UNITRODE

U-513 Using the bq2040

Smart Battery System Gas Gauge IC

Introduction

This document supplements the *Smart Battery Systems Specifications* and the bq2040 data sheet.

The bq2040 Gas Gauge IC meets the requirements for systems incorporating the industry standard Smart Battery System bus and data set. It is based on Unitrode's proven technology for accurately monitoring battery capacity.

In this tutorial, "user" is the battery system designer who determines the configuration of a pack, not the end-user of a system. Terms from the SMB/SBD specifications are printed with the first letter of each word capitalized as printed in those specifications, while configuration and status parameters specific to the bq2040 are fully capitalized.

System Components and Operation

SMB Two-Wire Serial Port

The SMB serial port meets all DC and AC parameters in the SMB 1.0 specification.

SBD Data Set

The bq2040 supports the Smart Battery Data Specification 1.0.

Measurement Subsystems

Of primary importance in any battery management solution are the analog measurement components. The parameters that must be measured include battery voltage, battery temperature and battery current. Because current-sensing requires the measurement of low-level signals with a wide dynamic range, while measuring battery voltage and temperature do not, the bq2040 has two measurement units. A successive approximation A/D is used to measure battery voltage and temperature, and a voltage-to-frequency converter is used to measure battery current.

Measuring Voltage and Temperature

Battery voltage is monitored at the SB input. The pack voltage is typically divided down by a resistor divider to represent the average single cell voltage of nickel chemistry cells or half that of the average lithium-ion chemistry cell. These ratios of division are the most common, although not required. The 10-bit A/D at the SB input measures voltages between 0 and 2.4V.

Battery temperature is measured by an internal sensor and the 10-bit A/D. In designing the mechanics of a battery pack, the proximity of the bq2040 to the cells and the thermal characteristics of the packaging must be considered. This consideration is most important for nickel chemistry applications where $\Delta T/\Delta t$ charge termination is desired.

Measuring Current

Battery current is monitored at the SR input by measuring the voltage drop across a series sense resistor. The most common value for the sense resistor is 0.05 ohms; however, the bq2040 can be calibrated to any value down to 0.0125 ohms and to well above a practical limit of about 0.2 ohms. Accurate capacity monitoring requires measuring battery current over a wide dynamic range, and since battery systems operate over long time periods, small errors can accumulate with time and cause the capacity to be reported inaccurately. To provide an accurate, cost-effective solution to this problem, the bq2040 employs a voltage-to-frequency converter (VFC) to monitor the voltage drop across the series current sense resistor. VFCs are less conventional, but they allow the measurement of very small signals without the quantization error associated with more widely used A/D converters. Also, the input offset of the VFC in the bq2040 is typically 50µV, much lower than that achievable with most A/D implementations.

The VFC integrates the voltage at its input and supplies a pulse to an internal counter for each 45mVs that has been integrated. Because the voltage at the SR input represents current, the integral of the voltage represents charge and thus the internal counter increments with each packet of charge detected. Two pulses are available, one for positive inputs on SR and one for negative inputs. The counter is incremented for charge entering the battery or decremented for charge leaving the battery. The relation of current, sense resistance, and the period of pulses to the counter within the VFC is

$$t_i = \frac{0.045}{i_{SR} \cdot R_{SR}} \left[s \right]$$

Measurements performed with a VFC are inherently average values rather than instantaneous values. This is an advantage for applications such as capacity monitoring because the input is sampled nearly continuously.

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Alternatively, an A/D which typically samples its input briefly at relatively infrequent intervals can miss significant but short duration current drain events, such as spinning up a hard drive or turning on a fan.

The use of a VFC optimizes the accuracy of charge and discharge measurement, the prime objective of the Gas Gauge IC. It is also dynamically balanced to enhance the charge measurement accuracy. Current flow in and out of the battery may be calculated from the rate of charge accumulation, but is typically a noisy measurement since it is a derivative of the charge accumulation measurement. The current calculation is averaged to achieve a more stable reported value. The resulting delay and granularity in reported current do not indicate inaccurate capacity reporting. An implementation optimized for very accurate and smoothed current indication, with correspondingly less capacity-gauging accuracy, may not meet the user's need for accurate capacity gauging.

The current reported in Current (0x0a) is the average of the current over the previous 20 seconds. The current reported in AverageCurrent (0x0b) is the average of the current over the previous 60 seconds. The reported AverageCurrent is updated every 20 seconds. The granularity in current reporting may be determined by use of the above formula for both the 20-second and 60-second average current values. Current is reported as zero if it is less than this minimum granularity value (15mA average current with a .05 ohm sense resistor).

Even with reported currents of zero, the capacity gauge continues to measure charge and discharge of the battery accurately as long as the current develops more voltage across the sense resistor than the digital filter threshold (5mA minimum with .05 ohm sense resistor and 250µV digital filter threshold). The current reported by Current (0x0a) and AverageCurrent (0x0b) may be calibrated by adjustment of the IRES60 current-measurement gain factor to account for variations in the effective sense resistor value from unit to unit. The maximum reported current flow is limited to the value that drops 285mV across the sense resistor.

Capacity Monitoring

Minimum Measurable Current Flow

Systems expected to measure very small signals must establish a minimum signal level. The minimum signal level should be larger than the errors due to circuit offsets or noise. In the case of capacity monitoring this insures that the capacity counter does not increment or decrement while there is no current flowing. In the bq2040 a user-settable filter sets this minimum level and disallows changes to capacity from signal levels below the digital filter. Every bq2040 is tested to 150µV input offset of the SR pin, although typically the offset is 50µV. SR input offset is greatly affected by the printed circuit board layout and bypass capacitor selection. A digital filter cutoff value of 250µV is usually recommended but may be adjusted for individual designs. A bq2040 and PCB layout with an offset of 100µV and a digital filter of 250µV with a 0.1 ohm sense resistor translates to minimum measurable current of 3.5mA with 1mA of absolute error.

Coulomb Counting

The internal counter mentioned earlier is a 24-bit counter whose unit count value is (1/256)mAh. The upper 16-bits of the counter are displayed as the SBD Function RemainingCapacity(0x0f) (RM). Each charge packet detected increments or decrements the 24-bit coulomb counter by an amount calculated from the current polarity, sense-resistor value, battery charge efficiency and the measured battery temperature. The base mAh value of the packets are programmed in the parameter called current integration gain, or DELCAP, which has the units of (1/256)mAh. This configuration parameter scales the charge packets to the sense-resistor. The base value for a 0.05 ohm sense-resistor is 0.25mAh.

Charge Compensation

The value of charge accumulated during battery charging is adjusted for battery charge efficiency. Charge compensation is determined using a two-segment piece-wise linear model. The two segments are divided at the point where the cells are considered full for fast-charge purposes, such as the point that a $\Delta T/\Delta t$ termination occurs. This point is user selected, and referred to as full-charge percentage or FULPCT. If RelativeStateofCharge (0x0d) is below FULPCT, charging occurs at the high efficiency rate (HEFF), and above this point charging is counted at the low efficiency rate (LEFF). The LEFF and HEFF charge efficiency factors are used whether CHM is a 1 or 0. The charge efficiencies are generally programmed for 100% charge efficiency for lithium-ion batteries. The charge efficiency is also modified by temperature, but only if CHM=0. If CHM=0, both LEFF and HEFF are decreased by 2 percentage points for temperatures between 30°C and 40°C, and by 5 percentage points for temperatures above 40°C.

