Application Report
SLUA375–January 2006

Impedance Track™ Gas Gauge for Novices

Simon Wen
PMP Portable Power

ABSTRACT

This application report introduces the bq20z80 Impedance Track™ and bq29312A chipset gas gauge solution.

Contents

List of Figures

1 Introduction

This application report provides an introductory overview of the following bq20z80 Impedance Track™ gas gauge topics:

- The Basics
  - The bq20z80 Impedance Track™ Gas Gauge Overview
  - Impedance Track™ Technology Operation Principle
  - Gas Gauge Hardware
    - bq29312A Analog Front-End Protector
    - How the bq20z80 and bq29312A Operate Together
    - bq2941x 2nd-Level Overvoltage Protector
  - bq20z80EVM-001 Evaluation Module
  - bqEVSW Software for Use With bq20z80
- Next Steps
  - Developing a PCB for bq20z80/bq29312A/ bq2941x Chipset
  - Solution Development Process
  - Mass Production Setup
- Glossary
- Appendix – Reference Schematic

Impedance Track is a trademark of Texas Instruments.
Windows is a trademark of Microsoft Corporation.

2 The Basics

2.1 *bq20z80 Impedance Track™ Gas Gauge Overview*

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
- Supports the Smart Battery Specification SBS V1.1
- Works with the TI bq29312A analog front-end (AFE) protection IC to provide a complete pack electronics solution
- Full array of programmable voltage, current, and temperature protection features
- Integrated time base removes need for external crystal with optional crystal input
- Supporting 2-, 3-, and 4-cell battery packs with few external components
- Based on a powerful low-power 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
- Optional pulse charging feature for improved charge times
- Drives 3-, 4-, or 5-segment LED display for remaining capacity indication
- Optional cell-balancing feature for increased battery life

The bq20z80 is an advanced, SBS v1.1-compliant, feature-rich battery gas gauge IC, designed for accurate reporting of available charge of Li-ion or Li-polymer batteries. The bq20z80 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 bq20z80 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 (SMBus).

The heart of the bq20z80 programmable battery management IC is a high-performance, low-power, reduced instruction-set (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 bq20z80 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 bq20z80 is designed to work with the bq29312A analog front-end (AFE) protection IC to provide a complete pack electronics solution. Figure 1 shows a simplified system diagram of a typical multicell gas-gauging solution consisting of the bq20z80 and the bq29312A. The main task of the AFE bq29312A is to provide safety protection of overcharge, overload, and short-circuit of the battery. The AFE can be configured to autonomously shut off the FET drives at overload or short-circuit conditions. In addition, the AFE serves as a voltage translator for the bq20z80 gas gauge IC, providing individual cell or battery voltages to the gas gauge IC. In case of overvoltage and undervoltage conditions as detected by the gas gauge IC, the AFE performs actions such as turning on/off charge/discharge FETs as instructed or programmed by the gas gauge IC.

