bq27500

Application Book

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TEXAS INSTRUMENTS

Texas Instruments
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Contents

Chapter 1

Glossary

Table 1. Glossary

OCV:	Open circuit voltage of a battery.
Passed/Charge:	Coulomb counter integrated charge during battery charge or discharge.
Battery Impedance:	Battery internal impedance when load is applied, defined as: (OCV – Battery Voltage Under Load) / Average Load Current
DOD:	Depth of discharge, DOD = 1 – SOC
DOD_0:	Last DOD reading before charge or discharge.
DOD_{charge}:	DOD at a fully charged pack.
Q:	Passed charge from full charge state.
Q_{max}:	Maximum battery chemical capacity.
Q_{start}:	Charge that would have passed to make DOD = DOD_0
RM:	Remaining capacity
FCC:	Full Charge Capacity, the amount of charge passed from the fully charged state to the Terminate Voltage, defined as: FCC = Q_{start} + PassedCharge + RM.
SOC:	State of charge at any moment, defined as: SOC = Q / Q_{max}.
RSOC:	Relative State of Charge, defined as: RSOC = RM / FCC.
FET:	Field-Effect transistor
FET opened/closed:	A common phrase is that the FET is opened or closed. Used throughout the document, this term means that the FET is turned on or off, respectively.
System:	A host system that is consuming current from the battery pack that includes fuel gauge device.
Golen Image:	The data flash contents, after chemistry is identified and programmed and the learning cycling is completed, so that all the flash contents are updated correctly for the desired battery pack.
EMI:	Electromagnetic interference
ESD:	Electrostatic discharge
Flag:	This word usually represents a read-only status bit that indicates some action has occurred or is occurring. This bit typically cannot be modified by the user.
Learning Cycle:	A battery charge and discharge cycle with battery resistance and Q_{max} updated during the cycling
DFI:	Data Flash Image file. Binary image of the fuel gauge data flash with modified value based on the application.

Chapter 2

Single-Cell Impedance Track™ Gas Gauge for Novices

Michael Vega *PMP Portable Power*

ABSTRACT

This application report introduces the bq27350 Impedance Track™ gas gauge solution.

2.1 Introduction

This application report provides an introductory overview of the following bq27350 Impedance Track™ gas gauge topics:

- The Basics
  - The bq27350 Impedance Track™ Gas Gauge Overview
  - Impedance Track™ Technology Operation Principle
  - Gas Gauge Hardware
  - bq27350EVM-001 Evaluation Module
  - bqEVSW Software for Use with bq27350
- Next Steps
  - Developing a PCB for bq27350
  - Solution Development Process
  - Mass Production Setup
- Glossary
- Appendix – Reference Schematic

2.2 The Basics

bq27350 Impedance Track™ Gas Gauge Overview

2.2.1.1 Key Features:

- Patented Impedance Track™ technology accurately measures available charge in Li-ion and Li-polymer batteries.
- Better than 1% capacity estimate error over the lifetime of the battery
- Instant capacity estimate accuracy – no learning cycle required
- Based on a powerful low-power reduced instruction-set (RISC) CPU core with high-performance peripherals
- Integrated, field-programmable FLASH memory eliminates the need for external configuration memory
- Measures charge flow using a high-resolution, 16-bit integrating delta-sigma converter
- Uses 16-bit delta-sigma converter for accurate voltage and temperature measurements
- Extensive data reporting options for improved system interaction

The bq27350 is an advanced, feature-rich battery gas gauge IC, designed for accurate reporting of available charge of Li-ion or Li-polymer batteries in single-cell applications. The bq27350 incorporates the patented Impedance Track™ technology, whose unique algorithm allows for real-time tracking of battery capacity change, battery impedance, voltage, current, temperature, and other critical information of the battery pack. Unlike the *current integration*- or *voltage correlation*-based gas gauge algorithms, the Impedance Track™ algorithm takes full advantage of battery response to electronic and thermal stimuli and therefore maintains the best capacity estimate accuracy over the lifetime of the battery. The bq27350 automatically accounts for charge and discharge rate, self-discharge, and cell aging, resulting in excellent gas-gauging accuracy even when the battery ages. The IC also provides a variety of battery performance parameters to a system host over a standard serial communication bus (I^2C).

The heart of the bq27350 programmable battery management IC is a high-performance, low-power, RISC CPU, which offers powerful information processing capability that is crucial to battery management functional calculation and decision-making. The IC also integrates plenty of program and data flash memory and an array of peripheral and communication ports, facilitating rapid development of custom implementations and eliminating the need for external configuration memory.

The bq27350 is equipped with two high-resolution, analog-to-digital converters (ADC) dedicated for accurate coulomb counting and voltage/temperature measurements. These low-power analog peripherals improve accuracy beyond discrete implementations.

The bq27350 measures cell voltage, temperature, current, and integrated passed charge using the two delta-sigma ADCs of the bq27350.

Impedance Track™ Technology Operation Principle

What makes the Impedance Track™ technology unique and much more accurate than existing solutions is a self-learning mechanism that accounts for the change of (1) battery impedance and (2) the no-load chemical full capacity (Qmax) due to battery aging. A fact that is often ignored is that battery impedance increases when the battery ages. As an example, typical Li-ion batteries double the impedance after approximately 100 cycles of discharge. Furthermore, battery impedance also varies significantly between cells and at different usage conditions, such as temperature and state-of-charge. Therefore, to achieve sufficient accuracy, a large, multidimension impedance matrix must be maintained in the IC flash memory, making the implementation difficult. Acquiring such a database is also time-consuming. The Impedance Track™ technology significantly simplifies gas-gauging implementation by continuously updating the battery impedance during the usage lifetime of the battery, and thus only needs a simple, initial impedance data base. Temperature and load effects are automatically accounted for when calculating the full-charge capacity (FCC) and the remaining capacity (RM). On the other hand, the Qmax is calculated also and updated during the usage of the battery — only in more strict conditions as mentioned later in this section.

The full-fledged monitoring mechanisms of the bq27350 allow for accurate measurement of the following key properties:

- OCV: Open-circuit voltage of a battery, usually assuming the battery is already in relaxation mode

- Battery impedance: $\dfrac{\text{OCV} - \text{BatteryVoltageUnder Load}}{\text{AverageLoad Current}}$
- PassedCharge: Coulomb counter integrated charge during battery charge or discharge
- SOC: State-of-charge at any moment, defined as SOC=Q/Qmax, where Q is the PassedCharge from the full-charge state
- DOD: Depth of discharge; DOD= 1-SOC
- DOD_0: Last DOD reading before charge or discharge
- DODcharge: DOD for a fully charged pack
- Qstart: Charge that would have passed to make DOD = DOD_0
- Qmax: Maximum battery chemical capacity
- RM: Remaining capacity
- FCC: Full-charge capacity, the amount of charge passed from the fully charged state to the terminate voltage

Figure 1 illustrates charge, discharge, and relaxation modes of the battery. The times and current thresholds that are noted in the graph are values that are programmed by the user in Flash memory. As seen in Figure 1, relaxation starts after *Chg Relax Time* or *Dsg Relax Time* has elapsed after the pack current measured by the ADC is within ±*Quit Current*. The relaxation ends after *Quit Relax Time* elapses following a pack current detected that exceeds either *Charge Current Threshold* or *Discharge Current Threshold*.

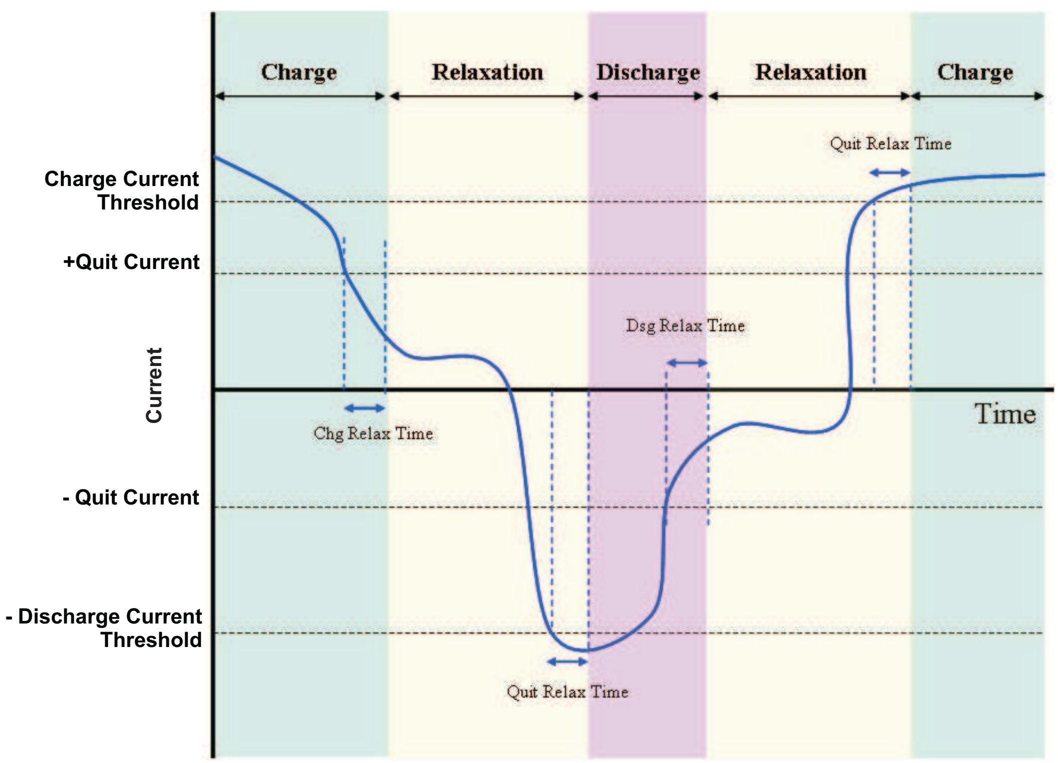


Figure 1. Algorithm Operation Mode Changes With Varying Battery Current

The SOC is estimated based on the OCV of the battery because of a strong correlation of SOC to OCV for a particular battery chemistry, shown in Figure 2 as an example. In the relaxation mode, where no load current is present and the current is below a user-chosen *quit current* level, the SOC is determined using the measured cell voltage (must meet certain voltage settling criteria; see the *Fuel Gauging* section in the bq27350 data sheet, SLUS754, for details) and the predefined OCV versus SOC relationship.

During charging and discharging, the SOC is continuously calculated using the relationship of present Qmax to the integrated passed charge measured by the coulomb counter ADC:

$$Q_{max} = \frac{\text{Passedcharge}}{|SOC1 - SOC2|} \quad (1)$$

The derivation of this equation is discussed in the following paragraphs. Figure 3 graphically illustrates some of the Impedance Track™ terminology.

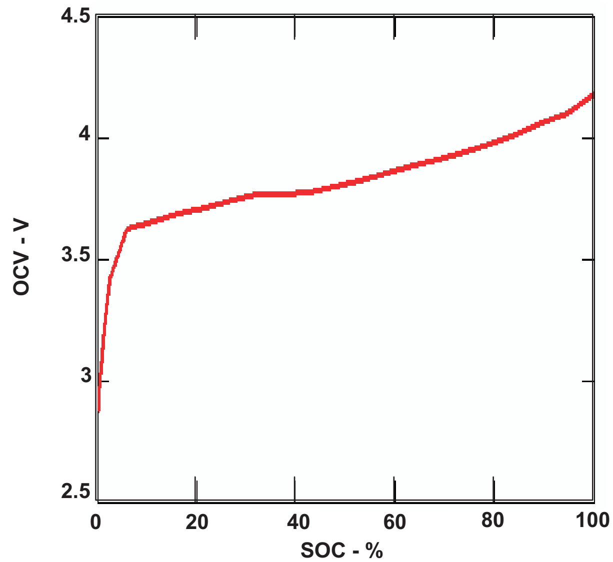


Figure 2. SOC Dependency on OCV

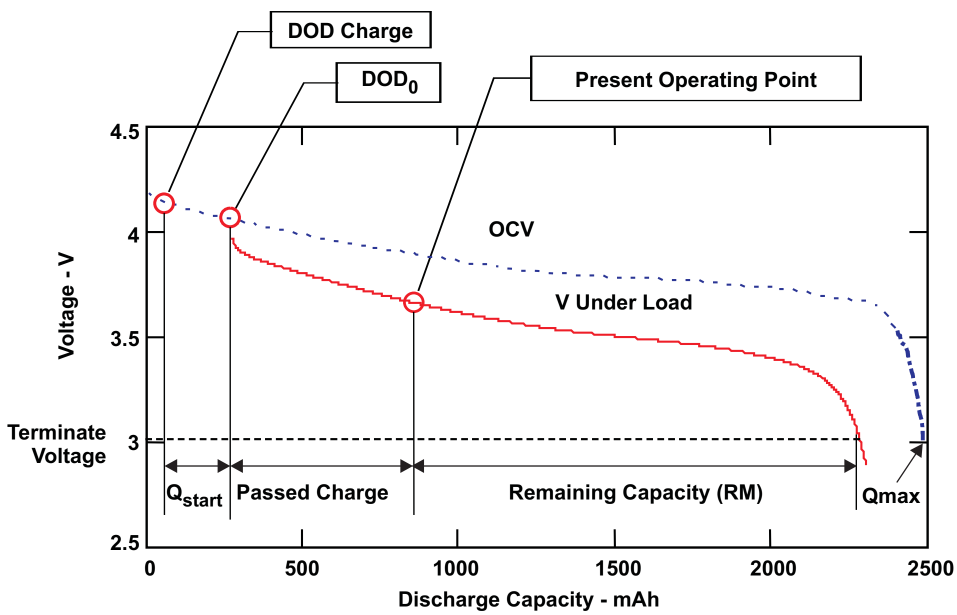


Figure 3. OCV Characteristics (Dotted Curve) and Battery Discharge Curve Under Load (Solid Curve)

Qmax is calculated with two OCV readings (leading to calculation of two SOC values, SOC1 and SOC2) taken at fully relaxed state (dV/dt < 4 µV/s) before and after charge or discharge activity and when the passed charge is more than 37% of battery design capacity, using Equation 2:

$$SOC1 = \frac{Q1}{Qmax}, \; SOC2 = \frac{Q2}{Qmax} \quad (2)$$

subtracting these two equations yields

$$Q_{max} = \frac{\text{Passedcharge}}{|\text{SOC1} - \text{SOC2}|}, \text{ where Passedcharge} = |\text{Q1} - \text{Q2}|. \tag{3}$$

This equation demonstrates that it is unnecessary to have a complete discharge cycle to learn the battery chemical capacity.

When an external load is applied, the impedance of the cell is measured by finding the difference between the measured voltage under load and the open-circuit voltage (OCV) specific to the cell chemistry at the present state-of-charge (SOC). This difference, divided by the applied load current, yields the impedance. In addition, the impedance is correlated with the temperature at time of measurement to fit in a model that accounts for temperature effects.

With the impedance information, the remaining capacity (RM) can be calculated using a voltage simulation method implemented in the firmware. The simulation starts from the present DOD, i.e., DOD_{start} and calculates a future voltage profile under the same load with a 4% DOD increment consecutively:

$$V(DOD_I,T) = OCV\ (DOD_I,T) + I \times R(DOD_I,T),$$

where $DOD_I = DOD_{start} + I \times 4\%$ and I represents the number of increments, and $R(DOD_I,T)$ is the battery impedance under DOD_I and temperature T. Once the future voltage profile is calculated, the Impedance Track™ algorithm predicts the value of DOD that corresponds to the system termination voltage and captures this as DOD_{final}. The remaining capacity then is calculated using:

$$RM = (DOD_{final} - DOD_{start}) \times Q_{max}$$

FCC (Full-charge capacity) is the amount of charge passed from the fully charged state to the termination voltage, and can be calculated using:

$$FCC = Qstart + PassedCharge + RM$$

The following section presents a more detailed description of the gas gauge hardware.

Gas Gauge Hardware

To perform the Impedance Track algorithm the gas gauge must be able to obtain cell voltage, temperature and pack current measurements. This section briefly discusses the hardware blocks that make the necessary measurements.

2.2.3.2 TPS77025 LDO Regulator The TPS77025 serves an important role for the bq27350 1-cell lithium-ion battery pack gas gauge chipset solution. The TPS77025 powers the bq27350 directly from its 2.5-V, 50-mA low-dropout (LDO) regulating output, which is powered by the battery voltage. This LDO has an enable low pin that is used such that if the Dsg FET from the protector circuit opens and the bq27350 enters SHUTDOWN mode (see bq27350 datasheet) then the LDO is shut off to prevent any loading to the cell from the LDO and gas gauge.

2.2.3.3 Cell Voltage Measurement The maximum input voltage for the CELL+ pin is 1 V. Given that a cell under normal conditions can have a voltage as high as 4.2 V, there's a voltage divider network (R5 and R7) that is configured to translate the cell voltage into ground-referenced voltage, which can be measured by the bq27350 gas gauge IC. The voltage divider is only active enough time to allow the signal at the CELL+ pin to stabilize and for the ADC to take several samples to determine a battery voltage measurement.

2.2.3.4 Temperature Measurement The ADC that is used for the battery voltage measurement is shared with the temperature measurement function. The TS pin is the input used when measuring the voltage across a thermistor to determine temperature. The reference design demonstrates the necessary components needed along with an NTC103AT thermistor so that the bq27350 can correlate the voltage at TS pin with a temperature reported in °C. The bq27350 has the option to use either the external or internal temperature sensing. This is selected with the [TEMPS] bit in *Pack Configuration* flash register.

2.2.3.5 Pack Current Measurement The SRP and SRN pins are the high impedance inputs to the integrating ADC (coulomb counter). A very low value sense resistor is placed in series with the cell on the ground side to convert the pack current to a voltage that the ADC can measure. The ADC differential input is limited to ±200 mV. The low-pass filter that feeds the sense resistor voltage to the bq27350 SRP and SRN inputs filters out system noise and does not affect the coulometric measurement accuracy, because the low-pass filter does not change the integrated value of the waveform.

Additional Pack Circuit Components

2.2.4.6 R5402-Series Pack Protector IC All Li-ion battery packs should include safety provisions due to the danger present of allowing the cells to operate in extreme conditions such as overcharging. Some IC circuits are dedicated to monitor the voltage and current of a battery pack exclusively to control the flow of current into or out of the Li-ion cell that makes up the pack. The reference design used in this document shows the R5402-series protector IC manufactured by Ricoh. This device independently controls two N-channel MOSFETs which are dedicated to restrict charge or discharge paths.

The pin that controls the discharge MOSFET turns off if the voltage detected by the IC's VDD is under a specific voltage threshold (typically 2.3 V) that is defined within the IC, or if the voltage detected at the high input impedance V-pin is greater than the discharge overcurrent threshold (typically 100 mV). The voltage at the V-pin is a representation of current measurement due to voltage drop across MOSFETs. To recover from an undervoltage condition the Protection IC must detect a voltage above the discharge recovery threshold (typically 3 V).

The charge MOSFET is turned off if the voltage detected at the VDD pin is greater than an overcharge threshold (typically 4.275 V) or if the V- pin detects a voltage less than the charge overcurrent threshold (typically -100 mV). To recover from this condition, it is expected that the cell is discharged until it reaches a recovery threshold which is typically 200 mV less than the overcharge threshold.

Many IC manufacturers can provide products similar to the R5402 series. It is up to designers to select which protector IC to include in their pack circuit design.

2.2.4.7 bq26100 Authentication IC Many counterfeit batteries are being manufactured and lack the necessary safety features so that cost can be reduced. Many OEMs are opting to add some means of authentication to their authorized battery packs to ensure that they are not liable for any accidents that could occur due to the use of these unauthorized packs.

The bq26100 IC provides a method to allow a microcontroller that is embedded in the main system to query the IC that is contained in the authorized pack and to verify that it responds with an expected result based on a challenge and a secret key. The bq26100 uses the well-known SHA-1 algorithm to process the challenge given by the system and return a digest that the system considers valid or unacceptable.

The reference design presented in this document uses the bq26100 with the bq27350. The system accesses the bq26100 through I^2C commands given to the bq27350. The bq27350 handles the SDQ communication with the bq26100 and then retrieves the response so that the system can read it from the bq27350.

bq27350EVM-001 Evaluation Module

The bq27350EVM-001 evaluation module (EVM) is a complete evaluation system for the bq27350 battery pack electronics system. The EVM includes:

1. One bq27350 circuit module
2. A current sense resistor
3. An NTC103AT thermistor
4. An EV2300 PC interface board for gas gauge interface
5. A PC USB cable
6. Windows™-based PC software

The circuit module includes one bq27350 IC, one TPS77025 IC, and all other onboard components necessary to monitor and predict capacity, in single-cell Li-ion or Li-polymer battery packs. The circuit module connects directly across the cell in a battery. With the EV2300 interface board and software, the user can read the bq27350 data registers, program the chipset for different pack configurations, log cycling data for further evaluation, and evaluate the overall functionality of the bq27350 solution under different charge and discharge conditions.

The bq27350 EVM is simpler than the reference design presented in this document. The EVM board does not include a pack protector circuit and an optional shutdown circuit. The purpose for the EVM is for customers to evaluate specifically the gas gauge operation.

bqEVSW Software for Use With bq27350

The bqEVSW is a Windows™-based evaluation software program provided by TI for functional evaluation of the bq27350/TPS77025 chipset. On opening the software, it automatically detects the presence of EV2300 USB module and the chipset. Once the device type and version of firmware are identified, the software displays the I^2C interface. The users may also toggle between DataRAM, Data Flash, I2C Pro, Calibrate, and Auth screens for a variety of information about the battery pack and the chipset settings. The bqEVSW can also be used for battery cycle data logging. See the bq27350EVM user's guide and application reports for more information.

2.3 Next Steps

Developing a PCB for bq27350 and TPS77025 Chipset

Using the 1-cell reference design schematic in the Appendix as a guide, a battery pack schematic should be designed to meet the individual requirements. A single-cell protector circuit IC must be selected by the pack module designer. The one used in this reference design is similar in functionality to many pack protector IC from other manufacturers. The pack protector IC controls a pair of FETs that are opened in case of overvoltage, undervoltage, overcurrent and short-circuit conditions.

Next, the current-sense resistor should be selected. As a general guideline, 20 mΩ is appropriate for a single (1P) 18650 cell, whereas 10 mΩ is recommended for a 2P pack.

Printed-circuit board layout requires careful consideration when developing a smart battery application. The high currents developed during a battery short-circuit event can be incompatible with the micropower design of the semiconductor devices. It is important to realize that battery transients can be capacitively or magnetically coupled into low-level circuits resulting in unwanted behavior. Success with a first-pass design can depend on realizing that parallel circuit board traces are indeed small capacitors and current transformers. The ideal board layout would have the entire high-current path physically located away from the low-current electronics. Because this is not often possible, the coupling principle must be taken into account. Short-circuit, ESD, and EMI testing should be part of the initial checkout of a new design.

With regard to component placement, several components surrounding the bq27350 need special attention. Most important are the power-supply decoupling capacitor C11 and the low pass filters for the differential input of the coulomb counter ADC (C7, C8, R9, and R10). The C11 capacitor must be close to the gas gauge device and have low-resistance / low-inductance connections that do not form large loops. The low pass filter components should be as close as possible to the SRP and SRN pins. Components of lesser priority but still a concern are the master reset network C9, R11. These should all be placed in the general vicinity of the IC.

Proper sensing of voltage and current requires the use of Kelvin connections at the sense resistor and at the top and bottom battery terminals. If top and bottom connections to the cells allow too much voltage drop, then the resulting error in cell voltage measurement has an effect on the measurement accuracy of battery capacity and therefore the remaining run time.

It Is important to have correct grounding. There should be high and low current ground paths. These should be kept separate, only joining together at the sense resistor.

Solution Development Process

Browsing the data flash screens of the bq27350 evaluation software can be a challenging experience. However, the default value for most of them can be easily used. The first step is to set up the data flash value for the coulomb capacity for a specific application (*Design Capacity*).

With different types of cells and number of parallel cells, capacity settings are different. To determine the values for *Qmax Cell 0*, *Qmax Pack*, *and Design Capacity* multiply the corresponding value for a single cell by the number of cells in parallel.

With the preceding changes in place, the evaluation module should function normally with the target cell configuration. The next step is to review all of the selectable features in the *Pack Configuration* register . Use the data sheet to review each configuration bit in this register and configure them for a specific application. See the EVM user's guide (SLUU253) schematic for implementation details.

Mass Production Setup

One of the main benefits of Impedance Track™ technology is the significant reduction in the complexity of battery pack mass production. Because many data flash values are adaptively derived with use, it is possible to simply transfer the knowledge gained from a single *golden* pack to each individual pack as it leaves the assembly line. Charging and discharging each pack in order to force it to learn its capacity is unnecessary.

A good strategy for production is a 7-step process flow:

1. Write the data flash image to each device. This image was read from a *golden* pack
2. Calibrate the device.
3. Update any individual flash locations, such as serial number, lot code, and date that could be entered in *Manufacturer Info* registers.
4. Perform any desired protection tests.
5. Connect the cell.
6. Initiate the Impedance Track™ algorithm.
7. Seal the pack.

The TI application report *Data Flash Programming and Calibrating the bq27350 Gas Gauge* (SLUA415) discusses the first two steps in detail. Description of steps 6 and 7 can be found in the bq27350 data sheet (SLUS754). Calibration is presented as sample VB6 code for those who wish to develop their own calibrator. However, Texas Instruments has higher-level support for high-speed programming and calibration steps. A single channel test and calibration program is available, with open-source code. Also, a multistation test system is available.

For additional application reports covering various aspect of bq27350 Impedance Track solution, see the Texas Instruments bq27350 online product folder.

2.4 Glossary

- OCV: Open-circuit voltage of a battery
- Passed Charge: Coulomb counter integrated charge during battery discharge or battery charge
- Qmax: Maximum battery chemical capacity
- Design Capacity: Cell chemical capacity specified by cell manufacturer times number of paralleled cells
- SOC: State-of-charge at any moment, defined as SOC=Q/Qmax (usually in %), where Q is the Passed Charge from full charge state
- DOD: Depth of discharge; DOD= 1-SOC (usually in %)
- DOD_0: Last DOD reading before charge or discharge
- DODcharge: DOD for a fully charged pack
- Qstart: Charge that would have passed from fully charged state to make DOD = DOD_0
- RM: Remaining capacity, in mAh or mWh
- FCC: Full-charge capacity, the amount of charge passed from the fully charged state to the terminate voltage, in mAh or mWh
- Quit current: user-defined current levels for both charge and discharge, usually about ~10 mA
- Relaxation mode: the state of the battery when the current is below user-defined *quit current* levels and after a user-defined minimum charge relax time (see Figure 1)

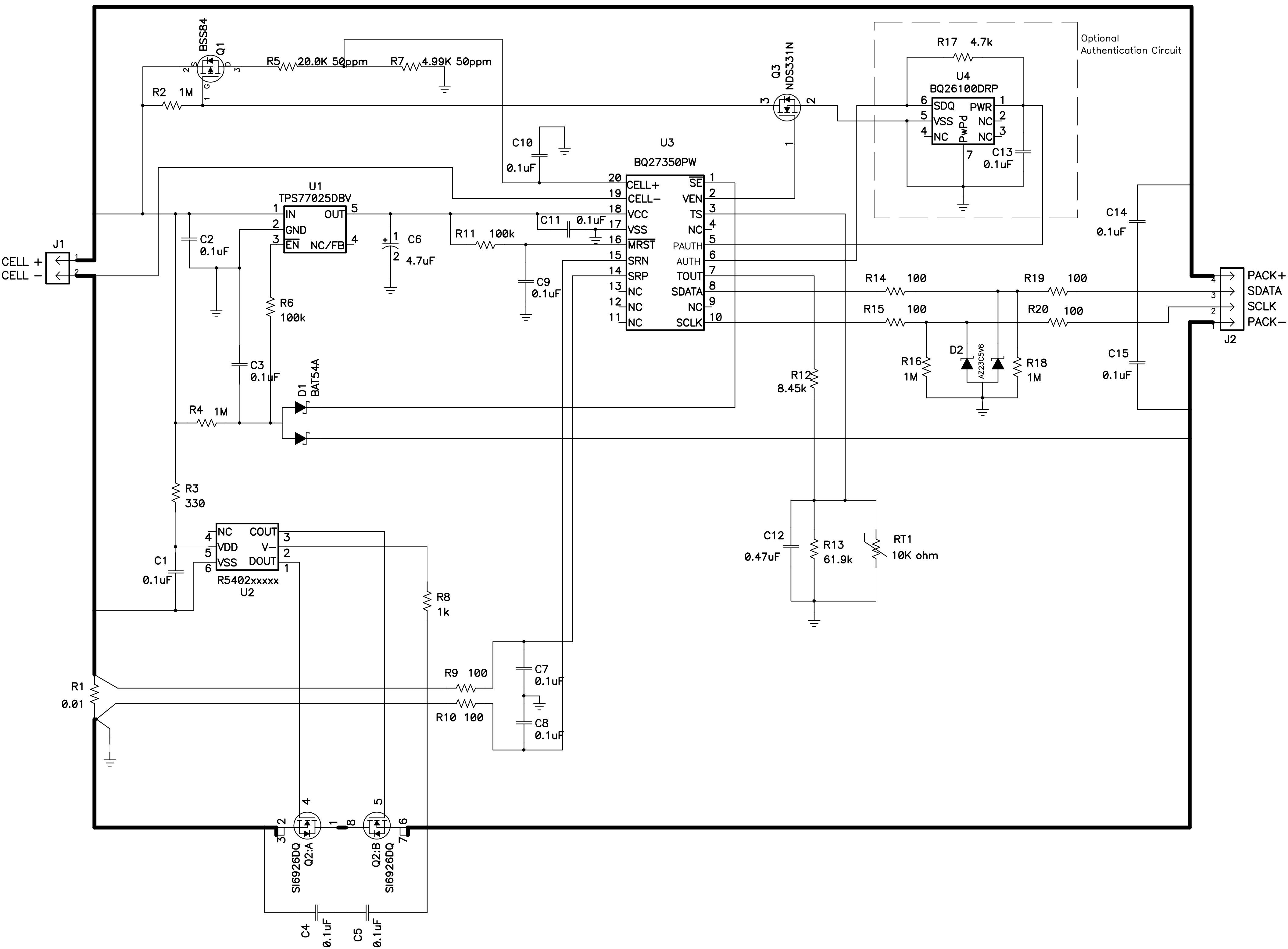
Reference Documents

The following documents should also serve as reference when researching the bq27350 and Single Cell Impedance Track products:

- *bq27350, Single Cell Li-Ion Battery Manager With Impedance Track Fuel Gauge Technology* data sheet (SLUS754)
- *bq27350EVM Single Cell Impedance Track Technology Evaluation Module* user's guide (SLUU253)
- *Configuring the bq27350 Data Flash* application report (SLUA419)
- *Data Flash Programming and Calibrating the bq27350 Gas Gauge* application report (SLUA415)

Reference Design Schematic

The reference design schematic is affixed to this page.


CELL +
CELL −
J1
BSS84
Q1
R5 20.0K 50ppm
R7 4.99K 50ppm
R2 1M
Q3
NDS331N
R17 4.7k
Optional
Authentication Circuit
U4
BQ26100DRP
SDQ
VSS
NC
PWR
NC
NC
PwPd
C13
0.1uF
C10
0.1uF
U3
BQ27350PW
CELL+
CELL−
VCC
VSS
MRST
SRN
SRP
NC
NC
NC
SE
VEN
TS
NC
PAUTH
AUTH
TOUT
SDATA
NC
SCLK
U1
TPS77025DBV
IN
GND
EN
OUT
NC/FB
C2
0.1uF
C6
4.7uF
C11
0.1uF
R11 100k
C9
0.1uF
R6
100k
C3
0.1uF
D1
BAT54A
R4 1M
R3
330
C14
0.1uF
C15
0.1uF
PACK+
SDATA
SCLK
PACK−
J2
R14 100
R19 100
R15 100
R20 100
D2
AZ23C5V6
R16
1M
R18
1M
R12
8.45k
C12
0.47uF
R13
61.9k
RT1
10K ohm
NC
VDD
VSS
COUT
V−
DOUT
R5402xxxxx
U2
C1
0.1uF
R8
1k
R1
0.01
R9 100
R10 100
C7
0.1uF
C8
0.1uF
SI6926DQ
Q2:A
Q2:B
SI6926DQ
C4
0.1uF
C5
0.1uF

Chapter 3

Configuring the bq27500 Data Flash

Ming Yu and Michael Vega *PMP - Portable Power*

ABSTRACT

The bq27500 has many data flash constants that can configure the device with various, different options for most features. The data flash of the bq27500 is split into sections, which are described in detail in this document.

3.1 Glossary

FCC: Full charge capacity

FET: Field-effect transistor

FET opened/closed: It is common to say that the FET is opened or closed. Used throughout the document, this term means that the FET is turned on or off, respectively.

Flag: This word usually represents a read-only status bit that indicates some action has occurred or is occurring. This bit typically cannot be modified by the user.

RCA: Remaining capacity alarm

RM: Remaining capacity

SOC: This generic acronym means state-of-charge. It can also mean RSOC or percentage of actual chemical capacity.

System: The word system is sometimes used in this document. When used, it always means a host system that is consuming current from the battery pack that includes the bq27500.

Italics: All words in this document that are in italics represent names of data flash locations exactly as they are shown in the EV software.

Bold Italics: All words that are bold italic represent SBS-compliant registers exactly as they are shown in the EV software.

[brackets]: All words or letters in brackets represent bit/flag names exactly as they are shown in the SBS and data flash in the EV software.

(–): This is commonly used in this document to represent a minus sign. It is written this way to ensure that the sign is not lost in the translation of formulas in the text of this document.

3.2 Configuration

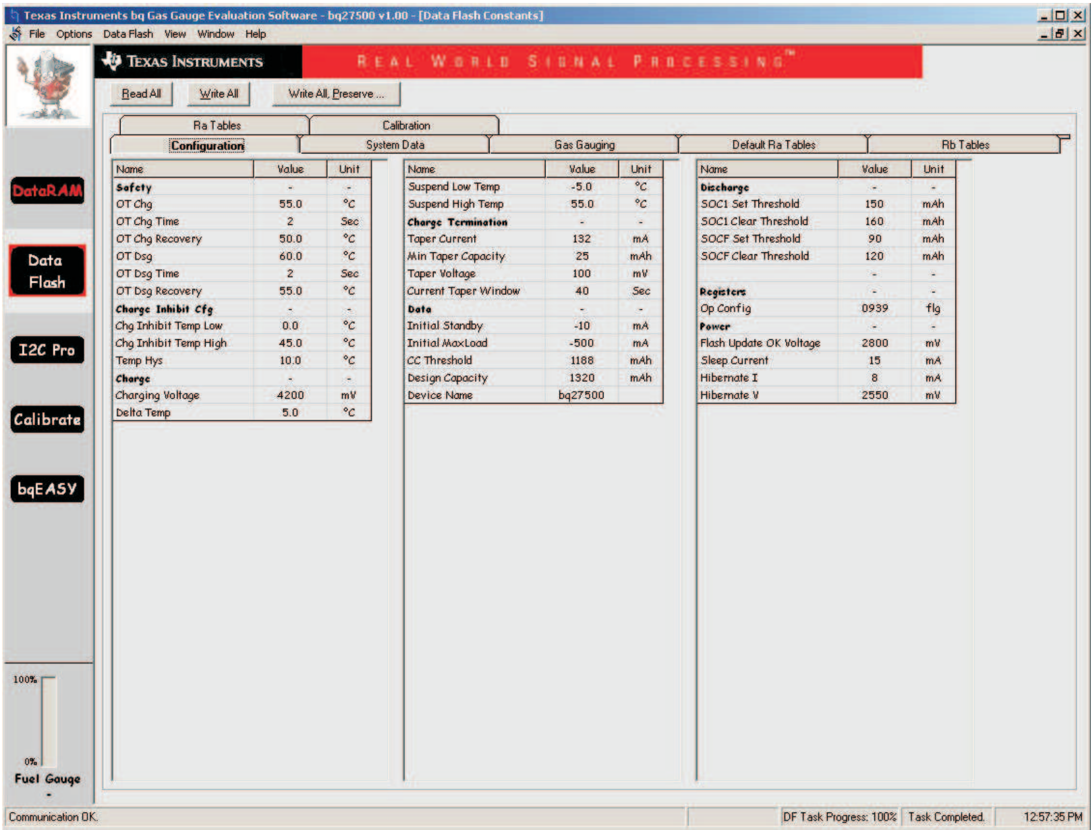


Figure 4. Configuration Screen

Safety

OT Chg

When the pack temperature measured by ***Temperature*** rises to or above the Over Temperature Charge (*OT Chg*) threshold while charging (***Current*** > *Chg Current Threshold*), then the Over Temperature in charge direction [OTC] is set in ***Flags*** after *OT Chg Time*. If the OTC condition clears prior to the expiration of the *OT Chg Time* timer, then no [OTC] is set in ***Flags***. If the condition does not clear, then [OTC] is set in ***Flags***.

Normal Setting: This setting depends on the environment temperature and the battery specification. Verify that the battery specification allows temperatures up to this setting while charging, and verify that these setting are sufficient for the application temperature. The default is 55°C, which should be sufficient for most Li-ion applications.

OT Chg Time

See *OT Chg*. This is a buffer time allotted for Over Temperature in the charge direction condition. The timer starts every time that ***Temperature*** measured is greater than *OT Chg* and while charging. When the timer expires, the bq27500 forces an [OTC] in ***Flags***. Setting the *OT Chg Time* to 0 disables this function.

Normal Setting: This is normally set to 2 seconds which should be sufficient for most applications. Temperature is normally a slow-acting condition that does not need high-speed triggering. It must be set long enough to prevent false triggering of the [OTC] in ***Flags***, but short enough to prevent damage to the battery pack.

OT Chg Recovery

OT Chg Recovery is the temperature at which the battery recovers from an *OT Chg* fault. This is the only recovery method for an *OT Chg* fault.

Normal Setting: The default is 50°C which is a 5-degree difference from the *OT Chg*.

OT Dsg

When the pack temperature measured by ***Temperature*** rises to or above this threshold while discharging (***Current*** < (-)(*Dsg Current Threshold*)), then the Over Temperature in discharge direction [OTD] is set in ***Flags*** after *OT Dsg Time*. If the OTD condition clears prior to the expiration of the *OT Dsg Time* timer, then no [OTD] is set in ***Flags***. If the condition does not clear, then [OTD] is set in ***Flags***.

Normal Setting: This setting depends on the environment temperature and the battery specification. Verify that the battery specification allows temperatures up to this setting while charging, and verify that these setting are sufficient for the application temperature. The default is 60°C which is sufficient for most Li-ion applications. The default *OT Dsg* setting is higher than the default *OT Chg* because Li-ion can handle a higher temperature in the discharge direction than in the charge direction.

OT Dsg Time

See *OT Dsg*. This is a buffer time allotted for Over Temperature in the discharge direction condition. The timer starts every time that ***Temperature*** measured is greater than *OT Dsg* and while discharging. When the timer expires, then the bq27500 forces an [OTD] in ***Flags***. Setting the *OT Dsg Time* to 0 disables this function.

Normal Setting: This is normally set to 2 seconds which is sufficient for most applications. Temperature is normally a slow-acting condition that does not need high-speed triggering. It should be set long enough to prevent false triggering of the [OTD] in ***Flags***, but short enough to prevent damage to the battery pack.

OT Dsg Recovery

OT Dsg Recovery is the temperature at which the battery recovers from an *OT Dsg* fault. This is the only recovery method for an *OT Dsg* fault.

Normal Setting: The default is 55°C which is a 5-degree difference from the *OT Dsg*.

Charge Inhibit Configuration

Chg Inhibit Temp Low

When the [PFC] is set to 1, if pack temperature measured by ***Temperature*** falls to or below the charge inhibit temperature low (*Chg Inhibit Temp Low*) threshold while charging (***Current*** > *Chg Current Threshold*), then the Charge Inhibit [CHG_INH] is set in ***Flags***. In this mode, the /BAT_GD line used to disable battery charging when battery temperatures is outside the range defined by ***[Chg Inhibit Temp Low , Chg Inhibit Temp High]***. The /BAT_GD line is returned to its "low" state, once battery temperature returns to the range ***[Chg Inhibit Temp Low + Temp Hys, Chg Inhibit Temp High - Temp Hys]***.

Normal Setting: This setting depends on the environment temperature and the battery specification. Verify that the battery specification allows temperatures up to this setting while charging, and verify that these setting are sufficient for the application temperature. The default is 0°C, which should be sufficient for most Li-ion applications.

Chg Inhibit Temp High

When the [PFC] is set to 1, if the pack temperature measured by ***Temperature*** rises to or above the charge inhibit temperature high (*Chg Inhibit Temp high*) threshold while charging (***Current*** > *Chg Current Threshold*), then the Charge Inhibit [CHG_INH] is set in ***Flags***. In this mode, the /BAT_GD line used to disable battery charging when battery temperatures is outside the range defined by ***[Chg Inhibit Temp Low , Chg Inhibit Temp High]***. The /BAT_GD line is returned to its "low" state, once battery temperature returns to the range ***[Chg Inhibit Temp Low + Temp Hys, Chg Inhibit Temp High - Temp Hys]***.

Normal Setting: This setting depends on the environment temperature and the battery specification. Verify that the battery specification allows temperatures up to this setting while charging, and verify that these setting are sufficient for the application temperature. The default is 45°C, which should be sufficient for most Li-ion applications.

Temp Hys

When pack temperature is measured by ***Temperature***, the temperature hysteresis (*Temp Hys*) is defined to prevent false temperature measurement.

Normal Setting: This setting depends on the environment temperature and the battery specification. Verify that the battery specification allows temperatures up to this setting while charging, and verify that these setting are sufficient for the application temperature. The default is 10°C, which should be sufficient for most Li-ion applications.

Charge

Charging Voltage

The bq27500 uses this value along with *Taper Voltage* to detect charge termination.

Normal Setting: This value depends on the charger that is expected to be used for the battery pack containing the bq27500. The default is 4.2 V.

Delta Temp

If the pack temperature measured by ***Temperature*** is outside the suspend temperature range ***[Suspend Low Temp, Suspend High Temp]***) threshold while charging (***Current*** > *Chg Current Threshold*), then the Charge Suspend Alert [XCHG] is set in ***Flags***. The Charge Suspend Alert [XCHG] is reset to "0" once battery temperature returns to the range ***[Suspend Low Temp + Delta Temp, Suspend High Temp - Delta Temp]***.

Normal Setting: This value depends on the charger that is expected to be used for the battery pack containing the bq27500. The default is 5 °C.

Suspend Low Temp

When the pack temperature measured by ***Temperature*** falls to or below the suspend low temperature (*Suspend Low Temp*) threshold while charging (***Current*** > *Chg Current Threshold*), then the Charge Suspend Alert [XCHG] is set in ***Flags***.

Normal Setting: This value depends on the charger that is expected to be used for the battery pack containing the bq27500. The default is (-)5 °C.

Suspend High Temp

When the pack temperature measured by ***Temperature*** rises to or above the suspend high temperature (*Suspend HighTemp*) threshold while charging (***Current*** > *Chg Current Threshold*), then the Charge Suspend Alert [XCHG] is set in ***Flags***.

Normal Setting: This value depends on the charger that is expected to be used for the battery pack containing the bq27500. The default is 55 °C.

Charge Termination

Taper Current

Taper Current is used in the Primary Charge Termination algorithm. ***Average Current*** is integrated over each of the two *Current Taper Window* periods separately, and then they are averaged separately to give two averages. Both of these averages must be below the *Taper Current* to qualify for a Primary Charge Termination. In total, a primary charge termination has the following requirements:

1. During two consecutive periods of *Current Taper Window*, the ***Average Current*** is < *Taper Current*.
2. During the same periods, the accumulated change in capacity > 0.25 mAh/*Current Taper Window*.
3. ***Voltage*** > *Charging Voltage* - *Taper Voltage*.

When this occurs, the [FC] bit of Flags( ) is set and [CHG] bit is cleared. Also, if the [RMFCC] bit of *Operation Config* is set, then ***Remaining Capacity*** is set equal to ***Full Charge Capacity.***

Normal Setting: This register depends on battery cell characteristics and charger specifications, but typical values are C/10 to C/20. ***Average Current*** is not used for this qualification because its time constant is not the same as the *Current Taper Window*. The reason for making two Current Taper qualifications is to prevent false current taper qualifications. False primary terminations happen with pulse charging and with random starting and stopping of the charge current. This is particularly critical at the beginning or end of the qualification period. It is important to note that as the *Current Taper Window* value is increased, the current range in the second requirement for primary charge termination is lowered. If you increase the *Current Taper Window*, then the current used to integrate to the 0.25 mAh is decreased; so, this threshold becomes more sensitive. Therefore, take care when modifying the *Current Taper Window*. The default is 100 mA.

Taper Voltage

During Primary Charge Termination detection, one of the three requirements is that ***Voltage*** must be above (*Charging Voltage – Taper Voltage*) for the bq27500 to start trying to qualify a termination. It must be above this voltage before bq27500 starts trying to detect a primary charge termination.

Normal Setting: This value depends on charger characteristics. It needs to be set so that ripple voltage, noise, and charger tolerances are taken into account. A high value selected can cause early termination. If the value selected is too low, then it can cause no termination or late termination detection. An example value is 100 mV (see *Taper Current*).

Current Taper Window

During Primary Charge Termination detection, all three requirements as described in *Taper Current* must be valid for two periods of this *Current Taper Window* for the bq27500 to detect a primary charge termination.

Normal Setting: This register does not need to be modified for most applications. It is important to note that as the *Current Taper Window* value is increased, the current range in the second requirement for primary charge termination is lowered. If the user increases the *Current Taper Window*, then the current used to integrate to the 0.25 mAh is decreased; so, this threshold becomes more sensitive. Therefore, take care when modifying the *Current Taper Window*. The default value is 40 seconds.

Data

Initial Standby Current

This is the first value that is reported in ***Standby Current***. The ***Standby Current*** value is updated every 1 second when the measured current is above the *Deadband* and is less than or equal to 2 x *Initial Standby Current*.

Normal Setting: This value depends on the system. The initial standby current is the current load drawn by the system when in low-power mode. The default value is (-)10 mA.

Initial MaxLoad

This is the first value that is reported in ***MaxLoad Current***. If the measured current is ever greater than *Initial MaxLoad* Current, then ***MaxLoad Current*** updates to the new current. ***MaxLoad Current*** is reduced to the average of the previous value and *Initial MaxLoad* Current whenever the battery is charged to full after a previous discharge to an SOC less than 50%. This prevents the reported value from maintaining an unusually high value.

Normal Setting: This value depends on the system. The default value is (-)500 mA.

CC Threshold

This value is always used to increment ***Cycle Count***. When the bq27500 accumulates enough discharge capacity equal to the *CC Threshold*, then it increments ***Cycle Count*** by 1. This discharge capacity does not have to be consecutive. The internal register that accumulates the discharge is not cleared at any time except when the internal accumulating register equals the *CC Threshold*, and increments ***Cycle Count***.

Normal Setting: This is normally set to about 90% of the *Design Capacity*. The default is 900 mAh.

Design Capacity

This value is used for the compensated battery capacity remaining and capacity when fully charged calculations that are done by the bq27500.

Normal Setting: This value should be set based on the application battery specification. See the battery manufacturer's data sheet. The default is 1000 mAh.

Device Name

This is string data that can be a maximum of 7 characters. This field does not affect the operation, nor is it used by the part in any way. It is returned by reading addresses 0x63 through 0x69. The default is the ASCII values for "bq27500".

Discharge

The bq27500 has two flags accessed by the ***Flags*** that warns when the battery's SOC has fallen to critical levels.

SOC1 Set Threshold

When ***Remaining Capacity*** falls below the first capacity threshold, specified in *SOC1 Set Threshold*, the [SOC1] (*State of Charge Initial*) bit is set in ***Flags***. This bit is cleared once ***Remaining Capacity*** rises above *SOC1 Clear Threshold*. The bq27500's BAT_LOW pin automatically reflects the status of the [SOC1] bit in ***Flags***.

Normal Setting: This is a user preference. It is normally set around 150 mAh.

SOC1 Clear Threshold

When ***Remaining Capacity*** rises to or above this value set by *SOC1 Clear Threshold*, then [SOC1] in ***Flags*** is cleared.

Normal Setting: This is a user preference. If used, it is normally set around 10mAh higher than *SOC1 Set Threshold*. In this case, it is set to 160 mAh.

SOCF Set Threshold

When ***Remaining Capacity*** falls below the first capacity threshold, specified in *SOCF Set Threshold*, the [SOCF] (*State of Charge Final*) bit is set in ***Flags*** serving as a final discharge warning. If *SOCF Set Threshold* = (-)1, the flag is inoperative during discharge. This bit is cleared once ***Remaining Capacity*** rises above *SOCF Clear Threshold*.

Normal Setting: This is a user preference. It is normally set around 90 mAh.

SOCF Clear Threshold

When ***Remaining Capacity*** rises to or above this value set by *SOCF Clear Threshold*, then [SOCF] in ***Flags*** is cleared.

Normal Setting: This is a user preference. If used, it is normally set around 30 mAh higher than *SOC1 Set Threshold*. In this case, it is set to 120 mAh.

Registers

Op Config (Operation Config)

This register is used to enable or disable various functions of the bq27500.

RESCAP	RSVD	RSVD	PFC_CFG1	PFC_CFG0	IWAKE	RSNS1	RSNS0
RSVD	IDSELEN	SLEEP	RMFCC	BATL_POL	BATG_POL	RSVD	TEMPS

- RESCAP [15]: If set, a no-load rate of compensation is applied to the reserve capacity.

  Normal Setting: This bit defaults to 0.
- RSVD [14, 13]: These bits are reserved (RSVD).
- PFC_CFG1, PFC_CFG0 [12, 11]: Pin function code (PFC) mode selection: PFC 0, 1, or 2 selected by 2 bits: 0/0, 0/1, or 1/0, respectively. When the PFC is set to 0, bq27500 only measures battery temperature under discharge and relaxation conditions. The charger does not receive any information from the bq27500 about the temperature readings, and therefore operates open-loop with respect to battery temperature. A PFC of 1 is like a PFC of 0, except temperature is also monitored during battery charging. If charging temperature falls outside of the preset range defined in data flash, a charger can be disabled via the BAT_GD pin, until cell temperature recovers. Finally when the PFC is set to 2, the battery thermistor can be shared between the fuel gauge and the charger. The charger has full usage of the thermistor during battery charging, while the fuel gauge uses the thermistor exclusively during discharge and battery relaxation.

  Normal Setting: This bit defaults to a 1.
- IWAKE, RSNS1, RSNS0 [10, 9, 8]: The wake-up comparator is used to indicate a change in cell current while the bq27500 is in either Sleep or Hibernate modes. *Op Config* uses bits [RSNS1-RSNS0] to set the sense resistor selection. *Op Config* uses the [IWAKE] bit to select one of two possible voltage threshold ranges for the given sense resistor selection. An internal interrupt is generated when the threshold is breached in either charge or discharge directions. A setting of 0x00 of RSNS1..0 disables this feature. See Table 2 for values.

Normal Setting: The default setting for these bits is 001.

- RSVD [7]: This bit is reserved.
- IDSELEN [6]: If set, the gas gauge enables cell profile selection feature.

  Normal Setting: This bit defaults to a 1.
- SLEEP [5]: If set, the gas gauge can enter sleep if operating conditions allow. The bq27500 enters SLEEP if ***Average Current*** ≤ *Sleep Current*.

  Normal Setting: This bit defaults to a 1, which should be used in most applications. Only a few reasons require this bit to be set to 0.
- RMFCC [4]:If set, on valid charge termination, ***Remaining Capacity*** is updated with the value from ***Full Charge Capacity*** on valid charge termination.

