Application Note

SWCA095A–January 2011–Revised July 2011

TWL6030 Gas Gauging Basics

ABSTRACT

The new generation of wireless devices, PDAs, internet audio players, and other appliances demand accurate battery capacity monitoring.

The gas gauge, also called current gauge, uses the coulomb counting method to provide the user with accurate and reliable information about the state of charge of the battery.

This application note provides the basic information for building an accurate gas-gauging feature using the TWL6030 gas gauge.

Contents

1 Acronyms, Abbreviations, and Definitions

ACRONYM	DEFINITION
A	Ampere
ADC	Analog-to-digital converter
As	Ampere second
IACC	Accumulated current
IAVG	Average current
CC	Coulomb counter
Δt	Change in time
FS	Input clock frequency
NTC	Negative temperature coefficient
RM0	Remaining capacity at time 0
RM1	Remaining capacity at time 1
R_S	External sense resistor
s	Second
SW	Software
TTE@RATE	Time to empty at the average current consumption
V_{FS}	Usable input voltage range

2 System Components

Measuring battery charge and discharge current and reporting state of charge to an end user requires several components:

- TWL6030 gas gauge: Contains highly-accurate coulomb counters, communication interfaces, and other functions
- 10-mΩ current sense resistor (R_S): Connected to the negative side of the battery and provides a means for the battery monitor to measure the current flowing into or out of the battery. The battery monitor senses the voltage across this resistor.
- Processor: Required to provide intelligence to the battery monitoring setup, the processor handles all communication with the gas gauge and performs calculations with data read from the battery monitor to determine the state of charge of the battery.

3 What Is Coulomb Counting?

Coulomb counting measures the charge input to and subsequently removed from the battery. To accomplish this, first the charge and discharge current is measured across a low-value series sense resistor between the negative terminal of the battery and the battery pack ground contact. The voltage drop across the sense resistor is then integrated over time to provide an accurate representation of the state of the charge of the battery.

Battery monitor devices use an ADC CC to measure the voltage drop across the sense resistor (see Figure 1). The output of the CC is then converted to an accumulated count in CC_ACCUM [31:0] bits (FG_REG_04, FG_REG_05, FG_REG_06 and FG_REG_07 registers) to represent the charge flow into and out of the battery.

