Not Recommended for New Designs

Single Chip 3 or 4 Cell Li-Ion Battery Management Controller With PowerPump™ Cell Balancing Technology

FEATURES

- **Advanced SmartSafety™**
  - **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™ Active Cell Balancing Results 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 Δ-Σ A/Ds: 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 μA Active, < 150 μA Standby, < 40 μA Ship, and < 1 A Under-Voltage Shutdown**
- **Accurate, Advanced Temperature Monitoring of Cells and MOSFETs With up to 13 Sensors**
- **Fully Programmable Voltage, Current, Balance and Temperature Protection Features**
- **Cell Balancing Transfers Charge Efficiently From Cell to Cell During all Operating Conditions**
- **Fail-Safe Operation of Pack Protection Circuits and MOSFETs**
- **Designed for 3 to 4 Series Cell Battery Packs**
- **Smart Battery System 1.1 Compliant**
- **Integrated Support for Intel™ AMPS**
- **Field Upgradeable Flash Memory**

APPLICATIONS

- **Notebook Computer Battery Packs**
- **Portable Medical Equipment**
- **Portable Test Equipment**

DESCRIPTION

The bq6400 Battery Management Controller is a complete Li-Ion control, monitoring, and safety solution designed for notebook computers and portable equipment. It is designed specifically to provide an enhanced, optimized solution for packs using three or four series cells.

The bq6400 provides accurate gas gauging while providing control, communications and safety functions for the system. It provides simultaneous, synchronized voltage and temperature measurements using one A/D per-cell technology. Voltage measurements are also simultaneous 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 loads.

PowerPump™ technology transfers charge between cells to balance their voltage and capacity. Balancing is programmable 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 cell cycle life.

Temperature is sensed by one internal and *up to 12 external sensors*. This permits accurate temperature monitoring of each cell individually as well as pack protection MOSFETs. Internal firmware is then able to compensate for the temperature induced effects on cell capacity, impedance, and OCV on a cell-by-cell basis, resulting in superior charge/discharge and balancing control.

Support for Intel™ Adaptive Mobile Power System (AMPS) requirements for battery and MOSFET control is built-in. User definable inputs require no external hardware translation logic.

The bq6400 is completely user-configurable with parametric tables in flash memory to suit a variety of cell chemistries, operating conditions, safety control, and data reporting needs. It is easily configured using the supplied *Battery Wizard*™ graphical user interface. The device is fully programmed and requires no algorithm or firmware development.

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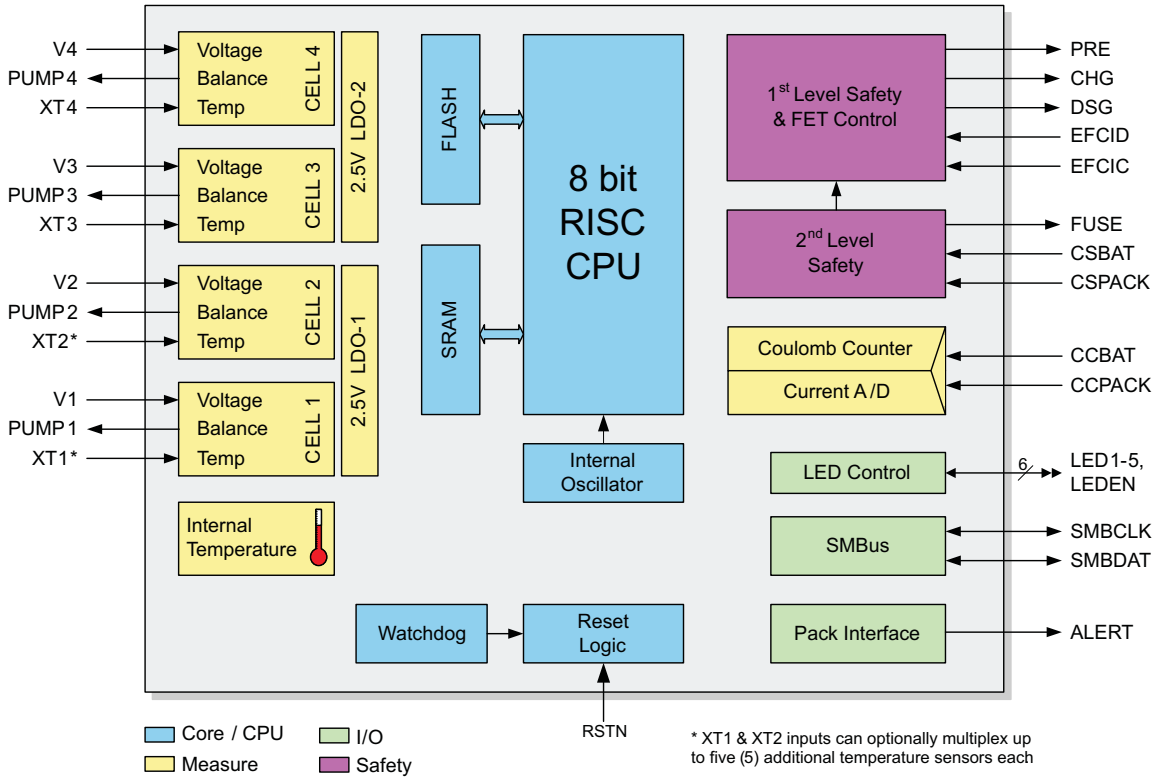
These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