  Normal Setting: The default setting for this bit is 1.
- BATL_POL [3]: BAT_LOW pin polarity setting. If set, BAT_LOW pin is active-high.

  Normal Setting: The default setting is 1.
- BATG_POL [2]: $\overline{\text{BAT}}$_GD pin polarity setting. If cleared, $\overline{\text{BAT}}$_GD pin is active low.

  Normal Setting: The default setting is 0.
- RSVD [1]: This bit is reserved.
- TEMPS [0]: This bit is used to tell the bq27500 the temperature sensor configuration. The bq27500 can use an external sensor, and an internal sensor is also available, if needed. These sensors are able to use two configurations to report temperature in the ***Temperature*** register.
  - 1 = Temperature sensor TS1 is used to generate ***Temperature***.
  - 0 = Internal temperature sensor is used to generate ***Temperature***.

  Normal Setting: The default setting for this bit is 1. The bq27500 default configuration is for a Semitec 103AT thermistor. The internal temperature sensor is slightly less accurate than using a Semitec 103AT and is not recommended. It also is not as accurate because it cannot be placed as close to the battery cells in the application as can an external thermistor.

Table 2. I_{WAKE} Threshold Settings(1)

RSNS1	RSNS0	IWAKE	Vth(SRP-SRN)
0	0	0	Disabled
0	0	1	Disabled
0	1	0	+1.25 mV or –1.25 mV
0	1	1	+2.5 mV or –2.5 mV
1	0	0	+2.5 mV or –2.5 mV
1	0	1	+5 mV or –5 mV
1	1	0	+5 mV or –5 mV
1	1	1	+10 mV or –10 mV

(1) The actual resistance value versus the setting of the sense resistor is not important; just the actual voltage threshold when calculating the configuration.

Power

Flash Update OK Voltage

This register controls one of several data flash protection features. It is critical that data flash is not updated when the battery voltage is too low. Data flash programming takes much more current than normal operation of the bq27500, and with a depleted battery, this current can cause the battery voltage to drop dramatically, forcing the bq27500 into reset before completing a data flash write. The effects of an incomplete data flash write can corrupt the memory, resulting in unpredictable and extremely undesirable results. The voltage setting in *Flash Update OK Voltage* is used to prevent any writes to the data flash below this value. If a charger is detected, then this register is ignored.

Normal Setting: The default for this register is 2800 mV. Ensure that this register is set to a voltage where the battery has plenty of capacity to support data flash writes but below any normal battery operation conditions.

Sleep Current

When ***Average Current*** is less than *Sleep Current* or greater than (–)*Sleep Current* in mA, the bq27500 enters SLEEP mode if the feature is enabled (*Op Config* [SLEEP] = 1) .

The bq27500 does an analog-to-digital converter (ADC) calibration and then goes to sleep.

Normal Setting: This setting should be below any normal application currents. The default is 15 mA, which should be sufficient for most applications.

Hibernate I

When ***Average Current*** is less than *Hibernate I* or greater than (–)*Hibernate I* in mA, the bq27500 enters Hibernate mode if *Control Status* [HIBERNATE] = 1.

Normal Setting: This setting should be below any normal application currents. The default is 8 mA, which should be sufficient for most applications.

Hibernate V

When ***Voltage*** is less than *Hibernate V* or greater than (–)*Hibernate V* in mV, the bq27500 enters Hibernate mode if *Control Status* [HIBERNATE] = 1.

Normal Setting: This setting should be below any normal application currents. The default is 2550 mV, which should be sufficient for most applications.

3.3 System Data

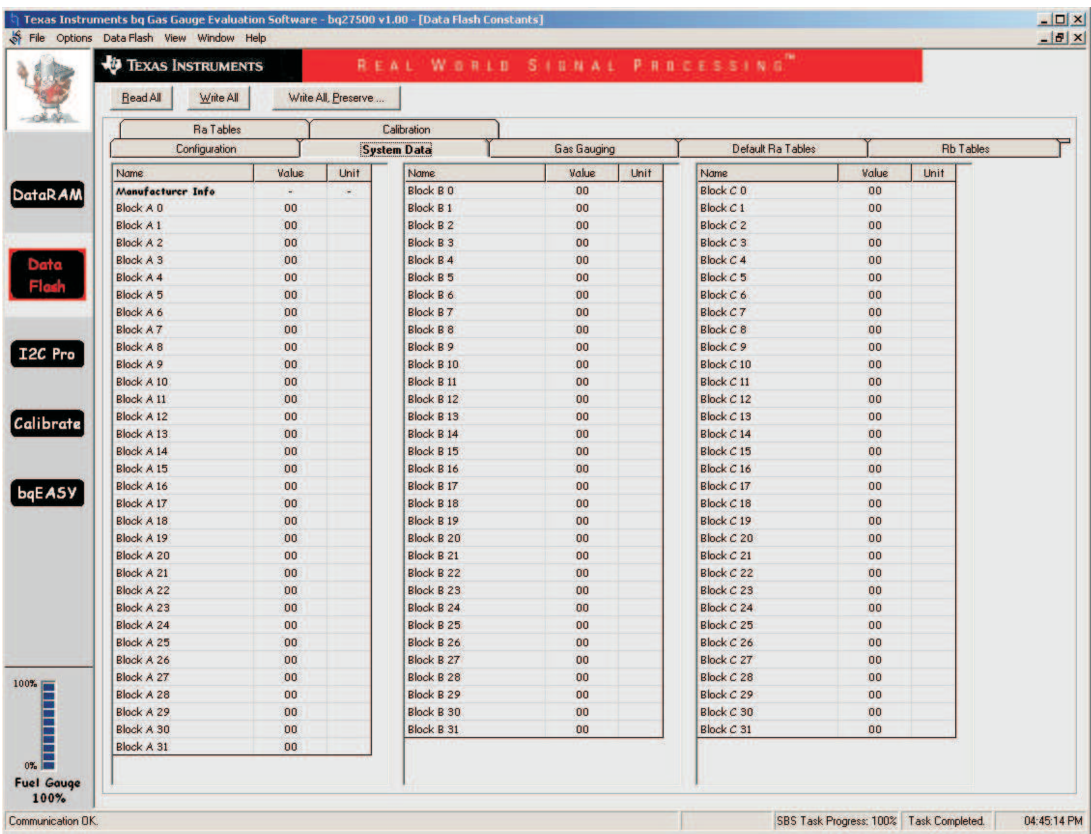


Figure 5. System Data Screen

Manufacturer Info

Block A

This is string data that can be any user data. It can be a maximum of 8 characters.

Normal Setting: Can be used for any user data. The default is all data 0.

Block B

This is string data that can be any user data. It can be a maximum of 8 characters.

Normal Setting: Can be used for any user data. The default is all data 0.

Block C

This is string data that can be any user data. It can be a maximum of 8 characters.

Normal Setting: Can be used for any user data. The default is all data 0.

3.4 Gas Gauging

Figure 6. Gas Gauging Screen

IT Cfg

Load Select

Load Select defines the type of power or current model to be used for ***Remaining Capacity*** computation in the Impedance Track™ algorithm. If *Load Mode* = Constant Current, then the following options are available:

0 = Average discharge current from previous cycle: An internal register records the average discharge current through each entire discharge cycle. The previous average is stored in this register.

1 = Present average discharge current (default): This is the average discharge current from the beginning of this discharge cycle until present time.

2 = *Current*: Based off of ***Current***

3 = ***Average Current*** : Based off of ***Average Current***

4 = ***Design Capacity***/5: C Rate based off of ***Design Capacity***/5 or a C/5 rate in mA.

5 = ***At Rate*** (mA): Use whatever current is in ***At Rate*** register.

6 = *User Rate-mA*: Use the value in *User Rate-mA*. This gives a completely user-configurable method.

If *Load Mode* = Constant Power, then the following options are available:

0 = Average discharge power from previous cycle: An internal register records the average discharge power through each entire discharge cycle. The previous average is stored in this register.

1 = Present average discharge power (default): This is the average discharge power from the beginning of this discharge cycle until present time.

2 = ***Current*** × ***Voltage***: Based off of ***Current*** and ***Voltage***

3 = ***Average Current*** × ***Voltage*** : Based off of ***Average Current*** and ***Voltage***

4 = ***Design Energy***/5: C Rate based off of ***Design Energy***/5 or a C/5 rate in mA

5 = ***At Rate*** (10 mW): Use whatever value is in ***At Rate*** register.

6 = *User Rate-mW*: Use the value in *User Rate-mW*. This gives a completely user-configurable method.

Normal Setting: The default for this register is 1. This is application dependent.

Load Mode

Load Mode is used to select either the constant current or constant power model for the Impedance Track™ algorithm as used in *Load Select*. (See *Load Select*.)

- 0: Constant Current Mode
- 1: Constant Power Mode

Normal Setting: This is normally set to 0 (Constant Current Mode) but it is application specific. If the application load profile more closely matches a constant power mode, then set to 1. This provides a better estimation of remaining run time, especially close to the end of discharge where current increases to compensate for decreasing battery voltage.

Terminate Voltage

Terminate Voltage is used in the Impedance Track™ algorithm to help compute ***Remaining Capacity***. This is the absolute minimum voltage for end of discharge, where the remaining chemical capacity is assumed to be zero.

Normal Setting: This register is application dependent. It should be set based on battery cell specifications to prevent damage to the cells or the absolute minimum system input voltage, taking into account impedance drop from the PCB traces, FETs, and wires. The default is 3000 mV.

User Rate-mA

User Rate-mA is only used if *Load Select* is set to 6 and *Load Mode* = 0. If these criteria are met, then the current stored in this register is used for the ***Remaining Capacity*** computation in the Impedance Track™ algorithm. This is the only function that uses this register.

Normal Setting: It is unlikely that this register is used. An example application that would require this register is one that has increased predefined current at the end of discharge. With this type of discharge, it is logical to adjust the rate compensation to this period because the IR drop during this end period is affected the moment *Terminate Voltage* is reached. The default is 0 mA.

User Rate-mW

User Rate-mW is only used if Load Select is set to 6 and *Load Mode* = 1. If these criteria are met, then the power stored in this register is used for the ***Remaining Capacity*** computation in the Impedance Track™ algorithm. This is the only function that uses this register.

Normal Setting: It is unlikely that this register is used. An example application that would require this register is one that has increased predefined power at the end of discharge. With this application, it is logical to adjust the rate compensation to this period because the IR drop during this end period is affected the moment *Terminate Voltage* is reached. The default is 0 to 10-mW units.

Reserve Cap-mAh

Reserve Cap-mAh determines how much actual remaining capacity exists after reaching 0 ***Remaining Capacity*** before *Terminate Voltage* is reached. This register is only used if *Load Mode* is set to 0.

Normal Setting: This register defaults to 0, which disables this function. This is the most common setting for this register. This register is application dependent. This is a specialized function for allowing time for a controlled shutdown after 0 ***Remaining Capacity*** is reached.

Reserve Cap-mWh

Reserve Cap-10mWh determines how much actual remaining capacity exists after reaching 0 ***Remaining Capacity*** before *Terminate Voltage* is reached. This register is only used if *Load Mode* is set to 1.

Normal Setting: This register defaults to 0, which basically disables this function. This is the most common setting for this register. This register is application dependent. This is a specialized function for allowing time for a controlled shutdown after 0 ***Remaining Capacity*** is reached.

Current Thresholds

Dsg Current Threshold

This register is used as a threshold by many functions in the bq27500 to determine if actual discharge current is flowing out of the battery. This is independent from [DSG] in ***Flags***, which indicates whether the bq27500 is in discharge mode or charge mode.

Normal Setting: The [DSG] flag in ***Flags*** is the method for determining charging or discharging. If the bq27500 is charging, then [DSG] is 0 and any other time (***Average Current*** less than or equal to 0) the [DSG] flag is equal to 1. Many algorithms in the bq27500 require more definitive information about whether current is flowing in either the charge or discharge direction. *Dsg Current Threshold* is used for this purpose. The default for this register is 60 mA which should be sufficient for most applications. This threshold should be set low enough to be below any normal application load current but high enough to prevent noise or drift from affecting the measurement.

Chg Current Threshold

This register is used as a threshold by many functions in the bq27500 to determine if actual charge current is flowing into the battery. This is independent from [DSG] in Battery Status which indicates whether the bq27500 is in discharge mode or charge mode.

Normal Setting: Many algorithms in the bq27500 require more definitive information about whether current is flowing in either the charge or discharge direction. This is what *Chg Current Threshold* is used for. The default for this register is 75 mA which should be sufficient for most applications. This threshold should be set low enough to be below any normal application load current but high enough to prevent noise or drift from affecting the measurement.

Quit Current

The *Quit Current* is used as part of the Impedance Track™ algorithm to determine when the bq27500 goes into relaxation mode from a current-flowing mode in either the charge direction or the discharge direction. Either of the following criteria must be met to enter relaxation mode:

1. ***Average Current*** is **greater than** (–)*Quit Current* and then goes within (±)*Quit Current* for *Dsg Relax Time*.
2. ***Average Current*** is **less than** *Quit Current* and then goes within (±)*Quit Current* for *Chg Relax Time*.

After 30 minutes in relaxation mode, bq27500 starts checking if the dV/dt < 4 µV/s requirement for OCV readings is satisfied. When the battery relaxes sufficiently to satisfy this criteria, bq27500 takes OCV reading for updating Qmax and for accounting for self-discharge. These updates are used in the Impedance Track™ algorithms.

Normal Setting: It is critical that the battery voltage be relaxed during OCV readings to get the most accurate results. This current must not be higher than C/20 when attempting to go into relaxation mode; however, it should not be so low as to prevent going into relaxation mode due to noise. This should always be less than *Chg Current Threshold* or *Dsg Current Threshold*. Default is 40 mA.

Dsg Relax Time

The *Dsg Relax Time* is used in the function to determine when to go into relaxation mode. When ***Current*** is greater than (–)*Quit Current* and then goes within (±)*Quit Current* the *Dsg Relax Time*, the timer is initiated. If the current stays within (±)*Quit Current* until the *Dsg Relax Time* timer expires, then the bq27500 goes into relaxation mode. After 30 minutes in relaxation mode, the bq27500 starts checking if the dV/dt < 4 µV/s requirement for OCV readings is satisfied. When the battery relaxes sufficiently to satisfy these criteria, the bq27500 takes OCV reading for updating Qmax and for accounting for self-discharge. These updates are used in the Impedance Track™ algorithms.

Normal Setting: Care should be taken when interpreting discharge descriptions in this document while determining the direction and magnitude of the currents because they are in the negative direction. This is application specific. Default is 1800 seconds.

Chg Relax Time

The *Chg Relax Time* is used in the function to determine when to go into relaxation mode. When ***Current*** is greater than *Quit Current* and then goes within (±)*Quit Current* the *Chg Relax Time*, the timer is initiated. If the current stays within (±)*Quit Current* until the Chg Relax Time timer expires, then the bq27500 goes into relaxation mode. After approximately 30 minutes in relaxation mode, the bq27500 attempts to take accurate OCV readings. An additional requirement of dV/dt < 4µV/s (delta voltage over delta time) is required for the bq27500 to perform Qmax updates. These updates are used in the Impedance Track™ algorithms.

Normal Setting: This is application specific. Default is 60 seconds.

Quit Relax Time

The *Quit Relax Time* is a delay time to exit relaxation. If current is greater than *Chg Current Threshold* or less than *Dsg Current Threshold* and this condition is maintained during *Quit Relax Time*, then exiting relaxation is permitted.

Normal Setting: This is particular to handheld applications in which low duty cycle dynamic loads are possible. Default is 1 second.

State

IT Enable

This shows if the Impedance Track™ algorithm is active. When the Impedance Track™ algorithm is enabled, it is set to 1. The bq27500 also sets the *Update Status* to 0x01 and sets the ***flags*** [VOK] =1 and ***flags*** [QEN]=1

Normal Setting: This is set to 0 by default and has to be set manually to 1 after calibration and the golden image file is loaded.

App Status

This is for the cell profile status information.

RSVD	RSVD	RSVD	RSVD	RSVD	RSVD	UNSUPBAT	LU_PROF

- RSVD [7, 2]: These bits are reserved (RSVD).
- UNSUPBAT [1]: Indicating inserted battery is not supported in the current cell profiles. True when set.

  Normal Setting: Default is 0.
- LU_PROF [0]: last profile used by bq27500. When it is cleared, Cell 0 is last used. When it is set, Cell 1 is last used.

  Normal Setting: Default is 0.

Qmax Cell 0 , Qmax Cell 1

These are the maximum chemical capacity of the battery cell 0 and battery cell 1. The bq27500 can have two cell profiles stored. It also corresponds to capacity at a low rate of discharge such as a C/20 rate. This value is updated continuously by the bq27500 during use to keep capacity measuring as accurate as possible.

Normal Setting: Initially should be set to the battery cell data-sheet capacity. Default is 1000 mAh.

Cycle Count 0, Cycle Count 1

These are the numbers of cycles the battery has experienced with a range of 0 to 65.535. One cycle occurs when accumulated discharge ≥ *CC Threshold*.

Normal Setting: Initially should be set to 0 for fresh battery cell. The default is 0.

Update Status 0, Update Status 1

Two bits in this register are important:

- Bit 0 (0x01) of *Update Status 0* or *Update Status 1* register indicates that the bq27500 has learned new Qmax parameters and is accurate for cell 0 or cell 1, respectively.

The remaining bits are reserved.

Normal Setting: Bit 0 is user configurable; however, it is also a status flag that can be set by the bq27500. This bit should never be modified except when creating a golden image file. Bit 0 is updated as needed by the bq27500.

Avg I Last Run

The bq27500 logs the ***Average Current*** averaged from the beginning to the end of each discharge cycle. It stores this average current from the previous discharge cycle in this register.

Normal Setting: This register should never need to be modified. It is only updated by the bq27500 when required.

Avg P Last Run

The bq27500 logs the power averaged from the beginning to the end of each discharge cycle. It stores this average power from the previous discharge cycle in this register. To get a correct average power reading, the bq27500 continuously multiplies instantaneous Current to ***Voltage*** to get power. It then logs this data to derive the average power.

Normal Setting: This register should never need to be modified. It is only updated by the bq27500 when required.

3.5 Ra Tables

Figure 7. Ra Table Screen

This data is automatically updated during device operation. No user changes should be made except for reading the values from another pre-learned pack for creating “Golden Image Files”. See the application report *Going to Production With the bq2750x* (SLUA449). Profiles have format *Pack0 Ra* M or *Pack1 Ra* M where M is the number indicating state of charge to which the value corresponds.

Each subclass pair (*Pack0 Ra – Pack0 Rax* or *Pack1 Ra – Pack1 Rax*) in the Ra Table class is a separate profile of resistance values normalized at 0 degrees for the pack in a design. Pack0 (or Pack1) has two profiles. They are denoted by the x or absence of the x at the end of the subclass Title: **Ra,** or **Rax**. The purpose for two profiles for the pack is to ensure that at any given time at least one profile is enabled and is being used while attempts can be made to update the alternate profile without interference. Having two profiles also helps reduce stress on the flash memory.

Pack0 Ra

Pack0 Ra status

At the beginning of each of the two subclasses (profiles) is a status flag called *Pack0 Ra status*. This status flag indicates the validity of the table data associated with this flag and whether this particular table is enabled/disabled. Each status has one byte. It indicates whether the table is currently enabled or disabled. It has the following options:

1. 0x00: The data associated with this flag has had a resistance update and the *QMax Cell 0* has been updated
2. 0x05: The resistance data associated with this flag has been updated and the pack is no longer discharging (this is prior to a *Qmax Cell 0* update).
3. 0x55: The resistance data associated with this flag has been updated, and the pack is still discharging. (Qmax update attempt is not possible until discharging stops.)
4. 0xff: The resistance data associated with this flag is all default data.

Pack0 Ra flag

The next flag of each of the two subclasses (profiles) is a flag called *Pack0 Ra flag*. This flag indicates the validity of the table data associated with this flag and whether this particular table is enabled/disabled. Each status has one byte. It indicates whether the table is currently enabled or disabled. It has the following options:

1. 0x00 : This means that the table has had a resistance update in the past; however, it is not the currently enabled table for the pack. (The alternate table for the cell must be enabled at this time.)
2. 0xff: This means that the values in this table are default values. These table resistance values have never been updated, and this table is not the currently enabled table for the pack. (The alternate table for the indicated cell must be enabled at this time.)
3. 0x55: This means that this table is enabled for the indicated pack. (The alternate table must be disabled at this time.)

This data is used by the bq27500 to determine which tables need updating and which tables are being used for the Impedance Track™ algorithm.

Normal Setting: This data is used by the bq27500 Impedance Track™ algorithm. The only reason this data is displayed and accessible is to give the user the ability to update the resistance data on golden image files. This description of the *Pack0 Rax flags* are intended for information purposes only. It is not intended to give a detailed functional description for the bq27500 resistance algorithms.

Pack0 Ra Base R

Base R is the first data point in the normalized resistance table. It is used with *Ra Gain* and normalized *Ra M* (*M* is from 1–14) data to get the actual *Ra* value.

Pack0 Ra Gain

Gain is the data that is being used with *Base R* and normalized *Ra M* (*M* is from 1–14) data to get the actual *Ra* value.

Pack0 Ra 1 – Pack0 Ra 14

The **Ra Table** class has 15 values for each Ra subclass. Each of these values represent a resistance value normalized at 0°C for the associated *Qmax Cell 0* -based SOC gridpoint as found by the following rules:

For *Pack0 Ra M* where:

1. If $0 \leq M \leq 7$: The data is the resistance normalized at 0° for: SOC = 100% – (M × 11.1%)
2. If $8 \leq M \leq 14$: The data is the resistance normalized at 0° for: SOC = 100% – [77.7% + (M – 7) × 3.3%]

This gives a profile of resistance throughout the entire SOC profile of the battery cells concentrating more on the values closer to 0%.

Normal Setting: SOC as stated in this description is based on *Qmax Cell 0 or Qmax Cell 1*. It is not derived as a function of SOC. These resistance profiles are used by the bq27500 for the Impedance Track™ algorithm. The only reason this data is displayed and accessible is to give the user the ability to update the resistance data on golden image files. This resistance profile description is for information purposes only. It is not intended to give a detailed functional description for the bq27500 resistance algorithms. It is important to note that this data is in mΩ units and is normalized to 0°C. The following are useful observations to note with this data throughout the application development cycle:

1. Watch for negative values in the **Ra Table** class. Negative numbers in profiles should never be anywhere in this class.
2. Watch for smooth consistent transitions from one profile gridpoint value to the next throughout each profile. As the bq27500 does resistance profile updates, these values should be roughly consistent from one learned update to another without huge jumps in consecutive gridpoints.

Pack1 Ra

Similar to *Pack0 Ra* section, this section is for Pack1. See *Pack0 Ra* section for all the definitions.

Pack0 Rax

This is the mirror profile of *Pack0 Ra* profile. The purpose is to ensure that at any given time at least one profile is enabled and is being used while attempts can be made to update the alternate profile without interference. Having two profiles also helps reduce stress on the flash memory. See *Pack0 Ra* section for all the definitions.

Pack1 Rax

This is the mirror profile of *Pack1 Ra* profile. The purpose is to ensure that at any given time at least one profile is enabled and is being used while attempts can be made to update the alternate profile without interference. Having two profiles also helps reduce stress on the flash memory. See *Pack0 Ra* section for all the definitions.

3.6 Default Ra Tables

Figure 8. Default Ra Table Screen

This data is automatically updated when “Golden Image Files“ from another pre-learned pack is programmed into the current pack. No user change should be made. This data is kept in the data flash through the life of the 27500 unless another manual data flash updated is executed.

Def0 Ra, Def1 Ra

Each subclass (*Def0 Ra – Def1 Ra*) in the Default Ra Table class is a separate profile of resistance values normalized at 0 degrees for the two packs in a design. Similar to the Ra Table, each of the subclasses has *Ra Status, Ra flag, Ra Base R, Ra Gain, and Ra1–Ra14*. Impedance Track™ only updates one set of Ra tables in an initial learning cycle. Then the *Def0 Ra*, *Def1 Ra*, *Pack0 Rax*, *Pack1 Ra*, and *Pack1Rax* are all the same as the Pack0 Ra after the learning cycle that makes Update Status = 02.

3.7 Calibration

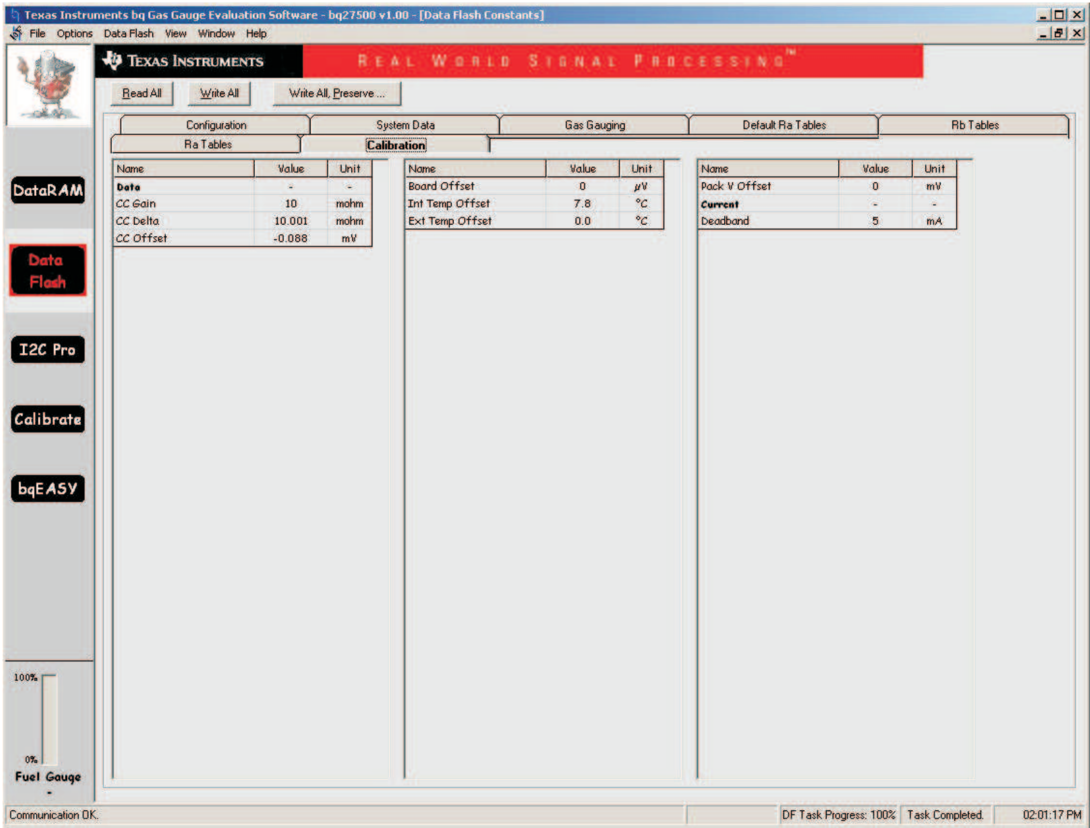


Figure 9. Calibration Screen

Data

Most of these values should never require modification by the user. They should only be modified by the Calibration commands in Calibration mode as explained in the application report *Going to Production With the bq2750x* (SLUA449).

CC Gain

This is the gain factor for calibrating Sense Resistor, Trace, and internal Coulomb Counter (integrating ADC delta sigma) errors. It is used in the algorithm that reports ***Average Current***. The difference between *CC Gain* and *CC Delta* is that the algorithm that reports Current cancels out the time base because ***Average Current*** does not have a time component (it reports in mA) and CC Delta requires a time base for reporting ***Remaining Capacity*** (it reports in mAh).

Normal Setting: *CC Gain* should never need to be modified directly by the user. It is modified by the current calibration function from Calibration mode. See the application report *Going to Production With the bq2750x* (SLUA449) for more information.

CC Delta

This is the gain factor for calibrating Sense Resistor, Trace, and internal Coulomb Counter (integrating ADC delta sigma) errors. It is used in the algorithm that reports charge and discharge in and out of the battery through the ***Remaining Capacity*** register. The difference between *CC Gain* and *CC Delta* is that the algorithm that reports ***Average Current*** cancels out the time base because ***Average Current*** does not have a time component (it reports in mA) and *CC Delta* requires a time base for reporting ***Remaining Capacity*** (it reports in mAh).

Normal Setting: *CC Delta* should never need to be modified directly by the user. It is modified by the current calibration function from Calibration mode. See the application report *Going to Production With the bq2750x* (SLUA449) for more information.

CC Offset

Two offsets are used for calibrating the offset of the internal Coulomb Counter, board layout, sense resistor, copper traces, and other offsets from the Coulomb Counter readings. *CC Offset* is the calibration value that primarily corrects for the offset error of the bq27500 Coulomb Counter circuitry. The other offset calibration is *Board Offset* and is described next. To minimize external influences when doing *CC Offset* calibration either by automatic *CC Offset* calibration or by the *CC Offset* calibration function in Calibration Mode, an internal short is placed across the SRP and SRN pins inside the bq27500. *CC Offset* is a correction for small noise/errors; therefore, to maximize accuracy, it takes about 20 seconds to calibrate the offset. Because it is impractical to do a 20-s offset during production, two different methods for calibrating *CC Offset* were developed.

1. The first method is to calibrate *CC Offset* by the putting the bq27500 in Calibration mode and initiating the *CC Offset* function as part of the entire bq27500 calibration suite. See the application report *Going to Production With the bq2750x* (SLUA449) for more information on the Calibration mode. This is a short calibration that is not as accurate as the second method, *Board Offset*. Its primary purpose is to calibrate *CC Offset* enough so that it does not affect any other Coulomb Counter calibrations. This is only intended as a temporary calibration because the automatic calibration, *Board Offset*, is done the first time the I2C Data and Clock is low for more than 20 seconds, which is a much more accurate calibration.
2. During normal Gas Gauge Operation when the I2C clock and data lines are low for more than 5 seconds and ***Average Current*** is less than *Sleep Current* in mA, then an automatic *CC Offset* calibration is performed. This takes approximately 16 seconds and is much more accurate than the method in Calibration mode.

Normal Setting: *CC Offset* should never be modified directly by the user. It is modified by the current calibration function from Calibration mode or by Automatic Calibration. See the application report *Going to Production With the bq2750x* (SLUA449) for more information on calibration.

Board Offset

Board Offset is the second offset register. Its primary purpose is to calibrate all that the *CC Offset* does not calibrate out. This includes board layout, sense resistor and copper trace, and other offsets that are external to the bq27500 integrated circuit (IC). The simplified ground circuit design in the bq27500 requires a separate board offset for each tested device.

Normal Setting: This value should only be set one time when all the other data flash constants are modified during the pack production process.

Int Temp Offset

The bq27500 has a temperature sensor built into the IC. The *Int Temp Offset* is used for calibrating offset errors in the measurement of the reported ***Temperature*** if the internal temperature sensor is used. The gain of the internal temperature sensor is accurate enough that a calibration for gain is not required.

Normal Setting: *Int Temp Offset* should never need to be modified by the user. It is modified by the internal temperature sensor calibration command in Calibration mode. *Int Temp Offset* should only be calibrated if the internal temperature sensor is used. See the application report *Going to Production With the bq2750x* (SLUA449) for more information on calibration.

Ext Temp Offset

Ext Temp Offset is for calibrating the offset of the thermistor connected to the TS1 pin of the bq27500 as reported by ***Temperature***. The gain of the thermistor is accurate enough that a calibration for gain is not required.

Normal Setting: *Ext Temp Offset* should never need to be modified by the user. It is modified by the external temperature sensor calibration command in Calibration Mode. *Ext Temp Offset* should only be calibrated if a thermistor is connected to the TS pin of the bq27500. See the application report *Going to Production With the bq2750x* (SLUA449) for more information on calibration.

Pack V Offset

This is the offset to calibrate the bq27500 analog-to-digital converter for cell voltage measurement.

Normal Setting: *Pack V Offset* should never be modified directly by the user. It is modified by the Voltage Calibration function from Calibration mode. This value should only be set one time when all the other data flash constants are modified during the pack production process.

Current

Deadband

The purpose of the *Deadband* is to create a filter window to the reported ***Average Current*** register where the current is reported as 0. Any negative current above this value or any positive current below this value is displayed as 0.

Normal Setting: This defaults to 3 mA. Only a few reasons may require changing this value:

1. If the bq27500 is not calibrated.
2. *Board Offset* has not been characterized.
3. If the PCB layout has issues that cause inconsistent board offsets from board to board.
4. An extra noisy environment along with reason 3.

Chapter 4

Feature Set Comparison of bq27x00, bq27x10, bq27500 and bq27510

Ming Yu

Provides a side-by-side comparison of the devices.

		bq27000	bq27200	bq27010	bq27210	bq27500	bq27510
HARDWARE	package designator	SON-DRK	SON-DRK	SON-DRK	SON-DRK	SON-DRZ	SON-DRZ
	package size	4x3mm	4x3mm	4x3mm	4x3mm	4x2.5mm	4x2.5mm
	device pin	10	10	10	10	12	12
	BAT pin Voltage Divider	No	No	No	No	Internal	Internal
	Register backup	through RBI pin	through RBI pin	through RBI pin	through RBI pin	No	No
	Thermistor	internal	internal	internal	internal	internal or external	internal or external
	GPIO count	1	1	1	1	0	0
	internal LDO	No	No	No	No	No	Yes
COMMUNICATION	interface	HDQ	I2C	HDQ	I2C	I2C	I2C
FIRMWARE		ROM code	ROM code	enhanced ROM code	enhance ROM code	Flash with ROM	Flash with ROM
GAUGING ALGORITHM	method	EDV	EDV	compensated EDV (CEDV)	compensated EDV (CEDV)	Impedance Track	Impedance Track
	OCV look up table	OCV table loacted in host	OCV table loacted in host	NOT compute the maximum load current, maximum load time-to-empty, available energy, and average power	NOT compute the maximum load current, maximum load time-to-empty, available energy, and average power	OCV table located in device	OCV table located in device
		compute the maximum load current, maximum load time-to-empty, available energy, and average power	compute the maximum load current, maximum load time-to-empty, available energy, and average power	improved remaining capacity compensation at cold temperature, age compensation of remaining capacity, and rate and temperature compensation. NOT compute the maximum load current, maximum load time-to-empty, available energy, and average power.	improved remaining capacity compensation at cold temperature, age compensation of remaining capacity, and rate and temperature compensation, NOT compute the maximum load current, maximum load time-to-empty, available energy, and average power.	accurately measuring the remaining capacity and predict run time based on impedance track algorithm	accurately measuring the remaining capacity and predict run time based on impedance track algorithm
Application	system side or pack side	pack	pack	system or pack special memory location assigned for multiple cell tracking	system or pack special memory location assigned for multiple cell tracking	system	system

Chapter 5

Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family

Ming Yu, Yevgen Barsukov, and Michael Vega

Battery Management

ABSTRACT

This application report outlines the theory of Impedance Track™[1] (IT) technology used in the bq2750x series of fuel gauge ICs for single-cell Li-ion application (e.g., smart phones, media players, and PDAs). The implementation of the IT algorithm in the bq2750x family is reviewed, and the setting of data flash constants associated with the fuel-gauging algorithm is described in detail.

(1) Impedance Track algorithm is protected by US Patents US6832171, US6789026, and US6892148.

5.1 Summary of the Algorithm Operation

The gas gauge algorithm uses three types of information to calculate remaining capacity (*DataRAM.Remaining Capacity( )*) and full-charge capacity (*DataRAM.Full Charge Capacity( )*).

1. Chemical: depth of discharge (DOD) and total chemical capacity Q_{max}
2. Electrical: internal battery resistance dependence on DOD
3. External: load and temperature

DataRAM.Full Charge Capacity( ) is defined as the amount of charge passed from a fully charged state until the voltage defined in *DF.Terminate Voltage* flash constant is reached at a given rate of discharge, after subtracting the reserve capacity *(DF.Reserve Capacity)*.

Note that *DataRAM.Full Charge Capacity( )* depends on the rate of discharge and is lower at higher rates and low temperatures because the cell I*R drop causes the Terminate Voltage threshold to be reached earlier.

5.2 Parameters Updated by the Gas Gauge in More Detail

Modes of Algorithm Operation

The algorithm differentiates between *charge*, *discharge*, and *relaxation* modes of operation. During *charge* mode, the *DataRAM.Flags( ) [DSG]* bit is cleared, and during *discharge* and *relaxation* mode, it is set. Entry and exit of each mode is controlled by Data Flash (DF) parameters in the subclass Gas Gauging: Current Thresholds section as illustrated in Figure 10. Charge mode is exited, and relaxation mode is entered when *DataRAM.Average Current( )* goes below *DF.Quit Current* after *DF.Chg Relax Time* period. Discharge mode is entered when *DataRAM.Average Current( )* goes below *DF.Dsg Current Threshold* and after *DF. Quit Relax Time* period. Discharge mode is exited, and relaxation mode is entered when *DataRAM.Average Current( )* goes above negative *DF.Quit Current* threshold and after *DF.Dsg Relax Time* period. Charge mode is entered when *DataRAM.Average Current( )* goes above *DF.Chg Current Threshold* and after *DF.Quit Relax Time* period.

Update of Chemical Depth of Discharge (DOD)

The gas gauge updates information on chemical depth of discharge (DOD_0) based on open-circuit voltage (OCV) readings when in a *relaxed* state. DOD is found by correlating DOD with OCV using a predefined table DOD(OCV,T) stored as reserved data flash parameters. The table is specific for a particular chemistry such as $LiCoO_2$/carbon, $LiMn_2O_4$/carbon etc., and can be identified by reading the chemistry ID through sending ChemID( ) command 0x0008, then reading ChemID(). The gas gauge can be set up for a particular chemistry by using a specific firmware file (*.senc) that can be downloaded from bq2750x production folder on power.ti.com. The chemistry profile also can be programmed into bq2750x using the bqEASY wizard.

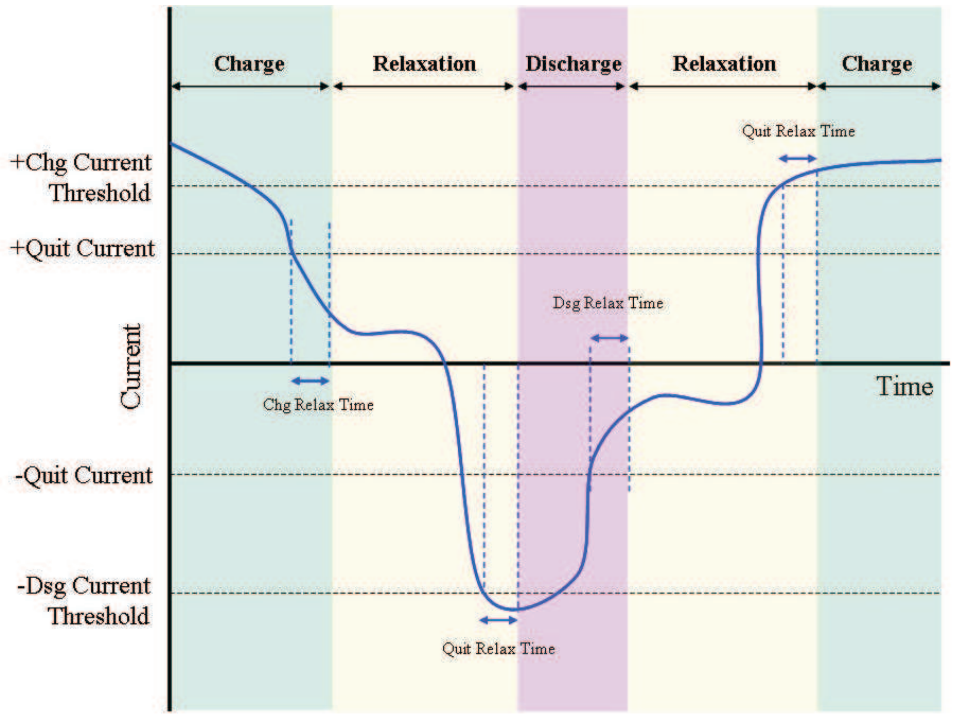


Figure 10. Example of Algorithm Operation Mode Changes With Varying *DataRAM.Average Current( )*

Figure 11 shows the timing of parameter updates during relaxation mode. After a 30-minute relaxation period is passed, the dV/dt <4 µV/s condition is checked. Once it is satisfied, OCV readings are taken. After that, OCV readings continue to be taken every 100 seconds. DOD is calculated based on each measured OCV reading using linear interpolation DOD = f(OCV,T). Integrated PassedCharge is set to zero at each DOD_0 update.

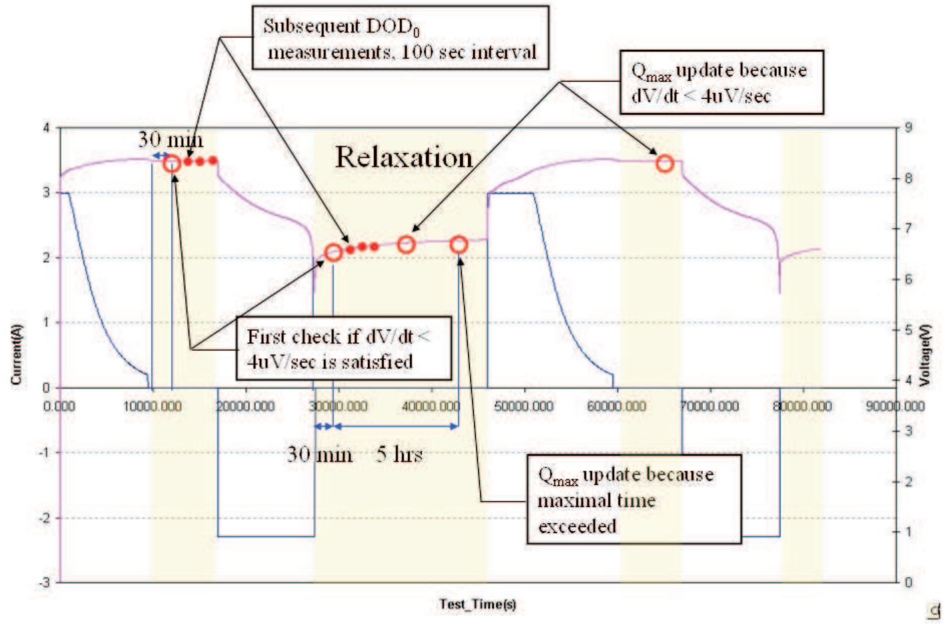


Figure 11. Timing of DOD_0 and Q_{max} Updates During Relaxation Mode

If the current during the OCV reading is non-zero, then an IR correction is done. The first iteration of DOD is found from the uncorrected OCV reading; then the resistance value is found from the R(DOD) table and used to correct the OCV value as OCV`=OCV-I*R. Then, the corrected DOD is found from OCV`. This method achieves the best accuracy if the current during relaxation mode is below a C/20 rate. This is why it is recommended that the *DF.Quit Current* not exceed C/20.

If no DOD_0 has been measured until the relaxation state is exited, the previous DOD_0 is used along with the PassedCharge integrated since the last DOD reading.

During charge and discharge modes, the *present* DOD is recalculated every second as DOD = DOD_0 + PassedCharge/Q_{max}. DOD is used for determining when a resistance update needs to occur, as well as the starting point for a Remaining Capacity (and FCC) calculation. Remaining capacity calculations occur immediately after discharge onset, at every resistance update, and after entering relaxation mode

Update of Q_{max}

Maximal chemical capacity Q_{max} for a battery cell is stored in Data Flash as *DF.Qmax Cell x*, where x = 0,1, the cell number. The GG updates Q_{max} based on two DOD readings made before and after charge, or discharge. For example, DOD_1 is taken during relaxation, then a discharge mode starts, and PassedCharge is integrated. Following this, another relaxation mode is entered, and DOD_2 is taken;

DOD_1 and DOD_2 are calculated from OCV readings in a well-relaxed state, as exemplified in Figure 11 for subsequent DOD_0 measurement. A well-relaxed state is detected if dV/dt<4 µV/s or maximal waiting time of 5 hours is exceeded. The first condition is satisfied in typical batteries after approximately 1 hour if DOD is between 0 and 80%, and 3–4 hours if DOD is above 80%. At low temperature relaxation takes a longer time.

In order to ensure high accuracy of the DOD measurement, the Q_{max} calculation does not occur if the temperature is above 40°C, or below 10°C. It also does not occur if at least one of voltage measurements for DOD_1 or DOD_2 was taken in the cell voltage range between 3737 mV and 3800 mV because of very flat OCV(DOD) dependence in this range. These limits are chemistry dependent and are specified for different chemistries separately.

Q_{max} is calculated as Q_{max} = PassedCharge / (DOD_2 – DOD_1)

The data flash constant *DF.Update Status* increments by 1 when the first Q_{max} update takes place (e.g., from 0 to 1 if no resistance update were made or from 1 to 2 if a resistance update was made).

PassedCharge has to be more than 37% of *DF.Design Capacity* for an update to occur. For the first cycle (with *DF.Update Status* = 0), 90% of *DF.Design Capacity* is required because this cycle takes place in the factory settings and Q_{max} is learned for the first time.

In order to prevent Q_{max} fluctuations, a first-order smoothing filter is applied to all Q_{max} readings except in the first cycle. Readings with lower PassedCharge are assigned lower weights in the smoothing.

Update of Resistance

Resistance is updated during discharge, as summarized in Figure 12. The first resistance update happens after a certain waiting time to prevent distortion from transients after a load onset. The waiting time is 500 seconds by default, but later the update waiting time decreases if the maximal discharge duration (*DF.Max Dsg Duration*) is less than 500 seconds. The waiting time is defined as *DF.Max Dsg Duration* –200. Waiting time can decrease to as short as 100 seconds.

The calculation is performed by comparing the measured voltage with the OCV value at the same DOD, that is taken from the OCV(DOD,T) table:

dV = V – OCV(DOD,T)

R(DOD) = dV/I

Resistance measurements are taken continuously and stored in RAM.

Resistance is updated in the Data Flash (in *DF.Ra Table*) after each 11.1% of DOD charge is exceeded (DOD charge is PassedCharge/Q_{max}). When DOD reaches 77.7%, resistance is updated after each 3.3%. The final resistance update is made after discharge is terminated. .

The constant *DF.Update Status* increments by 1 when the first grid-point resistance update takes place (e.g., from 0 to 1 if no Q_{max} update were made before, or from 1 to 2 if a Q_{max} update was made before).

Before storage to Data Flash, the resistance values are normalized to 0°C as Ra[dod] = R[dod]/exp(Rb[dod]*T) where R is the measured resistance value at a given DOD. Rb[DOD] is the value of temperature coefficient of impedance change at a given DOD stored as a reserved data-flash table, and T is temperature in °C. Note that values of resistance normalized to 0°C are somewhat larger than values at room temperature and so cannot be directly compared with R=dV/I values.

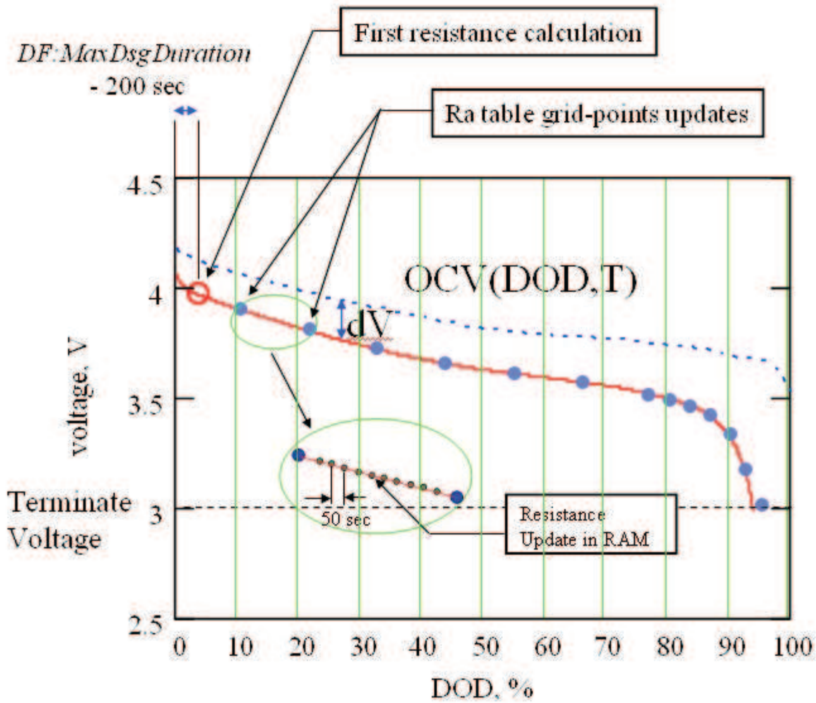


Figure 12. Impedance Updates

Resistance values for the grid points with a higher DOD than presently updated are scaled by the same factor as the present grid-point change, e.g., by factor Ra_new/Ra_old. In this way, faster convergence of the resistance profile is achieved.

Values in *DF.Ra Table* are stored in milliohm units, in the format *DF.PackX Ra N* where X is pack number from 0 to 1, and N is grid-point number from 0 to 14 that corresponds to 11.1% increments of DOD until 77.7%, and then 3.3% increments of DOD. In bq27500, there are two Ra tables (Ra and Rax) for each of the supported two battery packs. To save data-flash space, tables are compressed. Two additional parameters (Base R and Gain) are used in compression. The *decompression* formula for I=1..14 is R[i] = Base R + sum(R_compressed[k], k = 1 .. I)$\times 2^{Gain}$, and R[0]=Base R.

The *DF.PackX Ra flag* and *DF.PackX Rax flag* are used for interchanging data-flash column usage for reducing the number of DF writes. A flag value of 55 indicates the presently used data column, whereas FF indicates the presently unused data column.

Before *DF.Update Status* is set to 2, if during resistance update DOD exceeds 100%, or resistance appears negative, which are both indications of a too-small DF.Q_{max} Cellx initial guess, *DF.Qmax Cell x* will increment by 11.1%, and all resistances will be recalculated. This is normal behavior during the first *learning* cycle. However, if the initial guess of *DF.Qmax Cell x* was too far from the correct value, a second cycle might be needed to achieve full resistance accuracy. To avoid this, set *DF.Qmax Cell x* to a value specified by the cell manufacturer, multiplied by number of parallel cells.

After *DF.Update Status* is set to 2, resistance change is limited to below 5 times and above 0.2 times of its original value, and to positive values.

Update of Temperature Model

Because temperature changes significantly during the course of a discharge, the algorithm needs to be able to predict the future temperature. This is needed for temperature correction of battery impedance (R = Ra x exp(Rb x T)) during voltage simulation near the end of discharge. To achieve this, the algorithm collects T(t) dependence data during discharge. It is used to update parameters of a simple thermal model including a heat exchange coefficient and a thermal time constant. These parameters are updated at the same time as resistances. The algorithm also records the outside temperature (T_out) during relaxation periods. These parameters are used to define a function T(t, T_start) that calculates a temperature profile starting from present temperature, T_start, and continuing until the end of discharge.

Update of DataRAM.Remaining Capacity (RM) and DataRAM.Full Charge Capacity (FCC)

Update of RM and FCC takes place after each resistance grid-point update, at the end of discharge, and at the exit of relaxation mode.

FCC consists of three parts:

DataRAM.Full Charge Capacity( ) = Q_{start}+ PassedCharge + RM

Components of FCC are indicated in an example in Figure 13.

