bq40z60 Programmable Battery Pack Manager

Technical Reference Manual

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Preface

Read this First

This manual discusses the modules and peripherals of the bq40z60 device, and how each is used to build a complete battery pack gas gauge, charging control, and protection solution.

Notational Conventions

The following notation is used if SBS commands and data flash values are mentioned within a text block:

- SBS commands: *italics* with parentheses and no breaking spaces; e.g., *RemainingCapacity()*.
- Data Flash: *italics*, **bold**, and breaking spaces; e.g., ***Design Capacity***.
- Register Bits and Flags: *italics* and brackets; e.g., *[TDA]*
- Data Flash Bits: *italics* and **bold**; e.g., ***[LED1]***
- Modes and states: ALL CAPITALS; e.g., UNSEALED

The reference format for SBS commands is: SBS:Command Name(Command No.): Manufacturer Access(MA No.)[Flag]; for example:

SBS:Voltage(0x09), or SBS:ManufacturerAccess(0x00): Seal Device(0x0020)

Trademarks

Impedance Track is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

Introduction

The bq40z60 device provides feature-rich battery management, with gas gauging, battery charge control, and protection solutions for 2-series cell to 4-series cell battery-pack applications. The device has extended capabilities, including:

- Fully Integrated 2-Series to 4-Series Li-Ion or Li-Polymer Cell Battery Pack Manager and Protection
- Next-Generation Patented Impedance Track™ Technology Accurately Measures Available Charge in Li-Ion and Li- Polymer Batteries
- High Side N-CH Protection FET Drive
- Integrated Cell Balancing While Charging or At Rest
- Low Power Modes
  - LOW POWER
  - SLEEP
- Full Array of Programmable Protection Features
  - Voltage
  - Current
  - Temperature
  - Charge Timeout
  - CHG/DSG FETs
  - Cell Imbalance
- Sophisticated Charge Algorithms, with gas gauge that directly communicates to Battery Charger the programmed charging parameters
  - JEITA
  - Enhanced Charging
  - Adaptive Charging
  - Cell Balancing
- Diagnostic Lifetime Data Monitor
- Black Box Event Recorder
- Supports Two-Wire SMBus v1.1 Interface
- SHA-1 Authentication
- Ultra-Compact Package: 32-Lead QFN

Protections

2.1 Introduction

All protection items can be enabled or disabled under ***Settings:Enable Protections A*** and ***Settings:Enable Protections B***.

2.2 Cell Undervoltage Protection

The device can detect cell undervoltage in batteries and protect cells from damage by preventing further discharge.

STATUS	CONDITION	ACTION
Normal	Min cell voltage1..4 > ***CUV:Threshold***	*SafetyAlert()[CUV]* = 0 *BatteryStatus()[TDA]* = 0
Alert	Min cell voltage1..4 ≤ ***CUV:Threshold***	*SafetyAlert()[CUV]* = 1 *BatteryStatus()[TDA]* = 1
Trip	Min cell voltage1..4 ≤ ***CUV:Threshold*** for ***CUV:Delay*** duration	*SafetyAlert()[CUV]* = 0 *SafetyStatus()[CUV]* = 1 *BatteryStatus()[FD]* = 1, *[TDA]* = 0 *OperationStatus()[XDSG]* = 1
Recovery	Condition 1: *SafetyStatus()[CUV]* = 1 AND Min cell voltage1..4 ≥ ***CUV:Recovery*** AND ***Protection Configuration[CUV_RECOV_CHG]*** = 0	*SafetyStatus()[CUV]* = 0 *BatteryStatus()[FD]* = 0, *[TDA]* = 0 *OperationStatus()[XDSG]* = 0
	OR Condition 2: *SafetyStatus()[CUV]* = 1 AND Min cell voltage1..4 ≥ ***CUV:Recovery*** AND ***Protection Configuration[CUV_RECOV_CHG]*** = 1 AND Charging detected (that is, *BatteryStatus()[DSG]* = 0)	

2.2.1 Cell Undervoltage Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	CUV	Threshold	I2	0	32767	2500	mV
Protections	CUV	Delay	U1	0	255	2	s
Protections	CUV	Recovery	I2	0	32767	3000	mV

2.3 Cell Undervoltage Compensated Protection

The device can detect cell undervoltage in batteries and protect cells from damage by preventing further discharge. The *Current()* × CellResistance1..4 compensates the protection.

STATUS	CONDITION	ACTION
Normal	Min cell voltage1..4 – *Current()* × Cell Resistance > ***CUVC: Threshold***	*SafetyAlert()[CUVC]* = 0 *BatteryStatus()[TDA]* = 0
Alert	Min cell voltage1..4 – *Current()* × Cell Resistance ≤ ***CUVC: Threshold***	*SafetyAlert()[CUVC]* = 1 *BatteryStatus()[TDA]* = 1
Trip	Min cell voltage1..4 – *Current()* × Cell Resistance ≤ ***CUVC: Threshold*** for ***CUVC:Delay*** duration	*SafetyAlert()[CUVC]* = 0 *SafetyStatus()[CUVC]* = 0 *BatteryStatus()[FD]* = 1, *[TDA]* = 0 *OperationStatus()[XDSG]* = 1

STATUS	CONDITION	ACTION
Recovery	Condition 1: *SafetyAlert()[CUVC]* = 1 AND Min cell voltage1..4 – *Current()* × Cell Resistance > ***CUVC: Recovery*** AND ***Protection Configuration[CUV_RECOV_CHG]*** = 0	*SafetyStatus()[CUVC]* = 0 *BatteryStatus()[FD]* = 0, *[TDA]* = 0 *OperationStatus()[XDSG]* = 0
	OR Condition 2: *SafetyAlert()[CUVC]* = 1 AND Min cell voltage1..4 – *Current()* × Cell Resistance > ***CUVC: Recovery*** AND ***Protection Configuration[CUV_RECOV_CHG]*** = 1 AND Charging detected (that is, *BatteryStatus()[DSG]* = 0)	

2.3.1 Cell Undervoltage Compensated Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	CUVC	Threshold	I2	0	32767	2400	mV
Protections	CUVC	Delay	U1	0	255	2	s
Protections	CUVC	Recovery	I2	0	32767	3000	mV

2.4 Cell Overvoltage Protection

The device can detect cell overvoltage in batteries and protect cells from damage by preventing further charging.

NOTE: The temperature settings of the advanced charging algorithm and the measured temperature may influence the protection detection threshold.

STATUS	CONDITION	ACTION
Normal, *ChargingStatus()[UT] or [LT]* = 1	Max cell voltage1..4 < ***COV:Threshold Low Temp***	*SafetyAlert()[COV]* = 0
Normal, *ChargingStatus()[STL] or [STH]* = 1	Max cell voltage1..4 < ***COV:Threshold Standard Temp***	
Normal, *ChargingStatus()[RT]* = 1	Max cell voltage1..4 < ***COV:Threshold Rec Temp***	
Normal, *ChargingStatus()[HT] or [OT]* = 1	Max cell voltage1..4 < ***COV:Threshold High Temp***	
Alert, *ChargingStatus()[UT] or [LT]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold Low Temp***	*SafetyAlert()[COV]* = 1 *BatteryStatus()[TCA]* = 1
Alert, *ChargingStatus()[STL] or [STH]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold Standard Temp***	
Alert, *ChargingStatus()[RT]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold Rec Temp***	
Alert, *ChargingStatus()[HT] or [OT]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold High Temp***	
Trip, *ChargingStatus()[UT] or [LT]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold Low Temp*** for ***COV:Delay*** duration	*SafetyAlert()[COV]* = 0 *SafetyStatus()[COV]* = 1 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1
Trip, *ChargingStatus()[STL] or [STH]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold Standard Temp*** for ***COV:Delay*** duration	*SafetyAlert()[COV]* = 0 *SafetyStatus()[COV]* = 1 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1
Trip, *ChargingStatus()[RT]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold Rec Temp*** for ***COV:Delay*** duration	
Trip, *ChargingStatus()[HT] or [OT]* = 1	Max cell voltage1..4 ≥ ***COV:Threshold High Temp*** for ***COV:Delay*** duration	

STATUS	CONDITION	ACTION
Recovery, *ChargingStatus()[UT] or [LT]* = 1	*SafetyStatus()[COV]* = 1 AND Max cell voltage1..4 ≤ ***COV:Recovery Low Temp***	*SafetyStatus()[COV]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0
Recovery, *ChargingStatus()[STL] or [STH]* = 1	*SafetyStatus()[COV]* = 1 AND Max cell voltage1..4 ≤ ***COV:Recovery Standard Temp***	
Recovery, *ChargingStatus()[RT]* = 1	*SafetyStatus()[COV]* = 1 AND Max cell voltage1..4 ≤ ***COV:Recovery Rec Temp***	
Recovery, *ChargingStatus()[HT] or [OT]* = 1	*SafetyStatus()[COV]* = 1 AND Max cell voltage1..4 ≤ ***COV:Recovery High Temp***	

2.4.1 Cell Overvoltage Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	COV	Threshold Low Temp	I2	0	32767	4300	mV
Protections	COV	Threshold Standard Temp	I2	0	32767	4300	mV
Protections	COV	Threshold High Temp	I2	0	32767	4300	mV
Protections	COV	Threshold Rec Temp	I2	0	32767	4300	mV
Protections	COV	Delay	U1	0	255	2	s
Protections	COV	Recovery Low Temp	I2	0	32767	3900	mV
Protections	COV	Recovery Standard Temp	I2	0	32767	3900	mV
Protections	COV	Recovery High Temp	I2	0	32767	3900	mV
Protections	COV	Recovery Rec Temp	I2	0	32767	3900	mV

2.5 Overcurrent in Charge Protection

The device has two, independent overcurrent, in-charge protections that can be set to different current and delay thresholds to accommodate different charging behaviors.

STATUS	CONDITION	ACTION
Normal	*Current()* < ***OCC1:Threshold***	*SafetyAlert()[OCC1]* = 0
Normal	*Current()* < ***OCC2:Threshold***	*SafetyAlert()[OCC2]* = 0
Alert	*Current()* ≥ ***OCC1:Threshold***	*SafetyAlert()[OCC1]* = 1 *BatteryStatus()[TCA]* = 1
Alert	*Current()* ≥ ***OCC2:Threshold***	*SafetyAlert()[OCC2]* = 1 *BatteryStatus()[TCA]* = 1
Trip	*Current()* continuous ≥ ***OCC1:Threshold*** for ***OCC1:Delay*** duration	*SafetyAlert()[OCC1]* = 0 *SafetyStatus()[OCC1]* = 1 *BatteryStatus()[TCA]* = 0 Charging is not allowed. *OperationStatus()[XCHG]* = 1
Trip	*Current()* continuous ≥ ***OCC2:Threshold*** for ***OCC2:Delay*** duration	*SafetyAlert()[OCC2]* = 0 *SafetyStatus()[OCC2]* = 1 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1
Recovery	*SafetyStatus()[OCC1]* = 1 AND *Current()* continuous ≤ ***OCC:Recovery Threshold*** for ***OCC:Recovery Delay*** time	*SafetyStatus()[OCC1]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0
Recovery	*SafetyStatus()[OCC2]* = 1 AND *Current()* continuous ≤ ***OCC:Recovery Threshold*** for ***OCC:Recovery Delay*** time	*SafetyStatus()[OCC2]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0

2.5.1 Overcurrent in Charge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OCC1	Threshold	I2	–32768	32767	6000	mA
Protections	OCC1	Delay	U1	0	255	6	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OCC2	Threshold	I2	–32768	32767	8000	mA
Protections	OCC2	Delay	U1	0	255	3	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OCC	Recovery Threshold	I2	–32768	32767	–200	mA
Protections	OCC	Recovery Delay	U1	0	255	5	s

2.6 Overcurrent in Discharge Protection

The device has two, independent overcurrent, in discharge protections that can be set to different current and delay thresholds to accommodate different load behaviors.

STATUS	CONDITION	ACTION
Normal	*Current()* > ***OCD1:Threshold***	*SafetyAlert()[OCD1]* = 0
Normal	*Current()* > ***OCD2:Threshold***	*SafetyAlert()[OCD2]* = 0
Alert	*Current()* ≤ ***OCD1:Threshold***	*SafetyAlert()[OCD1]* = 1 *BatteryStatus()[TDA]* = 1
Alert	*Current()* ≤ ***OCD2:Threshold***	*SafetyAlert()[OCD2]* = 1 *BatteryStatus()[TDA]* = 1
Trip	*Current()*continuous ≤ ***OCD1:Threshold*** for ***OCD1:Delay*** duration	*SafetyAlert()[OCD1]* = 0 *SafetyStatus()[OCD1]* = 1 *BatteryStatus()[TDA]* = 0 *OperationStatus()[XDSG]* = 1
Trip	*Current()*continuous ≤ ***OCD2:Threshold*** for ***OCD2:Delay*** duration	*SafetyAlert()[OCD2]* = 0 *SafetyStatus()[OCD2]* = 1 *BatteryStatus()[TDA]* = 0 *OperationStatus()[XDSG]* = 1
Recovery	*SafetyStatus()[OCD1]* = 1 AND *Current()* continuous ≥ ***OCD:Recovery Threshold*** for ***OCD:Recovery Delay*** time	*SafetyStatus()[OCD1]* = 0 *BatteryStatus()[TDA]* = 0 *OperationStatus()[XDSG]* = 0
Recovery	*SafetyStatus()[OCD2]* = 1 AND *Current()* continuous ≥ ***OCD:Recovery Threshold*** for ***OCD:Recovery Delay*** time	*SafetyStatus()[OCD2]* = 0 *BatteryStatus()[TDA]* = 0 *OperationStatus()[XDSG]* = 0

2.6.1 Overcurrent in Discharge Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OCD1	Threshold	I2	–32768	32767	–6000	mA
Protections	OCD1	Delay	U1	0	255	6	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OCD2	Threshold	I2	–32768	32767	–8000	mA
Protections	OCD2	Delay	U1	0	255	3	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OCD	Recovery Threshold	I2	–32768	32767	200	mA
Protections	OCD	Recovery Delay	U1	0	255	5	s

2.7 Adapter Overvoltage Protection

The input voltage on the ACP pin is monitored for an overvoltage condition.

STATUS	CONDITION	ACTION
Normal	*VACP()* < ACOV Threshold	*SafetyStatus()[ACOV]* = 0
Trip	*VACP()* > ACOV Threshold for 250ms	*SafetyStatus()[ACOV]* = 1 *OperationStatus()[XCHG]* = 1
Recovery	*VACP()* < ACOV Recovery	*SafetyStatus()[ACOV]* = 0 *OperationStatus()[XDSG]* = 0

2.7.1 Adapter Overvoltage Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	ACOV	Threshold	I2	0	32767	20000	mV
Protections	ACOV	Recovery	I2	0	32767	19000	mV

2.8 Hardware-Based Protection

The bq40z60 device has three main hardware protections—Overload in Discharge (AOLD), Short Circuit in Charge (ASCC), and Short Circuit in Discharge (ASCD1,2)—with adjustable current and delay time. Setting ***AFE Protection Configuration[RSNS]*** divides the threshold values in half. The ***threshold*** settings are in mV; hence, the actual current that triggers the protection is based on the R_{SENSE} used in the schematic design.

In addition, setting the ***AFE Protection Configuration[SCDDx2]*** bit provides an option to double all of the SCD1,2 delay times for maximum flexibility towards the application's needs.

For details on how to configure the AFE hardware protection, refer to the tables in Appendix A.

All of the hardware-based protections provide short-term Trip, Alert, and Recovery protection to account for a current spike as well as a Trip/Alert/Latch protection for persistent fault condition. The latch feature also stops the FETs from toggling on and off continuously, preventing damage to the FETs.

In general, when a fault is detected after the ***Delay*** time, both CHG and DSG FETs will be disabled (Trip stage), and an internal fault counter will be incremented (Alert stage). Since both FETs are off, the current will drop to 0 mA. After ***Recovery*** time, the CHG and DSG FETs will be turned on again (Recovery stage).

If the alert is caused by a current spike, the fault count will be decremented after ***Counter Dec Delay*** time. If this is a persistent faulty condition, the device will enter the Trip stage after ***Delay*** time, and repeat the Trip/Alert/Recovery cycle. The internal fault counter is incremented every time the device goes through the Trip/Alert/Recovery cycle. Once the internal fault counter hits the ***Latch Limit***, the protection enters a Latch stage and the fault will only be cleared through the Latch Reset condition.

The Trip/Alert/Recovery/Latch stages are documented in each of the following hardware-based protection sections.

The recovery condition for removable pack (***[NR]*** = 0) is based on the transition on the SYSPRES pin, while the recovery condition for embedded pack (***[NR]*** = 1) is based on meeting the recovery condition. ***Non-Removable Config()*** gives an additional recovery option for removable battery pack (***[NR]*** = 0) to recover by the recovery condition if the corresponding bit in ***Non-Removable Config()*** is set.

2.8.1 Overload in Discharge Protection

The device has a hardware-based overload in discharge protection with adjustable current and delay.

STATUS	CONDITION	ACTION
Normal	*Current()* > (***OLD Threshold[3:0]*** / R $_{SENSE}$)	*SafetyAlert()[AOLDL]* = 0, if OLDL counter = 0
Trip	*Current()*continuous ≤ (***OLD Threshold[3:0]*** / R $_{SENSE}$) for ***OLD Threshold[7:4]*** duration	*SafetyStatus()[AOLD]* = 1 *OperationStatus()[XDSG]* = 1 Increment AOLDL counter
Recovery	*SafetyStatus()[AOLD]* = 1 for ***OLD:Recovery*** time	*SafetyStatus()[AOLD]* = 0 *OperationStatus()[XDSG]* = 0 if *SafetyStatus()[AOLDL]* = 0.
Latch Alert	AOLDL counter > 0	*SafetyAlert()[AOLDL]* = 1 Decrement AOLDL counter by one after each ***OLD:Counter Dec Delay*** period
Latch Trip	AOLDL counter ≥ ***OLD:Latch Limit***	*SafetyAlert()[AOLDL]* = 0 *SafetyStatus()[AOLDL]* = 1 *OperationStatus()[XDSG]* = 1
Latch Reset (***[NR]*** = 0)	*SafetyStatus()[AOLDL]* = 1 AND ***DA Configuration[NR]*** = 0 AND Low-high-low transition on SYSPRES pin	*SafetyStatus()[AOLDL]* = 0 Reset AOLDL counter *OperationStatus()[XDSG]* = 0 if *SafetyStatus()[AOLD]* = 0.
Latch Reset (***[NR]*** = 1)	*SafetyStatus()[AOLDL]* = 1 AND ***DA Configuration[NR]*** = 1 for ***OLD:Reset*** time	*SafetyStatus()[AOLDL]* = 0 Reset AOLDL counter *OperationStatus()[XDSG]* = 0 if *SafetyStatus()[AOLD]* = 0.

2.8.1.1 Overload in Discharge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	AOLD	Latch Limit	U1	0	255	0	—
Protections	AOLD	Counter Dec Delay	U1	0	255	10	s
Protections	AOLD	Recovery	U1	0	255	5	s
Protections	AOLD	Reset	U1	0	255	15	s
Protections	AOLD	Threshold	U1	0	0xff	0xf4	hex

2.8.2 Short Circuit in Charge Protection

The device has a hardware-based short circuit in charge protection with adjustable current and delay.

STATUS	CONDITION	ACTION
Normal	*Current()* < (***SCC Threshold[2:0]*** / R $_{SENSE}$)	*SafetyAlert()[ASCCL]* = 0, if ASCCL counter = 0
Trip	*Current()* continuous ≥ (***SCC Threshold[2:0]*** / R $_{SENSE}$) for ***SCC Threshold[7:4]*** duration	*SafetyStatus()[ASCC]* = 1 *OperationStatus()[XCHG]* = 1 increment ASCCL counter
Recovery	*SafetyStatus()[ASCC]* = 1 for ***SCC:Recovery*** time	*SafetyStatus()[ASCC]* = 0 *OperationStatus()[XCHG]* = 0 if *SafetyStatus()[ASCCL]* = 0.
Latch Alert	ASCCL counter > 0	*SafetyAlert()[ASCCL]* = 1 Decrement ASCCL counter by one after each ***SCC:Counter Dec Delay*** period
Latch Trip	ASCCL counter ≥ ***SCC:Latch Limit***	*SafetyAlert()[ASCCL]* = 0 *SafetyStatus()[ASCCL]* = 1 *OperationStatus()[XCHG]* = 1
Latch Reset (***[NR]*** = 0)	*SafetyStatus()[ASCCL]* = 1 AND ***DA Configuration[NR]*** = 0 AND Low-high-low transition on SYSPRES pin	*SafetyStatus()[ASCCL]* = 0 *OperationStatus()[XCHG]* = 0 if *SafetyStatus()[ASCC]* = 0.
Latch Reset (***[NR]*** = 1)	*SafetyStatus()[ASCCL]* = 1 AND ***DA Configuration[NR]*** = 1 for ***SCC:Reset*** time	*SafetyStatus()[ASCCL]* = 0 *OperationStatus()[XCHG]* = 0 if *SafetyStatus()[ASCC]* = 0.

2.8.2.1 Short Circuit in Charge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	ASCC	Latch Limit	U1	0	255	0	—
Protections	ASCC	Counter Dec Delay	U1	0	255	10	s
Protections	ASCC	Recovery	U1	0	255	5	s
Protections	ASCC	Reset	U1	0	255	15	s
Protections	ASCC	Threshold	U1	0	0xff	0x77	hex

2.8.3 Short Circuit in Discharge Protection

The device has a hardware-based short circuit in discharge protection with adjustable current and delay.

STATUS	CONDITION	ACTION
Normal	*Current()* > (***SCD1 Threshold[2:0]*** / R_{SENSE}) AND *Current()* > (***SCD2 Threshold[2:0]*** / R_{SENSE})	*SafetyAlert()[ASCDL]* = 0 if ASCDL counter = 0
Trip	*Current()* continuous ≤ (***SCD1 Threshold[2:0]*** / R_{SENSE}) for ***SCD1 Threshold[7:4]*** duration OR *Current()* continuous ≤ (***SCD2 Threshold[2:0]*** / R_{SENSE}) for ***SCD2 Threshold[7:4]*** duration	*SafetyStatus()[ASCD]* = 1 *OperationStatus()[XDSG]* = 0 Increment ASCDL counter
Recovery	*SafetyStatus()[ASCD]* = 1 for ***SCD:Recovery*** time	*SafetyStatus()[ASCD]* = 0 *OperationStatus()[XDSG]* = 0 if *SafetyStatus()[ASCDL]* = 0.
Latch Alert	ASCDL counter > 0	*SafetyAlert()[ASCDL]* = 1 Decrement ASCDL counter by one after each ***SCD:Counter Dec Delay*** period
Latch Trip	SCD counter ≥ ***SCD:Latch Limit***	*SafetyStatus()[ASCD]* = 0 *SafetyStatus()[ASCDL]* = 1 *OperationStatus()[XDSG]* = 1
Latch Reset (***[NR]*** = 0)	*SafetyStatus()[ASCDL]* = 1 AND ***DA Configuration[NR]*** = 0 AND Low-high-low transition on SYSPRES pin	*SafetyStatus()[ASCDL]* = 0 *OperationStatus()[XDSG]* = 0 if *SafetyStatus()[ASCD]* = 0.
Latch Reset (***[NR]*** = 1)	*SafetyStatus()[ASCCL]* = 1 AND ***DA Configuration[NR]*** = 1 for ***SCD:Reset*** time	*SafetyStatus()[ASCDL]* = 0 *OperationStatus()[XDSG]* = 0 if *SafetyStatus()[ASCD]* = 0.

2.8.3.1 Short Circuit in Discharge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	ASCD	Latch Limit	U1	0	255	0	—
Protections	ASCD	Counter Dec Delay	U1	0	255	10	s
Protections	ASCD	Recovery	U1	0	255	5	s
Protections	ASCD	Reset	U1	0	255	15	s
Protections	ASCD	Threshold 1	U1	0	0xff	0x77	hex
Protections	ASCD	Threshold 2	U1	0	0xff	0xE7	hex

2.9 Temperature Protections

The device provides overtemperature and undertemperature protections based on Cell Temperature measurement and FET temperature measurements. The Cell Temperature based protections are further divided into a protection-in-charging direction and discharging directions. This section describes in detail each of the protection functions.

For temperature reporting, the device supports a maximum of four external thermistors and one internal temperature sensor. Unused temperature sensors must be disabled by clearing the corresponding flag in ***Settings:Temperature Enable[TS4][TS3][TS2][TS1][TSInt]***.

Each of the external thermistors and the internal temperature sensor can be set up individually as a source for Cell Temperature or FET Temperature reporting. Setting the corresponding flag to 1 in ***Settings:Temperature Mode[TS4 Mode][TS3 Mode][TS2 Mode][TS1 Mode][TSInt Mode]*** configures that temperature sensor to report for FET Temperature. Clearing the corresponding flag sets that temperature sensor to report for Cell Temperature. The ***Settings:DA Configuration[FTEMP][CTEMP]*** allows users to use the maximal (setting the corresponding flag to 0) or the average (setting the corresponding flag to 1) of the source temperature sensors for Cell Temperature and FET Temperature reporting.

The *Temperature()* command returns the Cell Temperature measurement. The MAC and extended command *DAStatus2()* also returns the temperature measurement from the internal temperature sensor, the external thermistors TS1, TS2, TS3, and TS4, and the Cell and FET Temperatures.

The Cell Temperature based overtemperature and undertemperature safety provide protections in charge and discharge conditions. The battery pack is considered in CHARGE mode when *BatteryStatus()[DSG]* = 0, where *Current()* > ***Chg Current Threshold***. The overtemperature and undertemperature in charging protections are active in this mode. The *BatteryStatus()[DSG]* is set to 1 in a NON-CHARGE mode condition, which includes RELAX and DISCHARGE modes. The overtemperature and undertemperature in discharge protections are active in these two modes. See Section 7.3 for detailed descriptions of the gas gauge modes.

2.10 Overtemperature in Charge Protection

The device has overtemperature protection for cells under charge. Once the over-temperature is tripped, the charger will be disabled and will not be enabled until the temperature drops below OTC:Recovery and the OTC:Recovery period expires.

STATUS	CONDITION	ACTION
Normal	*Temperature()* < ***OTC:Threshold*** OR not charging	*SafetyAlert()[OTC]* = 0
Alert	*Temperature()* ≥ ***OTC:Threshold*** AND charging	*SafetyAlert()[OTC]* = 1 *BatteryStatus()[TCA]* = 1
Trip	*Temperature()* ≥ ***OTC:Threshold*** AND Charging for ***OTC:Delay*** duration	*SafetyAlert()[OTC]* = 0 *SafetyStatus()[OTC]* = 1 *BatteryStatus()[OTA]* = 1 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1 if **FET Options[OTFET]** = 1.
Recovery	*SafetyStatus()[OTC]* AND *Temperature()* ≤ ***OTC:Recovery***	*SafetyStatus()[OTC]* = 0 *BatteryStatus()[OTA]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0

2.10.1 Overtemperature in Charge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OTC	Threshold	I2	–400	1500	550	0.1°C
Protections	OTC	Delay	U1	0	255	2	s
Protections	OTC	Recovery	I2	–400	1500	500	0.1°C

2.11 Charge Overtemperature

The charger has an independent temperature comparator with a trip point defined by $T_{SHUTDOWN}$ in the datasheet. Once the overtemperature condition is detected, the charger will be disabled. The charger will not be re-enabled until the temperature is below $T_{SHUTDOWN} – T_{Hys}$ for *COT:Recovery Delay*.

2.11.1 Charger Overtemperature Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	COT	Recovery Delay	U1	0	255	5	s

2.12 Overtemperature in Discharge Protection

The device has overtemperature protection for cells in DISCHARGE or RELAX state (that is, non-charging state with *BatteryStatus[DSG]* = 1).

STATUS	CONDITION	ACTION
Normal	*Temperature()* < ***OTD:Threshold*** OR charging	*SafetyAlert()[OTD]* = 0
Alert	*Temperature()* ≥ ***OTD:Threshold*** AND Not charging (that is, *BatteryStatus[DSG]* = 1)	*SafetyAlert()[OTD]* = 1 *BatteryStatus()[TDA]* = 1
Trip	*Temperature()* ≥ ***OTD:Threshold*** AND Not charging (that is, *BatteryStatus[DSG]* = 1) for ***OTD:Delay*** duration	*SafetyAlert()[OTD]* = 0 *SafetyStatus()[OTD]* = 1 *BatteryStatus()[OTA]* = 1 *OperationStatus()[XDSG]* = 1 if ***FET Options[OTFET]*** = 1. *BatteryStatus()[TDA]* = 0
Recovery	*SafetyStatus()[OTD]* AND *Temperature()* ≤ ***OTD:Recovery***	*SafetyStatus()[OTD]* = 0 *BatteryStatus()[OTA]* = 0 *OperationStatus()[XDSG]* = 0 *BatteryStatus()[TDA]* = 0

2.12.1 Overtemperature in Discharge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OTD	Threshold	I2	–400	1500	600	0.1°C
Protections	OTD	Delay	U1	0	255	2	s
Protections	OTD	Recovery	I2	–400	1500	550	0.1°C

2.13 Overtemperature FET Protection

The device has overtemperature protection to limit the FET temperature.

STATUS	CONDITION	ACTION
Normal	FET Temperature in *DAStatus2()* < ***OTF:Threshold***	*SafetyAlert()[OTF]* = 0
Alert	FET Temperature in *DAStatus2()* ≥ ***OTF:Threshold***	*SafetyAlert()[OTF]* = 1 *BatteryStatus()[TDA]* = 1, *[TCA]* = 1
Trip	FET Temperature in *DAStatus()* ≥ ***OTF:Threshold*** for ***OTF:Delay*** duration	*SafetyAlert()[OTF]* = 0 *SafetyStatus()[OTF]* = 1 *BatteryStatus()[OTA]* = 1 *BatteryStatus()[TDA]* = 0, *[TCA]* = 0 *OperationStatus()[XCHG][XDSG]* = 1,1 if ***FET Options[OTFET]*** = 1
Recovery	*SafetyStatus()[OTF]* AND FET Temperature in *DAStatus2()* ≤ ***OTF:Recovery***	*SafetyStatus()[OTF* = 0 *BatteryStatus()[OTA]* = 0 *BatteryStatus()[TDA]* = 0, *[TCA]* = 0 *OperationStatus()[XCHG][XDSG]* = 0,0

2.13.1 Overtemperature FET Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OTF	Threshold	I2	–400	1500	800	0.1°C
Protections	OTF	Delay	U1	0	255	2	s
Protections	OTF	Recovery	I2	–400	1500	650	0.1°C

2.14 Undertemperature in Charge Protection

The device has undertemperature protection for cells in charge direction.

STATUS	CONDITION	ACTION
Normal	*Temperature()* > ***UTC:Threshold*** OR not charging	*SafetyAlert()[UTC]* = 0
Alert	*Temperature()* ≤ ***UTC:Threshold*** AND charging	*SafetyAlert()[UTC]* = 1
Trip	*Temperature()* ≤ ***UTC:Threshold*** AND Charging for ***UTC:Delay*** duration	*SafetyAlert()[UTC]* = 0 *SafetyStatus()[UTC]* = 1 *OperationStatus()[XCHG]* = 1
Recovery	*SafetyStatus()[UTC]* AND *Temperature()* ≥ ***UTC:Recovery***	*SafetyStatus()[UTC]* = 0 *OperationStatus()[XCHG]* = 0

2.14.1 Undertemperature in Charge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	UTC	Threshold	I2	–400	1500	0	0.1°C
Protections	UTC	Delay	U1	0	255	2	s
Protections	UTC	Recovery	I2	–400	1500	50	0.1°C

2.15 Undertemperature in Discharge Protection

The device has undertemperature protection for cells in DISCHARGE or RELAX state (that is, non-charging state with *BatteryStatus[DSG]* = 1).

STATUS	CONDITION	ACTION
Normal	*Temperature()* > ***UTD:Threshold*** OR charging	*SafetyAlert()[UTD]* = 0
Alert	*Temperature()* ≤ ***UTD:Threshold*** AND Not charging (that is, *BatteryStatus[DSG]* = 1)	*SafetyAlert()[UTD]* = 1
Trip	*Temperature()* ≤ ***UTD:Threshold*** AND Not charging (that is, *BatteryStatus[DSG]* = 1) for ***UTD:Delay*** duration	*SafetyAlert()[UTD]* = 0 *SafetyStatus()[UTD]* = 1 *OperationStatus()[XDSG]* = 1
Recovery	*SafetyStatus()[UTD]* AND *Temperature()* ≥ ***UTD:Recovery***	*SafetyStatus()[UTD]* = 0 *OperationStatus()[XDSG]* = 0

2.15.1 Undertemperature in Discharge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	UTD	Threshold	I2	–400	1500	0	0.1°C
Protections	UTD	Delay	U1	0	255	2	s
Protections	UTD	Recovery	I2	–400	1500	50	0.1°C

2.16 SBS Host Watchdog Protection

The device can check periodic communication over SBS and prevent usage of the battery pack if no valid communication is detected.

STATUS	CONDITION	ACTION
Trip	No valid SBS transaction for ***HWD:Delay*** duration	*SafetyStatus()[HWD]* = 1 *OperationStatus()[XCHG]* = 1
Recovery	Valid SBS transaction detected	*SafetyStatus()[HWD]* = 0 *OperationStatus()[XCHG]* = 0

2.16.1 SBS Host Watchdog Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	HWD	Delay	U1	0	255	10	s

2.17 Precharge Timeout Protection

The device can measure the precharge time and stop charging if it exceeds the adjustable period.

STATUS	CONDITION	ACTION
Enable	*Current()*> ***PTO:Charge Threshold*** AND *ChargingStatus()[PV]* = 1	Start PTO timer *SafetyAlert()[PTOS]* = 0
Suspend or Recovery	*Current()*< ***PTO:Suspend Threshold***	Stop PTO timer *SafetyAlert()[PTOS]* = 1
Trip	PTO timer > ***PTO:Delay***	Stop PTO timer *SafetyStatus()[PTO]* = 1 *OperationStatus()[XCHG]* = 1
Reset	*SafetyStatus()[PTO]* = 1 AND ***DA Configuration[NR]*** = 0 AND (Discharge by an amount of ***PTO:Reset*** OR low-high-low transition on SYSPRES)	Stop and reset PTO timer *SafetyAlert()[PTOS]* = 0 *SafetyStatus()[PTO]* = 0 *OperationStatus()[XCHG]* = 0
Reset	*SafetyStatus()[PTO]* = 1 AND ***DA Configuration[NR]*** = 1 AND (Discharge by an amount of ***PTO:Reset***)	Stop and reset PTO timer *SafetyAlert()[PTOS]* = 0 *SafetyStatus()[PTO]* = 0 *OperationStatus()[XCHG]* = 0

2.17.1 Precharge Timeout Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	PTO	Charge Threshold	I2	–32768	32767	2000	mA
Protections	PTO	Suspend Threshold	I2	–32768	32767	1800	mA
Protections	PTO	Delay	U2	0	65535	1800	s
Protections	PTO	Reset	I2	0	32767	2	mAh

2.18 Fast Charge Timeout Protection

The device can measure the charge time and stop charging if it exceeds the adjustable period.

STATUS	CONDITION	ACTION
Enable	*Current()* > ***CTO:Charge Threshold*** AND (*ChargingStatus()[LV]* = 1 OR *ChargingStatus()[MV]* = 1 OR *ChargingStatus()[HV]* = 1)	Start CTO timer *SafetyAlert()[CTOS]* = 0
Suspend or Recovery	*Current()* < ***CTO:Suspend Threshold***	Stop CTO timer *SafetyAlert()[CTOS]* = 1
Trip	CTO time > ***CTO:Delay***	Stop CTO timer *SafetyStatus()[CTO]* = 1 *OperationStatus()[XCHG]* = 1

STATUS	CONDITION	ACTION
Reset	*SafetyStatus()[CTO]* = 1 AND ***DA Configuration[NR]*** = 0 AND (Discharge by an amount of ***CTO:Reset*** OR low-high-low transition on SYSPRES)	Stop and reset CTO timer *SafetyAlert()[CTOS]* = 0 *SafetyStatus()[CTO]* = 0 *OperationStatus()[XCHG]* = 0
Reset	*SafetyStatus()[CTO]* = 1 AND ***DA Configuration[NR]*** = 1 AND (Discharge by an amount of ***CTO:Reset***)	Stop and reset CTO timer *SafetyAlert()[CTOS]* = 0 *SafetyStatus()[CTO]* = 0 *OperationStatus()[XCHG]* = 0

2.18.1 Fast Charge Timeout Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	CTO	Charge Threshold	I2	–32768	32767	2500	mA
Protections	CTO	Suspend Threshold	I2	–32768	32767	2000	mA
Protections	CTO	Delay	U2	0	65535	54000	s
Protections	CTO	Reset	I2	0	32767	2	mAh

2.19 Overcharge Protection

The device can prevent charging to continue if the pack is charged in excess over *FullChargeCapacity()*.

STATUS	CONDITION	ACTION
Normal	*RemainingCapacity()* < *FullChargeCapacity()*	*SafetyAlert()[OC]* = 0
Alert	*RemainingCapacity()* ≥ *FullChargeCapacity()*, AND Internal charge counter > 0	*SafetyAlert()[OC]* = 1 *BatteryStatus()[TCA]* = 1
Trip	*RemainingCapacity()* ≥ *FullChargeCapacity()*, AND Internal charge counter ≥ ***OC:Threshold***	*SafetyAlert()[OC]* = 0 *SafetyStatus()[OC]* = 1 *BatteryStatus()[TCA]* = 0, *[OCA]* = 1 if the device is in charge state (that is, *BatteryStatus[DSG]* = 0). *OperationStatus()[XCHG]* = 1
Recovery, ***[NR]*** = 0	*SafetyStatus()[OC]* = 1 AND ***DA Configuration[NR]*** = 0 AND (Low-high-low transition on SYSPRES pin)	*SafetyStatus()[OC]* = 0 *BatteryStatus()[TCA]* = 0, *[OCA]* = 0 *OperationStatus()[XCHG]* = 0
Recovery ***[NR]*** = 1	Condition 1: *SafetyStatus()[OC]* = 1 AND ***DA Configuration[NR]*** = 1 AND continuous discharge of ***Recovery*** OR Condition 2: *SafetyStatus()[OC]* = 1 AND ***DA Configuration[NR]*** = 1 AND *RelativeStateOfCharge()* < ***OC:RSOC Recovery***	*SafetyStatus()[OC]* = 0 *BatteryStatus()[TCA]* = 0, *[OCA]* = 0 *OperationStatus()[XCHG]* = 0

2.19.1 Overcharge Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	OC	Threshold	I2	–32768	32767	300	mAh
Protections	OC	Recovery	I2	–32768	32767	2	mAh
Protections	OC	RSOC Recovery	U1	0%	100%	90%	

2.20 OverChargingVoltage() Protection

The device can stop charging if it measures a difference between the requested *ChargingVoltage()* and the delivered voltage from the charger.

NOTE: *ChargingVoltage()* will be set to 0 mV when the protection is tripped. The *ChargingVoltage()* for the recovery is the intended or targeted Charging Voltage, not the 0 mV that was set due to the trip of protection.

STATUS	CONDITION	ACTION
Normal	Pack pin voltage in *DAStatus1()* < *ChargingVoltage()* + ***CHGV:Threshold***	*SafetyAlert()[CHGV]* = 0
Alert	Pack pin voltage in *DAStatus1()* ≥ *ChargingVoltage()* + ***CHGV:Threshold***	*SafetyAlert()[CHGV]* = 1 *BatteryStatus()[TCA]* = 1
Trip	Pack pin voltage in *DAStatus1()* continuous ≥ *ChargingVoltage()* + ***CHGV:Threshold*** for ***CHGV:Delay*** period	*SafetyAlert()[CHGV]* = 0 *SafetyStatus()[CHGV]* = 1 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1
Recovery	SafetyStatus()[CHGV] = 1 AND Pack pin voltage in *DAStatus1()* ≤ intended *ChargingVoltage()* + ***CHGV Recovery***	*SafetyStatus()[CHGV]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0

2.20.1 OverChargingVoltage() Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	CHGV	Threshold	I2	–32768	32767	500	mV
Protections	CHGV	Delay	U1	0	255	30	s
Protections	CHGV	Recovery	I2	–32768	32767	–500	mV

2.21 OverChargingCurrent() Protection

The device can stop charging if it measures a difference between the requested *ChargingCurrent()* and the delivered current from the charger. This protection is designed to recover by a discharge event; therefore, ***CHGC:Recovery*** should be set to a negative value in data flash.

STATUS	CONDITION	ACTION
Normal	*Current()* < *ChargingCurrent()* + ***CHGC:Threshold***	*SafetyAlert()[CHGC]* = 0
Alert	*Current()* ≥ *ChargingCurrent()* + ***CHGC:Threshold***	*SafetyAlert()[CHGC]* = 1 *BatteryStatus()[TCA]* = 1
Trip	*Current()* continuous ≥ *ChargingCurrent()* + ***CHGC:Threshold*** for ***CHGC:Delay*** period	*SafetyAlert()[CHGC]* = 0 *SafetyStatus()[CHGC]* = 1 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1
Recovery	*SafetyStatus()[CHGC]* = 1 AND *Current()* ≤ ***CHGC:Recovery Threshold*** for ***CHGC:Recovery Delay*** time	*SafetyStatus()[CHGC]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0

2.21.1 OverChargingCurrent() Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	CHGC	Threshold	I2	–32768	32767	500	mA
Protections	CHGC	Delay	U1	0	255	8	s
Protections	CHGC	Recovery Threshold	I2	–32768	32767	100	mA
Protections	CHGC	Recovery Delay	U1	0	255	2	s

2.22 OverPreChargingCurrent() Protection

The device can stop charging if it measures a difference between the requested *ChargingCurrent()* and the delivered current from the charger during precharge. This protection is designed to recover by a discharge event; therefore, ***PCHGC:Recovery*** should be set to a negative value in data flash.

STATUS	CONDITION	ACTION
Normal	*Current()* < *ChargingCurrent()* + ***PCHGC:Threshold*** AND *ChargingStatus()[PV]* = 1	*SafetyAlert()[PCHGC]* = 0
Alert	*Current()* ≥ *ChargingCurrent()* + ***PCHGC:Threshold*** AND *ChargingStatus()[PV]* = 1	*SafetyAlert()[PCHGC]* = 1 *BatteryStatus()[TCA]* = 1
Trip	*Current()*continuous ≥ *ChargingCurrent()* + ***PCHGC:Threshold*** for ***PCHGC:Delay*** period AND *ChargingStatus()[PV]* = 1	*SafetyAlert()[PCHGC]* = 0 *SafetyStatus()[PCHGC]* = 1 If charging, *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 1
Recovery	*SafetyStatus()[PCHGC]* = 1 AND *Current()* ≤ ***PCHGC:Recovery Threshold*** for ***PCHGC:Recovery Delay*** time	*SafetyStatus()[PCHGC]* = 0 *BatteryStatus()[TCA]* = 0 *OperationStatus()[XCHG]* = 0

2.22.1 OverPreChargingCurrent() Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Protections	PCHGC	Threshold	I2	–32768	32767	50	mA
Protections	PCHGC	Delay	U1	0	255	2	s
Protections	PCHGC	Recovery Threshold	I2	–32768	32767	10	mA
Protections	PCHGC	Recovery Delay	U1	0	255	2	s

2.23 Other Protection Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Protection	Protection Configuration	B1	0	0x03	0	hex
Settings	Protection	Enabled Protections A	U1	0	0xff	0xff	hex
Settings	Protection	Enabled Protections B	U1	0	0xff	0x7f	hex
Settings	Protection	Enabled Protections C	U1	0	0xff	0xfd	hex
Settings	Protection	Enabled Protections D	U1	0	0x2f	0x2f	hex

2.23.1 Protection Configuration

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	RSVD	RSVD	CUV_RECOV_CHG	SUV_MODE

RSVD	[7:2]	Reserved - Do not use	
CUV_RECOV_CHG	[1]	Require charge to recover *SafetyStatus()[CUV]*	**1**: Enabled **0**: Disabled
SUV_MODE	[0]	Copper deposition check for *PFStatus()[CUV]*	**1**: Enabled **0**: Disabled

2.23.2 Enabled Protections A

B7	B6	B5	B4	B3	B2	B1	B0
AOLDL	AOLD	OCD2	OCD1	OCC2	OCC1	COV	CUV

AOLDL	[7]	Overload in Discharge Latch	**1**: Enabled **0**: Disabled
AOLD	[6]	Overload in Discharge	**1**: Enabled **0**: Disabled
OCD2	[5]	Over-Current in Discharge 2nd Tier	**1**: Enabled **0**: Disabled
OCD1	[4]	Over-Current in Discharge in 1st Tier	**1**: Enabled **0**: Disabled
OCC2	[3]	Over-Current in Charge 2nd Tier	**1**: Enabled **0**: Disabled
OCC1	[2]	Over-Current in Charge 1st Tier	**1**: Enabled **0**: Disabled
COV	[1]	Cell Over-Voltage	**1**: Enabled **0**: Disabled
CUV	[0]	Cell Under-Voltage	**1**: Enabled **0**: Disabled

2.23.3 Enabled Protections B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	CUVC	OTD	OTC	ASCDL	ASCD	ASCCL	ASCC

RSVD	[7]	Reserved - Do not use	
CUVC	[6]	IR Compensated Cell Under-Voltage	**1**: Enabled **0**: Disabled
OTD	[5]	Over-Temperature during Discharge	**1**: Enabled **0**: Disabled
OTC	[4]	Over-Temperature during Charge	**1**: Enabled **0**: Disabled
ASCDL	[3]	Latch Short circuit during Discharge	**1**: Enabled **0**: Disabled
ASCD	[2]	Short circuit during Discharge	**1**: Enabled **0**: Disabled
ASCCL	[1]	Latch Short circuit during Charge	**1**: Enabled **0**: Disabled
ASCC	[0]	Short circuit during Charge	**1**: Enabled **0**: Disabled

2.23.4 Enabled Protections C

B7	B6	B5	B4	B3	B2	B1	B0
CHGC	OC	RSVD	CTO	RSVD	PTO	HWDF	OTF

CHGC	[7]	Flag *ChargingCurrent()* higher than requested	**1**: Enabled **0**: Disabled
OC	[6]	Flag Over-Charge	**1**: Enabled **0**: Disabled
RSVD	[5]	Reserved - Do not use	
CTO	[4]	Flag Charge Timeout	**1**: Enabled **0**: Disabled
RSVD	[3]	Reserved - Do not use	
PTO	[2]	Flag Pre-Charge Timeout	**1**: Enabled **0**: Disabled
HWDF	[1]	Flag SBS Host Watchdog Timeout	**1**: Enabled **0**: Disabled
OTF	[0]	Flag FET Over-Temperature	**1**: Enabled **0**: Disabled

2.23.5 Enabled Protections D

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	ACOV	RSVD	UTD	UTC	PCHGC	CHGV

RSVD	[7:6]	Reserved - Do not use	
ACOV	[5]	Flag Over-Voltage on ADP	**1**: Enabled **0**: Disabled
RSVD	[4]	Reserved - Do not use	
UTD	[3]	Flag Under-Temperature while NOT charging	**1**: Enabled **0**: Disabled
UTC	[2]	Flag Under-Temperature while charging	**1**: Enabled **0**: Disabled
PCHGC	[1]	Flag *ChargingVoltage()* higher than requested in Pre-Charge	**1**: Enabled **0**: Disabled
CHGV	[0]	Flag *ChargingVoltage()* higher than requested during fast charge/CCCV charge	**1**: Enabled **0**: Disabled

Permanent Fail

3.1 Introduction

The device can permanently disable the use of the battery pack in case of a severe failure. The permanent failure checks, except for IFC and DFW, can be individually enabled or disabled by setting the appropriate bit in ***Settings:Enabled PF A***, ***Settings:Enabled PF B***, ***Settings:Enabled PF C***, and ***Settings:Enabled PF D***. All permanent failure checks, except for IFC and DFW, are disabled until *ManufacturingStatus()[PF]* is set. When any *PFStatus()* bit is set, the device enters PERMANENT FAIL mode and the following actions are taken in sequence:

1. Precharge, charge, and discharge FETs are turned off.
2. *OperationStatus()[PF]* = 1, *[XCHG]* = 1, *[XDSG]* = 1
3. The following SBS data is changed: *BatteryStatus()[TCA]* = 1, *BatteryStatus()[TDA]* = 1, *ChargingCurrent()* = 0, and *ChargingVoltage()* = 0.
4. A backup of the internal AFE hardware registers are written to data flash: ***AFE Interrupt Status***, ***AFE FET Status***, ***AFE RXIN***, ***AFE Latch Status***, ***AFE Interrupt Enable***, ***AFE FET Control***, ***AFE RXIEN***, ***AFE RLOUT***, ***AFE RHOUT***, ***AFE RHINT***, ***AFE Cell Balance***, ***AFE AD/CC Control***, ***AFE ADC Mux***, ***AFE State Control***, ***AFE Protection Control***, ***AFE OCD***, ***AFE SCC***, ***AFE SCD1***, and ***AFE SCD2***.
5. The black box data of the last three *SafetyStatus()* changes leading up to PF with the time difference is written into the black box data flash along with the 1st *PFStatus()* value.
6. The following SBS values are preserved in data flash for failure analysis:
   - *SafetyAlert()*
   - *SafetyStatus()*
   - *PFAlert()*
   - *PFStatus()*
   - *OperationStatus()*
   - *ChargingStatus()*
   - *GaugingStatus()*
   - Voltages in *DAStatus1()*
   - *Current()*
   - TSINT, TS1, TS2, TS3, and TS4 from *DAStatus2()*
   - Cell DOD0 and passed charge
7. Data flash writing is disabled (except to store subsequent *PFStatus()* flags).
8. The FUSE pin is driven high if configured for specific failures and *Voltage()* is above ***Min Blow Fuse Voltage*** or there is a CHG FET (CFETF) or DSG FET (DFETF) failure. The FUSE pin will remain asserted until the ***Fuse Blow Timeout*** expired.

