bq78PL114 and bq78PL114S12 Technical Reference Manual

Technical Reference

Literature Number: SLUU330B
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Preface

1.1 Read This First

This document discusses the bq78PL114 and bq78PL114S12 device modules which are used to build a complete battery-pack gas gauge and protection solution. In this document, all descriptions for the bq78PL114 apply to the bq78PL114S12 except where different bq78PL114S12 functionality is specifically described.

The text makes frequent references to alert flags being set when a safety rule condition is detected. The alert flags and their status are only visible when using the bqWizard™ application.

1.2 Notational Conventions

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

The reference format for SBS commands is: SBS:Command Name(Command No.), for example: SBS:Voltage(0x09), or SBS:BatteryStatus(0x16):[TCA]

The reference format for programmable parameters values is: Value Name, for example: COV Threshold

1.3 Scope and Definitions

The scope of this document is to convey descriptive information on the multiple configuration parameters (thresholds) available in the bq78PL114 to control both basic fuel-gauging operation and safety operation. Multiple parameters are provided for custom configuration of the bq78PL114 to allow flexible use in a variety of 3- to 8-cell Li-Ion applications. (Note that for cell counts greater than four, additional bq76PL102 parts are required in addition to the bq78PL114.)

This document includes detail on such parameters, their settings, ranges, and uses. Additional information is included which describes the fuel-gauging algorithm, calibration steps, and similar operational notes to allow a more complete understanding of the usage of this part.

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1.4 bq78PL114 and bq78PL114S12 Comparison Chart

The default firmware that ships with the bq78PL114 must not be used. Upgrading to FW5000 is required.

Area	Feature	bq78PL114	bq78PL114S12
Configuration	Firmware version	4452	5000
	FW build	N/A	12
	bqWizard™ version	2.4.30 or higher	2.5.7 or higher
Hardware	Max # series cells	8	12
	Maximum- temperature sensors	13 (with multiplexing)	13 (multiplexing not available)
	Sense resistor	Single selection, default 5 mΩ	3 options, 1, 3, and 10 mΩ. Default is 10 mΩ. Configuration utility available.
	Display options	LED only, fixed configuration	LED, LCD, and EPD options. The display bit configuration and RSOC ranges can be externally configured.
	Cell balancing	Three algorithm types selectable, OCV, impedance corrected, and SOC	Same three algorithms. Cell balancing can be given priority over temperature measurement to allow a higher percentage of balancing (SuperPump).
		-	Balancing can be disabled during charge or discharge
	Forensic data	Maintains histogram of cell voltage and temperature history	Not available
	Cell history	Provides maximum and minimum voltage and temperature on a cell-by-cell basis.	Not available
	Cell learned parameters	Idle_OCV, VBUS errors, impedance growth ratio, SOC target all retained for access	Impedance, Qmax, Qremaining, HF-Impedance
	Safety events	10 events, each with maximum, minimum, and average cell voltage and cell number of maximum and minimum cell	10 events, each with maximum, minimum, and average cell voltage and cell number of maximum and minimum cell
External Communications	SBData mapping	Can be externally configured to allow mapping of any internal parameters. Base address is configurable.	Individual cell voltages mapped to SBS command 0x3C and up.
	SBData enhanced commands	Not available	Extended SBData commands available for configuration and calibration.
	SBData address	Fixed, 0x16	Programmable, default = 0x16
	API	None	bq78PL114S12 API
Support Tools	AUX File Generator	None	AUX GUI in bqWizard™ software

1.5 Design Flow Overview

The development cycle for a battery management system based on the PowerLAN™ Master Gateway Battery Management Controller is outlined in Figure 1-1. Prototype designs are developed in the laboratory environment using the bqWizard™ software. Once development is complete, the prototype's configuration is saved and used to clone production packs.

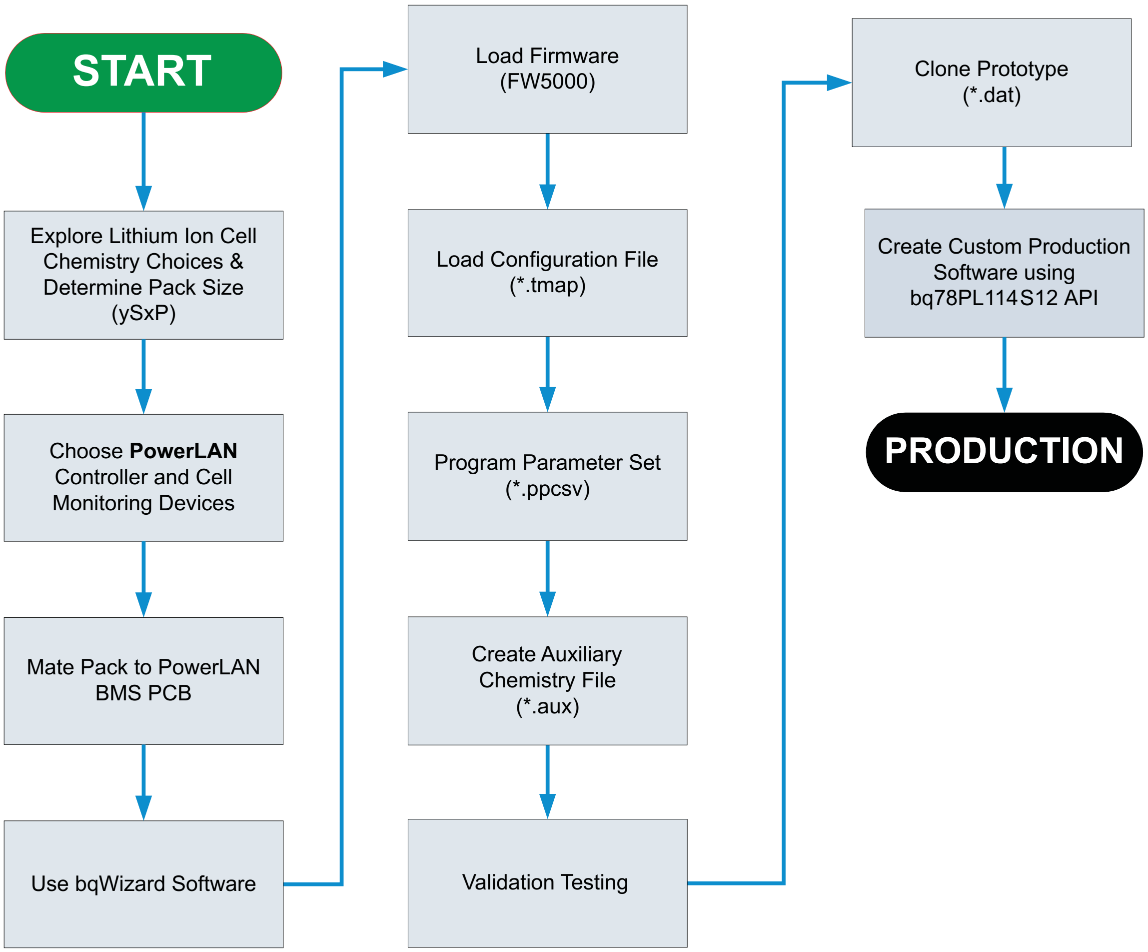

Figure 1-1. PowerLAN™ BMS Development Cycle

This introductory section gives an overview of the design flow required for PowerLAN™ Battery Management Systems.

1.5.1 EVM

Use the bq78PL114EVM-001 and the bqWizard™ software to explore the capabilities of the PowerLAN™ devices for 3-to-8 series cell packs. The EVM is ideal for an introduction to the PowerLAN™ architecture and to evaluate PowerPump™ cell balancing. The EVM includes the PowerLAN™ Master Gateway controller – bq78PL114, two PowerLAN™ Dual Cell Monitors – bq76PL102 and two Secondary Protectors – bq29410.

At first, use 10-Ω resistors and a power supply to simulator cell voltages; when familiar with the operation of the PowerLAN™ devices, then transition to use of a cell pack.

The bqWizard™ software that is included with the EVM is a powerful data acquisition tool that can log many different system parameters as well as help to generate small-lot production runs.

See the *bq78PL114 8S EVM User's Guide* (SLUU335) and the *bqWizard™ User's Guide* (SLUU336) for more details.

1.5.2 Battery Pack

To take advantage of the advanced-feature set of the PowerLAN™ Master Gateway Controller, the electrical and chemical characteristics of the battery pack must be communicated to the controller prior to use at the production level. This is done through various configuration files loaded by the bqWizard™ software. Three important characteristics are cell chemistry, pack size, and pack construction.

Simple experimentation can be performed without providing full description of the pack. However, some unexpected results may occur if the full characteristics of the pack are not provided.

1.5.2.1 Cell Chemistry

The PowerLAN™ Master Gateway Controller features a gas gauge whose performance is tied to the type of lithium ion cell chemistry used. Each cell chemistry requires that a matching chemistry file (*.chem) be used that accurately characterizes the cell. See the application report *Chemistry Selection for bq78PL114* (SLUA505).

The default chemistry loaded with the firmware is CHEM ID 101. Numerous chemistry files have been developed to date which are accessed through the bqWizard™ software. If the cell being used is not in the library of chemistry files, a characterization test must be performed to generate the chemistry file and subsequent CHEM ID number. For instance, the CHEM ID 0400 represents a $LiFePO_4$ chemistry type. Characterization of cell chemistry and generation of the CHEM ID is done by Texas Instruments Battery Management Application Engineering.

Chemistry data also is used for other advanced features such as PowerPump™ cell balancing and impedance growth calculations.

CAUTION: It is only after a chemistry file (.chem) and an auxiliary chemistry file (.aux) are loaded via the bqWizard™ software that the complete cell impedance information is written into the PowerLAN™ controller. Therefore, the auxiliary data collection run and subsequent .aux file must be created for the target pack. If a custom .aux file is not created, the default impedances (101), are used for calculations that require impedance values. This may cause errors if the target cell impedance is different from CHEM ID 101.

1.5.2.2 Pack Size and System Design

Battery pack size is described in terms of series count (y) and parallel count(x). An 8S3P pack means that the battery pack consists of three parallel cells connected in a series of eight cells. If each cell is a nominal 3.7 V and has a capacity of 2200 mAHr, the 8S3P pack is a nominal 29.6 V and with a 6600-mAHr capacity.

Specifying pack size in the PowerLAN™ Gateway Controller's parameter data set determines the number of PowerLAN™ nodes that are created to monitor cell voltage, cell temperature, and coordinate PowerPump™ balancing. The PowerLAN™ Master Gateway Controller monitors up to four series cells. For packs larger than four, a PowerLAN™ Dual Cell Monitor, bq76PL102, is used to monitor every two additional series cells.

Pack size, current measurement range, state-of-charge indication, and other aspects of the battery management system design are programmed by loading a Configuration File (*.tmap) in the bqWizard™ software. Details of the configuration file operation are found in the application report *What is a .tmap file?* (SLUA542).

1.5.2.3 Pack Construction

The chemistry file previously mentioned describes the operation of the unit cell. An auxiliary chemistry file (*.aux) is needed to change the .chem file so that it represents the cells when they are physically connected together to make up a battery pack. For example, cell strap impedance (length) for each cell connection may not be the same due to mechanical constraints. This is factored into the equivalent cell model to make an application-specific cell model. Pack modeling is accomplished through a data collection test run as described in the application report *Chemistry Selection for the bq78PL114* (SLUA505). The data then is processed by the bqWizard™ software and loaded into the device.

1.5.3 Conversion From Firmware 4452 to Firmware 5000

The bq78PL114 comes from the factory with firmware (FW) version 4452 and is configured to expect an 8S2P battery pack with chemistry ID 101 and no auxiliary chemistry data. Converting to FW 5000 effectively renames the part as bq78PL114S12. The default configuration of the bq78PL114S12 is 3S1P with chemistry ID 101 and no auxiliary chemistry data.

See Appendix C for the procedure to upgrade the firmware.

1.5.4 Design and Build Prototype Circuitry

1.5.4.1 System Design

See the application report *bq78PL114 System Design Guidelines* (SLUA537) for details on system design, reference schematic, and PCB layout.

1.5.5 Parameter Set

The parameter set specifies all of the values programmable by the user. The parameters are organized into sections called SBData Static, Charge Control, Cell Balancing, Cell Chemistry, Pack Configuration, Safety Level 1, and Safety Level 2. These sections correspond to the tabbed sections in the bqWizard™ software. Most values can either be edited in the bqWizard™ software or saved to a file (*.ppcsv), edited offline in a spreadsheet program, and then re-loaded into the device.

These parameters govern the operation of the system. Each parameter must be set to match the target battery pack in use. The default parameter set that is included with the FW 5000 is for a 3S1P pack with CHEM ID 101. The lowest cell count configuration was used as the default because it is considered the safest. If the user attempts to use a pack larger than 3S and neglects to update the parameter set, the pack overvoltage rule (POV) prematurely activates to open the charge MOSFET.

Many safety rules can be deactivated by setting their timer to zero. This allows the reduction of the safety rule set to a minimal level if only basic safety is needed.

1.5.6 Validation Testing

Final test and evaluation of the PowerLAN™ battery management system must only occur with a completely designed system that is representative of the production unit. Using hardware that is properly configured to manage and control the battery pack is critical to achieve the best performance. For instance, a CHEM ID file that does not match the cells under test can result in higher than normal gas gauge inaccuracy.

1.5.7 Production Readiness

1.5.7.1 Golden Flash File (*.dat)

The configuration files customize the PowerLAN™ controller to suit the application needs. These files (.tmap, .ppcsv, .chem, .aux) are then combined into a single production configuration file called a (.dat) file during the Production Readiness phase. The bqWizard™ software is used to extract the (.dat) file from the PowerLAN™ Master Gateway Controller. The (.dat) file then is used to clone each production pack. This file is often referred to as the *Golden Flash File*. The file is encoded and ensures a level of protection against unwanted tampering.

1.5.7.2 Production Software

The bqWizard™ software is intended for experimentation and development of a prototype system in a laboratory environment. The bq78PL114S12 API is a Windows™ .NET Application Programming Interface (API). The API is intended to allow users to automate their production flow. Essential tasks such as configuration and calibration of each battery pack can be accomplished using the API and the appropriate software and hardware interfaces.

1.5.7.3 Production Hardware

The SMBus interface to be used in production is the USB-TO-GPIO EVM. This is available through Texas Instruments. This USB adapter provides the communication and control needed to complete the typical production flow. The USB-TO-GPIO is based on Texas Instruments' Universal Serial Bus General-Purpose Device Controller TUSB3210. Schematic, bill of materials, and PCB layout information for the USB-TO-GPIO EVM is available if users wish to incorporate the circuit into their production hardware.

First-Level Protection Features

The bq78PL114 supports multilevel safety functions for a variety of battery-pack parameters. The first-level safety protection features are a group of safety thresholds and responses which can be reset and which can occur at various speeds and threshold limits. Tier 1: Typically slow to act, and activation includes opening protection MOSFETs to interrupt current flow in the battery pack. Tier 2: Faster-reacting action, usually a higher threshold needed to cause the reaction, and activation which includes opening protection MOSFETs to interrupt current flow in the battery pack. Hardware Safety: Very fast reaction, on the order of milliseconds, usually at still-higher activation thresholds which also cause the protection MOSFETs to interrupt current flow in the battery pack. This wide range of battery and system protection features is easily configured or enabled via the integrated data flash. The bq78PL114 and bq78PL114S12 do not support the JEITA standard.

Some safety functions are configured using the Hardware Configuration or Algorithm registers.

Setting threshold values and other configuration parameters can be accomplished using the bqWizard™ graphical user interface (GUI)

2.1 Cell Overvoltage

The bq78PL114 can detect cell overvoltage and protect battery cells from damage.

This condition is evaluated once per second after all cell voltages are measured. The following user-defined parameters govern the behavior of this rule:

(a) COV Threshold: Set in units of mV

(b) COV Time: Set in units of 1 second. Setting to zero disables the function.

(c) COV Recovery: Set in units of mV

(d) COV High-Temperature Adjust: Set in units of 0.1°C

(e) COV High-Temperature Threshold: Set in units of mV

Activation criteria/behavior: When any cell voltage rises above the COV Threshold, an alert flag for this condition is set to indicate the presence of the overvoltage condition. If the condition remains true beyond the COV Time, then the status flag for this condition is set, and the following safety actions are taken. If the condition clears within the COV Time, then no action is taken, and the alert flag is cleared. If any cell temperature exceeds the COV High Temperature Adjust, the COV High Temperature Threshold is used instead of the COV Threshold for determining activation.

Activation of this rule exhibits the following behavior:

(a) Charge and precharge MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:ChargingVoltage(0x15) is set to 0.

(d) SBS:ChargingCurrent(0x14) is set to 0.

(e) BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

Deactivation criteria/behavior: When all cell voltages fall below COV Recovery, the following actions are taken:

(a) Charge and precharge MOSFETs are closed.

(b) Safety-status and alert flags for this condition are cleared.

(c) SBS:ChargingVoltage(0x15) is set to allow charge.

(d) SBS:ChargingCurrent (0x14) is set to allow charge.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

2.2 Cell Undervoltage

The bq78PL114 can detect cell undervoltage and protect battery cells from damage.

This condition is evaluated once per second after all cell voltages are measured. The following user-defined parameters govern the behavior of this rule:

(a) CUV Threshold: Set in units of mV

(b) CUV Time: Set in units of 1 second. Setting to zero disables the function.

(c) CUV Recovery: Set in units of mV

Activation criteria/behavior: When any cell voltage falls below the CUV Threshold, an alert flag for this condition is set to indicate the presence of the undervoltage condition. If the condition remains beyond the CUV Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the CUV Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The discharge MOSFET is opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:BatteryStatus(0x16):[TCA] Terminate Discharge Alarm bit is set.

(d) SBS:BatteryStatus(0x16):[FD] Fully Discharged bit is set.

Deactivation criteria/behavior: When all cell voltages rise above CUV Recovery, the following actions are taken:

(a) The discharge MOSFET is closed.

(b) Safety-status and alert flags for this condition are cleared.

In cell undervoltage condition, the DSG FET is turned on during charging to prevent overheating of the DSG FET body diode.

2.3 Extreme Cell Undervoltage

The bq78PL114 can detect cell undervoltage and protect battery cells from damage.

This condition is evaluated once per second after all cell voltages are measured. The following user-defined parameters govern the behavior of this rule:

(a) EUV Threshold: Set in units of mV

(b) EUV Time: Set in units of 1 second. Setting to zero disables the function.

(c) EUV Recovery: Set in units of mV, normally 2700 mV

Activation criteria/behavior: When any cell voltage falls below the EUV Threshold, an alert flag for this condition is set to indicate the presence of the undervoltage condition. If the condition remains beyond the EUV Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the EUV Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The charge and discharge MOSFETs are opened.

(b) SBS:BatteryStatus(0x16):[TCA] Terminate Discharge Alarm bit is set.

