

## PowerLAN™ Master Gateway Battery Management Controller With PowerPump™ Cell Balancing Technology

### FEATURES

- Designed for Managing up to 12 Series Cell Battery Systems
- SmartSafety Features:
  - Prevention: Optimal Cell Management
  - Diagnosis: Improved Sensing of Cell Problems
  - Fail Safe: Detection of Event Precursors
- Rate-of-Change Detection of All Important Cell Characteristics:
  - Voltage
  - Impedance
  - Cell Temperature
- PowerPump Technology Transfers Charge Efficiently From Cell to Cell During All Operating Conditions, Resulting in Longer Run Time and Cell Life
- High-Resolution 18-Bit Integrating Delta-Sigma Coulomb Counter for Precise Charge-Flow Measurements and Gas Gauging
- Multiple Independent  $\Delta-\Sigma$  ADCs: One-per-Cell Voltage, Plus Separate Temperature, Current, and Safety
- Simultaneous, Synchronous Measurement of Pack Current and Individual Cell Voltages
- Very Low Power Consumption: < 250  $\mu\text{A}$  Active, < 150  $\mu\text{A}$  Standby, < 40  $\mu\text{A}$  Ship, and < 1- $\mu\text{A}$  Undervoltage Shutdown
- Accurate, Advanced Temperature Monitoring of Cells and MOSFETs With up to Six Sensors
- Fail-Safe Operation of Pack Protection Circuits: Up to Three Power MOSFETs and One Secondary Safety Output (Fuse)
- Fully Programmable Voltage, Current, Balance, and Temperature-Protection Features
- External Inputs for Auxiliary MOSFET Control
- Smart Battery System 1.1 Compliant via SMBus or SPI Interface With SHA-1 Authentication Option

### APPLICATIONS

- Portable Medical Instruments and Test Equipment
- Mobility Devices (E-Bike)
- Uninterruptible Power Supplies and Hand-Held Tools

### DESCRIPTION

The bq78PL114 master gateway battery controller is part of a complete Li-Ion control, monitoring, and safety solution designed for large series cell strings.

The bq78PL114, along with PowerLAN cell monitors, provides complete battery system control, communications, and safety functions for a structure of three to 12 series cells. This PowerLAN system provides simultaneous, synchronized voltage and temperature measurements using one-ADC-per-cell technology. Voltage measurements are also synchronized with pack current measurements, eliminating system-induced noise from measurements. This allows the precise, continuous, real-time calculation of cell impedance under all operating conditions, even during widely fluctuating load conditions.

PowerPump technology transfers charge between cells to balance their voltage and capacity. Balancing is possible during all battery modes: charge, discharge, and rest. Highly efficient charge-transfer circuitry nearly eliminates energy loss while providing true real-time balance between cells, resulting in longer run-time and improved cycle life.

Temperature is sensed by up to six external sensors. This permits accurate temperature monitoring of each cell individually. Firmware is then able to compensate for the temperature-induced effects on capacity, impedance, and OCV on a cell-by-cell basis, resulting in superior charge/ discharge and balancing control.

External MOSFET control inputs provide user-definable direct hardware control over MOSFET states. Smart control prevents excessive current through MOSFET body diodes. Auxiliary inputs can be used for enhanced safety and control in large multicell arrays.



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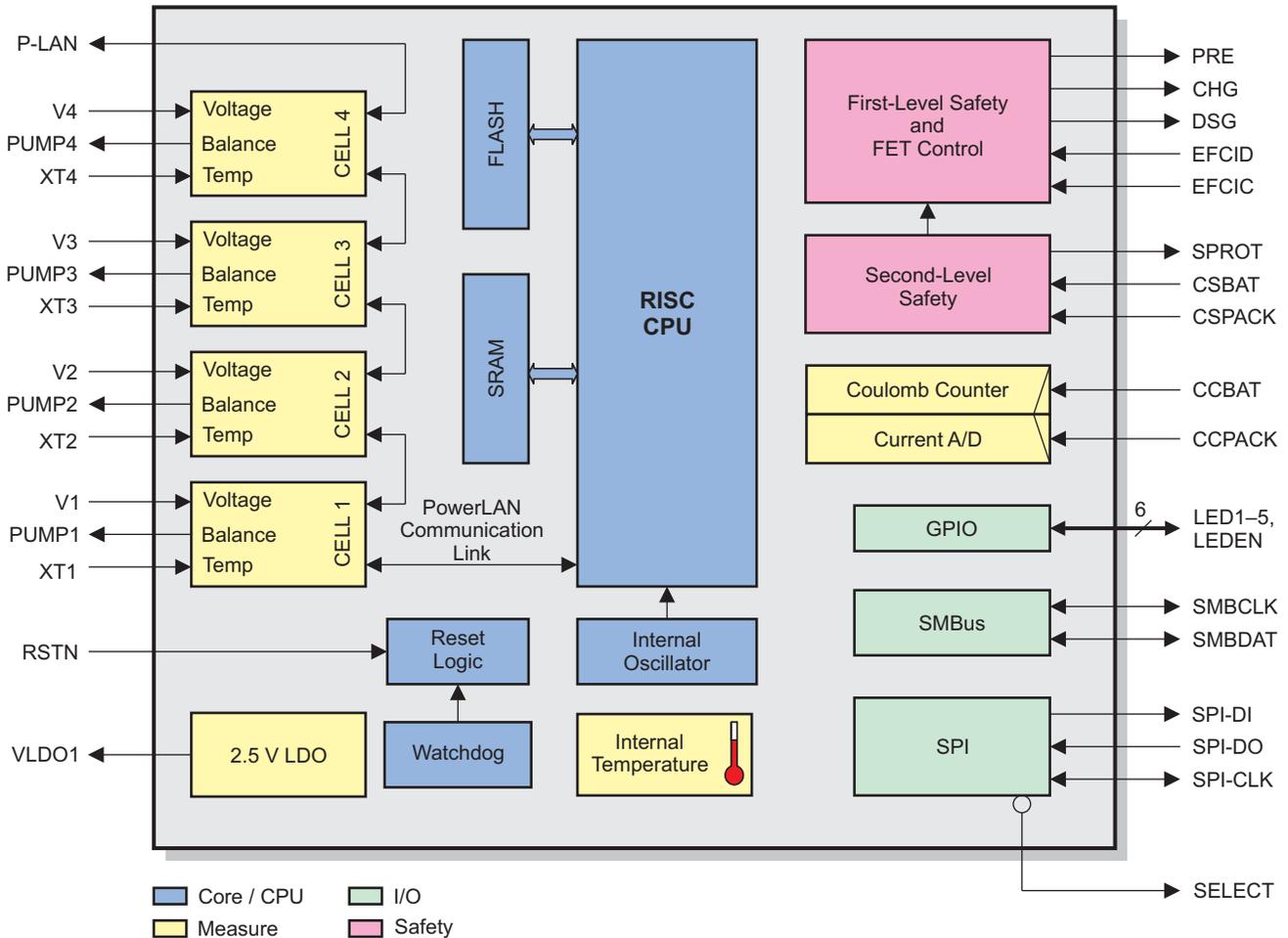
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These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

