maximum run time from the battery when spikes are small.

Delta Voltage defaults to 2 mV.

5.5.3.7 Thermal Rise Factor

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
82	State	13	T Rise	I2	0	32767	20	number

This is the thermal rise factor that is used in the single time constant heating-cooling thermal modeling. If set to 0, this feature is disabled and simulations in the IT algorithm will not account for self-heating of the battery cell. Larger values of ***T Rise*** lead to higher temperature rise estimates for the IT simulation.

T Rise defaults to 20.

5.5.3.8 Thermal Time Constant

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
82	State	15	T Time Constant	I2	0	32767	1000	number

This is the thermal time constant that is used in single time constant heating-cooling thermal modeling. The default setting can be used, or it can be modified to improve low-temperature accuracy if testing shows the model does not match the actual performance.

T Time Constant defaults to 1000. This is sufficient for many applications. However, it can be modified if better predictive accuracy at low temperatures is desired.

5.6 OCV Table Class

5.6.1 OCVa Table Subclass

5.6.1.1 Chemistry Identification

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
83	OCVa Table	0	Chem ID	H2	0x0000	0xFFFF	0x128	flags

The ***Chem ID*** determines the type of chemistry which is programmed on the gauge. Changing this value by replacing it in data flash has no effect on what is programmed on to the gauge. In order to obtain a new chemistry you must go through an actual chemistry tool. For the fuel gauge, this can be done using the bqCONFIG tool.

It defaults to 0128 when you program the default flash image which can be obtained from the Texas Instruments website.

5.7 Ra Table Class

This data is automatically updated during device operation. Do not make changes except for reading the values from another pre-learned pack for creating *Golden Image Files*. Profiles have format *Cell0 R_a* M where M is the number indicating state of charge to which the value corresponds.

Cell0 R_a flag

xCell0 R_a flag

Each subclass (R_a0 and R_a0x) in the Ra Table class is a separate profile of resistance values normalized at 0 degrees for the cell in a design. The cell has two profiles. They are denoted by the x or absence of the x at the end of the subclass title:

R_a0 or **R_a0x**.

The purpose for two profiles for the cell is to ensure that at any given time at least one profile is enabled and is being used while attempts can be made to update the alternate profile without interference. Having two profiles also helps reduce stress on the flash memory. At the beginning of each of the two subclasses (profiles) is a flag called ***Cell0 R_a flag*** or ***xCell0 R_a flag***. This flag is a status flag that indicates the validity of the table data associated with this flag and whether this particular table is enabled or disabled.

Each flag has two bytes:

1. The least-significant byte (LSB) indicates whether the table is currently enabled or disabled. It has the following options:
   (a) 0x00: means the table had a resistance update in the past; however, it is not the currently enabled table for the cell. (The alternate table for the cell must be enabled at this time.)
   (b) 0xFF: This means that the values in this table are default values. These table resistance values have never been updated, and this table is not the currently enabled table for the cell. (The alternate table for the indicated cell must be enabled at this time.)
   (c) 0x55: This means that this table is enabled for the indicated cell. (The alternate table must be disabled at this time.)
2. The most-significant byte (MSB) indicates the status of the data in this particular table. The possible values for this byte are:
   (a) 0x00: The data associated with this flag has a resistance update and the *Qmax Pack* is updated.
   (b) 0x05: The resistance data associated with this flag is updated and the pack is no longer discharging (this is prior to a *Qmax Pack* update).
   (c) 0x55: The resistance data associated with this flag is updated and the pack is still discharging. (Qmax update attempt not possible until discharging stops.)
   (d) 0xFF: The resistance data associated with this flag is all default data.

This data is used by the fuel gauge to determine which tables need updating and which tables are being used for the Impedance Track algorithm.

This data is used by the Impedance Track algorithm. The only reason this data is displayed and accessible is to allow the resistance data on golden image files to be updated. This description of the ***xCell0 R_a flags*** are intended for information purposes only. It is not intended to give a detailed functional description for the resistance algorithms.

Cell0 R_a0 – Cell0 R_a14,

xCell0 R_a0 – xCell0 R_a14,

The ***Ra Table*** class has 15 values for each R_a subclass. Each of these values represent a resistance value normalized at 0°C for the associated *Qmax Pack*-based SOC grid point as found by the following rules:

For ***Cell0 R_aM*** where:

1. If 0 ≤ M ≤ 7: The data is the resistance normalized at 0° for: SOC = 100% – (M × 11.1%)
2. If 8 ≤ M ≤ 14: The data is the resistance normalized at 0° for: SOC = 100% – [77.7% + (M – 7) × 3.3%)]

This gives a profile of resistance throughout the entire SOC profile of the battery cells concentrating more on the values closer to 0% where resistance quickly increases.

SOC, as stated in this description is based on *Qmax Pack*. It is not derived as a function of SOC. These resistance profiles are used by the fuel gauge for the Impedance Track algorithm. The only reason this data is displayed and accessible is to allow the resistance data on golden image files to be updated. This resistance profile description is for information purposes only. It is not intended to give a detailed functional description for the resistance algorithms. It is important to note that this data is in mΩ units and is normalized to 25°C. The following are useful observations to note with this data throughout the application development cycle:

- Watch for negative values in the **Ra Table** class. Negative numbers in profiles should never be anywhere in this class.

Watch for smooth consistent transitions from one profile grid point value to the next throughout each profile. As the fuel gauge does resistance profile updates, these values should be roughly consistent from one learned update to another without huge jumps in consecutive grid points.

5.7.1 R_a0 Subclass

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
88	R_a0	0	Cell0 R_a flag	H2	0x0000	0x0000	0xFF55	hex
		2	Cell0 R_a 0	I2	183	183	936	2^{-10} Ω
		4	Cell0 R_a 1	I2	181	181	936	2^{-10} Ω
		6	Cell0 R_a 2	I2	198	198	1224	2^{-10} Ω
		8	Cell0 R_a 3	I2	244	244	1616	2^{-10} Ω
		10	Cell0 R_a 4	I2	254	254	1184	2^{-10} Ω
		12	Cell0 R_a 5	I2	261	261	1076	2^{-10} Ω
		14	Cell0 R_a 6	I2	333	333	1188	2^{-10} Ω
		16	Cell0 R_a 7	I2	338	338	920	2^{-10} Ω
		18	Cell0 R_a 8	I2	345	345	924	2^{-10} Ω
		20	Cell0 R_a 9	I2	350	350	1044	2^{-10} Ω
		22	Cell0 R_a 10	I2	382	382	1104	2^{-10} Ω
		24	Cell0 R_a 11	I2	429	429	904	2^{-10} Ω
		26	Cell0 R_a 12	I2	502	502	1336	2^{-10} Ω
		28	Cell0 R_a 13	I2	545	545	4656	2^{-10} Ω
		30	Cell0 R_a 14	I2	366	366	10516	2^{-10} Ω