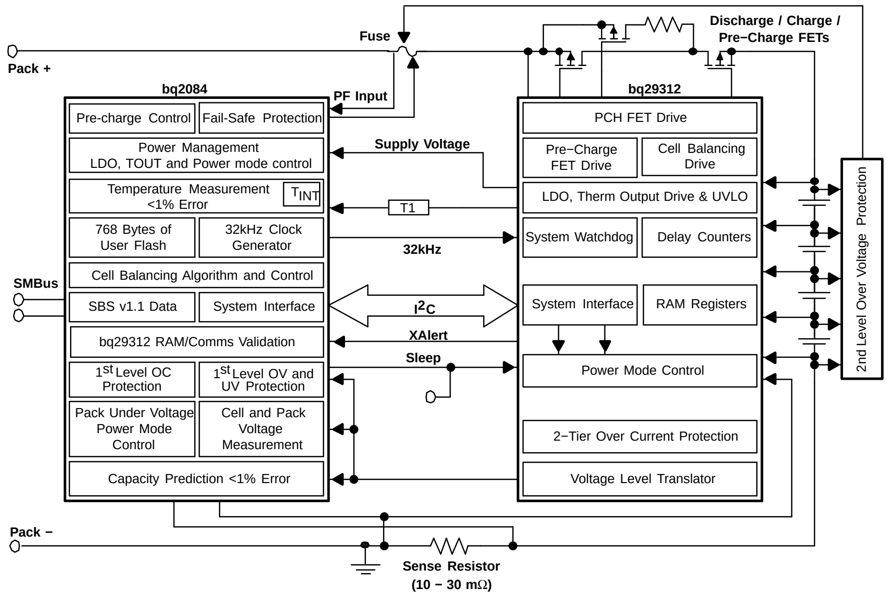


Figure 1. Battery Management Unit Block Diagram

The bq20z80 measures individual cell and pack voltages, temperature, current, and integrated passed charge using the analog interface of the bq29312A AFE and the two delta-sigma ADCs of the bq20z80.

2.2 *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 database. 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 also calculated 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 bq20z80 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 2 illustrates charge, discharge, and relaxation modes of the battery.

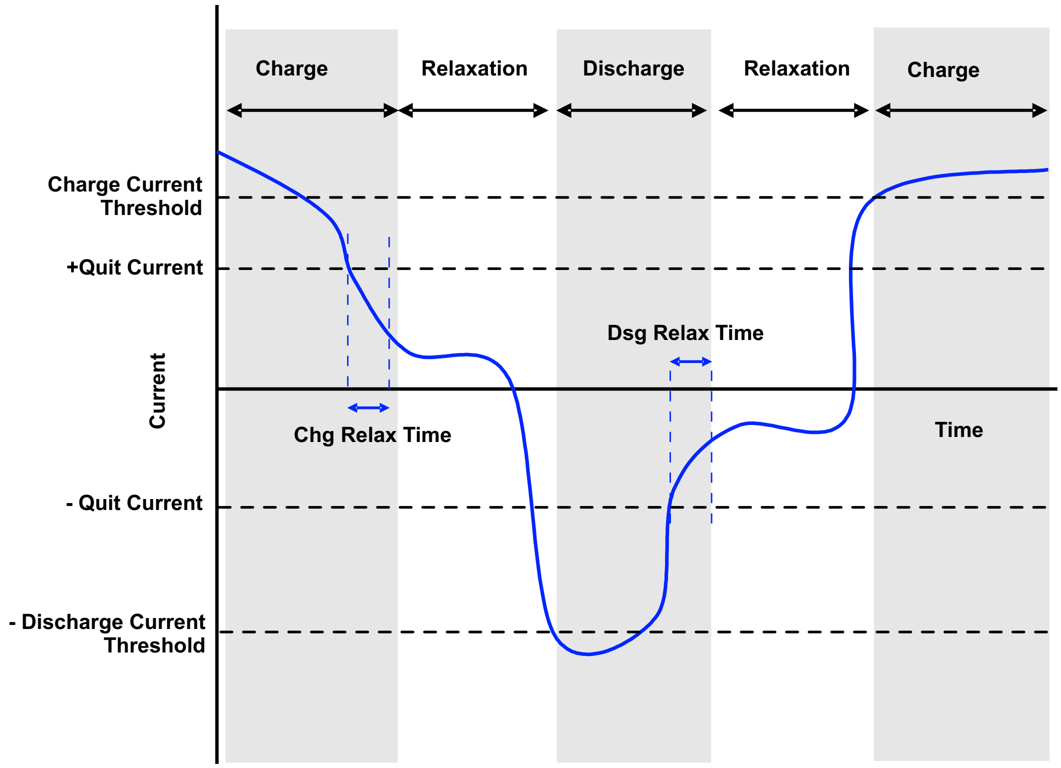


Figure 2. Algorithm Operation Mode Changes With Varying Battery Current

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 3 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 *Gas Gauging* section in the bq20z80 data sheet, SLUS681, 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:

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

The derivation of this equation is discussed in the following paragraphs. Figure 4 illustrates graphically illustrates some of the Impedance Track™ terminology.