Discharge Compensation

There is no compensation during discharge. The coulomb counter is decremented by the value of DELCAP for each charge packet detected with a negative signal on SR. DELCAP is a programmable value and is normally calibrated to account for variation in effective sense-resistor values from unit to unit to achieve optimal accuracy.

Self-Discharge

The bq2040 also estimates self-discharge of the cells. The user selects the estimated rate for the range 20-30°C and the capacity is decreased by that rate each day. For each ten degrees above the 20–30°C range the rate doubles (up to a maximum 70–80°C range) and for each 10 degrees below the 20–30°C range, the rate halves (down to a minimum 0–10°C range). Self-discharge estimation is made by reducing Nominal Available Capacity (NAC), and consequently RemainingCapacity (0x0f), by 1/256th of its present value.

The self-discharge estimation is varied by adjusting the time interval between self-discharge estimation adjustments. At 25°C, the self-discharge estimation is made every Sdtime with a corresponding Sdest per day. These values are related to the programmed SDRATE at 25°C as follows:

$$Sdtime = 640 \times 2's[SDRATE][s]$$

$$Sdest = \frac{13500}{256\,x2's[SDRATE]}[\%day]$$

Self-discharge estimation is not done unless Discharging flag in BatteryStatus is set. No self-discharge estimation is done while charging.

Calibration Cycles

To keep the capacity counter accurate and adjust the full capacity register to changes in capacity over the life of the battery, calibration or learning cycles are required from time to time. A calibration cycle consists of a valid discharge from full to empty. The full condition is defined as RemainingCapacity (0x0f) (RM) equal to FullChargeCapacity (0x10) (FCC). The empty condition is defined as reaching a programmable First End of Discharge Voltage (EDV1) threshold. The RelativeStateofCharge(0x0d) value associated with this voltage is also a programmable value.

If the battery is used in an application where it very seldom is empty, the use of a higher EDV1 threshold associated with a non-zero remaining capacity allows the battery to go through a calibration cycle more often during normal use. If the battery is discharged until the battery voltage drops below the EDV1 threshold, RM is written down to the programmed EDV1 Battery Low Percentage (BLPCT) times FCC unless RM is already equal to or less than this value.

If RM reaches the appropriate capacity threshold value before the battery voltage falls below the EDV1 threshold on a discharge, further decrementing of RM does not occur until the EDV1 voltage threshold is reached. Further discharge below EDV1 causes RM to continue decrementing.

The various thresholds for EDV1, EDVF, and BLPCT should be programmed such that RM decreases to zero before the battery voltage falls below the Final End of Discharge Voltage (EDVF) threshold. If not already zero, RM is set to zero when the EDVF threshold is reached.

If a calibration cycle is completed, FCC is updated with a new learned capacity. The Valid Discharge Flag (VDQ) in FLAGS1 indicates that a valid discharge is in progress. VDQ is set whenever RM equals FCC on a charge. It is reset if there is a charge cycle large enough to set VQ (at least 10 mAh) or if the battery sits unused long enough to accumulate a total self-discharge estimation of at least 256mAh. VDQ is also reset if the Low Temperature Fault flag is set or if battery voltage is dropping so fast that Voltage is 256mV or more below the EDV1 threshold at the time that EDV1 flag in FLAGS1 is set.

A new FCC value is computed as the old FCC times BLPCT plus the discharge capacity measured by the Discharge Count Register (DCR) during the valid discharge cycle. This capacity reflects the available capacity that the battery is able to deliver under use conditions. If the new learned capacity is lower than the previous capacity, the new FCC value is limited to a maximum decrease of 256mAh from the prior FCC value. The update to FCC is made after detection of a valid charge (10mAh) following completion of a valid calibration cycle. MaxError (0x0c) is changed to 0x0002 (2%) and the updated FCC value is stored in EEPROM if the FCC value before update was more than 256mAh and was not more than 256mAh greater than the new updated FCC value.

Repeated Accuracy

The bq2040 measurement circuits and basic capacity monitoring methodology were accurate to less than 10% error in tests where a battery was cycled 30 times between 70% and 30%; i.e., without reaching full or empty.

Charge Control

The bq2040 can be used to control a Smart Battery Charger that complies with the Smart Battery System Smart Battery Charger Specification 1.0. To enable the bq2040 to manage the charging, the CC bit *must* be set. The effects of this are explained in the following sections.

The bq2040 controls the Smart Charger by broadcasting the ChargingCurrent and ChargingVoltage to the charger every 10 seconds. If a charger alarm bit is set in BatteryStatus, the broadcast includes the AlarmWarning message and the charging current is set to zero.

Charge Suspension

The charge may be suspended temporarily by the bq2040 if fault conditions are detected. The fault conditions are explained below.

Overcurrent

An overcurrent condition exists when the current measured by the bq2040 exceeds the ChargingCurrent broadcast to the charger by 25%. If the charging current is less than 1024mA, an overcurrent condition is determined as 256mA more than the ChargingCurrent. Once an overcurrent condition is detected the ChargingCurrent is zeroed and the AlarmWarning Terminate_Charge_ Alarm bit is set. The Smart Charger receives a broadcast of AlarmWarning, ChargingVoltage and ChargingCurrent, with ChargingCurrent = 0. Charging is suspended until the bq2040 measures current below 256mA.

Overvoltage

An overvoltage condition exists when the voltage measured by the bq2040 exceeds ChargingVoltage by 5%. When an overvoltage condition is detected, the ChargingCurrent is set to zero, and the AlarmWarning Terminate_Charge_Alarm bit is set. The Smart Charger receives a broadcast of AlarmWarning, ChargingVoltage and ChargingCurrent, with ChargingCurrent = 0. Charging is suspended until the bq2040 measures current below 256mA and voltage less than 105% of ChargingVoltage.

Low Temperature

If the temperature is measured to be less than 12°C then ChargingCurrent is set to the trickle rate. Once the temperature is at or above 15°C, the charging rate is restored to the appropriate rate.

Maximum Temperature

The maximum temperature, safety termination is programmable from 45°C to 69°C in 1.6°C increments. When the battery temperature equals or exceeds the user-programmed maximum temperature, the Over_Temp_ Alarm and Terminate_Charge_Alarm bits are set and ChargingCurrent is zeroed. These Alarm bits are not cleared until the temperature falls to 43°C or below the maximum temperature minus 5°C. A maximum temperature termination is not a valid charge termination but only a charge suspension and as such, the Over_Charged_Alarm bit is not set.

Undervoltage

When the battery voltage is below the EDVF threshold, the Terminate_Discharge_Alarm is set and ChargingCurrent is set to the EDVF rate. Once the voltage is above EDVF, the charging rate is restored to the fast rate unless LTF flag is set (sets trickle rate) and the Terminate_Discharge_Alarm is reset.

PSTAT

When the PSTAT input is greater than or equal to 1.5V, a suspend charge condition is gererated. The ChargingCurrent is set to zero and the Terminate_Charge_Alarm is set if the Discharging flag in BatteryStatus is not set. The Terminate_Charge_Alarm clears when the PSTAT input is less than 1.0V.

