

## Low-Cost NiCd/NiMH Gas Gauge IC

### Features

- Accurate measurement of available capacity in NiCd or NiMH batteries
- Low-cost battery management solution for pack integration
  - As little as ½ square inch of PCB for complete circuit
  - Low operating current (120µA typical)
  - Less than 100nA of data retention current
- High-speed (5kb/s) single-wire communication interface (HDQ bus) for critical battery parameters
- Communication with an external charge controller such as the bq2004
- Direct drive of remaining capacity LEDs
- Automatic rate and temperature compensation of measurements
- 16-pin narrow SOIC

### General Description

The bq2014H NiCd/NiMH Gas Gauge IC is intended for battery-pack or in-system installation to maintain an accurate record of available battery capacity. The IC monitors a voltage drop across a sense resistor connected in series between the negative battery terminal and ground to determine charge and discharge activity of the battery. Compensations for battery temperature, self-discharge, and rate of discharge are applied to the charge counter to provide available capacity information across a wide range of operating conditions. Battery capacity is automatically recalibrated, or “learned,” in the course of a discharge cycle from full to empty.

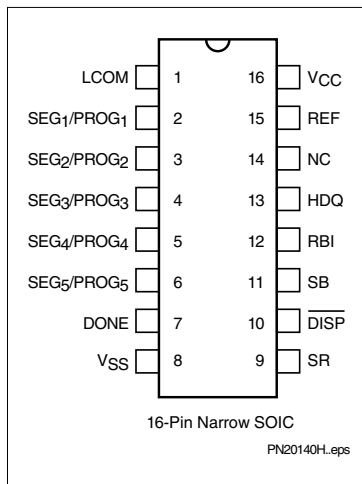
Nominal available capacity may be directly indicated using a five-segment LED display. The bq2014H also supports a simple single-line

bidirectional serial link to an external processor (common ground). The 5kb/s HDQ bus interface reduces communications overhead in the external microcontroller.

Internal registers include available capacity and energy, temperature, voltage and current, and battery status. The external processor may also overwrite some of the bq2014H gas gauge data registers.

The bq2014H can operate from the batteries in the pack. The REF output and an external transistor allow a simple, inexpensive voltage regulator to supply power to the circuit from the cells.

### Pin Connections



### Pin Names

|                                     |                                   |                          |                                       |
|-------------------------------------|-----------------------------------|--------------------------|---------------------------------------|
| LCOM                                | LED common output                 | V <sub>SS</sub>          | System ground                         |
| SEG <sub>1</sub> /PROG <sub>1</sub> | LED segment 1/<br>program 1 input | SR                       | Sense resistor input                  |
| SEG <sub>2</sub> /PROG <sub>2</sub> | LED segment 2/<br>program 2 input | $\overline{\text{DISP}}$ | Display control input                 |
| SEG <sub>3</sub> /PROG <sub>3</sub> | LED segment 3/<br>program 3 input | SB                       | Battery sense input                   |
| SEG <sub>4</sub> /PROG <sub>4</sub> | LED segment 4/<br>program 4 input | RBI                      | Register backup input                 |
| SEG <sub>5</sub> /PROG <sub>5</sub> | LED segment 5/<br>program 5 input | HDQ                      | Serial communications<br>input/output |
| DONE                                | Charge complete<br>input          | NC                       | No connect                            |
|                                     |                                   | REF                      | Voltage reference output              |
|                                     |                                   | V <sub>CC</sub>          | Supply voltage                        |

## bq2014H

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### Pin Descriptions

#### LCOM LED common output

Open-drain output that switches  $V_{CC}$  to source current for the LEDs. The switch is off during initialization to allow reading of the soft pull-up or pull-down program resistors. LCOM is also high impedance when the display is off.

#### SEG<sub>1</sub>–SEG<sub>5</sub> LED display segment outputs (dual function with PROG<sub>1</sub>–PROG<sub>5</sub>)

Outputs that each may activate an LED to sink the current sourced from LCOM.

#### PROG<sub>1</sub>–PROG<sub>2</sub> Programmed full count selection inputs (dual function with SEG<sub>1</sub>–SEG<sub>2</sub>)

Three-level input pins that define the programmed full count (PFC) thresholds described in Table 2.

#### PROG<sub>3</sub>–PROG<sub>4</sub> Power gauge scale selection inputs (dual function with SEG<sub>3</sub>–SEG<sub>4</sub>)

Three-level input pins that define the scale factor described in Table 2.

#### PROG<sub>5</sub> Self-discharge rate selection (dual function with SEG<sub>5</sub>)

Three-level input pin that defines the self-discharge and battery-compensation factors as shown in Table 1.

#### DONE Charge complete input

Communicates the status of an external charge-controller such as the bq2004 Fast-Charge IC to the bq2014H. Note: This pin must be pulled down to  $V_{SS}$  using a 200k $\Omega$  resistor.

#### VSS Ground

#### SR Sense resistor input

The voltage drop ( $V_{SR}$ ) across the sense resistor  $R_S$  is monitored and integrated over time to interpret charge and discharge activity.  $V_{SR} < V_{SS}$  indicates discharge, and  $V_{SR} > V_{SS}$  indicates charge. The effective voltage drop,  $V_{SRO}$ , as seen by the bq2014H is  $V_{SR} + V_{OS}$ .

#### $\overline{DISP}$

#### Display control input

$\overline{DISP}$  high disables the LED display.  $\overline{DISP}$  tied to  $V_{CC}$  allows PROG<sub>X</sub> to connect directly to  $V_{CC}$  or  $V_{SS}$  instead of through a pull-up or pull-down resistor.  $\overline{DISP}$  floating allows the LED display to be active during charge.  $\overline{DISP}$  low activates the display. See Table 1.

#### SB

#### Secondary battery input

Monitors the battery cell-voltage potential through a high-impedance resistive divider network for end-of-discharge voltage (EDV) thresholds and for battery-removed detection.

#### RBI

#### Register backup input

Provides backup potential to the bq2014H registers while  $V_{CC} \leq 3V$ . A storage capacitor or a battery can be connected to RBI.

#### HDQ

#### Serial communication input/output

This is the open-drain bidirectional communications port.

#### NC

#### No connect

#### REF

#### Voltage reference output

REF provides a voltage reference output for an optional microregulator.

#### VCC

#### Supply voltage input

## Functional Description

### General Operation

The bq2014H determines battery capacity by monitoring the amount of current input to or removed from a rechargeable battery. The bq2014H measures discharge and charge currents, measures battery voltage, estimates self-discharge, monitors the battery for low battery-voltage thresholds, and compensates for temperature and charge/discharge rate. Current measurement is made by monitoring the voltage across a small-value series sense resistor between the negative battery terminal and ground. The bq2014H compensates the nominal available capacity register for discharge rate and temperature and reports the compensated available capacity. The bq2014H uses the compensated available

capacity to drive the LED display. In addition, the bq2014H estimates the available energy using the average battery voltage during the discharge cycle and remaining compensated available capacity.

Figure 1 shows a typical battery pack application of the bq2014H using the LED display capability as a charge-state indicator. The bq2014H is configured to display capacity in relative display mode. The relative display mode uses the last measured discharge capacity of the battery as the battery “full” reference. A push-button display feature is available for momentarily enabling the LED display.

The bq2014H monitors the charge and discharge currents as a voltage across a sense resistor. (See  $R_S$  in Figure 1.) A filter between the negative battery terminal and the SR pin is required.

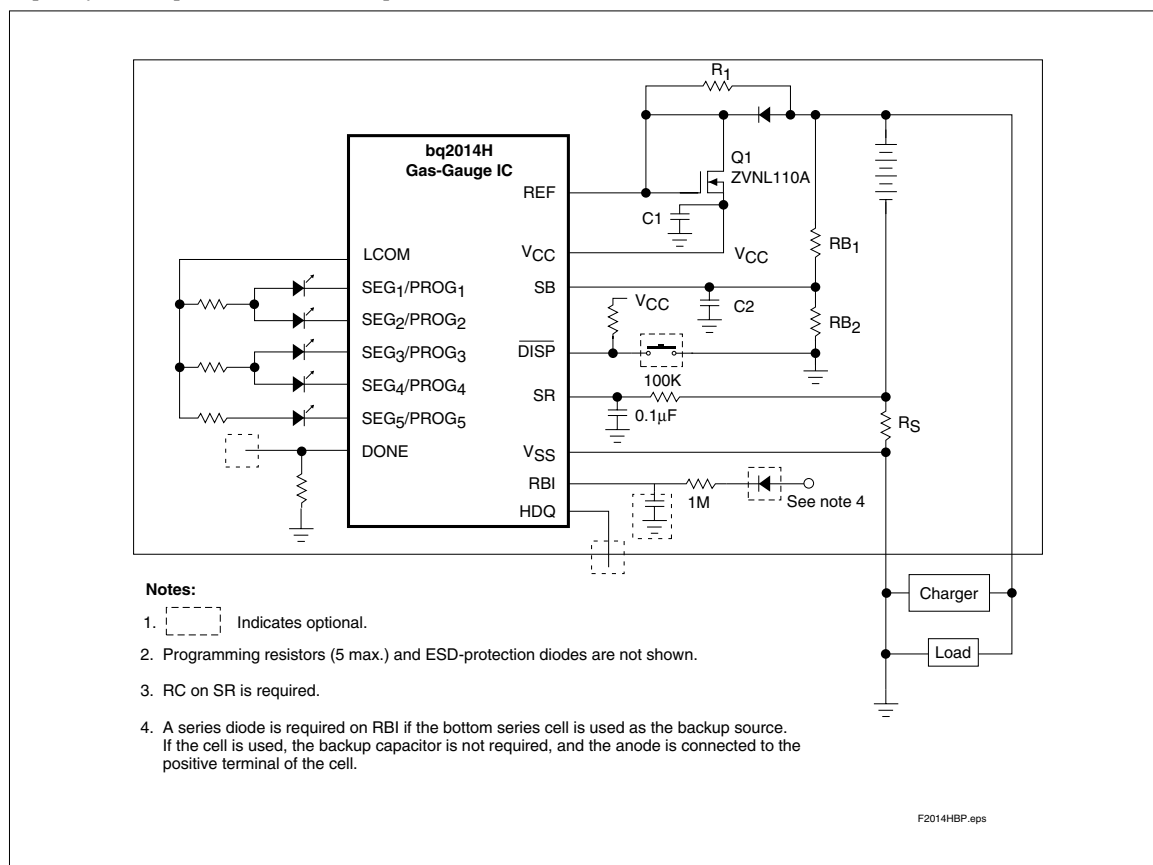


Figure 1. Battery Pack Application Diagram—LED Display

# bq2014H

## Voltage Thresholds

In conjunction with monitoring  $V_{SR}$  for charge/discharge currents, the bq2014H monitors the battery potential through the SB pin for the end-of-discharge voltage (EDV) thresholds.