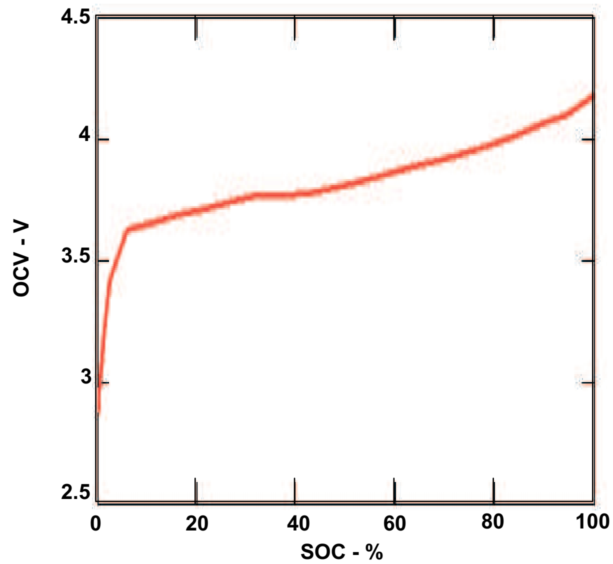


Figure 3. SOC Dependency on OCV

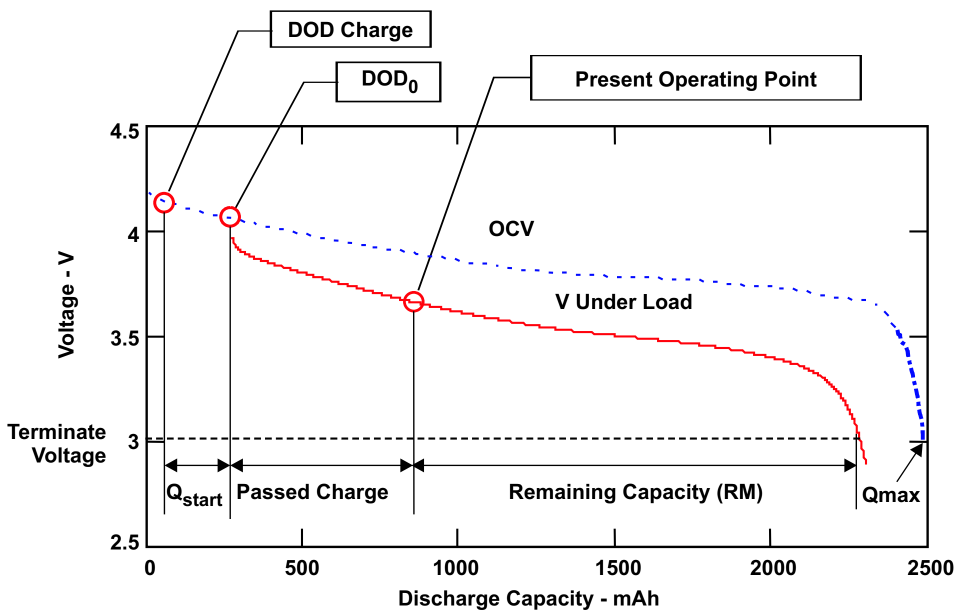


Figure 4. OCV Characteristics (Dotted Curve) and Battery Discharge Curve Under Load (Solid Curve)

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/sec) before and after charge or discharge activity and when the passed charge is more than 37% of battery design capacity, using Equation 2:

$$\text{SOC1} = \frac{\text{Q1}}{\text{Qmax}},\ \text{SOC2} = \frac{\text{Q2}}{\text{Qmax}} \tag{2}$$

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 each 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.

