

Gas Gauge IC With SMBus Interface

Features

- Provides accurate measurement of available charge in NiCd, NiMH, and Li-Ion batteries
- Supports SBS v1.0 data set and two-wire interface
- Monitors charge FET in Li-Ion pack protection circuit
- Designed for battery pack integration
 - Low operating current
 - Complete circuit can fit on less than $\frac{3}{4}$ square inch of PCB space
- Supports SBS charge control commands for NiCd, NiMH, and Li-Ion
- Drives a four-segment LED display for remaining capacity indication
- 16-pin narrow SOIC

General Description

The bq2040 Gas Gauge IC With SMBus Interface is intended for battery-pack or in-system installation to maintain an accurate record of available battery charge. The bq2040 directly supports capacity monitoring for NiCd, NiMH, and Li-Ion battery chemistries.

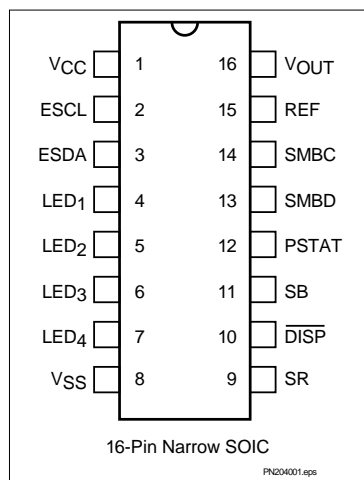
The bq2040 uses the System Management Bus v1.0 (SMBus) protocol and supports the Smart Battery Data (SBDData) commands. The bq2040 also supports the SBDData charge control functions. Battery state-of-charge, remaining capacity, remaining time, and chemistry are available over the serial link. Battery-charge state can be directly indicated using a four-segment LED display to graphically depict battery full-to-empty in 25% increments.

The bq2040 estimates battery self-discharge based on an internal timer and temperature sensor and user-programmable rate information stored in external EEPROM. The bq2040 also automatically recalibrates or "learns" battery capacity in the full course of a discharge cycle from full to empty.

The bq2040 may operate directly from three nickel chemistry cells. With the REF output and an external transistor, a simple, inexpensive regulator can be built to provide V_{CC} for other battery cell configurations.

An external EEPROM is used to program initial values into the bq2040 and is necessary for proper operation.

Pin Connections



Pin Names

| | | | |
|--------------------|-----------------------|-----------|--------------------------|
| V_{CC} | 3.0–6.5V | SB | Battery sense input |
| ESCL | EEPROM clock | PSTAT | Protector status input |
| ESDA | EEPROM data | SMBD | SMBus data input/output |
| LED ₁₋₄ | LED segment 1-4 | SMBC | SMBus clock |
| V_{SS} | System ground | REF | Voltage reference output |
| SR | Sense resistor input | V_{OUT} | EEPROM supply output |
| \overline{DISP} | Display control input | | |

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Pin Descriptions

VCC **Supply voltage input**

ESCL **Serial memory clock**

Output used to clock the data transfer between the bq2040 and the external non-volatile configuration memory.

ESDA **Serial memory data and address**

Bidirectional pin used to transfer address and data to and from the bq2040 and the external nonvolatile configuration memory.

LED₁–LED₄ **LED display segment outputs**

Each output may drive an external LED.

VSS **Ground**

SR **Sense resistor input**

The voltage drop (V_{SR}) across pins SR and VSS is monitored and integrated over time to interpret charge and discharge activity. The SR input is connected to the sense resistor and the negative terminal of the battery. $V_{SR} < V_{SS}$ indicates discharge, and $V_{SR} > V_{SS}$ indicates charge. The effective voltage drop, V_{SRO} , as seen by the bq2040 is $V_{SR} + V_{OS}$. (See Table 3.)

\overline{DISP}

Display control input

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

SB

Secondary battery input

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

PSTAT

Protector status input

Provides overvoltage status from the Li-Ion protector circuit and can initiate a charge suspend request.

SMBD

SMBus data

Open-drain bidirectional pin used to transfer address and data to and from the bq2040.

SMBC

SMBus clock

Open-drain bidirectional pin used to clock the data transfer to and from the bq2040.

REF

Reference output for regulator

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

VOUT

Supply output

Supplies power to the external EEPROM configuration memory.

Functional Description

General Operation

The bq2040 determines battery capacity by monitoring the amount of charge put into or removed from a rechargeable battery. The bq2040 measures discharge and charge currents, estimates self-discharge, and monitors the battery for low-battery voltage thresholds. The charge is measured by monitoring the voltage across a small-value series sense resistor between the battery's negative terminal and ground. The available battery charge is determined by monitoring this voltage over time and correcting the measurement for the environmental and operating conditions.

Figure 1 shows a typical battery pack application of the bq24040 using the LED capacity display, the serial port, and an external EEPROM for battery pack programming information. The bq24040 must be configured and calibrated for the battery-specific information to ensure proper operation. Table 1 outlines the configuration information that must be programmed in the EEPROM.

An internal temperature sensor eliminates the need for an external thermistor—reducing cost and components. An internal, temperature-compensated time-base eliminates the need for an external resonator, further reducing cost and components. The entire circuit in Figure 1 can occupy less than $\frac{3}{4}$ square inch of board space.