bq6400 BLOCK DIAGRAM



AVAILABLE OPTIONS(1)

PRODUCT	PACKAGE	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	ORDERING NUMBER	TRANSPORT MEDIA QUANTITY
bq6400	QFN-48 7×7mm	RGZ	–40°C to 85°C	bq6400RGZR	Reel

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.

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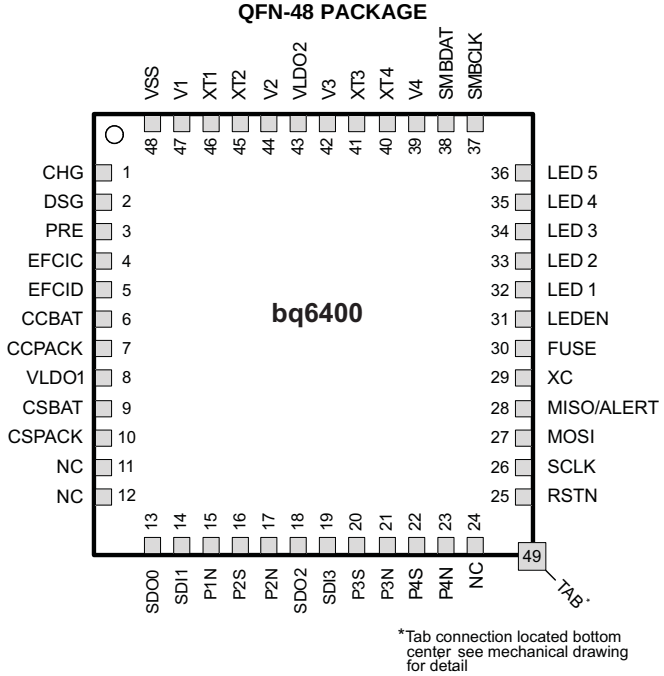
QFN-48 PACKAGE



TERMINAL FUNCTIONS

TERMINAL		I/O(1)	DESCRIPTION
NO.	NAME		
1	CHG	O	Charge MOSFET control (Active high, enables current flow.)
2	DSG	O	Discharge MOSFET Control (Active high. Low opens MOSFET.)
3	PRE	O	Pre-Charge MOSFET control (Active high.)
4	EFCIC	I	External Charge FET Control, Intel™ AMPS compatible input
5	EFCID	I	External Discharge FET Control, Intel™AMPS compatible input
6	CCBAT	IA	Coulomb counter input (sense resistor), connect to battery negative
7	CCPACK	IA	Coulomb counter input (sense resistor), connect to pack negative
8	VLDO1	P	Internal LDO-1 output, bypass with capacitor
9	CSBAT	IA	Current sense input (safety), connect to battery negative
10	CSPACK	IA	Current sense input (safety), connect to pack negative
11	N/C	–	Do not connect to this pin
12	N/C	–	Do not connect to this pin
13	SDO0	O	Requires 100kΩ pull-up resistor to VLDO1
14	SDI1	I	Connect to SDO0 via a capacitor
15	P1N	O	Charge balance gate drive, cell 1 North
16	P2S	O	Charge balance gate drive, cell 2 South
17	P2N	O	Charge balance gate drive, cell 2 North
18	SDO2	O	Connect to SDI3 via capacitor
19	SDI3	I	Connect to SDO2 via capacitor
20	P3S	O	Charge balance gate drive, cell 3 South
21	P3N	O	Charge balance gate drive, cell 3 North
22	P4S	O	Charge balance gate drive, cell 4 South
23	P4N	O	Charge balance gate drive, cell 4 North
24	N/C	–	Do not connect to this pin
25	RSTN	I	Device reset, active low