2.3 Gas Gauge Hardware

2.3.1 bq29312A Analog Front-End Protector

The bq29312A AFE serves an important role for the bq20z80 2-, 3-, or 4-cell lithium-ion battery pack gas gauge chipset solution. The bq29312A powers the bq20z80 directly from its 3.3-V, 25-mA low-dropout regulator (LDO), which is powered by either the battery voltage or the pack+ voltage. The AFE also provides all the high-voltage interface needs (the battery cell voltage levels need to be down-converted to meet the input range requirement of bq20z80 ADC) and current protection features. The AFE offers an I^2C-compatible interface to allow the bq20z80 to have access to the battery information and to configure the AFE's protection features. Other features of the AFE include cell balance control, thermistors drive circuit, precharge function, etc. Figure 5 presents a functional block diagram of the bq29312A AFE.

The AFE can be configured to translate each of the series cell voltages or the pack voltage into ground-referenced voltage, which can be measured by the bq20z80 gas gauge IC. The allowable AFE input range for an individual cell is 0 V to 4.5 V. Because voltage measurement accuracy is crucial for minimizing battery capacity estimate errors, the bq29312A AFE provides means for the bq20z80 to measure its voltage monitor amplifier offset and gain errors, leading to accurate gas gauge calibration.

In many situations, the state-of-charge (SOC) of the individual cells may differ from each other in a multicell battery pack, causing cell imbalance and voltage difference between cells. The bq29312A AFE incorporates a bypass path for each of the series element. These bypass paths can be used to reduce the charging current into any cell and thus allow for an opportunity to balance the SOC of the cells during charging. The bq20z80 enables and disables these paths as needed through the I^2C bus.

The bq29312A is also responsible for overload and short-circuit detection and protection of the pass FETs (i.e., charge and discharge FETs), cells, and any other inline components from excessive current conditions. The overload detection is used to detect excessive currents in the discharge direction, whereas the short-circuit detection is used to detect excessive current in either the charge or discharge direction. Threshold and delay time of overload and short-circuit can be programmed by bq20z80. When an overload or short-circuit is detected and a programmed delay time has expired, the FETs are turned off and the details of the condition are reported in the STATUS (b0:b2) register of bq29312A. Next, the XALERT output is triggered, signaling the bq20z80 to investigate the failure.

Another feature of the AFE is the precharging function. In some cases, the battery that needs to be charged is deeply depleted. When the CHG-FET is turned on, the voltage at the pack pin of bq29312A is as low as the battery voltage, which can be too low for the AFE to operate. The bq29312A provides three precharging/0-V charging options to remedy this problem.

2.3.2 How the bq20z80 and bq29312A Operate Together

The bq20z80 is the master of this chipset because it implements the entire Impedance Track™ algorithm. The bq29312A is configured by the bq20z80 for how it should respond to handle gas-gauging situations. These include when and which cell voltage information it needs to provide to the gas gauge IC, and what overload and short-circuit threshold and delay value should be used.

On the other hand, the bq20z80 requires the bq29312A to create a full solution for 2-, 3- or 4-series-cell Li-Ion battery packs. The bq20z80 cannot operate without the AFE. As shown in Figure 1, the bq20z80 relies on the AFE to provide scaled cell/pack voltage information to perform gas gauging and voltage/current protection functions. The bq20z80 can only access the charge and discharge FETs by sending control commands to the AFE. The bq20z80 has two tiers of charge/discharge overcurrent protection settings, and the AFE provides a third level of discharge overcurrent protection. In case of short-circuit condition, which does not need more than a brief amount of time to damage the circuit, the gas gauge chipset entirely depends on the AFE to autonomously shut off the FETs before such damage occurs.