The EDV threshold levels are used to determine when the battery has reached an “empty” state.

The EDV thresholds for the bq2014H are programmable with the default values fixed as follows:

$$EDV1 \text{ (first)} = 0.76V$$

$$EDVF \text{ (final)} = EDV1 - 0.025V = 0.735V$$

The battery voltage divider (RB1 and RB2 in Figure 1) is used to scale these values to the desired threshold.

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 is disabled if the discharge rate is greater than 2C (OVL D Flag = 1) and resumes  $\frac{1}{2}$  second after the rate falls below 2C. The  $V_{SB}$  value is available over the serial port.

## RBI Input

The RBI input pin is used with a storage capacitor or external supply to provide backup potential to the internal bq2014H registers when  $V_{CC}$  drops below 3.0V.  $V_{CC}$  is output on RBI when  $V_{CC}$  is above 3.0V. If using an external supply (such as the bottom series cell) as the backup source, an external diode is required for isolation.

## Reset

The bq2014H can be reset by removing  $V_{CC}$  and grounding the RBI pin for 15 seconds or by commands over the serial port. The serial port reset command sequence requires writing 00h to register PPFC (address = 1Eh) and then writing 00h to register LMD (address = 05h).

## Temperature

The bq2014H internally determines the temperature in 10°C steps centered from approximately -35°C to +85°C. The temperature steps are used to adapt charge and discharge rate compensations, self-discharge counting, and available charge display translation.

The temperature range is available over the serial port in 10°C increments, as shown in the following table

| TMP (hex) | Temperature Range |
|-----------|-------------------|
| 0x        | < -30°C           |
| 1x        | -30°C to -20°C    |
| 2x        | -20°C to -10°C    |
| 3x        | -10°C to 0°C      |
| 4x        | 0°C to 10°C       |
| 5x        | 10°C to 20°C      |
| 6x        | 20°C to 30°C      |
| 7x        | 30°C to 40°C      |
| 8x        | 40°C to 50°C      |
| 9x        | 50°C to 60°C      |
| Ax        | 60°C to 70°C      |
| Bx        | 70°C to 80°C      |
| Cx        | > 80°C            |

## Layout Considerations

The bq2014H 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:

- The capacitors (C1 and C2) should be placed as close as possible to the  $V_{CC}$  and SB pins, respectively, 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 should be placed as close as possible to the SR pin.
- The sense resistor ( $R_S$ ) should be as close as possible to the bq2014H.

## Gas Gauge Operation

The operational overview diagram in Figure 2 illustrates the operation of the bq2014H. The bq2014H accumulates a measure of charge and discharge currents, as well as an estimation of self-discharge. The accumulated charge and discharge currents are adjusted for temperature and rate to provide the indication of compensated available capacity to the host system or user.

The main counter, Nominal Available Capacity (NAC), represents the available battery capacity at any given time. Battery charging increments the NAC register, while battery discharging and self-discharge decrement the NAC register and increment the DCR (Discharge Count Register).

The Discharge Count Register is used to update the Last Measured Discharge (LMD) register only if a complete battery discharge from full to empty occurs without any partial battery charges. Therefore, the bq2014H adapts its capacity determination based on the actual conditions of discharge.

The battery's initial capacity equals the Programmed Full Count (PFC) shown in Table 2. Until LMD is updated, NAC counts up to but not beyond this threshold during subsequent charges. This approach allows the gas gauge to be charger-independent and compatible with any type of charge regime.

### 1. Last Measured Discharge (LMD) or learned battery capacity:

LMD is the last measured discharge capacity of the battery. On initialization (application of  $V_{CC}$  or battery replacement),  $LMD = PFC$ . During subsequent discharges, the LMD is updated with the 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 LMD register. The LMD also serves as the 100% reference threshold used by the relative display mode.

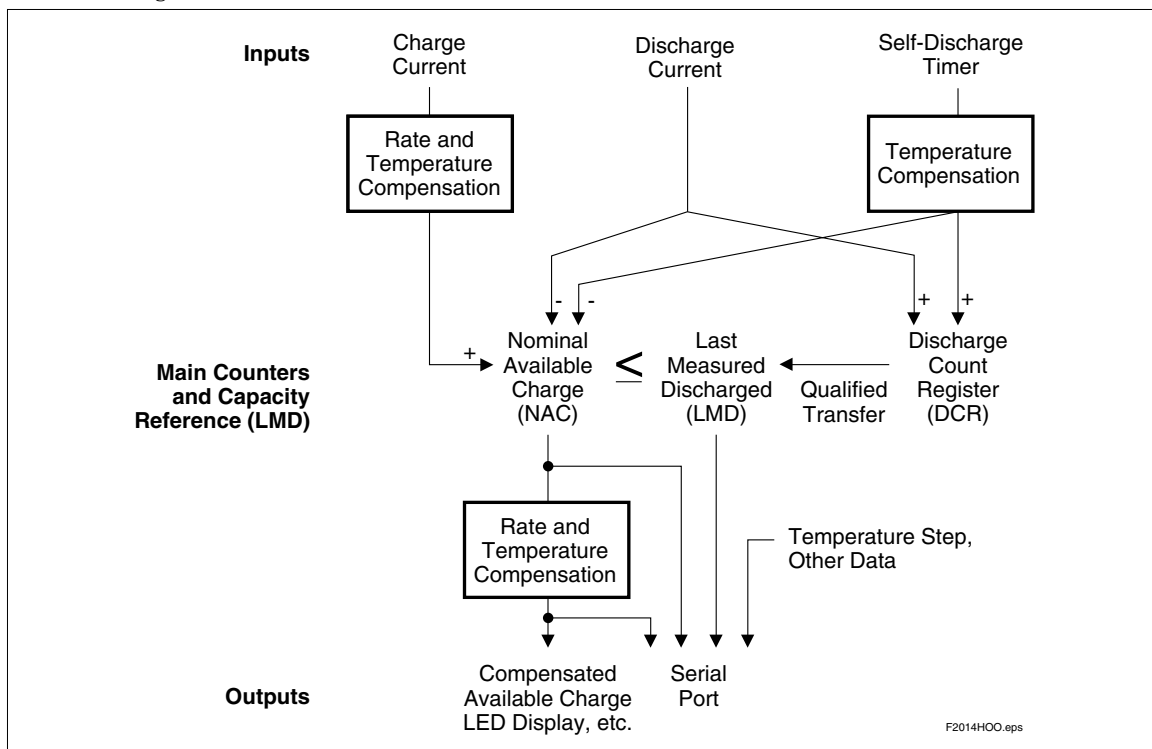


Figure 2. Operational Overview

## bq2014H

### 2. Programmed Full Count (PFC) or initial battery capacity:

The initial LMD and gas gauge rate values are programmed by using PROG<sub>1</sub>–PROG<sub>4</sub>. The bq2014H is configured for a given application by selecting a PFC value from Table 2. The correct PFC may be determined by multiplying the rated battery capacity in mAh by the sense resistor value:

$$\text{Battery capacity (mAh)} * \text{sense resistor } (\Omega) = \text{PFC (mVh)}$$

Selecting a PFC slightly less than the rated capacity provides a conservative capacity reference until the bq2014H “learns” a new capacity reference.

### Example: Selecting a PFC Value

Given:

Sense resistor = 0.05Ω  
 Number of cells = 10  
 Capacity = 3500mAh, NiMH  
 Current range = 50mA to 1A  
 Relative display mode  
 Self-discharge =  $\frac{NAC}{47}$  per day @ 25°C  
 Voltage drop over sense resistor = 2.5mV to 50mV  
 Nominal discharge voltage = 1.2V

Therefore:

$$3500\text{mAh} * 0.05\Omega = 175\text{mVh}$$

**Table 1. Self-Discharge and Capacity Compensation**

| Pin Connection | PROG <sub>5</sub><br>Self-Discharge Rate | DISP<br>Display State |
|----------------|------------------------------------------|-----------------------|
| H              | Disabled                                 | LEDs disabled         |
| Z              | $\frac{NAC}{64}$                         | LEDs on when charging |
| L              | $\frac{NAC}{47}$                         | LEDs on for 4s        |