Charge Termination

The bq2040 terminates a charge in three ways. The primary charge terminations are ΔT/Δt and current taper, while the secondary safety termination is a capacity based overcharge termination.

ΔT/Δt

The ΔT/Δt algorithm detects a preset temperature step over a specified time rather than an instantaneous slope in the temperature. The ΔT/Δt rate is programmable in both the temperature step (1.6°C–4.6°C) and the time (20s-300s) over which the step is allowed to occur. Typical settings for 1C/minute include 2C/120s and 3C/180s. Longer times are required for increased slope resolution. Note that the ΔT/Δt calculation is not made continuously, but only at the end of each Δt interval.

In addition to the ΔT/Δt timer, there is a hold-off timer which starts when the battery is being charged at more than 255mA and is hotter than 25C. The hold-off timer is programmable from 20s to 300s. Until it times out, the ΔT/Δt detection is suspended. If any of the conditions cease, the timer resets and will restart only when all conditions are met again. The ΔT/Δt termination conditions are checked regardless of the state of the chemistry bit; therefore, the various ΔT/Δt constants must be programmed to values that prevent an unwanted ΔT/Δt termination with a lithium chemistry battery.

When a ΔT/Δt detection occurs, the Over_Charged_Alarm, Terminate_Charge_Alarm, and Fully_Charged bits are set and ChargingCurrent is zeroed. When the charger turns off and Current < 256mA, the alarm bits are cleared.

Current Taper

The current taper method is intended for lithium-ion batteries. ChargingVoltage (0x15) must be set to the pack voltage desired during the constant-voltage phase of charging. The bq2040 detects a current taper termination when the AverageCurrent (0x0b) decreases to less than the user programmable TAPER current and still remains non-zero for at least 100 seconds while also meeting the criterion of a pack voltage measurement greater than the ChargingVoltage (0x15) less 128mV. As with ΔT/Δt, the Over_Charged_Alarm, Terminate_Charge_Alarm, and Fully_Charged bits are set and ChargingCurrent is zeroed. The alarm bits is cleared when AverageCurrent falls below 256mA.

Capacity-Based Overcharge Termination

The capacity based overcharge termination is a safety termination. It occurs if the battery continues to be charged more than a user selected maximum overcharge limit (MAXOVQ) after RM = FCC. When this point is reached, the Fully_Charged bit is set and current is requested at the trickle rate. Note that the LEFF efficiency is applied to the overcharge before it is counted and compared with MAXOVQ. This is not a valid charge termination and the Over_Charged_Alarm is not set.

Writing RM to FULPCT on Charge Termination

When a $\Delta T/\Delta t$ or Current Taper charge termination occurs, the RM register is set by the internal controller to a programmed full-charge percentage (FULPCT) of FCC if the CC bit is set This does not occur, however, if RM is already above this value or if the CC bit is not set. The Fully_Charged bit is also set when a valid charge termination occurs, but is immediately cleared if CC=0 and RM < FULPCT.

LED Display

A four-segment LED display is available to indicate either RelativeStateOfCharge or AbsoluteStateOfCharge in 25% increments. This selection depends on the state of the msb in FLAGS2&1(0x2f). RelativeStateOfCharge is selected if the msb is set. The display is controlled by the state of the $\overline{\text{DISP}}$ pin. With $\overline{\text{DISP}}$ pulled to Vcc, the display is off. With $\overline{\text{DISP}}$ floating, the display turns on when AverageCurrent(0x0b) is at least +100mA. $\overline{\text{DISP}}$ can also be switched to Vss, in which case the display is active for four seconds. Reactivation of the display requires that it return to the float or Vcc level before switching to Vss. A battery low condition is signaled by blinking LED1 at a 4 Hz rate instead of the normal steady display when the LED display is enabled. LED1 blinks if EDVF is not set, AverageCurrent(0x0b) is at least +100ma (charging), and Remainin_Capacity_Alarm in BatteryStatus(0x16) is set (RemainingCapacity(0x0f) < RemainingCapacityAlarm(0x01)). If EDVF is set, the display is blanked regardless of the state of /$\overline{\text{DISP}}$.

Master Mode Messages

The bq2040 supports the SBData charge-control functions. Master Modes messages are periodically broadcast to a Smart Charger or Host unless disabled. ChargingCurrent and ChargingVoltage are broadcast to the Smart Charger (slave address = 0x12) approximately every 10 seconds. If any alarm bits are set in BatteryStatus (upper byte), the BatteryStatus word is also broadcast. It is broadcast to the Smart Charger in addition to the ChargingCurrent and ChargingVoltage messages if any of the 6 msbs are set (any alarms except Remaining_Time_Alarm and Remaining_Capacity_Alarm). It is also broadcast to the Host (slave address = 0x10) if any alarm bits are set (including Remaining_Time_Alarm and Remaining_Capacity_Alarm).

Configuration and Calibration of the bq2040

The bq2040 reads configuration data from an external EEPROM on power-up or when a software reset is issued. Although it is possible to write to the EEPROM through the SMBus port of the bq2040, not all the locations are accessible, so the EEPROM should be preprogrammed with initial values by an external programmer either before pack assembly or before the devices are soldered to the PC board. After PCB or pack assembly, a few parameters may be adjusted for better accuracy in measuring voltage, temperature, and current.

EEPROM Initialization Parameters

SBD Data Registers Initialized from the EEPROM

RemainingCapacityAlarm (0x01)

RemainingTimeAlarm (0x02)

FullyChargedCapacity (0x10)

ChargingCurrent (0x14)

ChargingVoltage (0x15)

BatteryStatus (0x16)

CycleCount (0x17)

DesignCapacity (0x18)

DesignVoltage (0x19)

SpecificationInfo (0x1a)

ManufactureDate (0x1b)

SerialNumber (0x1c)

ManufacturerName (0x20) text string =11 bytes

DeviceName (0x21) text string = 7 bytes

DeviceChemistry (0x22)text string = 5 bytes

ManufacturerData (0x23)text string = 5 bytes

Gas Gauging Parameters Initialized from EEPROM

FLAGS1 This is the startup value for FLAGS1 and should be set to 0x00.

FLAGS2 This is the startup value for flags2. User should determine display mode, chemistry, and CC mode, and should set the other bits to 0.

SDRATE The self-discharge-rate byte register, calculated according to

$$SRATE = 2's\left[\frac{52.73}{X}\right]$$

where X is the desired self-discharge percentage per day at 25C.

EDV1 (edv1l and edv1h) This 16-bit word register holds the 2's complement of the first end of discharge threshold. [mV]

EDVF (edvfl and edvfh) This 16-bit word register holds the 2's complement of the final end of discharge threshold. [mV]

IOVLD (iovldl and iovldh) This 16-bit word register holds the absolute value of the overload current. AverageCurrent greater than or equal to this value prevents EDV flags from setting.