5.7.2 R_a0x Subclass

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
89	R_a0x	0	xCell0 R_a flag	H2	0xFFFF	0xFFFF	0xFFFF	hex
		2	xCell0 R_a 0	I2	183	183	936	2^{-10} Ω
		4	xCell0 R_a 1	I2	181	181	936	2^{-10} Ω
		6	xCell0 R_a 2	I2	198	198	1224	2^{-10} Ω
		8	xCell0 R_a 3	I2	244	244	1616	2^{-10} Ω
		10	xCell0 R_a 4	I2	254	254	1184	2^{-10} Ω
		12	xCell0 R_a 5	I2	261	261	1076	2^{-10} Ω
		14	xCell0 R_a 6	I2	333	333	1188	2^{-10} Ω
		16	xCell0 R_a 7	I2	338	338	920	2^{-10} Ω
		18	xCell0 R_a 8	I2	345	345	924	2^{-10} Ω
		20	xCell0 R_a 9	I2	350	350	1044	2^{-10} Ω
		22	xCell0 R_a 10	I2	382	382	1104	2^{-10} Ω
		24	xCell0 R_a 11	I2	429	429	904	2^{-10} Ω
		26	xCell0 R_a 12	I2	502	502	1336	2^{-10} Ω
		28	xCell0 R_a 13	I2	545	545	4656	2^{-10} Ω
		30	xCell0 R_a 14	I2	366	366	10516	2^{-10} Ω

5.8 Calibration Class

5.8.1 Data Subclass

Most of the following values never require modification by the user. They are only modified by the calibration commands in calibration mode. For calibration using a host system, see Appendix A, *Factory Calibration*.

5.8.1.1 CC Sense Resistor Gain

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
104	Data	0	CC Gain	F4	0.100	40.00	0.9536	mΩ

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 and discharge in and 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).

5.8.1.2 Coulomb Counter Delta

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
104	Data	4	CC Delta	F4	29800	1190000	1119000	mΩ

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 and discharge in and 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).

5.8.1.3 Coulomb Counter Offset

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
104	Data	8	CC Offset	I2	–32768	32767	–1500	mA

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-s offset during production, two different methods have been selected for calibrating ***CC Offset***.

- 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. This is a short calibration that is not as accurate as the second method mentioned below. 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 is done the first time the I^2C Data and Clock is low for more than 20 seconds, which is a much more accurate calibration.
- During normal Gas Gauge Operation when the I^2C 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.

5.8.1.4 Board Offset

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
104	Data	10	Board Offset	I1	–128	127	0	µA

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 chip. The simplified ground circuit design in the fuel gauge requires a separate board offset for each tested device.

5.8.1.5 Internal and External Temperature Offset

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
104	Data	11	Int Temp Offset	I1	–128	127	0	°C
		12	Ext Temp Offset	I1	–128	127	0	°C

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 of the reported *Temperature( )* if the internal temperature sensor is used. 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 TS1 pin of the fuel gauge as reported by *Temperature( )*. The gain of the thermistor is accurate enough that a calibration for gain is not required.

5.8.1.6 Pack Voltage Offset

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
104	Data	13	Pack V Offset	I1	–128	127	0	mV

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.

5.8.2 Current Subclass

5.8.2.1 Filter

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
107	Current	0	Filter	U1	0	255	239	number

Filter specifies the value for *AverageCurrent( )* filter.

5.8.2.2 Deadband

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	Max	Default	
107	Current	1	Deadband	U1	0	255	5	mA

Deadband creates a filter window to the reported *AverageCurrent( )* register where the current is reported as 0. Any negative current above this value or any positive current below this value is displayed as 0.

This defaults to 5 mA. Only a few reasons may require changing this value:

1. If the fuel gauge is not calibrated.
2. ***Board Offset*** has not been characterized.
3. If the PCB layout has issues that cause inconsistent board offsets from board to board.
4. An extra noisy environment along with reason 3.

5.9 Security Class

5.9.1 Codes Subclass

Subclass ID	Subclass	Offset	Name	Data Type	Value			Unit
					Min	**Max**	**Default**	
112	Codes	0	Sealed to Unsealed	H4	0	0xFFFF FFFF	0x3672 0414	hex
		4	Unsealed to Full	H4	0	0xFFFF FFFF	0xFFFF FFFF	hex
		8	Authen Key3	H4	0	0xFFFF FFFF	0x123 4567	hex
		12	Authen Key2	H4	0	0xFFFF FFFF	0x89AB CDEF	hex
		16	Authen Key1	H4	0	0xFFFF FFFF	0xFEDC BA98	hex
		20	Authen Key0	H4	0	0xFFFF FFFF	0x7654 3210	hex

5.9.1.1 Sealed to Unsealed

This register contains the security code to transition the device from SEALED mode to UNSEALED mode.

The default code is set to 0x36720414.

5.9.1.2 Unsealed to Full Access

This register contains the security code to transition the device from UNSEALED mode to FULL ACCESS mode.

The default code is set to 0xFFFFFFFF.

5.9.1.3 Authentication Keys

This is the register to store the SHA-1 authentication key to allow a system to authenticate the battery pack.

The default key is set to 0x0123456789ABCDEFFEDCBA9876543210.

