Application Note

Design Considerations of Current Sensing With BQ769x2 Family for Battery Management System

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ABSTRACT

High-current sensing accuracy is essential in battery management system (BMS) which can benefit the accuracy of battery state of charge (SoC) and improve the reliability of entire system. This article shares the design considerations of current sensing and shows how to realize high-precision and high-reliable current measurement with a battery monitor device BQ76972.

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1 Introduction

Battery-powered products are becoming more and more popular, such as energy storage, vacuum cleaners, power tools, e-bikes and e-scooters. Because of the weight limit and longer endurance needs, the battery cell chemistry is shifting from Lead-acid to Li-ion, Li-polymer, or Li-ion phosphate (LiFePO4) types. Good measurement accuracy is always required, especially the cell voltage, pack current, and cell temperature. Precision is necessary for accurate protections and battery pack state of charge (SoC) calculations. This is especially true for LiFePO4 battery pack applications because of the flat voltage.

This article takes a deeper look at current sensing for lithium-based battery, including the error calculation and proper system configurations. The high-accuracy battery monitors and protectors for battery packs, BQ76972, which is designed especially for applications using lithium-ion, lithium-polymer or lithium-phosphate cells, are used for an example.

2 BQ769x2 Coulomb Counter Current Error Calculation

The current measurement error consists of the BQ76972 coulomb counter error and the error from the sense resistor. This article shows the calculation of the worst-case BQ769x2 coulomb counter error in whole range of current measurement can be calculated by adding up the individual worst-case offset, gain, DNL and INL errors. The effect of noise is not considered a measurement result.

The specifications of the coulomb counter can be found in *BQ76972 3-Series to 16-Series High Accuracy Battery Monitor and Protector for Li-Ion, Li-Polymer, and LiFePO4 Battery Packs* data sheet, shown in Table 2-1.

Table 2-1. BQ76972 Coulomb Counter Specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{(CC\_IN)}$	Input voltage range for measurements	$V_{SRP} – V_{SRN}$	–0.2		0.2	V
$V_{(CC\_IN)}$	Input voltage range for measurements	V_{SRP}, V_{SRN}	–0.2		0.2	V
$V_{(CC\_IN\_EXTENDED)}$	Extended input voltage range for measurements	$V_{SRP} – V_{SRN}$, swept over range to determine where measurements flatten out	–1		1	V
$B_{(CC\_INL)}$	Integral nonlinearity	16-bit, best fit over input voltage range, using 0V common mode voltage.		±5.2	±22.3	LSB
$B_{(CC\_DNL)}$	Differential nonlinearity	16-bit, no missing codes		±0.1		LSB
$V_{(CC\_OFF)}$	Offset error	16-bit, uncalibrated	–1		1	LSB
$V_{(CC\_OFF\_DRIFT)}$	Offset error drift	16-bit, post-calibration	–0.03		0.03	LSB/°C
$B_{(CC\_GAIN)}$	Gain	16-bit, over designed for input voltage range	130845	131454	132335	LSB/V
$R_{(CC\_IN)}$	Effective input resistance			2		MΩ

Typically, considering the thermal performance, the ±0.2V input range is not fully utilized. For example, to sense the continuous 100A discharging current, a sense resistance of less than 0.5mohm is selected for less than 5W power loss. The worst-case error for 50mV input range is calculated from the individual error are specified in terms of ADC resolution as LSB. The total error can be calculated by the following equations:

$$Error_{total} = Error_{Offset} + Error_{Gain} + Error_{DNL} + Error_{INL} \tag{1}$$

The temperature drift also need to be considered when calculating the worst-case offset error. This calculation assumes a biggest temperature change, from 25℃ to -40℃. The worst-case offset error can be calculated by:

$$Error_{Offset} = 1 + 0.03 \times (25 - (-40)) = 2.95 \quad LSB \tag{2}$$

The gain error is the difference between the typical gain value and the worst-case gain factor over a particular gain range. Using the 50mV input range, the worst case gain error can be calculated by:

$$Error_{Gain} = 0.05 \times (132335 - 131454) = 44.05 \quad LSB \tag{3}$$

The data sheet only specs the typical value of 0.1 LSB. This calculation assumes 1 LSB worst-case DNL error. The worst-case INL error only happens around 200mV input voltage. For 50mV input range, 5.2 LSB is used for calculation.