(1) I – input, IA – analog input, O – output, OA – analog output, OD – open drain output, p – power

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TERMINAL FUNCTIONS (continued)

TERMINAL		I/O(1)	DESCRIPTION
NO.	NAME		
26	SCLK	–	Do not connect to this pin
27	MOSI	I	Do not connect to this pin
28	MISO/ALERT	O	Optional ALERT output – asserted low on alarm condition (interrupt)
29	XC	O	Aux control
30	FUSE	O	Safety fuse control output, active high
31	LEDEN	O	LED common anode drive (hi), Aux Temp(n) input enable (low)
32	LED1	IO	SOCi LED drive (active low), Aux Temp input
33	LED2	IO	SOCi LED drive (active low), Aux Temp input
34	LED3	IO	SOCi LED drive (active low), Aux Temp input
35	LED4	IO	SOCi LED drive (active low), Aux Temp input
36	LED5	IO	SOCi LED drive (active low), Aux Temp input
37	SMBCLK	IO	SMBus clock signal
38	SMBDAT	IO	SMBus data signal
39	V4	IA	Cell 4 positive input
40	XT4	IA	External temperature sensor 4 input
41	XT3	IA	External temperature sensor 3 input
42	V3	IA	Cell 3 positive input
43	VLDO2	P	Internal LDO-2 output, bypass with capacitor
44	V2	IA	Cell 2 positive input
45	XT2	IA	External temperature sensor 2 input / mux temp input 2
46	XT1	IA	External temperature sensor 1 input / mux temp input 1
47	V1	IA	Cell 1 positive input
48	VSS	IA	Cell 1 negative input
TAB	TAB	P	Connect to VSS

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ABSOLUTE MAXIMUM RATINGS(1)

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

		RANGE	UNITS
T_A	Operating free-air temperature (ambient)	–40 to 85	°C
$T_{STORAGE}$	Storage temperature	–65 to 150	°C
V4-V3	Max cell voltage	–0.5 to 5.0	V
V3-V2	Max cell voltage	–0.5 to 5.0	V
V2-V1	Max cell voltage	–0.5 to 5.0	V
V1-VSS	Max cell voltage	–0.5 to 5.0	V
Voltage on LED_{1-5}	With respect to VSS	0.5 to 5.0	V
Voltage on CCBAT, CCPACK, CSBAT, CSPACK, XT1, XT2,SDI_X, SDO_X, LEDEN, FUSE	Max voltage on any I/O pin	(VSS – 0.5) to (VLDO1 + 0.5)	V
Voltage on XT3, XT4	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, ALERT	With respect to VSS	–0.5 to 6.0V	V
Voltage on PRE, CHG, DSG	With respect to VSS	–0.5 to (VLDO1 + 0.5)	V
Current through PRE, CHG, DSG, LEDEN, LED_{1-5}	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 Ω, C=100 pF	2	kV
Lead Temperature Soldering	Total time < 3 seconds	< 300	°C

(1) Stresses or conditions in excess of those listed may cause permanent damage to the device. Exposure to these conditions for prolonged periods may adversely affect device reliability. These ratings are provided for reference only, and not meant to imply functional operation at these maxima or other circumstances beyond those indicated under recommended operating conditions.

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ELECTRICAL CHARACTERISTICS

T_A = –40°C to 85°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
DC CHARACTERISTICS						
V_{CELL} (1)	Operating range	Cells balanced	2.3		4.5	V
I_{DD}	Operating mode current	Measure / report state		250		µA
I_{STBY}	Standby mode current	SMBCLK = SMBDAT = L		150		µA
I_{SHIP}	Ship mode current			40		µA
I_{ECUV} (2)	Extreme cell under voltage shutdown current	All cells < 2.7 V and any cell < ECUV setpoint			1.0	µA
V_{OL}	General I/O pins	I_{OL} < 4.0 mA	0		0.5	V
V_{OH} (3)		I_{OH} < –4.0 mA	V_{LDO1}–0.10			
V_{IL}					V_{LDO1}× 0.25	
V_{IH}			V_{LDO1}× 0.75			
VOLTAGE MEASUREMENT CHARACTERISTICS						
	Measurement range		2.500		4.500	V
	Resolution			<1		mV
	Accuracy			±3		mV
CURRENT SENSE CHARACTERISTICS						
	Measurement range (4)		–0.100		0.100	V
	Input Offset			±50		µV
	Resolution			10		µV
	Accuracy (5)			±10 µV ±0.1% of reading		µV
COULOMB COUNTER CHARACTERISTICS (6) (7)						
	Resolution	Default range		2.8 (8)		nVh
	Integral non-linearity			0.008%		
	Snap-to-Zero (deadband)			±30 (9)		µV