Chapter 6

Reference Schematics

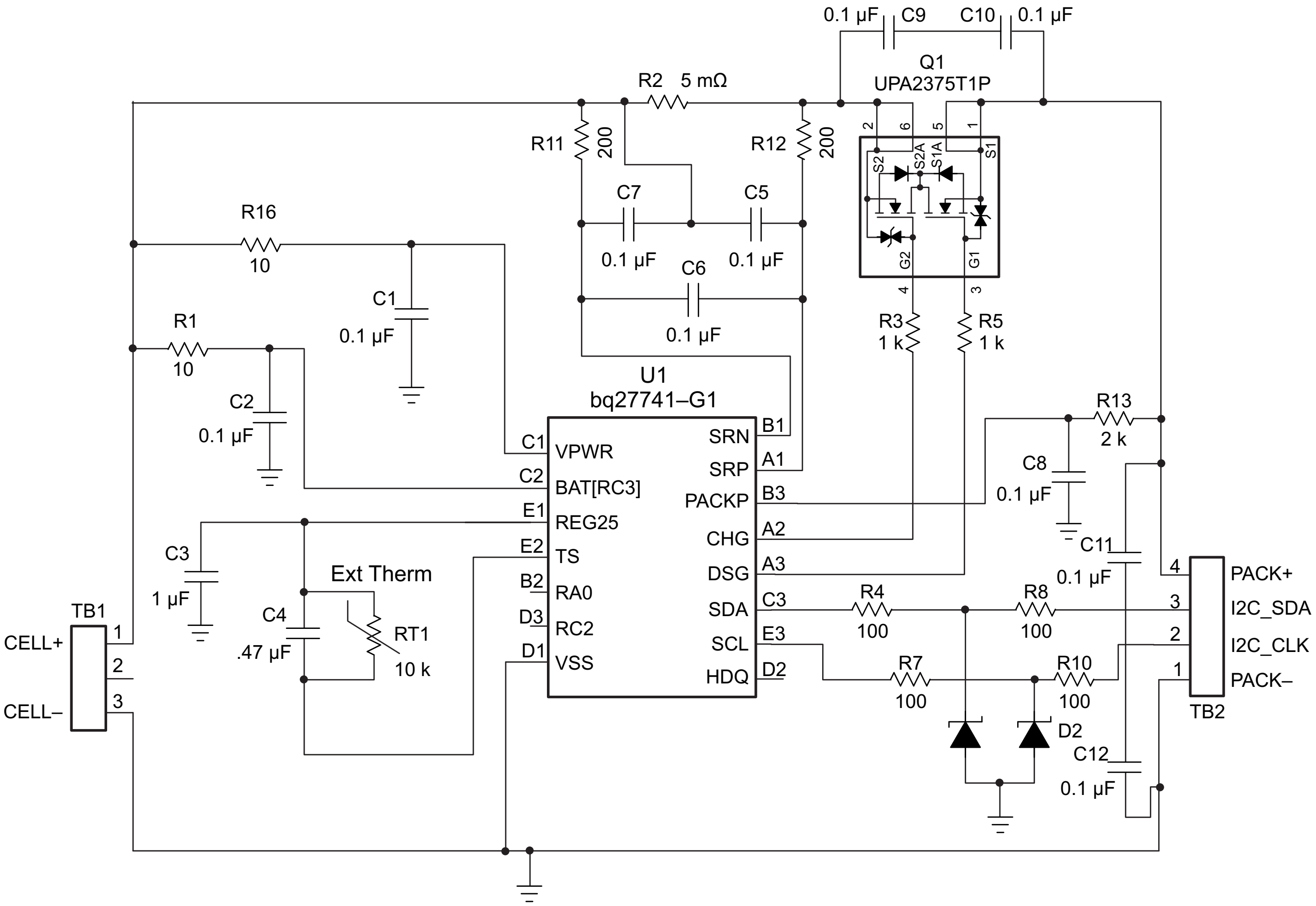


Figure 6-1. I^{2}C Mode

NOTE: R7, R8, and R9 are optional pulldown resistors if pullup resistors are applied.

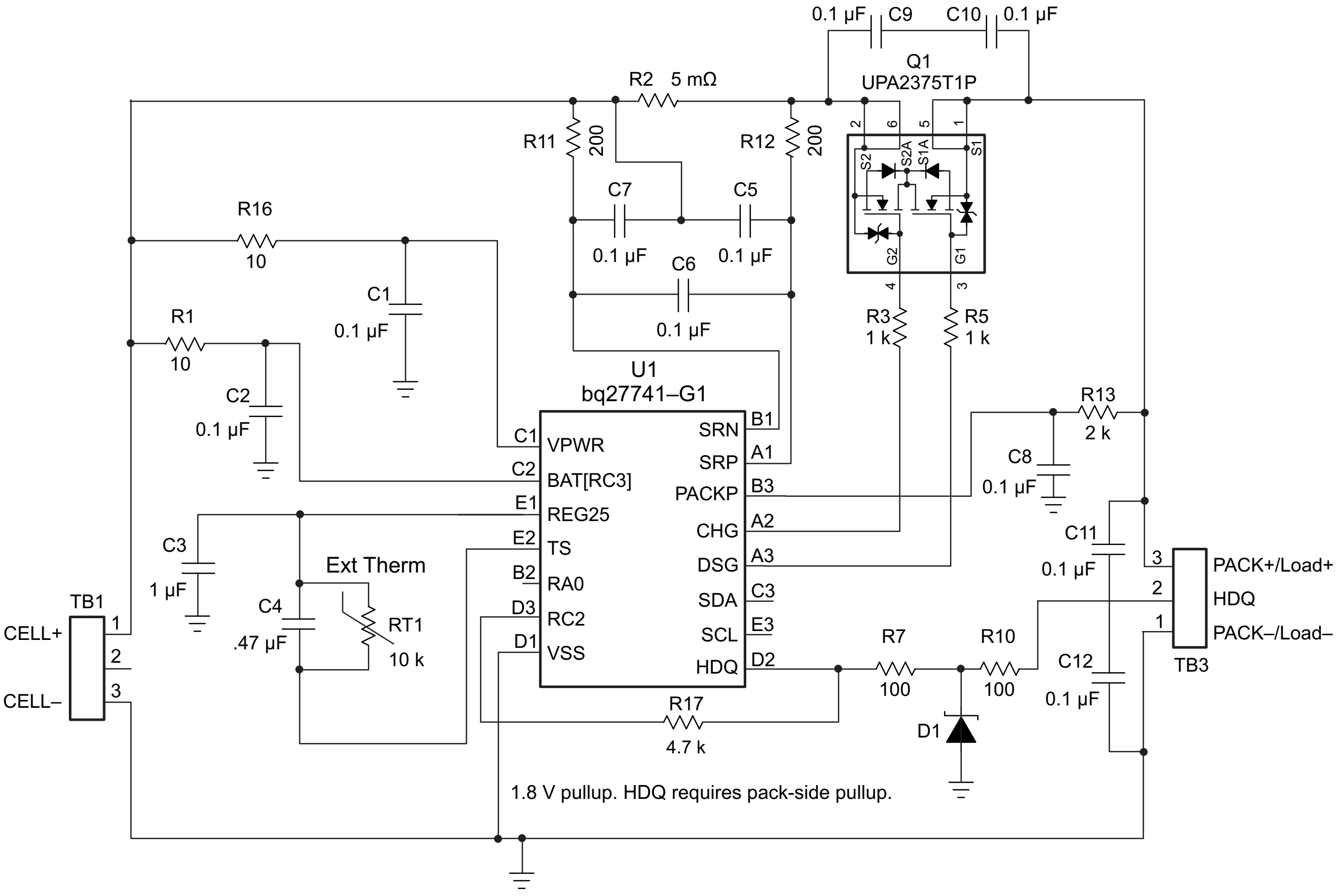


Figure 6-2. HDQ Mode

Factory Calibration

The bq27741-G1 fuel gauge requires factory calibration. The gauge performs only a limited number of calibration functions. The rest must be performed by a host system using commands provided by the gauge for this purpose. The following sections give a detailed description of the various calibration sequences with the help of flow charts.

