UNITRODE

bq2092

Gas Gauge IC with SMBus-Like Interface

Features

- ➤ Provides accurate measurement of available charge in NiCd, NiMH, and Li-Ion rechargeable batteries
- ➤ Supports SBData charge control commands for Li-Ion, NiMH, and NiCd chemistries
- ➤ Designed for battery pack integration
  - 120µA typical operating current
  - Small size enables implementations in as little as ¾ square inch of PCB
- ➤ Two-wire SMBus-like interface
- ➤ Measurements compensated for current and temperature
- ➤ Programmable self-discharge and charge compensation
- ➤ 16-pin narrow SOIC

General Description

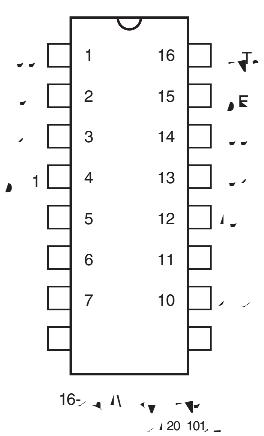
The bq2092 Gas Gauge IC With SMBus-Like Interface is intended for battery-pack or in-system installation to maintain an accurate record of available battery charge. The bq2092 directly supports capacity monitoring for NiCd, NiMH, and Li-Ion battery chemistries.

The bq2092 uses the SMBus protocol that supports many of the Smart Battery Data (SBData) commands. The bq2092 also supports SBData charge control. Battery state-of-charge, capacity remaining, remaining time and chemistry are available over the serial link. Battery-charge state can be directly indicated using a four-segment LED display to graphically depict battery full-to-empty in 25% increments.

The bq2092 estimates battery self-discharge based on an internal timer and temperature sensor and user-programmable rate information stored in external EEPROM. The bq2092 also automatically recalibrates or "learns" battery capacity in the full course of a discharge cycle from full to empty.

The bq2092 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 is used to program initial values into the bq2092 and is necessary for proper operation.



V_{CC}	3.0–5.5V
SCL	Serial memory clock
SDA	Serial memory data
SEG_1	LED segment 1
SEG_2	LED segment 2
SEG_3	LED segment 3
SEG_4	LED segment 4
V_{SS}	System ground

Pin Descriptions

CC

C

This output is used to clock the data transfer between the bq2092 and the external nonvolatile configuration memory.

DA

This bi-directional pin is used to transfer address and data to and from the bq2092 and the external configuration memory.

1

4

D

Each output may activate an external LED to sink the current sourced from V_{CC}.

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 bq2092 is $V_{SR} + V_{OS}$ (see Table 3).

D

D

$\overline{DISP}$ 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.

B

This input monitors the cell pack voltage as a single-cell potential through a high-impedance resistor divider network. The cell pack voltage is reported in the SBD register function Voltage (0x09) and is compared to end-of-discharge voltage and charging voltage parameters.

C

CD

This open-drain bidirectional pin is used to transfer address and data to and from the bq2092.

CC

This open-drain bidirectional pin is used to clock the data transfer to and from the bq2092.

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

This output supplies power to the external EEPROM configuration memory.

Functional Description

General Operation

The bq2092 determines battery capacity by monitoring the amount of charge input to or removed from a rechargeable battery. The bq2092 measures discharge and charge currents, estimates self-discharge, and monitors the battery for low-battery voltage thresholds. The charge measurement is made 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.