**Table 2. bq2014H Programmed Full Count mVh, V<sub>SR</sub> Gain Selections**

| PROG <sub>x</sub>                               |   | Pro-grammed Full Count (PFC) | PROG <sub>4</sub> = L |                       |                       | PROG <sub>4</sub> = Z or H |                       |                       | Units     |
|-------------------------------------------------|---|------------------------------|-----------------------|-----------------------|-----------------------|----------------------------|-----------------------|-----------------------|-----------|
| 1                                               | 2 |                              | PROG <sub>3</sub> = H | PROG <sub>3</sub> = Z | PROG <sub>3</sub> = L | PROG <sub>3</sub> = H      | PROG <sub>3</sub> = Z | PROG <sub>3</sub> = L |           |
| -                                               | - | -                            | SCALE = 1/80          | SCALE = 1/160         | SCALE = 1/320         | SCALE = 1/640              | SCALE = 1/1280        | SCALE = 1/2560        | mVh/count |
| H                                               | H | 49152                        | 614                   | 307                   | 154                   | 76.8                       | 38.4                  | 19.2                  | mVh       |
| H                                               | Z | 45056                        | 563                   | 282                   | 141                   | 70.4                       | 35.2                  | 17.6                  | mVh       |
| H                                               | L | 40960                        | 512                   | 256                   | 128                   | 64.0                       | 32.0                  | 16.0                  | mVh       |
| Z                                               | H | 36864                        | 461                   | 230                   | 115                   | 57.6                       | 28.8                  | 14.4                  | mVh       |
| Z                                               | Z | 33792                        | 422                   | 211                   | 106                   | 53.0                       | 26.4                  | 13.2                  | mVh       |
| Z                                               | L | 30720                        | 384                   | 192                   | 96.0                  | 48.0                       | 24.0                  | 12.0                  | mVh       |
| L                                               | H | 27648                        | 346                   | 173                   | 86.4                  | 43.2                       | 21.6                  | 10.8                  | mVh       |
| L                                               | Z | 25600                        | 320                   | 160                   | 80.0                  | 40.0                       | 20.0                  | 10.0                  | mVh       |
| L                                               | L | 22528                        | 282                   | 141                   | 70.4                  | 35.2                       | 17.6                  | 8.8                   | mVh       |
| V <sub>SR</sub> equivalent to 2 counts/s (nom.) |   |                              | 90                    | 45                    | 22.5                  | 11.25                      | 5.6                   | 2.8                   | mV        |

Select:

PFC = 27648 counts or 173mVh  
 PROG<sub>1</sub> = low  
 PROG<sub>2</sub> = high  
 PROG<sub>3</sub> = float  
 PROG<sub>4</sub> = low  
 PROG<sub>5</sub> = low

The initial full battery capacity is 173mVh (3460mAh) until the bq2014H “learns” a new capacity with a qualified discharge from full to EDV1.

### 3. Nominal Available Capacity (NAC):

NAC counts up during charge to a maximum value of LMD and down during discharge and self-discharge to 0. NAC is reset to 0 on initialization and on the first valid charge following discharge to EDV1. To prevent overstatement of charge during periods of overcharge, NAC stops incrementing when NAC = LMD or  $0.94 * \text{LMD}$  if  $T < 0^{\circ}\text{C}$ .

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

The DCR counts up during discharge independent of NAC and could continue increasing after NAC has decremented to 0. Prior to NAC = 0 (empty battery), both discharge and self-discharge increment the DCR. After NAC = 0, only discharge increments the DCR. The DCR resets to 0 when  $\text{NAC} \geq 0.94 * \text{LMD}$  and a discharge is detected. The DCR does not roll over but stops counting when it reaches FFh.

The DCR value becomes the new LMD value on the first charge after a valid discharge to VEDV1 if all the following conditions are met:

- No valid charge initiations (charges greater than 2 NAC updates where  $\text{VSRO} > \text{VSRQ}$ ) occurred during the period between  $\text{NAC} \geq 0.94 * \text{LMD}$  and EDV1.
- The self-discharge is less than 6.25% of NAC.
- The temperature is  $\geq 0^{\circ}\text{C}$  when the EDV1 level is reached during discharge.
- The discharge begins when  $\text{NAC} \geq 0.94 * \text{LMD}$ .
- VDQ is set.

The valid discharge flag (VDQ) indicates whether the present discharge is valid for LMD update. If the DCR update value is less than  $0.94 * \text{LMD}$ , LMD will only be modified by  $0.94 * \text{LMD}$ . This prevents invalid DCR values from corrupting LMD.

### 5. Scaled Available Energy (SAE):

SAE is useful in determining the available energy within the battery, and may provide a more useful

capacity reference in battery chemistries with sloped voltage profiles during discharge. SAE may be converted to an mWh value using the following formula:

$$E(\text{mWh}) = (\text{SAEH} * 256 + \text{SAEL}) * \frac{1.2 * \text{SCALE} * (\text{RB1} + \text{RB2})}{\text{RS} * \text{RB2}}$$

where RB1, RB2, and RS are resistor values in ohms, as shown in Figure 1. SCALE is the selected scale from Table 2.

### 6. Compensated Available Capacity (CACT)

CACT counts similarly to NAC, but contains the available capacity compensated for discharge rate and temperature.

## Charge Counting

Charge activity is detected based on a positive voltage on the SR input. If charge activity is detected, the bq2014H increments NAC at a rate proportional to VSR and, if enabled, activates the LED display.

The bq2014H counts charge activity when the voltage at the SR input (VSRO) exceeds the minimum charge threshold (VSRQ). A valid charge is detected when NAC has been updated twice without discharging or reaching the digital magnitude filter time-out. Once a valid charge is detected, charge counting continues until VSR, including offset, falls below VSRQ.

## Discharge Counting

Discharge activity is indicated by a negative voltage on the SR input. All discharge counts where VSRO is less than the minimum discharge threshold (VSRD) cause the NAC register to decrement and the DCR to increment.

## Self-Discharge Counting

The bq2014H continuously decrements NAC and increments DCR for self-discharge on the basis of time and temperature.

## Charge/Discharge Current

The bq2014H current-scale registers, VSRH and VSRL, can be used to determine the battery charge or discharge current. See the Current Scale Register description for details.

## Count Compensations

### Charge Compensation

Two charge efficiency compensation factors are used for trickle and fast charge. Trickle charge is defined as a rate of charge  $< C/3$ . The compensation defaults to the fast-charge factor until the actual charge rate is determined.

Temperature adapts the charge rate compensation factors over two ranges between nominal and hot temperatures. The compensation factors are shown below.

| Charge Temperature     | Trickle-Charge Compensation | Fast-Charge Compensation |
|------------------------|-----------------------------|--------------------------|
| $< 40^{\circ}\text{C}$ | 0.81                        | 0.94                     |
| $> 40^{\circ}\text{C}$ | 0.75                        | 0.88                     |

### Compensated Available Capacity

NAC is adjusted for rate of discharge and temperature to derive the CACD and CACT values.

Corrections for the rate of discharge are made by adjusting an internal discharge compensation factor. The discharge factor is based on the discharge rate. This compensation is applied to NAC to derive the value in the CACD register.

The compensation factors during discharge are:

| Approximate Discharge Rate | Rate Efficiency Factor |
|----------------------------|------------------------|
| $< 2\text{C}$              | 100%                   |
| $> 2\text{C}$              | 95%                    |

Temperature compensation during discharge also takes place. At lower temperatures, the compensation factor increases by 0.05 for each  $10^{\circ}\text{C}$  temperature range below  $10^{\circ}\text{C}$ . This compensation is applied to CACD to derive the value in the CACT register. The temperature compensation factor follows the equation

$$\text{Temperature Efficiency Factor} = 1.00 - (0.05 * N)$$

where  $N$  = number of  $10^{\circ}\text{C}$  steps below  $10^{\circ}\text{C}$ .

For example,

$T > 10^{\circ}\text{C}$ : Nominal compensation,  $N = 0$

$0^{\circ}\text{C} < T < 10^{\circ}\text{C}$ :  $N = 1$  (temperature efficiency = 95%)

$-10^{\circ}\text{C} < T < 0^{\circ}\text{C}$ :  $N = 2$  (temperature efficiency = 90%)

$-20^{\circ}\text{C} < T < -10^{\circ}\text{C}$ :  $N = 3$  (temperature efficiency = 85%)

$-20^{\circ}\text{C} < T < -30^{\circ}\text{C}$ :  $N = 4$  (temperature efficiency = 80%)

### Self-Discharge Compensation

The self-discharge compensation is programmed for a nominal rate of  $\frac{1}{64} * \text{NAC}$  per day,  $\frac{1}{47} * \text{NAC}$  per day, or disabled. This is the rate for a battery within the  $20^{\circ}\text{C}$ – $30^{\circ}\text{C}$  temperature range (TMPGG = 6x). This rate varies across 8 ranges from  $<10^{\circ}\text{C}$  to  $>70^{\circ}\text{C}$ , doubling

**Table 3. Self-Discharge Compensation**

| Temperature Step                | Typical Rate        |                      |
|---------------------------------|---------------------|----------------------|
|                                 | PROG5 = Z           | PROG5 = L            |
| $< 10^{\circ}\text{C}$          | $\text{NAC}/_{256}$ | $\text{NAC}/_{188}$  |
| $10\text{--}20^{\circ}\text{C}$ | $\text{NAC}/_{128}$ | $\text{NAC}/_{94}$   |
| $20\text{--}30^{\circ}\text{C}$ | $\text{NAC}/_{64}$  | $\text{NAC}/_{47}$   |
| $30\text{--}40^{\circ}\text{C}$ | $\text{NAC}/_{32}$  | $\text{NAC}/_{23.5}$ |
| $40\text{--}50^{\circ}\text{C}$ | $\text{NAC}/_{16}$  | $\text{NAC}/_{11.8}$ |
| $50\text{--}60^{\circ}\text{C}$ | $\text{NAC}/_{8}$   | $\text{NAC}/_{5.88}$ |
| $60\text{--}70^{\circ}\text{C}$ | $\text{NAC}/_{4}$   | $\text{NAC}/_{2.94}$ |
| $> 70^{\circ}\text{C}$          | $\text{NAC}/_{2}$   | $\text{NAC}/_{1.47}$ |

with each higher temperature step ( $10^{\circ}\text{C}$ ). See Table 3.

### Digital Magnitude Filter

The bq2014H has a digital filter to eliminate charge and discharge counting below a set threshold. The threshold for both VSRD and VSRQ is  $250\mu\text{V}$ .

Table 6. bq2014H Current-Sensing Errors

| Symbol | Parameter                          | Typical | Maximum | Units | Notes                                                                     |
|--------|------------------------------------|---------|---------|-------|---------------------------------------------------------------------------|
| INL    | Integrated non-linearity error     | $\pm 2$ | $\pm 4$ | %     | Add 0.1% per °C above or below 25°C and 1% per volt above or below 4.25V. |
| INR    | Integrated non-repeatability error | $\pm 1$ | $\pm 2$ | %     | Measurement repeatability given similar operating conditions.             |

## Error Summary

### Capacity Inaccurate

The LMD is susceptible to error on initialization or if no updates occur. On initialization, the LMD value includes the error between the programmed full capacity and the actual capacity. This error is present until a valid discharge occurs and LMD is updated. (See the DCR description.) The other cause of LMD error is battery wear-out. As the battery ages, the measured capacity must be adjusted to account for changes in actual battery capacity.