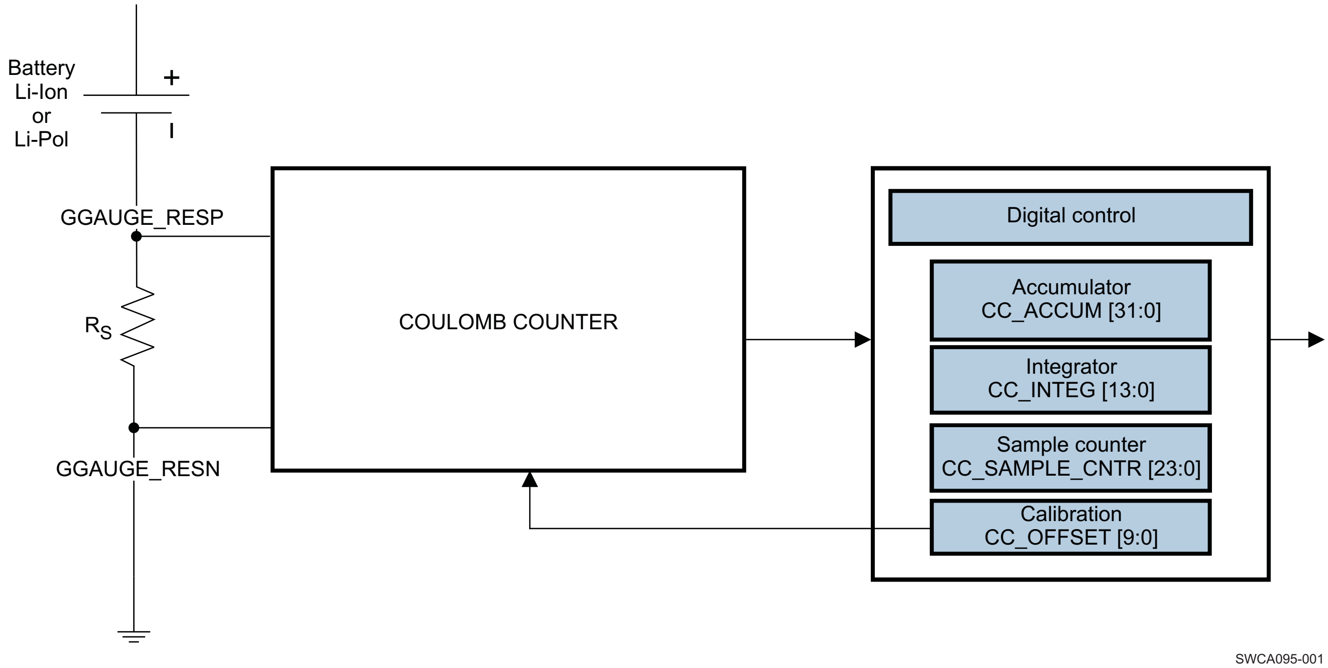

Figure 1. Battery Monitoring Using a Coulomb Counter

The gas gauge module works continuously, which means that the new measurement starts immediately after the previous result becomes available. The averaging and the compensation are accomplished by the TWL6030 digital module but also requires software controls. To enable (or disable) the gas gauge, software must write 1 in FGS (or FGR) bits in the TOGGLE1 register. The gas gauge operation status is available in the FG_EN bit of the PWDNSTATUS1 register.

The CC is connected so that a positive voltage is developed across the sense resistor when current is flowing into the battery (that is, charge). Conversely, a negative voltage is developed across the sense resistor and, thus, the CC inputs when current is flowing out of the battery (that is, discharging). Charge and discharge activities are accumulated in the CC_ACCUM [31:0] bits on 32-bit signed accumulator value 2s complement format; battery charging gives a positive result (sign bit = 0) and battery discharging gives a negative result (sign bit = 1).

The sample counter value (CC_SAMPLE_CNTR [23:0]) is also stored in the following registers: FG_REG_01, FG_REG_02, and FG_REG_03. The CC_SAMPLE_CNTR runs while the battery charges and also runs while the battery discharges.

4 Sense Resistor Selection

An external sense resistor (R_S) of 10 mΩ is used to sense the current flowing into or from the battery. This resistor must be connected between these two pads:

- GGAUGE_RESN: Sense resistor input signal negative (ground side)
- GGAUGE_RESP: Sense resistor input signal positive (battery negative side)

GGAUGE_RESN and GGAUGE_RESP balls must be routed differentially up to the sense resistor. The parasitic resistances between TWL6030 balls and the sense resistance must be minimized.

Accuracy of the resistance has a direct impact on the accuracy of the gas gauge.

5 Autocalibration

Setting the CC_CAL_EN bit high starts the autocalibration procedure. During the calibration, the gas gauge performs eight measurements so that the inputs for the ADC are short-circuited. The result indicates the offset error of the gas gauge and is stored in the CC_OFFSET [9:0] register bits of the FG_REG_08 and FG_REG_09 registers. The completion of the measurement procedure is indicated by the CC_AUTOCAL interrupt. Software must read the offset error result and use it to compensate the actual measurement results. The CC_CAL_EN bit self clears when the calibration is complete. The gas gauge must be enabled while calibration is running. Because the temperature variation changes the offset error, the recalibration is preferred during operation.

6 Dithering

Setting the FGDITHS bit in the TOGGLE1 register to 1 to enable dithering in the ADC is recommended. This prevents idle tones from being generated with a DC input value. This bit is not affected by the CC_AUTOCLEAR bit. To disable dithering, the FGDITHR bit in the TOGGLE1 register must be set to 1. The dithering feature status is available in the FGDITH_EN bit of the PWDNSTATUS1 register.

7 Integration Period

The integration period of the CC is programmable from 3.9 to 250 ms using the CC_ACTIVE_MODE [1:0] bits (see Table 1).

Table 1. Programming the CC Integration Period

CC_ACTIVE_MODE [1:0]	Integration Period (ms)
00	250 (default)
01	62.5
10	15.625
11	3.90625

Before changing the integration period, the CC_PAUSE bit must be set to 1. Setting the CC_AUTOCLEAR bit to 1 clears the CC_OFFSET [9:0], CC_SAMPLE_CNTR [23:0], and CC_ACCUM [31:0] registers. The CC_AUTOCLEAR register bit self-clears once the registers are reset.

Setting CC_PAUSE to 1 keeps the analog from updating the integrator, accumulator, and sample counter registers. The integrator continues to run. If an integration periods ends while CC_PAUSE is 1, the value that is normally written to these registers is lost because the next integration period starts automatically.

8 Programming Model

This section describes the main registers accessed to use the gas gauge.