Table 1. Configuration Memory Programming Values

Parameter Name	Address	Length	Units
Design capacity	0x00/0x01	16 bits: low byte, high byte	mAh
Initial battery voltage	0x02/0x03	16 bits: low byte, high byte	mV
Fast charging current	0x04/0x05	16 bits: low byte, high byte	mA
Charging voltage	0x06/0x07	16 bit: low byte, high byte	mV
Remaining capacity alarm	0x08/0x09	16 bits: low byte, high byte	mAh
FLAGS1	0x0a	8 bits	N/A
FLAGS2	0x0b	8 bits	N/A
Current measurement gain	0x0c/0x0d	16 bits: low byte, high byte	N/A
EDV_1	0x0e/0x0f	16 bits: low byte, high byte	mV
EDV_F	0x10/0x11	16 bits: low byte, high byte	mV
Temperature offset	0x12	8 bits	0.1°K
Maximum charge temperature/ΔT/Δt	0x13	8 bits	N/A
Self-discharge rate	0x14	8 bits	N/A
Digital filter	0x15	8 bits	N/A
Current integration gain	0x16/0x17	16 bits: low byte, high byte	N/A
Full charge percentage	0x18	8 bits	N/A
Charge compensation	0x19	8 bits	N/A
Battery voltage offset	0x1a	8 bits	mV
Battery voltage gain	0x1b/0x1c	16 bits: high byte, low byte	N/A
Serial number	0x1d/0x1e	16 bits: low byte, high byte	N/A
Hold-off timer	0x1f	8 bits	N/A
Cycle count	0x20/0x21	16 bits: low byte, high byte	N/A
Maintenance charge current	0x22/0x23	16 bits: low byte, high byte	mA
Reserved	0x24/0x31	–	–
Design voltage	0x32/0x33	16 bits: low byte, high byte	mV
Specification information	0x34/0x35	16 bits: low byte, high byte	N/A
Manufacturer date	0x36/0x37	16 bits: low byte, high byte	N/A
Reserved	0x38/0x3f	–	–
Manufacturer name	0x40/0x4f	8 + 120 bits	N/A
Device name	0x50/0x5f	8 + 120 bits	N/A
Chemistry	0x60/0x6f	8 + 120 bits	N/A
Manufacturer data	0x70/0x7f	8 +120 bits	N/A

N/A = Not applicable; data packed or coded. See “Programming the bq2092” for details.

Voltage Thresholds

In conjunction with monitoring V_{SR} for charge/discharge currents, the bq2092 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

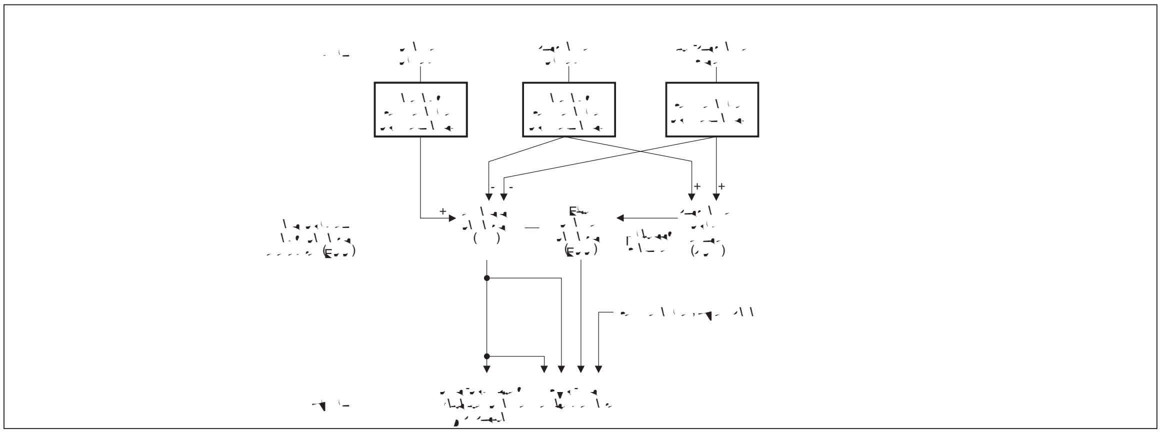


Figure 2. Operational Overview

2. D C (DC):

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

3. C ( ):

RM counts up during charge to a maximum value of FCC and down during discharge and self-discharge to 0. RM is reset to 0000Ah when EDV1 = 1 and a valid charge is 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 when the battery pack is under bq2092 charge control. See the Charge Control section for further details.

