UNITRODE

bq2945

Gas Gauge IC with SMBus Interface

Features

- ➤ Provides accurate measurement of available charge in NiCd, NiMH, and Li-Ion batteries
- ➤ Supports SBS v1.0 data set and two-wire interface
- ➤ Two programmable general purpose output ports for added flexibility
- ➤ Designed for battery pack integration
  - Low operating current
  - Complete circuit can fit on less than ¾ square inch of PCB space
- ➤ Supports SBS charge control commands for NiCd, NiMH, and Li-Ion
- ➤ Drives a five-segment LED display for remaining capacity indication
- ➤ 16-pin narrow SOIC

General Description

The bq2945 Gas Gauge IC With SMBus Interface is intended for battery-pack or in-system installation to maintain an accurate record of available battery charge. The bq2945 directly supports capacity monitoring for NiCd, NiMH, and Li-Ion battery chemistries.

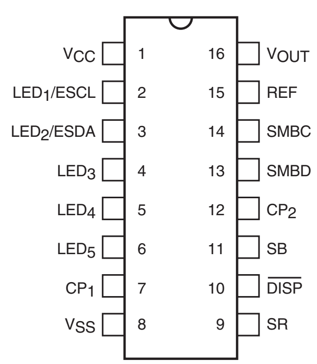
The bq2945 uses the System Management Bus v1.0 (SMBus) protocol and supports the Smart Battery Data (SBData) commands. The bq2945 also supports the SBData charge control functions. Battery state-of-charge, remaining capacity, remaining time, and chemistry are available over the serial link. Battery-charge state can be directly indicated using a five-segment LED display to graphically depict battery full-to-empty in 20% increments.

The bq2945 estimates battery self-discharge based on an internal timer and temperature sensor and user-programmable rate information stored in external EEPROM. The bq2945 also automatically recalibrates or "learns" battery capacity in the full course of a discharge cycle from full to empty.

The bq2945 may operate directly from three nickel chemistry cells. With the REF output and an external transistor, a simple, inexpensive regulator can be built to provide V_{CC} for other battery cell configurations.

An external EEPROM programs initial values into the bq2945 and is necessary for proper operation.

Pin Connections



16-Pin Narrow SOIC

PN294501.eps

Pin Names

V_{CC}	3.0–6.5V	SR	Sense resistor input
LED_1	LED segment 1/ EEPROM clock	$\overline{DISP}$	Display control input
LED_2	LED segment 2/ EEPROM data	SB	Battery sense input
LED_3	LED segment 3	CP_2	Control pin 2
LED_4	LED segment 4	SMBD	SMBus data input/output
LED_5	LED segment 5	SMBC	SMBus clock
CP_1	Control pin 1	REF	Voltage reference output
V_{SS}	System ground	V_{OUT}	EEPROM supply output

6/99 C

Pin Descriptions

V_{CC} **Supply voltage input**

LED_1–LED_5 **LED display segment outputs**

Each output may drive an external LED.

ESCL **Serial memory clock**

Output used to clock the data transfer between the bq2945 and the external nonvolatile configuration memory.

ESDA **Serial memory data and address**

Bidirectional pin used to transfer address and data to and from the bq2945 and the external nonvolitile configuration memory.

CP_1–CP_2 **Control pins 1 and 2**

These open-drain outputs can be controlled by an SMBus command from the host. CP_2 can also act as a digital input.

V_{SS} **Ground**

SR **Sense resistor input**

The voltage drop (V_{SR}) across pins SR and V_{SS} is monitored and integrated over time to interpret charge and discharge activity. The SR input is connected to the sense resistor and the negative terminal of the battery. $V_{SR} < V_{SS}$ indicates discharge, and $V_{SR} > V_{SS}$ indicates charge. The effective voltage drop, V_{SRO}, as seen by the bq2945 is $V_{SR} + V_{OS}$. (See Table 3.)

$\overline{DISP}$ **Display control input**

$\overline{DISP}$ high disables the LED display. $\overline{DISP}$ floating allows the LED display to be active during charge if the rate is greater than 100mA. $\overline{DISP}$ low activates the display for 4 seconds.

SB **Secondary battery input**

Monitors the pack voltage through a high-impedance resistor divider network. The pack voltage is reported in the SBD register function Voltage (0x09) and is monitored for end-of-discharge voltage and charging voltage parameters.

SMBD **SMBus data**

Open-drain bidirectional pin used to transfer address and data to and from the bq2945.

SMBC **SMBus clock**

Open-drain bidirectional pin used to clock the data transfer to and from the bq2945.

REF **Reference output for regulator**

REF provides a reference output for an optional FET-based micro-regulator.

V_{OUT} **Supply output**

Supplies power to the external EEPROM configuration memory.

Functional Description

General Operation

The bq2945 determines battery capacity by monitoring the amount of charge put into or removed from a rechargeable battery. The bq2945 measures discharge and charge currents, estimates self-discharge, and monitors the battery for low-battery voltage thresholds. The charge is measured by monitoring the voltage across a small-value series sense resistor between the battery's negative terminal and ground. The available battery charge is determined by monitoring this voltage over time and correcting the measurement for the environmental and operating conditions.

Figure 1 shows a typical battery pack application of the bq2945 using the LED capacity display, the serial port, and an external EEPROM for battery pack programming information. The bq2945 must be configured and calibrated for the battery-specific information to ensure proper operation. Table 1 outlines the configuration information that must be programmed in the EEROM.

An internal temperature sensor eliminates the need for an external thermistor—reducing cost and components. An internal, temperature-compensated timebase eliminates the need for an external resonator, further reducing cost and components. The entire circuit in Figure 1 can occupy less than ¾ square inch of board space.

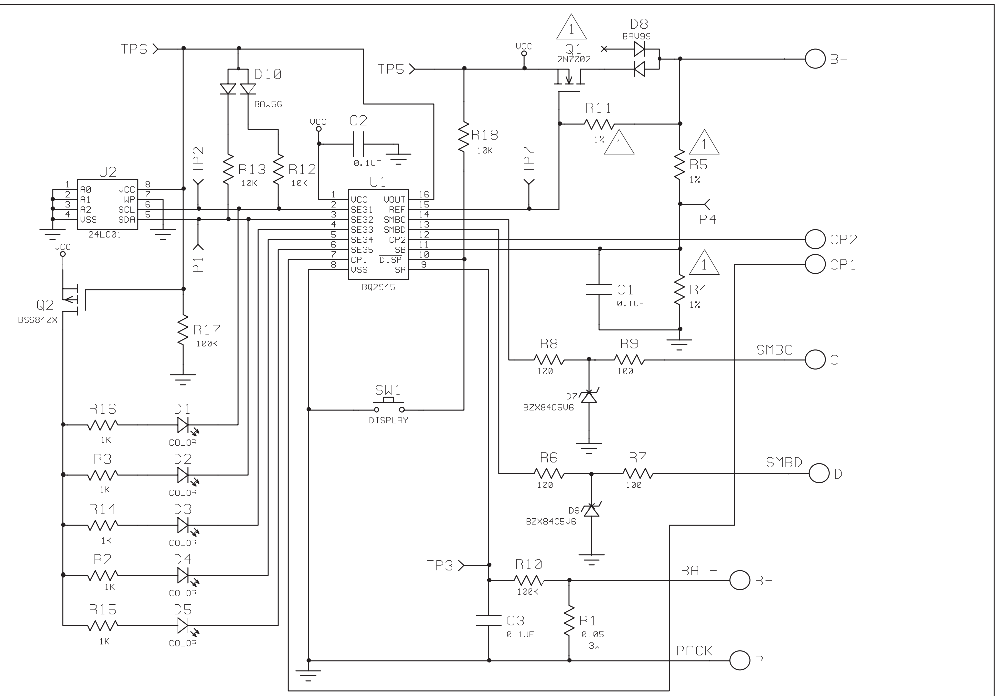


	Chart 1				
	No. of Cells	Q1	R4	R5	R11
Li-Ion	2	BSS138	100K	301K	604K
	3	BSS138	100K	499K	806K
	4	2N7002	100K	698K	604K
NiMH	6	BSS138	100K	499K	499K
	8	BSS138	100K	698K	806K
	9	2N7002	100K	806K	499K
	10	2N7002	100K	909K	604K
	12	2N7002	86.5K	909K	909K

(1) See Chart 1 for resistor values and Q1 FET selection

Notes: R4, R5, and R11 values depend on the battery voltage. R12 and R13 nominal values must be 10k