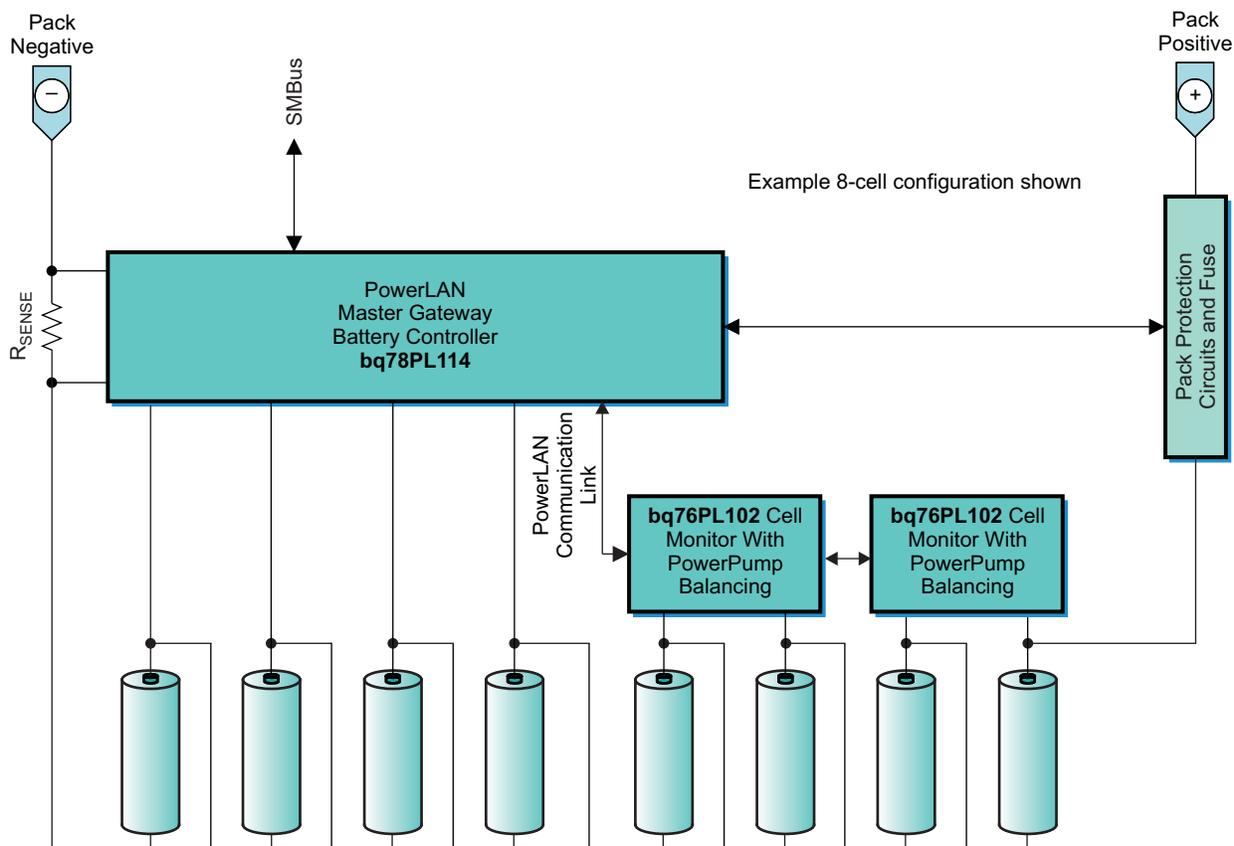
### DESCRIPTION (CONTINUED)

The bq78PL114 is completely user-configurable, with parametric tables in flash memory to suit a variety of cell chemistries, operating conditions, safety controls, and data reporting needs. It is easily configured using the supplied bqWizard™ graphical user interface (GUI). The device is fully programmed and requires no algorithm or firmware development.



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Figure 1. bq78PL114 Internal Block Diagram



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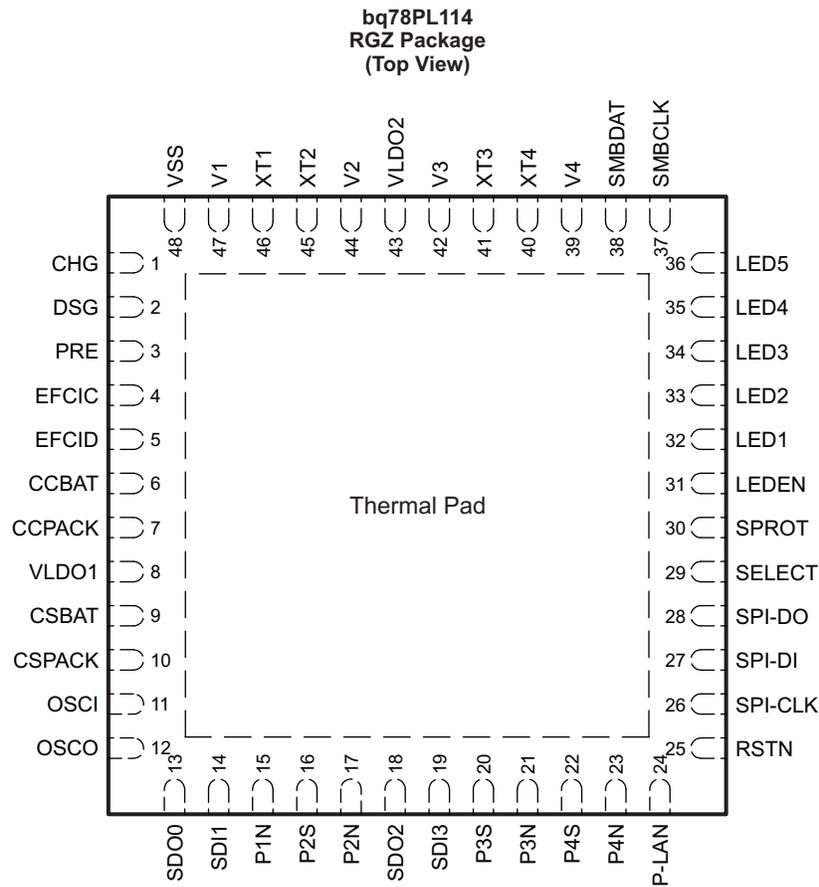
Figure 2. Example PowerLAN Multicell System Implementation

ORDERING INFORMATION<sup>(1)</sup>

Product	Cell Configuration <sup>(2)</sup>	Package	Package Designator	Temperature Range	Ordering Number	Quantity, Transport Media
bq78PL114	3 to 8 series cells	QFN-48, 7-mm x 7-mm	RGZ	-40°C to 85°C	bq78PL114RGZT	250, tape and reel
					bq78PL114RGZR	2500, tape and reel
bq78PL114 (PREVIEW)	3 to 10 series cells				bq78PL114S10RGZT <sup>(3)</sup>	250, tape and reel
					bq78PL114S10RGZR <sup>(3)</sup>	2500, tape and reel
bq78PL114 (PREVIEW)	3 to 12 series cells				bq78PL114S12RGZT <sup>(3)</sup>	250, tape and reel
					bq78PL114S12RGZR <sup>(3)</sup>	2500, tape and reel

- (1) Authentication options are also available; contact TI for additional information.
- (2) For configurations consisting of more than four series cells, additional bq76PL102 parts must be used.
- (3) Some historical data storage limits exist for the S10 and S12 versions.