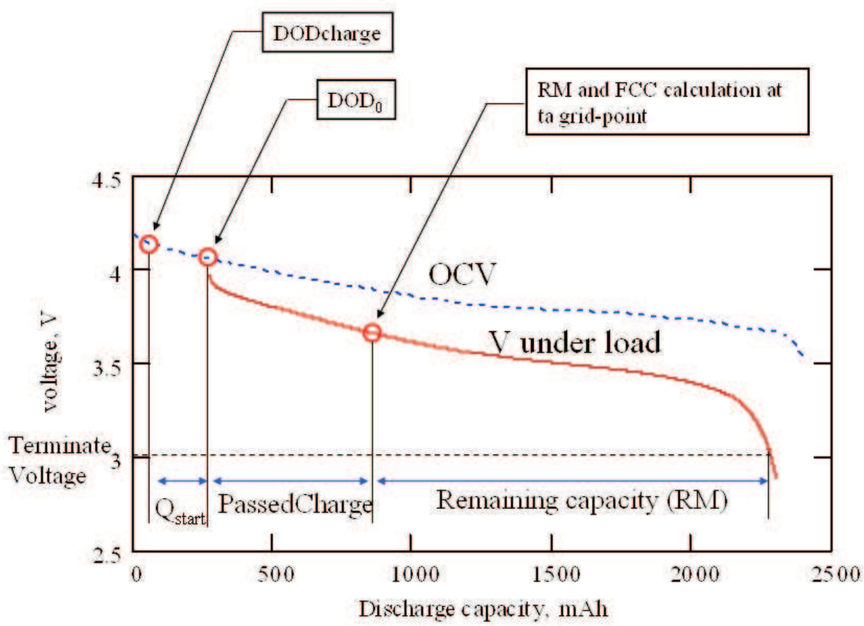


Figure 13. Components of *DataRAM.Full Charge Capacity( )* Value

1. Q_{start} is the charge that would have passed to make DOD = DOD_0 from a fully charged state (DODcharge). For a fully charged battery Q_{start} = 0. Q_{start} is recalculated at the exit of relaxation mode. In the case of constant current, it is simply $Q_{start} = Q_{max} \times (DOD_0 - \text{DODcharge})$, but for the constant power case a voltage simulation is run. DODcharge is assigned equal to DOD_0 at first DOD_0 update after charge termination by taper current. Note that DODcharge is somewhat higher than 0 because chargers typically do not charge a battery to full.
2. PassedCharge is the coulomb count integrated during the present discharge or charge and set to zero at every DOD_0 update.
3. Remaining capacity is calculated after each resistance grid-point update and at the end of discharge

DataRAM.Remaining Capacity( ) (RM) is calculated using a voltage simulation. The GG starts a simulation at the present DODstart = DOD_0 + PassedCharge/Q_{max} and continues calculating voltage V(DODx,T) = OCV(DODx,T)+ I×R(DODx,T) by incrementing DOD with dDOD increment of 4%. DOD[i]=DODstart + dDOD×I. This incrementing is continued until the simulated voltage V(DOD[i]) becomes less than *DF.Terminate Voltage*. Once that happens, the final DOD is revealed. *DataRAM.Remaining Capacity( )* = (DODfin-DODstart)×Q_{max}.

Current that is used in the simulation is the average current during the present discharge (several types of averaging can be selected using *DF.Load Select* data flash constant). A simulation can run in constant current mode (*DF.Load Mode* = 0) or constant power mode (*DF.Load Mode* = 1).

Update of DataRAM.Remaining Capacity( ) and DataRAM.State Of Charge( ) Values

Whereas *DataRAM.Full Charge Capacity( )* is only updated at a few points during a discharge as previously described, the *DataRAM.Remaining Capacity( )* is updated continuously (every 1 second) based on the integrated charge. *DataRAM.Remaining Capacity( )* = RM – Q_integrated where Q_integrated is charge passed since the last RM calculation. The value of *DataRAM.Remaining Capacity( )* is also used to update relative *DataRAM.State Of Charge( )* every second as relative *DataRAM.State Of Charge( ) = DataRAM.Remaining Capacity( )* × 100/ *DataRAM.Full Charge Capacity( )*.

The same value is used to calculate run time to empty as *DataRAM.Time To Empty( ) = DataRAM.Remaining Capacity( )* / *DataRAM.Average Current( )*.

Note that even if a simulation of RM is run in constant power mode (*DF.Load Mode* = 1), the reporting of *DataRAM.Remaining Capacity( )* and *DataRAM.Time To Empty( )* can be done in both mAh or in 10-mWh values. These values are always reported in mAh or are derived from mAh values:

- *DataRAM.Remaining Capacity( )*
- *DataRAM.Full Charge Capacity( )*
- *DataRAM.Time To Empty( )*
- *DataRAM.Nominal Avail. Capacity( )*
- *DataRAM.Full Available Capacity( )*
- *DataRAM.State of Charge( )*

These values are always reported in mWh or derived from mWh values:

- *DataRAM.Available Energy( )*
- *DataRAM.Average Power( )*
- *DataRAM.TimeToEmpty Const. Power( )*

In case of constant power mode (*DF.LoadMode* = 1), the run time to empty is calculated as *DataRAM.TimeToEmpty( ) = DataRAM.AvailableEnergy( )* / *DataRAM.AveragePower( )* and is generally more accurate for most devices because of increased power consumption at low voltages.

5.3 Real Application Example

GSM Smart Phone Application

Unlike notebook battery applications with a relatively constant load profile, cell phone/smart phone or PDA, depending on the actual communication protocol (GSM, CDMA, 3G GSM or 3G CDMA), has a pulsating load profile. Questions for this type of application are always related to how the Impedance Track™ can accurately predict the battery remaining capacity. What is the impact of the pulsating current? In this example, a GSM smart phone is used to check out the Impedance Track™ accuracy.

As previously mentioned, both the Q_{max} and Resistance can be updated only when certain criteria are met. Under a pulsating current, an accurate OCV reading may be difficult to achieve. A discussion of careful examination of these criteria follows.

First of all, it has to be made clear that zero current is NOT needed for an OCV reading. Only a LOW current (i.e., less than C/20 rate) is needed. This is common in cell phone/smart phone application when the phone is in standby mode. During the relaxation, a short spike current pulse will not wake-up the gauge from relaxation mode because the *DF.Quit Relax Time = 1* by default. Current has to stay high longer than 1 second to exit the relaxation mode.

Secondly, if a single voltage read point was taken exactly at the moment of the spike, it is ignored because the IT checks if the current exceeded *DF.Dsg Current Threshold*. If it did, then the previous OCV reading is used. As shown in Figure 12, these reading are stored in RAM.

The GSM phone used in this testing is a registered phone. During testing, actual phone calls along with applications such as playing games, checking emails, as well as standby mode, are used. The battery voltage and the discharge current are logged with time stamp. The reported RSOC by IT is also logged.

As shown in Figure 15, the current reported by IT is being averaged by both a analog-to-digital converter (ADC) in the device as well as by IT algorithm. Although the GSM phone is running on GSM protocol* but the reported peak current is around 200 mA to 300 mA when the phone's LCD screen is on and only around 80 mA when the screen is off.

*GSM waveform: 1A for 0.48ms and 72mA for 4.76ms

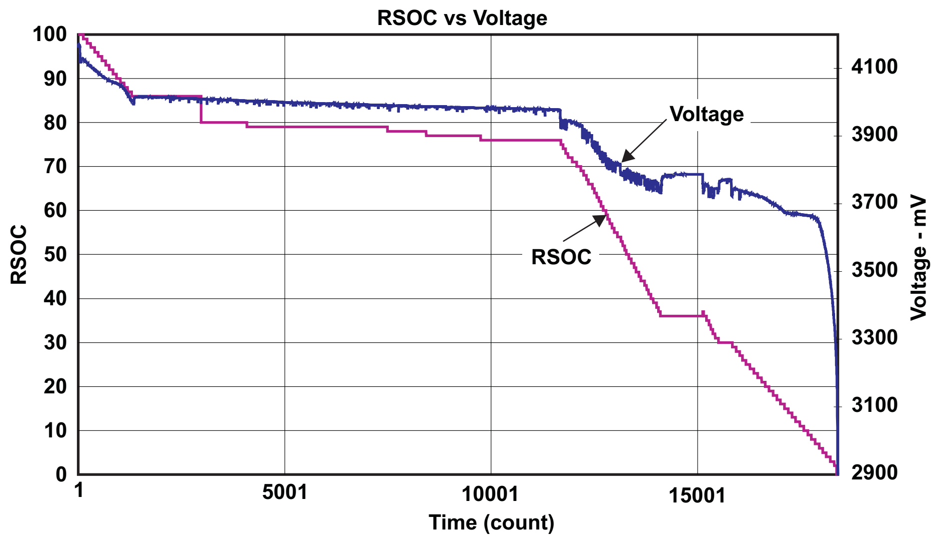


Figure 14. GSM Smart Phone: Relative State of Charge (RSOC) vs Battery Voltage

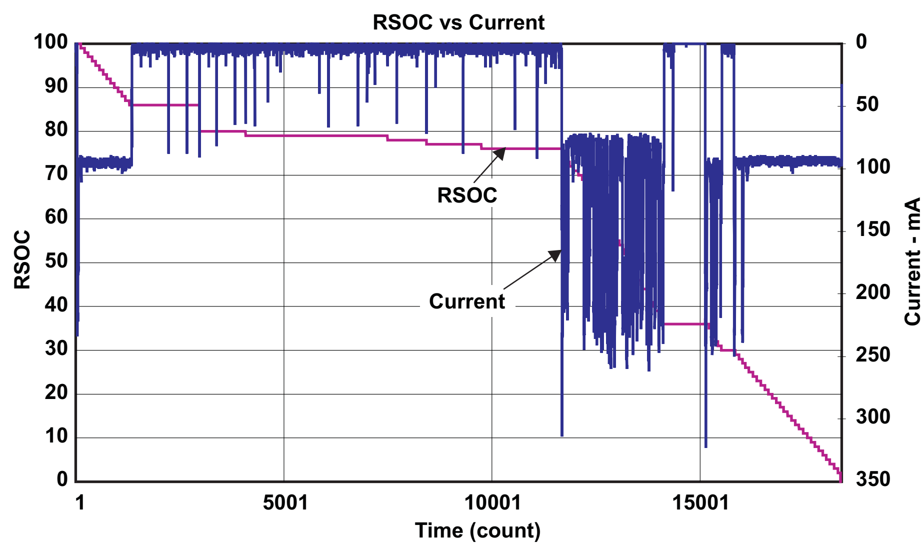


Figure 15. GSM Smart Phone: Relative State of Charge (RSOC) vs Discharge Current

The RSOC accuracy for this particular test then is calculated from the data log file and Figure 16 shows the RSOC accuracy during the whole discharge cycle. As the discharge starts, the error is around 4% but as the phone goes into standby mode, which is around RSOC = 85%, the accurate OCV reading is taken by IT regardless of the high-current spikes (with delay). From RSOC = 80% down to RSOC = 0%, the accuracy is within 2%.

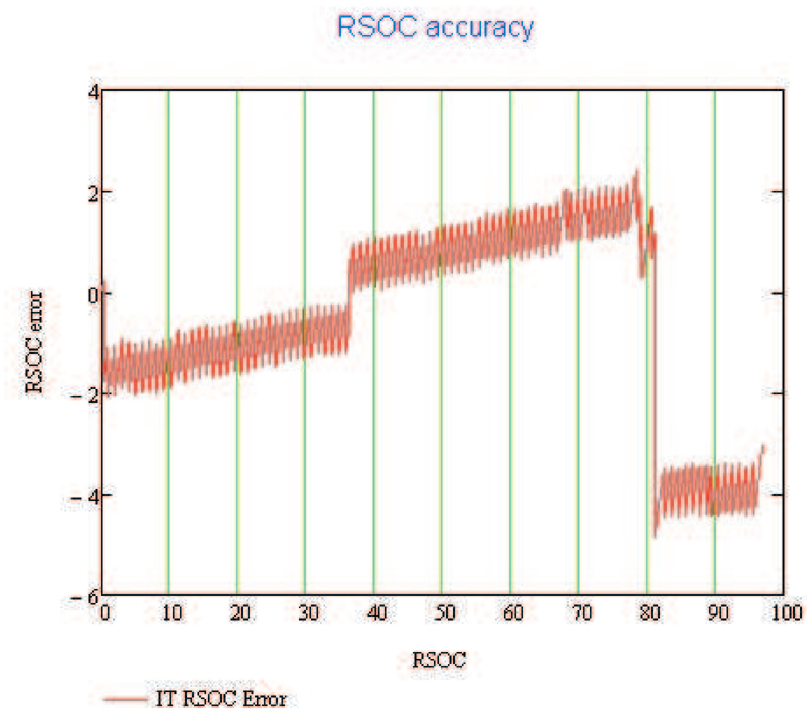


Figure 16. GSM Smart Phone: RSOC Accuracy

This test has proved that the IT algorithm works as expected even for a pulsating load profile. The high-current spike does not affect the IT accuracy.

After comparing the original data flash contents against the final data flash contents (see Figure 17), it is clearly shown that Q_{max} has been updated during the real application test. It has proven that the gauge can meet the Q_{max} update conditions to complete Q_{max} update as well as RSOC update.

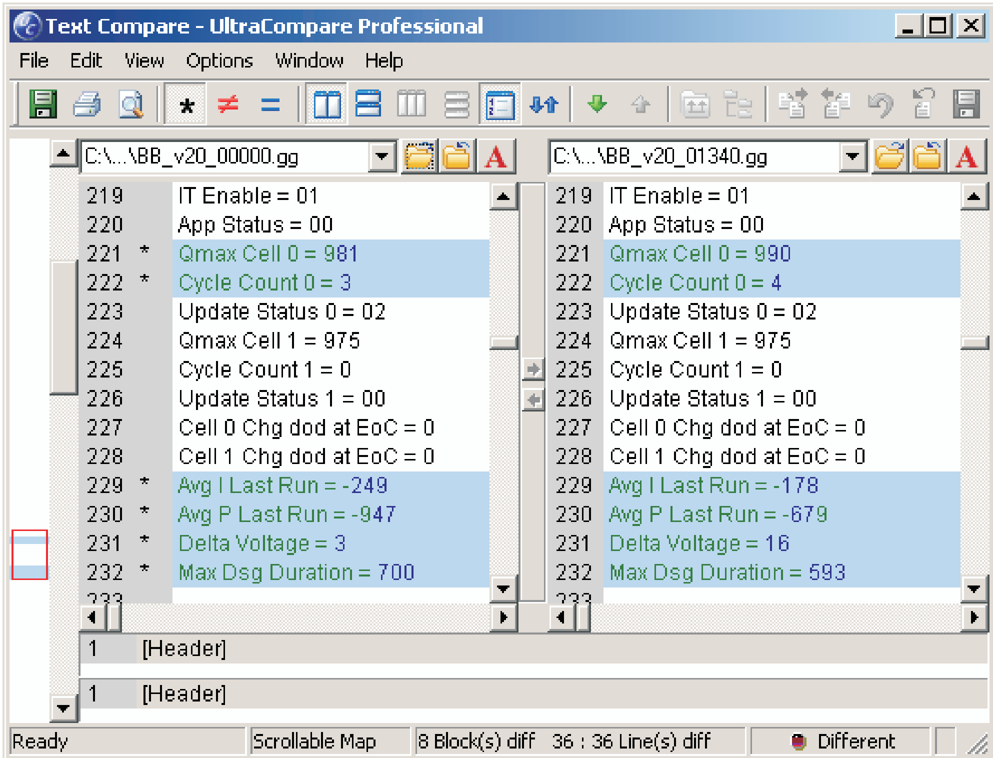


Figure 17. Flash Data Log Shown Q_{max} Has Been Updated

Chapter 6

bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module

This evaluation module (EVM) is a complete evaluation system for the bq2750x. The EVM includes one bq2750x circuit module, a current sense resistor, one thermistor, an EV2300 PC interface board for gas gauge interface, a PC USB cable, and Windows™-based PC software. The circuit module includes one bq27500 or bq27501 integrated circuit (IC), one TPS71525 IC, and all other onboard components necessary to monitor and predict capacity for a system side fuel gauge solution. The circuit module connects directly across the battery pack. With the EV2300 interface board and software, the user can read the bq2750x data registers, program the chipset for different pack configurations, log cycling data for further evaluation, and evaluate the overall functionality of the bq2750x solution under different charge and discharge conditions.

6.1 Features

- Complete evaluation system for the bq2750x gas gauge with Impedance Track™ Technology
- Populated circuit module for quick setup
- PC software and interface board for easy evaluation
- Software that allows data logging for system analysis

Kit Contents

- bq2750x/TPS71525 circuit module (HPA291)
- EV2300 PC interface board
- Software CD with the evaluation software
- USB connection cable to interface board
- NTC103AT Thermistor
- Set of support documentation

Ordering Information

Table 3. Ordering Information

EVM PART NUMBER	CHEMISTRY	CONFIGURATION	CAPACITY
bq27500EVM	Li-ion	1 cell	Any
bq27501EVM	Li-ion	1 cell	Any

6.2 bq2750x-Based Circuit Module

The bq2750x-based circuit module is a complete and compact example solution of a bq2750x circuit for battery management. The circuit module incorporates a bq2750x battery gas gauge IC, a TPS71525 LDO regulator, and all other components necessary to accurately predict the capacity of 1-series Li-Ion cell.

Circuit Module Connections

Contacts on the circuit module provide the following connections:

- Direct connection to the battery pack (J8 or J9): PACK+, PACK-, T and RID (bq27501 only)
- To the serial communications port (J4): SDA, SCL and VSS
- The system load and charger connect across charger and load (J6 and J7): CHARGER+/LOAD+ and CHARGER-/LOAD-
- Access to signal outputs (J2): BAT_LOW and /BAT_GD
- Optional 2.5V input if powering IC from actual system power (J3): 2.5V INPUT and VSS

Pin Descriptions

PIN NAME	DESCRIPTION
PACK+	Pack positive terminal
PACK-	Pack negative terminal
T	Pack thermistor input
NC/RID	Pack resistor ID input (bq27501 only)
SDA	I^2C communication data line
SCL	I^2C communication clock line
VSS	Signal return for communication line, shared with charger and ground
CHARGER+/LOAD+	High potential of load or charger connection
CHARGER-/LOAD-	Low potential of load or charger connection (System VSS)
BAT_LOW	Access to push-pull output that signals low State-of-charge
/BAT_GD	Access to open drain output that indicates that pack is ready to be connected to system

6.3 bq2750x Circuit Module Schematic

Schematic

The schematic follows the bill of materials in this user's guide.

6.4 Circuit Module Physical Layouts and Bill of Materials

This section contains the board layout, bill of materials, and assembly drawings for the bq2750x circuit module.

Board Layout

This section shows the PCB layers (Figure 18 through Figure 21), and assembly drawing for the bq2750x module.

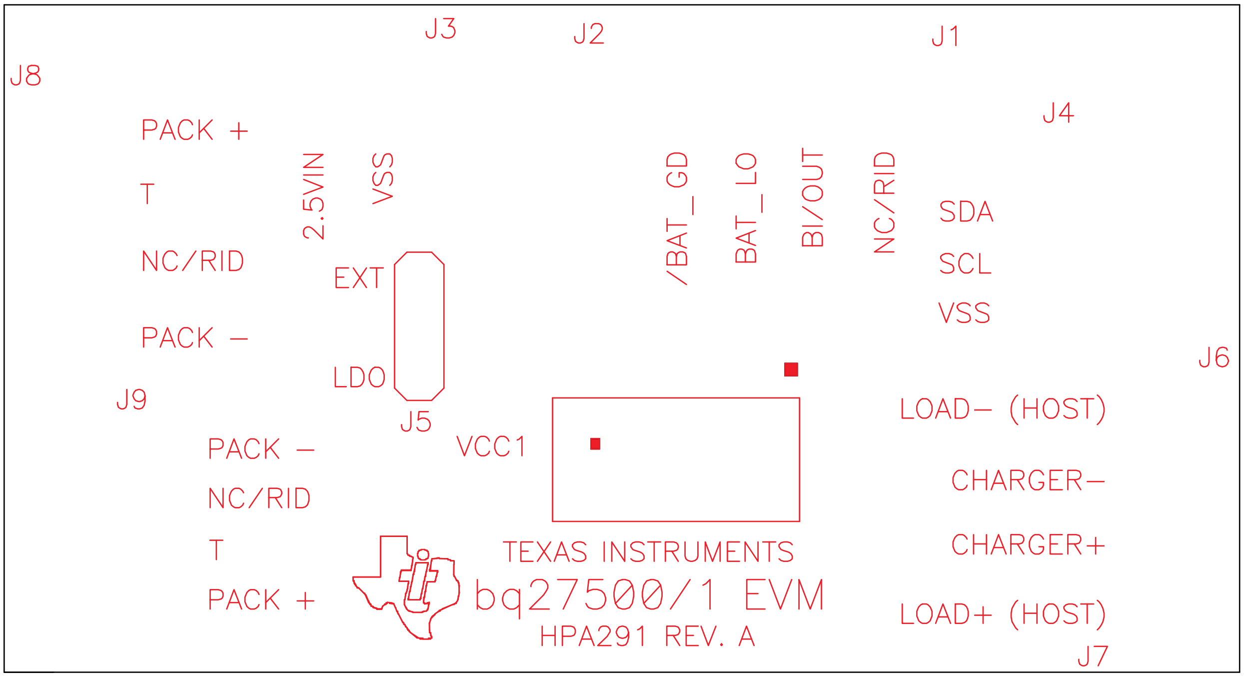


Figure 18. bq27500EVM-001 Layout (Silk Screen)

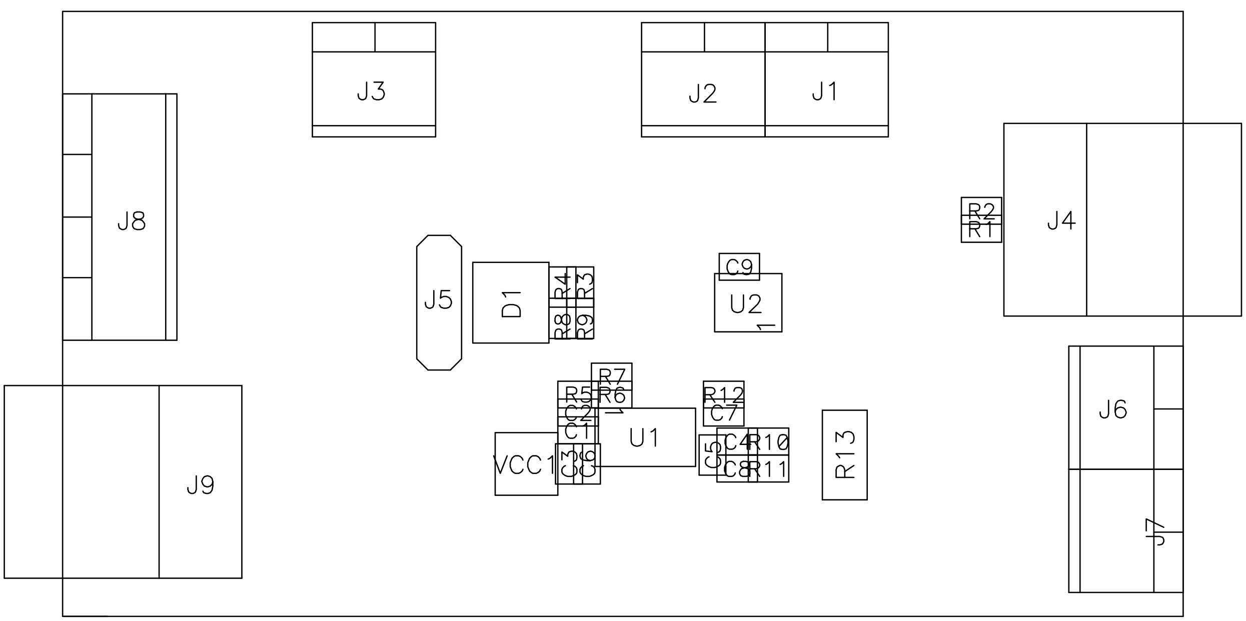


Figure 19. Top Assembly

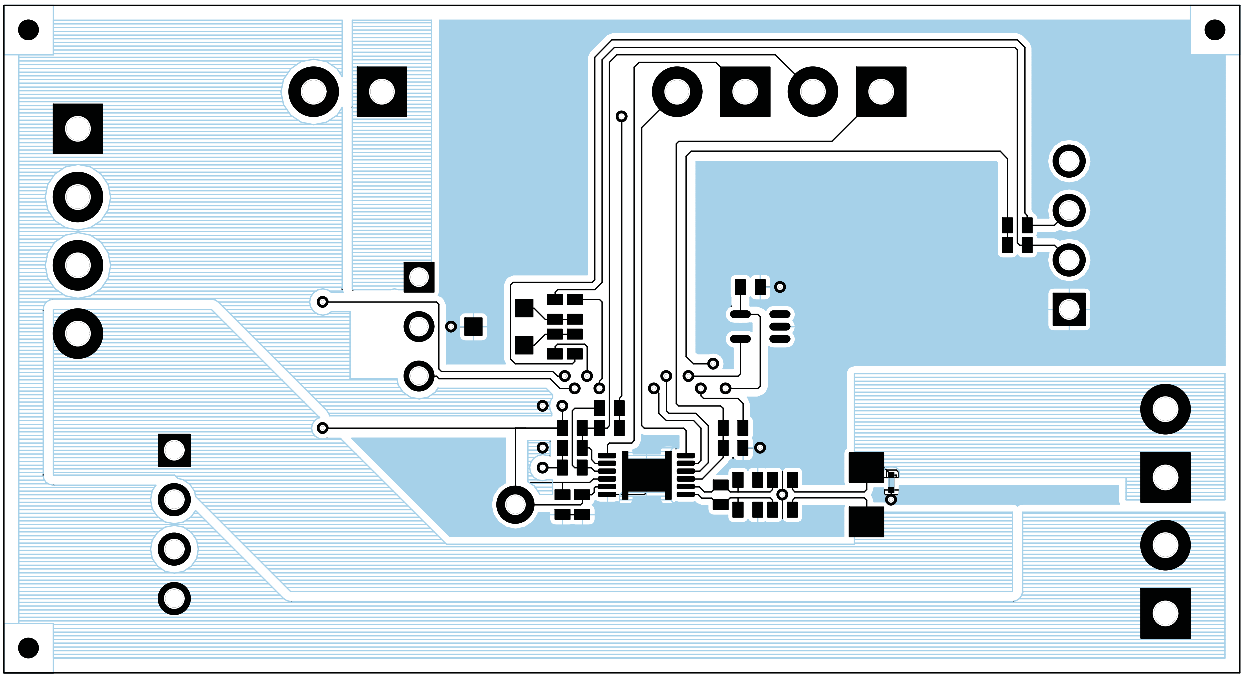


Figure 20. Top Layer

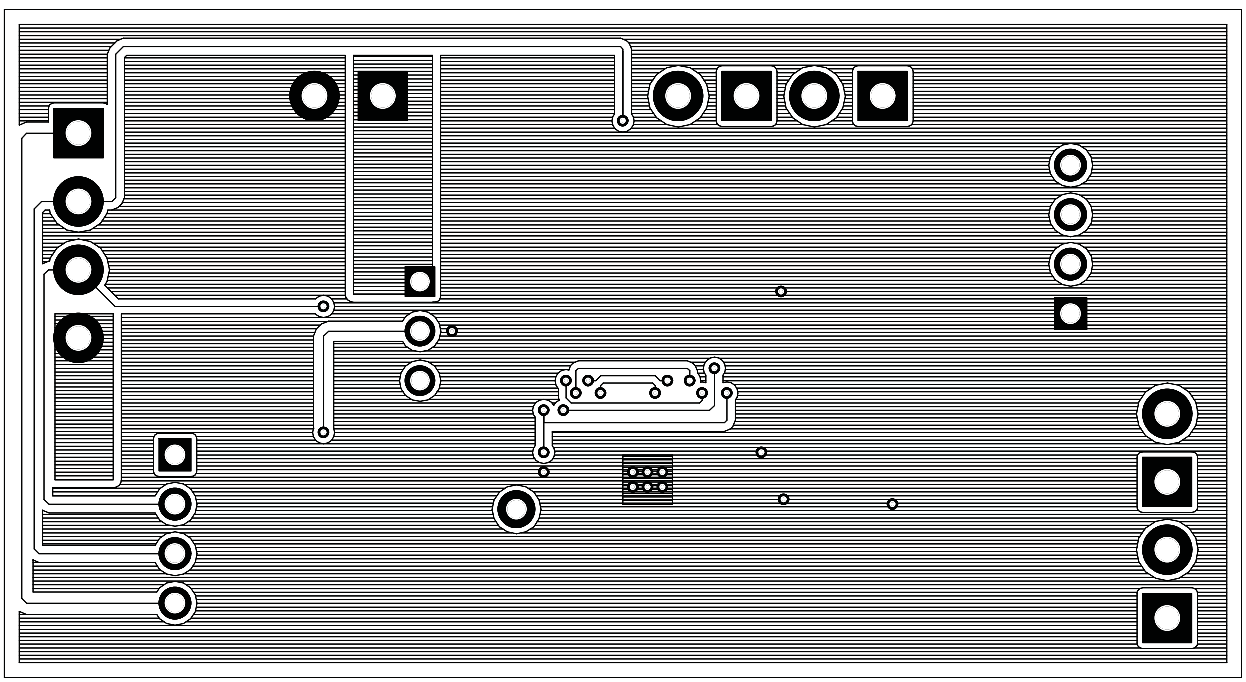


Figure 21. Bottom Layer

Bill of Materials and Schematic

Table 4. Bill of Materials

'500 Count	'501 Count	Ref Des	Description	Size	Manufacturer	Part No.
7	7	C1, C3, C4, C5, C7, C8, C9	Capacitor, Ceramic, 0.1uF, 10V, X5R	402	Murata	GRM155R61A104KA01D
1	1	C2	Capacitor, Ceramic, 0.033uF, 10V, X7R, +/-10%	402	Murata	GRM155R71A333KA01D
1	1	C6	Capacitor, Ceramic, 0.47uF, 6.3V, X5R	402	Murata	GRM155R60J474KE19D
1	1	D1	Diode, Dual, Zener, 5.6V, 300mW	SOT23	Diodes	AZ23C5V6
4	4	J2, J3, J6, J7	Terminal Block, 2-pin, 6-A, 3.5mm	0.27 x 0.25 inch	OST	ED555/2DS
0	1	J1	Terminal Block, 2-pin, 6-A, 3.5mm	0.27 x 0.25 inch	OST	ED555/2DS
2	2	J4, J9	Header, Friction Lock Assy, 4-pin Right Angle	0.400 x 0.500	Molex	22-05-3041
1	1	J5	Header, Male 3-pin, 100mil spacing, (36-pin strip)	0.100 inch x 3	Sullins	PTC36SAAN
1	1	J8	Terminal Block, 4-pin, 6-A, 3.5mm	0.55 x 0.25 inch	OST	ED555/4DS
2	2	R1, R2	Resistor, Chip, 10k-Ohms, 1/16-W, 5%	402	Std	Std
0	1	R12	Resistor, Chip, 300-Ohms, 1/16-W, 5%	402	Std	Std
1	1	R13	Resistor, Chip, 0.01-Ohms, 0.25W, 1%	1206	Vishay	WSL1206R0100FEA
6	6	R3, R4, R8, R9, R10, R11	Resistor, Chip, 100-Ohms, 1/16-W, 5%	402	STD	STD
1	1	R5	Resistor, Chip, 1.80-MOhms, 1/16-W, 5%	402	Std	Std
1	1	R6	Resistor, Chip, 18.2-kOhms, 1/16-W, 5%	402	Std	Std
1	1	R7	Resistor, Chip, 1-kOhms, 1/16-W, 5%	402	Std	Std
1	0	U1	IC, Host-Side Impedance-Track Fuel Gauge	QFN12	TI	BQ27500DRZ
0	1	U1	IC, Host-Side Impedance-Track Fuel Gauge	QFN12	TI	BQ27501DRZ
1	1	U2	IC, High Input Voltage, Micropower, 3.2 µA @ 50 mA LDO, 2.5V	SOP-5 (DCK)	TI	TPS71525DCKR
1	1	VCC1	Test Point, Black, Thru Hole Color Keyed	0.100 x 0.100 inch	Keystone	5001
1	1	RT1 (component not part of layout. It is added to board at PCB test)	Thermistor, 10k Ohms	0.095 x 0.150 inches	Semitec	NTC103AT

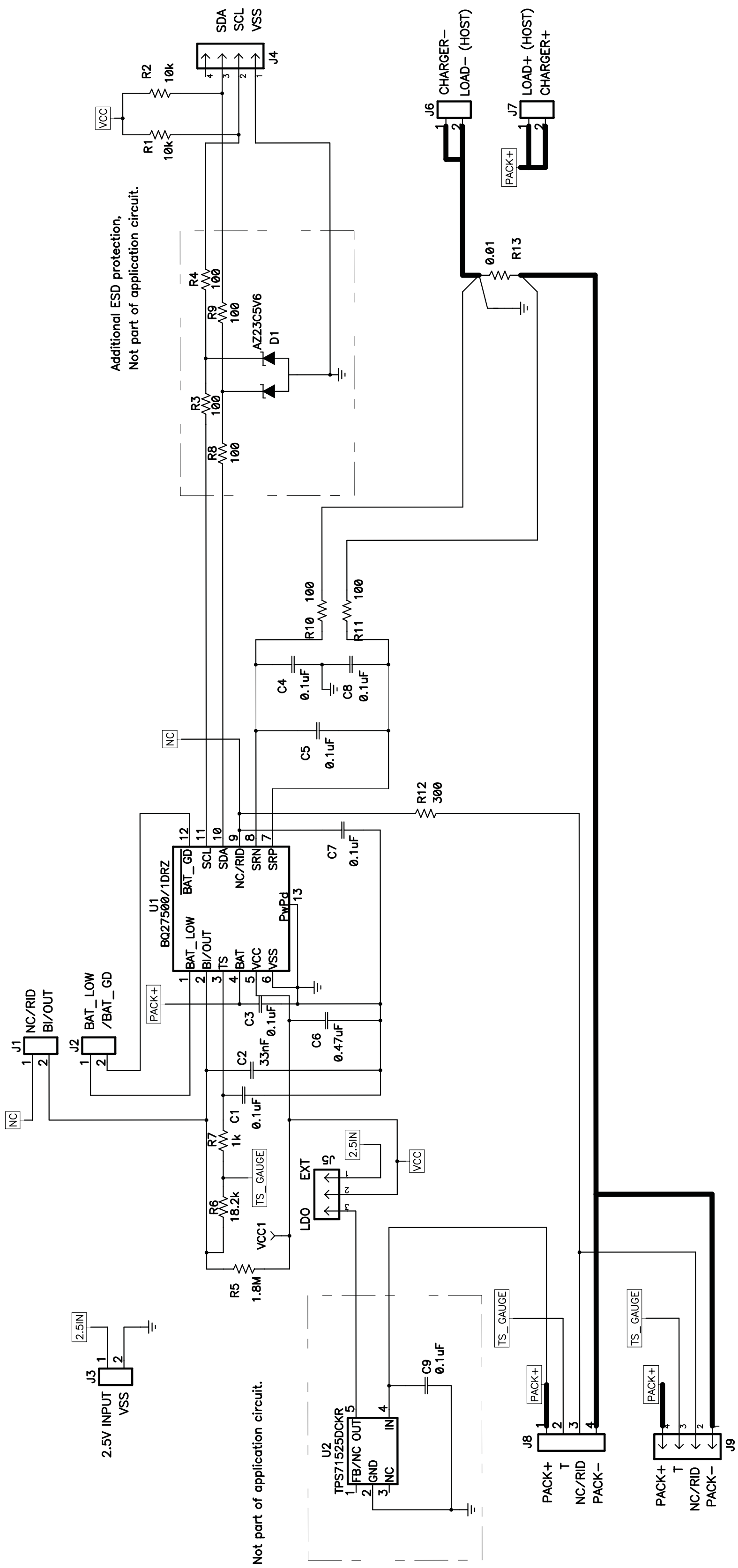


Figure 22. Schematic

bq2750x Circuit Module Performance Specification Summary

This section summarizes the performance specifications of the bq27500 circuit module.

Table 5. Performance Specification Summary

Specification	Min	Typ	Max	Units
Input voltage Pack+ to Pack–	2.7	3.6	4.3	V
Input voltage BAT+ to BAT–	2.7	3.6	4.3	V
Charge and discharge current	0	1	2	A

6.5 EVM Hardware and Software Setup

This section describes how to install the bq27500EVM-001 PC software and how to connect the different components of the EVM.

System Requirements

The bq27500EVSW software requires Windows 2000 or Windows XP. Drivers for Windows 98SE are provided, but Microsoft™ no longer supports Windows 98; there may be issues in Windows 98 with USB driver support. The EV2300 USB drivers have been tested for Windows 98SE, but no assurance is made for problem-free operation with specific system configurations.

Software Installation

Find the latest software version in the bq27500 or bq27501 tool folder on power.ti.com. Use the following steps to install the bq27500EVSW software:

1. Ensure that EV2300 is not connected to PC through USB cable before staring this procedure.
2. Browse the included CD and go to the Software directory, and open the bqEV-EASYSetup00.09.38_bq27500v1.00_bqEasy1.00.exe file or obtain the latest version from the TI Web site.
3. Follow the instructions on screen until completing the software installation.
4. Before starting the evaluation software, connect the EV2300 to the computer using the USB cable.
5. Wait until system prompt “new hardware found” appears. Choose “select location manually”, and use the “browse” button to point to subdirectory TIUSBWin2K-XP-1.
6. Answer “continue” to the warning that drivers are not certified with Microsoft™.
7. After installation finishes, another system prompt "new hardware found" appears. Repeat steps 1 through 5, but specify the directory as TIUSBWin2K-XP-2.
8. Answer "continue" to the warning that drivers are not certified with Microsoft. Driver installation is now finished.

If files were downloaded from the TI Web site:

1. Open the archive containing the installation package, and copy its contents into a temporary directory.
2. Follow the preceding steps 1–8.

6.6 Troubleshooting Unexpected Dialog Boxes

The user that is downloading the files must be logged in as the administrator.

The driver is not signed, so the administrator must allow installation of unsigned drivers in the operating system policy.

6.7 Hardware Connection

The bq27500EVM-001 comprises three hardware components: the bq2750x/TPS71525 circuit module, the EV2300 PC interface board, and the PC.

Connecting the bq27500 Circuit Module to a Battery Pack

Figure 23 shows how to connect the bq27500 circuit module to the cells and system load/charger.

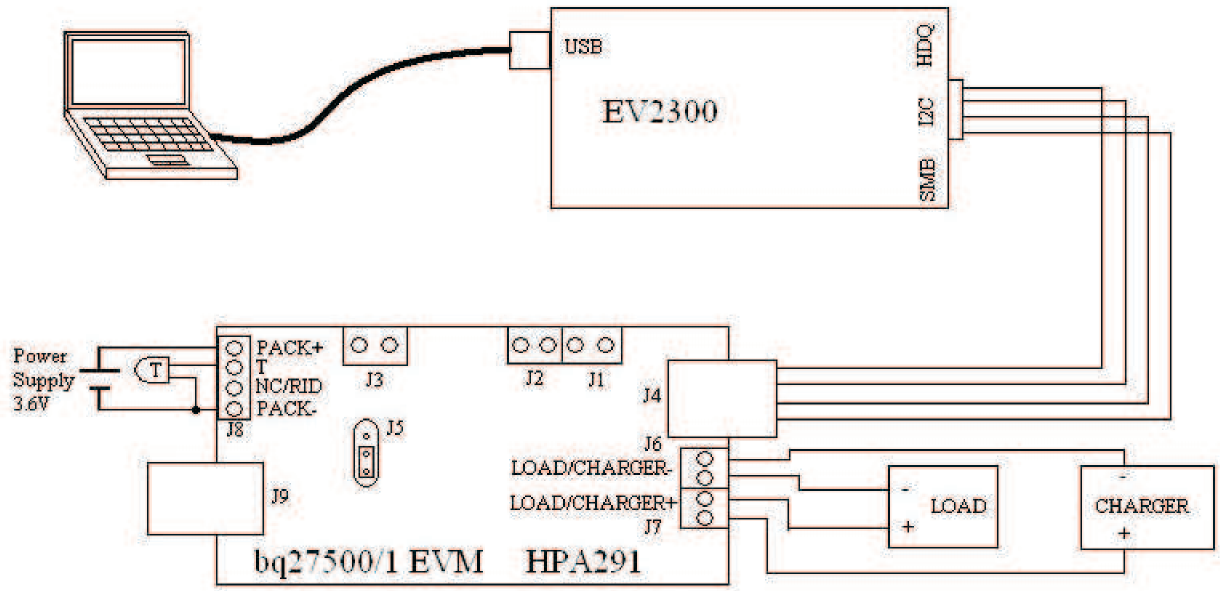


Figure 23. bq27500 Circuit Module Connection to Cell and System Load/Charger

PC Interface Connection

The following steps configure the hardware for interface to the PC:

1. Connect the bq2750x-based EVM to the EV2300 using wire leads as shown in Table 6.

Table 6. Circuit Module to EV2300 Connections

bq2750x-Based Battery	EV2300
SDA	SDA
SCL	SCL
VSS	GND

2. Connect the PC USB cable to the EV2300 and the PC USB port.

The bq27500EVM-001 is now set up for operation.

6.8 Operation

This section details the operation of the bq27500 EVSW software.

Starting the Program

Run bq27500 EVSW from the Start | Programs | Texas Instruments | bq Evaluation Software menu sequence. The DataRAM screen (Figure 24) appears. Data begins to appear once the <Refresh> (single time scan) button is clicked, or when the <Keep Scanning> check box is checked. To disable the scan feature, deselect <Keep Scanning>.

The continuous scanning period can be set via the | Options | and | Set Scan Interval | menu selections. The range for this interval is 0 ms to 65,535 ms. Only items that are selected for scanning are scanned within this period.

The bq27500 EVSW provides a logging function which logs the values that were last scanned by EVSW. To enable this function, select the *Start Logging* button; this causes the *Keep Scanning* button to be selected. When logging is *Stopped*, the keep scanning button is still selected and has to be manually unchecked.

The logging intervals are specified under the | Options | menu with the maximum value of 65,535 ms. The *Log* interval cannot be smaller than the scan interval because this results in the same value being logged at least twice.

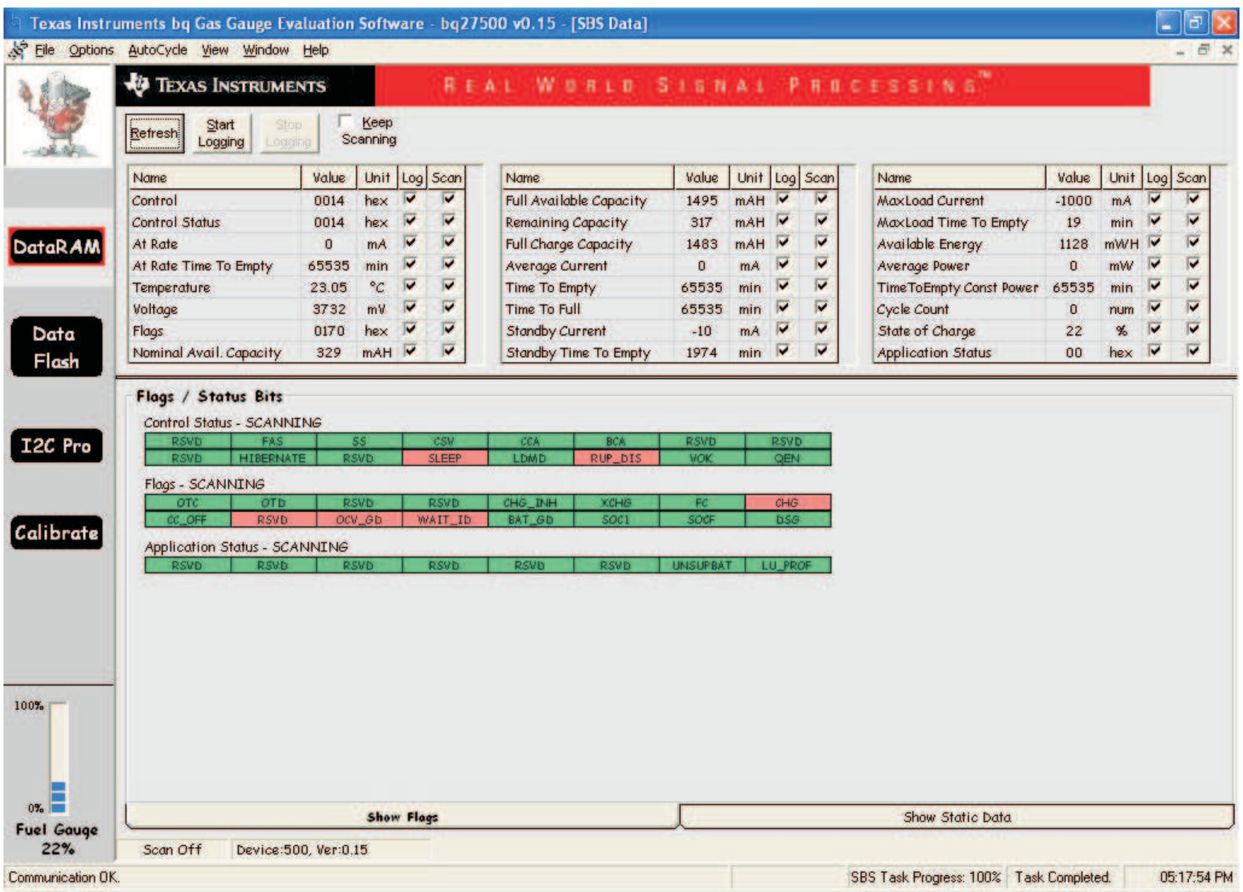


Figure 24. DataRAM Screen

This screen (Figure 24) shows the RAM data set Additional Flag and Status data can be viewed at the bottom of the DataRAM screen.

Dragging the splitter bar (line that separates the Flags/Static data from SBS values) changes the height of the Flags/Static Data display. Selecting | View |, then | Auto Arrange | returns the splitter bar to its original location.

Setting Programmable bq27500 Options

The bq2750x data flash comes configured per the default settings detailed in the bq27500 data sheet. Ensure that the settings are correctly changed to match the pack and application for the bq2750x solution being evaluated.

IMPORTANT: The correct setting of these options is essential to get the best performance.

The settings can be configured using the Data Flash screen (Figure 25).

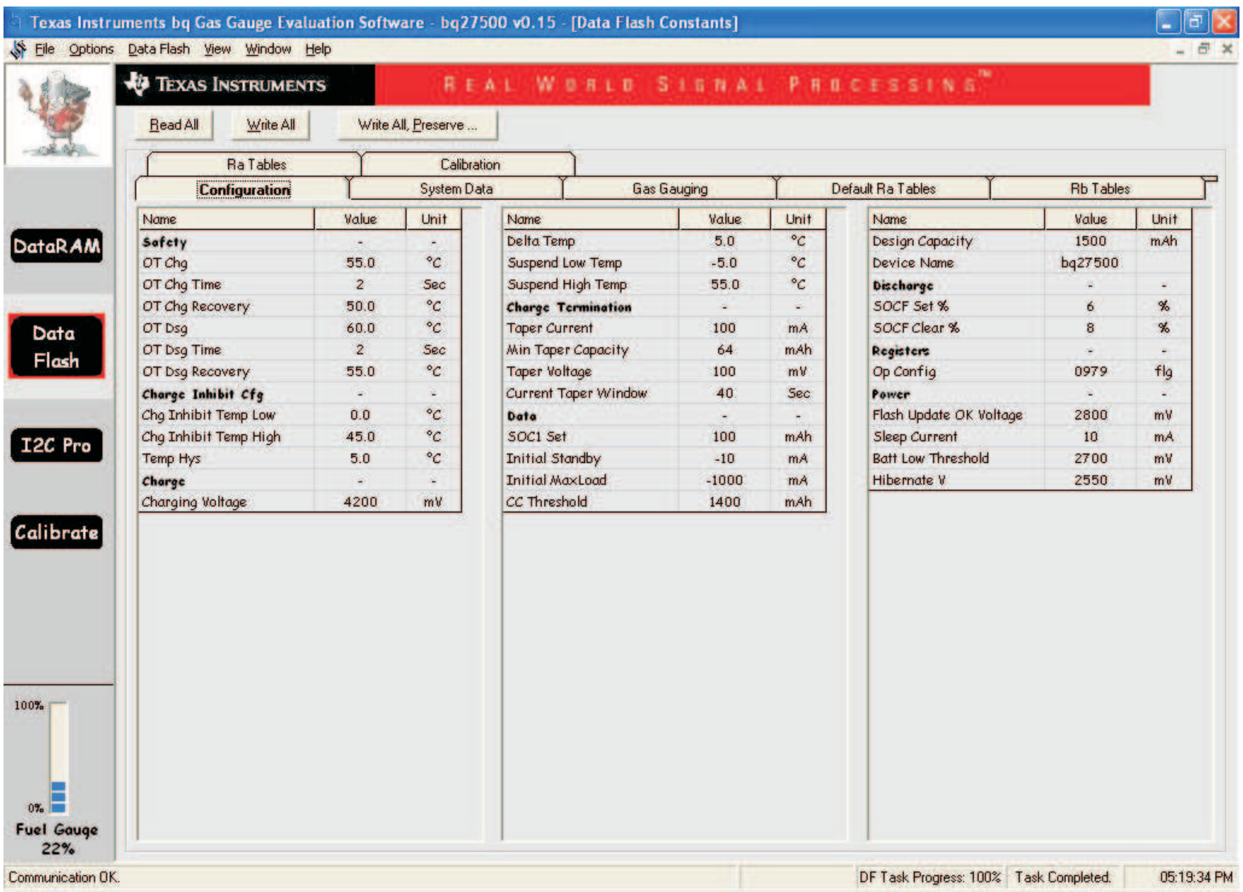


Figure 25. Data Flash Screen

To read all the data from the bq2750x data flash, click on menu option | Data Flash | Read All |.

To write to a data flash location, click on the desired location, enter the data and press <Enter>, which writes the entire tab of flash data, or select menu option | Data Flash | Write All |. The data flash must be read before any writes are performed to avoid any incorrect data being written to the device.

The | File | Special Export | menu options allows the data flash to be exported, but it configures the exported data flash to a learned state ready for mass production use.

The data flash configuration can be saved to a file by selecting | File | Export | and entering a file name. A data flash file also can be retrieved in this way, imported, and written to the bq2750x using the | Write All | button.

The module calibration data is also held in the bq2750x data flash.

The bq2750x allows for an automatic data flash export function, similar to the DataRAM logging function. This feature, when selected via | Options | Auto Export |, exports Data Flash to a sequential series of files named as *FilenameNNNNN.gg* where N = a decimal number from 0 to 9.

The AutoExport interval is set under the | Options menu | with a minimum value of 15 s. The AutoExport filename is also set under the | Options menu |.

When a check is next to | AutoExport |, the AutoExport is in progress. The same menu selection is used to turn on / off AutoExport.

If the data flash screen is blank, then the bq2750x that is being used may not be supported by the bqEVSW version that is being used. An upgrade may be required.

6.9 Calibrate Screen

To ensure proper calibration follow the order described below. These steps may or may not be required, depending on the type of calibration being performed.

To Calibrate the bq2750x

Select the types of calibration to be performed (see Figure 26).

Enter the measured values for the types selected.

If *Temperature Calibration* is selected, then select the sensor that is to be calibrated.

Press the *Calibrate Part as indicated below* button.

CC Offset Calibration

This performs the internal calibration of the coulomb counter input offset.

Board Offset Calibration

This performs the offset calibration for the current offset of the board.

It is expected that no current is flowing through the sense resistor while performing this calibration step. Remove load and short PACK– to LOAD–.