(c) SBS:BatteryStatus(0x16):[FD] Fully Discharged bit is set.

(d) Enter undervoltage low-power state

While in the EUV state, all functions cease and the device is in reset. The part recovers when cell voltages rise above the hardware recovery level (see data sheet). When this occurs, the following actions are taken:

(a) The discharge MOSFET is closed.

(b) Safety-status and alert flags for this condition are cleared.

(c) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is cleared

(d) The undervoltage low-power state is exited.

NOTE: The EUV condition is not logged to nonvolatile memory.

2.4 Pack Overvoltage

The bq78PL114 can detect battery pack overvoltage and protect the battery pack from damage.

This condition is evaluated once per second. The pack voltage is constructed as a summation of the individual cell voltage measurements, which occur once per second.

The following user-defined parameters govern the behavior of this rule:

(a) POV Threshold: Set in units of mV

(b) POV Time: Set in units of 1 second. Setting to zero disables the function.

(c) POV Recovery: Set in units of mV

Activation criteria/behavior: When the pack voltage rises above the POV Threshold, an alert flag for this condition is set to indicate the presence of the pack overvoltage condition. If the condition remains beyond the POV Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the POV Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) Charge and precharge MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:ChargingVoltage(0x15) is set to 0.

(d) SBS:ChargingCurrent(0x14) is set to 0.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

Deactivation criteria/behavior: When the pack voltage falls below POV Recovery, the following actions are taken:

(a) Charge and precharge MOSFETs are closed.

(b) Safety-status and alert flags for this condition are cleared.

(c) SBS:ChargingVoltage(0x15) is set to allow charge.

(d) SBS:ChargingCurrent(0x14) is set to allow charge.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

2.5 Pack Undervoltage

The bq78PL114 can detect battery pack undervoltage and protect the battery pack from damage.

This condition is evaluated once per second. The Pack Voltage is constructed as a summation of the individual cell voltage measurements, which occur once per second.

The following user-defined parameters govern the behavior of this rule:

(a) PUV Threshold: Set in units of mV

(b) PUV Time: Set in units of 1 second. Setting to zero disables the function.

(c) PUV Recovery: Set in units of mV

Activation criteria/behavior: When the pack voltage falls below the PUV Threshold, an alert flag for this condition is set to indicate the presence of the undervoltage condition. If the condition remains beyond the PUV Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the PUV Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The discharge MOSFET is opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

(d) SBS:BatteryStatus(0x16):[FD] Fully Discharged bit is set.

Deactivation criteria/behavior: When the pack voltage rises above PUV Recovery, the following actions are taken:

(a) The discharge MOSFET is closed.
(b) Safety alert and status flags for this condition are cleared.
(c) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is cleared.

2.6 Charge Overcurrent – Tier 1

The first level of bq78PL114 overcurrent protection for charge is discussed as follows.

This condition is evaluated once per second after the current measurement is complete.

The following user-defined parameters govern the behavior of this rule:

(a) OC Charge Tier 1 Threshold: Set in units of mA
(b) OC Charge Tier 1 Time: Set in units of 1 second. Setting to zero disables the function.
(c) OC Charge Tier 1 Recovery: Set in units of 1 second
(d) OC Max Attempts: Integer units. Setting to zero causes rule to immediately start trip/try at 255-second intervals; setting to 255 enables continuous retries at intervals equal to OC Charge Tier 1 Recovery.

Activation criteria/behavior: When the current during charge exceeds OC Charge Tier 1 Threshold, an alert flag for this condition is set to indicate the presence of an overcurrent condition. If the condition remains beyond the OC Charge Tier 1 Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the OC Charge Tier 1 Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The charge and precharge MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) SBS:ChargingVoltage(0x15) is set to 0.
(d) SBS:ChargingCurrent(0x14) is set to 0.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

Deactivation criteria/behavior: When the OC Charge Tier 1 Recovery time has elapsed, the following actions are taken:

(a) The charge and precharge MOSFETs are closed.
(b) The safety alert and status flags for this condition are cleared.
(c) SBS:ChargingVoltage(0x15) is set to allow charge.
(d) SBS:ChargingCurrent(0x14) is set to allow charge.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

If the *Activation criteria/behavior* condition still exists, then the process repeats for the number of times specified by OC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

2.7 Discharge Overcurrent – Tier 1

The first level of bq78PL114 overcurrent protection for discharge is described as follows.

This condition is evaluated once per second after the current measurement is complete.

The following user-defined parameters govern the behavior of this rule:

(a) OC Discharge Tier 1 Threshold: Set in units of mA
(b) OC Discharge Tier 1 Time: Set in units of 1 second. Setting to zero disables the function.
(c) OC Discharge Tier 1 Recovery: Set in units of 1 second
(d) OC Max Attempts: Integer units. (This value is set with the Charge Over Current – Tier 1 parameters.)

Activation criteria/behavior: When the current during discharge exceeds OC Discharge Tier 1 Threshold, an alert flag for this condition is set to indicate the presence of an overcurrent condition. If the condition remains beyond the OC Discharge Tier 1 Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the OC Discharge Tier 1 Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The discharge MOSFET is opened.

(b) The fault is logged into nonvolatile memory.

Deactivation criteria/behavior: When OC Discharge Tier 1 Recovery time has elapsed, the following actions are taken:

(a) The discharge MOSFET is closed.

(b) The safety alert and status flags for this condition are cleared.

(c) SBS:ChargingCurrent(0x14) is set to allow full charge.

If the *Activation criteria/behavior* condition still exists, then the process repeats for the number of times specified by OC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

2.8 Charge Overcurrent – Tier 2

The bq78PL114 has a second threshold for overcurrent on charge conditions.

This condition is evaluated once per second after the current measurement is complete.

The following user-defined parameters govern the behavior of this rule:

(a) OC Charge Tier 2 Threshold: Set in units of mA

(b) OC Charge Tier 2 Time: Set in units of 1 second. Setting to zero disables the function.

(c) OC Charge Tier 2 Recovery: Set in units of 1 second

(d) OC Max Attempts: Integer units. Setting to zero causes rule to immediately start trip/try at 255 second intervals; setting to 255 enables continuous retries at intervals equal to OC Charge Tier 1 Recovery. (This value is set with the Charge Over Current – Tier 1 parameters.)

Activation criteria/behavior: When the current during charge exceeds OC Charge Tier 2 Threshold, an alert flag for this condition is set to indicate the presence of an overcurrent condition. If the condition remains beyond the OC Charge Tier 2 Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the OC Charge Tier 2 Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The charge and precharge MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:ChargingVoltage(0x15) is set to 0.

(d) SBS:ChargingCurrent(0x14) is set to 0.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

Deactivation criteria/behavior: When the OC Charge Tier 2 Recovery time has elapsed, the following actions are taken:

(a) The charge and precharge MOSFETs are closed.

(b) The safety alert and status flags for this condition are cleared.

(c) SBS:ChargingVoltage(0x15) is set to allow charge.

(d) SBS:ChargingCurrent(0x14) is set to allow charge.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

If the *Activation criteria/behavior* condition still exists, then the process repeats for the number of times specified by OC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

2.9 Discharge Overcurrent – Tier 2

The bq78PL114 provides a second level of overcurrent on discharge detection.

This condition is evaluated once per second after the current measurement is complete.

The following user-defined parameters govern the behavior of this rule:

(a) OC Discharge Tier 2 Threshold: Set in units of mA

(b) OC Discharge Tier 2 Time: Set in units of 1 second. Setting to zero disables the function.

(c) OC Discharge Tier 2 Recovery: Set in units of 1 second

(d) OC Max Attempts: Integer units. (This value is set with the Charge Over Current – Tier 1 parameters.)

Activation criteria/behavior: When the current during discharge exceeds OC Discharge Tier 2 Threshold, an alert flag for this condition is set to indicate the presence of an overcurrent condition. If the condition remains beyond the OC Discharge Tier 2 Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within OC Discharge Tier 2 Time, no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The discharge MOSFET is opened.

(b) The fault is logged into nonvolatile memory.

Deactivation criteria/behavior: When the OC Discharge Tier 2 Recovery time elapses, the following actions are taken:

(a) The discharge MOSFET is closed.

(b) The safety alert and status flags for this condition are cleared.

(c) SBS:ChargingCurrent(0x14) is set to allow full charge.

If the *Activation criteria/behavior* condition still exists, then the process repeats for the number of times specified by OC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

2.10 Hardware Overcurrent Charge

The bq78PL114 provides fast-acting overcurrent detection mechanisms, such as for overcurrent during charge. A selection of delay times and activation thresholds is available. The condition for overcurrent on charge is continuously monitored by hardware.

In some applications, it may be desirable to have different thresholds and trip times when in standby mode. The bq78PL114 provides an alternate threshold and time parameter set for when the part is in low-power standby mode. When the bq78PL114 transitions to standby mode, the Hardware LP Charge Threshold and Hardware LP Charge Duration parameters are loaded in place of the respective Hardware OC Charge Threshold and Hardware OC Charge Time parameters. The condition for hardware low-power overcurrent charge is continuously monitored by hardware while the part is in standby mode. If an overcurrent condition is detected, the original hardware overcurrent parameters are restored and the part transitions to active mode. The user must set Hardware LP Overcurrent Charge threshold and duration parameters to be the same as their corresponding Hardware Overcurrent Charge Threshold and Hardware Overcurrent Charge Time parameters if they are not being used.

Note: The bq78PL114 uses a 5-mΩ current-sense resistor.

CAUTION: All hardware-based safety functions have a minimum activation threshold of 42 mV across the current-sense resistor. For the 5-mΩ current-sense resistor used by the bq78PL114, this corresponds to a 8.4-A minimum threshold.

Setting a register value for a threshold below this limit causes the safety condition never to be detected, regardless of the setting.

The following user-defined parameters govern the behavior of this rule:

(a) Hardware OC Charge Threshold: Set as an integer register value between 0 and 220, where each increment corresponds to a –250 mA step from 62 A maximum (register value of 0) to 8.4 A minimum (register value of 220).

Example: A register value of 128 sets the OC Charge Threshold limit to 32 A. Settings are stable to within 2 step increments or approximately 500 mA. A value of 128 nominally trips at 32 A, but could trip as low as 31.5 A or as high as 32.5 A.

CAUTION: With the 5-mW sense resistor, the register value must never be set above 220, which corresponds to an OC charge threshold of 8.4 A.

(b) Hardware OC Charge Time: Set as an integer register value between 1 and 127, where each increment corresponds to an 830-μs step from 900 μs minimum (register value of 1) to 106 ms maximum (register value of 127).

(c) Hardware LP Charge Threshold: Set as an integer register value between 0 and 220, where each increment corresponds to a –250-mA step from 62 A maximum (register value of 0) to 8.4 A minimum (register value of 220).

(d) Hardware LP Charge Duration: Set as an integer register value between 1 and 127, where each increment corresponds to an 830-μs step from 900 μs minimum (register value of 1) to 106 ms maximum (register value of 127).

Example: A register value of 1 sets the OC Charge Time limit to 900 μs, whereas a register value of 63 sets the time limit to 52.6 ms.

(e) Hardware OC Charge Recovery: Set in units of seconds

(f) HOC Max Attempts: Integer units. Setting to zero causes rule to immediately start trip/try at 255 second intervals; setting to 255 enables continuous retries at intervals equal to Hardware OC Charge Recovery.

Activation criteria/behavior: Hardware is activated when the charge current exceeds Hardware OC Charge Threshold for the Hardware OC Charge Time.

Activation of this rule exhibits the following behavior:

(a) The safety-status flag for this function is set.
(b) The fault is logged into nonvolatile memory.
(c) All MOSFETs are opened (hardware controlled).
(d) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(e) SBS:ChargingVoltage(0x15) is set to 0.
(f) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When the Hardware OC Charge Recovery time elapses, the following actions are taken:

(a) All MOSFETs are closed.
(b) The status flag for this condition is cleared.
(c) SBS:ChargingVoltage(0x15) is set to allow charge.
(d) SBS:ChargingCurrent(0x14) is set to allow charge.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

If the *Activation criteria/behavior* condition still exists, then the process repeats for the number of times specified by HOC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

bq78PL114S12

The following table provides details on the hardware overcurrent charge threshold levels for the bq78PL114 and the bq78PL114S12. The tolerance value is the amount the actual trip threshold may vary below and above the typical point. Each decrease of 1 in the register value increases the overcurrent charge threshold by an amount corresponding to the step size. If the register value is set for a threshold below the lowest point, the charge overcurrent condition is not detected.

Device	Sense Resistor (mΩ)	Hardware OC CHG Threshold	HW OC CHG Register Value, Decimal	Hardware Overcurrent Charge Threshold (Amps)				
				Min	Typ	Max	Tolerance	Step Size
bq78PL114	5	Lowest	220	8.07	8.56	9.05	±0.490	0.245
		Highest	0	61.89	62.38	62.87		

Device	Sense Resistor (mΩ)	Hardware OC CHG Threshold	HW OC CHG Register Value, Decimal	Hardware Overcurrent Charge Threshold (Amps)				
				Min	Typ	Max	Tolerance	Step Size
bq78PL114S12	10	Lowest	220	4.04	4.28	4.53	±0.244	0.122
		Highest	0	30.94	31.19	31.43		
	3	Lowest	220	13.45	14.27	15.08	±0.816	0.408
		Highest	0	103.15	103.96	104.78		
	1	Lowest	220	40.36	42.81	45.25	±2.446	1.223
		Highest	0	309.44	311.89	314.33		

2.11 Hardware Overcurrent Discharge

The bq78PL114 provides fast-acting overcurrent detection mechanisms, such as overcurrent during discharge. The condition for hardware overcurrent on discharge is continuously monitored by hardware.

In some applications it may be desirable to have different thresholds and trip times when in standby mode. The bq78PL114 provides an alternate threshold and time parameter set for when the part is in low power standby mode. When the bq78PL114 transitions to standby mode, the Hardware LP Discharge Threshold and Hardware LP Discharge Duration parameters are loaded in place of the respective Hardware OC Discharge Threshold and Hardware OC Discharge Time parameters. The condition for hardware low-power overcurrent discharge is continuously monitored by hardware while the part is in standby mode. If an overcurrent condition is detected, the original hardware overcurrent parameters are restored and the part transitions to active mode. The user must set Hardware LP Overcurrent Discharge threshold and duration parameters to be the same as their corresponding Hardware Overcurrent Discharge Threshold and Hardware Overcurrent Charge Time parameters if they are not being used.

Note: The bq78PL114 uses a 5-mΩ current-sense resistor.

CAUTION: All hardware-based safety functions have a minimum activation threshold of 42 mV across the current-sense resistor. For a 5-mΩ current-sense resistor, this corresponds to a 8.4-A minimum threshold.

Setting a register value for a threshold below this limit causes that safety condition never to be detected, regardless of the setting.

The following user-defined parameters govern the behavior of this rule:

(a) Hardware OC Discharge Threshold: Set as an integer register value between 35 and 255, where each increment corresponds to a 250-mA step to 62 A maximum (register value of 255).

Example: A register value of 128 sets the threshold limit to 32 A. Settings are stable to within 2 step increments, or approximately 500 mA. A value of 128 nominally trips at 32 A, but could trip as low as 31.5 A or as high as 32.5 A.

CAUTION: When the 5-mΩ sense resistor, the register value must never be set below 35, which corresponds to an OC discharge threshold of 8.6 A.

(b) Hardware OC Discharge Time: Set as an integer register value between 1 and 127, where each increment corresponds to an 830-μs step from 900 μs minimum (register value of 1) to 106 ms maximum (register value of 127).

(c) Hardware LP Discharge Threshold: Set as an integer register value between 35 and 255, where each increment corresponds to a 250-mA step to 62 A maximum (register value of 255).

(d) Hardware LP Discharge Duration: Set as an integer register value between 1 and 127, where each increment corresponds to an 830-μs step from 900 μs minimum (register value of 1) to 106 ms maximum (register value of 127).

Example: A register value of 1 sets the OC discharge time limit to 900 μs, whereas a register value of 63 sets the time limit to 52.6 ms.

Activation of this rule exhibits the following behavior:

(a) The safety-status flag for this function is set.
(b) The fault is logged into nonvolatile memory.
(c) All MOSFETs are opened (hardware controlled).
(d) SBS:BatteryStatus(0x16):[TCA] Terminate Discharge Alarm bit is set.
(e) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When the Hardware OC Discharge Recovery time elapses, the following actions are taken:

(a) All MOSFETs are closed.
(b) The status flag for this condition is cleared.
(c) SBS:ChargingCurrent(0x14) is set to allow charge.
(d) SBS:BatteryStatus(0x16):[TCA] Terminate Discharge Alarm bit is cleared.

If the *Activation criteria/behavior* condition still exists, then the process repeats for the number of times specified by HOC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

(a) Hardware OC Discharge Recovery: Set in units of seconds

(b) HOC Max Attempts: Integer units. (This value is set with the Hardware Over Current Charge parameters.)

Activation criteria/behavior: Hardware is activated when current exceeds Hardware OC Discharge Threshold limit for Hardware OC Discharge Time.

bq78PL114S12

The following table provides details on the hardware overcurrent discharge threshold levels for the bq78PL114 and the bq78PL114S12. The tolerance value is the amount the actual trip threshold may vary below and above the typical point. Each increase of 1 in the register value increases the overcurrent discharge threshold by an amount corresponding to the step size. If the register value is set for a threshold below the lowest point,the discharge overcurrent condition is not detected.

Device	Sense Resistor mΩ	Hardware OC DSG Threshold	HW OC DSG Register Value, Decimal	Hardware Overcurrent Discharge Threshold (A)				
				Min	Typ	Max	Tolerance	Step Size
bq78PL114	5	Lowest	35	8.07	8.56	9.05	±0.490	0.245
		Highest	255	61.89	62.38	62.87		
bq78PL114S12	10	Lowest	35	4.04	4.28	4.53	±0.244	0.122
		Highest	255	30.94	31.19	31.43		
	3	Lowest	35	13.45	14.27	15.08	±0.816	0.408
		Highest	255	103.15	103.96	104.78		
	1	Lowest	35	40.36	42.81	45.25	±2.446	1.223
		Highest	255	309.44	311.89	314.33		

2.12 Hardware Short Circuit

The bq78PL114 provides an overcurrent-on-discharge threshold meant to detect short-circuit (very high-discharge) events.

The condition for hardware short circuit is continuously monitored in hardware.

Note: The bq78PL114 uses a 5-mΩ current-sense resistor.

CAUTION: All hardware-based safety functions have a minimum activation threshold of 42 mV across the current-sense resistor. For a 5-mΩ current-sense resistor, this corresponds to a 8.4-A minimum threshold. Setting a register value for a threshold below this limit causes that safety condition never to be detected, regardless of the setting.

The following user-defined parameters govern the behavior of this rule:

(a) Hardware Short-Circuit Threshold: Set as an integer register value between 37 and 63, where each increment corresponds to a 2-A step to 62 A maximum (register value of 63).