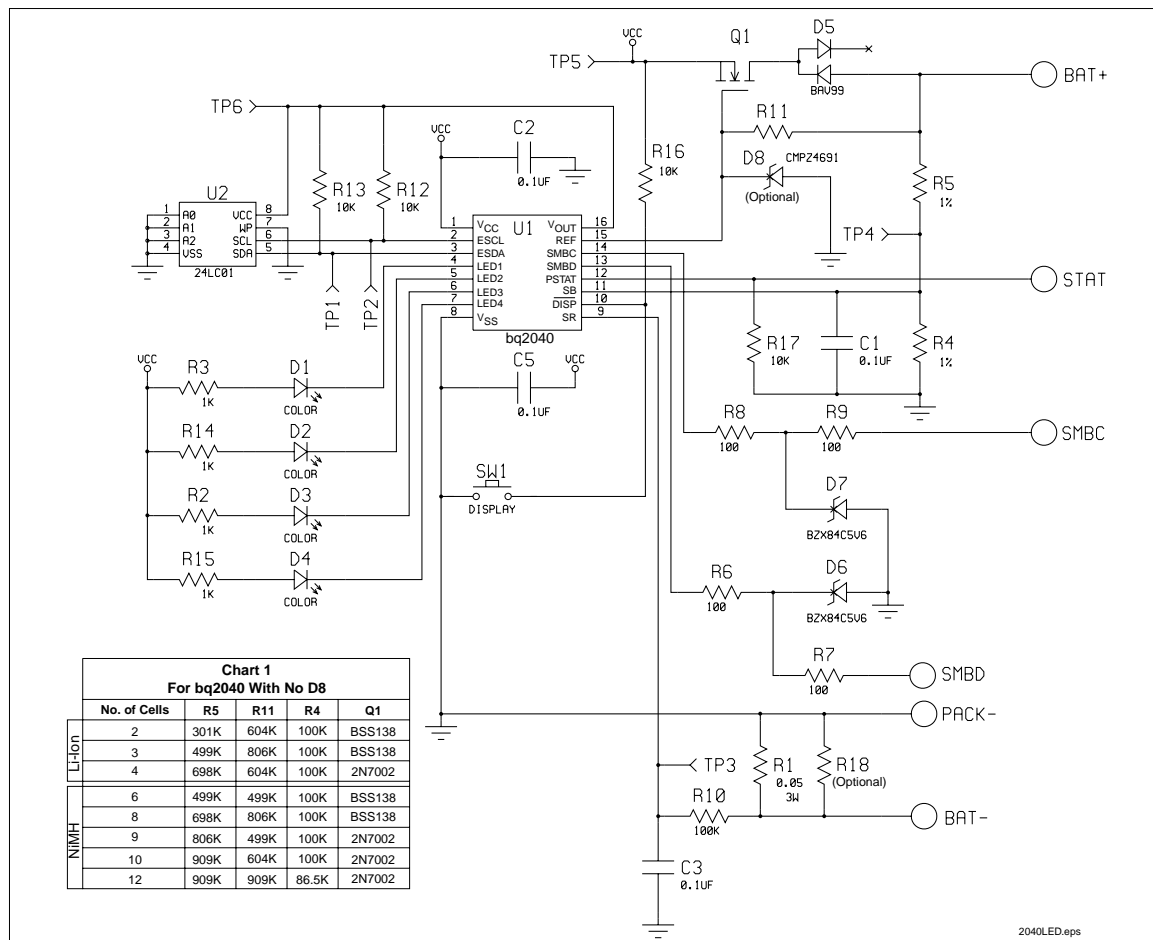


Figure 1. Battery Pack Application Diagram—LED Display

Table 1. Configuration Memory Map

| Parameter Name | Address | Description | Length | Units |
|---|-----------|---|---------|---------|
| EEPROM length | 0x00 | Number of EEPROM data locations must = 0x64 | 8 bits | NA |
| EEPROM check1 | 0x01 | EEPROM data integrity check byte, must = 0x5b | 8 bits | NA |
| Remaining time alarm | 0x02/0x03 | Sets RemainingTimeAlarm (0x02) | 16 bits | minutes |
| Remaining capacity alarm | 0x04/0x05 | Sets RemainingCapacityAlarm (0x01) | 16 bits | mAh |
| Reserved | 0x06/0x07 | Reserved for future use | 16 bits | NA |
| Initial charging current | 0x08/0x09 | Sets the initial charging current | 16 bits | mA |
| Charging voltage | 0x0a/0x0b | Sets ChargingVoltage (0x15) | 16 bits | mV |
| Battery status | 0x0c/0x0d | Initializes BatteryStatus (0x16) | 16 bits | NA |
| Cycle count | 0x0e/0x0f | Initializes and stores CycleCount (0x17) | 16 bits | cycles |
| Design capacity | 0x10/0x11 | Sets DesignCapacity (0x18) | 16 bits | mAh |
| Design voltage | 0x12/0x13 | Sets DesignVoltage (0x19) | 16 bits | mV |
| Specification information | 0x14/0x15 | Programs SpecificationInfo (0x1a) | 16 bits | NA |
| Manufacture date | 0x16/0x17 | Programs ManufactureDate (0x1b) | 16 bits | NA |
| Serial number | 0x18/0x19 | Programs SerialNumber (0x1c) | 16 bits | NA |
| Fast-charging current | 0x1a/0x1b | Sets ChargingCurrent (0x14) | 16 bits | mA |
| Maintenance-charge current | 0x1c/0x1d | Sets the trickle current request | 16 bits | mA |
| Reserved | 0x1e/0x1f | Reserved must = 0x0000 | 16 bits | mAh |
| Manufacturer name | 0x20-0x2b | Programs ManufacturerName (0x20) | 96 bits | NA |
| Current overload | 0x2c/0x2d | Sets the overload current threshold | 16 bits | mA |
| Battery low % | 0x2e | Sets the battery low amount | 8 bits | % |
| Reserved | 0x2f | Reserved for future use | 8 bits | NA |
| Device name | 0x30-0x37 | Programs DeviceName (0x21) | 64 bits | NA |
| Li-Ion taper current | 0x38/0x39 | Sets the upper limit of the taper current for charge termination | 16 bits | mA |
| Maximum overcharge limit | 0x3a/0x3b | Sets the maximum amount of overcharge | 16 bits | NA |
| Reserved | 0x3c | Reserved must = 0x00 | 8 bits | NA |
| Access protect | 0x3d | Locks commands outside of the SBS data set | 8 bits | NA |
| FLAGS1 | 0x3e | Initializes FLAGS1 | 8 bits | NA |
| FLAGS2 | 0x3f | Initializes FLAGS2 | 8 bits | NA |
| Device chemistry | 0x40-0x45 | Programs DeviceChemistry (0x22) | 48 bits | NA |
| Current measurement gain | 0x46/0x47 | Sense resistor calibration value | 16 bits | NA |
| Battery voltage offset | 0x48 | Voltage calibration value | 8 bits | NA |
| Temperature offset | 0x49 | Temperature calibration value | 8 bits | NA |
| Maximum temperature and ΔT step | 0x4a | Sets the maximum charge temperature and the ΔT step for $\Delta T/\Delta t$ termination | 8 bits | NA |

Table 1. Configuration Memory Map (Continued)

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

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Voltage Thresholds

In conjunction with monitoring V_{SR} for charge/discharge currents, the bq2040 monitors the battery potential through the SB pin. The voltage potential is determined through a resistor-divider network per the following equation:

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

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

The battery voltage is monitored for the end-of-discharge voltages (EDV1 and EDVF) and for alarm warning conditions. EDV threshold levels are used to determine when the battery has reached a programmable “empty” state. The bq2040 generates an alarm warning when the battery voltage exceeds the maximum charging voltage by 5% or if the voltage is below EDVF. The battery voltage gain, the two EDV thresholds, and the charging voltage are programmable in the EEPROM.

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

EDV monitoring may be disabled under certain conditions. If the discharge current is greater than the value stored in location 0x2c and 0x2d in the EEPROM (EE 0x2c/0x2d), EDV monitoring is disabled and resumes after the current falls below the programmed value.

Reset

The bq2040 is reset when first connected to the battery pack. On power-up, the bq2040 initializes and reads the EEPROM configuration memory. The bq2040 can also be reset with a command over the SMBus. The software reset sequence is the following: (1) write MaxError (0x0c) to 0x0000; (2) write the reset register (0x64) to 0x8009. A software reset can only be performed if the bq2040 is in an unlocked state as defined by the value in location 0x3d of the EEPROM (EE 0x3d) on power-up.

Temperature

The bq2040 monitors temperature sensing using an internal sensor. The temperature is used to adapt charge and self-discharge compensations as well as to monitor for maximum temperature and $\Delta T/\Delta t$ during a bq2040 controlled charge. Temperature may also be accessed over the SMBus with command 0x08.

Layout Considerations

The bq2040 measures the voltage differential between the SR and V_{SS} pins. V_{OS} (the offset voltage at the SR pin) is greatly affected by PC board layout. For optimal results, the PC board layout should follow the strict rule of a single-point ground return. Sharing high-current ground with small signal ground causes undesirable noise on the small signal nodes. Additionally, in reference to Figure 1:

- The capacitors (C1 and C2) should be placed as close as possible to the SB and V_{CC} pins, and their paths to V_{SS} should be as short as possible. A high-quality ceramic capacitor of 0.1 μ f is recommended for V_{CC} .
- The sense resistor capacitor (C3) should be placed as close as possible to the SR pin.
- The bq2040 should be in thermal contact with the cells for optimum temperature measurement.

Gas Gauge Operation

The operational overview diagram in Figure 2 illustrates the operation of the bq2040. The bq2040 accumulates a measure of charge and discharge currents, as well as an estimation of self-discharge. Charge currents are compensated for temperature and state-of-charge of the battery. Self-discharge is temperature-compensated.

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

The Discharge Count Register is used to update the FullChargeCapacity (FCC) register only if a complete battery discharge from full to empty occurs without any partial battery charges. Therefore, the bq2040 adapts its capacity determination based on the actual conditions of discharge.

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

The battery's empty state is also programmed in the EEPROM. The battery low percentage (EE 0x2e) stores the percentage of FCC that will be written to RM when the battery voltage drops below the EDV1 threshold.