Figure 1. Battery Pack Application Diagram—LED Display

Table 1. Configuration Memory Map

Parameter Name	Address	Description	Length	Units
EEPROM length	0x00	Number of EEPROM data locations must = 0x64	8 bits	NA
EEPROM check1	0x01	EEPROM data integrity check byte must = 0x5b	8 bits	NA
Remaining time alarm	0x02/0x03	Sets RemainingTimeAlarm (0x02)	16 bits	minutes
Remaining capacity alarm	0x04/0x05	Sets RemainingCapacityAlarm (0x01)	16 bits	mAh
Reserved	0x06/0x07	Reserved for future use	16 bits	NA
Initial charging current	0x08/0x09	Sets the initial charging current	16 bits	mA
Charging voltage	0x0a/0x0b	Sets ChargingVoltage (0x15)	16 bits	mV
Battery status	0x0c/0x0d	Initializes BatteryStatus (0x16)	16 bits	NA
Cycle count	0x0e/0x0f	Initializes and stores CycleCount (0x17)	16 bits	cycles
Design capacity	0x10/0x11	Sets DesignCapacity (0x18)	16 bits	mAh
Design voltage	0x12/0x13	Sets DesignVoltage (0x19)	16 bits	mV
Specification information	0x14/0x15	Programs SpecificationInfo (0x1a)	16 bits	NA
Manufacturer date	0x16/0x17	Programs ManufactureDate (0x1b)	16 bits	NA
Serial number	0x18/0x19	Programs SerialNumber (0x1c)	16 bits	NA
Fast-charging current	0x1a/0x1b	Sets ChargingCurrent (0x14)	16 bits	mA
Maintenance-charge current	0x1c/0x1d	Sets the trickle current request	16 bits	mA
Reserved	0x1e/0x1f	Reserved must = 0x0000	16 bits	mAh
Manufacturer name	0x20-0x2b	Programs ManufacturerName (0x20)	96 bits	NA
Current integration gain	0x2c/0x2d	Programs the sense resistor scale	16 bits	NA
Reserved	0x2e/0x2f	Reserved for future use	16 bits	NA
Device name	0x30-0x37	Programs DeviceName (0x21)	64 bits	NA
Li-Ion taper current	0x38/0x39	Sets the upper limit of the taper current for charge termination	16 bits	mA
Maximum overcharge limit	0x3a/0x3b	Sets the maximum amount of overcharge	16 bits	NA
Reserved	0x3c	Reserved must = 0x00	8 bits	NA
Access protect	0x3d	Locks commands outside of the SBS data set	8 bits	NA
FLAGS1	0x3e	Initializes FLAGS1	8 bits	NA
FLAGS2	0x3f	Initializes FLAGS2	8 bits	NA
Device chemistry	0x40-0x47	Programs DeviceChemistry (0x22)	64 bits	NA
Battery voltage offset	0x48	Voltage calibration value	8 bits	NA
Temperature offset	0x49	Temperature calibration value	8 bits	NA
Maximum temperature and ΔT step	0x4a	Sets the maximum charge temperature and the ΔT step for $\Delta T/\Delta t$ termination	8 bits	NA

Table 1. Configuration Memory Map (Continued)

Parameter Name	Address	Description	Length	Units
Charge efficiency	0x4b	Sets the high/low charge rate efficiencies	8 bits	NA
Full-charge percentage	0x4c	Sets the percent at which the battery is considered fully charged	8 bits	NA
Digitial filter	0x4d	Sets the minimum charge/discharge threshold	8 bits	NA
Reserved	0x4e	Reserved for future use	8 bits	NA
Self-discharge rate	0x4f	Sets the battery's self-discharge rate	8 bits	NA
Manufacturer data	0x50-0x55	Programs ManufacturerData (0x23)	48 bits	NA
Voltage gain1	0x56/0x57	Battery divider calibration value	16 bits	NA
Reserved	0x58-0x59	Reserved	16 bits	NA
Current measurement gain	0x5a/0x5b	Sense resistor calibration value	16 bits	NA
End of discharge voltage1	0x5c/0x5d	Sets EDV1	16 bits	NA
End of discharge voltage final	0x5e/0x5f	Sets EDVF	16 bits	NA
Full-charge capacity	0x60/0x61	Initializes and stores FullChargeCapacity (0x10)	16 bits	mAh
Δt step	0x62	Sets the Δt step for $\Delta T/\Delta t$ termination	8 bits	NA
Hold-off time	0x63	Sets $\Delta T/\Delta t$ hold-off timer	8 bits	NA
EEPROM check 2	0x64	EEPROM data integrity check byte must = 0xb5	8 bits	NA
Reserved	0x65-0x7f	Reserved for future use		NA

Voltage Thresholds

In conjunction with monitoring V_{SR} for charge/discharge currents, the bq2945 monitors the battery potential through the SB pin. The voltage potential is determined through a resistor-divider network per the following equation:

$$\frac{R_5}{R_4} = \frac{MBV}{2.25} - 1$$

where MBV is the maximum battery voltage, R_5 is connected to the positive battery terminal, and R_4 is connected to the negative battery terminal. R_5/R_4 should be rounded to the next higher integer. R_5 and R_4 should be sized so that the voltage at the SB pin (V_{SB}) should never exceed 2.4V.

The battery voltage is monitored for the end-of-discharge voltages (EDV1 and EDVF) and for alarm warning conditions. EDV threshold levels are used to determine when the battery has reached an “empty” state. The bq2945 generates an alarm warning when the battery voltage exceeds the maximum charging voltage by 5% or if the voltage is below EDVF. The battery voltage gain, the two EDV thresholds, and the charging voltage are programmable in the EEPROM.

If V_{SB} is below either of the two EDV thresholds, the associated flag is latched and remains latched, independent of V_{SB}, until the next valid charge.

EDV monitoring may be disabled under certain conditions. If the discharge current is greater than approximately 6A, EDV monitoring is disabled and resumes after the current falls below 6A.

Reset

The bq2945 is reset when first connected to the battery pack. On power-up, the bq2945 initializes and reads the EEPROM configuration memory. The bq2945 can also be reset with a command over the SMBus. The software reset sequence is the following: (1) write MaxError (0x0c) to 0x0000; (2) write the reset register (0x64) to 0x8009. A software reset can only be performed if the bq2945 is in an unlocked state as defined by the value in location 0x3d of the EEPROM (EE 0x3d) on power-up.

Temperature

The bq2945 monitors temperature sensing using an internal sensor. The temperature is used to adapt charge and self-discharge compensations as well as to monitor for maximum temperature and $\Delta T/\Delta t$ during a bq2945 controlled charge. Temperature may also be accessed over the SMBus with command 0x08.

Layout Considerations

The bq2945 measures the voltage differential between the SR and V_{SS} pins. V_{OS} (the offset voltage at the SR pin) is greatly affected by PC board layout. For optimal results, the PC board layout should follow the strict rule of a single-point ground return. Sharing high-current ground with small signal ground causes undesirable noise on the small signal nodes. Additionally, in reference to Figure 1:

- The capacitors (C1 and C2) should be placed as close as possible to the SB and V_{CC} pins, and their paths to V_{SS} should be as short as possible. A high-quality ceramic capacitor of 0.1µf is recommended for V_{CC}.
- The sense resistor capacitor (C3) should be placed as close as possible to the SR pin.
- The bq2945 should be in thermal contact with the cells for optimum temperature measurement.
- An optional zener (D9) may be necessary to ensure that V_{CC} is not above the maximum rating during operation.

Gas Gauge Operation

The operational overview diagram in Figure 2 illustrates the operation of the bq2945. The bq2945 accumulates a measure of charge and discharge currents, as well as an estimation of self-discharge. Charge currents are compensated for temperature and state-of-charge of the battery. Self-discharge is temperature-compensated.

The main counter, RemainingCapacity (RM), represents the available battery capacity at any given time. Battery charging increments the RM register, whereas battery discharging and self-discharge decrement the RM register and increment the internal Discharge Count Register (DCR).

The Discharge Count Register is used to update the FullChargeCapacity (FCC) register only if a complete battery discharge from full to empty occurs without any partial battery charges. Therefore, the bq2945 adapts its capacity determination based on the actual conditions of discharge.

The battery's initial full capacity is set to the value stored in EE 0x60-0x61. Until FCC is updated, RM counts up to, but not beyond, this threshold during subsequent charges.

1. **FullChargeCapacity or learned-battery capacity:**

   FCC is the last measured discharge capacity of the battery. On initialization (application of V_{CC} or reset), FCC is set to the value stored in the EEPROM. During subsequent discharges, FCC is updated with the

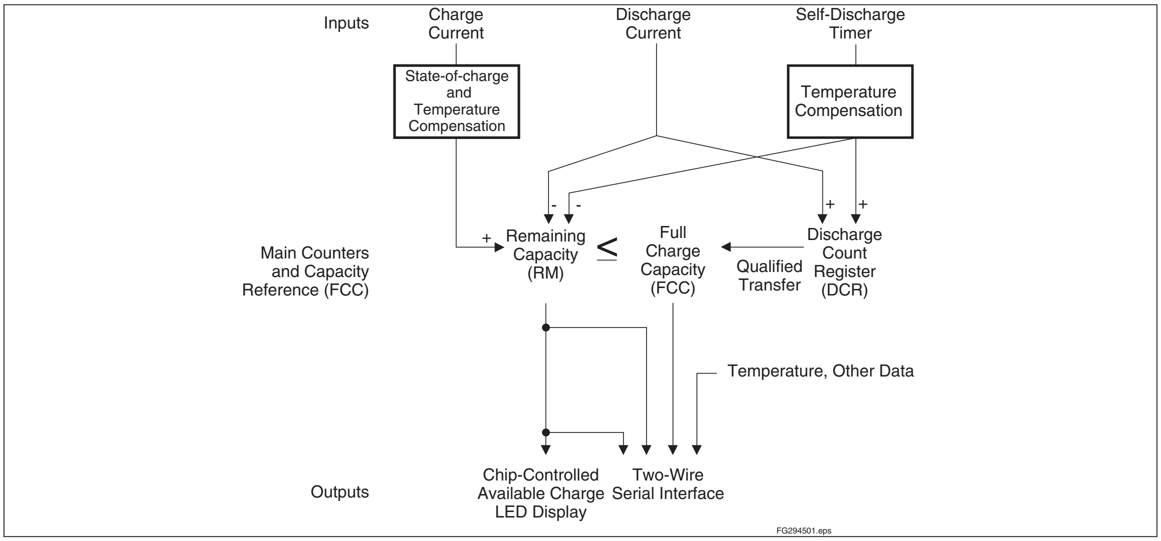


Figure 2. Operational Overview

latest measured capacity in the Discharge Count Register, representing a discharge from full to below EDV1. A qualified discharge is necessary for a capacity transfer from the DCR to the FCC register. Once updated, the bq2945 writes the new FCC to the EEPROM. The FCC also serves as the 100% reference threshold used by the relative state-of-charge calculation and display.