DELCAP The current integration gain, an 8-bit word register, holds the incremental change in capacity for each tick of the voltage-to-frequency converter assuming 100% efficiency. It is programmed in the EEPROM according to the following formula:

$$DELCAP = \frac{32}{R_{SR}}[mAh/256]$$

BLPCT This 8-bit word register holds the percentage of FCC that represents the capacity of the battery when the battery voltage falls to EDV1. It is programmed in the EEPROM according to the following formula:

BLPCT = 2.56 * (%RM at EDV1)

Programmable Charge Compensations

Charge compensations are programmable in the CEFF variable stored in RAM and EEPROM. One compensation factor (HEFF) is applied while the RelativeStateofCharge is less than FULPCT. A second factor (LEFF) is applied when the RelativeStateofCharge is greater than or equal to FULPCT. These factors are programmable from 76% to 100%. Both factors are varied across temperature in three ranges. Below 30°C the factors are as programmed, for 30°C to 40°C the factors are decreased by 2%, and when Temperature is above 40°C the factors are decreased by 5%.

CEFF Charge efficiency is a packed byte containing the two charge compensations. Bits b7-4 encode LEFF, the low efficiency factor used at or above FULPCT. Bits b3-0 encode HEFF, the high efficiency factor used below FULPCT. The nibble values are each calculated from percent efficiency by the following formula:

$$CEFF\_nibble = \frac{(eff\,\% \cdot 256 - 196)}{4}$$

The user should note the effect of rounding the result of first calculation by calculating the effective efficiency factor using the following:

$$CEFF\_value = \frac{\{CEFF\_nibble\} \cdot 4 + 196}{256}\,\%$$

For example: If LEFF=85% and HEFF=95%, choose CEFF=0x5c. This results in LEFF=84.3%, HEFF=95.3%.

FULPCT Percentage of FullChargeCapacity at which the battery is to be considered fully charged. RemainingCapacity may be written to this percentage of fccp on a valid charge termination. Charging current requests are at the slow rate when RemainingCapacity is more than this percentage of FCC. FULPCT is stored in RAM and EEPROM in 2's complement form.

Programmable Minimum Current Signal filter

DIGFIL

The digital filter byte register holds the threshold for filtering false counting due to Vos. The value represents the number of seconds to wait for VFC interrupts before ignoring them.

$$DIGFIL = \frac{0.045}{V_{SRD}} [s]$$

where V_{SRD} is the smallest voltage on SR that allows NAC to count.

Capacity-Based Maximum Overcharge

MAXOVQ

Maximum overcharge that is measured after RM = FCC. The measurement is compensated for efficiency and temperature where applicable. MAXOVQ is a 16-bit word register that holds the 2's complement of the amount of overcharge in mAh.

Programmable Current Taper Detection

TAPER

Upper limit of current taper detection for terminating charging. TAPER is a 16-bit word register that holds the 2's complement of the taper current.

Programmable ΔT/Δt Threshold

The delta-T portion of the ΔT/Δt rate is programmed into the lower nibble of EEPROM address 0x4a. The Δτ portion is programmed in EEPROM address 0x62.

$$\Delta T = \frac{(\Delta T\_value\_in\_EEPROMx2 + 16)}{10} [°C]$$

$$\Delta t = 320 - \Delta t\_value\_in\_EEPROMx20[\text{sec}]$$

ΔT Value in EEPROM	ΔT (°C)	Δ t Value in EEPROM	Δ t Timer Period (s)
0	1.6	**00**	320
1	1.8	**01**	300
2	2.0	**02**	280
3	2.2	**03**	260
4	2.4	**04**	240
5	2.6	**05**	220
6	2.8	**06**	200
7	3.0	**07**	180
8	3.2	**08**	160
9	3.4	**09**	140
a	3.6	**0a**	120
b	3.8	**0b**	100
c	4.0	**0c**	80
d	4.2	**0d**	60
e	4.4	**0e**	40
f	4.6	**0f**	20

ΔT/Δt Hold-off Timer

The hold-off timer is programmed in EEPROM address 0x63. No ΔT/Δt termination is allowed until the hold-off time expires after a valid charge is detected. The hold-off time is 320s minus 20 times the EEPROM value.

Value in EEPROM	Hold-Off Time [s]	HO Value in EEPROM	Hold-Off Time [s])
00	320	**08**	160
01	300	**09**	140
02	280	**0a**	120
03	260	**0b**	100
04	240	**0c**	80
05	220	**0d**	60
06	200	**0e**	40
07	180	**0f**	20

Programmable Maximum Temperature Fault

The maximum temperature is programmable in EEPROM over a range of 45°C to 69°C. The value is programmed in to the upper-nibble of EEPROM address 0x4a.

$$Maximum\ Temperature = 69 - (mt\_value\_in\_EEPROM \cdot 1.6)[°C]$$

mt_value_in_ EEPROM	Maximum Temperature	mt_value_in_ EEPROM	Maximum Temperature
0	69.0	**8**	56.2
1	67.4	**9**	54.6
2	65.8	**a**	53.0
3	64.2	**b**	51.4
4	62.6	**c**	49.8
5	61.0	**d**	48.2
6	59.4	**e**	46.6
7	57.8	**f**	45.0

Measurement Parameters and Calibration

A few more parameters are required to configure the bq2040's measurement subsystems. Additionally, measurement accuracy can be improved by calibrating these factors for variations in the battery voltage divider resistors, sense-resistor, PC board conductor resistance in high current paths and for variations in the bq2040 devices themselves. The calibration can be done on PC board assemblies or on assembled and sealed packs by using a feature of the bq2040 which writes data to the EEPROM from an SMBus command.

SMBus Write-through to EEPROM

The SMBus write through function writes two bytes at a time. The correct data word to be changed in the EEPROM may be determined from the E2 Map in the reference section. To modify an EEPROM location from an SMBus command, the WRALL bit must be set and the following sequence must be executed:

1. Write the new information to be updated into the appropriate RAM location using a normal SMB write command.
2. Execute a SMB write command to address 0x3c with the EEPROM location to modify as the LSB data and the access key 0xb3 as the MSB data written with CMD (0x3c). The EEPROM location should always be an even address. A full 16-bit word consisting of both the LSB byte in the even address and MSB byte in the next higher address are written at the same time into the EEPROM. The RAM address is not needed by the processor, as the map relating the two sets of addresses is internal to the processor. The write operation occurs within 0.5 seconds. The processor clears the 0xb3 access key from the msb of CMD (0x3c) when the operation is completed.
3. Confirmation of a successful EEPROM write is only possible by checking the RAM locations initialized from the EEPROM after a full device reset. The calibration factors in the EEPROM cannot be read directly from the SMBus.

WRALL: The WRALL bit controls read and write access to a number of register locations. CMD (0x3c) is read only unless WRALL is set, thus preventing an EEPROM write-through. CMD (0x64) is not accessible unless WRALL is set, preventing a software reset command. WRALL comes up set if EEPROM location 0x3d (BUSYFLG) has bit b3 = 1.

RESET: A software reset reinitializes all register values from the EEPROM. It is the only way to verify that EEPROM values have indeed been updated. A software reset is performed by the following sequence:

1. Check the value of MaxError (0x0c). If this value is 0x0002 (2%), it must be first written to any different value.
2. Write 0x8009 into CMD (0x64).
3. Confirmation of a successful reset may be accomplished by verifying that MaxError (0x0c) is now 0x0064 (100%) and that Temperature (0x08) is 0x0b72 (293.0°K). Temperature is updated to the actual reading 20 seconds after the reset.