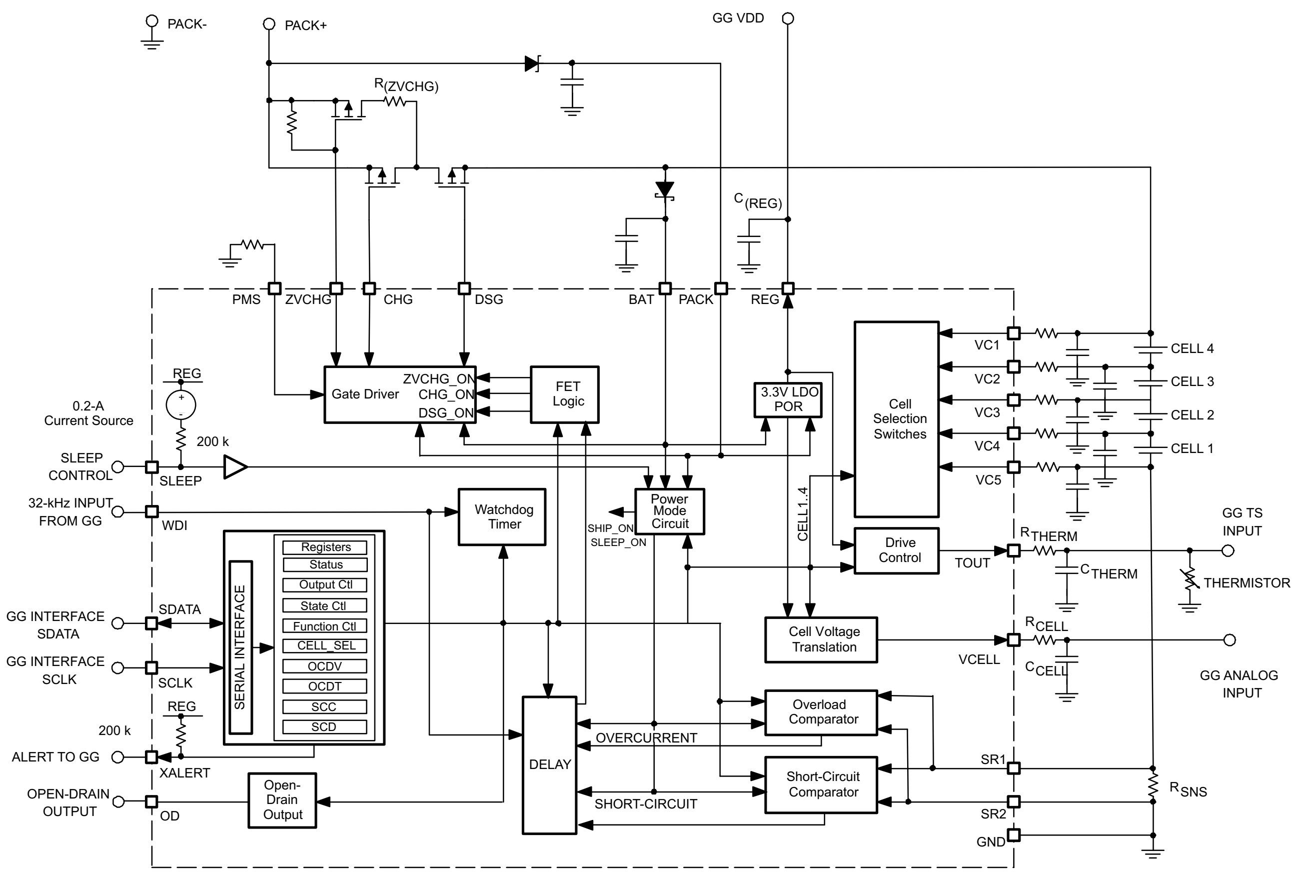


Figure 5. bq29312A Functional Block Diagram

2.3.3 The bq2941x 2nd-Level Overvoltage Protector

Although the bq20z80 and its associated AFE provide overvoltage protection, the sampled nature of the voltage monitoring limits the response time of this protection system. Most applications require a fast-response, real-time, independent overvoltage monitor operating with the bq20z80 and the AFE. Texas

Instruments offers the bq2941x 2nd-level protector IC for this purpose. The bq2941x monitors individual cell voltages independently of the gas gauge and AFE and provides a logic level output which toggles if any of the cells reaches a hard-coded overvoltage limit. The response time of the IC is determined by the value of an external delay capacitor. In a typical application, the output of the bq2941x would be tied to a heater fuse or other fail-safe protection device.