4. D C (DC):

The DCR counts up during discharge independent of RM and can continue increasing after RM has decremented to 0. Before 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 valid discharge to V_{EDV1} if:

- 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) indicates whether the present discharge is valid for 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 V_{SR} input. If charge activity is detected, the bq2092 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 rate and temperature.

The bq2092 determines charge activity sustained at a continuous rate equivalent to $V_{SRO} > |V_{SRD}|$. **A**

10 A. Once a valid charge is detected, charge 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 bq2092 continuously decrements RM and increments DCR for self-discharge based on time and temperature. The self-discharge rate is dependent on the battery chemistry. The bq2092 self-discharge estimation rate is externally programmed in EEPROM and can be programmed from 0 to 25% per day at 20-30°C. This rate doubles every 10°C increase until T > 70°C or is halved every 10° decrease until T < 10°C.

The self-discharge estimate reduces RM by 0.39% of its current value at time intervals spaced so that the average reduction equals the programmed value adjusted for temperature. The EEPROM program constant is the 2's complement of 52.73/ , where = %/ self-discharge rate desired at 25°C.

Charge Control

The bq2092 supports SBD charge control by broadcasting ChargingCurrent() and ChargingVoltage() to the Smart Charger address. Smart Charger broadcasts can in full charge percentage, RM is set to full charge percentage of FCC on valid charge termination. If RM is above the full charge percentage, RM is not modified.

Count Compensations

Charge activity is compensated for temperature and state-of-charge before updating the RM and/or DCR. RM is compensated for temperature before updating the RM register. 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. For Li-Ion chemistry cells, the charge efficiency is unity for all cases. The charge efficiency for nickel chemistry cells, however, is adjusted using the following equation:

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

where RelativeStateofCharge $\leq$ FullChargePercentage

and Q_{EFC} is the programmed fast charge efficiency varying from .75 to .99.

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

where RelativeStateofCharge $\geq$ FullChargePercentage

and Q_{ETC} is the programmed maintenance (trickle) charge efficiency varying from 0.50 to 0.97.

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

$$Q_{ET} = 0 \text{ if } T < 30°C$$

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

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

Remaining Capacity Compensation

The bq2092 adjusts the RM as a function of temperature. This adjustment accounts for the reduced capacity of the battery at colder temperatures. The following equation is used to adjust RM:

If $T \geq 5°C$

RemainingCapacity =
Nominal Available Capacity (NAC)

If $T < 5°C$

$$RM() = NAC() \ (1 + TCC * (T - 5°C))$$

Where T = temperature °C

TCC = 0.004

Table 2. Typical Digital Filter Settings

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

RM adjusts upward to Nominal Available Capacity as the temperature increases.

Digital Magnitude Filter

The bq2092 has a programmable digital filter to eliminate charge and discharge counting below a set threshold. Table 2 shows typical digital filter settings. The proper digital filter setting can be calculated using the following equation.

$$|V_{SRD} (mV)| = 45 / DMF$$

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 valid discharge occurs and FCC is updated (see the DCR description on page 6). 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 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_{SRO} is between V_{SRQ} and V_{SRD}.

Display

The bq2092 can directly display capacity information using low-power LEDs. The bq2092 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 25% of the FCC.

Table 3. bq2092 Current-Sensing Errors

Symbol	Parameter	Typical	Maximum	Units	Notes
V_{OS}	Offset referred to V_{SR}	± 50	± 150	µV	$\overline{DISP}$ = V_{CC}.
INL	Integrated non-linearity error	± 2	± 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	± 1	± 2	%	Measurement repeatability given similar operating conditions.

In absolute mode, each segment represents a fixed amount of charge, 25% of the design capacity. 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.