(1) Device remains operational to 1.85 V with reduced accuracy and performance.
(2) All cells at 2.3V at 25°C.
(3) Does not apply to SMBus pins
(4) Default range. Corresponds to ±10A using a 10mΩ sense resistor. Other gains and ranges available (8 options).
(5) After calibration. Accuracy is dependent on system calibration and temperature coefficient of sense resistor.
(6) Shares common inputs with *Current Sense* section.
(7) After calibration. Accuracy is dependent on system calibration and temperature coefficient of sense resistor.
(8) Corresponds to 0.0003mAh using 10mΩ sense resistor.
(9) Corresponds to 3mA using 10mΩ sense resistor.

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ELECTRICAL CHARACTERISTICS (Continued)

T_A = –40°C to 85°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
CURRENT SENSE (SAFETY) CHARACTERISTICS(1)						
	Measurement Range – Gain 1		–0.650		0.650	V
	Resolution (short circuit detection)			20		mV
	Resolution (over-current detection, charge and discharge)			2.5		mV
	Measurement Range – Gain 2		–0.325		0.325	V
	Resolution (Short circuit detection)			10		mV
	Resolution (over-current detection, charge and discharge)			1.25		mV
INTERNAL TEMPERATURE SENSOR CHARACTERISTICS						
	Measurement Range		–30		85	°C
	Resolution			0.1		°C
	Accuracy (after calibration)	T_A = –30°C to 85°C		1		°C
EXTERNAL TEMPERATURE SENSOR(s) TYPICAL CHARACTERISTICS(2)						
	Measurement Range(3)		–40		90	°C
	Resolution			0.2		°C
	Accuracy(4)	T_A = 25°C		±1		°C
		T_A = 0°C to 85°C		±2		
SMBus CHARACTERISTICS(5)						
V_{IL}	Input low voltage		0		0.8	V
V_{IH}	Input high voltage		2.1		5.5	V
V_{OL}(6)	Output low voltage	350 µA sink current	0		0.4	V
C_I	Capacitance each I/O pin				10	pF
F_{SCL}	SCLK nominal clock frequency	T_A = 25°C		100		kHz
R_{PU}(7)	Pull-up resistors for SCLK, SDATA	V_{BUS} 5V nominal	13.3		15.3	kΩ
		V_{BUS} 3V nominal	2.4		6.8	

(1) Post calibration: Dependent on calibration and temperature coefficient of sense resistor. Uncertainty 1.5 LSB.
(2) Typical for dual diode (MMBD4148 or equivalent) external sensor using recommended circuit.
(3) Range of diode sensors may exceed operational limits of IC and battery cells.
(4) Typical behavior after calibration, final result dependent on specific component characteristics.
(5) SMBus timing and signals meet the SMBus 2.0 specification requirements under normal operating conditions. All signals are measured with respect to PACK-Negative.
(6) Parameter not tested in production.
(7) Pull-ups are typically implemented external to battery pack, and are selected to meet SMBus requirements.