Voltage Parameters

NCCAL	Byte register to calibrate the Voltage (0x09) function. NCCAL/256 is the fractional multiplier of the voltage on the SB pin.
NCELLS	Byte register to calibrate the Voltage (0x09) function. NCELLS is the integer multiplier of the voltage on the SB pin.

VOFF

Byte register to calibrate the Voltage (0x09) function. VOFF is a signed integer which is represents the number of millivolts used to correct for voltage offset in the conversion of the signal on the SB input. Voltage is calculated according to the following formula which uses the preceding byte registers and A/D conversion of the SB input:

$$Voltage = [(Vsb \cdot 1000) + VOFF] \cdot [NCELLS + NCCAL / 256][mV]$$

the offset correction is applied before the gain (ncells.nccal) is applied.

Temperature Calibration

TTRIM

Temperature offset trim is a byte value used to calibrate the internal temperature sensor. The nominal value is 0x80, and represents 12.8°C added to a raw result of temperature. To calibrate the Temperature function TTRIM can be increased to 0xff, 25.5C, or decreased to 0x00, 0C. Thus the calibration range is +12.7K,-12.8K.

Current Calibration

IRES60

Current-measurement gain factor word is used to calibrate the Current and AverageCurrent functions.

$$IRES60 = 192/R_{SR}$$

where R_{SR} is the value of the sense resistor in ohms.

Coulomb Counting Calibration

DELCAP

Based on the accuracy of the current sense, DELCAP may have to be adjusted for more accurate gas gauging. Remember that DELCAP is the sense resistor gain factor word used to calibrate the RemainingCapacity function.

$$DELCAP = 3.2/R_{SR}$$

where R_{SR} is the value of the sense resistor in ohms.

Reference Section

Smart Battery Slave Functions: Details of how they work in the bq2040

ManufacturerAccess (0x00)

ManufacterAccess is currently unused. It is available for read/write access by the user.

RemainingCapacityAlarm (0x01)

This value is initialized from the EEPROM, but can be written by the user at any time. When RemainingCapacity(0x0f) falls below this value, the Remaining_Capacity_Alarm bit is set in BatteryStatus(0x16).

RemainingTimeAlarm (0x02)

This value is initialized from the EEPROM, but can be written by the user at any time. When the AverageTimeToEmpty(0x12) falls below this value, the Remaining_Time_Alarm bit is set in BatteryStatus(0x16).

BatteryMode (0x03)

This read/write word is used to control Smart Charger and Host broadcast messages from the bq2040. Writing bit 14 to a 1 disables these Master Mode broadcast messages to the charger and host. Bit 14 is automatically reset if the SMBC and SMBD communication lines are held low for greater than 2 seconds. If resetting bit 14 is required when the battery pack is removed from the system, 1M pull-down resistors should be added within the battery pack from SMBC and SMBD to Vss to force a logic low on the communication lines. If bit 13 is written to a 1, the Master Mode broadcast messages are also disabled, but this disable is not automatically reset like bit 14. The EEPROM can be configured to initialize bit 13 to a 1 by programming bit b3 in address 0x3f (location that initializes FLAGS2) to a 1.

AtRate(0x04)-(0x07)

The AtRate functions (0x05)-(0x07) are updated every twenty seconds and immediately after AtRate(0x04) is written. Reading commands (0x05)-(0x07) while they are being recalculated results in a no-acknowledge of the command and the error code not ready is reported in BatteryStatus(0x16).

Temperature (0x08)

The temperature measurement is updated every 20 seconds.

Voltage (0x09)

The voltage measurement is updated approximately every 2 seconds.

Current (0x0a)

The current measurement is a 20 second average of ticks from the voltage-to-frequency converter.

AverageCurrent (0x0b)

The value reported for the AverageCurrent function is a 60 second rolling average of the Current function. It is updated every 20 seconds.

MaxError (0x0c)

MaxError is set to 100% upon initial power up or full device reset. It is set to 2% when FULCAP is calibrated and to 5% when the request condition cycle bit (b7) is set in BatteryMode.

RelativeStateOfCharge(0x0d)

The value reported for RelativeStateOfCharge is calculated from RemainingCapacity/FullChargeCapacity at least every 500ms.

AbsoluteStateOfCharge(0x0e)

The value reported for AbsoluteStateOfCharge is calculated from RemainingCapacity/DesignCapacity at least every 500ms.

RemainingCapacity (0x0f)

The value reported from RemainingCapacity is the current battery capacity in mAh and ranges from 0 to a maximum of FullChargeCapacity.

FullChargeCapacity (0x10)

This value is the latest measurement of the battery capacity in mAh.

RunTimeToEmpty(0x11)

The value for RunTimeToEmpty is calculated from Current and RemainingCapacity at least every 500ms.

AverageTimeToEmpty(0x12)

The value for AverageTimeToEmpty is calculated from AverageCurrent and RemainingCapacity every 20s.

AverageTimeToFull(0x13)

The value for AverageTimeToFull is calculated from AverageCurrent and RemainingCapacity every 20s.

ChargingCurrent (0x14)

The value stored in this register changes according to various battery conditions. The value in this register is broadcast to the Smart Charger every 10 seconds if Master Mode messages are enabled. The value in this register is initially loaded with the value programmed into the EEPROM locations 0x08 and 0x09. This value is updated as soon as the gauge determines the charge state of the battery. The value programmed into the EEPROM fast-charging current (FCHGI) location is the value normally loaded in ChargingCurrent. If The Terminate_Charge_Alarm in BatteryStatus is set, ChargingCurrent is set to zero. When the Fully_Charged bit in BatteryStatus or the Low Temperature Fault bit in FLAGS2 is set, ChargingCurrent is set to the maintenance charging current (TCHGI) rate programmed in the EEPROM. If the Terminate_Discharge_Alarm in BatteryStatus is set, ChargingCurrent is set to the EDVF charging current (MCHGI) rate programmed in the EEPROM.

ChargingVoltage (0x15):

The value programmed into the EEPROM for ChargingVoltage (CHGV) determines the contents of this register. This register value is broadcast to the Smart Charger every 10 seconds if Master Mode messages are enabled.

BatteryStatus (0x16)

This 16-bit register reports the system status including alarms, charge state, and communication errors. If any of the alarm bits (b10-b15) in this word are set, this word is broadcast to the Smart Charger. If any bits b8-b15 in this word are set, this word is broadcast to the System Host. These broadcasts occur every 10 seconds unless Master Mode messages are disabled.

b15	**Over_Charged_Alarm:** Set when a current taper or ΔT/Δt condition occurs during a charge. Cleared during discharge or when current taper and ΔT/Δt conditions cease during a charge. This bit indicates a ***valid*** *charge termination* and causes RemainingCapacity to be written to FULPCT of FCC if the CC bit in FLAGS2 is set.
b14	**Terminate_Charge_Alarm:** Set when overcurrent, overvoltage, current taper, over-temperature or ΔT/Δt conditions occur during a charge. Cleared during discharge or when all of the setting conditions cease during a charge. Charging current is set to zero when this bit is set. This bit indicates a *charge suspend*.
b13	**Reserved**
b12	**Over_Temp_Alarm:** Set when the temperature is above the programmed maximum temperature. Cleared when the temperature is at or below 43°C or below the maximum temperature minus 5°C. This bit indicates a *charge suspend*.