**AVAILABLE OPTIONS**



P0023-16

**Figure 3. bq78PL114 Pinout**

**TERMINAL FUNCTIONS**

NAME	NO.	TYPE <sup>(1)</sup>	DESCRIPTION
CCBAT	6	IA	Coulomb counter input (sense resistor), connect to battery negative
CCPACK	7	IA	Coulomb counter input (sense resistor), connect to pack negative
CHG	1	O	Charge MOSFET control (active-high, enables current flow)
CSBAT	9	IA	Current sense input (safety), connect to battery negative
CSPACK	10	IA	Current sense input (safety), connect to pack negative
DSG	2	O	Discharge MOSFET control (active-high, low opens MOSFET)
EFCIC	4	I	External charge MOSFET control input
EFCID	5	I	External discharge MOSFET control input
LED1	32	IO	LED1 – active-low
LED2	33	IO	LED2 – active-low
LED3	34	IO	LED3 – active-low
LED4	35	IO	LED4 – active-low
LED5	36	IO	LED5 – active-low
LEDEN	31	IO	LEDEN – common-anode drive (active-high)
OSCI	11	I	External oscillator input (optional)
OSCO	12	O	External oscillator output (optional)

(1) I – input, IA – analog input, O – output, OA – analog output, P – power

**TERMINAL FUNCTIONS (continued)**

NAME	NO.	TYPE <sup>(1)</sup>	DESCRIPTION
P1N	15	O	Charge-balance gate drive, cell 1 north
P2S	16	O	Charge-balance gate drive, cell 2 south
P2N	17	O	Charge-balance gate drive, cell 2 north
P3N	21	O	Charge-balance gate drive, cell 3 north
P3S	20	O	Charge-balance gate drive, cell 3 south
P4N	23	O	Charge-balance gate drive, cell 4 north
P4S	22	O	Charge-balance gate drive, cell 4 south
P-LAN	24	IO	PowerLAN I/O to external bq76PL10x nodes
PRE	3	O	Pre-Charge MOSFET control (active-high.)
RSTN	25	I	Device reset, active-low
SDI1	14	I	Connect to SDO0 via a capacitor
SDI3	19	I	Internal PowerLAN connection – connect to SDO2
SDO0	13	O	Requires 100-kΩ pullup resistor to VLDO1
SDO2	18	O	Internal PowerLAN connection – connect to SDI3
SELECT	29	O	Auxiliary SPI control output <sup>(2)</sup>
SMBCLK	37	IO	SMBus clock signal
SMBDAT	38	IO	SMBus data signal
SPI-CLK	26	IO	SPI port clock <sup>(2)</sup>
SPI-DI	27	I	SPI master-out-slave-in <sup>(2)</sup>
SPI-DO	28	O	SPI master-in-slave-out <sup>(2)</sup>
SPROT	30	O	Secondary protection output, active-high (FUSE)
V1	47	IA	Cell-1 positive input
V2	44	IA	Cell-2 positive input
V3	42	IA	Cell-3 positive input
V4	39	IA	Cell-4 positive input
VLDO1	8	P	Internal LDO-1 output, bypass with capacitor
VLDO2	43	P	Internal LDO-2 output, bypass with capacitor
VSS	48	IA	Cell-1 negative input
XT1	46	IA	External temperature-sensor-1 input
XT2	45	IA	External temperature-sensor-2 input
XT3	41	IA	External temperature-sensor-3 input
XT4	40	IA	External temperature-sensor-4 input
–	–	P	Thermal pad. Connect to VSS

(2) SPI functionality requires a firmware option, consult the factory for additional information.

**ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>**

over operating free-air temperature range (unless otherwise noted)

		<b>RANGE</b>	<b>UNITS</b>
$T_A$	Operating free-air temperature (ambient)	–40 to 85	°C
$T_{stg}$	Storage temperature	–65 to 150	°C
V4–V3	Maximum cell voltage	–0.5 to 5.0	V
V3–V2	Maximum cell voltage	–0.5 to 5.0	V
V2–V1	Maximum cell voltage	–0.5 to 5.0	V
V1–VSS	Maximum cell voltage	–0.5 to 5.0	V
Voltage on LED1–LED5, CCBAT, CCPACK, CSBAT, CSPACK, XT1, XT2, OSCI, OSCO, SDIx, SDOx, SPROT, P-LAN	Maximum voltage on any I/O pin	(VSS – 0.5) to (VLDO1 + 0.5)	V
Voltage on XT3, XT4, LEDEN	Maximum voltage range	(V2 – 0.5) to (VLDO2 + 0.5)	V
EFCIC, EFCID	With respect to VSS	–0.5 to 5.5	V
Voltage on SMBCLK, SMBDAT	With respect to VSS	–0.5 to 6	V
Voltage on PRE, CHG, DSG	With respect to VSS	–0.5 to (VLDO1 + 0.5)	V
Current through PRE, CHG, DSG, LED1–LED5, P-LAN	Maximum current source/sink	20	mA
VLDO1 maximum current	Maximum current draw from VLDO	20	mA
ESD tolerance	JEDEC, JESD22-A114 human-body model, R = 1500 $\Omega$ , C = 100 pF	2	kV
Lead temperature, soldering	Total time < 3 seconds	300	°C

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS

$T_A = -40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$  (unless otherwise noted)

### DC Characteristics

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{\text{CELL}}^{(1)}$ Operating range	Cells balanced	2.3		4.5	V
$I_{\text{DD}}$ Operating-mode current	Measure / report state		250		$\mu\text{A}$
$I_{\text{STBY}}$ Standby-mode current	SMBCLK = SMBDAT = L		100		$\mu\text{A}$
$I_{\text{SHIP}}$ Ship-mode current			30		$\mu\text{A}$
$I_{\text{ECUV}}$ Extreme cell under voltage shutdown current	All cells < 2.7 V and any cell < ECUV set point			1	$\mu\text{A}$
$V_{\text{OL}}$ General I/O pins	$I_{\text{OL}} < 4 \text{ mA}$	0		0.5	V
$V_{\text{OH}}^{(2)}$ General I/O pins	$I_{\text{OH}} < -4 \text{ mA}$	$V_{\text{LDO1}} - 0.1$			V
$V_{\text{IL}}$ General I/O pins			0.25 $V_{\text{LDO1}}$		V
$V_{\text{IH}}$ General I/O pins		0.75 $V_{\text{LDO1}}$			V

(1) Device remains operational to 1.85 V with reduced accuracy and performance.

(2) Does not apply to SMBus pins.

### Voltage-Measurement Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		2.5		4.5	V
Resolution			<1		mV
Accuracy	25°C		±5		mV
	0°C to 60°C		±10		

### Current-Sense Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range <sup>(1)</sup>		-0.2		0.2	V
Input offset	$T_A = 25^{\circ}\text{C}$		±50		$\mu\text{V}$
Offset drift	$T_A = 0^{\circ}\text{C}$ to $60^{\circ}\text{C}$		0.5		$\mu\text{V}/^{\circ}\text{C}$
Resolution			18		$\mu\text{V}$
Full-scale error <sup>(2)</sup>	$T_A = 25^{\circ}\text{C}$		±0.1%		
Full-scale error drift	$T_A = 0^{\circ}\text{C}$ to $60^{\circ}\text{C}$		50		PPM/°C

(1) Default range. Corresponds to ±10 A using a 10-m $\Omega$  sense resistor. Other gains and ranges are available (eight options).

(2) After calibration. Accuracy is dependent on system calibration and temperature coefficient of sense resistor.

### Coulomb-Counter Characteristics<sup>(1) (2)</sup>

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Resolution			5		nVh
Integral nonlinearity			0.008%		
Snap-to-zero (deadband)			±100 <sup>(3)</sup>		$\mu\text{V}$

(1) Shares common input with **Current Sense** section

(2) After calibration. Accuracy is dependent on system calibration and temperature coefficient of sense resistor.

(3) Corresponds to 20 mA using 5-m $\Omega$  sense resistor

### Current-Sense (Safety) Characteristics<sup>(1)</sup>

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		-0.312		0.312	V
Resolution	Short-circuit detection		10		mV
	Overcurrent detection, charge and discharge		1.25		

(1) Post calibration: Dependent on system calibration and temperature coefficient of sense resistor. Uncertainty 1.5 LSB.

