

SBS-COMPLIANT GAS GAUGE IC FOR USE WITH THE bq29311

FEATURES

- Provides Accurate Measurement of Available Charge in Li-Ion and Li-Polymer Batteries
- Supports the Smart Battery Specification (SBS) V1.1
- Integrated Time Base Removes Need for External Crystal
- Works With the TI bq29311 Analog Front End (AFE) Protection IC to Provide Complete Pack Electronics for 10.8-V or 14.4-V Battery Packs With Few External Components
- Based on a Powerful Low-Power RISC CPU Core With High-Performance Peripherals
- Integrated Flash Memory Eliminates the Need for External Configuration EEPROM
- Measures Charge Flow Using a High Resolution 16-Bit Integrating Converter
 - Better Than 3-nVh of Resolution
 - Self-Calibrating
 - Offset Error Less Than 1- μ V
- Uses 16-Bit Delta Sigma Converter for Accurate Voltage and Temperature Measurements

- Programmable Cell Modeling for Maximum Battery Fuel Gauge Accuracy
- Drives 3-, 4-, or 5-Segment LED Display for Remaining Capacity Indication
- 38-Pin TSSOP (DBT)

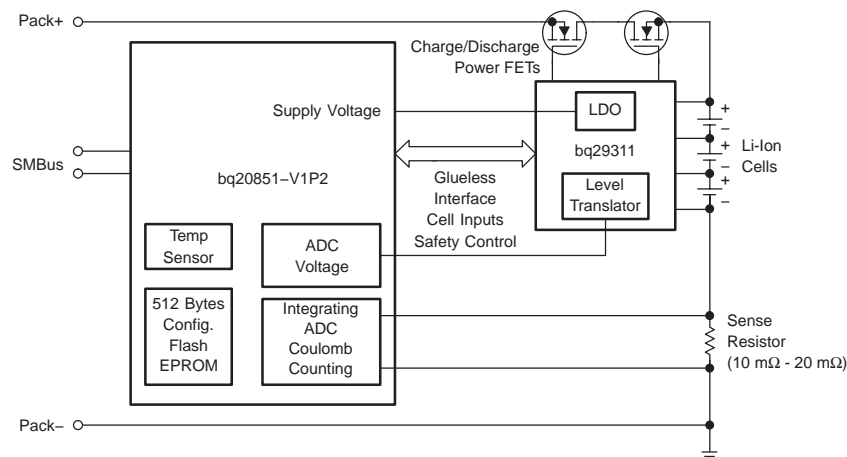
APPLICATIONS

- Notebook PCs

DESCRIPTION

The bq20851-V1P2 SBS-compliant gas gauge IC for battery pack installation maintains an accurate record of available charge in Li-ion or Li-polymer batteries. The bq20851-V1P2 monitors capacity and other critical parameters of the battery pack and reports the information to the system host controller over a serial communication bus. It is designed to work with the bq29311 analog front-end (AFE) protection IC to maximize functionality and safety and minimize component count and cost in smart battery circuits. Using information from the bq20851-V1P2, the host controller can manage remaining battery power to extend the system run time as much as possible.

BLOCK DIAGRAM



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

DESCRIPTION (CONTINUED)

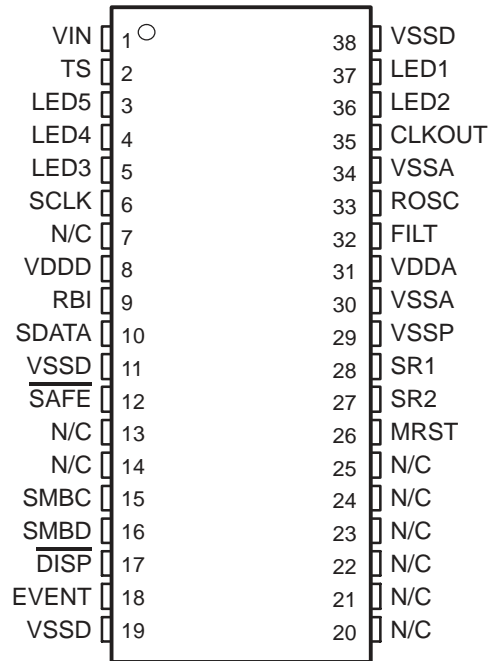
The bq20851-V1P2 uses an integrating converter with continuous sampling for the measurement of battery charge and discharge currents. Optimized for coulomb counting in portable applications, the self-calibrating integrating converter has a resolution better than 3-nVh and an offset measurement error of less than 1-μV (typical). For voltage and temperature reporting, the bq20851-V1P2 uses a 16-bit A-to-D converter. In conjunction with the bq29311, the onboard ADC also monitors individual cell voltages in a battery pack and allows the bq20851-V1P2 to generate the control signals necessary to implement the cell balancing and the required safety protection for Li-ion and Li-polymer battery chemistries.

The bq20851-V1P2 supports the Smart Battery Data (SBData) commands and charge-control functions. It communicates data using the System Management Bus (SMBus) 2-wire protocol. The data available include the battery's remaining capacity, temperature, voltage, current, and remaining run-time predictions. The bq20851-V1P2 provides LED drivers and a push-button input to depict remaining battery capacity from full to empty in 20%, 25%, or 33% increments with a 3-, 4-, or 5-segment display.

The bq20851-V1P2 contains 512 bytes of internal data flash memory, which store configuration information. The information includes nominal capacity and voltage, self-discharge rate, rate compensation factors, and other programmable cell-modeling factors used to accurately adjust remaining capacity for use-conditions based on time, rate, and temperature. The bq20851-V1P2 also automatically calibrates or learns the true battery capacity in the course of a discharge cycle from programmable near full to near empty levels.

The bq29311 AFE protection IC provides power to the bq20851-V1P2 from a 3 or 4 series Li-ion cell stack, eliminating the need for an external regulator circuit.

**TSSOP PACKAGE
(TOP VIEW)**



NC – No internal connection

AVAILABLE OPTIONS

| TA | PACKAGE 38-PIN TSSOP (DBT) |
|---------------|----------------------------------|
| -20°C to 85°C | bq20851DBT-V1P2 ⁽¹⁾ |

⁽¹⁾ The bq20851-V1P2 is available taped and reeled. Add an R suffix to the device type (e.g., bq20851DBTR-V1P2) to order tape and reel version.

Terminal Functions

| TERMINAL | | I/O | DESCRIPTION |
|----------|--------------------------|-----|--|
| NAME | No. | | |
| CLKOUT | 35 | I | 32.768-kHz output to the bq29311 |
| DISP | 17 | I | Display control for the LED drivers LED1 through LED5 |
| FILT | 32 | I | Analog input connected to the external PLL filter |
| EVENT | 18 | I | Input from bq29311 XALERT output |
| LED1 | 37 | O | LED display segments that each may drive an external LED |
| LED2 | 36 | O | |
| LED3 | 5 | O | |
| LED4 | 4 | O | |
| LED5 | 3 | O | |
| MRST | 26 | I | Master reset input that forces the device into reset when held high |
| N/C | 20–24, 7, 13, 14, 25, | – | No connection |
| RBI | 9 | I | Register backup that provides backup potential to the bq20851-V1P2 data registers during periods of low operating voltage. RBI accepts a storage capacitor or a battery input. |
| ROSC | 33 | I | Internal time base bias input |
| SAFE | 12 | O | Output for additional level of safety protection; e.g., fuse blow. |
| SCLK | 6 | O | Communication clock to the bq29311 |
| SDATA | 10 | I/O | Data transfer to and from bq29311 |
| SMBC | 15 | I/O | SMBus clock open-drain bidirectional pin used to clock the data transfer to and from the bq20851-V1P2 |
| SMBD | 16 | I/O | SMBus data open-drain bidirectional pin used to transfer address and data to and from the bq20851-V1P2 |
| SR1 | 28 | I | Connections for a small-value sense resistor to monitor the battery charge- and discharge-current flow |
| SR2 | 27 | I | |
| TS | 2 | I | Thermistor voltage input connection to monitor temperature |
| VDDA | 31 | I | Positive supply for analog circuitry |
| VDDD | 8 | I | Positive supply for digital circuitry and I/O pins |
| VIN | 1 | I | Single cell voltage input from the bq29311 |
| VSSA | 30, 34 | I | Negative supply for analog circuitry |
| VSSD | 11, 19, 38 | I | Negative supply for digital circuitry |
| VSSP | 29 | I | Negative supply for output circuitry |



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

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature (unless otherwise noted)⁽¹⁾

| | | UNITS |
|--|-----|----------------------------|
| Supply voltage range, V_{DD} relative to V_{SS} ⁽²⁾ | | -0.3 V to 6 V |
| Open-drain I/O pins, $V_{(IOD)}$ relative to V_{SS} ⁽²⁾ | | -0.3 V to 6 V |
| Input voltage range to all other pins, V_I relative to V_{SS} ⁽²⁾ | | -0.3 V to $V_{DD} + 0.3$ V |
| Operating free-air temperature range, T_A | | -20°C to 85°C |
| Storage temperature range, T_{stg} | | -65°C to 150°C |
| ESD rating | HBM | 1.5 kV |
| | CDM | 1.5 kV |
| | MM | 50 V |

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

(2) V_{SS} refers to the common node of $V_{(SSA)}$, $V_{(SSD)}$, and $V_{(SSP)}$.

ELECTRICAL CHARACTERISTICS

$V_{DD} = 3.0$ V to 3.6 V, $T_A = -20^\circ\text{C}$ to 85°C (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|-------------|---|-------------------------|----------------|----------------|-----|------------------|
| V_{DD} | Supply voltage | V_{DDA} and V_{DDD} | 3.0 | 3.3 | 3.6 | V |
| I_{DD} | Operating current | No flash programming | | 350 | | μA |
| $I_{(SLP)}$ | Low-power storage mode current | Hibernate mode | | 1 | | μA |
| $V_{(OLS)}$ | Output voltage low: (LED1–LED5) | $I_{(OLS)} = 10$ mA | | | 0.4 | V |
| V_{IL} | Input voltage low $\overline{\text{DISP}}$ | | -0.3 | | 0.8 | V |
| V_{IH} | Input voltage high $\overline{\text{DISP}}$ | | 2 | $V_{CC} + 0.3$ | | V |
| V_{OL} | Output voltage low SMBC, SMBD, SDATA, SCLK, EVENT, SAFE | $I_{OL} = 0.5$ mA | | | 0.4 | V |
| $V_{(ILS)}$ | Input voltage low SMBC, SMBD, SDATA, SCLK, EVENT, SAFE | | -0.3 | | 0.8 | V |
| $V_{(IHS)}$ | Input voltage high SMBC, SMBD, SDATA, SCLK, EVENT, SAFE | | 1.7 | | 6 | V |
| $V_{(AI)}$ | Input voltage range VIN, TS, OC | | $V_{SS} - 0.3$ | | 1.0 | V |
| $Z_{(AI1)}$ | Input impedance SR1, SR2 | 0 V–1.0 V | 10 | | | $\text{M}\Omega$ |
| $Z_{(AI2)}$ | Input impedance VIN, TS, OC | 0 V–1.0 V | 8 | | | $\text{M}\Omega$ |

Power-On Reset (see Figure 1)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|-----------|------------------------------|-----------------|-----|-----|-----|------|
| V_{IT-} | Negative-going voltage input | | 2.1 | 2.3 | 2.5 | V |
| V_{hys} | Power-on reset hysteresis | | 50 | 125 | 210 | mV |

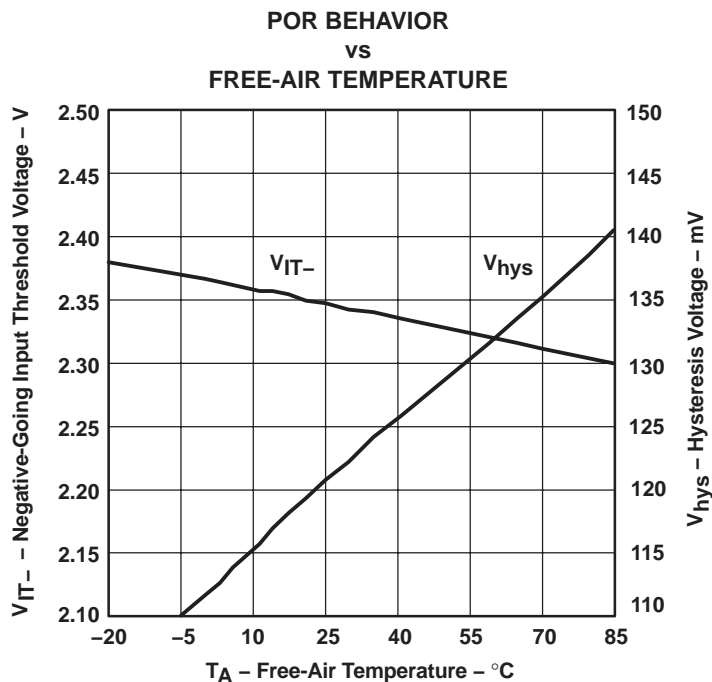


Figure 1

INTEGRATING ADC CHARACTERISTICS

V_{DD} = 3.0 V to 3.6 V, T_A = -20°C to 85°C (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--|-----------------------------------|------|--------|--------|------|
| V(SR) Input voltage range, V(SR2) and V(SR1) | V _{SR} = V(SR2) - V(SR1) | -0.3 | | 1.0 | V |
| V(SROS) Input offset | | | 1 | | μV |
| INL Integral nonlinearity error | | | 0.003% | 0.009% | |

PLL SWITCHING CHARACTERISTICS

V_{DD} = 3.0 V to 3.6 V, T_A = -20°C to 85°C (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|--|-----------------------|-----|-----|-----|------|
| t _(sp) Start-up time ⁽¹⁾ | ±0.5% frequency error | | 2 | 5 | ms |

⁽¹⁾ The frequency error is measured from 32.768 Hz.

Internal Oscillator

V_{DD} = 3.0 V to 3.6 V, T_A = -20°C to 85°C (unless otherwise noted)

| PARAMETER | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|-------------------------|-----|-----|-----|------|
| f _(exo) Frequency error ⁽¹⁾ | | -2% | | 2% | |
| | V _{DD} = 3.3 V | -1% | | 1% | |
| f _(sxo) Start-up time ⁽²⁾ | | | | 275 | μs |

⁽¹⁾ The frequency error is measured from 32.768 Hz.

⁽²⁾ The start-up time is defined as the time it takes for the oscillator output frequency to be ±1%.

SMBUS TIMING SPECIFICATIONS
 $V_{DD} = 3.0\text{ V to }3.6\text{ V}$, $T_A = -20^\circ\text{C to }85^\circ\text{C}$ (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|-----------------|---|--|------|------|------|---------------|
| f_{SMB} | SMBus operating frequency | Slave mode, SMBC 50% duty cycle | 10 | | 100 | kHz |
| f_{MAS} | SMBus master clock frequency | Master mode, no clock low slave extend | | 51.2 | | kHz |
| t_{BUF} | Bus free time between start and stop | | 4.7 | | | μs |
| $t_{hd}(STA)$ | Hold time after (repeated) start | | 4.0 | | | μs |
| $t_{su}(STA)$ | Repeated start setup time | | 4.7 | | | μs |
| $t_{su}(STO)$ | Stop setup time | | 4.0 | | | μs |
| $t_{hd}(DAT)$ | Data hold time | Receive mode | 0 | | | ns |
| | | Transmit mode | 300 | | | |
| $t_{su}(DA)$ | Data setup time | | 250 | | | ns |
| $t_{TIMEOUT}$ | Error signal/detect | See Note 1 | 25 | | 35 | ms |
| t_{low} | Clock low period | | 4.7 | | | μs |
| t_{high} | Clock high period | See Note 2 | 0.05 | | 125 | ms |
| $t_{low}(SEXT)$ | Cumulative clock low slave extend time | See Note 3 | | | 25 | ms |
| $t_{low}(MEXT)$ | Cumulative clock low master extend time | See Note 4 | | | 10 | ms |
| t_f | Clock/data fall time | See Note 5 | | | 300 | ns |
| t_r | Clock/data rise time | See Note 6 | | | 1000 | ns |

- (1) The bq20851-V1P2 times out when any clock low exceeds $t_{TIMEOUT}$
- (2) t_{high} Max. is minimum bus idle time. SMBC = 1 for $t > 125\text{ ms}$ causes reset of any transaction involving bq20851-V1P2 that is in progress.
- (3) $t_{low}(SEXT)$ is the cumulative time a slave device is allowed to extend the clock cycles in one message from initial start to the stop.
- (4) $t_{low}(MEXT)$ is the cumulative time a master device is allowed to extend the clock cycles in one message from initial start to the stop.
- (5) Rise time, $t_r = (V_{ILMAX} - 0.15\text{ V})$ to $(V_{IHMIN} + 0.15\text{ V})$
- (6) Fall time, $t_f = 0.9 V_{DD}$ to $(V_{ILMAX} - 0.15\text{ V})$

DATA FLASH MEMORY SWITCHING CHARACTERISTICS
 $V_{DD} = 3.0\text{ V to }3.6\text{ V}$, $T_A = -20^\circ\text{C to }85^\circ\text{C}$ (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|-------------------|--------------------------------|-----------------|-----|--------|-----|--------|
| $t_{(RETENSION)}$ | Data retention | See Note 1 | 10 | | | Years |
| | Flash programming write-cycles | See Note 1 | | 10^5 | | Cycles |
| $t_{(WORDPROG)}$ | Word programming time | See Note 1 | | | 2 | ms |
| $I_{(DDPROG)}$ | Flash-write supply current | See Note 1 | | 14 | 16 | mA |

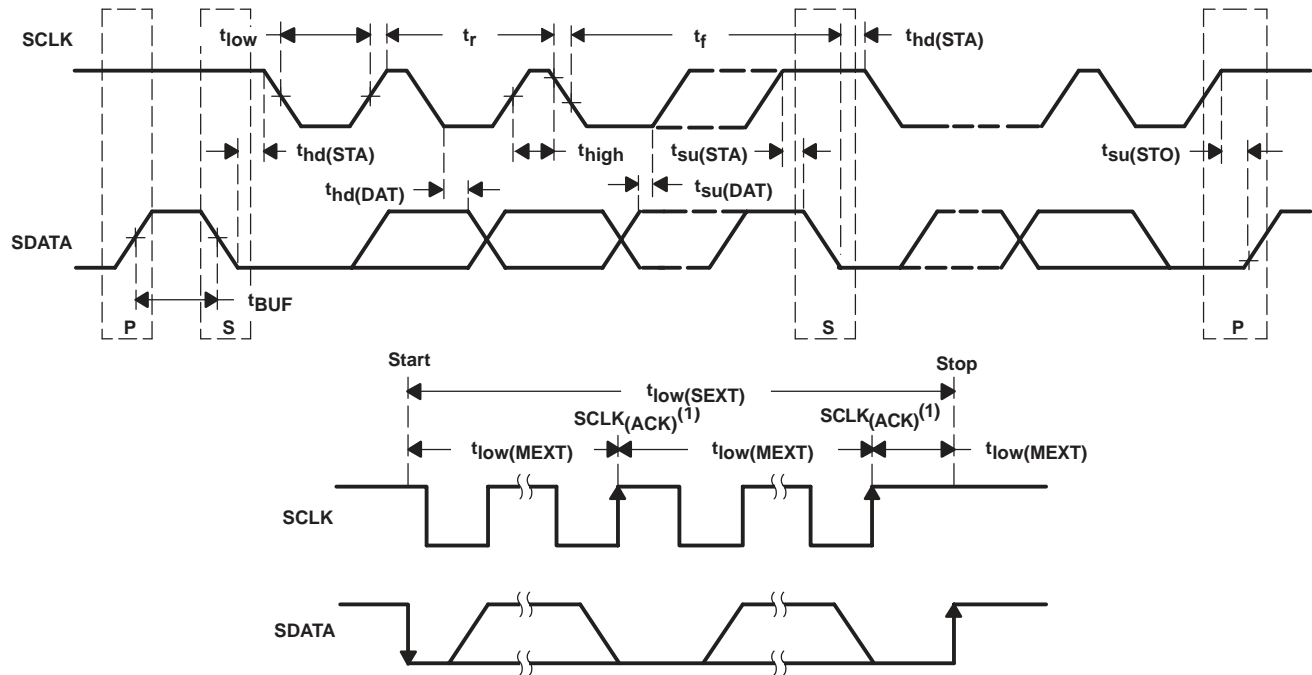
- (1) Specified by design. Not production tested.