b11	**Terminate_Discharge_Alarm:** Set when the battery voltage is below the EDVF threshold. Cleared otherwise. While this bit is set, charging current is requested at the EDVF (MCHGI) rate.
b10	**Reserved**
b9	**Remaining_Capacity_Alarm:** Set when RemainingCapacity (0x0f) is less than RemainingCapacityAlarm (0x01). Cleared otherwise.
b8	**Remaining_Time_Alarm:** Set when AverageTimeToEmpty (0x12) is less than the value in RemainingTimeAlarm (0x02). Cleared otherwise.
b7	**Initialized:** Set or cleared according to the default register data loaded from the EEPROM on a full reset of bq2040.
b6	**Discharging:** Set when not charging. Cleared when charging.
b5	**Fully_Charged:** Set when a *valid charge termination* or capacity based overcharge termination occurs. Cleared when the RelativeStateOfCharge (0x0d) is less than FULPCT.
b4	**Fully_Discharged:** Set when set when pack voltage is less than EDVF. Cleared when RelativeStateOfCharge 20%.
b3-0	**Communication Error Codes:** As described in the SBD specification.

CycleCount (0x17)

The cycle count algorithm matches the method described in the SBD specification. When a valid charge is detected, the value of AbsoluteStateOfCharge at the beginning of the previous discharge is used to determine if the battery has been discharged 15 percentage points. Cycle count is saved in EEPROM each time the value is incremented.

DesignCapacity (0x18)

This word returns the programmed value for the design capacity of the battery in mAh. It is used as the 100% reference charge value for the AbsoluteStateOfCharge(0x0e) calculation.

DesignVoltage (0x19)

This word contains the nominal output voltage of the battery pack in mV. It is output as the initial value for the Voltage(0x09) until the first calculation update is made after a reset.

SpecificationInfo (0x1a)

This word should be programmed to the SMB specification revision that the bq2040 supports plus scale factors on reported voltage and current. It should be programmed to 0x1000 for the bq2040, representing SMB specification version 1.0 and scale factors of unity on reported voltage and current.

ManufactureDate (0x1b)

This word is for the battery manufacturer to use to program the date of manufacture of the battery pack. The packed word is determined as follows:

$$(\text{year}–1980) * 512 + \text{month} * 32 + \text{day}$$

SerialNumber (0x1c)

This word is for the battery manufacturer to use to program the serial number of the battery pack.

ManufacturerName (0x20)

This word contains an ASCII character string containing the manufacturer's name. The first byte contains the number of characters in the name and following bytes contain the appropriate ASCII character codes. The maximum number of characters is 11.

DeviceIName (0x21)

This word contains an ASCII character string containing the battery name. The first byte contains the number of characters in the name and following bytes contain the appropriate ASCII character codes. The maximum number of characters is 7.

DeviceChemistry (0x22)

This word contains an ASCII character string containing the battery chemistry. The first byte contains the number of characters in the name, and following bytes contain the appropriate ASCII character codes. The maximum number of characters is 5.

ManufacturerData (0x23)

This word contains an ASCII character string containing the manufacturer's data. The first byte contains the number of characters in the name and following bytes contain the appropriate ASCII character codes. The maximum number of characters is 5.

Description of bq2040 Specific Flag Bits

The bq2040 has additional bit-registers to manage internal status. The most useful is Flags2&1 (0x2f).

b15 **DMODE:** User-selectable mode to display capacity. When set the bq2040 is in relative mode and the FullChargeCapacity is used as the 100% reference. In absolute mode the DesignCapacity is used as the 100% reference.

b14 **PSTAT:** This bit reflects the state of the PSTAT input pin to the part. It is a 1 if the input voltage is ≥1.5V and is a 0 if the input voltage is less than 1.0V. This flag could be used to monitor an external function, such as the on/off state of a charge FET in a protector.

b13 **CHM:** User-selected chemistry mode. When set the charge efficiency factors (HEFF and LEFF) are not adjusted for temperature. When not set, HEFF and LEFF charge efficiencies are adjusted with appropriate reductions for temperatures above 30C.

b12 **CC:** When the Charge Control bit is set, the RemainingCapacity is set to FULPCT times FullChargeCapacity when a ***valid charge termination*** occurs unless the capacity is already above this value.

b11 **EINT:** The Enable Interrupt flag is set when the voltage on SR is greater than the digital filter cutoff. When the flag is set, the bq2040 counts charge or discharge interrupts from the voltage-to-frequency converter.

b10 **OV:** overvoltage flag set indicates that the bq2040 detected a pack voltage that is 5% over the value of ChargingVoltage. This flag is cleared when the Voltage is not more than 5% above ChargingVoltage. Overvoltage checking is bypassed if the value in ChargingVoltage (0x15) is greater than 0xf2ff.

b9 **LTF:** The Low Temperature Fault is set when the internal temperature sensor detects a temperature of less than 12°C and reset when the temperature is 15°C or greater.

b8 **OC:** The overcurrent flag denotes that the current measured by the bq2040 is 25% more than the ChargingCurrent (0x14), if Charging Current is at least 1024mA. If ChargingCurrent is less than 1024mA, then OC is set if Current is 256mA more than ChargingCurrent. OC is cleared when Current is less than 256mA. Overcurrent checking is bypassed when the value in ChargingCurrent (0x14) is greater than 0xcbff.

b7 **$\Delta T/\Delta t$:** The $\Delta T/\Delta t$ flag is set when the rate of increase in temperature exceeds the programmed rate. The flag is cleared with the temperature rise slows below the programmed rate, temperature falls below 25C, or AverageCurrent falls below 256mA.

b6 **IMIN:** The IMIN flag is set when a valid current taper charge termination is detected. This occurs when Voltage (0x09) is above ChargingVoltage (0x15) minus 128mV and AverageCurrent (0x0b) is less than the programmed TAPER limit but greater than 0 for at least 100 seconds. When set, the Fully_Charged, Over_Charged, and Terminate_Charge bits are set and ChargingCurrent (0x14) is set to 0.

b5 **VQ:** The Valid Charge flag is set during a charge cycle which has incremented RemainingCapacity by at least 10mAh. It is reset whenever discharge current above the digital filer threshold is detected.

b4 **Reserved**

b3 **VDQ:** The Valid Discharge flag is set when the pack is discharged from full. VDQ is reset if a valid charge occurs or the temperature goes out of range. If discharged to EDV with VDQ set, the FullChargeCapacity is updated on the next valid charge with the amount of charge removed while VDQ was set.

b2 **OVLD:** The Overload flag is set when discharge current is at or above programmed IOVLD value. Reset when discharge current is less than IOVLD value. EDV1 and EDVF are not set if OVLD is set.

b1 **EDV1**: The First End of Discharge Voltage threshold flag is set when the pack voltage is below the threshold programmed in the EEPROM, OVLD not set, and Current is not positive (charging). EDV1 is reset when VQ is set. LED1 flashes when EDV1 is set, EDVF is not set, and the display is enabled.

b0 **EDVF:** The Final End of Discharge Voltage threshold flag is set when the pack voltage is below the threshold programmed in the EEPROM, OVLD not set, and Current is not positive (charging). EDVF is reset when VQ is set. The LED display is blanked when EDVF is set.