A.1 General I^{2}C Command Information

In the following flow charts, all I^{2}C functions take 3 arguments. Write command arguments:

- Address
- Data
- Wait time in ms

Read command arguments:

- Address
- Number of bytes read
- Wait time in ms

A.2 Calibration

A.2.1 Method

The calibration method is broken up into the following sections. The first four sequences are subroutines to be used in the main calibration sequences.

- Section A.3, *Enter Calibration Mode*
- Section A.4, *Exit Calibration Mode*
- Section A.7, *Obtain Raw Calibration Data*
- Section A.11, *Floating Point Conversion*
- Section A.5, *CC Offset*
- Section A.6, *Board Offset*
- Section A.8, *Current Calibration*
- Section A.9, *Voltage Calibration*
- Section A.10, *Temperature Calibration*

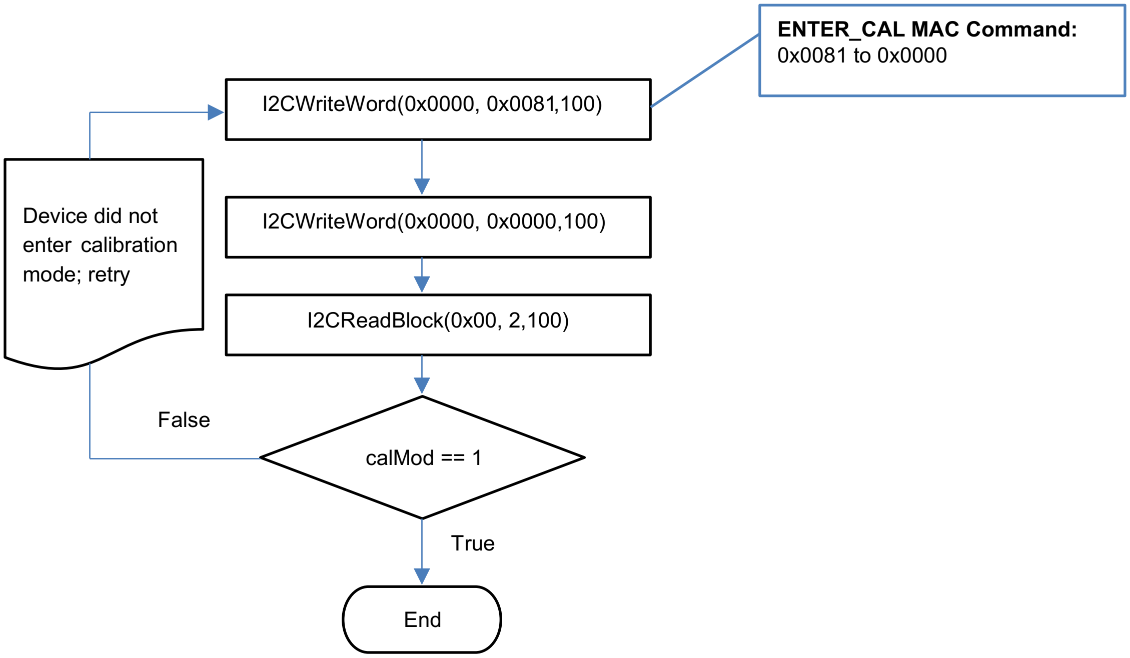
A.2.2 Sequence

Please, perform the following calibration sequence during battery pack manufacturing process:

1. Perform CC Offset
2. Perform Board Offset
3. Perform Current Calibration
4. Perform Voltage Calibration
5. Perform Temperature Calibration
6. Write calibration results to data flash

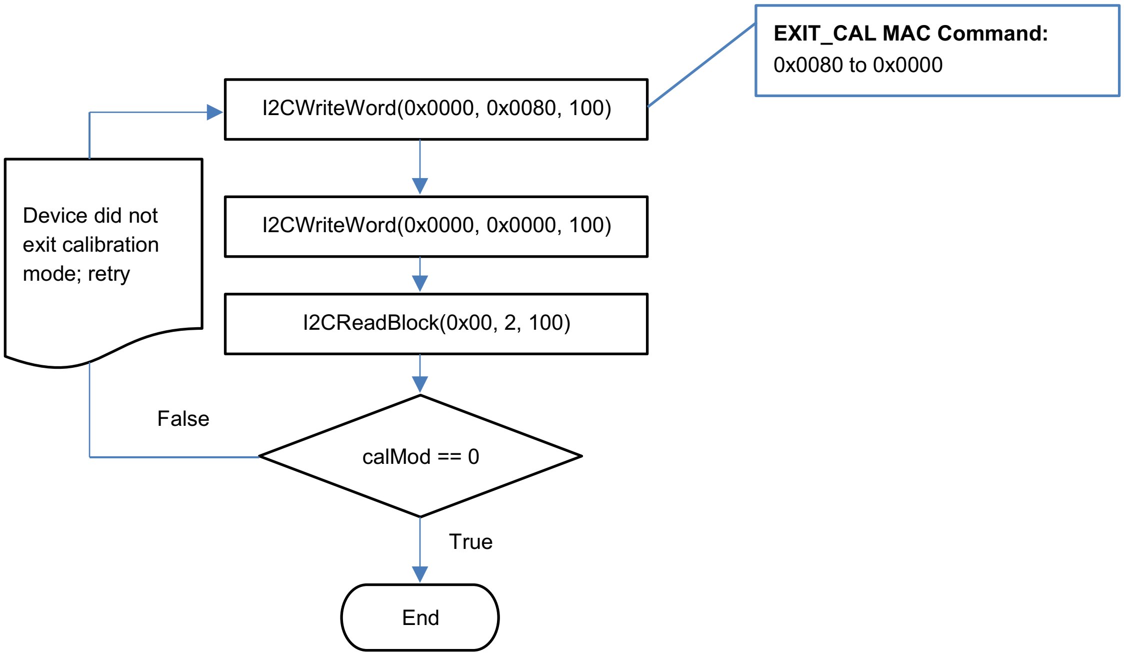
A.3 Enter Calibration Mode

This sequence puts the gauge into calibration mode. These steps must be performed when gauge is in UNSEALED mode.