2.4 bq20z80EVM-001 Evaluation Module

The bq20z80EVM-001 evaluation module (EVM) is a complete evaluation system for the bq20z80/bq29312A/bq29412 battery pack electronics system. The EVM includes:

1. One bq20z80/bq29312A/bq29412 circuit module
2. A current sense resistor
3. Two thermistors
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 bq20z80 IC, one bq29312A IC, one bq29412 IC, and all other onboard components necessary to monitor and predict capacity, perform cell balancing, monitor critical parameters, protect the cells from overcharge, overdischarge, short-circuit, and overload in 2-, 3-, or 4-series-cell Li-ion or Li-polymer battery packs. The circuit module connects directly across the cells in a battery. With the EV2300 interface board and software, the user can read the bq20z80 data registers, program the chipset for different pack configurations, log cycling data for further evaluation, and evaluate the overall functionality of the bq20z80/bq29312A/bq29412 solution under different charge and discharge conditions.

2.5 bqEVSW Software for Use With the bq20z80

The bqEVSW is a Windows™-based evaluation software program provided by TI for functional evaluation of the bq20z80/bq29312A/bq2941x chipset. The bqEVSW provides the standard Smart Battery System (SBS) data commands as well as extended SBS commands. 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 SBS interface. The users may also toggle between SBS, Data flash, Calibration, and Pro screens for a variety of information about the battery pack and the chipset settings. The bqEVSW can also be used to program or update the firmware of the bq20z80 and for battery cycle data logging. See the bq20z80EVM user's guide and application reports for more information.

3 Next Steps

3.1 Developing a PCB for the bq20z80 and bq29312A Chipset

Using the 3-cell reference design schematic in the Appendix as a guide, a battery pack schematic should be designed to meet the individual requirements. Start with the number of cells. Note that in this schematic, pins VC1 and VC2 are connected on both the bq29312A and the bq29412. For packs with 2-series cells, connect VC1, VC2, and VC3 of each device together and remove the filter components R8, C7, R28, and C23. For a 4-cell design, follow the pattern of the 3-cell schematic but add an additional RC network at the VC1 input of both ICs.

Next, the current-sense resistor should be selected. As a general guideline, 20 mΩ is appropriate for a single (1P) string of 18650 cells, whereas 10 mΩ is recommended for a 2P pack. See the bq29312A data-sheet tables to ensure that the desired short-circuit and over-current protection levels fall within the available range for the selected sense resistor.

The use of a chemical fuse is recommended. Using information from the fuse data sheet, ensure that the FET used to ignite the fuse has a low enough on-resistance to succeed in opening the fault. Also, note that the gate of Q3 (see the reference design schematic in the Appendix) is driven by a 3.3-V output port from the bq20z80 in series with a Schottky diode. Ensure that the selected FET turns on adequately to provide the required ignition current. The output voltage of the bq29412 is around 6 V, providing an adequate 3 V to the gate of Q3.

The bq29312A is flexible with regard to the precharge function. The schematic in the Appendix uses the *Common FET* mode for precharge, where the Charge FET is turned on at initialization allowing for precharge current to flow. Two other precharge modes are also supported, but require the use of a dedicated precharge FET. The bq29312A data sheet (SLUS629) contains detailed theory of operation for each mode

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 bq20z80 need special attention. Most important are the two, power-supply decoupling capacitors C10 and C11 and the oscillator resistor R13. Each of these must be close to the gas gauge device and have low-resistance / low-inductance connections that do not form large loops. C10 should be placed between pins 8 and 11. C11 should be located between pins 31 and 29. The trace from R13 to U2-34 must not include return currents from other components. Also, C29 should be close to U2. Components of lesser priority but still a concern are the PLL filter components R14, C14, and C15 and the master reset network C4, R9. These should all be placed in the general vicinity of the IC. Over on the bq29312A, C8, C18, and C24 should be placed as close to U3 as practically possible, with the loop area minimized.