1. FullChargeCapacity or learned-battery capacity:

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

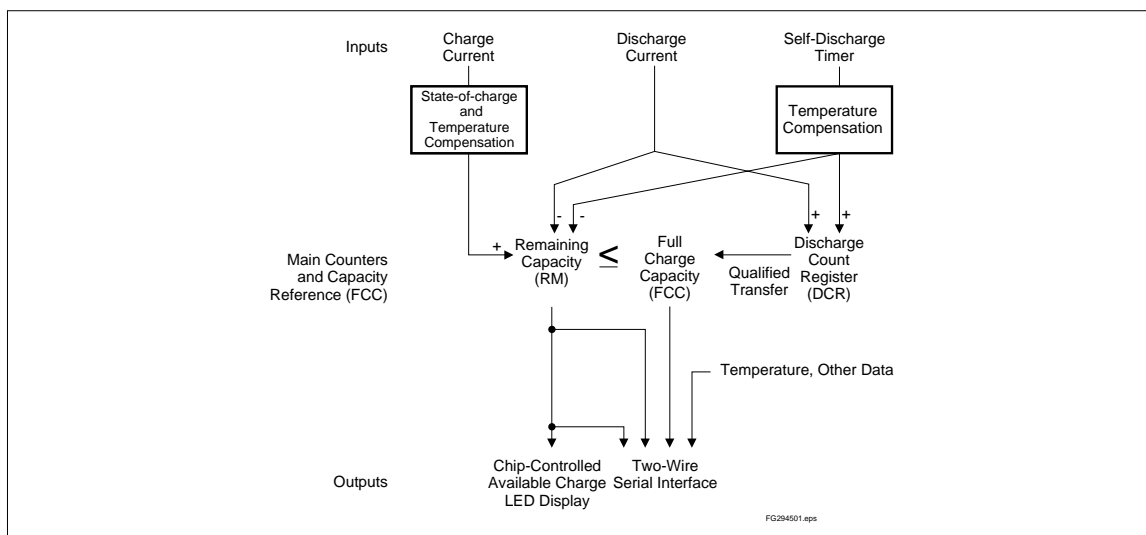


Figure 2. Operational Overview

ing subsequent discharges, FCC is updated with the latest measured capacity in the Discharge Count Register plus the battery low amount, representing a discharge from full to below EDV1. A qualified discharge is necessary for a capacity transfer from the DCR to the FCC register. Once updated, the bq2040 writes the new FCC to the EEPROM. The FCC also serves as the 100% reference threshold used by the relative state-of-charge calculation and display.

2. DesignCapacity (DC):

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

3. RemainingCapacity (RM):

RM counts up during charge to a maximum value of FCC and down during discharge and self-discharge to 0. RM is set to the battery low amount after the EDV1 threshold has been reached. If RM is already equal to or less than the battery low amount, RM is not modified. If RM reaches the battery low amount before the battery voltage falls below EDV1 on discharge, RM stops counting down until the EDV1 threshold is reached. RM is set to 0 when the battery voltage reaches EDVF. To prevent overstatement of charge during periods of overcharge, RM stops incrementing when RM = FCC. RM may optionally be written to a user-defined value when fully charged if the battery pack is under bq2040 charge control. On initialization, RM is set to 0.

4. Discharge Count Register (DCR):

The DCR counts up during discharge independent of RM and can continue increasing after RM has decremented to 0. Prior to RM = 0, both discharge and self-discharge increment the DCR. After RM = 0, only discharge increments the DCR. The DCR resets to 0 when RM = FCC and stops counting at EDV1 on discharge. The DCR does not roll over but stops counting when it reaches FFFFh.

FCC is updated on the first charge after a qualified discharge to EDV1. The updated FCC equals the battery low percentage times the current FCC plus the DCR value. A qualified discharge to EDV1 occurs if all of the following conditions exist:

- No valid charge initiations (charges greater than 10mAh, where $V_{SRO} > +V_{SRD}$ occurred during the period between RM = FCC and EDV1 detected.
- The self-discharge count is not more than 256mAh.
- The low temperature fault bit in FLAGS2 is not set when the EDV1 level is reached during discharge.
- Battery voltage is not more than 256mV below the EDV1 threshold when EDV1 is set.

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

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Charge Counting

Charge activity is detected based on a positive voltage on the SR input. If charge activity is detected, the bq2040 increments RM at a rate proportional to V_{SRO} and, if enabled, activates an LED display. Charge actions increment the RM after compensation for charge state and temperature.

The bq2040 determines charge activity sustained at a continuous rate equivalent to $V_{SRO} > +V_{SRD}$. **A valid charge equates to sustained charge activity greater than 10 mAh.** Once a valid charge is detected, charge threshold counting continues until V_{SRO} falls below V_{SRD} . V_{SRD} is a programmable threshold as described in the Digital Magnitude Filter section.

Discharge Counting

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

Self-Discharge Estimation

The bq2040 continuously decrements RM and increments DCR for self-discharge based on time and temperature provided that the discharge flag in BatteryStatus is set (charge not detected). The bq2040 self-discharge estimation rate is programmed in EE 0x4f and can be set from 0 to 25% per day for 20–30°C. This rate approximately doubles for every 10°C increase until the temperature is $\geq 70^\circ\text{C}$ or halves every 10°C decrease until the temperature is $< 10^\circ\text{C}$.

Charge Control

The bq2040 supports SBS charge control by broadcasting the ChargingCurrent and the ChargingVoltage to the Smart Charger address. The bq2040 broadcasts charging commands every 10 seconds; the broadcasts can be disabled by writing bit 14 of BatteryMode to 1. On reset, the initial charging current broadcast to the charger is set to the value programmed in EE 0x08–0x09. The bq2040 updates the value used in the charging current broadcasts based on the battery's state of charge, voltage, and temperature.

The bq2040 internal charge control is compatible with nickel-based and Li-Ion chemistries. The bq2040 uses current taper detection for Li-Ion primary charge termination and $\Delta T/\Delta t$ for nickel based primary charge termination. The bq2040 also provides a number of safety terminations based on battery capacity, voltage, and temperature.

Current Taper

For Li-Ion charge control, the ChargingVoltage must be set to the desired pack voltage during the constant voltage charge phase. The bq2040 detects a current taper termination when it measures the pack voltage to be within 128mV of the requested charging voltage and when the AverageCurrent is less than the programmed threshold in EE 0x38–0x39 and non-zero for at least 100s.

$\Delta T/\Delta t$

The $\Delta T/\Delta t$ used by the bq2040 is programmable in both the temperature step (1.6°C–4.6°C) and time step (20 seconds–320seconds). Typical settings for 1°C/min include 2°C over 120 seconds and 3°C over 180 seconds. Longer times are required for increased slope resolution.

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

$$\frac{[(\text{lower nibble of EE } 0x4a) * 2 + 16] / 10}{[320 - (\text{EE } 0x62) * 20]} \left[\frac{^\circ\text{C}}{\text{s}} \right]$$

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

Charge Termination

Once the bq2040 detects a valid charge termination, the Fully_Charged, Terminate_Charge_Alarm, and the Over_Charged_Alarm bits are set in BatteryStatus, and the requested charge current is set to zero. Once the terminating conditions cease, the Terminate_Charge_Alarm and the Over_Charged_Alarm are cleared, and the requested charging current is set to the maintenance rate. The bq2040 requests the maintenance rate until RM falls below the amount determined by the programmable full-charge percentage. Once this occurs, the Fully_Charged bit is cleared, and the requested charge current and voltage are set to the fast-charge rate.

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

Charge Suspension

The bq2040 may temporarily suspend charge if it detects a charging fault. The charging faults include the following conditions:

- **Maximum Overcharge:** If charging continues for more than the programmed maximum overcharge limit as defined in EE 0x3a—0x3b beyond RM=FCC, the Fully_Charged bit is set, and the requested charging current is set to the maintenance rate.
- **Overvoltage:** An over-voltage fault exists when the bq2040 measures a voltage more than 5% above the ChargingVoltage. When the bq2040 detects an overvoltage condition, the requested charge current is set to 0 and the Terminate_Charge_Alarm bit is set in BatteryStatus. The alarm bit is cleared when the current drops below 256mA and the voltage is less than 105% of ChargingVoltage.
- **Overcurrent:** An overcurrent fault exists when the bq2040 measures a charge current more than 25% above the ChargingCurrent. If the ChargingCurrent is less than 1024mA, an overcurrent fault exists if the charge current is more than 1mA above the lowest multiple of 256mA that exceeds the ChargingCurrent. When the bq2040 detects an overcurrent condition, the requested charge current is set to 0 and the Terminate_Charge_Alarm bit is set in BatteryStatus. The alarm bit is cleared when the current drops below 256mA.
- **Maximum Temperature:** When the battery temperature equals the programmed maximum temperature, the requested charge current is set to zero and the Over_Temp_Alarm and the Terminate_Charge_Alarm bits are set in BatteryStatus. The Over_Temp_Alarm bit is cleared when the temperature drops to 43°C below the maximum temperature threshold minus 5°C.
- **PSTAT:** When the PSTAT input is $\geq 1.5V$, the requested charge current is set to 0 and the Terminate_Charge_Alarm bit is set in BatteryStatus if the Discharging flag is not set. The alarm bit is cleared when the PSTAT input is $< 1.0V$ or the Discharging flag is set.
- **Low Temperature:** When the battery temperature is less than 12°C (LTF bit in FLAGS2 set), the requested charge current is set to the maintenance rate. Once the temperature is above 15°C, the requested charge current is set to the fast rate.
- **Undervoltage:** When the battery voltage is below the EDVF threshold, the requested charge current is set to the EDVF rate stored in EE0x5a/0x5b. Once the voltage is above EDVF, the requested charge current is set to the fast or maintenance rate depending on the state of the LTF bit.