A Capacity Inaccurate counter (CPI) is maintained and incremented each time a valid charge occurs (qualified by NAC; see the CPI register description). It is reset whenever LMD is updated from the DCR. The counter does not wrap around but stops counting at 255. The capacity inaccurate flag (CI) is set if LMD has not been updated following 64 valid charges.

### Current-Sensing Error

Table 6 shows the non-linearity and non-repeatability errors associated with the bq2014H current sensing.

Table 7 illustrates the current-sensing error as a function of  $V_{OS}$ . A digital filter prevents charge and discharge counts to the NAC register when  $V_{SRQ}$  is between  $V_{SRQ}$  and  $V_{SRD}$ .

**Table 7.  $V_{OS}$ -Related Current Sense Error (Current = 1A)**

| $V_{OS}$<br>( $\mu V$ ) | Sense Resistor |      |      |            |
|-------------------------|----------------|------|------|------------|
|                         | 20             | 50   | 100  | m $\Omega$ |
| 50                      | 0.25           | 0.10 | 0.05 | %          |
| 100                     | 0.50           | 0.20 | 0.10 | %          |
| 150                     | 0.75           | 0.30 | 0.15 | %          |
| 180                     | 0.90           | 0.36 | 0.18 | %          |

## Done Input

A charge-control IC or a microcontroller uses the DONE input to communicate charge status to the bq2014H. When the DONE input is asserted high on charge completion, the bq2014H sets  $NAC = LMD$  and  $VDQ = 1$ . The DONE input should be maintained high as long as the charge controller or microcontroller keeps the batteries full; otherwise, the pin should be held low.

## Communicating with the bq2014H

The bq2014H includes a simple single-pin (HDQ plus return) serial data interface. A host processor uses the interface to access various bq2014H registers. Battery characteristics may be easily monitored by adding a single contact to the battery pack. The open-drain HDQ pin on the bq2014H should be pulled up by the host system, or may be left floating if the serial interface is not used.

The interface uses a command-based protocol, in which the host processor sends a command byte to the bq2014H. The command directs the bq2014H to either store the next eight bits of data received to a register specified by the command byte or output the eight bits of data specified by the command byte. (See Figure 4.)

The communication protocol is asynchronous return-to-one. Command and data bytes consist of a stream of eight bits that have a maximum transmission rate of 5K bits/sec. The least-significant bit of a command or data byte is transmitted first. The protocol is simple enough that it can be implemented by most host processors using either polled or interrupt processing. Data input from the bq2014H may be sampled using the pulse-width capture timers available on some microcontrollers.

If a communication error occurs (e.g.,  $t_{CYCB} > 250\mu s$ ), the bq2014H should be sent a BREAK to reinitiate the serial interface. A BREAK is detected when the HDQ pin is driven to a logic-low state for a time,  $t_B$  or greater. The HDQ pin should then be returned to its normal ready-high logic state for a time,  $t_{BR}$ . The bq2014H is now ready to receive a command from the host processor.

## bq2014H

The return-to-one data bit frame consists of three distinct sections:

1. The first section is used to start the transmission by either the host or the bq2014H taking the HDQ pin to a logic-low state for a period,  $t_{STRH,B}$ .
2. The next section is the actual data transmission, where the data should be valid by a period,  $t_{DSU,B}$ , after the negative edge used to start communication. The data should be held for a period,  $t_{DH,DV}$ , to allow the host or bq2014H to sample the data bit.
3. The final section is used to stop the transmission by returning the HDQ pin to a logic-high state by at least a period,  $t_{SSU,B}$ , after the negative edge used to start communication. The final logic-high state should be until a period  $t_{CYCH,B}$ , to allow time to ensure that the bit transmission was stopped properly. The timings for data and break communication are given in the serial communication timing specification and illustration sections.

Communication with the bq2014H is always performed with the bit transmitted first. Figure 5 shows an example of a communication sequence to read the bq2014H NACH register.

### bq2014H Command Code and Registers

The bq2014H status registers are listed in Table 8 and described below. All registers are Read/Write in the bq2014H. **Caution: When writing to bq2014H registers ensure that proper data are written. A write-verify read is recommended.**

#### Command Code

The bq2014H latches the command code when eight valid command bits have been received by the bq2014H. The command code contains two fields:

- $\overline{W/R}$  bit
- Command address

The  $\overline{W/R}$  bit of the command code is used to select whether the received command is for a read or a write function:

The  $\overline{W/R}$  values are

| Command Code Bits |   |   |   |   |   |   |   |
|-------------------|---|---|---|---|---|---|---|
| 7                 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| $\overline{W/R}$  | - | - | - | - | - | - | - |

where  $\overline{W/R}$  is

- 0 The bq2014H outputs the requested register contents specified by the address portion of command code.
- 1 The following eight bits should be written to the register specified by the address portion of command code.

The lower 7-bit field of the command code contains the address portion of the register to be accessed:

| Command Code Bits |     |     |     |     |     |     |           |
|-------------------|-----|-----|-----|-----|-----|-----|-----------|
| 7                 | 6   | 5   | 4   | 3   | 2   | 1   | 0         |
| -                 | AD6 | AD5 | AD4 | AD3 | AD2 | AD1 | AD0 (LSB) |

#### Primary Status Flags Register (FLGS1)

The FLGS1 register (address = 01h) contains the primary bq2014H flags.

The **charge status** flag (CHGS) is asserted when a valid charge rate is detected. Charge rate is deemed valid when  $VSRO > VSRQ$ . A  $VSRO$  of less than  $VSRQ$  or discharge activity clears CHGS.

The CHGS values are

| FLGS1 Bits |   |   |   |   |   |   |   |
|------------|---|---|---|---|---|---|---|
| 7          | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CHGS       | - | - | - | - | - | - | - |

where CHGS is

- 0 Either discharge activity detected or  $VSRO \leq VSRQ$
- 1  $VSRO > VSRQ$

The **battery replaced** flag (BRP) is asserted whenever the bq2014H is reset either by application of  $VCC$  or by a serial port command. BRP is reset when either a valid charge action increments NAC to be equal to LMD, or a valid charge action is detected after the EDV1 flag is asserted. BRP = 1 signifies that the device has been reset.

The BRP values are

| FLGS1 Bits |     |   |   |   |   |   |   |
|------------|-----|---|---|---|---|---|---|
| 7          | 6   | 5 | 4 | 3 | 2 | 1 | 0 |
| -          | BRP | - | - | - | - | - | - |

where BRP is

- 0 Battery is charged until  $NAC = LMD$  or discharged until the EDV1 flag is asserted
- 1 bq2014H is reset