The displayed capacity is compensated for the present battery temperature. The displayed capacity varies as temperature varies, indicating the available charge at the present conditions.

When $\overline{DISP}$ is tied to V_{CC}, the SEG_{1-4} outputs are inactive. When $\overline{DISP}$ is left floating, the display becomes active whenever the bq2092 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.

The segment outputs are modulated as two banks of two, with segments 1 and 3 alternating with segments 2 and 4. The segment outputs are modulated at approximately 100Hz with each segment bank active for 30% of the period.

SEG_1 blinks at a 4Hz rate whenever V_{SB} has been detected to be below V_{EDV1} (EDV_1 = 1), indicating a low-battery condition. V_{SB} below V_{EDVF} (EDV_F = 1) disables the display output.

Microregulator

The bq2092 can operate directly from three nickel chemistry cells. To facilitate the power supply requirements of the bq2092, an REF output is provided to regulate an external low-threshold n-FET. A micropower source for the bq2092 can be inexpensively built using the FET and an external resistor; see Figure 1. Note that an optional zener diode may be necessary to limit V_{CC} during charge.

Communicating With the bq2092

The bq2092 includes a simple two-pin (SCC and SCD) bidirectional serial data interface. A host processor uses the interface to access various bq2092 registers; see Table 4. This allows battery characteristics to be easily monitored. The open-drain SCD and SCC pins on the bq2092 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 bq2092. The command directs the bq2092 to either store the next data received to a register specified by the command byte or output the data specified by the command byte.

bq2092 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 bq2092. (See Figure 3.)

Host-to-bq2092 Message Protocol

The Bus Host communicates with the bq2092 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-bq2092 Messages (see Table 4)

ManufacturerAccess() (0x00)

This optional function is not operational for the bq2092.

RemainingCapacityAlarm() (0x01)

This function sets or returns the low-capacity alarm value. When RM falls below the RemainingCapacityAlarm value, the Remaining_Capacity_Alarm bit is set in BatteryStatus (0x16). The system may alter this alarm value during operation.

Function	Code	Access	Units	Defaults[1]
ManufacturerAccess	0x00	read/write	-	-
RemaningCapacityAlarm	0x01	read/write	unsigned int.	E[2]
RemainingTimeAlarm	0x02	read/write	unsigned int.	10
BatteryMode	0x03	read/write	bit flag	-
Temperature	0x08	read	0.1°K	-
Voltage	0x09	read	mV	-
Current	0x0a	read	mA	0000h
AverageCurrent	0x0b	read	mA	0000h
MaxError	0x0c	read	percent	100
RelativeStateOfCharge	0x0d	read	percent	0000h
AbsoluteStateOfCharge	0x0e	read	percent	0000h
RemainingCapacity	0x0f	read	mAh	0000h
FullChargeCapacity	0x10	read	mAh	E[2]
RunTimeToEmpty	0x11	read	minutes	-
AverageTimeToEmpty	0x12	read	minutes	-
Reserved	0x13	-	-	-
ChargingCurrent	0x14	read	mA	E[2]
ChargingVoltage	0x15	read	mV	E[2]
BatteryStatus	0x16	read	number	0000h
CycleCount	0x17	read	count	E[2]
DesignCapacity	0x18	read	mAh	E[2]
DesignVoltage	0x19	read	mV	E[2]
SpecificationInfo	0x1a	read	number	E[2]
ManufactureDate	0x1b	read	unsigned int	E[2]
SerialNumber	0x1c	read	number	E[2]
Reserved	0x1d - 0x1f	-	-	-
ManufacturerName	0x20	read	string	E[2]
DeviceName	0x21	read	string	E[2]
DeviceChemistry	0x22	read	string	E[2]
ManufacturerData	0x23	read	string	E[2]
FLAGS1 and FLAGS2	0x2f	read	bit flag	E[2]
Endof DischargeVoltage1	0x3e	read	mV	E[2]
EndofDischargeVoltageFinal	0x3f	read	mV	E[2]

20 202,

Input/Output: unsigned integer. This sets/returns the value where the Remaining Capacity Alarm bit is set in BatteryStatus.