Count Compensations

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

Charge Compensation

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

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

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

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

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

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

$$Q_{ET} = 0 \text{ if } T < 30^{\circ}C$$

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

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

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

Digital Magnitude Filter

The bq2040 has a programmable digital filter to eliminate charge and discharge counting below a set threshold, V_{SRD} . Table 2 shows typical digital filter settings. The proper digital filter setting can be calculated using the following equation.

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

Table 2. Typical Digital Filter Settings

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

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Table 3. bq2040 Current-Sensing Errors

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

Error Summary

Capacity Inaccurate

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

Current-Sensing Error

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

Display

The bq2040 can directly display capacity information using low-power LEDs. The bq2040 displays the battery charge state in either absolute or relative mode. In relative mode, the battery charge is represented as a percentage of the FCC. Each LED segment represents 25% of the FCC.

In absolute mode, each segment represents a fixed amount of charge, 25% of the DesignCapacity. As the battery wears out over time, it is possible for the FCC to be below the design capacity. In this case, all of the LEDs may not turn on in absolute mode, representing the reduction in the actual battery capacity.

When $\overline{\text{DISP}}$ is tied to V_{CC}, the LED₁₋₄ outputs are inactive. When $\overline{\text{DISP}}$ is left floating, the display becomes active whenever the bq2040 detects a charge rate of 100mA or more. When pulled low, the segment outputs become active immediately for a period of approximately 4 seconds. The $\overline{\text{DISP}}$ pin must be returned to float or V_{CC} to reactivate the display.

LED₁ blinks at a 4Hz rate indicating a low battery condition whenever the display is active, EDVF is not set,

and Remaining_Capacity_Alarm is set. V_{SB} below EDVF (EDVF = 1) disables the display output.

Microregulator

The bq2040 can operate directly from three nickel chemistry cells. To facilitate the power supply requirements of the bq2040, an REF output is provided to regulate an external low-threshold n-FET. A micropower source for the bq2040 can be built inexpensively using a 2N7002 or BSS138 FET and an external resistor. (See Figure 1.) The value of R11 depends on the battery pack's nominal voltage.

Communicating With the bq2040

The bq2040 includes a simple two-pin (SMBC and SMBD) bi-directional serial data interface. A host processor uses the interface to access various bq2040 registers; see Table 4. This method allows battery characteristics to be monitored easily. The open-drain SMBD and SMBC pins on the bq2040 are pulled up by the host system, or may be connected to V_{SS}, if the serial interface is not used.

The interface uses a command-based protocol, where the host processor sends the battery address and an eight-bit command byte to the bq2040. The command directs the bq2040 to either store the next data received to a register specified by the command byte or output the data specified by the command byte.

bq2040 Data Protocols

The host system, acting in the role of a Bus master, uses the read word and write word protocols to communicate integer data with the bq2040. (See Figure 3).

Host-to-bq2040 Message Protocol

The Bus Host communicates with the bq2040 using one of three protocols:

- Read word
- Write word

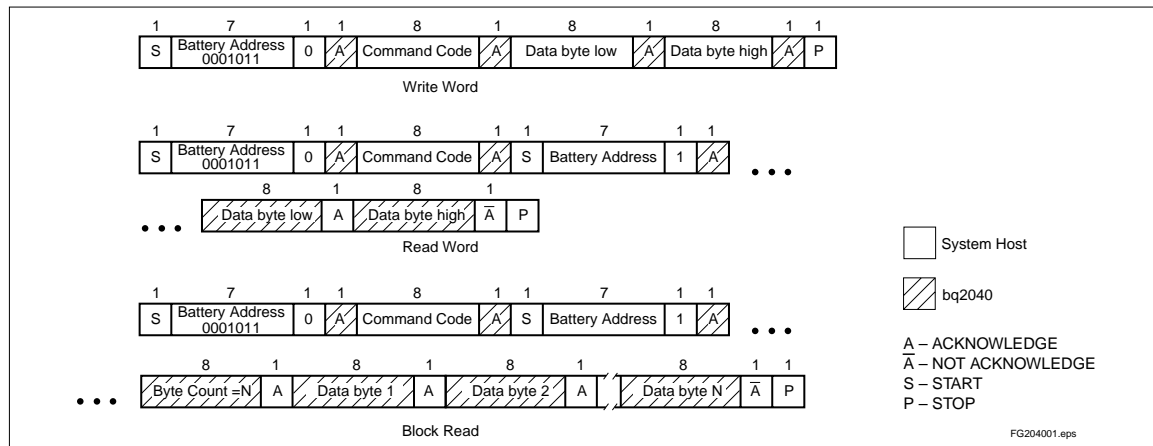


Figure 3. Host Communication Protocols

■ Read block

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

Host-to-bq2040 Messages (see Table 4)

ManufacturerAccess() (0x00)

This read/write word is an open location.

Input/Output: word.

RemainingCapacityAlarm() (0x01)

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

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

Units: mAh

Range: 0 to 65,535mAh

RemainingTimeAlarm() (0x02)

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

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

Units: minutes

Range: 0 to 65,535 minutes

BatteryMode() (0x03)

This read/write word selects the various battery operational modes. The bq2040 supports the battery capacity information specified in mAh. This function also determines whether the bq2040 charging values are broadcasted to the Smart Battery Charger address.

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

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

Bit 7 is the condition request flag. It is set when the bq2040 is initialized from the EEPROM and reset when a learning cycle has been completed. It is also set to a 1 if CycleCount increases by 32 without a new learning cycle.

AtRate() (0x04)

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

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Table 4. bq2040 Register Functions

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

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

Table 4. bq2040 Register Functions (Continued)

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

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

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- 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.

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

Units: mA

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

AtRateTimeToFull() (0x05)

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

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

Units: minutes

Range: 0 to 65,534min

Granularity: 2 min or better

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

AtRateTimeToEmpty() (0x06)

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

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

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

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

AtRateOK() (0x07)

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

Boolean: Indicates if the battery can supply additional energy.

Units: Boolean

Range: TRUE \neq 0, FALSE = 0

Temperature() (0x08)

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

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

Units: 0.1°K

Range: 0 to +500.0°K

Granularity: 0.5°K or better

Accuracy: $\pm 3^\circ\text{K}$ after calibration

Voltage() (0x09)

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

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

Units: mV

Range: 0 to 65,535mV

Granularity: 0.2% of DesignVoltage

Accuracy: $\pm 1\%$ of DesignVoltage after calibration

Current() (0x0a)

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

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

Units: mA

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

Granularity: 0.2% of the DesignCapacity or better

Accuracy: $\pm 1\%$ of the DesignCapacity after calibration

AverageCurrent() (0x0b)

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

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

Units: mA

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

Granularity: 0.2% of the DesignCapacity or better

Accuracy: $\pm 1\%$ of the DesignCapacity after calibration

MaxError() (0x0c)

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

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

Units: %

Range: 0 to 100%

RelativeStateOfCharge() (0x0d)

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

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

Units: %

Range: 0 to 100%

Granularity: 1%

Accuracy: $\pm \text{MaxError}$ after circuit and capacity calibration

AbsoluteStateOfCharge() (0x0e)

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

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

Units: %

Range: 0 to 65,535%

Granularity: 1%

Accuracy: $\pm \text{MaxError}$ after circuit and capacity calibration

RemainingCapacity() (0x0f)

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

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

Units: mAh

Range: 0 to 65,535mAh

Granularity: 0.2% of DesignCapacity or better

Accuracy: $\pm \text{MaxError} * \text{FCC}$ after circuit and capacity calibration

FullChargeCapacity() (0x10)

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

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

Units: mAh

Range: 0 to 65,535mAh

Granularity: 0.2% of DesignCapacity or better

Accuracy: $\pm \text{MaxError} * \text{FCC}$ after circuit and capacity calibration

RunTimeToEmpty() (0x11)

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

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

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

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

AverageTimeToEmpty() (0x12)

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

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

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

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

AverageTimeToFull() (0x13)

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

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

Units: minutes

Range: 0 to 65,534min

Granularity: 2min or better

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

ChargingCurrent() (0x14)

If enabled, the bq2040 sends the desired charging rate in mA to the Smart Battery Charger.