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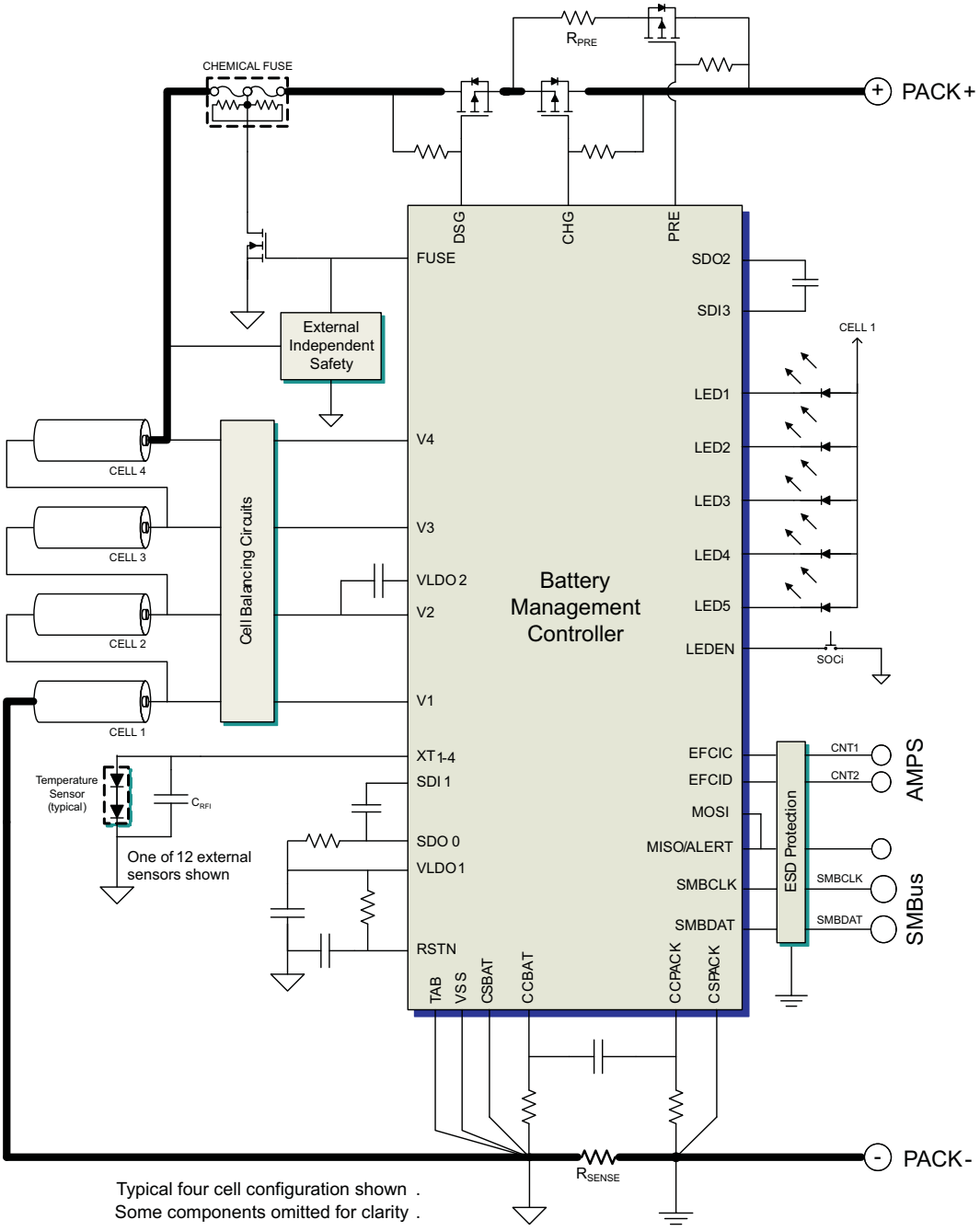

Figure 1. bq6400 Simplified Example Circuit Diagram

FEATURE SET

Primary (1st Level) Safety Features

The bq6400 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/under voltage protection
- Battery pack over/under voltage protection

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- Charge and discharge over-current protection
- Short circuit protection
- Intel™ AMPS compatible external MOSFET control inputs
- One internal temperature sensor
- External MOSFET Control Inputs (EFCIx) with programmable polarity
- Up to twelve (12) external temperature inputs for accurate cell and MOSFET monitoring
- Watchdog timer protection
- Unconnected FUSE drive output
- Brownout detection and protection against extreme pack under voltage

Secondary (2nd Level) Safety Features

The bq6400 can detect more serious system faults and activate the FUSE 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, rate of change, etc.)
  - Disconnected cell voltage inputs
  - Cell imbalance exceeds safety limit
  - Impedance rise due to cell or weld strap fault
- MOSFET failure or loss of MOSFET control
- Safety over-voltage, pack and cell
- Safety over-temperature, limits for both charge and discharge
- Safety over-current, 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 tracked 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 FET control
- Programmable, chemistry-specific parameters
- Fault reporting

Fuel Gauging

- The bq6400 accurately reports battery cell and pack state-of-charge (SOC), with greater than 1% precision. No full charge/discharge cycle is required for accurate reporting.
- State-Of-Charge is reported via SMBus and available via LED display. Data available in Amp-hours and Watt-hours.
- 18-bit Integrating Delta-Sigma A/D Coulomb Counter, with programmable snap-to-zero value.

LED Display

- The bq6400 drives a three to five segment LED display in response to a push-button (LEDEN) input signal. Each LED pin can sink up to 10 mA.