RemainingTimeAlarm() (0x02)

This function sets or returns the low remaining time alarm value. When the AverageTimeToEmpty (0x12) falls below this value, the Remaining_Time_Alarm bit in BatteryStatus is set. The default value for this register is set in EEPROM. The system may alter this alarm value during operation.

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

BatteryMode() (0x03)

This read/write word selects the various battery operational modes. The bq2092 supports the battery capacity information specified in mAh. This function also determines whether the bq2092 charging values are broadcasted to the Smart Battery Charger address.

Writing bit 14 to 1 disables voltage and current Smart Battery Charger messages. Bit 14 is reset to 0 once the pack is removed from the system (SCC and SCD = 0 for greater than 2 seconds.)

Writing bit 13 to 1 disables all Smart Battery Charger messages including alarm messages. This bit remains set until overwritten. Programming bit 3 of FLAGS2 in EEPROM (EE 0x0b) initializes bit 13 of BatteryMode to 1.

Temperature() (0x08)

This read-only word returns the cell-pack's internal temperature (0.1°K).

Output: unsigned integer. Returns 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 battery terminal voltage in mV

Units: mV

Range: 0 to 65,535 mV

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 32,767 mA for charge or 0 to –32,768 mA 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. For the bq2092 Current = AverageCurrent. 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 32,767 mA for charge or 0 to –32,768 mA for discharge

Granularity: 0.2% of the DesignCapacity or better

Accuracy: ±1% of the DesignCapacity after calibration

MaxError() (0x0c)

This read-only word returns the expected margin of error (%).

Output: unsigned integer. Returns percent uncertainty

Units: %

Range: 0 to 100%

RelativeStateOfCharge() (0x0d)

This read-only word returns the predicted remaining battery capacity expressed as a percentage of FullChargeCapacity (%). [illegible] C [illegible] 10,400 A .

Output: unsigned integer. Returns the percent of remaining capacity

Units: %

Range: 0 to 100%

Granularity: 1%

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%. **A** [illegible] **C** [illegible] **10,400 A**.

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

Units: %

Range: 0 to 65,535 %

Granularity: 1% or better

Accuracy: ±MaxError

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 65,535 mAh

Granularity: 0.2% of DesignCapacity or better

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.

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

Units: mAh

Range: 0 to 65,535 mAh

Granularity: 0.2% of DesignCapacity or better

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 65,534 minutes

Granularity: 2 minutes 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 65,534 minutes

Granularity: 2 minutes or better

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

ChargingCurrent() (0x14)

If enabled, the bq2092 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 65,534 mA

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 bq2092 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 cur-

ManufacturerName() (0x20)

This read-only string returns a character string where the

Where CHM is:

0 Selects Nickel

1 Selects Li-Ion

Bit 4, the *C*[illegible] *C*[illegible] flag (CC), determines whether a bq2092-based charge termination will set RM to a user-defined programmable full charge capacity.

The CC values are:

Where CC is:

0 RM is not modified on valid bq2092 charge termination

1 RM is set to a programmable percentage of the FCC when a valid bq2092 charge termi-

WRINH should be set at the time of pack assembly and tested to prevent special read-write registers from accidental over-writing.

The [illegible] ***D***[illegible] 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:

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 [illegible] ***D***[illegible]

Table 7. Error Codes (BatteryStatus() (0x16))

Error	Code	Access	Description
OK	0x0000	read/write	bq2092 processed the function code without detecting any errors
Busy	0x0001	read/write	bq2092 is unable to process the function code at this time
NotReady	0x0002	read/write	bq2092 cannot read or write the data at this time—try again later
UnsupportedCommand	0x0003	read/write	bq2092 does not support the requested function code
AccessDenied	0x0004	write	bq2092 detected an attempt to write to a read-only function code
Overflow/Underflow	0x0005	read/write	bq2092 detected a data overflow or underflow
BadSize	0x0006	write	bq2092 detected an attempt to write to a function code with an incorrect size data block
UnknownError	0x0007	read/write	bq2092 detected an unidentifiable error

Reading the bq2092 after an error clears the error code.