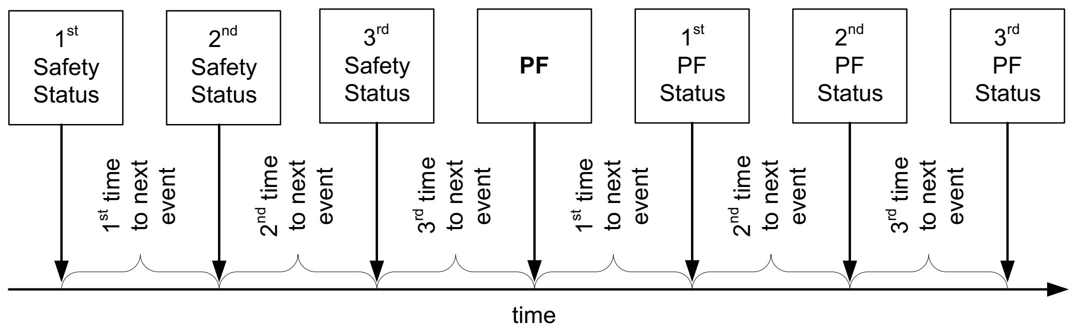
NOTE: If ***[ACP_FUSE]*** = 0, *Voltage()* is used to check for ***Min Blow Fuse Voltage***, indicating the fuse is connected to the BAT side.

If ***[ACP_FUSE]*** = 1 (that is, Fuse is connected to the ACP side and is required to have a charger connected in order to blow the fuse), then the pack voltage is used to check for ***Min Blow Fuse Voltage*** threshold.

While the device is in PERMANENT FAIL mode, any new *SafetyAlert()*, *SafetyStatus()*, *PFAlert()*, and *PFStatus()* flags that are set are added to the permanent fail log. Any new *PFStatus()* flags that occur during PERMANENT FAIL mode can trigger the FUSE pin. In addition, new *PFStatus()* flags are recorded in the Black Box Recorder 2 nd and 3 rd PF Status entries.

3.2 Black Box Recorder

The Black Box Recorder maintains the last three updates of *SafetyStatus()* in memory. When entering PERMANENT FAIL mode, this information is written to data flash together with the first three updates of *PFStatus()* after the PF event.



NOTE: This information is useful in failure analysis and can provide a full recording of the events and conditions leading up to the permanent failure.

If there were less than three safety events before PF, then some information will be left blank.

3.2.1 Black Box Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Black Box	Safety Status	1st Status Status A	U1	0	0xff	0	hex
Black Box	Safety Status	1st Status Status B	U1	0	0xff	0	hex
Black Box	Safety Status	1st Safety Status C	U1	0	0xff	0	hex
Black Box	Safety Status	1st Safety Status D	U1	0	0xff	0	hex
Black Box	Safety Status	1st Time to Next Event	U1	0	255	0	s
Black Box	Safety Status	2nd Status Status A	U1	0	0xff	0	hex
Black Box	Safety Status	2nd Status Status B	U1	0	0xff	0	hex
Black Box	Safety Status	2nd Safety Status C	U1	0	0xff	0	hex
Black Box	Safety Status	2nd Safety Status D	U1	0	0xff	0	hex
Black Box	Safety Status	2nd Time to Next Event	U1	0	255	0	s
Black Box	Safety Status	3rd Status Status A	U1	0	0xff	0	hex
Black Box	Safety Status	3rd Status Status B	U1	0	0xff	0	hex
Black Box	Safety Status	3rd Safety Status C	U1	0	0xff	0	hex
Black Box	Safety Status	3rd Safety Status D	U1	0	0xff	0	hex
Black Box	Safety Status	3rd Time to Next Event	U1	0	255	0	s

NOTE: The bit information in the 1st, 2nd, and 3rd Safety Status registers are identical, so only one is shown.

3.2.1.1 Safety Status A

B7	B6	B5	B4	B3	B2	B1	B0
AOLDL	AOLD	OCD2	OCD1	OCC2	OCC1	COV	CUV

AOLDL	[7]	Overload in Discharge Latch	**1**: Detected **0**: Undetected
AOLD	[6]	Overload in Discharge	**1**: Detected **0**: Undetected
OCD2	[5]	Over-Current in Discharge 2nd Tier	**1**: Detected **0**: Undetected
OCD1	[4]	Over-Current in Discharge in 1st Tier	**1**: Detected **0**: Undetected
OCC2	[3]	Over-Current in Charge 2nd Tier	**1**: Detected **0**: Undetected
OCC1	[2]	Over-Current in Charge 1st Tier	**1**: Detected **0**: Undetected
COV	[1]	Cell Over-Voltage	**1**: Detected **0**: Undetected
CUV	[0]	Cell Under-Voltage	**1**: Detected **0**: Undetected

3.2.1.2 Safety Status B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	CUVC	OTD	OTC	ASCDL	ASCD	ASCCL	ASCC

RSVD	[7]	Reserved - Do not use	
CUVC	[6]	IR Compensated Cell Under-Voltage	**1**: Detected **0**: Undetected
OTD	[5]	Over-Temperature during Discharge	**1**: Detected **0**: Undetected
OTC	[4]	Over-Temperature during Charge	**1**: Detected **0**: Undetected
ASCDL	[3]	Latch Short circuit during Discharge	**1**: Detected **0**: Undetected
ASCD	[2]	Short circuit during Discharge	**1**: Detected **0**: Undetected
ASCCL	[1]	Latch Short circuit during Charge	**1**: Detected **0**: Undetected
ASCC	[0]	Short circuit during Charge	**1**: Detected **0**: Undetected

3.2.1.3 Safety Status C

B7	B6	B5	B4	B3	B2	B1	B0
CHGC	OC	RSVD	CTO	RSVD	PTO	HWDF	OTF

CHGC	[7]	Flag *ChargingCurrent()* higher than requested	**1**: Detected **0**: Undetected
OC	[6]	Flag Over-Charge	**1**: Detected **0**: Undetected
RSVD	[5]	Reserved - Do not use	
CTO	[4]	Flag Charge Timeout	**1**: Detected **0**: Undetected
RSVD	[3]	Reserved - Do not use	
PTO	[2]	Flag Pre-Charge Timeout	**1**: Detected **0**: Undetected
HWDF	[1]	Flag SBS Host Watchdog Timeout	**1**: Detected **0**: Undetected
OTF	[0]	Flag FET Over-Temperature	**1**: Detected **0**: Undetected

3.2.1.4 Safety Status D

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	ACOV	RSVD	UTD	UTC	PCHGC	CHGV

RSVD	[7:6]	Reserved - Do not use	
ACOV	[5]	Flag Over-Voltage on ADP	**1**: Detected **0**: Undetected
RSVD	[4]	Reserved - Do not use	
UTD	[3]	Flag Under-Temperature while NOT charging	**1**: Detected **0**: Undetected
UTC	[2]	Flag Under-Temperature while charging	**1**: Detected **0**: Undetected
PCHGC	[1]	Flag *ChargingVoltage()* higher than requested in Pre-Charge	**1**: Detected **0**: Undetected
CHGV	[0]	Flag *ChargingVoltage()* higher than requested during fast charge/CCCV charge	**1**: Detected **0**: Undetected

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Black Box	PF Status	1st PF Status A	U1	0	0xff	0	hex
Black Box	PF Status	1st PF Status B	U1	0	0xff	0	hex
Black Box	PF Status	1st PF Status C	U1	0	0xff	0	hex
Black Box	PF Status	1st PF Status D	U1	0	0xff	0	hex
Black Box	PF Status	1st Time to Next Event	U1	0	255	0	s
Black Box	PF Status	2nd PF Status A	U1	0	0xff	0	hex
Black Box	PF Status	2nd PF Status B	U1	0	0xff	0	hex
Black Box	PF Status	2nd PF Status C	U1	0	0xff	0	hex
Black Box	PF Status	2nd PF Status D	U1	0	0xff	0	hex
Black Box	PF Status	2nd Time to Next Event	U1	0	255	0	s
Black Box	PF Status	3rd PF Status A	U1	0	0xff	0	hex
Black Box	PF Status	3rd PF Status B	U1	0	0xff	0	hex
Black Box	PF Status	3rd PF Status C	U1	0	0xff	0	hex
Black Box	PF Status	3rd PF Status D	U1	0	0xff	0	hex
Black Box	PF Status	3rd Time to Next Event	U1	0	255	0	s

NOTE: The bit information in the 1st, 2nd, and 3rd PF Status registers are identical, so only one set is shown.

3.2.1.5 PF Status A

B7	B6	B5	B4	B3	B2	B1	B0
QIM	SOTF	RSVD	SOT	SOCD	SOCC	SOV	SUV

QIM	[7]	QMax Imbalance	**1**: Detected **0**: Undetected
SOTF	[6]	Safety Overtemperature FET	**1**: Detected **0**: Undetected
RSVD	[5]	Reserved - Do not use	
SOT	[4]	Safety Overtemperature	**1**: Detected **0**: Undetected
SOCD	[3]	Safety Overcurrent in Discharge	**1**: Detected **0**: Undetected
SOCC	[2]	Safety Overcurrent in Charge	**1**: Detected **0**: Undetected
SOV	[1]	Safety Cell Overvoltage	**1**: Detected **0**: Undetected
SUV	[0]	Safety Cell Undervoltage	**1**: Detected **0**: Undetected

3.2.1.6 PF Status B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	VIMA	VIMR	CD	IMP	CB

RSVD	[7]	Reserved - Do not use	
RSVD	[6]	Reserved - Do not use	
RSVD	[5]	Reserved - Do not use	
VIMA	[4]	Voltage Imbalance Active	**1**: Detected **0**: Undetected
VIMR	[3]	Voltage Imbalance at Rest	**1**: Detected **0**: Undetected
CD	[2]	Capacity Degradation	**1**: Detected **0**: Undetected
IMP	[1]	Cell Impedance	**1**: Detected **0**: Undetected
CB	[0]	Cell Balancing	**1**: Detected **0**: Undetected

3.2.1.7 PF Status C

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	2LVL	AFEC	AFER	FUSE	RSVD	DFETF	CFETF

RSVD	[7]	Reserved - Do not use	
2LVL	[6]	Second Level Protection	**1**: Detected **0**: Undetected
AFEC	[5]	AFE Communication	**1**: Detected **0**: Undetected
AFER	[4]	AFE Register	**1**: Detected **0**: Undetected
FUSE	[3]	Fuse	**1**: Detected **0**: Undetected
RSVD	[2]	Reserved - Do not use	
DFETF	[1]	DSG FET Failure	**1**: Detected **0**: Undetected
CFETF	[0]	CHG FET Failure	**1**: Detected **0**: Undetected

3.2.1.8 PF Status D

B7	B6	B5	B4	B3	B2	B1	B0
TS4	TS3	TS2	TS1	RSVD	DFW	OPNCELL	IFC

TS4	[7]	Temperature Sensor 4	**1**: Detected **0**: Undetected
TS3	[6]	Temperature Sensor 3	**1**: Detected **0**: Undetected
TS2	[5]	Temperature Sensor 2	**1**: Detected **0**: Undetected
TS1	[4]	Temperature Sensor 1	**1**: Detected **0**: Undetected
RSVD	[3]	Reserved - Do not use	
DFW	[2]	Data Flash wear out	**1**: Detected **0**: Undetected
OPNCELL	[1]	Open Cell tab	**1**: Detected **0**: Undetected
IFC	[0]	Instruction Flash checksum	**1**: Detected **0**: Undetected

3.3 Safety Cell Undervoltage Permanent Fail

The device can permanently disable the battery in the case of severe undervoltage in any of the cells.

STATUS	CONDITION	ACTION
Normal	Min cell voltage1..4 > ***SUV:Threshold***	*PFAlert()[SUV]* = 0 *BatteryStatus()[TDA]* = 0
Alert	Min cell voltage1..4 ≤ ***SUV:Threshold***	*PFAlert()[SUV]* = 1 *BatteryStatus()[TDA]* = 1
Trip	Min cell voltage1..4 continuous ≤ ***SUV:Threshold*** for ***SUV:Delay*** duration	*PFAlert()[SUV]* = 0 *PFStatus()[SUV]* = 1 *BatteryStatus()[FD]* = 1

3.3.1 SUV Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	SUV	Threshold	I2	0	32767	2200	mV
Permanent Fail	SUV	Delay	U1	0	255	5	s

3.3.2 SUV Check Option

When ***Protection Configuration[SUV_MODE]*** is set, the SUV PF check only applies when the gauge wakes up from shutdown. The CHG and DSG FETs are disabled for the duration of the test (***SUV:Delay***) to prevent an applied charge voltage from masking a copper deposition condition.

3.4 Safety Cell Overvoltage Permanent Fail

The device can permanently disable the battery in the case of severe overvoltage in any of the cells.

STATUS	CONDITION	ACTION
Normal	Max cell voltage1..4 < ***SOV:Threshold***	*PFAlert()[SOV]* = 0
Alert	Max cell voltage1..4 ≥ ***SOV:Threshold***	*PFAlert()[SOV]* = 1 *BatteryStatus()[TCA]* = 1
Trip	Max cell voltage1..4 continuous ≥ ***SOV:Threshold*** for ***SOV:Delay*** duration	*PFAlert()[SOV]* = 0 *PFStatus()[SOV]* = 1

3.4.1 SOV Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	SOV	Threshold	I2	0	32767	4500	mV
Permanent Fail	SOV	Delay	U1	0	255	5	s

3.5 Safety Overcurrent in Charge Permanent Fail

The device can permanently disable the battery in the case of severe overcurrent in charge state.

STATUS	CONDITION	ACTION
Normal	*Current()* < ***SOCC:Threshold***	*PFAlert()[SOCC]* = 0
Alert	*Current()* ≥ ***SOCC:Threshold***	*PFAlert()[SOCC]* = 1 *BatteryStatus()[TCA]* = 1 *BatteryStatus()[OCA]* = 1
Trip	*Current()* ≥ ***SOCC:Threshold*** for ***SOCC:Delay*** duration	*PFAlert()[SOCC]* = 1 *PFStatus()[SOCC]* = 1

3.5.1 SOCC Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	SOCC	Threshold	I2	–32768	32767	10000	mA
Permanent Fail	SOCC	Delay	U1	0	255	5	s

3.6 Safety Overcurrent in Discharge Permanent Fail

The device can permanently disable the battery in the case of severe overcurrent in discharge or RELAX state.

STATUS	CONDITION	ACTION
Normal	*Current()* > ***SOCD:Threshold***	*PFAlert()[SOCD]* = 0
Alert	*Current()* ≤ ***SOCD:Threshold***	*PFAlert()[SOCC]* = 1 *BatteryStatus()[TDA]* = 1
Trip	*Current()* ≤ ***SOCD:Threshold*** for ***SOCD:Delay*** duration	*PFAlert()[SOCC]* = 1 *PFStatus()[SOCC]* = 1

3.6.1 SOCD Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	SOCD	Threshold	I2	–32768	32767	–10000	mA
Permanent Fail	SOCD	Delay	U1	0	255	5	s

3.7 Safety Overtemperature Cell Permanent Fail

The device can permanently disable the battery pack in case of severe overtemperature of the cells detected using the external TS1...4 temperature sensor(s), which are configured to report as cell temperature, *Temperature()*. The *Temperature()* measurement configuration is done by setting the corresponding flag in ***Temperature Mode*** and ***DA Configuration[CTEMP]***.

STATUS	CONDITION	ACTION
Normal	*Temperature()* < ***SOT:Threshold***	*PFAlert()[SOT]* = 0
Alert	*Temperature()* ≥ ***SOT:Threshold***	*PFAlert()[SOT]* = 1 *BatteryStatus()[OTA]* = 1
Trip	*Temperature()* continuous ≥ ***SOT:Threshold*** for ***SOT:Delay*** duration	*PFAlert()[SOT]* = 0 *PFStatus()[SOT]* = 1 *BatteryStatus()[OTA]* = 1

3.7.1 SOT Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	SOT	Threshold	I2	–400	1500	650	0.1°C
Permanent Fail	SOT	Delay	U1	0	255	5	s

3.8 Safety Overtemperature FET Permanent Fail

The device can permanently disable the battery pack in case of severe overtemperature on the power FET. The temperature sensors can be configured to report as FET Temperature in *DAStatus2()* by setting the corresponding flag in ***Temperature Mode*** and ***DA Configuration[FTEMP]***.

STATUS	CONDITION	ACTION
Normal	FET Temperature in *DAStatus2()* < ***SOTF:Threshold***	*PFAlert()[SOTF]* = 0
Alert	FET Temperature in *DAStatus2()* ≥ ***SOTF:Threshold***	*PFAlert()[SOTF]* = 1 *BatteryStatus()[OTA]* = 1
Trip	FET Temperature in *DAStatus2()* continuous ≥ ***SOTF:Threshold*** for ***SOTF:Delay*** duration	*PFAlert()[SOTF]* = 0 *PFStatus()[SOTF]* = 1 *BatteryStatus()[OTA]* = 1

3.8.1 SOTF Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	SOTF	Threshold	I2	–400	1500	1000	0.1°C
Permanent Fail	SOTF	Delay	U1	0	255	5	s

3.9 QMax Imbalance Permanent Fail

The device can permanently disable the battery pack in case the capacity of one of the cells is much lower than the other cells.

STATUS	CONDITION	ACTION
Normal	*[Max(QMax Cell 1..4) – Min(QMax1..4)] / Qmax Pack* × 100 < ***QIM:Delta Threshold***	*PFAlert()[QIM]* = 0
Alert	*[Max(QMax Cell 1..4) – Min(QMax1..4)] / Qmax Pack* × 100 > ***QIM:Delta Threshold***	*PFAlert()[QIM]* = 1
Trip	*[Max(QMax Cell 1..4) – Min(QMax1..4)] / Qmax Pack* × 100 continuous ≥ ***QIM:Delta Threshold*** for number of ***QIM:Delay***[(1)] updates	*PFAlert()[QIM]* = 0 *PFStatus()[QIM]* = 1

(1) The delay for this check is counted each time ***QMax Cycle Count*** is updated.

3.9.1 QIM Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	QIM	Delta Threshold	I2	0	32767	150	0.1 %
Permanent Fail	QIM	Delay	U1	0	255	2	updates

3.10 Cell Balancing Permanent Fail

The device can permanently disable the battery pack in case one of the cells in the stack is cell-balanced much more than the other cells.

STATUS	CONDITION	ACTION
Normal	Δ(*Time Cell 1..4*) < ***CB:Delta Threshold***	*PFAlert()[CB]* = 0
Alert	Δ(*Time Cell 1..4*) ≥ ***CB:Delta Threshold***	*PFAlert()[CB]* = 1
Trip	Δ(*Time Cell 1..4*) continuous ≥ ***CB:Delta Threshold*** for ***CB:Delay***[(1)] cycles	*PFAlert()[CB]* = 0 *PFStatus()[CB]* = 1 *BatteryStatus()[TCA]* = 1 *BatteryStatus()[TDA]* = 1
Trip	Max (*Time Cell 1..4*) ≥ ***CB:Max Threshold***	*PFAlert()[CB]* = 0 *PFStatus()[CB]* = 1

(1) The delay for this check is counted each time ***QMax Cycle Count*** is updated.

3.10.1 CB Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	CB	Max Threshold	I2	0	32767	120	2h
Permanent Fail	CB	Delta Threshold	U1	0	255	20	2h
Permanent Fail	CB	Delay	U1	0	255	2	cycles

3.11 Impedance Permanent Fail

The device can permanently disable the battery pack in case the impedance of one of the cells is much higher than the other cells.

NOTE: ***Reference Grid*** is configurable from 0 (resistance at fully charged cell) to 14 (resistance at fully discharged cell). The default setting of ***Reference Grid*** = 4 is a good typical value to use because it is close to the average in the range of 20% to 100% SOC. ***Design Resistance*** is automatically calculated and updated during the learning cycle and is part of the golden image).

This check is only performed when the gauge updates the ***Ra*** data for the ***Reference Grid*** directly. If a selected grid point is typically being scaled rather than directly updated by the gauge (for example, grid point 0 or grid point 14), this check is effectively disabled. It is recommended to use the default ***Design Resistance*** setting.

STATUS	CONDITION	ACTION
Normal	Δ(Cell1..4 R_a at ***IT Cfg:Reference Grid***) < (***IMP:Delta Threshold*** × ***IT Cfg:Design Resistance***)	*PFAlert()[IMP]* = 0
Alert	Δ(Cell1..4 R_a at ***IT Cfg:Reference Grid***) ≥ (***IMP:Delta Threshold*** × ***IT Cfg:Design Resistance***)	*PFAlert()[IMP]* = 1
Trip	Δ(Cell1..4 R_a at ***IT Cfg:Reference Grid***) ≥ (***IMP:Delta Threshold*** × ***IT Cfg:Design Resistance***) for ***IMP:Ra Update Counts***	*PFAlert()[IMP]* = 0 *PFStatus()[IMP]* = 1 *BatteryStatus()[TCA]* = 1 *BatteryStatus()[TDA]* = 1
Trip	Δ(Cell1..4 R_a at ***IT Cfg:Reference Grid***) ≥ (***IMP:Max Threshold*** × ***IT Cfg:Design Resistance***)	*PFAlert()[IMP]* = 0 *PFStatus()[IMP]* = 1

3.11.1 IMP Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	IMP	Delta Threshold	I2	0%	32767%	300%	
Permanent Fail	IMP	Max Threshold	I2	0%	32767%	400%	
Permanent Fail	IMP	Ra Update Counts	U1	0	255	2	counts

3.12 Capacity Degradation Permanent Fail

The device can permanently disable the battery pack in case the capacity of the battery is degraded below a threshold.

STATUS	CONDITION	ACTION
Normal	***QMax pack*** > ***CD:Threshold***	*PFAlert()[CD]* = 0
Alert	***QMax pack*** ≤ ***CD:Threshold***	*PFAlert()[CD]* = 1
Trip	***QMax pack*** continuous ≤ ***CD:Threshold*** for ***CD:Delay*** (1) cycles	*PFAlert()[CD]* = 0 *PFStatus()[CD]* = 1

(1) The delay for this check is counted each time ***QMax Cycle Count*** is updated.

3.12.1 CD Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	CD	Threshold	I2	0	32767	0	mAh
Permanent Fail	CD	Delay	U1	0	255	2	cycles

3.13 Voltage Imbalance at Rest Permanent Fail

The device can permanently disable the battery pack in case of a voltage difference between the cells in a stack while at rest.

STATUS	CONDITION	ACTION
Normal	Max cell voltage1..4 < ***VIMR:Check Voltage*** OR | *Current()* | > ***VIMR:Check Current*** OR Max cell voltage1..4 – Min cell voltage1..4 < ***VIMR:Delta Threshold***	*PFAlert()[VIMR]* = 0
Alert	Max cell voltage1..4 ≥ ***VIMR:Check Voltage*** AND | *Current()* | < ***VIMR:Check Current*** for ***VIMR:Duration*** AND Max cell voltage1..4 – Min cell voltage1..4 ≥ ***VIMR:Delta Threshold***	*PFAlert()[VIMR]* = 1
Trip	Max cell voltage1..4 ≥ ***VIMR:Check Voltage*** AND | *Current()* | < ***VIMR:Check Current*** for ***VIMR:Duration*** AND Max cell voltage1..4 – Min cell voltage1..4 ≥ ***VIMR:Delta Threshold*** for ***VIMR:Delta Delay***	*PFAlert()[VIMR]* = 0 *PFStatus()[VIMR]* = 1

3.13.1 VIMR Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	VIMR	Check Voltage	I2	0	5000	3500	mV
Permanent Fail	VIMR	Check Current	I2	0	32767	10	mA
Permanent Fail	VIMR	Delta Threshold	I2	0	5000	500	mV
Permanent Fail	VIMR	Delta Delay	U1	0	255	5	s
Permanent Fail	VIMR	Duration	U2	0	65535	100	s

3.14 Voltage Imbalance Active Permanent Fail

The device can permanently disable the battery pack in case of a voltage difference between the cells in a stack while active.

STATUS	CONDITION	ACTION
Normal	Max cell voltage1..4 < ***VIMA:Check Voltage*** OR *Current()* < ***VIMA:Check Current*** OR Max cell voltage1..4 – Min cell voltage1..4 < ***VIMA:Delta Threshold***	*PFAlert()[VIMA]* = 0
Alert	Max Cell voltage ≥ ***VIMA:Check Voltage*** AND *Current()* > ***VIMA:Check Current*** AND Max cell voltage1..4 – Min cell voltage1..4 ≥ ***VIMA:Delta Threshold***	*PFAlert()[VIMA]* = 1
Trip	Max cell voltage1..4 ≥ ***VIMA:Check Voltage*** AND *Current()* > ***VIMA:Check Current*** AND Max cell voltage1..4 – Min cell voltage1..4 ≥ ***VIMA:Delta Threshold*** for ***VIMA:Delay***	*PFAlert()[VIMA]* = 0 *PFStatus()[VIMA]* = 1

3.14.1 VIMA Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	VIMA	Check Voltage	I2	0	5000	3700	mV
Permanent Fail	VIMA	Check Current	I2	0	32767	50	mA
Permanent Fail	VIMA	Delta Threshold	I2	0	5000	200	mV
Permanent Fail	VIMA	Delay	U1	0	255	5	s

3.15 Charge FET Permanent Fail

The device can permanently disable the battery pack in case the charge FET is not working properly.

STATUS	CONDITION	ACTION
Normal	CHGR off AND CHG FET off AND *Current()* < ***CFET:OFF Threshold***	*PFAlert()[CFETF]* = 0
Alert	CHGR off AND CHG FET off AND *Current()* ≥ ***CFET:OFF Threshold***	*PFAlert()[CFETF]* = 1
Trip	CHGR off AND CHG FET off AND *Current()* continuously ≥ ***CFET:OFF Threshold*** for ***CFET:OFF Delay*** duration	*PFAlert()[CFETF]* = 0 *PFStatus()[CFETF]* = 1

3.15.1 CFET Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	CFET	OFF Threshold	I2	0	500	5	mA
Permanent Fail	CFET	OFF Delay	U1	0	255	5	s

3.16 Discharge FET Permanent Fail

The device can permanently disable the battery pack in case the discharge FET is not working properly.

STATUS	CONDITION	ACTION
Normal	CHGR off AND CHG FET *Current()* > ***DFET:OFF Threshold***	*PFAlert()[DFETF]* = 0
Alert	CHGR off AND CHG FET *Current()* ≤ ***DFET:OFF Threshold***	*PFAlert()[DFETF]* = 1
Trip	CHGR off AND CHG FET *Current()* continuously ≤ ***DFET:OFF Threshold*** for ***DFET:OFF Delay*** duration	*PFAlert()[DFETF]* = 0 *PFStatus()[DFETF]* = 1

3.16.1 DFET Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	DFET	OFF Threshold	I2	–500	0	–50	mA
Permanent Fail	DFET	OFF Delay	U1	0	255	5	s

3.17 Chemical Fuse Permanent Fail

The device can detect a non-working fuse. It cannot disable the battery pack permanently, but can record this event for analysis.

STATUS	CONDITION	ACTION
Normal	FUSE pin = high AND |*Current()* | < ***FUSE:Threshold***	*PFAlert()[FUSE]* = 0
Alert	FUSE pin = high AND |*Current()* | ≥ ***FUSE:Threshold***	*PFAlert()[FUSE]* = 1
Trip	FUSE pin = high AND |*Current()* | continuous ≥ ***FUSE:Threshold*** for ***FUSE:Delay*** duration	*PFAlert()[FUSE]* = 0 *PFStatus()[FUSE]* = 1

3.17.1 FUSE Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Fuse	PF Fuse A	U1	0	0xff	0	hex
Settings	Fuse	PF Fuse B	U1	0	0xff	0	hex
Settings	Fuse	PF Fuse C	U1	0	0xff	0	hex
Settings	Fuse	PF Fuse D	U1	0	0xff	0	hex
Settings	Fuse	Min Blow Fuse Voltage	I2	0	0xffff	3500	mV
Settings	Fuse	Fuse Blow Timeout	U1	0	255	30	s

3.17.1.1 PF Fuse A

B7	B6	B5	B4	B3	B2	B1	B0
QIM	SOTF	RSVD	SOT	SOCD	SOCC	SOV	SUV

QIM	[7]	Blow fuse for QMax Imbalance	**1**: Enabled **0**: Disabled
SOTF	[6]	Blow fuse for Safety Over-temperature FET	**1**: Enabled **0**: Disabled
RSVD	[5]	Reserved - Do not use	
SOT	[4]	Blow fuse for Safety Over-temperature	**1**: Enabled **0**: Disabled
SOCD	[3]	Blow fuse for Safety Over-current in Discharge	**1**: Enabled **0**: Disabled
SOCC	[2]	Blow fuse for Safety Over-current in Charge	**1**: Enabled **0**: Disabled
SOV	[1]	Blow fuse for Safety Cell Over-voltage	**1**: Enabled **0**: Disabled
SUV	[0]	Blow fuse for Safety Cell Under-voltage	**1**: Enabled **0**: Disabled

3.17.1.2 PF Fuse B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	VIMA	VIMR	CD	IMP	CB

RSVD	[7:5]	Reserved - Do not use	
VIMA	[4]	Blow fuse for Voltage Imbalance in Active state	**1**: Enabled **0**: Disabled
VIMR	[3]	Blow fuse for Voltage Imbalance in Rest state	**1**: Enabled **0**: Disabled
CD	[2]	Blow fuse for Capacity Degradation	**1**: Enabled **0**: Disabled
IMP	[1]	Blow fuse for Cell impedance	**1**: Enabled **0**: Disabled
CB	[0]	Blow fuse for Cell balancing	**1**: Enabled **0**: Disabled

3.17.1.3 PF Fuse C

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	2LVL	AFEC	AFER	FUSE	RSVD	DFETF	CFETF

RSVD	[7]	Reserved - Do not use	
2LVL	[6]	Blow fuse by external 2nd level protection	**1**: Enabled **0**: Disabled
AFEC	[5]	Blow fuse for AFE communication errors	**1**: Enabled **0**: Disabled
AFER	[4]	Blow fuse for AFE register errors	**1**: Enabled **0**: Disabled
FUSE	[3]	Fuse blows	**1**: Enabled **0**: Disabled
RSVD	[2]	Reserved - Do not use	
DFETF	[1]	Blow fuse for Discharge FET malfunction	**1**: Enabled **0**: Disabled
CFETF	[0]	Blow fuse for Charge FET malfunction	**1**: Enabled **0**: Disabled

3.17.1.4 PF Fuse D

B7	B6	B5	B4	B3	B2	B1	B0
TS4	TS3	TS2	TS1	RSVD	DFW	OPNCELL	IFC

TS4	[7]	Blow fuse for Temperature Sensor 4 malfunction	**1**: Enabled **0**: Disabled
TS3	[6]	Blow fuse for Temperature Sensor 3 malfunction	**1**: Enabled **0**: Disabled
TS2	[5]	Blow fuse for Temperature Sensor 2 malfunction	**1**: Enabled **0**: Disabled
TS1	[4]	Blow fuse for Temperature Sensor 1 malfunction	**1**: Enabled **0**: Disabled
RSVD	[3]	Reserved - Do not use	
DFW	[2]	Blow fuse due to Data Flash wear out	**1**: Enabled **0**: Disabled
OPNCELL	[1]	Blow fuse for open cell tab	**1**: Enabled **0**: Disabled
IFC	[0]	Blow fuse due to Instruction Flash checksum error	**1**: Enabled **0**: Disabled

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	FUSE	Threshold	I2	0	255	5	mA
Permanent Fail	FUSE	Delay	U1	0	255	5	s

3.18 AFE Register Permanent Fail

The device compares the AFE hardware register periodically with a RAM backup and corrects any errors. If any errors are found during the check, the device increments the AFE register fail counter. If the comparison fails too many times, the device disables the pack permanently.

STATUS	CONDITION	ACTION
Normal	AFE register fail counter = 0	*PFAlert()[AFER]* = 0 Compare AFE register and RAM backup every ***AFER:Compare Period***
Alert	AFE register fail counter > 0	*PFAlert()[AFER]* = 1 Decrement AFE register fail counter by one after each ***AFER:Delay Period*** Compare AFE register and RAM backup every ***AFER:Compare Period***
Trip	AFE register fail counter ≥ ***AFER:Threshold***	*PFAlert()[AFER]* = 0 *PFStatus()[AFER]* = 1

3.18.1 AFE Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	AFE Regs	AFE Interrupt Status	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE FET Status	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE RXIN	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE Latch Status	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE Interrupt Enable	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE FET Control	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE RXIEN	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE RLOUT	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE RHOUT	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE RHINT	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE Cell Balance	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE AD/CC Control	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE ADC Mux	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE LED Output	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE State Control	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE LED/Wake Control	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE Protection Control	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE OCD	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE SCC	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE SCD1	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE SCD2	U1	0	0xff	0	hex
PF Status	AFE Regs	AFE Charger Lock	U1	0	0xff	0	—
PF Status	AFE Regs	AFE Charger Voltage	U1	0	0xff	0	—
PF Status	AFE Regs	AFE Charger Current	U1	0	0xff	0	—

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	AFER	Threshold	U1	0	255	100	—
Permanent Fail	AFER	Delay Period	U1	0	255	2	s
Permanent Fail	AFER	Compare Period	U1	0	255	5	s

3.19 AFE Communication Permanent Fail

The device monitors the internal communication to the AFE hardware and increments the AFE read/write fail counter on any communication error. If the read or write fails exceed a limit within a configurable timeframe, the device disables the pack permanently.

STATUS	CONDITION	ACTION
Normal	AFE read/write fail counter = 0	*PFAlert()[AFEC]* = 0
Alert	AFE read/write fail counter > 0	*PFAlert()[AFEC]* = 1 Decrement AFE read/write fail counter by one after each ***AFEC:Delay Period***
Trip	Read and Write Fail counter ≥ ***AFEC:Threshold***	*PFAlert()[AFEC]* = 0 *PFStatus()[AFEC]* = 1

3.19.1 AFEC Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	AFEC	Threshold	U1	0	255	100	—
Permanent Fail	AFEC	Delay Period	U1	0	255	5	s

3.20 Second Level Protection Permanent Fail

The device can detect an external trigger of the chemical fuse by an external protection circuit such as a 2nd-level protector by monitoring the FUSE pin state.

If the device detects a FUSE pin high state, the CHG and DSG FETs are turned off.

Setting ***Enabled PF C[2LVL]*** = 0 will not prevent the second level protector from triggering and blowing the fuse, setting ***[2LVL]*** = 0 will only prevent the gauge from detecting the fuse state.

STATUS	CONDITION	ACTION
Normal	Reset AFE and FUSE pin = low AND No FUSE trigger by firmware	*PFAlert()[2LVL]* = 0
Alert	FUSE pin = high AND No FUSE trigger by firmware	*PFAlert()[2LVL]* = 1 Reset AFE FUSE bit
Trip	FUSE pin continuously high for ***2LVL:Delay*** period AND No FUSE trigger by firmware	*PFAlert()[2LVL]* = 0 *PFStatus()[2LVL]* = 1

3.20.1 2LVL Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	2LVL	Delay	U1	0	255	5	s

3.21 Instruction Flash (IF) Checksum Permanent Fail

The device can permanently disable the battery if it detects a difference between the stored IF checksum and the calculated IF checksum only following a device reset.

STATUS	CONDITION	ACTION
Normal	Stored and calculated IF checksum match	—
Trip	Stored and calculated IF checksum after reset does not match	*PFStatus()[IFC]* = 1

3.22 Open Cell Voltage Connection Permanent Fail

The device can permanently disable the battery if it detects a difference between the BAT pin voltage and the sum of the individual cell voltages. *Recommendation*: Perform BAT pin calibration in production if this protection is enabled.

STATUS	CONDITION	ACTION
Normal	| *Voltage()* – BAT voltage in *DAStatus1()* |	*PFAlert()[OPNCELL]* = 0
Alert	| *Voltage()* – BAT voltage in *DAStatus1()* | ≥ ***OPNCELL:Threshold***	*PFAlert()[OPNCELL]* = 1
Trip	| *Voltage()* – BAT voltage in *DAStatus1()* | continuous ≥ ***OPNCELL:Threshold*** for ***OPNC:Delay*** Period	*PFAlert()[OPNCELL]* = 0 *PFStatus()[OPNCELL]* = 1

3.22.1 OPNCELL Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	OPNCELL	Threshold	I2	0	32767	5000	mV
Permanent Fail	OPNCELL	Delay	U1	0	255	5	s

3.23 Data Flash (DF) Permanent Fail

The device can permanently disable the battery in case a data flash write fails.

NOTE: A DF write failure causes the gauge to disable further DF writes.

STATUS	CONDITION	ACTION
Normal	Data flash write OK	—
Trip	Data flash write not successful	*PFStatus()[DFW]* = 1

3.24 Open Thermistor Permanent Fail (TS1, TS2, TS3, TS4)

The device can permanently disable the battery if it detects an open thermistor on TS1, TS2, TS3, or TS4. The state of TS1..4 and the internal temperature sensor is available in *DAStatus2()*.

STATUS	CONDITION	ACTION
Normal, TS1	TS1 Temperature > ***Open Thermistor:Threshold*** OR Internal Temperature ≤ TS1 Temperature + ***Cell Delta*** if ***Temperature Mode[TS1 Mode] = 0*** OR Internal Temperature ≤ TS1 Temperature + ***FET Delta*** if ***Temperature Mode[TS1 Mode] = 1***	*PFAlert()[TS1]* = 0
Normal, TS2	TS2 Temperature > ***Open Thermistor:Threshold*** OR Internal Temperature ≤ TS2 Temperature + ***Cell Delta*** if ***Temperature Mode[TS2 Mode] = 0*** OR Internal Temperature ≤ TS2 Temperature + ***FET Delta*** if ***Temperature Mode[TS2 Mode] = 1***	*PFAlert()[TS2]* = 0
Normal, TS3	TS3 Temperature > ***Open Thermistor:Threshold*** OR Internal Temperature ≤ TS3 Temperature + ***Cell Delta*** if ***Temperature Mode[TS3 Mode] = 0*** OR Internal Temperature ≤ TS3 Temperature + ***FET Delta*** if ***Temperature Mode[TS3 Mode] = 1***	*PFAlert()[TS3]* = 0
Normal, TS4	TS4 Temperature > ***Open Thermistor:Threshold*** OR Internal Temperature ≤ TS4 Temperature + ***Cell Delta*** if ***Temperature Mode[TS4 Mode] = 0*** OR Internal Temperature ≤ TS4 Temperature + ***FET Delta*** if ***Temperature Mode[TS4 Mode] = 1***	*PFAlert()[TS4]* = 0
Alert, TS1	Condition 1: TS1 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS1 Temperature + ***Cell Delta*** if ***Temperature Mode[TS1 Mode] = 0***	*PFAlert()[TS1]* = 1
	OR Condition 2: TS1 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS1 Temperature + ***FET Delta*** if ***Temperature Mode[TS1 Mode] = 1***	

STATUS	CONDITION	ACTION
Alert, TS2	Condition 1: TS2 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS2 Temperature + ***Cell Delta*** if ***Temperature Mode[TS2 Mode] = 0***	*PFAlert()[TS1]* = 1
	OR Condition 2: TS2 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS2 Temperature + ***FET Delta*** if ***Temperature Mode[TS2 Mode] = 1***	
Alert, TS3	Condition 1: TS3 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS3 Temperature + ***Cell Delta*** if ***Temperature Mode[TS3 Mode] = 0***	*PFAlert()[TS1]* = 1
	OR Condition 2: TS3 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS3 Temperature + ***FET Delta*** if ***Temperature Mode[TS3 Mode] = 1***	
Alert, TS4	Condition 1: TS4 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS4 Temperature + ***Cell Delta*** if ***Temperature Mode[TS4 Mode] = 0***	*PFAlert()[TS1]* = 1
	OR Condition 2: TS4 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS4 Temperature + ***FET Delta*** if ***Temperature Mode[TS4 Mode] = 1***	
Trip, TS1	Condition 1: TS1 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS1 Temperature + ***Cell Delta*** for ***Open Thermistor:Delay*** duration if ***Temperature Mode[TS1 Mode] = 0***	*PFAlert()[TS1]* = 0 *PFStatus()[TS1]* = 1
	OR Condition 2: TS1 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS1 Temperature + ***FET Delta*** for ***OpenThermistor:Delay*** duration if ***Temperature Mode[TS1 Mode] = 1***	
Trip, TS2	Condition 1: TS2 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS2 Temperature + ***Cell Delta*** for ***Open Thermistor:Delay*** duration if ***Temperature Mode[TS2 Mode] = 0***	*PFAlert()[TS2]* = 0 *PFStatus()[TS2]* = 1
	OR Condition 2: TS2 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS2 Temperature + ***FET Delta*** for ***OpenThermistor:Delay*** duration if ***Temperature Mode[TS2 Mode] = 1***	
Trip, TS3	Condition 1: TS3 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS3 Temperature + ***Cell Delta*** for ***Open Thermistor:Delay*** duration if ***Temperature Mode[TS3 Mode] = 0***	*PFAlert()[TS3]* = 0 *PFStatus()[TS3]* = 1
	OR Condition 2: TS3 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS3 Temperature + ***FET Delta*** for ***OpenThermistor:Delay*** duration if ***Temperature Mode[TS3 Mode] = 1***	
Trip, TS4	Condition 1: TS4 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS4 Temperature + ***Cell Delta*** for ***Open Thermistor:Delay*** duration if ***Temperature Mode[TS4 Mode] = 0***	*PFAlert()[TS4]* = 0 *PFStatus()[TS4]* = 1
	OR Condition 2: TS4 Temperature ≤ ***Open Thermistor:Threshold*** AND Internal Temperature > TS4 Temperature + ***FET Delta*** for ***OpenThermistor:Delay*** duration if ***Temperature Mode[TS4 Mode] = 1***	

3.24.1 Open Thermistor Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Permanent Fail	Open Thermistor	Threshold	I2	0	32767	2232	0.1°K
Permanent Fail	Open Thermistor	Delay	U1	0	255	5	s
Permanent Fail	Open Thermistor	Fet Delta	I2	–400	1500	200	0.1°C
Permanent Fail	Open Thermistor	Cell Delta	I2	–400	1500	200	0.1°C

3.25 Additional PF Data Flash

3.25.1 Enabled Permanent Faults

These values describe which permanent faults are enabled.