Lifetime Data Logging (readable via SMBus)

- Recording of faults, events, anomalies, min and max values

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- Maximum/minimum cell temperature
- Maximum/minimum pack voltage
- Maximum/minimum cell voltages
- Maximum discharge power

Forensic Data Logging (Readable via SMBus)

- Last known full capacity of the battery
- Capacity (or SOC) at the time of failure
- Cycle count and/or cumulative number of Ah delivered by the battery
- Battery pack status; being charged, discharged or at rest
- Balancing effort required by each bank of cells to maintain balance
- Cell bank impedance information
- Last ten (10) previous failures causing primary (first level) safety action
- *Degree days* histogram (time that the battery has spent in a temperature range)
- Voltage Hours – Time for each cell measurement spent above/below safety limits
- Forensic data up-loadable to Host CPU via SMBus (see below)
- Forensic data recording of anomalies and events

Power Modes

- **Normal Mode:** The bq6400 performs measurements and calculations, makes decisions, and updates internal data at approximately once per second. *All safety circuitry is fully functional in this mode.*
- **Standby Mode:** The bq6400 performs as in normal mode, but at a reduced measurement rate to lower power consumption at times when the host computer is inactive or the pack is removed from the system. *All safety circuitry remains fully functional in this mode.*
- **Ship Mode:** The bq6400 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 command is issued and then only when the SMBus lines are set to logic low. Exit occurs when the SMBus lines return to an active state.
- **Extreme Cell Under-Voltage (ECUV) Shutdown Mode:** In this mode, the bq6400 draws minimal current and the Charge and Discharge protection MOSFETs are disabled (opened). The Pre-Charge 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 under-voltage conditions (ECUV). The ECUV threshold is fully programmable below 2.7V.

STATE	CURRENT DRAW (TYP)	OVER-CURRENT	ENTRY CONDITION	EXIT CONDITION
Active	< 250 µA	Fully active	Normal operation as determined by firmware	Firmware directed to operating modes below
Standby	< 150 µA	Fully active	No load current flowing for predetermined time	Load activity
Ship	< 40 µA	Not active	Protected SMBus command and SMBus then off (low)	Either SMBus line high
Extreme Cell Under-Voltage	< 1 µA	Not active (Pre-Charge enabled)	Enabled when Vcell < ECUV	Vcell charge above ECUV recovery threshold (2.7V/cell typical)

OPERATION

The bq6400 Battery Management Controller serves as the master controller for a Li-Ion battery system consisting of three or four cells in series. Any number may be connected in parallel; other system or safety issues will limit this to a more practical number. The bq6400 provides extraordinarily precise State-of-Charge gas gauging, and first and second level pack safety functions. Voltage and current measurements are performed synchronously and simultaneously for all cells in the pack allowing a level of precision not previously possible in battery

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management. Temperature is measured by one internal sensor and up to 12 additional multiplexed external temperature sensors, for a total of up to 13 independent measurement points in the pack. Coulomb counting is captured continuously by a dedicated 18-bit integrating Delta-Sigma A/D converter. The bq6400 is also responsible for pack data calculations, black-box forensic data storage and communicating parameters via SMBus to a host processor as the core of a Smart Battery System (SBS).

Safety

Unique in the battery management controller market, the bq6400 simultaneously measures voltage and current using independent and highly accurate Delta-Sigma A/D converters. This technique removes virtually all systemic noise from measurements, which are made during all modes of battery operation – charge, discharge, and rest. Battery impedance and self-discharge characteristics are thus measured with an unprecedented level of accuracy in real-time. The device 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 bq6400 uses its enhanced measurement system to detect pack faults including cell under and over-voltage, cell under and over-temperature, pack over-voltage, and pack over-current, over-charge, and short circuit conditions. First level safety algorithms will first attempt to open the MOSFET safety switches. If this fails, 2nd level safety algorithms will open the in-line chemical fuse and provide permanent, hard protection for the pack and user. External MOSFET control inputs with programmable polarity can also be used to operate the protection MOSFETs under control of user supplied circuitry. The bq6400 continuously monitors these inputs. If the MOSFETs fail to open when commanded, the 2nd level safety algorithms will also activate the fuse. All 1st and 2nd level safety algorithms have programmable time delays to prevent false triggering on noise events.

Cell Balancing

Patented PowerPump™ cell balancing drastically increases the useful life of battery packs by eliminating the cycle life fade of multi-cell packs due to cell imbalance. PowerPump™ efficiently transfers charge from cell to cell, rather than simply bleeding off charging energy as heat the way competitor's circuits using resistive-bleed balancing do. Balancing is configurable and may be performed during any combination of battery operational modes – charge, discharge, and rest. Compared to resistive bleed balancing, virtually no energy is lost as heat. The actual balance current is externally scalable and can range from 10mA to 1A depending on component selection and application or cell requirements.