Register Backup

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|-------------|--------------------------------------|---|-----|-----|-----|------|
| $I_{(RBI)}$ | RBI data-retention input current (1) | $V_{RB} > 3.0\text{ V}$, $V_{DD} < V_{IT}$ | | 10 | 100 | nA |
| $V_{(RBI)}$ | RBI data-retention voltage | | 1.3 | | | V |

- (1) Specified by design. Not production tested.

SMBUS TIMING DIAGRAMS



(1) $SCLK_{ACK}$ is the acknowledge-related clock pulse generated by the master.

Figure 2. SMBus Timing Diagram

FUNCTIONAL DESCRIPTION

Internal Oscillator

The internal oscillator performance is additionally dependent on the tolerance of the 113k resistor connected between RSOC (pin 33) and VSSA (pin 34). It is recommended that this resistor be as close to the bq20851-V1P2 as possible and that it have a specification of $\pm 0.1\%$ tolerance and ± 50 ppm temperature drift or better. The layout of the PCBA is also an additional contributing factor to performance degradation.

The average temperature drift error of the oscillator function over a learning charge or discharge cycle introduces an equal capacity prediction error in a learned full charge capacity (FCC).

General Operation

The bq20851-V1P2 determines battery capacity by monitoring the amount of charge input or removed from a rechargeable battery. In addition to measuring charge and discharge, the bq20851-V1P2 measures battery voltage, temperature, and current, estimates battery self-discharge, and monitors the battery for low-voltage thresholds. The bq20851-V1P2 measures charge and discharge activity by monitoring the voltage across a small-value series sense resistor between the battery's negative terminal and the negative terminal of the battery pack. The available battery charge is determined by monitoring this voltage and correcting the measurement for environmental and operating conditions.

The bq20851-V1P2 interfaces with the bq29311 to perform battery protection, cell balancing, and voltage translation functions.

The bq20851-V1P2 can accept any NTC thermistor (default is Semitec 103AT) for temperature measurement or can be configured to use its internal temperature sensor. The bq20851-V1P2 uses temperature to monitor the battery pack and to compensate the self-discharge estimate.

Measurements

The bq20851-V1P2 uses an integrating sigma-delta analog-to-digital converter (ADC) for current measurement and a second sigma delta ADC for battery voltage and temperature measurement. Voltage, current, and temperature measurements are made every second.

Charge and Discharge Counting

The integrating ADC measures the charge and discharge flow of the battery by monitoring a small-value sense resistor between the SR1 and SR2 pins as shown in the schematic. The integrating ADC measures bipolar signals from -0.3 to 1.0 V. The bq20851-V1P2 detects charge activity when $V_{SR} = V_{(SR1)} - V_{(SR2)}$ is positive and discharge activity when

$V_{SR} = V_{(SR1)} - V_{(SR2)}$ is negative. The bq20851-V1P2 continuously integrates the signal over time, using an internal counter. The fundamental rate of the counter is 2.6 nVh. The bq20851-V1P2 updates Remaining Capacity() with the charge or discharge accumulated in this internal counter once every second.

Offset Calibration

The bq20851-V1P2 provides an autocalibration feature to cancel the voltage offset error across SR₁ and SR₂ for maximum charge measurement accuracy. The bq20851-V1P2 performs autocalibration when the SMBus lines stay low for a minimum of 20 s. The bq20851-V1P2 is capable of automatic offset calibration down to 1μV.

Digital Filter

The bq20851-V1P2 does not measure charge or discharge counts below the digital filter threshold. The digital filter threshold is programmed in the *Digital Filter* DF 0x2b and should be set sufficiently high to prevent false signal detection with no charge or discharge flowing through the sense resistor.

Voltage

While monitoring SR1 and SR2 for charge and discharge currents, the bq20851-V1P2 monitors the individual series cell voltages through the bq29311. The bq20851-V1P2 configures the bq29311 to present the selected cell to the VCELL pin of the bq29311 which should be connected to VIN of the bq20851-V1P2. The internal ADC of the bq20851-V1P2 then measures the voltage and scales it appropriately. The bq20851-V1P2 then reports the Voltage() and the individual cell voltages in VCELL1, VCELL2, VCELL3, and VCELL4 located in 0x3c-0x3f.

Current

The bq20851-V1P2 uses the SR1 and SR2 inputs to measure and calculate the battery charge and discharge current as represented in the data register Current().

Temperature

The TS input of the bq20851-V1P2 in conjunction with an NTC thermistor measures the battery temperature as shown in the schematic. The bq20851-V1P2 reports temperature in Temperature().

The bq20851-V1P2 can also be configured to use its internal temperature sensor by setting the IT bit in *Misc Configuration* DF 0x2a. Data flash locations DF 0xa4 through DF 0xad also have to be changed to prescribed values if the internal temperature sensor option is selected.

Table 1. Data Flash Settings for Internal or External Temperature Sensor

| LABEL | LOCATION Dec (Hex) | INTERNAL TEMP SENSOR SETTING Dec (Hex) | EXTERNAL TEMP SENSOR SETTING (Semitec 103AT) Dec (Hex) |
|---------------------|-----------------------|---|--|
| Misc. Configuration | 42 (0x2a) | Bit 7 = 1 | Bit 7 = 0 |
| TS Const1 A3 | 164/5 (0xa4/5) | 0 (0x0000) | -28285 (0x9183) |
| TS Const2 A2 | 166/7 (0xa6/7) | 0 (0x0000) | 20848 (0x5170) |
| TS Const3 A1 | 168/9 (0xa8/9) | -11136 (0xd480) | -7537 (0xe28f) |
| TS Const4 A0 | 170/1 (0xaa/b) | 5734 (0x1666) | 4012 (0x0fac) |
| Min temp AD | 172/3 (0xac/d) | 0 (0x0000) | 0 (0x0000) |
| Max temp | 174/5 (0xae/f) | 5734 (0x1666) | 4012 (0x0fac) |

If AD < Min Temp AD then Temp = Max Temp

else

$$\text{Temp} = [(A3 \times AD \times 2^{\wedge} - 16 + A2) \times AD \times 2^{\wedge} - 16 + A1] \times AD \times 2^{\wedge} - 16 + A0$$

Gas Gauge Operation

General

The operational overview in Figure 3 illustrates the gas gauge operation of the bq20851-V1P2. Table 3 describes the bq20851-V1P2 registers.

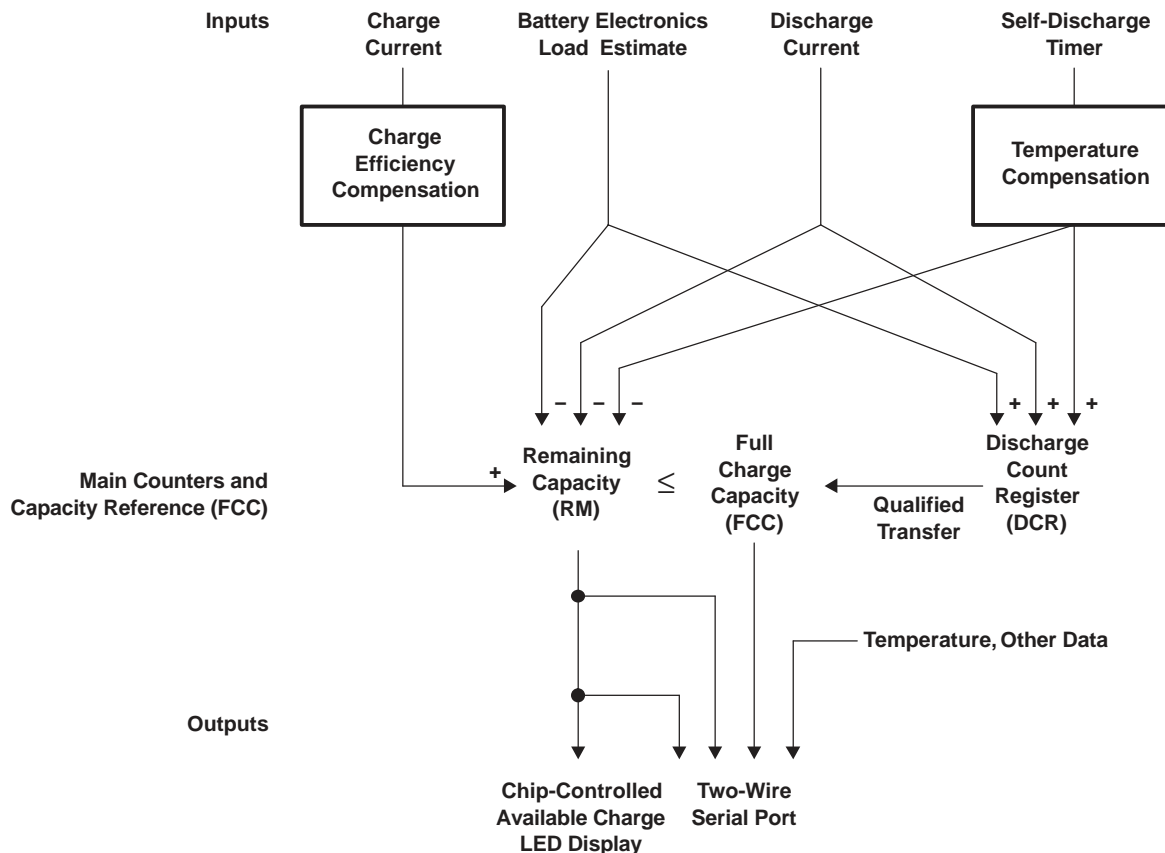


Figure 3. bq20851-V1P2 Operational Overview

The bq20851-V1P2 accumulates a measure of charge and discharge currents and estimates self-discharge of the battery. The bq20851-V1P2 compensates the charge current measurement for temperature and state-of-charge of the battery. The bq20851-V1P2 also adjusts the self-discharge estimation based on temperature.

The main charge counter RemainingCapacity() (RM) represents the available capacity or energy in the battery at any given time. The bq20851-V1P2 adjusts RM for charge, self-discharge, and other compensation factors. The information in the RM register is accessible through the SMBus interface and is also represented through the LED display.

The FullChargeCapacity() (FCC) register represents the last measured full discharge of the battery. It is used as the battery full-charge reference for relative capacity indication. The bq20851-V1P2 updates FCC after the battery undergoes a qualified discharge from nearly full to a low battery level. FCC is accessible through the SMBus interface.

The Discharge Count Register (DCR) is a non-accessible register that tracks discharge of the battery. The bq20851-V1P2 uses the DCR register to update the FCC register if the battery undergoes a qualified discharge from nearly full to a low battery level. In this way, the bq20851-V1P2 learns the true discharge capacity of the battery under system use conditions.

Main Gas-Gauge Registers

The gas-gauge register functions are described in Table 3.

RemainingCapacity() (RM)

RM represents the remaining capacity in the battery. The bq20851-V1P2 computes RM in units of either mAh or 10 mWh depending on the selected mode. See Battery Mode() (0x03) for units configuration.

RM counts up during charge to a maximum value of FCC and down during discharge and self-discharge to a minimum of 0. In addition to charge and self-discharge compensation, the bq20851-V1P2 calibrates RM at three low-battery-voltage thresholds, EDV2, EDV1, and EDV0 and three programmable midrange thresholds VOC25, VOC50, and VOC75. This provides a voltage-based calibration to the RM counter.

DesignCapacity() (DC)

DC is the user-specified battery full capacity. It is calculated from *Pack Capacity* DF 0x31-0x32 and is represented in units of mAh or 10 mWh. It also represents the full-battery reference for the absolute display mode.

FullChargeCapacity() (FCC)

FCC is the last measured discharge capacity of the battery. It is represented in units of either mAh or 10 mWh, depending on the selected mode. On initialization, the bq20851-V1P2 sets FCC to the value stored in *Last Measured Discharge* DF 0x35-0x36. During subsequent discharges, the bq20851-V1P2 updates FCC with the last measured discharge capacity of the battery. The last measured discharge of the battery is based on the value in the DCR register after a qualified discharge occurs. Once updated, the bq20851-V1P2 writes the new FCC value to data flash in mAh to *Last Measured Discharge*. FCC represents the full battery reference for the relative display mode and relative state of charge calculations.

Discharge Count Register (DCR)

The DCR register counts up during discharge, independent of RM. DCR counts discharge activity, battery load estimation, and self-discharge increment. The bq20851-V1P2 initializes DCR, at the beginning of a discharge, to FCC – RM when RM is within the programmed value in *Near Full* DF 0x2f. The DCR initial value of FCC – RM is reduced by FCC/128 if SC = 1 (bit 5 in *Gauge Configuration*) and is not reduced if SC = 0. DCR stops counting when the battery voltage reaches the EDV2 threshold on discharge.

Capacity Learning (FCC Update) and Qualified Discharge

The bq20851-V1P2 updates FCC with an amount based on the value in DCR if a qualified discharge occurs. The new value for FCC equals the DCR value plus the programmable nearly full and low battery levels, according to the following equation:

$$\text{FCC (new)} = \text{DCR (final)} = \text{DCR (initial)} + \text{Measured Discharge to EDV2} + (\text{FCC} \times \text{Battery Low\%}) \quad (1)$$

$$\text{Battery Low \%} = ((\text{value stored in DF 0x2e [MSByte] and 0xE3[LSByte]}) \times 2.56) / 655.36$$

A qualified discharge occurs if the battery discharges from $\text{RM} \geq \text{FCC} - \text{Near Full}$ to the EDV2 voltage threshold with the following conditions:

- No valid charge activity occurs during the discharge period. A valid charge is defined as a charge of 10 mAh into the battery.
- No more than 256 mAh of self-discharge or battery load estimation occurs during the discharge period.
- The temperature does not drop below the low temperature thresholds programmed in *Learning Low Temp* DF 0x9b during the discharge period.
- The battery voltage reaches the EDV2 threshold during the discharge period and the voltage is greater than or equal to the EDV2 threshold minus 256 mV when the bq20851-V1P2 detected EDV2.
- No midrange voltage correction occurs during the discharge period.
- Current remains $\geq 3C/32$ when EDV2 or *Battery Low %* level is reached.
- No overload condition exists when EDV2 threshold is reached or if $\text{RM}()$ has dropped to $\text{Battery Low\%} * \text{FCC}$.

The bq20851-V1P2 sets $\text{VDQ}=1$ in pack status when qualified discharge begins. The bq20851-V1P2 sets $\text{VDQ}=0$ if any disqualifying condition occurs. FCC cannot be reduced by more than 256 mAh or increased by more than 512 mAh during any single update cycle. The bq20851-V1P2 saves the new FCC value to the data flash immediately.

End-of-Discharge Thresholds and Capacity Correction

The bq20851-V1P2 monitors each cell for four low-voltage thresholds. From highest to lowest, these are EDV2, EDV1, EDV0 and *Cell Under Voltage*. EDV2 and EDV1 are calculated as a function of the various CEDV coefficients along with the present discharge rate, temperature and relative state of charge (RSOC). EDV2 is the variable voltage threshold that corresponds to the RSOC value stored in Battery Low %. This is typically 3–4%. EDV1 is the variable voltage threshold that corresponds to RSOC = 0%. EDV0 and *Cell Under Voltage* are typically fixed at 3.0 V and 2.75 V respectively. EDV0 sets the Terminate Discharge Alarm (TDA) bit. *Cell Under Voltage* causes shutdown of both the bq20851-V1P2 and the bq29311. The various low-voltage thresholds are determined on the basis of the lowest single-cell voltage.

The bq20851-V1P2 disables EDV detection if Current() exceeds the *Overload Current* threshold programmed in DF 0x58 – DF 0x59. The bq20851-V1P2 resumes EDV threshold detection after Current() drops below the *Overload Current* threshold. Any EDV threshold detected is reset after charge is applied and VDQ is cleared after 10 mAh of charge.

Table 2. State of Charge Based on Low Battery Voltage

| THRESHOLD | RELATIVE STATE OF CHARGE |
|-----------|--------------------------------|
| EDV0 | 0% (Terminate Discharge Alarm) |
| EDV1 | 0% (Fully Discharged Flag) |
| EDV2 | <i>Battery Low %</i> |

The bq20851-V1P2 uses the EDV thresholds to apply voltage-based corrections to the RM register according to Table 2. The bq20851-V1P2 adjusts RM as it detects each threshold. If the voltage threshold is reached before the corresponding capacity on discharge, the bq20851-V1P2 reduces RM to the appropriate amount as shown in Table 2. If RM reaches the capacity level before the voltage threshold is reached on discharge, the bq20851-V1P2 prevents RM from decreasing further until the battery voltage reaches the corresponding threshold.

If 0% RSOC occurs before the EDV1 threshold voltage is reached, then the Fully Discharged (FD) bit will be set. This is to accommodate the case of a partial charge/discharge cycle. When a partial charge is performed, the portion of the cell lattice structure that receives the charge has a lower series resistance than the sections that are charged later in the charge cycle. The subsequent discharge therefore provides a higher voltage as a function of remaining capacity than would be the case after a full charge. The coulometric value is more accurate than the voltage in this case.

Table 3. bq20851-V1P2 Register Functions

| FUNCTION | COMMAND CODE | ACCESS | UNITS |
|------------------------|--------------|------------|-------------|
| ManufacturerAccess | 0x00 | read/write | NA |
| RemainingCapacityAlarm | 0x01 | read/write | mAh, 10 mWh |
| RemainingTimeAlarm | 0x02 | read/write | minutes |
| BatteryMode | 0x03 | read/write | NA |
| AtRate | 0x04 | read/write | mA, 10mW |
| AtRateTimeToFull | 0x05 | read | minutes |
| AtRateTimeToEmpty | 0x06 | read | minutes |
| AtRateOK | 0x07 | read | Boolean |
| Temperature | 0x08 | read | 0.1°K |
| Voltage | 0x09 | read | mV |
| Current | 0x0a | read | mA |
| AverageCurrent | 0x0b | read | mA |
| MaxError | 0x0c | read | percent |
| RelativeStateOfCharge | 0x0d | read | percent |
| AbsoluteStateOfCharge | 0x0e | read | percent |
| RemainingCapacity | 0x0f | read | mAh, 10 mWh |
| FullChargeCapacity | 0x10 | read | mAh, 10 mWh |
| RunTimeToEmpty | 0x11 | read | minutes |
| AverageTimeToEmpty | 0x12 | read | minutes |
| AverageTimeToFull | 0x13 | read | minutes |

Table 3. bq20851-V1P2 Register Functions (Continued)

| FUNCTION | COMMAND CODE | ACCESS | UNITS |
|--------------------|--------------|--------|-------------|
| ChargingCurrent | 0x14 | read | mA |
| ChargingVoltage | 0x15 | read | mV |
| Battery Status | 0x16 | read | NA |
| CycleCount | 0x17 | read | cycles |
| DesignCapacity | 0x18 | read | mAh, 10 mWh |
| DesignVoltage | 0x19 | read | mV |
| SpecificationInfo | 0x1a | read | NA |
| ManufactureDate | 0x1b | read | NA |
| SerialNumber | 0x1c | read | integer |
| Reserved | 0x1d-0x1f | 0 | 0 |
| ManufacturerName | 0x20 | read | string |
| DeviceName | 0x21 | read | string |
| DeviceChemistry | 0x22 | read | string |
| ManufacturerData | 0x23 | read | string |
| Pack status | 0x2f (LSB) | read | NA |
| Pack configuration | 0x2f (MSB) | read | NA |
| VCELL4 | 0x3c | read | mV |
| VCELL3 | 0x3d | read | mV |
| VCELL2 | 0x3e | read | mV |
| VCELL1 | 0x3f | read | mV |

Self-Discharge

The bq20851-V1P2 estimates the self-discharge of the battery to maintain an accurate measure of the battery capacity during periods of inactivity. The bq20851-V1P2 makes self-discharge adjustments to RM() every 1/4 seconds when awake and periodically when in sleep mode. The period is determined by *Sleep Timer* DF 0xe7.

The self-discharge estimation rate for 25°C is doubled for each 10 degrees above 25°C or halved for each 10 degrees below 25°C. The following table shows the relation of the self-discharge estimation at a given temperature to the rate programmed for 25°C (Y% per day programmed in DF 0x2c).