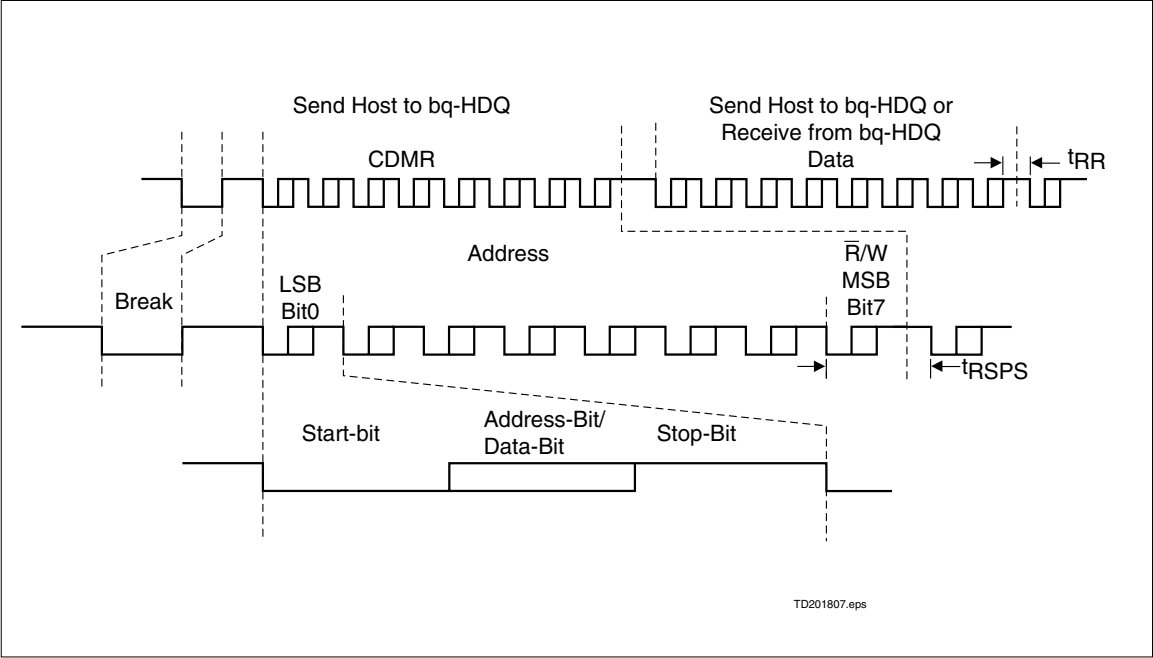


Figure 4. bq2014H Communication Example

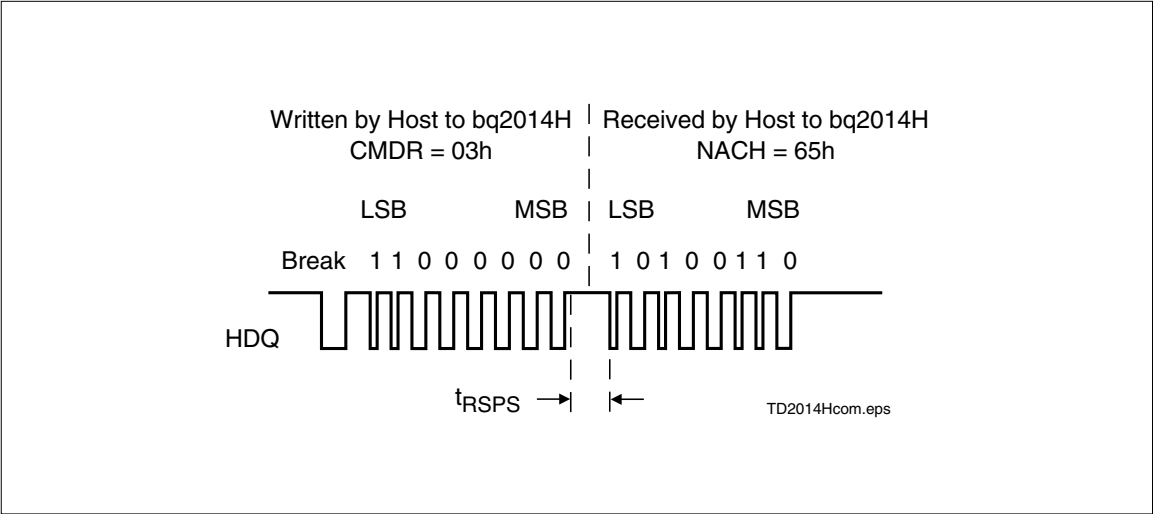


Figure 5. Typical Communication with the bq2014H

## bq2014H

**Table 8. bq2014H Command and Status Registers**

| Symbol | Register Name                                                 | Loc.<br>(hex) | Read/<br>Write | Control Field |        |        |        |        |        |        |        |
|--------|---------------------------------------------------------------|---------------|----------------|---------------|--------|--------|--------|--------|--------|--------|--------|
|        |                                                               |               |                | 7(MSB)        | 6      | 5      | 4      | 3      | 2      | 1      | 0(LSB) |
| FLGS1  | Primary status flags register                                 | 01h           | R              | CHGS          | BRP    | 0      | CI     | VDQ    | 1      | EDV1   | EDVF   |
| TMP    | Temperature register                                          | 02h           | R              | TMP3          | TMP2   | TMP1   | TMP0   | GG3    | GG2    | GG1    | GG0    |
| NACH   | Nominal available capacity high byte register                 | 03h           | R/W            | NACH7         | NACH6  | NACH5  | NACH4  | NACH3  | NACH2  | NACH1  | NACH0  |
| NACL   | Nominal available capacity low byte register                  | 17h           | R/W            | NACL7         | NACL6  | NACL5  | NACL4  | NACL3  | NACL2  | NACL1  | NACL0  |
| BATID  | Battery identification register                               | 04h           | R/W            | BATID7        | BATID6 | BATID5 | BATID4 | BATID3 | BATID2 | BATID1 | BATID0 |
| LMD    | Last measured discharge register                              | 05h           | R/W            | LMD7          | LMD6   | LMD5   | LMD4   | LMD3   | LMD2   | LMD1   | LMD0   |
| FLGS2  | Secondary status flags register                               | 06h           | R              | RSVD          | DR2    | DR1    | DR0    | ENINT  | VQ     | RSVD   | OVLD   |
| PPD    | Program pin pull-down register                                | 07h           | R              | RSVD          | RSVD   | RSVD   | PPD5   | PPD4   | PPD3   | PPD2   | PPD1   |
| PPU    | Program pin pull-up register                                  | 08h           | R              | RSVD          | RSVD   | RSVD   | PPU5   | PPU4   | PPU3   | PPU2   | PPU1   |
| CPI    | Capacity inaccurate count register                            | 09h           | R/W            | CPI7          | CPI6   | CPI5   | CPI4   | CPI3   | CPI2   | CPI1   | CPI0   |
| VSBS   | Battery voltage register                                      | 0bh           | R              | VSBS7         | VSBS6  | VSBS5  | VSBS4  | VSBS3  | VSBS2  | VSBS1  | VSBS0  |
| VTS    | End-of-discharge threshold select register                    | 0ch           | R/W            | VTS7          | VTS6   | VTS5   | VTS4   | VTS3   | VTS2   | VTS1   | VTS0   |
| CACT   | Temperature and discharge rate compensated available capacity | 0dh           | R/W            | CACT7         | CACT6  | CACT5  | CACT4  | CACT3  | CACT2  | CACT1  | CACT0  |
| CACD   | Discharge rate compensated available capacity                 | 0eh           | R/W            | CACD7         | CACD6  | CACD5  | CACD4  | CACD3  | CACD2  | CACD1  | CACD0  |
| SAEH   | Scaled available energy high byte register                    | 0fh           | R              | SAEH7         | SAEH6  | SAEH5  | SAEH4  | SAEH3  | SAEH2  | SAEH1  | SAEH0  |
| SAEL   | Scaled available energy low byte register                     | 10h           | R              | SAEL7         | SAEL6  | SAEL5  | SAEL4  | SAEL3  | SAEL2  | SAEL1  | SAEL0  |
| RCAC   | Relative CAC                                                  | 11h           | R              | -             | RCAC6  | RCAC5  | RCAC4  | RCAC3  | RCAC2  | RCAC1  | RCAC0  |
| VSRH   | Current scale high                                            | 12h           | R              | VSRH7         | VSRH6  | VSRH5  | VSRH4  | VSRH3  | VSRH2  | VSRH1  | VSRH0  |
| VSRL   | Current scale low                                             | 13h           | R              | VSRL7         | VSRL6  | VSRL5  | VSRL4  | VSRL3  | VSRL2  | VSRL1  | VSRL0  |
| DCR    | Discharge register                                            | 18h           | R/W            | DCR7          | DCR6   | DCR5   | DCR4   | DCR3   | DCR2   | DCR1   | DCR0   |
| PPFC   | Program pin data                                              | 1eh           | R/W            | RSVD          | RSVD   | RSVD   | RSVD   | RSVD   | RSVD   | RSVD   | RSVD   |
| INTSS  | VOS Interrupt                                                 | 38h           | R/W            | RSVD          | RSVD   | RSVD   | RSVD   | DCHGI  | RSVD   | RSVD   | CHGI   |

**Notes:** RSVD = reserved.  
All other registers not documented are reserved.

The **capacity inaccurate** flag (CI) is used to warn the user that the battery has been charged a substantial number of times since LMD has been updated. The CI flag is asserted on the 64th charge after the last LMD update or when the bq2014H is reset. The flag is cleared after an LMD update.

The CI values are

| FLGS1 Bits |   |   |    |   |   |   |   |
|------------|---|---|----|---|---|---|---|
| 7          | 6 | 5 | 4  | 3 | 2 | 1 | 0 |
| -          | - | - | CI | - | - | - | - |

where CI is

- 0 When LMD is updated with a valid full discharge
- 1 After the 64th valid charge action with no LMD updates or the bq2014H is reset

The **valid discharge** flag (VDQ) is asserted when the bq2014H is discharged from  $NAC = 0.94 * LMD$ . The flag remains set until either LMD is updated or one of three actions that can clear VDQ occurs:

- When NAC has been reduced by more than 6.25% because of self-discharge since VDQ was set.
- A valid charge action is sustained at  $V_{SRO} > V_{SRQ}$  for at least 2 NAC updates.
- The EDV1 flag was set at a temperature below 0°C

The VDQ values are

| FLGS1 Bits |   |   |   |     |   |   |   |
|------------|---|---|---|-----|---|---|---|
| 7          | 6 | 5 | 4 | 3   | 2 | 1 | 0 |
| -          | - | - | - | VDQ | - | - | - |

where VDQ is

- 0 Self-discharge of more than 6.25% of NAC, valid charge action detected, EDV1 asserted with the temperature less than 0°C, or reset
- 1 On first discharge after  $NAC \geq 0.94 * LMD$

The **first end-of-discharge warning** flag (EDV1) warns the user that the battery is almost empty. The first segment pin, SEG1, is modulated at a 4Hz rate if the display is enabled once EDV1 is asserted, which should warn the user that loss of battery power is imminent. The EDV1 flag is latched until a valid charge has been detected. The EDV1 threshold is externally controlled via the VTS register (see Voltage Threshold Register).

The EDV1 values are

| FLGS1 Bits |   |   |   |   |   |      |   |
|------------|---|---|---|---|---|------|---|
| 7          | 6 | 5 | 4 | 3 | 2 | 1    | 0 |
| -          | - | - | - | - | - | EDV1 | - |

where EDV1 is

- 0 Valid charge action detected,  $V_{SB} \geq V_{TS}$
- 1  $V_{SB} < V_{TS}$  providing that the discharge rate is  $< 2C$  (OVLN not set)

The **final end-of-discharge warning** flag (EDVF) flag is used to warn that battery power is at a failure condition. All segment drivers are turned off. The EDVF flag is latched until a valid charge has been detected. The EDVF threshold is set 25mV below the EDV1 threshold.

The EDVF values are

| FLGS1 Bits |   |   |   |   |   |   |      |
|------------|---|---|---|---|---|---|------|
| 7          | 6 | 5 | 4 | 3 | 2 | 1 | 0    |
| -          | - | - | - | - | - | - | EDVF |

where EDVF is

- 0 Valid charge action detected,  $V_{SB} \geq (V_{TS} - 25mV)$
- 1  $V_{SB} < (V_{TS} - 25mV)$  providing the discharge rate is  $< 2C$

## Temperature Register (TMP)

The TMP register (address=02h) contains the battery temperature.