A variety of techniques, such as voltage or State-Of-Charge balancing, are easily implemented by the bq6400. 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 bq6400.

Outputs

Charge Control

The open drain outputs CHG and PRE are used to drive MOSFET transistors controlling cell stack charging. Charge or Pre-charge mode is selected based on the current cell voltage compared to the user-definable cell pre-charge under-voltage thresholds. When below the limit, or when below the charge temperature minimum, the PRE signal is active and CHG signal is inactive. This turns on the Pre-Charge MOSFET and is used to charge a depleted pack 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 and provide a high current path between the charger and battery cells.

The CHG and PRE MOSFET control outputs are both disabled (low) when a cell reaches any 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 CHG 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 cell stack discharging. It is enabled (high) by default. If either a cell voltage falls below the lower threshold, or excessive current or other safety related fault is sensed, the DSG output is disabled (low) to prevent damage to the cell or pack.

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All facets of safely charging and discharging the cell stack are controlled by user-definable parameters which provide precise control over MOSFET states. Both pack and cell over and under-voltage 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

This pin is multi-purpose: It can provide output current to the LED display array; it can be used as an output to enable multiplexing of eleven external temperature sensors; or it can be a State-of-Charge indicator (SOCi) push-button input. (This pin can also be configured as a general purpose I/O pin.)

LED SOCi Outputs

LED1-5 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 3-5 LEDs to represent State-Of-Charge information.

Inputs

Current Measurement

Current is monitored by four (4) separate A/D converters. All utilize 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 utilize an R/C filter for noise reduction. (CSBAT and CSPACK are direct connections used for secondary safety.)

A 14-bit Delta-Sigma A/D converter is used to accurately measure current flow in both directions. The measurements are taken simultaneously and synchronously with the cell voltage measurements. This value is used for internal calculations, and SMBus reporting.

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 A/D converter. This allows the bq6400 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 A/D converters are used to directly monitor for over current or short-circuit current conditions, independently of the internal microcontroller. This provides a direct and rapid response to insure pack integrity and safe operation.

Voltage Measurement

Voltage measurement is performed by four independent Delta-Sigma A/D converters which operate simultaneously and are triggered synchronously so that all four voltages are read at precisely the same moment. Voltage is converted with better than 1mV of resolution providing superior accuracy. One A/D 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 voltages without signal loss.

Temperature Measurement

Temperature measurement is performed by up to twelve (12) external low cost sensor diodes, and one internal silicon sensor. Each external sensor consists of a low cost silicon diode and capacitor combination. These may be used to monitor individual cell conditions, sense resistor or MOSFET temperatures, or other sources determined by the user. The bq6400 can report all of these temperatures individually, and as an average.

XT1-2 can be used as dedicated inputs, or they can be used as multiplexed inputs providing ten (10) external temperature sensors to the pack designer. In this configuration, the cathodes of five (5) of the sensors are connected to the cathodes of the LED_{1-5} connections. The anodes are connected together and then to XT1. The bq6400 internally multiplexes the LEDEN, LED and XT1 pins to read the temperature sensors using this scheme. Similarly, another five (5) sensors can be connected together and read via the XT2 input.

XT3-4 are dedicated inputs directly connected to the external temperature sensors, providing the eleventh and twelfth external inputs.

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EFCIx

The External FET 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 MOSFETs to an OFF state. The inputs control the MOSFETs directly through hardware, no firmware is used. The second mode of operation is used to implement the Intel™ AMPS interface signals *CNT1* and *CNT2* without additional circuitry.

COMMUNICATIONS

SMBus

The bq6400 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 bq6400, and includes clock stretching, bus fault timeout detection, and optional Packet Error Checking (PEC). For additional information, see the www.smbus.org or www.sbs-forum.org websites.

Smart Battery Data (SBData)

The data content and formatting of the bq6400 information conforms to the Smart Battery System's (SBS) Smart Battery Data specification, version 1.1. The reader is directed to the SBS/SMBus site at 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.

The bq6400 provides a wealth of control and battery information beyond the SBData standard. For the additional data, new command codes have been defined. In addition, new battery data features, such as State-of-Health, use newly defined extended SBData command codes are used.

SBS Standard Data Parameter List (abridged)

1. Parameters 0x00 – 0x3F are compatible with the SBDATA specification.
2. Parameters 0x40 – 0x7F are reserved for compatibility with other manufacturer's assignments
3. Parameters 0x80 – 0xFF are specific for internal use.
4. By default, the bq6400 initially responds to the SBData slave address <0001 011R/W> (0x16, 0x17).