2. **DesignCapacity (DC):**

The DC is the user-specified battery capacity and is programmed from external EEPROM. The DC also provides the 100% reference for the absolute display mode.

3. **RemainingCapacity (RM):**

RM counts up during charge to a maximum value of FCC and down during discharge and self-discharge to 0. RM is set to 000Ah after the EDV1 threshold has been reached and a valid charge has been detected. To prevent overstatement of charge during periods of overcharge, RM stops incrementing when RM = FCC. RM may optionally be written to a user-defined value when fully charged if the battery pack is under bq2945 charge control. On initialization, RM is set to the value stored in EE 0x1e—0x1f.

4. **Discharge Count Register (DCR):**

The DCR counts up during discharge independent of RM and can continue increasing after RM has decremented to 0. Prior to RM = 0 (empty battery), both discharge and self-discharge increment the DCR. After RM = 0, only discharge increments the DCR. The DCR resets to 0 when RM = FCC. The DCR does not roll over but stops counting when it reaches FFFFh.

The DCR value becomes the new FCC value on the first charge after a qualified discharge to EDV1. A qualified discharge to EDV1 occurs if all of the following conditions exist:

- No valid charge initiations (charges greater than 10mAh), where $V_{SRO} > +V_{SRD}$ occurred during the period between RM = FCC and EDV1 detected.
- The self-discharge count is not more than 256mAh.
- The temperature is ≥ 273°K (0°C) when the EDV1 level is reached during discharge.

The valid discharge flag (VDQ) in FLAGS1 indicates whether the present discharge is valid for an FCC update. FCC cannot be reduced by more than 256mAh during any single cycle.

Charge Counting

Charge activity is detected based on a positive voltage on the SR input. If charge activity is detected, the bq2945 increments RM at a rate proportional to V_{SRO} and, if enabled, activates an LED display. Charge actions increment the RM after compensation for charge state and temperature.

The bq2945 determines charge activity sustained at a continuous rate equivalent to V_{SRO} > +V_{SRD}. **A valid charge equates to sustained charge activity greater than 10 mAh**. Once a valid charge is detected, charge threshold counting continues until V_{SRO} falls below V_{SRD}. V_{SRD} is a programmable threshold as described in the Digital Magnitude Filter section.

Discharge Counting

All discharge counts where V_{SRO} < -V_{SRD} cause the RM register to decrement and the DCR to increment. V_{SRD} is a programmable threshold as described in the Digital Magnitude Filter section.

Self-Discharge Estimation

The bq2945 continuously decrements RM and increments DCR for self-discharge based on time and temperature. The bq2945 self-discharge estimation rate is programmed in EE 0x4f and can be set from 0 to 25% per day for 20–30°C. This rate doubles every 10°C from 30°C to 70°C and halves every 10°C from 20°C to 0°C.

Charge Control

The bq2945 supports SBS charge control by broadcasting the ChargingCurrent and the ChargingVoltage to the Smart Charger address. The bq2945 broadcasts charging commands every 10 seconds; the broadcasts can be disabled by writing bit 14 of BatteryMode to 1. On reset, the initial charging current broadcast to the charger is set to the value programmed in EE 0x08-0x09. The bq2945 updates the value used in the charging current broadcasts based on the battery's state of charge, voltage, and temperature.

The bq2945 internal charge control is compatible with nickel-based and Li-Ion chemistries. The bq2945 uses current taper detection for Li-Ion primary charge termination and ΔT/Δt for nickel based primary charge termination. The bq2945 also provides a number of safety terminations based on battery capacity, voltage, and temperature.

Current Taper

For Li-Ion charge control, the ChargingVoltage must be set to the desired pack voltage during the constant voltage charge phase. The bq2945 detects a current taper termination when it measures the pack voltage to be within 128mV of the requested charging voltage and when the AverageCurrent is between the programmed threshold in EE 0x38—0x39 and 100 mA for at least 40s.

ΔT/Δt

The ΔT/Δt used by the bq2945 is programmable in both the temperature step (1.6°C–4.6°C) and time step (20 seconds–320seconds). Typical settings for 1°C/min include 2°C over 120 seconds and 3°C over 180 seconds. Longer times are required for increased slope resolution.

$\frac{\Delta T}{\Delta t}$ is set by the formula: $\frac{\Delta T}{\Delta t}$ =

$$\frac{[(\text{lower nibble of EE 0x4a}) * 2 + 16] / 10}{[2^{\prime}s(\text{EE 0x62}) * 20]} \left[\frac{{}^{o}\text{C}}{\text{s}}\right]$$

In addition to the ΔT/Δt timer, there is a hold-off timer, which starts when the battery is being charged at more than 255mA and the temperature is above 25°C. Until this timer expires, ΔT/Δt is suspended. If the temperature falls below 25°C, or if charging current falls below 255mA, the timer is reset and restarts only if these conditions are once again within range. The hold-off time is programmed in EE 0x63.

Charge Termination

Once the bq2945 detects a valid charge termination, the Fully_Charged, Terminate_Charge_Alarm, and the Over_Charged_Alarm bits are set in BatteryStatus, and the requested charge current is set to zero. Once the terminating conditions cease, the Terminate_Charge_Alarm and the Over_Charged_Alarm are cleared, and the requested charging current is set to the maintenance rate. The bq2945 requests the maintenance rate until RM falls below 95% of full-charge percentage. Once this occurs, the Fully_Charged bit is cleared, and the requested charge current and voltage are set to the fast-charge rate.

Bit 4 (CC) in FLAGS2 determines whether RM is modified after a ΔT/Δt or current taper termination occurs. If CC = 1, RM may be set from 0 to 100% of the FullChargeCapacity as defined in EE 0x4c. If RM is below the full-charge percentage, RM is set to the full-charge percentage of FCC. If RM is above the full-charge percentage, RM is not modified.

Charge Suspension

The bq2945 may temporarily suspend charge if it detects a charging fault. The charging faults include the following conditions:

- **Maximum Overcharge:** If charging continues for more than the programmed maximum overcharge limit as defined in EE 0x3a—0x36 beyond RM=FCC, the Fully_Charged bit is set, and the requested charging current is set to the maintenance rate.
- **Overvoltage:** An over-voltage fault exists when the bq2945 measures a voltage more than 5% above the ChargingVoltage. When the bq2945 detects an overvoltage condition, the requested charge current is set to 0 and the Terminate_Charge_Alarm bit is set in Battery Status. The alarm bit is cleared when

the current drops below 256mA and the voltage is less than 105% of ChargingVoltage.

- **Overcurrent:** An overcurrent fault exists when the bq2945 measures a charge current more than 25% above the ChargingCurrent. If the ChargingCurrent is less than 1024mA, an overcurrent fault exists if the charge current is more than 256mA above the ChargingCurrent. When the bq2945 detects an overcurrent condition, the requested charge current is set to 0 and the Terminate_Charge_Alarm bit is set in Battery Status. The alarm bit is cleared when the current drops below 256mA.
- **Maximum Temperature**: When the battery temperature exceeds the programmed maximum temperature, the requested charge current is set to zero and the Over_Temp_Alarm and the Terminate_Charge_Alarm bits are set in Battery Status. The alarm bits are cleared when the temperature drops below 50°C.
- **Low Temperature:** When the battery temperature is less than 0°C, the requested charge current is set to the maintenance rate. Once the temperature is above 5°C, the requested charge current is set to the fast rate.
- **Undervoltage:** When the battery voltage is below the EDVF threshold, the requested charge current is set to the maintenance rate. Once the voltage is above EDVF, the requested charge current is set to the fast rate.

Count Compensations

Charge activity is compensated for temperature and state-of-charge before updating the RM and/or DCR. Self-discharge estimation is compensated for temperature before updating RM or DCR.

Charge Compensation

Charge efficiency is compensated for state-of-charge, temperature, and battery chemistry. The charge efficiency is adjusted using the following equations:

$$1.)\ RM = RM * (Q_{EFC} - Q_{ET})$$

where RelativeStateOfCharge < FullChargePercentage, and Q_{EFC} is the programmed fast-charge efficiency varying from 0.75 to 1.0.

$$2.)\ RM = RM * (Q_{ETC} - Q_{ET})$$

where RelativeStateOfCharge ≥ FullChargePercentage and Q_{ETC} is the programmed maintenance (trickle) charge efficiency varying from 0.75 to 1.0.

Q_{ET} is used to adjust the charge efficiency as the battery temperature increases according to the following:

$$Q_{ET} = 0 \text{ if } T < 30°C$$

$$Q_{ET} = 0.02 \text{ if } 30°C \le T < 40°C$$

$$Q_{ET} = 0.05 \text{ if } T \ge 40°C$$

Q_{ET} is 0 over the entire temperature range for Li-Ion.

Digital Magnitude Filter

The bq2945 has a programmable digital filter to eliminate charge and discharge counting below a set threshold, V_{SRD}. Table 2 shows typical digital filter settings. The proper digital filter setting can be calculated using the following equation.

$$DMF = \frac{45}{V_{SRD}}$$

Table 2. Typical Digital Filter Settings

DMF	DMF Hex.	V_{SRD} (mV)
75	4B	0.60
100	64	0.45
150	96	0.30
175	AF	0.26
200	C8	0.23

Error Summary

Capacity Inaccurate

The FCC is susceptible to error on initialization or if no updates occur. On initialization, the FCC value includes the error between the design capacity and the actual capacity. This error is present until a qualified discharge occurs and FCC is updated (see the DCR description). The other cause of FCC error is battery wear-out. As the battery ages, the measured capacity must be adjusted to account for changes in actual battery capacity. Periodic qualified discharges from full to empty will minimize errors in FCC.