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Permanent Failure	Enabled PF A	U1	0	0xff	0x0	hex
Settings	Permanent Failure	Enabled PF B	U1	0	0xff	0x0	hex
Settings	Permanent Failure	Enabled PF C	U1	0	0xff	0x0	hex
Settings	Permanent Failure	Enabled PF D	U1	0	0xff	0x0	hex

3.25.1.1 Enabled PF A

B7	B6	B5	B4	B3	B2	B1	B0
QIM	SOTF	RSVD	SOT	SOCD	SOCC	SOV	SUV

QIM	[7]	Permanent Fault for QMax Imbalance	**1**: Enabled **0**: Disabled
SOTF	[6]	Permanent Fault for Safety Over-temperature FET	**1**: Enabled **0**: Disabled
RSVD	[5]	Reserved - Do not use	
SOT	[4]	Permanent Fault for Safety Over-temperature	**1**: Enabled **0**: Disabled
SOCD	[3]	Permanent Fault for Safety Over-current in Discharge	**1**: Enabled **0**: Disabled
SOCC	[2]	Permanent Fault for Safety Over-current in Charge	**1**: Enabled **0**: Disabled
SOV	[1]	Permanent Fault for Safety Cell Over-voltage	**1**: Enabled **0**: Disabled
SUV	[0]	Permanent Fault for Safety Cell Under-voltage	**1**: Enabled **0**: Disabled

3.25.1.2 Enabled PF B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	VIMA	VIMR	CD	IMP	CB

RSVD	[7:5]	Reserved - Do not use	
VIMA	[4]	Permanent Fault for Voltage Imbalance in Active state	**1**: Enabled **0**: Disabled
VIMR	[3]	Permanent Fault for Voltage Imbalance in Rest state	**1**: Enabled **0**: Disabled
CD	[2]	Permanent Fault for Capacity Degradation	**1**: Enabled **0**: Disabled
IMP	[1]	Permanent Fault for Cell impedance	**1**: Enabled **0**: Disabled
CB	[0]	Permanent Fault for Cell balancing	**1**: Enabled **0**: Disabled

3.25.1.3 Enabled PF C

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	2LVL	AFEC	AFER	FUSE	RSVD	DFETF	CFETF

RSVD	[7]	Reserved - Do not use	
2LVL	[6]	Permanent Fault by external 2nd level protection	**1**: Enabled **0**: Disabled
AFEC	[5]	Permanent Fault for AFE communication errors	**1**: Enabled **0**: Disabled
AFER	[4]	Permanent Fault for AFE register errors	**1**: Enabled **0**: Disabled
FUSE	[3]	Fuse blows	**1**: Enabled **0**: Disabled
RSVD	[2]	Reserved - Do not use	
DFETF	[1]	Permanent Fault for Discharge FET malfunction	**1**: Enabled **0**: Disabled
CFETF	[0]	Permanent Fault for Charge FET malfunction	**1**: Enabled **0**: Disabled

3.25.1.4 Enabled PF D

B7	B6	B5	B4	B3	B2	B1	B0
TS4	TS3	TS2	TS1	RSVD	RSVD	OPNCELL	RSVD

TS4	[7]	Permanent Fault for Temperature Sensor 4 malfunction	**1**: Enabled **0**: Disabled
TS3	[6]	Permanent Fault for Temperature Sensor 3 malfunction	**1**: Enabled **0**: Disabled
TS2	[5]	Permanent Fault for Temperature Sensor 2 malfunction	**1**: Enabled **0**: Disabled
TS1	[4]	Permanent Fault for Temperature Sensor 1 malfunction	**1**: Enabled **0**: Disabled
RSVD	[3:2]	Reserved - Do not use	
OPNCELL	[1]	Permanent Fault for open cell tab	**1**: Enabled **0**: Disabled
RSVD	[0]	Reserved - Do not use	

3.25.2 Device Voltage and Temperature Data

When a permanent fault is triggered, the voltage of each cell and the temperature of the internal sensor and any external thermal sensors are captured.

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Voltage Data	Cell 1 Voltage	I2	–32768	32767	0	mV
PF Status	Device Voltage Data	Cell 2 Voltage	I2	–32768	32767	0	mV
PF Status	Device Voltage Data	Cell 3 Voltage	I2	–32768	32767	0	mV
PF Status	Device Voltage Data	Cell 4 Voltage	I2	–32768	32767	0	mV
PF Status	Device Voltage Data	Battery Direct Voltage	I2	–32768	32767	0	mV
PF Status	Device Voltage Data	Pack Voltage	I2	–32768	32767	0	mV

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Temperature Data	Internal Temperature	I2	–32768	32767	0	0.1°K
PF Status	Device Temperature Data	External 1 Temperature	I2	–32768	32767	0	0.1°K

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Temperature Data	External 2 Temperature	I2	–32768	32767	0	0.1°K
PF Status	Device Temperature Data	External 3 Temperature	I2	–32768	32767	0	0.1°K
PF Status	Device Temperature Data	External 4 Temperature	I2	–32768	32767	0	0.1°K

3.25.3 Device Status Data at Permanent Fault

When a permanent fault is triggered, device status at the time of the fault is captured to flash.

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Status Data	Safety Alert A	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Status A	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Alert B	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Status B	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Alert C	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Status C	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Alert D	U1	0	0xff	0	hex
PF Status	Device Status Data	Safety Status D	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Alert A	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Status A	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Alert B	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Status B	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Alert C	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Status C	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Alert D	U1	0	0xff	0	hex
PF Status	Device Status Data	PF Status D	U1	0	0xff	0	hex
PF Status	Device Status Data	Fuse Flag	U2	0	0xffff	0	hex
PF Status	Device Status Data	Operation Status A	B2	0	0xffff	0	hex
PF Status	Device Status Data	Operation Status B	B2	0	0xffff	0	hex
PF Status	Device Status Data	Temp Range	U1	0	0xff	0	hex
PF Status	Device Status Data	Charging Status A	B1	0	0xff	0	hex
PF Status	Device Status Data	Charging Status B	B1	0	0xff	0	hex
PF Status	Device Status Data	Charger Status	B1	0	0xff	0	hex
PF Status	Device Status Data	Gauging Status	B1	0	0xff	0	hex

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Status Data	IT Status	B2	0	0xffff	0	hex

3.25.3.1 Charger Status

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	RSVD	LCHG	CHGSTAT	CHRG

RSVD	[7:3]	Reserved - Do not use	
LCHG	[2]	Pre-charge mode	**1**: Detected **0**: Undetected
CHGSTAT	[1]	Charger current to battery	**1**: Detected **0**: Undetected
CHRG	[0]	Charger enabled	**1**: Detected **0**: Undetected

3.25.3.2 Charging Status A

B7	B6	B5	B4	B3	B2	B1	B0
VCT	MCHG	SU	IN	HV	MV	LV	PV

VCT	[7]	Valid Charge Termination	**1**: Detected **0**: Undetected
MCHG	[6]	Maintenance charge	**1**: Detected **0**: Undetected
SU	[5]	Charge Suspend	**1**: Detected **0**: Undetected
IN	[4]	Charge Inhibit	**1**: Detected **0**: Undetected
HV	[3]	Max cell voltage in High Voltage region	**1**: Detected **0**: Undetected
MV	[2]	Max cell voltage in Middle Voltage region	**1**: Detected **0**: Undetected
LV	[1]	Max cell voltage in Low Voltage region	**1**: Detected **0**: Undetected
PV	[0]	Minimum cell voltage in Pre-charge Voltage region	**1**: Detected **0**: Undetected

3.25.3.3 Charging Status B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	CVRD	RSVD	RSVD	RSVD	CVR	CCR

RSVD	[7:6]	Reserved - Do not use	
CVRD	[5]	Current/Voltage Override Mode	**1**: Active **0**: Inactive
RSVD	[4:2]	Reserved - Do not use	
CVR	[1]	Charging Voltage Rate of Change	**1**: Active **0**: Inactive
CCR	[0]	Charging Current Rate of Change	**1**: Active **0**: Inactive

3.25.3.4 IT Status

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	RSVD	OCVFR	LDMD	RX	QMAX	VDQ
RSVD	[15:13]	Reserved - Do not use					
OCVFR	[12]	Open Circuit Voltage Flat Region				**1**: Detected **0**: Undetected	
LDMD	[11]	LOAD mode				**1**: Constant Power **0**: Constant Current	
RX	[10]	Resistance Update				Toggle on update	
QMAX	[9]	QMax Update				Toggle on update	
VDQ	[8]	Discharge Qualified for Learning				**1**: Detected **0**: Undetected	
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
NSFM	RSVD	SLPQMAX	QEN	VOK	RDIS	RSVD	REST
NSFM	[7]	Negative Ra Scale Factor Mode				**1**: Detected **0**: Undetected	
RSVD	[6]	Reserved - Do not use					
SLPQMAX	[5]	OCV update in SLEEP mode				**1**: Active **0**: Inactive	
QEN	[4]	Impedance Track Gauging				**1**: Enabled **0**: Disabled	
VOK	[3]	Voltages are OK for QMax update				**1**: Detected **0**: Undetected	
RDIS	[2]	Resistance Updates Disabled				**1**: No Updates **0**: Updates	
RSVD	[1]	Reserved - Do not use					
REST	[0]	OCV Measurement taken in REST mode				**1**: Detected **0**: Undetected	

3.25.3.5 Operation Status A

B15	B14	B13	B12	B11	B10	B9	B8
SLEEP	XCGH	XDSG	PF	SS	SDV	SEC[1]	SEC[0]
SLEEP	[15]	SLEEP mode				**1**: Detected **0**: Undetected	
XCGH	[14]	Charge FET disabled				**1**: Detected **0**: Undetected	
XDSG	[13]	Discharge FET disabled				**1**: Detected **0**: Undetected	
PF	[12]	Permanent Fault condition				**1**: Detected **0**: Undetected	
SS	[11]	Safety Mode				**1**: Detected **0**: Undetected	
SDV	[10]	Shutdown triggered due to low pack voltage				**1**: Detected **0**: Undetected	
SEC[1:0]	[9:8]	Security Status					
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
BTP_INT	ACLW	FUSE	ACFET	PCHG	CHG	DSG	PRES
BTP_INT	[7]	Battery Trip Point Interrupts				**1**: Asserted **0**: Unasserted	
ACLW	[6]	Adaptor voltage below threshold				**1**: Detected **0**: Undetected	
FUSE	[5]	Fuse status				**1**: Asserted **0**: Unasserted	
ACFET	[4]	AC FET status				**1**: Enabled **0**: Disabled	
PCHG	[3]	External Pre-charge FET status				**1**: Enabled **0**: Disabled	
CHG	[2]	Charge FET status				**1**: Enabled **0**: Disabled	
DSG	[1]	Discharge FET status				**1**: Enabled **0**: Disabled	
PRES	[0]	System Present				**1**: Detected **0**: Undetected	

3.25.3.6 Operation Status B

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	EMSHUT	CB	SLPCC	SLPAD	SMBLCAL	INIT

Name	Bits	Description	Value
RSVD	[15:14]	Reserved—Do not use.	
EMSHUT	[13]	Emergency shutdown	**1**: Detected **0**: Undetected
CB	[12]	Cell balancing	**1**: Active **0**: Inactive
SLPCC	[11]	CC Measurement in SLEEP mode	**1**: Active **0**: Inactive
SLPAD	[10]	ADC Measurement in SLEEP mode	**1**: Active **0**: Inactive
SMBLCAL	[9]	Auto CC calibration when SMBus low	**1**: Active **0**: Inactive
INIT	[8]	Initialization after full reset	**1**: Detected **0**: Undetected

B7	B6	B5	B4	B3	B2	B1	B0
SLEEPM	XL	CAL_OFFSET	CAL	AUTOCALM	AUTH	LED	SDM

Name	Bits	Description	Value
SLEEPM	[7]	SLEEP mode triggered via command	**1**: Active **0**: Inactive
XL	[6]	400-kHz SMBus mode	**1**: Active **0**: Inactive
CAL_OFFSET	[5]	Calibration output (raw CC) generated when *OutputShortedCCADCCal()* sent	**1**: Active **0**: Inactive
CAL	[4]	Calibration output (raw ADC and CC) generated when *OutputCCADCCal()* and *OutputShortedCCADCCal()* sent	**1**: Active **0**: Inactive
AUTOCALM	[3]	Auto CC Offset Calibration by MAC *AutoCCOffset()*	**1**: Active **0**: Inactive
AUTH	[2]	Authentication in progress	**1**: Active **0**: Inactive
LED	[1]	LED Display	**1**: Active **0**: Inactive
SDM	[0]	Shutdown triggered via command	**1**: Active **0**: Inactive

3.25.3.7 PF Alert/Status A

The bit description between PF Alert and Status are the same. Alerts are flagged for temporary conditions and statuses are flagged when an additional threshold has been exceeded.

B7	B6	B5	B4	B3	B2	B1	B0
QIM	SOTF	RSVD	SOT	SOCD	SOCC	SOV	SUV

Name	Bits	Description	Value
QIM	[7]	QMax Imbalance Failure	**1**: Detected **0**: Undetected
SOTF	[6]	Safety Over-Temperature Failure	**1**: Detected **0**: Undetected
RSVD	[5]	Reserved - do not use.	
SOT	[4]	Safety Over-Temperature Cell Failure	**1**: Detected **0**: Undetected
SOV	[1]	Safety Cell Over-Voltage Failure	**1**: Detected **0**: Undetected
SUV	[0]	Safety Cell Under-Voltage Failure	**1**: Detected **0**: Undetected

3.25.3.8 PF Alert/Status B

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	VIMA	VIMR	CD	IMP	CB

RSVD	[7:5]	Reserved - do not use.	
VIMA	[4]	Voltage Imbalance while Pack Active	**1**: Detected **0**: Undetected
VIMR	[3]	Voltage Imbalance while Pack Resting	**1**: Detected **0**: Undetected
CD	[2]	Capacity Degradation Failure	**1**: Detected **0**: Undetected
IMP	[1]	Impedance Failure	**1**: Detected **0**: Undetected
CB	[0]	Cell Balancing Failure	**1**: Detected **0**: Undetected

3.25.3.9 PF Alert/Status C

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	2LVL	AFEC	AFER	FUSE	RSVD	DFETF	CFETF

RSVD	[7]	Reserved - do not use.	
2LVL	[6]	Second Level Protector Failure	**1**: Detected **0**: Undetected
AFEC	[5]	AFE Communication Failure	**1**: Detected **0**: Undetected
AFER	[4]	AFE Register Failure	**1**: Detected **0**: Undetected
FUSE	[3]	Chemical Fuse Failure	**1**: Detected **0**: Undetected
RSVD	[2]	Reserved - do not use.	
DFETF	[1]	Discharge FET Failure	**1**: Detected **0**: Undetected
CFETF	[0]	Charge FET Failure	**1**: Detected **0**: Undetected

3.25.3.10 PF Alert/Status D

B7	B6	B5	B4	B3	B2	B1	B0
TS4	TS3	TS2	TS1	RSVD	RSVD	OPNC	RSVD

TS4	[7]	Open Thermistor - TS4 Failure	**1**: Detected **0**: Undetected
TS3	[6]	Open Thermistor - TS3 Failure	**1**: Detected **0**: Undetected
TS2	[5]	Open Thermistor - TS2 Failure	**1**: Detected **0**: Undetected
TS1	[4]	Open Thermistor - TS1 Failure	**1**: Detected **0**: Undetected
RSVD	[3:2]	Reserved - do not use.	
OPNC	[1]	Open Cell Tab Connection Failure	**1**: Detected **0**: Undetected
RSVD	[0]	Reserved - do not use.	

3.25.3.11 Safety Alert/Status A

The bit descriptions of Safety Alert A and Safety Status A are identical.

B7	B6	B5	B4	B3	B2	B1	B0
AOLDL	AOLD	OCD2	OCD1	OCC2	OCC1	COV	CUV

AOLDL	[7]	Latched Overload During Discharge	**1**: Detected **0**: Undetected
AOLD	[6]	Overload During Discharge	**1**: Detected **0**: Undetected
OCD2	[5]	Over-current during Discharge 2	**1**: Detected **0**: Undetected
OCD1	[4]	Over-current during Discharge 1	**1**: Detected **0**: Undetected
OCC2	[3]	Over-current during Charge 2	**1**: Detected **0**: Undetected
OCC1	[2]	Over-current during Charge 1	**1**: Detected **0**: Undetected
COV	[1]	Cell Over-voltage	**1**: Detected **0**: Undetected
CUV	[0]	Cell Under-Voltage	**1**: Detected **0**: Undetected

3.25.3.12 Safety Alert/Status B

The bit descriptions of Safety Alert B and Safety Status B are identical.

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	CUVC	OTD	OTC	ASCDL	ASCD	ASCCL	ASCC

RSVD	[7]	Reserved - Do not use	
CUVC	[6]	Compensated Cell Under-Voltage	**1**: Detected **0**: Undetected
OTD	[5]	Over-temperature during Discharge	**1**: Detected **0**: Undetected
OTC	[4]	Over-temperature during Charge	**1**: Detected **0**: Undetected
ASCDL	[3]	Latched Short Circuit during Discharge	**1**: Detected **0**: Undetected
ASCD	[2]	Short Circuit during Discharge	**1**: Detected **0**: Undetected
ASCCL	[1]	Latched Short Circuit during Charge	**1**: Detected **0**: Undetected
ASCC	[0]	Short Circuit during Charge	**1**: Detected **0**: Undetected

3.25.3.13 Safety Alert C

B7	B6	B5	B4	B3	B2	B1	B0
CHGC	OC	CTOS	RSVD	PTOS	RSVD	RSVD	OTF

CHGC	[7]	Charging Over-current	**1**: Detected **0**: Undetected
OC	[6]	Over Charge	**1**: Detected **0**: Undetected
CTOS	[5]	Charge Timeout Suspend	**1**: Detected **0**: Undetected
RSVD	[4]	Reserved - Do not use	
PTOS	[3]	Pre-charge Timeout Suspend	**1**: Detected **0**: Undetected
RSVD	[2:1]	Reserved - Do not use	
OTF	[0]	FET Over-temperature	**1**: Detected **0**: Undetected

3.25.3.14 Safety Status C

B7	B6	B5	B4	B3	B2	B1	B0
CHGC	OC	RSVD	CTO	RSVD	PTO	HWDF	OTF

CHGC	[7]	Charging Over-current	**1**: Detected **0**: Undetected
OC	[6]	Over Charge	**1**: Detected **0**: Undetected
RSVD	[5]	Reserved - Do not use	
CTO	[4]	Charge Timeout	**1**: Detected **0**: Undetected
RSVD	[3]	Reserved - Do not use	
PTO	[2]	Pre-charge Timeout	**1**: Detected **0**: Undetected
HWDF	[1]	SBS Host Watchdog Timeout	**1**: Detected **0**: Undetected
OTF	[0]	FET Over-temperature	**1**: Detected **0**: Undetected

3.25.3.15 Safety Alert D

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	COT	UTD	UTC	PCHGC	CHGV

RSVD	[7:5]	Reserved - Do not use	
COT	[4]	Charge Over-temperature	**1**: Detected **0**: Undetected
UTD	[3]	Discharge Under-temperature	**1**: Detected **0**: Undetected
UTC	[2]	Charge Under-temperature	**1**: Detected **0**: Undetected
PCHGC	[1]	Pre-charge Over-current	**1**: Detected **0**: Undetected
CHGV	[0]	Charge Over-voltage	**1**: Detected **0**: Undetected

3.25.3.16 Safety Status D

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	ACOV	COT	UTD	UTC	PCHGC	CHGV

RSVD	[7:6]	Reserved - Do not use	
ACOV	[5]	Adaptor Over-Voltage	**1**: Detected **0**: Undetected
COT	[4]	Charge Over-temperature	**1**: Detected **0**: Undetected
UTD	[3]	Discharge Under-temperature	**1**: Detected **0**: Undetected
UTC	[2]	Charge Under-temperature	**1**: Detected **0**: Undetected
PCHGC	[1]	Pre-charge Over-current	**1**: Detected **0**: Undetected
CHGV	[0]	Charge Over-voltage	**1**: Detected **0**: Undetected

3.25.3.17 Temp Range

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	OT	HT	STH	RT	STL	LT	UT

RSVD	[7]	Reserved—Do not use.	
OT	[6]	Over Temperature	**1**: Detected **0**: Undetected
HT	[5]	High Temperature	**1**: Detected **0**: Undetected
STH	[4]	Standard Temperature High	**1**: Detected **0**: Undetected
RT	[3]	Recommended Temperature	**1**: Detected **0**: Undetected
STL	[2]	Standard Temperature Low	**1**: Detected **0**: Undetected
LT	[1]	Low Temperature	**1**: Detected **0**: Undetected
UT	[0]	Under Temperature	**1**: Detected **0**: Undetected

3.25.4 Device Gauging Data at Permanent Fault

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Gauging Data	Cell 1 Dod0	I2	–32768	32767	0	—
PF Status	Device Gauging Data	Cell 2 Dod0	I2	–32768	32767	0	—
PF Status	Device Gauging Data	Cell 3 Dod0	I2	–32768	32767	0	—
PF Status	Device Gauging Data	Cell 4 Dod0	I2	–32768	32767	0	—
PF Status	Device Gauging Data	Passed Charge	I2	–32768	32767	0	mAh

3.25.4.1 Gauging Status

B7	B6	B5	B4	B3	B2	B1	B0
CF	DSG	EDV	BAL_EN	TCA	TDA	FC	FD

CF	[7]	Conditioning Flag - Conditioning cycle needed	**1**: Detected **0**: Undetected
DSG	[6]	Discharging or RELAX	**1**: Detected **0**: Undetected
EDV	[5]	End Discharge Voltage	**1**: Detected **0**: Undetected
BAL_EN	[4]	Cell Balancing enabled	**1**: Detected **0**: Undetected
TCA	[3]	Terminate Charge Alarm	**1**: Detected **0**: Undetected
TDA	[2]	Terminate Discharge Alarm	**1**: Detected **0**: Undetected
FC	[1]	Full charge	**1**: Detected **0**: Undetected
FD	[0]	Full discharge	**1**: Detected **0**: Undetected

3.25.5 Device Current Data

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
PF Status	Device Current Data	Current	I2	–32768	32767	0	mA

Advanced Charge Algorithm

4.1 Introduction

The bq40z60 integrates a switch-mode charge controller for multi-cell Li-Ion systems. The charger can supply power to the system while simultaneously charging the battery, automatically reducing the charging current when the system load increases and the total current (battery charge current and system load) is greater than what is set as the charge current. The architecture also allows the battery to supplement the system current when the charger cannot deliver enough power. The charger is designed as a Narrow Voltage DC (NVDC) system, meaning that the output voltage is never higher than the fully charged battery-stack voltage. The device can change the values of *ChargingVoltage()* and *ChargingCurrent()* based on *Temperature()* and cell voltages, allowing for a flexible charging algorithm that is JEITA compatible and can also meet other specific cell manufacturer charge requirements. The *ChargingStatus()* register shows the state of the charging algorithm.

Figure 4-1 shows a simplified block diagram of the charger and power path. The resistor R_{CHG} is used to measure the cycle-by-cycle current limit of the charge controller. By measuring the voltage across this resistor, charger output voltage automatically regulates to ensure the current can be delivered up to the voltage set by *ChargingVoltage()*. The resistor R_{SNS} is used to provide an averaged current into and out of the battery. The charger also offers simple adapter overvoltage protection.

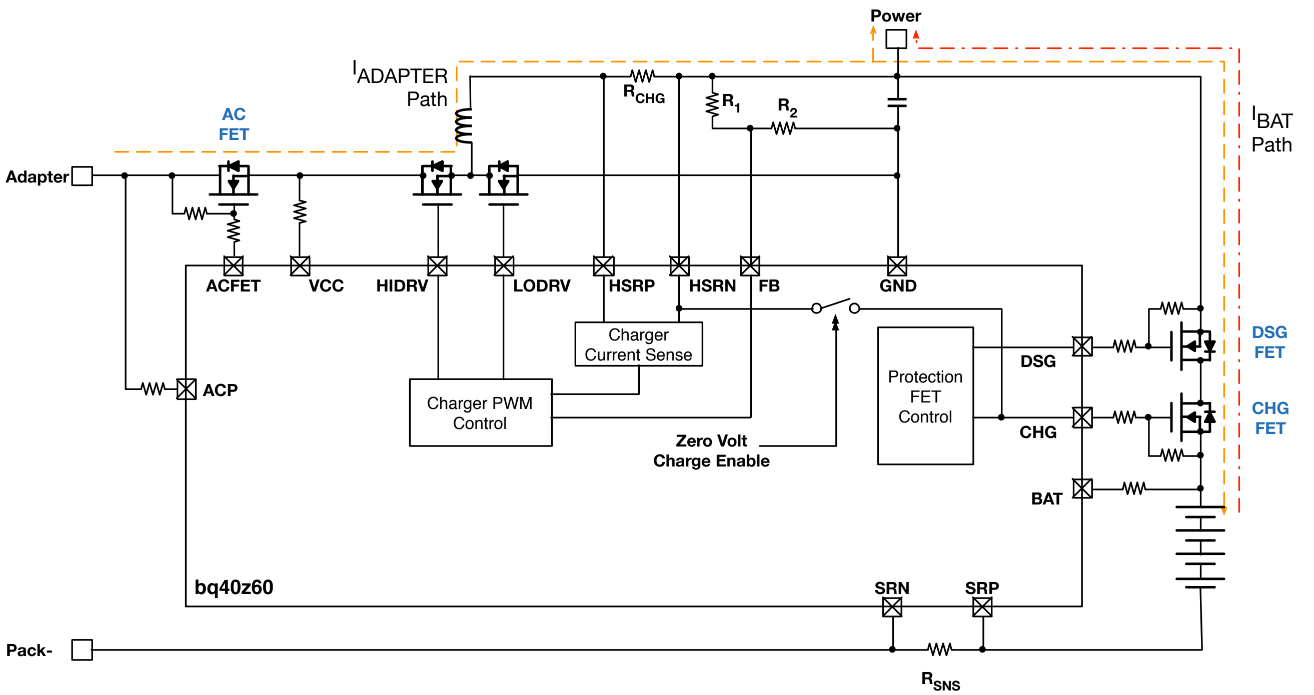


Figure 4-1. Simplified Power Path Diagram

The charger support the standard charging states of Pre-Charge, Constant Current, Constant Voltage, and Termination as shown in Figure 4-2. The firmware allows for complete flexibility in the setting of thresholds for all of these states.

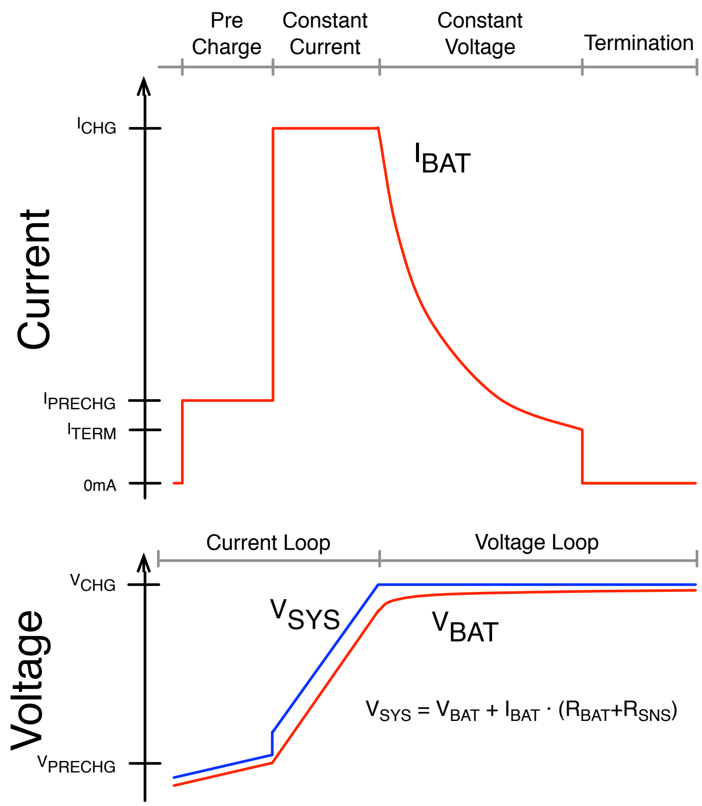
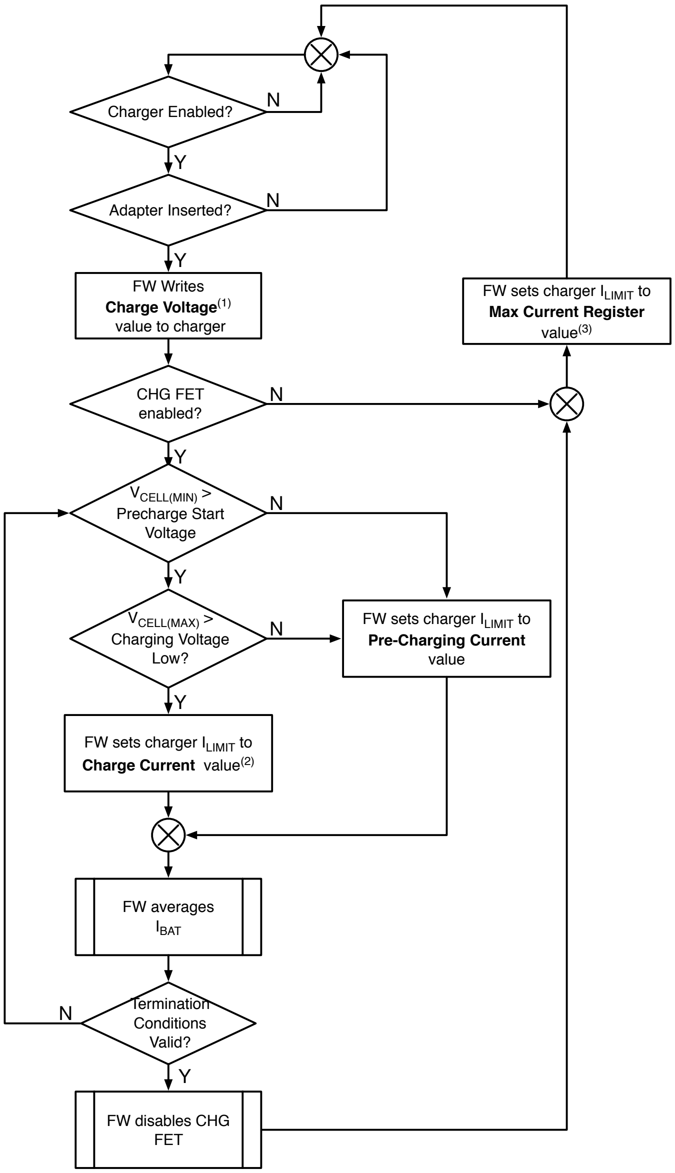


Figure 4-2. Charging States

The general operational flow of the charger is shown in Figure 4-3. Note that the charge voltage and current is temperature and cell voltage dependent, which is explained in more detail in the following sections.

As shown in Figure 4-3, the cell voltage and temperature can affect the charge current in the Constant Current (CC) charging mode. Figure 4-4 provides a guide to understand the influence of temperature and maximum cell voltage on the current selected. By setting different values for the temperature thresholds T1 through T6, low, medium, and high voltage thresholds, as well as the currents in each box, the battery charging can be controlled very precisely.



Notes:

(1) Charge voltage will be based on temperature.

(2) Charge current will be based on temperature and cell voltage.

(3) I_{LIMIT} = **Max Current Register** / (R_{CHG} · 2550)

Figure 4-3. Charger Operational Flow

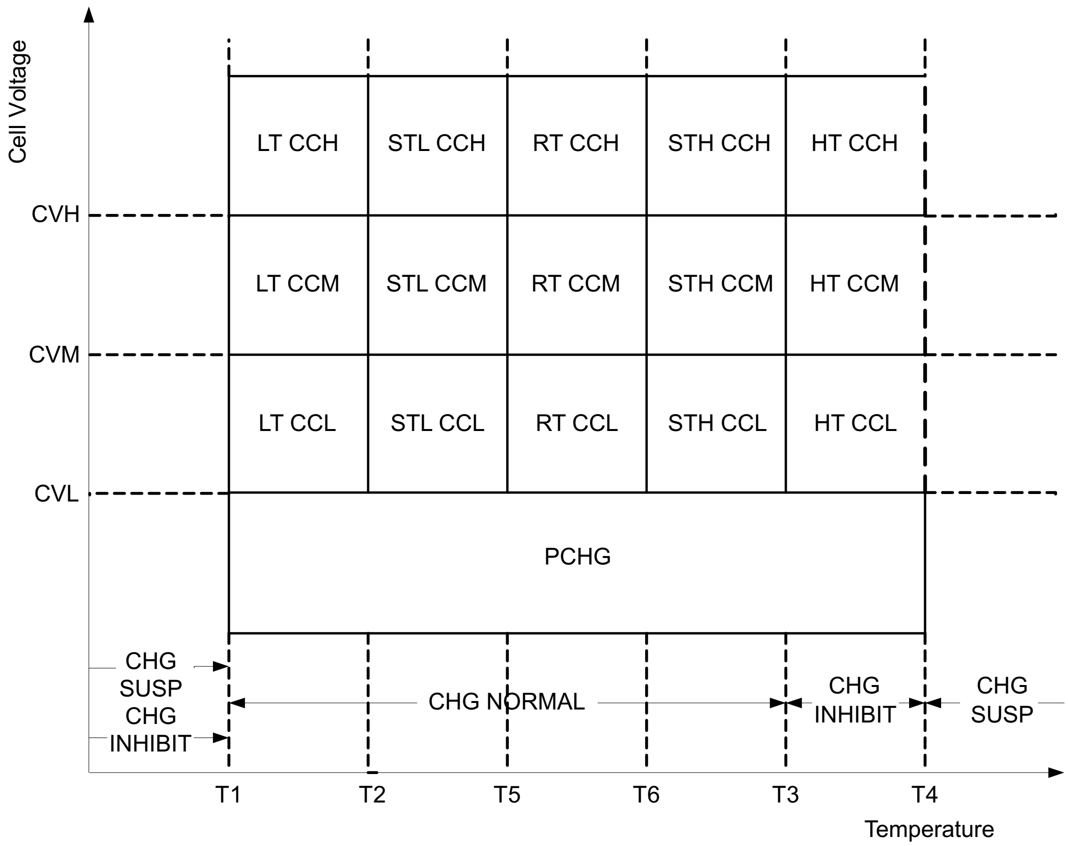


Figure 4-4. Constant Current Mode Matrix

4.2 Charger Setup

In order to setup the charger, the data flash values in Advanced Charge Algorithm:Charger must be set properly. Resistor values shown in the following equations all reference Figure 4-1.

Minimum Voltage Output sets the minimum voltage of the charger.

$$\text{Minimum Voltage Output} = 610 \cdot (1 + R_1 / R_2) \tag{1}$$

Voltage Resolution sets the resolution of each voltage setting from the firmware.

$$\text{Voltage Resolution} = \frac{610 \cdot (1 + R_1 / R_2)}{256} \tag{2}$$

Current Resolution sets the resolution of each current setting from the firmware.

$$\text{Current Resolution} = \frac{0.39}{R_{CHG}} \tag{3}$$

Max Current Register sets the current limit of the charger when the CHG FET is disabled, meaning that the battery is fully charged or charge is inhibited for some reason.

$$\text{Max Current Register} = I_{LIMIT} \cdot R_{CHG} \cdot 2550 \tag{4}$$

VACP Hysteresis is the amount of voltage above the pack voltage needed to detect the adapter voltage.

4.2.1 Charger Data Flash

4.2.1.1 Charging Configuration

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	Charging Configuration	B1	0	0x77	0x00	hex

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	CVRD_EN	LCHGS	LCHGM	RSVD	MLC	MLCSOH	CRATE

RSVD	[7]	Reserved - Do not use	
CVRD_EN	[6]	Allow host controller to override charge current/voltage from firmware	**1**: Enabled **0**: Disabled
LCHGS	[5]	Allow firmware to maintain current in pre-charge region	**1**: Enabled **0**: Disabled
LCHGM	[4]	Internal pre-charge current control	**1**: Enabled **0**: Disabled
RSVD	[3]	Reserved - Do not use	
MLC	[2]	Multi-level charging Unsupported - keep disabled	**1**: Enabled **0**: Disabled
MLCSOH	[1]	Multi-level charging State of Health Unsupported - keep disabled	**1**: Enabled **0**: Disabled
CRATE	[0]	Current Rate of Change support	**1**: Enabled **0**: Disabled

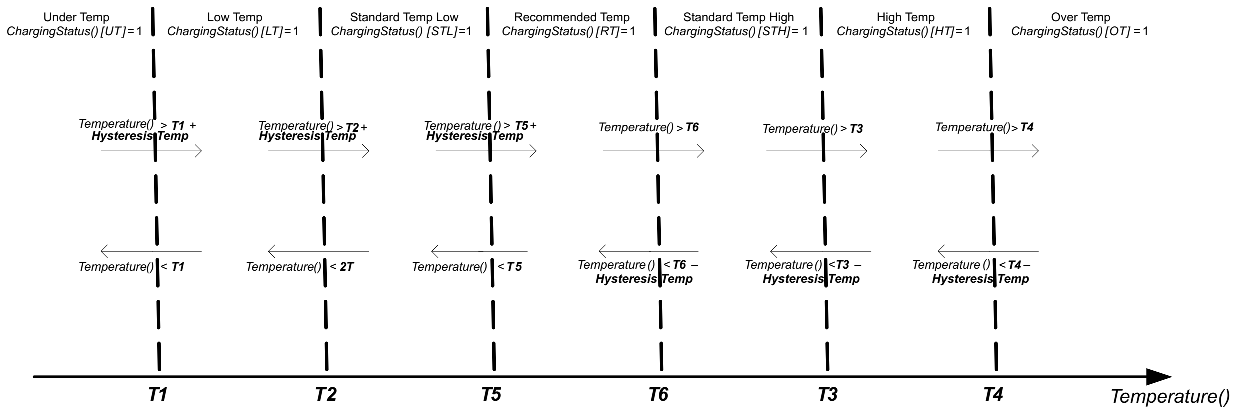
4.2.1.2 Charge Algorithm Parameters

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Charger	Minimum Voltage Output	I2	0	32767	6294	mV
Advanced Charge Algorithm	Charger	Voltage Resolution	I1	0	127	25	mV
Advanced Charge Algorithm	Charger	LCHG Current Resolution	I1	0	127	8	mA
Advanced Charge Algorithm	Charger	Current Resolution	I1	0	127	39	mA
Advanced Charge Algorithm	Charger	Max Current Register	U1	0	255	255	—
Advanced Charge Algorithm	Charger	Vacp Hysteresis	I2	–32768	32767	0	mV

4.3 Charge Temperature Ranges

The measured temperature is segmented into several temperature ranges. The charging algorithm adjusts *ChargingCurrent()* and *ChargingVoltage()* according to the temperature range. The temperature ranges set in data flash should adhere to the following format:

T1*≤ *T2* ≤ *T5* ≤ *T6* ≤ *T3* ≤ *T4.



4.3.1 *Charging Temperature Data Flash*

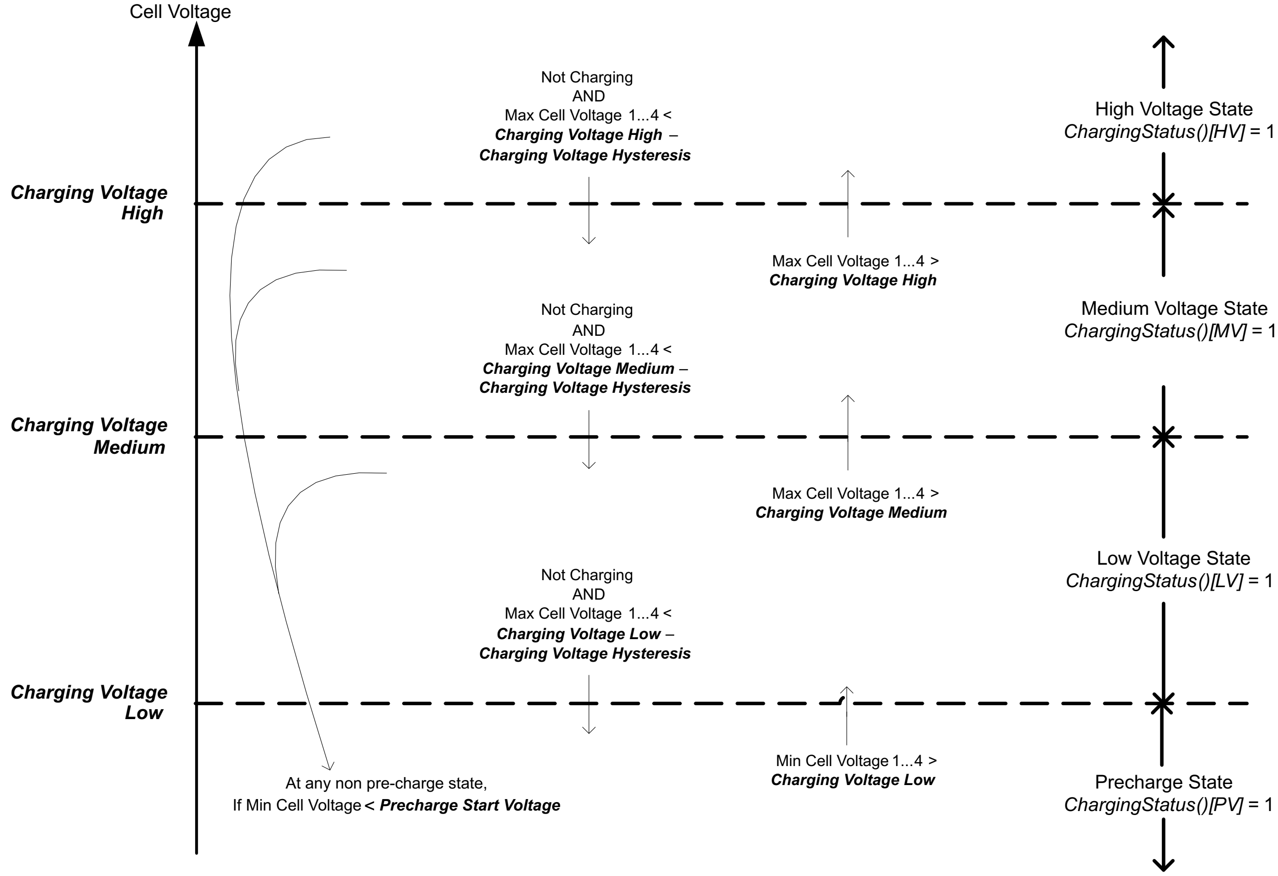
CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Temperature Ranges	T1 Temp	I1	–128	127	0	°C
Advanced Charge Algorithm	Temperature Ranges	T2 Temp	I1	–128	127	12	°C
Advanced Charge Algorithm	Temperature Ranges	T5 Temp	I1	–128	127	20	°C
Advanced Charge Algorithm	Temperature Ranges	T6 Temp	I1	–128	127	25	°C
Advanced Charge Algorithm	Temperature Ranges	T3 Temp	I1	–128	127	30	°C
Advanced Charge Algorithm	Temperature Ranges	T4 Temp	I1	–128	127	55	°C
Advanced Charge Algorithm	Temperature Ranges	Hysteresis Temp	I1	–128	127	1	°C

4.4 Voltage Range

The measured cell voltage is segmented into several voltage ranges. The charging algorithm adjusts *ChargingCurrent()* according to the temperature range and voltage range. The voltage ranges set in data flash need to adhere to the following format:

Charging Voltage Low ≤ Charging Voltage Med ≤ Charging Voltage High ≤ [Standard or Recommended] Temp Charging:Voltage

Depending on the specific charging profile, the ***Low Temp Charging:Voltage*** and ***High Temp Charging:Voltage*** settings do not necessarily have the highest setting values.



4.5 Charging Voltage

The *ChargingVoltage()* changes depending on the detected temperature per the charge algorithm.

NOTE: Table priority is top to bottom.

TEMP RANGE	CONDITION	ACTION
Any	*OperationStatus()[XCHG]* = 1	*ChargingVoltage()* = 0
UT or OT	—	*ChargingVoltage()* = 0
LT	—	*ChargingVoltage()* = ***Low Temp Charging:Voltage*** × (***DA Configuration[CC1:CC0]*** + 1)
STL or STH	—	*ChargingVoltage()* = ***Standard Temp Charging:Voltage*** × (***DA Configuration[CC1:CC0]*** + 1)
RT	—	*ChargingVoltage()* = ***Rec Temp Charging:Voltage*** × (***DA Configuration[CC1:CC0]*** + 1)
HT	—	*ChargingVoltage()* = ***High Temp Charging:Voltage*** × (***DA Configuration[CC1:CC0]*** + 1)

4.5.1 Charging Voltage Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Voltage Range	Precharge Start Voltage	I2	0	32767	2500	mV
Advanced Charge Algorithm	Voltage Range	Charging Voltage Low	I2	0	32767	2900	mV
Advanced Charge Algorithm	Voltage Range	Charging Voltage Med	I2	0	32767	3600	mV
Advanced Charge Algorithm	Voltage Range	Charging Voltage High	I2	0	32767	4000	mV
Advanced Charge Algorithm	Voltage Range	Charging Voltage Hysteresis	U1	0	255	0	mV

4.6 Charging Current

The *ChargingCurrent()* value changes depending on the detected temperature and voltage per the charging algorithm.

The ***Charging Configuration[CRATE]*** flag provides an option to adjust the *ChargingCurrent()* based on *FullChargeCapacity()/DesignCapacity()*.

For example, with ***[CRATE]*** = 1, if *FullChargeCapacity()* / *DesignCapacity()* = 90% and ***Rec Temp Charging: Current Med*** is active per the charging algorithm, the *ChargeCurrent()* = ***Rec Temp Charging: Current Med*** × 90%.

NOTE: Table priority is top to bottom.