### Internal Temperature-Sensor Characteristics<sup>(1)</sup>

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range		-30		85	°C
Resolution			0.1		°C
Accuracy <sup>(1)</sup>	-30° to 85°		±1		°C

(1) After calibration.

### External Temperature-Sensor(s) Typical Characteristics<sup>(1)</sup>

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Measurement range <sup>(2)</sup>		-40		90	°C
Resolution			0.2		°C
Accuracy <sup>(3)</sup>	25°		±1		°C
	0° to 85°		±2		

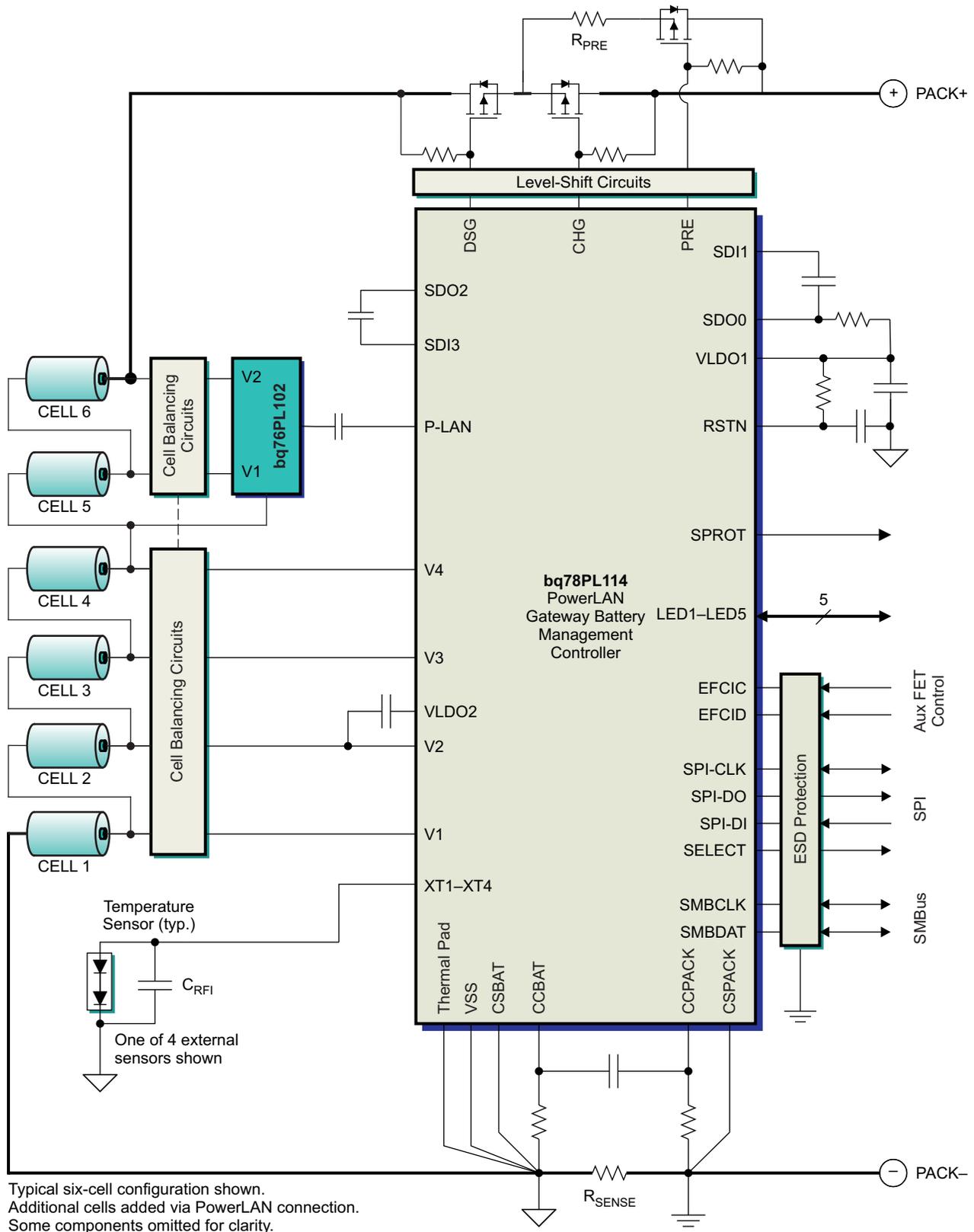
- (1) Typical for dual diode (MMBD4148 or equivalent) external sensor using recommended circuit.  
 (2) Range of diode sensors may exceed operational limits of IC and battery cells.  
 (3) Typical behavior after calibration, final result dependent on specific component characteristics.

### SMBus Characteristics<sup>(1)</sup>

over operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>IL</sub> Input low voltage		0		0.8	V
V <sub>IH</sub> Input high voltage		2.1		5.5	V
V <sub>OL</sub> Output low voltage	350-μA sink current	0		0.4	V
C <sub>I</sub> Capacitance, each I/O pin				10	pF
f <sub>SCL</sub> SCLK nominal clock frequency	T <sub>A</sub> = 25°C		100		kHz
R <sub>PU</sub> <sup>(2)</sup> Pullup resistors for SCLK, SDATA	V <sub>BUS</sub> 5 V nominal	13.3		45.3	kΩ
	V <sub>BUS</sub> 3 V nominal	2.4		6.8	

- (1) SMBus timing and signals meet the SMBus 2.0 specification requirements under normal operating conditions. All signals are measured with respect to PACK-negative.  
 (2) Pullups are typically implemented external to battery pack, and are selected to meet SMBus requirements.



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Figure 4. bq78PL114 Simplified Example Circuit Diagram

## FEATURE SET

### Primary (First-Level) Safety Features

The bq78PL114 implements a breadth of system protection features which are easily configured by the customer. First-level protections work by controlling the MOSFET switches. These include:

- Battery cell over/undervoltage protection
- Pack over/undervoltage protection
- Charge and discharge overcurrent protection
- Short-circuit protection
- External MOSFET control inputs (EFCIx) with programmable polarity
- Up to four external temperature inputs for accurate cell and MOSFET monitoring
- Watchdog timer protection
- Brownout detection and protection against extreme pack undervoltage

### Secondary (Second-Level) Safety Features

The bq78PL114 can detect more serious system faults and activate the SPROT pin, which can be used to open an in-line chemical fuse to permanently disable the pack. Secondary optional features include

- Fully independent of first-level protections
- SmartSafety algorithms for early detection of potential faults
  - Temperature abnormalities (variances, extremes, rate of change, etc.)
  - Disconnected cell voltage inputs
  - Cell imbalance exceeds safety limits
  - Impedance rise due to cell or weld strap fault
- MOSFET failure or loss of MOSFET control
- Safety overvoltage, pack and cell
- Safety overtemperature, limits for both charge and discharge
- Safety overcurrent, charge and discharge
- Failed current measurement, voltage measurement, or temperature measurement

### Charge Control Features

- Meets SMBus 2.0 and Smart Battery System (SBS) Specification 1.1 requirements
- Active cell balancing using patented PowerPump technology, which eliminates unrecoverable capacity loss due to normal cell imbalance
- Balancing-current monitoring to detect cell problems
- Simultaneous, synchronous measurement of all cell voltages in a pack
- Simultaneous, synchronous measurement of pack current with cell voltages
- Reports target charging current and/or voltage to an SBS Smart Charger
- Reports the chemical state-of-charge for each cell and pack
- Supports precharging and zero-volt charging with separate MOSFET control
- Programmable, Chemistry-specific parameters
- Fault reporting

### Gas Gauging

- The bq78PL114 accurately reports battery cell and pack state-of-charge (SOC). No full charge/discharge cycle is required for accurate reporting.
- State-of-charge is reported via SMBus and optional LED display.
- 18-bit integrating delta-sigma ADC coulomb counter, with programmable snap-to-zero value

### LED Display

- The bq78PL114 drives a three- to five-segment LED display in response to a pushbutton (LEDEN) input signal. Each LED pin can sink up to 10 mA.