Current-Sensing Error

Table 3 illustrates the current-sensing error as a function of V_{SR}. A digital filter eliminates charge and discharge counts to the RM register when $-V_{SRD} < V_{SRO} < +V_{SRD}$.

Display

The bq2945 can directly display capacity information using low-power LEDs. The bq2945 displays the battery charge state in either absolute or relative mode. In relative mode, the battery charge is represented as a percentage of the FCC. Each LED segment represents 20% of the FCC.

Table 3. bq2945 Current-Sensing Errors

Symbol	Parameter	Typical	Maximum	Units	Notes
V_{OS}	Offset referred to V_{SR}	± 75	± 150	µV	$\overline{DISP}$ = V_{CC}.
INL	Integrated non-linearity error	± 1	± 4	%	Add 0.1% per °C above or below 25°C and 1% per volt above or below 4.25V.
INR	Integrated non-repeatability error	± 0.5	± 1	%	Measurement repeatability given similar operating conditions.

In absolute mode, each segment represents a fixed amount of charge, 20% of the DesignCapacity. As the battery wears out over time, it is possible for the FCC to be below the design capacity. In this case, all of the LEDs may not turn on in absolute mode, representing the reduction in the actual battery capacity.

When $\overline{DISP}$ is tied to V_{CC}, the LED_{1-5} outputs are inactive. When $\overline{DISP}$ is left floating, the display becomes active whenever the bq2945 detects a charge rate of 100mA or more. When pulled low, the segment outputs become active immediately for a period of approximately 4 seconds. The $\overline{DISP}$ pin must be returned to float or V_{CC} to reactivate the display.

LED_1 blinks at a 4Hz rate whenever V_{SB} has been detected to be below EDV1 (EDV1 = 1), indicating a low-battery condition. V_{SB} below EDVF (EDVF = 1) disables the display output.

Microregulator

The bq2945 can operate directly from three nickel chemistry cells. To facilitate the power supply requirements of the bq2945, an REF output is provided to regulate an external low-threshold n-FET. A micropower source for the bq2945 can be inexpensively built using a 2N7002 or BSS138 FET and an external resistor. (See Figure 1.) The value of R11 depends on the battery pack's nominal voltage.

Communicating with the bq2945

The bq2945 includes a simple two-pin (SMBC and SMBD) bi-directional serial data interface. A host processor uses the interface to access various bq2945 registers; see Table 4. This method allows battery characteristics to be monitored easily. The open-drain SMBD and SMBC pins on the bq2945 are pulled up by the host system, or may be connected to V_{SS}, if the serial interface is not used.

The interface uses a command-based protocol, where the host processor sends the battery address and an eight-bit command byte to the bq2945. The command directs the bq2945 to either store the next data received to a register specified by the command byte or output the data specified by the command byte.

bq2945 Data Protocols

The host system, acting in the role of a Bus master, uses the read word and write word protocols to communicate integer data with the bq2945. (See Figure 3.)

Host-to-bq2945 Message Protocol

The Bus Host communicates with the bq2945 using one of three protocols:

- Read word
- Write word
- Read block

The particular protocol used is a function of the command. The protocols used are shown in Figure 3.

Host-to-bq2945 Messages (see Table 4)

ManufacturerAccess() (0x00)

This function is used to control CP_1 and CP_2. (See Table 7.)

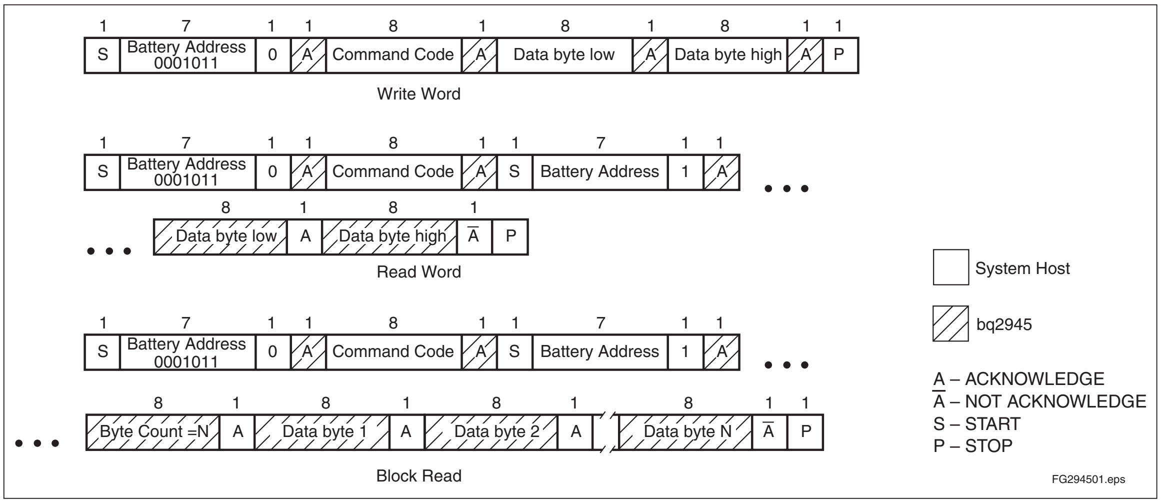


Figure 3. Host Communication Protocols

RemainingCapacityAlarm() (0x01)

This function sets or returns the low-capacity alarm value. When RM falls below the RemainingCapacityAlarm value initialized from the external EEPROM, the Remaining_Capacity_Alarm bit is set in BatteryStatus. The system may alter this alarm during operation.

Input/Output: unsigned integer. This sets/returns the value where the Remaining_Capacity_Alarm bit is set in Battery Status.

Units: mAh

Range: 0 to 65,535mAh

RemainingTimeAlarm() (0x02)

This function sets or returns the low remaining time alarm value. When the AverageTimeToEmpty falls below this value, the Remaining_Time_Alarm bit in BatteryStatus is set. The default value for this register is programmed in EE 0x02-0x03. The system may alter this alarm during operation.

Input/Output: unsigned integer. This sets/returns the value where the Remaining_Time_Alarm bit is set in Battery Status.

Units: minutes

Range: 0 to 65,535 minutes

BatteryMode() (0x03)

This read/write word selects the various battery operational modes. The bq2945 supports the battery capacity information specified in mAh. This function also determines whether the bq2945 charging values are broadcasted to the Smart Battery Charger address.

Writing bit 14 to 1 disables voltage and current Master Mode broadcasts to the Smart Battery Charger. Bit 14 is automatically reset to 0 if SMBC and SMBD = 0 for greater than 2 seconds (i.e. pack removal).

Writing bit 13 to 1 disables all Master Mode broadcasts including alarm messages to the Smart Battery Charger and Host. The bit remains set until overwritten. Programming bit 3 of FLAGS2 in the EEPROM (EE0x3f) initializes this bit to a 1.

Bit 7 is the condition request flag. It is set when the bq2945 is initialized from the EEPROM and reset when a learning cycle has been completed. It is also set to a 1 if CycleCount increases by 32 without a new learning cycle.

AtRate() (0x04)

This read/write word is the first half of a two-function set used to set the AtRate value used in calculations made by the AtRateTimeToFull and AtRateTimeToEmpty.

- When the AtRate value is positive, the AtRateTimeToFull function returns the predicted time to full-charge at the AtRate value of charge.

Table 4. bq2945 Register Functions

Function	Code	Access	Units	Defaults[1]
ManufacturerAccess	0x00	read/write	-	-
Remaning_Capacity_Alarm	0x01	read/write	mAh	E^2
Remaining_Time_Alarm	0x02	read/write	minutes	E^2
BatteryMode	0x03	read/write	bit flag	-
AtRate	0x04	read/write	mA	-
AtRateTimeToFull	0x05	read	minutes	-
AtRateTimeToEmpty	0x06	read	minutes	-
AtRateOK	0x07	read	Boolean	-
Temperature	0x08	read	0.1°K	2930
Voltage	0x09	read	mV	E^2
Current	0x0a	read	mA	0
AverageCurrent	0x0b	read	mA	0
MaxError	0x0c	read	percent	100
RelativeStateOfCharge	0x0d	read	percent	-
AbsoluteStateOfCharge	0x0e	read	percent	-
RemainingCapacity	0x0f	read	mAh	E^2
FullChargeCapacity	0x10	read	mAh	E^2
RunTimeToEmpty	0x11	read	minutes	-
AverageTimeToEmpty	0x12	read	minutes	-
AverageTimeToFull	0x13	read	minutes	-
ChargingCurrent	0x14	read	mA	E^2
ChargingVoltage	0x15	read	mV	E^2
Battery Status	0x16	read	bit flags	E^2
CycleCount	0x17	read	cycle	E^2
DesignCapacity	0x18	read	mAh	E^2
DesignVoltage	0x19	read	mV	E^2
Specification Info	0x1a	read	-	E^2
ManufactureDate	0x1b	read	-	E^2
SerialNumber	0x1c	read	integer	E^2
Reserved	0x1d - 0x1f	-	-	-
ManufacturerName	0x20	read	string	E^2
DeviceName	0x21	read	string	E^2

Note: 1. Defaults after reset or power-up.