A.4 Exit Calibration Mode

This sequence takes gauge out of calibration mode. These steps must be performed when gauge is in UNSEALED mode.



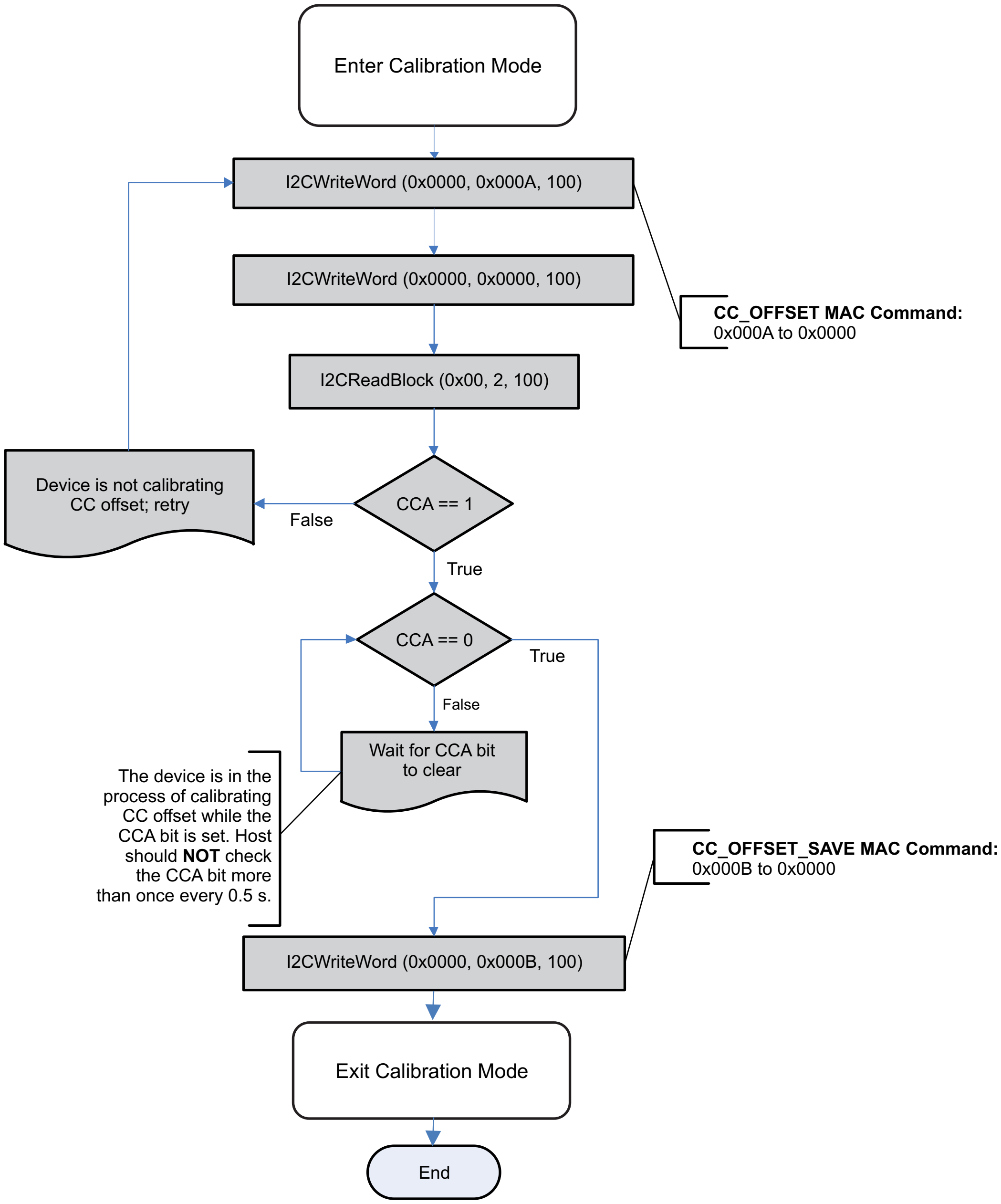
A.5 CC Offset

Use MAC commands for ***CC Offset*** calibration. The host system does not need to write information to the Data Flash (DF). See Section 4.1.1.1 for the description of the *CONTROL_STATUS[CCA]* bit. The host system needs to make sure the fuel gauge is unsealed.

NOTE: While the device is calibrating the ***CC Offset***, the host system must not read the *CONTROL_STATUS* register at a rate greater than once every 0.5 seconds.

NOTE: The step labeled **Enter Calibration Mode** refers to Section A.3, *Enter Calibration Mode*.

The step labeled **Exit Calibration Mode** refers to Section A.4, *Exit Calibration Mode*.