Example: A register value of 50 sets the threshold limit to 35 A. Settings are stable to within 2 step increments, or approximately 4 A. A value of 50 nominally trips at 35 A, but could trip as low as 31 A or as high as 39 A.

CAUTION: When the 5-mΩ sense resistor, the register value must never be set below 37, which corresponds to a short-circuit threshold of 10 A.

(b) Hardware Short-Circuit Time: Set as an integer register value between 1 and 31, where each increment corresponds to a 104-μs step from 100 μs minimum (register value of 1) to 3.2 ms maximum (register value of 31).

Example: A register value of 2 sets the hardware short-circuit time limit to 200 μs, whereas a register value of 15 sets the time limit to 1.6 ms.

(c) Hardware Short Circuit Recovery: Set in units of seconds

(d) HSC Max Attempts: Integer units. Setting to zero causes the rule to immediately start trip/try at 255 second intervals; setting to 255 enables retry at intervals equal to Hardware Short Circuit Recovery.

Activation criteria/behavior: Hardware activated when current exceeds Hardware Short Circuit Threshold for Hardware Short Circuit Time. Activation of this rule exhibits the following behavior:

(a) The safety-status flag for this function is set.
(b) The fault is logged into nonvolatile memory.
(c) All MOSFETs are opened (hardware controlled).
(d) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(e) SBS:ChargingVoltage(0x15) is set to 0.
(f) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When the Hardware Short Circuit Recovery time elapses, the following actions are taken:

(a) All MOSFETs are closed.
(b) The safety-status flag for this condition is cleared.
(c) SBS:ChargingCurrent(0x14) is set to allow charge.
(d) SBS:ChargingVoltage(0x15) is set to allow charge.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

If the *Activation criteria* condition still exists, then the process repeats for the number of times specified by HSC Max Attempts. After the maximum number of attempts has been reached, the rule continues to trip/try indefinitely at the maximum recovery time (255 seconds) until the fault is removed.

bq78PL114S12
The following table provides details on the hardware short circuit threshold levels for the bq78PL114 and the bq78PL114S12. The tolerance value is the amount the actual trip threshold may vary below and above the typical point. Each increase of 1 in the register value increases the over short circuit threshold by an amount corresponding to the step size. If the register value is set for a threshold below the lowest point the short circuit condition will not be detected.

Device	Sense Resistor mΩ	SC Trip Level	HW SC Register Value, Decimal	Hardware Short Circuit Threshold (Amps)				
				Min	Typ	Max	Tolerance	Step Size
bq78PL114	5	Lowest	37	5.95	9.92	13.89	±3.968	1.984
		Highest	63	57.54	61.51	65.48		
bq78PL114S12	10	Lowest	37	2.98	4.96	6.94	±1.984	0.992
		Highest	63	28.77	30.75	32.74		
	3	Lowest	37	9.92	16.53	23.15	±6.614	3.307
		Highest	63	95.90	102.51	109.13		
	1	Lowest	37	29.76	49.60	69.44	±19.842	9.921
		Highest	63	287.70	307.54	327.38		

2.13 Overtemperature Charge

The bq78PL114 can be configured to interrupt charge current based on temperature.

This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) OT Charge Threshold: Set in units of 0.1°C
(b) OT Charge Time: Set in units of 2 seconds. Setting to zero disables the function.
(c) OT Charge Recovery: Set in units of 0.1°C

Activation criteria/behavior: During charge, when any cell temperature rises above the OT Charge Threshold, an alert flag for this condition is set to indicate the presence of an overtemperature condition. If the condition remains beyond the OT Charge Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the OT Charge Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) Charge and precharge MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.

(c) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(d) SBS:BatteryStatus(0x16):[OTA] Over Temperature Alarm bit is set.
(e) SBS:ChargingVoltage(0x15) is set to 0.
(f) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When all cell temperatures fall below OT Charge Recovery, the following actions are taken:

(a) Charge and precharge MOSFETs are closed.
(b) Safety-status and alert flags for this condition are cleared.
(c) SBS:ChargingVoltage(0x15) is set to allow charge.
(d) SBS:ChargingCurrent(0x14) is set to allow charge.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.
(f) SBS:BatteryStatus(0x16):[OTA] Over Temperature Alarm bit is cleared.

Note: Although charge likely ceases when the activation of this rule occurs (due to the charge MOSFET being opened), the rule is still considered active until the deactivation criteria is met.

2.14 Overtemperature Discharge

The bq78PL114 can be configured to interrupt discharge based on temperature.

This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) OT Discharge Threshold: Set in units of 0.1°C
(b) OT Discharge Time: Set in units of 2 seconds. Setting to zero disables the function.
(c) OT Discharge Recovery: Set in units of 0.1°C

Activation criteria/behavior: During discharge, when any cell temperature rises above the OT Discharge Threshold, an alert flag for this condition is set to indicate the presence of an overtemperature condition. If the condition remains beyond the OT Discharge Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the OT Discharge Time, then no action is taken, and the alert flag is cleared.

Activation of this rule exhibits the following behavior:

(a) The discharge MOSFET is opened.
(b) The fault is logged into nonvolatile memory.
(c) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(d) SBS:BatteryStatus(0x16):[OTA] Over Temperature Alarm bit is set.

Deactivation criteria/behavior: When all cell temperatures fall below OT Discharge Recovery, the following actions are taken:

(a) The discharge MOSFET is closed.
(b) Safety-status and alert flags for this condition are cleared.
(c) SBS:BatteryStatus(0x16):[OTA] Over Temperature Alarm bit is cleared.
(d) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

Note: Although discharge likely ceases when the activation of this rule occurs (due to the discharge MOSFET being opened), the rule is still considered active until the deactivation criteria are met.

2.15 Host Watchdog Timeout

The bq78PL114 can be configured to require the host system to communicate with the battery periodically, else the battery disables charging and discharging.

Evaluation Interval. This condition is evaluated once every 2 seconds.

The following user-defined parameter governs the behavior of this rule:

(a) Host Watchdog Timeout: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: When SMBus lines are energized (high) and SMBus communication ceases for Host Watchdog Timeout, the following actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When the presence of SMBus activity is detected, the following actions are taken:

(a) All MOSFETs are closed.
(b) Safety-status flag for this condition is cleared.
(c) SBS:ChargingVoltage(0x15) is set to allow charge.
(d) SBS:ChargingCurrent(0x14) is set to allow charge.
(e) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is cleared.
(f) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

2.16 Board Overtemperature

The bq78PL114 allocates one temperature sensor to monitor the circuit board temperature. (Note: The specific temperature sensor used for board temperature sensing is configurable in the tmap configuration file.) The bq78PL114S12 defaults to using the on-chip temperature sensor for board-temperature sensing. A new tmap file can be created using the bq78PL114S12 configuration utility.

This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) Board Over Temperature: Set in units of 0.1°C
(b) Board Over Temperature Time: Set in units of 2 seconds. Setting to zero disables the function.
(c) Board Over Temperature Recovery: Set in units of 0.1°C

Activation criteria/behavior: At any time, when the board-mounted temperature sensor (usually mounted near the protection MOSFETs) detects a temperature that is above Board Over Temperature, an alert flag for this condition is set to indicate the presence of an overtemperature condition. If the condition remains beyond the Board Over Temperature Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the Board Over Temperature Time, then no action is taken, and the alert flag is cleared. Activation of this rule exhibits the following behavior:

(a) The charge, precharge, and discharge MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus0x16):[OTA] Over Temperature Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When the board-mounted temperature-sensor indication falls below Board Over Temperature Recovery, the following actions are taken:

(a) The discharge MOSFET is closed.
(b) Safety-status and alert flags for this condition are cleared.
(c) SBS:BatteryStatus(0x16):[OTA] Over Temperature Alarm bit is cleared.
(d) SBS:ChargingVoltage(0x15) is set to allow charge.
(e) SBS:ChargingCurrent(0x14) is set to allow charge.
(f) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is cleared.

(g) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is cleared.

2.17 Discharge Undertemperature

The bq78PL114 can be configured to detect undertemperature conditions using the multiple temperature sensors.

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) Discharge Under Temperature: Set in units of 0.1°C

(b) Discharge Under Temperature Time: Set in units of 2 seconds. Setting to zero disables the function.

(c) Discharge Under Temperature Recovery: Set in units of 0.1°C

Activation criteria/behavior: During discharge, when any cell temperature drops below the Discharge Under Temperature Threshold, an alert flag for this condition is set to indicate the presence of an undertemperature condition. If the condition remains beyond the Discharge Under Temperature Time, then the status flag for this condition is set, and safety action is taken. If the condition clears within the Discharge Under Temperature Time, then no action is taken, and the alert flag is cleared. Activation of this rule exhibits the following behavior:

(a) The discharge MOSFET is opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

Deactivation criteria/behavior: When all cell temperatures rise above Discharge Under Temperature Recovery, the following actions are taken:

(a) The discharge MOSFET is closed.

(b) Safety-status and alert flags for this condition are cleared.

(c) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is cleared.

Note: Although discharge likely ceases when the activation of this rule occurs (due to the discharge MOSFET being opened), the rule is still considered active until the deactivation criteria are met.

2.18 PowerLAN™ Communications Bus Failure

This condition is evaluated once every 2 seconds.

The following user-defined parameter governs the behavior of this rule:

(a) PowerLAN™ Communications Bus Fail Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: If PowerLAN™ communications bus failure is detected, the safety alert flag for this condition is set. If the condition exists for longer than the period specified by PowerLAN™ Communications Bus Fail Time, the status flag for this condition is set, and the following actions are taken:

(a) Charge and discharge MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

(f) SBS:ChargingVoltage(0x15) is set to 0.

(g) SBS:ChargingCurrent(0x14) is set to 0.

(h) Cell balancing is discontinued.

Second-Level Protection Features

The bq78PL114 provides features that can be used to indicate a more serious fault via the SPROT output. These outputs can be used to blow an inline fuse to permanently disable the battery pack from charge or discharge activity.

If any second-level protection threshold condition is met, the appropriate alert flag is set. If the threshold condition is cleared within the time limit, the appropriate flag is cleared. But if the threshold condition continues beyond the limit, then the bq78PL114 goes into a permanent failure condition and the appropriate flag is set.

Some safety functions are configured using the hardware configuration or algorithm enable registers. See Section 9.3 for a description of these registers.

3.1 Safety Cell Overvoltage (SOV)

Evaluation Interval. This condition is evaluated once every 2 seconds.

The following user-defined parameters govern the behavior of this rule:

(a) SOV Threshold: Set in units of mV

(b) SOV Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: When any cell voltage rises above the SOV Threshold, the safety alert flag for this condition is set. If any cell voltage exceeds SOV Threshold for SOV Time, the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

(f) SBS:ChargingVoltage(0x15) is set to 0.

(g) SBS:ChargingCurrent(0x14) is set to 0.

(h) Cell balancing is discontinued.

(i) Hardware to blow the fuse is activated, and associated flags are set.

3.2 Safety Overcurrent (SOC) Charge

Evaluation Interval. This condition is evaluated once every 2 seconds, although current measurements occur every second.

The following user-defined parameters govern the behavior of this rule:

(a) SOC Charge Threshold: Set in units of mA

(b) SOC Charge Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: When battery charge current exceeds the SOC Charge Threshold, the safety alert flag for this condition is set. If the condition remains for longer than SOC Charge Time, the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.3 Safety Overcurrent (SOC) Discharge

Evaluation Interval. This condition is evaluated once every 2 seconds, although current measurements occur every second.

The following user-defined parameters govern the behavior of this rule:

(a) SOC Discharge Threshold: Set in units of mA
(b) SOC Discharge Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: When battery discharge current exceeds SOC Discharge Threshold, the safety alert flag for this condition is set. If the condition remains for longer than SOC Discharge Time, the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.4 Safety Overtemperature (SOT) Charge

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) SOT Charge Threshold: Set in units of 0.1°C
(b) SOT Charge Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: During charge, if any cell temperature exceeds SOT Charge Threshold, the safety alert flag for this condition is set. If the condition remains for longer than SOT Charge Time, the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.5 Safety Overtemperature (SOT) Discharge

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) SOT Discharge Threshold: Set in units of 0.1°C

(b) SOT Discharge Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: During discharge, if any cell temperature exceeds SOT Discharge Threshold, the safety alarm flag for this condition is set. If the condition remains for longer than SOT Discharge Time, the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

(f) SBS:ChargingVoltage(0x15) is set to 0.

(g) SBS:ChargingCurrent(0x14) is set to 0.

(h) Cell balancing is discontinued.

(i) Hardware to blow the fuse is activated, and associated flags are set.

3.6 Cell Imbalance

Evaluation Interval. This condition is evaluated once every 2 seconds, although cell voltages are measured every second.

The following user-defined parameters govern the behavior of this rule:

(a) Cell Imbalance Current: Set in units of mA

(b) Cell Imbalance Fail Voltage: Set in units of mV

(c) Cell Imbalance Time: Set in units of 2 seconds; range is 0 to 65,535 seconds. Setting to zero disables the function.

(d) OCV Idle Qualifier: Set in units of minutes, range is 0 to 255 minutes.

(e) Cell Imbalance SOC Inhibit: Set in units of one percent (%)

Activation criteria/behavior: When at least one cell has a state-of-charge (SOC) that is above the Cell Imbalance SOC Inhibit, AND battery current (charge or discharge) has been below the Cell Imbalance Current limit for OCV Idle Qualifier, AND the difference between the highest and lowest cell voltage exceeds the Cell Imbalance Fail Voltage, then the safety alert flag for this condition is set. If all these conditions persist longer than the Cell Imbalance Time, then the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

(f) SBS:ChargingVoltage(0x15) is set to 0.

(g) SBS:ChargingCurrent(0x14) is set to 0.

(h) Cell balancing is discontinued.

(i) Hardware to blow the fuse is activated, and associated flags are set.

3.7 Open Temperature Sensor

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) Open Temperature Sensor Threshold: Set in units of 0.1°C

(b) Open Temperature Sensor Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: When any cell temperature falls below Open Temperature Sensor Threshold, the safety alert flag for this condition is set. If the condition remains for longer than Open Temperature Sensor Time, the temperature sensor providing that temperature reading is considered to have failed open. The status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.8 Discharge Protection MOSFET Verification

This condition is evaluated once every 2 seconds.

The following user-defined parameters govern the behavior of this rule:

(a) Transition to Discharge Current: Set in units of mA
(b) FET Fail Time: Set in units of 2 seconds. Setting to zero disables both Protection MOSFET Verification functions.

Activation criteria/behavior: If discharge is not permitted (discharge MOSFET is open), but a discharge current is detected that is greater in magnitude than Transition to Discharge Current, then the safety alert flag for this condition is set. If this condition remains for longer than FET Fail Time, then the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.9 Charge Protection MOSFET Verification

Evaluation Interval. This condition is evaluated once every 2 seconds.

The following user-defined parameters govern the behavior of this rule:

(a) Transition to Charge Current: Set in units of mA
(b) FET Fail Time: Set in units of 2 seconds. Setting to zero disables both Protection MOSFET Verification functions. (This value is set with the Discharge Protection MOSFET Verification parameters.)

Activation criteria/behavior: If charge is not permitted (precharge and discharge MOSFETs are open), but a charge current is detected that is greater in magnitude than the Transition to Charge Current, then the safety alert flag for this condition is set. If this condition remains for longer than FET Fail Time, then the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.10 Current Measurement Failure

This condition is evaluated once every 2 seconds, although current measurements occur every second.

The following user-defined parameter governs the behavior of this rule:

(a) Current Measurement Fail Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: If the current-measurement system has failed to operate properly by producing multiple errors during a data cycle, the safety alert flag for this condition is set. If the condition exists for longer than the period specified by Current Measurement Fail Time, the status flag for this condition is set, and the following actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.11 Fuse Failure

This condition is evaluated once every 2 seconds in order to detect the failure of a fuse activation (if utilized).

The following user-defined parameters govern the behavior of this rule:

(a) Fuse Fail Limit: Set in units of mA
(b) Fuse Fail Time: Set in units of 2 seconds. Setting to zero disables the function.

Activation criteria/behavior: If the external pack protection fuse has been activated (blown), and either a charge or discharge current exceeding Fuse Fail Limit has been detected, the safety alert flag for this condition is set. If the condition remains longer than Fuse Fail Time, then the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.12 Impedance Growth

This condition is event-driven and not evaluated on a regular interval. The condition is tested when the relative state-of-charge (RSOC) is greater than 20%, and a current step larger than Current Delta has been detected. The test checks for abnormal impedance increases.

The following user-defined parameters govern the behavior of this rule:

(a) Current Delta: Set in units of mA
(b) IGR Fail Count: Integer units. Setting to zero disables the function.
(c) IGR Limit: Integer units.
(d) Default Impedance Cell 1–4…8 (up to eight cells are supported. Twelve cells are supported in the bq78PL114S12.): Set in units of mΩ for each parallel-combination series element. (Parallel cell configurations have lower impedance values than individual cells.)

Activation criteria/behavior: When the relative state-of-charge (RSOC) is greater than 20% and a current step greater than Current Delta has occurred, the cell impedance growth rate is calculated for each series-cell element. If the calculated cell impedance growth rate is greater than IGR Limit, then the cell impedance growth-rate counter is incremented. If the cell impedance growth-rate counter exceeds the IGR Fail Count, then the following actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.13 Impedance Growth Ratio

This condition is event-driven and not evaluated on a regular interval. The condition is tested when the relative state-of-charge (RSOC) is greater than 20%, and a current step larger than Current Delta has been detected.

The following user-defined parameters govern the behavior of this rule:

(a) Current Delta: Set in units of mA (This value is set with the impedance-growth parameters.)
(b) IGR Ratio Fail Count: Integer units. Setting to zero disables the function.
(c) IGR Ratio Limit: Integer units
(d) Default Impedance Cell 1–4…8 (up to eight cells are supported. Twelve cells are supported by the bq78PL114S12.): Set in units of mΩ. (This value is set with the impedance-growth parameters.)

Activation criteria/behavior: When the relative state-of-charge (RSOC) is greater than 20% and a current step greater than Current Delta has occurred, the cell impedance growth rate ratio is calculated for each series-cell element. If the calculated cell impedance growth rate ratio is greater than IGR Ratio Limit, then the cell impedance growth-rate ratio counter is incremented. If the cell impedance growth rate ratio counter exceeds the IGR Ratio Fail Count, then the following actions are taken:

(a) All MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) The status flag for this condition is set.
(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.
(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(f) SBS:ChargingVoltage(0x15) is set to 0.
(g) SBS:ChargingCurrent(0x14) is set to 0.
(h) Cell balancing is discontinued.
(i) Hardware to blow the fuse is activated, and associated flags are set.

3.14 Cell-Temperature Rate-of-Rise

This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) Rate Limit Threshold: Set in units of 0.1°C per minute (0.1°C/min.)

(b) Rate Limit Activation Count: Integer units. Setting to zero disables the function.