### Lifetime Data Logging (Readable via SMBus or SPI)

- Recording of faults, events, anomalies, minimum and maximum values
- Maximum/minimum temperature
- Maximum/minimum pack voltage
- Maximum/minimum cell voltages
- Maximum charge and discharge currents

### Forensic Data Logging (Readable via SMBus or SPI)

- Last known full capacity of each cell
- Cycle count and/or cumulative number of ampere-hours delivered by the battery
- Battery pack status: being charged, discharged, or at rest
- Balancing effort required by each bank of cells to maintain balance
- Information for each cell bank for period leading up to failure
- Last 10 failures causing first-level safety action
- Forensic data up-loadable to host CPU via SMBus or SPI
- Forensic data recording of anomalies and events

### Power Modes

- **Normal Mode:** The bq78PL114 performs measurements and calculations, makes decisions, and updates internal data approximately once per second. *All safety circuitry is fully functional in this mode.*
- **Standby Mode:** The bq78PL114 performs as in normal mode, but at a dramatically reduced rate to lower power consumption at times when the host computer is inactive or the battery system is not being used. *All safety circuitry remains fully functional in this mode.*
- **Ship Mode:** The bq78PL114 disables (opens) all the protection MOSFETs, and continues to monitor temperature and voltage, but at a reduced measurement rate to dramatically lower power consumption. Environmental data is saved in flash as a part of the historical record. *Safety circuitry is disabled in this mode.* The device does not enter this power state as a part of normal operation; it is intended for use after factory programming and test. Entry occurs only after a unique SMBus or SPI command is issued. Exit occurs when the SMBus or SPI lines return to an active state.
- **Extreme Cell Undervoltage (ECUV) Shutdown Mode:** In this mode, the bq78PL114 draws minimal current and the charge and discharge protection MOSFETs are disabled (opened). The precharge MOSFET remains enabled when a charge voltage is present. *Safety circuitry is disabled in this mode.* The device does not enter this mode as a part of normal operation; it enters this state during extreme cell undervoltage conditions (ECUV). The ECUV threshold is fully programmable below 2.7V.

STATE	CURRENT DRAW (Typ)	OVERCURRENT PROTECTION	ENTRY CONDITION	EXIT CONDITION
Active	< 250 $\mu$ A	Fully active	Normal operation as determined by firmware	Firmware directed to the following operating modes
Standby	< 150 $\mu$ A	Fully active	No load current flowing for predetermined time	Load activity
Ship	< 40 $\mu$ A	Not active	Protected SMBus or SPI command	SMBus or SPI becomes active
Extreme cell undervoltage	< 1 $\mu$ A	Not active (precharge enabled)	Enabled when $V_{cell} < ECUV$	$V_{cell}$ charge above ECUV recovery threshold (2.7 V/cell typical)

### OPERATION

The bq78PL114 battery management controller serves as the master controller for a Li-Ion battery system consisting of up to 12 cells in series. Any number may be connected in parallel; other system or safety issues limit the number of parallel cells. The bq78PL114 provides extraordinarily precise state-of-charge gas gauging along with first and second level pack safety functions. Voltage and current measurements are performed synchronously and simultaneously for **all** cells in the system, allowing a level of precision not previously possible

in battery management. Temperature is measured by up to four additional external temperature sensors, for a total of five independent measurement points. (Additional cell temperature sensors are available in remote bq76PL102 dual-cell battery monitors.) Coulomb counting is captured continuously by a dedicated 18-bit integrating delta-sigma ADC in the bq78PL114. The CPU in the bq78PL114 is also responsible for system data calculations, black-box forensic data storage, and communicating parameters via the SMBus or SPI interface.

### PowerLAN Communication Link

PowerLAN technology is Texas Instruments' patented serial network and protocol designed specifically for battery management in a multicell system environment. The PowerLAN link is used to initiate and report measurements of cell voltage and temperature, and control cell balancing. The bq78PL114 serves as the master controller of the PowerLAN link and can interface to multiple bq76PL102 dual-cell battery monitors, which measure and balance additional cells. The bq78PL114 monitors the first three or four cells, and bq76PL102s can be added to monitor more series cells.

The PowerLAN link isolates voltages from adjacent bq76PL102 devices to permit high-voltage stack assembly without compromising precision and accuracy. The PowerLAN link is expandable to support up to 12 cells in series. Each bq76PL102 handles voltage and temperature measurements, as well as balancing for two cells. The PowerLAN link provides high ESD tolerance and high immunity to noise generated by nearby digital circuitry or switching currents. Each bq76PL102 has both a PowerLAN input and PowerLAN output: Received data is buffered and retransmitted, permitting high numbers of nodes without loss of signal fidelity. Signals are capacitor-coupled between nodes, providing dc isolation.

### Safety

Unique in the battery-management controller market, the bq78PL114 simultaneously measures voltage and current using independent and highly accurate delta-sigma ADCs. This technique removes virtually all systemic noise from measurements, which are made during all modes of battery operation: charge, discharge, and rest. The bq78PL114 also directs all connected bq76PL102 dual-cell battery monitors to measure each cell voltage simultaneously with the bq78PL114 measurements. Battery impedance and self-discharge characteristics are thus measured with an unprecedented level of accuracy in real time. The bq78PL114 applies this precise information to SmartSafety algorithms to detect certain anomalies and conditions which may be indicative of internal cell faults, before they become serious problems.

The bq78PL114 uses its enhanced measurement system to detect system faults including cell under- and overvoltage, cell under- and overtemperature, system overvoltage, and system overcurrent. First-level safety algorithms first attempt to open the MOSFET safety switches. If this fails, second-level safety algorithms activate the SPROT output, normally used to open a fuse and provide permanent, hard protection for the systems. External MOSFET control inputs with programmable polarity can also be used to operate the safety MOSFETs under control of user supplied circuitry. The bq78PL114 continuously monitors these inputs. If any MOSFET fails to open when commanded; the 2<sup>nd</sup> level safety algorithms also activate the SPROT output. All first- and second-level safety algorithms have fully programmable time delays to prevent false triggering.

### Cell Balancing

Patented PowerPump cell balancing technology drastically increases the useful life of battery packs by eliminating the cycle life fade of multi-cell packs due to cell imbalance. PowerPump technology efficiently transfers charge from cell to cell, rather than simply bleeding off charging energy as heat as is typically done with resistive-bleed balancing circuits. Balancing is configurable and may be performed during any battery operational modes: charge, discharge, or rest. Compared to resistive bleed balancing, virtually no energy is lost as heat. The actual balance current is externally scalable and can range from 10 mA to 1 A (100 mA typical) depending on component selection and system or cell requirements.

A variety of techniques, such as simple terminal voltage, terminal voltage corrected for impedance and temperature effects, or state-of-charge balancing, is easily implemented by the bq78PL114. In some cases, chemistry-specific algorithms are available. By tracking the balancing required by individual cells, overall battery safety is enhanced, often allowing early detection of soft shorts or other cell failures. Balancing is achieved between all cells within the pack as dynamically determined by the bq78PL114.