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

Units: mA

Range: 0 to 65,534mA

Granularity: 0.2% of the design capacity or better

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

ChargingVoltage() (0x15)

If enabled, the bq2040 sends the desired voltage in mV to the Smart Battery Charger.

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

Units: mV

Range: 0 to 65,534mV

Granularity: 0.2% of the DesignVoltage or better

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

BatteryStatus() (0x16)

This read-only word returns the battery status word.

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

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

Table 5. Status Register

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

CycleCount() (0x17)

This read-only word returns the number of charge/discharge cycles the battery has experienced. A charge/discharge cycle starts from a base value equivalent to the battery's state-of-charge on completion of a charge cycle. The bq2040 increments the cycle counter during the current charge cycle if the battery has been discharged 15% below the state-of-charge at the end of the last charge cycle. This prevents false reporting of small charge/discharge cycles. The cycle count is stored in EEPROM within 400ms of an update.

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

Units: cycles

Table 6. Bit Descriptions for FLAGS1 and FLAGS2

| | (MSB) 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 (LSB) |
|--------|---------------------|------------------|-----|----|-----|-------|------|---------|
| FLAGS2 | DMODE | PSTAT | CHM | CC | - | OV | LTF | OC |
| FLAGS1 | $\Delta T/\Delta t$ | I _{MIN} | VQ | - | VDQ | OVL D | EDV1 | EDVF |

Note: - = Reserved

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

Granularity: 1 cycle

DesignCapacity() (0x18)

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

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

Units: mAh

Range: 0 to 65,535mAh

DesignVoltage() (0x19)

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

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

Units: mV

Range: 0 to 65,535mV

SpecificationInfo() (0x1a)

This read-only word returns the specification revision the bq2040 supports.

ManufactureDate() (0x1b)

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

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

SerialNumber() (0x1c)

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

Output: unsigned integer

ManufacturerName() (0x20)

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

Output: string or ASCII character string

DeviceName() (0x21)

This read-only string returns a character string where the first byte is the number of characters available. The maximum number of characters is 7. The 7-byte character string contains the battery's name. For example, a DeviceName of "bq2040" indicates that the battery is a model bq2040.

Output: string or ASCII character string

DeviceChemistry() (0x22)

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

Output: string or ASCII character string

ManufacturerData() (0x23)

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

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

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End of Discharge Voltage1 (0x3e)

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

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

End of Discharge VoltageF (0x3f)

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

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

FLAGS1&2() (0x2f)

This read-only register returns an unsigned integer representing the internal status registers of the bq2040. The MSB represents FLAGS2, and the LSB represents FLAGS1. See Table 6 for the bit description for FLAGS1 and FLAGS2.

FLAGS2

The *Display Mode* flag (DMODE), bit 7 determines whether the bq2040 displays Relative or Absolute capacity.

The DMODE value is:

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

Where DMODE is:

- 0 Selects Absolute display
- 1 Selects Relative display

Bit 6 reflects the high/low state of PSTAT. PSTAT $\geq 1.5V$ generates a charge suspend condition.

The PSTAT value is:

| FLAGS2 Bits | | | | | | | |
|-------------|-------|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| - | PSTAT | - | - | - | - | - | - |

Where PSTAT is:

- 0 PSTAT input < 1.0V
- 1 PSTAT input $\geq 1.5V$

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

The CHM value is:

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

Where CHM is:

- 0 Selects Nickel
- 1 Selects Li-Ion

Bit 4, the *Charge Control* flag (CC), determines whether a bq2040-based charge termination will set RM to a user-defined programmable full charge capacity.

The CC value is:

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

Where CC is:

- 0 RM is not modified on valid bq2040 charge termination
- 1 RM is set to a programmable percentage of the FCC when a valid bq2040 charge termination occurs

Bit 3 is reserved.

Bit 2, the *Overvoltage* flag (OV), is set when the bq2040 detects a pack voltage 5% greater than the programmed charging voltage. This bit is cleared when the pack voltage falls 5% below the programmed charging voltage.

The OV value is:

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

Where OV is:

- 0 Voltage < 1.05 * ChargingVoltage
- 1 Voltage ≥ 1.05 * ChargingVoltage

Bit 1, the *Low Temperature Fault* flag (LTF), is set when Temperature is < 12°C and cleared when Temperature is $\geq 15^\circ C$.

The LTF value is:

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

Where LTF is:

- 0 Temperature > 15°C
- 1 Temperature < 12°C

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

The OC value is:

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

Where OC is:

- 0 Current is less than $1.25 * \text{ChargingCurrent}$ or less than 256mA if charging current is programmed less than 1024mA
- 1 Current exceeds $1.25 * \text{ChargingCurrent}$ or 256mA if the charging current is programmed less than 1024mA. This bit is cleared if Current < 256mA.

FLAGS1

Bits 7 indicates that a $\Delta T/\Delta t$ termination condition exists.

The $\Delta T/\Delta t$ value is:

| FLAGS1 Bits | | | | | | | |
|---------------------|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| $\Delta T/\Delta t$ | - | - | - | - | - | - | - |

Where $\Delta T/\Delta t$ is:

- 0 The $\Delta T/\Delta t$ rate drops below the programmed rate.
- 1 The $\Delta T/\Delta t$ rate exceeds the programmed rate.

Bit 6 indicates that a current taper termination condition exists.

| FLAGS1 Bits | | | | | | | |
|-------------|------------------|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| - | I _{MIN} | - | - | - | - | - | - |

The I_{MIN} value is:

Where I_{MIN} is:

- 0 A valid current taper termination condition is not present.
- 1 Valid current taper termination condition detected.

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

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

The VQ value is:

Where VQ is:

- 0 $V_{SRO} \leq |V_{SRD}|$
- 1 $V_{SRO} \geq |V_{SRD}|$ and 10mAh of charge has accumulated

Bit 4 is reserved.

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

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

The VDQ value is:

Where VDQ is:

- 0 Self-discharge is greater than 256mAh, EDV1 = 1 when $T < 0^\circ\text{C}$ or VQ = 1
- 1 On first discharge after RM=FCC

The Overload flag (OVLD), bit 2, is set when the discharge current is greater than the programmed rate and cleared when the discharge current falls below the programmed rate.

| FLAGS1 Bits | | | | | | | |
|-------------|---|---|---|---|------|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| - | - | - | - | - | OVLD | - | - |

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The OVLD value is:

Where OVLD is:

- 0 Current < programmed rate
- 1 Current > programmed rate

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

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

The EDV1 value is:

Where EDV1 is:

- 0 VQ = 1 and Voltage > EDV1
- 1 Voltage < EDV1 and OVLD = 0

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

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

The EDVF value is:

Where EDVF is:

- 0 VQ = 1 and Voltage > EDVF
- 1 Voltage < EDVF and OVLD = 0

Error Codes and Status Bits

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

SBD Seal

The bq2040 address space can be “locked” to enforce the SBS specified access to each command code. To lock the address space, the bq2040 must be initialized with EE 0x3d set to b0h. Once this is done, only commands 0x00-0x04 may be written. Attempting to write to any other address will cause a “no acknowledge” of the data. Reading will only be permitted from the command codes listed in the SBD specification plus the five locations designated as optional manufacturing functions 1–5 (0x2f, 0x3c–0x3f).

Programming the bq2040

The bq2040 requires the proper programming of an external EEPROM for proper device operation. Each module can be calibrated for the greatest accuracy, or general “default” values can be used. An EV2200-40 programming kit (interface board, software, and cable) for an IBM-compatible PC is available from Benchmarq.

The bq2040 uses a 24LC01 or equivalent serial EEPROM (capable of read operation to 2.0V) for storing the various initial values, calibration data, and string information. Table 1 outlines the parameters and addresses for this information. Tables 10 and 11 detail the various register contents and show an example program value for an 2400mAh 4-series Li-Ion battery pack, using a 50mΩ sense resistor.