The bq2014H contains an internal temperature sensor. The temperature is used to set charge and discharge efficiency factors as well as to adjust the self-discharge coefficient. The temperature register contents may be translated as shown in Table 9.

| TMP Temperature Bits |      |      |      |   |   |   |   |
|----------------------|------|------|------|---|---|---|---|
| 7                    | 6    | 5    | 4    | 3 | 2 | 1 | 0 |
| TMP3                 | TMP2 | TMP1 | TMP0 | - | - | - | - |

The bq2014H calculates the gas gauge bits, GG3-GG0 as a function of CACT and LMD. The results of the calculation give available capacity in  $\frac{1}{16}$  increments from 0 to  $\frac{15}{16}$ .

| TMP Gas Gauge Bits |   |   |   |     |     |     |     |
|--------------------|---|---|---|-----|-----|-----|-----|
| 7                  | 6 | 5 | 4 | 3   | 2   | 1   | 0   |
| -                  | - | - | - | GG3 | GG2 | GG1 | GG0 |

## bq2014H

**Table 9. Temperature Register**

| TMP3 | TMP2 | TMP1 | TMP0 | Temperature       |
|------|------|------|------|-------------------|
| 0    | 0    | 0    | 0    | T < -30°C         |
| 0    | 0    | 0    | 1    | -30°C < T < -20°C |
| 0    | 0    | 1    | 0    | -20°C < T < -10°C |
| 0    | 0    | 1    | 1    | -10°C < T < 0°C   |
| 0    | 1    | 0    | 0    | 0°C < T < 10°C    |
| 0    | 1    | 0    | 1    | 10°C < T < 20°C   |
| 0    | 1    | 1    | 0    | 20°C < T < 30°C   |
| 0    | 1    | 1    | 1    | 30°C < T < 40°C   |
| 1    | 0    | 0    | 0    | 40°C < T < 50°C   |
| 1    | 0    | 0    | 1    | 50°C < T < 60°C   |
| 1    | 0    | 1    | 0    | 60°C < T < 70°C   |
| 1    | 0    | 1    | 1    | 70°C < T < 80°C   |
| 1    | 1    | 0    | 0    | T > 80°C          |

### Nominal Available Capacity Registers (NACH/NACL)

The NACH high-byte register (address=03h) and the NACL low-byte register (address=17h) are the main gas gauging registers for the bq2014H. The NAC registers are incremented during charge actions and decremented during discharge and self-discharge actions. NACH and NACL are set to 0 during a bq2014H reset.

*Writing to the NAC registers affects the available charge counts and, therefore, affects the bq2014H gas gauge operation. Do not write the NAC registers to a value greater than LMD.*

### Battery Identification Register (BATID)

The BATID register (address=04h) is available for use by the system to determine the type of battery pack. The BATID contents are retained as long as VRBI is greater than 2V. The contents of BATID have no effect on the operation of the bq2014H. There is no default setting for this register.

### Last Measured Discharge Register (LMD)

LMD is the register (address=05h) that the bq2014H uses as a measured full reference. The bq2014H adjusts LMD based on the measured discharge capacity of the battery from full to empty. In this way the bq2014H updates the capacity of the battery. LMD is set to PFC during a bq2014H reset.

LMD is set to DCR upon the first valid charge after EDV is set if VDQ is set.

If DCR < 0.94 LMD, then LMD is set to 0.94 \* LMD.

### Secondary Status Flags Register (FLGS2)

The FLGS2 register (address=06h) contains the secondary bq2014H flags.

Bit 7 and bit 1 of FLGS2 are reserved. Do not write to these bits.

The **discharge rate** flags, DR2–0, are bits 6–4.

| FLGS2 Bits |     |     |     |   |   |   |   |
|------------|-----|-----|-----|---|---|---|---|
| 7          | 6   | 5   | 4   | 3 | 2 | 1 | 0 |
| -          | DR2 | DR1 | DR0 | - | - | - | - |

They are used to determine the current discharge regime as follows:

| DR2 | DR1 | DR0 | Discharge Rate    |
|-----|-----|-----|-------------------|
| 0   | 0   | 0   | DRATE < 0.5C      |
| 0   | 0   | 1   | 0.5C ≤ DRATE < 2C |
| 0   | 1   | 0   | 2C < DRATE        |

The **enable interrupt** flag (ENINT) is a test bit used to determine VSR activity sensed by the bq2014H. The state of this bit will vary and should be ignored by the system.

| FLGS2 Bits |   |   |   |       |   |   |   |
|------------|---|---|---|-------|---|---|---|
| 7          | 6 | 5 | 4 | 3     | 2 | 1 | 0 |
| -          | - | - | - | ENINT | - | - | - |

The **valid charge** flag (VQ), bit 2 of FLGS2, is used to indicate whether the bq2014H recognizes a valid charge condition. This bit is reset on the first discharge after NAC = LMD.

The VQ values are

| FLGS2 Bits |   |   |   |   |    |   |   |
|------------|---|---|---|---|----|---|---|
| 7          | 6 | 5 | 4 | 3 | 2  | 1 | 0 |
| -          | - | - | - | - | VQ | - | - |

where VQ is

- 0 Valid charge action not detected between a discharge from NAC = LMD and EDV1
- 1 Valid charge action detected

The **overload** flag (OVLN) is asserted when a discharge rate in excess of 2C is detected. OVLN remains asserted as long as the condition persists and is cleared 0.5 seconds after the rate drops below 2C. The overload condition is used to stop sampling of the battery terminal characteristics for end-of-discharge determination.

| FLGS2 Bits |   |   |   |   |   |   |     |
|------------|---|---|---|---|---|---|-----|
| 7          | 6 | 5 | 4 | 3 | 2 | 1 | 0   |
| -          | - | - | - | - | - | - | OVL |

### Program Pin Pull-Down Register (PPD)

The PPD register (address=07h) contains some of the programming pin information for the bq2014H. The segment drivers, SEG<sub>1-5</sub>, have a corresponding PPD register location, PPD<sub>1-5</sub>. A given location is set if a pull-down resistor has been detected on its corresponding segment driver. For example, if SEG<sub>1</sub> and SEG<sub>4</sub> have pull-down resistors, the contents of PPD are xxx01001.

### Program Pin Pull-Up Register (PPU)

The PPU register (address=08h) contains the rest of the programming pin information for the bq2014H. The segment drivers, SEG<sub>1-5</sub>, have a corresponding PPU register location, PPU<sub>1-5</sub>. A given location is set if a pull-up resistor has been detected on its corresponding segment driver. For example, if SEG<sub>3</sub> and SEG<sub>5</sub> have pull-up resistors, the contents of PPU are xxx10100.

| PPD/PPU Bits |      |      |                  |                  |                  |                  |                  |
|--------------|------|------|------------------|------------------|------------------|------------------|------------------|
| 7            | 6    | 5    | 4                | 3                | 2                | 1                | 0                |
| RSVD         | RSVD | RSVD | PPU <sub>5</sub> | PPU <sub>4</sub> | PPU <sub>3</sub> | PPU <sub>2</sub> | PPU <sub>1</sub> |
| RSVD         | RSVD | RSVD | PPD <sub>5</sub> | PPD <sub>4</sub> | PPD <sub>3</sub> | PPD <sub>2</sub> | PPD <sub>1</sub> |

### Capacity Inaccurate Count Register (CPI)

The CPI register (address=09h) is used to indicate the number of times a battery has been charged without an LMD update. Because the capacity of a rechargeable battery varies with age and operating conditions, the bq2014H adapts to the changing capacity over time. A complete discharge from full ( $NAC \geq 0.94 * LMD$ ) to empty ( $EDV1=1$ ) is required to perform an LMD update assuming there have been no intervening valid charges, the temperature is greater than or equal to 0°C, and there has been no more than a 6% self-discharge reduction.

The CPI register is incremented every time a valid charge is detected. When  $NAC \geq 0.94 * LMD$ , however, the CPI register increments on the first valid charge; CPI does not increment again for a valid charge until  $NAC < 0.94 * LMD$ . This prevents continuous trickle charging from incrementing CPI if self-discharge decrements NAC. The CPI register increments to 255 without rolling over. When the contents of CPI are incremented to 64, the capacity inaccurate flag, CI, is asserted in the FLGS1 register. The CPI register is reset whenever an update of the LMD register is performed, and the CI flag is also cleared.

### Battery Voltage Register (VSB)

The battery voltage register is used to read the single-cell battery voltage on the SB pin. The VSB register (address = 0Bh) is updated approximately once per second with the present value of the battery voltage.

$$VSB = 1.2V * (VSB/256).$$

| VSB Register Bits |      |      |      |      |      |      |      |
|-------------------|------|------|------|------|------|------|------|
| 7                 | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
| VSB7              | VSB6 | VSB5 | VSB4 | VSB3 | VSB2 | VSB1 | VSB0 |

### Voltage Threshold Register (VTS)

The end-of-discharge threshold voltages (EDV1 and EDVF) can be set using the VTS register (address = 0Ch). The VTS register sets the EDV1 trip point. EDVF is set 25mV below EDV1. The default value in the VTS register is A2h, representing  $EDV1 = 0.76V$  and  $EDVF = 0.735V$ .  $EDV1 = 1.2V * (VTS/256)$ .

| VTS Register Bits |      |      |      |      |      |      |      |
|-------------------|------|------|------|------|------|------|------|
| 7                 | 6    | 5    | 4    | 3    | 2    | 1    | 0    |
| VTS7              | VTS6 | VTS5 | VTS4 | VTS3 | VTS2 | VTS1 | VTS0 |

### Compensated Available Charge Registers (CACT/CACD)

The CACD register (address = 0Eh) contains the NAC value compensated for discharge rate. This is a monotonically decreasing value during discharge. If the discharge rate is  $> 2C$  then this value is lower than NAC. CACD is updated only when the discharge rate compensated NAC value is a lower value than CACD during discharge. During charge, CACD is continuously updated with the NAC value.

The CACT register (address = 0Dh) contains the CACD value compensated for temperature. CACT will contain a value lower than CACD when the battery temperature is below 10°C. The CACT value is also used in calculating the LED display pattern.

### Scaled Available Energy Registers (SAEH/SAEL)

The SAEH high-byte register (address = 0Fh) and the SAEL low-byte register (address = 10h) are used to scale battery voltage and CACT to a value that can be translated to watt-hours remaining under the present conditions.

### Relative CAC Register (RCAC)

The RCAC register (address = 11h) provides the relative battery state-of-charge by dividing CACT by LMD.

## bq2014H

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RCAC varies from 0 to 64h representing relative state-of-charge from 0 to 100%.