Press the *CC Board Offset Calibration* button.

Temperature Calibration

- Measure the temperature for PACK.
- Type the temperature value into *Enter Actual Temperature*.
- Select if the temperature sensor to calibrate is the internal or external.
- Press the *Calibrate Part as indicated below* button.

Pack Current Calibration

- Connect a load to LOAD– and LOAD+ that draws approximately 1 A, or connect a current source to LOAD– and Pack-.
- Measure the current and type value into *Enter Actual Current* using (-) for current in discharge direction.
- Press the *Calibrate Part as indicated below* button.

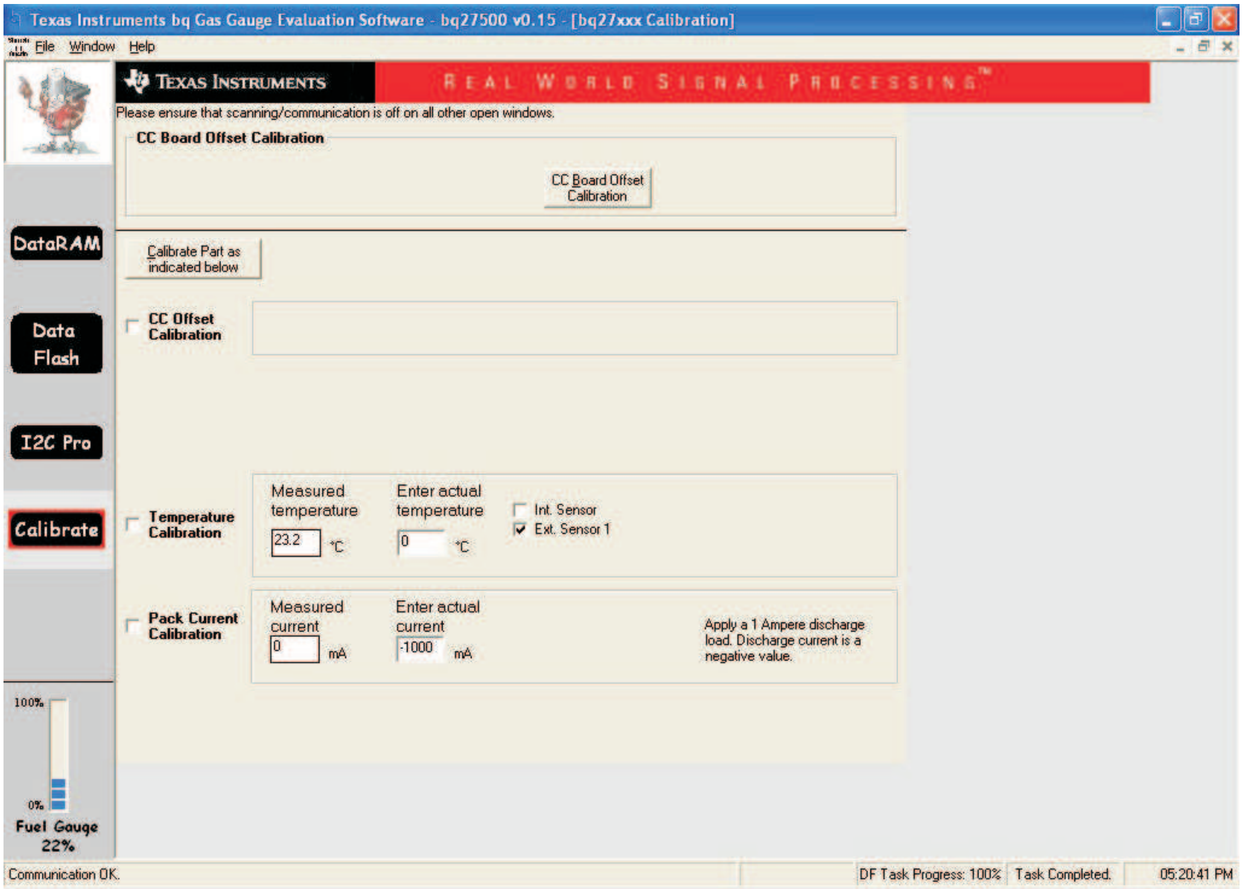


Figure 26. Calibration Screen

6.10 I2C Pro Screen

I²C Communication

The read/write operations of the I2C Pro function is not specific to any gas gauge. These operations serve as general-purpose communication tools (Figure 27).

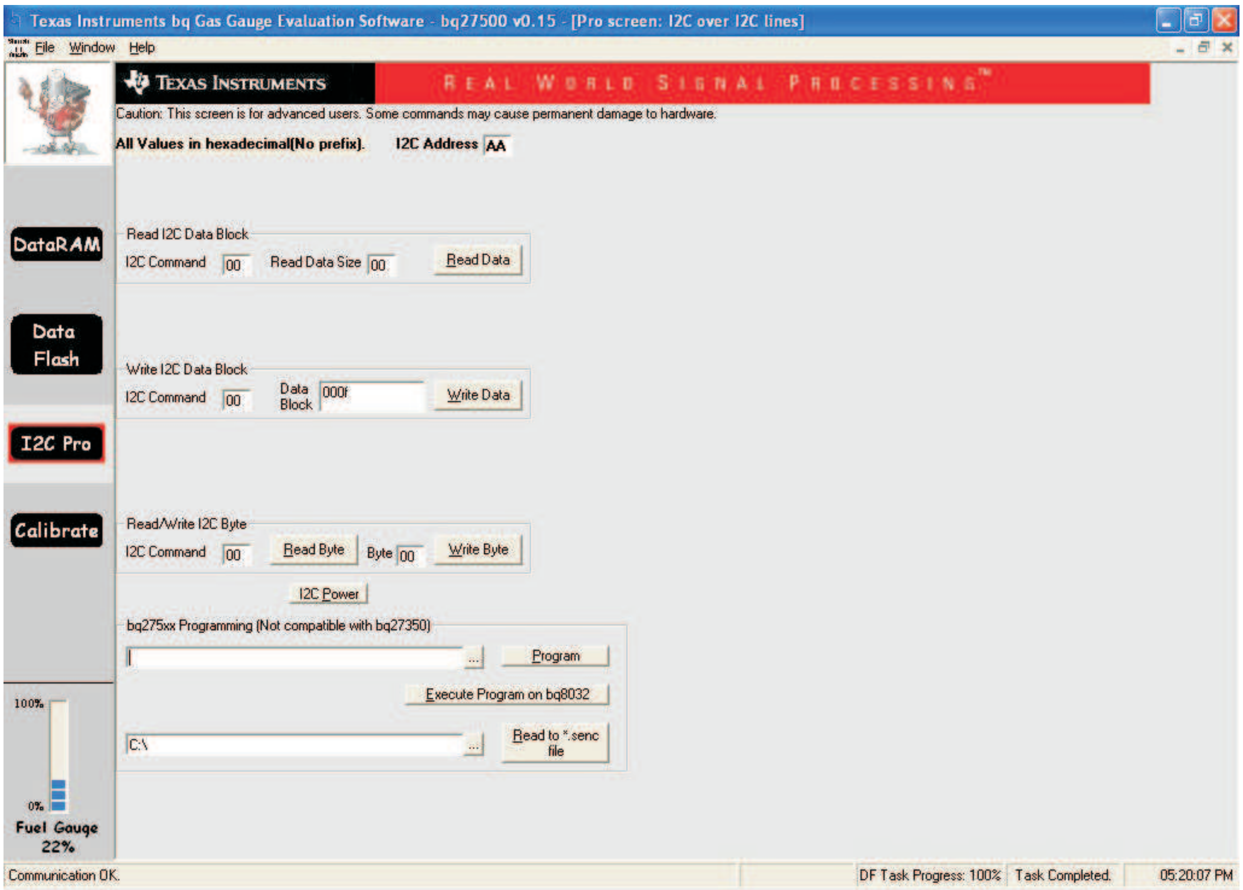


Figure 27. I2C Pro Screen

6.11 bqEasy

Introduction

Texas Instruments fuel gauges, employing the Impedance Track™ algorithm offer an unmatched array of features and benefits. Sometimes, however, the wide range of configuration settings can make it seem a bit challenging to get started with the evaluation process. In addition, determining the correct chemistry model and producing the 'golden image' file can be time consuming. The bqEASY program is designed to greatly simplify the process of configuring, calibrating, selecting chemistry and performing learning cycles through the step-by-step use of a wizard program.

The bqEasy software will run inside the current EV software when it is executed by clicking the bqEasy button in the left-hand column of buttons below the Calibrate button in the EV software.

Figure 28. bqEasy Welcome Screen

Program Navigation and Flowchart

The sequence of operation of bqEASY can be understood by reviewing the basic flowchart in Figure 29 . Using the program is simple – just start a new project and follow the steps sequentially from 1A to 5C. You can use the Next button, or click on the top tabs and left subsection labels to move to any desired page. Some operations must be completed in sequence due to data dependencies, or to implement the proper flow. Therefore it is recommended that the prescribed sequence be followed, at least at first.

Figure 29. bqEasy Flowchart

Simplified Configuration Procedures

These simplified configuration procedures can be used to quickly set up the parameters without navigating through the entire user interface.

1. Simple configuration of the Gas Gauge with default or custom data:

a. Open the current EV software and click the bqEasy button in the left-hand column of buttons below the "Calibrate" button in the EV software.
b. Click the "2. Configure" tab at the top row of bqEASY tabs. (Note: You can skip the 1st tab)
c. Answer all questions or leave defaults for all of tab "2", but be sure to click the ok button at the bottom of each tab "2" page to ensure that a Completion Checkmark appears for each page.
d. On page 2H, when you click the "OK" button, the software will ask you to write to the data flash memory. Click "Yes" for OK to write to the data flash.

Your Gas Gauge Module now has the data flash configured as you declared with all the information entered in tab "2. Configure".

2. Simple installation of the Chemistry data using bqEASY if the chemistry is a known chemistry available in the bqEASY software:
   a. Open the current EV software and click the bqEasy button in the left-hand column of buttons below the "Calibrate" button in the EV software.
   b. Click the "4. Chemistry" tab at the top row of bqEASY tabs. (Note: You can skip all tabs prior to this)
   c. Either select "Use Default Chemistry", or click "Enable Chemistry Selection" and select the correct chemistry from the list.
   d. If you cannot find the proper chemistry, check the device EVM tool folder on the TI Web site for any new bqChemistry file updates. These are updated more frequently than the EV software, so between EV software updates, we will create a self-extracting installer and post it in the EVM tool folder for the part being used. Install these updates if they are in the folder.

   The software will now configure all data flash locations on Your Gas Gauge Module that deal with chemistry functions. No other data flash locations will be modified.

Files

bqEASY uses four types of files to configure a fuel gauge.

1. **.ENCR –** These are default data-flash definition files found in the \bq_Evaluation_Software folder. The ENCR file is basically a copy of the entire data-flash from a fresh Gas Gauge prior to any data-flash updates either by the user or the Gas Gauge. They are unique for each version of each TI fuel gauge product. If you should be working with a new version fuel gauge and an older version of bqEASY, the correct file may not be present. This will require a new version of the EV software with bqEASY. Navigate to the TI Web site in the EVM tool folder for the device being used, and download the latest version, or contact TI. For bqEASY, the ENCR files act mainly as a dictionary to look up the address for a given data-flash location. For bqEVSW, they define screen parameters including address, display formulas and data type. An error message will appear if the correct .ENCR file cannot be found.
2. **.CHEM (Chemistry Files) –** These are read-only files found in the ..\bq_Evaluation_Software\Plugins\Chemistry folder of the application. When a new Li-Ion battery chemistry is developed, a new Impedance Track model is required to define the chemical model. During automated chemistry selection, each of these files is scanned in order to select the best match with the recorded data. If you are working with a newly developed chemistry, it is possible that an acceptable match will not be found. If this is the case, please check for updated bqEasy software or bqChemistry files on the TI Web site in the EVM tool folder for the part being used.
3. **.DFI (Data-Flash Image Files) –** These are binary images of the fuel gauge data-flash with modified values based on the application. Because of the binary format, it is quick and easy to transfer them to and from a gauge. Each fuel gauge model and firmware version has a unique read-only .DFI which is found in the ..\bq_Evaluation_Software\Plugins\Device_Defaults folder of the application. During the bqEASY process, intermediate versions of .DFI files are recorded with current updated data in order to prevent the possibility of corruption. Then, the final output of bqEASY is also a .DFI file which is the 'golden image' that will be programmed into each production unit. This output file will be placed in the ..\bq_Evaluation _Software\Plugins\Projects folder.
4. **.EZY (bqEASY Project Files)–** These are read-write text files which record header information regarding a project, answers to the wizard questions, and status regarding the stage of completion (the red check marks). They are kept in the ..\bq_Evaluation _Software\Plugins\Projects folder.

Completion Checkmarks

As the wizard questions and tasks are completed, completion checkmarks appear in two places – along the task list on the left and on the category tabs on top. A checkmark on a top tab will only appear after all tasks in the category have been completed. For example, in **Figure 3** all of the Setup tasks and all of the Configure tasks have been completed. Completion marks are saved in the .EZY project text file. When a completed or partially-completed project file is opened, the user is given the chance to erase the checkmarks.

Device Detection

BqEASY is designed to work with a fuel gauge present and already communicating with the bqEVSW evaluation software through the EV2300 USB interface. When the Evaluation software is started, it reads the device type and displays it on the upper title block. This information is used by bqEASY to select the correct default data-flash image (.DFI) and data-flash configuration file (.ENCR) for this particular device. To ensure that the device has not changed, bqEASY also checks the device type when the bqEASY button is pressed. If the correct files are not found, first check the TI Web site in the EVM tool folder for the part being used, and download the latest version of EV software with bqEASY support. If that does not help, then contact TI.

1. **Setup**

   As the wizard questions and tasks are completed, completion checkmarks appear in two places – along the task list on the left and on the category tabs on top. A checkmark on a top tab will only appear after all tasks in the category have been completed. Completion marks are saved in the .EZY project text file. When a completed or partially-completed project file is opened, the user is given the chance to erase the checkmarks.
2. **Configure**

   A series of eight screens is used to collect information about the battery pack application to enable automatic configuration of the most critical data-flash parameters.
3. **Calibrate**

   If you wish to proceed with either automatic chemistry selection or 'golden' unit learning cycles, the Impedance Track fuel gauge must be accurately calibrated. The bqEASY screens simply ask the user to use the calibration screen of the bqEVSW for this purpose.
4. **Chemistry**

   The chemistry choices presented in section 4B are based on files in the \Chemistry folder of the bqEASY application. The latest files are available for downloading from the ti.com Web site. Automation of the chemistry-selection cycle is made possible using a simple load and switch as depicted in Figure 30. The switch can be implemented with either a low VGS-threshold FET or a small relay such as the OMICRON G6RN-1 with a 5-VDC coil. Multiple 2N7000 FETs can be paralleled if nothing else is available. The load can be either a power resistor or an electronic load set to a discharge rate of C/5. Hint: Follow the instructions exactly, or errors may result.
5. **Cycle**

   When preparing for mass production, cell learning is required, but only on one 'golden' pack. The chemical information learned from one pack will be quickly transferred to all production units prior to calibration. Doing this correctly requires a series of charge and discharge cycles. The discharge part can be automated with bqEASY if the simple load circuit for the chemistry selection is available. Follow the screen instructions.

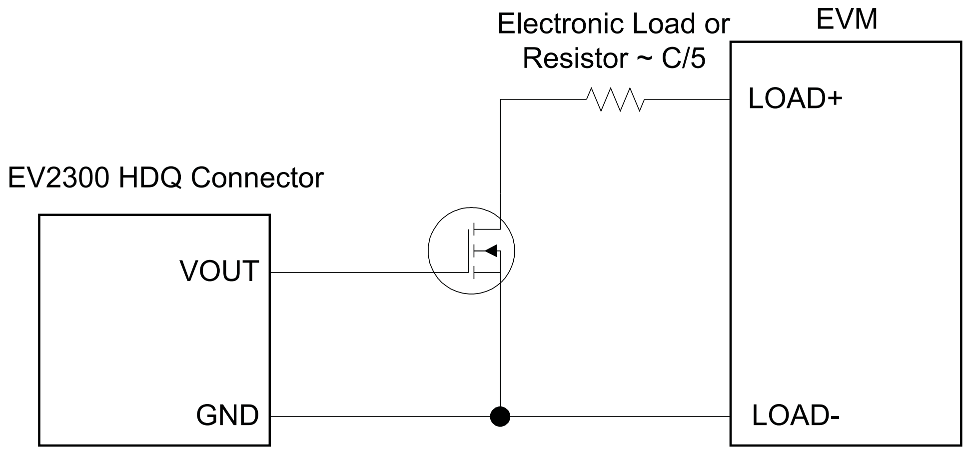


Figure 30. Block Diagram Caption

6.12 Related Documentation from Texas Instruments

To obtain a copy of any of the following TI documents, call the Texas Instruments Literature Response Center at (800) 477-8924 or the Product Information Center (PIC) at (972) 644-5580. When ordering, identify this document by its title and literature number. Updated documents can also be obtained through the TI Web site at www.ti.com .

6.13 Important Notice

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Texas Instruments (TI) provides the enclosed product(s) under the following conditions:

This evaluation board/kit is intended for use for **ENGINEERING DEVELOPMENT, DEMONSTRATION, OR EVALUATION PURPOSES ONLY** and is not considered by TI to be a finished end-product fit for general consumer use. Persons handling the product(s) must have electronics training and observe good engineering practice standards. As such, the goods being provided are not intended to be complete in terms of required design-, marketing-, and/or manufacturing-related protective considerations, including product safety and environmental measures typically found in end products that incorporate such semiconductor components or circuit boards. This evaluation board/kit does not fall within the scope of the European Union directives regarding electromagnetic compatibility, restricted substances (RoHS), recycling (WEEE), FCC, CE or UL, and therefore may not meet the technical requirements of these directives or other related directives.

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EVM WARNINGS AND RESTRICTIONS

It is important to operate this EVM within the input voltage range of 6 V to 25 V and the output voltage range of 0 V to 16.4 V.

Exceeding the specified input range may cause unexpected operation and/or irreversible damage to the EVM. If there are questions concerning the input range, please contact a TI field representative prior to connecting the input power.

Applying loads outside of the specified output range may result in unintended operation and/or possible permanent damage to the EVM. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative.

During normal operation, some circuit components may have case temperatures greater than 60°C. The EVM is designed to operate properly with certain components above 60°C as long as the input and output ranges are maintained. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors. These types of devices can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during operation, please be aware that these devices may be very warm to the touch.

Chapter 7

Quick Start Guide for bq2750x Family Gas Gauge

Ming Yu — *HVAL - Battery Management Solutions*

ABSTRACT

This application report provides you a design process overview, procedures to use the evaluation module and software, and helpful troubleshooting techniques.

7.1 Introduction

The Texas Instruments bq27500/01 system-side Li-Ion battery fuel gauge is a microcontroller peripheral that provides fuel gauging for single-cell Li-Ion battery packs. The device requires little system microcontroller firmware development. The bq27500/01 resides on the system main board, and manages an embedded battery (non-removable) or a removable battery pack.

The bq2750x uses a patented Impedance algorithm for fuel gauging, and provides information such as remaining battery capacity (mAh), state-of-charge (%), run-time to empty (min.), battery voltage (mV), and temperature (°C).

Battery fuel gauging with the bq27500 requires only PACK+ (P+), PACK– (P–), and Thermistor (T) connections to a removable battery pack or embedded battery. The bq27501 works with identification resistors in battery packs to gauge batteries of different fundamental chemistries and/or significantly different rated capacities.

Related Documentation

TI recommends that you familiarize yourself with these documents before working with the Impedance Track™ gas gauge devices.

- *Quick Start Guide for bq27500/1EVM Kit* (SLUU298)
- *Single-Cell Impedance Track™ Gas Gauge Introduction* (SLUA422)
- *Key Design Considerations for the bq27500 and bq27501* (SLUA439)
- *bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module* (SLUU287)
- *Host-side gas-gauge-system design considerations for single-cell handheld apps* (SLYT285)
- *Configuring the bq27500 Data Flash* (SLUA432)
- *bq2750x Datasheet* (SLUS785)
- *Using bqTester Single Site Software* (SLUA352)
- *bq27500 Theory and implementation of Impedance Track battery fuel-gauging algorithm* (SLUA450)
- *Data Flash Programming and Calibrating the bq27500 Gas Gauge* (SLUA440)
- *Going to Production with the bq2750x* (SLUA449)

Terminology

Acronym	Description	Acronym	Description
DF	Data Flash	IT	Impedance Track™
GG	Gas gauge	MAC	Manufacturer Access Command
SENC	Firmware file (encrypted)	DFI	Data Flash Image file (binary) with modified data
bqEASY	bq2750x programming wizard	ENCR	Data Flash file specific to a fresh TI fuel gauge
CHEM	Chemical model files for different LI-ion batteries	EZY	bqEASY project file

Document Overview

This document covers procedures for evaluation module setup and working with bq Evaluation Software. Additionally, the document highlights multiple approaches to troubleshooting the software connection, graphical user interface navigation, and key elements for the different configuration windows.

Example step-by-step procedures are described in Section 6 for:

- Choosing the correct chemistry
- Resetting the pack
- Logging data during testing
- Sealing and unsealing a pack

7.2 Getting Started With the bq2750x Evaluation Module

To get started with the bq2750x evaluation module (EVM), you will want to:

1. Gather all needed components
2. Acquaint yourself with the EVM board, pin descriptions, and basic EVM configuration
3. Download the bq Evaluation Software
4. Install the bq Evaluation Software
5. Install two USB drivers to communicate with the EV2300
6. Make the circuit module connections
7. Start the bq Evaluation Software
8. Become familiar with key Li-Ion battery fuel gauge software procedures

Necessary Components

To perform the bq2750x procedures described in this report, you need:

- bq2750x EVM board (HPA291) - check bq27500 Errata (SLUZ015) and bq27500 EVM (HPA291 Rev. A) Errata (SLUZ016)
- EV2300 USB PC Interface Board
- 4-colored wire set connector (I^2C communication from EVM **J4** to EV2300)
- USB cable (A-B type)
- NTC103AT Thermistor
- bq2750x EVM CD or latest documentation and software from the Texas Instruments Internet site (see Figure 33)
- PC host running the Windows™ 98SE, Windows XP, or Windows 2000 operating system and an available USB port
- Power supply or single-cell in series Li-ion battery (Li-ion battery preferred)
- Electronic load or electronic system (range 3 V to 4.2 V)
- Single-cell Li-ion battery charger (optional)

bq2750x EVM Board and Pin Description

Use this section to become familiar with the bq2750xEVM module, pin/jumper descriptions, and the basic EVM configuration.

Figure 31. bq2750x Evaluation Module

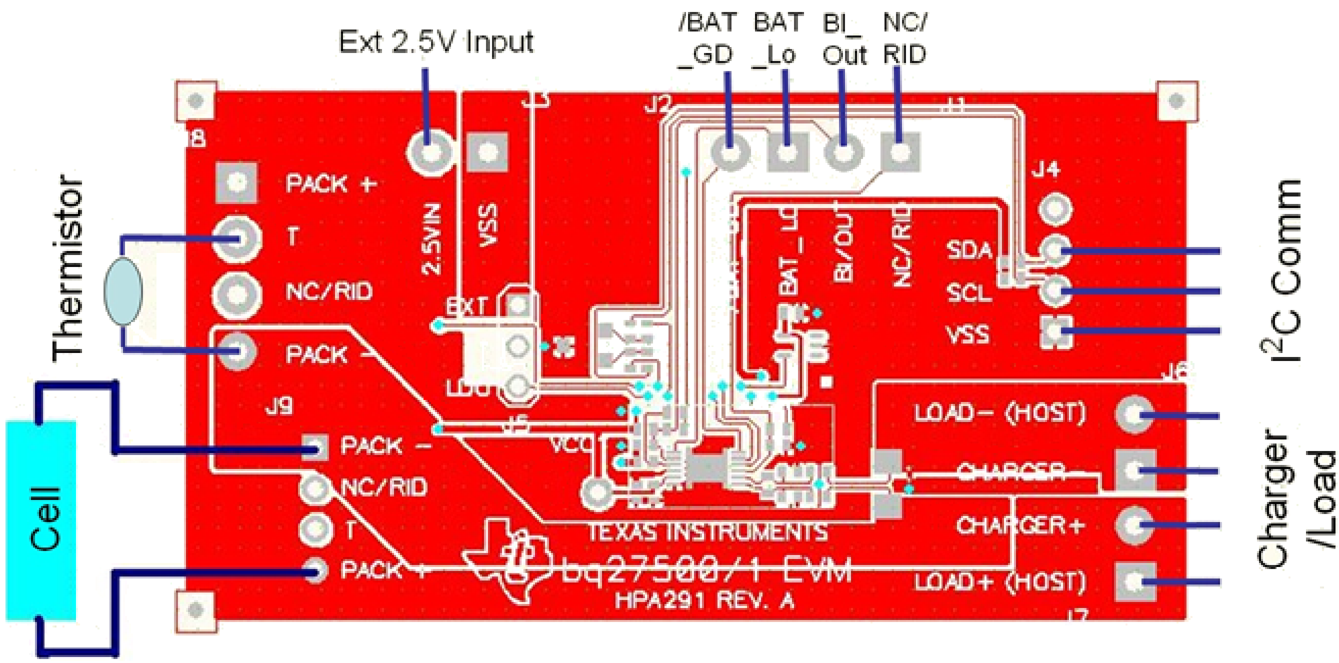
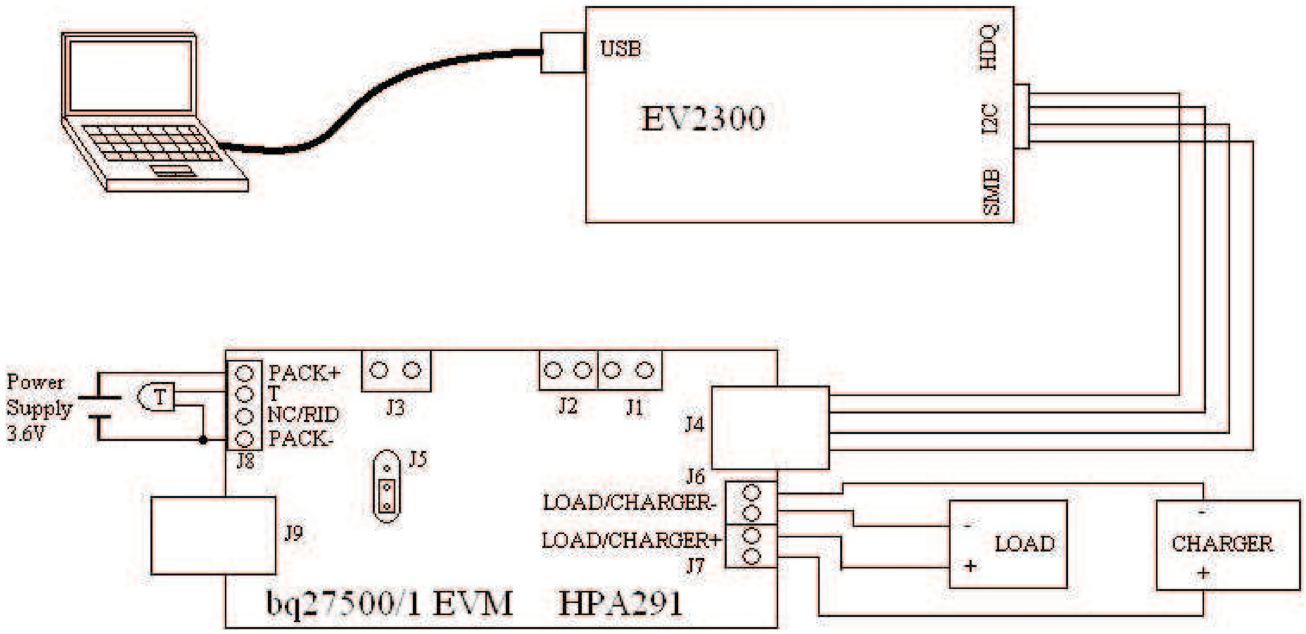


Table 7. bq2750x Pin/Jumper Descriptions

PIN NAME / Jumper	DESCRIPTION
PACK+ (**J8**)	Pack positive terminal
PACK– (**J8**)	Pack negative terminal
T	Pack thermistor input
NC/RID	Pack resistor ID input (only for bq27501)
SDA (**J4**)	I^2C communication data line
SCL (**J4**)	I^2C communication clock line
VSS (**J4**)	Signal return for communication line; shared with charger and ground
CHARGER+/LOAD+ (**J7**)	Power for load or charger connection
CHARGER–/LOAD– (**J6**)	Ground for load or charger connection (system VSS)
BAT_LOW	Access to push-pull output that signals low state-of-charge
$\overline{\text{BAT\_GD}}$	Access to open drain output indicating pack is ready to connect to the EVM
BI_OUT	Battery-Insertion detection input. Power pin for pack thermistor network.

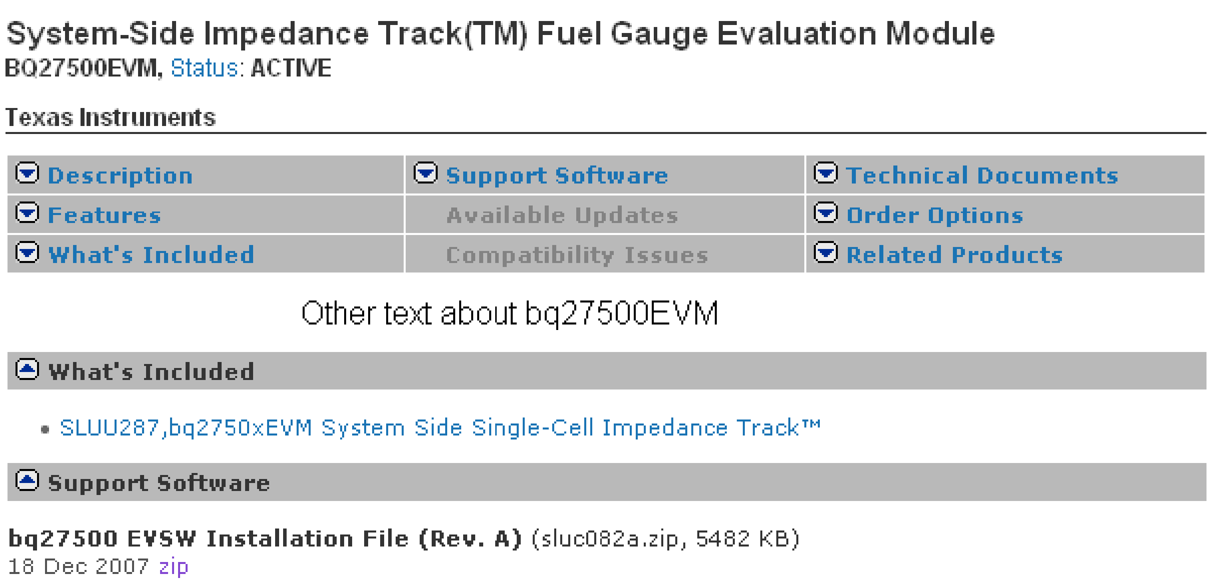
Figure 32. Basic bq2750xEVM Configuration



Download the bq2750x Evaluation Software

This software is included with the EVM on a CD or can be downloaded from the evaluation module product folder (use the Part Number *bq27500EVM* as the search keyword) from www.TI.com. Figure 33 displays the portion of the Internet page with the EVM software link named: *bq27500 EVSW installation File*.

Figure 33. bq27500EVM Product Folder



Install bq2750x Evaluation Software

Before you install the bq2750xEVM software, make sure the EV2300 communication box is disconnected from the PC Host.

Using the CD included with the bq2750xEVM or the zip file you downloaded from the TI Internet site:

1. {Download only) Unzip the SLUC082.zip file to a temporary directory.
2. In your temporary directory (or the EVM CD), browse for the preliminary software installation file with the generic name: bqEV-EASY-HH SWSetup00.**XX**.**yy**_bq27500v1.00_bqEasyv**z.zz**.exe, where **XX**=major preliminary number, **yy**=minor preliminary number, and **z.zz**= version number.
3. Double-click and follow the standard installation instructions; accept license agreement, choose folder, and display Readme file.

Install USB Drivers for EV2300 Communication

Before installing the USB drivers, use the supplied USB cable to connect the EV2300 to the computer that has the bq2750x evaluation software installed.

Installing the driver for the EV2300 communication box requires you to install two USB drivers for proper operation. Complete instructions for installing the USB drivers can be found in the *EV2300 Driver to USB Port Association* section of the *Using bqTester Single Site Software* document (SLUA352).

Briefly, the required steps are:

1. When the operating system prompts you with a **Found New Hardware Wizard**, Choose the *No, not at this time* option.
2. On the next screen, select the *Install from a list or specific location* option and use the **Browse** button to navigate to the PC Host folder (XP system): C:\Windows\TI\USB1
3. Respond **Continue Anyway** to the warning that drivers are not certified by Microsoft.

   You have successfully installed the *TI USB Firmware Updater*.
4. Once again, the operating system prompts you with a **Found New Hardware Wizard**, Choose the *No, not at this time* option.
5. On the next screen, select the *Install from a list or specific location* option and use the **Browse** button to navigate to the PC Host folder (XP system): C:\Windows\TI\USB2
6. Respond **Continue Anyway** to the warning that drivers are not certified by Microsoft.

   You have successfully installed the *TI USB bq2750x Driver*.

EVM Connection Setup

Refer to Figure 32 when performing the EVM setup:

1. Connect one side of the 4-wire-set connector to the EV2300's I2C port (black wire aligned with GND pin) and the other side to the board's **J4** connector (black wire aligned with the VSS pin).
2. Ensure that jumper in **J5** of board is connected at the bottom position as shown Figure 32.
3. Ensure that NTC103AT thermistor is connected to the T and PACK– terminals of the **J8** block of the board.
4. Ensuring proper polarity, connect the 3-V to 4.2-V power supply or single-cell Li-ion battery between the PACK+ and PACK– terminals (**J8**) of the board.
5. To see current measurements, apply a load to **J7** and **J6** board connectors.

J6 is for host or charger *ground* and **J7** is for host or charger *power*.

6. To properly configure the fuel gauge IC for a given application, proceed to the **bqEASY** area of the evaluation software (Section 4.5) and the bq2750x EVM User's Guide (SLUU287).

For detailed instructions on operating the fuel gauge system, see the *bq2750x Datasheet* (SLUS785) and the *bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module* User's Guide (SLUU287).

Starting the bq2750EVM Software

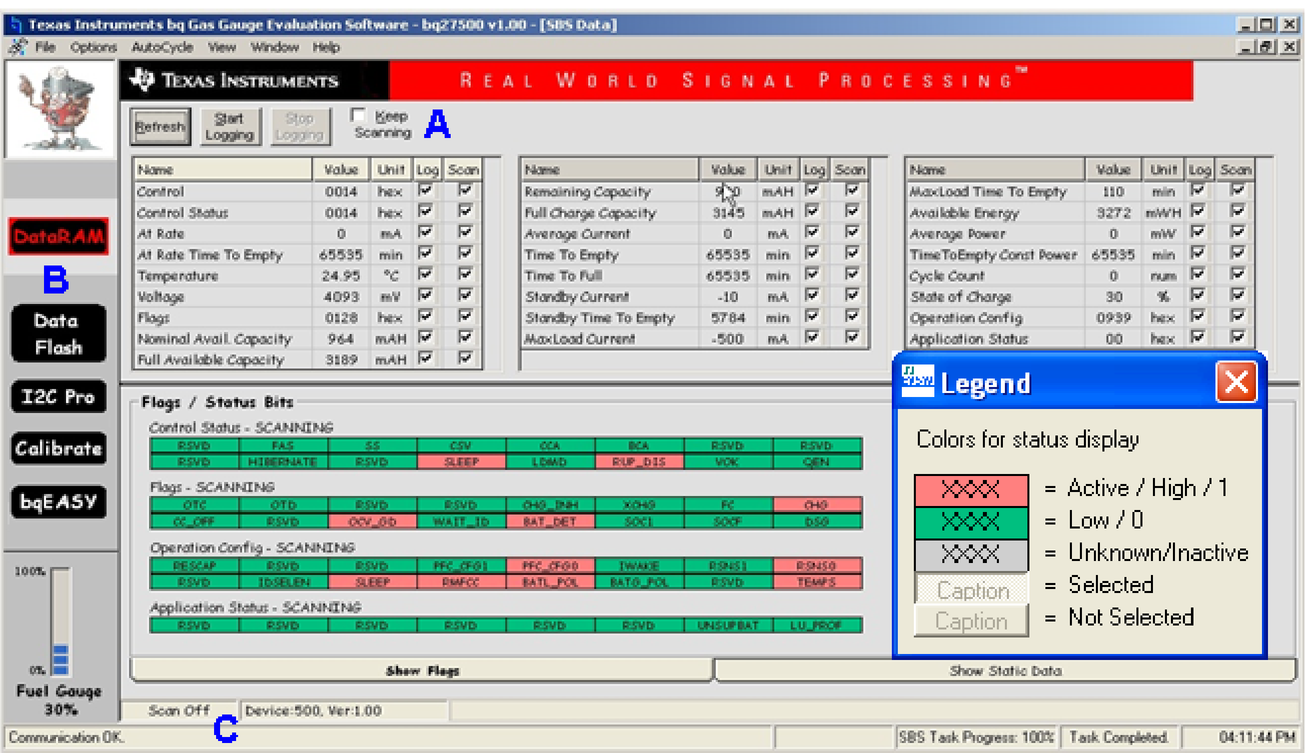
Beginning at the Windows Start menu, start the bq27500x evaluation software by selecting the application from the cascading menus: **start** → **Programs** → **Texas Instruments** → **bq Evaluation Software**. To become familiar with the bq2750x evaluation module (EVM) you can simulate a battery cell with resistors and a power supply. You can vary the voltage across these resistors to simulate different states of charge. This configuration is shown in Figure 32 and described in the *bq2750xEVM System Side Single-Cell Impedance Track ™ Technology Evaluation Module* application note (SLUU287).

bqEVSW Software Sections

The bq2750x evaluation software uses five major sections (Figure 34):

- **DataRAM**—standard I^{2}C information you can read from the pack when it is sealed and important IC status registers.
- **Data Flash**—shows all the parameters you can change when designing your system. Because this multiple-dialog window contains so much information, you can right-click the mouse to display a Help pop-up window that describes each value name.
- **I2C Pro**—reads and writes data from any gas gauge, plus can also load a new firmware file.
- **Calibrate**—performs temperature, coulomb counter (CC) input, board current, and pack current calibration tests.
- **bqEASY**—software wizard that acts like a workflow to simplify the configuring, chemistry selection, and performing learning cycles needed to produce the final "golden image" file.

Figure 34. bq2750x EVM Software Organization



A. Check box to **Keep Scanning** while you make changes.

B. Switches you quickly between major software areas.

C. Area provides information on Communication status, device type, and firmware version number.

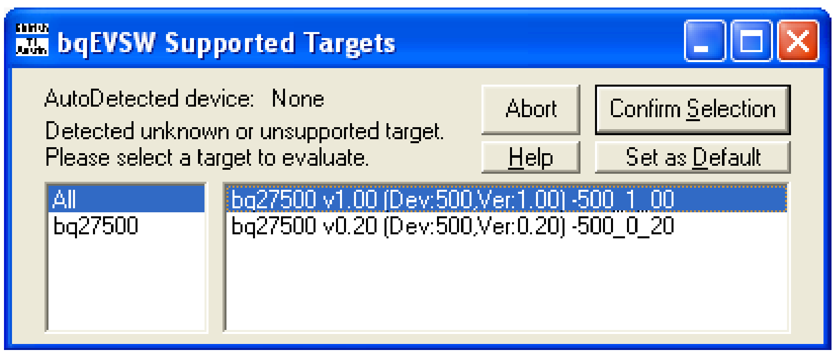
7.3 Software Communication and Trouble Shooting

When you start the bq2750x EVM software (**bqEVSW**), it should automatically recognize the firmware and hardware version. If there is a EV2300 USB PC Interface board communication problem, the message in Figure 35 displays.

Figure 35. bqEVSW Unable to Communicate With EV2300

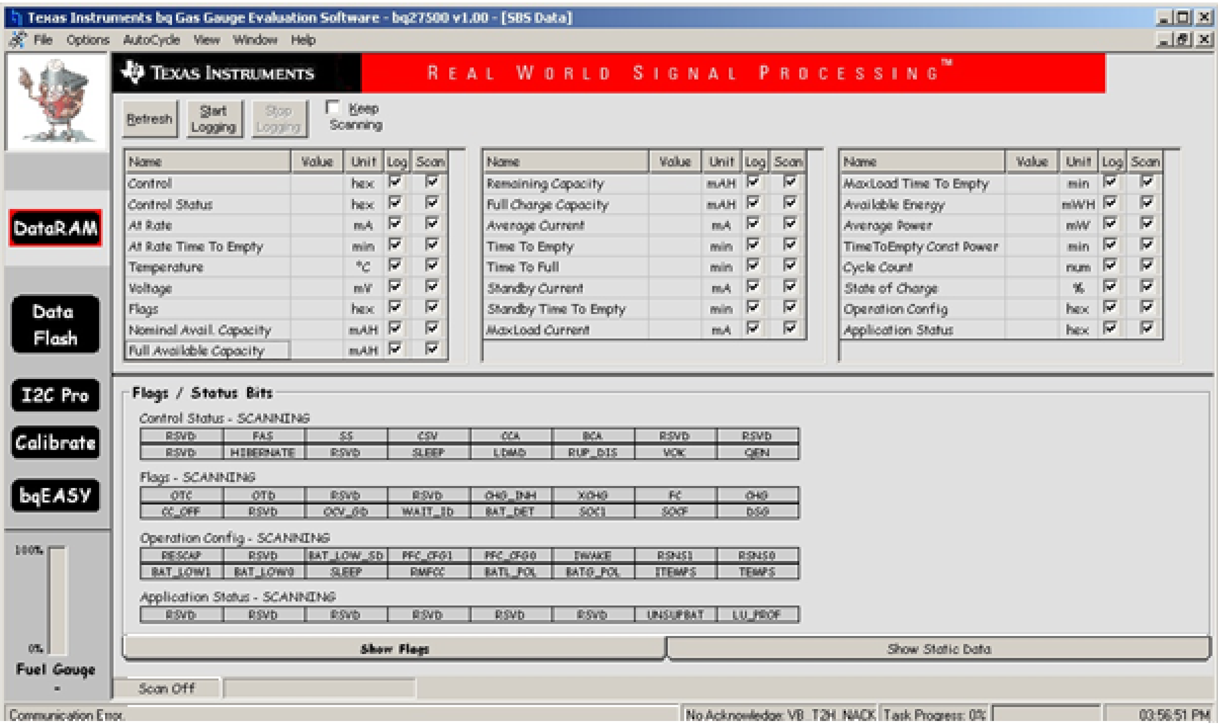
Click **OK** and the software requests you to choose a device in use. If you get to this point, you are not going to have proper communication with the EVM.

Figure 36. Select bq2750x device



If you choose one of the devices and firmware revisions, you eventually can display the DataRAM window; however key flags and status bits are grayed-out (Figure 37). The bq2750x EVM software uses color codes to describe the current status for the DataRam Flags and Status bits. Please familiarize yourself with the legend in Figure 34 and Figure 40.

Figure 37. DataRAM Window displaying No EV2300 Communication



Troubleshooting USB Communication Issues

If you are having EVM communication issues, try these steps:

- Do you have the EV2300 USB cable connected (Figure 38) as shown in the Basic bq2750xEVM Configuration?
- Have you properly installed the required *TI USB Firmware Updater* and the *TI USB bq2750x* drivers, as discussed in Install USB Drivers for EV2300 Communication?
- Did you *kick start* the EVM by connecting power momentarily to PACK+ and PACK– to simulate a charger insertion?
- Are the I^{2}C lines connected to the EVM (Figure 32)?
- Is there another instance of the software already running? Press Cntl+Alt+Delete keys to display the Task Manager and look for another instance of the bq2750x EVM software (**bqEVSW**) running.
- Try restarting your computer if you do not see the *TI USB bq2750x driver* displayed in the **System Properties** → **Hardware dialog tab** → **Device Manager** window.

Figure 38. bqEVSW software shows no USB board if EV2300 is not connected

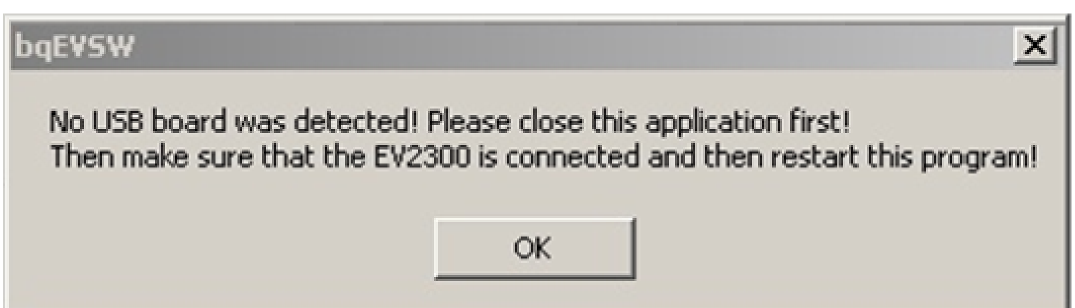
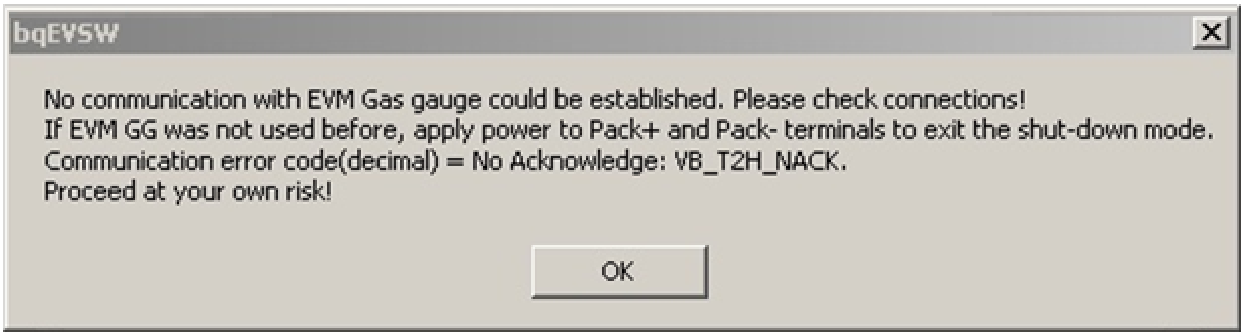


Figure 39. bqEVSW Complains if no EVM or EVM not powered up



7.4 bq2750x Evaluation Software Sections

The DataRAM screen displays as the default window, providing you access to the context-sensitive help and the five windows used to organize the software GUI controls:

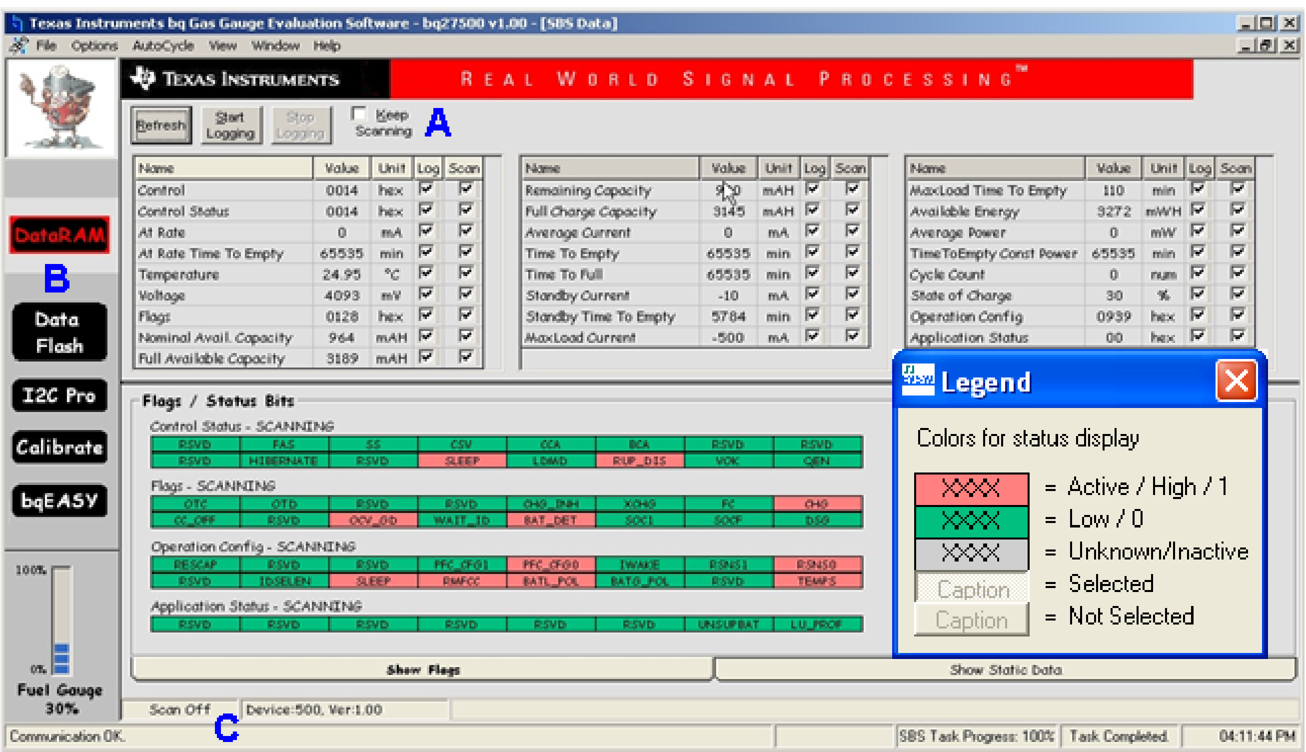
- DataRAM
- Data Flash, with context-sensitive (right-mouse) help
- I2C Pro
- Calibrate
- bqEASY Wizard

DataRam window

If everything is working OK, a DataRAM window similar to Figure 40 displays with green/orange indicators in the status registers. Also, *Communication OK* will be in the lower left-hand corner. Click on the *Keep Scanning* box at the top of the window. The software will keep updating these values throughout your testing process.

The DataRAM window shows the standard I^2C information you can read from the pack when it is sealed, as well as showing important status registers on the IC which can only be seen when the pack is unsealed or in full access mode (no FAS or SS bit set in Control Status register). By default, the IC is configured in full access mode.