Table 8. Status Bits

Alarm Bits		
Bit Name	**Set When:**	**Reset When:**
OVER_CHARGE_ALARM	bq2092 detects over-temperature or ΔT/Δt. ([illegible]).	A discharge occurs or when ΔT/Δt, or over-temperature, ceases during charge.
TERMINATE_CHARGE_ALARM	bq2092 detects over-current, over-voltage, over-temperature, or ΔT/Δt conditions exist during charge. Charging current is set to zero, indicating a charge suspend.	A discharge occurs or when all conditions causing the event cease.
ΔT/Δt_ALARM	bq2092 detects the rate-of-temperature increase is above the programmed value (valid termination)	The temperature rise falls below the programmed rate.
OVER_TEMP_ALARM	bq2092 detects that its internal temperature is greater than the programmed value (valid termination).	Internal temperature falls below 50°C.
TERMINATE_DISCHARGE_ALARM	bq2092 determines that it has supplied all the charge that it can without being damaged (EDVF).	$V_{BAT} > V_{EDVF}$ signifying that the battery has reached a state of charge sufficient for it to once again safely supply power.
REMAINING_CAPACITY_ALARM	bq2092 detects that the RemainingCapacity() is less than that set by the RemainingCapacity() 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	bq2092 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	bq2092 is set when the bq2092 has reached a full or empty state.	Battery detects that power-on or user-initiated reset has occurred.
DISCHARGING	bq2092 determines that it is not being charged.	Battery detects that it is being charged.
FULLY_CHARGED	bq2092 determines a valid charge termination. RM will then be set to full charge percentage if necessary.	RM discharges below the full charge percentage
FULLY_DISCHARGED	bq2092 determines that it has supplied all the charge that it can without being damaged (that is, continued use will result in permanent capacity loss to the battery)	RelativeStateOfCharge is greater than or equal to 20%

Table 9. Example Register Contents

Description	EEPROM Address Low Byte	EEPROM Address High Byte	EEPROM Hex Contents Low Byte	EEPROM Hex Contents High Byte	Example Values	Notes
Design Capacity	0x00	0x01	08	07	1800mAh	This sets the initial full charge battery capacity stored in FCC. FCC is updated with the actual full to empty discharge capacity after a valid discharge from RM = FCC to Voltage() = EDV1.
Initial Battery Voltage	0x02	0x03	30	2a	10800mV	This register is used to set the battery voltage on reset.
Fast charging current	0x04	0x05	08	07	1800mA	This register is used to set the fast charge current for the Smart Charger.
Fast charging voltage	0x06	0x07	c4	3b	15300mV	This register is used to set the fast charge voltage for the Smart Charger.
Remaining Capacity Alarm	0x08	0x09	b4	00	180mAh	This value represents the low capacity alarm value.
FLAGS1	0x0a		10			FLAGS1 should be set to 10h before pack shipment to inhibit undesirable writes to the bq2092. (WRINH = 1.)
FLAGS2	0x0b		90		Li-Ion = b0h NiMH = 90h	See FLAGS2 register for the bit description and the proper value for programming FLAGS2. Selects relative display mode, selects NiMH compensation factors, and enables bq2092 Smart Charger control.
Current Measurement Gain[1]	0x0c	0x0d	ee	02	37.5/.05	The current gain measurement and current integration gain are related and defined for the bq2092 current measurement. 0x0c = 37.5/sense resistor value in ohms.
EDV1	0x0e	0x0f	16	db	9450mV (1.05V/cell)	The value programmed is the two's complement of the threshold voltage in mV.
EDVF	0x10	0x11	d8	dc	9000mV (1.0V/cell)	The value programmed is the two's complement of the threshold voltage in mV.