Activation criteria/behavior: When the calculated cell temperature rate of rise for any cell exceeds the Rate Limit Threshold, then the cell rate-limit counter is incremented, and the condition is logged into nonvolatile memory. If the cell rate limit counter exceeds the Rate Limit Activation Count, then the following actions are taken:

(a) All MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set.

(e) SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.

(f) SBS:ChargingVoltage(0x15) is set to 0.

(g) SBS:ChargingCurrent(0x14) is set to 0.

(h) Cell balancing is discontinued.

(i) Hardware to blow the fuse is activated, and associated flags are set.

Charge and Discharge Control

The bq78PL114 allows programmable thresholds for various aspects of both charge and discharge. For example, during charge, the bq78PL114 can report the appropriate charging current needed for the constant charging current and the charging voltage needed for constant-voltage charging per charging algorithm to a smart charger using the *ChargingCurrent* and the *ChargingVoltage* functions. (Actual charging parameters are listed as follows.) Similarly, discharge can be limited due to temperature or various alarm settings, also detailed as follows.

4.1 Precharge Voltage Timeout

This condition is evaluated once every 2 seconds, although voltages measurements occur every second.

The following user-defined parameters govern the behavior of this rule:

(a) Precharge Voltage Timeout: Set in units of seconds. (Range is 65,535 seconds maximum.) Setting to zero disables the function.

(b) Precharge Voltage: Set in units of mV

Activation criteria/behavior: During precharge, if any cell voltage fails to reach the limits required to exit the precharge state (i.e., any cell voltage remains below Precharge Voltage) for a period of time equal to precharge voltage timeout, then the status flag for this condition is set, and the following permanent actions are taken:

(a) Charge and precharge MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:ChargingVoltage(0x15) is set to 0.

(e) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria: If current greater than Transition to Discharge Current is detected:

(a) Charge and precharge MOSFETs are closed.

(b) SBS:ChargingVoltage(0x15) is set to allow charge.

(c) SBS:ChargingCurrent(0x14) is set to allow charge.

(d) The safety-status and alert flags for this condition are cleared.

4.2 Charge Timeout

This condition is evaluated once every 2 seconds.

The following user-defined parameters govern the behavior of this rule:

(a) Charge Duration Timeout: Set in units of seconds. (Range is 65,535 seconds maximum.) Setting to zero disables the function.

NOTE: Other end-of-charge termination values are set with Charge Completion parameters.

Activation criteria/behavior: During charge, if charging continues without a charge completion occurring before Charge Duration Timeout elapses, then the status flag for this condition is set, and the following permanent actions are taken:

(a) All MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) The status flag for this condition is set.

(d) SBS:ChargingVoltage(0x15) is set to 0.
(e) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria: If current greater than Transition to Discharge Current is detected:

- Charge and precharge MOSFETs are closed.
- SBS:ChargingVoltage(0x15) is set to allow charge.
- SBS:ChargingCurrent(0x14) is set to allow charge.
- The safety-status and alert flags for this condition are cleared.

4.3 Charge-Inhibit Temperature

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur AND only if the Charge Suspend-Temperature rule is not active.

The following user-defined parameters govern the behavior of this rule:

(a) Charge Inhibit Temperature Low: Set in units of 0.1°C
(b) Charge Inhibit Temperature High: Set in units of 0.1°C
(c) Charge Inhibit Recovery Temperature Low: Set in units of 0.1°C
(d) Charge Inhibit Recovery Temperature High: Set in units of 0.1°C

Activation criteria/behavior: If the pack is discharging or in idle and any of the cell temperatures falls below Charge Inhibit Temperature Low or rises above Charge Inhibit Temperature High, then the status flag for this condition is set, and the following actions are taken:

(a) Charge and precharge MOSFETs are opened.
(b) The fault is logged into nonvolatile memory.
(c) SBS:ChargingVoltage(0x15) is set to 0.
(d) SBS:ChargingCurrent(0x14) is set to 0

Deactivation criteria/behavior: When all of the cell temperatures are between Charge Inhibit Recovery Temperature Low and Charge Inhibit Recovery Temperature High, the following actions are taken:

(a) Charge and precharge MOSFETs are closed.
(b) The status flag for this condition is cleared.
(c) SBS:ChargingVoltage(0x15) is set to allow charge.
(d) SBS:ChargingCurrent(0x14) is set to allow charge.

4.4 Precharge Voltage and Current

Evaluation Interval. This condition is evaluated once every 2 seconds, although voltage measurements occur every second.

The following user-defined parameters govern the behavior of this rule:

(a) Precharge Voltage: Set in units of mV
(b) Precharge Current: Set in units of mA
(c) Precharge Recovery: Set in units of mV

Activation criteria/behavior: If any cell voltage falls below Precharge Voltage, the status bit for this condition is set, and the following actions are taken:

(a) The charge MOSFET is opened. (Precharge MOSFET remains closed.)
(b) The fault is logged into nonvolatile memory.
(c) SBS:ChargingCurrent(0x14) is set to the defined Precharge Current value.

Deactivation criteria/behavior: When all cell voltages are above Precharge Recovery, then the following actions are taken:

(a) Charge MOSFET is closed.
(b) The status flag for this condition is cleared.
(c) SBS:ChargingCurrent(0x14) is set to allow charge.

4.5 Precharge Temperature

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) Precharge Temperature: Set in units of 0.1°C

(b) Precharge Current: Set in units of mA. (This value is set with the Precharge Voltage parameters.)

Activation criteria/behavior: If any one of the cell temperatures falls below Precharge Temperature, the status bit for this condition is set, and the following actions are taken:

(a) The charge MOSFET is opened. (Precharge MOSFET remains closed.)

(b) The fault is logged into nonvolatile memory.

(c) SBS:ChargingCurrent(0x14) is set to the defined Precharge Current value.

Deactivation criteria/behavior: When all of the cell temperatures are above Precharge Temperature, then the following actions are taken:

(a) Charge MOSFET is closed.

(b) The status flag for this condition is cleared.

(c) SBS:ChargingCurrent(0x14) is set to allow charge.

4.6 Charge Suspend –Temperature

Evaluation Interval. This condition is evaluated once every 2 seconds after all temperature measurements occur.

The following user-defined parameters govern the behavior of this rule:

(a) Charge Suspend Temperature Low: Set in units of 0.1°C

(b) Charge Suspend Temperature High: Set in units of 0.1°C

(c) Charge Suspend Recovery Temperature High: Set in units of 0.1°C

(d) Charge Suspend Recovery Temperature Low: Set in units of 0.1°C

Activation criteria/behavior: If the pack is charging and any one of the cell temperatures falls below Charge Suspend Temperature Low OR rises above Charge Suspend Temperature High, then the status flag for this condition is set, and the following actions are taken:

(a) Charge and precharge MOSFETs are opened.

(b) The fault is logged into nonvolatile memory.

(c) SBS:ChargingCurrent(0x14) is set to 0.

Deactivation criteria/behavior: When all of the cell temperatures are above Charge Suspend Recovery Temperature Low AND below Charge Suspend Recovery Temperature High, then the following actions are taken:

(a) Charge and precharge MOSFETs are closed.

(b) The status flag for this condition is cleared.

(c) SBS:ChargingCurrent(0x14) is set to allow charge. Note: Although charge likely ceases when the activation of this rule occurs (due to the charge MOSFET being opened), the rule is still considered active until the deactivation criteria are met.

4.7 Charge Completion

Evaluation Interval. This condition is evaluated once every second after all voltage and current measurements occur. Pack voltage is constructed as a summation of the individual cell-voltage measurements.

The following user-defined parameters govern the behavior of this rule:

(a) Charge Completion Pack Voltage Qualifier: Set in units of mV

(b) Charge Completion Taper Current: Set in units of mA

(c) Charge Completion Time: Set in units of seconds. Setting to zero disables the function.

(d) Charge Completion FET Activation Time: Set in units of seconds. Setting to zero disables the MOSFET activation function, that is, the charge MOSFET is not opened at completion of charge.
(e) Transition to Idle Current: Set in units of mA. (This value is set with the Misc. Control parameters.)
(f) TCA Set SOC Threshold: Set in units of percent (%). (This value is set with the Terminate Charge Alarm (TCA) control parameters.)
(g) FC Set SOC Threshold: Set in units of percent (%). (This value is set with the Fully Charged (FC) bit-control parameters.)

Activation criteria/behavior: If the pack voltage is at or above Charge Completion Pack Voltage Qualifier, and the charge current is below Charge Completion Taper Current but above Charge Completion Taper Current value divided by 2 for a time duration of Charge Completion Time, then the status flag for this condition is set, and the following actions are taken:

(a) If FC Set SOC Threshold is –1, then SBS:BatteryStatus(0x16):[FC] FullyCharged status flag is set.
(b) If TCA Set SOC Threshold is –1, then SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set.
(c) SBS:ChargingVoltage(0x15) is set to 0 after the FETs are opened.
(d) SBS:ChargingCurrent(0x14) is set to 0 after the FETs are opened.
(e) SBS:FullChargeCapacity(0x10) may be updated.
(f) Additional internal capacity updates may be calculated.
(g) SBS:RelativeSOC(0x0d) is set to 100%.
(h) SBS:MaxError(0x0c) may be reset or reduced.
(i) SBS:RemainingCapacity(0x0f) is updated.
(j) SBS:AverageTimeToFull(0x13) is set to 0.
(k) SBS:AbsoluteSOCl(0x0e) is updated.
(l) Timer for Charge Completion FET Activation Time (if non-zero) is started.

If the charge current does not drop below the Transition to Idle Current value for a non-zero time duration of Charge Completion FET Activation Time after the end of Charge Completion Time, then the following action is taken:

(a) Charge and precharge MOSFETs are opened.

Deactivation criteria/behavior: If a discharge current is observed, OR if the charge current drops below the Transition to Idle Current value before the Charge Completion FET Activation Time elapses, then the following actions are taken:

(a) Status condition for this event is cleared.
(b) Charge Completion FET Activation timer is reset.
(c) Charge and precharge MOSFETs are closed.

4.8 Terminate Charge Alarm (TCA) Control

Evaluation Interval. This condition is evaluated once every 2 seconds after all voltage and current measurements occur. Pack voltage is constructed as a summation of the individual cell-voltage measurements.

This condition depends on the following parameters and values calculated elsewhere.

(a) TCA Set SOC Threshold: Set in units of percent (%). Setting to –1 disables this portion of the function, so that the Terminate Charge Alarm bit is set by conditions in the Charge Completion function.
(b) TCA Clear SOC Threshold: Set in units of percent (%). Note: This is the only method that can clear the Terminate Charge Alarm bit.
(c) SBS:RelativeSOC(0x0d)

Activation criteria/behavior: If the TCA Set SOC Threshold is not –1, AND the SBS:RelativeSOC(0x0d) value is greater than or equal to the TCA Set SOC Threshold, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[TCA] Terminate Charge Alarm bit is set to 1.

If the TCA Clear SOC Threshold is not –1, AND SBS:RelativeSOC(0x0d) value is less than or equal to the TCA Clear SOC Threshold, then the following action is taken:

(a) The Terminate Charge Alarm (TCA) bit in SBS:BatteryStatus(0x16) is cleared to 0.

4.9 Fully Charged (FC) Bit Control

Evaluation Interval. This condition is evaluated when once every 2 seconds. Pack voltage is constructed as a summation of the individual cell-voltage measurements.

The following user-defined parameters govern the behavior of this rule:

(a) FC Set SOC Threshold: Set in units of one percent (%). Setting to –1 disables this portion of the function so that so that the Fully Charged bit is set by conditions in the Charge Completion function.
(b) FC Clear SOC Threshold: Set in units of one percent (%). Note: This is the only method that can clear the Fully Charged bit.

Activation criteria/behavior: If the FC Set SOC Threshold is not –1, AND the SBS:RelativeSOC(0x0d) value is greater than or equal to the FC Set SOC Threshold, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[FC] Fully Charged bit is set to 1.

If SBS:RelativeSOC(0x0d) is equal to or less than FC Clear SOC Threshold, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[FC] Fully Charged bit is cleared to 0.

4.10 Discharge Completion

Evaluation Interval. This condition is evaluated once every second after all voltage and current measurements occur. Pack voltage is constructed as a summation of the individual cell-voltage measurements.

The following user-defined parameters govern the behavior of this rule:

(a) Discharge Completion Pack Voltage Qualifier: Set in units of mV
(b) Discharge Completion Time: Set in units of seconds. Setting to zero disables whole function.
(c) Discharge Completion FET Activation Time: Set in units of seconds. Setting to zero disables the MOSFET activation function, that is, the discharge MOSFET is not opened at completion of discharge.
(d) Transition to Idle Current: Set in units of mA (This value is set with the Misc. Control parameters.)
(e) FD Set SOC Threshold: Set in units of percent (%). (This value is set with the Fully Discharged (FD) Bit Control parameters.)
(f) TDA Set SOC Threshold: Set in units of percent (%). (This value is set with the Terminate Discharge Alarm (TDA) Control parameters.)

Activation criteria/behavior: If the pack voltage is at or below the Discharge Completion Pack Voltage Qualifier for a time duration of Discharge Completion Time, then the status flag for this condition is set, and the following actions are taken:

(a) SBS:FullChargeCapacity(0x10) may be updated.
(b) Additional internal capacity updates may be calculated.
(c) SBS:RelativeSOC(0x0d) is set to 0%.
(d) SBS:MaxError(0x0c) may be reset or reduced.
(e) SBS:RemainingCapacity(0x0f) is updated.
(f) SBS:AverageTimeToEmpty(0x13) is set to 0.
(g) SBS:AbsoluteSOC(0x0e) is updated.
(h) Timer for Discharge Completion FET Activation Time (if non-zero) is started.

If the discharge current is not reduced below the value of Transition to Idle Current for a non-zero time duration of Discharge Completion FET Activation Time after the end of Discharge Completion Time, then the following action is taken:

(a) Discharge MOSFET is opened.

Deactivation criteria/behavior: If a charge current is observed, OR if the discharge current drops below the Transition to Idle Current value before the Discharge Completion FET Activation Time elapses, then the following actions are taken:

(a) Status condition for this event is cleared.
(b) Discharge Completion FET Activation timer is reset.

4.11 Terminate Discharge Alarm (TDA) Control

Evaluation Interval. This condition is evaluated once every 2 seconds after all voltage and current measurements occur. Pack voltage is constructed as a summation of the individual cell-voltage measurements.

This condition depends on the following parameters and values calculated elsewhere.

(a) TDA Set SOC Threshold: Set in units of percent (%). Setting to –1 disables this portion of the function.
(b) TDA Clear SOC Threshold: Set in units of percent (%). Setting to –1 disables this portion of the function.
(c) TDA Clear Voltage: Set in units of mV.
(d) TDA Set Voltage Threshold: Set in units of mV of pack voltage
(e) TDA Set Voltage Time: Set in units of seconds. Setting this to zero disables the voltage-based set/clear of the TDA.
(f) SBS:RelativeSOC(0x0d)
(g) Calculated pack voltage

Activation criteria/behavior: If the TDA Set SOC Threshold is not –1, AND the SBS:RelativeSOC(0x0d) value is less than or equal to the TDA Set SOC Threshold, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is set to 1.

If the TDA Clear SOC Threshold is not –1, AND the SBS:RelativeSOC(0x0d) value is greater than or equal to TDA Clear SOC Threshold, then the following actions are taken:

(a) The SBS:BatteryStatus(0x16):[TDA] Terminate Discharge Alarm bit is cleared to 0.

If the TDA SET VOLTAGE TIME is non-zero and the pack voltage is below TDA set voltage for TDA SET VOLTAGE TIME, the TDA flag is set.

If the TDA SET VOLTAGE TIME is non-zero and the pack voltage is above TDA CLEAR VOLTAGE, the TDA flag is cleared.

4.12 Fully Discharged (FD) Bit Control

Evaluation Interval. This condition is evaluated once every 2 seconds. Pack voltage is constructed as a summation of the individual cell voltage measurements.

The following user-defined parameters govern the behavior of this rule:

(a) FD Set SOC Threshold: Set in units of one percent (%). Setting to –1 disables this portion of the function.
(b) FD Clear SOC Threshold: Set in units of one percent (%). Setting to –1 disables this portion of the function.
(c) FD Clear Voltage: Set in units of mV.
(d) FD Set Voltage: Set in units of mV of pack voltage
(e) FD Set Voltage Time: Set in units of seconds. Setting this to zero disables the voltage-based set/clear of FD.

Activation criteria/behavior: If the FD Set SOC Threshold is not –1, AND the SBS:RelativeSOC(0x0d) value is less than or equal to the FD Set SOC Threshold, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[FD] Fully Discharged bit is set to 1.

If the FD Clear SOC Threshold is not –1, AND the SBS:RelativeSOC(0x0d) value is greater than or equal to the FD Clear SOC Threshold, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[FD] Fully Discharged bit is cleared to 0.

If FD SET VOLTAGE TIME is non-zero, and the pack voltage is below the TDA set voltage for FD SET VOLTAGE TIME, the FD flag is set.

If FD SET VOLTAGE TIME is non-zero and the pack voltage is above FD CLEAR VOLTAGE, the FD flag is cleared.

4.13 Overcharge Alarm (OCA) Control

This condition is evaluated once every 2 seconds after all voltage and current measurements occur.

This condition depends on the following parameters and values calculated elsewhere.

(a) Charge Completion Pack Voltage Qualifier: Set in units of mV. (This value is set with the Charge Completion parameters.)
(b) OCA Set Voltage: Set in units of mV
(c) OCA Activation Time: Set in units of 2 seconds

Activation criteria/behavior: If the calculated pack voltage (summation of individual cell voltages) is above the OCA Set Voltage, then the safety-alert flag for this condition is set. If the condition remains longer than OCA Activation Time, then the status flag for this condition is set, and the following action is taken:

(a) The SBS:BatteryStatus(0x16):[OCA] Over Charge Alarm bit is set to 1.

If the calculated pack voltage falls below the Charge Completion Pack Voltage Qualifier, then the following action is taken:

(a) The SBS:BatteryStatus(0x16):[OCA] Over Charge Alarm bit is cleared to 0.

4.14 Misc. Control Parameters

The following parameters are used by various charge and discharge functions previously mentioned, but also include uses in various other algorithms.

(a) Transition to Idle Current: Set in units of mA. Used to indicate that the pack has reached an idle level of usage, and is neither being charged or discharged, even if this is a non-zero value.
(b) Transition to Idle Time: Set in units of seconds. Used to gate the transition into Idle (see *Transition to Idle Current*, Section 4.14a) to prevent false entry due to short durations of low discharge current.
(c) Transition to Discharge Current: Set in units of mA. Used to indicate that a discharge current has started. (This value is also used by the Discharge Protection MOSFET Verification function.)
(d) Transition to Charge Current: Set in units of mA. Used to indicate that a charge current has started. (This value is also used by the Charge Protection MOSFET Verification function.)