Table 4. Self-Discharge for Rate Programmed

| TEMPERATURE (°C) | SELF-DISCHARGE RATE |
|------------------|---------------------|
| Temp < 10 | 1/4 Y% per day |
| 10 ≤ Temp <20 | 1/2 Y% per day |
| 20 ≤ Temp <30 | Y% per day |
| 30 ≤ Temp <40 | 2Y% per day |
| 40 ≤ Temp <50 | 4Y% per day |
| 50 ≤ Temp <60 | 8Y% per day |
| 60 ≤ Temp <70 | 16Y% per day |
| 70 ≤ Temp | 32Y% per day |

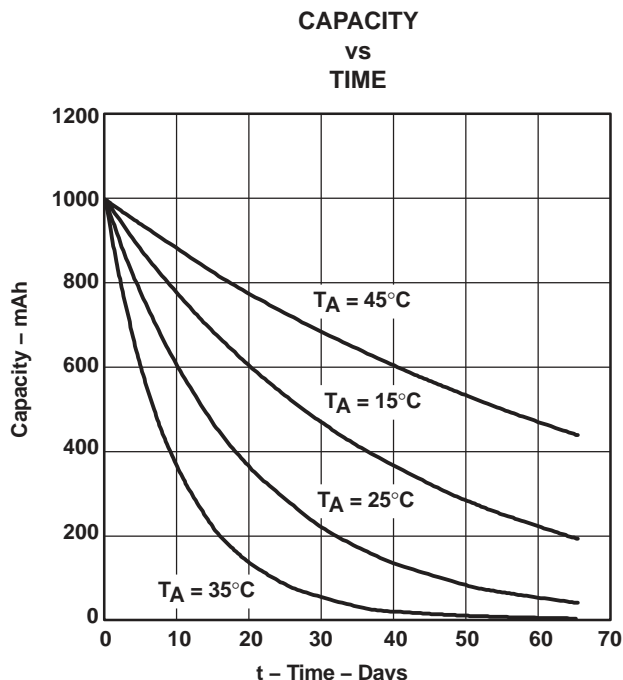


Figure 4. Self-Discharge at 2.5%/Day at 25°C

Figure 4 illustrates how the self-discharge estimate algorithm adjusts RemainingCapacity() versus temperature.

Battery Electronic Load Compensation

The bq20851-V1P2 can be configured to compensate for a constant load (as from battery electronics) present in the battery pack at all times. The bq20851-V1P2 applies the compensation continuously when the charge or discharge is below the digital filter. The bq20851-V1P2 applies the compensation in addition to self-discharge. The compensation occurs at a rate determined by the value stored in *Electronics Load DF 0x2d*. The compensation range is 0 μ A–765 μ A in steps of approximately 3 μ A.

Midrange Capacity Corrections

The bq20851-V1P2 applies midrange capacity corrections when the VCOR bit is set in *Gauge Configuration DF 0x29*. The bq20851-V1P2 adjusts RM to the associated percentage at three different voltage levels: VOC25, VOC50, and VOC75. The VOC values represent the open circuit battery voltage at which RM corresponds to the associated for each threshold.

For the midrange corrections to occur, the temperature must be in the range of 19°C to 31°C inclusive and the Current() and AverageCurrent() must both be between –64 mA and 0. The bq20851-V1P2 makes midrange corrections as shown in Table 5. For a correction to occur, the bq20851-V1P2 must detect the need for correction twice during subsequent 20-s intervals. With the VCOR bit set, the bq20851-V1P2 makes midrange corrections whenever conditions permit. If the OTVC bit in *Gauge Configuration DF 0x29* is set and VCOR = 0, the bq20851-V1P2 makes a single attempt of mid-range correction immediately after device reset and does not require a second validation.

Table 5. Midrange Corrections

| CONDITION | RESULT |
|---|--|
| Voltage() \geq VOC75 and RelativeStateOfCharge() \leq 63% | RelativeStateOfCharge() \rightarrow 75% |
| < VOC75 and RelativeStateOfCharge() \geq 87% | RelativeStateOfCharge() \rightarrow 75% |
| \geq VOC50 and RelativeStateOfCharge() \leq 38% | RelativeStateOfCharge() \rightarrow 50% |
| < VOC50 and RelativeStateOfCharge() \geq 62% | RelativeStateOfCharge() \rightarrow 50% |
| \geq VOC25 and RelativeStateOfCharge() \leq 13% | RelativeStateOfCharge() \rightarrow 25% |
| < VOC25 and RelativeStateOfCharge() \geq 37% | RelativeStateOfCharge() \rightarrow 25% |

Charge Control

Charging Voltage and Current Broadcasts

The bq20851-V1P2 supports SBS charge control by broadcasting the ChargingCurrent() and ChargingVoltage() to the Smart Charger address. The bq20851-V1P2 broadcasts the requests every 10 seconds. The bq20851-V1P2 updates the values used in the charging current and voltage broadcasts based on the battery's state of charge, voltage, and temperature. The charge voltage is programmed in *Charging Voltage* DF 0x039-0x3a. The charge current may take any of four different values: Fast Charging Current DF (0x3d-0x3c), Maintenance Charging Current (DF 0x3f), Precharge Current (0x41), or 0. The charge current depends on charge state and operating conditions.

The bq20851-V1P2 internal charge control is compatible with the constant current/constant voltage profile for Li-Ion. The bq20851-V1P2 detects primary charge termination on the basis of the tapering charge current during the constant-voltage phase.

Alarm Broadcasts to Smart Charger and Host

If any of the bits 8–15 in BatteryStatus() are set, the bq20851-V1P2 broadcasts an AlarmWarning() message to the Host address. If any of the bits 12–15 in BatteryStatus() are set, the bq20851-V1P2 also sends an AlarmWarning() message to the Smart Charger address. The bq20851-V1P2 repeats the AlarmWarning() messages every 10 seconds until the alarm bits are cleared.

Precharge Qualification

The bq20851-V1P2 sets ChargingCurrent() to the precharge rate as programmed in *Precharge Current* DF 0x41 under the following conditions:

- Voltage: The bq20851-V1P2 requests the precharge charge rate when Voltage() drops below the precharge threshold or when the EDV0 threshold is detected. Once requested, a precharge rate remains until Voltage() increases above the precharge threshold and the EDV0 condition does not exist. The precharge threshold is programmed in *Precharge Voltage* DF 0x3b-0x3c.
- Temperature: The bq20851-V1P2 requests the precharge rate when Temperature() is between 0°C and the precharge threshold programmed in *Precharge Temp* 0x43. Temperature() must be equal to or greater than the precharge threshold to allow the fast-charge rate.

Charge Suspension

The bq20851-V1P2 may temporarily suspend charge if it detects a charging fault. A charging fault includes the following conditions.

- Overcurrent: An overcurrent condition exists when the bq20851-V1P2 measures the charge current to be equal to or greater than *Overcurrent Margin* plus ChargingCurrent(). *Overcurrent Margin* is programmed in DF 0x5c-0x5d. On detecting an overcurrent condition, the bq20851-V1P2 sets the ChargingCurrent() to zero and sets the TERMINATE_CHARGE_ALARM bit in Battery Status(). The overcurrent condition and TERMINATE_CHARGE_ALARM are cleared when the measured current drops below *Overcurrent Margin*.
- Overvoltage: An overvoltage condition exists when the bq20851-V1P2 measures the battery voltage to be more than *Over Voltage Margin* plus ChargingVoltage(), or when a cell voltage has exceeded the overvoltage limit programmed in *Cell Over Voltage*. *Over Voltage Margin* is programmed in DF 0x5a-0x5b and *Cell Over Voltage* in DF 0x60. On detecting an overvoltage condition, the bq20851-V1P2 sets the ChargingCurrent() to zero and sets the TERMINATE_CHARGE_ALARM bit in BatteryStatus(). The bq20851-V1P2 clears the TERMINATE_CHARGE_ALARM bit when it detects that the battery is no longer being charged (DISCHARGING bit set in BatteryStatus()). The bq20851-V1P2 continues to broadcast zero charging current until the overvoltage condition is cleared. The overvoltage condition is cleared when the measured battery voltage drops below the ChargingVoltage() plus the *Over Voltage Margin* and all cell voltages are less than the *Cell Over Voltage* Reset threshold in DF 0x6f, 0xd0.
- Overtemperature: An overtemperature condition exists when Temperature() is greater than or equal to the *Max Temperature* value programmed in DF 0x53, 0x54. On detecting an overtemperature condition, the bq20851-V1P2 sets the ChargingCurrent() to zero and sets the OVER_TEMP_ALARM and TERMINATE_CHARGE_ALARM bit in BatteryStatus() and the CVOV bit in pack status. The overtemperature condition is cleared when Temperature() is equal to or below (*Max Temperature* – *Temperature Hysteresis* DF 0x55, 0x56) or 43°C.
- Overcharge: An overcharge condition exists if the battery is charged more than the *Maximum Overcharge* value after RM = FCC. *Maximum Overcharge* is programmed in DF 0x4e-0x4f. On detecting an overcharge condition, the bq20851-V1P2 sets the ChargingCurrent() to zero and sets the OVER_CHARGED_ALARM, TERMINATE_CHARGE_ALARM, and FULLY_CHARGED bits in BatteryStatus(). The bq20851-V1P2 clears the

TERMINATE_CHARGE_ALARM when it detects that the battery is no longer being charged and clears the OVER_CHARGED_ALARM when 2mAh of discharge are measured. The FULLY_CHARGED bit remains set and the bq20851-V1P2 continues to broadcast zero charging current until RelativeStateOfCharge() is less than *Fully Charged Clear%* programmed in DF 0x47. The counter used to track overcharge capacity is reset with 2 mAh of discharge.

- **Undertemperature:** An undertemperature condition exists if Temperature() < 0°C. On detecting an under temperature condition, the bq20851-V1P2 sets ChargingCurrent() to zero. The bq20851-V1P2 sets ChargingCurrent() to the appropriate precharge rate or fast-charge rate when Temperature() ≥ 0°C.

Primary Charge Termination

The bq20851-V1P2 terminates charge if it detects a charge-termination condition based on current taper. A charge-termination condition includes the following:

For current taper, ChargingVoltage() must be set to the pack voltage desired during the constant-voltage phase of charging. The bq20851-V1P2 detects a current taper termination when the pack voltage is greater than or equal to ChargingVoltage() minus *Current Taper Qual Voltage* in DF 0x4a and the charging current is below a threshold determined by *Current Taper Threshold* in DF 0x48-0x49 and above 22.5 mA for two consecutive 40-second intervals.

Once the bq20851-V1P2 detects a Primary Charge Termination, the bq20851-V1P2 sets the TERMINATE_CHARGE_ALARM and FULLY_CHARGED bits in BatteryStatus(), and sets the ChargingCurrent() to the maintenance charge rate as programmed in *Maintenance Charging Current* DF 0x3f, 0x40. On termination, the bq20851-V1P2 also sets RM to a programmed percentage of FCC, provided that RelativeStateOfCharge() is below the desired percentage of FCC and the CSYNC bit in *Gauge Configuration* DF 0x29 is set. The programmed percentage of FCC, *Fast Charge Termination %*, is set in DF 0x46. The bq20851-V1P2 clears the FULLY_CHARGED bit when RelativeStateOfCharge() is less than the programmed *Fully Charged Clear %*. The bq20851-V1P2 broadcasts the fast-charge rate when the FULLY_CHARGED bit is cleared and voltage and temperature permit. The bq20851-V1P2 clears the TERMINATE_CHARGE_ALARM when it no longer detects that the battery is being charged or it no longer detects the termination condition. See Table 6 for a summary of BatteryStatus() alarm and status bit operation.

Table 6. Alarm and Status Bit Summary

| BATTERY STATE | CONDITIONS | CC() CURRENT AND STATUS BITS SET | STATUS CLEAR CONDITION |
|----------------------------|---|--|---|
| Overcurrent | $C() = CC() + \text{OvercurrentMargin}$ | $CC() = 0, TCA = 1$ | $C() < \text{OvercurrentMargin}$ |
| Prolonged Overcurrent | $AC() = \text{Fast-ChargingCurrent} + \text{OvercurrentMargin}$ | $CVOV = 1$ $CC() = 0, TCA = 1$ | $AC() < 0 \text{ mA}$ |
| Overload | $AC() = -\text{OverloadCurrent}$ | $CVUV = 1$ | $AC() < -0 \text{ mA}$ |
| Overvoltage | $V() = CV() + \text{Over Voltage Margin}$ $VCELL1, 2, 3, \text{ or } 4 = \text{Cell Over Voltage}$ | $TCA = 1$ | $DISCHARGING = 1$ |
| | | $CC() = 0, CVOV = 1$ | $V() < CV() + \text{Over Voltage Margin}$ $VCELL(\text{all}) = \text{Cell Over Voltage Reset}$ |
| Overtemperature | $T() = \text{Max Temperature}$ | $CC() = 0, OTA = 1,$ $TCA = 1, CVOV = 1$ | $T() = \text{Max Temperature} - \text{Temperature Hysteresis}$ or $T() = 43^\circ\text{C}$ |
| Overcharge | Capacity added after $RM() = FCC() = \text{MaximumOvercharge}$ | $CC() = 0, FC = 1$ | $RSOC() < \text{Fully Charged Clear } \%$ |
| | | $OCA = 1, TCA = 1$ | $DISCHARGING = 1,$ and 2 mAh of discharge is measured |
| Undertemperature | $T() < 0^\circ\text{C}$ | $CC() = 0$ | $0^\circ\text{C} \Rightarrow T()$ |
| | $0^\circ\text{C} = T() < LTF$ | $CC() = \text{Precharge}$ | $T() = LTF + DF 0x44$ (default = 3°C) |
| Primary Charge Termination | Current taper | $FC = 1, TCA = 1$ $CC() = \text{Maintenance ChargingCurrent}$ | $RSOC() < \text{Fully Charged Clear}\%$ |
| Fully Discharged | $RM() = 0 \%$ and $DISCHARGING = 1$ | $FD = 1$ | $RSOC() = 20\%$ |
| Overdischarged | $V() \leq EDV0$ or <i>Terminate Voltage</i> | $TDA = 1$ | $V() > \text{Terminate Voltage}$ and $\text{Charging Current} > 0$ |
| Low Capacity | $RM() < RCA()$ | $RCA = 1$ | $RM() = RCA()$ |
| Low Run Time | $ATTE() < RTA()$ | $RTA = 1$ | $ATTE() = RTA()$ |

NOTE: AC() = AverageCurrent(), C() = Current(), CV() = ChargingVoltage(), CC() = ChargingCurrent(), V() = Voltage(), T() = Temperature(), TCA = TERMINATE_CHARGE_ALARM, OTA = OVER_TEMPERATURE_ALARM, OCA = OVER_CHARGED_ALARM, TDA = TERMINATE_DISCHARGE_ALARM, FC = FULLY_CHARGED, FD = FULLY_DISCHARGED, RSOC() = RelativeStateOfCharge(). RM() = RemainingCapacity(), RCA = REMAINING_CAPACITY_ALARM, RTA = REMAINING_TIME_ALARM, ATTE() = AverageTimeToEmpty(), RTA() = RemainingTimeAlarm(), RCA() = RemainingCapacityAlarm(). LTF = Low Temperature Fault threshold FCC() = Full Charge Capacity

Cell Balancing

The bq20851-V1P2 balances the cells during charge by discharging those cells above the threshold set in *Cell Balance Threshold* DF 0xd7-0xd8, if the maximum difference in cell voltages exceeds the value programmed in *Cell Balance Min* DF 0xdb. For cell balancing, the bq20851-V1P2 measures the cell voltages at an interval set in *Cell Balance Interval* DF 0xdc. On the basis of the cell voltages, the bq20851-V1P2 either selects the appropriate cell to discharge or adjusts the cell balance threshold up by the value programmed in *Cell Balance Window* 0xd9-0xda when all cells exceed the cell balance threshold or the highest cell exceeds the cell balance threshold by the cell balance window.

The cell balance threshold is reset to the value in *Cell Balance Threshold* at the start of every charge cycle. The threshold can be adjusted no more than once during a balance interval.

DISPLAY PORT

General

The display port drives a 5-LED bar-graph display. The display is activated by a logic signal on the \overline{DISP} input. The bq20851-V1P2 can display RemainingCapacity() in either a relative or absolute mode with each LED representing a percentage of the full-battery reference. In relative mode, the bq20851-V1P2 uses FullChargeCapacity() as the full-battery reference; in absolute mode, it uses Design Capacity (DC). The DMODE bit in *Pack Configuration* DF 0x28 programs the bq20851-V1P2 for the absolute or relative display mode.

Activation

Activation is usually accomplished with a pullup resistor and a pushbutton switch. Detection of the transition activates the display. Reactivation of the display requires that the \overline{DISP} input return to a logic-high state and then transition low again. The second high-to-low transition can be detected only after the display timer expires. If unused, the \overline{DISP} input must be pulled up to V_{CC} . The \overline{DISP} input is ignored if the bq20851-V1P2 detect charge activity, see charging mode below for further information.

Display Modes

In relative mode, each LED output represents a % of the `RelativeStateOfCharge()` value. In absolute mode, each LED output represents a% of the `AbsoluteStateOfCharge()` value. In either mode, the bq20851-V1P2 blinks the LED display if `RemainingCapacity()` is less than `RemainingCapacityAlarm()`. The display is disabled if `EDV0 = 1`. The default condition is all LEDs off.

Discharging Mode

The bq20851-V1P2 display port is in this mode when the battery is in the system but not charging or removed from the system. On activation of the `DISP` input in this mode the active LEDs with turn on sequentially with a `LED_DELAY`, DF 0xe8 (default = 50 ms) delay between the illumination of each active LEDs. When all active LEDs are ON they will remain on for the LED HOLD time, which is programmable in DF 0xeb, 0xec, and then all LEDs will turn OFF together. When State of Charge < 10% then LED1 will repeatedly flash at a rate of on for `LED_FLASH`, DF 0xe9 (default = 50 ms) then off for `LED_FLASH`.

| STATE OF CHARGE | LED1 | LED2 | LED3 | LED4 | LED5 |
|-----------------|-------|------|------|------|------|
| 0% | OFF | OFF | OFF | OFF | OFF |
| 0% to 10% | Flash | OFF | OFF | OFF | OFF |
| 11% to 30% | ON | OFF | OFF | OFF | OFF |
| 31% to 50% | ON | ON | OFF | OFF | OFF |
| 51% to 70% | ON | ON | ON | OFF | OFF |
| 71% to 88% | ON | ON | ON | ON | OFF |
| 89% to 100% | ON | ON | ON | ON | ON |

Charging Mode

The bq20851-V1P2 display port is in this mode when the battery is in the system and is being charged but the battery is not full. When the battery is full then all LEDs are OFF. The `DISP` input is ignored until the battery is full (100% where all LEDs are OFF. When charging is activated all active LEDs are sequenced ON and then the LED representing the portion of capacity being charged will blink at a rate of ON for `LED_BLINK`, DF 0xea (default = 750 mS) and then OFF for `LED_BLINK` indicating charge behavior.

| STATE OF CHARGE | LED1 | LED2 | LED3 | LED4 | LED5 |
|-----------------|-------|-------|-------|-------|-------|
| 0% to 30% | Blink | OFF | OFF | OFF | OFF |
| 31% to 50% | ON | Blink | OFF | OFF | OFF |
| 51% to 70% | ON | OFF | Blink | OFF | OFF |
| 71% to 88% | ON | ON | ON | Blink | OFF |
| 89% to 100% | ON | ON | ON | ON | Blink |

Li-Ion Protector Control

The bq20851-V1P2 provides protection for Li-Ion batteries, as shown in Table 7. The bq20851-V1P2 uses the bq29311 to measure and report individual series cell voltages. The bq20851-V1P2 determines if a voltage protection condition has been breached and turns off the respective control FET via I²C communication to the bq29311. It is recommended that the bq20851-V1P2 protection control be validated by two successive measurements by setting `VOD=1` in *Misc Configuration*.

The bq29311 can detect and protect the load from an overcurrent (OC) or short circuit (SC). The bq29311 alerts the bq20851-V1P2 with the XALERT output when ever an overcurrent or short circuit threshold is breached in either the charge or discharge directions.

The bq20851-V1P2 asserts CVOV and instructs the bq29311 to turn off the charge FET if an Overvoltage or Overtemperature condition exists, or if $AverageCurrent() \geq Fast-Charging Current + Over Current Margin$ (Prolonged Overcurrent condition in Table 6). The bq20851-V1P2 does not turn off the charge FET if there is a discharge current > 50 mA. The bq20851-V1P2 instructs the bq29311 to turn on the charge FET when Overvoltage and Overtemperature conditions no longer exist, and $AverageCurrent() < 256$ mA (if Prolonged Overcurrent generated the fault condition).

The bq20851-V1P2 asserts CVUV and instructs the bq29311 to turn off the discharge FET if an Overdischarged condition exists, or if $AverageCurrent() \leq -overload\ current$ (Overload). The bq20851-V1P2 does not turn off the discharge FET if there is a charge current ≥ 50 mA. The bq20851-V1P2 instructs the bq29311 to turn on the discharge FET when the Overdischarged condition no longer exists and $AverageCurrent() > -256$ mA (if Overload generated the fault condition).