Table 4. bq2945 Register Functions (Continued)

Function	Code	Access	Units	Defaults[1]
DeviceChemistry	0x22	read	string	E^2
ManufacturerData	0x23	read	string	E^2
FLAG1 and FLAG2	0x2f	read	bit flags	E^2
End of Discharge Voltage 1 (EDV1)	0x3e	read	-	E^2
End of Discharge Voltage Final (EDVF)	0x3f	read	-	E^2

Note: 1. Defaults after reset or power-up.

- When the AtRate value is negative, the AtRateTimeToEmpty function returns the predicted operating time at the AtRate value of discharge.

  Input/Output: signed integer. AtRate is positive for charge and negative for discharge.

  Units: mA

  Range: -32,768mA to 32,767mA

AtRateTimeToFull() (0x05)

This read-only word returns the predicted remaining time to fully charge the battery at the AtRate value (mA) and is valid only if read immediately after an AtRate command.

Output: unsigned integer. Returns the predicted time to full charge.

Units: minutes

Range: 0 to 65,534min

Granularity: 2 min or better

Invalid Data Indication: 65,535 indicates that the AtRate value is negative.

AtRateTimeToEmpty() (0x06)

This read-only word returns the predicted remaining operating time if the battery is discharged at the AtRate value and is valid only if read immediately after an AtRate command.

Output: unsigned integer. Returns the predicted time to empty.

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

Invalid Data Indication: 65,535 indicates that the AtRate value is not negative.

AtRateOK() (0x07)

This read-only word returns a Boolean value that indicates whether or not the EDVF flag has been set.

Boolean: Indicates if the battery can supply additional energy.

Units: Boolean

Range: TRUE $\neq$ 0, FALSE = 0

Temperature() (0x08)

This read-only word returns the cell-pack's internal temperature.

Output: unsigned integer. Returns the cell temperature in tenths of degrees Kelvin increments.

Units: 0.1°K

Range: 0 to +500.0°K

Granularity: 0.5°K or better

Accuracy: ±3°K after calibration

Voltage() (0x09)

This read-only word returns the cell-pack voltage (mV).

Output: unsigned integer. Returns the battery terminal voltage in mV.

Units: mV

Range: 0 to 65,535mV

Granularity: 0.2% of DesignVoltage

Accuracy: ±1% of DesignVoltage after calibration

Current() (0x0a)

This read-only word returns the current through the battery's terminals (mA).

Output: signed integer. Returns the charge/discharge rate in mA, where positive is for charge and negative is for discharge

Units: mA

Range: 0 to 32,767mA for charge or 0 to –32,768mA for discharge

Granularity: 0.2% of the DesignCapacity or better

Accuracy: ±1% of the DesignCapacity after calibration

AverageCurrent() (0x0b)

This read-only word returns a rolling average of the current through the battery's terminals. The AverageCurrent function returns meaningful values after the battery's first minute of operation.

Output: signed integer. Returns the charge/discharge rate in mA, where positive is for charge and negative is for discharge

Units: mA

Range: 0 to 32,767mA for charge or 0 to –32,768mA for discharge

Granularity: 0.2% of the DesignCapacity or better

Accuracy: ±1% of the DesignCapacity after calibration

MaxError() (0x0c)

Returns the expected margin of error (%) in the state of charge calculation.

Output: unsigned integer. Returns the percent uncertainty for selected information.

Units: %

Range: 0 to 100%

RelativeStateOfCharge() (0x0d)

This read-only word returns the predicted remaining battery capacity expressed as a percentage of FullChargeCapacity (%). **RelativeStateOfCharge is only valid for battery capacities more than 1504mAh and less than 10,400mAh.**

Output: unsigned integer. Returns the percent of remaining capacity.

Units: %

Range: 0 to 100%

Granularity: 1%

Accuracy: ±MaxError after circuit and capacity calibration

AbsoluteStateOfCharge() (0x0e)

This read-only word returns the predicted remaining battery capacity expressed as a percentage of DesignCapacity (%). Note that AbsoluteStateOfCharge can return values greater than 100%. **Absolute StateOfCharge is only valid for battery capacities more than 1504mAh and less than 10,400mAh**.

Output: unsigned integer. Returns the percent of remaining capacity.

Units: %

Range: 0 to 65,535%

Granularity: 1%

Accuracy: ±MaxError after circuit and capacity calibration

RemainingCapacity() (0x0f)

This read-only word returns the predicted remaining battery capacity. The RemainingCapacity value is expressed in mAh.

Output: unsigned integer. Returns the estimated remaining capacity in mAh.

Units: mAh

Range: 0 to 65,535mAh

Granularity: 0.2% of DesignCapacity or better

Accuracy: ±MaxError ∗ FCC after circuit and capacity calibration

FullChargeCapacity() (0x10)

This read-only word returns the predicted pack capacity when it is fully charged. FullChargeCapacity defaults to the value programmed in the external EEPROM until a new pack capacity is learned. The new FCC is stored to EEPROM within 400ms of a valid charge after a qualified discharge.

Output: unsigned integer. Returns the estimated full charge capacity in mAh.

Units: mAh

Range: 0 to 65,535mAh

Granularity: 0.2% of DesignCapacity or better

Accuracy: ±MaxError ∗ FCC after circuit and capacity calibration

RunTimeToEmpty() (0x11)

This read-only word returns the predicted remaining battery life at the present rate of discharge (minutes). The RunTimeToEmpty value is calculated based on Current.

Output: unsigned integer. Returns the minutes of operation left.

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

Invalid data indication: 65,535 indicates battery is not being discharged.

AverageTimeToEmpty() (0x12)

This read-only word returns the predicted remaining battery life at the present average discharge rate (minutes). The AverageTimeToEmpty is calculated based on AverageCurrent.

Output: unsigned integer. Returns the minutes of operation left.

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

Invalid data indication: 65,535 indicates battery is not being discharged.

AverageTimeToFull() (0x13)

This read-only word returns the predicted time until the Smart Battery reaches full charge at the present average charge rate (minutes).

Output: unsigned integer. Returns the remaining time in minutes to full.

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

Invalid data indication: 65,535 indicates battery is not being charged.

ChargingCurrent() (0x14)

If enabled, the bq2945 sends the desired charging rate in mA to the Smart Battery Charger.

Output: unsigned integer. Transmits/returns the maximum charger output current in mA.

Units: mA

Range: 0 to 65,534mA

Granularity: 0.2% of the design capacity or better

Invalid data indication: 65,535 indicates that the Smart Charger should operate as a voltage source outside its maximum regulated current range.

ChargingVoltage() (0x15)

If enabled, the bq2945 sends the desired voltage in mV to the Smart Battery Charger.

Output: unsigned integer. Transmits/returns the charger voltage output in mV.

Units: mV

Range: 0 to 65,534mV

Granularity: 0.2% of the DesignVoltage or better

Invalid data indication: 65,535 indicates that the Smart Battery Charger should operate as a current source outside its maximum regulated voltage range.

BatteryStatus() (0x16)

This read-only word returns the battery status word.

Output: unsigned integer. Returns the status register with alarm conditions bitmapped as shown in Table 5.

Some of the BatteryStatus flags (Remaining_Capacity_Alarm and Remaining_Time_Alarm) are calculated based on current. See Table 8 and 9 for definitions.

Table 5. Status Register

Alarm Bits	
0x8000	Over_Charged_Alarm
0x4000	Terminate_Charge_Alarm
0x2000	Reserved
0x1000	Over_Temp_Alarm
0x0800	Terminate_Discharge_Alarm
0x0400	Reserved
0x0200	Remaining_Capacity_Alarm
0x0100	Remaining_Time_Alarm
Status Bits	
0x0080	Initialized
0x0040	Discharging
0x0020	Fully_Charged
0x0010	Fully_Discharged
Error Code	
0x0000-0x000f	Reserved for error codes

CycleCount() (0x17)

This read-only word returns the number of charge/discharge cycles the battery has experienced. A charge/discharge cycle starts from a base value equivalent to the battery's state-of-charge on completion of a charge cycle. The bq2945 increments the cycle counter during the current charge cycle if the battery has been discharged 15% below the state-of-charge at the end of the last charge cycle. This prevents false reporting of small charge/discharge cycles. The cycle count is stored in EEPROM within 400ms of an update.

Output: unsigned integer. Returns the count of charge/discharge cycles the battery has experienced.

Units: cycles

Range: 0 to 65,535 cycles; 65,535 indicates battery has experienced 65,535 or more cycles.

Granularity: 1 cycle

DesignCapacity() (0x18)

This read-only word returns the theoretical capacity of a new pack. The DesignCapacity value is expressed in mAh at the nominal discharge rate.

Table 6. Bit Descriptions for FLAGS1 and FLAGS2

	(MSB) 7	6	5	4	3	2	1	0 (LSB)
FLAGS2	DMODE	CP2 DI	CHM	CC	-	OV	LTF	OC
FLAGS1	-	-	VQ	-	VDQ	SEDV	EDV1	EDVF

Note: - = Reserved

Output: unsigned integer. Returns the battery capacity in mAh.

Units: mAh

Range: 0 to 65,535mAh

DesignVoltage() (0x19)

This read-only word returns the theoretical voltage of a new pack in mV.

Output: unsigned integer. Returns the battery's normal terminal voltage in mV.

Units: mV

Range: 0 to 65,535mV

Specification Info() (0x1a)

This read-only word returns the specification revision the bq2945 supports.

ManufactureDate() (0x1b)

This read-only word returns the date the cell was manufactured in a packed integer word. The date is packed as follows: (year - 1980) ∗ 512 + month ∗ 32 + day.