4.15 Remaining Capacity Alarm Status

This condition is evaluated once every 2 seconds after all voltage and current measurements occur.

This condition depends on the following values:

(a) SBS:RemainingCapacity(0x0f) value
(b) SBS:RemainingCapacityAlarm(0x01): Set in units of mAhr or 10 mWhr. Setting to zero disables this alarm function.

Activation criteria/behavior: If value of SBS:RemainingCapacity(0x0f) is equal or less than the value of SBS:RemainingCapacityAlarm(0x01), then the following action is taken:

(a) The Remaining Capacity Alarm bit in SBS:BatteryStatus(0x16):[RCA] is set to 1.

If this condition is not met, and a charge above Transition to Idle Current is detected, then the following actions are taken:

1. The Remaining Capacity Alarm bit in SBS:BatteryStatus(0x16):[RCA] is cleared to 0.

4.16 Remaining Time Alarm Status

This condition is evaluated once every 2 seconds after all voltage and current measurements occur.

This condition depends on the following values:

(a) SBS:AverageTimeToEmpty(0x12)
(b) SBS:RemainingTimeAlarm(0x02): Set in units of minutes. Setting to zero disables this alarm function.

Activation criteria/behavior: If value of SBS:AverageTimeToEmpty(0x12) is equal or less than the value of SBS:RemainingTimeAlarm(0x02), then the following action is taken:

(a) The Remaining Time Alarm bit in SBS:BatteryStatus(0x16):[RTA] is set to 1.

If this condition is not met, then the following action are taken:

1. The Remaining Time Alarm bit in SBS:BatteryStatus(0x16):[RTA] is cleared to 0.

Device Operating Modes

The bq78PL114 has several device power modes. During these modes, the bq78PL114 modifies its operation to minimize power consumption from the battery.

5.1 Normal Mode

During normal operation, the bq78PL114 takes *Current*, *Voltage* and *Temperature* measurements, performs calculations, updates SBS data, and makes protection and status decisions at regular intervals.

5.2 Battery Pack Removed Mode/System-Present Detection

5.2.1 Battery Pack Removed

The bq78PL114 detects that the battery pack has been removed when the SMbus signals are not pulled high.

5.2.2 System-Present FET Control

The system-present detection system can optionally open FETs when the pack is removed from the host.

Optional FET control is activated by setting the SYSTEM PRESENT FET CONTROL bit in the HARDWARE CONFIGURATION register. If this bit is cleared, all FETs remain on while the pack is removed from the host.

When the SYSTEM PRESENT FET CONTROL bit is set, only the discharge FET remains on when the host system is not present.

Note 1: All FETs are opened while in ship mode, regardless of system-present configuration.

Note 2: The host system relies on power from the pack for SMBus operation. Therefore, when using SMBus as the means of detecting system presence, the discharge FET must remain on.

5.3 Standby Mode

The bq78PL114 goes into standby mode when the SMBus signals are not pulled high, no current flow exists, no safety rules are active, and no cell balancing is required. In standby mode, the bq78PL114 periodically checks the safety rules, detects any change in SMBus status, senses current flow, checks for pushbutton pressed if implemented, and checks for cells out of balance. Any of these events causes the device to exit standby mode. The LP threshold settings replace the normal hardware trip settings while in standby mode. See the *bq78PL114 PowerLAN™ Master Gateway Battery Management Controller With PowerPump™ Cell Balancing* data sheet (SLUS850) for electrical specifications.

Parameters:

(a) Hardware LP Discharge Threshold: This current threshold determines when the discharge (DSG) MOSFET is opened when in standby mode.

(b) Hardware LP Discharge Duration: This is the duration that Hardware LP Discharge Threshold current must be observed before the discharge (DSG) MOSFET is opened while in standby mode.

(c) Hardware LP Charge Threshold: This current threshold determines when the charge (CHG) MOSFET is opened when in standby mode.

(d) Hardware LP Charge Duration: This is the duration that Hardware LP Charge Threshold current must be observed before the charge (CHG) MOSFET is opened while in standby mode.

Entrance Criteria: The device can enter standby mode when all of the following criteria are satisfied.

(a) Pack is removed from host computer.
(b) No safety events are pending or active.
(c) Fuse is not blown.
(d) Balancing is not required.
(e) Pushbutton is not pressed.
(f) No LED patterns are being displayed. See Table 9-9 for bq78PL114S12 display operation.

Exit criteria: The device exits standby mode when one or more of the following criteria is satisfied.

(a) Pack inserted into computer (SMBus activity or SYSTEM PRESENT pin)
(b) Pushbutton pressed
(c) Safety issue detected
(d) Current flow greater than Transition to Discharge Current or Transition to Charge Current is detected.

Mode behavior: While in standby mode, the bq78PL114 behaves as follows:

(a) Tests for pack insertion at 2-second intervals (SMBus activity or SYSTEM PRESENT pin)
(b) Tests for button press at 2-second intervals
(c) Tests for current flow at 2-second intervals
(d) Runs all measurements for a duration of 4 seconds every 10 minutes
(e) Tests for safety conditions at 10-minute intervals for a duration of 4 seconds
(f) Assesses need for balancing at 10-minute intervals for a duration of 4 seconds
(g) Hardware safety circuitry remains active, but is set to the LP levels. There is no HW SC LP setting. See Section 2.10 and Section 2.11.

5.4 Ship Mode

Ship mode is an ultralow-power state where all functionality is periodically suspended except for an internal timer.

The MOSFETs are always open in ship mode when in this ultralow-power state. This mode is not entered in normal operation. It is intended for use after factory programming and test. See the *bq78PL114 PowerLAN™ Master Gateway Battery Management Controller With PowerPump™ Cell Balancing* data sheet (SLUS850) for electrical specifications.

Entrance Criteria: The device can enter Ship mode when all of the following criteria are satisfied.

(a) Ship mode is enabled via the bqWizard™ interface by issuing: Commands → Toggle Ship Bit.
(b) Pack is removed from host computer.
(c) No safety events pending or active
(d) Fuse not blown
(e) Balancing is not required.
(f) Pushbutton not pressed
(g) When configured for LED display, no pattern is displayed. See Table 9-9 for bq78PL114S12 display operation.

Exit criteria: The device exits ship mode when one or more of the following criteria are satisfied.

(a) Pack inserted into computer
(b) Pushbutton pressed

NOTE: Once ship mode is exited, it cannot be re-entered without re-enabling it via the bqWizard™ GUI.

Mode behavior: While in ship mode, the device behaves as follows:

(a) Tests for pack insertion at 2-second intervals. (SMBus pins detected as high.)
(b) Tests for button press at 2-second intervals.
(c) Runs all measurements for a duration of 4 seconds every 10 minutes.
(d) Tests for safety conditions at 10-minute intervals for a duration of 4 seconds.

Calibration

6.1 Cell Voltage Calibration

The bq78PL114 and bq78PL114S12 parts are calibrated at the factory for cell voltage. No calibration by the customer is required to achieve data sheet accuracy ratings. Cell voltage offset and gain correction for cells 1 to 4 are stored in the bq78PL114S12.

6.1.1 Cell Voltage Calibration Data Transfer

Systems that have five or more series cells require the use of one or more bq76PL102 Dual Cell Monitor devices. The cell voltage calibration information for each bq76PL102 is stored internally. This calibration information (offset and gain) must be transferred down to the bq78PL114S12 for cell voltage measurement. This is done by selecting the command to Load a Configuration File (.tmap) and Relearn from the bqWizard™ File menu. This can also be accomplished via the bq78PL114S12 API by Loading the production clone file (.dat) and then issuing a Commit command.

Three or four series cell applications do not include bq76PL102s and therefore do not require any cell voltage calibration data transfer.

6.2 Temperature Sensor Calibration

Temperature calibration must be performed as part of the PCB manufacturing flow. Because performance is based on the sensors attached to the bq78PL114S12 and the internal sensor, each system must be calibrated. One calibration file cannot be loaded to many packs.

Temperature calibration occurs after a Configuration File (.tmap) is loaded and relearned. In other words, all cell voltages must be reading within specifications and the desired temperature sensor mapping must be established before temperature calibration can occur.

Temperature calibration is performed using a single known temperature in a certain range (18 °C to 30°C). The bqWizard™ software or bq78PL114S12 API communicates the value to the bq78PL114S12 and it applies an offset correction to its temperature calculation.

6.3 Current Calibration

Current calibration must be performed as part of the PCB manufacturing flow. Because performance is based on the sense resistor attached to the bq78PL114S12, each system must be calibrated. One calibration file cannot be loaded to many packs.

Current calibration occurs after temperature calibration is completed. The current measurement system uses device temperature as a parameter in its current calculation.

An offset correction based on the system is obtained when the user applies an open circuit to the pack terminals and alerts the bq78PL114S12 via the bqWizard™ calibration utility or through the bq78PL114S12 API. A gain correction based on the system is obtained when the user applies an average load current at the pack terminals and alerts the bq78PL114S12 via the bqWizard™ calibration utility or through the bq78PL114S12 API. The applied current for gain correction can be -32000 mA to +32000 mA.

NOTE: For systems that use the 1-mΩ resistor, the current value entered for gain correction is the actual current divided by 10.

6.4 Calibration File

The calibration information of the device can be saved in a unique calibration file (.cal). This information is exclusive to the system in which it was calibrated. The file contents are encoded and are not intended to be readable, except by the firmware. The offsets for cell voltage, temperature and current are stored and the gain corrections for cell voltage and current are also stored. Creation of the file is through the bqWizard™ software or the bq78PL114S12 API.

Possible uses of the file are to restore a calibration that may have been lost or to track system gain and offset values for statistical processing. A single calibration file cannot be used to calibrate multiple packs.

Communications

The bq78PL114 uses SMBus v1.1 with master-mode.

7.1 SMBus On and Off States

The bq78PL114 detects an SMBus off state when SMBC and SMBD are logic-low for ≥ 2 seconds. Clearing this state requires either SMBC or SMBD to transition high. Within 1 ms, the communication bus is available.

7.2 Packet Error Checking

The bq78PL114 can only receive or transmit data with a PEC. The SpecificationInfo() bits 4…7 are set to [0011] for Version 1.1 with optional PEC support. These bits must really be set by the firmware to [0010] to accurately reflect Version 1.1 and mandatory PEC usage. Future revisions of the firmware may include operation with and without a PEC and a correction to bits 4…7.

7.3 bq78PL114 Slave Address

The bq78PL114 uses the address 0x16 on SMB for communication.

7.4 Broadcasts to Smart Charger and Smart Battery Host

The bq78PL114 and bq78PL114S12 do not support broadcasts to a smart charger or smart battery host.

Gas Gauging

The bq78PL114 measures individual cell voltages, pack voltage, temperatures, and current as inputs to an algorithm used to determine capacity of the battery pack.

8.1 Introduction

The bq78PL114 gas-gauging algorithm uses open-circuit voltage (OCV) when the system is in a relaxed state along with charge integration when the system is under load conditions to determine State of Charge (SOC) and Chemical Capacity (Qmax). It acquires dynamic cell impedance at times of load current change and updates the Battery Impedance Profile during normal battery usage. It further uses the Battery Impedance Profile along with SOC and Qmax to determine SBS:FullChargeCapacity(0x10) and SBS:RelativeStateOfCharge(0x0d) specific for the average load of a given application. SBS:FullChargeCapacity(0x10) is reported as capacity or energy passed from a fully charged battery under present load until Discharge Completion Pack Voltage Qualifier is reached by SBS:Voltage(0x09).

8.2 Basic Measurements

The gas-gauging calculations depend on several basic measurements provided by the measurement subsystem of the bq78PL114. These are:

- Synchronous measurements of cell voltages and pack current
- An independent continual coulomb count of passed charge
- Individual cell temperatures
- Various derived parameters such as average current, dynamic cell impedance, etc.

8.2.1 Pack Current and Charge

The instantaneous pack current reflected by the voltage across the current-sense resistor is acquired by a continuously running delta-sigma modulator. This single bit stream is used to produce both charge and current by appropriate decimation. Bit-stream accumulation over a 2-second window (box car) results in passed-charge increments for coulomb counting. Decimation of the bit stream using an 80-ms tapered window results in the basic current reading. The window is triggered synchronously with similar windows for cell-voltage measurement. Current and voltage readings are updated every second. To minimize ADC offset and offset drift, the ADC input is commutated every second under firmware control. (Current readings are derived from two contiguous windows positioned across the commutation instance).

In addition, there is a one-time, board-level calibration of residual offset and gain for current and coulomb readings. (Independent calibration parameters are used for current and coulomb readings). The coulomb reading only is subject to a snap-to-zero before use in the GG algorithm. The coulomb counter resolution is approximately 1 mC or 0.000278 mAh. Current reported as SBS:Current(0x0a) in mA is based on the coulomb reading after snap-to-zero. Current flow in the discharge direction is reported as negative.

8.2.2 Cell Voltage

All cell voltages are updated every second using 80-ms measurement windows synchronous with the current measurements. Each cell has its own ADC. Cell voltages are compensated for ADC offset and ADC gain. Cell voltages are reported in mV by SBS:VCELLx(0x3c–0x3f) for cells 1 to 4 and by SBS:VCELLx(0x40–0x43) for cells 5 to 8. The bq78PL114S12 reports voltages for cells 9 through 12 by SBS:VCELLx(0x44–0x47).

8.2.3 Cell Temperatures

Temperatures external to the bq78PL114 are sensed by means of forward voltage drop of a dual diode (excitation current ~50 μA). Temperature voltages are acquired every 2 seconds using an 80-ms measurement window. Readings are compensated for ADC offset and ADC gain. In addition, there is a one-time, board-level, room-temperature calibration of diode offset. (The temperature coefficient of the dual diode is known, a priori, from characterization.) SBS:Temperature(0x08) is updated based on the maximum cell temperature and reported in 0.1°K units.

8.2.4 Cell Dynamic Impedance Definition

The dynamic impedance is derived from the changes in pack current and resultant changes in cell voltage between two sets of synchronous measurements. The reading is qualified for minimum delta I and represents the real impedance in the range $\sim 1^{-10}$ Hz. By using this approach, impedance is found directly without assumptions about the correctness of Qmax, SOC, and OCV curve.

Calculation: R = DV/DI

Update Condition: DI > Pack Configuration:Current Delta

The dynamic impedance is used both in safety rules (impedance growth) and also gas gauging to update the impedance profile; impedance updates, qualified in SOC and temperature, are normalized for temperature (normalized dynamic impedance, NDI) and used to update the shape (Ra terms) of each cell.

8.3 Gas-Gauge Key Parameters

The bq78PL114 uses dynamic impedance to determine SBS:RemainingCapacity(0x0f), SBS:FullChargeCapacity(0x10), and several other SBS-related parameters. This section identifies the key parameters used. Note: SBS parameters are defined elsewhere. The following are noted for ease of understanding only.

8.3.1 OCV

The OCV estimate is a function of SOC and temperature. The bq78PL114 uses the TI standard cell chemistry files as the initial inputs for gas gauging.

8.3.2 OCV Idle Time

OCV Idle Qualifier is the time qualifier that must be satisfied before the cell voltages can be considered to represent a true OCV value. The time is specified in minutes.

8.3.3 Design Capacity

Design Capacity is a parameter in the data set. It is not changed by the gas-gauging algorithms, but is used in the determination of Absolute State of Charge. There are two parameters, one for capacity in constant-current mode and one for constant-power mode.

8.3.4 Qmax

QMax is the chemical capacity of the cell. That is, it is the capacity obtained at a very low discharge rate with no compensation for the cell impedance and corresponding IR drop. The equivalent compensated value is the Full Charge Capacity, FCC.

8.3.5 Qrem

Qrem is the value of the remaining chemical capacity of the cell or pack. That is, it is the capacity with no compensation for impedance. The equivalent compensated value is the Remaining Capacity.

8.4 State and Mode Definitions

Central to the behavior of the gas gauge are current-flow states and reporting modes.

8.4.1 Current Flow States

The pack resides in one of three current-flow states: Charge/Idle/Discharge

Transition between states occurs when the following conditions are met:

Idle when: Abs(Current) < [Transition to Idle Current] for Time > [Transition to Idle Time]

Discharge when: Current < [Transition to Discharge Current]

Charge when: Current > [Transition to Charge Current]

A transition between current flow states forces a simulation to update the predictions of Remaining Capacity and Time to Full/Empty.

8.4.2 Reporting Modes

The reporting of the predicted remaining capacity, SBS:RemainingCapacity(0x0f), and time to empty, SBS:RunTimeToEmpty(0x11) depends on the mode configured:

- Current mode: Assumes the load continues as a constant current over the predicted remaining time to empty. SBS:RemainingCapacity(0x0f) is reported in mAh.
- Power Mode: Assumes the load continues as a constant power over the predicted remaining time to empty. SBS:RemainingCapacity(0x0f) is reported in mWh. The average time to full, SBS:AverageTimeToFull(0x13) prediction always assumes CC/CV charging and is not affected by reporting mode.

8.5 Gas-Gauge Behavior

The description of the gas-gauge behavior is best grouped in terms of conditions or events which result in gas-gauge activity.

- Always, based on coulomb counting
- During Idle, based on time and other qualifiers
- Waypoint events, such as SOC grid points
- Delta change of current/voltage synchronous measurements

8.5.1 Always, Based on Coulomb Counting:

The coulomb counter is always active. Its reading is extended into an interim accumulator, quantized to integer mAh, and the mAh events used to update the following:

- Qrem for each cell
- RemCap for the pack
- Passed charge since last learning point
- Lifetime passed charge and Total Equivalent Cycles

The cycle count provides a predictive fade for the cell impedance NDI and also Qmax as a backup until the next qualified learning event for these parameters.

Qmax is updated by applying the fade parameter (Cell Chemistry:Cycle Fade) for any cycle which completes without a learning event. In addition, if an NDI update has not been done in the cycle, the increase in NDI due to aging is approximated using an increase which is logarithmic with respect to the number of cycles.

The reported value of Remaining capacity is clipped at 0. The reported values of RTTE, ATTF are decremented in between simulation updates based on elapsed time.

8.5.2 During Idle, Based on Time and Other Qualifiers

OCV Learning and Qrem Updates

During the idle state, as defined in Section 8.4.1, cell relaxation is qualified by the OCV Idle Qualifier Time parameter (typically 45 minutes) and every minute thereafter. A qualified relaxation event (P1 and P2 described later) results in OCV learning. This triggers the following calculations for each cell leading to Qrem(n), where n = 1 to total number of cells.

- SOC(n) = f(OCV, T(n), Chem) based on chemistry file look-up table
- Qrem(n)' = Qmax(n) × SOC(n)
- Qrem(n) = weighted update towards Qrem(n)', where the weighting is a function of the slope of the OCV curve between P1 and P2.