TEMP RANGE	VOLTAGE RANGE	CONDITION	ACTION
Any	Any	*OperationStatus()[XCHG]* = 1	*ChargingCurrent()* = 0
Under Temp or Over Temp	Any	—	*ChargingCurrent()* = 0
Any	Precharge	—	*ChargingCurrent()* = ***Pre-Charging:Current***
Any	Low, Medium, or High	*ChargingStatus()[MCHG]* = 1	*ChargingCurrent()* = ***Maintenance Charging:Current***
Low Temp	Low	—	*ChargingCurrent()* = ***Low Temp Charging:Current Low***
	Medium	—	*ChargingCurrent()* = ***Low Temp Charging:Current Med***
	High	—	*ChargingCurrent()* = ***Low Temp Charging:Current High***
Standard Temp Low or Standard Temp High	Low	—	*ChargingCurrent()* = ***Standard Temp Charging:Current Low***
	Medium	—	*ChargingCurrent()* = ***Standard Temp Charging:Current Med***
	Hgh	—	*ChargingCurrent()* = ***Standard Temp Charging:Current High***
Recommended Temp	Low	—	*ChargingCurrent()* = ***Rec Temp Charging:Current Low***
	Medium	—	*ChargingCurrent()* = ***Rec Temp Charging:Current Med***
	High	—	*ChargingCurrent()* = ***Rec Temp Charging:Current High***

TEMP RANGE	VOLTAGE RANGE	CONDITION	ACTION
High Temp	Low	—	*ChargingCurrent()* = ***High Temp Charging:Current Low***
	Medium	—	*ChargingCurrent()* = ***High Temp Charging:Current Med***
	High	—	*ChargingCurrent()* = ***High Temp Charging:Current High***

4.6.1 Charging Current Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Low Temp Charging	Voltage	I2	0	32767	4000	mV
Advanced Charge Algorithm	Low Temp Charging	Current Low	I2	0	32767	132	mA
Advanced Charge Algorithm	Low Temp Charging	Current Med	I2	0	32767	352	mA
Advanced Charge Algorithm	Low Temp Charging	Current High	I2	0	32767	264	mA

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Standard Temp Charging	Voltage	I2	0	32767	4200	mV
Advanced Charge Algorithm	Standard Temp Charging	Current Low	I2	0	32767	1980	mA
Advanced Charge Algorithm	Standard Temp Charging	Current Med	I2	0	32767	2000	mA
Advanced Charge Algorithm	Standard Temp Charging	Current High	I2	0	32767	2000	mA

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Rec Temp Charging	Voltage	I2	0	32767	4100	mV
Advanced Charge Algorithm	Rec Temp Charging	Current Low	I2	0	32767	2000	mA
Advanced Charge Algorithm	Rec Temp Charging	Current Med	I2	0	32767	2000	mA
Advanced Charge Algorithm	Rec Temp Charging	Current High	I2	0	32767	2000	mA

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	High Temp Charging	Voltage	I2	0	32767	4000	mV
Advanced Charge Algorithm	High Temp Charging	Current Low	I2	0	32767	1012	mA
Advanced Charge Algorithm	High Temp Charging	Current Med	I2	0	32767	1980	mA
Advanced Charge Algorithm	High Temp Charging	Current High	I2	0	32767	1496	mA

4.7 Valid Charge Termination

The charge termination condition must be met to enable valid charge termination. The device has the following actions at charge termination, based on the flags settings:

- If ***FET Option[CHGFET] = 1***, CHG FET turns off.
- If ***SBS Gauging Configuration[CSYNC]*** = 1, *RemainingCapacity()* = *FullChargeCapacity()*.

- If ***SBS Gauging Configuration[RSOCL]*** = 1, *RelativeStateOfCharge()* and *RemainingCapacity()* are held at 99% until charge termination occurs. Only on entering charge termination is 100% displayed.
- If ***SBS Gauging Configuration[RSOCL]*** = 0, *RelativeStateOfCharge()* and *RemainingCapacity()* are not held at 99% until charge termination occurs. Fractions of % greater than 99% are rounded up to display 100%.

STATUS	CONDITION	ACTION
Charging	*GaugingStatus()[DSG]* = 0	Charge Algorithm active
Valid Charge Termination	All of the following conditions must occur for two consecutive 40-s periods: Charging (that is, *BatteryStatus[DSG]* = 0) AND *AverageCurrent()* < ***Charge Term Taper Current*** AND Max cell voltage1..4 + ***Charge Term Voltage*** ≥ *ChargingVoltage()* / number of cells in series AND The accumulated change in capacity > 0.25 mAh.	*ChargingStatus()[VCT]* = 1 *ChargingStatus()[MCHG]* = 1 *ChargingVoltage()* = Charging Algorithm *ChargingCurrent()* = Charging Algorithm *BatteryStatus()[FC]* = 1 and *GaugingStatus()[FC]* = 1 if ***SOCFlagConfig A[FCSETVCT]*** = 1 *BatteryStatus()[TCA]* = 1 and *GaugingStatus()[TCA]* = 1 if ***SOCFlagConfig B[TCASETVCT]*** = 1

4.7.1 Charge Termination Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Termination Config	Charge Term Taper Current	I2	0	32767	250	mA
Advanced Charge Algorithm	Termination Config	Charge Term Voltage	I2	0	32767	75	mV

4.8 Charge and Discharge Termination

4.8.1 Termination Flags

The *[TC]* and *[FC]* bits in *GaugingStatus()* can be set at charge termination as well as based on RSOC or cell voltages. If multiple set and clear conditions are selected, then the corresponding flag will be set whenever a valid set or clear condition is met. If both set and clear conditions are true at the same time, the flag will clear. The same functionality is applied to the *[TD]* and *[FD]* bits in *GaugingStatus()*.

NOTE: *GaugingStatus()[TC][TD][FC][FD]*are the status flags based on the gauging conditions only. These flags are set and cleared based on ***SOC Flag Config A*** and ***SOC Flag Config B***.

The *BatteryStatus()[TAC][FC][TDA][FD]* flags will be set and cleared according to the *BatteryStatus()[TC][FC][TD][FD]* flags as well as the safety and permanent failure protections status. For more information, see Section 4.8.2.

The *[FC]* flag is identical between gauging status and battery status, but not *[TD]*. The table below summarizes the various options to set and clear the *[TC]* and *[FC]* flags in *GaugingStatus()*.

FLAG	SET CRITERIA	SET CONDITION	ENABLE
[TC]	cell voltage	Max cell voltage1..4 ≥ ***TC: Set Voltage Threshold***	***SOC Flag Config A[TCSetV]*** = 1
	RSOC	*RelativeStateOfCharge()* > = ***T C: Set % RSOC Threshold***	***SOC Flag Config A[TCSetRSOC]*** = 1
	Valid Charge Termination (enable by default)	When *ChargingStatus[VCT]* = 1	***SOC Flag Config A[TCSetVCT]*** = 1

FLAG	SET CRITERIA	SET CONDITION	ENABLE
[FC]	cell voltage	Max cell voltage1..4 ≥ ***FC: Set Voltage Threshold***	***SOC Flag Config B[FCSetV]*** = 1
	RSOC	*RelativeStateOfCharge()* > = ***FC: Set % RSOC Threshold***	***SOC Flag Config B[FCSetRSOC]*** = 1
	Valid Charge Termination (enable by default)	When *ChargingStatus[VCT]* = 1	***SOC Flag Config A[FCSetVCT]*** = 1

FLAG	CLEAR CRITERIA	CLEAR CONDITION	ENABLE
[TC]	cell voltage	Max cell voltage1..4 ≤ ***TC: Clear Voltage Threshold***	***SOC Flag Config A[TCClearV]*** = 1
	RSOC (enable by default)	*RelativeStateOfCharge()* ≤ ***TC: Clear % RSOC Threshold***	***SOC Flag Config A[TCClearRSOC]*** = 1
[FC]	cell voltage	Max cell voltage1..4 ≤ ***FC: Clear Voltage Threshold***	***SOC Flag Config B[FCClearV]*** = 1
	RSOC (enable by default)	*RelativeStateOfCharge()* ≤ ***FC: Clear % RSOC Threshold***	***SOC Flag Config B[FCClearRSOC]*** = 1

*[TD]*and *[FD]* both have extra conditions. If gauging status *[FD]* is set then battery status is always set, but clearing depends also on some safety conditions (CUV/SUV).

The table below summarizes the various options to set and clear the *[TD]*, and *[FD]* flags in *GaugingStatus()*.

FLAG	SET CRITERIA	SET CONDITION	ENABLE
[TD]	cell voltage	Min cell voltage1..4 ≤ ***TD: Set Voltage Threshold***	***SOC Flag Config A[TDSetV]*** = 1
	RSOC (enable by default)	*RelativeStateOfCharge()* < = ***TD: Set % RSOC Threshold***	***SOC Flag Config A[TDSetRSOC]*** = 1
[FD]	cell voltage	Min cell voltage1..4 ≤ ***FD: Set Voltage Threshold***	***SOC Flag Config B[FDSetV]*** = 1
	RSOC (enable by default)	*RelativeStateOfCharge()* < = ***FD: Set % RSOC Threshold***	***SOC Flag Config B[FDSetRSOC]*** = 1

FLAG	CLEAR CRITERIA	CLEAR CONDITION	ENABLE
[TD]	cell voltage	Min cell voltage1..4 ≥ ***TD: Clear Voltage Threshold***	***SOC Flag Config A[TDClearV]*** = 1
	RSOC (enable by default)	*RelativeStateOfCharge()* ≥ ***TD: Clear % RSOC Threshold***	***SOC Flag Config A[TDClearRSOC]*** = 1
[FD]	cell voltage	Min cell voltage1..4 ≥ ***FD: Clear Voltage Threshold***	***SOC Flag Config B[FDClearV]*** = 1
	RSOC (enable by default)	*RelativeStateOfCharge()* ≥ ***FD: Clear % RSOC Threshold***	***SOC Flag Config B[FDClearRSOC]*** = 1

4.8.2 Termination Alarms

When the protections and permanent fails are triggered, the *BatteryStatus()[TCA][TDA][FD][OCA][OTA][FC]* will be set according to the type of safety protections. Here is a summary of the set conditions of the various alarms flags.

[TCA] = 1 if

- *SafetyAlert()[OCC1]*, *[OCC2]*, *[COV]*, *[OTC]*, *[OTF]*, *[OC]*, *[CHGC]*, *[CHGV]*, or *[PCHGC]* = 1, OR
- *PFAlert()[SOV] or [SOCC]* = 1, OR
- *Any PFStatus()* = 1, OR

- *OperationStatus()[PRES]* = 0, OR
- *GaugingStatus()[TC]* = 1 AND in CHARGE mode

[FC] = 1 if

- GaugingStatus()[FC] = 1

[OCA] = 1 if

- *SafetyStatus()[OC]* = 1 AND in CHARGE mode

[TDA] = 1 if

- *SafetyAlert()[OCD1]*, *[OCD2]*, *[CUV]*, *[CUVC]*, *[OTD]*, or *[OTF]* = 1, OR
- *PFAlert()[SUV]*or *[SOCD]* = 1, OR
- Any *PFStatus()* = 1, OR
- *OperationStatus()[PRES]* = 0
- *GaugingStatus()[TD]* = 1 AND in DISCHARGE mode

[FD] = 1 if

- *SafetyStatus()[CUV]* = 1, OR
- *PFStatus()[SUV]* = 1, OR
- *GaugingStatus()[FD]*

[OTA] = 1 if

- *SafetyStatus()[OTC]*, *[OTD]*, or *[OTF]* = 1, OR
- *PFStatus()[SOT]*or *[SOTF]* = 1

4.8.3 Charge and Discharge Termination Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	TC	Set Voltage Threshold	I2	0	5000	4200	mV
Gas Gauging	TC	Clear Voltage Threshold	I2	0	5000	4100	mV
Gas Gauging	TC	Set % RSOC Threshold	U1	0%	100%	100%	
Gas Gauging	TC	Clear % RSOC Threshold	U1	0%	100%	95%	

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	FC	Set Voltage Threshold	I2	0	5000	4200	mV
Gas Gauging	FC	Clear Voltage Threshold	I2	0	5000	4100	mV
Gas Gauging	FC	Set % RSOC Threshold	U1	0%	100%	100%	
Gas Gauging	FC	Clear % RSOC Threshold	U1	0%	100%	95%	

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	TD	Set Voltage Threshold	I2	0	5000	3200	mV
Gas Gauging	TD	Clear Voltage Threshold	I2	0	5000	3300	mV
Gas Gauging	TD	Set % RSOC Threshold	U1	0%	100%	6%	
Gas Gauging	TD	Clear % RSOC Threshold	U1	0%	100%	8%	

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	FD	Set Voltage Threshold	I2	0	5000	3000	mV
Gas Gauging	FD	Clear Voltage Threshold	I2	0	5000	3100	mV
Gas Gauging	FD	Set % RSOC Threshold	U1	0%	100%	0%	
Gas Gauging	FD	Clear % RSOC Threshold	U1	0%	100%	5%	

4.9 Precharge

The gauge enters PRECHARGE mode if,

1. Min cell voltage1..4 < ***Precharge Start Voltage***, OR
2. Max cell voltage1..4 < ***Charging Voltage Low – Charging Voltage Hysteresis*** and not in CHARGE mode

An external precharge FET or CHG FET can be used in PRECHARGE mode. Setting the ***Precharge Start Voltage and Charging Voltage Low*** = 0 mV disables the precharge function.

The device also supports 0-V charging using either an external precharge FET or CHG FET. If ***[PCHG_COMM]*** = 1, the gauge enables the hardware 0-V charging circuit automatically when the battery stack voltage is below the minimum operation voltage of the device (see the *bq40z60 Programmable Battery Pack Manager* data sheet [SLUSAW3] for bq40z60 electrical specifications).

4.9.1 Pre-Charge Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Pre-Charging	Current	I2	0	32767	250	mA

4.10 Maintenance Charge

Maintenance charge can be configured to provide charge current after charge termination is reached.

If the Overcharge Protection is enabled, ***Enabled Protections C[OC]*** = 1, extra margin may be needed for ***OC:Threshold*** to prevent triggering the OC protection by the maintenance charging.

4.10.1 Maintenance Charge Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Maintenance Charging	Current	I2	0	32767	44	mA

4.11 Charge Control SMBus Broadcasts

If the ***[HPE]*** bit is enabled, MASTER mode broadcasts to the host address are PEC enabled. If the ***[CPE]*** bit is enabled, MASTER mode broadcasts to the smart-charger address are PEC enabled. The ***[BCAST]*** bit enables all broadcasts to a host or a smart charger. When the ***[BCAST]*** bit is enabled, the following broadcasts are sent:

- *ChargingVoltage()*and *ChargingCurrent()* broadcasts are sent to the smart-charger device address (0x12) every 10 to 60 s.
- If any of the *[OCA]*, *[TCA]*, *[OTA]*, *[TDA]*, *[RCA]*, *[RTA]* flags are set, the *AlarmWarning()* broadcast is sent to the host device address (0x14) every 10 seconds. Broadcasts stop when all flags above have been cleared.
- If any of the *[OCA]*, *[TCA]*, *[OTA]*, *[TDA]* flags are set, the *AlarmWarning* () broadcast is sent to a smart-charger device address every 10 seconds. Broadcasts stop when all flags above have been cleared.

4.12 Charge Disable and Discharge Disable

The device can disable charging if certain safety conditions are detected, setting the *OperationStatus()[XCHG]* = 0.

STATUS	CONDITION	ACTION
Normal	*ALL PFStatus()* = 0 AND *SafetyStatus()[COV]* = 0 AND *SafetyStatus()[OCC1][OCC2]* = 0,0 AND *SafetyStatus()[ASCC]* = 0 AND *SafetyStatus()[ASCCL]* = 0 AND *SafetyStatus()[CTO]* = 0 AND *SafetyStatus()[PTO]* = 0 AND *OperationStatus()[PRES]* = 1 AND *GaugingStatus()[TCA]* = 0 if ***Charging Configuration[CHGFET]*** = 1	*ChargingVoltage()* = Charging Algorithm *ChargingCurrent()* = Charging Algorithm *OperationStatus()[XCHG]* = 0
Trip	*ManufacturingStatus()[FET_EN]* = 0 OR *ANY PFStatus()[]* = 1 OR *SafetyStatus()[COV]* = 1 OR *SafetyStatus()[OCC1]* = 1 OR *SafetyStatus()[OCC2]* = 1 OR *SafetyStatus()[ASCC]* = 1 OR *SafetyStatus()[ASCCL]* = 1 OR *SafetyStatus()[CTO]* = 1 OR *SafetyStatus()[PTO]* = 1 OR *SafetyStatus()[HWDF]* = 1 OR *SafetyStatus()[OC]* = 1 OR *SafetyStatus()[CHGC]* = 1 OR *SafetyStatus()[CHGV]* = 1 OR *SafetyStatus()[PCHGC]* = 1 OR *SafetyStatus()[UTC]* = 1 OR *SafetyStatus()[OTC]* = 1 if ***[OTFET]*** = 1 OR *ChargingStatus()[IN]* = 1 if ***[CHGIN]*** = 1 OR *ChargingStatus()[SU]* = 1 OR *OperationStatus()[SLEEP]* = 1 if ***[NR]*** = 1 OR *OperationStatus()[EMSHUT]* = 1 OR *OperationStatus()[PRES]* = 0 OR *GaugingStatus()[TCA]* = 1 if ***Charging Configuration[CHGFET]*** = 1	*ChargingVoltage()* = 0 *ChargingCurrent()* = 0 *OperationStatus()[XCHG]* = 1

Similarly, the device can disable discharge if certain safety conditions of any if the following conditions is detected, setting the *OperationStatus()[XDSG]* = 1.

- *ManufacturingStatus()[FET_EN]* = 0, OR
- Any *PFStatus()* set, OR
- *SafetyStatus()[OCD1]*or *[OCD2]* or *[CUV]* or *[CUVC]* or *[AOLD]* or *[AOLDL]* or *[ASCD]* or *[ASCDL]* or *[UTD]* = 1, OR

- *SafetyStatus()[OTD]* or *[OTF]* = 1 if ***[OTFET]*** = 1, OR
- *OperationStatus()[PRES]* = 0, OR
- *OperationStatus()[EMSHUT]* = 1,OR
- *OperationStatus()[SDM]* = 1 AND delay time > ***FET Off Time***, OR
- *OperationStatus()[SDV]* = 1 AND low voltage time ≥ ***Shutdown Time***

4.13 Charge Inhibit

The device can inhibit the start of charging at high and low temperatures to prevent damage of the cells. This feature prevents the start of charging when the temperature is at the inhibit range; therefore, if the device is already in the charging state when the temperature reaches the inhibit range, a FET action will not take place even if ***FET Options[CHGIN]*** = 1.

STATUS	CONDITION	ACTION
Normal	*ChargingStatus()[LT]* = 1 OR *ChargingStatus()[STL]* = 1 OR *ChargingStatus()[RT]* = 1 OR *ChargingStatus()[STH]* = 1	*ChargingStatus()[IN]* = 0 *ChargingVoltage()* = charging algorithm *ChargingCurrent()* = charging algorithm
Trip	Not charging AND (*ChargingStatus()[HT]* = 1 OR *ChargingStatus()[OT]* = 1 OR *ChargingStatus()[UT]* = 1	*ChargingStatus()[IN]* = 1 *ChargingStatus()[SU]* = 0 *ChargingVoltage()* = 0 *ChargingCurrent()* = 0 *OperationStatus()[XCHG]* = 1 if ***FET Options[CHGIN]*** = 1.

4.14 Charge Suspend

The device can stop charging at high and low temperatures to prevent damage of the cells.

The *ChargingStatus()[SU]* condition is only active in the CHARGING mode. Once charge suspend is triggered, the gauge will exit CHARGING mode after ***Chg Relax Time*** and the charge suspend will change to charge inhibit.

STATUS	CONDITION	ACTION
Normal	*ChargingStatus()[LT]* = 1 OR *ChargingStatus()[STL]* = 1 OR *ChargingStatus()[RT]* = 1 OR *ChargingStatus[STH]* = 1 OR *ChargingStatus()[HT]* = 1	*ChargingStatus()[SU]* = 0 *ChargingVoltage()* = charging algorithm *ChargingCurrent()* = charging algorithm
Trip	*ChargingStatus()[UT]* = 1 OR *ChargingStatus()[OT]* = 1	*ChargingStatus()[SU]* = 1 *ChargingVoltage()* = 0 *ChargingCurrent()* = 0 *OperationStatus()[XCHG]* = 1

4.15 Voltage/Current Rate of Change

The rate of change of both charging voltage and charging current can be controlled by setting the appropriate Rate of Change data flash parameter. By setting these parameters to a value higher than 1, the firmware will control the slope of change, avoiding any undesired large change in the value when moving from one voltage or temperature setting as shown in Figure 4-4. The feature can be disabled for voltage and current separately by setting the parameter to 1, meaning that the disabled parameter will move in a single step from the old value to its new value.

4.15.1 ChargingVoltage() Rate of Change

Setting the ***Voltage Rate*** to 1 disables this feature and the *ChargingVoltage()* changes in one step.

STATUS	CONDITION	ACTION
Trip	*ChargingVoltage()*Change	*ChargingStatus()[CVR]* = 1 *ChargingVoltage()* = Old + n × (New – Old) / ***Voltage Rate*** , where Old = present *ChargingVoltage()* New = the target *ChargingVoltage()* that the device is going to change to n = 1.. ***Voltage Rate***, increment in steps of one per second.

4.15.2 ChargingCurrent() Rate of Change

Setting the ***Current Rate*** to 1 disables this feature and the *ChargingCurrent()* changes in one step.

STATUS	CONDITION	ACTION
Trip	*ChargingCurrent()*Change	*ChargingStatus()[CCR]* = 1 *ChargingCurrent()* = Old + n × (New – Old) / ***Current Rate***, where Old = present *ChargingCurrent()* New = the target *ChargingCurrent()* that the device is going to change to n = 1.. ***Current Rate***, increment in steps of 1 per second.

4.15.3 Charging Rate of Change Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Charging Rate of Change	Current Rate	U1	1	255	1	steps
Advanced Charge Algorithm	Charging Rate of Change	Voltage Rate	U1	1	255	1	steps

4.16 Charging Voltage and Current Override

The bq40z60 provides a mechanism where an external host micro-controller can be used to set the charger voltage and current. This would allow a specialized charging algorithm to be used beyond the flexibility provided by the bq40z60. *ChargingStatus()[CVRD]* can be set by sending the CVRD_ARM MAC 0x00C1; once [CVRD] is set, the charging voltage can be set by issuing command 0x15 and the charging current can be set by issuing command 0x14.

STATUS	CONDITION	ACTION
Normal	*ChargingStatus()[CVRD]* = 0	*ChargingVoltage()* = charging algorithm *ChargingCurrent()* = charging algorithm
Trip	*ChargingStatus()[CVRD]* = 1	*ChargingVoltage()* = must be written by external host *ChargingCurrent()* = must be written by external host

Power Modes

5.1 Introduction

To enhance battery life, the bq40z60 supports several power modes to minimize power consumption during operation.

5.2 NORMAL Mode

In NORMAL mode, the device takes voltage, current, and temperature readings every 250 ms, performs protection and gauging calculations, updates SBS data, and makes status decisions at 1-s intervals. Between these periods of activity, the device is in a reduced power state.

If the [NR] bit is set, the SYSPRES input can be left floating, as it is not monitored.

5.2.1 BATTERY ACP REMOVED Mode/System Present Detection

5.2.1.1 System Present

SYSPRES is sampled four times per second and if SYSPRES is high for four samples (one second), the *OperationStatus[PRES]* flag is cleared. If SYSPRES is low for four samples (one second), the *OperationStatus [PRES]* flag is set, indicating the system is present (the battery is inserted). If the ***[NR]*** bit is set, the SYSPRES input is ignored and can be left floating.

5.2.1.2 Battery Pack Removed

The bq40z60 detects the BATTERY ACP REMOVED mode if the ***[NR]*** bit is set to 0 AND the SYSPRES input is high (*[PRES]* = 0).

On entry to the BATTERY ACP REMOVED mode, the *[TCA]* and *[TDA]* flags are set, *ChargingCurrent()* and *ChargingVoltage()* are set to 0, the CHG and DSG FETs are turned off, and the Precharge FET is turned off (if used).

Polling of the SYSPRES pin continues at a rate of once every 1 s.

The bq40z60 exits the BATTERY ACP REMOVED state if the ***[NR]*** flag is set to 0 AND the SYSPRES input is low (*[PRES]* = 1). When this occurs, the *[TCA]* and *[TDA]* flags are reset.

5.3 SLEEP Mode

5.3.1 Device Sleep

When the sleep conditions are met, the device goes into SLEEP mode with periodic wake-ups for voltage, temperature, and current measurements to reduce power consumption.

OperationStatus()[SLPAD] is set when the gauge wakes to measure voltage and temperature. Similarly, the *[SLPCC]* is set when the gauge wakes for current measurement. In general, it is not possible to read these flags because an SMBus communication will wake up the gauge.

The device returns to NORMAL mode if any exit sleep condition is met.

STATUS	CONDITION	ACTION
Activate	SMBus low for ***Bus Timeout*** [(1)] if ***[IN_SYSTEM_SLEEP]*** = 0, or no communication for ***Bus Timeout*** if ***[IN_SYSTEM_SLEEP]*** = 1 AND ***DA Config[SLEEP]*** = 1 [(1)] AND | *Current()* | ≤ ***Sleep Current*** AND ***Voltage Time*** > 0 AND (*OperationStatus()[PRES]* = 0 OR ***DA Config[NR]*** = 1) AND *OperationStatus()[SDM]* = 0 AND No *PFAlert()* bits set AND [(2)] No *PFStatus()* bits set AND No *SafetyAlert()* bits set AND [(2)] No [AOLD], [AOLDL], [ASCC], [ASCCL], [ASCD], [ASCDL] set in *SafetyStatus()*	Turn off CHG FET and PCHG FET Device goes to sleep. Device wakes up every ***Sleep:Voltage Time*** period to measure voltage and temperature. Device wakes up every ***Sleep:Current Time*** period to measure current.
Exit	SMBus connected [(1)] OR SMBus command received [(3)] OR ***DA Config[SLEEP]*** = 1 [(1)] OR | *Current()* | > ***Sleep Current*** OR Wake comparator activates [(4)] OR ***Voltage Time*** = 0 OR (*OperationStatus()[PRES]* = 1 AND ***DA Config[NR]*** = 0) OR *OperationStatus()[SDM]* = 1 OR *PFAlert()* bits set OR *PFStatus()* bits set OR *SafetyAlert()* bits set OR *[AOLD], [AOLDL], [ASCC], [ASCCL], [ASCD], [ASCDL]* set in *SafetyStatus()*	Return to NORMAL mode

(1) ***DA Config[SLEEP]*** and SMBus low are not checked if the *ManufacturerAccess()* SLEEP mode command is used to enter SLEEP mode.

(2) *SafetyAlert()[PTO]*, *[PTOS]*, *[CTO]*, *[CTOS]* or *PFAlert()[QIM]*, *[OC]*, *[IMP]*, *[CB]* will not prevent the gauge to enter SLEEP mode.

(3) Wake on SMBus command is only possible when the gas gauge is put to sleep using the *ManufacturerAccess*() SLEEP mode command or ***[IN_SYSTEM_SLEEP]*** is enabled with ***Bus Timeout*** = 0. Otherwise, the gas gauge wakes on an SMBus connection (clock or data high).

(4) The wake comparator threshold is set through ***Power.WakeComparator[WK1,WK0]*** (see Section 5.3.4).

5.3.2 In System Sleep

The device provides an option for removable packs (that is, ***DA Config[NR]*** = 0) to enter SLEEP mode in-system. When the ***DA Config[IN_SYSTEM_SLEEP]*** = 1, the device will enter SLEEP mode even if the *OperationStatus()[PRES] = 1*. This option ignores the SYSPRES pin status only. All the other sleep conditions must be met for the device to enter SLEEP mode.

In the IN SYSTEM SLEEP mode, it is possible to read the *[SLPAC]* and *[SLPCC]* flags if ***[IN_SYSTEM_SLEEP]*** = 1 and ***Bus Timeout*** = 0. This setting allows the gauge to enter SLEEP mode with active communication in progress.

NOTE: Setting the ***Bus Timeout*** = 0 with ***[IN_SYTEM_SLEEP]*** can be used for testing purposes, but it is not recommended to set the ***Bus Timeout*** = 0 in the field. If ***Bus Timeout*** = 0, the device's sleep and wake condition is strictly controlled by current detection. If the host system performs a low load operation periodically (for example, wireless detection in a tablet application), this small load current may be missed, introducing an error into remaining capacity tracking. Having a non-zero ***Bus Timeout*** setting enables the gauge to wake up by a communication and capture the current measurement.

5.3.3 ManufacturerAccess() MAC Sleep

The SLEEP MAC command can override the requirement for bus low to enter sleep. In this case, the bq40z60 clock and data high condition is ignored for sleep to exit, though sleep will also exit if there is any further SMBus communication. The device can be sent to sleep with *ManufacturerAccess()* if specific sleep entry conditions are met.

5.3.4 Wake Function

The device can exit SLEEP mode if enabled by the presence of a voltage across SRP and SRN. The voltage threshold needed for the device to wake from SLEEP mode is programmed in ***Power:Wake Comparator***. This allows the gauge to wake up quickly in response to a higher current detection. Otherwise, the gauge only wakes up every ***Sleep Current Time*** to detect if **|** *Current()* **|** is > Sleep Current.

Reserved (Bits 7–4, 1–0): Reserved. Do not use.

WK1,0 (Bits 3–2): Wake Comparator Threshold

WK1	WK0	VOLTAGE
0	0	±0.625 mV
0	1	±1.25 mV
1	0	±2.5 mV
1	1	±5 mV

5.3.5 Sleep Mode Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Sleep	Sleep Current	I2	0	32767	10	mA
Power	Sleep	Bus Timeout	U1	0	255	5	s
Power	Sleep	Voltage Time	U1	0	255	5	s
Power	Sleep	Current Time	U1	0	255	20	s
Power	Sleep	Wake Comparator	U1	0	0xff	0	hex

5.3.5.1 Wake Comparator

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	WK[1]	WK[0]	RSVD	RSVD

RSVD	[7:4]	Reserved - Do not use
WK[1:0]	[3:2]	Wake Comparator Threshold 2'b11 = 5 mV 2'b10 = 2.5 mV 2'b01 = 1.25 mV 2'b00 = 0.625 mV
RSVD	[1:0]	Reserved - Do not use

5.4 SHUTDOWN Mode

5.4.1 Voltage Based Shutdown

To minimize power consumption and to avoid draining the battery, the device can be configured to shut down at a programmable stack voltage threshold.

STATUS	CONDITION	ACTION
Enable	Min cell voltage < ***Shutdown Voltage***	*OperationStatus()[SDV]* = 1
Trip	Min cell voltage continuous < ***Shutdown Voltage*** for ***Shutdown Time***	Turn DSG FET off
Shutdown	Voltage at ACP pin < ***Charger Present Threshold***	Send device into SHUTDOWN mode
Exit	Voltage at ACP pin > $V_{STARTUP}$	*OperationStatus()[SDV]* = 0 Return to NORMAL mode

NOTE: The device goes through a full reset when exiting from SHUTDOWN mode, which means the device will re-initialize. On power up, the gauge will check some special memory locations. If the memory checksum is incorrect, or if the gauge or the AFE watchdog has been triggered, the gauge will do a full reset.

The memory checksum is good; for example, in a case of a short power glitch, the gauge will do a partial reset. The initialization is faster in a partial reset, and certain memory data will not be re-initialized (for example, all SBS registers, last known FET state, last ADC and CC readings, and so on) and so a partial reset is usually transparent to the host.

5.4.2 ManufacturerAccess() MAC Shutdown

In SHUTDOWN mode, the device turns off the FETs after ***FET Off Time***, and then shuts down to minimize power consumption after ***Delay*** time. Both ***FET Off Time*** and ***Delay*** time are referenced to the time the gauge receives the command. Thus, the ***Delay*** time must be set longer than the ***FET Off Time***. The device returns to NORMAL mode when voltage at ACP pin > $V_{STARTUP}$. The device can be sent to this mode with the *ManufacturerAccess() Shutdown* command. Charger voltage must not be present for the device to enter SHIP SHUTDOWN mode.

NOTE: If the gauge is unsealed and the MAC *Shutdown()* command is sent twice in a row, the gauge will execute the shutdown sequence immediately and skip the normal delay sequence.

5.4.3 Time-based Shutdown

The device can be configured to shut down after staying in SLEEP mode without communication for a preset time interval specified in the ***Auto Ship Time***. Setting the ***PowerConfig[AUTO_SHIP_EN]*** = 1 enables this feature. Any communication to the device will restart the timer. When the timer reaches the Auto Ship Time, the time-based shutdown effectively triggers the MAC shutdown command to start the shutdown sequence. The device returns to NORMAL mode when voltage at ACP pin > $V_{STARTUP}$.

5.4.4 Emergency Shutdown (EMSHUT)

The Emergency Shutdown function provides an option to disable the battery power to the system by opening up both CHG and DSG FETs before removing an embedded battery pack. There are two ways to enter the EMERGENCY SHUTDOWN state:

(a) Use an external signal (for example, a push-button switch) to detect a low-level threshold signal on the SHUTDN pin.

(b) Send a Manual FET Control (MFC) sequence to *ManufacturerAccess()*.

When the gauge is in the EMERGENCY SHUTDOWN state, the *OperationStatus()[EMSHUT]* = 1.

5.4.4.1 Enter Emergency Shutdown through SHUTDN

When a high-to-low transition on the SHUTDN pin is detected with a debounce delay of about 1 s for the low-level threshold, the gauge will turn off both CHG and DSG FETs immediately. This entry method only applies if ***[NR]*** = 1 and ***DA Configuration[EMSHUT]*** = 1. If ***[NR]*** = 0, the SHUTDN pin will restore to the regular system present detection.

5.4.4.2 Enter Emergency Shutdown through MFC

Alternately, sending a Manual FET Control (MFC) sequence using the steps below also puts the gauge to the EMERGENCY SHUTDOWN state. This entry method applies to ***NR]*** = 0 and ***[NR]*** = 1.

(a) Send word 0x2706 to *ManufacturerAccess()* (0x00) to enable the MFC.

(b) Within 4 s, send word 0x043D to *ManufacturerAccess()* (0x00) to turn off CHG and DSG FETs.

(c) The CHG and DSG FETs will be off after ***Manual FET Control Delay***.

5.4.4.3 Exit Emergency Shutdown

Regardless of which EMSHUT entry method is used, the gauge can exit the EMSHUT mode by turning on the CHG and DSG FETs with the following conditions:

- A high-to-low transition on the SHUTDN pin is detected with a debounce delay of 1 s for the low-level threshold. For example, a push button is pressed again.
- Send word 0x23A7 to *ManufacturerAccess()* (0x00).

In addition to these exit conditions, if the gauge enters EMSHUT (via a push-button, for example), it can exit the EMSHUT mode after a shutdown restore timeout defined by the ***Timeout*** parameter.

For the case of ***[NR]*** = 0, a battery insertion will also exit the EMERGENCY SHUTDOWN mode.

5.4.5 Shutdown Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Shutdown	Shutdown Voltage	I2	0	32767	1750	mV
Power	Shutdown	Shutdown Time	U1	0	255	10	s
Power	Shutdown	PF Shutdown Voltage	I2	0	32767	1750	mV
Power	Shutdown	PF Shutdown Time	U1	0	255	10	s
Power	Shutdown	Charger Present Threshold	I2	0	32767	3000	mV

5.5 Other Power Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Power	Valid Update Voltage	I2	0	32767	3500	mV

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Power Off	Debounce	U1	1	255	4	250ms
Power	Power Off	Timeout	U2	0	65535	30	min

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Manual FET Control	MFC Delay	U1	0	255	60	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Ship	FET Off Time	U1	0	127	10	s
Power	Ship	Delay	U1	0	254	20	s
Power	Ship	Auto Ship Time	U2	0	65535	1440	min

IO Configuration

6.1 Overview

The bq40z60 integrates a number of different functions on a minimal number of pins, so additional data flash setup is necessary to get the necessary functions.

The possibility options are:

- LED support on pins 10, 11, 12, and 13
- LED Button Control input on pin 15
- System Present or Battery Trip Point Alert on pin 14
- External Pre-charge Control on pin 14

6.2 Configurations

6.2.1 IO Config Data Flash

Configuration of the IO requires the data flash values found in the IO Config value as well as the state of the NR bit located in the DA Configuration value (see Section 12.2.3).

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	IO Config	B1	0	0xf3	0x00	hex

B7	B6	B5	B4	B3	B2	B1	B0
PCHGBTP	ESHUTBUT	LED3BTPALT	LED2ACOK	RSVD	RSVD	BTP_POL	BTP_EN

PCHGBTP	[7]	External Pre-charge or BTP Indicator on pin 14	**1**: BTP output **0**: Pre-charge control
ESHUTBUT	[6]	Emergency Shutdown/System Present or LED display button on pin 15	**1**: Emergency Shutdown / System Present **0**: LED display button
LED3BTPALT	[5]	BTP Output or LED3 indictor on pin 12	**1**: BTP output (TS3 disabled) **0**: LED3 output
LED2ACOK	[4]	Charge current indicator or LED2 indicator on pin 13	**1**: Charge current indicator (TS2 disabled) **0**: LED2 output
RSVD	[3:2]	Reserved - Do not use	
BTP_POL	[1]	Battery Trip Point polarity	**1**: Assert high **0**: Assert low
BTP_EN	[0]	Battery Trip Point control	**1**: Enabled **0**: Disabled

6.2.2 System Present Support

System Present, asserted low, is supported on pin 15 when the NR bit is **0**. In this condition, ESHUTBUT state is ignored. When system present support is enabled, the pin must be low for the gas gauge to detect the presence of a battery stack.

If NR = 1, no SYSTEM Present is required.

6.2.3 Emergency Shutdown Support

The Emergency Shutdown feature is selected when NR is **1** and ESHUT_EN is **1**. The input is read on pin 15 when ESHUTBUT is **1** and on pin 14 when ESHUTBUT is **0**; the value of PCHGBTP is not considered when ESHUTBUT is **0** and the device operates without precharge FET control. When the Emergency Shutdown feature is selected, the configured pin becomes an input, allowing the system to be disabled when the pin is asserted low for a configurable debounce time. In emergency shutdown, the charger is disabled and the discharge FET is opened. The charger is re-enabled and the discharge FET closed when a configurable timeout period has expired or the input is asserted again.

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Power	Power Off	Debounce	U1	1	255	4	250ms
Power	Power Off	Timeout	U2	0	65535	30	min

6.2.4 Precharge Support

Pin 14 can be used to control an external circuit for precharge when NR is **1**, ESHUT_EN is **0**, and PCHGBTP is **0**.When configured for external precharge, the pin will be high when the precharge condition is true, meaning that NMOS FETs should be used in the circuit. The *EVM User's Guide* () has a schematic showing the necessary connections.

6.2.5 Battery Trip Point (BTP) Support

BTP can be supported when NR is **1**, ESHUT_EN is **0**, and PCHGBTP is **1**.When configured for BTP support, the pin's polarity to signal a true condition can be set with the BTP_POL bit. There is also the BTP_EN bit that acts as a master enable for BTP IO support; BTP_EN does not affect OperationStatus[BTP_INT]. BTP can be supported on pin 12 when LED3BTPALT = 1, otherwise it is on pin 14.

6.2.6 LED Support

The bq40z60 supports on pins 10, 11, 12, and 13 to display Relative State of Charge (RSOC) or Absolute State of Charge (ASOC) percentage. The LED support is available even if thermistors are used or if BTP IO support is enabled. If using the LEDs, ESHUTBUT should be set to **0** to allow for external enable/disable control on pin 15.

Care must be taken to ensure that the state of LED3BTPALT and LED2ACOK are set appropriately to achieve the desired LED configuration.

6.2.6.1 LED Configuration Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	LED Configuration	B1	0	0x0d	0x00	hex

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	LEDMODE	LEDCHG	RSVD	LEDR

RSVD	[7:4]	Reserved - Do not use	
LEDMODE	[3]	Capacity display for LEDs	**1**: ASOC/DC **0**: RSOC
LEDCHG	[2]	Enable the LEDs during charge	**1**: Enabled **0**: Disabled
RSVD	[1]	Reserved - Do not use	
LEDR	[0]	Enable LED at Exit of Device Reset	**1**: Enabled **0**: Disabled

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
LED Support	LED Config	LED Delay	U2	16	65535	100	488us
LED Support	LED Config	LED Hold Time	U1	1	63	16	0.25s
LED Support	LED Config	CHG Thresh 1	I1	0	100	25	%
LED Support	LED Config	CHG Thresh 2	I1	0	100	50	%
LED Support	LED Config	CHG Thresh 3	I1	0	100	75	%
LED Support	LED Config	CHG Thresh 4	I1	0	100	100	%
LED Support	LED Config	DSG Thresh 1	I1	0	100	25	%
LED Support	LED Config	DSG Thresh 2	I1	0	100	50	%
LED Support	LED Config	DSG Thresh 3	I1	0	100	75	%
LED Support	LED Config	DSG Thresh 4	I1	0	100	100	%

Gauging

7.1 Introduction

The bq40z60 measures individual cell voltages, pack voltage, temperature, and current. It determines battery state of charge by analyzing individual cell voltages when certain relax time has passed since the last charge or discharge activity of the battery.

The bq40z60 measures charge and discharge activity by monitoring the voltage across a small-value series sense resistor (1 mΩ typical) between the negative terminal of the cell stack and the negative terminal of the battery pack. The battery state of charge is adjusted subsequently during a load or charger application using the integrated charge passed through the battery. The device is capable of supporting a maximum battery pack capacity of 32Ah. See the *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq20zxx Product Family* (SLUA364B) for further details.

The default for Impedance Track gauging is *off*. To enable the gauging function, set ***Manufacturing Status[GAUGE_EN]*** = 1. The gauging function will be enabled after a reset or a seal command is set. Alternatively, the MAC command, *Gauging()*, can be used to turn on and off the gauging function. The *Gauging()* will take effect immediately and the ***[GAUGE_EN]*** will be updated accordingly.

The *ITStatus1()*, *ITStatus2()*, and *ITStatus3()* commands return various gauging related information that is useful for problem analysis.

7.2 Impedance Track Configuration

Load Mode — During normal operation, the battery-impedance profile compensation of the Impedance Track algorithm can provide more accurate full-charge and remaining state- of-charge information if the typical load type is known. The two selectable options are constant current (***Load Mode*** = 0) and constant power (***Load Mode*** = 1).

Load Select — To compensate for the I × R drop near the end of discharge, the bq40z60 must be configured for whatever current (or power) will flow in the future. While it cannot be exactly known, the bq40z60 can use load history such as the average current of the present discharge to make a sufficiently accurate prediction.

The bq40z60 can be configured to use several methods of this prediction by setting the ***Load Select*** value. Because this estimate has only a second-order effect on remaining capacity accuracy, different measurement-based methods (methods 0 to 3, and method 7) result in only minor differences in accuracy. However, methods 4–6, where the user arbitrarily assigns an estimate, can result in significant error if a fixed estimate is far from the actual load. For highly variable loads, selection 7 provides the most conservative estimate and is preferable.

	Constant Current (***Load Mode*** = 0)	**Constant Power** (***Load Mode*** = 1)
0 =	***Avg I Last Run***	***Avg P Last Run***
1 =	Present average discharge current	Present average discharge power
2 =	*Current()*	*Current()* × *Voltage()*
3 =	*AverageCurrent()*	*AverageCurrent()* × average *Voltage()*
4 =	***Design Capacity*** / 5	***Design Energy*** / 5
5 =	*AtRate()* (mA)	*AtRate()* (10 mW)
6 =	***User Rate-mA***	***User Rate-mW***
7 =	***Max Avg I Last Run*** (default)	***Max Avg P Last Run***

Pulsed Load Compensation and Termination Voltage — To take into account pulsed loads while calculating remaining capacity until ***Term Voltage*** threshold is reached, the bq40z60 monitors not only average load but also short load spikes. The maximum voltage deviation during a load spike is updated continuously during discharge and stored in ***Delta Voltage***.

Reserve Battery Capacity — The bq40z60 allows an amount of capacity to be reserved in either mAh (***Reserve Cap-mAh***, ***Load Mode*** = 0) or 10 mWh (***Reserve Cap-mWh***, ***Load Mode*** = 1) units between the point where the *RemainingCapacity()* function reports zero capacity and the absolute minimum pack voltage, ***Term Voltage***. This enables a system to report zero energy, but still have enough reserve energy to perform a controlled shutdown or provide an extended sleep period for the host system.

The reserve capacity is compensated at the present discharge rate as selected by ***Load Select***.

Pack-Based and Cell-Based Termination — The bq40z60 forces *RemainingCapacity()* to 0 mAh when the battery stack voltage reaches the ***Term Voltage***. If ***IT Gauging Configuration[CELL_TERM]*** = 1, the battery can terminate based on cell voltage or pack voltage. When the cell-based termination is used, the ***Term Min Cell V*** threshold is checked for the termination condition. The cell-based termination can provide an option to enable the gauge to reach 0% before the device triggers CUV for a pack imbalance.

7.3 Gas Gauge Modes

Resistance updates take place only in DISCHARGE mode, while open circuit voltage (OCV) and QMax updates only take place in RELAX mode. If fast Qmax is enabled, the Qmax also updates at the end of discharge given a minimum of 37% delta change of charge. Entry and exit of each mode is controlled by data flash parameters in the subclass ***Gas Gauging: Current Thresholds*** section. When the device is determined to be in RELAX mode and OCV is taken, the *GaugingStatus()[REST]* flag is set. In RELAX mode or DISCHARGE mode, the DSG flag in *BatteryStatus()* is set.