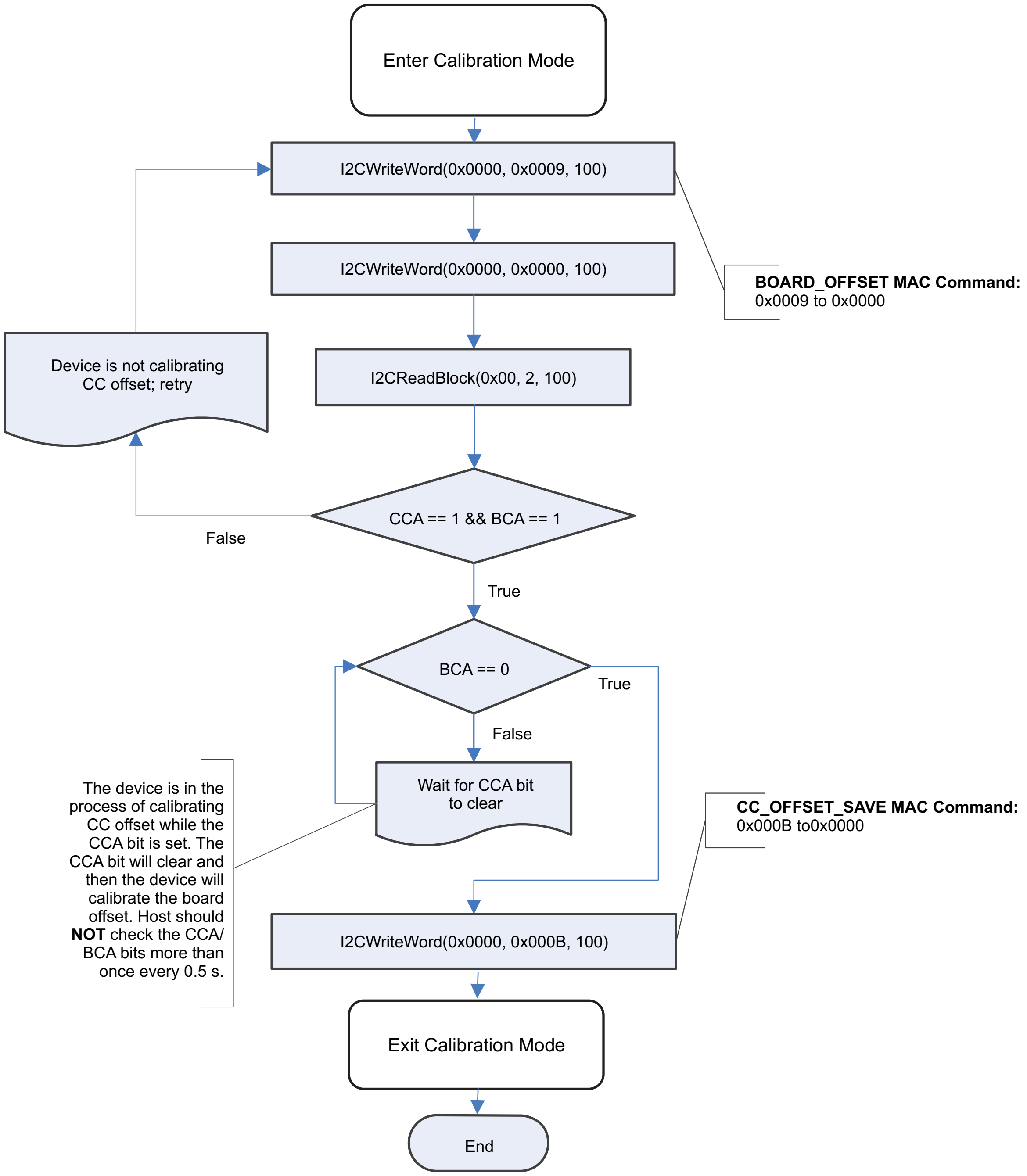
A.6 Board Offset

Use MAC commands for ***Board Offset*** calibration. The host system does not need to write information to the DF. The host system needs to make sure the fuel gauge is unsealed. See Section 4.1.1.1 for the description of the *CONTROL_STATUS[CCA]* and *[BCA]* bits. Note that calculating the ***Board Offset*** will also calculate the ***CC Offset***, therefore, it is not necessary to go through the ***CC Offset*** calibration process if the ***Board Offset*** calibration process is implemented.

NOTE: While the device is calibrating the ***CC Offset***, the host system should not read the *CONTROL_STATUS()* register at a rate greater than once every 0.5 seconds.

NOTE: The step labeled **Enter Calibration Mode** refers to Section A.3, *Enter Calibration Mode*.

The step labeled **Exit Calibration Mode** refers to Section A.4, *Exit Calibration Mode*.



BOARD_OFFSET MAC Command:
0x0009 to 0x0000

CC_OFFSET_SAVE MAC Command:
0x000B to0x0000

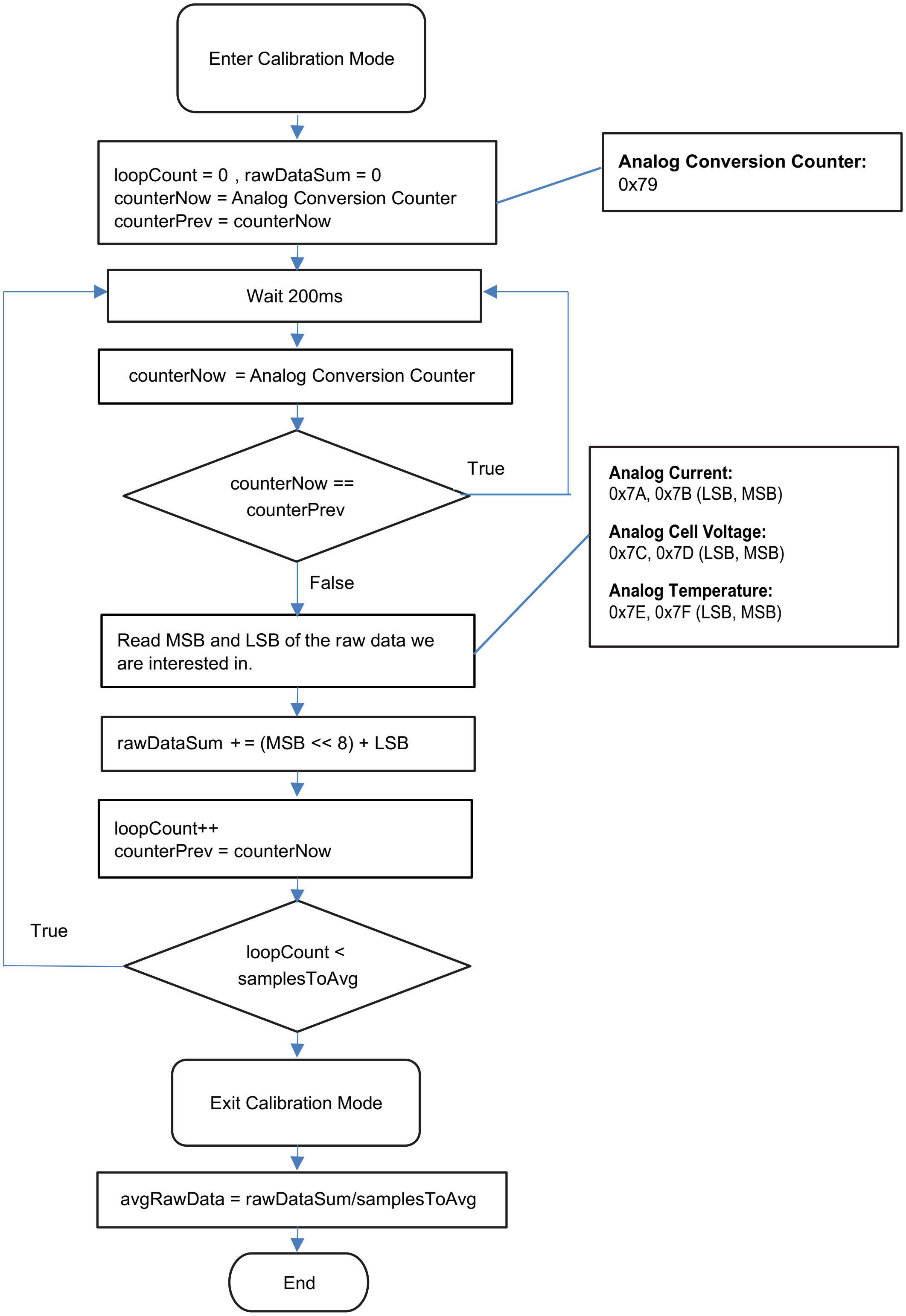
The device is in the process of calibrating CC offset while the CCA bit is set. The CCA bit will clear and then the device will calibrate the board offset. Host should **NOT** check the CCA/ BCA bits more than once every 0.5 s.