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. On the reference design schematic in the Appendix, two separate symbols are used for low-level analog and low-level digital grounds. These should be kept separate, only joining together at the sense resistor as shown. The Pack– terminal (also known as ESD ground) is the suggested return point for C19, SW1, and the D3 network. For additional information, see the TI application report *Avoiding ESD and EMI Problems in bq20zxx Battery Pack Electronics* (SLUA368).

3.2 Solution Development Process

Browsing the data flash screens of the bq20z80 evaluation software can be a challenging experience. Approximately 300 individual settings are possible. However, the default value for most of them can be easily used. The first step is to set up the data flash values for the number of cells and the coulomb capacity for a specific application. This simple process is described in detail in the application report *bq20z80 EVM Data Flash Settings for Number of Serial Cells and Pack Capacity* (SLVA208).

With different numbers of cells, several voltage settings must change. Application report SLVA208 presents the suggested default settings for Pack Over Voltage, Pack Under Voltage, Safety Over Voltage, Charging Voltage, Design Voltage, Cell Configuration, Flash Update OK Voltage, Shutdown Voltage, Charger Present Voltage, and Charge Terminate Voltage.

With different types of cells and number of parallel cells, capacity settings are different. Suggested values are presented for Qmax Cells, Qmax Pack, Design Capacity, and Design Energy in the same application report (SLVA208).

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 configuration registers A and B. Use the data sheet to review each configuration bit in these registers and configure them for a specific application. Note that if you use the default of 0 for the NR bit in Configuration Register B, then a System_Present signal needs to be implemented on the pack connector. See the EVM user's guide (SLUU205) schematic for implementation details.

3.3 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. Although the individual packs will contain cells with varying impedances, that is quickly corrected during normal use as impedance is constantly measured and updated by the bq20z80 gas gauge.

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.
4. Perform any desired protection tests.
5. Connect the cells.
6. Initiate the Impedance Track™ algorithm.
7. Seal the pack.

The TI application report *Data Flash Programming/Calibrating the bq20z80 Gas Gauges* (SLUA355) discusses the first three steps in detail. TI application report *Pack Assembly and the bq20z80* (SLUA335) discusses step 5 in detail. Description of steps 6 and 7 can be found in the bq20z80 data sheet (SLUS681). 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.