## Outputs

### **Charge Control**

The CHG and PRE outputs are ordinarily used to drive MOSFET transistors controlling charge to the cell stack. Charge or precharge mode is selected based on the present cell voltage compared to the user-definable cell precharge, undervoltage, and temperature thresholds. When below these limits, the PRE signal is active and the CHG signal is inactive. This turns on the precharge MOSFET and is used to charge a depleted system through a current-limiting series resistor. When all cell voltages are above the limit and the temperature is above the charge temperature minimum, then the CHG output also becomes active and enables the charge MOSFET to turn on, providing a high-current path between charger and battery cells.

The CHG and PRE MOSFET control outputs are both disabled (low) when any cell reaches the safety cutoff limit or temperature threshold. During active charging modes (and above cell voltage thresholds), the discharge MOSFET is also enabled to avoid excessive heating of the body diode. Similarly, the charge MOSFET is active during discharge, provided current flow is in the correct direction and no safety violations are present.

The CHG and PRE outputs are intended to drive buffer transistors acting as inverting level shifters.

### **Discharge Control**

The DSG output operates similarly to control-system discharging. It is enabled (high) by default. If a cell voltage falls below a programmable threshold, or excessive current or other safety related fault is sensed, the DSG output is disabled (low) to prevent damage to the cells.

All facets of safely charging and discharging the cell stack are controlled by user-definable parameters which provide precise control over MOSFET states. Both system and cell over- and undervoltage limits are provided, as well as programmable hysteresis to prevent oscillation. Temperature and current thresholds are also provided, each with independent timers to prevent nuisance activations.

### **LEDEN**

LEDEN is a dual-function pin. One function is to provide output current to the LED display array. It also serves as an input that monitors for closure of a state-of-charge indicator (SOCi) push-button switch.

### **LED SOCi Outputs**

LED1–LED5 are current-sinking outputs designed to drive low-current LEDs. The LEDs can be activated by the LEDEN pin via a pushbutton switch. They can be configured (using SBS parameters) to operate in bar or dot mode and to use three to five LEDs to represent state-of-charge information.

## Inputs

### **Current Measurement**

Current is monitored by four separate ADCs. All use the same very low-value sense resistor, typically either 5 or 10 milliohms in series with the pack negative connection. CCBAT and CCPACK connections to the sense resistor use an R/C filter for noise reduction. (CSBAT and CSPACK are direct connections used for secondary safety.) It is possible to use even lower values for the sense resistor in very high-current designs by employing external circuitry. Contact Texas Instruments directly for details.

A 14-bit delta-sigma ADC is used to measure current flow accurately in both directions. The measurements are taken simultaneously and synchronously with all the cell voltage measurements, even those cells measured by bq76PL102 dual-cell battery monitors.

### **Coulomb Counting**

A dedicated coulomb counter is used to measure charge flow with 18 bit precision in both directions by a calibrated, integrating delta-sigma ADC. This allows the bq78PL114 to keep very accurate state-of-charge (SOC) information and battery statistics. A small deadband is applied to further reduce noise effects. The coulomb counter is unique in that it continues to accumulate (integrate) current flow in either direction even as the rest of the internal microcontroller is placed in a very low power state, further lowering power consumption without compromising system accuracy.

### **Safety Current**

Two additional ADCs are used to directly monitor for overcurrent or short-circuit current conditions, independently of the internal function. This provides a direct and rapid response to insure pack integrity and safe operation by opening the appropriate MOSFETs. These functions are implemented in hardware, and do not require firmware for functionality.

### **Voltage Measurement**

Voltage measurement is performed by four independent delta-sigma ADCs which operate simultaneously and are triggered synchronously so that all voltages are read at precisely the same moment. The bq78PL114 coordinates the attached bq76PL102 dual-cell battery monitors so they also perform their cell voltage measurements in sync with the bq78PL114 voltage and current measurements. Voltage measurements are converted with better than 1 mV of resolution, providing superior accuracy. One-ADC-per-cell technology means that voltage is also measured simultaneously with current, permitting accurate, real-time cell impedance calculation during all operating conditions. This technique also provides greatly enhanced noise immunity and filtering of the input signal without signal loss.

### **Temperature Measurement**

XT1–XT4 are dedicated temperature inputs. Each external sensor consists of a low-cost silicon diode (dual diode in one package is recommended) and capacitor combination. XT1, multiplexed with the LED1 and LED2 inputs, is used to measure cells 1 and 3. XT2, multiplexed with the LED1 and LED2 inputs, is used to measure cells 2 and 4. XT3 is a dedicated IC-temperature sensor, which should be placed near the bq78PL114 IC. XT4 is dedicated to protection-MOSFET temperature and governed by safety rules. The sensor attached to XT4 should be placed near the pack-disconnect MOSFETs. Temperatures for cells 5 and above are measured by external bq76PL102(s), and the temperature data is received by the bq78PL114 over the PowerLAN link for processing. The bq78PL114 can report all of these temperatures individually and as an average. A single internal, integrated silicon sensor is also supplied in the bq78PL114.

Note that additional external temperature sensors can be added using bq76PL102 dual-cell battery monitors operating on the PowerLAN link. Each bq76PL102 contains one internal temperature monitor and two additional external temperature-sensor inputs (in addition to the two cell-voltage measurements and cell balancing).

### **EFCIx**

The external MOSFET control inputs are for user control of MOSFETs based on external circuitry and conditions. The polarity of the input signal is user programmable. Two modes of operation are possible. The first mode is used to implement additional hardware safety inputs, and is used to force the protection MOSFETs to an OFF state. The polarity of the input signals is programmable. The inputs can also be used to control the MOSFETs directly through hardware, with no firmware operation required.

## **COMMUNICATIONS**

### **SMBus**

The bq78PL114 uses the industry-standard Smart Battery System's two-wire System Management Bus (SMBus) communications protocol for all external communication. SMBus version 2.0 is supported by the bq78PL114, and includes clock stretching, bus fault time-out detection, and optional packet error checking (PEC). For additional information, see the [www.smbus.org](http://www.smbus.org) and [www.sbs-forum.org](http://www.sbs-forum.org) Web sites.

### **SPI**

The bq78PL114 provides a standard serial peripheral interface (SPI) port consisting of SELECT, SPI-DI, SPI-DO, and SPI-CLK signals. This port may be operated as a master or slave SPI port. A typical system configuration uses the bq78PL114 as a SPI slave device so that a host controller could access the various battery data using the industry-standard Smart Battery Data specification for content.

Alternatively, the SPI port may be operated as a master to allow the bq78PL114 to write selected system data to another device for use in an autonomous application.

Contact Texas Instruments for additional SPI options and details.

### Smart Battery Data (SBData)

The data content and formatting of the bq78PL114 information conforms to the Smart Battery System's (SBS) Smart Battery Data specification, version 1.1. See the SBS/SMBus site at [www.sbs-forum.com](http://www.sbs-forum.com) for further information regarding these specifications.

This SBS Data (SBData) specification defines read/write commands for accessing data commonly required in laptop computer applications. The commands are generic enough to be useful in most applications.

Because the bq78PL114 provides a wealth of control and battery information beyond the SBData standard, new command codes have been defined by Texas Instruments. In addition, new battery data features, such as state-of-health, use newly defined extended SBData command codes. Standard SMBus protocols are used, although additional data values beyond those defined by the Smart Battery Data specification are employed. (For example, the bq78PL114 typically is used in a multicell battery system and may report individual cell voltages for up to 12 cells. The SBData command set only defines four cell-voltage registers.)