A.7 Obtain Raw Calibration Data

The following flow chart demonstrates how the host system obtains the raw data to calibrate current, voltage, and temperature. The host system uses this flow in conjunction with the Current, Voltage, and Temperature flows described in this appendix. It is recommended that the host system samples the raw data multiple times, at a rate of once per second, to obtain an average of the raw current, voltage and temperature. The host system needs to make sure the fuel gauge is UNSEALED.

NOTE: The step labeled **Enter Calibration Mode** refers to Section A.3, *Enter Calibration Mode*.

The step labeled **Exit Calibration Mode** refers to Section A.4, *Exit Calibration Mode*.

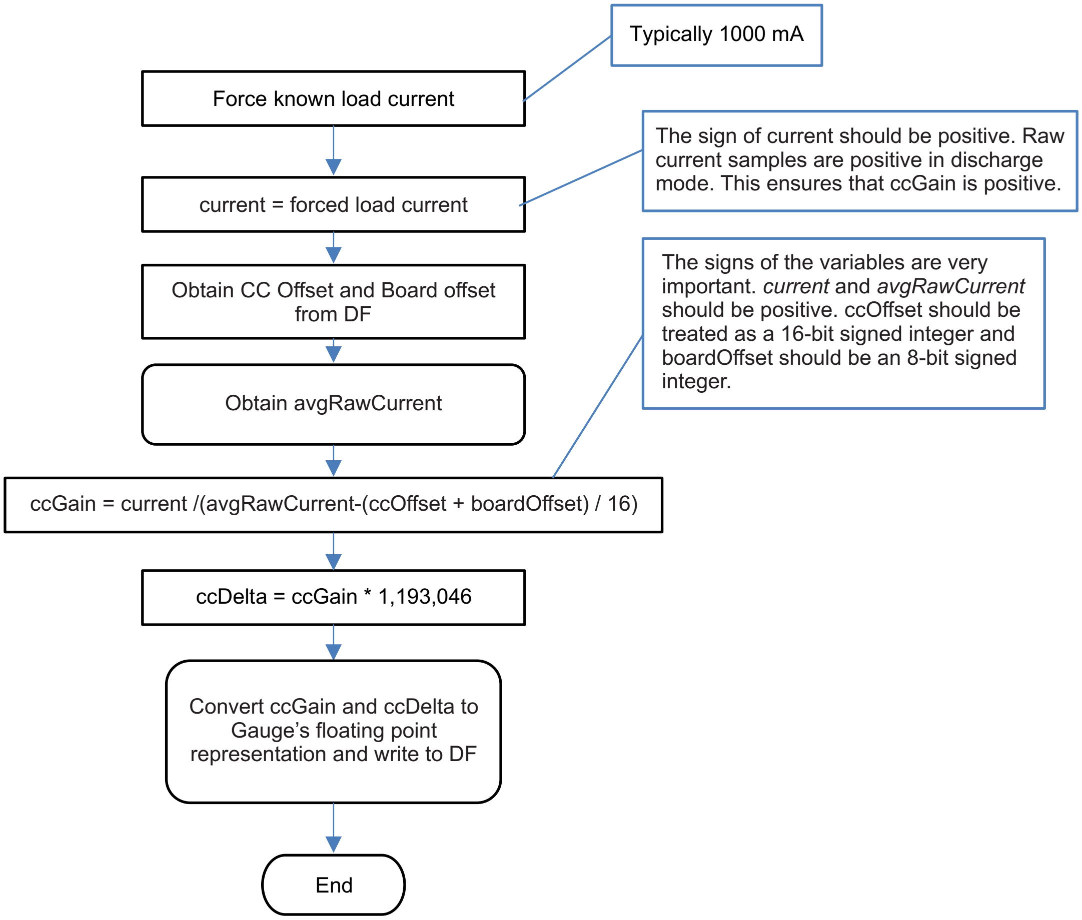

Enter Calibration Mode
loopCount = 0 , rawDataSum = 0
counterNow = Analog Conversion Counter
counterPrev = counterNow
Analog Conversion Counter:
0x79
Wait 200ms
counterNow = Analog Conversion Counter
counterNow == counterPrev
True
False
Analog Current:
0x7A, 0x7B (LSB, MSB)
Analog Cell Voltage:
0x7C, 0x7D (LSB, MSB)
Analog Temperature:
0x7E, 0x7F (LSB, MSB)
Read MSB and LSB of the raw data we are interested in.
rawDataSum += (MSB << 8) + LSB
loopCount++
counterPrev = counterNow
True
loopCount < samplesToAvg
Exit Calibration Mode
avgRawData = rawDataSum/samplesToAvg
End

A.8 Current Calibration

The ***CC Gain*** and ***CC Delta*** are two calibration parameters of concern for current calibration. A known load, typically 1000 mA, is applied to the device during this process. Details on converting the ***CC Gain*** and ***CC Delta*** to floating point format are in Section A.11, *Floating Point Conversion*. The host system needs to ensure the fuel gauge is UNSEALED.

NOTE: The step labeled **Obtain avgRawCurrent** refers to Section A.7, *Obtain Raw Calibration Data*.

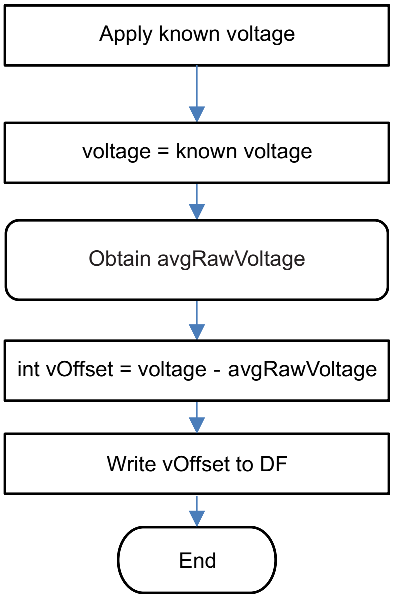
The step labeled **Convert ccGain and ccDelta to Gauge's floating point representation and write to DF** refers to Section A.11, *Floating Point Conversion*.