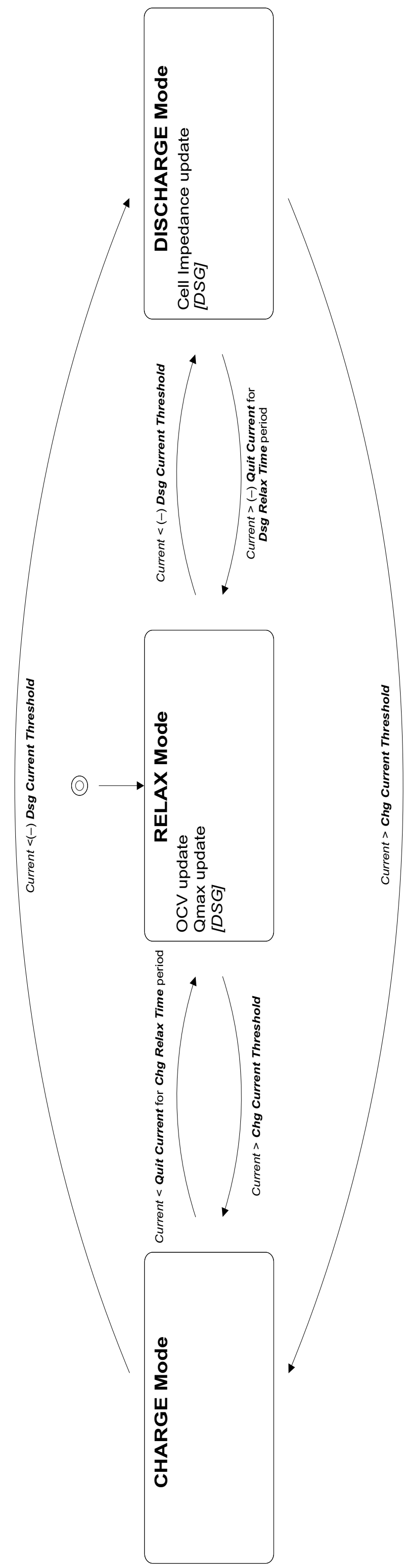


Figure 7-1. Gas Gauge Operating Modes

CHARGE mode is exited and RELAX mode is entered when *Current* goes below ***Quit Current*** for a period of ***Chg Relax Time***. DISCHARGE mode is entered when *Current* goes below ***(–)Dsg Current Threshold***. DISCHARGE mode is exited and RELAX mode is entered when *Current* goes above ***(–)Quit Current*** threshold for a period of ***Dsg Relax Time*** . CHARGE mode is entered when *Current* goes above ***Chg Current Threshold***.

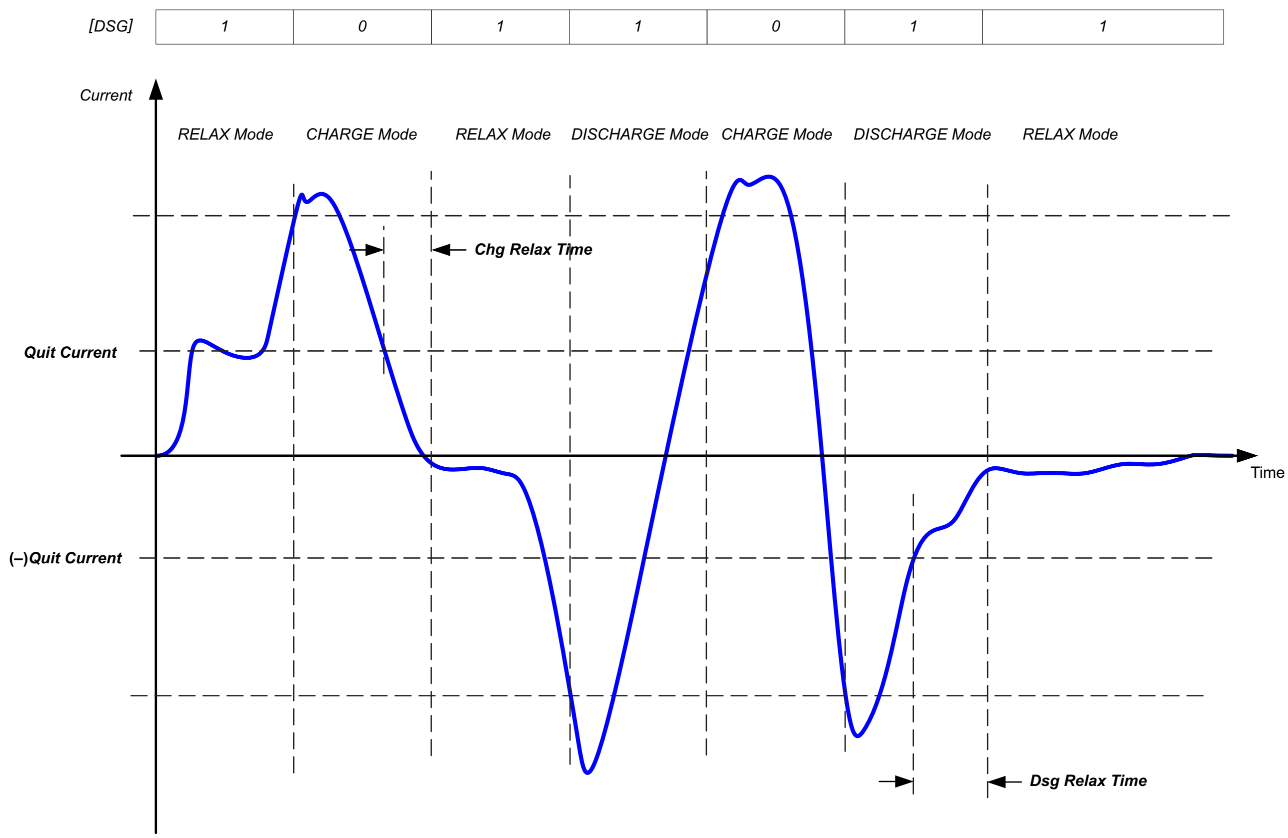


Figure 7-2. Gas Gauge Operating Mode Example

7.4 QMax and Ra

The total battery capacity is found by comparing states of charge before and after charge and discharge with the amount of charge passed. When an applications load is applied, the impedance of each cell is measured by comparing the open circuit voltage (OCV) obtained from a predefined function for present state of charge with the measured voltage under load.

Measurements of OCV and charge integration determine chemical state of charge and Chemical Capacity (*QMax*).

The bq40z60 acquires and updates the battery-impedance profile during normal battery usage. It uses this profile, along with state-of-charge and the *QMax* values, to determine *FullChargeCapacity* and *RelativeStateOfCharge* specifically for the present load and temperature. *FullChargeCapacity* reports a capacity or energy available from a fully charged battery reduced by ***Reserve Cap- mAh*** or ***Reserve Cap-mWh*** under the present load and present temperature until *Voltage* reaches the ***Term Voltage***.

7.4.1 QMax Initial Values

The initial ***QMax Pack***, ***QMax Cell 0***, ***QMax Cell 1***, ***QMax Cell 2***, and ***QMax Cell 3*** values should be taken from the cell manufacturers' data sheet multiplied by the number of parallel cells. These values are also used for the *DesignCapacity* function value in the ***Design Capacity*** data flash value.

See the *Theory and Implementation of Impedance Track Battery Fuel-Gauging Algorithm in bq20zxx Product Family Application Report* (SLUA364B) for further details.

7.4.2 QMax Update Conditions

QMax update is enabled when gauging is enabled. The ***GaugingStatus[QEN]*** flag indicates this. The bq40z60 updates the no-load full capacity (QMax) when two open circuit voltage (OCV) readings are taken. These OCV readings are taken when the battery is in a relaxed state before and after charge or discharge activity. A relaxed state is achieved if the battery voltage has a dV/dt of < 4 µV/s. Typically it takes 2 hours in a charged state and 5 hours in a discharged state to ensure that the dV/dt condition is satisfied. If 5 hours is exceeded, a reading is taken even if the dV/dt condition was not satisfied. The *GaugingStatus()[REST]* flag is set when a valid OCV reading occurs. If a valid DOD0 (took at the previous QMax update) is available, then QMax will also be updated when a valid charge termination is detected.

The flag is cleared at the exit of a relaxed state. A QMax update is disqualified under the following conditions:

Temperature — If *Temperature* is outside of the range 10°C to 40°C.

Delta Capacity — If the capacity change between suitable battery rest periods is less than 37%.

Voltage — If *CellVoltage4..1* is inside a flat voltage region. (See the *Support of Multiple Li-Ion Chemistries With Impedance Track Gas Gauges Application Report* (SLUA372) for the voltage ranges of other chemistries.) This flat region is different with different chemistry. The *GaugingStatus[OCVFR]* flag indicates if the cell voltage is inside this flat region.

Offset Error — If offset error accumulated during time passed from previous OCV reading exceeds 1% of *Design Capacity*, update is disqualified. Offset error current is calculated as ***CC Deadband*** / sense resistor value.

Several flags in *GaugingStatus()* are helpful to track for QMax update conditions. The *[REST]* flag indicates an OCV is taken in RELAX mode. The *[VOK]* flag indicates the last OCV reading is qualified for the QMax update. The *[VOK]* is set when charge or discharge starts. It clears when the QMax update occurs, when the offset error for a QMax disqualification is met, or when there is a full reset. The *[QMax]* flag will be toggled when the QMax update occurs. *ITStatus2()* and *ITStatus3()* return the QMax and DOD (depth of discharge, corresponding to the OCV reading) data.

7.4.3 Fast QMax Update Conditions

The Fast QMax update conditions are very similar to the QMax update conditions with the following differences:

- Instead of taking two OCV readings for QMax update, Fast QMax update requires only one OCV reading, AND
- The battery pack should discharge below 10% RSOC.

The differences in requirements allow the Fast QMax feature to have QMax update at the end of discharge (given one OCV reading is already available and discharge below 10% RSOC) without a longer relax time after a discharge event. Typically, it can take up to 5 hours in a discharge state to ensure the dV/dt < 4 µV/s condition is satisfied. The Temperature, Delta Capacity, Voltage, and Offset Error requirements for QMax update are still required for the Fast QMax update.

This feature is particularly useful for reducing production QMax learning cycle time or for an application, which is mostly in charge or discharge stage with infrequent relaxation. Setting ***IT Gauging Configuration[FAST_QMAX_LRN]*** = 1 enables Fast QMax during production learning only (that is, ***Update Status*** = 6). When setting ***IT Gauging Configuration[FAST_QMAX_FLD]*** = 1, Fast QMax is enabled when Impedance Track is enabled and ***Update Status*** ≥ 6.

7.4.4 QMax and Fast QMax Update Boundary Check

The bq40z60 implements a QMax and Fast QMax check prior to saving the value to data flash. This improves the robustness of the QMax update in case of potential QMax corruption during the update process.

The verifications are as follows:

1. Verify that the updating QMax or Fast QMax value is within ***QMaxMaxDeltaPercent***, which is the maximum allowed QMax change for each update. If the updating value is outside of this data flash parameter, the bq40z60 caps the change to ***QMaxMaxDeltaPercent*** of the Design Capacity.
2. Bound the absolute QMax value, ***UpperBoundQMax***. This is the maximum allowed QMax value over the lifetime of the pack.
3. Ensure that QMax is greater than 0 before saving to data flash.

7.4.5 Ra Table Initial Values

The Ra table is part of the impedance profile that updates during discharge when gauging is enabled. The initial ***Cell0 R_a0...14***, ***Cell 1 R_a0...14***, ***Cell 2 R_a0...14***, ***Cell 3 R_a0...14*** values should be programmed by selecting the correct chemistry data during data flash configuration. A chemistry database is updated constantly and can be downloaded from the Gas Gauge Chemistry Updater product web page (http://www.ti.com/tool/gasgaugechem-sw). The initial ***xCell0 R_a0...14***, ***xCell 1 R_a0...14***, ***xCell 2 R_a0...14***, ***xCell 3 R_a0...14*** values are a copy of the non-x data set. Two sets of Ra tables are used alternatively when gauging is enabled to prevent wearing out the data flash.

The ***Cell0 R_a Flag***, ***Cell 1 R_a Flag***, ***Cell 2 R_a Flag***, ***Cell 3 R_a Flag*** and the ***xCell0 R_a Flag***, ***xCell 1 R_a Flag***, ***xCell 2 R_a Flag***, ***xCell 3 R_a Flag*** indicate the validity of the cell impedance table for each cell.

NOTE: FW updates these values: It is not recommended to change them manually.

HIGH BYTE		LOW BYTE	
0x00	Cell impedance and QMax updated	0x00	Table not used and QMax updated
0x05	RELAX mode and QMax update in progress	0x05	RSVD
0x55	DISCHARGE mode and cell impedance updated	0x55	Table is used
0xFF	Cell impedance never updated	0xFF	A fast Qmax update without OCV read will also clear the R_DIS flag. Table never used, no QMax or cell impedance update.

7.4.5.1 Ra Table Data Flash

The Ra tables, R_a<#>, are replicated in the R_a<#>x tables. For this reason, only the R_a<#> table information is shown below.

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Ra Table	R_a0	Cell0 R_a flag	B2	0	0xffff	0xff55	—
Ra Table	R_a0	Cell0 R_a 0	I2	0	32767	67	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 1	I2	0	32767	71	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 2	I2	0	32767	83	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 3	I2	0	32767	110	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 4	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 5	I2	0	32767	77	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 6	I2	0	32767	96	2^{-10} Ω

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Ra Table	R_a0	Cell0 R_a 7	I2	0	32767	86	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 8	I2	0	32767	84	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 9	I2	0	32767	82	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 10	I2	0	32767	81	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 11	I2	0	32767	92	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 12	I2	0	32767	103	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 13	I2	0	32767	123	2^{-10} Ω
Ra Table	R_a0	Cell0 R_a 14	I2	0	32767	658	2^{-10} Ω

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Ra Table	R_a1	Cell1 R_a flag	B2	0	0xffff	0xff55	—
Ra Table	R_a1	Cell1 R_a 0	I2	0	32767	67	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 1	I2	0	32767	71	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 2	I2	0	32767	83	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 3	I2	0	32767	110	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 4	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 5	I2	0	32767	77	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 6	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 7	I2	0	32767	86	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 8	I2	0	32767	84	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 9	I2	0	32767	82	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 10	I2	0	32767	81	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 11	I2	0	32767	92	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 12	I2	0	32767	103	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 13	I2	0	32767	123	2^{-10} Ω
Ra Table	R_a1	Cell1 R_a 14	I2	0	32767	658	2^{-10} Ω

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Ra Table	R_a2	Cell2 R_a flag	B2	0	0xffff	0xff55	—
Ra Table	R_a2	Cell2 R_a 0	I2	0	32767	67	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 1	I2	0	32767	71	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 2	I2	0	32767	83	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 3	I2	0	32767	110	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 4	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 5	I2	0	32767	77	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 6	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 7	I2	0	32767	86	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 8	I2	0	32767	84	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 9	I2	0	32767	82	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 10	I2	0	32767	81	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 11	I2	0	32767	92	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 12	I2	0	32767	103	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 13	I2	0	32767	123	2^{-10} Ω
Ra Table	R_a2	Cell2 R_a 14	I2	0	32767	658	2^{-10} Ω

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Ra Table	R_a3	Cell3 R_a flag	B2	0	0xffff	0xff55	—
Ra Table	R_a3	Cell3 R_a 0	I2	0	32767	67	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 1	I2	0	32767	71	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 2	I2	0	32767	83	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 3	I2	0	32767	110	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 4	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 5	I2	0	32767	77	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 6	I2	0	32767	96	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 7	I2	0	32767	86	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 8	I2	0	32767	84	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 9	I2	0	32767	82	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 10	I2	0	32767	81	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 11	I2	0	32767	92	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 12	I2	0	32767	103	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 13	I2	0	32767	123	2^{-10} Ω
Ra Table	R_a3	Cell3 R_a 14	I2	0	32767	658	2^{-10} Ω

7.4.6 Ra Table Update Conditions

The impedance is different across different DOD states. Each cell has 15 Ra grid points presenting the impedance from 0%~100% DOD. In general, the Ra table is updated during discharge. The *GaugingStatus()[RX]* flag will toggle when the Ra grid point is updated. The Ra update is disabled if any of the following conditions are met. The *GaugingStatus()[R_DIS]* is set to indicate the Ra update is disabled.

- During the optimization cycle, the Ra update is disabled until QMax is updated (that is, Ra will not be updated if Update Status = 4), OR
- Ra update is disabled if the charge accumulation error > 2% of Design Capacity, OR
- During a discharge, a bad Ra value is calculated:
  - A negative Ra is calculated or
  - A bad RaScale value is calculated.

A valid OCV reading during RELAX mode or a fast Qmax update without an OCV read will clear the *[R_DIS]* flag.

7.5 FullChargeCapacity(FCC), RemainingCapacity(RemCap), and RelativeStateOfCharge(RSOC)

The Impedance Track algorithm applies QMax, impedance, temperature, voltage, and current data to predict the runtime *FullChargeCapacity()*, *RemainingCapacity()*, and *RelativeStateOfCharge()*. These values are updated if any of the following conditions are met, reflecting the battery capacity at real time.

- QMax update occurs
- Ra update occurs
- At onset of charge and discharge
- At exit of discharge
- Every 5 hours in RELAX mode
- If temperature changes more than 5°C

7.6 Impedance Track Configuration Options

The bq40z60 provides several Impedance Track (IT) configuration options to fine-tune the gauging performance. These configurations can be turned on or off through the corresponding flags in ***SBS Gauging Configuration*** or ***IT Gauging Configuration***.

[LOCK0]: After a discharge event, cell voltage will usually recover to a slightly higher voltage during RELAX state. A new OCV reading during this time can result in a slightly higher state of charge. This flag provides an option to keep *RemainingCapacity()* and *RelativeStateOfCharge()* jumping back during relaxation after 0% and FD are reached during discharge.

[RSOC_HOLD]: An IT simulation will run at the onset of discharge. If charge terminates at a low temperature and a discharge occurs at a higher temperature, the difference in temperature could cause a small rise of RSOC for a short time period at the beginning of discharge. This flag option prevents RSOC rises during discharge. RSOC will be held until the calculated value falls below the actual state.

[RSOCL]: When set, RSOC will be held at 99% until charge termination is detected. See Section 4.7 for details.

[RFACTSTEP]: The gauge keeps track of the Ra factor of the (old Ra) / (new Ra) during the Ra update. This factor is used for Ra scaling. It is limited to a maximum of 3. During an Ra update, if (old Ra) / (new Ra) is > 3, the gauge can take on two different actions based on the setting of this flag.

If this flag is set to 1 (default), the gauge allows Ra to update once using the max factor of 3, then disables the Ra update. If this flag is set to 0, the gauge will not update Ra and will also disable the Ra update. The recommendation is to keep the default setting.

[OCVFR]: An OCV reading is taken when a dV/dt condition is met. This is not the case if charging stops within the flat voltage region.

By default, this flag is set. The device will take a 48-hour wait before taking an OCV reading if charging stops below the FlatVoltMax. A discharge will not cancel this 48-hour wait. The 48-hour wait will only clear if charging stops above the FlatVoltMax level. Setting this flag to 0 removes the 48-hour wait requirement, and OCV is taken when the dV/dt condition is met. Removing the 48-hour requirement can be useful sometimes to reduce test time during evaluation.

[DOD0EW]: DOD0 readings have an associated error based on the elapsed time since the reading, the conditions at the time of the reading (reset, charge termination, and so forth), the temperature, and the amount of relax time at the time of the reading, and so forth. This flag provides an option to take into account both the previous and new calculated DOD0, which are weighted according to their respective accuracies. This can result in improved accuracy and in reduction of RSOC jumps after relaxation.

[LFP_RELAX]: This is an option for LiFePO4 chemistry. This flag can be enabled even if non-LiFePO4 chemistry is programmed. The device will check for the chemistry ID (that is, ChemID = 4xx series) before activating this function.

The LiFePO4 has a unique slow Configuration relaxation near full charge. Detailed, in-house test data suggests that the relaxation after a full charge takes a few days to settle. The slow decaying voltage causes RSOC to continue to drop every 5 hours. Depending on the full charge taper current, the fully settled voltage could be close to or even below FlatVoltMax in some cases. For the chemID 4xx (LiFePO4) series, the condition to exit the long RELAX mode is if the pack had previously charged to full or near full state, and then either a significant long relaxation or a non-trivial discharge has happened, such that when in relaxation, the OCV < FlatVoltMax.

The QMax update is disabled because DOD will not be taken as long as it is in LFP_relax mode. By the time the gas gauge exits the LFP_relax mode, the OCV is already in the flat zone. Therefore, the QMax update takes an alternative approach: Once full charge occurs ([FC] bit set), DOD0=Dod_at_EOC is automatically assigned and valid for a QMax update. ***[VOK]*** is set if there is no QMax update. If QMax is updated, ***[VOK]*** is cleared. The DOD error, because of this action, is zero or negligible, because in the LiFePO4 table, OCV voltage corresponding to DOD= 0 is much lower.

[Fast_QMAX_LRN]and ***[Fast_QMAX_FLD]*** : The first flag enables fast Qmax during the learning cycle when ***Update Status*** = 06. The second flag enables fast Qmax in the field when ***Update Status*** ≥ 06. See Section 7.4.3 for more details.

[RSOC_CONV]: This function is also called fast scaling. It is an option to address the convergence of RSOC to 0% at a low temperature and a very high rate of discharge. Under such conditions, it is possible to have a drop of RSOC to 0%, especially if the termination voltage is reached at the DOD region with a higher Ra grid interval. To account for the error caused by the high granularity of the impedance grid interval, the ***[RSOC_CONV]***, when enabled, applies a scale factor to impedance, which allows more frequent impedance data updates that are used for RemCap simulation leading up to 0% RSOC.

If ***[RSOC_CONV]*** is enabled, it is recommended to start this function around the knee region of the discharge curve. This is usually around 10% of RSOC or around 3.3 V~3.5 V. This function will check for both cell voltage and RSOC status and start the function when either condition is met. The RSOC and cell voltage setting can be configured through ***Fast Scale Start SOC*** or ***Term Voltage Delta***.

[FF_NEAR_EDV]: Fast Filter Near EDV. If this flag is set, the gauge applies an alternative filter, ***Near EDV Ra Param Filter***, for an Ra update in the fast scaling region (starting around 10% RSOC). This flag should be kept to 1 as default. When this flag is 0, the gauge uses the regular Ra filter, ***Resistance Parameter Filter***. Both of the DF filters should not be changed from the default.

[SMOOTH]: A change in temperature or current rate can cause a significant change in Remaining Capacity (RemCap) and Full Charge Capacity (FCC), resulting in a jump or drop in the Relative State Of Charge (RSOC). This function provides an option to prevent an RSOC jump or drop during charge and discharge.

If a jump or drop of RSOC occurs, the device:

- Examines the amount of RSOC jump or drop versus the expected end point (that is, the charge termination for the charging condition or the EDV for the discharge condition)
- Smooths the change of RSOC automatically
- Always converges with the filtered (or smoothed) value to the actual charge termination or EDV point.

The actual and filtered values are always available. The ***[SMOOTH]*** flag selects either the actual or the filtered values returned by the SBS commands.

[RELAX_JUMP_OK] and ***[RELAX_SMOOTH_OK]*** : When the battery enters RELAX mode from CHARGE or DISCHARGE mode, the transient voltage may change to RSOC as the battery goes into its RELAX state. Once the battery is in RELAX mode, a change in temperature or self-discharge may also cause a change in RSOC.

If ***[RELAX_JUMP_OK]*** = 1, this allows the RSOC jump to occur during RELAX mode. Otherwise, RSOC holds constant during RELAX mode and any RSOC jump will be passed into the onset of the charge or discharge phase.

If ***[RELAX_SMOOTH_OK]*** = 1, this allows the amount of the RSOC jump to be smoothed out over a period of ***Smooth Relax Time***. Otherwise, the additional RSOC jump amount will be passed into the onset of charge or discharge phase.

If both flags are set to 1, the ***[RELAX_JUMP_OK]*** = 1 takes higher priority and the RSOC jump is allowed during RELAX mode.

[TDELAV]: This flag setting defines how the ***Delta Voltage*** is calculated. By setting this flag to 1, the gauge will calculate ***Delta Voltage*** that corresponds to the power spike defined in ***Min Turbo Power***. This flag must be set to 1 if TURBO BOOST mode is used. Otherwise, leaving this flag to 0 as default enables the gauge to calculate ***Delta Voltage*** by using the maximal difference between instantaneous and average voltage.

[CELL_TERM]: This flag provides an option to have a cell voltage based discharge termination. If the minimum cell voltage reaches ***Term Min Cell V***, *RemainingCapacity()* will be forced to 0 mAh. For more details, see the *Pack Based and Cell Based Termination*, Section 7.2.

[CSYNC]: This flag, if set to 1, will synchronize *RemainingCapacity()* to *FullChargeCapacity()* at valid charge termination.

[CCT]: This flag provides an option to use *FullChargeCapacity()* (***[CCT]*** = 1) or *DesignCapacity()* (***[CCT]*** = 0) for cycle count threshold calculation. If *FullChargeCapacity()* is selected for cycle count threshold calculation, the minimum cycle count threshold is always 10% of Design Capacity. This is to avoid any erroneous cycle count increment caused by extremely low *FullChargeCapacity()*.

[VOLTAGE_CONSIST]: Voltage Consistency Check. This function helps to prevent an RSOC jump. The flag should be set to 1 as default. The resistance toward the EDV level is not linear. The non- linearity can result in a raise in voltage in DISCHARGE mode. When this function is enabled, the gauge checks will ignore the increase of voltage from the voltage measurement. Instead, an interpolation using previous measurements is applied. The voltage consistency check will take place when the voltage is within the ***Voltage Consistency Delta*** from the ***Term Voltage***.

7.6.1 Impedance Track Configuration Data Flash

7.6.1.1 Settings Configuration Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	Sbs Gauging Configuration	B1	0	0x0f	0x4	hex
Settings	Configuration	IT Gauging Configuration	B2	0	0xffff	0xd4fe	hex
Settings	Configuration	IT Gauging 2 Configuration	B1	0	0x7e	0x3e	—

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	IT Cfg	Load Select	U1	0	7	7	—
Gas Gauging	IT Cfg	Load Mode	U1	0	1	0	—
Gas Gauging	IT Cfg	Design Resistance	I2	1	32767	42	mΩ
Gas Gauging	IT Cfg	User Rate-mA	I2	–9000	0	0	mA
Gas Gauging	IT Cfg	User Rate-cW	I2	–32768	0	0	cW
Gas Gauging	IT Cfg	Reserve Cap-mAh	I2	0	9000	0	mAh
Gas Gauging	IT Cfg	Reserve Cap-cWh	I2	0	32000	0	cWh
Gas Gauging	IT Cfg	Pack Resistance	I2	0	32767	30	mΩ
Gas Gauging	IT Cfg	System Resistance	I2	0	32767	0	mΩ
Gas Gauging	IT Cfg	Ra Filter	U2	0	999	500	0.1 %
Gas Gauging	IT Cfg	Ra Max Delta	U1	0%	255%	15%	
Gas Gauging	IT Cfg	Reference Grid	U1	0	14	4	—
Gas Gauging	IT Cfg	Resistance Parameter Filter	U2	1	65535	65142	—
Gas Gauging	IT Cfg	Near EDV Ra Param Filter	U2	1	65535	59220	—
Gas Gauging	IT Cfg	Qmax Delta	U1	3%	100%	5%	
Gas Gauging	IT Cfg	Qmax Upper Bound	U1	100%	255%	130%	
Gas Gauging	IT Cfg	Term Voltage	I2	0	32767	9000	mV
Gas Gauging	IT Cfg	Term V Hold Time	U1	0	255	1	s
Gas Gauging	IT Cfg	Term Voltage Delta	I2	0	32767	300	mV
Gas Gauging	IT Cfg	Term Min Cell V	I2	0	32767	2800	mV
Gas Gauging	IT Cfg	Voltage Consistency Delta	I2	0	32767	300	mV
Gas Gauging	IT Cfg	Fast Scale Start SOC	U1	0%	100%	10%	

7.7 State Of Health (SoH)

The bq40z60 implements a new State of Health (SoH) function. Previously, the state of health (SoH) of a battery was represented typically by the actual runtime ***FullChargeCapacity/Design Capacity*** (or FCC/DC). Using the runtime FCC, however, was not a very good representation for the state of health because the runtime FCC reflects the usable capacity under load. A high current load reduces the runtime FCC. If using just the FCC/DC calculation for SoH, the SoH under high load will be worse than the SoH under typical load. However, a smaller usable capacity at high load does not mean the SoH of a battery is degraded. This is the same when FCC is reduced at a lower temperature.

The bq40z60 implementation of state of health addresses these concerns. It provides the SoH of the battery through an SBS command, *SoH()*. The *SoH()* is calculated using the FCC simulated at 25°C with current specified by ***SoH Load Rate***. The ***SoH Load Rate*** can be set to the typical current of the application, and it is specified in hour-rate (that is, ***Design Capacity/SoH Load Rate*** will be the current used for the SoH simulation). This data flash setting is used for *SOH()* calculation only. This SoH FCC is updated at the same time ASOC and RSOC are updated. Since this implementation removes the variation of current or temperature, it is a better representation of a battery's state of health. The SoH FCC is available on MAC *StateOfHealth()*.

7.7.1 State Of Health Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	SoH	SoH Load Rate	U1	0	255	50	0.1hour Rate

7.8 TURBO BOOST Mode

A system with TURBO BOOST mode applies short high-power pulses (for example, 10 ms) during the turbo boost operation. These high-power pulses may drop down battery voltage. If the battery voltage drops below the ***Shutdown Voltage***, the system will shut down. To avoid shutting down the system during turbo boost operation, the system should never apply a pulse with power that would cause the battery power to go below the system shutdown voltage.

The TURBO BOOST mode in the bq40z60 helps the system to adjust the power level by providing information about maximal power depending on the battery state of charge, temperature, and present battery impedance. In particular, the gauge predicts the maximum power pulse (*TURBO_POWER()*) and maximum current pulse (*TURBO_CURRENT()*) the system can draw for 10 ms without system input power delivered by the battery dropping below the termination voltage. The *TURBO_POWER()* and *TURBO_CURRENT()* are updated every 1 s in the NORMAL mode of operation.

The ***Max C Rate*** specifies the maximal discharge current. If the calculated turbo current is larger than the ***Max C Rate***, then the reported *TURBO_CURRENT()* is capped to this value. The *TURBO_POWER()* is adjusted accordingly. The ***IT Gauging Configuration[TDELTAV]*** must be set when TURBO BOOST mode is in use. This flag calls the gauge to calculate the ***Delta Voltage*** that corresponds to the power spike defined in ***Min Turbo Power***. The ***Pack Resistance*** and the ***System Resistance*** are additional resistance inputs of the overall system that should be specified to archive an accurate maximum power and current computation. The ***High Frequency Resistance*** is a cell chemistry and battery pack configuration specific parameter; it is required in order to use the TURBO BOOST mode. To learn about the ***High Frequency Resistance*** measurement, see *bq30z554 TURBO Mode Application Report* (SLUA663).

The system should always consume less power than the *TURBO_POWER()* level to avoid system shutdown. However, depending on how often the system polls the *TURBO_POWER()* data and how fast the system can switch to a lower power mode, it is possible to exceed the *TURBO_POWER()* level during the present power consumption. To avoid any system shutdown, the gauge provides a ***Reserve Energy %*** setting, which can be served as a "buffer" to ensure there is available energy at the present average discharge rate until the maximal peak power reported by *TURBO_POWER()*.

7.8.1 TURBO BOOST Mode Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Turbo Cfg	Min Turbo Power	I2	–32768	0	0	cW
Gas Gauging	Turbo Cfg	Max C Rate	I1	–127	0	–4	C
Gas Gauging	Turbo Cfg	High Frequency Resistance	I2	0	32767	33	mΩ
Gas Gauging	Turbo Cfg	Reserve Energy %	I1	0%	100%	0%	

7.9 Battery Trip Point (BTP)

Required for WIN8 OS, the battery trip point (BTP) feature indicates when the RSOC of a battery pack has depleted to a certain value set in a DF register.

The BTP feature allows a host to program two capacity-based thresholds that govern the triggering of a BTP interrupt on the BTP_INT pin and the setting or clearing of the *OperationStatus()[BTP_INT]* based on *RemainingCapacity()*. The interrupt is enabled or disabled via ***Settings.Configuration.IO Config[BTP_EN]***. Similarly, the polarity of the interrupt is configurable based on the value set in ***Settings.Configuration.IO Config[BTP_POL]***.

- *OperationStatus()[BTP_INT]*is set when:
  - Current > 0 and RemCap > “clear” threshold (“charge set threshold”). This threshold is initialized at reset from ***Settings.BTP.Init Charge Set***.
  - Current ≤ 0 and RemCap < “set” threshold (“discharge set threshold”). This threshold is initialized at reset from ***Settings.BTP.Init Discharge Set***.
- When *OperationStatus()[BTP_INT]* is set, if ***Settings.Configuration.IO Config[BTP_EN]*** is set, then the BTP_INT pin output is asserted.
  - If ***Settings.Configuration.IO Config[BTP_POL]*** is set, it will assert high; otherwise, it will assert low.
- When either *BTPDischargeSet()* or *BTPChargeSet()* commands are received, *OperationStatus()[BTP_INT]* will clear and the pin will be de- asserted. The new threshold is written to either *BTPDischargeSet()* or *BTPChargeSet()*.
- At reset, the pin is set to the de-asserted state.
  - If you change ***[BTP_POL]***, one of the BTP commands must be reset or sent to “clear" the state.

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	BTP	Init Discharge Set	I2	0	32767	150	mAH
Settings	BTP	Init Charge Set	I2	0	32767	175	mAH

7.10 Other Gas Gauge Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	State	Cycle Count	U2	0	65535	0	—
Gas Gauging	State	Qmax Cell 1	I2	0	32767	4400	mAh
Gas Gauging	State	Qmax Cell 2	I2	0	32767	4400	mAh
Gas Gauging	State	Qmax Cell 3	I2	0	32767	4400	mAh
Gas Gauging	State	Qmax Cell 4	I2	0	32767	4400	mAh
Gas Gauging	State	Qmax Pack	I2	0	32767	4400	mAh
Gas Gauging	State	Qmax Cycle Count	U2	0	65535	0	—
Gas Gauging	State	Update Status	B1	0	0x0E	0	—
Gas Gauging	State	Cell 1 Chg Voltage at EoC	I2	0	32767	4200	mV
Gas Gauging	State	Cell 2 Chg Voltage at EoC	I2	0	32767	4200	mV
Gas Gauging	State	Cell 3 Chg Voltage at EoC	I2	0	32767	4200	mV
Gas Gauging	State	Cell 4 Chg Voltage at EoC	I2	0	32767	4200	mV
Gas Gauging	State	Current at EoC	I2	0	32767	250	mA
Gas Gauging	State	Avg I Last Run	I2	–32768	32767	–2000	mA
Gas Gauging	State	Avg P Last Run	I2	–32768	32767	–3022	cW
Gas Gauging	State	Delta Voltage	I2	–32768	32767	0	mV
Gas Gauging	State	Temp k	I2	0	32767	100	0.1°C/256 cW
Gas Gauging	State	Temp a	I2	0	32767	1000	—

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	State	Max Avg I Last Run	I2	–32768	32767	–2000	mA
Gas Gauging	State	Max Avg P Last Run	I2	–32768	32767	–3022	cW

7.10.1 Update Status

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	Qmax_FldUpdtd	Enable	UPDATE[1]	UPDATE[0]

RSVD	[7:4]	Reserved - Do not use	
Qmax_FldUpdtd	[3]	Qmax update in the field	**1**: Updated **0**: Not Updated
Enable	[2]	Impedance Track gauging and lifetime updating	**1**: Enabled **0**: Disabled
UPDATE[1:0]	[1:0]	Update status	**1**: Detected **0**: Undetected

UPDATE[1]	UPDATE[0]	UPDATE STATUS
0	0	Impedance Track gauging and lifetime updating is disabled.
0	1	Qmax updated
1	0	Qmax and Ra tables updated
1	1	Undefined

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Smoothing	Smooth Relax Time	I2	1	32767	1000	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Max Error	Time Cycle Equivalent	U1	1	255	12	2h
Gas Gauging	Max Error	Cycle Delta	U1	0	255	5	0.01 %

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Design	Design Capacity mAh	I2	0	32767	4400	mAh
Gas Gauging	Design	Design Capacity cWh	I2	0	32767	6336	cWh
Gas Gauging	Design	Design Voltage	I2	0	32767	10800	mV

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Cycle	Cycle Count Percentage	U1	0	100	90	%

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Current Thresholds	Dsg Current Threshold	I2	–32768	32767	100	mA
Gas Gauging	Current Thresholds	Chg Current Threshold	I2	–32768	32767	50	mA
Gas Gauging	Current Thresholds	Quit Current	I2	0	32767	10	mA
Gas Gauging	Current Thresholds	Dsg Relax Time	U1	0	255	1	s
Gas Gauging	Current Thresholds	Chg Relax Time	U1	0	255	60	s

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Current Thresholds	Dsg Body Diode Protect Threshold	I2	–32768	32767	100	mA
Gas Gauging	Current Thresholds	Chg Body Diode Threshold	I2	–32768	32767	100	mA

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Gas Gauging	Condition Flag	Max Error Limit	U1	0	100	100	%

Cell Balancing

8.1 Introduction

The bq40z60 can determine the chemical state of charge of each cell using the Impedance Track algorithm. The cell-balancing algorithm used in the device decreases the differences in imbalanced cells in a fully charged state gradually, which prevents fully charged cells from becoming overcharged, causing excessive degradation. This increases overall pack energy by preventing premature charge termination.

The algorithm determines the amount of charge needed to charge each cell fully. There is a bypass FET in parallel with each cell that is connected to the gas gauge. The FET is enabled for each cell with a charge greater than the lowest charged cell to reduce charge current through those cells. Each FET is enabled for a precalculated time as calculated by the cell-balancing algorithm. When any bypass FET is turned on, then the *OperationStatus()[CB]* operation status flag is set; otherwise, the *[CB]* flag is cleared.

The gas gauge balances the cells by balancing the SOC difference. Thus, a field updated QMax (***Update Status*** = 0E) is required prior to any attempt of Cell Balance Time calculation. This ensures the accurate SOC delta is calculated for the cell balancing operation. If Qmax update has only occurred once (***Update Status*** = 06), then the gauge will only attempt to calculate the Cell Balance Time if a fully charged state is reached, *GaugingStatus()[FC]* = 1.

The cell balancing is enabled if ***Settings:Balancing Configuration [CB]*** = 1. The cell balancing at rest can be enabled separately by setting ***Balancing Configuration [CBR]*** = 1. If ***Settings:Balancing Configuration [CB]*** = 0, both cell balancing at charging and at rest are disabled.

The cell balancing at rest can be configured by determining the data flash ***Min Start Balance Delta***, ***Relax Balance Interval***, and ***Min RSOC for Balancing***. For the data flash setting description, see Section 8.5. The gas gauge balances cells by bypassing the energy. It is recommended to perform cell balancing at rest when there is capacity in the battery pack.

8.2 Cell Balancing Setup

The bq40z60 is required to be in RELAX mode before it can determine if the cells are unbalanced and how much balancing is required. The bq40z60 enters RELAX mode when:

| *Current()* |< ***Quit Current*** for at least ***Dsg Relax Time*** when coming from DISCHARGE mode or ***Chg Relax Time*** when coming for CHARGE mode.

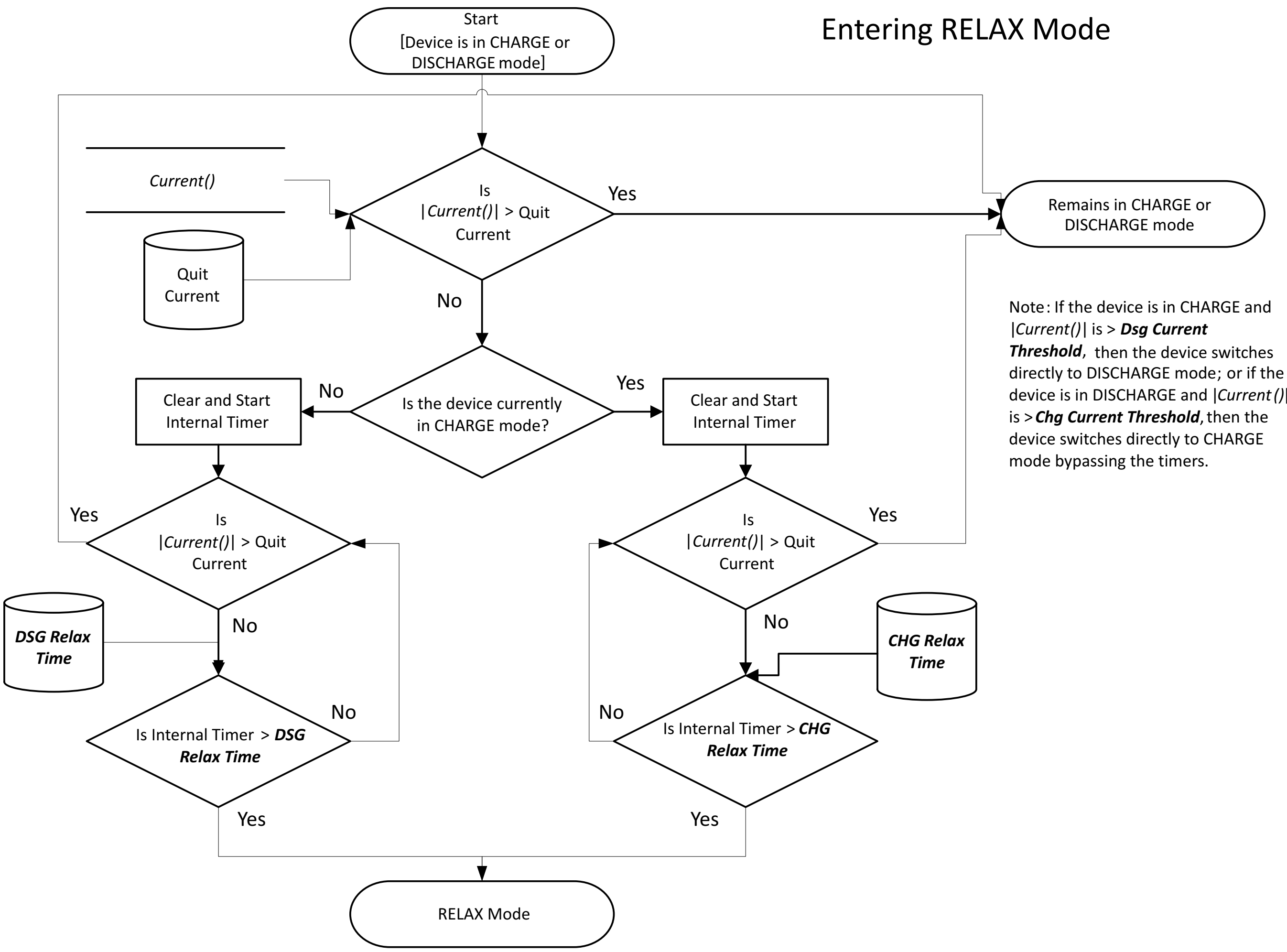


Figure 8-1. Entering CHARGE or RELAX Mode

Once in RELAX mode, the bq40z60 waits until an OCV measurement is taken, which occurs after:

1. A dV/dt condition of < 4 µV/s is satisfied,
2. After 5 hours from when | *Current()* | < ***Quit Current***,
3. Upon gas gauge reset,
4. An IT Enable command is issued.

The determination of when to update the OCV data is part of the normal Impedance Track algorithm and is not specific to the cell-balancing algorithm.

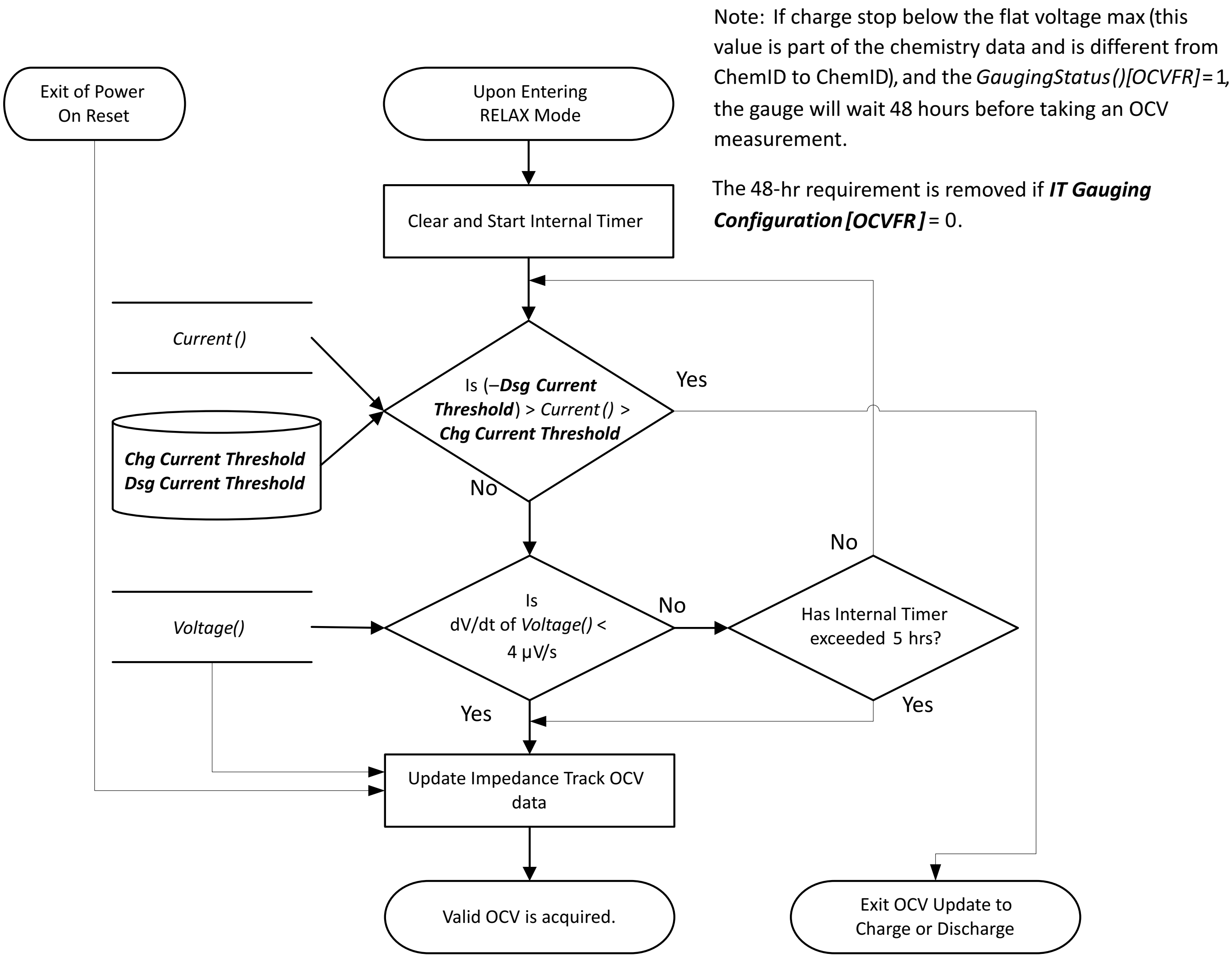


Figure 8-2. OCV Measurement

The bq40z60 then calculates the amount of charge difference between cells with a higher state of charge than the lowest cell SOC. The value, dQ, is determined for each cell based by converting the measured OCV to Depth-of-Discharge (DOD) percentages using a temperature-compensated DOD vs. OCV table lookup table. If the measured, OCV does not coincide with a specific table entry, then the DOD value is linearly interpolated from the two adjacent DODs of the respective table adjacent OCVs.