Table 7. bq20851-V1P2 to bq29311 Interface (FET Protection Control)

| Battery State (Table 6) | DISCHARGING FET | CHARGING FET |
|---|-----------------------|-----------------------|
| CVOV = 1: Prolonged Overcurrent, Overvoltage, Overtemperature | Normal ⁽¹⁾ | Off ⁽²⁾ |
| CVOV = CVUV = 0 | Normal ⁽¹⁾ | Normal ⁽²⁾ |
| CVUV = 1: Overload, Overdischarged | Off ⁽³⁾ | Normal ⁽¹⁾ |

(1) State determined by bq29311

(2) On if there is a discharge current ≥ 50 mA(3) On if there is a charge current ≥ 50 mA.**Table 8. Stand-Alone bq29311 Protection Control**

| MODE | CONDITION | CLEAR ⁽⁴⁾ |
|--------------------------|---|-------------------------|
| Over Load | <i>AFE Over Curr Dsg</i> (DF 0xb2) is breached for <i>Over Curr Delay</i> (DF 0xb4) | AverageCurrent() = 0 mA |
| Over Current | <i>AFE Over Curr Chg</i> (DF 0xb3) is breached for <i>Over Curr Delay</i> (DF 0xb4) | AverageCurrent() = 0 mA |
| Short Circuit, Discharge | <i>AFE Short Circ Thresh</i> (DF 0xb6) is breached for <i>AFE Short Circuit Delay</i> (DF 0xb7, lower nibble) | AverageCurrent() = 0 mA |
| Short Circuit, Charge | <i>AFE Short Circ Thresh</i> (DF 0xb6) is breached for <i>AFE Short Circuit Delay</i> (DF 0xb7, upper nibble) | AverageCurrent() = 0 mA |

(4) Clear is detected and controlled by the bq20851-V1P2.

SAFE Output

The $\overline{\text{SAFE}}$ output of the bq20851-V1P2 provides an additional level of safety control. The active low safety output can blow a fuse or control another switch on the basis of temperature, pack-voltage level, a cell-voltage, or an integrity check of the AFE registers.

The $\overline{\text{SAFE}}$ output is driven low in any of the following 4 conditions if the AC bit in *Misc Configuration* (DF 0x2a) is set. If the $\overline{\text{SAFE}}$ output activates, the bq20851-V1P2 sets the SOV bit in pack status. SOV remains set until the bq20851-V1P2 is reset. The $\overline{\text{SAFE}}$ output can be pulled high (cleared) by a POR of the bq20851-V1P2 only.

$\overline{\text{SAFE}}$ activation conditions:

- When CVOV = 1 AND after a minimum of 1s Voltage() > *Safety Over Voltage* (DF 0x68 and 0x69), or
- When CVOV = 1 AND after a minimum of 1s the Temperature() > *Safety Temperature* (DF 0x6a and 0x6b)
- When *Miscellaneous Configuration* (0x2a) bit 5 AC is set, and the AFE has failed at least *AFE Fail Times* (DF 0xd3, d4)

The bq20851-V1P2 checks the programming of the AFE registers at a period determined by *AFE Check Time* DF 0xe4. The units of the check period are seconds unless the bq20851-V1P2 is in sleep mode, in which case the period is *AFE Check Time* x *Sleep Current Time* (DF 0xe7). If the data is not correct, the bq20851-V1P2 increments an internal counter.

The CVOV flag in *PackStatus*() (x2f) is set in any of the following ways:

- Voltage() \geq ChargingVoltage() + OverVoltageMargin (DF 0x5a, 0x5b)
- AverageCurrent() \geq FastCurrent + OvercurrentMargin (DF 0x5c, 0x5d)
- Any cell voltage \geq CellOverVoltage (DF 0x60, 0x61)
- The BatteryStatus() Over temperature bit is set

An example circuit using the $\overline{\text{SAFE}}$ output to blow a fuse is shown in Figure 5.

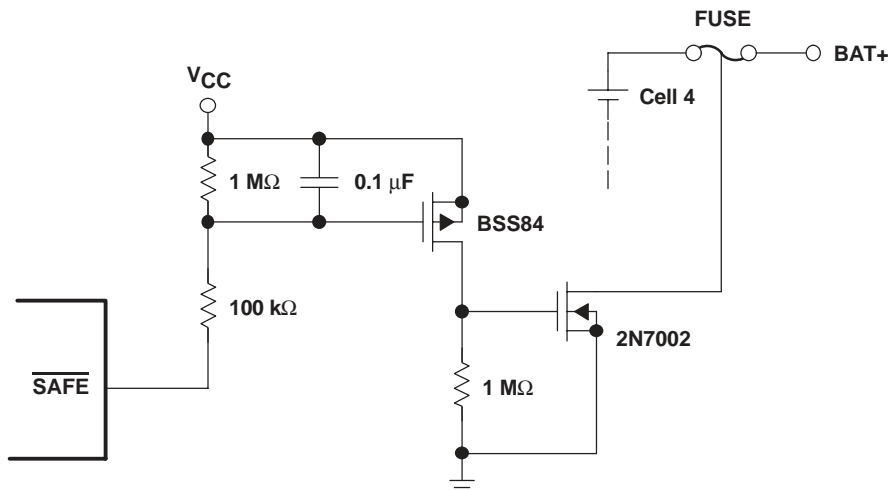


Figure 5. Example $\overline{\text{SAFE}}$ Circuit Implementation

Low-Power Modes

The bq20851-V1P2 enters sleep mode when the charge and discharge current is less than the threshold programmed in *Sleep Current Threshold* DF 0xe5, the SMBus lines are low for at least 2 s, and bit 4 of *Misc. Configuration* DF 0x2a is set to zero. The bq20851-V1P2 wakes up periodically to monitor voltage and temperature and to apply self-discharge adjustment. The sleep period is set in *Sleep Timer* DF 0xe7. The bq20851-V1P2 wakes up at a period set by *Sleep Current Time* DF 0xe6 to measure current. The bq20851-V1P2 comes out of sleep when the SMBus lines go high or if the current is greater than *Sleep Current Threshold*. A rising edge on SMBC or SMBD restores the bq20851-V1P2 to the full operating mode.

When any cell voltage reaches the Cell Under Voltage Threshold voltage, the bq20851-V1P2 turns off the DSG FET via the bq29311 and writes the SHUTDOWN threshold voltage of the bq29311 to 10.975 V. If the battery is already below this voltage threshold then the bq29311 will enter its SHUTDOWN mode causing the battery electronics to enter an ultra low power mode when the bq20851-V1P2 is powered down.

Reset Conditions

On power-up the entire IC is reset and data is loaded from Data Flash to configure the SBS Data and the system. On a partial reset (loss of VCC but RBI holds RAM valid) then a limited number of locations are taken.

These actions are the following:

- The AFE registers are rewritten.
- PackStatus() VDQ flag is cleared (the proposed change is not to clear VDQ).
- PackStatus() EDV2 flag is cleared.
- BatteryStatus() DISCHARGING flag is cleared.
- The charger and alarm broadcast period is set to 10 seconds between broadcasts.

COMMUNICATION

The bq20851-V1P2 includes an SMBus communication port. The SMBus interface is a 2-wire bidirectional protocol using the SMBC (clock) and SMBD (data) pins. The communication lines are isolated from VCC and may be pulled-up higher than VCC. Also, the bq20851-V1P2 does not pull these lines low if VCC to the part is zero.

The communication ports allow a host controller, an SMBus compatible device, or other processor to access the memory registers of the bq20851-V1P2. In this way a system can efficiently monitor and manage the battery.

SMBus

The SMBus interface is a command-based protocol. A processor acting as the bus master initiates communication to the bq20851-V1P2 by generating a start condition. A start condition consists of a high-to-low transition of the SMBD line while the SMBC is high. The processor then sends the bq20851-V1P2 device address of 0001011 (bits 7-1) plus a R/W bit (bit 0) followed by an SMBus command code. The R/W bit (LSB) and the command code instruct the bq20851-V1P2 to either store the forthcoming data to a register specified by the SMBus command code or output the data from the specified register. The processor completes the access with a stop condition. A stop condition consists of a low-to-high transition of the SMBD line while the SMBC is high. With SMBus, the most-significant bit (MSB) of a data byte is transmitted first.

In some instances, the bq20851-V1P2 acts as the bus master. This occurs when the bq20851-V1P2 broadcasts charging requirements and alarm conditions to device addresses 0x12 (SBS Smart Charger) and 0x10 (SBS Host Controller).

SMBus Protocol

The bq20851-V1P2 supports the following SMBus protocols:

- Read word
- Write word
- Block read

A processor acting as the bus master uses the three protocols to communicate with the bq20851-V1P2. The bq20851-V1P2 acting as the bus master uses the write word protocol.

The SMBD and SMBC pins are open drain and require external pullup resistors. A 1-M Ω pulldown resistor in the battery pack on SMBC and SMBD is required to assure the detection of the SMBus offstate, the performance of automatic offset calibration, and the initiation of the low-power sleep mode when the battery pack is removed.

SMBus Packet Error Checking

The bq20851-V1P2 supports packet error checking as a mechanism to confirm proper communication between it and another SMBus device. Packet error checking requires that both the transmitter and receiver calculate a packet error code (PEC) for each communication message. The device that supplies the last byte in the communication message appends the PEC to the message. The receiver compares the transmitted PEC to its PEC result to determine if there is a communication error.

PEC Protocol

The bq20851-V1P2 can receive or transmit data with or without PEC. Figure 6 shows the communication protocol for the read word, write word, and read block messages without PEC. Figure 7 includes PEC.

In the read word protocol, the bq20851-V1P2 receives the PEC after the last byte of data from the host. If the host does not support PEC, the last byte of data is followed by a stop condition. After receipt of the PEC, the bq20851-V1P2 compares the value to its calculation. If the PEC is correct, the bq20851-V1P2 responds with an ACKNOWLEDGE. If it is not correct, the bq20851-V1P2 responds with a NOT ACKNOWLEDGE and sets an error code.

In the write word and block read, the host generates an ACKNOWLEDGE after the last byte of data sent by the bq20851-V1P2. The bq20851-V1P2 then sends the PEC and the host acting as a master-receiver generates a NOT ACKNOWLEDGE and a stop condition.

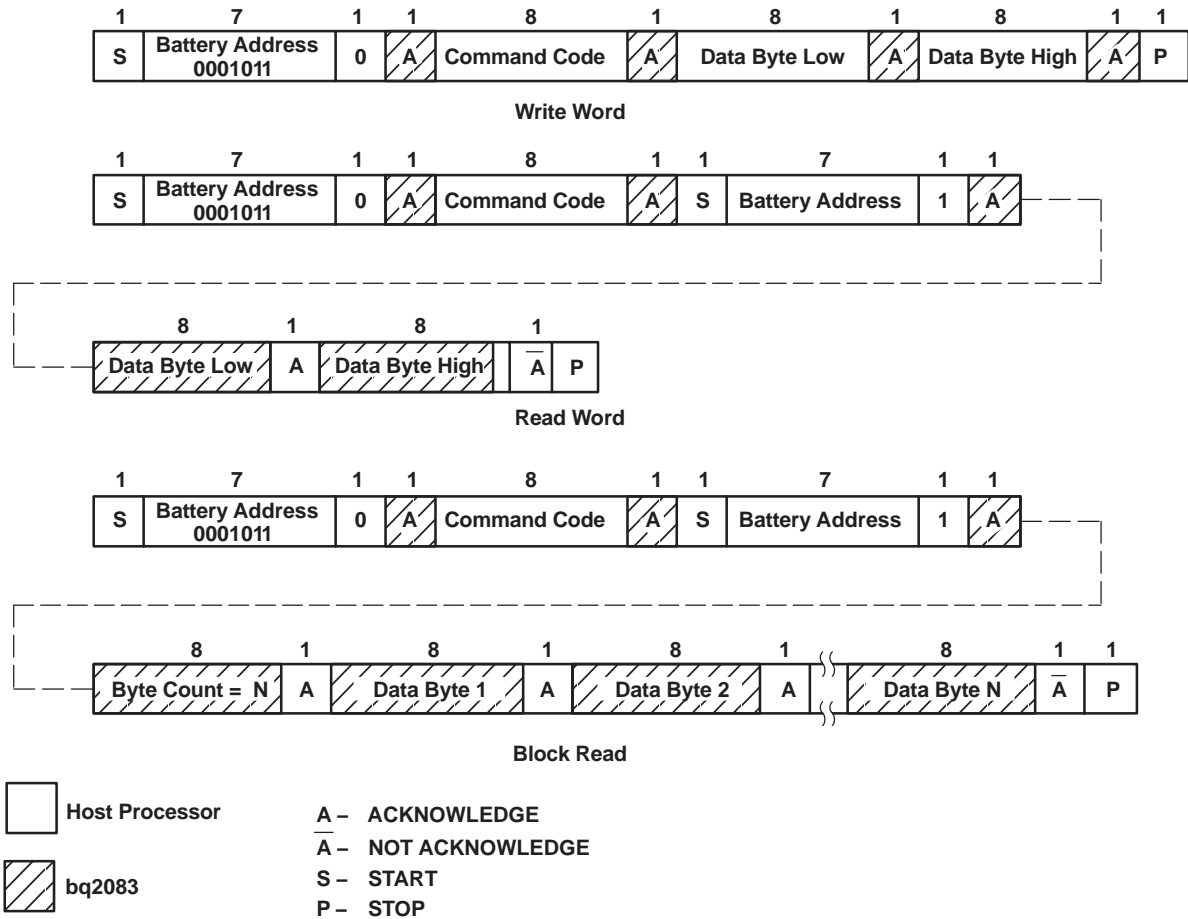


Figure 6. SMBus Communication Protocol Without PEC

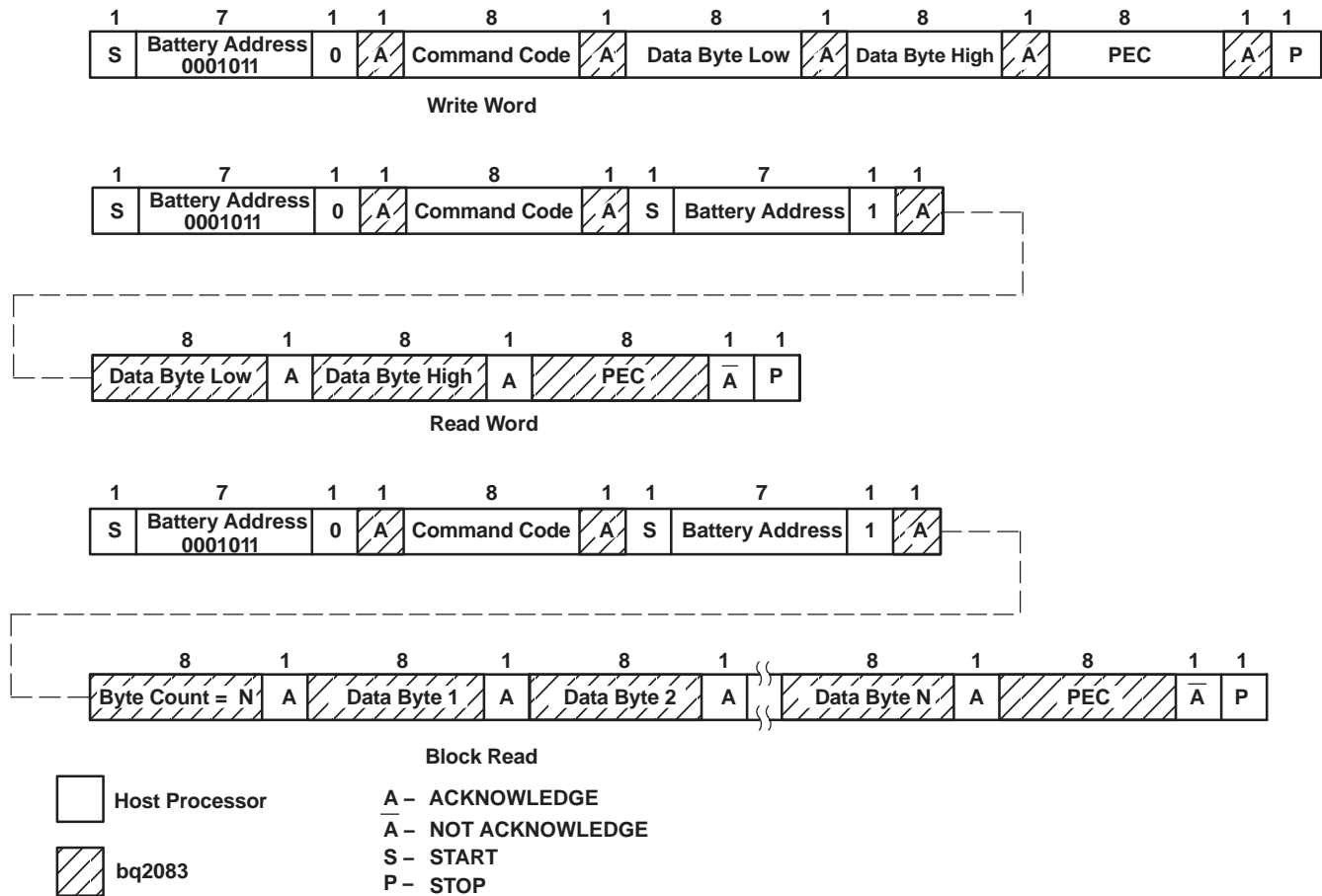


Figure 7. SMBus Communication Protocol With PEC

PEC Calculation

The basis of the PEC calculation is an 8-bit cyclic redundancy check (CRC-8) based on the polynomial $C(X) = X^8 + X^2 + X^1 + 1$. The PEC calculation includes all bytes in the transmission, including address, command, and data. The PEC calculation does not include ACKNOWLEDGE, NOT ACKNOWLEDGE, start, stop, and repeated start bits.

For example, the host requests RemainingCapacity() from the bq20851-V1P2. This includes the host following the read word protocol. The bq20851-V1P2 calculates the PEC based on the following 5 bytes of data, assuming the remaining capacity of the battery is 1001 mAh.

- Battery Address with $R/\bar{W} = 0$: 0x16
- Command Code for RemainingCapacity(): 0x0f
- Battery Address with $R/\bar{W} = 1$: 0x17
- RemainingCapacity(): 0x03e9

For 0x160f17e903, the bq20851-V1P2 transmits a PEC of 0xe8 to the host.

PEC Enable in Master Mode

PEC for master mode broadcasts to the charger, host, or both can be enabled/disabled with the combination of the bits HPE and CPE in *Pack Configuration DF 0x28*.

SMBus On and Off State

The bq20851-V1P2 detects whether the SMBus enters the off state by monitoring the SMBC and SMBD lines. When both signals are continually low for at least 2.0 s, the bq20851-V1P2 detects the off state. When the SMBC and SMBD lines go high, the bq20851-V1P2 detects the on state and can begin communication within 1 ms. One-M Ω pulldown resistors on SMBC and SMBD are recommended for reliable off state detection.

COMMAND CODES

The SMBus command codes are in (). Temperature(), Voltage(), Current(), and AverageCurrent(), performance specifications are at bq29311 regulated V_{CC} ($V_{(REG)}$) and a temperature of 0-70°C.

ManufacturerAccess() (0x00)

Description: This function provides writable command codes to control the bq20851-V1P2 during normal operation and pack manufacture. The following commands are available:

0x0001 Device Type instructs the bq20851-V1P2 to return the IC part number; i.e., 20851 to Manufacture Access() so it can be read.

0x0002 Firmware Revision instructs the bq20851-V1P2 to return the firmware revision.

0x0003 EDV Level instructs the bq20851-V1P2 to return the pending end-of-discharge voltage level so it can be read.

0x062b SEAL instructs the bq20851-V1P2 to restrict access to those functions listed in Table 3. The bq20851-V1P2 completes the seal function and clears ManufacturerAccess().

Purpose: The ManufacturerAccess() function provides the system host access to bq20851-V1P2 functions that are not defined by the SBD.

SMBus protocol: Read or write word

Input/Output: Word

RemainingCapacityAlarm() (0x01)

Description: Sets or gets the low-capacity threshold value. Whenever the RemainingCapacity() falls below the low capacity value, the bq20851-V1P2 sends AlarmWarning() messages to the SMBus host with the REMAINING_CAPACITY_ALARM bit set. A low-capacity value of 0 disables this alarm. The bq20851-V1P2 initially sets the low-capacity value to *Remaining Capacity Alarm* value programmed in DF 0x02-0x03. The low-capacity value remains unchanged until altered by the RemainingCapacityAlarm() function. The low-capacity value may be expressed in either current (mA) or power (10 mWh) depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: The RemainingCapacityAlarm() function can be used by systems that know how much power they require to save their operating state. It enables those systems to more finely control the point at which they transition into suspend or hibernate state. The low-capacity value can be read to verify the value in use by the bq20851-V1P2 low-capacity alarm.