RAM, EEPROM, and Bit-Register Maps

RAM Locations for Test/Calibration/Programming

Name	Description	CMD		RAM Address
NACL	NAC low byte, mAh	(0x1f)	lsb	0x3e
NACH	NAC hi byte, mAh*256		msb	0x3f
MANFNAM	ManufacturerName string data, max length = 11	(0x20)		0x40 - 0x4b
DEVNAME	DeviceName string data, max length = 7	(0x21)		0x50 - 0x57
DEVCHM	DeviceChemistry string data, max length = 5	(0x22)		0x60 - 0x65
MANDT	ManufacturerData string data, max length = 5	(0x23)		0x70 - 0x75
IOVLDL	Current overload, absolute value low	(0x26)	lsb	0x4c
IOVLDH	Current overload, absolute value high		msb	0x4d
BLPCT	Battery low %, relative capacity at EDV1 BLPCT = 2.56 * (%RM at EDV1)	(0x27)	lsb	0x4e
UNUSED			msb	0x4f
TAPERL	Li-Ion taper current low, 2's	(0x2c)	lsb	0x58
TAPERH	Li-Ion taper current high, 2's		msb	0x59
MAXOVQL	Maximum overcharge limit low, 2's	(0x2d)	lsb	0x5a
MAXOVQH	Maximum overcharge limit high, 2's		msb	0x5b
MFLAG	Master mode flag register	(0x2e)	lsb	0x5c
BUSYFLG	Access protect register		msb	0x5d
FLGS1	FLAGS1 register	(0x2f)	lsb	0x5e
FLGS2	FLAGS2 register		msb	0x5f
IRES60L	Current-measurement gain factor low	(0x33)	lsb	0x66
IRES60H	Current-measurement gain factor high IRES60 = 192/R_{SR}		msb	0X67
VOFF	Battery voltage offset trim, signed integer in mV bvolt = (Vsb*1000+VOFF)*(NCELLS + NCCAL/256) (mV)	(0x34)	lsb	0x68
TTRIM	Temperature trim, [0.1K] btemp = TTRIM + raw temp calc (.1°K), nominal value = 80°		msb	0x69
MT_DT	Max Temp fault/ Delta Temp step value (^{o}C) MT=b7-4, maxT = 69 - (MT*1.6) (^{o}C) DT=b3-0, ΔT step = 16+DT*2 (0.1^{o}C)	(0x35)	lsb	0x6a
CEFF	Charge efficiency, LEFF=b7-4, HEFF=b3-0 LEFF, HEFF = [eff(%)*256 - 196]/4		msb	0x6b
FULPCT	Full-charge percentage, 2's complement	(0x36)	lsb	0x6c
DIGFIL	Digital filter value = 0.045/Vsrd (s)		msb	0x6d
DELCAP	Current integration gain factor = 3.2/Rrsr (mAh/256)	(0x37)	lsb	0x6e

RAM Locations for Test/Calibration/Programming (Continued)

Name	Description	CMD		RAM Address
SDRATE	Self-discharge rate, SDRATE = 2's[52.73/X], X = % discharge rate per day		msb	0x6f
NCCAL	Number of cells fraction	(0x3b)	lsb	0x76
NCELLS	Number of cells integer, Voltage gain = NCELLS + NCCAL/256		msb	0x77
I2CWAA	I^2C write EEPROM address to update (MUST BE EVEN)	(0x3c)	lsb	0x78
I2CWAK	I^2C write access key {0xb3}		msb	0x79
MCHGIL	EDVF charging current low (used below EDVF)	(0x3d)	lsb	0x7a
MCHGIH	EDVF charging current high (used below EDVF)		msb	0x7b
EDV1L	EDV1 threshold low, 2's complement	(0x3e)	lsb	0x7c
EDV1H	EDV1 threshold high, 2's complement		msb	0x7d
EDVFL	EDVF threshold low, 2's complement	(0x3f)	lsb	0x7e
EDVFH	EDVF threshold high, 2's complement		msb	0x7f
DTTIM	Δ t step = 320 - DTTIM * 20 [s], ΔT timer = b4-7	(0x41)	lsb	0x82
HLDTIM	Hold-off time = 320 - HLDTIM * 20 [s]		msb	0x83

Bit Registers

Name	b15	b14	b13	b12	b11	b10	b9	b8
Bat-Modeh (0x03)	**mWh**	**ChgrMod**	**DIS-MAST**	-	-	-	-	-
	b7	b6	b5	b4	b3	b2	b1	b0
BatModel (0x03)	**Req Cond. Cycle**	-	-	-	-	-	-	-
	b15	b14	b13	b12	b11	b10	b9	b8
Batsth (0x16)	**OvrChg Alarm**	**TermChg Alarm**	**Reserved**	**OvrTemp Alarm**	**TermDsg Alarm**	-	**RemCap Alarm**	**RemTime Alarm**
	b7	b6	b5	b4	b3	b2	b1	b0
Batstl (0x16)	**Initialized**	**Dsg**	**FullyChg**	**FullyDsg**	**smb error**	**smb error**	**smb error**	**smb error**
	b15	b14	b13	b12	b11	b10	b9	b8
FLAGS2 (0x2f)	**DMODE**	**PSTAT**	**CHM**	**CC**	**ENINT (DISMM)**	**OV**	**LTF**	**OC**
	b7	b6	b5	b4	b3	b2	b1	b0
FLAGS1 (0x2f)	ΔT/Δt	**IMIN**	**VQ**	-	**VDQ**	**OVLD**	**EDV1**	**EDVF**

E^2 Map

Name	Description	CMD		E^2addr (bq2040)
EELENGTH	EEPROM length Number of bytes to read from EEPROM = 0x64			0x00 *
CHKBYTE1	EEPROM check 1 MUST equal 0x5b			0x01 *
RTMALML	Remaining time alarm low	(0x02)	lsb	0x02 *
RTMALMH	Remaining time alarm hi	(0x02)	msb	0x03 *
RCPALML	Remaining capacity alarm low	(0x01)	lsb	0x04 *
RCPALMH	Remaining capacity alarm hi	(0x01)	msb	0x05 *
UNUSED	Reserved		lsb	0x06
UNUSED	Reserved		msb	0x07
CHGIL	Initial charging current after reset low	(0x14)	lsb	0x08
CHGIH	Initial charging current after reset hi	(0x14)	msb	0x09
CHGVL	Charging voltage low	(0x15)	lsb	0x0a
CHGVH	Charging voltage hi	(0x15)	msb	0x0b
BATSTL	Initial BatteryStatus low	(0x16)	lsb	0x0c
BATSTH	Initial BatteryStatus hi	(0x16)	msb	0x0d
CYCLEL	Cycle count low byte	(0x17)	lsb	0x0e
CYCLEH	Cycle count hi byte	(0x17)	msb	0x0f
DESCAPL	Design capacity low byte	(0x18)	lsb	0x10
DESCAPH	Design capacity hi byte	(0x18)	msb	0x11
DESVL	Design voltage low	(0x19)	lsb	0x12
DESVH	Design voltage hi	(0x19)	msb	0x13
SPECL	Specification information low	(0x1a)	lsb	0x14
SPECH	Specification information hi	(0x1a)	msb	0x15
MDATEL	Manufactures date low	(0x1b)	lsb	0x16
MDATEH	Manufactures date hi	(0x1b)	msb	0x17
SERNUML	Serial number low byte	(0x1c)	lsb	0x18
SERNUMH	Serial number hi byte	(0x1c)	msb	0x19
FCHGIL	Fast-charging current low	(0x1d)	lsb	0x1a
FCHGIH	Fast-charging current hi	(0x1d)	msb	0x1b
TCHGIL	Maintenance charging current low	(0x1e)	lsb	0x1c
TCHGIH	Maintenance charging current hi	(0x1e)	msb	0x1d
NACL	Initial NAC value low	(0x1f)	lsb	0x1e
NACH	Initial NAC value hi	(0x1f)	msb	0x1f