Qmax Learning

Qmax is learned from the change in SOC and Passed Charge between two qualified points, P1 and P2, which may cover a partial cycle. The qualification criterion is that the local slope of the OCV curve around P1 and around P2 must be greater than the Min OCV Slope parameter. And, P1 is deleted if the time since its acquisition > Stale FCC Timeout parameter.

In order for Qmax(n) learning to take place, the absolute value of the change in SOC since last learning point must be at least 30% of Qmax(n). Qmax(n) learning is calculated as follows:

Qmax(n)' = Passed Charge/Change in SOC

Qmax(n) = Weighted updated toward Qmax(n)', where weight is given by change in SOC

Following an update, the Passed Charge is reset to zero, and the initial leaning point, P1, is replaced by P2.

8.5.3 On Waypoint Events:

The following events trigger the play-forward simulation, which predicts the termination points for charge/discharge:

1. SOC has just transitioned a gridpoint (i.e., the boundaries between the 15 segments in the Ra vs SOC table).
2. A transition between any two current-flow states (Charge/Idle/Discharge)
3. Every 10th Qrem update in Idle

The play-forward simulation is a function of Cell Impedance, Load Current, and Qrem for the worst-case cell (the cell with lowest Qrem). Load Current is defined as Average Filtered Current for discharge state or last qualified Average Current for other states. The output of the simulation is Pack RemainingCapacity and RTTE and RTTF. In addition, FCC may be computed on a change of effective load current. Pack RemainingCapacity is used to derive ASOC and RSOC as defined in the SBS data.

If NDI has been flagged as new (updated by life cycle fade or actual measurement), then the Ra table is updated prior to running the simulation.

The simulation algorithm used depends on the charge/discharge state and reporting mode:

Discharge Simulation – CC Mode. Searching from the present RSOC, find the lowest SOC% prior to 0%. Compute RTTE from RemainingCapacity(mAHrs) as derived from change in SOC.

Discharge Simulation – CP Mode. Searching from the present RSOC, find the lowest SOC% prior to 0% for this load power. Compute RTTE from RemainingCapacity(mWh) as derived from integration of time at this power level from present SOC to termination.

Charge Simulation. The CC and CV phases are treated independently.

- For CC, searching from present SOC, find the start of taper where OCV + Current x Impedance = Default Charging Voltage parameter / n. Compute T1 = Change in SOC x (Qmax/Current), where T1 > 0 and Qmax is the minimum Qmax(n).
- For CV, the current taper decays with a first-order exponential time constant, so T2 = Tau10 x ln(Current/Charge Completion Taper Current Qualifier) Then, ATTF = T1 + T2.

8.5.4 On Delta Change of Current/Voltage Synchronous Measurements

Dynamic impedance is computed as described in Section 8.2.4 on changes in pack current. For use in the gas gauge, the dynamic impedance is further qualified for temperature and SOC range before computing the normalized dynamic impedance, NDI, for each cell. The NDI values are flagged as new to trigger an update of the Ra table on the next simulation run. Ra table updates are a function of the initial value of the Ra table and the ratio of the newly calculated NDI to the initial NDI.

Miscellaneous Parameters

9.1 Default SBData Values

Preset default values for programmable SBData functions:

(a) Default Charging Voltage: Set in units of mV. Used for reporting SBS:ChargingVoltage(0x15) value
(b) Default Charging Current: Set in units of mA. Used for reporting SBS:ChargingCurrent(0x14) value
(c) Design Capacity mah: Set in units of mA. Used for reporting SBS:DesignCapacity(0x18) value in current units
(d) Design Capacity 10 mwh: Set in units of 10 mW. Used for reporting SBS:DesignCapacity(0x18) value in power units
(e) Manufacturer Name: ASCII characters up to 32 bytes in length. Used for reporting SBS:ManufacturerName(0x20) value
(f) Device Name: ASCII characters up to 32 bytes in length. Used for reporting SBS:DeviceName(0x21) value
(g) Device Chemistry: ASCII characters up to 32 bytes in length. Used for reporting SBS:DeviceChemistry(0x22) value
(h) Manufacturer Data: Used for reporting SBS:ManufacturerData(0x23) value
(i) Serial Number: Set in integer units (word). Used for reporting SBS:SerialNumber(0x1c) value
(j) Manufacture Date: Set in integer units (coded word). Used for reporting SBS:ManufactureDate(0x1b) value. See ManufactureDate() description in Smart Battery Data Specification for coded word packing algorithm.
(k) Design Voltage: Set in units of mV of pack voltage. Used for reporting SBS:DesignVoltage(0x19) value

9.2 Cell Balancing

The bq78PL114 can use PowerPump™ cell balancing to decrease the differences in imbalanced cells at any time: while at rest, while charging, or while discharging. By maintaining cell-to-cell balance, pack performance is increased and cells are not excessively overcharged or overdischarged.

This increases overall pack energy by preventing premature charge termination. More Information can be found in the "Cell Balancing Using the bq78PL114" Application Report.

The automatically operated algorithm determines the amount of charge needed to fully charge each cell. See the algorithm configuration register (Section 9.3.2) for balancing-algorithm options.

Parameter used for cell balancing:

(a) Minimum Cell Differential for Balancing: Set in units of mV

When the difference in voltage between any two cells exceeds the Minimum Cell Differential for Balancing value, then PowerPump™ cell balancing is activated.

The bq78PL114S12 supports the following configurable cell balancing features:

(a) SuperPump mode. When enabled, this allows 60%–70% pump, cell balancing, availability when there are no active safety events and current is not flowing.
(b) Disable cell balancing during discharge.
(c) Disable cell balancing during charge.

SuperPump mode is turned off or is blocked from being enabled when:

- Any current flow (charge/discharge) is detected.

- A safety event becomes active with the following exceptions:
  - Overtemperature charge
  - Overtemperature discharge
  - Host watchdog timeout
  - Charge-inhibit temperature
  - Precharge voltage
  - Precharge temperature
  - Charge suspend – temperature (high and low)
  - Charge completion
  - Discharge completion
  - Charge timeout
  - Precharge voltage timeout
  - Board overtemperature
  - Discharge undertemperature

During SuperPump cycle, temperature reading is suspended for the number of temperature measurement cycles selected when SuperPump mode was enabled. Temperature measurements are normally taken at 2s intervals. When in SuperPump mode, temperature measurements are suspended for 2 × (n + 1) seconds where n = the value between 1 and 15 programmed into bq78PL114S12 Algorithm Register bits [10:7].

While in SuperPump mode, Temperature ROR Safety rule checking is postponed until 4 seconds has elapsed since the last SuperPump cycle.

Table 9-1 summarizes the percentage of time that pumping is active as a function of the Algorithm Register bits Turbo[3:0] suspended temperature measurement count settings. The greatest increase in pumping availability occurs at low settings between 0001b and 0100b. As the count is increased the curve flattens out, and no significant improvement is observed. The entries in the table are nominal values.

Table 9-1. bq78PL114S12 Pumping Availability vs Algorithm Enable Register Bits Turbo[3:0]

Turbo[3:0]	8 Cells	10 Cells	12 Cells
0000 (default)	42%	38%	32%
0001	55%	50%	47%
0010	59%	55%	52%
0011	62%	58%	53%
0100	63%	59%	56%
0101	64%	60%	57%
0110	65%	61%	58%
1000	66%	62%	59%
1010	66%	62%	60%

9.3 Configuration Registers

The hardware configuration and algorithm enable registers allow specific controls to be enabled or disabled.

9.3.1 Hardware Configuration Register (Read/Write)

Table 9-2. bq78PL114 Hardware Configuration Register

Bit #	Description	Details
0	Reserved, internal use	Set to 1
1	Reserved, internal use	Cleared to 0
2	Reserved, internal use	Cleared to 0
3	Reserved, internal use	Set to 1

Table 9-2. bq78PL114 Hardware Configuration Register (continued)

Bit #	Description	Details
4	Reserved, internal use	Set to 1
5	Reserved, internal use	Set to 1
6	Reserved, internal use	Cleared to 0
7	Calibration transfer enable	0 = Disable transfer of bq76PL102 calibration data (default). 1 = Enables the transfer of calibration data from bq76PL102 EEPROM to calibration tables located in bq78PL114 flash memory. The transfer occurs when a relearn/initialize command is sent to the bq78PL114.
8	EFCI_D_Sense	0 = Turn off DSG FET when EFCID pin is low. 1 = Turn off DSG FET when EFCID pin is high. Default configuration is EFCI_D_Sense = 1 and EFCID pin = low.
9	EFCI_C_Sense	0 = Turn off CHG FET when EFCIC pin is low. 1 = Turn off CHG FET when EFCIC pin is high. Default configuration is EFCI_C_Sense = 1 and EFCIC pin = low.
10	Relearn	When = 1, resets to initial default values and clears history. Default = 0.
11	Reserved, internal use	Cleared to 0
12	Reserved, internal use	Cleared to 0
13	System present FET control	When = 0, the CFET and PFET are on in standby mode (default). When = 1, the CFET and PFET are turned off when the part is in standby mode.
14	Reserved, internal use	Cleared to 0
15	Balancing disabled	When = 1, disables all pumping (cell balancing). Default = 1.

Table 9-3. bq78PL114S12 Hardware Configuration Register

Bit #	Description	Details
0	Disp 0	0x00 = Reserved, 0x01 = LED (Default)[(1)], 0x10 = LCD, 0x11 = EPD
1	Disp 1	
2	Reserved, not used	Cleared to 0
3	Reserved, not used	Cleared to 0
4	Reserved, internal use	Reserved, set to 0x11
5	Reserved, internal use	
6	EPD Polarity	0=black segments on white background (default) 1=white segments on black background.
7	Reserved, internal use	Cleared to 0
8	EFCI_D_Sense	0 = Turn off DSG FET when EFCID pin is low. 1 = Turn off DSG FET when EFCID pin is high. Default configuration is EFCI_D_Sense = 1 and EFCID pin = low.
9	EFCI_C_Sense	0 = Turn off CHG FET when EFCIC pin is low. 1 = Turn off CHG FET when EFCIC pin is high. Default configuration is EFCI_C_Sense = 1 and EFCIC pin = low.
10	Sense 0	Sense Resistor 0x00 = Reserved, 0x01 = 10 mΩ (Default), 0x10 = 3 mΩ, 0x11 = 1 mΩ
11	Sense 1	
12	Reserved, not used	–
13	System present FET control	When = 0, the CFET and PFET are on in standby mode (default). When = 1, the CFET and PFET are turned off when the part is in standby mode.
14	Reserved, not used	Cleared to 0
15	Reserved, not used	Cleared to 0

(1) Five LEDs or display segments are supported: Each indicates 20% of SBS:RelativeSOC(0x0d)

9.3.2 Algorithm Enable Register (Read/Write)

Table 9-4. bq78PL114 Algorithm Enable Register

Bit #	Description	Details
0	PumpAlgorithm 0	See Table 9-6
1	PumpAlgorithm 1	See Table 9-6
2	Pump Mode	See Table 9-6
3	WIRED	When = 0, disables all safety, pumping, and data writes (default). When = 1, safety, pumping, and data writes are enabled.
4	Reserved, not used	Cleared to 0
5	Configured	When = 1, indicates configuration is complete (parameters updated/programmed). Default = 0
6	Reserved, not used	Cleared to 0
7	Reserved, internal use	Cleared to 0
8	Reserved, not used	Set to 1
9	Reserved, not used	Cleared to 0
10	Reserved, not used	Cleared to 0
11	Reserved, internal use	Cleared to 0
12	Force D_FET	Direct control of discharge pack protection MOSFET (See bit 15). When = 1, FET is turned on. Default = 0.
13	Force C_FET	Direct control of charge pack protection MOSFET (See bit 15). When = 1, FET is turned on. Default = 0.
14	Force P_FET	Direct control of precharge pack protection MOSFET (See bit 15). When = 1, FET is turned on. Default = 0.
15	Inhibit Safety Rules	When = 0, enables safety rules. When = 1, disables safety rules and allows MOSFETs to be directly controlled using bits 12–14 (default).

Table 9-5. bq78PL114S12 Algorithm Enable Register

Bit #	Description	Details
0	PumpAlgorithm 0	See Table 9-6
1	PumpAlgorithm 1	See Table 9-6
2	Pump Mode	See Table 9-6
3	WIRED	When = 0, disables all safety, pumping, and data writes (default). When = 1, safety, pumping, and data writes are enabled.
4	Reserved, not used	–
5	Inhibit Pump During Charge	When = 0, cell balancing is enabled during charge (default). When = 1, inhibit cell balancing during charge.
6	Inhibit Pump During Discharge	When = 0, cell balancing is enabled during discharge (default), When = 1, inhibit cell balancing during discharge.
7	Turbo 0	Enables SuperPump mode when nonzero and no current is flowing and no safety rules are active. Temperature measurements are suspended for n cycles while SuperPump is active where n = 0x0001 through 0x1111. After n suspended cycles a temperature measurement is always taken. Default value is 0x0000, turbo mode = off.
8	Turbo 1	
9	Turbo 2	
10	Turbo 3	
11	Reserved, not used	Cleared to 0
12	Force DFET	Direct control of discharge pack protection MOSFET (See bit 15). When = 1, FET is turned on.
13	Force CFET	Direct control of charge pack protection MOSFET (See bit 15). When = 1, FET is turned on.
14	Force PFET	Direct control of precharge pack protection MOSFET (See bit 15). When = 1, FET is turned on.
15	Inhibit safety rules	When = 0, enables safety rules. When = 1, disables safety rules and allows MOSFETs to be directly controlled using bits 12–14 (default).

Table 9-6. Pumping (Balancing) Algorithm Table

Pump Mode	PumpAlgorithm(1:0)	Function
NORMAL		
1	00	Reserved, not used
1	01	State-of-charge pumping algorithm
1	10	Open-circuit-voltage pumping algorithm (default)
1	11	Terminal-voltage pumping algorithm
TESTING		
0	XX	Reserved

9.3.3 bq78PL114S12 System Control Register (Read/Write)

Table 9-7. bq78PL114S12 System Control Register

Bit #	Description	Details
[14:0]	Reserved, not used	Cleared to 0
15	Pump Disable	When = 0, cell balancing, pumping are enabled. When = 1, disables all cell balancing, pumping (default).

9.4 Display Operation

Pins LED1 to LED5 are configured to drive five LEDs in sequence when the pushbutton switch is activated. Each LED represents 20% State-of-Charge, using the value contained in SBS:RelativeStateOfCharge(0x0d). The LEDs light to indicate the SOC within 3 seconds of pressing the button, and LED illumination is maintained for at least 2 seconds (see Table 9-8). If the button is held down continuously, the LED indication turns off after 2 seconds and stays off unless the button is released and pushed again. LED1 is the least-significant and LED5 is the most-significant. A battery that is at or below 20% RSOC only has LED1 on. When the bq78PL114S12 is configured for EPD or LCD, only SEG1 is on. A battery that is above 80% RSOC has all five LEDs on, or in the case of EPD or LCD configuration, all five segments are on.

Table 9-8. Status-of-Charge (SOC) Indication

SOC	Indication
SOC > 80%	5 segments on
60% < SOC ≤ 80%	4 segments on
40% < SOC ≤ 60%	3 segments on
20% < SOC ≤ 40%	2 segments on
SOC ≤ 20%	1 segments on

During flash reprogramming, the LEDs indicate the progress of the code download. The LEDs also indicate a failed download if it occurs. An LED pattern is present during power-on reset and any subsequent reset.

The bq78PL114S12 is configurable to drive LED, liquid crystal (LCD), and electronic paper (EPD) type displays. See Table 9-3.

An EPD is a static display that only consumes power when it is being updated and does not require periodic refreshing. See EPD reference schematic in the bq78PL114S12 datasheet.

Table 9-9 summarizes display activity vs device operating mode. Table 8-4 describes display related pins and their operation as a function of selected display type.

The bq78PL114S12 EPD driver periodically updates the display whenever there is a change. An external power supply having a nominal 15-V output powers the display. A lower voltage may be used depending on the display and system qualification requirements. This increases the display write time. A voltage multiplier or charge pump power supply can be used to generate the required 15V. See EPD reference schematic in the bq78PL114S12 data sheet. It is advised to validate system design and configuration with the display vendor.

The bq78PL114S12 pulses the EPD display signals every time the display is updated. This occurs for the time defined in EPD Pump Time parameter. During this pump time, the TP signal can be used to drive a voltage multiplier or charge pump circuit to generate the display voltage. When EPD Pump time parameter is set to zero no pulsing occurs and the display subsystem must obtain its power from the cell stack or a separate voltage regulator connected to the cell stack.

Table 9-9. bq78PL114S12 Display Activity vs Device Operating Mode

Operating Mode	LED	LCD	EPD
Active / Normal	Enabled (push button)	Enabled	Enabled
Standby	Enabled (push button)	Enabled	Enabled
Ship	Disabled	Disabled	Enabled
Extreme Cell Undervoltage Shutdown	Disabled	Disabled	Enabled[1]

(1) In EPD mode no display refresh occurs when the device is in Extreme Cell Undervoltage Shutdown mode

Table 9-10. bq78PL114S12 Display Pin Operation As Function Of Display Type

Pin	LED	EPD	LCD
PSH/BP/TP	**PSH - Pushbutton.detect for LED display**	**TP -Top Plane and charge pump drive.**	**BP -LCD Backplane**
FIELD	–	Field segment	–
LED1/SEG1	LED1	SEG1	SEG1
LED2/SEG2	LED2	SEG2	SEG2
LED3/SEG3	LED3	SEG3	SEG3
LED4/SEG4	LED4	SEG4	SEG4
LED5/SEG5	LED5	SEG5	SEG5

9.4.1 Display Parameters

The following parameters located in the Pack Configuration section are used for configuring display operation:

1. EPD Pump Time: Set in units of cycle counts. (Number of Display Driver Frequency cycles). A value of 0 disables the pumping function. Default = 120 cycles.
2. EPD Write Time: Set in units of cycle counts. (Number of Display Driver Frequency cycles). Default = 90 cycles.
3. Display Driver Frequency: Set in units of Hz. This is the LCD refresh frequency or the EPD charge pump frequency. Default = 30Hz.
4. EPD Global Refresh Period. Set in units of minutes. Default = 1440min.

9.4.2 bq78PL114 and bq78PL114S12 Bootloader LED Patterns

The display is also used to show the progress of firmware downloads. Note that EPD- and LCD-type displays are not supported for firmware downloads. During firmware download, an LCD or EPD may show random patterns. Also see Table 9-3, *bq78PL114S12 Hardware Configuration Register*.

LED order is from left to right (leftmost = LED5, rightmost = LED1).

Note: For the bq78PL114, the following sequence is followed by a second sequence in which all LEDs are turned on and then off after a brief period. This sequence does not occur with the bq78PL114S12.