SMBus protocol: Read or write word

Input/Output: Unsigned integer-value below which Low Capacity messages are sent.

| | BATTERY MODES | |
|-------------|--------------------------|--------------------------|
| | CAPACITY_MODE BIT = 0 | CAPACITY_MODE BIT = 1 |
| Units | mAh at C/5 | 10 mWh at P/5 |
| Range | 0-65,535 mAh | 0-65,535 10 mWh |
| Granularity | Not applicable | |
| Accuracy | See RemainingCapacity() | |

RemainingTimeAlarm() (0x02)

Description: Sets or gets the *Remaining Time Alarm* value. Whenever the AverageTimeToEmpty() falls below the remaining time value, the bq20851-V1P2 sends AlarmWarning() messages to the SMBus host with the REMAINING_TIME_ALARM bit set. A remaining time value of 0 effectively disables this alarm. The bq20851-V1P2 initially sets the remaining time value to the *Remaining Time Alarm* value programmed in DF 0x00-0x01. The remaining time value remains unchanged until altered by the RemainingTimeAlarm() function.

Purpose: The RemainingTimeAlarm() function can be used by systems that want to adjust when the remaining time alarm warning is sent. The remaining time value can be read to verify the value in use by the bq20851-V1P2 RemainingTimeAlarm().

SMBus protocol: Read or write word

Input/Output: Unsigned integer—the point below which remaining time messages are sent.

Units: Minutes

Range: 0 to 65,535 minutes

Granularity: Not applicable

Accuracy: See AverageTimeToEmpty().

BatteryMode() (0x03)

Description: Selects the various battery operational modes and reports the battery's mode and requests.

Defined modes include

- Whether the battery capacity information is specified in units of mAh or 10 mWh (CAPACITY_MODE bit)
- Whether the ChargingCurrent() and ChargingVoltage() values are broadcast to the smart battery charger when the CHARGER_MODE bit is set.
- Whether all broadcasts to the smart battery charger and host are disabled

The defined request condition is the battery requesting a conditioning cycle (RELEARN_FLAG).

Purpose: The CAPACITY_MODE bit allows power management systems to best match their electrical characteristics with those reported by the battery. For example, a switching power supply represents a constant power load, whereas a linear supply is better represented by a constant current model. The CHARGER_MODE bit allows a SMBus host or smart battery charger to override the smart battery desired charging parameters by disabling the bq20851-V1P2 broadcasts. The RELEARN_FLAG bit allows the bq20851-V1P2 to request a conditioning cycle.

SMBus protocol: Read or write word

Input/Output: Unsigned integer—bit mapped— see below.

Units: Not applicable

Range: 0-1

Granularity: Not applicable

Accuracy: Not applicable

The BatteryMode() word is divided into two halves, the MSB (bits 8-15) which is read/write and the LSB (bits 0-7) which is read only. The bq20851-V1P2 forces bits 0-6 to zero and prohibits writes to bit 7.

Table 9 summarizes the meanings of the individual bits in the BatteryMode() word and specifies the default values, where applicable, are noted.

INTERNAL_CHARGE_CONTROLLER bit is not used by the bq20851-V1P2.

PRIMARY_BATTERY_SUPPORT bit is not used by the bq20851-V1P2.

RELEARN_FLAG bit set indicates that the bq20851-V1P2 is requesting a capacity relearn cycle for the battery. The bq20851-V1P2 sets the RELEARN_FLAG on a full reset and if it detects 20 cycle counts without an FCC update. The bq20851-V1P2 clears this flag after a learning cycle has been completed.

CHARGE_CONTROLLER_ENABLED bit is not used by the bq20851-V1P2. The bq20851-V1P2 forces this bit to zero.

PRIMARY_BATTERY bit is not used by the bq20851-V1P2. The bq20851-V1P2 forces this bit to zero.

Table 9. Battery Mode Bits and Values

| Battery Mode() BITS | BITS USED | FORMAT | ALLOWABLE VALUES |
|----------------------------|-----------|--------------------|---|
| INTERNAL_CHARGE_CONTROLLER | 0 | Read only bit flag | |
| PRIMARY_BATTERY_SUPPORT | 1 | Read only bit flag | |
| Reserved | 2–6 | | |
| RELEARN_FLAG | 7 | Read only bit flag | 0—Battery OK 1—Relearn cycle requested |
| CHARGE_CONTROLLER_ENABLED | 8 | R/W bit flag | |
| PRIMARY_BATTERY | 9 | R/W bit flag | |
| Reserved | 10–12 | | |
| ALARM_MODE | 13 | R/W bit flag | 0—Enable alarm broadcast (default) 1—Disable alarm broadcast |
| CHARGER_MODE | 14 | R/W bit flag | 0—Enable charging broadcast (default) 1—Disable charging broadcast |
| CAPACITY_MODE | 15 | R/W bit flag | 0—Report in mA or mAh (default) 1—Report in 10mW or 10 mWh |

ALARM_MODE bit is set to disable the bq20851-V1P2's ability to master the SMBus and send AlarmWarning() messages to the SMBus host and the smart battery charger. When set, the bq20851-V1P2 does *not* master the SMBus, and AlarmWarning() messages are not sent to the SMBus host and the smart battery charger for a period of no more than 60 seconds and no less than 59 seconds. When cleared (default), the smart battery sends the AlarmWarning() messages to the SMBus host and the smart battery charger any time an alarm condition is detected.

- The ALARM broadcast does not occur more often than once every 10 s. Whenever the BATTERY_MODE command is received, the bq20851-V1P2 resets the bit and starts or restarts a 60-seconds (nominal) timer. After the timer expires, the bq20851-V1P2 automatically enables alarm broadcasts to ensure that the accidental deactivation of broadcasts does not persist. An SMBus host that does not want the bq20851-V1P2 to be a master on the SMBus must therefore continually set this bit at least once per 59 seconds to keep the bq20851-V1P2 from broadcasting alarms.
- The ALARM_MODE bit defaults to a cleared state when the bq20851-V1P2 enters SLEEP mode.
- The condition of the ALARM-MODE bit does *not* affect the operation or state of the CHARGER_MODE bit, which is used to prevent broadcasts of ChargingCurrent() and ChargingVoltage() to the smart battery charger.

CHARGER_MODE bit enables or disables the bq20851-V1P2's transmission of ChargingCurrent() and ChargingVoltage() messages to the smart battery charger. When set, the bq20851-V1P2 does *not* transmit ChargingCurrent() and ChargingVoltage() values to the smart battery charger. When cleared, the bq20851-V1P2 transmits the ChargingCurrent() and ChargingVoltage() values to the smart battery charger. The CHARGER_MODE bit defaults to a cleared state when the bq20851-V1P2 enters SLEEP mode.

CAPACITY_MODE bit indicates if capacity information is reported in mA/mAh or 10mW/10 mWh. When set, the bq20851-V1P2 reports capacity information in 10 mW/10 mWh as appropriate. When cleared, the bq20851-V1P2 reports capacity information in mA/mAh as appropriate. The CAPACITY_MODE bit defaults to a cleared state when the bq20851-V1P2 enters SLEEP mode.

The following functions are changed to accept or return values in mA/mAh or 10 mW/10 mWh depending on the CAPACITY_MODE bit:

- RemainingCapacityAlarm()
- AtRate()
- RemainingCapacity()
- FullChargeCapacity()
- DesignCapacity()

The following functions are calculated on the basis of capacity and may be calculated differently depending on the CAPACITY_MODE bit:

- AtRateOK()
- AtRateTimeToEmpty()
- AtRateTimeToFull()
- RunTimeToEmpty()
- AverageTimeToEmpty()
- AverageTimeToFull()
- Remaining Time Alarm()
- BatteryStatus()

The bq20851-V1P2 updates the non-AtRate related register values within 1 s of changing the state of the CAPACITY_MODE bit. The AtRate() values are updated after the next AtRate value is written to the bq20851-V1P2 (or after the next 1 s scheduled refresh calculation).

AtRate() (0x04)

Description: The AtRate() function is the first half of a two-function call-set used to set the AtRate value used in calculations made by the AtRateTimeToFull(), AtRateTimeToEmpty(), and AtRateOK() functions. The AtRate value may be expressed in either current (mA) or power (10 mW) depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: Since the AtRate() function is the first half of a two-function call-set, it is followed by the second function of the call-set that calculates and returns a value based on the AtRate value and the battery’s present state.

- When the AtRate() value is positive, the AtRateTimeToFull() function returns the predicted time to full-charge at the AtRate value of charge.
- When the AtRate() value is negative, the AtRateTimeToEmpty() function returns the predicted operating time at the AtRate value of discharge.
- When the AtRate() value is negative, the AtRateOK() function returns a boolean value that predicts the battery’s ability to supply the AtRate value of *additional* discharge energy (current or power) for 10 seconds.

The default value for AtRate() is zero.

SMBus protocol: Read or write word

Input/Output: Signed integer-charge or discharge; the AtRate() value is positive for charge, negative for discharge, and zero for neither (default).

| | BATTERY MODES | |
|-----------------|--------------------------|--------------------------|
| | CAPACITY_MODE BIT = 0 | CAPACITY_MODE BIT = 1 |
| Units | mA | 10 mW |
| Charge range | 1 to 32,767 mA | 1 to 32,767 10 mW |
| Discharge range | -1 to -32,768 mA | -1 to -32,768 10 mW |
| Granularity | 1 Unit | |
| Accuracy | NA | |

AtRateTimeToFull() (0x05)

Description: Returns the predicted remaining time to fully charge the battery at the AtRate() value (mA).

Purpose: The AtRateTimeToFull() function is part of a two-function call-set used to determine the predicted remaining charge time at the AtRate value in mA. The bq20851-V1P2 updates AtRateTimeToFull() within 5 ms after the SMBus host sets the AtRate value. The bq20851-V1P2 automatically updates AtRateTimeToFull() based on the AtRate() value every 1 s.

SMBus protocol: Read word

Output: Unsigned integer—predicted time in minutes to fully charge the battery.

Units: Minutes

Range: 0 to 65,534 min

Granularity: 2 min or better

Accuracy: $\pm \text{MaxError}() \cdot \text{FullChargeCapacity}() / |\text{AtRate}()|$

Invalid Data Indication: 65,535 indicates the $\text{AtRate}() \leq 0$.

AtRateTimeToEmpty() (0x06)

Description: Returns the predicted remaining operating time if the battery is discharged at the $\text{AtRate}()$ value.

Purpose: The $\text{AtRateTimeToEmpty}()$ function is part of a two-function call-set used to determine the remaining operating time at the $\text{AtRate}()$ value. The bq20851-V1P2 updates $\text{AtRateTimeToEmpty}()$ within 5 ms after the SMBus host sets the $\text{AtRate}()$ value. The bq20851-V1P2 automatically updates $\text{AtRateTimeToEmpty}()$ based on the $\text{AtRate}()$ value every 1 s.

SMBus protocol: Read word

Output: Unsigned integer—estimated operating time left.

Units: Minutes

Range: 0 to 65,534 min

Granularity: 2 min or better

Accuracy: $-0, +\text{MaxError}() \times \text{FullChargeCapacity}() / |\text{AtRate}()|$

Invalid Data Indication: 65,535 indicates $\text{AtRate}() \geq 0$.

AtRateOK() (0x07)

Description: Returns a boolean value that indicates whether or not the battery can deliver the $\text{AtRate}()$ value of *additional* energy for 10 seconds. If the AtRate value is zero or positive, the $\text{AtRateOK}()$ function always returns OK (logic 1).

Purpose: The $\text{AtRateOK}()$ function is part of a two-function call-set used by power management systems to determine if the battery can safely supply enough energy for an additional load. The bq20851-V1P2 updates $\text{AtRateOK}()$ within 5 ms after the SMBus host sets the $\text{AtRate}()$ value. The bq20851-V1P2 automatically updates $\text{AtRateOK}()$ based on the $\text{AtRate}()$ value every 1 second.

SMBus protocol: Read word

Output: Boolean—indicates if the battery can supply the *additional* energy requested.

Units: Boolean

Range: 1, 0

Granularity: Not applicable

Accuracy: Not applicable

Temperature() (0x08)

Description: Returns the temperature (K) measured by the bq20851-V1P2.

Purpose: The $\text{Temperature}()$ function provides accurate cell temperatures for use by battery chargers and thermal management systems. A battery charger can use the temperature as a safety check. Thermal management systems may use the temperature because the battery is one of the largest thermal sources in a system.

SMBus protocol: Read word

Output: Unsigned integer—cell temperature in tenth-degree Kelvin increments.

Units: 0.1°K

Range: 0 to +6553.5°K (real range)

Granularity: 0.1°K

Accuracy: $\pm 1.5^\circ\text{K}$ (from ideal Semitec 103AT thermistor performance, after calibration)

Voltage() (0x09)

Description: Returns the cell-pack voltage (mV).

Purpose: The Voltage() function provides power management systems with an accurate battery terminal voltage. Power management systems can use this voltage, along with battery current information, to characterize devices they control. This ability helps enable intelligent, adaptive power-management systems.

SMBus protocol: Read word

Output: Unsigned integer—battery terminal voltage in mV.

Units: mV

Range: 0 to 20,000 mV

Granularity: 1 mV

Accuracy: $\pm 0.25\%$ (after calibration)

Current() (0x0a)

Description: Returns the current being supplied (or accepted) by the battery (mA).

Purpose: The Current() function provides a snapshot for the power management system of the current flowing into or out of the battery. This information is of particular use in power-management systems because they can characterize individual devices and tune their operation to actual system power behavior.

SMBus protocol: Read word

Output: Signed integer—charge/discharge rate in mA increments-positive for charge, negative for discharge.

Units: mA

Range: -32,768 to 32,767 mA

Granularity: 1 mA

Accuracy: 0.25% or 5 mA, whichever is greater

AverageCurrent() (0x0b)

Description: Returns a value that approximates a one-minute rolling average of the current being supplied (or accepted) through the battery terminals (mA). The AverageCurrent() function returns values equivalent to Current() during the battery's first minute of operation.

Purpose: The AverageCurrent() function provides the average current flowing into or out of the battery for the power management system.

SMBus protocol: Read word

Output: Signed integer—charge/discharge rate in mA increments-positive for charge, negative for discharge.

Units: mA

Range: -32,768 to 32,767 mA

Granularity: 1 mA

Accuracy: 0.25% or 5 mA, whichever is greater

MaxError() (0x0c)

Description: Returns the expected margin of error (%) in the state of charge calculation. For example, when MaxError() returns 10% and RelativeStateOfCharge() returns 50%, the Relative StateOfCharge() is more likely between 50% and 60%. The bq20851-V1P2 sets MaxError() to 100% on a full reset. The bq20851-V1P2 sets MaxError() to 2% on completion of a learning cycle, unless the bq20851-V1P2 limits the learning cycle to the +512/-256 mAh maximum adjustment values. If the learning cycle is limited, the bq20851-V1P2 sets MaxError() to 8% unless MaxError() was already below 8%. In this case MaxError() does not change. The bq20851-V1P2 increments MaxError() by 1% after four increments of CycleCount() without a learning cycle.

If voltage-based corrections are applied to the coulomb counter, MaxError() is set to 25%.

Purpose: The MaxError() function has real value in two ways: first, to give the user a confidence level about the state of charge and second, to give the power management system information about how aggressive it should be, particularly as the battery nears the end of its life.

SMBus protocol: Read word

Output: Unsigned integer—percent uncertainty for selected information.

Units: %

Range: 2–100%

Granularity: 1%

Accuracy: Not applicable

RelativeStateOfCharge() (0x0d)

Description: Returns the predicted remaining battery capacity expressed as a percentage of FullChargeCapacity() (%).

Purpose: The RelativeStateOfCharge() function is used to estimate the amount of charge remaining in the battery relative to the last learned capacity.

SMBus protocol: Read word

Output: Unsigned integer-percent of remaining capacity.

Units: %

Range: 0–100%

Granularity: 1%

Accuracy: -0, +MaxError()

AbsoluteStateOfCharge()(0x0e)

Description: Returns the predicted remaining battery capacity expressed as a percentage of DesignCapacity() (%). Note that AbsoluteStateOfCharge() can return values greater than 100%.

Purpose: The AbsoluteStateOfCharge() function is used to estimate the amount of charge remaining in the battery relative to the nominal or DesignCapacity().

SMBus protocol: Read word

Output: Unsigned integer—percent of remaining capacity.

Units: %

Range: 0–100+%

Granularity: 1%

Accuracy: -0, +MaxError()

RemainingCapacity() (0x0f)

Description: Returns the predicted charge or energy remaining in the battery. The RemainingCapacity() value is expressed in either charge or energy, depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: The RemainingCapacity() function returns the battery’s remaining capacity. This information is a numeric indication of remaining charge or energy given by the Absolute or RelativeStateOfCharge() functions and may be in a better form for use by power management systems.

SMBus protocol: Read word

Output: Unsigned integer—remaining charge in units of mAh or 10 mWh.

| | BATTERY MODES | |
|-------------|--|--------------------------|
| | CAPACITY_MODE BIT = 0 | CAPACITY_MODE BIT = 1 |
| Units | mAh | 10 mWh |
| Range | 0–65,535mAh | 0–65,535 10 mWh |
| Granularity | mAh | 10 mWh |
| Accuracy | –0, +MaxError() * FullChargeCapacity() | |

FullChargeCapacity() (0x10)

Description: Returns the predicted pack capacity when it is fully charged. The FullChargeCapacity() value is expressed in either current (mAh at a C/5 discharge rate) or power (10 mWh at a P/5 discharge rate) depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: The FullChargeCapacity() function provides a means of understanding the tank size of the battery. This information, along with information about the original capacity of the battery, indicates battery wear.

SMBus protocol: Read word

Output: Unsigned integer—estimated full-charge capacity in units of mAh or 10 mWh.

| | BATTERY MODES | |
|-------------|--|--------------------------|
| | CAPACITY_MODE BIT = 0 | CAPACITY_MODE BIT = 1 |
| Units | mAh | 10 mWh |
| Range | 0–65,535 mAh | 0–65,535 10 mWh |
| Granularity | mAh | 10 mWh |
| Accuracy | –0, +MaxError() * FullChargeCapacity() | |

RunTimeToEmpty() (0x11)

Description: Returns the predicted remaining battery life at the present rate of discharge (minutes). The RunTimeToEmpty() value is calculated based on either current or power depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: The RunTimeToEmpty() provides the power management system with information about the relative gain or loss in remaining battery life in response to a change in power policy. This information is **not** the same as the AverageTimeToEmpty(), which is not suitable to determine the effects that result from a change in power policy.

SMBus protocol: Read word

Output: Unsigned integer—minutes of operation left.

Units: Minutes

Range: 0 to 65,534 min

Granularity: 2 min or better

Accuracy: –0, +MaxError() * FullChargeCapacity() / Current()

Invalid Data Indication: 65,535 indicates battery is not being discharged.

AverageTimeToEmpty() (0x12)

Description: Returns a one-minute rolling average of the predicted remaining battery life (minutes). The AverageTimeToEmpty() value is calculated based on either current or power depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: The AverageTimeToEmpty() displays state-of-charge information in a more useful way. It averages the instantaneous estimations so the remaining time does not appear to jump around.

SMBus protocol: Read word

Output: Unsigned integer—minutes of operation left.

Units: Minutes

Range: 0 to 65,534 min

Granularity: 2 min or better

Accuracy: –0, +MaxError() * FullChargeCapacity() / AverageCurrent()

Invalid Data Indication: 65,535 indicates battery is not being discharged.

AverageTimeToFull() (0x13)

Description: Returns a one-minute rolling average of the predicted remaining time until the battery reaches full charge (minutes).

Purpose: The AverageTimeToFull() function can be used by the SMBus host's power management system to aid in its policy. It may also be used to find out how long the system must be left on to achieve full charge.

SMBus protocol: Read word

Output: Unsigned integer—remaining time in minutes.

Units: Minutes

Range: 0 to 65,534 minutes

Granularity: 2 minutes or better

Accuracy: $-0, +\text{MaxError}() * \text{FullChargeCapacity}() / \text{AverageCurrent}()$

Invalid Data Indication: 65,535 indicates the battery is not being charged.

ChargingCurrent() (0x14)

Description: Returns the desired charging rate in mA.

Purpose: The ChargingCurrent() function sets the maximum charge current of the battery. The ChargingCurrent() value should be used in combination with the ChargingVoltage() value to set the charger's operating point. Together, these functions permit the bq20851-V1P2 to dynamically control the charging profile (current/voltage) of the battery. The bq20851-V1P2 can effectively turn off a charger by returning a value of 0 for this function. The charger may be operated as a constant-voltage source above its maximum regulated current range by returning a ChargingCurrent() value of 65,535.