The delta in DOD% between each cell and the cell of lowest SOC is multiplied by the respective cells QMax to create dQ: for example, dQ = CellnDOD – CellLOWEST_SOC DOD × CellnQMax (mAh).

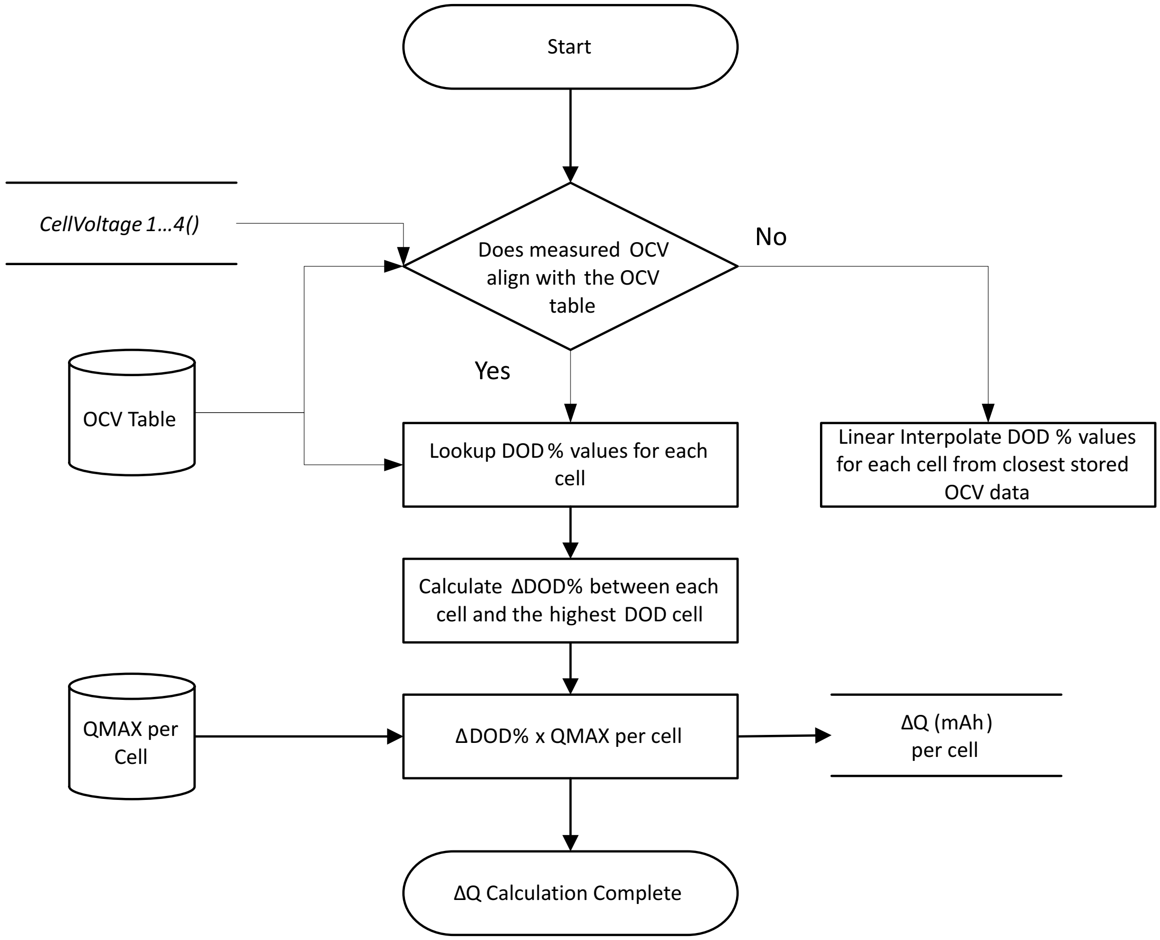


Figure 8-3. ΔQ Calculation

The bq40z60 calculates the required balancing time using dQ and ***Bal Time/mAh Cell 1*** (for Cell 1) or Bal Time/mAh Cell 2–4 (for cells 2–4). The value of ***Bal Time/mAh Cell 1*** and ***Bal Time/mAh Cell 2–4*** are fixed value determined based on key system factors and is calculated by:

Bal Time/mAh Cell 1 = 3600 mAs/(V_{CELL} /RVCx + R_{cb}) × DUTY/1000

Bal Time/mAh Cell 2–4 = 3600 mAs/(V_{CELL} /(2×RVCx + Rcb) × DUTY)/1000

Where:

V_{CELL} = average cell voltage (for example, 3.7 V for most chemistry)

RVCx = resistor value in series to VCx input (for example, 100 Ω, based on the reference schematic)

R_{cb} = cell balancing FET R_{dson}, which is 150 Ω

DUTY = cell balancing duty cycle, which is 66% typ

The cell balancing time for each cell to be balanced is calculated by: dQCelln × ***Bal Time/mAh Cell 1*** for cell1 or dQCelln × ***Bal Time/mAh Cell 2–4*** for Cell 2–4. The cell balancing time is stored in the 16-bit RAM register CellnBalanceTimer, providing a maximum calculated time of 65535 s (or 18.2 hrs). This update only occurs if a valid QMax update has been made; otherwise, they are all set to 0.

8.3 Balancing Multiple Cells Simultaneously

The bq40z60 can balance multiple cells simultaneously if internal cell balancing is selected, ***Balancing Configuration[CBM]*** = 0.

If external cell balancing is selected, ***[CMB]*** = 1, the gauge will perform a rotation cell balancing with only one cell to be balanced at a time, starting on the cell with highest dQ first. For example, at time 0, Cell 1 has the highest dQ while Cell 2 has the 2nd highest dQ on a 3S pack. The external cell balancing will start to balance Cell 1 first. As time goes by, the dQ in cell will reduce, and Cell 2 becomes the cell with the highest dQ, the gauge will then switch to balance Cell 2. The cell balancing rotation between Cell 1 and Cell 2 continues until all the cells are balanced.

8.4 Cell Balancing Operation

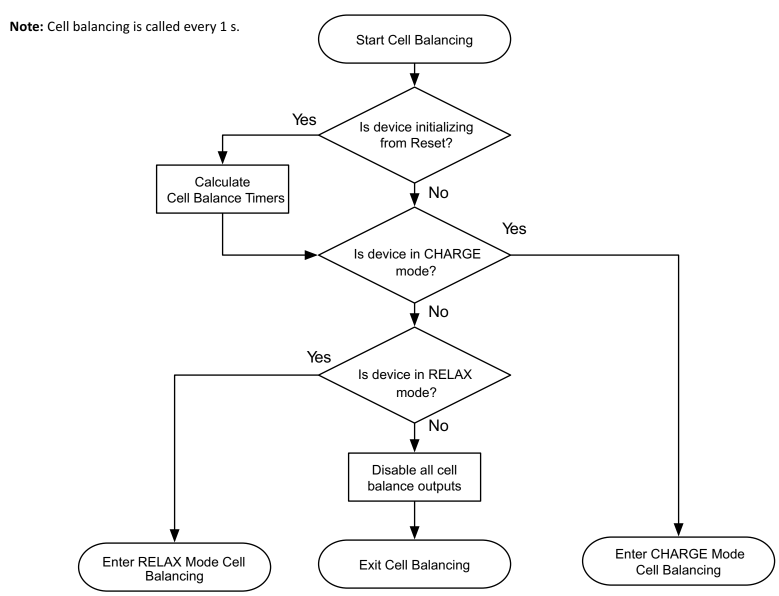


Figure 8-4. Cell Balance Mode Detection

The bq40z60 calls the cell-balancing algorithm every 1 s during normal operation. Cell balancing is not called when the device is in SLEEP mode. All algorithm decisions are made on this same 1-s timer.

In RELAX mode, if cell balancing at rest is enabled, ***Balancing Configuration[CBR]*** = 1, the gauge will verify if the dv/dt condition is met at the entry of the RELAX mode. If so, then the cell balance at rest will start when all of the following conditions are met:

- Any of the pre-calculated Cell Balance Timer is non-zero, AND
- *RelativeStateofCharge()*> ***Min RSOC for Balancing***

The gauge will attempt to re-calculate the cell balancing time in RELAX mode every ***Relax Balance Interval***. The cell balancing time is updated if the following conditions are met:

- The Relax Balance Interval has passed, AND
- A OCV measurement is taken, AND
- The max cell voltage delta > ***Min Start Balance Delta***

On exit of the RELAX mode, cell balancing time is re-calculated as long as a valid OCV update is available.

Note that cell balancing is paused during OCV measurement.

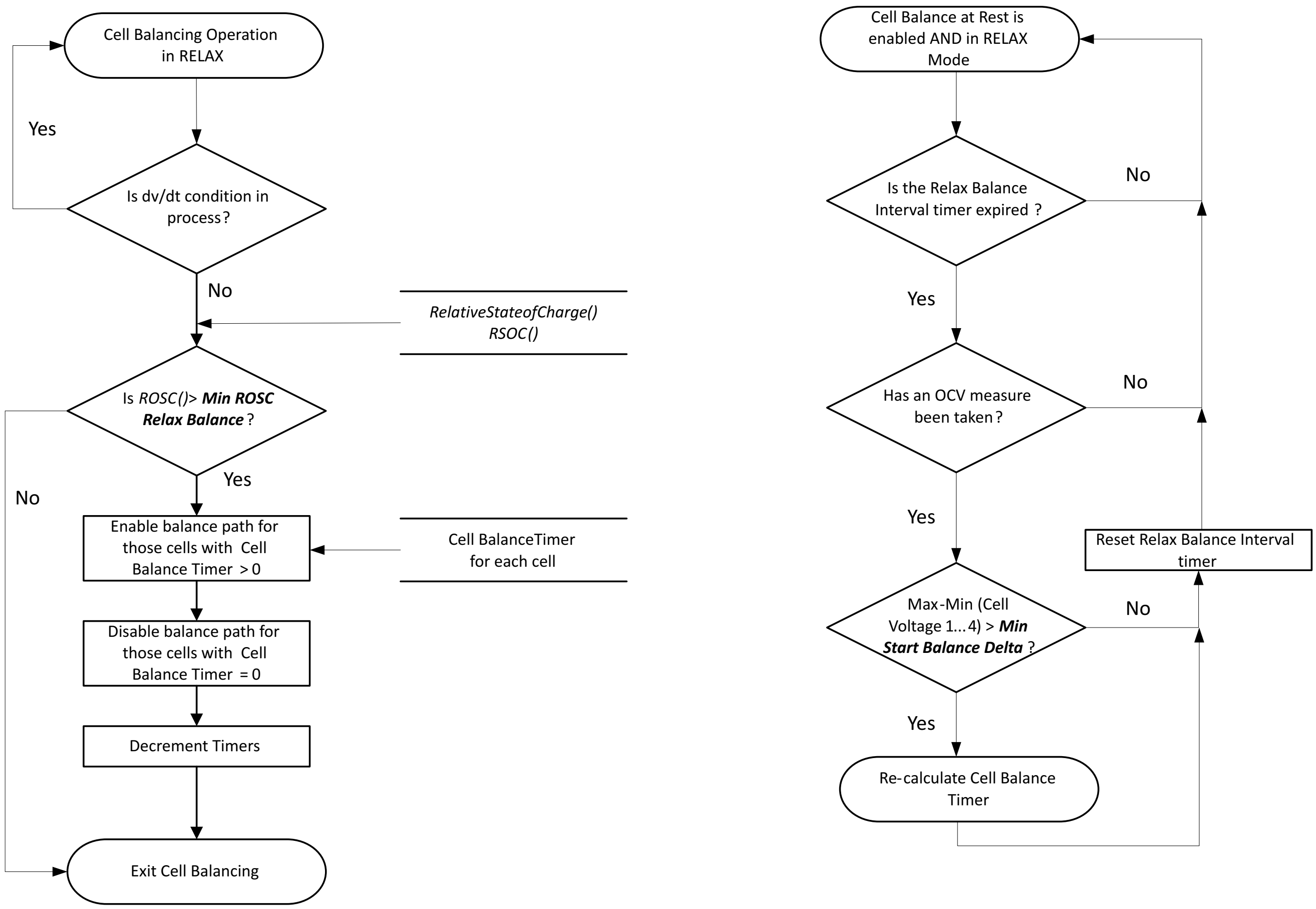


Figure 8-5. Cell Balance Operation in RELAX Mode

When the bq40z60 is in CHARGE mode, then it follows these steps during cell balancing:

(a) Check if any of the pre-calculated Cell Balance Timers are > 0.

(b) The cell balance FETs are turned ON for the corresponding cell balance timers that are ≠ 0.

NOTE: There are no SOC restrictions controlling the enabling of cell balancing in CHARGE mode.

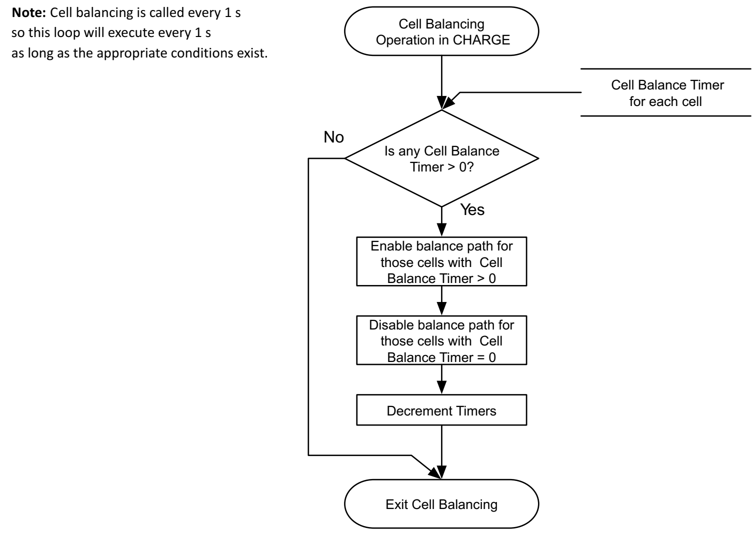


Figure 8-6. Cell Balance Operation in CHARGE Mode

8.5 Cell Balancing Data Flash

8.5.1 Balancing Configuration

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	Balancing Configuration	B1	0	0xff	0x1	hex

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	RSVD	CBR	CBM	CB

RSVD		Reserved - Do not use	
CBR	[2]	Enable Cell Balancing during Rest	**1**: Enabled **0**: Disabled
CBM	[1]	Cell Balancing method selection	**1**: External **0**: Internal
CB	[0]	Enable Cell Balancing	**1**: Enabled **0**: Disabled

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Advanced Charge Algorithm	Cell Balancing Config	Bal Time/mAh Cell 1	U2	0	65535	367	s/mAh
Advanced Charge Algorithm	Cell Balancing Config	Bal Time/mAh Cell 2-4	U2	0	65535	514	s/mAh
Advanced Charge Algorithm	Cell Balancing Config	Min Start Balance Delta	U1	0	255	3	mV
Advanced Charge Algorithm	Cell Balancing Config	Relax Balance Interval	U4	0	4294967295	18000	s
Advanced Charge Algorithm	Cell Balancing Config	Min Rsoc for Balancing	U1	0%	100%	80%	

Lifetime Data Collection

9.1 Description

Useful for analysis, the device has extensive capabilities for logging events over the life of the battery. The Lifetime data collection is enabled by setting *ManufacturingStatus()[LF_EN]* = 1. The data is collected in RAM and only written to DF under the following conditions to avoid wearing out the data flash:

- Every 10 hours if RAM content is different from flash.
- In permanent fail, before data flash updates are disabled.
- A reset counter increments. The lifetime RAM data is reset; therefore, only the reset counters are updated to data flash.
- Before scheduled shutdown
- Before low voltage shutdown and the voltage is above the ***Valid Update Voltage***.

The lifetime data stops collecting under following conditions:

- After permanent fail
- Lifetime Data collection is disabled by setting *ManufacturingStatus()[LF_EN]* = 0.

When the gauge is unsealed, the following *ManufacturingStatus()* can be used for testing lifetime data.

- *Lifetime Data Reset()* can be used to reset the lifetime data.
- *Lifetime Data Flush()* can be used to flush out RAM lifetime data to data flash.
- *Lifetime Data Speedup Mode()* can be used to increase the rate the lifetime data is incremented.

Total firmware Runtime starts when lifetime data is enabled.

- Voltage
  - Max/Min Cell Voltage Each Cell
  - Max Delta Cell Voltage at any given time (that is, the max cell imbalance voltage)
- Current
  - Max Charge/Discharge Current
  - Max Average Discharge Current
  - Max Average Discharge Power
- Safety Events that trigger the *SafetyStatus()* (The 12 most common are tracked.)
  - Number of Safety Events
  - Cycle Count at Last Safety Event(s)
- Charging Events
  - Number of Valid Charge Terminations (That is, the number of times *[VCT]* is set.)
  - Cycle Count at Last Charge Termination
- Gauging Events
  - Number of QMax updates
  - Cycle Count at Last QMax update

  - Number of RA updates and disable
  - Cycle Count at Last RA update and disable
- Power Events
  - Number of Resets, Partial Resets, and Watchdog Resets
  - Number of shutdowns
- Cell Balancing (This data is stored with a resolution of 2 hours up to a limit of 510 hours.)
  - Cell Balancing Time each Cell
- Temperature
  - Max/Min Cell Temp
  - Delta Cell Temp (This is the max delta cell temperature across the thermistors that are used to report cell temperature.)
  - Max/Min Int Temp Sensor
  - Max FET Temp
- Time (This data is stored with a resolution of 2 hours.)
  - Total runtime
  - Time spent different temperature ranges

9.2 Lifetimes Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Cell Balancing	Cb Time Cell 1	U1	0	255	0	2h
Lifetimes	Cell Balancing	Cb Time Cell 2	U1	0	255	0	2h
Lifetimes	Cell Balancing	Cb Time Cell 3	U1	0	255	0	2h
Lifetimes	Cell Balancing	Cb Time Cell 4	U1	0	255	0	2h

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Charging Events	No Valid Charge Term	U2	0	32767	0	events
Lifetimes	Charging Events	Last Valid Charge Term	U2	0	32767	0	cycles

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Current	Max Charge Current	I2	0	32767	0	mA
Lifetimes	Current	Max Discharge Current	I2	–32768	0	0	mA
Lifetimes	Current	Max Avg Dsg Current	I2	–32768	0	0	mA
Lifetimes	Current	Max Avg Dsg Power	I2	–32768	0	0	cW

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Gauging Events	No Of Qmax Updates	U2	0	32767	0	events
Lifetimes	Gauging Events	Last Qmax Update	U2	0	32767	0	cycles
Lifetimes	Gauging Events	No Of Ra Updates	U2	0	32767	0	events
Lifetimes	Gauging Events	Last Ra Update	U2	0	32767	0	cycles
Lifetimes	Gauging Events	No Of Ra Disable	U2	0	32767	0	events
Lifetimes	Gauging Events	Last Ra Disable	U2	0	32767	0	cycles

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Power Events	No Of Shutdowns	U1	0	255	0	events

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Safety Events	No Of COV Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last COV Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of CUV Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last CUV Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OCD1 Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OCD1 Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OCD2 Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OCD2 Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OCC1 Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OCC1 Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OCC2 Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OCC2 Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of AOLD Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last AOLD Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of ASCD Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last ASCD Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of ASCC Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last ASCC Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OTC Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OTC Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OTD Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OTD Event	U2	0	32767	0	cycles
Lifetimes	Safety Events	No Of OTF Events	U2	0	32767	0	events
Lifetimes	Safety Events	Last OTF Event	U2	0	32767	0	cycles

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Temperature	Max Temp Cell	I1	–128	127	–128	°C
Lifetimes	Temperature	Min Temp Cell	I1	–128	127	127	°C
Lifetimes	Temperature	Max Delta Cell Temp	I1	–128	127	0	°C
Lifetimes	Temperature	Max Temp Int Sensor	I1	–128	127	–128	°C
Lifetimes	Temperature	Min Temp Int Sensor	I1	–128	127	127	°C
Lifetimes	Temperature	Max Temp Fet	I1	–128	127	–128	°C

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Time	Total Fw Runtime	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In UT	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In LT	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In STL	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In RT	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In STH	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In HT	U2	0	65535	0	2h
Lifetimes	Time	Time Spent In OT	U2	0	65535	0	2h

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Lifetimes	Voltage	Cell 1 Max Voltage	I2	0	32767	0	mV
Lifetimes	Voltage	Cell 2 Max Voltage	I2	0	32767	0	mV
Lifetimes	Voltage	Cell 3 Max Voltage	I2	0	32767	0	mV
Lifetimes	Voltage	Cell 4 Max Voltage	I2	0	32767	0	mV
Lifetimes	Voltage	Cell 1 Min Voltage	I2	0	32767	32767	mV
Lifetimes	Voltage	Cell 2 Min Voltage	I2	0	32767	32767	mV
Lifetimes	Voltage	Cell 3 Min Voltage	I2	0	32767	32767	mV
Lifetimes	Voltage	Cell 4 Min Voltage	I2	0	32767	32767	mV
Lifetimes	Voltage	Max Delta Cell Voltage	I2	0	32767	0	mV

Device Security

10.1 Description

There are three levels of secured operation within the device. To switch between the levels, different operations are needed with different keys. The three levels are SEALED, UNSEALED, and FULL ACCESS. The device also supports SHA-1 HMAC authentication with the host system.

10.2 SHA-1 Description

The SHA-1 is known as a one-way hash function, meaning there is no known mathematical method of computing the input given only the output. The specification of the SHA-1, as defined by FIPS 180–2, states that the input consists of 512-bit blocks with a total input length less than 2^{64} bits. Inputs that do not conform to integer multiples of 512-bit blocks are padded before any block is input to the hash function. The SHA-1 algorithm outputs 160 bits, commonly referred to as the digest.

(As of April 23, 2004, the latest revision is FIPS 180–2.) SHA-1 or secure hash algorithm is used to compute a condensed representation of a message or data also known as hash.

The device generates a SHA-1 input block of 288 bits (total input = 160-bit message + 128-bit key). To complete the 512-bit block size requirement of the SHA-1, the device pads the key and message with a 1, followed by 159 0s, followed by the 64 bit value for 288 (000...00100100000), which conforms to the pad requirements specified by FIPS 180–2.

Detailed information about the SHA-1 algorithm can be found in the following:

1. http://www.itl.nist.gov/fipspubs/fip180–1.htm
2. http://csrc.nist.gov/publications/fips
3. www.faqs.org/rfcs/rfc3174.html

10.3 HMAC Description

The SHA-1 engine calculates a modified HMAC value. Using a public message and a secret key, the HMAC output is considered a secure fingerprint that authenticates the device used to generate the HMAC.

To compute the HMAC: Let H designate the SHA-1 hash function, M designate the message transmitted to the device, and KD designate the unique 128-bit Unseal/Full Access/Authentication key of the device. HMAC(M) is defined as:

H[KD || H(KD || M)], where || symbolizes an append operation.

The message, M, is appended to the unseal/full access/authentication key, KD, and padded to become the input to the SHA-1 hash. The output of this first calculation is then appended to the unseal/full access/authentication key, KD, padded again, and cycled through the SHA-1 hash a second time. The output is the HMAC digest value.

10.4 Authentication

1. Generate 160-bit message M using a random number generator that meets approved random number generators described in FIPS PUB 140–2.
2. Generate SHA-1 input block B1 of 512 bytes (total input = 128-bit authentication key KD + 160 bit message M + 1 + 159 0s + 100100000).
3. Generate SHA-1 hash HMAC1 using B1.
4. Generate SHA-1 input block B2 of 512 bytes (total input = 128-bit authentication key KD + 160 bit hash HMAC1 + 1 + 159 0s + 100100000).

5. Generate SHA-1 hash HMAC2 using B2.
6. With no active *Authentication()* data waiting, write 160-bit message M to *Authentication()* in the format 0xAABBCCDDEEFFGGHHIIJJKKLLMMNNOOPPQQRRSSTT, where AA is LSB.
7. Wait 250 ms, then read *Authentication()* for HMAC3.
8. Compare host HMAC2 with device HMAC3, it matches, both host and device have the same key KD and device is authenticated.

10.5 Security Modes

10.5.1 FULL ACCESS or UNSEALED to SEALED

The MAC *Seal Device()* command instructs the device to limit access to the SBS functions and data flash space and sets the *[SEC1][SEC0]* flags. In SEALED mode, standard SBS functions have access (per the Smart Battery Data Specification). Most of the extended SBS functions and data flash are not accessible. Once in SEALED mode, the gauge can never permanently return to UNSEALED or FULL ACCESS modes.

10.5.2 SEALED to UNSEALED

SEALED to UNSEALED instructs the device to extend access to the SBS and data flash space and clears the *[SEC1][SEC0]* flags. In UNSEALED mode, all data, SBS, and DF have read/write access. Note that although the gauge accepts writing to most of the SBS commands, the gauge will immediately overwrite the written data, so the write action is ignored. Unsealing is a two-step command performed by writing the first word of the unseal key to *ManufacturerAccess() (MAC)*, followed by the second word of the unseal key to *ManufacturerAccess()*. The two words must be sent within 4 s. The unseal key can be read and changed via the *MAC SecurityKey()* command when in the FULL ACCESS mode. To return to the SEALED mode, either a hardware reset is needed or the *MAC Seal Device()* command is needed to transit from FULL ACCESS or UNSEALED to SEALED.

10.5.3 UNSEALED to FULL ACCESS

UNSEALED to FULL ACCESS instructs the device to allow full access to all SBS commands and data flash. The device is shipped from TI in this mode. The keys for UNSEALED to FULL ACCESS can be read and changed via the MAC command *SecurityKey()* when in FULL ACCESS mode. Changing from UNSEALED to FULL ACCESS is performed by using the *ManufacturerAccess()* command, by writing the first word of the Full Access Key to *ManufacturerAccess()*, followed by the second word of the Full Access Key to *ManufacturerAccess()*. The two words must be sent within 4 s. In FULL ACCESS mode, the command to go to boot ROM can be sent.

SBS Commands

11.1 0x00 ManufacturerAccess() and 0x44 AlternateManufacturerAccess()

*AlternateManufacturerAccess()*provides a method of reading and writing data in the Manufacturer Access System (MAC). The MAC command is sent via *AlternateManufacturerAccess()* by the SMBus block protocol. The result is returned on *AlternateManufacturerAccess()* via an SMBus block read.

Example: Send a MAC *Gauging()* to enable IT via *AlternateManufacturerAccess().*

1. With Impedance Track disabled, send *Gauging()* (0x0021) to *AlternateManufacturerAccess()*
   (a) SMBus block write. Command = 0x44. Data = 21 00 (data must be sent in little endian)
2. IT is enabled, *ManufacturingStatus()[GAUGEN_EN]* = 1.

Example: Read *Chemical ID()* (0x0006) via *AlternateManufacturerAccess()*

1. Send *Chemical ID()* to *AlternateManufacturerAccess().*
   (a) SMBus block write. Command = 0x44. Data sent = 06 00 (data must be sent in little endian)
2. Read the result from *AlternateManufacturerAccess().*
   (a) SMBus block read. Command = 0x44. Data read = 06 00 00 01 (each data entity is returned in little endian).
   (b) The first 2 bytes, “06 00”, is the MAC command.
   (c) The second 2 bytes, “00 01”, is the chem ID returning in little endian. That is 0x0100, chem ID 100.

For backwards compatibility with the bq30zxy families, the previous MAC access via *ManufacturerAccess()* (0x00) as well as the returning data on *ManufacturerData()* are supported. Note that MAC commands are sent through *ManufacturerAccess()* (0x00) by an SMBus write word protocol. The result reading from *ManufacturerData()* does not include the MAC command.

Example: Send a MAC *Gauging()* to enable IT via *ManufacturerAccess().*

1. With Impedance Track disabled, send *Gauging()* (0x0021) to *ManufacturerAccess()*.
   (a) SMBus word write. Command = 0x00. Data = 00 21
2. IT is enabled, *ManufacturingStatus()[GAUGEN_EN]* = 1.

Example: Read *Chemical ID()* (0x0006) via *ManufacturerAccess()*

1. Send *Chemical ID()* to *ManufacturerAccess()*
   (a) SMBus word write. Command = 0x00. Data sent = 00 06
2. Read the result from *ManufacturerData()*
   (a) SMBus block read. Command = 0x23. Data read = 00 01
   (b) That is 0x0100, chem ID 100.

The *ManufacturerAccess()* and *AlternateManufacturerAccess()* are interchangeable. The result can be read from *ManufacturerData()* or *AlternateManufacturerAccess()* regardless of how the MAC command is sent.

Table 11-1. ManufacturerAccess() Command List

FUNCTION	MANUFACTURER ACCESS COMMAND	SBS COMMAND	ACCESS	FORMAT	DATA READ ON 0x44 OR 0x23	AVAILABLE IN SEALED MODE
DeviceType	0x0001		R	Block	Yes	Yes
FirmwareVersion	0x0002		R	Block	Yes	Yes

Table 11-1. ManufacturerAccess() Command List (continued)

FUNCTION	MANUFACTURER ACCESS COMMAND	SBS COMMAND	ACCESS	FORMAT	DATA READ ON 0x44 OR 0x23	AVAILABLE IN SEALED MODE
HardwareVersion	0x0003		R	Block	Yes	Yes
IFChecksum	0x0004		R	Block	Yes	Yes
StaticDFSignature	0x0005		R	Block	Yes	Yes
ChemID	0x0006		R	Block	Yes	Yes
StaticChemDFSignature	0x0008		R	Block	Yes	Yes
AllDFSignature	0x0009		R	Block	Yes	Yes
ShutdownMode	0x0010		W	—	—	Yes
SleepMode	0x0011		W	—	—	—
AutoCCOfset	0x0013		W	—	—	—
FuseToggle	0x001D		W	—	—	—
PrechargeFET	0x001E		W	—	—	—
ChargeFET	0x001F		W	—	—	—
DischargeFET	0x0020		W	—	—	—
Gauging	0x0021		W	—	—	—
FETControl	0x0022		W	—	—	—
LifetimeDataCollection	0x0023		W	—	—	—
PermanentFailure	0x0024		W	—	—	—
BlackBoxRecorder	0x0025		W	—	—	—
Fuse	0x0026		W	—	—	—
LEDDisplayEnable	0x0027		W	—	—	—
LifetimeDataReset	0x0028		W	—	—	—
PermanentFailureData Reset	0x0029		W	—	—	—
LifetimeDataFlush	0x002E		W	—	—	—
LifetimeDataSpeedUp Mode	0x002F		W	—	—	—
BlackBoxRecorderReset	0x002A		W	—	—	—
LEDToggle	0x002B		W	—	—	—
LEDDisplayPress	0x002C		W	—	—	—
CalibrationMode	0x002D		W	—	—	—
SealDevice	0x0030		W	—	—	—
SecurityKeys	0x0035		R/W	Block	Yes	—
AuthenticationKey	0x0037		R/W	Block	—	—
DeviceReset	0x0041		W	—	—	—
SafetyAlert	0x0050	0x50	R	Block	Yes	Yes
SafetyStatus	0x0051	0x51	R	Block	Yes	Yes
PFAlert	0x0052	0x52	R	Block	Yes	Yes
PFStatus	0x0053	0x53	R	Block	Yes	Yes
OperationStatus	0x0054	0x54	R	Block	Yes	Yes
ChargingStatus	0x0055	0x55	R	Block	Yes	Yes
GaugingStatus	0x0056	0x56	R	Block	Yes	Yes
ManufacturingStatus	0x0057	0x57	R	Block	Yes	Yes
AFERegister	0x0058	0x58	R	Block	Yes	Yes
LifetimeDataBlock1	0x0060	0x60	R	Block	Yes	Yes
LifetimeDataBlock2	0x0061	0x61	R	Block	Yes	Yes
LifetimeDataBlock3	0x0062	0x62	R	Block	Yes	Yes
ManufacturerInfo	0x0070	0x70	R	Block	Yes	Yes
DAStatus1	0x0071	0x71	R	Block	Yes	Yes
DAStatus2	0x0072	0x72	R	Block	Yes	Yes
GaugeStatus1	0x0073	0x73	R	Block	Yes	Yes
GaugeStatus2	0x0074	0x74	R	Block	Yes	Yes

Table 11-1. ManufacturerAccess() Command List (continued)

FUNCTION	MANUFACTURER ACCESS COMMAND	SBS COMMAND	ACCESS	FORMAT	DATA READ ON 0x44 OR 0x23	AVAILABLE IN SEALED MODE
GaugeStatus3	0x0075	0x75	R	Block	Yes	Yes
StateofHealth	0x0077		R	Block	Yes	Yes
CHGR_EN	0x00C0		W	—	—	No
CVRD_ARM	0x00C1		W	—	—	Yes
ACFETEST	0x00C2		W	—	—	No
CHGONTEST	0x00C3		W	—	—	No
ROMMode	0x0F00		W	—	—	—
ExitCalibrationOutput	0xF080		R/W	Block	Yes	—
OutputCCandADCfor Calibration	0xF081		R/W	Block	Yes	—
OutputShortedCCand ADCforCalibration	0xF082		R/W	Block	Yes	—

11.1.1 *ManufacturerAccess() 0x0000*

A read word on this command returns the low word (16 bits) *OperationStatus()* data.

11.1.2 *ManufacturerAccess() 0x0001 Device Type*

The device can be checked for the IC part number via this command that returns 2 bytes in Little Endian on *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.3 *ManufacturerAccess() 0x0002 Firmware Version*

The device can be checked for the firmware version of the IC via this command that returns 11 bytes on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTE	DESCRIPTION
1:0	Device Number
3:2	Version
5:4	Build Number
6	Firmware Type
8:7	Impedance Track Version
9	Reserved
10	Reserved

11.1.4 *ManufacturerAccess() 0x0003 Hardware Version*

The hardware revision is returned on a subsequent read of *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.5 *ManufacturerAccess() 0x0004 Instruction Flash Signature*

The IF signature returns on a subsequent read on *AlternateManufacturerAccess()* or *ManufacturerData()* after a wait time of 250 ms.

11.1.6 *ManufacturerAccess() 0x0005 Static DF Signature*

The 2-byte signature of all static DF returns on a subsequent read of *AlternateManufacturerAccess()* or *ManufacturerData()* after a wait time of 250 ms.

NOTE: MSB is set to 1 if the calculated signature does not match the signature stored in DF.

11.1.7 ManufacturerAccess() 0x0006 Chemical ID

The 2 byte chemical ID of the OCV tables used in the gauging algorithm is returned on a subsequent read of *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.8 ManufacturerAccess() 0x0008 Static Chem DF Signature

The 2-byte signature of all static chemistry DF returns on subsequent read of *AlternateManufacturerAccess()* or *ManufacturerData()* after a wait time of 250 ms.

NOTE: MSB is set to 1 if the calculated signature does not match the signature stored in DF.

11.1.9 ManufacturerAccess() 0x0009 All DF Signature

The 2-byte signature of all DF parameters returns on a subsequent read on *AlternateManufacturerAccess()* or *ManufacturerData()* after a wait time of 250 ms.

NOTE: MSB is set to 1 if the calculated signature does not match the signature stored in DF, but it is normally expected that this signature will change due to update of lifetime, gauging, and other information.

11.1.10 ManufacturerAccess() 0x0010 SHUTDOWN Mode

To reduce power consumption, the device can be sent to SHUTDOWN mode before shipping. After sending this command, *OperationStatus()[SDM]* sets to **1**, an internal counter will start and the CHG and DSG FETs will be turned off when the counter reaches ***Ship FET Off Time***. When the counter reaches Ship Delay time, the device will enter SHUTDOWN mode if no charger is detected.

If the device is sealed, this feature requires the command to be sent twice in a row within 4 seconds (for safety purposes).

To wake up the device, a voltage > ***Charger Present Threshold*** must apply to the VACP pin. The device will power up and a full reset is applied.

11.1.11 ManufacturerAccess() 0x0011 SLEEP Mode

If the sleep conditions are met, the device can be sent to sleep with *ManufacturerAccess()*.

STATUS	CONDITION	ACTION
Enable	0x0011 to *ManufacturerAccess()*	*OperationStatus()[SLEEPM]* = 1
Activate	***DA Configuration[NR]*** = 0 **AND** *OperationStatus()[PRES]* = 0 **AND** | *Current()* | < ***Power:Sleep Current***	Turn off CHG FET, DSG FET, PCHG FET Device goes to sleep. Device wakes up every ***Power:Sleep Voltage Time*** period to measure voltage and temperature. Device wakes up every ***Power:Sleep Current Time*** period to measure current.
Activate	***DA Configuration[NR]*** = 1 **AND** | *Current()* | < ***Power:Sleep Current***	Turn off DSG FET, PCHG FET Turn off CHG FET Device goes to sleep. Device wakes up every Power***:Sleep Voltage Time*** period to measure voltage and temperature. Device wakes up every Power***:Sleep Current Time*** period to measure current.
Exit	***DA Configuration[NR]*** = 0 **AND** *OperationStatus()[PRES]* = 1	*OperationStatus()[SLEEPM]* = 0 Return to NORMAL mode
Exit	| *Current()* | > Configuration:Sleep Current	*OperationStatus()[SLEEPM]* = 0 Return to NORMAL mode
Exit	Wake Comparator trips	*OperationStatus()[SLEEPM]* = 0 Return to NORMAL mode
Exit	*SafetyAlert()*flag or *PFAlert()* flag set	*OperationStatus()[SLEEPM]* = 0 Return to NORMAL mode

11.1.12 ManufacturerAccess() 0x0013 AutoCCOfset

This command manually starts an Auto CC Offset calibration, which takes approximately 16 s. After completion this value is updated to CC Auto Offset and is used for cell current measurement. The cell current measurement is a current measurement taken simultaneously as the cell voltage measurement.

11.1.13 ManufacturerAccess() 0x001D Fuse Toggle

This command manually activates/deactivates the FUSE output for testing during manufacturing. If *OperationStatus()[FUSE]* = **0**, indicating the FUSE output is low, sending this command toggles the FUSE output to be high, and *OperationStatus()[FUSE]* is set to **1**. *OperationStatus()[FUSE]* will be cleared to **0** if this command is sent when *OperationStatus()[FUSE]* is **1.**

11.1.14 ManufacturerAccess() 0x001E PCHG FET Toggle

This command turns on/off PCHG FET drive function for testing during manufacturing. If *ManufacturingStatus[PCHG_TEST]* = **0**, sending this command will turn on the PCHG FET and set *ManufacturingStatus[PCHG_TEST]* to **1** and vice versa. This toggling command is only enabled if *ManufacturingStatus[FET_EN]* = **0**, indicating a FW FET control is not active and manual control is allowed. A reset clears the *ManufacturingStatus[PCHG_TEST]* flag to **0** and turns off the PCHG FET.

11.1.15 ManufacturerAccess() 0x001F CHG FET Toggle

This command turns on/off CHG FET drive function for testing during manufacturing. If *ManufacturingStatus[CHG_TEST]* = **0**, sending this command turns on the CHG FET and *ManufacturingStatus[CHG_TEST]* is set to **1** and vice versa. This toggling command is only enabled if *ManufacturingStatus[FET_EN]* = 0, indicating a FW FET control is not active and manual control is allowed. A reset clears*ManufacturingStatus[CHG_TEST]* flag to **0** and turns off the CHG FET.

11.1.16 ManufacturerAccess() 0x0020 DSG FET Toggle

This command turns on/off DSG FET drive function for testing during manufacturing. If the *ManufacturingStatus[DSG_TEST]* = **0**, sending this command turns on the DSG FET and the *ManufacturingStatus[DSG_TEST]* = **1** and vice versa. This toggling command is only enabled if *ManufacturingStatus[FET_EN]* = **0**, indicating a FW FET control is not active and manual control is allowed. A reset clears the *ManufacturingStatus[DSG_TEST]* flag to **0** and turns off the DSG FET.

11.1.17 ManufacturerAccess() 0x0021 Gauging

This command enables or disables the gauging function for testing during manufacturing. The initial setting is loaded from *MfgStatusInit[GAUGE_EN]*. If *ManufacturingStatus[GAUGE_EN]* = **0**, sending this command will enable gauging and *ManufacturingStatus[GAUGE_EN]* is set to **1** and vice versa.

In UNSEALED mode, the *ManufacturingStatus[GAUGE_EN]* status is copied to *MfgStatusInit[GAUGE_EN]* on a reset. Therefore, the device remains on its latest gauging status prior to a reset.

11.1.18 ManufacturerAccess() 0x0022 FET Control

This command disables/enables control of the CHG, DSG, and PCHG FET by the firmware. The initial setting is loaded from *MfgStatusInit[FET_EN]*. If *ManufacturingStatus[FET_EN]* = **0**, sending this command allows the FW to control the PCHG, CHG, and DSG FETs and the *ManufacturingStatus[FET_EN]* is set to **1** and vice versa.

In UNSEALED mode, the *ManufacturingStatus[FET_EN]* status is copied to ***MfgStatusInit[FET_EN]*** on a reset. Hence, the device will remain on its latest FET control status prior to a reset.

11.1.19 ManufacturerAccess() 0x0023 Lifetime Data Collection

This command disables/enables Lifetime data collection to help streamline production testing. The initial setting is loaded from *MfgStatusInit[LF_EN]*. If the *ManufacturingStatus[LF_EN]* = **0**, sending this command starts the Lifetime Data collection and *ManufacturingStatus[LF_EN]* is set to **1** and vice versa.

In UNSEALED mode, the *ManufacturingStatus[LF_EN]* status is copied to *MfgStatusInit[LF_EN]* on a reset. Therefore, the device remains on its latest Lifetime Data Collection setting prior to a reset.

11.1.20 ManufacturerAccess() 0x0024 Permanent Failure

This command disables/enables Permanent Failure to help streamline production testing.

The initial setting is loaded from *MfgStatusInit[PF_EN]*. If *ManufacturingStatus[PF_EN]* = **0**, sending this command enables Permanent Failure protections and *ManufacturingStatus[PF_EN]* is set to **1** and vice versa.

In UNSEALED mode, *ManufacturingStatus[PF_EN]* status is copied to *MfgStatusInit[PF_EN]* on a reset. Therefore, the device remains at its PF enable/disable setting prior to a reset.

11.1.21 ManufacturerAccess() 0x0025 Black Box Recorder

This command enables/disables black box recorder function to help streamline production testing. The initial setting is loaded from *MfgStatusInit[BBR_EN]*. If *ManufacturingStatus[BBR_EN]* = **0**, sending this command enables the Black Box Recorder and *ManufacturingStatus[BBR_EN]* is set to **1** and vice versa.

In UNSEALED mode, the *ManufacturingStatus[BBR_EN]* status is copied to *MfgStatusInit[BBR_EN]* on a reset. Therefore, the device remains on its latest Black Box Recorder enable/disable setting prior to a reset.

11.1.22 ManufacturerAccess() 0x0026 Fuse

This command disables/enables firmware-based fuse activation for testing during manufacturing. The initial setting is loaded from *MfgStatusInit[FUSE_EN]*. If *ManufacturingStatus[FUSE_EN]* = **0**, sending this command allows the FW to control the FUSE output and the *ManufacturingStatus[FUSE_EN]* is set to **1** and vice versa.

In UNSEALED mode, the *ManufacturingStatus[FUSE_EN]* status is copied to *MfgStatusInit[FUSE_EN]* on a reset. Therefore, the device remains on its latest Fuse Control setting prior to a reset.

11.1.23 ManufacturerAccess() 0x0027 LED DISPLAY Enable

This command enables or disables the LED display function to ease testing during manufacturing. The initial setting is loaded from *MfgStatusInit[LED_EN]*. If the *ManufacturingStatus[LED_EN]* = 0, sending this command will enable LED display and the *ManufacturingStatus[LED_EN]* = 1 and vice versa. In UNSEALED mode, the *ManufacturingStatus[LED_EN]* status is copied to *MfgStatusInit[LED_EN]* on a reset. Therefore, the device remains to its latest setting prior to a reset.

11.1.24 ManufacturerAccess() 0x0028 Lifetime Data Reset

If *ManufacturingStatus[LF_EN]* = **1**, sending this command resets Lifetime data in data flash to help streamline production testing.

11.1.25 ManufacturerAccess() 0x0029 Permanent Fail Data Reset

If *ManufacturingStatus[PF_EN]* = **1**, sending this command resets PF data in data flash to help streamline production testing.

11.1.26 ManufacturerAccess() 0x002A Black Box Recorder Reset

If *ManufacturingStatus[BBR_EN]* = **1**, sending this command resets the black box recorder data in data flash to help streamline production testing.

11.1.27 ManufacturerAccess() 0x002B LED TOGGLE

This command toggles the LED display on or off to help streamline testing during manufacturing. When the LED display is off, the *OperationStatus[LED]* = 0. Sending this command turns on all LED displays with *OperationStatus[LED]* set to 1, and vice versa.