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

| Error | Code | Access | Description |
|--------------------|--------|------------|---|
| OK | 0x0000 | read/write | bq2040 processed the function code without detecting any errors. |
| Busy | 0x0001 | read/write | bq2040 is unable to process the function code at this time. |
| ReservedCommand | 0x0002 | read/write | bq2040 cannot read or write the data at this time—try again later. |
| UnsupportedCommand | 0x0003 | read/write | bq2040 does not support the requested function code. |
| AccessDenied | 0x0004 | write | bq2040 detected an attempt to write to a read-only function code. |
| Overflow/Underflow | 0x0005 | read/write | bq2040 detected a data overflow or underflow. |
| BadSize | 0x0006 | write | bq2040 detected an attempt to write to a function code with an incorrect size data block. |
| UnknownError | 0x0007 | read/write | bq2040 detected an unidentifiable error. |

Note: Reading the bq2040 after an error clears the error code.

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Table 9. BatteryStatus Bits

| Alarm Bits | | |
|---------------------------|---|---|
| Bit Name | Set When: | Reset When: |
| OVER_CHARGED_ALARM | The bq2040 detects a $\Delta T/\Delta t$ or current taper termination. (Note: $\Delta T/\Delta t$ and current taper are valid charge terminations.) | A discharge occurs or when the $\Delta T/\Delta t$ or current taper termination condition ceases during charge. |
| TERMINATE_CHARGE_ALARM | The bq2040 detects an over-current, over-voltage, over-temperature, $\Delta T/\Delta t$, or current taper condition during charge. | A discharge occurs or when all conditions causing the event cease. |
| OVER_TEMP_ALARM | The bq2040 detects that its internal temperature is greater than the programmed value. | Internal temperature falls to 43°C or the maximum temperature threshold minus 5°C. |
| TERMINATE_DISCHARGE_ALARM | The bq2040 determines that it has supplied all the charge that it can without being damaged (Voltage < EDVF). | Voltage > EDVF signifies that the battery has reached a state of charge sufficient for it to once again safely supply power. |
| REMAINING_CAPACITY_ALARM | The bq2040 detects that the RemainingCapacity is less than that set by the RemainingCapacityAlarm function. | Either the value set by the RemainingCapacityAlarm function is lower than the Remaining Capacity or the RemainingCapacity is increased by charging. |
| REMAINING_TIME_ALARM | The bq2040 detects that the estimated remaining time at the present discharge rate is less than that set by the RemainingTimeAlarm function. | Either the value set by the RemainingTimeAlarm function is lower than the AverageTimeToEmpty or a valid charge is detected. |
| Status Bits | | |
| Bit Name | Set When: | Reset When: |
| INITIALIZED | The bq2040 loads from the EEPROM (bit 7 set in EE0x0c). | A bad EEPROM load is detected. |
| DISCHARGING | The bq2040 determines that it is not being charged. | Battery detects that it is being charged. |
| FULLY_CHARGED | The bq2040 determines a valid charge termination or a maximum overcharge state. | RM discharges below the full charge percentage. |
| FULLY_DISCHARGED | bq2040 determines that it has supplied all the charge that it can without being damaged. | RelativeStateOfCharge is greater than or equal to 20% |

Table 10. Example Register Contents

| Description | EEPROM Address | | EEPROM Hex Contents | | Example Values | Notes |
|----------------------------|----------------|-----------|---------------------|-----------|-----------------------|--|
| | Low Byte | High Byte | Low Byte | High Byte | | |
| EEPROM length | 0x00 | | 64 | | 100 | Must be equal to 0x64. |
| EEPROM check 1 | 0x01 | | 5b | | 91 | Must be equal to 0x5b. |
| Remaining time alarm | 0x02 | 0x03 | 0a | 00 | 10 minutes | Sets the low time alarm level. |
| Remaining capacity alarm | 0x04 | 0x05 | f0 | 00 | 240mAh | Sets the low capacity alarm level. |
| Reserved | 0x06 | 0x07 | 00 | 00 | 0 | Not currently used by the bq2040. |
| Initial charging current | 0x08 | 0x09 | 60 | 09 | 2400mA | Sets the initial charge request. |
| Charging voltage | 0x0a | 0x0b | d8 | 40 | 16600mV | Used to set the fast-charge voltage for the Smart Charger. |
| Battery status | 0x0c | 0x0d | 80 | 00 | 128 | Initializes BatteryStatus. |
| Cycle count | 0x0e | 0x0f | 00 | 00 | 0 | Contains the charge cycle count and can be set to zero for a new battery. |
| Design capacity | 0x10 | 0x11 | 60 | 09 | 2400mAh | Normal battery pack capacity. |
| Design voltage | 0x12 | 0x13 | 40 | 38 | 14400mV | Nominal battery pack voltage. |
| Specification information | 0x14 | 0x15 | 10 | 00 | 1.0 | Default value for this register in a 1.0 part. |
| Manufacture date | 0x16 | 0x17 | a1 | 20 | May 1, 1996 = 8353 | Packed per the ManufactureDate description. |
| Serial number | 0x18 | 0x19 | 12 | 27 | 10002 | Contains the optional pack serial number. |
| Fast-charging current | 0x1a | 0x1b | 60 | 09 | 2400mA | Used to set the fast-charge current for the Smart Charger. |
| Maintenance charge current | 0x1c | 0x1d | 00 | 00 | 0mA | Contains the desired maintenance current after fast-charge termination by the bq2040. |
| Reserved | 0x1e | 0x1f | 00 | 00 | 0 | Must be programmed to 0x00. |
| Current overload | 0x2c | 0x2d | 70 | 17 | 6000mA | Sets the discharge current at which EDV threshold monitoring is disabled. |
| Battery low % | 0x2e | | 08 | | 3% | Sets the battery capacity that RemainingCapacity is reduced to at EDV1. The value equals $2.56 * (\%RM \text{ at EDV1})$ |

bq2040

Table 10. Example Register Contents (Continued)

| Description | EEPROM Address | | EEPROM Hex Contents | | Example Values | Notes |
|---------------------------------------|----------------|-----------|---------------------|-----------|---|--|
| | Low Byte | High Byte | Low Byte | High Byte | | |
| Reserved | 0x2f | | 00 | | 0 | Not currently used by the bq2040. |
| Li-Ion taper current | 0x38 | 0x39 | 10 | ff | 240mA | Sets the upper taper limit for Li-Ion charge termination. Stored in 2's complement. |
| Maximum overcharge limit | 0x3a | 0x3b | 9c | ff | 100mAh | Sets the maximum amount of overcharge before a maximum overcharge charge suspend occurs. Stored in 2's complement. |
| Reserved | 0x3c | | 00 | | 0 | Must be programmed to 0. |
| Access protect | 0x3d | | b0 | | SBD access only | If the bq2040 is reset and bit 3 of this location is 0, the bq2040 locks access to any command outside of the SBS data set. Program to 0xb8 for full R/W access, 0xb0 for SBD access only. |
| FLAGS1 | 0x3e | | 00 | | 0 | Initializes FLAGS1 |
| FLAGS2 | 0x3f | | b0 | | Relative display Li-Ion chemistry bq2040 charge control | Initializes FLAGS2. |
| Current measurement gain ¹ | 0x46 | 0x47 | 00 | 0f | 3840 | The current gain measurement and current integration gain are related and defined for the bq2040 current measurement. This word equals 192/sense resistor value in ohms. |
| Battery voltage offset ¹ | 0x48 | | fe | | -2mV | Used to adjust the battery voltage offset according to the following: Voltage = (V _{SB} (mV) + V _{OFF}) * Voltage gain |
| Temperature offset ¹ | 0x49 | | 8a | | 13.8°C | The default value (zero adjustment) for the offset is 12.8°C or 0x80. TOFF _{NEW} = TOFF _{CURRENT} + (TEMP _{ACTUAL} - TEMP _{REPORTED})* 10 |
| Maximum temperature and ΔT step | 0x4a | | 5f | | Maximum temperature = 61.0°C ΔT step = 4.6°C | Maximum charge temperature is 69- (mt * 1.6)°C (mt = upper nibble). The ΔT step is (dT * 2 + 16)/10°C (dT = lower nibble). |
| Charge efficiency | 0x4b | | ff | | Maintenance compensation = 100% Fast compensation = 100% | Sets the fast-charge (high) and maintenance charge (low) efficiencies. The upper nibbles sets the low efficiency and the lower nibble adjusts the high efficiency according to the equation: Nibble = (efficiency% * 256 - 196)/4 |
| Full-charge percentage | 0x4c | | 9c | | 100% | This packed field is the two's complement of the desired value in RM when the bq2040 determines a full-charge termination. If RM is below this value, RM is set to this value. If RM is above this value, then RM is not adjusted. |