**SBS Standard Data Parameter List (Abridged)<sup>(1) (2)</sup>**

Command	Data Type	Description
00	R/W word (unsigned)	Manufacturer Access
01	R/W word (unsigned)	Remaining Capacity Alarm Level
02	R/W word (unsigned)	Remaining Time Alarm Level
03	R/W word (unsigned)	Battery Mode
04	R/W word (unsigned)	At Rate value used in AtRate calculations
05	Read word (unsigned)	At Rate Time to Full
06	Read word (unsigned)	At Rate Time to Empty
07	Read word (Boolean)	At Rate OK
08	Read word (unsigned)	Pack Temperature (maximum of all individual cells)
09	Read word (unsigned)	Pack Voltage (sum of individual cell readings)
0A	Read word (unsigned)	Pack Current
0B	Read word (unsigned)	Average Pack Current
0C	Read word (unsigned)	Max Error
0D	Read word (unsigned)	Relative State of Charge
0E	Read word (unsigned)	Absolute State of Charge
0F	Read word (unsigned)	Remaining Pack Capacity
10	Read word (unsigned)	Full Charge Capacity
11	Read word (unsigned)	Run Time to Empty
12	Read word (unsigned)	Average Time to Empty
13	Read word (unsigned)	Average Time to Full
14	Read word (unsigned)	Charging Current
15	Read word (unsigned)	Charging Voltage
16	Read word (unsigned)	Battery Status
17	Read word (unsigned)	Cycle Count
18	Read word (unsigned)	Design Capacity
19	Read word (unsigned)	Design Voltage
1A	Read word (unsigned)	Specification Information
1B	Read word (unsigned)	Manufacture Date
1C	Read word (unsigned)	Serial Number
1D–1F	Reserved	
20	Read block (string)	Pack Manufacturer Name (31 characters maximum)
21	Read block (string)	Pack Device Name (31 characters maximum)
22	Read block (string)	Pack Chemistry
23	Read block (string)	Manufacturer Data
24–2E	Reserved	
2F	R/W Block	Optional Manufacturer Function 5
30–3B	Reserved	
3C	R/W word (unsigned)	Optional Manufacturer Function 4 (Vcell 4)
3D	R/W word (unsigned)	Optional Manufacturer Function 3 (Vcell 3)
3E	R/W word (unsigned)	Optional Manufacturer Function 2 (Vcell 2)
3F	R/W word (unsigned)	Optional Manufacturer Function 1 (Vcell 1)
40–45	Unused	
46–47	Reserved	
48–4F	Unused	
50–55	Reserved	

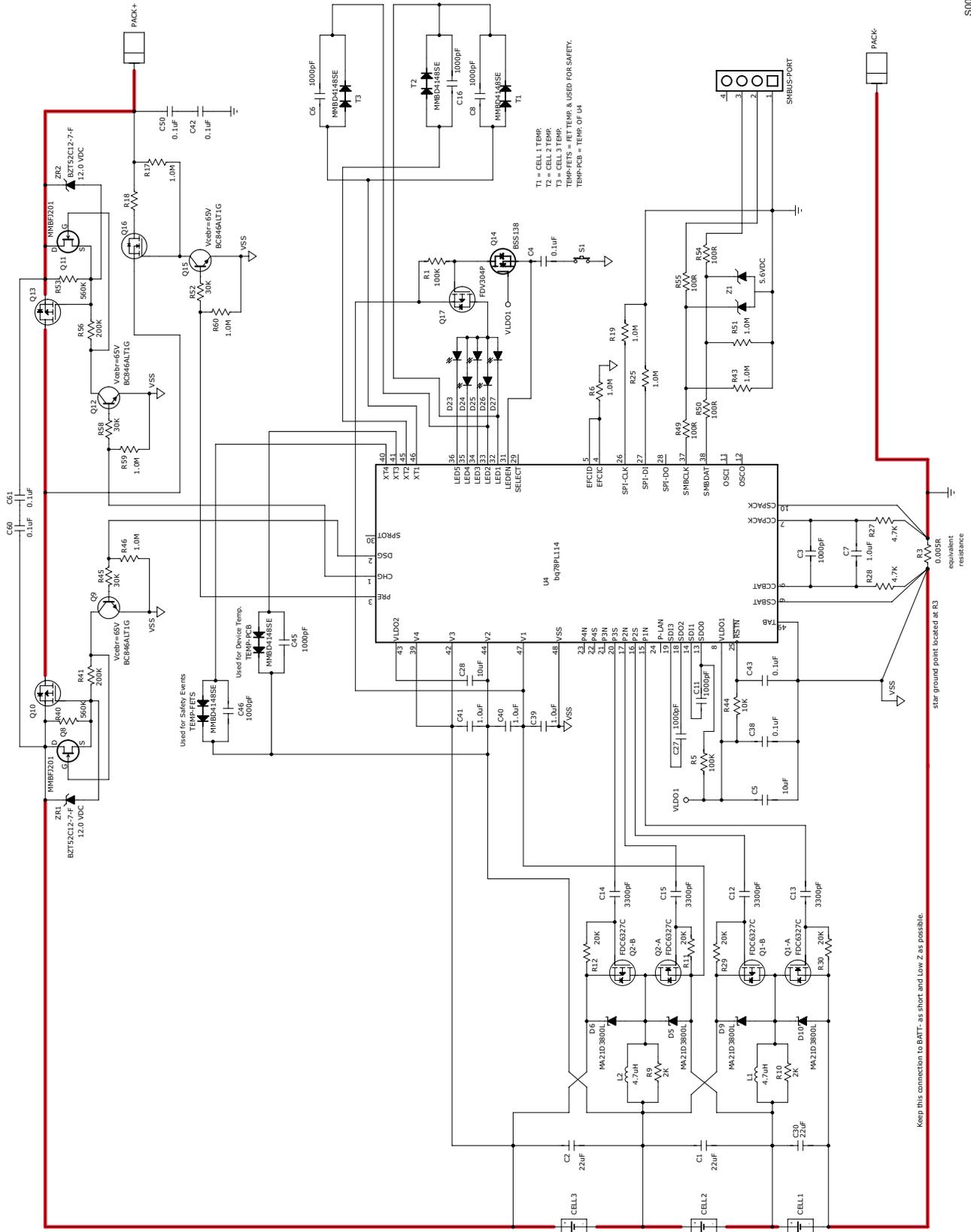
(1) Parameters 0x00–0x3F are compatible with the SBDATA specification.

(2) By default, the bq78PL114 initially responds to the SBData slave address <0001 011R/W> (0x16, 0x17).