11.1.28 ManufacturerAccess() 0x002C LED DISPLAY PRESS

This command simulates a low-high-low detection of the $\overline{\text{DISP}}$ pin, activating the LED display according to the LED Support data flash setting.

11.1.29 ManufacturerAccess() 0x002D CALIBRATION Mode

This command disables/enables entry into CALIBRATION mode. Status is indicated by the *ManufacturingStatus()[CAL_EN]* flag. CALIBRATION mode is disabled upon a reset.

STATUS	CONDITION	ACTION
Disable	*ManufacturingStatus()[CAL_EN]* = 1 **AND** 0x002D to *ManufacturerAccess()*	*ManufacturingStatus()[CAL_EN]* = 0 Disable output of ADC and CC raw data on *ManufacturingData()*
Enable	*ManufacturingStatus()[CAL_EN]* = 0 **AND** 0x002D to *ManufacturerAccess()*	*ManufacturingStatus()[CAL_EN]* = 1 Enable output of ADC and CC raw data on *ManufacturingData()* , controllable with 0xF081 and 0xF082 on *ManufacturerAccess()*

11.1.30 ManufacturerAccess() 0x002E Lifetime Data Flash

This command flushes the RAM lifetime data-to-data flash to help streamline evaluation testing.

11.1.31 ManufacturerAccess() 0x002F Lifetime Data SPEED UP Mode

Lifetime Data generally updates at 10-hr intervals. For ease of evaluation testing, this command enables a lifetime SPEED UP mode, and Lifetime Data will be updated approximately every 5 s. When the lifetime SPEED UP mode is enabled, *ManufacturingStatus[LT_TEST]* = **1**.

To disable SPEED UP mode, send the command again.

11.1.32 ManufacturerAccess() 0x0030 Seal Device

This command seals the device for the field, disabling certain SBS commands and access to data flash. See the SBS commands description for details.

When the device is sealed, *OperationStatus()[SEC1, SEC0]* = 2'b11.

11.1.33 ManufacturerAccess() 0x0035 Security Keys

This is a read/write command for the 8 bytes of UNSEAL and FULL ACCESS keys.

When reading the keys, data can be read from *ManufacturerData()* or *Alternate ManufacturerAccess()*. The keys are return in the following format: aaAAbbBBccCCddDD, where:

BYTES	DESCRIPTION
1:0	First word of the UNSEAL key
3:2	Second word of the UNSEAL key
5:4	First word of the FULL ACCESS key
7:6	Second word of the FULL ACCESS key

The default UNSEAL key is 0x0414 and 0x3672. The default FULL ACCESS key is 0xFFFF and 0xFFFF.

NOTE: It is highly recommend to change the UNSEAL and FULL ACCESS keys from default.

The keys can only be changed through the Alternate ManufacturerAccess().

The first word of the keys cannot be the same or match any existing MAC command. That means an UNSEAL key with 0xABCD 0x1234 and FULL ACCESS key with 0xABCD 0x5678 are not valid because the first word is the same.

Example: Change UNSEAL key to 0x1234, 0x5678, and leave the FULL ACCESS as default.
Send an SMBus block write with Command = 0x44.

Data = MAC command + New UNSEAL key + New FULL ACCESS KEY
= 35 00 34 12 78 56 FF FF FF FF

11.1.34 ManufacturerAccess() 0x0037 Authentication Key

This command enters a new authentication key into the device.

STATUS	CONDITION	ACTION
Initiate	*OperationStatus()[SEC1,SEC0]*= 0,1 **AND** 0x0037 to *ManufacturerAccess()*	*OperationStatus()[AUTH]*= 1 160-bit random number available at *ManufacturerInput()*
Enter Key	Correct 128-bit Key written to *ManufacturerInput()* in LSB to MSB format	Wait time 250 ms *OperationStatus()[AUTH]* = 0 Device returns 160-bit HMAC digest at *ManufacturerInput()* in LSB to MSB format. The HMAC digest was calculated using the random number + key. Compare with own calculations, check the validity of the key.

11.1.35 ManufacturerAccess() 0x0041 Device Reset

This command resets the device.

NOTE: Command 0x0012 also resets the device, providing backwards compatibility with the bq30z5x family of devices.

11.1.36 ManufacturerAccess() 0x0050 SafetyAlert

This command returns the *4 bytes of SafetyAlert()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.36.1 SafetyAlert() High Word

B31	B30	B29	B28	B27	B26	B25	B24
RSVD	RSVD	ACOV	COT	UTD	UTC	PCHGC	CHGV
RSVD		Reserved - Do not use					
UTD	[27]	Under temperature During Discharge				**1**: Detected **0**: Undetected	
UTC	[26]	Under temperature During Charge				**1**: Detected **0**: Undetected	
PCHGC	[25]	Over Pre-Charge Current				**1**: Detected **0**: Undetected	
CHGV	[24]	Over Charging Voltage				**1**: Detected **0**: Undetected	
B23	**B22**	**B21**	**B20**	**B19**	**B18**	**B17**	**B16**
CHGC	OC	RSVD	CTO	PTOS	RSVD	RSVD	OTF
CHGC	[23]	Over Charging Current				**1**: Detected **0**: Undetected	
OC	[22]	Over Charge				**1**: Detected **0**: Undetected	
CTO	[20]	Charge Timeout				**1**: Detected **0**: Undetected	
PTOS	[19]	Precharge Timeout Suspend				**1**: Detected **0**: Undetected	
OTF	[16]					**1**: Detected **0**: Undetected	

11.1.36.2 SafetyAlert() Low Word

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	CUVC	OTD	OTC	ASCDL	RSVD	ASCCL	RSVD
RSVD		Reserved - Do not use					
CUVC	[14]	Cell Undervoltage Compensated				**1**: Detected **0**: Undetected	
OTD	[13]	Over Temperature during Discharge				**1**: Detected **0**: Undetected	
OTC	[12]	Over Temperature during Charge				**1**: Detected **0**: Undetected	
ASCDL	[11]	Short-circuit during Discharge Latch				**1**: Detected **0**: Undetected	
ASCCL	[9]	Short-circuit during Charge Latch				**1**: Detected **0**: Undetected	
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
AOLDL	AOLD	OCD2	OCD1	OCC2	OCC1	COV	CUV
AOLDL	[7]	Overload during Discharge Latch				**1**: Detected **0**: Undetected	
AOLD	[6]	Overload during Discharge				**1**: Detected **0**: Undetected	
OCD2	[5]	Over Current during Discharge 2				**1**: Detected **0**: Undetected	
OCD1	[4]	Over Current during Discharge 1				**1**: Detected **0**: Undetected	
OCC2	[3]	Over Current during Charge 2				**1**: Detected **0**: Undetected	
OCC1	[2]	Over Current during Charge 1				**1**: Detected **0**: Undetected	
COV	[1]	Cell Over Voltage				**1**: Detected **0**: Undetected	
CUV	[0]	Cell Under Voltage				**1**: Detected **0**: Undetected	

11.1.37 ManufacturerAccess() 0x0051 SafetyStatus

This command returns the *4 bytes of SafetyStatus()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.37.1 SafetyStatus() High Word

B31	B30	B29	B28	B27	B26	B25	B24
RSVD	RSVD	ACOV	COT	UTD	UTC	PCHGC	CHGV
RSVD		Reserved - Do not use					
UTD	[27]	Under temperature During Discharge				**1**: Detected **0**: Undetected	
UTC	[26]	Under temperature During Charge				**1**: Detected **0**: Undetected	
PCHGC	[25]	Over Pre-Charge Current				**1**: Detected **0**: Undetected	
CHGV	[24]	Over Charging Voltage				**1**: Detected **0**: Undetected	
B23	**B22**	**B21**	**B20**	**B19**	**B18**	**B17**	**B16**
CHGC	OC	RSVD	CTO	PTOS	RSVD	RSVD	OTF
RSVD		Reserved - Do not use					
CHGC	[23]	Over Charging Current				**1**: Detected **0**: Undetected	
OC	[22]	Over Charge				**1**: Detected **0**: Undetected	
CTO	[20]	Charge Timeout				**1**: Detected **0**: Undetected	
PTOS	[19]	Precharge Timeout Suspend				**1**: Detected **0**: Undetected	
OTF	[16]					**1**: Detected **0**: Undetected	

11.1.37.2 SafetyStatus() Low Word

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	CUVC	OTD	OTC	ASCDL	RSVD	ASCCL	RSVD
RSVD		Reserved - Do not use					
CUVC	[14]	Cell Undervoltage Compensated				**1**: Detected **0**: Undetected	
OTD	[13]	Over Temperature during Discharge				**1**: Detected **0**: Undetected	
OTC	[12]	Over Temperature during Charge				**1**: Detected **0**: Undetected	
ASCDL	[11]	Short-circuit during Discharge Latch				**1**: Detected **0**: Undetected	
ASCCL	[9]	Short-circuit during Charge Latch				**1**: Detected **0**: Undetected	
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
AOLDL	AOLD	OCD2	OCD1	OCC2	OCC1	COV	CUV
AOLDL	[7]	Overload during Discharge Latch				**1**: Detected **0**: Undetected	
AOLD	[6]	Overload during Discharge				**1**: Detected **0**: Undetected	
OCD2	[5]	Over Current during Discharge 2				**1**: Detected **0**: Undetected	
OCD1	[4]	Over Current during Discharge 1				**1**: Detected **0**: Undetected	
OCC2	[3]	Over Current during Charge 2				**1**: Detected **0**: Undetected	
OCC1	[2]	Over Current during Charge 1				**1**: Detected **0**: Undetected	
COV	[1]	Cell Over Voltage				**1**: Detected **0**: Undetected	
CUV	[0]	Cell Under Voltage				**1**: Detected **0**: Undetected	

11.1.38 ManufacturerAccess() 0x0052 PFAlert

This command, available on *AlternateManufacturerAccess()* or *ManufacturerData()*, returns indications of pending safety issues, such as temperature or voltages that have risen high enough to trigger a *PFAlert* failure. 4 bytes are returned.

11.1.38.1 PFAlert() High Word

B31	B30	B29	B28	B27	B26	B25	B24
TS4	TS3	TS2	TS1	RSVD	RSVD	OPNC	RSVD

RSVD		Reserved - do not use.	
TS4	[31]	Open Thermistor - TS4 Failure	**1**: Detected **0**: Undetected
TS3	[30]	Open Thermistor - TS3 Failure	**1**: Detected **0**: Undetected
TS2	[29]	Open Thermistor - TS2 Failure	**1**: Detected **0**: Undetected
TS1	[28]	Open Thermistor - TS1 Failure	**1**: Detected **0**: Undetected
OPNC	[25]	Open Cell Tab Connection Failure	**1**: Detected **0**: Undetected

B23	B22	B21	B20	B19	B18	B17	B16
RSVD	2LVL	AFEC	AFER	FUSE	RSVD	DFETF	CFETF

RSVD		Reserved - do not use.	
2LVL	[22]	Second Level Protector Failure	**1**: Detected **0**: Undetected
AFEC	[21]	AFE Communication Failure	**1**: Detected **0**: Undetected
AFER	[20]	AFE Register Failure	**1**: Detected **0**: Undetected
FUSE	[19]	Chemical Fuse Failure	**1**: Detected **0**: Undetected
DFETF	[17]	Discharge FET Failure	**1**: Detected **0**: Undetected
CFETF	[16]	Charge FET Failure	**1**: Detected **0**: Undetected

11.1.38.2 PFAlert() Low Word

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	RSVD	VIMA	VIMR	CD	IMP	CB

RSVD		Reserved - do not use.	
VIMA	[12]	Voltage Imbalance while Pack Active	**1**: Detected **0**: Undetected
VIMR	[11]	Voltage Imbalance while Pack Resting	**1**: Detected **0**: Undetected
CD	[10]	Capacity Degradation Failure	**1**: Detected **0**: Undetected
IMP	[9]	Impedance Failure	**1**: Detected **0**: Undetected
CB	[8]	Cell Balancing Failure	**1**: Detected **0**: Undetected

B7	B6	B5	B4	B3	B2	B1	B0
QIM	SOTF	RSVD	SOT	SOCD	SOCC	SOV	SUV

QIM	[7]	QMax Imbalance Failure	**1**: Detected **0**: Undetected
SOTF	[6]	Safety Over-Temperature Failure	**1**: Detected **0**: Undetected
SOT	[4]	Safety Over-Temperature Cell Failure	**1**: Detected **0**: Undetected
SOV	[1]	Safety Cell Over-Voltage Failure	**1**: Detected **0**: Undetected
SUV	[0]	Safety Cell Under-Voltage Failure	**1**: Detected **0**: Undetected

Related Data Flash and SBS Commands	
DF	Configuration:Registers(64):Permanent Fail Cfg(6)
SBS	PFAlert2(0x6A), PFStatus(0x053), PFStatus2(0x6B)

11.1.39 ManufacturerAccess() 0x0053 PFStatus

This command returns the 4 bytes of *PFStatus()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.39.1 PFStatus() High Word

B31	B30	B29	B28	B27	B26	B25	B24
TS4	TS3	TS2	TS1	RSVD	RSVD	OPNC	RSVD
RSVD		Reserved - do not use.					
TS4	[31]	Open Thermistor - TS4 Failure				**1**: Detected **0**: Undetected	
TS3	[30]	Open Thermistor - TS3 Failure				**1**: Detected **0**: Undetected	
TS2	[29]	Open Thermistor - TS2 Failure				**1**: Detected **0**: Undetected	
TS1	[28]	Open Thermistor - TS1 Failure				**1**: Detected **0**: Undetected	
OPNC	[25]	Open Cell Tab Connection Failure				**1**: Detected **0**: Undetected	
B23	**B22**	**B21**	**B20**	**B19**	**B18**	**B17**	**B16**
RSVD	2LVL	AFEC	AFER	FUSE	RSVD	DFETF	CFETF
RSVD		Reserved - do not use.					
2LVL	[22]	Second Level Protector Failure				**1**: Detected **0**: Undetected	
AFEC	[21]	AFE Communication Failure				**1**: Detected **0**: Undetected	
AFER	[20]	AFE Register Failure				**1**: Detected **0**: Undetected	
FUSE	[19]	Chemical Fuse Failure				**1**: Detected **0**: Undetected	
DFETF	[17]	Discharge FET Failure				**1**: Detected **0**: Undetected	
CFETF	[16]	Charge FET Failure				**1**: Detected **0**: Undetected	

11.1.39.2 PFStatus() Low Word

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	RSVD	VIMA	VIMR	CD	IMP	CB
RSVD		Reserved - do not use.					
VIMA	[12]	Voltage Imbalance while Pack Active				**1**: Detected **0**: Undetected	
VIMR	[11]	Voltage Imbalance while Pack Resting				**1**: Detected **0**: Undetected	
CD	[10]	Capacity Degradation Failure				**1**: Detected **0**: Undetected	
IMP	[9]	Impedance Failure				**1**: Detected **0**: Undetected	
CB	[8]	Cell Balancing Failure				**1**: Detected **0**: Undetected	
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
QIM	SOTF	RSVD	SOT	SOCD	SOCC	SOV	SUV
RSVD		Reserved - do not use.					
QIM	[7]	QMax Imbalance Failure				**1**: Detected **0**: Undetected	
SOTF	[6]	Safety Over-Temperature Failure				**1**: Detected **0**: Undetected	
SOT	[4]	Safety Over-Temperature Cell Failure				**1**: Detected **0**: Undetected	
SOV	[1]	Safety Cell Over-Voltage Failure				**1**: Detected **0**: Undetected	
SUV	[0]	Safety Cell Under-Voltage Failure				**1**: Detected **0**: Undetected	

11.1.40 ManufacturerAccess() 0x0054 OperationStatus

This command returns the 4 bytes of *OperationStatus()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.40.1 OperationStatus() High Word

B31	B30	B29	B28	B27	B26	B25	B24
RSVD	RSVD	EMSHUT	CB	SLPCC	SLPAD	SMBLCAL	INIT

RSVD		Reserved - do not use	
EMSHUT	[29]	Emergency Shutdown	**1**: Active **0**: Inactive
CB	[28]	Cell Balancing	**1**: Active **0**: Inactive
SLPCC	[27]	CC Measurement in SLEEP mode	**1**: Active **0**: Inactive
SLPAD	[26]	ADC Measurement in SLEEP mode	**1**: Active **0**: Inactive
SMBLCAL	[25]	Auto CC calibration when the bus is low	**1**: Active **0**: Inactive
INIT	[24]	Initialization after full reset	**1**: Active **0**: Inactive

B23	B22	B21	B20	B19	B18	B17	B16
SLEEPM	XL	CAL_OFFSET	CAL	AUTOCALM	AUTH	LED	SDM

SLEEPM	[23]	SLEEP mode triggered via command	**1**: Active **0**: Inactive
XL	[22]	400 kHz SMBus mode	**1**: Active **0**: Inactive
CAL_OFFSET	[21]	Calibration output (raw CC) generated when *OutputShortedCCADCCal()* sent	**1**: Data available **0**: Data unavailable
CAL	[20]	Calibration output (raw ADC and CC) generated when *OutputCCADCCal()* **or** *OutputShortedCCADCCal()* sent	**1**: Data available **0**: Data unavailable
AUTOCALM	[19]	Auto CC Offset Calibration by MAC *AutoCCOffset()*	**1**: Active **0**: Inactive
AUTH	[18]	Authentication in progress	**1**: Active **0**: Inactive
LED	[17]	LED Display	**1**: Active **0**: Inactive
SDM	[16]	Shutdown triggered via command	**1**: Active **0**: Inactive

11.1.40.2 OperationStatus() Low Word

B15	B14	B13	B12	B11	B10	B9	B8
SLEEP	XCHG	XDSG	PF	SS	SDV	SEC[1]	SEC[0]

SLEEP	[15]	Sleep mode conditions met	**1**: Active **0**: Inactive
XCHG	[14]	Charging disabled	**1**: Active **0**: Inactive
XDSG	[13]	Discharging disabled	**1**: Active **0**: Inactive
PF	[12]	Permanent Fault mode	**1**: Active **0**: Inactive
SS	[11]	Safety mode	**1**: Active **0**: Inactive
SDV	[10]	Shutdown triggered via low pack voltage	**1**: Active **0**: Inactive
SEC[1:0]	[9:8]	Security Status	

B7	B6	B5	B4	B3	B2	B1	B0
BTP_INT	ACLW	FUSE	ACFET	PCHG	CHG	DSG	PRES

BTP_INT	[7]	Battery Trip Point interrupt	**1**: Active **0**: Inactive
ACLW	[6]	AC Voltage below threshold	**1**: Detected **0**: Undetected
FUSE	[5]	Fuse status	**1**: Active **0**: Inactive
ACFET	[4]	AC FET status	**1**: Active **0**: Inactive
PCHG	[3]	Pre-charge FET status	**1**: Active **0**: Inactive
CHG	[2]	Charge FET status	**1**: Active **0**: Inactive
DSG	[1]	Discharge FET status	**1**: Active **0**: Inactive
PRES	[0]	System Present	**1**: Detected **0**: Undetected

Table 11-2. Security Modes

SEC[1:0]	MODE
2'b00	Reserved
2'b01	Unsealed
2'b10	Full Access
2'b11	Sealed

11.1.41 ManufacturerAccess() 0x0055 ChargingStatus

This command returns the 1 byte of *ChargerStatus()* flags and 2 bytes of *ChargingStatus()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

B23	B22	B21	B20	B19	B18	B17	B16
RSVD	RSVD	RSVD	RSVD	RSVD	LCHG	CHGSTAT	CHRG

RSVD		Reserved - do not use	
LCHG	[2]	Low Charge Current Mode	**1**: Active **0**: Inactive
CHGSTAT	[1]	Charger providing current to battery	**1**: Active **0**: Inactive
CHRG	[0]	Charger Enable	**1**: Active **0**: Inactive

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	CVRD	MLC[2]	MLC[1]	MLC[0]	CVR	CCR

RSVD		Reserved - do not use	
CVRD	[13]	Voltage/Current Override Mode	**1**: Active **0**: Inactive
MLC[2:0]	[12:10]	Multi-level Charging Mode	Not supported - ignore
CVR	[9]	Charging Voltage Rate of Change	**1**: Active **0**: Inactive
CCR	[8]	Charging Current Rate of Change	**1**: Active **0**: Inactive

B7	B6	B5	B4	B3	B2	B1	B0
VCT	MCHG	SU	IN	HV	MV	LV	PV

VCT	[7]	Charge Termination	**1**: Active **0**: Inactive
MCHG	[6]	Maintenance Charge	**1**: Active **0**: Inactive
SU	[5]	Charge Suspend	**1**: Active **0**: Inactive
IN	[4]	Charge Inhibit	**1**: Active **0**: Inactive
HV	[3]	High Cell Voltage Charge Conditions	**1**: Active **0**: Inactive
MV	[2]	Medium Cell Voltage Charge Conditions	**1**: Active **0**: Inactive
LV	[1]	Low Cell Voltage Charge Conditions	**1**: Active **0**: Inactive
PV	[0]	Pre-Charge Cell Voltage Charge Conditions	**1**: Active **0**: Inactive

11.1.42 ManufacturerAccess() 0x0056 GaugingStatus

This command returns the 3 bytes of *GaugingStatus()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

B23	B22	B21	B20	B19	B18	B17	B16
RSVD	RSVD	RSVD	OCVFR	LDMD	RX	QMAX	VDQ

RSVD		Reserved - do not use	**1**: Detected **0**: Undetected
OCVFR	[28]	Open Circuit Voltage Flat Region during RELAX	**1**: Detected **0**: Undetected
LDMD	[27]	LOAD mode - battery under load	**1**: Detected **0**: Undetected
RX	[26]	Resistance Update to DataFlash, toggled after every resistance update	**1**: Detected **0**: Undetected
QMAX	[25]	QMax update to DataFlash, updated after every QMax update	**1**: Detected **0**: Undetected
VDQ	[24]	Discharge qualified for learning (opposite of the R_DIS flag)	**1**: Detected **0**: Undetected

11.1.42.1 GaugingStatus Low Word

B15	B14	B13	B12	B11	B10	B9	B8
NSFM	RSVD	SLPQMAX	QEN	VOK	RDIS	RSVD	REST

NSFM	[15]	Negative Ra resistance scaling mode	**1**: Detected **0**: Undetected
RSVD	[14]	Reserved - do not use	**1**: Detected **0**: Undetected
SLPQMAX	[13]	OCV update in SLEEP Mode	**1**: Active **0**: Inactive
QEN	[12]	Impedance Track - Ra and QMax updates occurring	**1**: Enabled **0**: Disabled
VOK	[11]	Voltages Ok for QMax update. Bit is updated when exiting RELAX mode and flags valid DOD updates	**1**: Detected **0**: Undetected
RDIS	[10]	Resistance table updates in DataFlash	**1**: Enabled **0**: Disabled
RSVD	[9]	Reserved - Do not use	
REST	[8]	In RELAX mode and OCV updates taken	**1**: Detected **0**: Undetected

B7	B6	B5	B4	B3	B2	B1	B0
CF	DSG	EDV	BAL_EN	TC	TD	FC	FD

CF	[7]	Condition Flag - *MaxError()* > Max Error Limit and condition cycle needed	**1**: Detected **0**: Undetected
DSG	[6]	Discharge/Relax - No current or current out of battery	**1**: Detected **0**: Undetected
EDV	[5]	End-of-Discharge Voltage reached during discharge. Cleared when not exiting DISCHARGE mode.	**1**: Detected **0**: Undetected
BAL_EN	[4]	Cell balancing if possible	**1**: Enabled **0**: Disabled
TC	[3]	Terminate Charge	**1**: Detected **0**: Undetected
TD	[2]	Terminate Discharge	**1**: Detected **0**: Undetected
FC	[1]	Fully Charged	**1**: Detected **0**: Undetected
FD	[0]	Fully Discharged	**1**: Detected **0**: Undetected

11.1.43 ManufacturerAccess() 0x0057 ManufacturingStatus

This command returns the 2 bytes of *ManufacturingStatus()* flags on *AlternateManufacturerAccess()* or *ManufacturerData()*.

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	RSVD	RSVD	RSVD	CHGR_EN	LED_EN	FUSE_EN

RSVD	[15]	Reserved - do not use	
RSVD	[14]	Reserved - do not use	
RSVD	[13]	Reserved - do not use	
RSVD	[12]	Reserved - do not use	
RSVD	[11]	Reserved - do not use	
CHGR_EN	[10]	Charger Enabled, independent of Adapter presences	**1**: Enabled **0**: Disabled
LED_EN	[9]	LED outputs	**1**: Enabled **0**: Disabled
FUSE_EN	[8]	Fuse control	**1**: Enabled **0**: Disabled

B7	B6	B5	B4	B3	B2	B1	B0
BBR_EN	PF_EN	LF_EN	FET_EN	GAUGE_EN	RSVD	RSVD	RSVD

BBR_EN	[7]	Black Box Recorder	**1**: Enabled **0**: Disabled
PF_EN	[6]	Permanent Faults	**1**: Enabled **0**: Disabled
LF_EN	[5]	Lifetime Recording	**1**: Enabled **0**: Disabled
FET_EN	[4]	FET Control by firmware	**1**: Enabled **0**: Disabled
GAUGE_EN	[3]	Battery Fuel Gauging	**1**: Detected **0**: Undetected
RSVD	[2]	Reserved - do not use	
RSVD	[1]	Reserved - do not use	
RSVD	[0]	Reserved - do not use	

11.1.44 ManufacturerAccess() 0x0058 AFE Register

This command returns the 21 byte *AFERegister()* values on *AlternateManufacturerAccess()* or *ManufacturerData()*. These are the AFE hardware registers and are intended for internal debug use only.

BYTE	DESCRIPTION
0	AFE Interrupt Status. AFE Hardware interrupt status (e.g., wake time, push-button, etc.)
1	AFE FET Status. AFE FET status (e.g., CHG FET, DSG FET, PCHG FET, FUSE input, etc.)
2	AFE RXIN. AFE I/O port input status
3	AFE Latch Status. AFE protection latch status
4	AFE Interrupt Enable. AFE interrupt control settings
5	AFE Control. AFE FET control enable setting
6	AFE RXIEN. AFE I/O input enable settings
7	AFE RLOUT. AFE I/O pins output status
8	AFE RHOUT. AFE I/O pins output status
9	AFE RHINT. AFE I/O pins interrupt status
10	AFE Cell Balance. AFE cell balancing enable settings and status
11	AFE ADC/CC Control. AFE ADC/CC Control settings
12	AFE ADC Mux Control. AFE ADC channel selections.
13	AFE LED Control
14	AFE Control. AFE control on various HW based features
15	AFE Timer Control. AFE comparator and timer control
16	AFE Protection. AFE protection delay time control
17	AFE OCD. AFE OCD settings

BYTE	DESCRIPTION
18	AFE SCC. AFE SCC settings
19	AFE SCD1. AFE SCD1 settings
20	AFE SCD2. AFE SCD2 settings

11.1.45 ManufacturerAccess() 0x0060 Lifetime Data Block 1

This command returns the 31 bytes of Lifetime data.

BYTE	DESCRIPTION
1:0	Cell 1 Max Voltage
3:2	Cell 2 Max Voltage
5:4	Cell 3 Max Voltage
7:6	Cell 4 Max Voltage
9:8	Cell 1 Min Voltage
11:10	Cell 2 Min Voltage
13:12	Cell 3 Min Voltage
15:14	Cell 4 Min Voltage
17:16	Max Delta Cell Voltage
19:18	Max Charge Current
21:20	Max Discharge Current
23:22	Max Avg Dsg Current
25:24	Max Avg Dsg Power
26	Max Temp Cell
27	Min Temp Cell
28	Max Delta Cell temp
29	Max Temp Int Sensor
30	Min Temp Int Sensor
31	Max Temp Fet

11.1.46 ManufacturerAccess() 0x0061 Lifetime Data Block 2

This command returns the 7 bytes of Lifetime data.

BYTES	DESCRIPTION
0	No. of Shutdowns
1	No. of Partial Resets
2	No. of Full Resets
3	No. of WDT resets
4	CB Time Cell 1
5	CB Time Cell 2
6	CB Time Cell 3
7	CB Time Cell 4

11.1.47 ManufacturerAccess() 0x0062 Lifetime Data Block 3

This command returns the 16 bytes of Lifetime data.

BYTES	DESCRIPTION
1:0	Total FW Runtime
3:2	Time Spent in UT
5:4	Time Spent in LT
7:6	Time Spent in STL
9:8	Time Spent in RT
11:10	Time Spent in STH
13:12	Time Spent in HT
15:14	Time Spent in OT

11.1.48 ManufacturerAccess() 0x0063 Lifetime Data Block 4

This command returns the 31 bytes of Lifetime data.

BYTES	DESCRIPTION
1:0	No. of COV Events
3:2	Last COV Event
5:4	No. of CUV Events
7:6	Last CUV Event
9:8	No. of OCD1 Events
11:10	Last OCD1 Event
13:12	No. of OCD2 Events
15:14	Last OCD2 Event
17:16	No. of OCC1 Events
19:18	Last OCC1 Event
21:20	No. of OCC2 Events
23:22	Last OCC2 Event
25:24	No. of AOLD Events
27:26	Last AOLD Event
29:28	No. of ASCD Events
31:30	Last ASCD Event

11.1.49 ManufacturerAccess() 0x0064 Lifetime Data Block 5

This command returns the 31 bytes of Lifetime data.

BYTES	DESCRIPTION
1:0	No. of ASCC Events
3:2	Last ASCC Event
5:4	No. of OTC Events
7:6	Last OTC Event
9:8	No. of OTD Events
11:10	Last OTD Event
13:12	No. of OTF Events
15:14	Last OTF Event
17:16	No. Valid Charge Term
19:18	Last Valid Charge Term
21:20	No. of Qmax Updates
23:22	Last Qmax Update
25:24	No. of Ra Updates
27:26	Last Ra Update
29:28	No. of Ra Disable
31:30	Last Ra Disable

11.1.50 ManufacturerAccess() 0x0070 ManufacturerInfo

This command returns the 32 bytes of ManufacturerInfo on *AlternateManufacturerAccess()* or *ManufacturerData()*.

11.1.51 ManufacturerAccess() 0x0071 DAStatus1

This command returns 32 bytes containing CellVoltages, PackVoltage, BatVoltage, CellCurrents, CellPowers, Power, and AveragePower on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
1:0	Cell Voltage 1
3:2	Cell Voltage 2
5:4	Cell Voltage 3
7:6	Cell Voltage 4
9:8	BAT Voltage. Voltage at the BAT pin
11:10	PACK Voltage
13:12	Cell Current 1. Simultaneous current measured during Cell Voltage1 measurement
15:14	Cell Current 2. Simultaneous current measured during Cell Voltage2 measurement
17:16	Cell Current 3. Simultaneous current measured during Cell Voltage3 measurement
19:18	Cell Current 4. Simultaneous current measured during Cell Voltage 4 measurement
21:20	Cell Power 1. Calculated using Cell Voltage1 and Cell Current 1 data
23:22	Cell Power 2. Calculated using Cell Voltage2 and Cell Current 2 data
25:24	Cell Power 3. Calculated using Cell Voltage3 and Cell Current 3 data
27:26	Cell Power 4
29:28	Power calculated by *Voltage()* × *Current()*
31:30	Average Power. Calculated by *Voltage()* × *AverageCurrent()*

11.1.52 ManufacturerAccess() 0x0072 DAStatus2

This command returns 14 bytes containing the temperatures from the internal temp sensor, TS1, TS2, TS3, TS4, Cell Temp, and FETTemp on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
1:0	Int Temperature
3:2	TS1 Temperature
5:4	TS2 Temperature
7:6	TS3 Temperature
9:8	TS4 Temperature
11:10	Cell Temperature
13:12	FET Temperature

11.1.53 ManufacturerAccess() 0x0073 GaugeStatus1

This command returns the 32 bytes of Impedance Track related gauging information on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
1:0	True Rem Q. True remaining capacity in mAh from IT simulation before any filtering or smoothing function. This value can be negative or higher than FCC.
3:2	True Rem E. True remaining energy in cWh from IT simulation before any filtering or smoothing function. This value can be negative or higher than FCC.
5:4	Initial Q. Initial capacity calculated from IT simulation
7:6	Initial E. Initial energy calculated from IT simulation
9:8	Reserve Q. Reserve Capacity
11:10	Reserve E. Reserve Energy
13:12	T_sim. Temperature during the last simulation run.
15:14	T_ambient. Current assumed ambient temperature used by the IT algorithm for thermal modeling
17:16	RaScale 0. Ra table scaling factor of Cell 1
19:18	RaScale 1. Ra table scaling factor of Cell 2
21:20	RaScale 2. Ra table scaling factor of Cell 3
23:22	RaScale 3. Ra table scaling factor of Cell 4
25:24	CompRes 0. Last temperature compensated Resistance of Cell 1
27:26	CompRes 1. Last temperature compensated Resistance of Cell 2
29:28	CompRes 2. Last temperature compensated Resistance of Cell 3
31:30	CompRes 3. Last temperature compensated Resistance of Cell 4

11.1.54 ManufacturerAccess() 0x0074 GaugeStatus2

This command returns the 32 bytes of Impedance Track related gauging information on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
0	Pack Grid. Active pack grid point (minimum of CellGrid0 to Cell Grid3)
1	BB: LStatus—Learned status of resistance table Bit 3 | Bit 2 | Bit 1| Bit 0 QMax | ITEN | CF1 | CF0 CF1, CF0: QMax Status 0,0 = Battery OK 0,1 = QMax is first updated in learning cycle. 1,0 = QMax and resistance table updated in learning cycle ITEN: IT enable 0 = IT disabled 1 = IT enabled QMax: QMax update in field 0 = QMax has not been updated in the field 1= QMax updated in the field
2	Cell Grid 0. Active grid point of Cell 1
3	Cell Grid 1. Active grid point of Cell 2
4	Cell Grid 2. Active grid point of Cell 3
5	Cell Grid 3. Active grid point of Cell 4
9:6	State Time. Time past since last state change (Discharge, Charge, Rest)
11:10	DOD0_0. Depth of discharge for Cell 1
13:12	DOD0_1. Depth of discharge for Cell 2
15:14	DOD0_2. Depth of discharge for Cell 3
17:16	DOD0_3. Depth of discharge for Cell 4
19:18	DOD0 Passed Q. Passed capacity since the last DOD0 update
21:20	DOD0 Passed E. Passed energy since last DOD0 update
23:22	DOD0 Time. Time passed since the last DOD0 update
25:24	DODEOC 0. Depth of discharge at end of charge of Cell 1
27:26	DODEOC 1. Depth of discharge at end of charge of Cell 2
29:28	DODEOC 2.Depth of discharge at end of charge of Cell 3
31:30	DODEOC 3. Depth of discharge at end of charge of Cell 4

11.1.55 ManufacturerAccess() 0x0075 GaugeStatus3

This command returns the 32 bytes Impedance Track related gauging information on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
1:0	QMax 0. QMax of Cell 1
3:2	QMax 1. QMax of Cell 2
5:4	QMax 2. QMax of Cell 3
7:6	QMax 3. QMax of Cell 4
9:8	QMax DOD0_0. DOD0 at last QMax update of Cell 1
11:10	QMax DOD0_1. DOD0 at last QMax update of Cell 2
13:12	QMax DOD0_2. DOD0 at last QMax update of Cell 3
15:14	QMax DOD0_3. DOD0 at last QMax update of Cell 4
17:16	QMax Passed Q. Pass capacity since last QMax update
19:18	QMax Time. Time passed since last QMax update
21:20	Temp k. Thermal Model temperature factor
23:22	Temp a. Thermal Model temperature

11.1.56 ManufacturerAccess() 0x0076 CBStatus

This command returns the 32 bytes of cell-balancing–related information on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
1:0	Cell Balance Time 0. Calculated cell balancing time of Cell 1
3:2	Cell Balance Time 1. Calculated cell balancing time of Cell 2
5:4	Cell Balance Time 2. Calculated cell balancing time of Cell 3
7:6	Cell Balance Time 3. Calculated cell balancing time of Cell 4

11.1.57 ManufacturerAccess() 0x0077 State of Health

This command returns the 4 bytes of State of Health FCC in mAh and energy in cWh.

BYTES	DESCRIPTION
1:0	State Of Health FCC in mAh
3:2	State Of Health energy in cWh

11.1.58 ManufacturerAccess() 0x00C0 CHGR_EN Toggle

This command turns on/off the charge controller. If *ManufacturingStatus[CHGR_EN]* = **0**, sending this command sets *ManufacturingStatus[CHGR_EN]* to **1**, allowing the charge controller to enable whenever the adaptor voltage is present and valid. If *ManufacturingStatus[CHGR_EN]* = **1** this command will disable the charger immediately and set *ManufacturingStatus[CHGR_EN]* to **0**.

11.1.59 ManufacturerAccess() 0x00C1 CVRD_ARM Toggle

This command allows host control of the charger voltage and current settings. If *Charging Configuration[CVRD_EN]* = **0**, sending this command allows the host system to controller the charging current and voltage, setting *Charging Configuration[CVRD_EN]* to **1** and vice versa.

11.1.60 ManufacturerAccess() 0x00C2 ACFET_TEST Toggle

This command turns on/off AC FET drive function for testing during manufacturing. If *ManufacturingStatus[ACFET_TEST]* = **0**, sending this command turns on the AC FET and the *ManufacturingStatus[ACFET_TEST]* is set to **1** and vice versa. This toggling command is only enabled if *ManufacturingStatus[FET_EN]* = **0**, indicating a FW FET control is not active and manual control is allowed. A reset clears *ManufacturingStatus[ACFET_TEST]* and turns off the AC FET.

11.1.61 ManufacturerAccess() 0x00C3 CHGON_TEST Toggle

This command turns on/off Charger FET drive function to ease testing during manufacturing. If *ManufacturingStatus[CHGON_TEST]* = **0**, sending this command turns on the Charger FET's and the *ManufacturingStatus[CHGON_TEST]* is set to **1** and vice versa. This toggling command is only enabled if *ManufacturingStatus[FET_EN]* = **0**, indicating a FW FET control is not active and manual control is allowed. A reset clears *ManufacturingStatus[CHGON_TEST]* and turns off the CHG FET.

11.1.62 ManufacturerAccess() 0x0F00 ROM Mode

This command sends the device into ROM mode in preparation for firmware re-programming. To enter ROM mode, the device must be in FULL ACCESS mode. To return from ROM mode to FW mode, issue the SMBus command 0x08.

NOTE: Command 0x0033 also puts the device in ROM mode for backwards compatibility with the bq30z5x family of devices.

11.1.63 0x4000–0x5FFF Data Flash Access()

Accessing data flash (DF) is only supported by the *AlternateManufacturerAccess()* by addressing the physical address.

To write to the DF, send the starting address, followed by the DF data block. The DF data block is the intended revised DF data to be updated to DF. The size of the DF data block ranges from 1 byte to 32 bytes. All individual data must be sent in little endian.

Write to DF example:

```
Assuming: data1 locates at address 0x4000 and data2 locates at address 0x4002.
                    Both data1 and data2 are U2 type.

To update data1 and data2, send an SMBus block write with command = 0x44
          block =   starting address + DF data block
                =   0x00 + 0x40 + data1_LowByte + data1_HighByte + data2_LowByte + data2_HighByte
```

To read the DF, send an SMBus block write to the *AlternateManufacturerAccess(),* followed by the starting address, then send an SMBus block read to the *AlternateManufacturerAccess()*. The return data contains the starting address followed by 32 bytes of DF data in little endian.

```
Read from DF example:
Taking the same assuming from the read DF example, to read DF,
a. Send SMBus write block with command 0x44, block = 0x00 + 0x40
b. Send SMBus read block with command 0x44
       The returned block  = a starting address + 32 bytes of DF data
                           = 0x00 + 0x40 + data1_LowByte + data1_HighByte + data2_LowByte + data2_HighByte....
                           data32_LowByte + data32_HighByte
```

The gauge supports an auto- increment on the address during a DF read. This greatly reduces the time required to read out the entire DF. Continue with the read from the DF example. If another SMBus read block is sent with command 0x44, the gauge returns another 32 bytes of DF data, starting with address 0x4020.

11.1.64 ManufacturerAccess() 0xF080 Exit Calibration Output Mode

This command stops the output of calibration data to the *AlternateManufacturerAccess()* or *ManufacturerData()* command.

STATUS	CONDITION	ACTION
Activate	*AlternateManufacturerAccess()***OR** *ManufacturerData()* = 1 **AND** 0xF080 to *ManufacturerAccess()*	Stop output of ADC or CC data on *AlternateManufacturerAccess()* or *ManufacturerData()*

11.1.65 ManufacturerAccess() 0xF081 Output CC and ADC for Calibration

This command instructs the device to output the raw values for calibration purposes on *AlternateManufacturerAccess()* or *ManufacturerData()*. All values are updated every 250 ms and the format of each value is 2's complement, MSB first.

STATUS	CONDITION
Disable	*ManufacturingStatus()[CAL]*= 1 **AND** 0xF080 to *ManufacturerAccess()*

Action: *ManufacturingStatus()[CAL]* = 0
Stop output of ADC and CC data on *AlternateManufacturerAccess()* or *ManufacturerData()*

STATUS	CONDITION
Enable	0xF081 to *ManufacturerAccess()*

Action: *ManufacturingStatus()[CAL]* = 1
Outputs the 24 bytes of raw CC and AD values on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BTYES	DESCRIPTION
0	Rolling 8-bit counter, increments when values are refreshed
1	Status, 1 when *ManufacturerAccess()* = 0xF081, 2 when *ManufacturerAccess()* = 0xF082
3:2	Current (coulomb counter)
5:4	Cell Voltage 1
7:6	Cell Voltage 2
9:8	Cell Voltage 3
11:10	Cell Voltage 4
13:12	PACK Voltage
15:14	BAT Voltage
17:16	Cell Current 1
19:18	Cell Current 2
21:20	Cell Current 3
23:22	Cell Current 4

11.1.66 ManufacturerAccess() 0xF082 Output Shorted CC and ADC for Calibration

This command instructs the device to output the raw values for calibration purposes on *AlternateManufacturerAccess()* or *ManufacturerData()*. All values are updated every 250 ms and the format of each value is 2's complement, MSB first. This mode includes an internal short on the coulomb counter inputs for measuring offset.

STATUS	CONDITION
Disable	*ManufacturingStatus()[CAL]*= 1 AND 0xF080 to *ManufacturerAccess()*

Action: *ManufacturingStatus()[CAL]* = 0
Stop output of ADC and CC data on *AlternateManufacturerAccess()* or *ManufacturerData()*

STATUS	CONDITION
Enable	0xF081 to *ManufacturerAccess()*

Action: *ManufacturingStatus()[CAL]* = 1
Outputs the 24 bytes of raw CC and AD values on *AlternateManufacturerAccess()* or *ManufacturerData()*.

BYTES	DESCRIPTION
0	Rolling 8-bit counter, increments when values are refreshed
1	Status, 1 when *ManufacturerAccess()* = 0xF081, 2 when *ManufacturerAccess()* = 0xF082
3:2	Current (coulomb counter)
5:4	Cell Voltage 1
7:6	Cell Voltage 2
9:8	Cell Voltage 3
11:10	Cell Voltage 4
13:12	PACK Voltage
15:14	BAT Voltage
17:16	Cell Current 1
19:18	Cell Current 2
21:20	Cell Current 3
23:22	Cell Current 4

11.2 0x01 RemainingCapacityAlarm()

This read/write word function sets a low capacity alarm threshold for the cell stack.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x01	*RemainingCapacityAlarm()*	R/W			Word	U2	0	700	300	mAh 10 mWh

NOTE: If *BatteryMode()[CAPM]* = 0, then the data reports in mAh.

If *BatteryMode()[CAPM]* = 1, then the data reports in 10 mWh.

11.3 0x02 RemainingTimeAlarm()

This read/write word function sets a low remaining time to fully discharge alarm threshold for the cell stack.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x02	*RemainingTimeAlarm()*	R/W			Word	U2	0	30	10	min

11.4 0x03 BatteryMode()

This read/write word function sets various battery operating mode options.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x03	*BatteryMode()*	R/W			Word	H2	0x0000	0xFFFF	—

B15	B14	B13	B12	B11	B10	B9	B8
CAPM	CHGM	AM	RSVD	RSVD	RSVD	PB	CC

CAPM	[15]	Capacity Mode	**1**: Reported in 10mW(h) increments **0**: Reported in 1mW(h) increments
CHGM	[14]	Manual Charge Control - external hosts sets *ChargingVoltage()* and *ChargingCurrent()*	**1**: Enabled **0**: Disabled
AM	[13]	Alarm Mode	**1**: Enabled **0**: Disabled
RSVD	[12]	Reserved - do not use	
RSVD	[11]	Reserved - do not use	
RSVD	[10]	Reserved - do not use	
PB	[9]	Sets the role of the pack and is not used in the bq40z60 - set to 0	
CC	[8]	Internal Charge Controller	**1**: Enabled **0**: Disabled

B7	B6	B5	B4	B3	B2	B1	B0
CF	RSVD	RSVD	RSVD	RSVD	RSVD	PBS	ICC

CF	[7]	Conditioning needed if *MaxError()* > CF Max Error Limit	**1**: Detected **0**: Undetected
RSVD	[6]	Reserved - do not use	
RSVD	[5]	Reserved - do not use	
RSVD	[4]	Reserved - do not use	
RSVD	[3]	Reserved - do not use	
RSVD	[2]	Reserved - do not use	
PBS	[1]	Primary battery support - unsupported, write to 0	
ICC	[0]	Internal Charge Controller enabled	**1**: Detected **0**: Undetected

11.5 0x04 AtRate()

This read/write word function sets the value used in calculating *AtRateTimeToFull()* and *AtRateTimeToEmpty()*.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x04	*AtRate()*	R/W			Word	I2	–32768	32767	0	mA 10 mW

NOTE: If *BatteryMode()[CAPM]* = 0, then the data reports in mA.

If *BatteryMode()[CAPM]* = 1, then the data reports in 10 mW.

11.6 0x05 AtRateTimeToFull()

This word read function returns the remaining time to fully charge the battery stack.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x05	*AtRateTimeToFull()*	R			Word	U2	0	65535	min

NOTE: 65535 indicates battery stack is not being charged.