E^2 Map (Continued)

Name	Description	CMD		E^2addr (bq2040)
MANFNAM	Manufacturer name string data	(0x20)		0x20 - 0x2b
	String length, max = 11			0x20 *
	ASCII character #1			0x21 *
	ASCII character #2			0x22 *
	ASCII character #3			0x23 *
	ASCII character #4			0x24 *
	ASCII character #5			0x25 *
	ASCII character #6			0x26 *
	ASCII character #7			0x27 *
	ASCII character #8	(0x24)	lsb	0x28
	ASCII character #9	(0x24)	msb	0x29
	ASCII character #10	(0x25)	lsb	0x2a
	ASCII character #11	(0x25)	msb	0x2b
IOVLDL	Current overload, absolute value low	(0x26)	lsb	0x2c
IOVLDH	Current overload, abolute value high	(0x26)	msb	0x2d
BLPCT	Battery low %, relative capacity at EDV1 BLPCT = 2.56 *(%RM at EDV1)	(0x27)	lsb	0x2e
UNUSED		(0x27)	msb	0x2f
DEVNAME	Device name string data	(0x21)		0x30 - 0x37
	String length, max = 7	(0x28)	lsb	0x30 *
	ASCII character #1	(0x28)	msb	0x31 *
	ASCII character #2	(0x29)	lsb	0x32
	ASCII character #3	(0x29)	msb	0x33
	ASCII character #4	(0x2a)	lsb	0x34
	ASCII character #5	(0x2a)	msb	0x35
	ASCII character #6	(0x2b)	lsb	0x36
	ASCII character #7	(0x2b)	msb	0x37
TAPERL	Li-Ion taper current low, 2's	(0x2c)	lsb	0x38
TAPERH	Li-Ion taper current high, 2's	(0x2c)	msb	0x39
MAXOVQL	Maximum overcharge limit low, 2's	(0x2d)	lsb	0x3a
MAXOVQH	Maximum overcharge limit high, 2's	(0x2d)	msb	0x3b
MFLAG	Master mode flags initial value (Program to 0)	(0x2e)	lsb	0x3c
BUSYFLG	Access protect (Program to 0xb0 for pack access protect, 0xb8 for unprotected pack access)	(0x2e)	msb	0x3d
FLGS1	FLAGS1 register initial value	(0x2f)	lsb	0x3e
FLGS2	FLAGS2 register initial value	(0x2f)	msb	0x3f
DEVCHM	Device chemistry string data	(0x22)		0x40 - 0x45
	String length, max = 5	(0X30)	lsb	0X40 *
	ASCII character #1	(0x30)	msb	0X41 *
	ASCII character #2	(0X31)	lsb	0X42
	ASCII character #3	(0x31)	msb	0X43
	ASCII character #4	(0X32)	lsb	0X44
	ASCII character #5	(0x32)	msb	0X45

E^2 Map (Continued)

Name	Description	CMD		E^2addr (bq2040)
IRES60L	Current-measurement gain factor low	(0x33)	lsb	0x46
IRES60H	Current-measurement gain factor high IRES60 = 192/R_{SR}	(0x33)	msb	0X47
VOFF	Battery voltage offset trim, signed integer in mV bvolt = (Vsb*1000+VOFF)*(NCELLS + NCCAL/256) (mV)	(0x34)	lsb	0x48
TTRIM	Temperature offset trim, [0.1°K] btemp = TTRIM + raw temp calc (.1°K), nom val = 80°	(0x34)	msb	0x49
MT_DT	Max Temp fault/ Delta Temp step value (°C) MT=b7-4, maxT = 69 - (MT*1.6) (°C) DT=b3-0, ΔT step = 16+DT*2 (0.1°C)	(0x35)	lsb	0x4a
CEFF	Charge efficiency, LEFF=b7-4, HEFF=b3-0 LEFF, HEFF = [eff(%)*256 - 196]/4	(0x35)	msb	0x4b
FULPCT	Full-charge percentage, 2's complement	(0x36)	lsb	0x4c
DIGFIL	Digital filter value = 0.045/Vsrd (s)	(0x36)	msb	0x4d
DELCAP	Current integration gain factor = 3.2/Rrsr (mAh/256)	(0x37)	lsb	0x4e
SDRATE	Self-discharge rate SDRATE = 2's[52.73/X], X = % discharge rate per day	(0x37)	msb	0x4f
MANDT	Manufacture data string data	(0x23)		0x50 - 0x55
	String length, max = 5 ASCII character #1 ASCII character #2 ASCII character #3 ASCII character #4 ASCII character #5	(0x38) (0x38) (0x39) (0x39) (0x3a) (0x3a)	lsb msb lsb msb lsb msb	0x50 * 0x51 * 0x52 0x53 ox54 ox55
NCCAL	Number of cells fraction	(0x3b)	lsb	0x56
NCELLS	Number of cells integer, Voltage gain1 = NCELLS + NCCAL/256	(0x3b)	msb	0x57
I2CWAA	I^2C write EEPROM address, Program to 0x00	(0x3c)	lsb	0x58
I2CWAK	I^2C write access key, Program to 0x00	(0x3c)	msb	0x59
MCHGIL	EDVF charging current low (used below EDVF)	(0x3d)	lsb	0x5a
MCHGIH	EDVF charging current high (used below EDVF)	(0x3d)	msb	0x5b
EDV1L	EDV1 threshold low, 2's complement	(0x3e)	lsb	0x5c
EDV1H	EDV1 threshold high, 2's complement	(0x3e)	msb	0x5d
EDVFL	EDVF threshold low, 2's complement	(0x3f)	lsb	0x5e
EDVFH	EDVF threshold high, 2's complement	(0x3f)	msb	0x5f

E^2 Map (Continued)

Name	Description	CMD		E^2addr (bq2040)
FULCAPL	Full-charge capacity low	(0x10)	lsb	0x60 *
FULCAPH	Full-charge capacity high	(0x10)	msb	0x61 *
DTTIM	Δ t step (b0-3) = 320 - DTTIM * 20 [s]	(0x41)	lsb	0x62
HLDTIM	Hold-off time (b0-3) = 320 - HLDTIM * 20 [s]	(0x41)	msb	0x63
CHKBYTE2	Check byte 2 MUST equal 0xb5			0x64 *
RESERVED				0x65 - 0x7f

* Difficult or impossible to update with SMB write-through function

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