A.9 Voltage Calibration

A known voltage must be applied to the device for voltage calibration. The calculated voltage offset must be written to the corresponding location in DF. The voltage offset is represented by an integer that is a single byte in size and can be written to the appropriate location in DF without any intermediate steps. The host system needs to ensure the fuel gauge is UNSEALED.

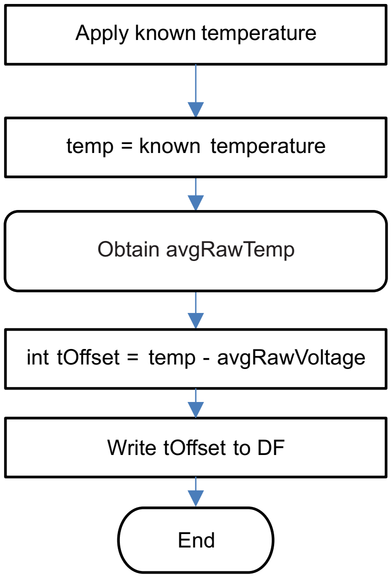
NOTE: The step labeled **Obtain avgRawVoltage** refers to Section A.7, *Obtain Raw Calibration Data*.



A.10 Temperature Calibration

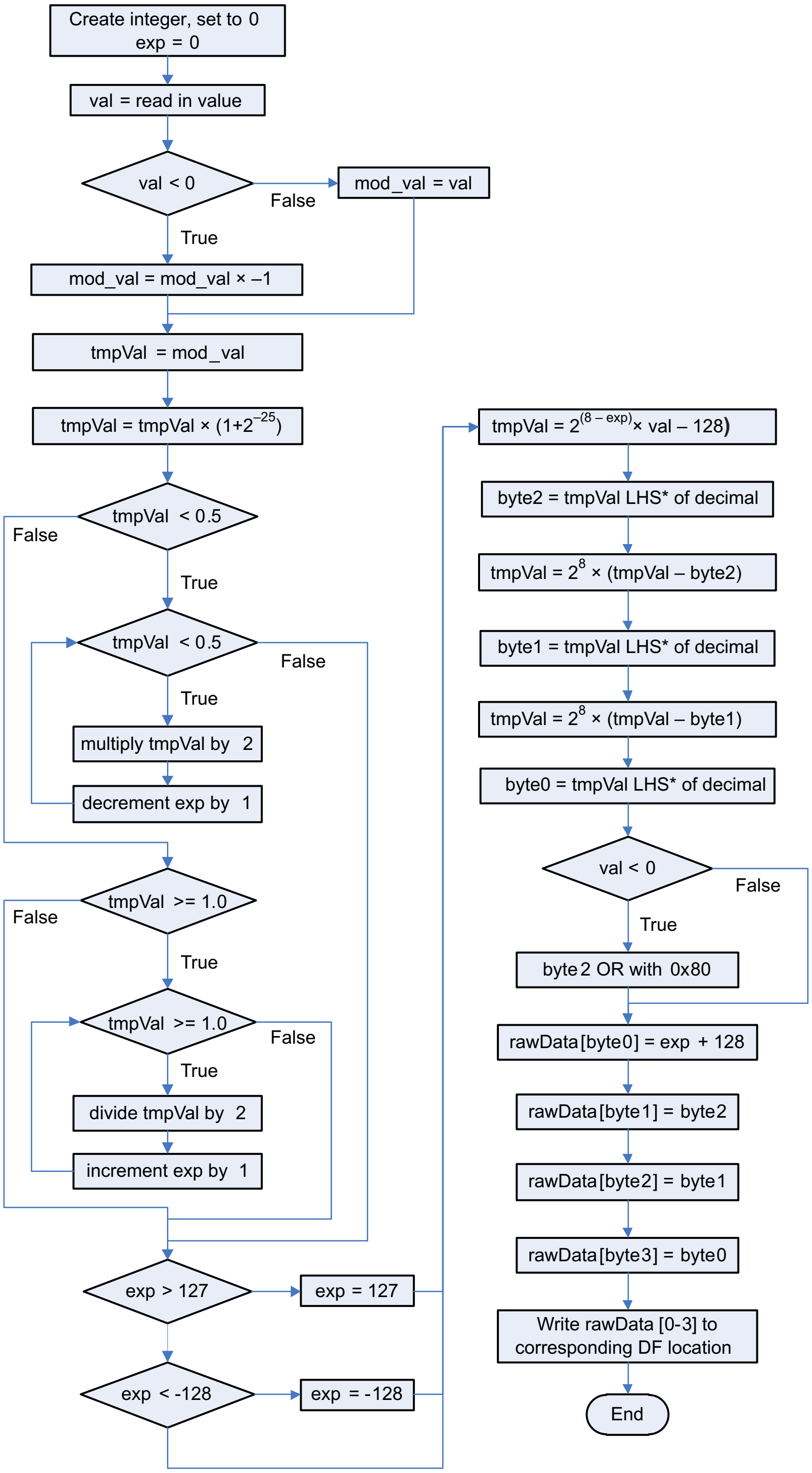
A known temperature must be applied to the device for temperature calibration. The calculated temperature offset is written to the corresponding location in DF. The temperature offset is represented by an integer that is a single byte in size and can be written to the appropriate location in DF without any intermediate steps. The host system needs to ensure the fuel gauge is unsealed.

NOTE: The step labeled **Obtain avgRawTemp** refers to Section A.7, *Obtain Raw Calibration Data*.



A.11 Floating Point Conversion

This section details how to convert the floating point ***CC Gain*** and ***CC Delta*** values to the format understood by the gauge.



* LHS is an abbreviation for Left Hand Side. This refers to truncating the floating point value by removing anything to the right of the decimal point.

Appendix B

Glossary

ACK	Acknowledge character
ADC	Analog-to-digital converter
BCA	Board calibration
CC	Coulomb counter
CCA	Coulomb counter calibration
CE	Chip enable
Charge Mode	Refers to a mode to where the gauge reads *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.
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.
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 occurred or is occurring. This bit typically cannot be modified. The flags are set and cleared automatically by the 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^{2}C	Inter-integrated circuit
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
Qmax	Maximum chemical capacity
Qpass	Qmax Passed Charge. The amount of charge passed between two DOD0 points required for learning Qmax.
RDIS	Resistance update disabled

Rem Cap	Present remaining capacity in the battery compensated for present load current, temperature, and aging effects (reduction in chemical capacity and increase in internal impedance).
RM	Remaining capacity
RW	Read or write
SCL	Serial clock: programmable serial clock used in the I^2C interface
SDA	Serial data: serial data bus in the I^2C 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
VOK	Indicates that Qmax has been saved to data flash. This bit is located on *CONTROL_STATUS* register bit 1.

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