The total error can be calculated by the following equations:

$$Error_{total} = Error_{Offset} + Error_{Gain} + Error_{DNL} + Error_{INL} = 53.2 \quad LSB \tag{4}$$

Corresponding to a voltage, 53.2 LSB is:

$$V_{error\_total} = 53.2 \times 7.6\mu V = 0.404mV \tag{5}$$

Finally, the coulomb counter has worst-case 0.81% error in percentage at 50mV input range. This calculation assume all the worst-case error factors are simply added together without any digital filters and calibration. In real applications, this error is unlikely to be as large.

The offset error and gain error can be calibrated out by following the *calibration* section of the *BQ769x2 Calibration and OTP Programming Guide*. Realistically, after calibration, the total voltage error becomes:

$$V_{error\_total} = (1.95 + 1 + 5.2) \times 7.6\mu V = 0.062mV \tag{6}$$

Which only causes 0.12% error in percentage at 50mV input range without any digital filter.

3 Sense Resistor Design Considerations

In battery management system, shunt resistor is the common choice to measure the charging and discharging current due to the high accuracy, low cost and simplicity. The error of shunt resistor can dominant the current measurement error without proper design and calibration.

The tolerance and temperature coefficient of resistance are key specs that represent the accuracy of resistor. A calibration can be performed at room temperature to remove the tolerance errors from the shunt but the temp drift errors are difficult to be calibrated out because this changes with temperature. Especially, for BMS application, some low voltage battery pack are natural cooling, meaning the small temperature coefficient can benefit the current sensing accuracy.

The thermal EMF also affects the accuracy according to the Seebeck effect. The thermal EMF can potentially bring dozens to hundreds of microvolts which is not acceptable when the full-scale range is very small. So, minimizing the temperature rise is important when choosing a shunt resistor.

To minimize the influence of temperature rise, a high power rating and small temperature coefficient shunt resistor is designed to select. Also, the PCB layout need to be carefully designed for better thermal performance and the current direction not affecting the shunt temperature coefficient.

Another approach need to be adopted is Kelvin connection,shown in Figure 3-1. Two separate wires are used to measure the differential voltage. This configuration can eliminate errors caused by wiring resistance and shunt copper electrode temp drift.

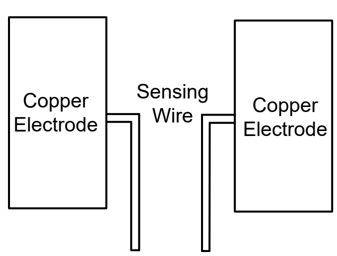

Figure 3-1. Kelvin Connection

4 Current Sensing Circuit Diagnostic

The shunt is directly connected to BQ76972 SRP and SRN pins with a filtering network. The BQ76972 can not distinguish the open-wire and short circuit event of the current sensing circuit. For functional safety consideration, a simple external circuit is required to diagnose these abnormal events and the working condition of BQ76972 current sensing function,shown in Figure 4-1.

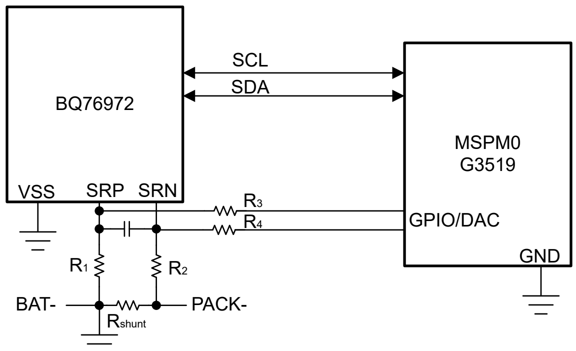

Figure 4-1. Current Sensing Circuit Diagnostic

Series resistors R_3 and R_4 are added between BQ76972 SRN/SRP pins and microcontroller GPIOs or DAC. R_3 and R_4 form an resistor divider between the filter resistors R_1 and R_2, and ground. In normal operation, the MCU pins are in high impedance state which has small enough leakage current so that the normal current sensing accuracy is not affected. In the diagnostic operation, MCU can drive pins high and then make a divided voltage between SRP and SRN, so by reading the BQ76972 current measurement, MCU can distinguish the SRP/SRN pins are not shorted together or to VSS. Also, this approach can be used to diagnose the BQ76972 SCD, OCC and OCD functions. The series resistance can be sized to trigger the current related protections alert or fault.

The effect of MCU pin leakage current can be ignored because the current measurement is differential. If only R3 or R4 is added, the leakage current of the MCU pins need be as low as enough in case of affecting the current sensing accuracy. The resolution of columb counter is 7.6uV so that the leakage current is recommended to be lower than 70nA to make sure the voltage drop on R1 or R2 can not cause LSB error.