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

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COMMAND	DATA TYPE	DESCRIPTION
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	
56-57	<unused>	
58-5A	Reserved	
5B-5F	<unused>	
60-62	Reserved	
63-6F	<unused>	
70	Reserved	
71-FF	<unused>	

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
BQ6400RGZR	NRND	VQFN	RGZ	48		TBD	Call TI	Call TI			
BQ6400RGZT	NRND	VQFN	RGZ	48		TBD	Call TI	Call TI			

(1) 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.

(2) 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)

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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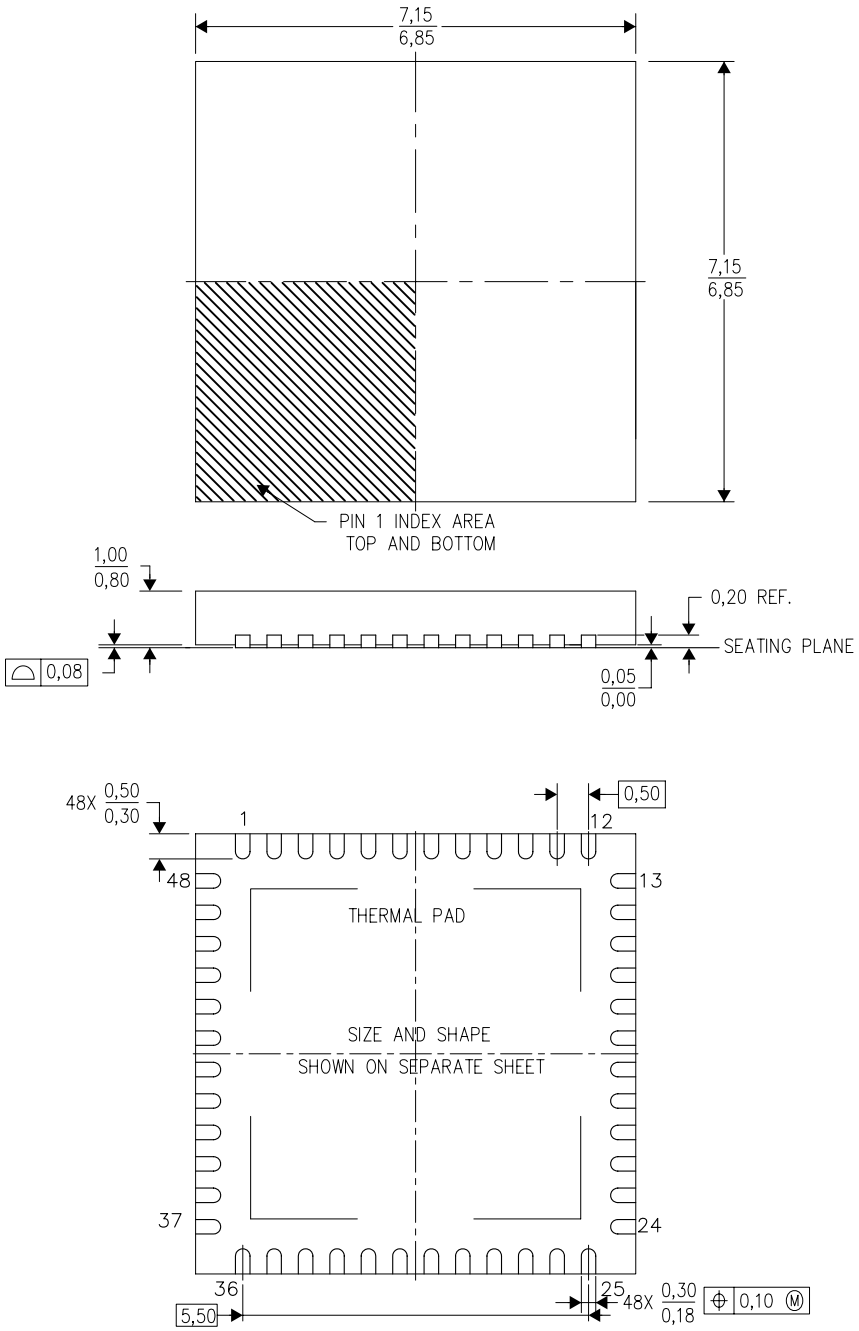
RGZ (S–PVQFN–N48) PLASTIC QUAD FLATPACK NO–LEAD



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.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
F. Falls within JEDEC MO–220.

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