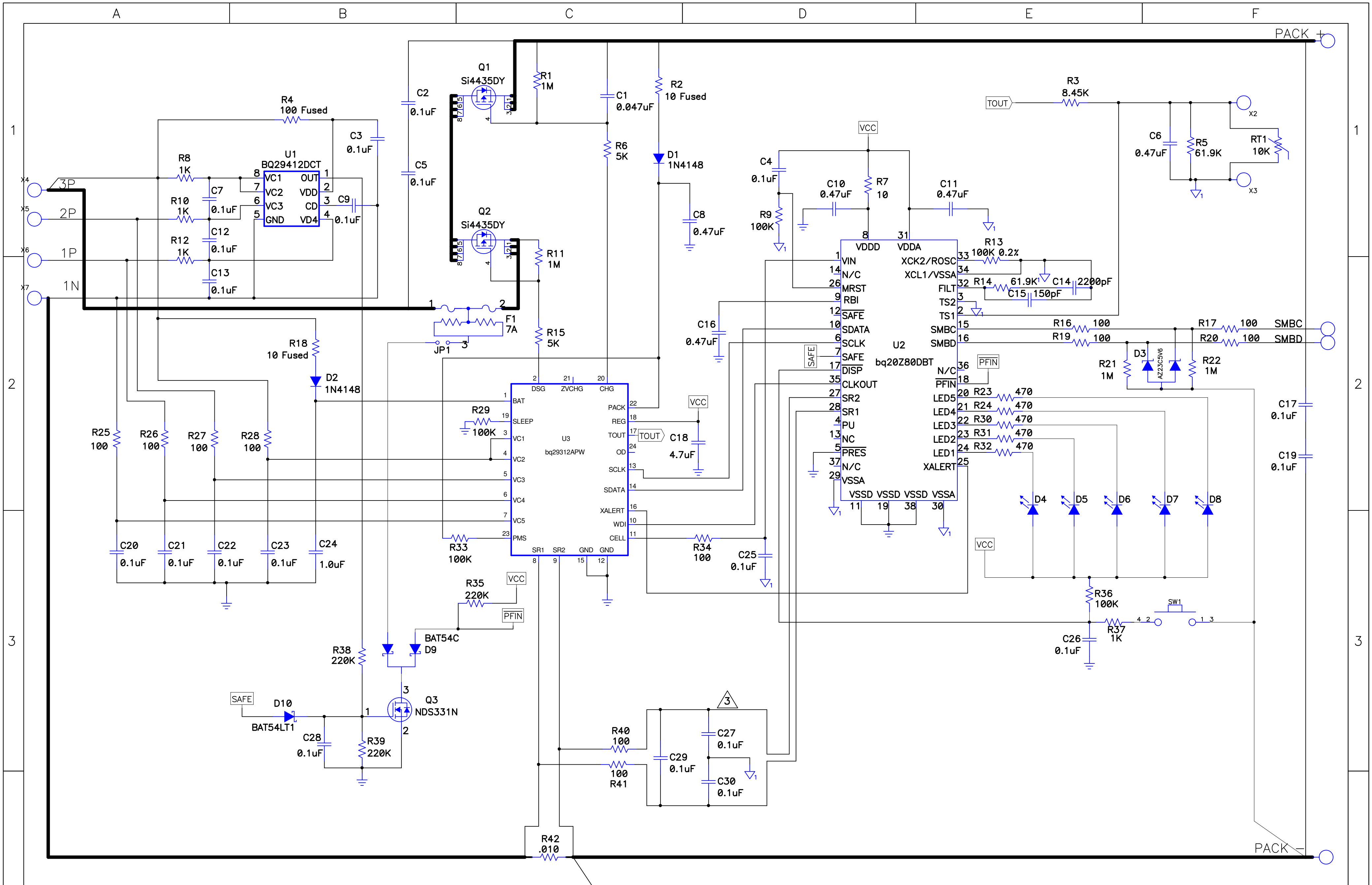
For additional application reports covering various aspect of bq20z80 Impedance Track solution, see the Texas Instruments bq20z80 online product folder.

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 2)
- AFE: Analog front-end, in this document, this refers to the bq29312A

Appendix A Reference Design Schematic

The reference design schematic is affixed to this page.



3 Place parts in a symmetric pattern and route traces as a differential pair from the Sense Resistor to the SR1 and SR2 inputs of the Gas Gauge. R40 and R41 should connect to the sense resistor through traces NOT the ground plane. The length of the route and the actual path (from the sense resistor to the SR1/2 inputs) should be as close to the same as possible–– same number of turns and vias. These 5 components should be located as close to U3 as possible

2 C10 must be very close to IC, connecting to pins 8 and 11. C11 is similar, connecting to pins 31 and 30.

1 Connect Analog and Digital Ground at a single point as close to the ground node of the Sense Resistor as possible

Texas Instruments

Title	bq20z80 3–Cell NR Ref Dsg		
Size C	Number {Drawing Number}		Rev
Date Sun Dec 11, 2005		Drawn by Williams	
Filename bq20z80 3CellNR.sch		Sheet 1 of 1	

IMPORTANT NOTICE

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

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265