Table 9-11. bq78PL114 and bq78PL114S12 Bootloader LED Patterns

Seq.	Event	Pattern 1 LED[5..1]	Pattern 1 LED[5..1]
1	In bootloader mode-1 (1)	■ □ ■ □ ■	■ ■ □ ■ □
2	In bootloader mode-2 (1)	□ □ ■ □ ■	□ ■ □ ■ □
3	Reboot (2)	□ □ ■ ■ ■	■ ■ ■ □ □
4	Power-on reset	□ ■ ■ ■ ■	■ ■ ■ ■ ■
5	External reset	□ ■ ■ ■ □	□ ■ ■ ■ ■
6	Shutdown (3)	■ ■ ■ □ ■	■ ■ ■ ■ □
7	Code downloading	Binary counting	
■ = Off; □ = On			

(1) Pattern-1 and -2 cycles every 15 seconds
(2) Reboot after code download or shutdown-mode timeout
(3) Unit is ready to disconnect power.

Application-code-driven patterns (gas gage) are described somewhere else.

9.5 Operating Current Ranges

The bq78PL114 supports a single operating current range based on a sense resistor value of 5mΩ.

Table 9-12. bq78PL114 Operating Current and Capacity

Sense Resistor (mΩ)	Current Resolution (mA)	Maximum Discharge Current (A)	Max Charge Current (A)	Hardware Safety Short-Circuit Discharge Threshold (A)		Hardware Safety Overcurrent Charge and Discharge Threshold (A)		SBS Reported Data		
				Min (1)	Max (1)	Min (1)	Max (1)	Maximum Capacity (Ah)	Maximum Current (A)	Specification Info IPScale [Bits 15:12]
5	1	–40	20	–9.92	–61.5	8.56	62.4	65.536	±32.767	0

(1) Typical values

bq78PL114S12

Three operating current ranges are supported with the bq78PL114S12. They are selected by changing the bits 10 and 11 in the Hardware Configuration register and then issuing a relearn/initialize command. This allows the pack designer to optimize for packs operating between 11A and 110A. Table 9-13 details the operating conditions available to the user as a function of the selected sense resistor.

Two operating capacities are supported, 65,536 mAh and 655,360 mAh. Although the reported current is actually divided by 10, the SpecificationInfo() register bits for the IPScale are not updated when the 1-mΩ resistor is used to reflect this scaling. Future firmware revisions may correct this. The SBS SpecificationInfo status register VScale value is always reported as zero.

Table 9-13. bq78PL114S12 Operating Current and Capacity Ranges

Sense Resistor (mΩ)	Current Resolution (mA)	Maximum Discharge Current (A)	Max Charge Current (A)	Hardware Safety Short-Circuit Discharge Threshold (A)		Hardware Safety Overcurrent Charge and Discharge Threshold (A)		SBS Reported Data		
				Min (1)	Max (1)	Min (1)	Max (1)	Maximum Capacity (Ah)	Maximum Current (A)	Specification Info IPScale [Bits 15:12]
10	1	–11.2	10.08	–4.96	–30.75	4.28	31.19	65.536	±32.767	0
3	1	–26	26	–16.5	–102.5	14.27	103.9	65.536	±32.767	0
1	10 (2)	–111	100	–49.6	–307.5	42.8	311.8	655.36 (2)	±327.67	1

(1) Typical values
(2) Battery capacity resolution is 10mAhr and current resolution is 10mA.

9.6 Cell Chemistry Configuration

The bq78PL114 has several cell chemistry parameters. These are accessible from the bqWizard™ Cell Chemistry tab. This section describes these parameters.

9.6.1 Chemistry ID

This is the ID of the standard TI chemistry file loaded into the bq78PL114. After a new chemistry file has been uploaded, this parameter changes to indicate the new chemistry file number.

Parameter type: Read-only

Units: Number

Update procedure: The chemistry data and reported version are updated using the bqWizard™ command: Menu → File → Load Chemistry Data.

9.6.2 Tau10

This is the time constant used for current taper during end of charge.

Parameter type: Read-only

Units: Number

Update procedure: The parameter is updated during a load of an Auxiliary chemistry file (.aux).

9.6.3 Normalized Dynamic Impedance Low Temperature

The normalized dynamic impedance is the impedance due to a step change in current and voltage ($\Delta V/\Delta I$) normalized to fixed reference temperature. This parameter is the temperature below which dynamic impedance normalization is not performed.

Parameter type: Read-only

Units: °C

Update procedure: The parameter is updated during a load of an Auxiliary chemistry file (.aux).

9.6.4 Normalized Dynamic Impedance High Temperature

This parameter is the temperature above which dynamic impedance normalization is not performed.

Parameter type: Read-only

Units: °C

Update procedure: The parameter is updated during a load of an Auxiliary chemistry file (.aux).

9.6.5 Normalized Dynamic Impedance SOC

This is the SOC level above which dynamic impedance normalization is not performed.

Parameter type: Read-only

Units: Percent

Update procedure: The parameter is updated during a load of an Auxiliary chemistry file (.aux).

9.6.6 Normalized Dynamic Impedance Gain

This is the weighting factor for new impedance measurements.

Parameter type: Read-only

Units: Number

Update procedure: The parameter is updated during a load of an Auxiliary chemistry file (.aux).

9.6.7 FCC Learn Qualifier

The full-charge capacity is learned by evaluating the passed charge between two periods of time where the pack was at rest long enough to allow using the voltage to look up the RSOC in the OCV table. In order to do this learning, the change in RSOC between these idle periods must be greater than the FCC Learn Qualifier.

Parameter type: Read/write

Units: Percent

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It is recommended to use the TI-provided default value.

9.6.8 Cycle Fade

Generally, the capacity fade is tracked by the FCC learning. In a situation where this is not possible, an estimate is made using the Cycle Fade parameter. For any cycle (defined as an accumulated discharge equal to the design capacity) which did not involve an update in FCC, the capacity is derated by the Cycle Fade parameter.

Parameter type: Read/write

Units: Percent

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It is recommended to use the TI-provided default value.

9.6.9 Min OCV Slope

Estimation of RSOC from the open-circuit voltage during idle periods is held off if the slope of the mV-to-RSOC table is less than this parameter.

Parameter type: Read/write

Units: 2 mV per % of RSOC

Update procedure: The parameter can be updated from bqWizard™ software and exported to the ppcsv parameter file. It is recommended to use the TI-provided default value.

9.6.10 OCV Idle Qualifier

In order to qualify as a rest interval long enough to allow use of the cell voltages to determine RSOC, the battery rest time must be larger than this time.

Parameter type: Read/write

Units: Minutes

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It is recommended to use the TI-provided default value.

9.6.11 Stale FCC Timeout

If the time since the previous rest period (and associated RSOC estimation) is greater than the Stale FCC timeout, the earlier RSOC estimate is discarded and the gas gauge algorithm does not use it for FCC update.

Parameter type: Read/write

Units: Minutes

Update procedure: The parameter can be updated from bqWizard™ software and exported to the ppcsv parameter file. It is recommended to use the TI-provided default value.

9.6.12 Default Charging Voltage

This is the voltage to be reported by the gauge over the SBdata bus during normal charging conditions.

Parameter type: Read/write

Units: Volts
NOTE: Per the Smart Battery Specification, the units are not affected by the setting of the VScale bits in SpecificationInfo().

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It must be set to correspond to the battery pack design requirements.

9.6.13 Default Charging Current

This is the charging current to be reported by the gauge over the SBdata bus during normal charging conditions.

Parameter type: Read/write

Units: mA
NOTE: Per the Smart Battery Specification, the units are not affected by the setting of the IPScale bits in SpecificationInfo().

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It must be set to correspond to the battery pack design requirements.

9.6.14 Capacity Algorithm

This parameter defines the load to use in pack capacity calculations.

0 → C/5
1 → Present current
2 → User-defined current
3 Average current (default)

Parameter type: Read/write

Units: Hexadecimal number

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It must be set to correspond to the battery pack design requirements.

9.6.15 User Rate

This is the discharge rate to be used when Capacity_Algorithm = 2.

Parameter type: Read/write

Units: mA

Update procedure: The parameter can be updated from the bqWizard™ software and exported to the ppcsv parameter file. It must be set to correspond to the battery pack design requirements.

Lifetime and Forensic Data

For forensic purposes, the bq78PL114 saves temperature, voltage, and safety history in flash memory. This information can be accessed using the bqWizard™ application under the commands menu. The bq78PL114S12 only stores the safety history.

10.1 Safety History

The bq78PL114 and bq78PL114S12 record the most recent 10 occurrences of any activation of a safety rule or a reset. The safety events correlate with the rules described in this document.

A safety event is recorded with its name and the value that caused the event. The time stamp, FET status, fuse status, temperature, and current at the time of the event are also recorded. The time stamp resolution is one hour. In the case of a voltage event, the number of the cell with the maximum value and the number of the cell with the minimum value are also recorded along with their respective voltages. The recorded temperature is always from the sensor with the highest temperature.

The bqWizard™ software permits the safety events to be saved as standard CSV text files. The file also contains the firmware version, the bqWizard™ version, a time stamp, and device epoch hour. The epoch hour is the time from last reset.

Both the bq78PL114 and bq78PL114S12 collect and save the safety history in flash.

Figure 10-1. Safety History Data

10.2 Voltage History

The bq78PL114 records a histogram of the voltage operating conditions for each cell since the battery pack woke up. The histogram records the percentage of total operating time that each cell has been in one of the four defined regions. The regions are *below low*, *near low*, *hear high*, and *above high*. The histogram data can be retrieved using the bqWizard™ application. The following table shows how the data is formatted.

The voltage bins are based on the following calculations:
•Low < CUV – (COV – CUV)/10
•CUV – (COV – CUV)/10 ≤ Near Low ≤ CUV + (COV – CUV)/10
•COV – (COV – CUV)/10 ≤ Near High ≤ COV + (COV – CUV)/10
•High > CUV + (COV – CUV)/10

Table 10-1. Example bq78PL114 Voltage History Data

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7	Cell 8
Below low	25%	25%	25%	25%	0	0	0	0
Near low	0	0	0	0	25%	25%	25%	25%
Near high	0	0	0	0	0	0	0	0
Above high	0	0	0	0	0	0	0	0

10.3 Temperature History

The bq78PL114 records a histogram of the temperature operating conditions for each cell since the battery pack woke up. The histogram records the percentage of total operating time that each cell has been in one of the four defined regions. The regions are *below low*, *near low*, *hear high*, and *above high*. The histogram data can be retrieved using the bqWizard™ application. The following table shows how the data is formatted.

The temperature bins are based on the following calculations:
•Low < CHGSUSPTEMPLOW – (CHGSUSPTEMPHIGH – CHGSUSPTEMPLOW)/10
•CHGSUSPTEMPLOW – (CHGSUSPTEMPHIGH – CHGSUSPTEMPLOW)/10 ≤ Near Low ≤ CHGSUSPTEMPLOW + (CHGSUSPTEMPHIGH – CHGSUSPTEMPLOW)/10
•CHGSUSPTEMPHIGH – (CHGSUSPTEMPHIGH – CHGSUSPTEMPLOW)/10 ≤ Near High ≤ CHGSUSPTEMPHIGH + (CHGSUSPTEMPHIGH – CHGSUSPTEMPLOW)/10
•High > CHGSUSPTEMPLOW + (CHGSUSPTEMPHIGH – CHGSUSPTEMPLOW)/10

Table 10-2. Example bq78PL114 Temperature History Data

	Cell 1	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**Cell 7**	**Cell 8**
Below low	25%	25%	25%	25%	0	0	0	0
Near low	0	0	0	0	25%	25%	25%	25%
Near high	0	0	0	0	0	0	0	0
Above high	0	0	0	0	0	0	0	0

Standard SBS Commands

The bq78PL114 SBS command set meets the SBD v1.1 specification. All SBS values are updated in 2-second intervals or less.

A.1 SBS Command Values

Table A-1. SBS COMMANDS

SBS Cmd	Mode	Name	Format	Size in Bytes	Min Value	Max Value	Unit
0x00	R/W	ManufacturerAccess	Hex	2	0x0000	0xffff	
0x01	R/W	RemainingCapacityAlarm	Unsigned int	2	0	65,535	mAh or 10 mWh
0x02	R/W	RemainingTimeAlarm	Unsigned int	2	0	65,535	min.
0x03	R/W	BatteryMode	Hex	2	0x0000	0xe383	
0x04	R/W	AtRate	Signed int	2	–32,768	32,767	mA or 10 mW
0x05	R	AtRateTimeToFull	Unsigned int	2	0	65,534	min.
0x06	R	AtRateTimeToEmpty	Unsigned int	2	0	65,534	min.
0x07	R	AtRateOK	Unsigned int	2	0	65,535	
0x08	R	Temperature	Unsigned int	2	0	65,535	0.1°K
0x09	R	Voltage	Unsigned int	2	0	65,535	mV
0x0a	R	Current	Signed int	2	–32,768	32,767	mA
0x0b	R	AverageCurrent	Signed int	2	–32,768	32,767	mA
0x0c	R	MaxError	Unsigned int	1	0	100	%
0x0d	R	RelativeStateOfCharge	Unsigned int	1	0	100	%
0x0e	R	AbsoluteStateOfCharge	Unsigned int	1	0	100+	%
0x0f	R/W	RemainingCapacity	Unsigned int	2	0	65,535	mAh or 10 mWh
0x10	R	FullChargeCapacity	Unsigned int	2	0	65,535	mAh or 10 mWh
0x11	R	RunTimeToEmpty	Unsigned int	2	0	65,534	min.
0x12	R	AverageTimeToEmpty	Unsigned int	2	0	65,534	min.
0x13	R	AverageTimeToFull	Unsigned int	2	0	65,534	min.
0x14	R	ChargingCurrent	Unsigned int	2	0	65,534	mA
0x15	R	ChargingVoltage	Unsigned int	2	0	65,534	mV
0x16	R	BatteryStatus	Unsigned int	2	0x0000	0xdbff	
0x17	R/W	CycleCount	Unsigned int	2	0	65,535	
0x18	R/W	DesignCapacity	Unsigned int	2	0	65,535	mAh or 10 mWh
0x19	R/W	DesignVoltage	Unsigned int	2	0	65,535	mV
0x1a	R/W	SpecificationInfo [(1)]	Hex	2	0x0000	0xffff	
0x1b	R/W	ManufactureDate	Unsigned int	2	–	–	ASCII
0x1c	R/W	SerialNumber	Hex	2	0x0000	0xffff	
0x20	R/W	ManufacturerName	String	32 max [(2)]	–	–	ASCII
0x21	R/W	DeviceName	String	32 max [(2)]	–	–	ASCII
0x22	R/W	DeviceChemistry	String	32 max [(2)]	–	–	ASCII
0x23	R/W	ManufacturerData	String	14 + 1	–	–	ASCII

(1) The current is displayed as actual current divided by 10 when a 1-mΩ resistor is selected. The IPScale bits 12...15 are not updated by the firmware to reflect this.

(2) The 32-byte maximum includes the null-termination character (SBData specification limit). Typical sizes are smaller. Text values are loaded using bqWizard™ interface.

A.2 CellVoltage

These read-word functions return an unsigned value of the calculated individual cell voltages, in mV, with a range of 0 to 65,535. *CellVoltage1* corresponds to the bottommost series-cell element, while *CellVoltage12* corresponds to the topmost series-cell element.

Table A-2. CellVoltage

SBS Cmd.	Mode	Name	Format	Size in Bytes	Min Value	Max Value	Unit	Applicable To
0x3C	R	CellVoltage1	Unsigned integer	2	0	65,535	mV	bq78PL114, bq78PL114S12
0x3D		CellVoltage2						
0x3E		CellVoltage3						
0x3F		CellVoltage4						
0x40		CellVoltage5						
0x41		CellVoltage6						
0x42		CellVoltage7						
0x43		CellVoltage8						
0x44		CellVoltage9	Unsigned integer	2	0	65,535	mV	bq78PL114S12
0x45		CellVoltage10						
0x46		CellVoltage11						
0x47		CellVoltage12						
0x48		CellTemperature1				6553.5	0.1°K	
0x49		CellTemperature2						
0x4A		CellTemperature3						
0x4B		CellTemperature4						

A.3 Battery Mode(0x03)CellTemperature1

Table A-3. SBS Battery Mode Command

	15	14	13	12	11	10	9	8
Read/Write	R/W	R	R	R	R	R	R	R
Function	Capacity mode	Charger mode	Alarm mode	Reserved	Reserved	Reserved	Primary battery	Charge controller enabled
Default Value	0	1	1	0	0	0	0	0

	7	6	5	4	3	2	1	0
Read/Write	R	R	R	R	R	R	R	R
Function	Condition flag	Reserved	Reserved	Reserved	Reserved	Reserve d	Primary battery support	Internal charge controller
Default Value	0	1	1	0	0	0	0	0

Capacity Mode (bit 15):
0 = Report in mA or mAh (Default)
1 = Report in 10 mW or 10 mWh

All other bits are read only. The bq78PL114 & bq78PL114S12 BatteryMode is configured as follows:

Charger Mode (bit 14)
1 = Disable broadcasts of charging voltage and charging current to smart battery charger.

Alarm Mode (bit 13)
1 = Disable alarm warning broadcasts to host and smart battery charger.

Condition Flag (bit 7)
0 = Battery OK

Primary Battery Support (bit 1)
0 = Function not supported

Internal Charge Controller (bit 0)
1 = Internal charge controller supported

bq78PL114 and bq78PL114S12 Default Parameter Sets

The following two tables contain the default values for the bq78PL114 and bq78PL114S12 parameters. The bq78PL114 IC has a default configuration for eight cells in series. The bq78PL114S12 firmware download has a default configuration for three cells in series. It is the responsibility of the responsible engineer to ensure that the parameters are configured according to the desired pack configuration and cell manufacturer's requirements.