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

Table 10. Example Register Contents (Continued)

| Description | EEPROM Address | | EEPROM Hex Contents | | Example Values | Notes |
|---------------------------------------|----------------|-----------|---------------------|-----------|----------------|--|
| | Low Byte | High Byte | Low Byte | High Byte | | |
| Digital filter | 0x4d | | 96 | | 0.30mV | Used to set the digital magnitude filter as described in Table 2. |
| Current integration gain ¹ | 0x4e | | 40 | 0 | 3.2/0.05 | Represents the following: 3.2/sense resistor in ohms. It is used by the bq2040 to scale the measured voltage values on the SR pin in mA and mAh. This register also compensates for variations in the reported sense resistor value. |
| Self-discharge rate | 0x4f | | 2d | | 0.25% | This packed field is the two's complement of (52.73/x) where x is the desired self-discharge rate per day (%) at room temperature. |
| Voltage gain ¹ | 0x56 | 0x57 | 17 | 07 | 7.09 | Voltage gain is packed as two units. For example, (R4 + R5)/R4 = 7.09 would be stored as: whole number stored in 0x57 as 7 and the decimal component stored in 0x56 as 256 x 0.09 = 23(= 17h). |
| Reserved | 0x58 | 0x59 | 00 | 00 | 0 | Should be programmed to 0. |
| EDVF charging current | 0x5a | 0x5b | 64 | 00 | 100mA | Contains the desired charge current below EDVF. |
| End of discharge voltage 1 | 0x5c | 0x5d | 20 | d1 | 12000mV | The value programmed is the two's complement of the threshold voltage in mV. |
| End-of-discharge voltage final | 0x5e | 0x5f | 40 | d4 | 11200mV | The value programmed is the two's complement of the threshold voltage in mV. |
| Full charge capacity | 0x60 | 0x61 | d0 | 07 | 2000mA | This value sets the initial estimated pack capacity. |
| Δt step | 0x62 | | 0f | | 20s | The Δt step for ΔT/Δt termination equals 320 - (byte value * 20). |
| Hold-off time | 0x63 | | 00 | | 320s hold-off | The hold-off time is 320 - (byte value * 20). |
| EEPROM check 2 | 0x64 | | b5 | | 181 | Must be equal to 0xb5. |
| Reserved | 0x65 | 0x7f | | | NA | Not currently used by the bq2040. |

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

bq2040

Table 11. Example Register Contents (String Data)

| String Description | Address | 0x X0 | 0x X1 | 0x X2 | 0x X3 | 0x X4 | 0x X5 | 0x X6 | 0x X7 | 0x X8 | 0x X9 | 0x Xa | 0x Xb |
|--------------------|---------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Manufacturer name | 0x20- 0x2b | 09 | 42 B | 45 E | 4e N | 43 C | 48 H | 4d M | 41 A | 52 R | 51 Q | - | - |
| Device name | 0x30- 0x37 | 06 | 42 B | 51 Q | 32 2 | 30 0 | 34 4 | 30 0 | - | | | | |
| Device chemistry | 0x40- 0x45 | 04 | 6c L | 69 I | 4f O | 4e N | - | | | | | | |
| Manufacturer data | 0x50- 0x55 | 05 | 42 B | 51 Q | 32 2 | 30 0 | 32 2 | | | | | | |

Absolute Maximum Ratings

| Symbol | Parameter | Minimum | Maximum | Unit | Notes |
|------------------|-----------------------------|---------|---------|------|---|
| V _{CC} | Relative to V _{SS} | -0.3 | +7.0 | V | |
| All other pins | Relative to V _{SS} | -0.3 | +7.0 | V | |
| REF | Relative to V _{SS} | -0.3 | +8.5 | V | Current limited by R11 (see Figure 1) |
| V _{SR} | Relative to V _{SS} | -0.3 | +7.0 | V | Minimum 100Ω series resistor should be used to protect SR in case of a shorted battery. |
| T _{OPR} | Operating temperature | 0 | +70 | °C | Commercial |

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

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

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

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

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

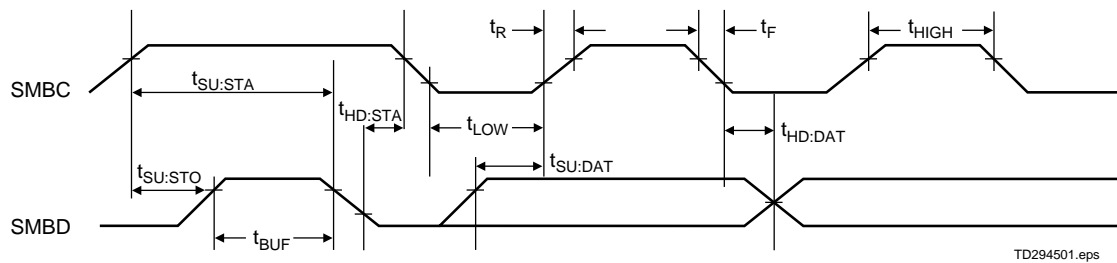
| Symbol | Parameter | Minimum | Typical | Maximum | Unit | Notes |
|-------------|--|----------------|---------|----------------|------------|---|
| V_{CC} | Supply voltage | 3.0 | 4.25 | 6.5 | V | V_{CC} excursion from $< 2.0V$ to $\geq 3.0V$ initializes the unit. |
| V_{REF} | Reference at 25°C | 5.7 | 6.0 | 6.3 | V | $I_{REF} = 5\mu A$ |
| | Reference at -40°C to +85°C | 4.5 | - | 7.5 | V | $I_{REF} = 5\mu A$ |
| R_{REF} | Reference input impedance | 2.0 | 5.0 | - | M Ω | $V_{REF} = 3V$ |
| I_{CC} | Normal operation | - | 90 | 135 | μA | $V_{CC} = 3.0V$ |
| | | - | 120 | 180 | μA | $V_{CC} = 4.25V$ |
| | | - | 170 | 250 | μA | $V_{CC} = 5.5V$ |
| V_{SB} | Battery input | 0 | - | V_{CC} | V | |
| R_{SBmax} | SB input impedance | 10 | - | - | M Ω | $0 < V_{SB} < V_{CC}$ |
| I_{DISP} | \overline{DISP} input leakage | - | - | 5 | μA | $V_{DISP} = V_{SS}$ |
| I_{LVOUT} | V_{OUT} output leakage | -0.2 | - | 0.2 | μA | EEPROM off |
| V_{SR} | Sense resistor input | -0.3 | - | 2.0 | V | $V_{SR} < V_{SS}$ = discharge; $V_{SR} > V_{SS}$ = charge |
| R_{SR} | SR input impedance | 10 | - | - | M Ω | $-200mV < V_{SR} < V_{CC}$ |
| V_{IH} | Logic input high | $0.5 * V_{CC}$ | - | V_{CC} | V | ESCL, ESDA |
| | | 1.4 | - | 5.5 | V | SMBC, SMBD |
| V_{IL} | Logic input low | 0 | - | $0.3 * V_{CC}$ | V | ESCL, ESDA |
| | | -0.5 | - | 0.6 | V | SMBC, SMBD |
| V_{OL} | Data, clock output low | - | - | 0.4 | V | $I_{OL} = 350\mu A$, SMBC, SMBD |
| I_{OL} | Sink current | 100 | - | 350 | μA | $V_{OL} \leq 0.4V$, SMBC, SMBD |
| V_{OLSL} | LED _X output low, low V_{CC} | - | 0.1 | - | V | $V_{CC} = 3V$, $I_{OLS} \leq 1.75mA$ LED ₁ –LED ₄ |
| V_{OLSH} | LED _X output low, high V_{CC} | - | 0.4 | - | V | $V_{CC} = 6.5V$, $I_{OLS} \leq 11.0mA$ LED ₁ –LED ₄ |
| V_{OHVL} | V_{OUT} output, low V_{CC} | $V_{CC} - 0.3$ | - | - | V | $V_{CC} = 3V$, $I_{VOUT} = -5.25mA$ |
| V_{OHVH} | V_{OUT} output, high V_{CC} | $V_{CC} - 0.6$ | - | - | V | $V_{CC} = 6.5V$, $I_{VOUT} = -33.0mA$ |
| I_{VOUT} | V_{OUT} source current | -33 | - | - | mA | At $V_{OHVH} = V_{CC} - 0.6V$ |
| I_{OLS} | LED _X sink current | 11.0 | - | - | mA | At $V_{OLSH} = 0.4V$ |

Note: All voltages relative to V_{SS} .