Field	Bits Used	Format	Allowable Value
Day	0–4	5-bit binary value	1–31 (corresponds to date)
Month	5–8	4-bit binary value	1–12 (corresponds to month number)
Year	9–15	7-bit binary value	0 ∗ 127 (corresponds to year biased by 1980)

SerialNumber() (0x1c)

This read-only word returns a serial number. This number, when combined with the ManufacturerName, the DeviceName, and the ManufactureDate, uniquely identifies the battery.

Output: unsigned integer

ManufacturerName() (0x20)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 11. The character string contains the battery manufacturer's name. For example, “Unitrode” identifies the battery pack manufacturer as Unitrode.

Output: string or ASCII character string

DeviceName() (0x21)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 7. The 7-byte character string contains the battery's name. For example, a DeviceName of “bq2945” indicates that the battery is a model bq2945.

Output: string or ASCII character string

DeviceChemistry() (0x22)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 5. The 5-byte character string contains the battery's chemistry. For example, if the DeviceChemistry function returns “NiMH,” the battery pack contains nickel-metal hydride cells.

Output: string or ASCII character string

ManufacturerData() (0x23)

This read-only string allows access to an up to 5-byte manufacturer data string.

Output: block data—data whose meaning is assigned by the Smart Battery's manufacturer.

End of Discharge Voltage1 (0x3e)

This read-only word returns the first end-of-discharge voltage programmed for the pack.

Output: two’s complemented unsigned integer. Returns battery end-of-discharge voltage programmed in EEPROM in mV.

End of Discharge VoltageF (0x3f)

This read-only word returns the final end-of-discharge voltage programmed for the pack.

Output: two's complemented unsigned integer. Returns battery final end-of-discharge voltage programmed in EEPROM in mV.

FLAGS1&2() (0x2f)

This read-only register returns an unsigned integer representing the internal status registers of the bq2945. The MSB represents FLAGS2, and the LSB represents FLAGS1. See Table 6 for the bit description for FLAGS1 and FLAGS2.

FLAGS2

The *Display Mode* flag (DMODE), bit 7 determines whether the bq2945 displays Relative or Absolute capacity.

The DMODE values are:

FLAGS2 Bits							
7	6	5	4	3	2	1	0
DMODE	-	-	-	-	-	-	-

Where DMODE is:

0 Selects Absolute display

1 Selects Relative display

Bit 6 reflects the high/low state of CP2.

FLAGS2 Bits							
7	6	5	4	3	2	1	0
-	CP2DI	-	-	-	-	-	-

The *Chemistry* flag (CHM), bit 5, selects Li-Ion or nickel compensation factors.

The CHM values are:

FLAGS2 Bits							
7	6	5	4	3	2	1	0
-	-	CHM	-	-	-	-	-

Where CHM is:

0 Selects Nickel

1 Selects Li-Ion

Bit 4, the *Charge Control* flag (CC), determines whether a bq2945-based charge termination will set RM to a user-defined programmable full charge capacity.

The CC values are:

FLAGS2 Bits							
7	6	5	4	3	2	1	0
-	-	-	CC	-	-	-	-

Where CC is:

0 RM is not modified on valid bq2945 charge termination

1 RM is set to a programmable percentage of the FCC when a valid bq2945 charge termination occurs

Bit 3 is reserved.

Bit 2, the *Overvoltage* flag (OV), is set when the bq2945 detects a pack voltage 5% greater than the programmed charging voltage. This bit is cleared when the pack voltage falls 5% below the programmed charging voltage.

The OV values are:

FLAGS2 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	-	OV	-	-

Where OV is:

0 Voltage $< 1.05 * \text{ChargingVoltage}$

1 Voltage $\geq 1.05 * \text{ChargingVoltage}$

Bit 1, the *Low Temperature Fault* flag (LTF), is set when temperature < 0°C and cleared when temperature > 5°C.

The LTF values are:

FLAGS2 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	-	-	LTF	-

Where LTF is:

0 Temperature > 5°C

1 Temperature < 0°C

Bit 0, the *Overcurrent* flag (OC), is set when the average current is 25% greater than the programmed charging current. If the charging current is programmed less than 1024mA, overcurrent is set if the average current is 256mA greater than the programmed charging current.

This flag is cleared when the average current falls below 256mA.

The OC values are:

FLAGS2 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	OC

Where OC is:

0 AverageCurrent is less than 1.25 ∗ ChargingCurrent or less than 256mA if charging current is programmed less than 1024mA

1 AverageCurrent exceeds 1.25 ∗ ChargingCurrent or 256mA if the charging current is programmed less than 1024mA. This bit is cleared if average current < 256mA.

FLAGS1

Bits 7 and 6 are reserved.

The *Valid Charge* flag (VQ), bit 5, is set when $V_{SRO} \geq |V_{SRD}|$ and 10mAh of charge has accumulated. This bit is cleared during a discharge and when $V_{SRO} \leq |V_{SRD}|$.

The VQ values are:

FLAGS1 Bits							
7	6	5	4	3	2	1	0
-	-	VQ	-	-	-	-	-

Where VQ is:

0 $V_{SRO} \leq |V_{SRD}|$

1 $V_{SRO} \geq |V_{SRD}|$ and 10mAh of charge has accumulated

Bit 4 is reserved.

The *Valid Discharge* flag (VDQ), bit 3, is set when a valid discharge is occurring (discharge cycle valid for learning new full charge capacity) and cleared if a partial charge is detected, EDV1 is asserted when T < 0°C, or self-discharge accounts for more than 256mAh of the discharge.

The VDQ values are:

FLAGS1 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	VDQ	-	-	-

Where VDQ is:

0 Self-discharge is greater than 256mAh, EDV1 = 1 when T < 0°C or VQ = 1

1 On first discharge after RM=FCC

The *Stop EDV* flag (SEDV), bit 2, is set when the discharge current > 6.15A and cleared when the discharge current falls below 6.15A.

The SEDV values are:

FLAGS1 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	-	SEDV	-	-

Where SEDV is:

0 Current < 6.15A

1 Current > 6.15A

The *First End-of-Discharge Voltage* flag (EDV1), bit 1, is set when Voltage < EDV1 and SEDV = 0 and cleared when VQ = 1 and Voltage > EDV1.

The EDV1 values are:

FLAGS1 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	-	-	EDV1	-

Where EDV1 is:

0 VQ = 1 and Voltage > EDV1

1 Voltage < EDV1 and SEDV = 0

The *Final End-of-Discharge Voltage* flag (EDVF), bit 0, is set when Voltage < EDVF and SEDV = 0 and cleared when VQ = 1 and Voltage > EDVF.

The EDVF values are:

FLAGS1 Bits							
7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	EDVF

Where EDVF is:

0 VQ = 1 and Voltage > EDVF

1 Voltage < EDVF and SEDV = 0

Error Codes and Status Bits

Error codes and status bits are listed in Table 8 and Table 9, respectively.

Control Pins 1 and 2 (CP_1, CP_2)

CP_1 and CP_2 are open drain outputs that are controlled by host command. Since they are under the control of the host, their use can be defined by the pack designer. Some uses for these pins are charger control, control of current path (charge FET, discharge FET, or fuse), or special LED function. CP_1 and CP_2 are controlled by the host writing a command to the battery's ManufacturerAccess slave function. Table 7 describes the commands that are available to control CP_1 and CP_2.

The CP_2 can also act as a digital input. The logical status can be monitored in bit 6 of the FLAGS2 register.

Table 7. ManufactureAccess Commands

CMD (0x00) =	Action
0x0505	CP_1 set to hi-Z
0x051b	CP_1 set low
0x0536	CP_2 set to hi-Z
0x054e	CP_2 set low
0x0563	CP_1 and CP_2 set to hi-Z
0x057d	CP_1 and CP_2 set low

SBD Seal

The bq2945 address space can be "locked" to enforce the SBS specified access to each command code. To lock the address space, the bq2945 must be initialized with EE 0x3d set to 00h. Once this is done, only commands 0x00-0x04 may be written. Attempting to write to any other address will cause a "no acknowledge" of the data. Reading will only be permitted from the command codes listed in the SBD specification plus the five locations designated as optional manufacturing functions 1—5 (0x2f, 0x3c—0x3f).

Programming the bq2945

The bq2945 requires the proper programming of an external EEPROM for proper device operation. Each module can be calibrated for the greatest accuracy, or general "default" values can be used. An EV2200-45 programming kit (interface board, software, and cable) for an IBM-compatible PC is available from Unitrode.

The bq2945 uses a 24LC01 or equivalent serial EEPROM (capable of read operation to 2.0V) for storing the various initial values, calibration data, and string information. Table 1 outlines the parameters and addresses for this information. Tables 10 and 11 detail the various register contents and show an example program value for an 2400mAh 4-series Li-Ion battery pack, using a 50mΩ sense resistor.

Table 8. Error Codes (BatteryStatus() (0x16))

Error	Code	Access	Description
OK	0x0000	read/write	bq2945 processed the function code without detecting any errors.
Busy	0x0001	read/write	bq2945 is unable to process the function code at this time.
ReservedCommand	0x0002	read/write	bq2945 cannot read or write the data at this time—try again later.
UnsupportedCommand	0x0003	read/write	bq2945 does not support the requested function code.
AccessDenied	0x0004	write	bq2945 detected an attempt to write to a read-only function code.
Overflow/Underflow	0x0005	read/write	bq2945 detected a data overflow or underflow.
BadSize	0x0006	write	bq2945 detected an attempt to write to a function code with an incorrect size data block.
UnknownError	0x0007	read/write	bq2945 detected an unidentifiable error.