B.1 bq78PL114 Default Parameters

bq78PL114 Parameter	Units	Value
<SBData Static>	1	
Manufacturer Name		TEXAS INSTRUMENTS
Device Name		bq78PL114
Device Chemistry		LION
Manufacturer Data		0E3132333435363738394142434445000 0000000000000000000000000000000
Serial Number		1234
Manufacture Date		14547
Design Voltage	mV	33600
At Rate	mAh/10mWh	0
Battery Mode		0x6001
Remaining Time Alarm	Minutes	10
Remaining Capacity Alarm	mAh/10mWh	560
<Charge Control>	3	
Charge Inhibit Temperature Low	Kelvin	273
Charge Inhibit Temperature High	Kelvin	318
Charge Inhibit Recovery Temperature Low	Kelvin	278
Charge Inhibit Recovery Temperature High	Kelvin	313
Pre-Charge Temperature	Kelvin	273
Pre-Charge Voltage	mV	3000
Pre-Charge Recovery	mV	3100
Pre-Charge Current	mA	240
Charge Suspend Temperature Low	Kelvin	278
Charge Suspend Recovery Temperature Low	Kelvin	283
Charge Suspend Temperature High	Kelvin	333
Charge Suspend Recovery Temperature High	Kelvin	328
Charge Completion Pack Voltage Qualifier	mV	32800
Charge Completion Taper Current Qualifier	mA	240
Charge Completion Time	Seconds RDTE	10
Charge Completion FET Activation Time	Seconds RDTE	10

bq78PL114 Parameter	Units	Value
Discharge Completion Pack Voltage Qualifier	mV	24800
Discharge Completion Time	Seconds RDTE	4
Discharge Completion FET Activation Time	Seconds RDTE	6
Discharge Under Temperature	Kelvin	263
Discharge Under Temperature Recovery	Kelvin	273
Discharge Under Temperature Time	Seconds RDTE	2
FC Set SOC Threshold	%	-1
FC Clear SOC Threshold	%	-1
FD Set SOC Threshold	%	-1
FD Clear SOC Threshold	%	-1
FD Set Voltage	mV	24800
FD Clear Voltage	mV	25600
FD Set Voltage Time	Seconds	0
Transition to Idle Current	mA	50
Transition to Idle Time	Seconds	30
Transition to Discharge Current	mA	-75
Transition to Charge Current	mA	75
Cell Shutdown Voltage	mV	2500
Design Capacity mAh	mAHrs	4800
Design Capacity 10mWh	10mWh	6912
TDA Set SOC Threshold	%	-1
TDA Set Voltage Threshold	mV	25600
TDA Set Voltage Time	Seconds	0
TDA Clear SOC Threshold	%	-1
TDA Clear Voltage	mV	29600
TCA Set SOC Threshold	%	-1
TCA Clear SOC Threshold	%	-1
OCA Set Voltage	mV	34400
OCA Activation Time	Seconds RDTE	2
<Cell Balancing>	5	
Minimum Cell Differential For Balancing	mV	10
<Cell Chemistry>	6	
Chemistry ID		101
Aux Chemistry Version		1
Tau10		279
Normalized Dynamic Impedance Low Temperature	Kelvin	293
Normalized Dynamic Impedance High Temperature	Kelvin	313
Normalized Dynamic Impedance SOC	%	15
Normalized Dynamic Impedance Age		2575
Normalized Dynamic Impedance Gain		32
FCC Learn Qualifier	%	30
Cycle Fade	%	0.05
Min OCV Slope	mV/% RSOC	2
OCV Idle Qualifier	Minutes	30
Stale FCC Timeout	Minutes	2880
Default Charging Voltage	mV	33600

bq78PL114 Parameter	Units	Value
Default Charging Current	mA	3400
Capacity Algorithm		0x0003
User Rate	mA	1000
<Pack Configuration>	7	
Hardware Configuration		0x8339
Algorithm Enable		0x810E
Current Delta	mA	100
Sense Resistance	mΩ	5
SBData Map Begin		0x003C
<Safety Level 1>	8	
COV Threshold	mV	4250
COV Recovery	mV	4100
COV High Temperature Threshold	mV	4250
COV High Temperature Adjust	Kelvin	323
COV Time	Seconds	2
CUV Threshold	mV	2700
CUV Recovery	mV	3000
CUV Time	Seconds	1
POV Threshold	mV	34000
POV Recovery	mV	32800
POV Time	Seconds	6
PUV Threshold	mV	22400
PUV Recovery	mV	24000
PUV Time	Seconds	1
OC Charge Tier 1 Threshold	mA	4800
OC Charge Tier 1 Recovery	Seconds	2
OC Charge Tier 1 Time	Seconds	6
OC Discharge Tier 1 Threshold	mA	-7200
OC Discharge Tier 1 Recovery	Seconds	2
OC Discharge Tier 1 Time	Seconds	8
OC Charge Tier 2 Threshold	mA	5200
OC Charge Tier 2 Recovery	Seconds	8
OC Charge Tier 2 Time	Seconds	2
OC Discharge Tier 2 Threshold	mA	-9600
OC Discharge Tier 2 Recovery	Seconds	8
OC Discharge Tier 2 Time	Seconds	1
OC Max Attempts		3
Hardware OC Charge Threshold		211
Hardware OC Charge Recovery	Seconds	1
Hardware OC Charge Time	Count	60
Hardware OC Discharge Threshold		98
Hardware OC Discharge Recovery	Seconds	1
Hardware OC Discharge Time	Count	37
HOC Max Attempts		3
Hardware Short Circuit Threshold		47
Hardware Short Circuit Recovery	Seconds	8
Hardware Short Circuit Time	Count	3
HSC Max Attempts		3

bq78PL114 Parameter	Units	Value
EUV Threshold	mV	2500
EUV Time	Seconds	2
EUV Recovery	mV	2900
OT Charge Threshold	Kelvin	323
OT Charge Recovery	Kelvin	318
OT Charge Time	Seconds RDTE	2
OT Discharge Threshold	Kelvin	333
OT Discharge Recovery	Kelvin	323
OT Discharge Time	Seconds RDTE	2
Host Watchdog Timeout	Seconds RDTE	0
Board Over Temperature	Kelvin	358
Board Over Temperature Recovery	Kelvin	338
Board Over Temperature Time	Seconds RDTE	2
Fuse Absent Activation Time[(1)]	Seconds	0
TK Factor[(1)]		-1480
Hardware LP Discharge Threshold		32
Hardware LP Discharge Duration		127
Hardware LP Charge Threshold		224
Hardware LP Charge Duration		127
xxx		
<Safety Level 2>	9	
SOV Threshold	mV	4350
SOV Time	Seconds RDTE	8
Cell Imbalance Current	mA	50
Cell Imbalance Fail Voltage	mV	500
Cell Imbalance Time	Seconds	180
Cell Imbalance SOC Inhibit Threshold	%	30
Fuse State Fail Time	Seconds RDTE	4
SOC Charge Threshold	mA	6000
SOC Charge Time	Seconds RDTE	2
SOC Discharge Threshold	mA	-12000
SOC Discharge Time	Seconds RDTE	2
SOT Charge Threshold	Kelvin	343
SOT Charge Time	Seconds RDTE	2
SOT Discharge Threshold	Kelvin	343
SOT Discharge Time	Seconds RDTE	2
Open Temperature Sensor Threshold	Kelvin	233
Open Temperature Sensor Time	Seconds RDTE	2
FET Fail Time	Seconds RDTE	2
Fuse Fail Limit	mA	40
Fuse Fail Time	Seconds RDTE	2
VLAN Fail Time	Seconds RDTE	2
Current Measurement Fail Time	Seconds RDTE	10
Pre-Charge Voltage Timeout	Seconds RDTE	900
IGR Limit		200
IGR Fail Count		255
IGR Ratio Limit		120
IGR Ratio Fail Count		255

(1) These parameters are not user programmable. Default values must be used.

bq78PL114 Parameter	Units	Value
Rate Limit Threshold		200
Rate Limit Activation Count		100
Charge Duration Timeout	Seconds RDTE	14,400

B.2 bq78PL114S12 Default Parameters

bq78PL114S12 Parameter	Units	Value
<SBData Static>	1	
Manufacturer Name		TEXAS INSTRUMENTS
Device Name		bq78PL114
Device Chemistry		LION
Manufacturer Data		0E4D616E2044617461202020202020000 0000000000000000000000000000000
Serial Number		1
Manufacture Date		14964
Design Voltage	mV	33600
At Rate	mAh/10mWh	0
Battery Mode		0x6001
Remaining Time Alarm	Minutes	10
Remaining Capacity Alarm	mAh/10mWh	560
<Charge Control>	3	
Pre-Charge Temperature	Kelvin	273
Pre-Charge Voltage	mV	3000
Pre-Charge Recovery	mV	3100
Pre-Charge Current	mA	240
Charge Inhibit Temperature Low	Kelvin	273
Charge Inhibit Temperature High	Kelvin	318
Charge Inhibit Recovery Temperature Low	Kelvin	278
Charge Inhibit Recovery Temperature High	Kelvin	313
Charge Suspend Temperature Low	Kelvin	278
Charge Suspend Recovery Temperature Low	Kelvin	283
Charge Suspend Temperature High	Kelvin	333
Charge Suspend Recovery Temperature High	Kelvin	328
Charge Completion Pack Voltage Qualifier	mV	32800
Charge Completion Taper Current Qualifier	mA	240
Charge Completion Time	Seconds RDTE	10
Charge Completion FET Activation Time	Seconds RDTE	10
Discharge Completion Pack Voltage Qualifier	mV	24800
Discharge Completion Time	Seconds RDTE	4
Discharge Completion FET Activation Time	Seconds RDTE	6
Discharge Under Temperature	Kelvin	263
Discharge Under Temperature Recovery	Kelvin	273
Discharge Under Temperature Time	Seconds RDTE	2
FC Set SOC Threshold	%	-1
FC Clear SOC Threshold	%	-1

bq78PL114S12 Parameter	Units	Value
FD Set SOC Threshold	%	-1
FD Clear SOC Threshold	%	-1
FD Set Voltage	mV	24800
FD Clear Voltage	mV	25600
FD Set Voltage Time	Seconds	0
Transition to Idle Current	mA	50
Transition to Idle Time	Seconds	30
Transition to Discharge Current	mA	-75
Transition to Charge Current	mA	75
Cell Shutdown Voltage	mV	2500
Design Capacity mAh	mAHrs	2400
Design Capacity 10mWh	10mWh	6912
TDA Set SOC Threshold	%	-1
TDA Set Voltage Threshold	mV	25600
TDA Set Voltage Time	Seconds	0
TDA Clear SOC Threshold	%	-1
TDA Clear Voltage	mV	29600
TCA Set SOC Threshold	%	-1
TCA Clear SOC Threshold	%	-1
OCA Set Voltage	mV	34400
OCA Activation Time	Seconds RDTE	2
<Cell Balancing>	5	
Minimum Cell Differential For Balancing	mV	10
<Cell Chemistry>	6	
Chemistry ID		101
FCC Learn Qualifier	%	30
Cycle Fade	%	0.05
Min OCV Slope	mV/% RSOC	2
OCV Idle Qualifier	Minutes	30
Stale FCC Timeout	Minutes	2880
Default Charging Voltage	mV	33600
Default Charging Current	mA	1680
Capacity Algorithm		0x0003
User Rate	mA	1000
<Pack Configuration>	7	
Hardware Configuration		0x0731
Algorithm Enable		0x800E
System Control		0x8000
Current Delta	mA	100
EPD Pump Time	Cycle Counts	120
EPD Write Time	Cycle Counts	70
Display Driver Frequency	Hz	30
Product Sub ID		0
<Safety Level 1>	8	
COV Threshold	mV	4250
COV Recovery	mV	4100
COV High Temperature Threshold	mV	4250
COV High Temperature Adjust	Kelvin	323

bq78PL114S12 Parameter	Units	Value
COV Time	Seconds	2
CUV Threshold	mV	2700
CUV Recovery	mV	3000
CUV Time	Seconds	1
POV Threshold	mV	34000
POV Recovery	mV	32800
POV Time	Seconds	6
PUV Threshold	mV	22400
PUV Recovery	mV	24000
PUV Time	Seconds	1
OC Charge Tier 1 Threshold	mA	4800
OC Charge Tier 1 Recovery	Seconds	2
OC Charge Tier 1 Time	Seconds	6
OC Discharge Tier 1 Threshold	mA	-7200
OC Discharge Tier 1 Recovery	Seconds	2
OC Discharge Tier 1 Time	Seconds	8
OC Charge Tier 2 Threshold	mA	5200
OC Charge Tier 2 Recovery	Seconds	8
OC Charge Tier 2 Time	Seconds	2
OC Discharge Tier 2 Threshold	mA	-9600
OC Discharge Tier 2 Recovery	Seconds	8
OC Discharge Tier 2 Time	Seconds	1
OC Max Attempts		3
Hardware OC Charge Threshold		211
Hardware OC Charge Recovery	Seconds	1
Hardware OC Charge Time	Count	60
Hardware OC Discharge Threshold		98
Hardware OC Discharge Recovery	Seconds	1
Hardware OC Discharge Time	Count	37
HOC Max Attempts		3
Hardware Short Circuit Threshold		47
Hardware Short Circuit Recovery	Seconds	8
Hardware Short Circuit Time	Count	3
HSC Max Attempts		3
EUV Threshold	mV	2500
EUV Time	Seconds	2
EUV Recovery	mV	2900
OT Charge Threshold	Kelvin	323
OT Charge Recovery	Kelvin	318
OT Charge Time	Seconds RDTE	2
OT Discharge Threshold	Kelvin	333
OT Discharge Recovery	Kelvin	323
OT Discharge Time	Seconds RDTE	2
Host Watchdog Timeout	Seconds RDTE	0
Board Over Temperature	Kelvin	358
Board Over Temperature Recovery	Kelvin	338
Board Over Temperature Time	Seconds RDTE	2
Hardware LP Discharge Threshold		32
Hardware LP Discharge Duration		127

bq78PL114S12 Parameter	Units	Value
Hardware LP Charge Threshold		224
Hardware LP Charge Duration		127
<Safety Level 2>	9	
SOV Threshold	mV	4350
SOV Time	Seconds RDTE	8
Cell Imbalance Current	mA	50
Cell Imbalance Fail Voltage	mV	500
Cell Imbalance Time	Seconds	180
Cell Imbalance SOC Inhibit Threshold	%	30
SOC Charge Threshold	mA	6000
SOC Charge Time	Seconds RDTE	2
SOC Discharge Threshold	mA	-12000
SOC Discharge Time	Seconds RDTE	2
SOT Charge Threshold	Kelvin	343
SOT Charge Time	Seconds RDTE	2
SOT Discharge Threshold	Kelvin	343
SOT Discharge Time	Seconds RDTE	2
Open Temperature Sensor Threshold	Kelvin	233
Open Temperature Sensor Time	Seconds RDTE	2
FET Fail Time	Seconds RDTE	2
Fuse Fail Limit	mA	40
Fuse Fail Time	Seconds RDTE	2
VLAN Fail Time	Seconds RDTE	2
Current Measurement Fail Time	Seconds RDTE	10
Pre-Charge Voltage Timeout	Seconds RDTE	900
Charge Duration Timeout	Seconds RDTE	14400
IGR Limit		200
IGR Fail Count		255
IGR Ratio Limit		120
IGR Ratio Fail Count		255
Rate Limit Threshold		200
Rate Limit Activation Count		aret100

Firmware Upgrade Instructions

C.1 Firmware Conversion Using bqWizard™ Software

The bqWizard™ software is used to upgrade firmware in a laboratory environment. The procedure for converting from FW 4452 to FW 5000 follows.

1. A minimum series cell count of three is required to power the bq78PL114 during the firmware conversion.
   (a) If the target circuit contains a series cell count less than eight, the cell voltages read 2000 mV in the bqWizard™ software and the Number of Rebuilds parameter under the Pack Configuration Tab in the bqWizard™ software increments if polling is active. This is expected because a nonmatching series cell count is looked on as a system error.
   (b) For cells counts above eight, those cells are not seen in the bqWizard™ software.
2. Apply power to the target circuit containing the bq78PL114.
   (a) The cell voltages applied must be in the range of normal operation (3600 mV).
3. Wait 10 seconds after application of power to the target circuit. Open the bqWizard™ software. Version 2.5.7 or later must be used.
4. Load the new firmware.
   (a) From the Utilities drop-down menu, select Bootstrap Loader…
   (b) Click Select File.
   (c) Locate the directory Configuration Files\bq78PL114S12\Firmware, and select the file FW_0001_0000_5000_0012.enc and click the Open button.
   (d) Click the Preserve Calibration check box. A warning message is displayed. Click the Yes button. This stores a copy of the factory calibration in the user-specified location.
   (e) Click the Download button. A dialog box opens and allows the location of the preserve calibration file to be specified. The default location is in the CalRestore directory. Type a filename called FW 4452_Calibration, and click the save button. Use this file only if the firmware 4452 is loaded back onto the system and cell calibration is needed. Reloading the FW 4452 generally is not needed and usually indicates a system error.
   (f) The firmware download proceeds. This takes approximately 50 seconds and shows a dialog box that reads "Calibration has been preserved." Click the OK button. The status in the Bootstrap Loader Dialog Box reads Completed followed by a programming duration in seconds.
   (g) Exit the bootstrap loader by selecting Close Bootstrap Loader from the File drop-down menu.
5. The bqWizard™ software reconnects to the device and displays a series cell count of three cells.
   (a) The cell voltages must read correctly.
   (b) The cell temperatures likely are not be correct. This is expected and only requires that they be calibrated.
   (c) Under the Pack Configuration Tab, verify that the values of the following parameters are correct
      (i) Firmware Version = 5000
      (ii) Parallel Cell Count = 1
      (iii) Expected Number of Cells = 3
      (iv) Actual Number of Cells = 3
      (v) Max Number of Cells = 12
      (vi) Temperature Sensor Count = 4
      (vii) Max Number of Temperature Sensors = 13
      (viii) Sense Resistor = 10000 μΩ
6. Toggle the wired bit.
7. Proceed by loading a configuration file (*.tmap) that matches the target application.

IMPORTANT: The preceding steps have to do with loading a configuration file for 3 or 4 cells under FW 4452; steps 4 and 5, are optional. Steps 4 and 5 are for helping users start up prototype circuits that may not have been proven yet. Once a target board is debugged, these steps can be omitted. The production flow certainly does not require these steps.

C.2 Firmware Conversion Using the bq78PL114S12 API

The firmware conversion can be accomplished using user-generated software that accesses the bq78PL114S12 API. This is the method of firmware upgrade in a production environment. See the *bq78PL114S12 API User's Guide* for details.

Glossary

ADC	Analog-to-digital converter
Alert	A warning set by the bq78PL114
Bit	A single binary digit in an SBS command or data-flash value which can be changed by the user
CC	Constant current (may also indicate coulomb counting)
CHG FET	Charge FET
COV	Cell overvoltage
CV	Constant voltage
CUV	Cell undervoltage
DSG FET	Discharge FET, connected to the DSG pin; used to enable or disable discharging
EFCI	External FET control input – allows control of pack-protection MOSFETs
FC	Fully charged
FD	Fully discharged
Flag	A single bit in an SBS command or data-flash value which is set by the bq78PL114 and indicates a status change
LED	Light-emitting diode
Li-Ion	Lithium-ion
NDI	Normalized dynamic impedance. This is the dynamic impedance due to a step change in current and voltage ($\Delta V/\Delta I$), normalized to a fixed reference temperature.
OC	Overcurrent
OCA	Overcharge alarm
OCV	Open-circuit voltage
PEC	Packet error checking
POV	Pack overvoltage
PRES	System-present flag
PUV	Pack undervoltage
Qmax	Maximum chemical capacity
RCA	Remaining Capacity Alarm
RDTE	Round down to even; the time value is an integral multiple of two seconds.
ROR	Rate of rise
RSOC	Relative state-of-charge
SBS	Smart battery system
SMBus	System-management bus
SOC	Safety overcurrent
SOC	State of charge
SOT	Safety overtemperature
TCA	Terminate charge alarm

TDA	Terminate discharge alarm