AC Specifications

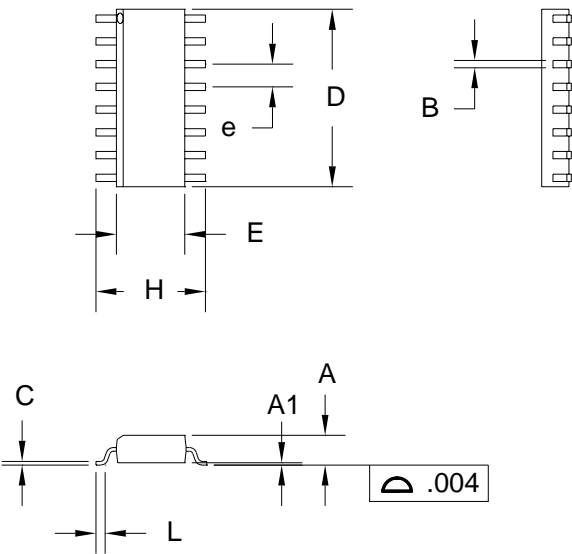
| Symbol | Parameter | Min | Max | Units | Notes |
|----------------|--|-----|------|---------|-------|
| F_{SMB} | SMBus operating frequency | 10 | 100 | KHz | |
| T_{BUF} | Bus free time between stop and start condition | 4.7 | | μs | |
| $T_{HD:STA}$ | Hold time after (repeated) start condition |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

Bus Timing Data



bq2040

16-Pin SOIC Narrow (SN)



16-Pin SN (SOIC Narrow)

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

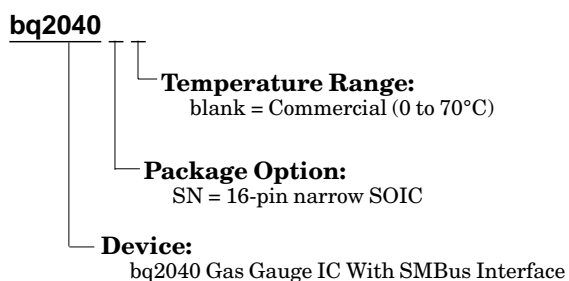
All dimensions are in inches.

Data Sheet Revision History

| ChangeNo. | Page No. | Description of Change |
|-----------|----------|---|
| 3 | 3 | Updated recommended application schematic. |
| 3 | 9 | Changed overcurrent fault condition for ChargingCurrent < 1024mA. |
| 3 | 10 | 4Hz operation of LED clarification. |
| 3 | 11 | Added descriptions for bits 7 and 13 of BatteryMode. |
| 3 | 14 | AtRateTimeToEmpty and AtRateTimeToFull invalid data indication correction. |
| 3 | 15, 16 | RunTimeToEmpty, AverageTimeToEmpty and AverageTimeToFull invalid data indication corrections. |
| 3 | 23 | Changed typical Battery low % value for Li-Ion with EDV1 = 3.0V/cell. |
| 3 | 24 | Li-Ion taper current is stored in 2's complement. |
| 3 | 24 | Changed typical ΔT step and Full-charge percentage for Li-Ion. |
| 3 | 25 | Voltage gain is $(R4 + R5)/R4$. |
| 3 | 25 | Changed typical EDV1 and EDVF values for Li-Ion. |
| 4 | 6 | Added V_{SB} should not exceed 2.4V |
| 4 | 8 | The self discharge rate <i>approximately</i> doubles or halves |
| 4 | 11 | Changed cycle count increase from 30 to 32 for condition request. |
| 4 | 14 | Changed AtRateOK() indication from EDV1 to EDVF |
| 4 | 25 | Changed self-discharge programming from 52.75/x to 52.73/x. |
| 4 | 25 | Changed recommended EDVF charging current from 0mA to 100mA |

Notes: Changes 1 and 2 refer to the 1998 Data Book
 Change 3 = June 1998 D changes from Jan. 1998 C.
 Change 4 = June 1999 E changes from June 1998 D.

Ordering Information



PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package Pins | Package qty Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---------------------------------|---------------|----------------------|----------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| BQ2040SN-C408 | Active | Production | SOIC (D) 16 | 40 TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 C408 |
| BQ2040SN-C408.B | Active | Production | SOIC (D) 16 | 40 TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 C408 |
| BQ2040SN-D111 | Active | Production | SOIC (D) 16 | 40 TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |
| BQ2040SN-D111.B | Active | Production | SOIC (D) 16 | 40 TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |
| BQ2040SN-D111G4 | Active | Production | SOIC (D) 16 | 40 TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |
| BQ2040SN-D111G4.B | Active | Production | SOIC (D) 16 | 40 TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |
| BQ2040SN-D111TR | Active | Production | SOIC (D) 16 | 2500 LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |
| BQ2040SN-D111TR.B | Active | Production | SOIC (D) 16 | 2500 LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |
| BQ2040SN-D111TRG4 | Active | Production | SOIC (D) 16 | 2500 LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | 0 to 70 | 2040 D111 |

⁽¹⁾ **Status:** For more details on status, see our [product life cycle](#).

⁽²⁾ **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

⁽³⁾ **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

⁽⁴⁾ **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

⁽⁵⁾ **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) Part marking: There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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TAPE AND REEL INFORMATION



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|-----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| BQ2040SN-D111TR | SOIC | D | 16 | 2500 | 330.0 | 16.4 | 6.5 | 10.3 | 2.1 | 8.0 | 16.0 | Q1 |
| BQ2040SN-D111TR | SOIC | D | 16 | 2500 | 330.0 | 16.4 | 6.5 | 10.3 | 2.1 | 8.0 | 16.0 | Q1 |

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|-----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| BQ2040SN-D111TR | SOIC | D | 16 | 2500 | 353.0 | 353.0 | 32.0 |
| BQ2040SN-D111TR | SOIC | D | 16 | 2500 | 350.0 | 350.0 | 43.0 |

TUBE



*All dimensions are nominal

| Device | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (μm) | B (mm) |
|-------------------|--------------|--------------|------|-----|--------|--------|--------|--------|
| BQ2040SN-C408 | D | SOIC | 16 | 40 | 505.46 | 6.76 | 3810 | 4 |
| BQ2040SN-C408 | D | SOIC | 16 | 40 | 506.6 | 8 | 3940 | 4.32 |
| BQ2040SN-C408.B | D | SOIC | 16 | 40 | 506.6 | 8 | 3940 | 4.32 |
| BQ2040SN-C408.B | D | SOIC | 16 | 40 | 505.46 | 6.76 | 3810 | 4 |
| BQ2040SN-D111 | D | SOIC | 16 | 40 | 505.46 | 6.76 | 3810 | 4 |
| BQ2040SN-D111 | D | SOIC | 16 | 40 | 506.6 | 8 | 3940 | 4.32 |
| BQ2040SN-D111.B | D | SOIC | 16 | 40 | 506.6 | 8 | 3940 | 4.32 |
| BQ2040SN-D111.B | D | SOIC | 16 | 40 | 505.46 | 6.76 | 3810 | 4 |
| BQ2040SN-D111G4 | D | SOIC | 16 | 40 | 505.46 | 6.76 | 3810 | 4 |
| BQ2040SN-D111G4.B | D | SOIC | 16 | 40 | 505.46 | 6.76 | 3810 | 4 |

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