11.7 0x06 AtRateTimeToEmpty()

This word read function returns the remaining time to discharge the battery stack fully.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x06	*AtRateTimeToEmpty()*	R			Word	U2	0	65535	min

NOTE: 65535 indicates battery stack is not being charged.

11.8 0x07 AtRateOK()

This read word function returns a Boolean value that indicates whether the battery can deliver *AtRate()* for at least 10 seconds.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x07	*AtRateOK()*	R			Word	U2	0	65535	—

NOTE: 0 = False. The gauge *cannot* deliver energy for 10 s, based on the discharge rate indicated in *AtRate()*.

> than 0 = True. The gauge *can* deliver energy for 10 s, based on the discharge rate indicated in *AtRate()*.

11.9 0x08 Temperature()

This read word function returns the temperature in units 0.1°K.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x08	*Temperature()*	R			Word	U2	0	65535	0.1°K

11.10 0x09 Voltage()

This read word function returns the sum of the measured cell voltages.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x09	*Voltage()*	R			Word	U2	0	65535	mV

11.11 0x0A Current()

This read word function returns the measured current from the coulomb counter.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x0A	*Current()*	R			Word	I2	–32767	32768	mA

11.12 0x0B AverageCurrent()

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x0B	*AverageCurrent()*	R			Word	I2	–32767	32768	mA

11.13 0x0C MaxError()

This read word function returns the expected margin of error, in %, in the state-of-charge calculation with a range of 1 to 100%.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x0C	*MaxError()*	R			Word	U1%	0%	100%	

CONDITION	ACTION
Full device reset	*MaxError()*= 100%
RA-table only updated	*MaxError()*= 5%
QMax only updated	*MaxError()*= 3%
RA-table and QMax updated	*MaxError()*= 1%
Each *CycleCount()* increment after last valid QMax update	*MaxError()*increment by 0.05%
The ***Configuration:Max Error Time Cycle Equivalent*** period passed since the last valid QMax update	*MaxError()*increment by 0.05%.

11.14 0x0D RelativeStateOfCharge()

This read word function returns the predicted remaining battery capacity as a percentage of *FullChargeCapacity()*.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x0D	*RelativeStateOfCharge()*	R			Word	U1	0%	100%	

11.15 0x0E AbsoluteStateOfCharge()

This read word function returns the predicted remaining battery capacity as a percentage.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x0E	*AbsoluteStateOfCharge()*	R			Word	U1	0%	100%	

11.16 0x0F RemainingCapacity()

This read word function returns the predicted remaining battery capacity.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x0F	*RemainingCapacity()*	R	R	R	Word	U2	0	65535	mAh 10 mWh

NOTE: If *BatteryMode()[CAPM]* = 0, then the data reports in mAh.

If *BatteryMode()[CAPM]* = 1, then the data reports in 10 mWh.

11.17 0x10 FullChargeCapacity()

This read word function returns the predicted battery capacity when full charged.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x10	*FullChargeCapacity()*	R	R	R	Word	U2	0	65535	mAh 10 mWh

NOTE: If *BatteryMode()[CAPM]* = 0, then the data reports in mAh.

If *BatteryMode()[CAPM]* = 1, then the data reports in 10 mWh.

11.18 0x11 RunTimeToEmpty()

This read word function returns the predicted remaining battery capacity based on the present rate of discharge.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x11	*RunTimeToEmpty()*	R	R	R	Word	U2	0	65535	min

NOTE: 65535 = Battery is not being discharged.

11.19 0x12 AverageTimeToEmpty()

This read word function returns the predicted remaining battery capacity based on *AverageCurrent()*.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x12	*AverageTimeToEmpty()*	R	R	R	Word	U2	0	65535	min

NOTE: 65535 = Battery is not being discharged.

11.20 0x13 AverageTimeToFull()

This read word function returns the predicted time to full charge based on *AverageCurrent()*.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x13	*AverageTimeToFull()*	R	R	R	Word	U2	0	65535	min

NOTE: 65535 = Battery is not being discharged.

11.21 0x14 ChargingCurrent()

This read word function returns the desired charging current.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x14	*ChargingCurrent()*	R	R	R	Word	U2	0	65535	mA

NOTE: 65535 = Request maximum current

11.22 0x15 ChargingVoltage()

This read word function returns the desired charging voltage.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x15	*ChargingVoltage()*	R	R	R	Word	U2	0	65535	mV

NOTE: 65535 = Request maximum voltage

11.23 0x16 BatteryStatus()

This read-word function returns various battery status information.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX
		SE	US	FA				
0x16	*BatteryStatus()*	R	R	R	Word	H2	—	—

B15	B14	B13	B12	B11	B10	B9	B8
OCA	TCA	RSVD	OTA	TDA	RSVD	RCA	RTA
OCA	[15]	Over-Current Alarm				**1**: Detected **0**: Undetected	
TCA	[14]	Terminate Charge Alarm				**1**: Detected **0**: Undetected	
RSVD	[13]	Reserved - do not use					
OTA	[12]	Over Temperature Alarm				**1**: Detected **0**: Undetected	
TDA	[11]	Terminate Discharge Alarm				**1**: Detected **0**: Undetected	
RSVD	[10]	Reserved - do not use					
RCA	[9]	Remaining Capacity Alarm - *RemainingCapacity()* < *RemainingCapacityAlarm()*				**1**: Detected **0**: Undetected	
RTA	[8]	Remaining Time Alarm - *AverageTimeToEmpty()* < *RemainingTimeAlarm()*				**1**: Detected **0**: Undetected	
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
INIT	DSG	FC	FD	EC[3]	EC[2]	EC[1]	EC[0]
INIT	[7]	Initialization status				**1**: Completed **0**: In Progress	
DSG	[6]	Discharge or Relaxing - no current to battery				**1**: Detected **0**: Undetected	
FC	[5]	Fully Charged				**1**: Detected **0**: Undetected	
FD	[4]	Fully Discharged				**1**: Detected **0**: Undetected	
EC[3:0]	[3:0]	Error Code				See Error Code Table	

Table 11-3. EC[3:0] Settings

EC[3:0]	ERROR
4'b0000	OK - no error
4'b0001	Busy
4'b0010	Reserved Command
4'b0011	Unsupported Command
4'b0100	Access Denied
4'b0101	Overflow or Underflow
4'b0110	Bad Size
4'b0111	Unknown Error
4'b1xxx	Unused

11.24 0x17 CycleCount()

This read word function returns the number of discharge cycles the battery has experienced. The default value is stored in data flash value ***Cycle Count***, which is updated in runtime.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x17	*CycleCount()*	R	R/W	R/W	Word	U2	0	65535	cycles

11.25 0x18 DesignCapacity()

This read word function returns the theoretical pack capacity. The default value is stored in data flash value ***Design Capacity mAh*** or ***Design Capacity cWh.***

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x18	*DesignCapacity()*	R	R/W	R/W	Word	U2	0	65535	4400	mAh
									6336	10 mWh

NOTE: If *BatteryMode()[CAPM]* = 0, then the data reports in mAh.

If *BatteryMode()[CAPM]* = 1, then the data reports in 10 mWh.

11.26 0x19 DesignVoltage()

This read word function returns the theoretical pack voltage. The default value is stored in data flash value ***Design Voltage***.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x19	*DesignVoltage()*	R	R/W	R/W	Word	U2	7000	18000	14400	mV

11.27 0x1A SpecificationInfo()

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX
		SE	US	FA				
0x1A	*SpecificationInfo()*	R	R/W	R/W	Word	H2	0x0000	0xFFFF

B15	B14	B13	B12	B11	B10	B9	B8
IPSCALE[3]	IPSCALE[2]	IPSCALE[1]	IPSCALE[0]	VSCALE[3]	VSCALE[2]	VSCALE[1]	VSCALE[0]
IPSCALE[3:0]	[15:12]	IP Scale Factor - Unsupported and should be written to **4'b0000**					
VSCALE[3:0]	[11:8]	Voltage Scale - Unsupported and should be written to **4'b0000**					
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
VERSION[3]	VERSION[2]	VERSION[1]	VERSION[0]	REVISION[3]	REVISION[2]	REVISION[1]	REVISION[0]
VERSION[3:0]	[7:4]	Version number - SBS 1.1 with optional PEC Support				**4'b0011**	
REVISION[3:0]	[3:0]	Revision number - Version 1.0 and 1.1				**4'b0001**	

11.28 0x1B ManufacturerDate()

This read word function returns the pack's manufacture date.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT
		SE	US	FA					
0x1B	*ManufacturerDate()*	R	R/W	R/W	Word	U2		65535	0

NOTE: *ManufacturerDate()* value is in the following format: Day + Month × 32 + (Year–1980) × 256.

11.29 0x1C SerialNumber()

This read word function returns the assigned pack serial number.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x1C	*SerialNumber()*	R	R/W	R/W	Word	H2	0x0000	0xFFFF	0x0001	

11.30 0x20 ManufacturerName()

This read block function returns the pack manufacturer's name.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x20	*ManufacturerName()*	R	R	R	Block	S11+1	—	—	Texas Inst.	ASCII

11.31 0x21 DeviceName()

This read block function returns the assigned pack name.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x21	*DeviceName()*	R	R	R	Block	S7+1	—	—	bq40z60	ASCII

11.32 0x22 DeviceChemistry()

This read block function returns the battery chemistry used in the pack.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x22	*DeviceChemistry()*	R	R	R	Block	S4+1	—	—	LION	ASCII

11.33 0x23 ManufacturerData()/CalibrationData()

This read block function returns several manufacturing- related pack information codes in the default mode. It is also used to return measured voltage, current, and temperature data for calibration purposes in CALIBRATION mode.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x23	*ManufacturerData()*	R	R	R	Block	H14+1			

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x23	*CalibrationData()*	R	R	R	Block	H2+S24			

STATUS	CONDITION	ACTION
ManufacturerData	Valid command sent	Return pack information on *ManufacturerData()*
CalibrationData	0x002D to *ManufacturerAccess()* to enable CALIBRATION mode 0xF081 or 0xF082 to *ManufacturerAccess()* to enable calibration data acquisition Valid command sent	Return measured voltage, current, and temperature on *ManufacturerData()*

11.34 0x2F Authenticate()/ManufacturerInput()

This read/write block function provides SHA-1 authentication in the default mode. It is also used to perform data flash read/writes in DATA FLASH ACCESS mode.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x2F	*Authenticate()*	R/W	R/W	R/W	Block	H20+1	—	—	—

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	UNIT
		SE	US	FA					
0x2F	*ManufacturerInput()*	R/W	R/W	R/W	Block	H32	—	—	—

11.35 0x3C CellVoltage4()

This read word function returns the cell 4 voltage.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x3C	*CellVoltage4()*	R	R	R	Word	U2	—	65535	0	mV

11.36 0x3D CellVoltage3()

This read word function returns the cell 3 voltage.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x3D	*CellVoltage3()*	R	R	R	Word	U2	—	65535	0	mV

11.37 0x3E CellVoltage2()

This read word function returns the cell 2 voltage.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x3E	*CellVoltage2()*	R	R	R	Word	U2	—	65535	0	mV

11.38 0x3F CellVoltage1()

This read word function returns the cell 1 voltage.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x3F	*CellVoltage1()*	R	R	R	Word	U2	—	65535	0	mV

11.39 0x4A InitDischargeSet()

This read/write word command updates the BTP set threshold that triggers the BTP interrupt and sets the *OperationStatus()[BTP_INT]* bit.

SBS CMD	NAME	ACCESS			PROTOCOL	SIZE IN BYTES	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x4A	*InitDischargeSet()*	R/W	R/W	R/W	Signed Int	2	—	65535	150	mAh

11.40 0x4B InitChargeSet()

The read/write word command updates the BTP clear threshold that de-asserts the BTP interrupt and clears the *OperationStatus()[BTP_INT]* bit.

SBS CMD	NAME	ACCESS			PROTOCOL	SIZE IN BYTES	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x4B	*InitChargeSet()*	R/W	R/W	R/W	Signed Int	2	—	65535	175	mAh

11.41 0x4F State of Health (SoH)

This read-word command returns the state of health (SoH) information of the battery in percentage of design capacity and design energy.

11.42 0x50 SafetyAlert

This command returns the *SafetyAlert()* flags. For a description of each bit flag, see the *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x50	*SafetyAlert()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.43 0x51 SafetyStatus

This command returns the *SafetyStatus()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x51	*SafetyStatus()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.44 0x52 PFAlert

This command returns the *PFAlert()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x52	*PFAlert()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.45 0x53 PFStatus

This command returns the *PFStatus()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x53	*PFStatus()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.46 0x54 OperationStatus

This command returns the *OperationStatus()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x54	*OperationStatus()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.47 0x55 ChargingStatus

This command returns the *ChargingStatus()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x55	*ChargingStatus()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.48 0x56 GaugingStatus

This command returns the *GaugingStatus()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x56	*GaugingStatus()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.49 0x57 ManufacturingStatus

This command returns the *ManufacturingStatus()* flags. For a description of each bit flag, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x57	*ManufacturingStatus()*	—	R	R	Block	H4	0x00000000	0xFFFFFFFF	—	—

11.50 0x58 AFE Register

This command returns a snapshot of the AFE register settings. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x58	*AFERegister()*	—	R	R	Block	—	—	—	—	—

11.51 0x59 TURBO_POWER

TURBO_POWER reports the maximal peak power value, MAX_POWER. The gauge computes a new RAM value every second. *TURBO_POWER()* is initialized to the result of the max power calculation at reset or power up.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x59	*TURBO_POWER()*	R	R	R/W	Word	—	—	—	—	cW

NOTE: Computes and provides Turbo Power information based on the battery pack configuration.

11.52 0x5A TURBO_FINAL

TURBO_FINAL sets ***Min Turbo Power***, which represents the minimal TURBO BOOST mode power level during active operation (such as, non-SLEEP) after all higher TURBO BOOST mode levels are disabled (expected at the end of discharge).

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x5A	*TURBO_FINAL()*	R/W	R/W	R/W	Word	—	—	—	—	cW

11.53 0x5B TURBO_PACK_R

TURBO_PACK_R sets the RAM value of the battery pack serial resistance, including resistance associated with FETs, traces, sense resistors, and so forth. *TURBO_PACK_R()* is initialized to the data flash value ***Pack Resistance***.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x5B	*TURBO_PACK_R()*	R/W	R/W	R/W	Word	—	—	—	—	mΩ

11.54 0x5C TURBO_SYS_R

TURBO_SYS_R sets the RAM value of the system serial resistance along the path from battery to system power converter input that includes FETs, traces, sense resistors, and so forth. *TURBO_SYS_R()* is initialized to the data flash value ***System Resistance***.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x5C	*TURBO_SYS_R()*	R/W	R/W	R/W	Word	—	—	—	—	mΩ

11.55 0x5D TURBO_EDV

TURBO_EDV sets the Minimal Voltage at the system-power converter input at which the system will still operate. *TURBO_EDV()* is initialized to the data flash value ***Terminate Voltage***. A write to this command will overwrite the DF value. Intended use is to write it once on first use to adjust for possible changes in system design from the time the battery pack was designed.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x5D	*TURBO_EDV()*	R/W	R/W	R/W	Word	—	—	—	—	mV

11.56 0x5E TURBO_CURRENT

The gauge computes a maximal discharge current supported by the cell design for a C-rate discharge pulse for 10 ms. This value is updated every 1 s for the system to read.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x5D	*TURBO_CURRENT()*	R	R	R/W	Word	—	—	—	—	mAh

NOTE: Computes a maximal discharge current supported by the cell design.

11.57 0x60 Lifetime Data Block 1

This command returns the first block of Lifetime data. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x60	*LifeTimeDataBlock1()*	—	R	R	Block	—	—	—	—	—

11.58 0x61 Lifetime Data Block 2

This command returns the second block of Lifetime data. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x61	*LifeTimeDataBlock2()*	—	R	R	Block	—	—	—	—	—

11.59 0x62 Lifetime Data Block 3

This command returns the third block of Lifetime data. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x62	*LifeTimeDataBlock3()*	—	R	R	Block	—	—	—	—	—

11.60 0x63 Lifetime Data Block 4

This command returns the third block of Lifetime data. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x63	*LifeTimeDataBlock4()*	—	R	R	Block	—	—	—	—	—

11.61 0x64 Lifetime Data Block 5

This command returns the third block of Lifetime data. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x64	*LifeTimeDataBlock5()*	—	R	R	Block	—	—	—	—	—

11.62 0x70 ManufacturerInfo

This command returns manufacturer information. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x70	*ManufacturerInfo()*	R	R	R	Block	—	—	—	—	—

11.63 0x71 DAStatus1

This command returns the CellVoltages, PackVoltage, BatVoltage, CellCurrents, CellPowers, Power, and AveragePower. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x71	*DAStatus1()*	—	R	R	Block	—	—	—	—	—

11.64 0x72 DAStatus2

This command returns the internal temp sensor, TS1, TS2, TS3, TS4, Cell Temp, and FETTemp. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x72	*DAStatus2()*	—	R	R	Block	—	—	—	—	—

11.65 0x73 GaugeStatus1

This command instructs the device to return Impedance Track related gauging information. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x73	*GaugeStatus1()*	—	R	R	Block	—	—	—	—	—

11.66 0x74 GaugeStatus2

This command instructs the device to return Impedance Track related gauging information. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x74	*GaugeStatus2()*	—	R	R	Block	—	—	—	—	—

11.67 0x75 GaugeStatus3

This command instructs the device to return Impedance Track related gauging information. For a description of returned data values, see *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x75	*GaugeStatus3()*	—	R	R	Block	—	—	—	—	—

11.68 0x76 CBStatus

This command instructs the device to return cell balancing information. For a description of returned data values, see the *ManufacturerAccess()* version of same command in Section 11.1.

SBS CMD	NAME	ACCESS			PROTOCOL	TYPE	MIN	MAX	DEFAULT	UNIT
		SE	US	FA						
0x76	*CBStatus3()*	—	R	R	Block	—	—	—	—	—

Data Flash Information

12.1 Data Formats

12.1.1 Unsigned Integer

Unsigned integer values are stored without changes as 1-byte, 2-byte, or 4-byte values in Little Endian byte order.

0
U1 MSB

0	1
U2 LSB	U2 MSB

0	1	2	3
U4 L LSB	U4 L MSB	U4 H LSB	U4 H MSB

12.1.2 Integer

Integer values are stored in 2's-complement format in 1-byte, 2-byte, or 4-byte values in Little Endian byte order.

0
I1 MSB

0	1
I2 LSB	I2 MSB

0	1	2	3
I4 L LSB	I4 L MSB	I4 H LSB	I4 H MSB

12.1.3 Floating Point

Floating-point values are stored using the IEEE754 Single Precision 4-byte format in Little Endian byte order.

0	1	2	3
Fract [0–7]	Fract [8–15]	Exp[0] + Fract[16–22]	Sign + Exp[1–7]

Where:

Exp: 8-bit exponent stored with an offset bias of 127. The values 00 and FF have unique meanings.

Fract: 23-bit fraction. If the exponent is > 0, then the mantissa is 1.fract. If the exponent is zero, then the mantissa is 0.fract.

The floating point value depends on the unique cases of the exponent:

- If the exponent is FF and the fraction is zero, this represents +/– infinity.
- If the exponent is FF and the fraction is non-zero this represents "not a number" (NaN).
- If the exponent is 00 then the value is a subnormal number represented by $(-1)^{sign} \times 2^{-126} \times 0.\text{fraction}$.
- Otherwise, the value is a normalized number represented by $(-1)^{sign} \times 2^{(exponent - 127)} \times 1.\text{fraction}$.

12.1.4 Hex

Bit register definitions are stored in unsigned integer format.

12.1.5 String

String values are stored with length byte first, followed by a number of data bytes defined with the length byte.

0	1	. . .	N
Length	Data0	. . .	DataN

12.2 Other Data Flash

12.2.1 System Data

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
System Data	Manufacturer Data	Manufacturer Info A Length	U1	1	32	32	—
System Data	Manufacturer Data	Manufacturer Info Block A01	U1	0	0xff	0x61	Hex
System Data	Manufacturer Data	Manufacturer Info Block A02	U1	0	0xff	0x62	Hex
System Data	Manufacturer Data	Manufacturer Info Block A03	U1	0	0xff	0x63	Hex
System Data	Manufacturer Data	Manufacturer Info Block A04	U1	0	0xff	0x64	Hex
System Data	Manufacturer Data	Manufacturer Info Block A05	U1	0	0xff	0x65	Hex
System Data	Manufacturer Data	Manufacturer Info Block A06	U1	0	0xff	0x66	Hex
System Data	Manufacturer Data	Manufacturer Info Block A07	U1	0	0xff	0x67	Hex
System Data	Manufacturer Data	Manufacturer Info Block A08	U1	0	0xff	0x68	Hex
System Data	Manufacturer Data	Manufacturer Info Block A09	U1	0	0xff	0x69	Hex
System Data	Manufacturer Data	Manufacturer Info Block A10	U1	0	0xff	0x6a	Hex

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
System Data	Manufacturer Data	Manufacturer Info Block A11	U1	0	0xff	0x6b	Hex
System Data	Manufacturer Data	Manufacturer Info Block A12	U1	0	0xff	0x6c	Hex
System Data	Manufacturer Data	Manufacturer Info Block A13	U1	0	0xff	0x6d	Hex
System Data	Manufacturer Data	Manufacturer Info Block A14	U1	0	0xff	0x6e	Hex
System Data	Manufacturer Data	Manufacturer Info Block A15	U1	0	0xff	0x6f	Hex
System Data	Manufacturer Data	Manufacturer Info Block A16	U1	0	0xff	0x70	Hex
System Data	Manufacturer Data	Manufacturer Info Block A17	U1	0	0xff	0x71	Hex
System Data	Manufacturer Data	Manufacturer Info Block A18	U1	0	0xff	0x72	Hex
System Data	Manufacturer Data	Manufacturer Info Block A19	U1	0	0xff	0x73	Hex
System Data	Manufacturer Data	Manufacturer Info Block A20	U1	0	0xff	0x74	Hex
System Data	Manufacturer Data	Manufacturer Info Block A21	U1	0	0xff	0x75	Hex
System Data	Manufacturer Data	Manufacturer Info Block A22	U1	0	0xff	0x76	Hex
System Data	Manufacturer Data	Manufacturer Info Block A23	U1	0	0xff	0x77	Hex
System Data	Manufacturer Data	Manufacturer Info Block A24	U1	0	0xff	0x7a	Hex
System Data	Manufacturer Data	Manufacturer Info Block A25	U1	0	0xff	0x78	Hex
System Data	Manufacturer Data	Manufacturer Info Block A26	U1	0	0xff	0x79	Hex
System Data	Manufacturer Data	Manufacturer Info Block A27	U1	0	0xff	0x30	Hex
System Data	Manufacturer Data	Manufacturer Info Block A28	U1	0	0xff	0x31	Hex
System Data	Manufacturer Data	Manufacturer Info Block A29	U1	0	0xff	0x32	Hex
System Data	Manufacturer Data	Manufacturer Info Block A30	U1	0	0xff	0x33	Hex
System Data	Manufacturer Data	Manufacturer Info Block A31	U1	0	0xff	0x34	Hex
System Data	Manufacturer Data	Manufacturer Info Block A32	U1	0	0xff	0x35	Hex

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
System Data	Integrity	Static DF Signature	U2	0	0x7fff	0	hex
System Data	Integrity	Static Chem DF Signature	U2	0	0x7fff	0x6c98	hex
System Data	Integrity	All DF Signature	U2	0	0x7fff	0	hex

12.2.2 Mfg Status Init

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Manufacturing	Mfg Status init	B2	0	0xffff	0x0000	hex

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	RSVD	RSVD	RSVD	CHGR_EN	LED_EN	FUSE_EN
RSVD	[15:11]	Reserved - Do not use					
CHGR_EN	[10]	Charger state when adapter voltage is present and valid				**1**: Enabled **0**: Disabled	
LED_EN	[9]	LED state				**1**: Enabled **0**: Disabled	
FUSE_EN	[8]	Allow fuse blowing				**1**: Enabled **0**: Disabled	
B7	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
BBR_EN	PF_EN	LF_EN	FET_EN	GAUGE_EN	RSVD	RSVD	RSVD
BBR_EN	[7]	Allow black box recording				**1**: Enabled **0**: Disabled	
PF_EN	[6]	Allow permanent faults				**1**: Enabled **0**: Disabled	
LF_EN	[5]	Allow lifetime data collection				**1**: Enabled **0**: Disabled	
FET_EN	[4]	Allow full FET control				**1**: Enabled **0**: Disabled	
GAUGE_EN	[3]	Allow gas gauging				**1**: Enabled **0**: Disabled	
RSVD	[2:0]	Reserved - Do not use					

12.2.3 DA Configuration

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	DA Configuration	B1	0	0xff	0x12	hex

B7	B6	B5	B4	B3	B2	B1	B0
FTEMP	CTEMP	EMSHUT_EN	SLEEP	IN_SYSTEM_SLEEP	NR	CC[1]	CC[0]
FTEMP	[7]	FET Temperature protection source				**1**: Average **0**: Max	
CTEMP	[6]	Cell Temperature protection source				**1**: Average **0**: Max	
EMSHUT_EN	[5]	Enable Emergency Shutdown				**1**: Enabled **0**: Disabled	
SLEEP	[4]	Enable SLEEP mode				**1**: Enabled **0**: Disabled	
IN_SYSTEM_SLEEP	[3]	Enable In-System SLEEP mode				**1**: Enabled **0**: Disabled	
NR	[2]	Non-Removable battery, use PRES for system detection				**1**: Enabled **0**: Disabled	
CC[1:0]	[1:0]	Cell Count = value + 1					

CC[1]	CC[0]	Cell Count
1	1	4 cells
1	0	3 cells
0	1	2 cells
0	0	1 cell (Not Supported)

12.2.4 FET Options

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	FET Options	B1	0	0xff	0x20	hex

B7	B6	B5	B4	B3	B2	B1	B0
PACK_FUSE	RSVD	RSVD	RSVD	RSVD	OTFET	RSVD	RSVD

PACK_FUSE	[7]	**Min Blow Fuse Voltage** voltage source	**1**: ACP **0**: Battery
RSVD	[6:3]	Reserved - Do not use	
OTFET	[2]	CHG FET/DSG FET state in OVERTEMPERATURE mode	**1**: Disabled **0**: No Action
RSVD	[1:0]	Reserved - Do not use	

12.2.5 IT Gauging Configuration

12.2.5.1 Settings Configuration Data Flash

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	Sbs Gauging Configuration	B1	0	0x0f	0x4	hex
Settings	Configuration	IT Gauging Configuration	B2	0	0xffff	0xd4fe	hex
Settings	Configuration	IT Gauging 2 Configuration	B1	0	0x7e	0x3e	—

B15	B14	B13	B12	B11	B10	B9	B8
VOLT_CONSIST	RELAX_SMOOTH_OK	TDELTAV	SMOOTH	RELAX_JUMP_OK	FF_NEAR_EDV	CELL_TERM	FAST_QMAX_FLD

VOLT_CONSIST	[15]	Voltage Consistency Check	**1**: Enabled **0**: Disabled
RELAX_SMOOTH_OK	[14]	Smooth RSCON in RELAX mode	**1**: Enabled **0**: Disabled
TDELTAV	[13]	TURBO mode Delta Voltage calculation: Use power spike defined in **Min Turbo Power** if enabled OR maximal delta between instantaneous and average voltages if disabled.	**1**: Enabled **0**: Disabled
SMOOTH	[12]	*Smooth FullChargeCapacity()* and *RemainingCapacity()*	**1**: Enabled **0**: Disabled
RELAX_JUMP_OK	[11]	Allow RSOC to jump during RELAX mode	**1**: Enabled **0**: Disabled
FF_NEAR_EDV	[10]	**Near EDV RA Param Filter** is used for Ra updates in the ***[RSOC_CONV*** region, else use the Resistance Parameter Filter	**1**: Enabled **0**: Disabled
CELL_TERM	[9]	Cell based termination	**1**: Enabled **0**: Disabled
FAST_QMAX_FLD	[8]	Fast Qmax update in field	**1**: Enabled **0**: Disabled

B7	B6	B5	B4	B3	B2	B1	B0
FAST_QMAX_LRN	RSOC_CONV	LFP_RELAX	DOD0EW	OCVFR	RFACTSTEP	CSYNC	CCT

FAST_QMAX_LRN	[7]	Fast Qmax update in learning	**1**: Enabled **0**: Disabled
RSOC_CONV	[6]	Fast scaling of RSOC convergence	**1**: Enabled **0**: Disabled
LFP_RELAX	[5]	Relax method for Lithium Iron Phosphate cells	**1**: Enabled **0**: Disabled
DOD0EW	[4]	Depth of Discharge 0 error weighting	**1**: Enabled **0**: Disabled
OCVFR	[3]	Open Circuit Voltage Flat region	**1**: Enabled **0**: Disabled
RFACTSTEP	[2]	Ra factor step	**1**: Enabled **0**: Disabled
CSYNC	[1]	Synchronize *RemainingCapacity()* with *FullChargeCapacity()* at valid charge termination	**1**: Enabled **0**: Disabled
CCT	[0]	Use CC % of *FullChargeCapacity()*, else use CC % of *DesignCapacity()*	**1**: Enabled **0**: Disabled

12.2.6 SOC Flag Config

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	SOC Flag Config A	B2	0	0xfff	0xc8c	hex
Settings	Configuration	SOC Flag Config B	B1	0	0xff	0x8c	hex

12.2.6.1 SOC Flag Config A

B15	B14	B13	B12	B11	B10	B9	B8
RSVD	RSVD	RSVD	RSVD	TCSETVCT	FCSETVCT	RSVD	RSVD

RSVD	[15:12]	Reserved - Do not use	
TCSETVCT	[11]	TC flag set by primary charge termination	**1**: Enabled **0**: Disabled
FCSETVCT	[10]	FC flag set by primary charge termination	**1**: Enabled **0**: Disabled
RSVD	[9:8]	Reserved - Do not use	

B7	B6	B5	B4	B3	B2	B1	B0
TCCLEARRSOC	TCSETRSOC	TCCLEARV	TCSETV	TDCLEARRSOC	TDSETRSOC	TDCLEARV	TDSETV

TCCLEARRSOC	[7]	TC flag clear by RSOC threshold	**1**: Enabled **0**: Disabled
TCSETRSOC	[6]	TC flag set by RSOC threshold	**1**: Enabled **0**: Disabled
TCCLEARV	[5]	TC flag clear by cell voltage threshold	**1**: Enabled **0**: Disabled
TCSETV	[4]	TC flag set by cell voltage threshold	**1**: Enabled **0**: Disabled
TDCLEARRSOC	[3]	TD flag clear by RSOC threshold	**1**: Enabled **0**: Disabled
TDSETRSOC	[2]	TD flag set by RSOC threshold	**1**: Enabled **0**: Disabled
TDCLEARV	[1]	TD flag clear by cell voltage threshold	**1**: Enabled **0**: Disabled
TDSETV	[0]	TD flag set by cell voltage threshold	**1**: Enabled **0**: Disabled

12.2.6.2 SOC Flag Config B

B7	B6	B5	B4	B3	B2	B1	B0
FCCLEARRSOC	FCSETRSOC	FCCLEARV	FCSETV	FDCLEARRSOC	FDSETRSOC	FDCLEARV	FDSETV

FCCLEARRSOC	[7]	FC flag clear by RSOC threshold	**1**: Enabled **0**: Disabled
FCSETRSOC	[6]	FC flag set by RSOC threshold	**1**: Enabled **0**: Disabled
FCCLEARV	[5]	FC flag clear by cell voltage threshold	**1**: Enabled **0**: Disabled
FCSETV	[4]	FC flag set by cell voltage threshold	**1**: Enabled **0**: Disabled
FDCLEARRSOC	[3]	FD flag clear by RSOC threshold	**1**: Enabled **0**: Disabled
FDSETRSOC	[2]	FD flag set by RSOC threshold	**1**: Enabled **0**: Disabled
FDCLEARV	[1]	FD flag clear by cell voltage threshold	**1**: Enabled **0**: Disabled
FDSETV	[0]	FD flag set by cell voltage threshold	**1**: Enabled **0**: Disabled

12.2.7 Sbs Configuration

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	Configuration	Sbs Gauging Configuration	B1	0	0x0f	0x4	hex
Settings	Configuration	Sbs Configuration	B1	0	0xff	0x20	hex

12.2.7.1 SBS Configuration

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	BLT[1]	BLT[0]	XL	HPE	CPE	BCAST

Field	Bits	Description	Values
RSVD	[7:6]	Reserved - Do not use	
BLT[1:0]	[5:4]	Bus low timeout See table below	
XL	[3]	400kHz COM mode	**1**: Enabled **0**: Disabled
HPE	[2]	Packet Error Checking (PEC) on host communication	**1**: Enabled **0**: Disabled
CPE	[1]	Packet Error Checking (PEC) on charger broadcast	**1**: Enabled **0**: Disabled
BCAST	[0]	Enable alert and charging broadcast from device to host	**1**: Enabled **0**: Disabled

BLT[1]	BLT[0]	Bus Low Timeout
1	1	3 seconds
1	0	2 seconds
0	1	1 seconds
0	0	No timeout

12.2.7.2 SBS Gauging Configuration

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	RSVD	RSVD	LOCK0	RSOC_HOLD	RSOCL

Field	Bits	Description	Values
RSVD	[7:3]	Reserved - Do not use	
LOCK0	[2]	Keep *RemainingCapacity()* and *RelativeStateOfCharge()* from jumping back during relaxation after 0 was reached during discharge.	**1**: Enabled **0**: Disabled
RSOC_HOLD	[1]	Prevent RSCO from increasing during discharge	**1**: Enabled **0**: Disabled
RSOCL	[0]	Hold *RelativeStateOfCharge()* and *RemainingCapacity()* at 99% until valid charge termination. Update to 100% on valid termination.	**1**: Enabled **0**: Disabled

12.2.8 Temperature Configuration

12.2.8.1 Temperature Enable

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	TS4	TS3	TS2	TS1	TSInt

RSVD	[7:5]	Reserved - Do not use	
TS4	[4]	External Temperature Sensor 4	**1**: Detected **0**: Disabled
TS3	[3]	External Temperature Sensor 3	**1**: Detected **0**: Disabled
TS2	[2]	External Temperature Sensor 2	**1**: Detected **0**: Disabled
TS1	[1]	External Temperature Sensor 1	**1**: Detected **0**: Disabled
TSInt	[0]	Internal Temperature Sensor	**1**: Detected **0**: Disabled

12.2.8.2 Temperature Mode

B7	B6	B5	B4	B3	B2	B1	B0
RSVD	RSVD	RSVD	TS4 Mode	TS3 Mode	TS2 Mode	TS1 Mode	TSInt Mode

RSVD	[7:5]	Reserved - Do not use	
TS4 Mode	[4]	Temperature Sensor 4 Cell or FET temperature selector	**1**: FET **0**: Cell
TS3 Mode	[3]	Temperature Sensor 3 Cell or FET temperature selector	**1**: FET **0**: Cell
TS2 Mode	[2]	Temperature Sensor 2 Cell or FET temperature selector	**1**: FET **0**: Cell
TS1 Mode	[1]	Temperature Sensor 1 Cell or FET temperature selector	**1**: FET **0**: Cell
TSInt Mode	[0]	Internal Temperature Sensor Cell or FET temperature selector	**1**: FET **0**: Cell

12.2.9 SBS Configuration

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
SBS Configuration	Data	Remaining AH Cap. Alarm	I2	0	32767	300	mAh
SBS Configuration	Data	Remaining WH Cap. Alarm	I2	0	32767	432	cWh
SBS Configuration	Data	Remaining Time Alarm	U2	0	65535	10	min
SBS Configuration	Data	Initial Battery Mode	B2	0	0xffff	0x81	hex
SBS Configuration	Data	Specification Information	U2	0	0xffff	0x31	hex
SBS Configuration	Data	Manufacture Date	U2	0	65535	0	date
SBS Configuration	Data	Serial Number	U2	0	0xffff	0x0001	hex
SBS Configuration	Data	Manufacturer Name	S21	x	x	Texas Instruments	—
SBS Configuration	Data	Device Name	S21	x	x	bq40z60	—
SBS Configuration	Data	Device Chemistry	S5	x	x	LION	—

AFE Threshold and Delay Settings

A.1 AFE Protection Settings

CLASS	SUBCLASS	NAME	TYPE	MIN	MAX	DEFAULT	UNIT
Settings	AFE	AFE Protection Control	U1	0	0xff	0x70	hex
Settings	AFE	ZVCHG Exit Threshold	I2	0	8000	2200	mV

B7	B6	B5	B4	B3	B2	B1	B0
RSTRIM[3]	RSTRIM[2]	RSTRIM[1]	RSTRIM[0]	RSVD	RSVD	SCDDx2	RSNS
RSTRIM[3:0]	[7:4]	Unsupported function. Changing this setting may cause an error in the AFE protection.					
RSVD		Reserved - Do not use					
SCDDx2	[1]	Double Short Circuit Detection time				**1**: Enabled **0**: Disabled	
RSNS	[0]	Force normal AFE Thresholds (AOLD, ASCC, ASCD1, ASCD2)				**1**: 100% Thresholds **0**: 50% Thresholds	

A.1.1 Overload in Discharge Protection (AOLD)

Table A-1. Overload in Discharge Protection Threshold (Settings:AFE:AFE Protection Control [RSNS] = 0) (1)

OLD THRESHOLD ([RSNS] = 0)			
SETTING	**THRESHOLD**	**SETTING**	**THRESHOLD**
0x00	–8.30 mV	0x08	–30.54 mV
0x01	–11.08 mV	0x09	–33.32 mV
0x02	–13.86 mV	0x0A	–36.10 mV
0x03	–16.64 mV	0x0B	–38.88 mV
0x04	–19.42 mV	0x0C	–41.66 mV
0x05	–22.20 mV	0x0D	–44.44 mV
0x06	–24.98 mV	0x0E	–47.22 mV
0x07	–27.76 mV	0x0F	–50.00 mV

(1) Data flash setting ***Protection:AFE Thresholds:OLD Threshold[3:0]*** sets the voltage threshold.

Table A-2. Overload in Discharge Protection Threshold (Settings:AFE:AFE Protection Control [RSNS] = 1) (1)

OLD THRESHOLD ([RSNS] = 1)			
SETTING	**THRESHOLD**	**SETTING**	**THRESHOLD**
0x00	–16.60 mV	0x08	–61.08 mV
0x01	–22.16 mV	0x09	–66.64 mV
0x02	–27.72 mV	0x0A	–72.20 mV
0x03	–33.28 mV	0x0B	–77.76 mV
0x04	–38.84 mV	0x0C	–83.32 mV

(1) Data flash setting ***Protection:AFE Thresholds:OLD Threshold[3:0]*** sets the voltage threshold.

Table A-2. Overload in Discharge Protection Threshold (Settings:AFE:AFE Protection Control [RSNS] = 1) [(1)] (continued)

OLD THRESHOLD ([RSNS] = 1)			
SETTING	THRESHOLD	SETTING	THRESHOLD
0x05	–44.40 mV	0x0D	–88.88 mV
0x06	–49.96 mV	0x0E	–94.44 mV
0x07	–55.52 mV	0x0F	–100.00 mV

Table A-3. Overload in Discharge Protection Delay [(1)]

SETTING	TIME	SETTING	TIME	SETTING	TIME	SETTING	TIME
0x00	1 ms	0x04	9 ms	0x08	17 ms	0x0C	25 ms
0x01	3 ms	0x05	11 ms	0x09	19 ms	0x0D	27 ms
0x02	5 ms	0x06	13 ms	0x0A	21 ms	0x0E	29 ms
0x03	7 ms	0x07	15 ms	0x0B	23 ms	0x0F	31 ms

(1) Data flash setting ***Protection:AFE Thresholds:OLD Threshold[7:4]*** sets the delay time.

A.1.2 Short Circuit in Charge (ASCC)

Table A-4. Short Circuit in Charge Threshold (Settings:AFE:AFE Protection Control [RSNS] = 0) [(1)]

SETTING	THRESHOLD	SETTING	THRESHOLD
0x00	22.2 mV	0x04	66.65 mV
0x01	33.3 mV	0x05	77.75 mV
0x02	44.4 mV	0x06	88.85 mV
0x03	55.5 mV	0x07	100 mV

(1) Data flash setting ***Protection:AFE Thresholds:SCC Threshold[2:0]*** sets the voltage threshold.

Table A-5. Short Circuit in Charge Threshold (Settings:AFE:AFE Protection Control [RSNS] = 1) [(1)]

Setting	Threshold	Setting	Threshold
0x00	44.4 mV	0x04	133.3 mV
0x01	66.6 mV	0x05	155.5 mV
0x02	88.8 mV	0x06	177.7 mV
0x03	111.1 mV	0x07	200 mV

(1) Data flash setting ***Protection:AFE Thresholds:SCC Threshold[2:0]*** sets the voltage threshold.

Table A-6. Short Circuit in Charge Delay [(1)]

SETTING	TIME	SETTING	TIME	SETTING	TIME	SETTING	TIME
0x00	0 µs	0x04	244 µs	0x08	488 µs	0x0C	732 µs
0x01	61 µs	0x05	305 µs	0x09	549 µs	0x0D	793 µs
0x02	122 µs	0x06	366 µs	0x0A	610 µs	0x0E	854 µs
0x03	183 µs	0x07	427 µs	0x0B	671 µs	0x0F	915 µs

(1) Data Flash setting ***Protection:AFE Thresholds:SCC Threshold[7:4]*** sets the delay time.

A.1.3 Short Circuit in Discharge (ASCD1 and ASCD2)

Table A-7. Short Circuit in Discharge Threshold (Settings:AFE:AFE Protection Control [RSNS] = 0) (1)

SETTING	THRESHOLD	SETTING	THRESHOLD
0x00	–22.2 mV	0x04	–66.65 mV
0x01	–33.3 mV	0x05	–77.75 mV
0x02	–44.4 mV	0x06	–88.85 mV
0x03	–55.5 mV	0x07	–100 mV

(1) Data flash setting ***Protection:AFE Thresholds:SCD1 Threshold[2:0]*** and ***Protection:AFE Thresholds:SCD2 Threshold[2:0]*** sets the voltage thresholds.

Table A-8. Short Circuit in Discharge Threshold (Settings:AFE:AFE Protection Control [RSNS] = 1) (1)

SETTING	THRESHOLD	SETTING	THRESHOLD
0x00	–44.4 mV	0x04	–133.3 mV
0x01	–66.6 mV	0x05	–155.5 mV
0x02	–88.8 mV	0x06	–177.7 mV
0x03	–111.1 mV	0x07	–200 mV

(1) Data flash setting ***Protection:AFE Thresholds:SCD1 Threshold[2:0]*** and ***Protection:AFE Thresholds:SCD2 Threshold[2:0]*** sets the voltage thresholds.

Table A-9. Short Circuit in Discharge 1 Delay (Settings:AFE:AFE Protection Control [SCDDx2] = 0) (1)

SETTING	TIME	SETTING	TIME	SETTING	TIME	SETTING	TIME
0x00	0 µs	0x04	244 µs	0x08	488 µs	0x0C	732 µs
0x01	61 µs	0x05	305 µs	0x09	549 µs	0x0D	793 µs
0x02	122 µs	0x06	366 µs	0x0A	610 µs	0x0E	854 µs
0x03	183 µs	0x07	427 µs	0x0B	671 µs	0x0F	915 µs

(1) Data flash setting ***Protection:AFE Thresholds:SCD1Threshold[7:4]*** sets the delay time.

Table A-10. Short Circuit in Discharge 1 Delay (Settings:AFE:AFE Protection Control [SCDDx2] = 1) (1)

Setting	Time	Setting	Time	Setting	Time	Setting	Time
0x00	0 µs	0x04	488 µs	0x08	976 µs	0x0C	1464 µs
0x01	122 µs	0x05	610 µs	0x09	1098 µs	0x0D	1586 µs
0x02	244 µs	0x06	732 µs	0x0A	1220 µs	0x0E	1708 µs
0x03	366 µs	0x07	854 µs	0x0B	1342 µs	0x0F	1830 µs

(1) Data flash setting ***Protection:AFE Thresholds:SCD1 Threshold[7:4]*** sets the delay time.

Table A-11. Short Circuit in Discharge 2 Delay (Settings:AFE:AFE Protection Control [SCDDx2] = 0) (1)

SETTING	TIME	SETTING	TIME	SETTING	TIME	SETTING	TIME
0x00	0 µs	0x04	122 µs	0x08	244 µs	0x0C	366 µs
0x01	31 µs	0x05	153 µs	0x09	275 µs	0x0D	396 µs
0x02	61 µs	0x06	183 µs	0x0A	305 µs	0x0E	427 µs
0x03	92 µs	0x07	214 µs	0x0B	335 µs	0x0F	458 µs

(1) Data Flash setting ***Protection:AFE Thresholds:SCD2 Threshold[7:4]*** sets the delay time.

Table A-12. Short Circuit in Discharge 2 Delay (Settings:AFE:AFE Protection Control [SCDDx2] = 1) [(1)]

SETTING	TIME	SETTING	TIME	SETTING	TIME	SETTING	TIME
0x00	0 µs	0x04	244 µs	0x08	488 µs	0x0C	732 µs
0x01	62 µs	0x05	306 µs	0x09	550 µs	0x0D	792 µs
0x02	122 µs	0x06	366 µs	0x0A	610 µs	0x0E	854 µs
0x03	184 µs	0x07	428 µs	0x0B	670 µs	0x0F	916 µs

(1) Data flash setting ***Protection:AFE Thresholds:SCD2 Threshold[7:4]*** sets the delay time.

Sample Filter Settings

Table B-1. Sample V/I/P Filter Settings and Associated Low-Pass Filter Time Constants [1]

AVERAGE V/I/P FILTER	EFFECTIVE LOW-PASS TIME CONSTANT
10	0.25 seconds
50	0.5 seconds
145	1 second
200	3 seconds

(1) Data Flash setting ***Calibration:Filter:Average V/I/P*** sets this threshold.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from C Revision (March 2016) to D Revision	Page
• Corrected typos in the document	9

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