Figure 40. DataRAM Displaying Appropriate Communication with EV2300



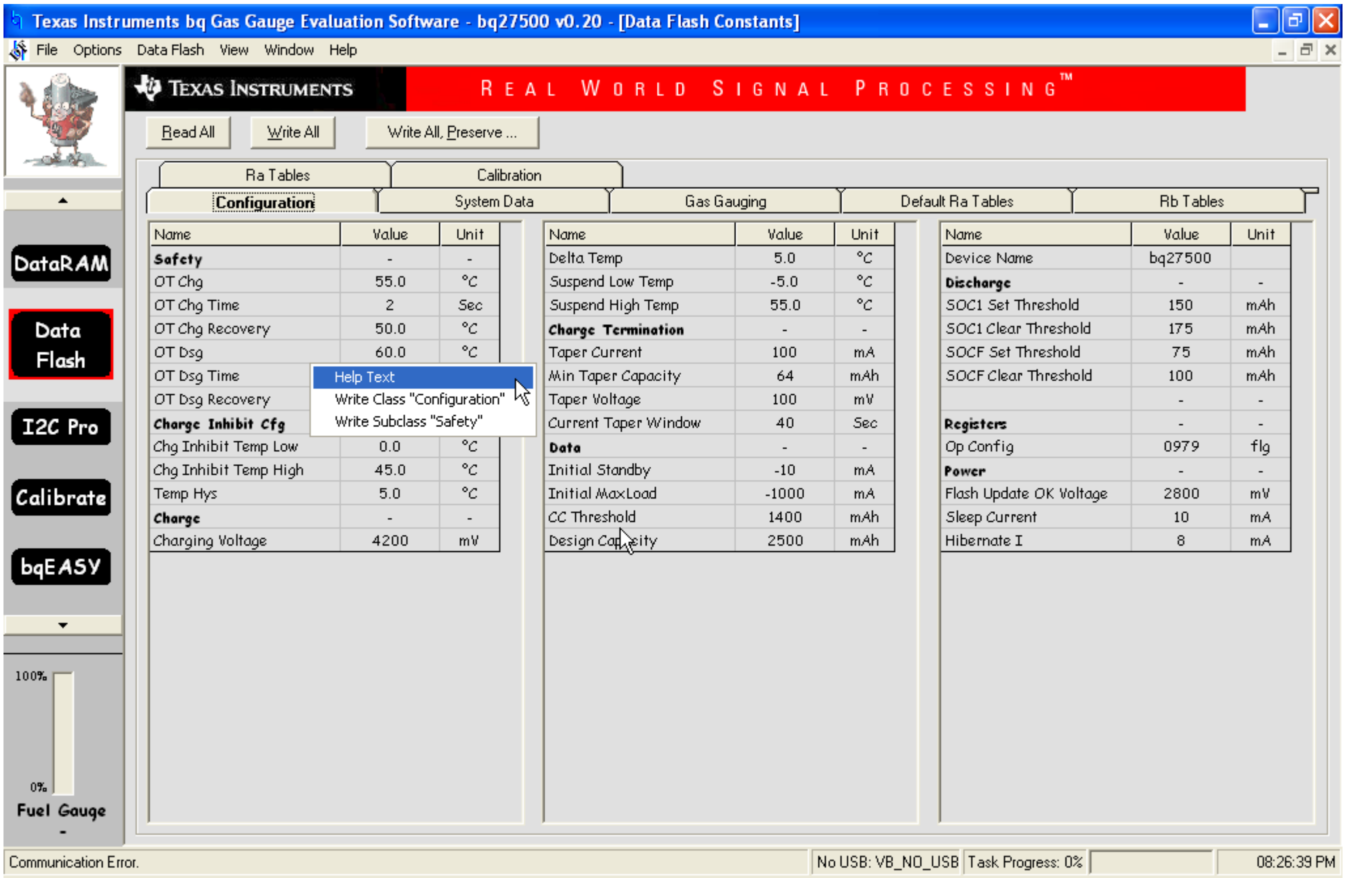
You can issue Manufacture Access commands (MAC) from this window by clicking in the **Control** field under the *Value* column (see Issuing MACs procedures). For example, this issue arises when writing the Unseal or Full Access commands. Examples of how to complete these processes is included in Seal and Unseal Process.

Data Flash Window

The Data Flash window (Figure 41) shows all the parameters you can change when designing your system. To begin, you can load the default values stored which shows the single cell pack configuration.

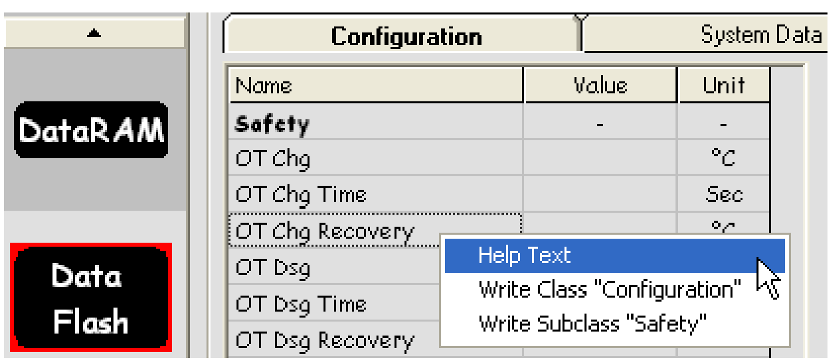
For detailed information on configuring the Data Flash for your particular design, see *Configuring the bq27500 Data Flash* (SLUA432)—a comprehensive resource for all Data Flash parameters.

Figure 41. Data Flash Window Displaying Default Parameters



Remembering all the nuances of the Data Flash parameters is not practical. However, all of the Data Flash definitions are listed in the *bq2750x Technical Reference Manual*. Additionally, you can right-click on any Data Flash parameter and choose *Help Text* (Figure 42), which displays an appropriate definition.

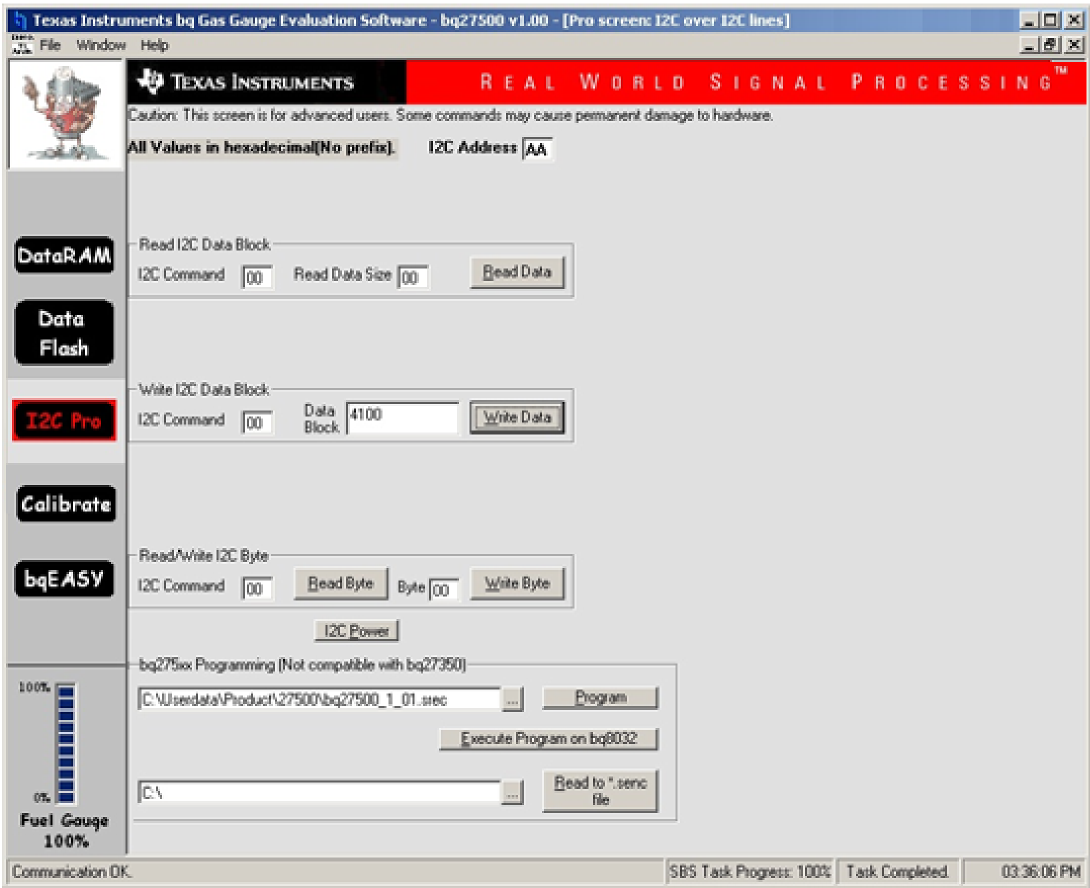
Figure 42. Data Flash Definitions Display with Right-click and Choosing Help Text



I2C Pro Window

The I2C Pro window helps you communicate with bq2750x IC. It is here where you can read and write byte, work, and block information. Also, you can upload a new **.SENC** file from this window by following the steps in the *Data Flash Programming and Calibrating the bq27500 Gas Gauge* (SLUA440).

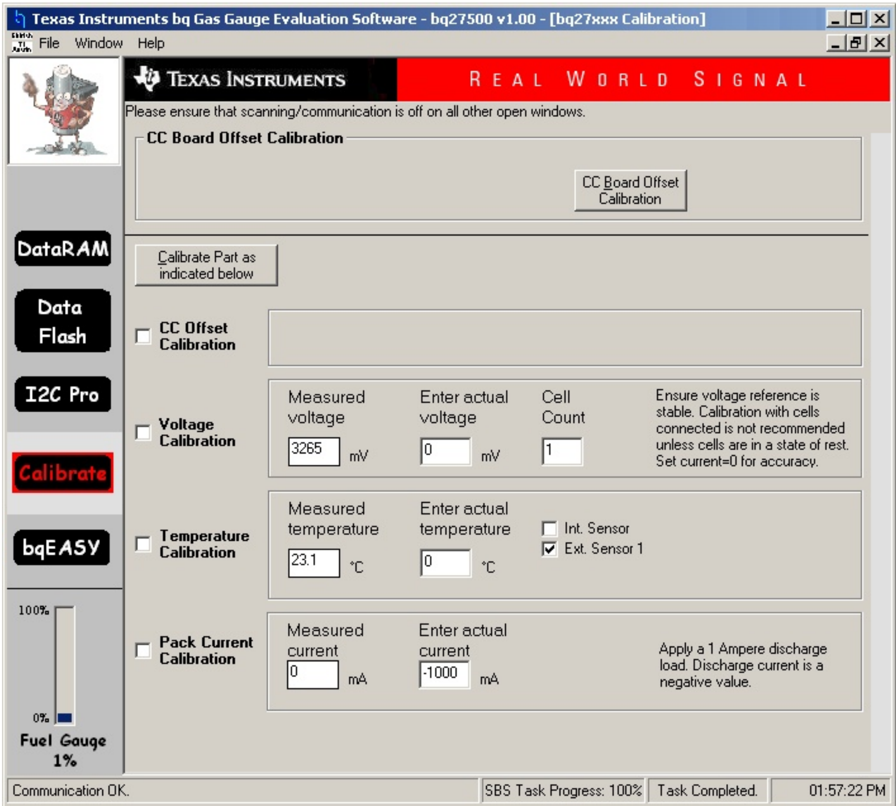
Figure 43. I2C Pro Window



Calibrate Window

The Calibrate window (Figure 44) helps you calibrate gas gauge voltage, current, temperature, and offsets. See similar procedures in the *Data Flash Programming and Calibrating the bq27500 Gas Gauge* (SLUA440).

Figure 44. Calibrate Window



bqEASY Wizard

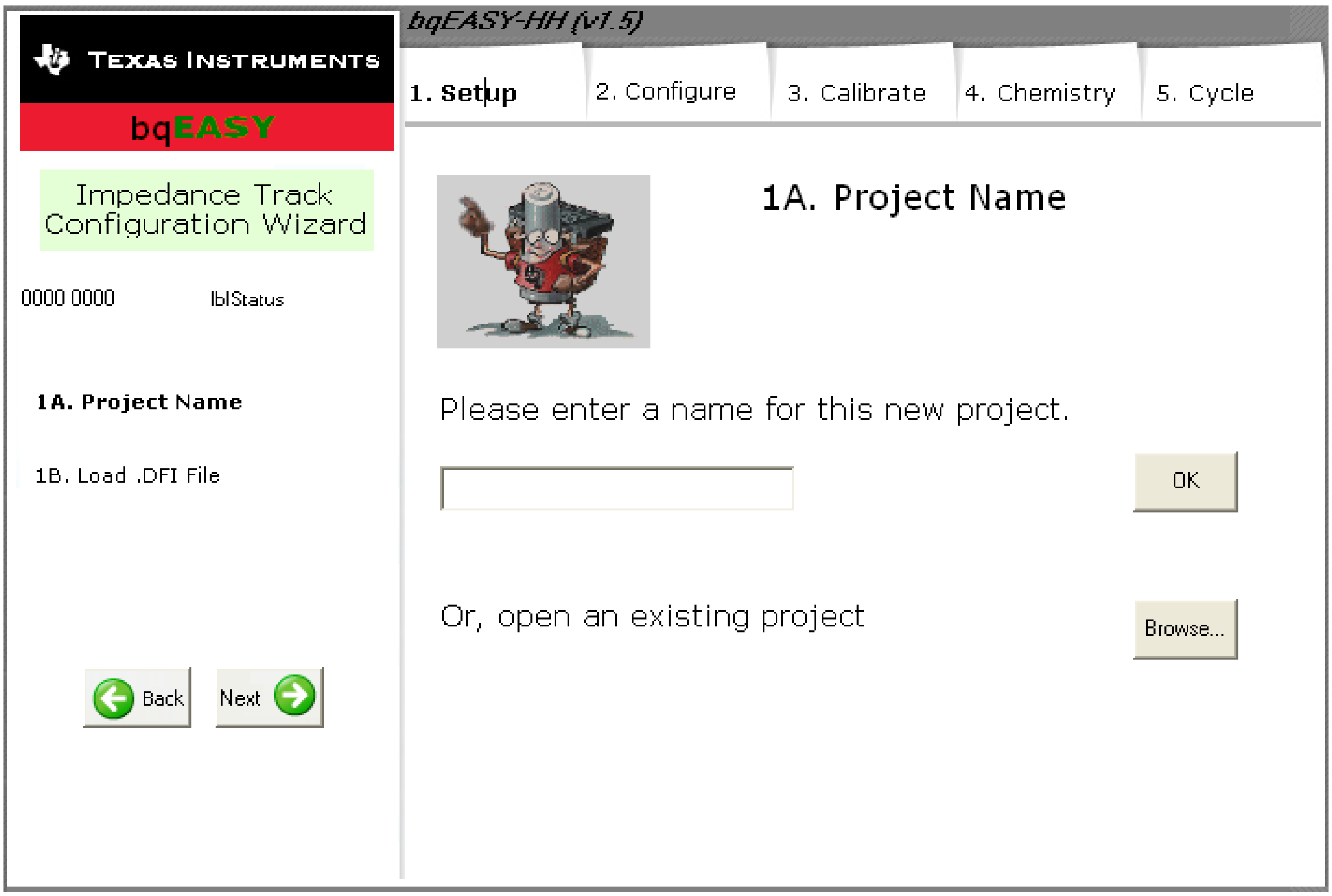
The bqEASY window (Figure 45) is a new feature in the bq Evaluation Software, used to program the Data Flash parameters, choose the proper battery chemistry, and perform the two cycle tests to create your Golden Image. If you are new to the Impedance Track™ technology, this is a great way to have a structured workflow to follow. (See details in Production Flow section.)

The bqEASY Wizard uses data entry dialogs to gather information and perform production tasks:

1. **Setup**—Impedance Track Configuration Wizard Splash screen
2. **Configure**—choose Data Flash parameters
   a. Cell Characteristics
   b. Charge Parameters
   c. Discharge Parameters
   d. Reserve Capacity
   e. Load Characteristics
   f. Application Configuration
   g. Remaining Capacity Method
   h. Miscellaneous Information
3. **Calibrate**
   a. CC Offset
   b. Voltage
   c. Temperature
   d. Pack Current

   e. Board Offset
   f. Review / Read DFI file
4. **Chemistry**
   a. Use Default Chemistry
   b. Select Chemistry Manually
   c. Do Chemistry Select Cycling
5. **Cycle**
   a. Learning Cycle
   b. Update Golden Pack

Figure 45. bqEASY Wizard



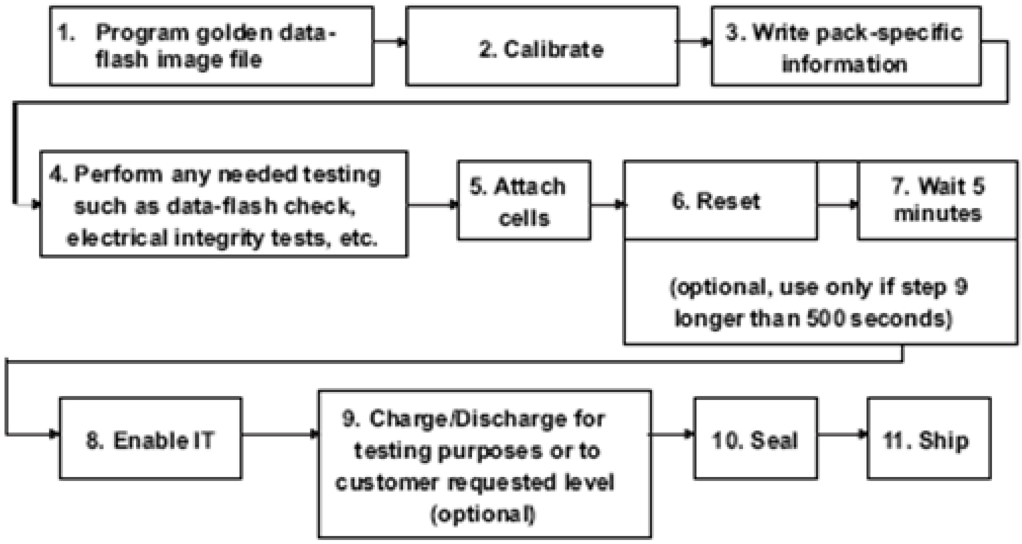
7.5 Creating Your Golden Image

One of the major benefits of using the Impedance Track technology, aside from super accurate gas gauging, is a simplified manufacturing process. No charge or discharge cycles are required after assembling the pack, which can take many hours.

Production Flow

Figure 46 is a procedure diagram showing the normal production flow of the bq2750x chipset. A detailed description of these states can be found in the *Going to Production with the bq27500* application report (SLUA449).

Figure 46. Production Flow Diagram



These are different steps in design, preproduction, and production.

Design and Evaluation

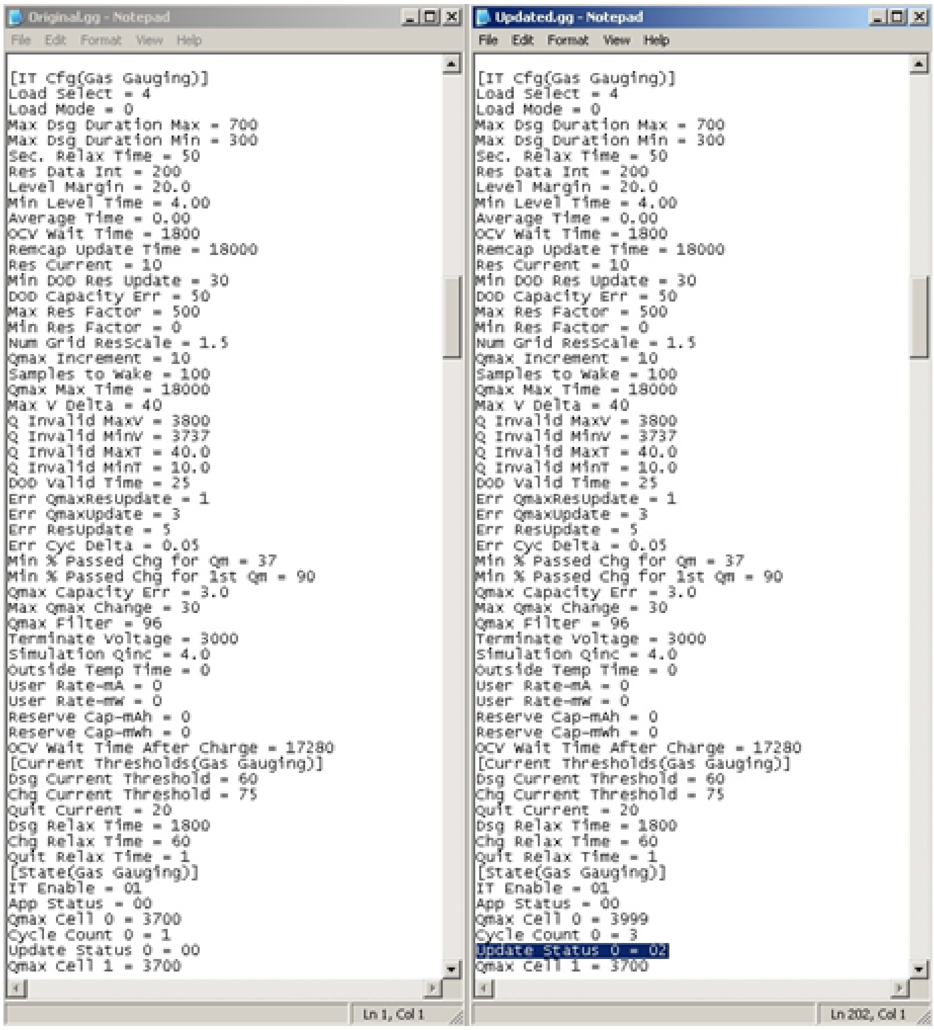
1. Install the bqEVSW software and EV2300 communication USB drivers.
2. Connect resistors and power supply to simulate battery pack.
3. "Kick-start" the EVM (connect power momentarily to the PACK+ and PACK– to simulate charger insertion).
4. Start bqEVSW software
5. Explore the different features of the software.
6. Load the correct .chem file corresponding to the chemistry of your battery cells using the bqEASY wizard (see Choosing the Correct Chemistry).
7. Program the necessary Data Flash constants specific to your design.
8. Connect a real battery cell to the EVM
9. Fully charge the cells and let reset for 2 hours.
10. Start Data Logging – both DataRAM parameters and the .GG gas gauge files.
11. Repeat these steps as often as necessary:
    – Enable Impedance Track Algorithm
    – Discharge Pack to termination voltage and let reset.
    – Repeat this process
12. Look for updated resistances and Update Status = 02 in the final .GG file.

    Once you have a properly cycled pack with updated values, we need to create a Golden image file that is programmed and incorporated into every pack coming off the production line.
13. Export the .GG file and make a few changes (disable IT and change cycle count to 0).
14. Reload the .DFI file to clear out Data Flash hidden values.
15. Import your changed .GG file.
16. Now you are ready to create the .DFI file used to program production packs.

The Gas Gauge File

The Gas Gauge (.GG) file stores all programmable Data Flash parameters as well as the updated cell resistance profile after doing the two cycle tests. Figure 47 displays a gas gauge file, showing its default values (specific to this chemistry) and it's updated values after the cycle tests.

Figure 47. Gas Gauge File (Default and Cycled Values)



Original.gg - Notepad

File Edit Format View Help

```
[IT Cfg(Gas Gauging)]
Load Select = 4
Load Mode = 0
Max Dsg Duration Max = 700
Max Dsg Duration Min = 300
Sec. Relax Time = 50
Res Data Int = 200
Level Margin = 20.0
Min Level Time = 4.00
Average Time = 0.00
OCV Wait Time = 1800
Remcap Update Time = 18000
Res Current = 10
Min DOD Res Update = 30
DOD Capacity Err = 50
Max Res Factor = 500
Min Res Factor = 0
Num Grid ResScale = 1.5
Qmax Increment = 10
Samples to wake = 100
Qmax Max Time = 18000
Max V Delta = 40
Q Invalid MaxV = 3800
Q Invalid MinV = 3737
Q Invalid MaxT = 40.0
Q Invalid MinT = 10.0
DOD Valid Time = 25
Err QmaxResUpdate = 1
Err QmaxUpdate = 3
Err ResUpdate = 5
Err Cyc Delta = 0.05
Min % Passed Chg for Qm = 37
Min % Passed Chg for 1st Qm = 90
Qmax Capacity Err = 3.0
Max Qmax Change = 30
Qmax Filter = 96
Terminate Voltage = 3000
Simulation Qinc = 4.0
Outside Temp Time = 0
User Rate-mA = 0
User Rate-mW = 0
Reserve Cap-mAh = 0
Reserve Cap-mWh = 0
OCV Wait Time After Charge = 17280
[Current Thresholds(Gas Gauging)]
Dsg Current Threshold = 60
Chg Current Threshold = 75
Quit Current = 20
Dsg Relax Time = 1800
Chg Relax Time = 60
Quit Relax Time = 1
[State(Gas Gauging)]
IT Enable = 01
App Status = 00
Qmax Cell 0 = 3700
Cycle Count 0 = 1
Update Status 0 = 00
Qmax Cell 1 = 3700
```

Ln 1, Col 1

Updated.gg - Notepad

File Edit Format View Help

```
[IT Cfg(Gas Gauging)]
Load Select = 4
Load Mode = 0
Max Dsg Duration Max = 700
Max Dsg Duration Min = 300
Sec. Relax Time = 50
Res Data Int = 200
Level Margin = 20.0
Min Level Time = 4.00
Average Time = 0.00
OCV Wait Time = 1800
Remcap Update Time = 18000
Res Current = 10
Min DOD Res Update = 30
DOD Capacity Err = 50
Max Res Factor = 500
Min Res Factor = 0
Num Grid ResScale = 1.5
Qmax Increment = 10
Samples to wake = 100
Qmax Max Time = 18000
Max V Delta = 40
Q Invalid MaxV = 3800
Q Invalid MinV = 3737
Q Invalid MaxT = 40.0
Q Invalid MinT = 10.0
DOD Valid Time = 25
Err QmaxResUpdate = 1
Err QmaxUpdate = 3
Err ResUpdate = 5
Err Cyc Delta = 0.05
Min % Passed Chg for Qm = 37
Min % Passed Chg for 1st Qm = 90
Qmax Capacity Err = 3.0
Max Qmax Change = 30
Qmax Filter = 96
Terminate Voltage = 3000
Simulation Qinc = 4.0
Outside Temp Time = 0
User Rate-mA = 0
User Rate-mW = 0
Reserve Cap-mAh = 0
Reserve Cap-mWh = 0
OCV Wait Time After Charge = 17280
[Current Thresholds(Gas Gauging)]
Dsg Current Threshold = 60
Chg Current Threshold = 75
Quit Current = 20
Dsg Relax Time = 1800
Chg Relax Time = 60
Quit Relax Time = 1
[State(Gas Gauging)]
IT Enable = 01
App Status = 00
Qmax Cell 0 = 3999
Cycle Count 0 = 3
Update Status 0 = 02
Qmax Cell 1 = 3700
```

Ln 202, Col 1

(1) Update Status as changed from 0x00 to 0x02

(2) QMAX for the individual cells and pack has been updated

(3) Resistance table (Ra Table) updated for each of the cells.

7.6 Example Procedures

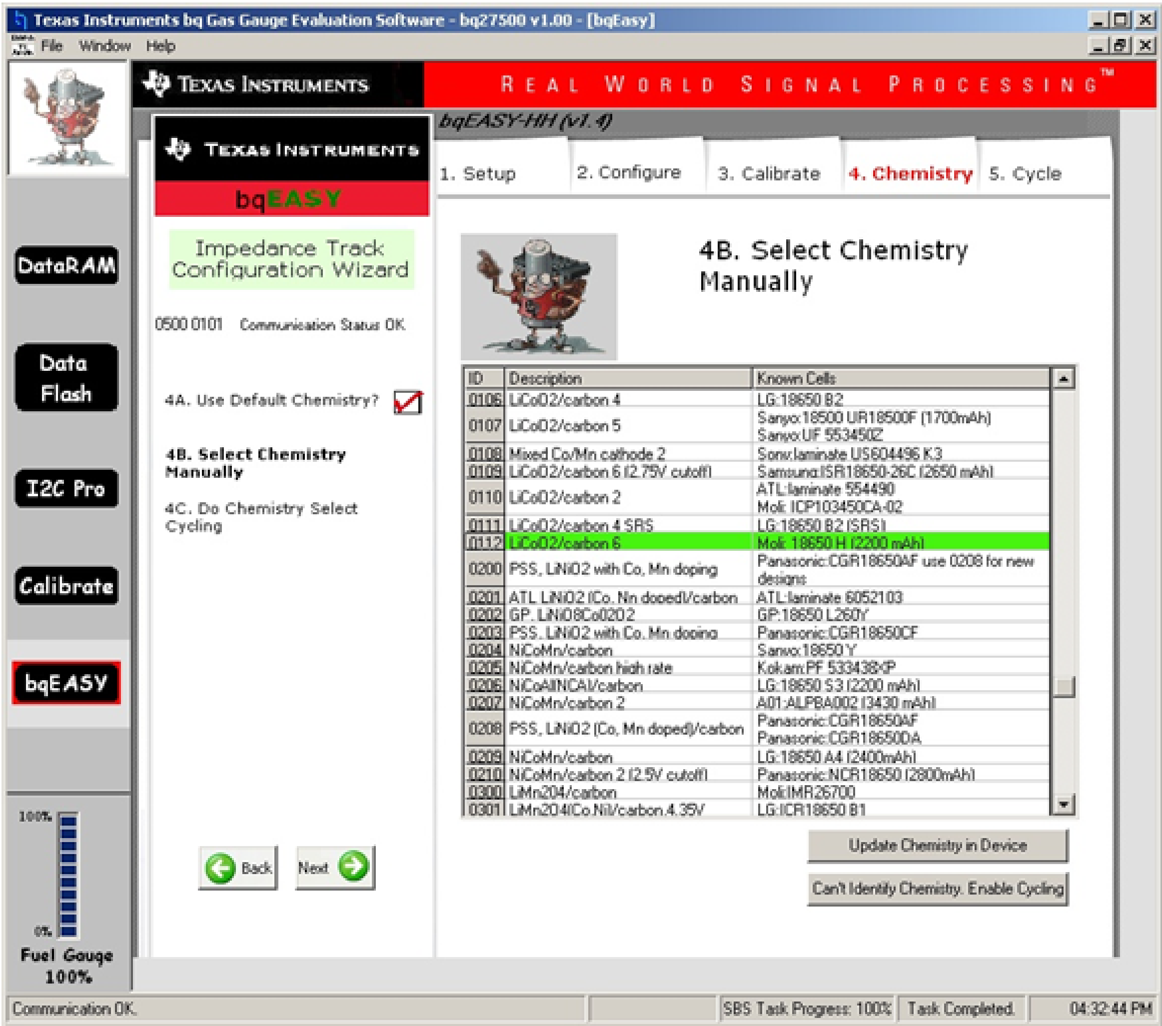
Choosing the Correct Chemistry

For the impedance track algorithm to work properly, the exact chemistry of the Lithium cells needs to be known and the correct .SENC file needs to be loaded.

The most updated chemistry files can be found installing the latest version of the bqEVSW software, which you found on the TI Internet site in the bq2750x Product Folder (Figure 33). The files are stored in the folder named: C:\Program FIles\Texas Instruments\bq Evaluation Software\Plugins\Chemistry The **Chem.ini** file describes the chemistry, manufacturer, and model numbers for the *.CHEM files in this folder.

You can use the bqEASY wizard (Figure 48) to display the chemistry information in an easy-to-use and organized manner. If you are using the bqEASY Wizard, it asks you to choose the correct chemistry from a list of manufacturers and model numbers. Alternatively, you can test for a compatible chemistry using a *4 point test*.

Figure 48. Chemistry Selection Table in bqEASY Wizard



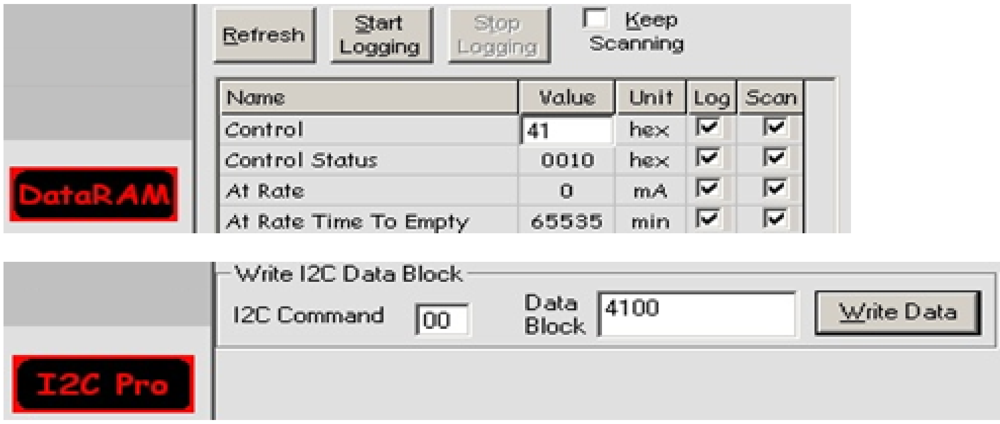
#IMPLIED. A unique chemical ID indicates a different battery chemistry being used.

Resetting the Pack

Vary the voltage of the power supply (careful not to exceed maximum voltages) and issue a **RESET** Manufacture Access Command (MAC) to the bq2750x. The I^{2}C double-word command is *0x00*, data *0x0041*.

There are two ways to do this (see Figure 49). The shortcut is to type *41* into the Manufacture Access **Value** of the DataRAM window. Alternatively, use the I2C Pro window to issue a reset command *00*, data *4100* from the **Write I2C Data Block** and click the **Write Data** button.

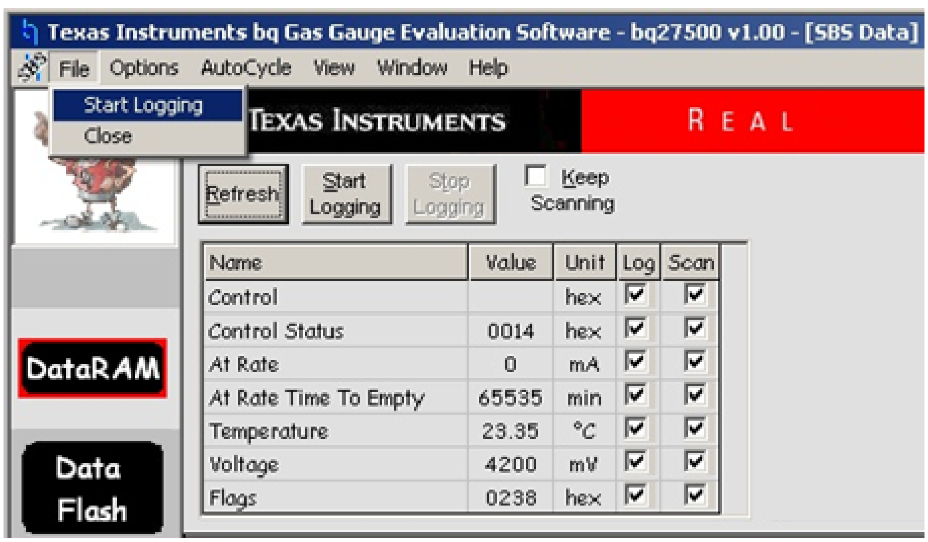
Figure 49. Sending MACs - DataRAM and I2C Pro Windows



Data Logging

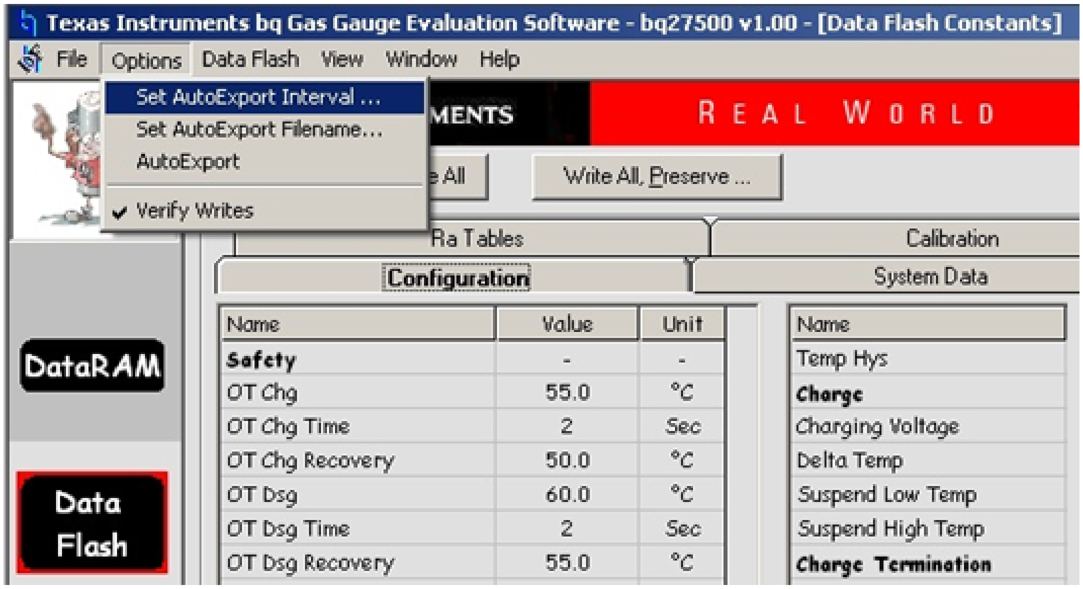
While you are running your charge and discharge tests you may want to log the DataRAM and gas gauge (.GG) flash data. This is done in two steps. The DataRAM data is logged by selecting the **File** → **Start Logging** menu command (Figure 50). The **Save As (Log File Name)** dialog asks what folder and what file name to use for the Log File.

Figure 50. DataRAM Data Logging Command



To save the iterations of the Gas Gauge (.GG) file, go to the **Data Flash** window and select the **Options** → **Set AutoExport Filename** command. A series of Gas Gauge files is created in the folder specified throughout the testing. You can adjust the save interval of AutoExport (every 15 minutes is usually acceptable) using the **Options** → **Set Export Interval** command. To start the logging, select the **Options** → **AutoExport** command (Figure 51) to begin saving the Gas Gauge files.

Figure 51. Gas Gauge Logging Setup and Start Commands



Seal and Unseal Process

Once you are finished with the production flow (see Figure 46) and have programmed the correct gas gauge (.gg) file for your "golden pack", you will want to seal the pack. If you do seal the pack, you can issue the Unseal command, followed by the Full Access command to make changes. However, if you removed power to IC, it returns to sealed mode and you would have to repeat this process again to unseal and subsequently move to full access mode. The only way to *reset* the IC to automatically come up in full access mode is to reload the .SENC file with defaults.

Be careful when reloading the .SENC file as it can erase any Data Flash constants or resistance updates through cycling that you may have made.

If you Seal your battery pack and later you decide to unseal it (for example, diagnosing a field failure), you must perform these steps to move from **Sealed**, to **Unsealed**, and finally to **Full Access** mode.

1. During production, you will want to change the default Unseal and Full Access Keys settings in the IC. To read the default Unseal and Full Access Key, the data flash portion of the device needs to be opened by the configuration file **.encr** and the *Security* dialog tab (Figure 52) can be accessed. The default Unseal Key and Full Access Key can be modified.
2. When the IC is sealed, and you connect the EV2300 and start the bq2750x evaluation software, the DataRAM window displays as in Figure 53. (Not all the status registers are accessible. These are grayed out in the DataRAM window.) Sealing the pack is done using Manufacture Access *0x0020*.

Do **not** seal your pack until after production.

---

3. The FAS (Full Access Seal Mode) and SS (Sealed State) bits are set when seal command is issued through control register. To move from Sealed to Unsealed mode, write to the bq2750x device with the UNSEAL Key (04from the previous step. After this command is issued you are able to read all the status registers, as shown in Figure 55. We still need to move from Unsealed to Full Access mode using the FullAccessKey.

The SS bit (Sealed) is cleared; however the FAS bit (Full Access) is still set in Figure 55.

---

4. After issuing the two *0xFFFF* Full Access Key through control register, the FAS bit (Figure 56) is also cleared.

Figure 52. Default Unseal Key and Full Access Key

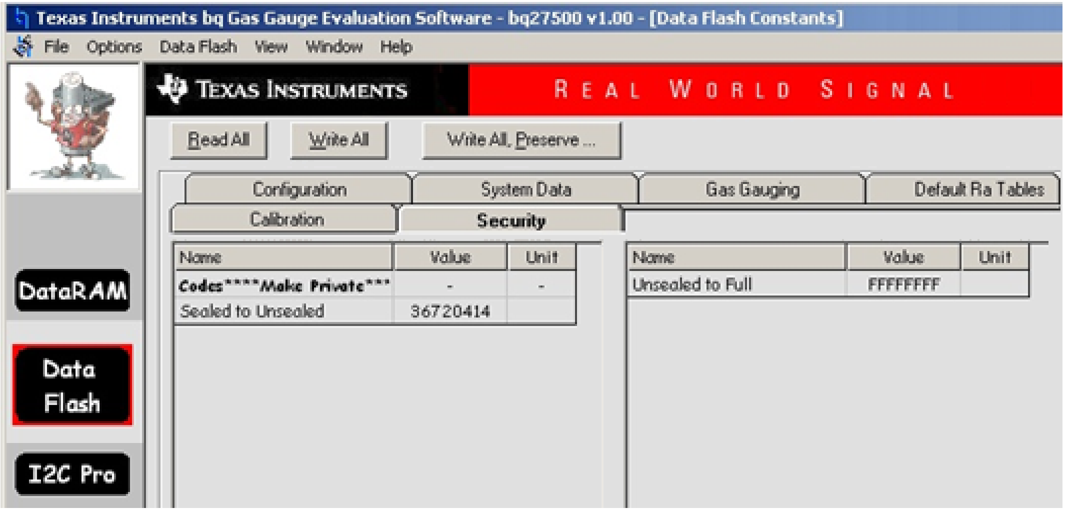


Figure 53. Sealed Mode for the bqEVSW DataRAM window

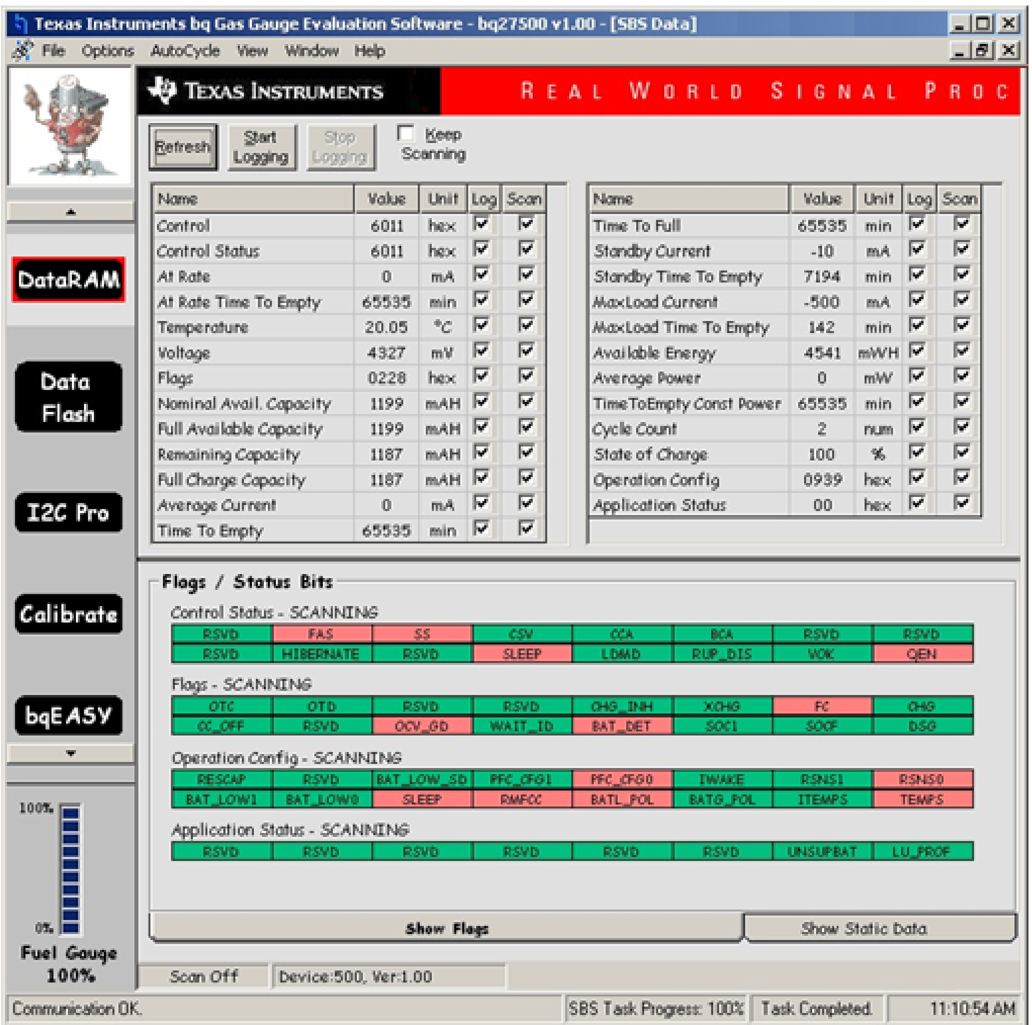


Figure 54. Default Unseal Command Using Control Register

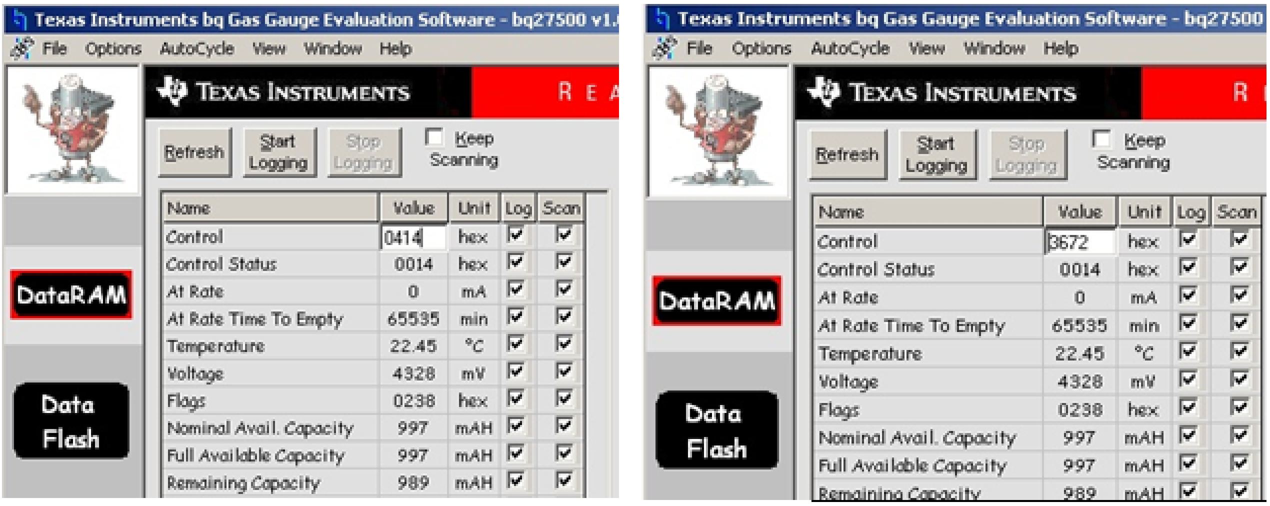


Figure 55. Status Showing Unsealed Mode With Full Access FAS Bit Set

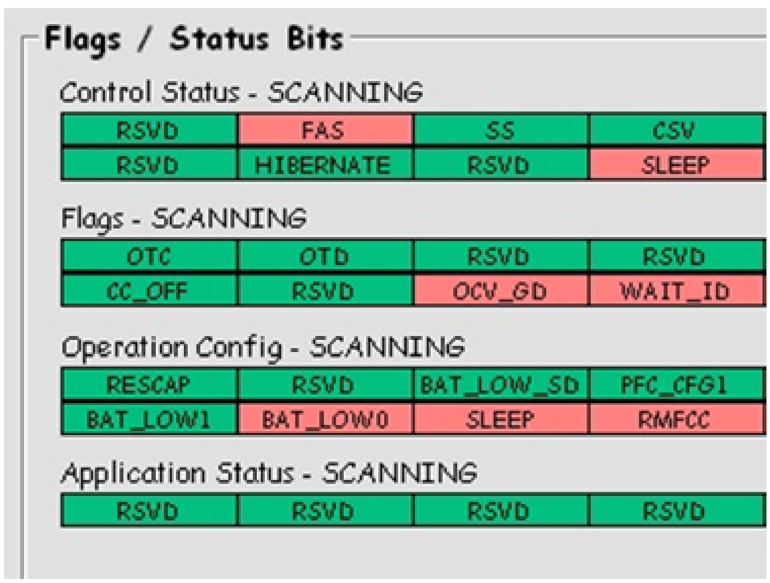
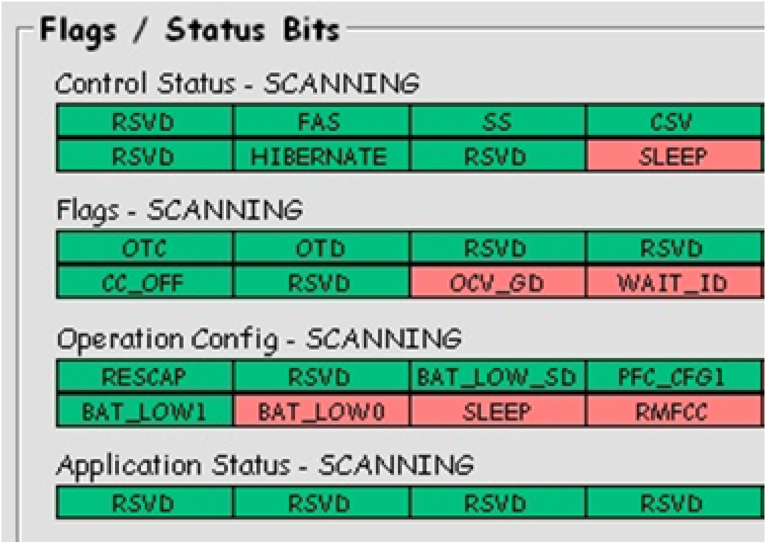


Figure 56. FAS and SS Bits are Cleared



Chapter 8

bqEASY™ for Single Cell Impedance Track™ Devices

Texas Instruments advanced fuel gauges, that employ the Impedance Track™ algorithm, offer an unmatched array of features and benefits. Sometimes the multiple configuration settings can make it challenging to begin the evaluation process. In addition, determining the correct chemistry model and producing the final *golden image* file can be time consuming. The bqEASY™ software is designed to simplify the process of configuring, calibrating, selecting chemistry, and performing the charge-discharge learning cycles using the step-by-step procedural interface.

8.1 Introduction

Evaluating the complex configuration options of the Texas Instruments advanced fuel gauges can be simplified by using the bqEASY software. The bqEASY software procedure provides detailed configuring, calibrating, and chemistry selection instructions, and works within the Evaluation Software (EVSW). The discharge portion of the chemistry and learning cycles can be performed automatically with the use of an additional circuit connected between the target device or Evaluation Module (EVM) and the EV2300. When the automated processes complete, a final *golden image* is generated that can be used in production application programming for all devices.

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Arbin Instruments is a trademark of Arbin Instruments.
Windows, Microsoft are trademarks of Microsoft Corporation.
All trademarks are the property of their respective owners.