1. Can be adjusted to calibrate the battery pack.

Table 9. 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
Temperature Offset[1]	0x12		32		5.0°C	The default value is 0x80 (12.8° + nominal value). Actual temp (20°C) = Nominal temp. (15°C) - temp. offset (5°C) where temperature determined by the bq2092 can be adjusted from 0° to 25.5° (Temperature offset (0-255) $*$ 0 .1) + nominal value temp.
Maximum Charge Temperature, ΔTemp.	0x13		87		MaxT = 61.2°C (74 - (8 * 1.6)) ΔT = 3°C ((7*2) + 16)/10	Maximum charge temperature is 74 - (mt x 1.6)°C (mt = upper nibble). The ΔT step is (dT*2+16)/10°C (dT = lower nibble).
Self-Discharge Rate	0x14		dd		1.5%	This packed field is the two's complement of 52.73/x, where x = %/day is the self-discharge rate desired at room temperature.
Digital Filter	0x15		96		0.3mV	This field is used to set the digital magnitude filter as described in Table 2.
Current Integration Gain[1]	0x16	0x17	40	00	3.2/0.05	This field represents the following: 3.2/sense resistor in ohms. It is used by the bq2092 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.
Full Charge Percentage	0x18		a0		96% = 60h 2's (60h) = a0h	This packed field is the two's complement of the desired value in RM when the bq2092 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.
Charge Compensation	0x19		bd		85% = maintenance comp. 95% = fast charge comp.	This packed value is used to set the fast charge and maintenance charge efficiency for nickel-based batteries. The upper nibble adjusts the maintenance charge compensation; the lower nibble adjusts the fast charge compensation. Maintenance, upper nibble = (eff% $*$ 256 - 128)/8 Fast charge, lower nibble = (eff% $*$ 256 - 192)/4
Battery Voltage Offset[1] (V_{OFF})	0x1a		0a		10mV	This value is used to adjust the battery voltage offset according to the following: Voltage () = (V_{SB} (mV) + V_{OFF}) $*$ Voltage Gain
Voltage Gain[1]	0x1b	0x1c	09	17	9.09	Voltage gain is packed as two units. For example, (R_4 + R_5)/R_4 = 9.09 would be stored as: whole number stored in 0x1b (=09h) and the decimal component stored in 0x1c as 256 x 0.09 = 23.
Serial Number	0x1d	0x1e	12	27	10002	This contains the optional pack serial number.

Table 9. Example Register Contents (Continued)

Description	EEPROM Address		EEPROM Hex Contents		Example Values	Notes
	Low Byte	High Byte	Low Byte	High Byte		
Hold-off Timer/ ΔTime	0x1f		07		320 s hold-off 180 s Δtime	Hold-off time is 20 s * the two's complement of the upper nibble value. ΔT is 20 s * the two's complement of the lower nibble value.
Charge Cycle Count	0x20	0x21	00	00	0	This field contains the charge cycle count and should be set to zero for a new battery.
Maintenance Charge Current	0x22	0x23	64	00	100mA	This field contains the desired maintenance current after fast charge termination by the bq2092.
Reserved	0x24	0x31				
Design Voltage	0x32	0x33	30	2a	10800mV	This is nominal battery pack voltage.
Specification Information	0x34	0x35	00	00		This is the default value for this register.
Manufacturer Date	0x36	0x37	a1	20	May 1, 1996 = 8353	Packed per the ManufactureDate description, which represents May 1, 1996 in this example.