Note: Reading the bq2945 after an error clears the error code.

Table 9. BatteryStatus Bits

Alarm Bits		
Bit Name	**Set When:**	**Reset When:**
OVER_CHARGED_ALARM	The bq2945 detects a ΔT/Δt or current taper termination. (**Note: ΔT/Δt and current taper are valid charge terminations**.)	A discharge occurs or when the ΔT/Δt or current taper termination condition ceases during charge.
TERMINATE_CHARGE_ALARM	The bq2945 detects an over-current, over-voltage, over-temperature, ΔT/Δt, or current taper condition during charge.	A discharge occurs or when all conditions causing the event cease.
OVER_TEMP_ALARM	The bq2945 detects that its internal temperature is greater than the programmed value.	Internal temperature falls below 50°C.
TERMINATE_DISCHARGE_ALARM	The bq2945 determines that it has supplied all the charge that it can without being damaged (Voltage < EDVF).	Voltage > EDVF signifies that the battery has reached a state of charge sufficient for it to once again safely supply power.
REMAINING_CAPACITY_ALARM	The bq2945 detects that the RemainingCapacity is less than that set by the RemainingCapacityAlarm function.	Either the value set by the RemainingCapacityAlarm function is lower than the Remaining Capacity or the RemainingCapacity is increased by charging.
REMAINING_TIME_ALARM	The bq2945 detects that the estimated remaining time at the present discharge rate is less than that set by the RemainingTimeAlarm function.	Either the value set by the RemainingTimeAlarm function is lower than the AverageTimeToEmpty or a valid charge is detected.
Status Bits		
Bit Name	**Set When:**	**Reset When:**
INITIALIZED	The bq2945 has completed a "learn" cycle.	Battery detects that power-on or user-initiated reset has occurred.
DISCHARGING	The bq2945 determines that it is not being charged.	Battery detects that it is being charged.
FULLY_CHARGED	The bq2945 determines a valid charge termination or a maximum overcharge state.	RM discharges below 95% of the full charge percentage.
FULLY_DISCHARGED	bq2945 determines that it has supplied all the charge that it can without being damaged.	RelativeStateOfCharge is greater than or equal to 20%

Table 10. Example Register Contents

Description	EEPROM Address		EEPROM Hex Contents		Example Values	Notes
	Low Byte	High Byte	Low Byte	High Byte		
EEPROM length	0x00		64		100	Must be equal to 0x64.
EEPROM check 1	0x01		5b		91	Must be equal to 0x5b.
Remaining time alarm	0x02	0x03	0a	00	10 minutes	Sets the low time alarm level.
Remaining capacity alarm	0x04	0x05	f0	00	240mAh	Sets the low capacity alarm level.
Reserved	0x06	0x07	00	00	0	Not currently used by the bq2945.
Initial charging current	0x08	0x09	60	09	2400mA	Sets the initial charge request.
Charging voltage	0x0a	0x0b	d8	40	16600mV	Used to set the fast-charge voltage for the Smart Charger.
Battery status	0x0c	0x0d	80	00	128	Initializes BatteryStatus.
Cycle count	0x0e	0x0f	00	00	0	Contains the charge cycle count and can be set to zero for a new battery.
Design capacity	0x10	0x11	60	09	2400mAh	Nominal battery pack capacity.
Design voltage	0x12	0x13	40	38	14400mV	Nominal battery pack voltage.
Specification information	0x14	0x15	10	00	1.0	Default value for this register in a 1.0 part.
Manufacturer date	0x16	0x17	a1	20	May 1, 1996 = 8353	Packed per the ManufactureDate description.
Serial number	0x18	0x19	12	27	10002	Contains the optional pack serial number.
Fast-charging current	0x1a	0x1b	60	09	2400mA	Used to set the fast-charge current for the Smart Charger.
Maintenance charge current	0x1c	0x1d	00	00	0mA	Contains the desired maintenance current after fast-charge termination by the bq2945.
Reserved	0x1e	0x1f	00	00	0	Must be programmed to 0x00.
Current integration gain[1]	0x2c	0x2d	40	00	3.2/0.05	Represents the following: 3.2/sense resistor in ohms. It is used by the bq2945 to scale the measured voltage values on the SR pin in mA and mAh. This register also compensates for variations in the reported sense resistor value.

Note: 1. Can be adjusted to calibrate the battery pack.

Table 10. Example Register Contents (Continued)

Description	EEPROM Address Low Byte	EEPROM Address High Byte	EEPROM Hex Contents Low Byte	EEPROM Hex Contents High Byte	Example Values	Notes
Reserved	0x2e	0x2f	00	00	0	Not currently used by the bq2945.
Li-Ion taper current	0x38	0x39	10	ff	240mA	Sets the upper taper limit for Li-Ion charge termination. Stored in 2's complement.
Maximum overcharge limit	0x3a	0x3b	9c	ff	100mAh	Sets the maximum amount of overcharge before a maximum overcharge charge suspend occurs. Stored in 2's complement.
Reserved	0x3c		00		0	Should be programmed to 0.
Access protect	0x3d		00		SBD access only	If the bq2945 is reset and this location is 0, the bq2945 locks access to any command outside of the SBD data set. Program to 0x08 for full R/W access.
FLAGS1	0x3e		00		0	Initializes FLAGS1
FLAGS2	0x3f		b0		Relative display Li-Ion chemistry bq2945 charge control	Initializes FLAGS2.
Battery voltage offset[1]	0x48		fe		-2mV	Used to adjust the battery voltage offset according to the following: Voltage = (V_{SB}(mV) + V_{OFF}) $*$ Voltage gain
Temperature offset[1]	0x49		8a		13.8°C	The default value (zero adjustment) for the offset is 12.8°C or 0x80. $TOFF_{NEW} = TOFF_{CURRENT} + (TEMP_{ACTUAL} - TEMP_{REPORTED}) * 10$
Maximum temperature and ΔT step	0x4a		8f		Maximum temperature = 61.2°C ΔT step = 4.6°C	Maximum charge temperature is 74 - (mt $*$ 1.6)°C (mt = upper nibble). The ΔT step is (dT $*$ 2 + 16)/10°C (dT = lower nibble)
Charge efficiency	0x4b		ff		Maintenance compensation = 100% Fast compensation = 100%	Sets the fast-charge (high) and maintenance charge (low) efficiencies. The upper nibbles sets the low efficiency and the lower nibble adjusts the high efficiency according to the equation: Nibble = (efficiency% $*$ 256 - 196)/4
Full-charge percentage	0x4c		9c		100%	This packed field is the two's complement of the desired value in RM when the bq2945 determines a full-charge termination. If RM is below this value, RM is set to this value. If RM is above this value, then RM is not adjusted.

Note: 1. Can be adjusted to calibrate the battery pack.

Table 10. Example Register Contents (Continued)

Description	EEPROM Address		EEPROM Hex Contents		Example Values	Notes
	Low Byte	High Byte	Low Byte	High Byte		
Digital filter	0x4d		96		0.30mV	Used to set the digital magnitude filter as described in Table 2.
Reserved	0x4e		00		0	Not currently used by the bq2945.
Self-discharge rate	0x4f		2d		0.25%	This packed field is the two's complement of (52.73/x) where x is the desired self-discharge rate per day (%) at room temperature.
Voltage gain[1]	0x56	0x57	17	07	7.09	Voltage gain is packed as two units. For example, (R4 + R5)/R4 = 7.09 would be stored as: whole number stored in 0x57 as 7 and the decimal component stored in 0x56 as 256 x 0.09 = 23 (= 17h).
Reserved	0x58	0x59	00	00	0	Should be programmed to 0.
Current measurement gain[1]	0x5a	0x5b	ee	02	750	The current gain measurement and current integration gain are related and defined for the bq2945 current measurement. This word equals 37.5/sense resistor value in ohms.
End of discharge voltage1	0x5c	0x5d	20	d1	12000mV	The value programmed is the two's complement of the threshold voltage in mV.
End of discharge voltage final	0x5e	0x5f	40	d4	11200mV	The value programmed is the two's complement of the threshold voltage in mV.
Full charge capacity	0x60	0x61	d0	07	2000mA	This value sets the initial estimated pack capacity.
Δt step	0x62		ff		20s	The Δt step for ΔT/Δt termination equals 20s ∗ the two's complement of the byte value.
Hold-off time	0x63		f0		320s hold-off	The hold-off time is 20s ∗ the two's complement of the byte value.
EEPROM check 2	0x64		b5		181	Must be equal to 0xb5.
Reserved	0x65	0x7f			NA	Not currently used by the bq2945.

Note: 1. Can be adjusted to calibrate the battery pack.

Table 11. Example Register Contents (String Data)

String Description	Address	0x X0	0x X1	0x X2	0x X3	0x X4	0x X5	0x X6	0x X7	0x X8	0x X9-Xf	0x xa	0x xb
Manufacturer name	0x20- 0x2b	09	42 B	45 E	4e N	43 C	48 H	4d M	41 A	52 R	51 Q	-	-
Device name	0x30- 0x37	06	42 B	51 Q	32 2	39 9	34 4	35 5	-				
Device chemistry	0x40- 0x47	04	6c L	69 I	4f O	4e N	-						
Manufacturer data	0x50- 0x55	05	42 B	51 Q	32 2	30 0	32 2						

Absolute Maximum Ratings

Symbol	Parameter	Minimum	Maximum	Unit	Notes
V_{CC}	Relative to V_{SS}	-0.3	+7.0	V	
All other pins	Relative to V_{SS}	-0.3	+7.0	V	
REF	Relative to V_{SS}	-0.3	+8.5	V	Current limited by R1 (See Figure 1.)
V_{SR}	Relative to V_{SS}	-0.3	+7.0	V	Minimum 100Ω series resistor should be used to protect SR in case of a shorted battery.
T_{OPR}	Operating temperature	0	+70	°C	Commercial

Note: Permanent device damage may occur if **Absolute Maximum Ratings** are exceeded. Functional operation should be limited to the Recommended DC Operating Conditions detailed in this data sheet. Exposure to conditions beyond the operational limits for extended periods of time may affect device reliability.