### Current Scale Register (VSRH/VSRL)

The VSRH register (address = 12h) and the VSRL register (address = 13h) report the average signal across the SR and VSS pins. The bq2050H updates this register pair every 22.5s. VSRH (high-byte) and VSRL (low-byte) form a 16-bit signed integer value representing the average current during this time. The battery pack current can be calculated from:

$$|I(\text{mA})| = (\text{VSRH} * 256 + \text{VSRL}) / (8 * R_S)$$

where:

$R_S$  = sense resistor value in  $\Omega$ .

VSRH = high-byte value of battery current

VSRL = low-byte value of battery current

The bq2014H indicates an average discharge current with a "1" in the MSB position of the VSRH register. To calculate discharge current, use the 2's complement if the concatenated register contents in the above equation.

### Discharge Count Register (DCR)

The DCR register (address = 18h) stores the high-byte of the discharge count. DCR is reset to zero at the start of a valid discharge cycle and can count to a maximum of FFh. DCR will not increment if EDV1 = 1 and will not roll over from FFh.

### Program Pin Full Count (PPFC)

The PPFC register contains information concerning the program pin configuration. This information is used to determine the data integrity of the bq2014H. **The only approved user application for this register is to write a zero to this register as part of a reset request.**

The recommended reset method for the bq2014H is

- Write PPFC to zero
- Write LMD to zero

After these operations, a software reset will occur.

Resetting the bq2014H sets the following:

- LMD = PFC
- CPI, VDQ, RCAC, NACH/L, CACH/L, SAEH/L, NMCV = 0
- CI and BRP = 1

### Voltage Offset (Vos) Interrupt (INTSS)

The INTSS register (address = 38h) is useful during initial characterization of bq2014H designs. When the bq2014H counts a charge pulse, CHGI (bit 0) will be set to 1. When the bq2014H counts a discharge pulse, DCHGI (bit 3) will be set to 1. All other locations in the INTSS register are reserved.

### Display

The bq2014H can directly display capacity information using low-power LEDs. If LEDs are used, the program pins should be resistively tied to VCC or VSS for a program high or program low, respectively.

The bq2014H displays the battery charge state in relative mode. In relative mode, the battery charge is represented as a percentage of the LMD. Each LED segment represents 20% of the LMD.

The capacity display is also adjusted for the present battery temperature and discharge rate. The temperature adjustment reflects the available capacity at a given temperature but does not affect the NAC register. The temperature adjustments are detailed in the CACT and CACD register descriptions.

When  $\overline{\text{DISP}}$  is tied to VCC, the SEG<sub>1-5</sub> outputs are inactive. When  $\overline{\text{DISP}}$  is left floating, the display becomes active whenever the bq2014H detects a charge in progress  $\text{VSRO} > \text{VSRQ}$ . When pulled low, the segment outputs become active for a period of four seconds,  $\pm 0.5$  seconds.

The segment outputs are modulated as two banks, with segments 1, 3, and 5 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<sub>1</sub> blinks at a 4Hz rate whenever VSB has been detected to be below VEDV1 (EDV1 = 1), indicating a low-battery condition. VSB below VEDVF (EDVF = 1) disables the display output.

### Microregulator

A micropower source for the bq2014H can be inexpensively built using a FET and an external resistor. (See Figure 1.)

## Absolute Maximum Ratings

| Symbol           | Parameter                   | Minimum | Maximum              | Unit | Notes                                                                            |
|------------------|-----------------------------|---------|----------------------|------|----------------------------------------------------------------------------------|
| V <sub>CC</sub>  | Relative to V <sub>SS</sub> | -0.3    | +7.0                 | V    |                                                                                  |
| All other pins   | Relative to V <sub>SS</sub> | -0.3    | +7.0                 | V    |                                                                                  |
| REF              | Relative to V <sub>SS</sub> | -0.3    | +8.5                 | V    | Current limited by R1 (see Figure 1)                                             |
| V <sub>SR</sub>  | Relative to V <sub>SS</sub> | -0.3    | V <sub>CC</sub> +0.7 | V    | 100kΩ series resistor should be used to protect SR in case of a shorted battery. |
| T <sub>OPR</sub> | 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<sub>A</sub> = T<sub>OPR</sub>; V = 3.0 to 6.5V)

| Symbol | Parameter           | Minimum       | Typical       | Maximum       | Unit | Notes                                        |
|--------|---------------------|---------------|---------------|---------------|------|----------------------------------------------|
| VEDV1  | First empty warning | 0.73          | 0.76          | 0.79          | V    | SB, default                                  |
| VEDVF  | Final empty warning | VEDV1 - 0.035 | VEDV1 - 0.025 | VEDV1 - 0.015 | V    | SB, default                                  |
| VSRO   | SR sense range      | -300          | -             | +500          | mV   | SR, V <sub>SR</sub> + V <sub>OS</sub>        |
| VSQR   | Valid charge        | 250           | -             | -             | μV   | V <sub>SR</sub> + V <sub>OS</sub> (see note) |
| VS RD  | Valid discharge     | -             | -             | -250          | μV   | V <sub>SR</sub> + V <sub>OS</sub> (see note) |

**Note:** V<sub>OS</sub> is affected by PC board layout. Proper layout guidelines should be followed for optimal performance. See "Layout Considerations."

**DC Electrical Characteristics** ( $T_A = T_{OPR}$ )

| Symbol | Parameter                                                  | Minimum   | Typical | Maximum   | Unit | Notes                                                     |
|--------|------------------------------------------------------------|-----------|---------|-----------|------|-----------------------------------------------------------|
| VCC    | Supply voltage                                             | 3.0       | 4.25    | 6.5       | V    | VCC excursion from < 2.0V to ≥ 3.0V initializes the unit. |
| VOS    | Offset referred to VSR                                     | -         | ±50     | ±150      | μV   | DISP = VCC                                                |
| VREF   | Reference at 25°C                                          | 5.7       | 6.0     | 6.3       | V    | IREF = 5μA                                                |
|        | Reference at -40°C to +85°C                                | 4.5       | -       | 7.5       | V    | IREF = 5μA                                                |
| RREF   | Reference input impedance                                  | 2.0       | 5.0     | -         | MΩ   | VREF = 3V                                                 |
| ICC    | Normal operation                                           | -         | 90      | 135       | μA   | VCC = 3.0V, HDQ = 0                                       |
|        |                                                            | -         | 120     | 180       | μA   | VCC = 4.25V, HDQ = 0                                      |
|        |                                                            | -         | 170     | 250       | μA   | VCC = 6.5V, HDQ = 0                                       |
| VSB    | Battery input                                              | 0         | -       | VCC       | V    |                                                           |
| RSBmax | SB input impedance                                         | 10        | -       | -         | MΩ   | 0 < VSB < VCC                                             |
| IDISP  | DISP input leakage                                         | -         | -       | 5         | μA   | VDISP = VSS                                               |
| ILCOM  | LCOM input leakage                                         | -0.2      | -       | 0.2       | μA   | DISP = VCC                                                |
| IRBI   | RBI data retention current                                 | -         | -       | 100       | nA   | VRBI > VCC < 3V                                           |
| RHDQ   | Internal pulldown                                          | 500       | -       | -         | KΩ   |                                                           |
| RSR    | SR input impedance                                         | 10        | -       | -         | MΩ   | -200mV < VSR < VCC                                        |
| VIHPFC | Logic input high                                           | VCC - 0.2 | -       | -         | V    | PROG1-5                                                   |
| VILPFC | Logic input low                                            | -         | -       | VSS + 0.2 | V    | PROG1-5                                                   |
| VIZPFC | Logic input Z                                              | float     | -       | float     | V    | PROG1-5                                                   |
| VOLSL  | SEG output low, low VCC                                    | -         | 0.1     | -         | V    | VCC = 3V, IOLS ≤ 1.75mA<br>SEG1-SEG5                      |
| VOLSH  | SEG output low, high VCC                                   | -         | 0.4     | -         | V    | VCC = 6.5V, IOLS ≤ 11.0mA<br>SEG1-SEG5                    |
| VOHML  | LCOM output high, low VCC                                  | VCC - 0.3 | -       | -         | V    | VCC = 3V, IOHLCOM = -5.25mA                               |
| VOHMH  | LCOM output high, high VCC                                 | VCC - 0.6 | -       | -         | V    | VCC > 3.5V, IOHLCOM = -33.0mA                             |
| IOLS   | SEG sink current                                           | 11.0      | -       | -         | mA   | At VOLSH = 0.4V, VCC = 6.5V                               |
| IOL    | Open-drain sink current                                    | 5.0       | -       | -         | mA   | At VOL = VSS + 0.3V, HDQ                                  |
| VOL    | Open-drain output low                                      | -         | -       | 0.3       | V    | IOL ≤ 5mA, HDQ                                            |
| VIHDQ  | HDQ input high                                             | 2.5       | -       | -         | V    | HDQ                                                       |
| VILDQ  | HDQ input low                                              | -         | -       | 0.8       | V    | HDQ                                                       |
| RPROG  | Soft pull-up or pull-down resistor value (for programming) | -         | -       | 200       | KΩ   | PROG1-5                                                   |
| RFLOAT | Float state external impedance                             | -         | 5       | -         | MΩ   | PROG1-5                                                   |

**Note:** All voltages relative to VSS.

### High-Speed Serial Communication Timing Specification (T<sub>A</sub> = T<sub>OPR</sub>)

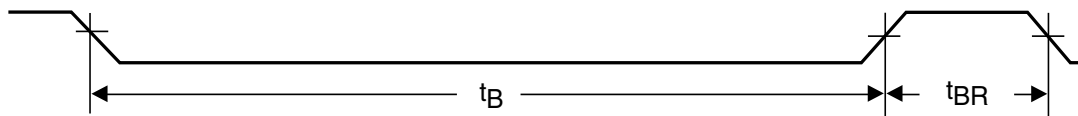
| Symbol | Parameter                           | Minimum | Typical | Maximum | Unit | Notes    |
|--------|-------------------------------------|---------|---------|---------|------|----------|
| tCYCH  | Cycle time, host to bq2014H (write) | 190     | -       | -       | μs   | See note |
| tCYCB  | Cycle time, bq2014H to host (read)  | 190     | 205     | 250     | μs   |          |
| tSTRH  | Start hold, host to bq2014H (write) | 5       | -       | -       | ns   |          |
| tSTRB  | Start hold, bq2014H to host (read)  | 32      | -       | -       | μs   |          |
| tDSU   | Data setup                          | -       | -       | 50      | μs   |          |
| tDSUB  | Data setup                          | -       | -       | 50      | μs   |          |
| tDH    | Data hold                           | 90      | -       | -       | μs   |          |
| tDV    | Data valid                          | -       | -       | 80      | μs   |          |
| tSSU   | Stop setup                          | -       | -       | 145     | μs   |          |
| tSSUB  | Stop setup                          | -       | -       | 145     | μs   |          |
| tRSPS  | Response time, bq2014H to host      | 190     | -       | 320     | μs   |          |
| tB     | Break                               | 190     | -       | -       | μs   |          |
| tBR    | Break recovery                      | 40      | -       | -       | μs   |          |

**Note:** The open-drain HDQ pin should be pulled to at least V<sub>CC</sub> by the host system for proper HDQ operation. HDQ may be left floating if the serial interface is not used.