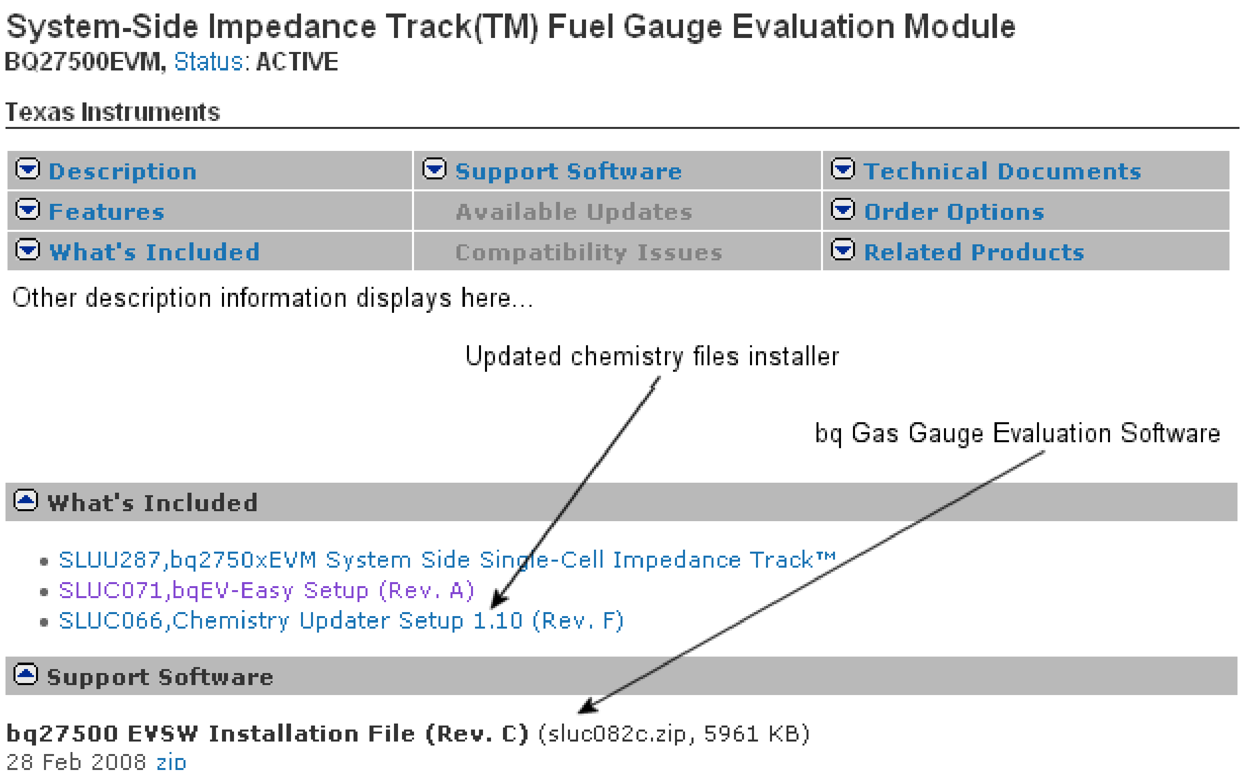
8.2 Software Installation

Software installation requires that the latest EVSW be installed from the TI Internet in the EVM tool folder, for the specific part. In this document, the *bq275xx* EVM tool folder is referenced, but any EVM tool folder that supports bqEASY can be used.

To install the software:

1. Ensure that the EV2300 is **not** connected to the computer, prior to software installation.
2. Go to the TI Internet and get the latest EVSW if not already done. As described above, this can be found on the TI Internet in the EVM tool folder Support Software section (see Figure 57) for the part being used. As an example, go to the *bq27500EVM* folder *Support Software* at http://focus.ti.com/docs/toolsw/folders/print/bq27500evm.html.

Figure 57. TI Internet bq27500EVM Product Folder



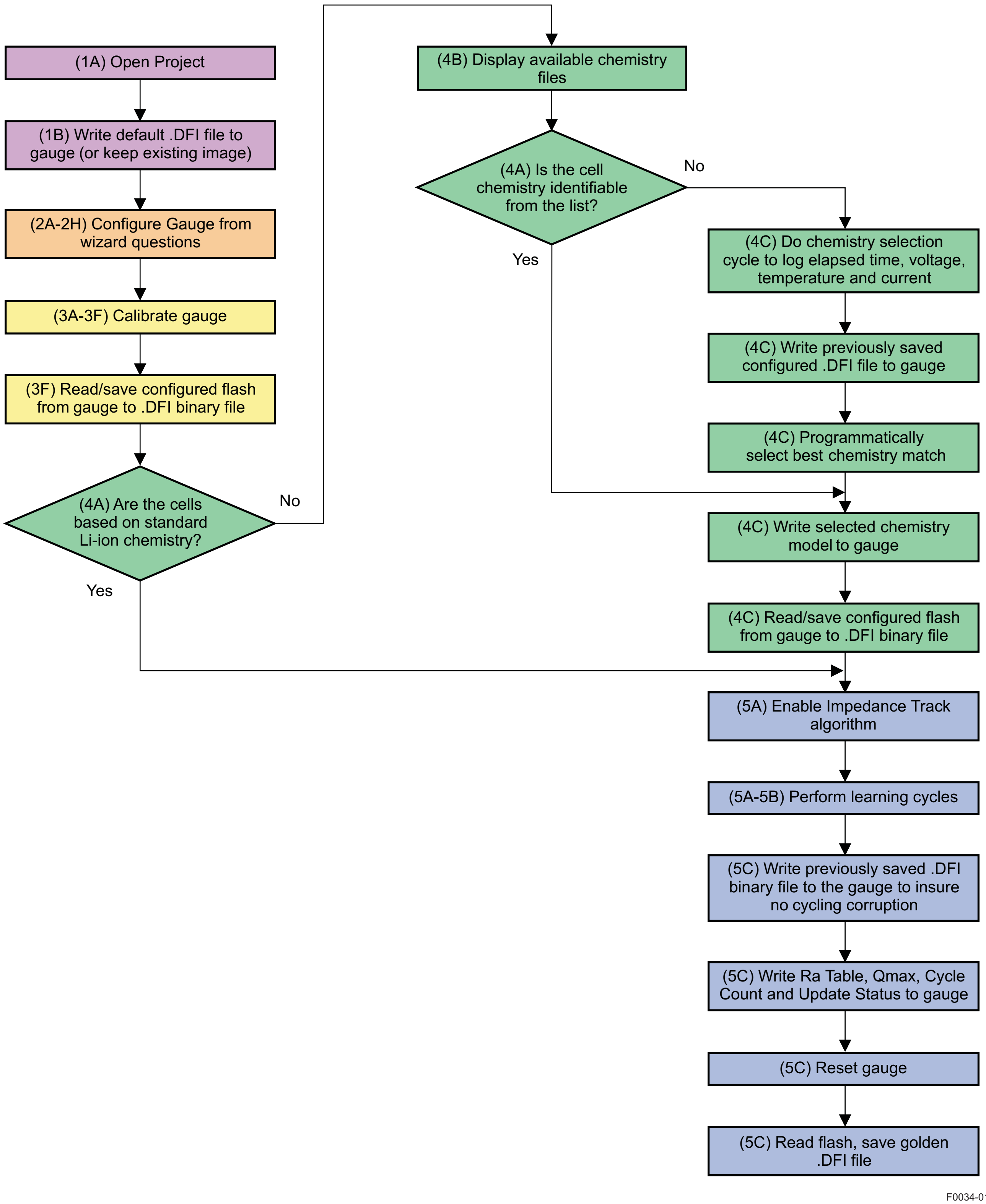
3. Install the EVSW using the Installer screen-displayed instructions. For additional assistance with EVSW installation, see the *Quick Start Guide for bq2750x Family Gas Gauges* (SLUA448). This document can also be found in the EVM tool folder (see Figure 57) for the product being used.
4. Once the EVSW is installed, verify its functionality by setting up the EV2300 and a known bq275xx module. Ensure that the computer, EV2300, and bq275XX module all are operating normally and that communication to the module is functioning. For additional assistance help, refer to *Quick Start Guide for bq2750x Family Gas Gauges* (SLUA448).
5. Because chemistry files are added to the device Internet EVM tool folder often, check this Internet page for updates. A self-extracting installer is available for updating the chemistry file. Install these updates if they exist in the Internet folder.
6. Start the bq Gas Gauge Evaluation Software using the menu commands **start** → **Programs** → **Texas Instruments** → **bq Evaluation Software**.
7. To access the bqEasy procedures, click the **bqEasy** button in the left column (below **Calibrate**) in the EVSW (Figure 58).

Figure 58. bqEASY Procedure Software

8.3 Program Navigation and Flowchart

The operation sequence of bqEASY can be understood by reviewing the procedure flowchart in Figure 59. Start a new project and follow the procedure steps. Use the **Next** button, or click the top dialog tabs and left sub-section labels to move among the bqEASY dialogs. Some operations must be completed in sequence because of data dependencies, or to implement the required steps. TI recommends following the prescribed sequence, initially.

Figure 59. bqEASY Process Flowchart



8.4 Configuration Procedures

These configuration procedures can be used to set up parameters without navigating through the entire EVSW user interface:

- **Gas Gauge configuration using default or custom data**
- **Chemistry data installation using available bqEASY chemistries**

To configure the gas gauge using default or custom data:

1. Start the EVSW (**start** → **Programs** → **Texas Instruments** → **bq Evaluation Software**) and click the **bqEasy** button in the left column (below **Calibrate**) in the user interface.
2. Click the **2. Configure** dialog tab at the top of bqEASY tabs. Note, the first dialog tab can be skipped.
3. Answer all questions or leave defaults for the **2. Configure** dialog tab. Be sure to click OK at the bottom of each **2. Configure** dialog to ensure that a completion check mark (Figure 60) displays for each page
4. On dialog **2H**, when clicking the **OK** button, the software asks if the user wants to write the information to the data flash memory. Click **Yes** to write the information to the data flash.

The Gas Gauge module now has the data flash configured with the information entered in **2. Configure** bqEASY dialogs.

To install chemistry data using available bqEASY chemistries:

1. Start the EVSW (**start** → **Programs** → **Texas Instruments** → **bq Evaluation Software**) and click the **bqEasy** button in the left column (below **Calibrate**) in the user interface.
2. Click the **4. Chemistry** dialog tab at the top of bqEASY tabs. Note, the initial three dialog tabs can be skipped.
3. Select **Use Default Chemistry** or click **Enable Chemistry Selection** and select the correct chemistry from the list.
4. If the proper chemistry is not found, check the device EVM tool folder on the TI Internet site for any new Chemistry file updates as described in the Software Installationsection and identified in Figure 57.

The software configures all data flash locations on the Gas Gauge Module that deal with chemistry functions. No other data flash locations are modified.

8.5 bqEASY Data Files

bqEASY uses several file types to configure a fuel gauge:

- ***.ENCR (Data Flash Files)—**default data-flash definition files found in the *...\bq_Evaluation_Software* folder. An ENCR file is a copy of the entire data-flash from a fresh Gas Gauge prior to any data-flash updates by the user or the Gas Gauge. These files are unique for every version of each TI fuel gauge product. If working with a newer version fuel gauge and an older version of bqEASY, the correct file may not be present in the software. This requires a new version of the EVSW with bqEASY. Navigate to the TI Internet in the EVM tool folder for the device being used, and download the latest version, or contact TI. For bqEASY, the ENCR files act as a dictionary to look up the address for a given data-flash location. For EVSW, the define window display parameters including address, display formulas, and data types. An error message displays if the correct .ENCR data flash file cannot be found.
- ***.CHEM (Chemistry Files)—**read-only files found in the *...\bq_Evaluation_Software\Plugins\Chemistry* application folder. When a new Li-Ion battery chemistry is developed, a new Impedance Track model is required to define the chemical model. During automated chemistry selection, each of these files is scanned to select the best match with the recorded data. If working with a newly developed chemistry, it is possible that an acceptable match will not be found. If this is the case, check for updated bqEASY software or Chemistry files on the TI Internet in the EVM tool folder for the part being used.
- ***.DFI (Data-Flash Image Files)—**binary images of the fuel gauge data-flash with modified values based on the application. Because of the binary format, it is easy to transfer them to and from a gauge. Each fuel gauge model and firmware version has a unique read-only .DFI which is found in the *...\bq_Evaluation_Software\Plugins\Device_Defaults* folder of the application. During the bqEASY

process, intermediate versions of .DFI files are recorded with current updated data to prevent data corruption. The final output of bqEASY is a .DFI file which is the called the *golden image* and used to program production units. This output file is placed in the *...\bq_Evaluation _Software\Plugins\Projects* folder.

- ***.EZY (bqEASY Project Files)—**read/write text files which record header information regarding a project, answers to the wizard questions, and status regarding the completion stages (red completion check marks in Figure 60). The files are stored in the *...\bq_Evaluation_Software\Plugins\Projects* folder.

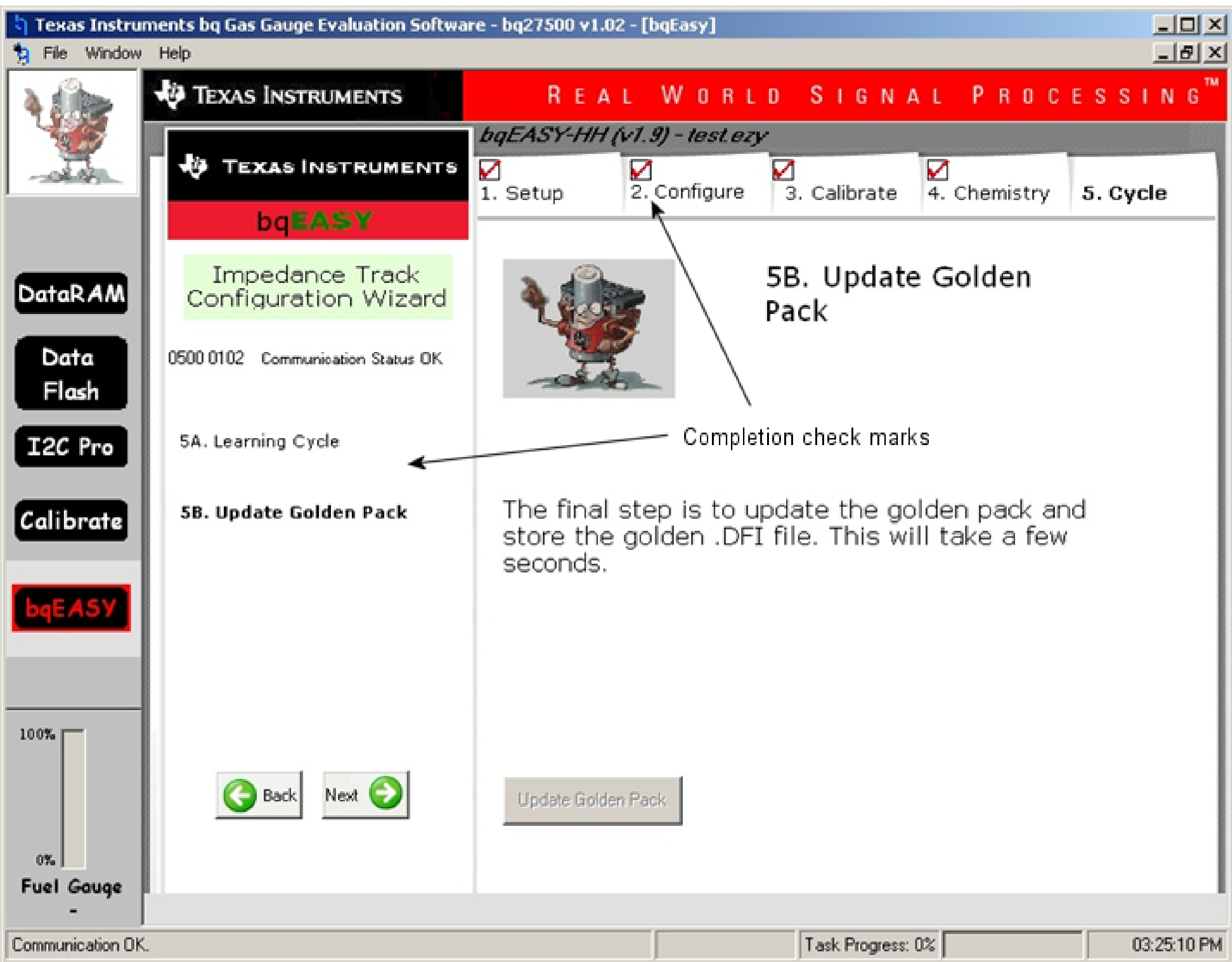
8.6 Completion Checkmarks

As the bqEASY questions and tasks are completed, completion checkmarks display in two places—along the task list on the left and on the top dialog tabs. A checkmark on a top dialog tab displays only after all category tasks are completed. For example, in Figure 60, all of the **Setup** tasks and **Configure** tasks are completed.

Completion marks are saved in the *.EZY bqEASY project text file. When a completed or partially-completed project file is opened, the user is given the option to erase the checkmarks.

Completion checkmarks for Categories (dialog tabs) and Tasks (above the ***Back*** and **Next** Buttons)

Figure 60. Process Completion Checkmarks



8.7 Device Detection

The bqEASY is designed to work with a fuel gauge present and already communicating with the Evaluation Software (EVSW) using the EV2300 USB interface. When the Evaluation software is started, it reads the device type and displays it on the upper title block. For example, in Figure 60, the bqEASY software detected a bq27500 that is running version 1.02 of the firmware. This information is used by bqEASY to select the correct default data-flash image (***.DFI**) and data-flash configuration file (*.ENCR) for this device. To ensure that the device has not changed, bqEASY also checks the device type each time the user clicks the **bqEASY** button. If the correct files are not found, first check the TI Internet in the EVM tool folder for the part being used, and download the latest version of EVSW (see Figure 57) with bqEASY support. If that does not help, then contact TI.

The major procedure areas in bqEASY are:

1. **Setup**

   Step 1A helps the user to continue with an existing project file or start a new one. A new project is given a project file with the *.EZY filename extension.

   Step 1B optionally loads the default data-flash image for the detected device. If starting from a *known* new device, this step can be skipped.

2. **Configure**

   A sequence of dialogs used to collect information about the battery pack application that enable automatic configuration of the most critical data-flash parameters.

3. **Calibrate**

   To proceed with automatic chemistry selection or *golden image* unit learning cycles, the Impedance Track fuel gauge must be accurately calibrated. The bqEASY dialogs ask the user to use the calibration window of the bqEASY for this purpose.

   With the Impedance Track devices, most calibration routines can be incorporated into firmware algorithms, which can be initiated with communication commands. The hardware necessary for calibration is simple. One current source, one voltage source, and one temperature sensor are required. The source stability is important, the accuracy is a secondary concern.

   However, accurately calibrated reference measurement equipment should be used for determining the actual arguments to the function. For periodic voltage measurement, a digital voltmeter with better than a 1-mV accuracy is required. The recommended strategy for bq27500/1 calibration is to perform the calibration using 20 to 30 final application systems containing the bq27500/1 IC. All the calibration flash values are recorded and averaged among the 20 to 30 samples. The average values are used when creating the DFI file needed for production.

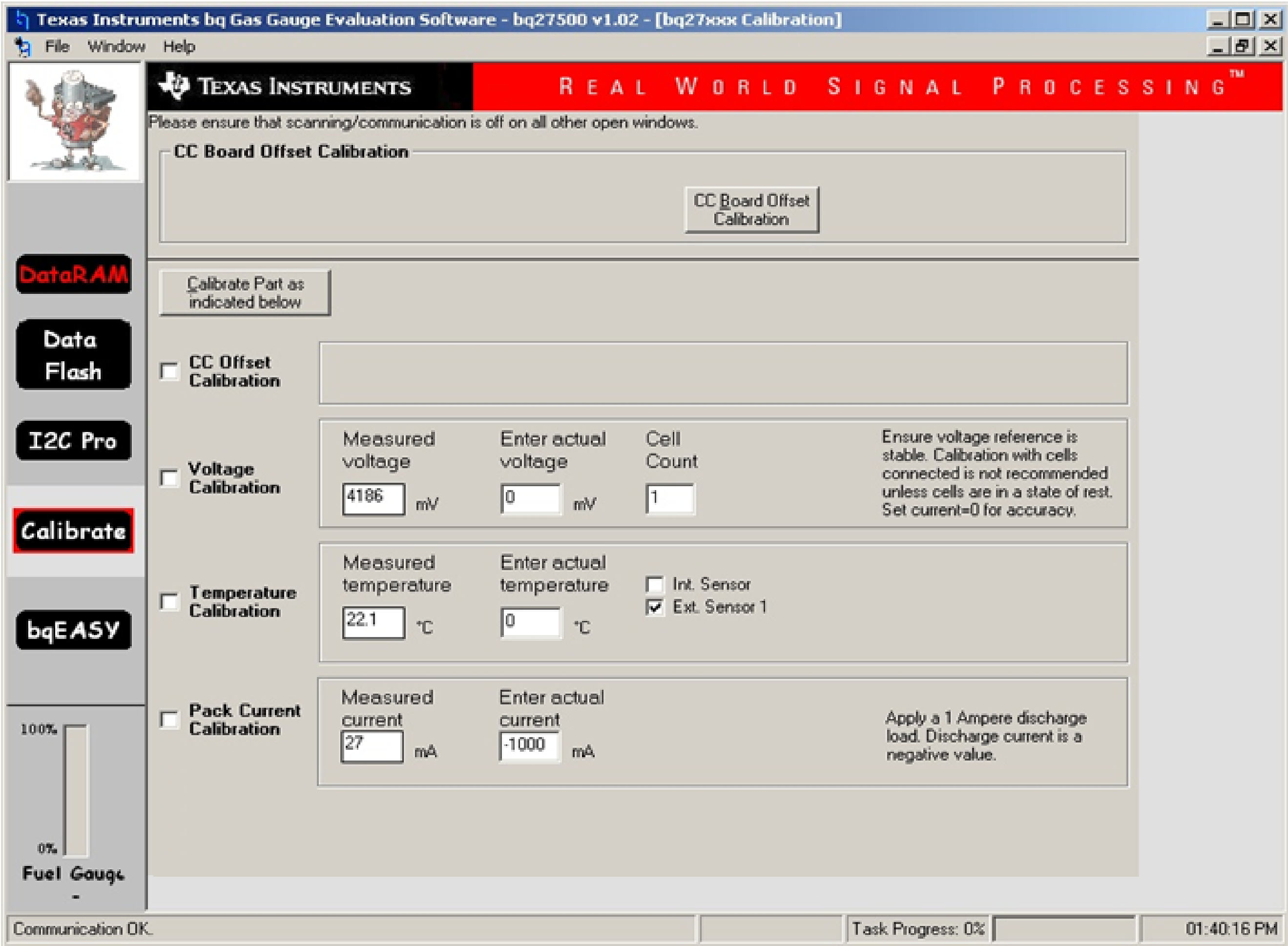
   At the time of calibration, access is required to the communication pins, both ends of the sense resistor, and battery power. The calibration process has to be completed in EVSW Calibrate dialog. The calibration consists of performing Coulomb Counter Offset Calibration, Voltage calibration, Temperature Calibration, Pack Current Calibration and CC Board Offset Calibration one at a time. The EVSW is used to perform all calibrations is shown in Figure 61. Each calibratino has to be completed seperately.

   After the calibration is completed, click the close window control **X** in the upper right corner of the calibration window to close it.

CAUTION

The Calibration window *must be closed* after the calibration completes. Otherwise, it interferes with the bqEASY learning cycle.Added caution to revision

Figure 61. EVSW Calibration Window



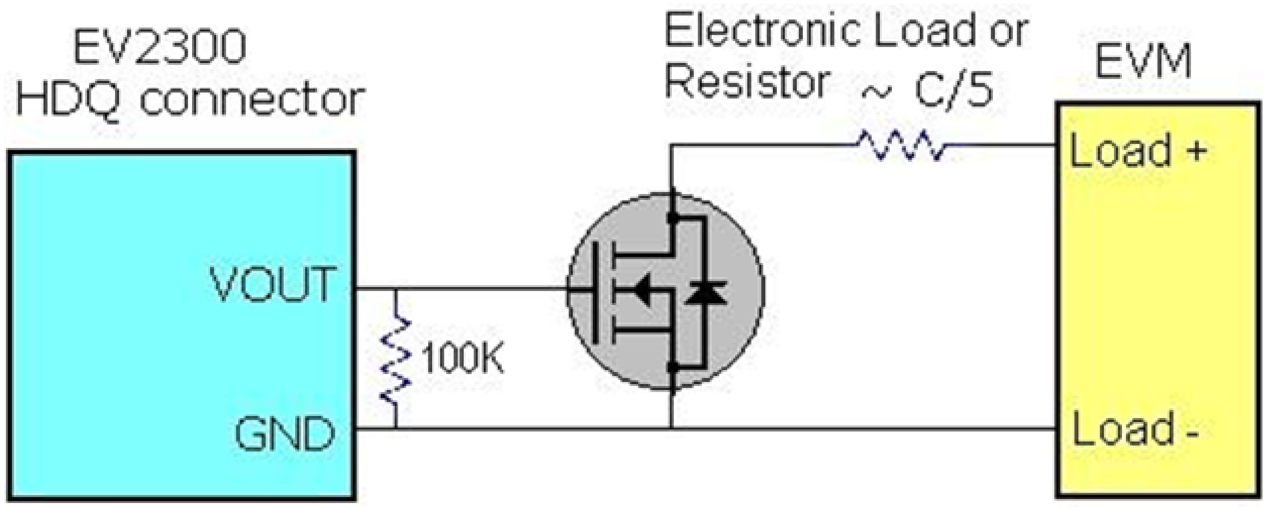
4. **Chemistry**

The choices presented in **4B Chemistry** section are based on files in the *Chemistry* folder of the bqEASY application. The latest files are available for downloading from the Texas Instruments Internet site.

Automation of the chemistry-selection cycle is made possible using a simple load and switch as depicted in Figure 62. The switch can be implemented with a low V_{GS}-threshold FET or a small relay such as the OMICRON G6RN-1 with a 5-VDC coil. Multiple 2N7000 FETs can be paralleled if nothing else is available. The load can be a power resistor or an electronic load set to a discharge rate of C/5.

Hint: Follow the bqEASY dialog instructions exactly to prevent errors.

Figure 62. Example Load



CAUTION

The cell *must be fully charged* to C/100 taper current. Insure that the cell is charged as closely as possible to 4.2V (+/-5mV), or to the manufacture's full charge value.Added caution to revision

5. **Cycle**

   When preparing for mass production, cell learning is required, but only on one *golden* pack. The chemical information learned from one pack can be transferred to all production units, prior to calibration. Doing this correctly requires a series of charge and discharge cycles. The discharge part can be automated with bqEASY if the simple load circuit for the chemistry selection is available, follow the bqEASY dialog instructions as shown in Figure 63. The bqEASY provides two ways to complete the learning cycle.

   The first method is to use bqEASY semi-automatically to complete leaning cycle. This includes:

   – auto-discharge the cell and auto-relax,
   – manual initialize the Impedance Track,
   – manual charge the cell to full and manul wait,
   – Auto-discharge to empty and auto-wait.

   Another way to complete the cycle is to complete above step 1 to 4 manually.

   The second method does not involve a constant voltage check by bqEASY, and can be used with datalogging without any interference.

Figure 63. EVSW Learning Cycle Window

Chapter 9

Updating Firmware With the bq2750x and EVM

Ming Yu and Michael Vega

ABSTRACT

This application report provides the procedure to update bq2750x firmware and the learned golden image (*.DFI file) in bq27500 data flash from the previous firmware version.

9.1 Save Data Flash Content Before and After Firmware Update

If the data flash has no learned value that needs to be saved, proceed to the section entitled *Update Firmware in the EVM*.

Before the firmware can be updated, the original data flash content must be saved as an old Data Flash Image (DFI) file to prevent loss of the learned data flash value. Once the firmware is updated, the original data flash content is lost. Instead, a default DFI is copied to the device during the firmware update. Assume that the original data flash content is generated from the learning cycle. It is critical that the data flash content is set back to the previous contents. The two methods to update the data flash after a firmware update follow.

1. Begin by proceeding through bqEASY to generate new data flash contents.
   This method is time consuming but it is less likely to generate a compatibility issue when running the new firmware.
2. Update the data flash using the old DFI file.

The DFI file saved from the previous firmware version has a different checksum than that of the current firmware version. Hence, the old version DFI cannot be directly used in new firmware. If bqEASY is used to configure the same battery pack, the only differences are the resistance Ra value and the Qmax value.

To update the old DFI file, perform the following steps.

1. Create DFI file (see Figure 64).
   Figure 64 is the user interface in bqEASY step 3F to save the DFI file to the default directory: C:\Program Files\Texas Instruments\bq Evaluation Software\Plugins\Projects with file name:*_0500_01xx_CONFIGURED.dfi* . This file can be renamed and used to update the same batch of devices which had a firmware update that also requires data flash update.

Figure 64. Create New DFI File

2. Load the old DFI file into the device with the old firmware version that matches the old DFI version using step 1B of bqEASY (see Figure 65).

Figure 65. Load the DFI File

3. Go to the Data Flash screen and read all the data flash contents, and export the data flash into the old.gg file (see Figure 67) . Modify the old.gg file to the new.gg file by opening the old.gg file and changing the firmware version in the file header.

4. Set the device into ROM mode, and program the new firmware as described in the section entitled *Update Firmware in the EVM* of this document.
5. Because the chemistry is already identified from the previous learning cycle, the chemistry can be programmed into the device directly from the chemistry table. In order to do this, go to step 4B of bqEASY to select the chemistry manually (see Figure 66).

Figure 66. Load Chemistry

6. Go to Data Flash screen and Import the new.gg file into the device (see Figure 67). After loading the new.gg file, click the ***Write All*** button to write these data flash values into the device. Because the data flash configuration may not be the same between old firmware version and new firmware version, an error message may occur.

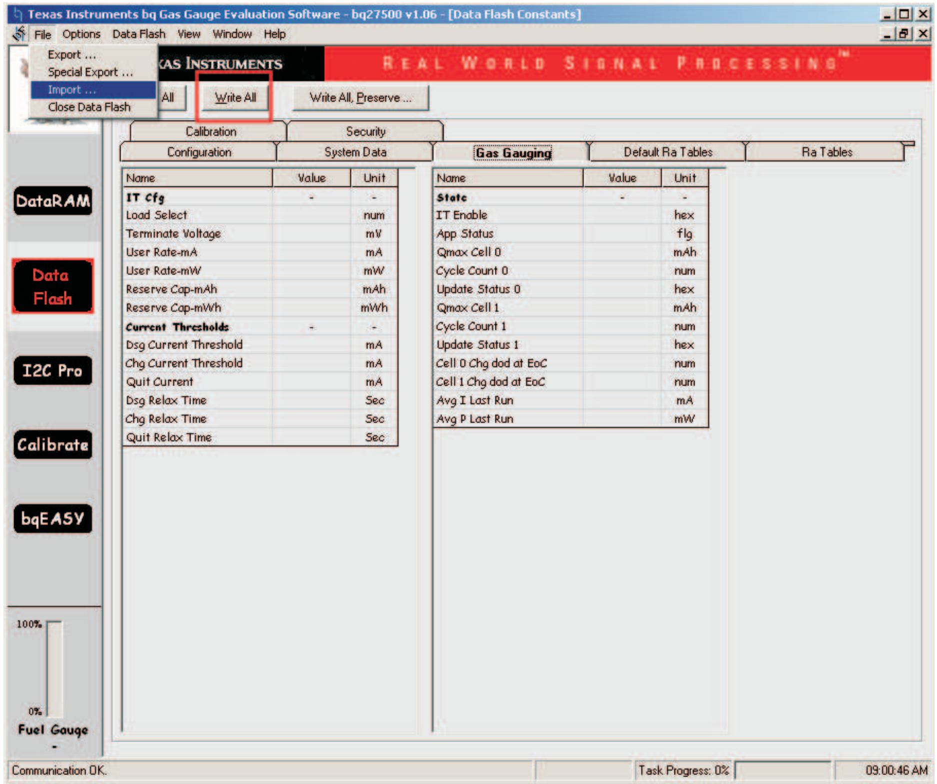


Figure 67. Export and Load *.gg File

7. Go to bqEASY step 3F (see Figure 64), and read the DFI under the updated firmware version. (**Caution**: Skipping this step will cause corrupted DFI)
8. Generate Golden Image file (see Figure 68).

   In order to generate the Golden Image file, the *Update Status* has to be set to **02** from the learning cycle.Figure 68 is the user interface in bqEASY step 5B to generate the Golden Image DFI file to the default directory: C:\Program Files\Texas Instruments\bq Evaluation Software\Plugins\Projects with file name: *_0500_01xx_GOLDEN.dfi* . bqEASY also updates the necessary data flash contents when generating the golden image before saving the DFI file. This file can be renamed and used in mass production.

Figure 68. Create New Golden Image File

9.2 Update Firmware in the EVM

1. Disable the scanning in DataRAM before updating the firmware.
2. Power up the evaluation module (EVM) by applying 4 Vdc between Pack+ and Pack–. This step is unnecessary if the cell is already attached.
3. Start the EV Software.
4. Navigate to the *I2C Pro* screen.
5. Put the device into ROM mode by setting the ***Write I2C Data Block*** section as: *I2C Command: 00 Data Block (hex): 000f*, and click the ***Write Data*** button (see Figure 69).

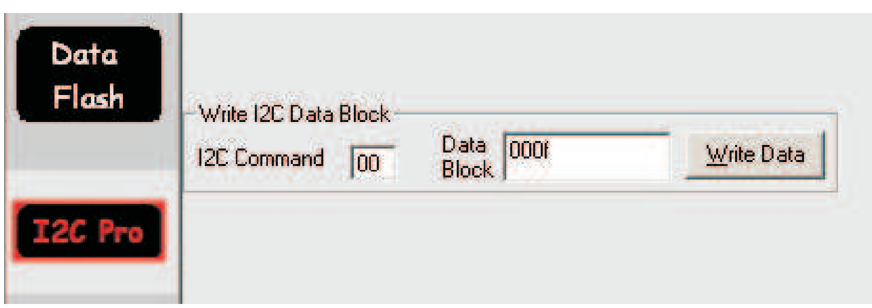


Figure 69. Command to Set the Device in ROM Mode for Firmware Programming

6. In the *bq275xx Programming* section, enter the path and file name for the new firmware file (*.senc). If needed, click the (…) button to browse for the file location (see Figure 70).

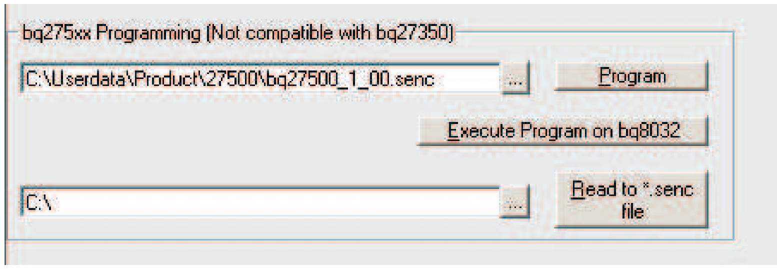


Figure 70. Programming the Firmware (Encrypted SREC)

7. Click the ***Program*** button to program the firmware (see Figure 70). All flash-constants information including calibration will be lost; so, export it beforehand into a (*.gg) file or *.DFI file
8. Once programming is finished, execute the program by clicking ***Execute Program on bq8032*** button (see Figure 70).
9. Close and restart the EV Software so that the new version of firmware is recognized.

Texas Instruments

Chapter 10

Host-Side Gas-Gauge-System Design Considerations for Single-Cell Handheld Apps

Jinrong Qian and Michael Vega

This article focuses on improving gas-gauge accuracy and on host-side battery-management design considerations such as high-accuracy Impedance Track™ gas gauges, battery insertion, and coordinating operation with the battery-charging system.

Host-side gas-gauge-system design considerations for single-cell handheld applications

By Jinrong Qian, *Applications Manager, Battery Management Applications,*
and Michael Vega, *Applications Engineer, Battery Management Applications*

Introduction

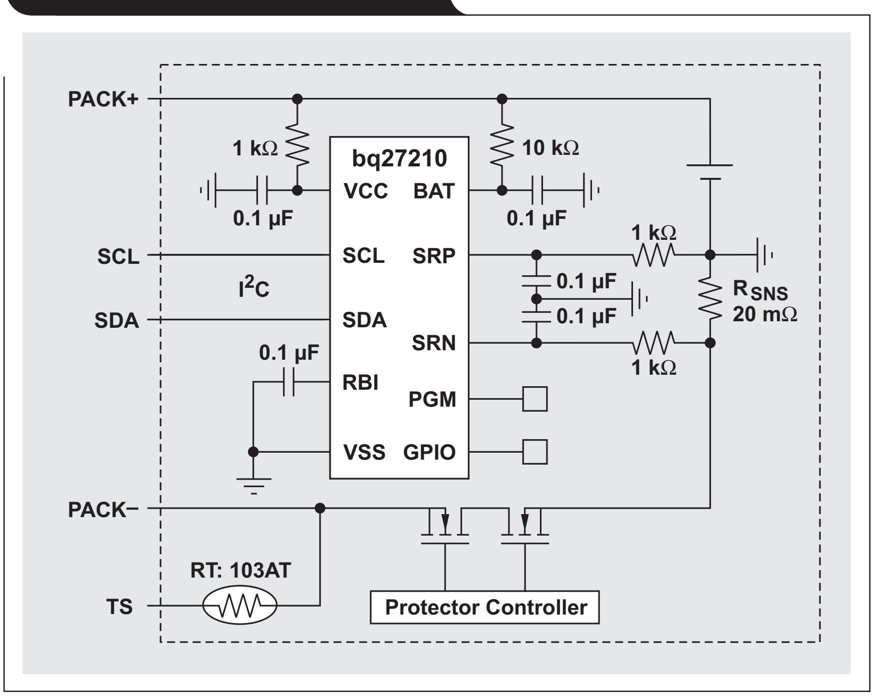
It is desirable to determine the remaining capacity of a battery for handheld devices such as smartphones, portable media players (PMPs), and personal digital assistants (PDAs). Many handheld portable devices have used voltage measurement alone to approximate the remaining battery capacity, but the need for a more accurate method has become critical in some applications. A host-side gas gauge has become more attractive than the traditional pack-side gas gauge since it can reduce the cost of a new battery pack when the life of the original battery is over. This article focuses on improving gas-gauge accuracy and on host-side battery-management design considerations such as high-accuracy Impedance Track™ gas gauges, battery insertion, and coordinating operation with the battery-charging system.

Problems of existing gas gauges

The traditional gas gauge is located in the battery pack as shown in Figure 1 and is always connected to the Li-ion cell. The gas gauge monitors the charging and discharging activity and uses an embedded algorithm to report the remaining battery capacity. When the battery life is over, the battery cell along with the pack electronics circuit will be thrown away, wasting the gas gauge that is still in good operation. The end user has to buy not only another battery pack but also another gas gauge. In the host-side gas-gauge system, the gas gauge is located in the motherboard, while the battery cell and pack-protection circuit are in the pack side. With this configuration, the user will not have to pay for a gas gauge when purchasing a new battery pack; but there are several design challenges, including battery-chemistry detection, battery-insertion detection, and coordinating operation with the battery charger.

A common erroneous belief is that the shrinking run time of a Li-ion battery is primarily due to depletion of the battery capacity. However, it is generally not the capacity loss but the increasing battery impedance that results in early system shutdown. The battery capacity actually drops by less than 5%, while the internal DC resistance of the battery increases by a factor of 2 after approximately 100 cycles. A direct effect of the higher resistance of an aging

Figure 1. Traditional battery pack



battery is a higher internal voltage drop in response to a load current. This voltage drop causes the aging battery to reach the minimum system operating voltage or battery cutoff voltage earlier than would a fresh battery.

Conventional gas-gauging technologies—mainly the voltage-based and coulomb-counting algorithms—have obvious performance limitations. The voltage-based scheme, widely adopted in handheld devices such as cellular phones due to its low cost and simplicity, suffers from changes in the battery resistance over time. The battery voltage is given by

$$V_{BAT} = OCV - I \times R_{BAT},$$

where OCV is the battery open-circuit voltage and R_{BAT} is the battery internal DC resistance. Figure 2 shows that the lower voltage of an aging battery causes the system to shut down earlier than it would with a fresh battery.

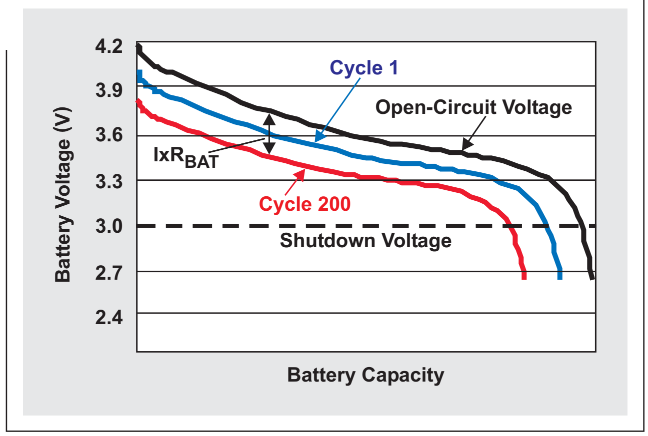
Load conditions and temperature variations can change the available battery capacity by up to 50%. Most end users have experienced early system shutdown in portable devices that lack a true gas gauge. The coulomb-counting scheme takes the alternative approach of continuously integrating coulombs going to and from the battery to compute the consumed charge and state-of-charge (SOC). With an established value for full capacity, coulomb counting allows the remaining capacity to be determined. The drawback of this approach is that self-discharge is difficult to model with accuracy, and without periodic full-cycle calibration the gauging error accrues over time. None of these algorithms addresses resistance variations of the battery. The designer must reserve more capacity by terminating system operation prematurely to avoid the unexpected shutdown, leaving a significant amount of energy unused.

Single-cell Impedance Track gas gauge

What makes Impedance Track technology unique and much more accurate than other solutions is a self-learning mechanism that accounts for the changes in chemical capacity (Q_{MAX}) and the increasing battery resistance that is due to aging. An Impedance Track gas gauge implements a dynamic modeling algorithm to learn and track the battery characteristics by first measuring and then tracking the impedance and capacity changes during battery use. With this algorithm, no periodic, full-cycle capacity calibration is required.

Impedance Track technology enables compensation for load and temperature to be modeled accurately. Most important, gas-gauging accuracy can be maintained during the whole lifetime of the battery. Because system design no longer requires a premature-shutdown scheme, the battery capacity can be fully utilized. Impedance Track gas gauges determine the remaining battery capacity more accurately than either coulomb counting or cell-voltage correlation. They actually use both techniques to overcome the effects of aging, self-discharge, and temperature variations.

Figure 2. Battery-discharge characteristics over cycle life



Impedance Track devices constantly maintain database tables to keep track of battery resistance (R_{BAT}) as a function of depth of discharge (DOD) and temperature. To understand when these tables are updated or utilized, it is helpful to know what operations occur during different states. Several current thresholds can be programmed into the gas gauge's nonvolatile memory to define a charge; a discharge; and "relaxation time," which allows the battery voltage to stabilize after ceasing charge or discharge.

When a handheld device is turned on, the gas gauge determines the exact SOC by measuring the battery open-circuit voltage (OCV) and correlating it with the OCV(DOD,T) table. After completing OCV measurement, the gas gauge applies the load, starts the integrating coulomb counter, and continuously calculates the SOC.

The total capacity, Q_{MAX}, is calculated through two OCV readings taken at fully relaxed states when the battery-voltage variation is small enough before and after the charge or discharge activity. As an example, before the battery is discharged, the SOC is given by

$$SOC_1 = \frac{Q_1}{Q_{MAX}}.$$

After the battery is discharged with a passed charge of ΔQ, the SOC is given by

$$SOC_2 = \frac{Q_2}{Q_{MAX}}.$$

Taking the difference of these two equations and solving for Q_{MAX} yields

$$Q_{MAX} = \frac{\Delta Q}{|SOC_1 - SOC_2|},$$

where $\Delta Q = Q_1 - Q_2$. This equation illustrates that it is not necessary to have a complete charge-and-discharge cycle to determine the battery's total capacity. The battery's time-consuming learning cycle during pack manufacturing can therefore be eliminated.

The battery's R_{BAT}(DOD,T) table is updated constantly during discharges, and the resistance is calculated as

$$R_{BAT}(DOD,T) = \frac{OCV(DOD,T) - \text{Battery Voltage Under Load}}{\text{Average Load Current}}.$$

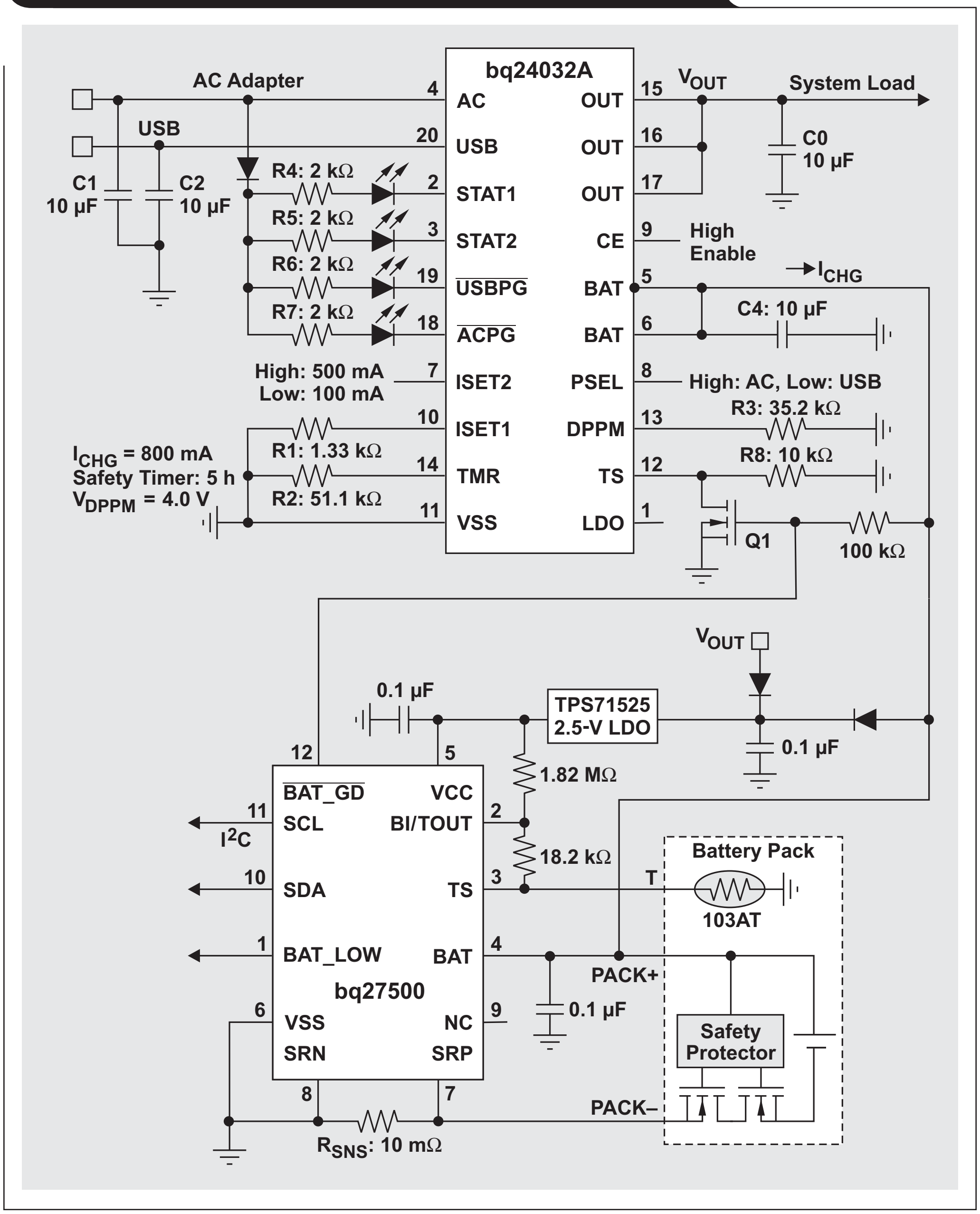
The gas gauge uses R_{BAT} to compute when the termination voltage will be reached at the present load and temperature. It also uses R_{BAT} to determine the remaining capacity (RM) by using a voltage-simulation method in the firmware. The simulation starts from the present SOC_{START} and calculates the future battery-voltage profile under the same load currents with consecutive SOC decrements. When the simulated battery voltage, $V_{BAT}(SOC_I,T)$, reaches the battery termination voltage (typically 3.0 V), the SOC corresponding to this voltage is captured as SOC_{FINAL}. The remaining capacity, RM, is calculated as

$$RM = (SOC_{START} - SOC_{FINAL}) \times Q_{MAX}.$$

Design considerations for host-side gas-gauge and battery-charging system

Figure 3 is a circuit diagram of a host-side battery-management system including the battery charger and gas gauge. The bq24032A is a power-path-management battery charger that can simultaneously power the system while charging the battery.

Figure 3. Host-side gas-gauge and battery-charging system



There are several host-side gauging-system design considerations. The first one is to get a new battery's initial capacity when it is inserted. Since there is a solid correlation between the battery OCV and SOC, the OCV must be measured before the battery charging or discharging starts. For accurate OCV measurement, the bq27500 does not allow the battery to be charged or discharged after it is inserted. It first determines if the battery is present or not by putting the BI/TOUT pin in high-impedance mode and detecting battery insertion when the BI/TOUT pin voltage is pulled down. Battery charging is disabled when the temperature-monitoring pin is pulled to ground by turning on MOSFET Q1. After the OCV reading is finished and the initial battery capacity is accurately learned, $\overline{\text{BAT\_GD}}$ is pulled low, which turns off MOSFET Q1. When the battery is inserted without an adapter, the gauging system should wait for a few milliseconds to measure the OCV before applying power to the system load.

The second design challenge is how to monitor the battery temperature for charging qualification and for adjusting the battery capacity. To minimize battery degradation, the gas gauge prohibits battery charging, typically when the cell temperature is out of the 0 to 45°C range. The gas gauge also has to monitor the cell temperature to adjust the battery impedance and capacity. The bq27500 can be configured to monitor the cell temperature through its TS pin, while the temperature threshold to qualify charging can be set through the data flash constants. To minimize power consumption, the gas gauge measures cell temperature every 1 second by internally pulling BI/TOUT high and measuring the voltage across the TS pin. If the cell temperature falls outside of the preset range, $\overline{\text{BAT\_GD}}$ is pulled high and turns on the MOSFET Q1 so that the battery charger is disabled until the cell temperature recovers. In the meantime, the temperature information is used to normalize cell impedance and adjust the capacity.

Another design consideration is how to minimize the gas gauge's total power consumption, since the gas gauge is always connected to the battery as long as the battery is inserted. There are four operation modes: NORMAL, SLEEP, HIBERNATE, and BAT INSERT CHECK. In NORMAL mode, the gas gauge measures current, voltage, and temperature and periodically updates the interface data set. Decisions to change states are also made. The most power consumed is typically 80 µA. When the SLEEP-mode bit is set and the average current is below a programmable sleep current, the bq27500 enters the SLEEP mode. It periodically wakes to take data measurements and update the data set, then returns to sleep to minimize current consumption, typically down to 15 µA. To further reduce current consumption, the gas gauge enters HIBERNATE mode and consumes only 4 µA if the average current is less than the HIBERNATE current value programmed in the flash memory and if the HIBERNATE-mode bit is set. A cell voltage measured lower than the HIBERNATE voltage value programmed in the flash memory can replace the HIBERNATE bit requirement. The BAT INSERT CHECK mode manages when charging and discharging are allowed so that OCV measurements can be taken when a battery pack is inserted into the system. No gauging occurs in this mode. Once battery insertion is detected and OCV readings are complete, the gauge proceeds to NORMAL mode.

Another important design consideration is how to safely and accurately indicate low battery capacity so that data can be saved and the system can be safely shut down. Traditionally, the low-battery indication has been based purely on the battery voltage because of simple hardware implementations and cheap solutions. When the battery voltage is below the preset threshold, the BAT_LOW pin changes the state and can be used to control the system for possibly reducing functionality and providing a warning signal to the end user. However, this method may not be accurate, since the battery voltage is a function of the load current, aging, and temperature. The status indicator may flicker for a pulsating load in handheld applications. Another method by which BAT_LOW could be configured is based on the relative SOC, which is more accurate than the pure voltage measurement. With this method, BAT_LOW will change its state when either the battery voltage or the relative SOC reaches the preset threshold. Therefore, the microprocessor can safely prepare for data saving and system shutdown in advance.