SMBus protocol: Read word

Output: Unsigned integer—maximum charger output current in mA.

Units: mA

Range: 0 to 65,535 mA

Granularity: 1 mA

Accuracy: Not applicable

Invalid Data Indication: 65,535 indicates that a charger should operate as a voltage source outside its maximum regulated current range.

ChargingVoltage() (0x15)

Description: Returns the desired charging voltage in mV.

Purpose: The ChargingVoltage() function sets the maximum charge voltage of the battery. The ChargingVoltage() value should be used in combination with the ChargingCurrent() value to set the charger's operating point. Together, these functions permit the bq20851-V1P2 to dynamically control the charging profile (current/voltage) of the battery. The charger may be operated as a constant-current source above its maximum regulated voltage range by returning a ChargingVoltage() value of 65,535.

SMBus protocol: Read word

Output: Unsigned integer—charger output voltage in mV.

Units: mV

Range: 0 to 65,535 mV

Granularity: 1mV

Accuracy: Not applicable

Invalid Data Indication: 65,535 indicates the charger should operate as a current source outside its maximum regulated voltage range.

BatteryStatus() (0x16)

Description: Returns the bq20851-V1P2 status word (flags). Some of the BatteryStatus() flags (REMAINING_CAPACITY_ALARM and REMAINING_TIME_ALARM) are calculated on the basis of either current or power depending on the setting of the BatteryMode() CAPACITY_MODE bit. This is important because use of the wrong calculation mode may result in an inaccurate alarm.

Purpose: The BatteryStatus() function is used by the power-management system to get alarm and status bits, as well as error codes from the bq20851-V1P2. This is basically the same information broadcast to both the SMBus host and the smart battery charger by the AlarmWarning() function except that the AlarmWarning() function sets the error code bits all high before sending the data.

SMBus protocol: Read word

Output: Unsigned Integer–status register with alarm conditions bit mapped as follows:

| ALARM BITS | |
|-------------|---------------------------|
| 0x8000 | OVER_CHARGED_ALARM |
| 0x4000 | TERMINATE_CHARGE_ALARM |
| 0x2000 | Reserved |
| 0x1000 | OVER_TEMP_ALARM |
| 0x0800 | TERMINATE_DISCHARGE_ALARM |
| 0x0400 | Reserved |
| 0x0200 | REMAINING_CAPACITY_ALARM |
| 0x0100 | REMAINING_TIME_ALARM |
| STATUS BITS | |
| 0x0080 | Initialized |
| 0x0040 | DISCHARGING |
| 0x0020 | FULLY_CHARGED |
| 0x0010 | FULLY_DISCHARGED |
| ERROR CODES | |
| 0x0007 | Unknown Error |
| 0x0006 | BadSize |
| 0x0005 | Overflow/Underflow |
| 0x0004 | AccessDenied |
| 0x0003 | UnsupportedCommand |
| 0x0002 | ReservedCommand |
| 0x0001 | Busy |
| 0x0000 | OK |

Alarm Bits

OVER_CHARGED_ALARM bit is set whenever the bq20851-V1P2 detects that the battery is being charged beyond the maximum overcharge limit. This bit is cleared when the bq20851-V1P2 detects that the battery is no longer being charged and there are 2 mAh of continuous discharge (i.e., the bq20851-V1P2 detects discharge activity or no activity above the digital filter).

TERMINATE_CHARGE_ALARM bit is set when the bq20851-V1P2 detects that one or more of the battery charging parameters are out of range (e.g., its voltage, current, or temperature is too high) or when the bq20851-V1P2 detects a primary charge termination. This bit is cleared when the parameter falls back into the allowable range, the termination condition ceases, or when the bq20851-V1P2 detects that the battery is no longer being charged.

OVER_TEMP_ALARM bit is set when the bq20851-V1P2 detects that the internal battery temperature is greater than or equal to the *Max Temperature* threshold. This bit is cleared when the internal temperature falls back into the acceptable range.

TERMINATE_DISCHARGE_ALARM bit is set when $Voltage() \leq Terminate\ Voltage$, or the CVUV bit in pack status is set indicating that a Li-Ion cell voltage has dropped below the limit programmed in *Cell Under*. The bit is cleared when $Voltage() > Terminate\ Voltage$, Charging Current > 0, and the CVUV bit is cleared.

REMAINING_CAPACITY_ALARM bit is set when the bq20851-V1P2 detects that RemainingCapacity() is less than that set by the RemainingCapacityAlarm() function. This bit is cleared when either the value set by the RemainingCapacityAlarm() function is lower than the RemainingCapacity() or when the RemainingCapacity() is increased by charging.

REMAINING_TIME_ALARM bit is set when the bq20851-V1P2 detects that the estimated remaining time at the present discharge rate is less than that set by the RemainingTimeAlarm() function. This bit is cleared when either the value set by the RemainingTimeAlarm() function is lower than the AverageTimeToEmpty() or when the AverageTimeToEmpty() is increased by charging.

Status Bits

The initialized bit is set when the bq20851-V1P2 is has detected a valid load of data flash at full or partial reset. It is cleared when the bq20851-V1P2 detects an improper data flash load.

DISCHARGING bit is set when the bq20851-V1P2 determines that the battery is not being charged. This bit is cleared when the bq20851-V1P2 detects that the battery is being charged.

FULLY_CHARGED bit is set when the bq20851-V1P2 detects a primary charge termination or an Overcharge condition. It is cleared when RelativeStateOfCharge() is less than the programmed *Fully Charged Clear %* in DF 0x47.

FULLY_DISCHARGED bit is set when Voltage() or VCELL is less than the EDV1 threshold and Current() < *Overload Current* or when RelativeStateOfCharge() < *Battery Low %*. This bit is cleared when RelativeStateOfCharge() is greater than or equal to 20%.

Error Codes

| ERROR CODES | DESCRIPTION |
|----------------|--|
| OK | The bq20851-V1P2 processed the function code without detecting any errors. |
| Busy | The bq20851-V1P2 is unable to process the function code at this time. |
| Reserved | The bq20851-V1P2 detected an attempt to read or write to a function code reserved by this version of the specification. The bq20851-V1P2 detected an attempt to access an unsupported optional manufacturer function code. |
| Unsupported | The bq20851-V1P2 does not support this function code which is defined in this version of the specification. |
| AccessDenied | The bq20851-V1P2 detected an attempt to write to a read-only function code. |
| Over/Underflow | The bq20851-V1P2 detected a data overflow or underflow. |
| BadSize | The bq20851-V1P2 detected an attempt to write to a function code with an incorrect data block. |
| UnknownError | The bq20851-V1P2 detected an unidentifiable error. |

CycleCount()(0x17)

Description: Returns the number of cycles the battery has experienced. The mAh value of each count is determined by programming the *Cycle Count Threshold* value in DF 0x37-0x38. The bq20851-V1P2 saves the cycle count value to *Cycle Count* DF 0x0c-0x0d after an update to CycleCount().

Purpose: The CycleCount() function provides a means to determine the battery wear. It may be used to give advance warning that the battery is nearing its end of life.

SMBus protocol: Read word

Output: Unsigned integer—count of total charge removed from the battery over its life.

Units: cycle

Range: 0 to 65,534 cycles; 65,535 indicates battery has experienced 65,535 or more cycles.

Granularity: 1 cycle

Accuracy: Absolute count

DesignCapacity() (0x18)

Description: Returns the theoretical or nominal capacity of a new pack. The DesignCapacity() value is expressed in either current (mAh at a C/5 discharge rate) or power, (10 mWh at a P/5 discharge rate) depending on the setting of the BatteryMode() CAPACITY_MODE bit.

Purpose: The DesignCapacity() function is used by the SMBus host’s power management in conjunction with FullChargeCapacity() to determine battery wear. The power management system may present this information to the user and also adjust its power policy as a result.

SMBus protocol: Read word

Output: Unsigned integer—battery capacity in units of mAh or 10 mWh.

| | BATTERY MODES | |
|-------------|--------------------------|--------------------------|
| | CAPACITY_MODE BIT = 0 | CAPACITY_MODE BIT = 1 |
| Units | mAh | 10 mWh |
| Range | 0–65,535 mAh | 0–65,535 10 mWh |
| Granularity | Not applicable | Not applicable |
| Accuracy | Not applicable | Not applicable |

DesignVoltage() (0x19)

Description: Returns the theoretical voltage of a new pack (mV). The bq20851-V1P2 sets DesignVoltage() to the value programmed in *Design Voltage* DF 0x04–0x05.

Purpose: The DesignVoltage() function can be used to give additional information about a particular smart battery expected terminal voltage.

SMBus protocol: Read word

Output: Unsigned integer—the battery’s designed terminal voltage in mV

Units: mV

Range: 0 to 65,535 mV

Granularity: Not applicable

Accuracy: Not applicable

SpecificationInfo() (0x1a)

Description: Returns the version number of the smart battery specification the battery pack supports, as well as voltage and current scaling information in a packed unsigned integer. Power scaling is the product of the voltage scaling times the current scaling. The SpecificationInfo is packed in the following fashion:

$$(\text{SpecID_H} * 0x10 + \text{SpecID_L}) + (\text{VScale} + \text{IPScale} * 0x10) * 0x100.$$

The bq20851-V1P2 VScale (voltage scaling) and IPScale (current scaling) should always be set to zero. The bq20851-V1P2 sets SpecificationInfo() to the value programmed in *Specification Information* DF 0x06-0x07.

Purpose: The SpecificationInfo() function is used by the SMBus host’s power management system to determine what information the smart battery can provide.

SMBus protocol: Read word

Output: Unsigned integer—packed specification number and scaling information:

| FIELD | BITS USED | FORMAT | ALLOWABLE VALUES |
|----------|-----------|--------------------|--|
| SpecID_L | 0...3 | 4-bit binary value | 0–15 |
| SpecID_H | 4...7 | 4-bit binary value | 0–15 |
| VScale | 8...11 | 4-bit binary value | 0 (multiplies voltage by 10 ^{VScale}) |
| IPScale | 12...15 | 4-bit binary value | 0 (multiplies current by 10 ^{IPScale}) |

ManufactureDate() (0x1b)

Description: This function returns the date the cell pack was manufactured in a packed integer. The date is packed in the following fashion: (year-1980) * 512 + month * 32 + day. The bq20851-V1P2 sets ManufactureDate() to the value programmed in *Manufacture Date* DF 0x08–0x09.

Purpose: The ManufactureDate() provides the system with information that can be used to uniquely identify a particular battery pack when used in conjunction with SerialNumber().

SMBus protocol: Read word

Output: Unsigned integer-packed date of manufacture:

| FIELD | BITS USED | FORMAT | ALLOWABLE VALUES |
|-------|-----------|--------------------|--|
| Day | 0...4 | 5-bit binary value | 0–31 (corresponds to date) |
| Month | 5...8 | 4-bit binary value | 1–12 (corresponds to month number) |
| Year | 9...15 | 7-bit binary value | 0–127 (corresponds to year biased by 1980) |

SerialNumber() (0x1c)

Description: This function is used to return a serial number. This number, when combined with the ManufacturerName(), the DeviceName(), and the ManufactureDate(), uniquely identifies the battery (unsigned integer). The bq20851-V1P2 sets SerialNumber() to the value programmed in *Serial Number* DF 0x0a–0x0b.

Purpose: The SerialNumber() function can be used to identify a particular battery. This may be important in systems that are powered by multiple batteries where the system can log information about each battery that it encounters.

SMBus protocol: Read word

Output: Unsigned integer

ManufacturerName() (0x20)

Description: The bq20851-V1P2 has an internal prefixed manufacturer name (). This value cannot be changed.

Purpose: The ManufacturerName() function returns the name of the smart battery manufacturer. The manufacturer's name can be displayed by the SMBus host's power management system display as both an identifier and as an advertisement for the manufacturer. The name is also useful as part of the information required to uniquely identify a battery.

SMBus protocol: Read block

Output: String—character string with maximum length of 11 characters (11 + length byte).

DeviceName() (0x21)

Description: This function returns a character string that contains the battery name. For example, a DeviceName() of bq20851-V1P2 indicates that the battery is a model bq20851-V1P2. The bq20851-V1P2 sets DeviceName() to the value programmed in *Device Name Length* DF 0x1a-0x21.

Purpose: The DeviceName() function returns the battery name for identification purposes.

SMBus protocol: Read block

Output: String—character string with maximum length of 7 characters (7 + length byte).

DeviceChemistry() (0x22)

Description: This function returns a character string that contains the battery chemistry. For example, if the DeviceChemistry() function returns *NiMH*, the battery pack contains nickel metal hydride cells. The bq20851-V1P2 sets DeviceChemistry() to the value programmed in *Device Chemistry Length* DF 0x22-0x26.

Purpose: The DeviceChemistry() function gives cell chemistry information for use by charging systems. The bq20851-V1P2 does not use DeviceChemistry() values for internal charge control or fuel gauging.

SMBus protocol: Read block

Output: String—character string with maximum length of 4 characters (4 + length byte).

The following is a partial list of chemistries and their expected abbreviations. These abbreviations are *not* case sensitive.

| | |
|---------------------------------|------|
| Lead acid | PbAc |
| Lithium ion | LION |
| Nickel cadmium | NiCd |
| Nickel metal hydride | NiMH |
| Nickel zinc | NiZn |
| Rechargeable alkaline-manganese | RAM |
| Zinc air | ZnAr |

The ManufacturerData() (0x23)

Description: This function allows access to the manufacturer data contained in the battery (data). The bq20851-V1P2 stores seven critical operating parameters in this data area.

Purpose: The ManufacturerData() function may be used to access the manufacturer's data area. The data fields of this command reflect the programming of eight critical data flash locations and can be used to facilitate evaluation of the bq20851-V1P2 under various programming sets. The ManufacturerData() function returns the following information in order: *Pack Configuration, Gauge Configuration, Misc Configuration, Digital Filter, Self Discharge Rate, Pack Load Estimate, Battery Low%, and Near Full* (2 bytes) AFE Status, and the pending EDV threshold voltage (low byte and high byte).

SMBus protocol: Read block

Output: Block data—data that reflects data flash programming as assigned by the manufacturer with maximum length of 13 characters (12 + length byte).

Pack Status and Pack Configuration (0x2f)

This function returns the pack status and pack configuration registers. The pack status register contains a number of status bits relating to bq20851-V1P2 operation. The pack status register is the least significant byte of the word.

The pack configuration register reflects how the bq20851-V1P2 is configured as defined by the value programmed in *Pack Configuration* in DF 0x28.

The pack status register consists of the following bits:

| b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|-----|------|----|-----|----|-----|------|------|
| AFE | EDV2 | SS | VDQ | 0 | SOV | CVOV | CVUV |

AFE

The AFE bit indicates whether the bq29311 RAM integrity check has failed.

- 0 bq29311 integrity check passed
- 1 bq29311 integrity check failed

EDV2

The EDV2 bit indicates that pack or cell voltage (program option) is less than the EDV2 threshold.

- 0 Voltage > EDV2 threshold (discharging)
- 1 Voltage ≤ EDV2 threshold

SS

The SS bit indicates the seal state of the bq20851-V1P2.

- 0 The bq20851-V1P2 is in the unsealed state.
- 1 The bq20851-V1P2 is in the sealed state.

VDQ

The VDQ bit indicates if the present discharge cycle is valid for an FCC update.

- 0 Discharge cycle not valid
- 1 Discharge cycle valid

SOV

The SOV bit indicates that the safety output limits have been exceeded. Once set, the flag stays set until the bq20851-V1P2 is reset.

- 0 Safety limits not exceeded
- 1 Safety limits exceeded

CVOV

The CVOV bit indicates that a protection limit has been exceeded. It is set on a Prolonged Overcurrent, Overvoltage, or Overtemperature condition. The bit is not latched and merely reflects the present fault status.

- 0 No secondary protection limits exceeded
- 1 A secondary protection limit exceeded

CVUV

The CVUV bit indicates that a protection limit has been exceeded. It is set on an overload or overdischarge condition. The bit is not latched and merely reflects the present fault status.

- 0 No secondary protection limits exceeded
- 1 A secondary protection limit exceeded

VCELL4-VCELL1 (0x3c-0x3f)

These functions return the calculated individual cell voltages in mV.

DATA FLASH

General

The bq20851-V1P2 accesses the internal data flash during reset and when storing historical data. The data flash stores basic configuration information for use by the bq20851-V1P2. The data flash must be programmed correctly for proper bq20851-V1P2 operation.

Memory Map

Table 10 shows the memory map for the data flash. It shows the default programming for the bq20851-V1P2. The default programming reflects example data for a 3s2p Li-Ion battery pack with a 0.02-Ω sense resistor. The data flash must be reprogrammed to meet the requirements of individual applications.

Table 10. Data Flash Memory Map

| DATA FLASH ADDRESS | | NAME | LI-ION EXAMPLE | DATA | |
|--------------------|----------|----------------------------------|----------------|------|-----|
| HIGH BYTE | LOW BYTE | | | MSB | LSB |
| 0x00 | 0x01 | <i>Remaining Time Alarm</i> | 10 minutes | 00 | 0a |
| 0x02 | 0x03 | <i>Remaining Capacity Alarm</i> | 360 mAh | 01 | 68 |
| 0x04 | 0x05 | <i>Design Voltage</i> | 10800 mV | 2a | 30 |
| 0x06 | 0x07 | <i>Specification Information</i> | v1.1/PEC | 00 | 31 |
| 0x08 | 0x09 | <i>Manufacture Date</i> | 2/15/02=11343 | 2c | 4f |
| 0x0a | 0x0b | <i>Serial Number</i> | 1 | 00 | 01 |
| 0x0c | 0x0d | <i>Cycle Count</i> | 0 | 00 | 00 |
| 0x0e | | <i>Manufacturer Name Length</i> | 5 | | 5 |
| 0x0f | | Character 1 | | | |
| 0x10 | | Character 2 | | | |
| 0x11 | | Character 3 | | | |
| 0x12 | | Character 4 | | | |
| 0x13 | | Character 5 | | | |
| 0x14 | | Character 6 | | | |
| 0x15 | | Character 7 | | | |
| 0x16 | | Character 8 | | | |
| 0x17 | | Character 9 | | | |
| 0x18 | | Character 10 | | | |
| 0x19 | | Character 11 | | | |
| 0x1a | | <i>Device Name Length</i> | 6 | | 06 |
| 0x1b | | Character 1 | b | | 42 |
| 0x1c | | Character 2 | q | | 51 |
| 0x1d | | Character 3 | 2 | | 32 |
| 0x1e | | Character 4 | 0 | | 30 |
| 0x1f | | Character 5 | 8 | | 38 |
| 0x20 | | Character 6 | 5 | | |
| 0x21 | | Character 7 | 1 | | |
| 0x22 | | <i>Device Chemistry Length</i> | 4 | | 04 |
| 0x23 | | Character 1 | L | | 4c |
| 0x24 | | Character 2 | l | | 49 |
| 0x25 | | Character 3 | O | | 4f |
| 0x26 | | Character 4 | N | | 4e |
| 0x27 | | <i>Manufacturer Data Length</i> | 12 | | 09 |

NOTE: Reserved locations must be set as shown. Locations marked with an * are typical calibration values that can be adjusted for maximum accuracy. For these locations the table shows the appropriate default or initial setting.