5 Accumulated Charge Integration of Coulomb Counter

BQ769x2 coulomb counter offers multiple current values for readout over the serial communications interface, including two using separate hardware digital filters, CC1 and CC2, as well as a firmware filter CC3.

To calculate the SOC, the CC1 filter can be used to generate a 16-bit current measurement , with one output generated every 250ms when the device is operating in NORMAL mode. CC1 current data is available from the *0x0075 DASTATUS5()* subcommand.

The integrated passed charge is available as a 64-bit value from the *0x0076 DASTATUS6()* subcommand, which includes the upper 32-bits of accumulated charge in units of userAh, the lower 32-bits of accumulated charge as the fractional portion, and a 32-bit accumulated time over which the charge has been integrated in units of seconds. The accumulated charge integration and timer can be reset using the *0x0082 RESET_PASSQ()* subcommand. If the device undergoes a partial reset or is reset using the RST_SHUT pin, the *0x0082 RESET_PASSQ()* needs to be sent to make sure the charge accumulation is properly initialized.

The accumulated charge is equal to the direct sum of the integer and fractional portions. For example, 0xFFFFFFFD is the integer portion of the measurement, which in 2s complement format, the data represents -3 in decimal. And, 0x7FFFFFFF is the readout fractional portion, which is always a positive number between zero and 2^{32} , the data represents 0.5 in decimal. The sum is measuring -2.5 mAh of accumulated charge.

The LSB size of coulomb counter is 7.6uV but the current less than LSB/R_{sense} can also be detected. The Coulomb counter was designed so that even if the system has a lower current, the internal circuitry still retains quantization from one sample to another. BQ769x2 is capable of sensing currents that give a sense resistor voltage far below 7.6uV and accumulating the charge.

Figure 5-1 gives the small discharge currents measurements test results across the 0.3mohm sense resistor. The currents below LSB/R_{sense} - 25mA can also be accumulated. BQ769x2 has 3-4 uV offset voltage under room temperature so that positive accumulated charge can be observed when applying zero diacharging current. The accumulated charge becomes zero when the discharging current becomes around 1.5mA.

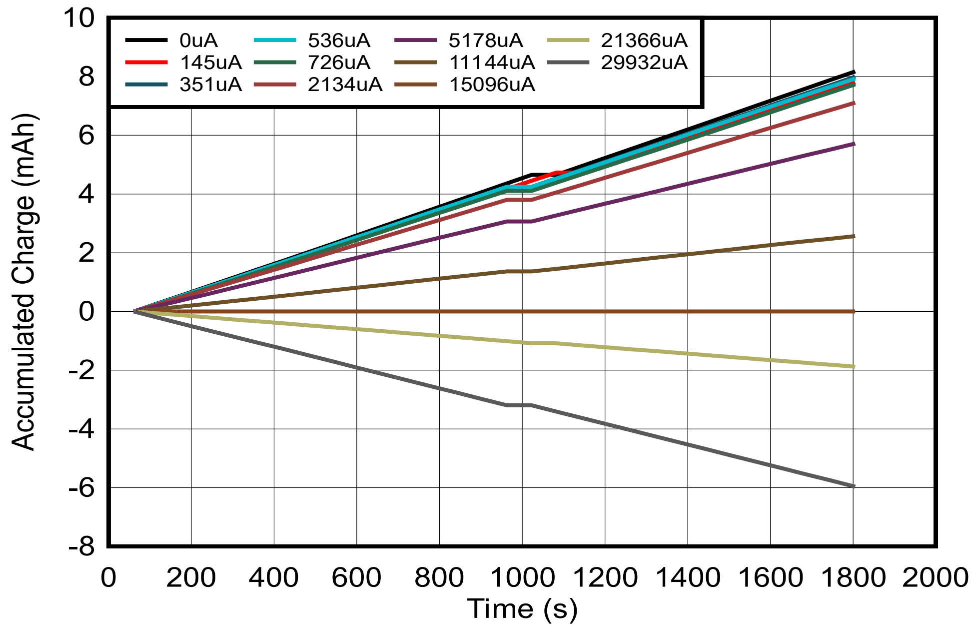

Figure 5-1. Accumulated Charge Results

Meanwhile, BQ769x2 can also support synchronized voltage and current measurement for SOC calculation. The *0x0071 DASTATUS1()*, *0x0072 DASTATUS2()*, *0x0073 DASTATUS3()*, and *0x0074 DASTATUS4()* subcommands provide raw ADC counts in 32-bit format of the cell voltage measurements, as well as the synchronized current measurements taken simultaneously with each cell voltage measurement. The data is generated in 24-bit format by the data converter but provided in 32-bit format. The 24-bit data is contained in the lower 3 bytes of the 32-bit data, and is sign-extended to create the upper byte. With the synchronized voltage and current measurement, user can filter and process the data with custom filtering algorithm, without the quantization to 16-bit when using CC1 current.