String Description	Address	0x X0	0x X1	0x X2	0x X3	0x X4	0x X5	0x X6	0x X7	0x X8	0x X9	0x Xa	0x Xb-Xf
Reserved	0x38-0x3f	00	00	00	00	00	00	00	00	00	00	00	00-00
Manufacturer's Name	0x40-0x4f												

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 (see the bq2092 application note for details).
T_{OPR}	Operating temperature	0	+70	°C	Commercial

Permanent device damage may occur if **A**[illegible] 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

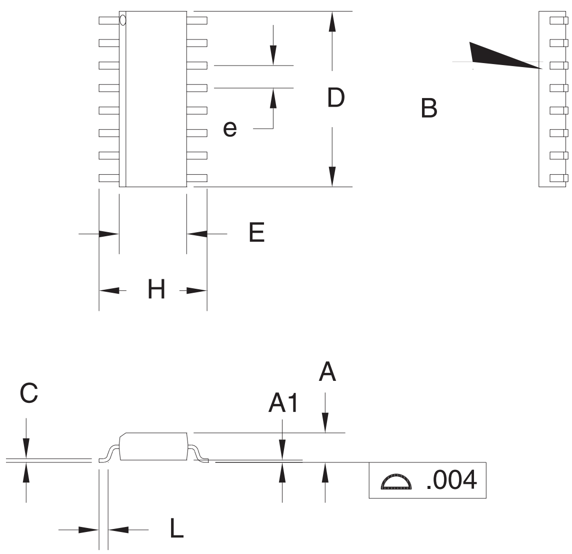
The accuracy of the voltage measurement may be improved by adjusting the battery voltage offset and gain, stored in external EEPROM. For proper operation, V_{CC} should be 1.5V greater than V_{SB}.

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

Symbol	Parameter	Minimum	Typical	Maximum	Unit	Notes
V_{CC}	Supply voltage	3.0	4.25	5.5	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	-	M	

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	250		ns	SCD
		4.7		µSMB-234F11.7	

16-Pin SOIC Narrow (SN)



16-Pin SN (0.150" SOIC)

Dimension	Inches		Millimeters	
	Min.	Max.	Min.	Max.
A	0.060	0.070	1.52	1.78
A1	0.004	0.010	0.10	0.25
B	0.013	0.020	0.33	0.51
C	0.007	0.010	0.18	0.25
D	0.385	0.400	9.78	10.16
E	0.150	0.160	3.81	4.06
e	0.045	0.055	1.14	1.40
H	0.225	0.245	5.72	6.22
L	0.015	0.035	0.38	0.89

Data Sheet Revision History

Change No.	Page No.	Description	Nature of Change
1	21	Correction in the Self-Discharge Rate EEPROM Hex contents	Was: f0 Is: df
1	21	Correction in the Self-Discharge Rate example values	Was: 0.15C Is: 1.5%
2	3	Updated application diagram	
2	5	Added VSB should not exceed 2.4V	
2	12	Clarified operation of bits 13 and 14 in BatteryMode()	
2	13	Clarified invalid data indication in RunTimeToEmpty()	
2	13	Clarified invalid data indication in AverageTimeToEmpty()	
2	21	Update formula for voltage divider in Voltage Gain.	

Note: Change 1 = Nov. 1997 B changes from April 1997.
Change 2 = June 1999 C changes from Nov. 1997 B.

Ordering Information

bq2092 _ _

Temperature Range:
blank = Commercial (-20 to +70°C)

Package Option:
SN = 16-pin narrow SOIC

Device:
bq2092 Gas Gauge IC With SMBus-Like Interface

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Top-Side Markings (4)	Samples
BQ2092SN-A309	OBSOLETE	SOIC	D	16		TBD	Call TI	Call TI	0 to 70		
BQ2092SN-A309TR	OBSOLETE	SOIC	D	16		TBD	Call TI	Call TI	0 to 70		
BQ2092SN-A311	ACTIVE	SOIC	D	16	40	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	0 to 70	2092 A311	Samples
BQ2092SN-A311G4	ACTIVE	SOIC	40								

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