Table 13. Data Flash Memory Map (Continued)

| DATA FLASH ADDRESS | | NAME | LI-ION EXAMPLE | DATA | |
|--------------------|----------|-------------------------------------|------------------|------|-----|
| HIGH BYTE | LOW BYTE | | | MSB | LSB |
| 0x28 | | <i>Pack Configuration</i> | DMODE, LED1, CC1 | | c2 |
| 0x29 | | <i>Gauge Configuration</i> | CSYNC | | 40 |
| 0x2a | | <i>Misc Configuration</i> | VOD | | 01 |
| 0x2b | | <i>Digital Filter</i> | 9860 nV | | 22 |
| 0x2c | | <i>Self-Discharge Rate</i> | 0.2% | | 14 |
| 0x2d | | <i>Electronics Load</i> | 0 mA | | 00 |
| 0x2e | | <i>Battery Low % (MSB)</i> | 7.03% | | 12 |
| 0x2f | 0x30 | <i>Near Full</i> | 200 mAh | 00 | c8 |
| 0x31 | 0x32 | <i>Design Capacity</i> | 3600 mAh | 0e | 10 |
| 0x33 | 0x34 | Reserved | 0 | 00 | 00 |
| 0x35 | 0x36 | <i>Last Measured Discharge</i> | 3600 mAh | 0e | 10 |
| 0x37 | 0x38 | <i>Cycle Count Threshold</i> | 2880 mAh | 0b | 40 |
| 0x39 | 0x3a | <i>Charging Voltage</i> | 12600 mV | 31 | 38 |
| 0x3b | 0x3c | <i>Precharge Voltage</i> | 8000 mV | 1f | 40 |
| 0x3d | 0x3e | <i>Fast-Charging Current</i> | 2500 mA | 09 | c4 |
| 0x3f | 0x40 | <i>Maintenance Charging Current</i> | 0 mA | 00 | 00 |
| 0x41 | 0x42 | <i>Precharge Current</i> | 100 mA | 00 | 64 |
| 0x43 | | <i>Precharge Temp</i> | 9.6°C | | 60 |
| 0x44 | | Reserved | | | 1e |
| 0x45 | | Reserved | | | 00 |
| 0x46 | | <i>Fast Charge Termination %</i> | 100% | | ff |
| 0x47 | | <i>Fully Charged Clear %</i> | 95% | | 5f |
| 0x48 | 0x49 | <i>Current Taper Threshold</i> | 240 mA | 00 | f0 |
| 0x4a | 0x4b | <i>Current Taper Qual Voltage</i> | 100 mV | 00 | 64 |
| 0x4c | | Reserved | | | 28 |
| 0x4d | | Reserved | | | 40 |
| 0x4e | 0x4f | <i>Maximum Overcharge</i> | 300 mAh | 01 | 2c |
| 0x50 | | Reserved | | | 02 |
| 0x51 | | <i>Charge Efficiency</i> | 100% | | ff |
| 0x52 | | Reserved | | | 64 |
| 0x53 | 0x54 | <i>MaxTemperature</i> | 54.6°C | 02 | 22 |
| 0x55 | | <i>Temperature Hysteresis</i> | 5°C | | 32 |
| 0x56 | 0x57 | Reserved | | 01 | ae |
| 0x58 | 0x59 | <i>Overload Current</i> | 5000 mA | 13 | 88 |
| 0x5a | 0x5b | <i>Over Voltage Margin</i> | 208 mV | 00 | d0 |
| 0x5c | 0x5d | <i>Overcurrent Margin</i> | 500 mA | 01 | f4 |
| 0x5e | 0x5f | Reserved | | 01 | 00 |
| 0x60 | 0x61 | <i>Cell Over Voltage</i> | 4350 mV | 10 | fe |
| 0x62 | 0x63 | <i>Cell Under Voltage</i> | 2300 mV | 08 | fc |
| 0x64 | 0x65 | <i>Terminate Voltage</i> | 8500 mV | 21 | 34 |
| 0x66 | 0x67 | Reserved | | 00 | 00 |
| 0x68 | 0x69 | <i>Safety Over Voltage</i> | 20000 mV | 4e | 20 |
| 0x6a | 0x6b | <i>Safety Over Temperature</i> | 70°C | 02 | bc |

NOTE: Reserved locations must be set as shown. Locations marked with an * are typical calibration values that can be adjusted for maximum accuracy. For these locations the table shows the appropriate default or initial setting.

Table 13. Data Flash Memory Map (Continued)

| DATA FLASH ADDRESS | | NAME | LI-ION EXAMPLE | DATA | |
|--------------------|----------|--------------------|----------------|------|-----|
| HIGH BYTE | LOW BYTE | | | MSB | LSB |
| 0x6c | | Reserved | | ef | |
| 0x6d | | Reserved | | 03 | |
| 0x6e | 0x6f | VOC75 | 11890 mV | 2e | 72 |
| 0x70 | | Reserved | | bf | |
| 0x71 | | Reserved | | 56 | |
| 0x72 | | Reserved | | 40 | |
| 0x73 | 0x74 | VOC50 | 11430 mV | 2c | a6 |
| 0x75 | | Reserved | | 7f | |
| 0x76 | | Reserved | | 3d | |
| 0x77 | | Reserved | | 27 | |
| 0x78 | 0x79 | VOC25 | 11270 mV | 2c | 06 |
| 0x7a | | Reserved | | 3f | |
| 0x7b | | Reserved | | 24 | |
| 0x7c | | Reserved | | 0e | |
| 0x7c | | Reserved | | 14 | |
| 0x7e | | Reserved | | 40 | |
| 0x7f | 0x80 | Reserved | | 0b | e1 |
| 0x81 | 0x82 | Reserved | | 0b | 68 |
| 0x83 | | Reserved | | | 19 |
| 0x84 | 0x85 | EMF/EDV0 | 3000 mV | 0b | b8 |
| 0x86 | 0x87 | EDV C0 Factor/EDV1 | 3250 mV | 0c | b2 |
| 0x88 | 0x89 | EDV R0 Factor/EDV2 | 3400 mV | 0d | 48 |
| 0x8a | 0x8b | EDV T0 Factor | 0 | 00 | 00 |
| 0x8c | 0x8d | EDV R1 Factor | 0 | 00 | 00 |
| 0x8e | | EDV TC Factor | 0 | | 00 |
| 0x8f | | EDV C1 Factor | 0 | | 00 |
| 0x90 | | Reserved | | | 08 |
| 0x91 | | Reserved | | | 9b |
| 0x92 | | Reserved | | | c7 |
| 0x93 | | Reserved | | | 64 |
| 0x94 | | Reserved | | | 14 |
| 0x95 | 0x96 | Reserved | | 02 | 00 |
| 0x97 | 0x98 | Reserved | | 01 | 00 |
| 0x99 | | Reserved | | | 08 |
| 0x9a | | Reserved | | | 02 |
| 0x9b | | Learning Low Temp | 11.9°C | | 77 |
| 0x9c | | Reserved | | | 0a |
| 0x9d | 0x9e | Reserved | | 01 | 80 |
| 0x9f | 0xa0 | Reserved | | 01 | 00 |
| 0xa1 | | Reserved | | | 08 |
| 0xa2 | | Reserved | | | 18 |
| 0xa3 | | Reserved | | | 14 |

NOTE: Reserved locations must be set as shown. Locations marked with an * are typical calibration values that can be adjusted for maximum accuracy. For these locations the table shows the appropriate default or initial setting.

Table 13. Data Flash Memory Map (Continued)

| DATA FLASH ADDRESS | | NAME | LI-ION EXAMPLE | DATA | |
|--------------------|----------|---------------------------------|--------------------------------------|------|-----|
| HIGH BYTE | LOW BYTE | | | MSB | LSB |
| 0xa4 | 0xa5 | TS Const 1 | 91 | 83 | |
| 0xa6 | 0xa7 | TS Const 2 | 51 | 70 | |
| 0xa8 | 0xa9 | TS Const 3 | e2 | 8f | |
| 0xaa | 0xab | TS Const 4 | 0f | ac | |
| 0xac | 0xad | TS Const 5 | 00 | 00 | |
| 0xae | 0xaf | Reserved | 0f | ac | |
| 0xb0 | | Reserved | | 32 | |
| 0xb1 | | <i>AFE Brnout Shutdn</i> | Shutdown = 6.475, Brownout = 7.975 V | | |
| 0xb2 | | <i>AFE Over Curr Dsg</i> | 140 mV | | |
| 0xb3 | | <i>AFE Over Curr Chg</i> | 70 mV | | |
| 0xb4 | | <i>AFE Over Curr Delay</i> | Charge = 31 ms, Discharge = 31 ms | | |
| 0xb5 | | Reserved | | 00 | |
| 0xb6 | | <i>AFE Short Circ Thrsh</i> | 275 mV | | |
| 0xb7 | | <i>AFE Short Circuit Delay</i> | 61 μ s (charge and discharge) | | |
| 0xb8 | 0xb9 | <i>AFE Vref*</i> | 26 | 16 | |
| 0xba | 0xbb | <i>Sense Resistor Gain*</i> | 3b | d0 | |
| 0xbc | 0xbd | <i>CC Delta*</i> | 94 | 08 | |
| 0xbe | 0xbf | <i>CC Delta*</i> | b1 | c0 | |
| 0xc0 | | Reserved | | fa | |
| 0xc1 | 0xc2 | <i>CC Offset*</i> | 05 | f8 | |
| 0xc3 | | <i>DSC Offset*</i> | | 10 | |
| 0xc4 | | <i>ADC Offset*</i> | | 11 | |
| 0xc5 | | <i>Temperature Offset*</i> | | 00 | |
| 0xc6 | | <i>Board Offset*</i> | | 00 | |
| 0xc7 | 0xc8 | Reserved | 00 | 40 | |
| 0xc9 | 0xca | Reserved | 01 | 00 | |
| 0xcb | | Reserved | | 05 | |
| 0xcc | 0xcd | Version | 01 | 01 | |
| 0xce | | Reserved | 00 | 32 | |
| 0xcf | 0xd0 | <i>Cell Over Voltage Reset</i> | 10 | 36 | |
| 0xd1 | 0xd2 | <i>Cell Under Voltage Reset</i> | 0b | b8 | |
| 0xd3 | 0xd4 | <i>AFE Fail Limit</i> | 00 | 02 | |
| 0xd5 | 0xd6 | Reserved | ff | ff | |
| 0xd7 | 0xd8 | <i>Cell Balance Thresh</i> | 0f | 3c | |
| 0xd9 | 0xda | <i>Cell Balance Window</i> | 00 | 64 | |
| 0xdb | | <i>Cell Balance Min</i> | | 28 | |
| 0xdc | | <i>Cell Balance Interval</i> | | 14 | |
| 0xdd | 0xde | Reserved | a5 | 5a | |
| 0xdf | 0xd0 | Reserved | 7a | 43 | |
| 0xe1 | 0xe2 | Reserved | 20 | 83 | |
| 0xe3 | | <i>Battery Low % (LSB)</i> | | 00 | |
| 0xe4 | | <i>AFE Check Time</i> | | 00 | |
| 0xe5 | | <i>Sleep Current Thresh</i> | | 04 | |

NOTE: Reserved locations must be set as shown. Locations marked with an * are typical calibration values that can be adjusted for maximum accuracy. For these locations the table shows the appropriate default or initial setting.

Table 13. Data Flash Memory Map (Continued)

| DATA FLASH ADDRESS | | NAME | LI-ION EXAMPLE | DATA | |
|--------------------|----------|---------------------------|-----------------|------|-----|
| HIGH BYTE | LOW BYTE | | | MSB | LSB |
| 0xe6 | | <i>Sleep Current Time</i> | 20 seconds | | 14 |
| 0xe7 | | <i>Sleep Time</i> | 5 counts | | 05 |
| 0xe8 | | <i>LED Delay</i> | 6 ms | | 6 |
| 0xe9 | | <i>LED Flash</i> | 6 ms | | 6 |
| 0xea | | <i>LED Blink</i> | 96 ms | | 60 |
| 0xeb | 0xec | <i>LED Hold Time</i> | 640 ms | | 280 |
| 0xed | 0xee | <i>LED No Display</i> | 0 mAh | | 00 |
| 0xef | | <i>Flash Threshold</i> | 10% | | 0a |
| 0xf0 | | <i>LED1 Threshold</i> | 30% | | 1e |
| 0xf1 | | <i>LED2 Threshold</i> | 50% | | 32 |
| 0xf2 | | <i>LED3 Threshold</i> | 70% | | 46 |
| 0xf3 | | <i>LED4 Threshold</i> | 88% | | 58 |
| 0xf4 | | <i>LED5 Threshold</i> | 100% | | 64 |
| 0xf5 | | <i>Shutdown Timer</i> | 20 s | | 14 |
| 0xf6 | 0xf7 | <i>EDV0 Threshold</i> | 3000 mV | 0b | b8 |
| 0xf8 | | <i>Reserved</i> | | 00 | 05 |
| 0xf9 | 0xfa | <i>EDV1</i> | minimum 3100 mV | 0c | 1c |

NOTE: Reserved locations must be set as shown. Locations marked with a * are typical calibration values that can be adjusted for maximum accuracy. For these locations the table shows the appropriate default or initial setting.

PROGRAMMING INFORMATION

DATA FLASH PROGRAMMING

The following sections describe the function of each data flash location and how the data is to be stored.

Fundamental Parameters

Sense Resistor Value

The 32-bit *CC Delta DF* 0xbc–0xbf corrects the coulomb counter for sense resistor variations. It represents the gain factor for the coulomb counter.

The 16-bit *Sense Resistor Gain* in DF 0xba-0xbb scales each integrating converter conversion to mAh. The Current() related measurement *Sense Resistor Gain* is based on the resistance of the series sense resistor. The following formula computes a nominal or starting value for *Sense Resistor Gain* from the sense resistor value.

$$\text{Sense Resistor Gain} = \frac{306.25}{R_s} \quad (2)$$

Digital Filter

The desired digital filter threshold, VDF (V), is set by the value stored in *Digital Filter DF* 0x2b.

$$\text{Digital Filter} = \frac{\text{VDF}}{290 \text{ nV}} \quad (3)$$

Cell and Pack Characteristics

Battery Pack Capacity and Voltage

Pack capacity in mAh units is stored in *Design Capacity*, DF 0x31–0x32. In mAh mode, the bq20851–V1P2 copies *Design Capacity* to DesignCapacity(). In mWh mode, the bq20851–V1P2 multiplies *Design Capacity* by *Design Voltage DF* 0x04–0x05 to calculate DesignCapacity() scaled to 10 mWh. *Design Voltage* is stored in mV.

The initial value for *Last Measured Discharge*, in mAh, is stored in DF 0x35–0x36. *Last Measured Discharge* is modified over the course of pack usage to reflect cell aging under the particular use conditions. The bq20851–V1P2 updates *Last Measured Discharge* in mAh after a capacity learning cycle. The bq20851–V1P2 uses the *Last Measured Discharge* value to calculate FullChargeCapacity() in units of mAh or 10 mWh.

Remaining Time and Capacity Alarms

Remaining Time Alarm in DF 0x00-0x01 and *Remaining Capacity Alarm* in 0x02-0x03 set the alarm thresholds used in the SMBus command codes 0x01 and 0x02, respectively. *Remaining Time Alarm* is stored in minutes and *Remaining Capacity Alarm* in units of mAh or 10 mWh, depending on the BatteryMode() setting.

EDV Thresholds and Near Full Percentage

The bq20851–V1P2 uses three pack-voltage thresholds to provide voltage-based warnings of low battery capacity. The bq20851–V1P2 uses the values stored in data flash for the EDV1 and EDV2 values or calculates the three thresholds from a base value and the temperature, capacity, and rate adjustment factors stored in data flash. EDV1 has a minimum value as defined in data flash locations 0xf9–0xfa. If EDV compensation is disabled then EDV1 and EDV2 are stored directly in mV DF 0x86–0x87 and DF 0x88–0x89, respectively. EDV0 is always set to the value programmed in DF 0xf6, 0xf7 regardless of the fixed or compensated EDV selection.

For capacity correction at EDV2, *Battery Low % DF* 0x2e, 0xe3 can be set at a desired state-of-charge, STATEOFCHARGE%, in the range of 3-19%. Typical values for STATEOFCHARGE% are 5-7%, representing 5-7% capacity.

$$\text{Battery Low \%} = (\text{STATEOFCHARGE\%} \times 633.56) \quad (4)$$

The bq20851–V1P2 updates FCC if a qualified discharge occurs from a near-full threshold of FCC – *Near Full*, until EDV2 condition is reached. The desired near-full threshold window is programmed in *Near Full* in DF 0x2f, 0x30 in mAh.

EDV Discharge Rate and Temperature Compensation

If EDV compensation is enabled, the bq20851–V1P2 calculates battery voltage to determine EDV1 and EDV2 thresholds as a function of battery capacity, temperature, and discharge load. The general equation for EDV0, EDV1, and EDV2 calculation is:

$$EDV_{1,2} = n (EMF \bullet FBL - |ILOAD| \bullet R0 \bullet FTZ) \quad (5)$$

EMF is a no-load cell voltage higher than the highest cell EDV threshold computed. EMF is programmed in mV in *EMF/EDV1* DF 0x84–0x85.

ILOAD is the current discharge load magnitude.
 n = the number of series cells

FBL is the factor that adjusts the EDV voltage for battery capacity and temperature to match the no-load characteristics of the battery.

$$FBL = f (C0, C + C1, T) \quad (6)$$

C (either 0%, 3%, or *Battery Low %* for EDV0, EDV1, and EDV2, respectively) and C0 are the capacity- related EDV adjustment factors. C0 is programmed in *EDV C0 Factor/EDV1* DF 0x86–87. C1 is the desired residual battery capacity remaining at EDV0 (RM = 0). The C1 factor is stored in *EDV C1 Factor* DF 0x8f.

T is the current temperature in °K.

R0 • FTZ represents the resistance of a cell as a function of temperature and capacity.

$$FTZ = f (R1 , T0, T, C + C1, TC) \quad (7)$$

R0 is the first order rate dependency factor stored in *EDV R0 Factor/EDV2* DF 0x88–0x89.

T is the current temperature; C is the battery capacity relating to EDV0, EDV1, and EDV2.

R1 adjusts the variation of impedance with battery capacity. R1 is programmed in *EDV R1 Rate Factor* DF 0x8c-0x8d.

T0 adjusts the variation of impedance with battery temperature. T0 is programmed in *EDV T0 Rate Factor* DF 0x8a–0x8b.

TC adjusts the variation of impedance for cold temperatures (T < 23°C). TC is programmed in *EDV TC* DF 0x8e.

Typical values for the EDV compensation factors, based on overall pack voltages for a Li-Ion 3s2p 18650 pack, are

- EMF = 11550/3
- T0 = 4475
- C0 = 235
- C1 = 0
- R0 = 5350/3
- R1 = 250
- TC = 3

The graphs in Figures 8 and 9 show the calculated EDV0, EDV1, and EDV2 thresholds versus capacity using the typical compensation values for different temperatures and loads for a Li-Ion 3s2p 18650 pack. The compensation values vary widely for different cell types and manufacturers and must be matched exactly to the unique characteristics for optimal performance.

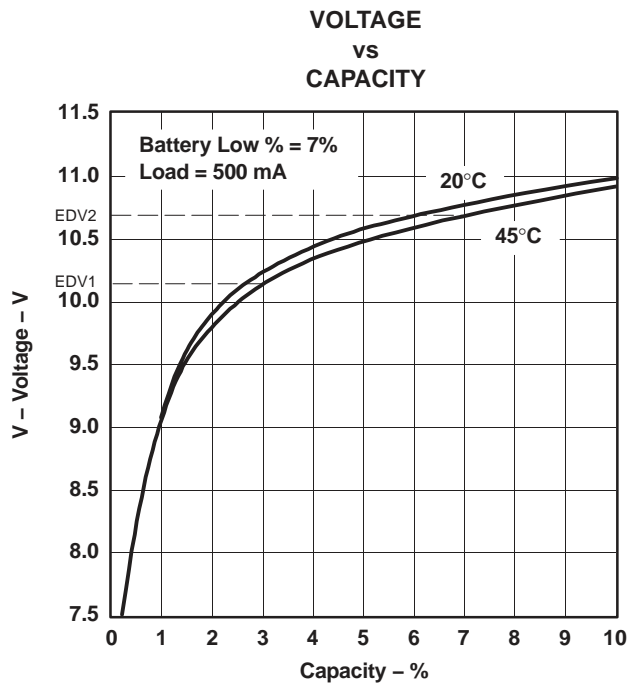


Figure 8. EDV Calculations vs Capacity for Various Temperatures

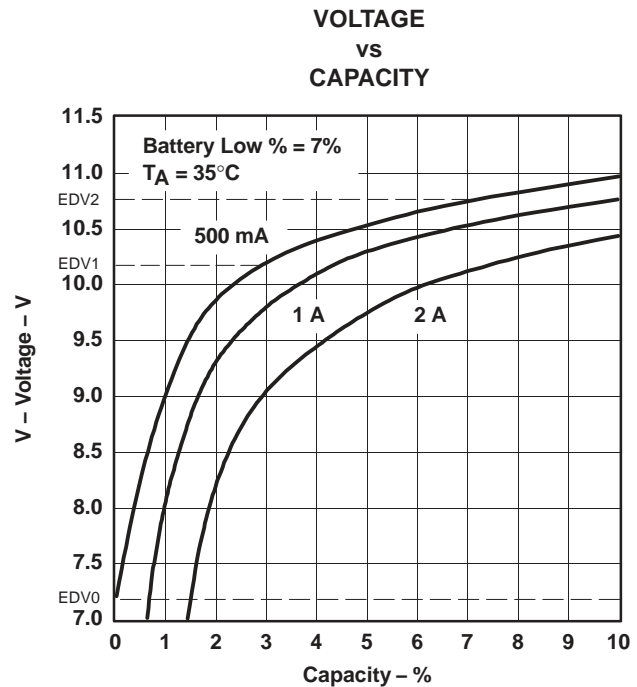


Figure 9. EDV Calculations vs Capacity for Various Loads

Overload Current Threshold

The overload protection disables discharge when the 16-bit limit programmed in DF 0x58–0x59 is breached. The threshold is stored in mA.