DC Voltage Thresholds ($T_A = T_{OPR}$; V = 3.0 to 5.5V)

Symbol	Parameter	Minimum	Typical	Maximum	Unit	Notes
E_{VSB}	Battery voltage error relative to SB	-50mV	-	50mV	V	See note

Note: The accuracy of the voltage measurement may be improved by adjusting the battery voltage offset and gain, stored in external EEPROM. For best operation, V_{CC} should be 1.5V greater than V_{SB}.

Recommended DC Operating Conditions ($T_A = T_{OPR}$)

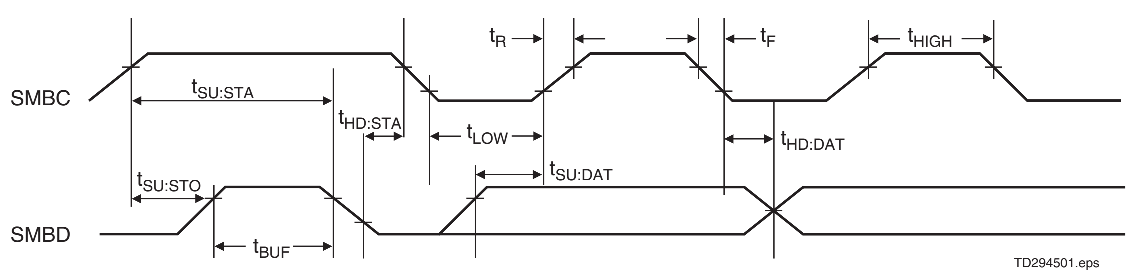
Symbol	Parameter	Minimum	Typical	Maximum	Unit	Notes
V_{CC}	Supply voltage	3.0	4.25	6.5	V	V_{CC} excursion from < 2.0V to ≥ 3.0V initializes the unit.
V_{REF}	Reference at 25°C	5.7	6.0	6.3	V	I_{REF} = 5µA
	Reference at -40°C to +85°C	4.5	-	7.5	V	I_{REF} = 5µA
R_{REF}	Reference input impedance	2.0	5.0	-	MΩ	V_{REF} = 3V
I_{CC}	Normal operation	-	90	135	µA	V_{CC} = 3.0V
		-	120	180	µA	V_{CC} = 4.25V
		-	170	250	µA	V_{CC} = 5.5V
V_{SB}	Battery input	0	-	V_{CC}	V	
R_{SBmax}	SB input impedance	10	-	-	MΩ	0 < V_{SB} < V_{CC}
I_{DISP}	$\overline{DISP}$ input leakage	-	-	5	µA	V_{DISP} = V_{SS}
I_{LVOUT}	V_{OUT} output leakage	-0.2	-	0.2	µA	EEPROM off
V_{SR}	Sense resistor input	-0.3	-	2.0	V	V_{SR} < V_{SS} = discharge; V_{SR} > V_{SS} = charge
R_{SR}	SR input impedance	10	-	-	MΩ	-200mV < V_{SR} < V_{CC}
V_{IH}	Logic input high	0.5 * V_{CC}	-	V_{CC}	V	ESCL, ESDA
		1.4	-	5.5	V	SMBC, SMBD
V_{IL}	Logic input low	0	-	0.3 * V_{CC}	V	ESCL, ESDA
		-0.5		0.6	V	SMBC, SMBD
V_{OL}	Data, clock output low	-	-	0.4	V	I_{OL}=350µA, SMBC, SMBD
I_{OL}	Sink current	100	-	350	µA	V_{OL}≤0.4V, SMBC, SMBD
V_{OLSL}	LED_X , CP_1, CP_2 output low, low V_{CC}	-	0.1	-	V	V_{CC} = 3V, I_{OLS} ≤ 1.75mA LED_1–LED_5, CP_1, CP_2
V_{OLSH}	LED_X , CP_1, CP_2 output low, high V_{CC}	-	0.4	-	V	V_{CC} = 6.5V, I_{OLS} ≤ 11.0mA LED_1–LED_5, CP_1, CP_2
V_{OHVL}	V_{OUT} output, low V_{CC}	V_{CC} - 0.3	-	-	V	V_{CC} = 3V, I_{VOUT} = -5.25mA
V_{OHVH}	V_{OUT} output, high V_{CC}	V_{CC} - 0.6	-	-	V	V_{CC} = 6.5V, I_{VOUT} = -33.0mA
I_{VOUT}	V_{OUT} source current	-33	-	-	mA	At V_{OHVH} = V_{CC} - 0.6V
I_{OLS}	LED_X , CP_1, CP_2 sink current	11.0	-		mA	At V_{OLSH} = 0.4V

Note: All voltages relative to V_{SS}.

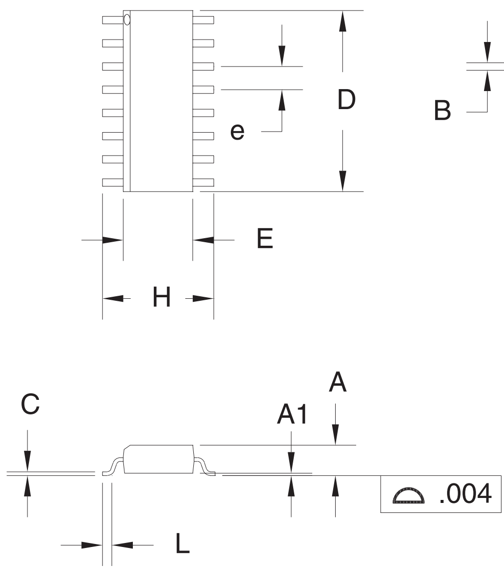
AC Specifications

Symbol	Parameter	Min	Max	Units	Notes
F_{SMB}	SMBus operating frequency	10	100	KHz	
T_{BUF}	Bus free time between stop and start condition	4.7		µs	
$T_{HD:STA}$	Hold time after (repeated) start condition	4.0		µs	
$T_{SU:STA}$	Repeated start condition setup time	4.7		µs	
$T_{SU:STO}$	Stop condition setup time	4.0		µs	
$T_{HD:DAT}$	Data hold time	300		ns	
$T_{SU:DAT}$	Data setup time	250		ns	
T_{LOW}	Clock low period	4.7		µs	
T_{HIGH}	Clock high period	4.0		µs	
T_F	Clock/Data fall time		300	ns	
T_R	Clock/data rise time		1000	ns	
$T_{LOW:SEXT}$	Cumulative clock low extend time (slave)		25	ms	
$T_{TIMEOUT}$		25	35	ms	

Bus Timing Data



16-Pin SOIC Narrow (SN)



16-Pin SN (SOIC Narrow)

Dimension	Minimum	Maximum
A	0.060	0.070
A1	0.004	0.010
B	0.013	0.020
C	0.007	0.010
D	0.385	0.400
E	0.150	0.160
e	0.045	0.055
H	0.225	0.245
L	0.015	0.035

All dimensions are in inches.

Data Sheet Revision History

ChangeNo.	Page No.	Description of Change
1	All	“Final” changes from “Preliminary” version
2	6	Added V_{SB} should not exceed 2.4V
2	11	Changed cycle count increase from 30 to 32 for condition request
2	14	Changed AtRateOK() indication from EDV1 to EDVF
2	25	Changed self discharge programming from 52.75/x to 52.73/x

Notes: Change 1 = June 1998 B changes from Sept. 1997 “Preliminary.”
Change 2 = June 1999 C changes from June 1998.

Ordering Information

bq2945 _ _

Temperature Range:
blank = Commercial (0 to 70°C)

Package Option:
SN = 16-pin narrow SOIC

Device:
bq2945 Gas Gauge IC With SMBus Interface

IMPORTANT NOTICE

Texas Instruments and its subsidiaries (TI) reserve the right to make changes to their products or to discontinue any product or service without notice, and advise customers to obtain the latest version of relevant information to verify, before placing orders, that information being relied on is current and complete. All products are sold subject to the terms and conditions of sale supplied at the time of order acknowledgement, including those pertaining to warranty, patent infringement, and limitation of liability.

TI warrants performance of its semiconductor products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

CERTAIN APPLICATIONS USING SEMICONDUCTOR PRODUCTS MAY INVOLVE POTENTIAL RISKS OF DEATH, PERSONAL INJURY, OR SEVERE PROPERTY OR ENVIRONMENTAL DAMAGE ("CRITICAL APPLICATIONS"). TI SEMICONDUCTOR PRODUCTS ARE NOT DESIGNED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE-SUPPORT DEVICES OR SYSTEMS OR OTHER CRITICAL APPLICATIONS. INCLUSION OF TI PRODUCTS IN SUCH APPLICATIONS IS UNDERSTOOD TO BE FULLY AT THE CUSTOMER'S RISK.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards must be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance or customer product design. TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used. TI's publication of information regarding any third party's products or services does not constitute TI's approval, warranty or endorsement thereof.