6 System Implementation

The Calculation shows the worst-case error of current measurement error, a physical board is also required to evaluate the real error. The BQ769x2 ground is recommended connected to the battery negative terminal. The recommended SRN and SRP pins voltage is -0.2V to 0.75V, so the trace between battery negative terminal and shunt resistor is recommended as short as enough. Otherwise, the pins voltage can exceed the recommended range during large transient current.

Before doing the accuracy test, current calibration needs to be performed to calibrate out the shunt tolerance error, coulomb counter offset and gain error. The board offset can be calibrated using the guidance of the *calibration* section of the *BQ769x2 Calibration and OTP Programming Guide*. Then gain error and shunt tolerance error can be calibrated with fix current and also following the guidance of this application note.

MSPM0 software development kit (SDK) provides the calibration demo code based on reference design *High-Accuracy Battery Management Unit Reference Design for 48–1500V Energy Storage System*. After installing the MSPM0 SDK and CCS, find the source code from MSPM0 SDK at:

```
<install_location>\ti<SDK_version>\examples\nortos\LP_MSPM0G3519\demos\bq769x2_TIDA010247
```

Figure 6-1 shows the TIDA-010247 pack current accuracy data under room temperature. CC3 current is used for the measurement with default 80 CC3 samples. The maximum current error is below 20mA when the discharging current is below 5A and 0.2% when the discharging current is above 5A.

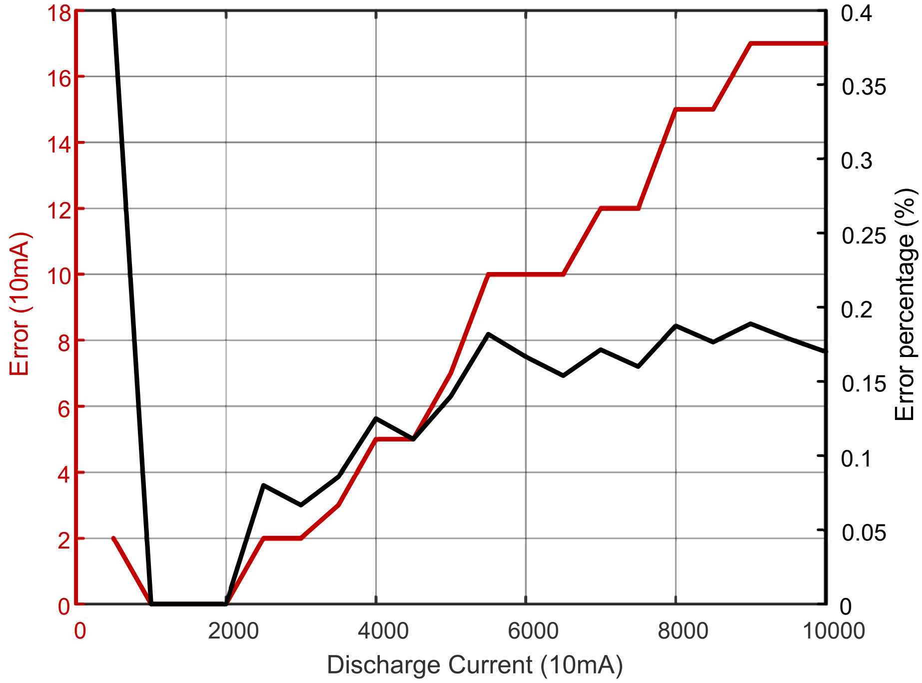

Figure 6-1. Pack Current Accuracy

7 Summary

This article provides the design considerations of BQ769x2 current sensing. The current accuracy can be calculated before starting the design and improved following the recommendations in this article. If the diagnostic is required for current sensing circuit, a diagnostic proposal is also recommended. This article also shows the example to read the accumulated charge integration that can be used for SoC calculation or other decision purposes.

8 References

- Texas Instruments, *[FAQ] BQ76952: How can I calculate the coulomb counter current error in the BQ769x2?*
- Texas Instruments, *BQ769x2 Calibration and OTP Programming Guide*
- Texas Instruments, *BQ769x2 Technical Reference Manual*

9 Revision History

Changes from Revision * (June 2025) to Revision A (August 2025) **Page**

- Updated the numbering format for tables, figures, and cross-references throughout the document................. 1
- Changed *mA* to *10mA* in the *Pack Current Accuracy* image..5

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