Midrange Capacity Corrections

Three voltage-based thresholds, *VOC25* DF 0x78–0x79, *VOC50* DF 0x73–0x74, and *VOC75* DF 0x6e–0x6f, are used to test the accuracy of the RM based on open-circuit pack voltages. These thresholds are stored in the data flash in mV. The values represent the open-circuit battery voltage at which the battery capacity should correspond to the associated state of charge for each threshold.

Self-Discharge Rate

The nominal self-discharge rate, %PERDAY (% per day), is programmed in an 8-bit value *Self-Discharge Rate* DF 0x2c by the following relation:

$$\text{Self-Discharge Rate} = \frac{\%PERDAY}{0.01} \tag{8}$$

Charge Efficiency

The bq20851–V1P2 applies the efficiency factor, EFF%, to all charge added to the battery. EFF% is encoded in *Charge Efficiency* DF 0x51 according to equation 16:

$$\text{Charge Efficiency} = (\text{EFF}\% \cdot 2.56 - 1) \tag{9}$$

Other Compensation

Battery Electronics Load

The amount of internal battery electronics load estimate in μA , BEL, is stored in *Electronics Load* DF 0x2d as follows:

$$\text{Electronics Load} = \frac{\text{BEL}}{3}$$

Charge Control

Charging Voltage

The 16-bit value, *Charging Voltage* DF 0x39–0x3a programs the *ChargingVoltage()* value broadcast to a smart charger. It also sets the base value for determining overvoltage conditions during charging and voltage compliance during a constant-voltage charging methodology. It is stored in mV.

Over Voltage

The 16-bit value, *Over Voltage Margin* DF 0x5a–0x5b, sets the limit over ChargingVoltage() in mV that is to be considered as an overvoltage charge-suspension condition.

Charging Current

ChargingCurrent() values are either broadcast to a Level 2 smart battery charger or read from the bq20851-V1P2 by a Level 3 smart battery charger. The bq20851-V1P2 sets the value of ChargingCurrent(), depending on the charge requirements and charge conditions of the pack.

When fast charge is allowed, the bq20851-V1P2 sets ChargingCurrent() to the rate programmed in *Fast-Charging Current* DF 0x3d–0x3e. *Fast-Charging Current* is stored in mA.

When fast charge terminates, the bq20851-V1P2 sets ChargingCurrent() to zero and then to the *Maintenance Charging Current* DF 0x3f, 0x40 when the termination condition ceases. The desired maintenance current is stored in mA.

When Voltage() is less than EDV0, the bq20851-V1P2 sets ChargingCurrent() to *Precharge Current* DF 0x41, 0x42. Typically this rate is larger than the maintenance rate to charge a deeply depleted pack up to the point where it may be fast charged. The desired precharge rate is stored in mA.

If temperature is between 0° and the precharge threshold PC (°C), the bq20851-V1P2 sets ChargingCurrent() to *PreCharge Current*. The threshold is programmed in the *Precharge Temp* DF 0x43.

$$\text{Precharge Temp} = \frac{\text{PC (}^\circ\text{C)}}{0.1} \quad (10)$$

The bq20851-V1P2 also sets ChargingCurrent() to the precharge rate if Voltage() is less than the value programmed in *Precharge Voltage* DF 0x3b–0x3c. *Precharge Voltage* is programmed in mV.

Charge Suspension

During charge, the bq20851-V1P2 compares the current to the ChargingCurrent() plus the value in *OverCurrent Margin* DF 0x5c–0x5d. If the pack is charged at a current above or equal to the ChargingCurrent() plus the programmed value, the bq20851-V1P2 sets ChargingCurrent() to zero to stop charging.

The desired *Overcurrent Margin* is programmed in mA.

The desired temperature threshold for charge suspension, MAXTEMP (°C), is programmed in *Max Temperature* DF 0x53, 0x54 and is stored as shown:

$$\text{Max Temperature} = \frac{\text{MAXTEMP}}{0.1} \quad (11)$$

The bq20851-V1P2 clears the maximum temperature condition when Temperature() drops by the amount programmed in *Temperature Hysteresis* DF 0x55 from MAXTEMP or when the temperature is less than or equal to 43.0°C. *Temperature Hysteresis* is stored in °C.

The bq20851-V1P2 suspends fast charge when fast charge continues past full by the amount programmed in *Maximum Overcharge* DF 0x4e–0x4f. *Maximum Overcharge* is programmed in mAh.

FULLY_CHARGED Bit Clear Threshold

The bq20851-V1P2 clears the FULLY_CHARGED bit in BatteryStatus() when RelativeStateOfCharge() reaches the value, *Fully Charged Clear %* DF 0x47. *Fully Charged Clear %* is an 8-bit value and is stored in percent.

Fast Charge Termination Percentage

The bq20851-V1P2 sets RM to a percentage of FCC on charge termination if the CSYNC bit is set in the gauge configuration register. The percentage of FCC, FCT%, is stored in *Fast Charge Termination %* in DF 0x46. The value is stored as shown:

$$\text{Fast Charge Termination\%} = (\text{FCT\%} * 2.56 - 1)$$

Cycle Count Initialization

Cycle Count DF 0x0c–0x0d stores the initial value for the CycleCount() function. It should be programmed to 0x0000.

Cycle Count Threshold

Cycle Count Threshold DF 0x37–0x38 sets the number of mAh that must be removed from the battery to increment `CycleCount()`. Cycle Count threshold is a 16-bit value stored in mAh.

Current Taper Termination Characteristics

Two factors in the data flash set the current taper termination for Li-Ion battery packs. The two locations are *Current Taper Qual Voltage* DF 0x4a and *Current Taper Threshold* DF 0x48–0x49. Current taper termination occurs during charging when the pack voltage is above or equal to the charging voltage minus the qualification voltage, and the charging current is below the taper threshold for at least 40 seconds. *Current Taper Qual Voltage* DF 0x4a is stored in mV and *Current Taper Threshold* DF 0x48–0x49 in mA.

Cell Balancing

Four constants set the cell balancing parameters. *Cell Balance Threshold* DF 0xd9–0xda sets the maximum voltage in mV that each cell must achieve to initiate cell balancing. *Cell Balance Window* DF 0xd9–0xda sets in mV the amount that the cell balance threshold can increase. *Cell Balance Min* DF 0xdb sets in mV the cell differential that must exist to initiate cell balancing and *Cell Balance Interval* DF 0xdc sets the cell balancing time interval in seconds. Programming *Cell Balance Threshold* to 65,535 disables cell balancing.

Pack Options

Pack Configuration

Pack Configuration DF 0x28 contains bit-programmable features.

| b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|-------|----|----|-----|-----|----|-----|-----|
| DMODE | — | — | HPE | CPE | SM | CC1 | CC0 |

DMODE

The DMODE bit determines whether the LED outputs indicate `AbsoluteStateOfCharge()` or `RelativeStateOfCharge()`.

- 0 LEDs reflect `AbsoluteStateOfCharge()`
- 1 LEDs reflect `RelativeStateOfCharge()`

HPE

The hpe bit enables/disables PEC transmissions to the smart battery host for master mode alarm messages.

- 0 No PEC byte on alarm warning to host
- 1 PEC byte on alarm warning to host

CPE

The CPE bit enables/disables PEC transmissions to the smart battery charger for master mode messages.

- 0 No PEC byte on broadcasts to charger
- 1 PEC byte on broadcasts to charger

SM

The SM bit enables/disables master mode broadcasts by the bq20851-V1P2.

- 0 Broadcasts to host and charger enabled
- 1 Broadcasts to host and charger disabled

If the SM bit is set, modifications to bits in `BatteryMode()` do not re-enable broadcasts.

CC1–CC0

The CC bits configure the bq20851-V1P2 for the number of series cells in the battery pack.

- 1–1 Configures the bq20851-V1P2 for four series cells
- 1–0 Configures the bq20851-V1P2 for three series cells

Gauge Configuration

Gauge Configuration DF 0x29 contains bit programmable features:

| b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|----|-------|----|------|------|-------|------|------|
| 0 | CSYNC | SC | CEDV | EDVV | OVSEL | VCOR | OTVC |

CSYNC

In usual operation of the bq20851-V1P2, the CSYNC bit is set so that the coulomb counter is adjusted when a fast charge termination is detected. In some applications, especially those where an externally controlled charger is used, it may be desirable *not* to adjust the coulomb counter. In these cases the CSYNC bit should be cleared.

- 0 The bq20851-V1P2 does not alter RM at the time of a valid charge termination.
- 1 The bq20851-V1P2 updates RM with a programmed percentage of FCC at a valid charger termination.

SC

The SC bit enables learning cycle optimization for a Smart Charger or independent charge.

- 1 Learning cycle optimized for independent charger
- 0 Learning cycle optimized for Smart Charger

CEDV

The CEDV bit determines whether the bq20851-V1P2 implements automatic EDV compensation to calculate the EDV1 and EDV2 thresholds base on rate, temperature, and capacity. If the bit is cleared, the bq20851-V1P2 uses the fixed values programmed in data flash for EDV1 and EDV2. If the bit is set, the bq20851-V1P2 calculates EDV1 and EDV2.

- 0 EDV compensation disabled
- 1 EDV compensation enabled

EDVV

The EDVV bit selects whether EDV termination is to be done with regard to voltage or the lowest single-cell voltage.

- 0 EDV conditions determined on the basis of the lowest single-cell voltage
- 1 EDV conditions determined on the basis of Voltage()

OVSEL

The OVSEL bit determines if safety over voltage is based on pack or highest cell voltages.

- 0 Safety over voltage based on pack voltage
- 1 Safety over voltage based on highest cell voltage multiplied by the number of cells and then compared to the safety voltage

VCOR

The VCOR bit enables the midrange voltage correction algorithm. When it is set, the bq20851-V1P2 compares the pack voltage to RM and may adjust RM according to the values programmed in VOC25, VOC50, and VOC75.

- 0 Continuous midrange corrections disabled
- 1 Continuous midrange corrections enabled

OTVC

The OTVC bit programs the bq20851-V1P2 to perform a midrange voltage one time after a device reset.

- 0 One-time midrange correction disabled
- 1 One-time midrange correction enabled

Safety Control

Secondary Protection Limits for Li-Ion

The cell undervoltage (VUV) and overvoltage (VOV) limits are programmed in *Cell Under and Cell Over Voltage* DF 0x62–0x63, DF 0x60–0x61, respectively. Both values are stored in mV. *Cell Over Voltage Reset* DF 0xef and *Cell Under Voltage Reset* 0xd1–0xd2 set the reset points in mV for these safety parameters.

SAFE Threshold

The safety voltage threshold is programmed in *Safety Over Voltage* DF 0x68–0x69. It is stored in mV.

If Misc Configuration bit 2 (OVSEL) = 0 then Safety Over Voltage is based on pack voltage, but if OVSEL = 1, then it is based on highest cell voltage.

The safety overtemperature (SOT) in °C is programmed in *Safety Over Temperature* DF 0x6a–0x6b. It is stored as

$$\text{SafetyOvertemperature} = \frac{\text{SOT}}{0.1} \quad (12)$$

AFE CONFIGURATION

The AFE protection limits are programmed as specified in the bq29311 data sheet.

AFE Brnout/Shutdn 0xb1 sets the brownout and shutdown voltage levels

AFE Over Curr Dsg DF 0xb2 sets the overcurrent threshold on discharge.

AFE Over Curr Chg DF 0xb3 sets the overcurrent threshold on charge.

AFE Over Curr Delay DF 0xb4 sets the delay timing for over current in the charge and discharge direction.

AFE Short Circ Thresh DF 0xb6 sets the short circuit threshold.

AFE Short Circuit Delay DF 0xb7 sets the short circuit delay time.

AFE INTEGRITY CHECK

AFE Check Time DF 0xe4 sets the period in seconds for the AFE integrity check.

The *AFE Fail Limit* (DF 0xd3,d4) is the number of AFE integrity check failures that occur before the AFE flag is set.

SLEEP MODE

The sleep current threshold, SLP (mA), is stored in *Sleep Current Thresh* DF 0xe5 as:

$$\text{Sleep Current Thresh} = \frac{\text{SLP(mA)}}{0.5} \quad (13)$$

The wake-up period for current measurement, WAT(s), is set in *Sleep Current Time* DF 0xe6 as:

$$\text{Sleep Current Time} = \frac{\text{WAT(s)}}{0.5} \quad (14)$$

Miscellaneous Configuration

Misc Configuration DF 0x2a contains additional bit programmable features.

| b7 | b6 | b5 | b4 | b3 | b2 | b1 | b0 |
|----|--------|----|----|----|------|-----|-----|
| IT | NC_SMB | AC | DS | OT | ELED | PHG | VOD |

IT

The IT bit configures the bq20851-V1P2 to use its internal temperature sensor.

- 0 bq20851-V1P2 requires an external thermistor.
- 1 bq20851-V1P2 uses its internal temperature sensor.

NC_SMB

The NC_SMB bit enables an extended bus high time-out which is not compliant with the SMBus specifications.

- 0 Normal bus high timeout
- 1 Extended bus high timeout

AC

The AC bit enables the $\overline{\text{SAFE}}$ output to function based on the AFE integrity check.

- 0 $\overline{\text{SAFE}}$ is not activated based on the AFE integrity check.
- 1 $\overline{\text{SAFE}}$ activated based on the AFE integrity check.

DS

The DS bit programs the bq20851-V1P2 to enter sleep mode on SMBus inactivity.

- 0 bq20851-V1P2 enters sleep mode when the SMBus is low for 2 s.
- 1 bq20851-V1P2 does not enter sleep mode.

OT

The OT bit programs the bq20851-V1P2 to turn off the discharge FET when the bq20851-V1P2 detects an overtemperature condition. Charge FET is always turned off in overtemperature conditions.

- 0 bq20851-V1P2 does not turn off the discharge FET on overtemperature.
- 1 bq20851-V1P2 turns off the discharge FET on overtemperature.

ECLED

The ECLED bit programs the LED activity during charging (DSG bit = 0).

- 0 The LEDs are not enabled during charging.
- 1 The LEDs are enabled during charging.

PHG

The PHG bit configures the bq20851-V1P2 to control a precharge FET.

- 0 The bq20851-V1P2 does not control a precharge FET.
- 1 The bq20851-V1P2 may turn on or off a precharge FET according to the programmed precharge conditions.

VOD

The VOD bit enables a 1-second time delay on the charge and discharge FET control.

- 0 No delay
- 1 1-second delay

CONSTANTS AND STRING DATA

Specification Information

Specification Information DF 0x06–0x07 stores the default value for the SpecificationInfo() function. It is stored in data flash in the same format as the data returned by the SpecificationInfo().

Manufacture Date

Manufacture Date DF 0x08–0x09 stores the default value for the ManufactureDate() function. It is stored in data flash in the same format as the data returned by the ManufactureDate().

Serial Number

Serial Number DF 0x0a–0x0b stores the default value for the SerialNumber() function. It is stored in data flash in the same format as the data returned by the SerialNumber().

Manufacturer Name Data

Manufacturer Name Length DF 0x0e stores the length of the desired string that is returned by the ManufacturerName() function. However, this data is always ignored as manufacturer name is internally fixed.

Device Name Data

Device Name Length DF 0x1a data is always ignored as manufacturer name is always fixed. The length of the desired string that is returned by the DeviceName() function. Locations DF 0x1b–0x21 store the characters for DeviceName() in ASCII code.

Device Chemistry Data

Device Chemistry Length DF 0x22 stores the length of the desired string that is returned by the DeviceChemistry() function. Locations DF 0x23–0x26 store the characters for DeviceChemistry() in ASCII code.

Manufacturers Data Length

Manufacturers Data Length DF 0x27 stores the length of the desired number of bytes that is returned by the ManufacturersData() function. It should be set to 9.

APPLICATION INFORMATION

The internal oscillator performance also depends on the tolerance of the 113-k Ω resistor connected between RSOC (pin 33) and VSSA (pin 34). It is recommended that this resistor be placed as close to the bq20851-V1P2 as possible and that it have a specification of $\pm 0.1\%$ tolerance and ± 50 ppm temperature drift or better. The layout of the PCBA is also an additional contributing factor to performance degradation.

The average temperature drift error of the oscillator function over a learning charge or discharge cycle introduces an equal capacity prediction error in a learned full charge capacity (FCC).

Figure 10 shows a typical bq20851-V1P2-based battery pack application. The circuit consists of the bq29311 analog front end (AFE) IC, LED display, temperature measurement network, data flash connections, serial port, and the sense resistor. The data flash stores basic battery pack configuration information and measurement calibration values. The data flash must be programmed properly for bq20851-V1P2 operation. Table 10 shows the data flash memory map and outlines the programmable functions available in the bq20851-V1P2.

PACKAGING INFORMATION

| Orderable Device | Status ⁽¹⁾ | Package Type | Package Drawing | Pins | Package Qty | Eco Plan ⁽²⁾ | Lead/Ball Finish | MSL Peak Temp ⁽³⁾ |
|--------------------|-----------------------|--------------|-----------------|------|-------------|-------------------------|------------------|------------------------------|
| BQ20851DBT-V1P2 | ACTIVE | SM8 | DBT | 38 | 50 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| BQ20851DBTR-V1P2 | ACTIVE | SM8 | DBT | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |
| BQ20851DBTR-V1P2G4 | ACTIVE | SM8 | DBT | 38 | 2000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR |

⁽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) 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.

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.

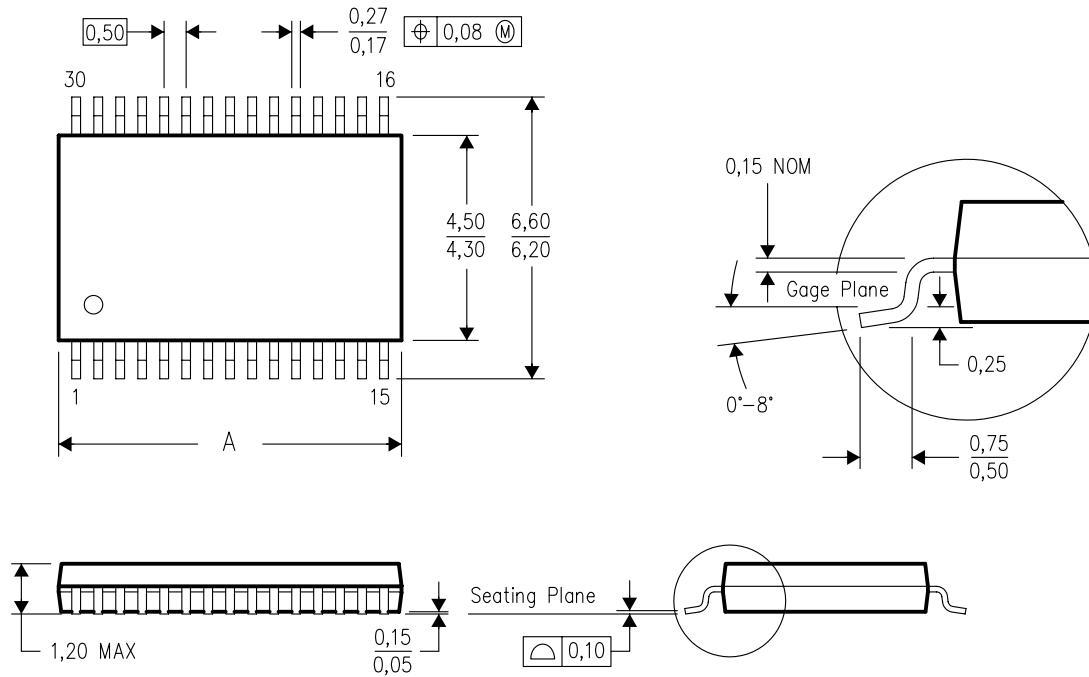
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DBT (R-PDSO-G**)

30 PINS SHOWN

PLASTIC SMALL-OUTLINE PACKAGE



| DIM \ PINS ** | 20 | 24 | 28 | 30 | 38 | 44 | 50 |
|---------------|------|------|------|------|------|-------|-------|
| A MAX | 5,10 | 6,60 | 7,90 | 7,90 | 9,80 | 11,40 | 12,60 |
| A MIN | 4,90 | 6,40 | 7,70 | 7,70 | 9,60 | 11,20 | 12,40 |

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- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion.
 - D. Falls within JEDEC MO-153 except 44 pin package length.

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