Conclusion

The host-side Impedance Track gas-gauging system provides high-accuracy gauging and a low system cost. The bq27500 is an ideal solution for handheld devices such as smartphones, PMPs, and PDAs. Understanding the Impedance Track technology and host-side design challenges is critical.

Related Web sites

power.ti.com
www.ti.com/sc/device/*partnumber*
Replace *partnumber* with bq24032A, bq27210, bq27500, or TPS71525

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products	
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Indonesia	001-803-8861-1006	Taiwan	0800-006800
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Single Cell Gas Gauge Circuit Design

Michael Vega and Ming Yu *Battery Management*

ABSTRACT

Components included in single-cell gas gauge circuit designs are explained in this application report. Design analysis and suggested tradeoffs are provided, where appropriate.

11.1 Introduction

The Single-Cell Gas Gauge circuit has approximately 15-20 components in the reference design for a 1-thermistor, 1-cell application. For clarity, these chipsets are grouped into the following classifications: High-Current Path, Gas Gauge Circuit, Current and Voltage Protection.

The discussion is based on the single-cell reference design for the bq275xx chipset. A complete schematic is available on the last page of this document.

11.2 High-Current Path

The high-current path begins at the PACK+ terminal of the battery pack. As charge current travels through the pack, it finds its way through the lithium-ion cell and cell connections, the sense resistor, protection FETs and then returns to the PACK– terminal (see the reference design schematic at the end of this document). In addition, some components are placed across the PACK+ and PACK– terminals to reduce effects from electrostatic discharge.

Protection FETs

The N-channel charge and discharge FETs should be selected for a given application. Most portable battery applications are a good match for the Si6926ADQ or equivalent.

The Vishay Si6926ADQ is packaged with two 4.1-A , 20-V devices with Rds(on) of 33mΩ when the gate drive voltage is 3V.

Capacitors C2 and C3 help to protect the FETs during an ESD event. The use of two devices ensures normal operation if one of them becomes shorted. In order to have good ESD protection, the copper trace inductance of the capacitor leads must be designed to be as short and wide as possible. Ensure that the voltage rating of both C2 and C3 are adequate to hold off the applied voltage if one of the capacitors becomes shorted.

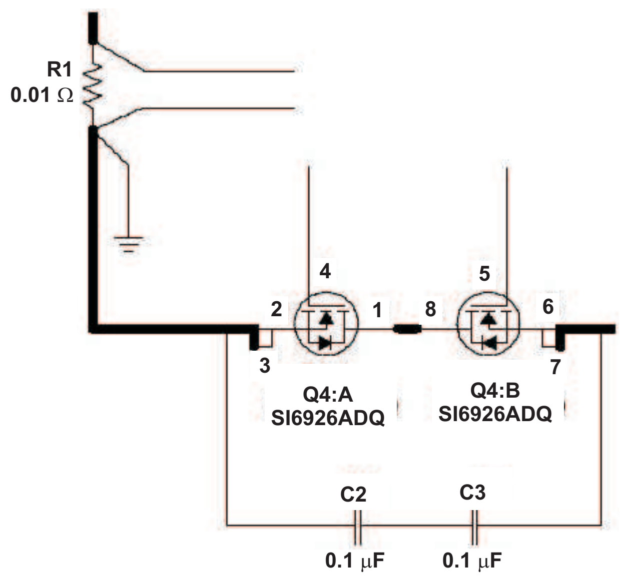


Figure 71. Protection FETs

Lithium-Ion Cell Connections

The important thing to remember about the cell connections is that high current flows through the top and bottom connections, and therefore the voltage sense leads at these points must be made with a Kelvin connection to avoid any errors due to a drop in the high-current copper trace. This is critical for gauging accuracy in the Impedance Track™ gauges.

Sense Resistor

As with the cell connections, the quality of the Kelvin connections at the sense resistor is critical. Not only the sense lines, but the single-point connection to the low-current ground system must be made here in a careful manner.

The sense resistor should have a temperature coefficient no greater than 100 ppm in order to minimize current measurement drift with temperature. The sense resistor value should be sized to accurately integrate the charge and discharge current that the system draws in its ON state. The maximum sense-resistor voltage that can be measured accurately by the coulomb counter is ±125 mV. The designer should ensure that the voltage across the sense resistor at maximum currents is less than this limit. It is often the power dissipation in the resistor at maximum load currents that sets the maximum acceptable sense-resistor value, particularly when space considerations restrict the maximum size allowable for the resistor. The physical size, power dissipation, and insertion loss (voltage drop) considerations of the sense resistor dictate that the smallest possible sense-resistor value be used. This has to be balanced against the accuracy requirements at low currents (slightly above the SLEEP threshold), where the sense-resistor voltage at minimum load currents might not be much larger than the measurement offset error if the sense-resistor value is too small. For a single-cell application, 10 mΩ is generally ideal .

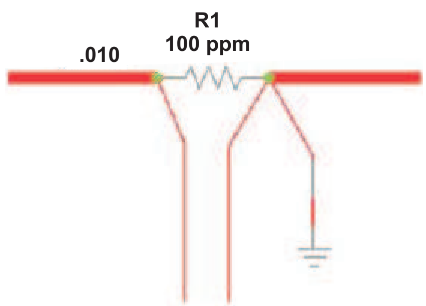


Figure 72. Sense Resistor

ESD Mitigation

A pair of series 0.1-µF ceramic capacitors is placed across the PACK+ and PACK– terminals to help in the mitigation of external electrostatic discharges. The two devices in series ensure continued operation of the pack if one of the capacitors should become shorted.

11.3 Gas Gauge Circuit

The Gas Gauge Circuit includes the bq275xx and its peripheral components. These components are divided into the following groups: Differential Low Pass Filter, Power Supply Decoupling/ and I^2C Communication.

Differential Low Pass Filter

As shown in Figure 73, a differential filter should precede the current sense inputs of the gas gauge. This filter eliminates the effect of unwanted digital noise, which could cause offset in the measured current. Even the best differential amplifier has less common-mode rejection at high frequencies. Without a filter, the amplifier input stage may rectify a strong RF signal, which then may appear as a dc offset error.

Five percent tolerance of the components is adequate because capacitor C6 shunts C3/C7 and reduces AC common-mode arising from component mismatch. It is important to locate C6 as close as possible to the gas gauge pins. The other components also should be relatively close to the IC. The ground connection of C3 and C7 should be close to the IC.

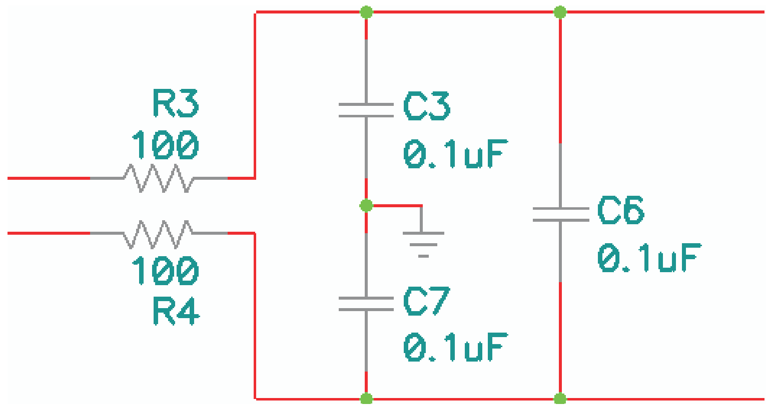


Figure 73. Differential Filter

Power Supply Decoupling

Power supply decoupling is important for optimal operation of the single cell gas gauges. A single 0.1-µF ceramic decoupling capacitor from V_{CC} to V_{SS} must be placed adjacent to the IC pins.

I²C Communication

The I²C clock and data signals interface to the outside world on the pack connector. With pack-side gas gauge implementation, each signal employs an ESD protection scheme consisting of a zener diode with it's anode connected to PACK–. A resistor is placed between the Zener diode and the external communication pin. Another resistor is placed between the IC's communication pin and the Zener diode. These two resistors limit the current that goes through the Zener in the event of ESD. It should be noted, however, that the Zener diodes must have nominal capacitance below 150 pF in order to meet the I²C specifications. The AZ23C5V6 is a recommended device. Also, the resistor on the pack side is only 100 Ω to maintain signal integrity. Note that the Zener diode will not survive a long-term short to a high voltage. If it is desirable to provide increased protection with a larger input resistor and/or Zener diode; carefully investigate the signal quality of the I²C signals under worst-case communication conditions.

Resistors R22 and R23 provide pulldown for the communication lines. When the gas gauge senses that both lines are low (such as during removal of the pack), the device performs auto offset calibration and then goes into sleep mode to conserve power.

For the I²C clock signal, R19 and part of D8 provide clamping for positive ESD pulses, while R18 limits the current coming out of the IC (in parallel with the current through D8) for negative ESD pulses.

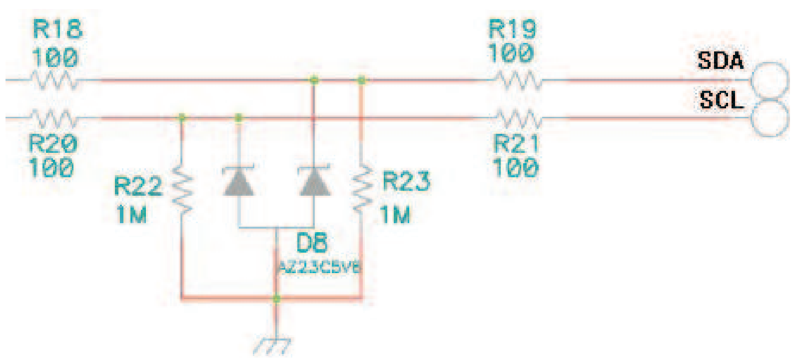


Figure 74. ESD Protection for Communication Using Zener Diodes

Some designers may want to use capacitors instead of Zener diodes to save board space or part cost. This can be acomplished by replacing the Zener diodes with a pair of 150-pF capacitors. If using the capacitors, R18 and R20 should be replaced with 300Ω resistors.

Cell and Battery Input

Also, as described previously in the High Current Path section, the top and bottom nodes of the cells must be sensed at the battery connections with a Kelvin connection to prevent voltage sensing errors caused by a drop in the high-current PCB copper.

BAT Pin Input

The BAT pin which is the input to the A/D converter that measures battery voltage, only requires a 0.1μF ceramic capacitor due to that adding a resistor in series with the pin will cause errors on the measurment. The pin actually gives access to a voltage divider before reaching the actual A/D input. Any additional resistance to the pin will alter the voltage divider ratio and lead to measurement errors.

Regulator Output

A low dropout regulator whether external or internal to gas gauge IC, requires capacitive compensation on their outputs. The 2.5V REG output should have a 0.47-μF ceramic capacitor placed close to the IC terminal.

Temperature Output

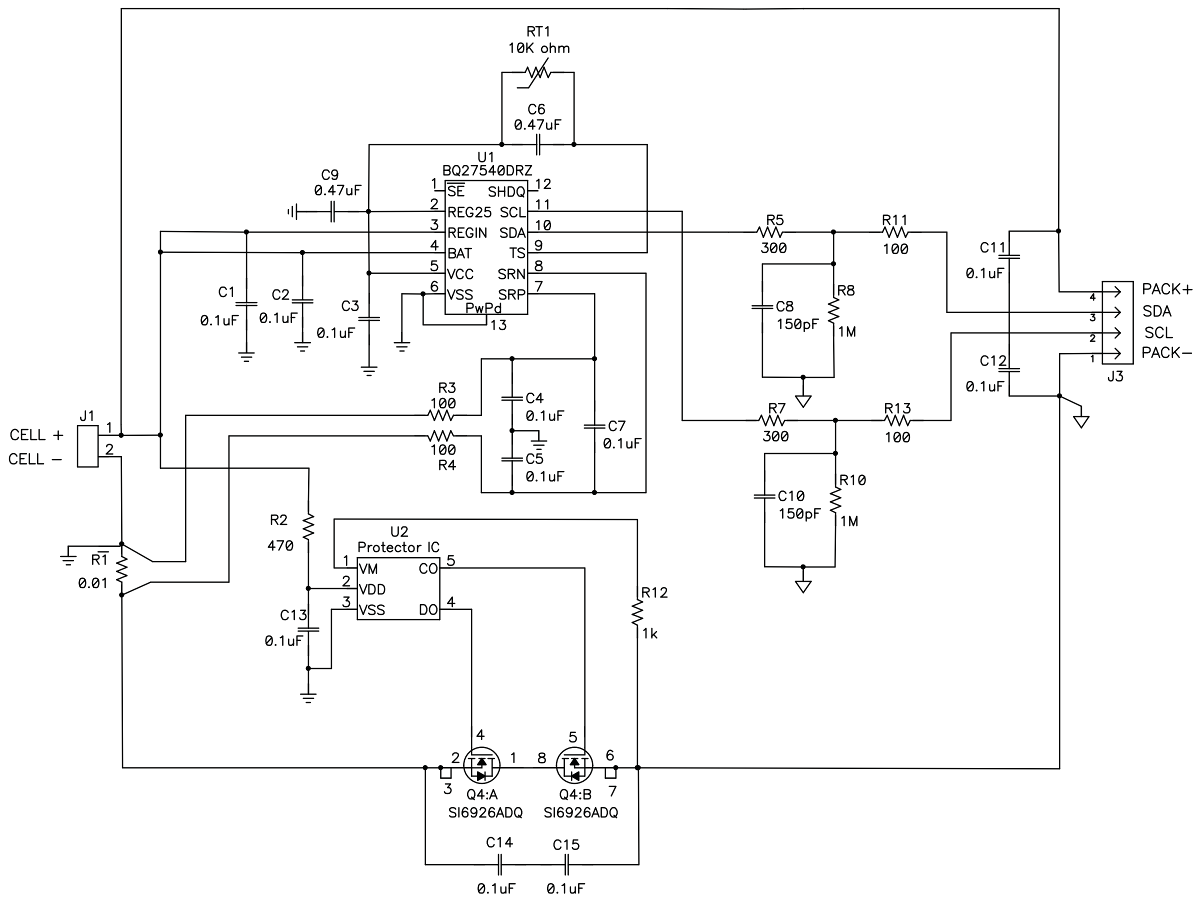
TOUT provides thermistor drive under program control. The reference design includes one NTC103AT 10-kΩ thermistor, RT1. Because these thermistors are normally external to the board, the ceramic capacitors are provided for ESD protection and measurement smoothing.

11.4 Current and Voltage Protection

The current and voltage protection is done by a circuit consisting of a cell protector IC and two NFETs. The protector drives one FET to enable a discharge path and drives the second FET to enable a charge path. The protector monitors the cell voltage through its Vdd pin and disables the charge FET whenever the voltage is greater than the Over-Voltage threshold. If the voltage is below the Under-Voltage threshold it will disable the discharge FET. The protector monitors current by measuring voltage across the two FETs with respect to protector's Vss. If it detects voltages surpassing the Over-Current thresholds it will disable the corresponding FET depending on the polarity of the voltage with respect to Vss. The protector will recover from a fault when opposing conditions are present. For example if under voltage is detected (over discharge condition) then it will not recover until a charger is applied to the pack.

Design considerations for the protector circuit is based on the protector being used. Given that over-current conditions are really dependent on voltage across the FET, then the actual current thresholds will depend on the Rds on of the NFETs used in design. See the reference design for an example of a protector IC design.

11.5 Reference Design Schematic



Chapter 12

Single Cell Impedance Track Printed-Circuit Board Layout Guide

Michael Vega and Ming Yu

Battery Management

ABSTRACT

Attention to layout is critical to the success of any battery-management circuit board. The mixture of high-current paths with an ultralow-current microcontroller creates the potential for design issues that can be challenging to solve. This application report presents guidelines to ensure a stable and well-performing project.

12.1 Introduction

Attention to layout is critical to the success of any battery management circuit board. The mixture of high-current paths with an ultralow-current microcontroller creates the potential for design issues that are not always trivial to solve. Careful placement and routing with regard to the principles described in the following text can ensure success.

12.2 Power Supply Decoupling Capacitor

Power supply decoupling from V_{CC} to ground is important for optimal operation of the Impedance Track™ gas gauge. To keep the loop area small, place this capacitor next to the IC and use the shortest possible traces. A large loop area renders the capacitor useless and forms a small-loop antenna for noise pickup.

Ideally, the traces on each side of the capacitor should be the same length and run in the same direction to avoid differential noise during ESD. If possible, place a via near the VSS pin to a ground plane layer.

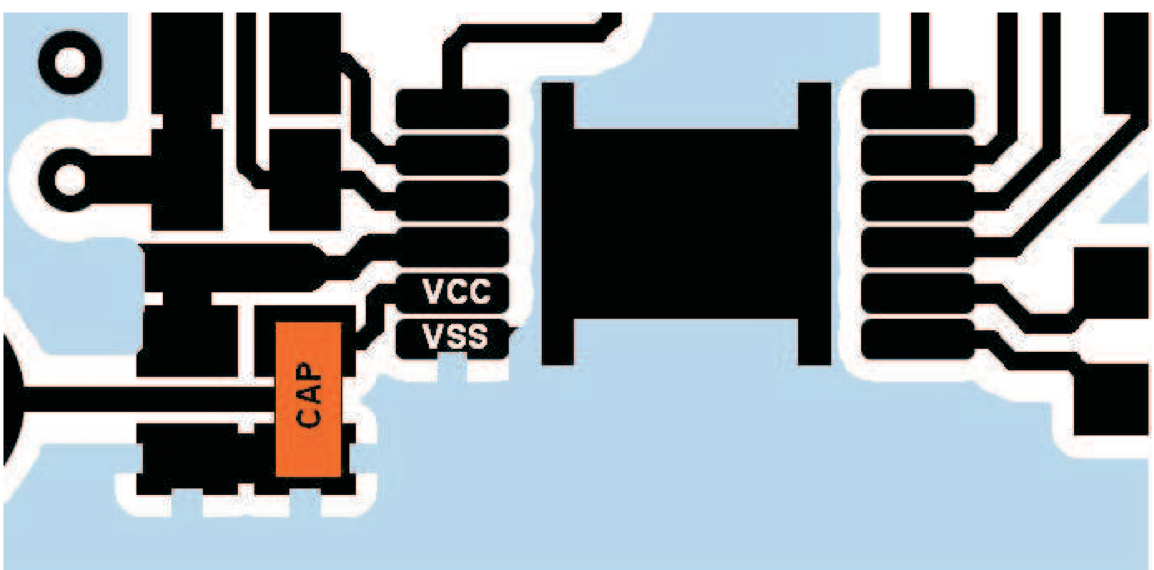


Figure 75. Recommended Placement of VCC Decoupling Capacitor

12.3 Capacitors

Power supply decoupling for the gas gauges requires a pair of 0.1-µF ceramic capacitors for (BAT) and (VCC) pins. These should be placed reasonably close to the IC, without using long traces back to VSS.

The LDO voltage regulator, whether it be external or internal to the main IC, requires a 0.47-µF ceramic capacitor to be placed fairly close to the regulation output pin. This capacitor is for amplifier loop stabilization and as an energy well for the 2.5-V supply.

12.4 Communication Line Protection Components

The 5.6-V Zener diodes, used to protect the communication pins of the gas gauge from ESD, should be located as close as possible to the pack connector. The grounded end of these Zener diodes should be returned to the Pack(–) node, rather than to the low-current digital ground system. This way, ESD is diverted away from the sensitive electronics as much as possible.

In a pack-side application it is sometimes necessary to cause transitions on the communication lines to trigger events that manage the gas gauge power modes. An example of one of these transitions is detecting a sustained low logic level on the communication lines to detect that a pack has been removed. Given that most of the gas gauges do not have internal pulldown networks, it is necessary to add a weak pulldown resistor to accomplish this when there's an absence of a strong pullup resistor on the system side. If the weak pulldown resistor is used, it may take less board space to use a small capacitor in parallel instead of the zener diode to absorb any ESD transients that are received through communication lines.

12.5 Protector FET Bypass and Pack Terminal Bypass Capacitors

The general principle is to use wide copper traces to lower the inductance of the bypass capacitor circuit. In Figure 76, an example layout demonstrates this technique.

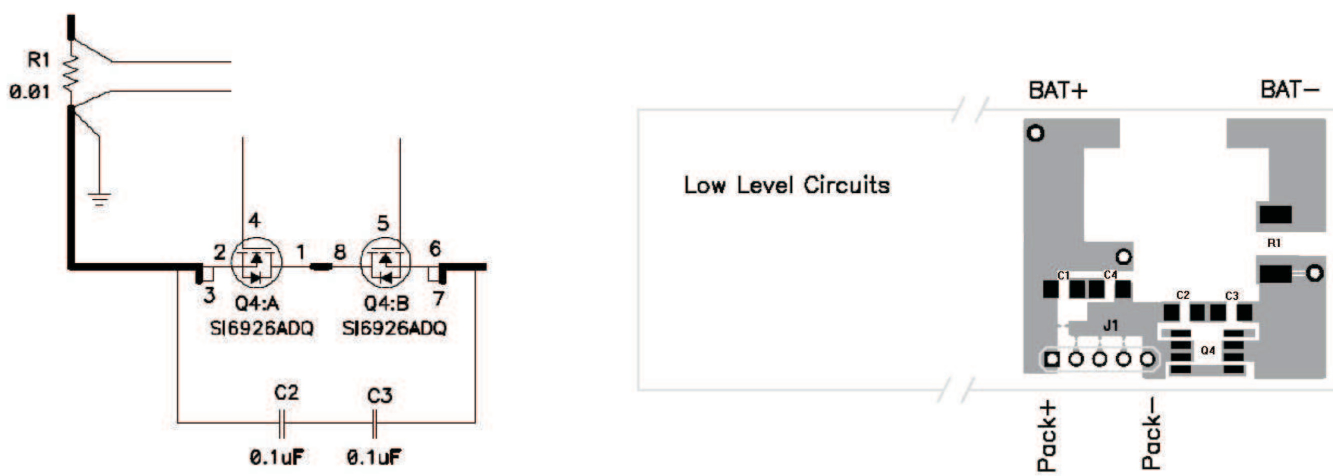


Figure 76. Use Wide Copper Traces to Lower the Inductance of Bypass Capacitors C1, C2, C3 and C4

12.6 Ground System

The single-cell gas gauges require a low-current ground system separate from the high-current PACK(–) path. ESD ground is defined along the high-current path from the Pack(–) terminal to the protector FETs. It is important that the low-current ground systems only connect to the PACK(–) path at the sense resistor Kelvin pick-off point. The use of an optional inner layer ground plane is recommended for the low-current ground system. In Figure 77, the green is an example of using the low-current ground as a shield for the gas gauge circuit. Notice how it is kept seperate from the high-current ground which is shown in red. The high-current path is joined with the low-current path only at one point shown with the small blue connection between the two planes.

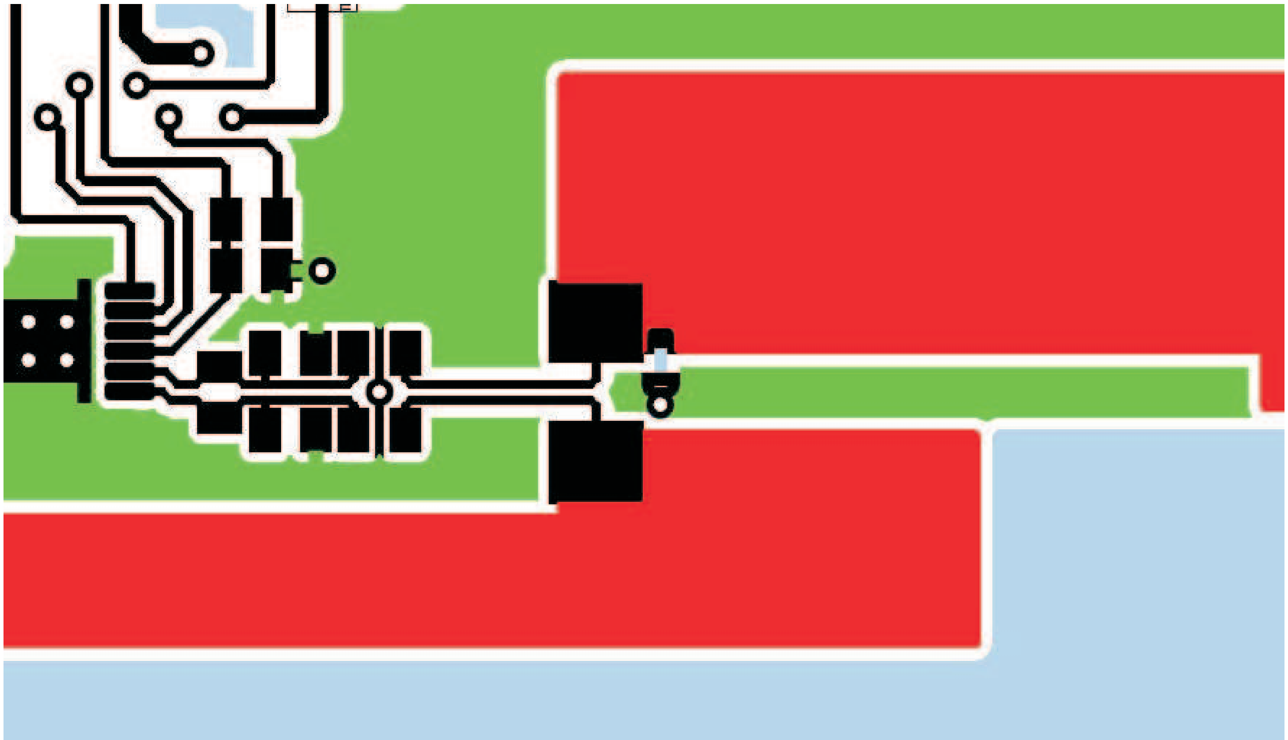


Figure 77. Differential Filter Components With Symmetrical Layout

12.7 Kelvin Connections

Kelvin voltage sensing is extremely important in order to accurately measure current and cell voltage. Notice how the differential connections at the sense resistor do not add any voltage drop across the copper etch that carries the high current path through the sense resistor. See Figure 77 and Figure 78.

12.8 Board Offset Considerations

Although the most important component for board offset reduction is the decoupling capacitor for Vcc, additional benefit is possible by using this recommended pattern for the coulomb counter differential low-pass filter network. Maintain the symmetrical placement pattern shown for optimum current offset performance. Use symmetrical shielded differential traces, if possible, from the sense resistor to the 100-Ω resistors as shown in Figure 78.

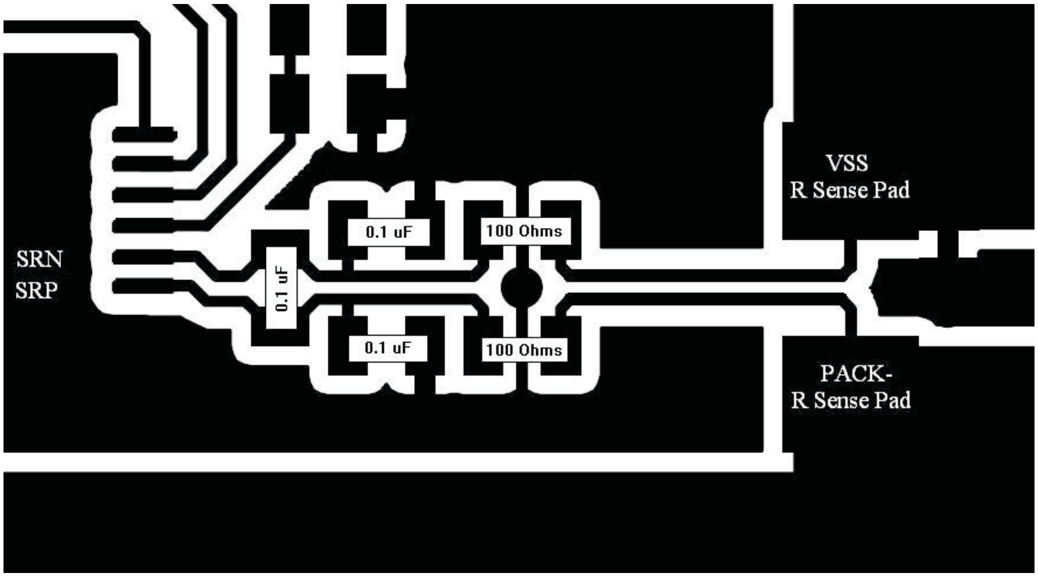


Figure 78. Differential Connection between SRP and SRN Pins with Sense Resistor

12.9 ESD Spark Gap

Protect I^2C clock, data, and other communication lines from ESD with a spark gap at the connector. The pattern below is recommended, with 0.2-mm spacing between the points.

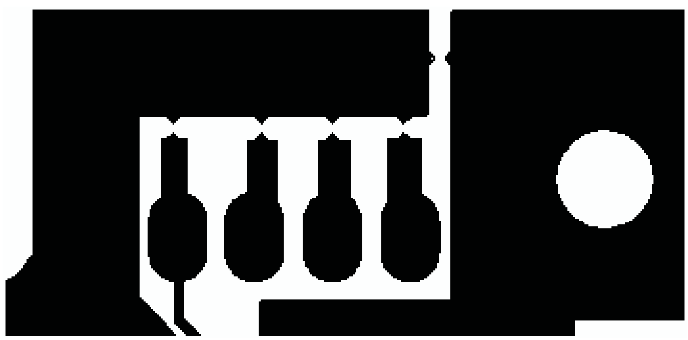


Figure 79. Recommended Spark-Gap Pattern Helps Protect Communication Lines From ESD

12.10 Unwanted Magnetic Coupling

A battery fuel gauge circuit board is a challenging environment due to the fundamental incompatibility of high-current traces and ultralow-current semiconductor devices. The best way to protect against unwanted trace-to-trace coupling is with a component placement such as that shown in Figure 80, where the high-current section is on the opposite side of the board from the electronic devices. Clearly this is not possible in many situations due to mechanical constraints. Still, every attempt should be made to route high-current traces away from signal traces, which enter the gas gauge directly.

IC references and registers can be disturbed and in rare cases damaged due to magnetic and capacitive coupling from the high-current path. During surge-current and ESD events, the high-current traces appear inductive and can couple unwanted noise into sensitive nodes of the gas gauge electronics.

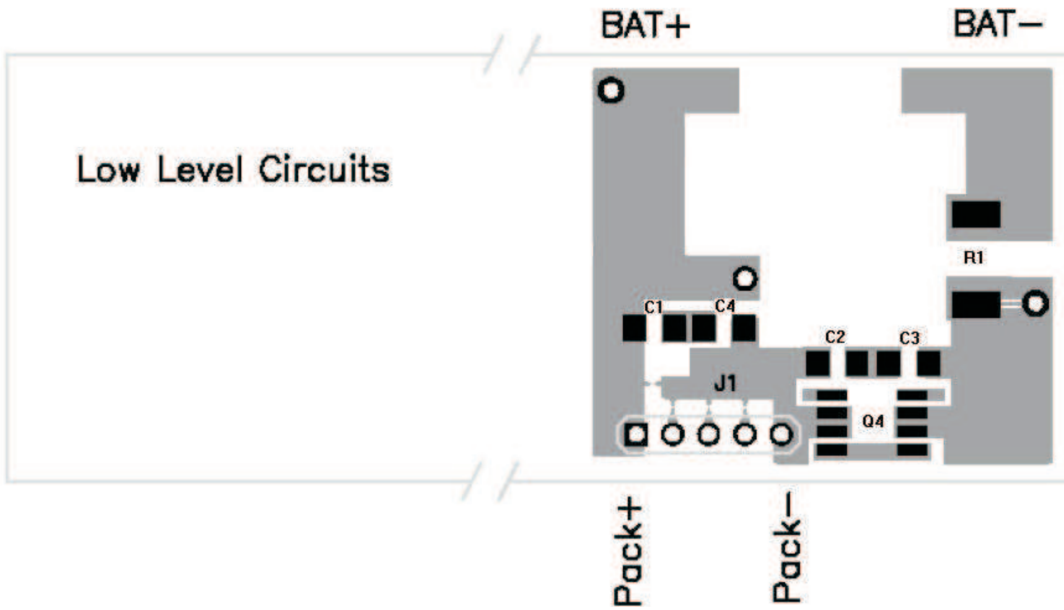


Figure 80. Separating High- and Low-Current Sections Provides an Advantage in Noise Immunity

Chapter 13

ESD and RF Mitigation in Handheld Battery Pack Electronics

Bill Jackson *HVAL*

ABSTRACT

It is imperative to protect the electronics in a consumer-removable battery pack from ESD damage. Even an upset without permanent damage may be unacceptable to the end-user. Handheld equipment that contains a transmitter also may require protection to guard against improper measurement and/or upset due to the affect of the radio frequency (RF) on the circuitry. Because the RF field strength varies as the cube of the distance from the RF source, a battery pack located close to the antenna in handheld equipment is exposed to a strong RF field.

13.1 ESD Issues

The typical gas gauge integrated circuit (IC) is rated for 2 kV at the IC pin without damage to the IC. It requires external ESD suppression to reduce the system ESD requirements, generally at least 8 kV, to a safe level for the IC. The design must further reduce the ESD level so that even an upset to the IC is avoided. For example, RAM corruption may occur as a result of ESD and is unacceptable if it causes the misreporting of available capacity or other critical information.

13.2 ESD Mitigation

Protecting the Communication Lines. The TI-recommended ESD protection for communication lines is a 5.6-V zener diode with a 100-Ω resistor between the zener diode and the battery connector pin and a second 100-Ω resistor between the zener diode and the communication pin on the IC. This circuitry appears in the reference schematics contained in the typical application schematics of the the gas gauge data sheet. The resistance between the connector pin and the zener diode limits the current flow if the pin is accidentally shorted to the positive pack terminal. Otherwise, the zener diode may likely fail and render the pack useless, as a zener diode often fails as a short. The resistance between the zener diode and the IC pin will limit the substrate current flow in the IC if the communication line suffers a negative voltage ESD event. Without the 100-Ω limiting resistance, the current divides between the zener diode and the ESD protection diode internal to the IC. The resulting substrate current flow may upset the gauge operation and result in device reset and/or RAM corruption. The protection zener diode must be connected to the high-current ground etch with a low-inductance connection. Some customers may use a transient suppressor instead of a conventional zener diode for communication line protection.

Recognizing Where the ESD Current Flows and Its Effects. One key to controlling ESD is to recognize where the current from the ESD event may flow and then take steps to reduce the amplitude, minimize the effect of the induced voltage spike along the path of the ESD current flow, and minimize the capacitive and magnetic field coupling from the ESD voltage and current pulse into sensitive circuitry. The ESD event results in a fast-rising voltage and current pulse on the line that receives the discharge. The discharge seeks the lowest-impedance path to earth ground. In a battery pack, the largest capacitance to earth ground is from the battery cells through the case to a hand or other surface adjacent to the pack. If the ESD event occurs on the Pack+ or Pack– connector terminals, the current path is obviously the high-current path from the connector to the cell. This path may pass through the lithium-ion protector FETs or through capacitors around these FETs, assuming that these capacitors are connected with low-impedance etch runs. If the ESD event occurs on a communication or other interface signal, the current finds the lowest-impedance path to the cells. Hopefully, this path is not through the communication pin of the IC. The ESD event may cause a 1-ns rise-time voltage pulse of several thousand volts and/or over 30 A of momentary current flow. The fast-rising voltage spike can capacitively couple onto any etch and components adjacent to the affected line. The fast-rising current flow from the discharge creates a large inductive voltage drop along the path of the current flow. The ESD current pulse also creates a magnetic field that can couple the transient into nearby components and etch runs.

Reducing the ESD Current Spike Amplitude. Placing a capacitor between the Pack+ and Pack– connector pins close to the connector with short and wide etch runs can improve the ESD susceptibility. This capacitor can provide an alternate path for a portion of the current pulse from a Pack+ or Pack– ESD event and reduce the peak current amplitude through any single etch run to the battery cells. This may provide some improvement in the peak ESD voltage transient level that the pack can withstand.

Avoiding ESD Currents in the Low-Current Ground Path. The recommended design practice is to separate the high-current ground etch from the low-current ground etch. Even a small inductance in the high-current ground path can develop a large potential due to the extremely fast dI/dt from the ESD event. If sensitive circuitry has multiple connections along the high-current discharge path, a large differential voltage between these connection points may occur during an ESD event. This differential voltage may allow some inputs to be momentarily pulled lower than Vss and the resulting substrate current flow can cause upset of the circuit performance. The best way to handle this issue is to connect all the low-current grounds and then tie the low-current ground to the high-current ground at a single point. Ensure that none of the ESD protection components, such as zener diodes or transient suppressors on the communication lines, tie to the low-current ground, but instead shunt any ESD fault currents directly to the high-current etch path. Ensure that the current path for these fault currents is indeed the lowest impedance path for the ESD current to flow by connecting the ESD protection components with short and wide etch to minimize the inductance in series with the components. A long, skinny etch run destroys the effectiveness of these components.

Avoiding Coupling From ESD Voltage and Current Pulse. It is difficult to eliminate coupling from the ESD pulse into the sensitive circuitry without physical separation of the high-current discharge path from the sensitive circuitry. This is difficult, if not impossible, in most miniature designs. Placing internal shield layers in the printed-circuit board (PCB) that shield the high-current path from the sensitive components may be the only practical thing that can be done. If the high-current etch path runs directly under sensitive components and etch that connects the sensitive components, then the ESD susceptibility of the design may be degraded.

Adding Spark Gaps. An approach that some designers have used to improve ESD susceptibility is the addition of spark gaps between the signal pins and Pack– at the connector etch pads. Figure 81 shows an example of this approach. The etch structure provides a small clearance between points, or corners, in the etch to encourage a breakdown from a high voltage across the clearance. The clearance must be kept free from the solder mask, as the solder mask would increase the voltage breakdown of the gap enormously. A 20-mil gap has a voltage breakdown at sea level of less than 3 kV and could help a marginal design pass the required ESD levels.

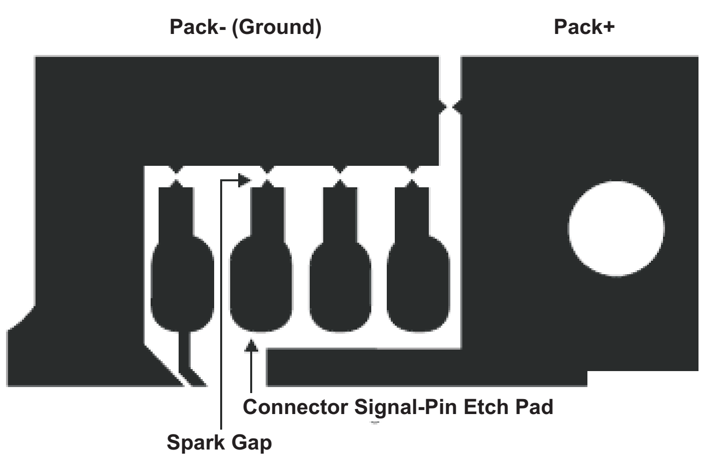


Figure 81. Typical ESD Spark-Gap Structure at Pack Connector

13.3 RF Issues

It is easy to demonstrate that radio-frequency (RF) energy can seriously affect the measurement accuracy and performance of various pieces of laboratory equipment. Just key a walkie-talkie or other transmitter while holding it close to a DVM and try to make a measurement. You can also key the transmitter while holding it close to the case of a laboratory power supply and observe how much the supply output is disturbed. A lot of laboratory equipment is not designed to operate accurately in the presence of a strong RF field. In these experiments, the RF is picked up by the wiring in the equipment, is rectified by various diode structures, and the resulting unexpected bias voltage at various nodes causes the circuitry to produce the undesirable behavior.

Likewise, RF can affect the gas gauge operation without proper precautions. The RF energy may be either conducted into the battery pack on the wiring from the battery pack connector or it may be coupled onto the battery pack wiring that may look like an RF antenna. Sometimes, the battery pack wiring may inadvertently act as an efficient antenna for the particular RF wavelength that is being used. For example, a 2.4-GHz, quarter-wavelength antenna is 3.125 cm long. It would not be unusual to find conductors in the battery pack wiring of approximately 3 cm long, that may efficiently pick up this frequency.

Many IC inputs are high impedance and do not significantly attenuate the RF amplitude present on the etch connecting to the IC input. Typical bypass capacitors, like a 0.1-μFd ceramic surface-mount capacitor, have low self-resonant frequencies and look inductive at the offending RF frequency. Small ceramic capacitors, like 68 pF to-100 pF, generally have much higher self-resonant frequencies and may have a much lower impedance than a larger ceramic capacitor, making them much more effective in filtering out RF at the IC input pins. The inputs to the gas gauge IC have ESD diode structures between the IC pins and Vss of the IC. These diodes can rectify the RF present at the IC pin and turn the energy into a negative bias at that pin and may even cause some small substrate current to flow. The extremely low current operation of some of the circuitry in the low-power IC can be disrupted by unwanted substrate current flow. Most inputs also have an ESD diode structure connected to Vcc of the IC. (They are purposely not used on the communication lines.) If the input is normally biased close to Vcc, rectified RF may bias the pin above Vcc which also causes substrate current flow and potentially upset the gauge performance.

13.4 RF Mitigation

Avoiding Critical Etch Run Lengths. It may be worthwhile to evaluate the various unshielded interconnects to ensure that none are sub-multiples of the transmitting wavelength. Avoiding quarter-wavelength and half-wavelength etch runs may help reduce the RF susceptibility. Shielding these etch runs from the RF through use of ground planes can significantly reduce the RF pickup on these runs.

Physical Separation and Shielding. Because the RF field strength drops with the cube of the distance from the transmitter antenna, physical separation of the sensitive components from the antenna is important. There are practical limitations as to how far the antenna can be physically separated from the components; shielding of the battery pack electronics may be required. However, if the transmitting antenna runs along one side of the battery pack and the critical circuitry is located on the side of the PCB nearest the antenna, reversing the PCB layout to move the circuitry to side of the PCB fartherest from the antenna can make a significant difference. For example, if the nominal distance from the antenna to the critical circuitry is 2.5 cm, moving the circuitry may result in a nominal 5-cm separation. This reduces the RF field strength by a factor of 8. A metal shield around the battery pack electronics would be desirable, but even a foil-backed insulator provides some shielding. Burying long etch runs in the PCB with ground planes as shields between the etch runs and the RF source helps reduce the RF coupled into the long etch runs.

RF filtering. If the sensitive components are separated and shielded sufficiently, wiring that is close to the antenna that connects to the battery pack can conduct the RF directly into the sensitive circuitry. RF feedthrough capacitors on all connections going into the battery pack is ideal, but difficult to implement in most designs. The large (low-frequency) bypass capacitors are minimally effective at removing RF from etch runs. Use of smaller ceramic capacitors, like 68 pF to 100 pF, are much more effective than the larger value capacitors at RF frequencies. Filtering RF off the connections to the battery pack and shielding long conductors may not eliminate all the RF. Filter capacitors may be needed on some of the critical inputs to further reduce the RF amplitude. These capacitors must be placed as close to the IC as practical and connected with short and wide conductors. Note that the Vss end of the capacitors must be connected with as much care as the signal end, as interconnect inductance in either connection can render it ineffective.

Chapter 14

Impedance Track Fuel Gauge Accuracy Test for GSM Phone Applications

Ming Yu and Michael Vega *Battery Management Solutions*

ABSTRACT

The Texas Instruments Impedance Track™ (IT) fuel gauge is designed for reporting remaining battery capacity and run time accurately. To effectively accomplish this reporting a real application environment must be used for test results. The test board should be designed as similar to the real application circuit as possible. This application report outlines the procedure for implementing an accuracy test for GSM and Smart phone applications using the TI System Side Single Cell Impedance Track Fuel Gauge bq27500. The test setups, battery chemistry selection, and battery learning cycle are discussed in this report. Finally, the test results demonstrate that less than 1% remaining capacity accuracy can be achieved by the Impedance Track Fuel Gauge.

14.1 Impedance Track Algorithm Background

The gas gauge algorithm uses three types of information to calculate Remaining Capacity (*RM*) and Full Charge Capacity (*FCC*):

- Chemical—Depth of Discharge (*DOD*), and maximum chemical capacity Q_{max}
- Electrical—internal battery resistance dependence on DOD, or State of Charge (SOC). SOC equals 1 minus DOD.
- External—load and temperature.

Full Charge Capacity is defined as the amount of charge passed from a fully charged state until the system Terminate Voltage is reached at a given rate of discharge (after subtracting the reserve capacity).

> FCC depends on the rate of discharge and is lower at higher rates and low temperatures because the cell I*R drop causes the *Terminate Voltage* threshold to be reached early.

Relative State of Charge (RSOC) is defined as:

$$\textbf{RSOC = (RM} \times \textbf{100)} \div \textbf{FCC}$$

The algorithm differentiates between *charge*, *discharge* and *relaxation* modes of operation. See the *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450) application report for additional details.

These items are updated by the Impedance Track algorithm:

- Chemical Depth of Discharge (DOD) or State of Charge (SOC = 1 – DOC)
- Q_{max}
- Resistance
- Temperature Model
- Remaining Capacity (RM) and Full Charge Capacity (FCC)

The Relative State of Charge (RSOC) Error is defined as:

RSOC Error = RSOC $_{\text{calculated}}$ **– RSOC**$_{\text{reported}}$

where

RSOC$_{\text{calculated}}$ **= (FCC – Q**$_{\text{start}}$ **– PassedQ)** $\times$ **100** $\div$ **FCC**

and **RSOC**$_{\text{reported}}$ is the RSOC reported by bq27500 Impedance Track algorithm.

Remaining Capacity Error is defined as:

RM Error = (RM$_{\text{calculated}}$ **– RM**$_{\text{reported}}$ **)** $\div$ **FCC**

where

RM $_{\text{calculated}}$ **= FCC – Q**$_{\text{start}}$ **– PassedQ**

and **RM** $_{\text{reported}}$ is the RM reported by bq27500 Impedance Track algorithm. **PassedQ** is passed charge from the beginning of discharge to present. **Q**$_{\text{start}}$ is the starting charge at the beginning of discharge.

References

For additional information related to this application report, see:

- *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450)
- *Going to Production with the bq2750x* (SLUA449)
- *bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module* (SLUU287)
- *bqEASY for Single Cell Impedance Track™ Devices* (SLUU307)

14.2 GSM Phone Accuracy Test Preparation

GSM Phone Application

Unlike notebook battery applications having a relatively constant load profile, cell phones, smart phones, or PDAs (GSM, CDMA, 3G GSM or 3G CDMA communication protocol dependent) have a *pulsating* load profile. This application type always raises questions regarding, "how well Impedance Track can accurately predict the battery remaining capacity and what is the impact of the pulsating current?" In this example, a NOKIA 6106b GSM phone is used to check the Impedance Track accuracy.

As mentioned in *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450) application report, the **Qmax** and **Resistance** can be updated only when certain criteria are met. There is some confusion that under a pulsating current, an accurate OCV reading may be difficult to achieve. In order to reveal the truth, this criteria should be carefully examined.

First, zero current is *not* needed for an Open Circuit Voltage (OCV) reading. Only a *low* current (that is, less than C/20 rate) is needed. This is very common in cell phone and smart phone applications when they are in standby mode. During the relaxation, a short spike current pulse does not *wake-up* the gauge from relaxation mode. The current must remain high and exceed a specified time limit for the cell to exit the relaxation mode.

Second, if a single voltage read point is taken exactly at the moment of the spike, it is ignored because the Impedance Track checks if the current exceeded a specific current threshold. If it does, Impedance Track uses the previous OCV reading.

Accuracy Test Requirements

To correctly measure and calculate the Remaining Capacity (*RM*) and Full Charge Capacity (*FCC*) to get Relative State of Charge (RSOC), (1) the battery cell chemistry must be accurately selected through battery chemistry selection cycling and (2) the battery cell resistance profile must be accurately learned through battery cell learning cycle.

Before starting all battery cycling, the Print Circuit Board (PCB) with bq27500 should be carefully calibrated. Check application report *Going to Production with the bq2750x* (SLUA449) for the correct calibration procedure.

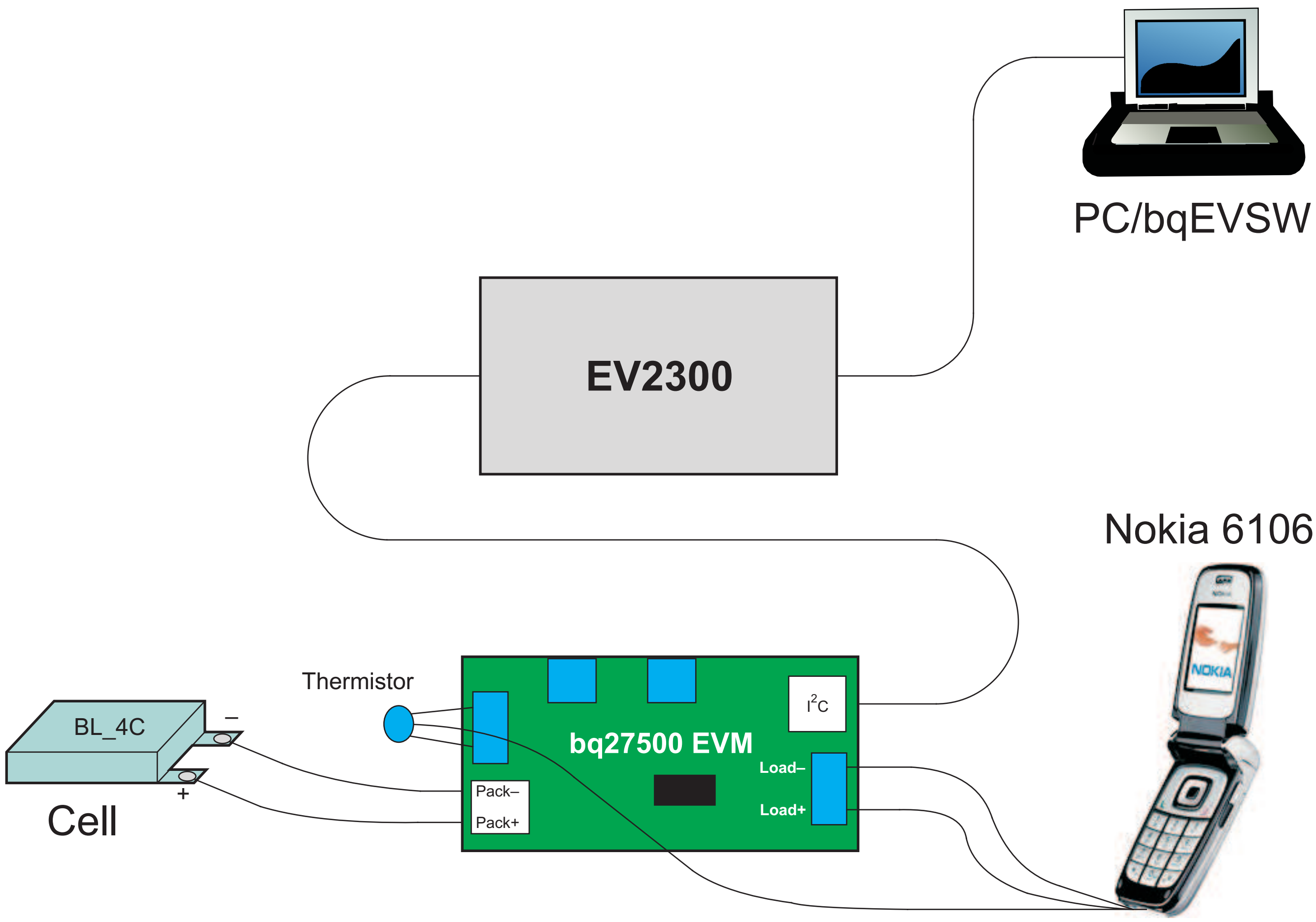
The test setup (Figure 82) includes:

- A bq27500 EVM or any application specified test board with bq27500.
- A PC with the bq Evaluation Software properly installed.
- A PC USB interface that is connected to the EV2300 communication module.