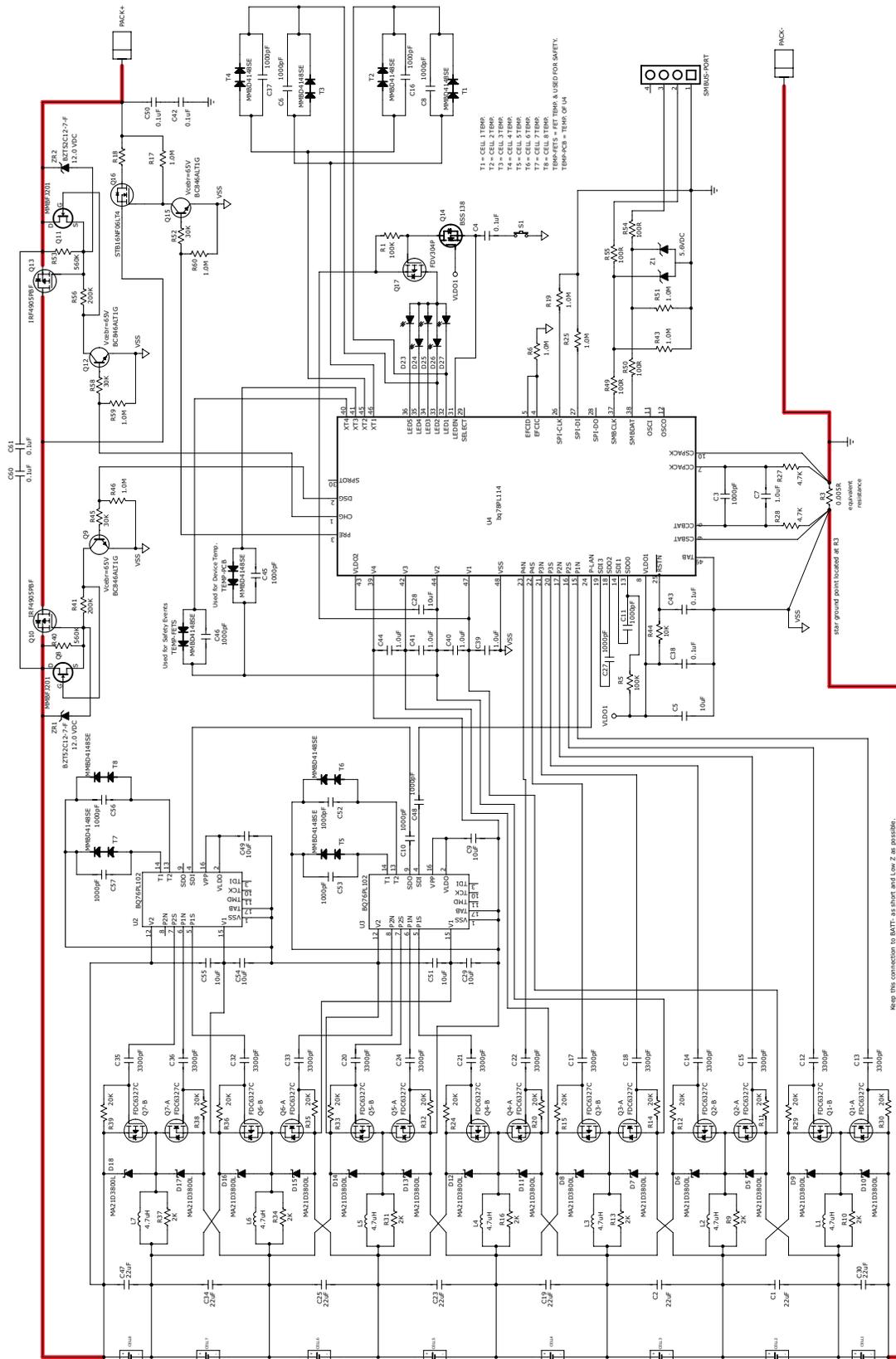
<b>Command</b>	<b>Data Type</b>	<b>Description</b>
56–57	Unused	
58–5A	Reserved	
5B–5F	Unused	
60–62	Reserved	
63–6F	Unused	
70	Reserved	
71–FF	Unused	

REFERENCE SCHEMATIC (3 Series Cells)

S001



REFERENCE SCHEMATIC (8 Series Cells)



S002

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
BQ78PL114RGZR	ACTIVE	QFN	RGZ	48	2500	TBD	Call TI	Call TI
BQ78PL114RGZT	ACTIVE	QFN	RGZ	48	250	TBD	Call TI	Call TI

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBsolete:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

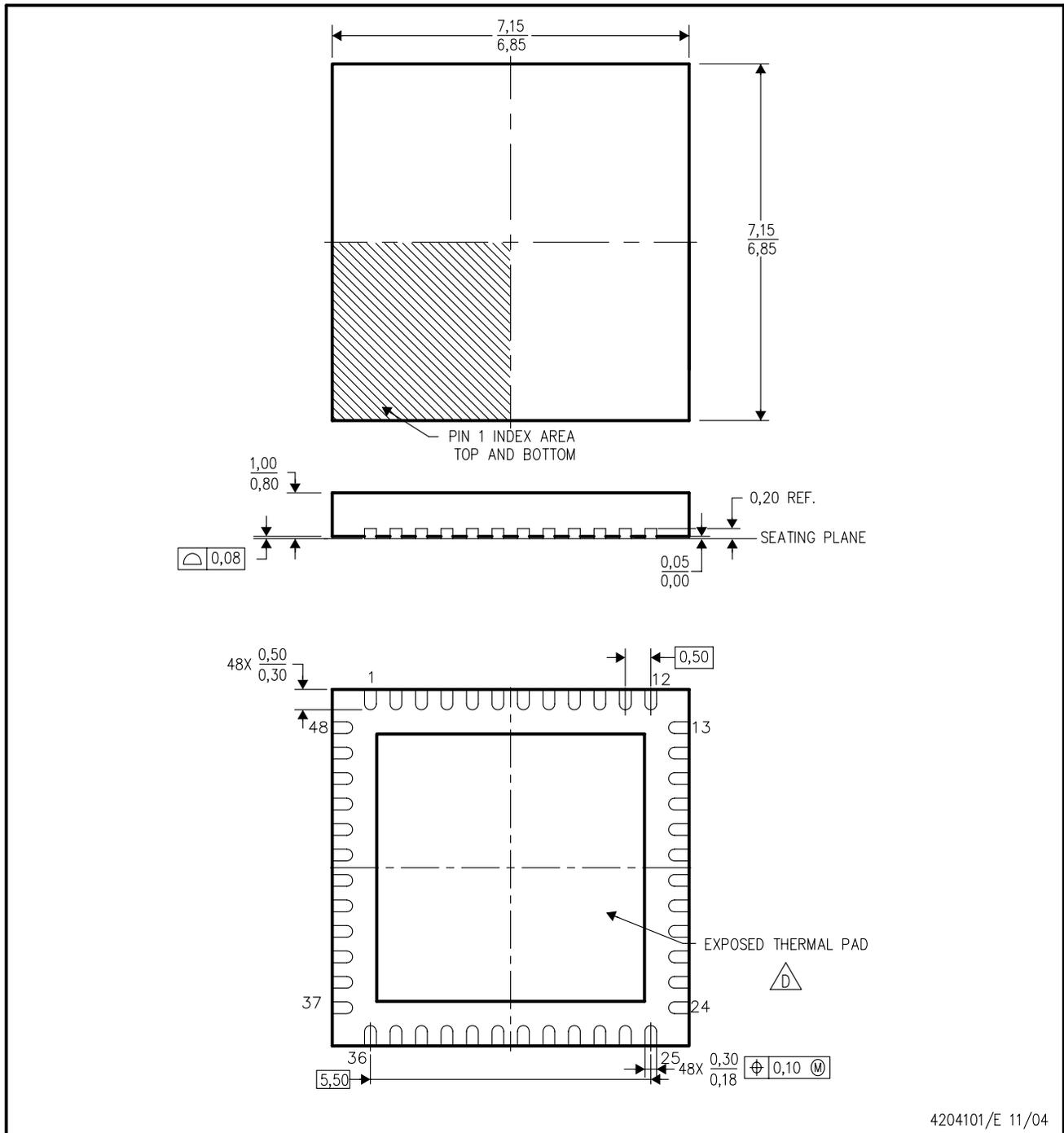
<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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RGZ (S-PQFP-N48)

PLASTIC QUAD FLATPACK



4204101/E 11/04

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - B. This drawing is subject to change without notice.
  - C. Quad Flatpack, No-leads (QFN) package configuration.
  -  The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
  - E. Falls within JEDEC MO-220.

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