## bq2014H

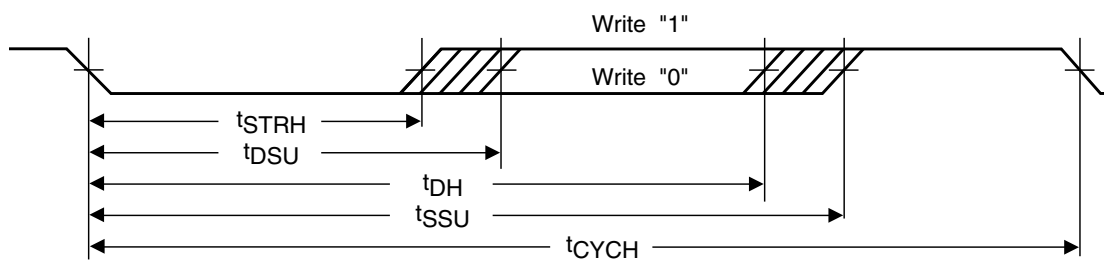
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### Break Timing

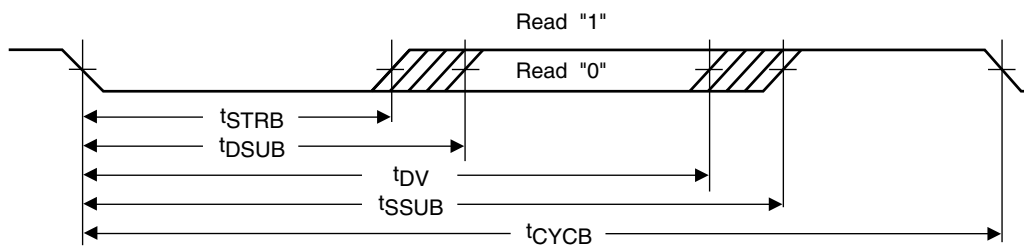


TD201803.eps

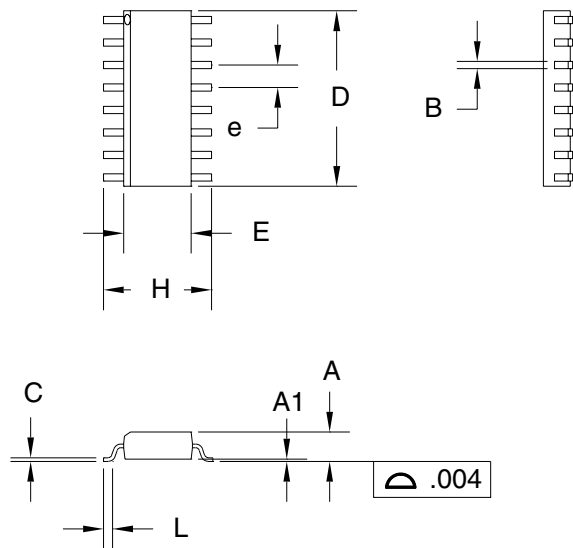
### Host to bq2014H



### bq2014H to Host



## 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  |

## Ordering Information

bq2014H

**Temperature Range:**

blank = Commercial (0 to +70°C)

**Package Option:**

SN = 16-pin narrow SOIC

**Device:**

bq2014H Gas-Gauge IC

## PACKAGING INFORMATION

| Orderable Device | Status<br>(1) | Package Type | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|--------------------|------|----------------|----------------------------|------------------|----------------------|--------------|-------------------------|-------------------------|
| BQ2014HSN        | ACTIVE        | SOIC         | D                  | 16   | 40             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR  | 0 to 70      | 2014H<br>A509           | <a href="#">Samples</a> |
| BQ2014HSNG4      | ACTIVE        | SOIC         | D                  | 16   | 40             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR  | 0 to 70      | 2014H<br>A509           | <a href="#">Samples</a> |
| BQ2014HSNTR      | ACTIVE        | SOIC         | D                  | 16   | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR  | 0 to 70      | 2014H<br>A509           | <a href="#">Samples</a> |
| BQ2014HSNTRG4    | ACTIVE        | SOIC         | D                  | 16   | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU        | Level-2-260C-1 YEAR  | 0 to 70      | 2014H<br>A509           | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

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

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

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

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

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

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

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

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

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

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

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

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

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

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**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

| Device      | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|-------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| BQ2014HSNTR | SOIC         | D               | 16   | 2500 | 330.0              | 16.4               | 6.5     | 10.3    | 2.1     | 8.0     | 16.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device      | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|-------------|--------------|-----------------|------|------|-------------|------------|-------------|
| BQ2014HSNTR | SOIC         | D               | 16   | 2500 | 367.0       | 367.0      | 38.0        |

D (R-PDSO-G16)

PLASTIC SMALL OUTLINE

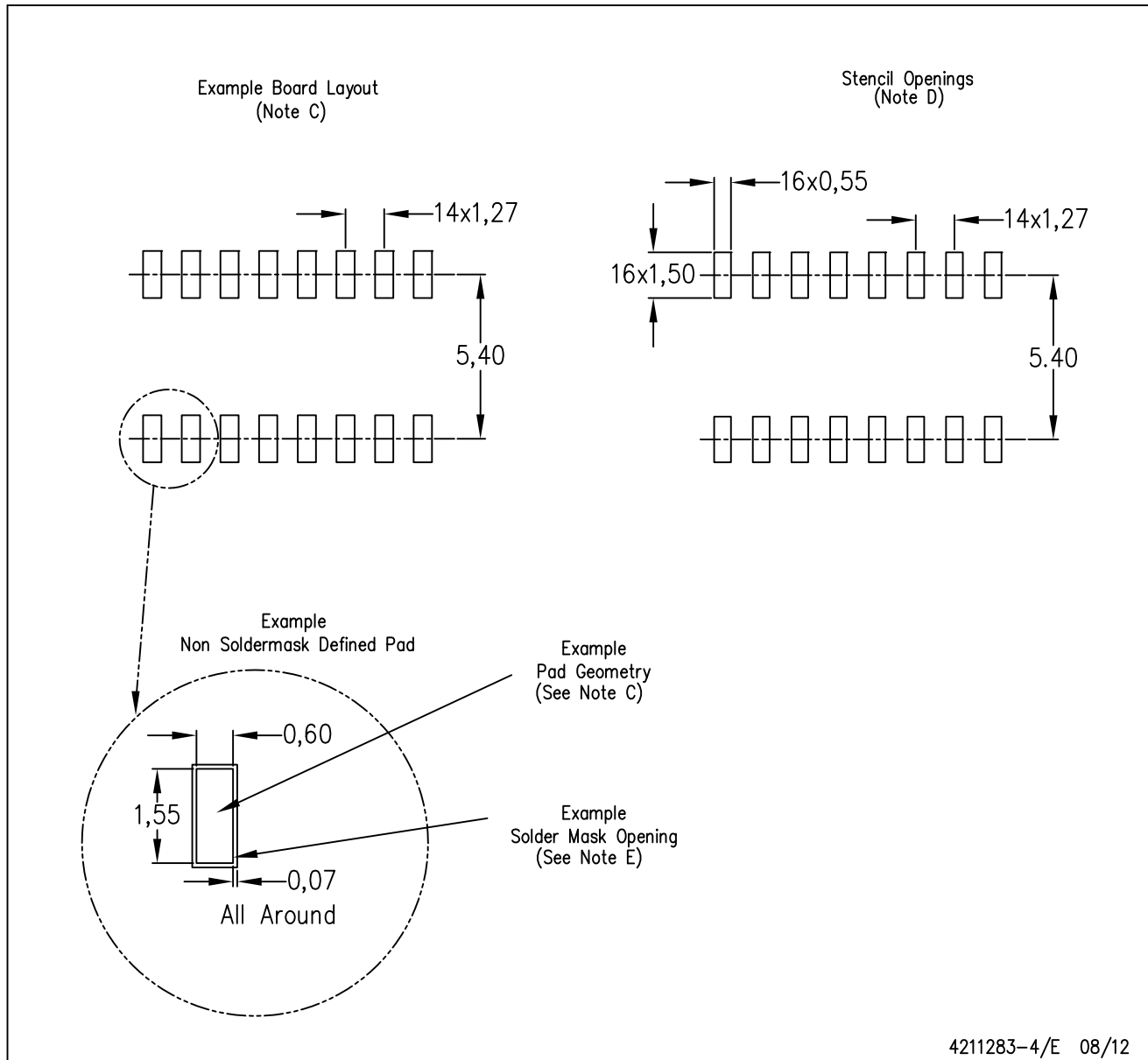


NOTES:

- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- $\triangle C$  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
- $\triangle D$  Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
- E. Reference JEDEC MS-012 variation AC.

D (R-PDSO-G16)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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