See the *bq2750xEVM System Side Single-Cell Impedance Track™ Technology Evaluation Module* (SLUU287) application report for detailed setup requirements.

The GSM phone original BL-4C battery pack is modified. The battery cell is carefully removed from the original battery pack. The cell protection circuit board is removed to expose the positive and negative terminal. The original thermistor is discarded. For proper operation of the phone, the thermistor terminal on the phone is connected to the thermistor on test board. The battery terminals from the phone then connect to battery terminals through wires. See Figure 82 for battery cell modification and test setup.

Figure 82. Test Setup With Battery Cell



Chemistry Selection Cycling

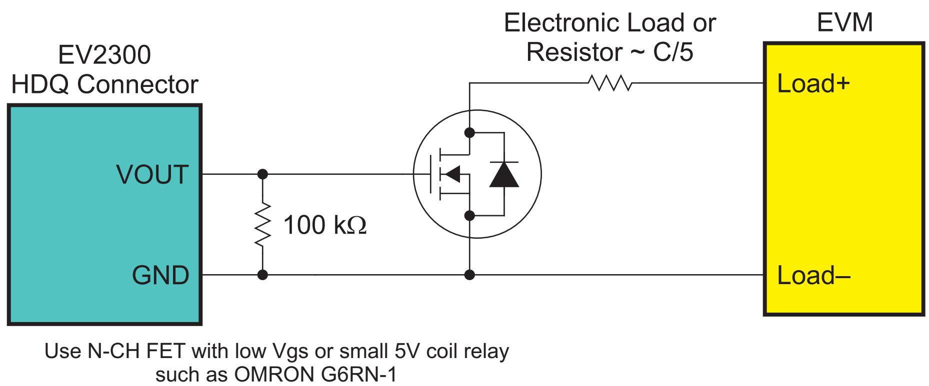
The battery cell chemistry must be carefully selected. The bq Evaluation Software provides a procedural tool called **bqEASY** that helps the user to set up the cell, based on the cell manufacturer specification and system requirements to do the chemistry selection cycle. bqEASY uses a four-point method for chemistry selection and the results are usually within 1% error of the actual chemistry learned from more sophisticated cycling system, such as the Arbin Instruments™system. TI offers the help for customer who needs to identify the cell chemistry using the Arbin Instruments system. The Arbin Instruments system takes more points when determining the cell chemistry, therefore it takes longer.

bqEASY has a chemistry database with most known chemistries that have been characterized in TI using the Arbin Instruments system. If the battery cell chemistry can not be matched to any known profiles, the battery cell needs to be sent back to TI to determine the actual chemistry through the Arbin Instruments system and a new profile can be generated.

For bqEASY to select the chemistry correctly, the cell must be charged very close to its maximum cell voltage. Normally, this is 4.2 V, before the chemistry selection cycling. The charge taper current should be less than C/100 when charging is terminated.

A programmable electronic load or resistor is also needed to generate a less than C/5 discharge rate during the discharge cycle. The chemistry selection cycle requires a controlled load profile (see Figure 83). The EV2300 HDQ port is used to periodically turn on the load using the FET or relay.

Figure 83. Configuration of Load Circuit



Chemistry selection cycling will select the correct chemistry profile from the bqEASY built-in chemistry database and program these values into the bq27500 data flash for Impedance Track algorithm to use.

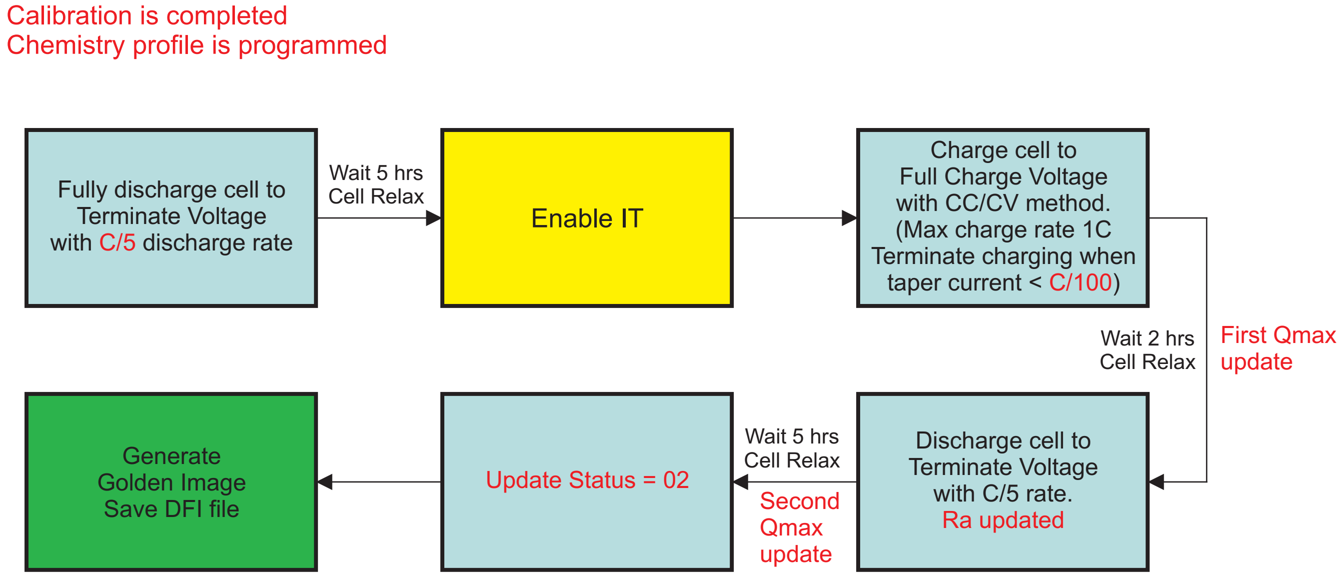
Battery Cell Learning Cycling

The battery learning cycle is used to obtain the actual cell Qmax and cell resistance value, updated based on the chemistry determined from Chemistry Selection Cycling. It is very critical that the correct chemistry be selected before proceeding with learning cycling.

A complete learning cycle consists of the procedure shown in Figure 84. Before starting the learning cycle, if the chemistry is known, the chemistry profile should be programmed into bq27500 data flash and the test board should be calibrated.

During the learning cycle, Qmax is updated twice. The first Qmax update happens after the charge cycle during the two-hour relaxation period. The second Qmax update happens after the second discharge cycle during the five-hour relaxation period. See the *Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm in bq2750x Family* (SLUA450) application report for more information.

Figure 84. Learning Cycle Flow Chart



Generate the Golden Image and Update bq27500 Flash Content

After the cell learning cycle has completed the final five-hour relaxation, bq27500 is ready to be updated with the *golden image* (flash contents learned during the cycling). bqEASY provides the user-interface that helps you generate the golden image file and at the correct time, update the necessary flash contents with the value learned during the learning cycle. This includes updating the OCV table with correct Qmax value, updating all the resistance tables with learned resistance values, resetting the cycle count, disabling the Impedance Track algorithm for mass programming, and so forth.

Once the golden image is programmed into bq27500, the set up is ready for real application testing.

14.3 GSM Phone Accuracy Test and Results

The Nokia 6106 GSM phone used in this test is a registered phone. During the test, actual phone calls in and out of this phone along with applications such as playing games are carried out. The battery voltage and the discharge current are logged with time stamp. Using TI provided bq Evaluation software, the logging process can be easily implemented. The logging information is needed for post-processing to obtain the accuracy results. Depending on the battery capacity and the actual application, the total test time can range from five to nine hours. In this test, the LCD screen is frequently turned on to maximize the phone battery use.

As shown in Figure 85, the discharge current reported by the Impedance Track is being averaged by the Analog to Digital Converter (ADC) in bq27500 and by the Impedance Track algorithm. Although the GSM phone is running on GSM protocol[1] but the reported peak current is around 200 mA when the phone's LCD screen is on and only around 80 mA when the screen is off. When receiving a call, the current spike can go up to between 300 mA and 400 mA.

(1) GSM waveform: 1 A for 0.48 ms and 72 mA for 4.76 ms.

Figure 85. Phone—RSOC and Discharge Current vs. Discharge Time

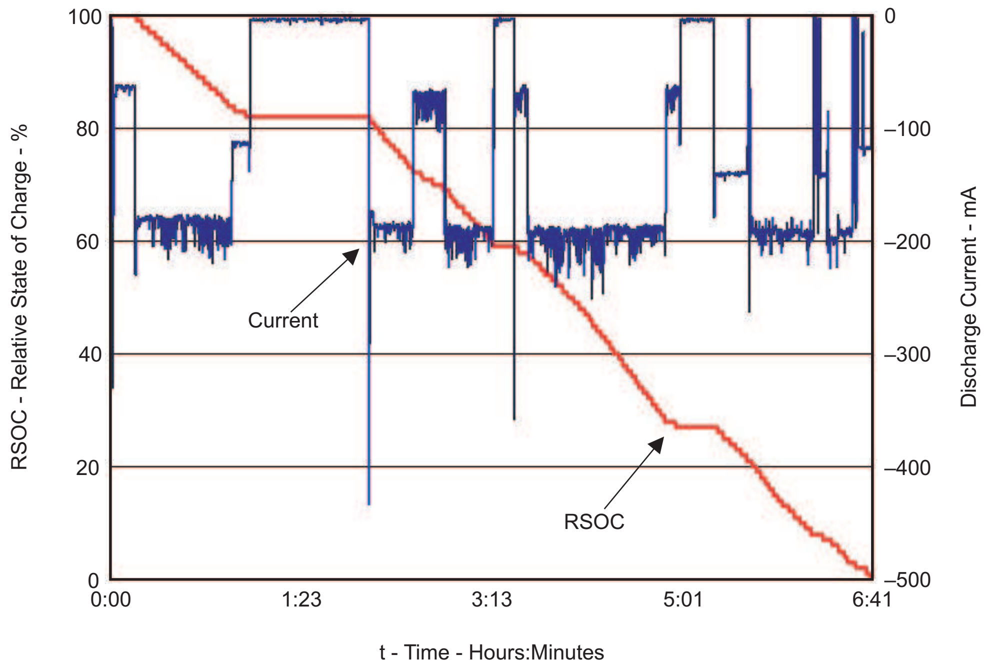
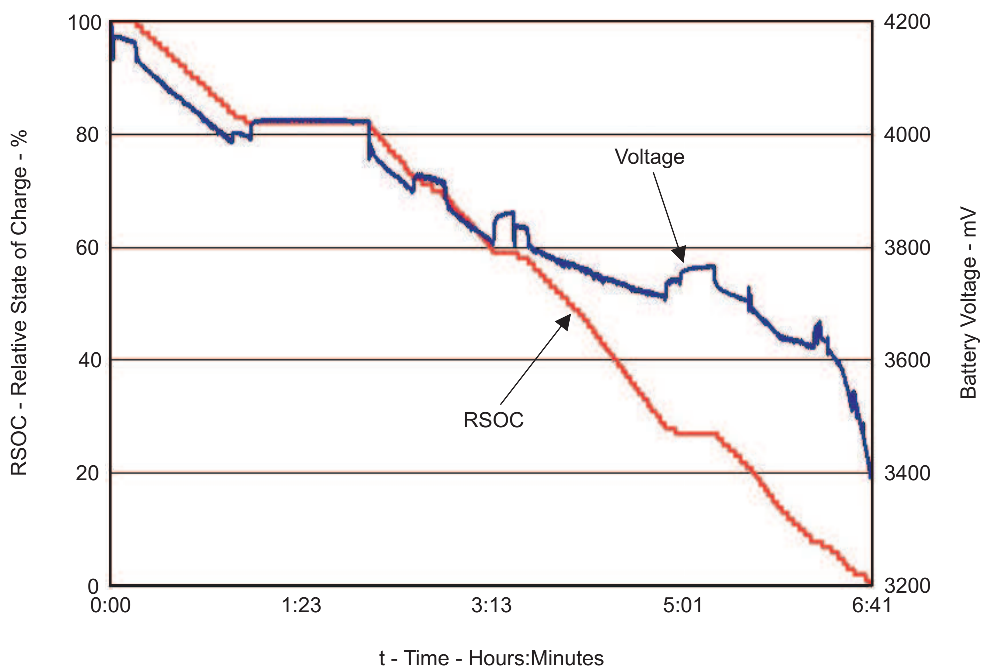
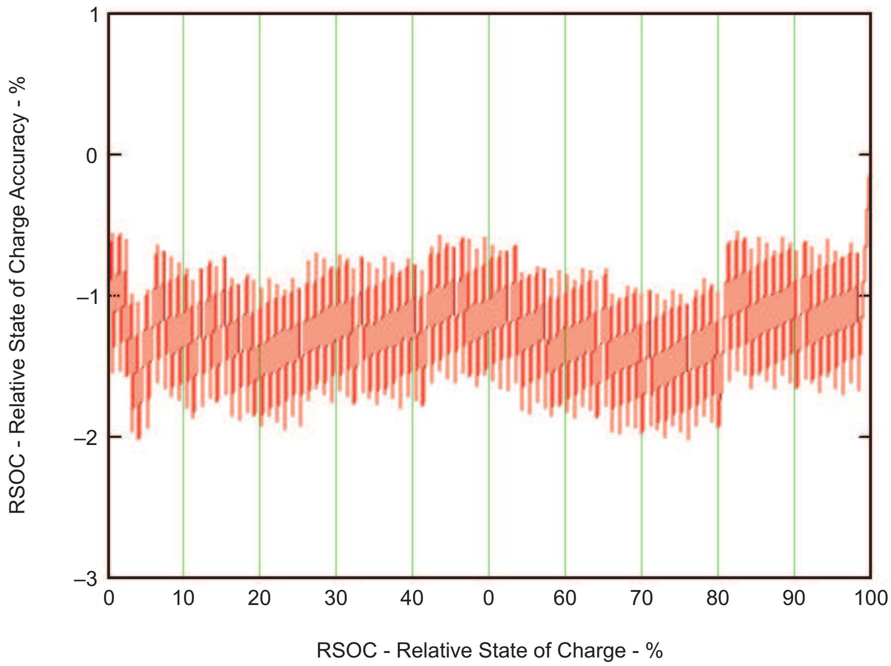


Figure 86. Phone—RSOC and Battery Voltage vs. Discharge Time



The RSOC accuracy for this particular test is calculated from the data log file and Figure 87 shows the RSOC accuracy during the entire discharge cycle. As the discharge starts, the error is about 1%, but as the phone goes into standby mode, which is around RSOC = 80%, the accurate OCV reading is taken by the Impedance Track, ir regardless of the high current spikes happening (with delay).

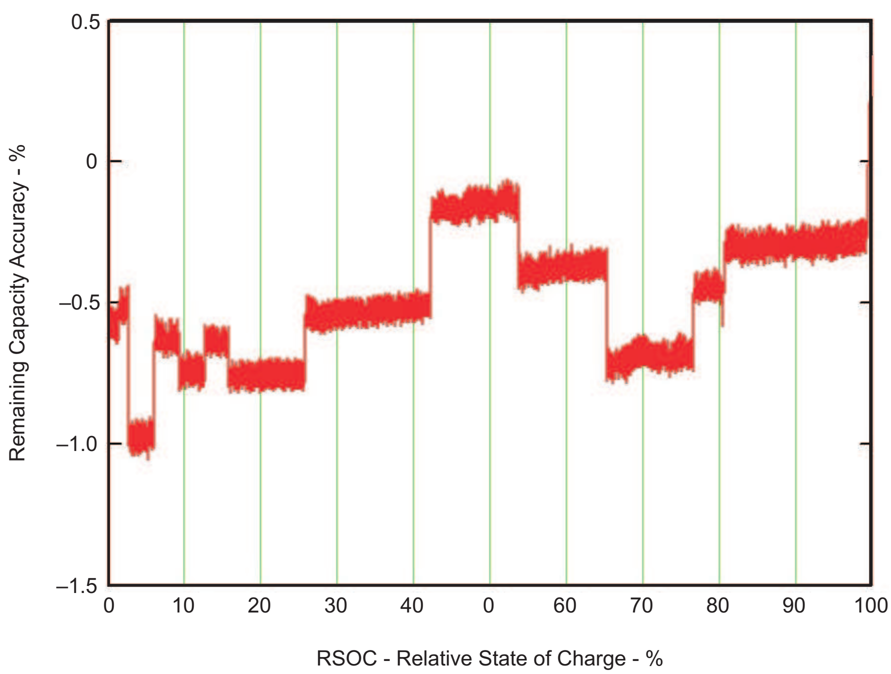
Figure 87. Phone—RSOC Accuracy vs. RSOC



This test has proved that the Impedance Track algorithm works as expected even for pulsating load profile. The high current spike does not affect Impedance Track accuracy.

The Remaining Capacity accuracy is calculated. This is one of the critical parameters that can predict the actual run time of the cell phone. As shown in Figure 88, the RM accuracy is within 1%. During the entire application cycle, the Impedance Track algorithm has made multiple RM adjustments based on the load current, the battery temperature, and so forth. The bq27500 has very accurately reported the remaining capacity with less than 1% error during the entire discharge cycle.

Figure 88. Phone—Remaining Capacity Accuracy vs. RSOC



Chapter 15

Going to Production With the bq2750x

Michael Vega and Ming Yu *HVAL - Battery Management Solutions*

ABSTRACT

This application report presents a strategy for high-speed and economical calibration and production programming of the bq27500/1 single-cell, gas gauge chipset. Flowchart examples are provided, along with step-by-step instructions for preparing a calibration data set that is required when creating the Golden Data Flash Image (DFI) that is programmed into all bq27500/1 devices at the original equipment manufacturer (OEM) production line.

15.1 Introduction

The bq27500/1 gas gauge is built with new technology and a new architecture for both data flash access and calibration. With this new architecture, unit production cost and capital equipment investment can be minimized, as there is no longer a need to perform a learning cycle on each pack. A single *golden data flash image* file (DFI) can be used to program each bq27500/1 in production. Also, the calibration method is quick and simple because most of the calibration routines are built into the firmware of the target device or can be based on average values.

15.2 Determining Data Flash Constants

To configure the bq27500/1 for a given application, the data flash set must be programmed depending on the cell, application system, and charger. The application report entitled *Configuring the bq27500 Data Flash* (SLUA432) gives a detailed description of all the data flash constants that the user can modify. All bq27500/1 integrated circuits (IC) for an application must contain the same data flash values.

The *golden data flash image* (DFI) is a file that contains all flash values and is used at the system application production line to program the bq27500/1. The DFI is programmed using I^2C communication with the bq27500/1. Creating the DFI can be summarized with the process depicted in Figure 89.

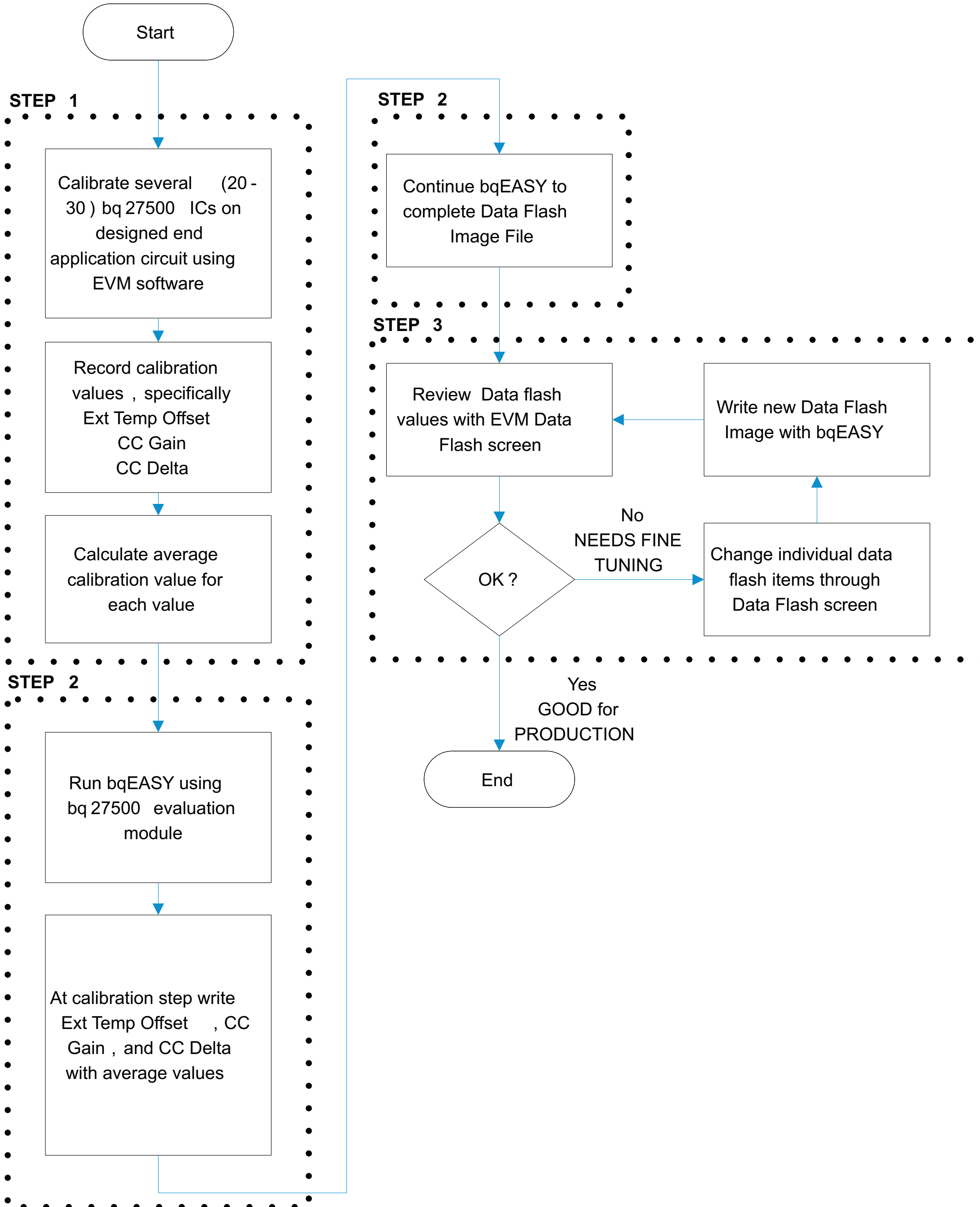


Figure 89. DFI Creation Flow

15.3 STEP 1: Characterize the Calibration Process

Devices of bq27500/1 single-cell gas gauges can be quickly and easily calibrated. With the Impedance Track™ devices, most calibration routines have been incorporated into firmware algorithms, which can be initiated with I^{2}C commands. The hardware necessary for calibration is also simple. One current source, one voltage source, and one temperature sensor are all that is required. The stability of the sources is important, not so much the accuracy. However, accurately calibrated reference measurement equipment should be used for determining the actual arguments to the function. For periodic voltage measurement, a digital voltmeter with better than a 1-mV accuracy is required.

The recommended strategy for bq27500/1 calibration is to perform the calibration using 20 to 30 final application systems containing the bq27500/1 IC. All the calibration flash values are to be recorded and averaged among the 20 to 30 samples taken. The average values are the ones to be used when creating the DFI file needed for production. At time of calibration, access is required to the I^{2}C pins, both ends of the sense resistor, and battery power . The calibration consists of performing coulomb counter offset, current gain, and temperature offset. The Evaluation Software (EVSW) is used to perform all calibration. By using the EVSW, it allows verification of the affected data flash values due to calibration (see Figure 90).

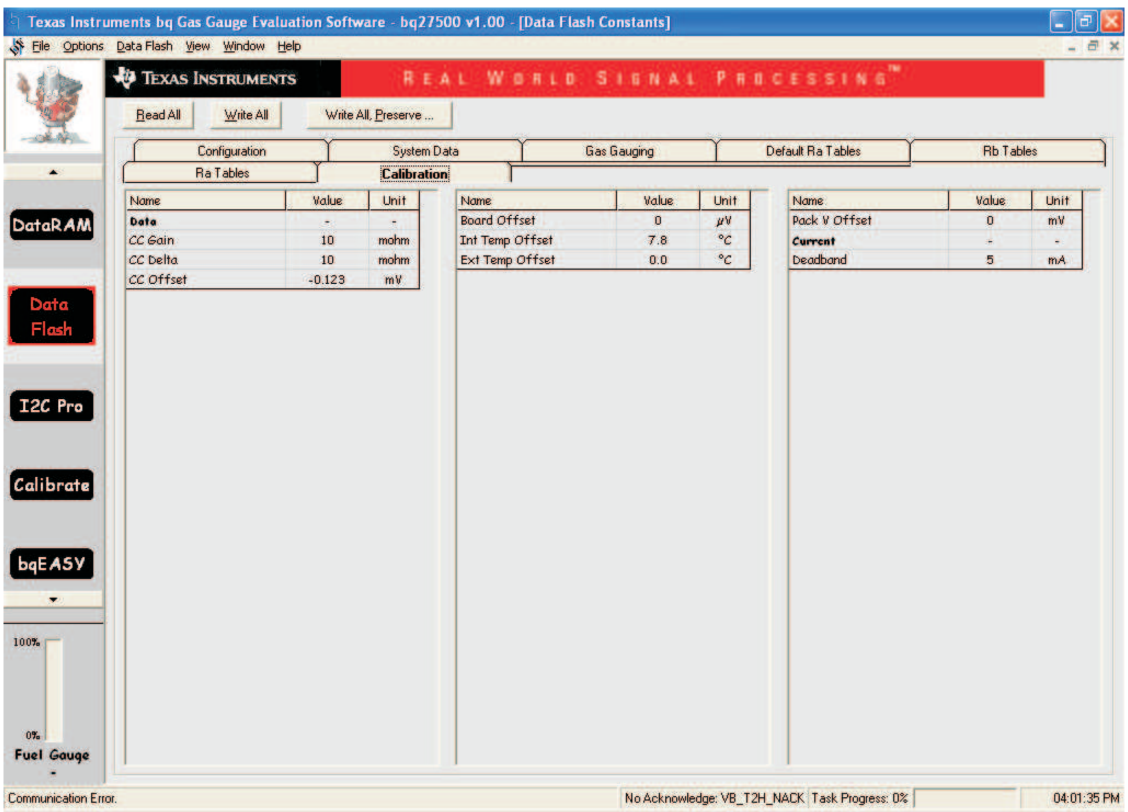


Figure 90. bq27500 EVSW Calibration Data Flash Screen

Perform the following calibration tests on each of the system samples:

CC Offset Calibration — Select the *CC Offset Calibration* checkbox. Then, click on the *Calibrate Part as indicated below* button (Figure 91), and wait for the EVSW to indicate that the calibration is completed. Read back the updated CC Offset data flash value by going to the Data Flash screen in EVSW and selecting the Calibration tab. Press the *Read All* button so that all the data is refreshed on the screen.

Temperature Calibration — Select the *Temperature Calibration* checkbox. Write the actual temperature to which the thermistor is exposed, obtained by the reference equipment measurement. Click on the *Calibrate Part as indicated below* button, and wait for the EVSW to indicate that the calibration is completed. Read back, and record the Ext Temp Offset value from the Data Flash screen.

Pack Current Calibration — Select the *Pack Current Calibration* checkbox; apply a current to flow through sense resistor; and write the actual current measured by meter. Click on the *Calibrate Part as indicated below* button, and wait for the EVSW to indicate that the calibration is completed. Note that a negative sign indicates current in the discharge direction. Read back, and record the updated CC Gain and CC Delta data flash values by going to Data Flash screen in EVSW and selecting the Calibration tab. Press *Read All* button so that all the data is refreshed on the screen.

The voltage and board offset calibration are not required unless there was poor layout that would add any offsets to voltage or current measurements. The EVSW does provide the means of calibrating these parameters. To perform board offset, it is expected that no loads are applied during calibration.

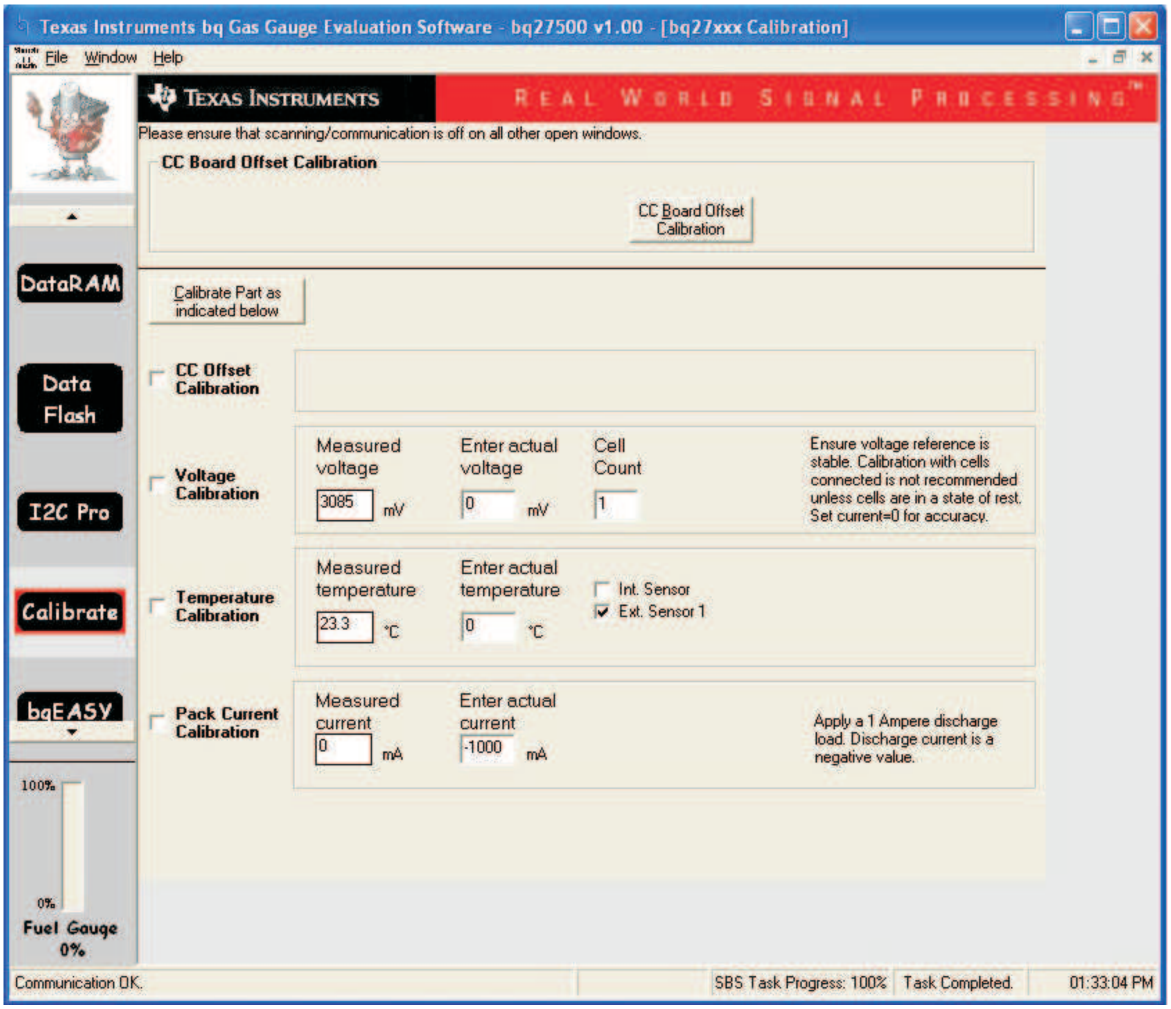


Figure 91. bq27500 EVSW Calibration Screen

The average Ext Temp Offset, CC Gain, and CC Delta values are entered into the DFI file in Step 2.

15.4 STEP 2: Using bqEASY for Production Preparation

The bqEASY (see Figure 92) is a tool embedded within the EVSW that provides detailed instructions and automates processes that on completion creates the DFI that is used at production to program all bq27500/1 for a given application.

Figure 92. bqEASY

The data flash of the bq27500/1 is configured based on a questions and answers session within the Configure section of bqEASY. The questions involve topics specific to the battery pack, the charger, and the system application.

At the Calibrate session of bqEASY, it is expected that the user navigates to the Data Flash section of the EVSW and enters the average calibrations obtained from the process described in the *Characterize the Calibration Process* section of this document.

The Chemistry session in bqEASY is a valuable tool that allows the user to select the chemistry of their battery pack from a database. If the user does not know the chemistry of its battery pack, then the bqEASY gives instructions on testing the battery for determining the chemistry. The discharge during the test is automated. For automated discharge, a setup as described in Figure 93 is required. The load must be selected so that it has a C/5 rate when turned on. During automated discharge, the EV2300 board controls when to enable and disable the discharge, allowing the necessary relaxation periods for OCV measurements. Once the chemistry is determined, the data flash of bq27500/1 is updated so that it contains the proper OCV data that is characteristic of the selected chemistry. Having proper chemistry data is integral for the Impedance Track™ algorithm performing accurately.

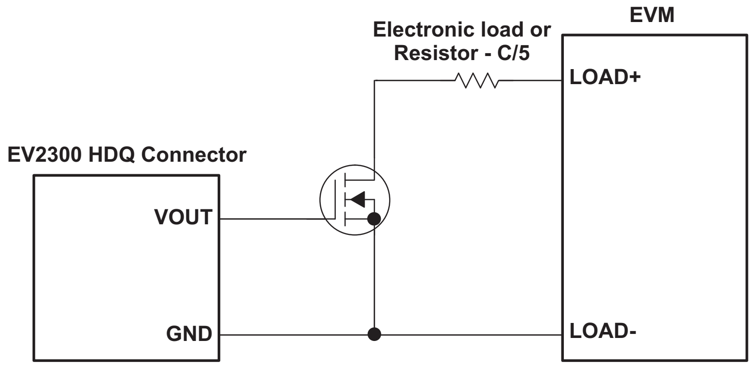


Figure 93. Load Connection for Automated Discharge

The final session of the bqEASY is for running a learning cycle so that Qmax and the impedance tables are updated. The bqEASY provides step-by-step instructions on how to perform the learning cycle. By having learned Qmax and the impedance values, the DFI can be created so that when used to program bq27500 ICs in production, a learning cycle is unnecessary before a device can perform accurate battery fuel gauging as of the first cycle in the system.

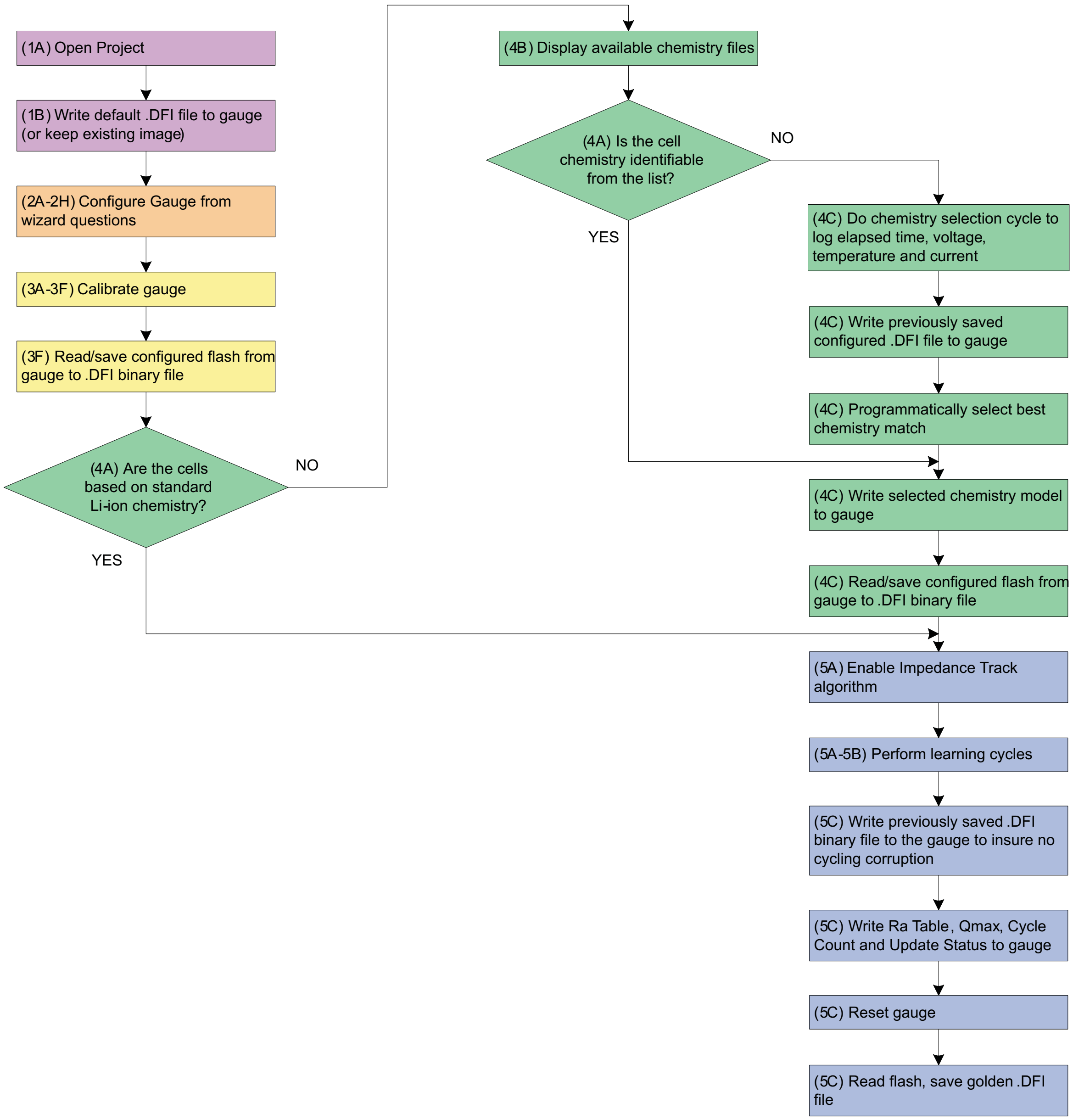


Figure 94. bqEASY Process Flowchart

15.5 STEP 3: Data Flash Review

While following the actual steps of bqEASY, the tool prompts the user to review the data flash constants for advanced configurations that might not have been addressed by bqEASY. The application report *Configuring the bq27500 Data Flash* (SLUA432) defines all the bq27500/1 data flash constants. Refer to this document when reviewing the data flash configuration against the application needs.

To modify the data flash constants, proceed to the Data Flash screen of the evaluation software and search for the desired data flash value to be modified, and change accordingly.

15.6 STEP 4: Writing the DFI at Production

System designers must ensure that there is access to the I^{2}C lines of the bq27500 and battery power access at the time of writing the DFI in production. It is expected that the OEMs add the Write DFI step within their final complete system test that verifies the product to be functional for release to market. The flowchart in Figure 96 shows the steps that must be followed to write the DFI created with bqEASY. System test developers can use the flowchart to call I^{2}C commands with their test setup and program all the flash of the bq27500 embedded in the application system.

The last step of the bq27500 configuration at production is to give the RESET (0x0041), IT ENABLE (0x0021), and SEALED (0x0020) commands. These commands are given by writing the corresponding two-byte data value into the CONTROL register (command 0x00/0x01) using I^{2}C.

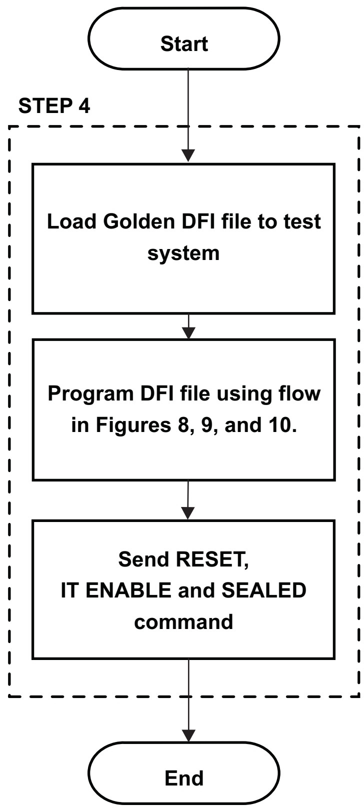


Figure 95. bq2750x Production Flow

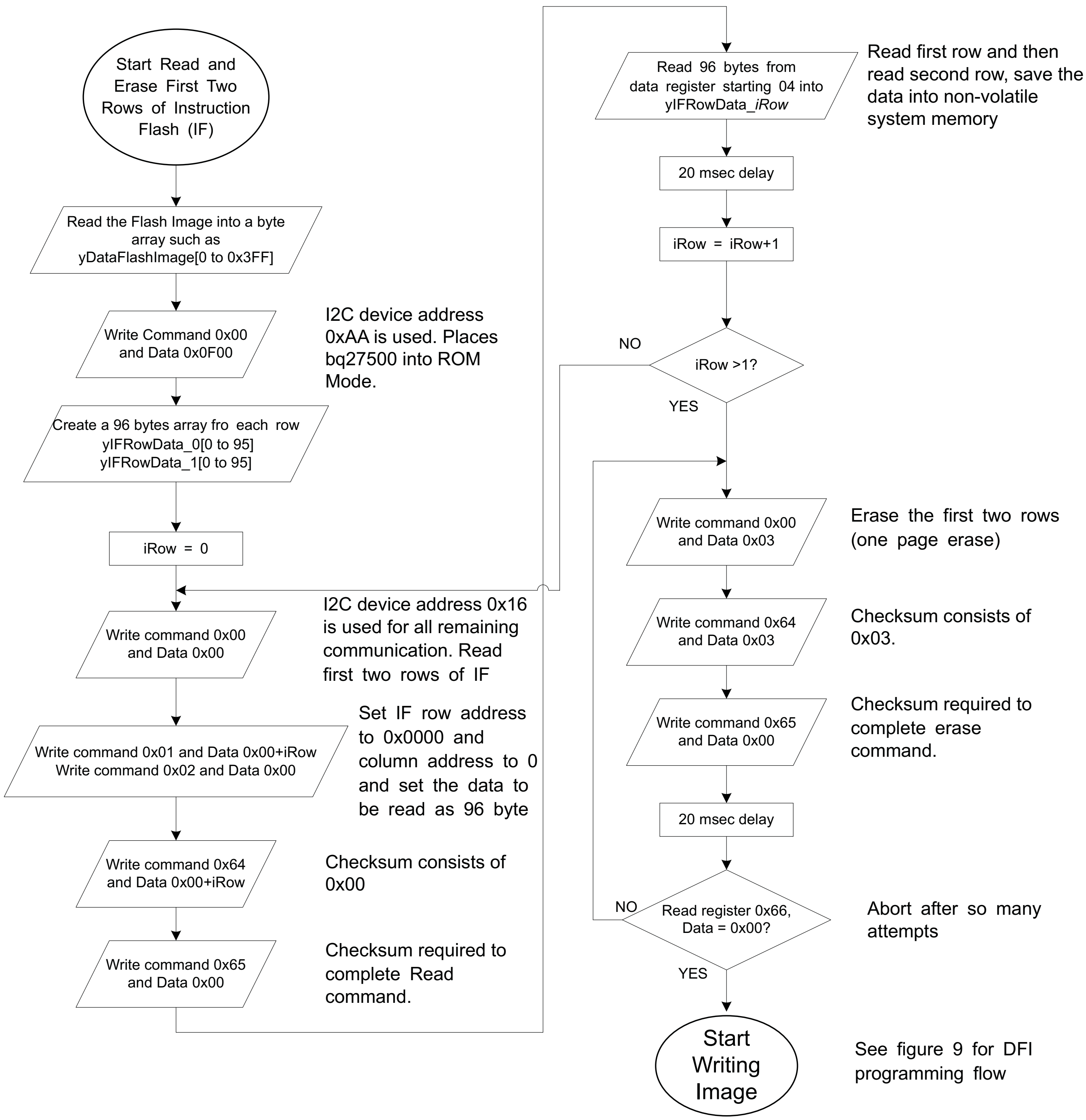


Figure 96. Instruction Flush First Two Row Record and Erase Flow

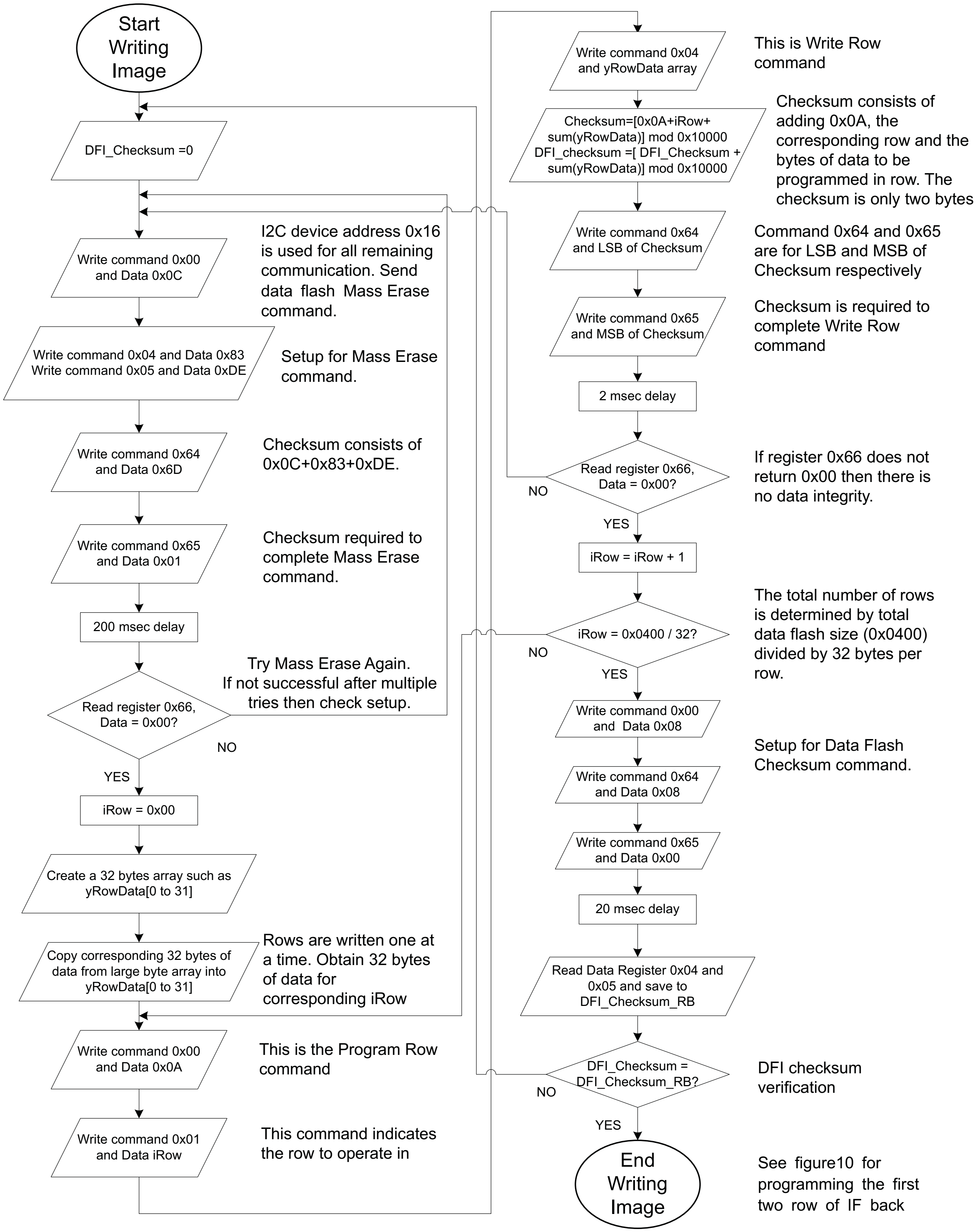


Figure 97. DFI Write Flow

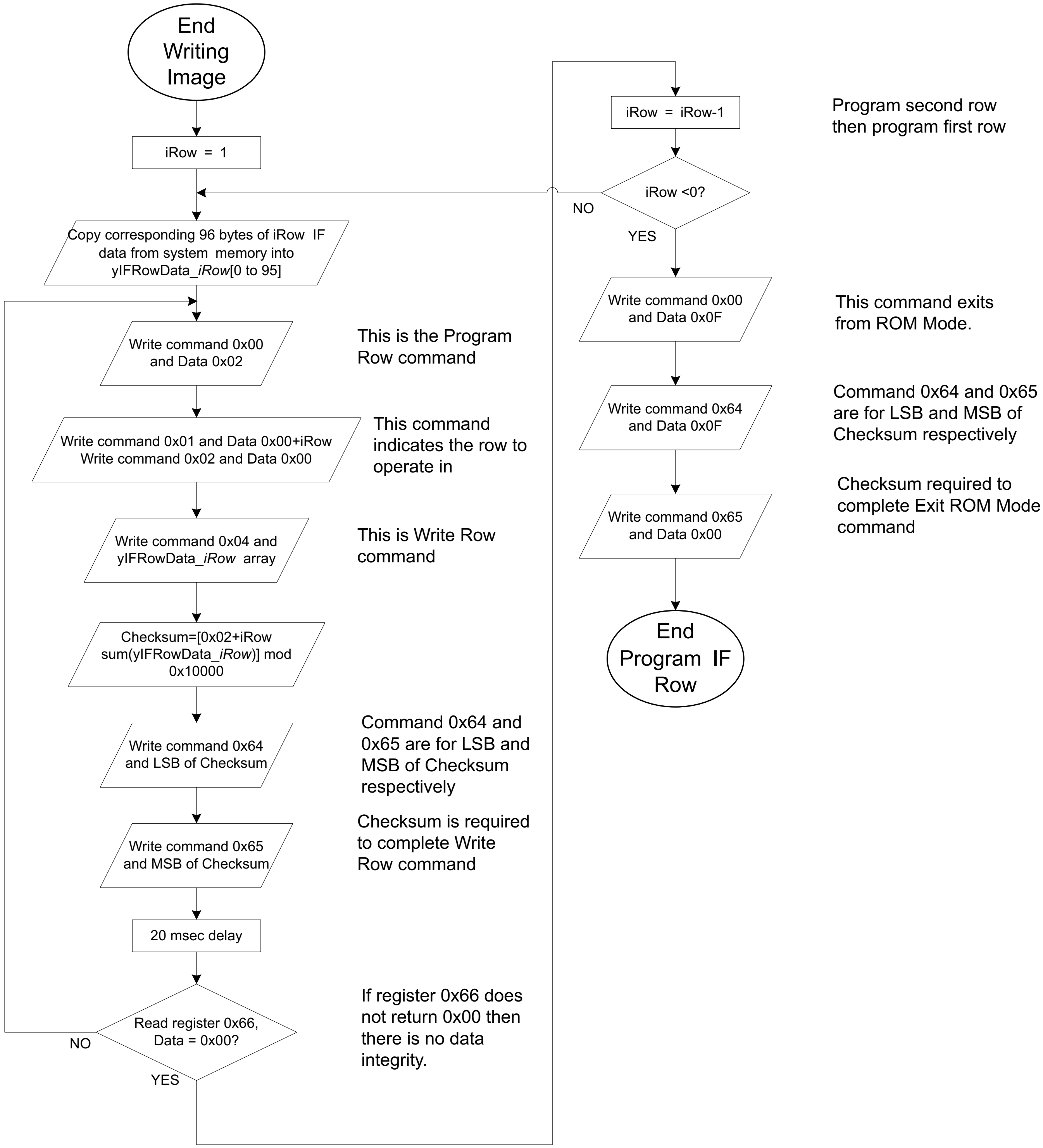


Figure 98. Instruction Flush First Two Row Reprogram Flow

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