1. To set the correct integration period, write the correct update rate in the CC_ACTIVE_MODE [1:0] bits of the FG_REG_00 register as follows:
   - 00 = 250-ms update rate.
   - 01 = 62.5-ms update rate.
   - 10 = 15.6-ms update rate.
   - 11 = 3.9-ms update rate.
2. To enable the gas gauge with dithering on, write 1 in the FGS and FGDITHS bits of the TOGGLE1 register.
3. Perform the calibration:
   (a) To start the calibration, write 1 in the CC_CAL_EN bit in FG_REG_00 register.
   (b) Wait until the CC_AUTOCAL interrupt is generated.
   (c) To stop the calibration, write 0 in the CC_CAL_EN bit of the FG_REG_00 register.
   (d) Read the offset in the CC_OFFSET [9:0] bits of the FG_REG_08 and FG_REG_09 registers.
   (e) Convert the 10-bit signed offset value 2s complement in decimal and store this value in CC_OFFSET.
4. To clear the CC_OFFSET [9:0], CC_SAMPLE_CNTR [23:0], and CC_ACCUM [31:0] bits, write 1 in the CC_AUTOCLEAR bit of the FG_REG_00 register.

5. To read the sample counter and accumulator results:
   (a) Write 1 in the CC_PAUSE bit of the FG_REG_00 register to inhibit analog updates to registers.
   (b) Read the CC_SAMPLE_CNTR [23:0] bits in the FG_REG_01/02/03 registers and store the decimal value as the CC_SAMPLE_CNTR0 value.
   (c) Read the CC_ACCUM [31:0] bits in the FG_REG_04/05/06/07 registers.
   (d) Convert the 24-bit unsigned sample counter value in decimal and store the result in CC_ACCUM0.
   (e) Write 0 in the CC_PAUSE bit of the FG_REG_00 register to allow analog updates to registers.
6. After Δt (t1 – t0), repeat step 5 to store CC_SAMPLE_CNTR1 and CC_ACCUM1.

CC_OFFSET, CC_SAMPLE_CNTR0, CC_ACCUM0, CC_SAMPLE_CNTR1, and CC_ACCUM1 are used hereafter to determine the charge and discharge time, the accumulated and average current, the remaining capacity, and the time to empty @ rate.

9 Calculating Charge and Discharge Time

The processor can calculate the change in time by reading CC_SAMPLE_CNTR at time 0, designated as CC_SAMPLE_CNTR0, and then reading them again some time later, designated as CC_SAMPLE_CNTR1. The change in time, in seconds:

$$\Delta t(s) = (CC\_SAMPLE\_CNTR1 - CC\_SAMPLE\_CNTR0)/(4 * N) \quad (1)$$

Where:

N = 1 for an integration period of 250 ms.

N = 4 for an integration period of 62.5 ms.

N = 16 for an integration period of 15.62 ms.

N = 64 for an integration period of 3.9 ms.

After Δt is calculated, the processor should store CC_SAMPLE_CNTR1 as CC_SAMPLE_CNTR0 for the next time period calculation.

The preceding discussion is meant to serve as a basis for the calculations to determine remaining capacity. The charge/discharge count registers and the change in time are two of the fundamental values necessary to calculate remaining capacity and time to empty.

10 Calculating Accumulated Current

Accumulated current calculates the absolute remaining capacity of the battery and requires knowledge of the capacity at some time. The battery design capacity is used typically when the battery goes through its first discharge from full. After that, a simple algorithm can be generated to learn the true battery capacity. This discussion assumes that the processor has communicated with the battery monitor and either stored initial values or performed maintenance to clear the CC_ACCUM and CC_SAMPLE_CNTR registers.

Either way, the initial readings are designated CC_ACCUM0 and CC_SAMPLE_CNTR0. The processor should read the CC_ACCUM and CC_SAMPLE_CNTR registers, which are referenced in the following equation as CC_ACCUM1 and CC_SAMPLE_CNTR1.

The accumulated current during the last time period:

$$IACC\ (As) = [CC\_ACCUM\ 1 - CC\_ACCUM\ 0 - [CC\_OFFSET * (CC\_SAMPLE\_CNTR1 - CC\_SAMPLE\_CNTR0)]] * V_{FS}/(R_S * F_S) \quad (2)$$

Where:

V_{FS} is the usable input voltage range.

R_S is the external sense resistor.

F_S is the input clock frequency based on the TWL6030 32K clock source (32.768 kHz).

11 Calculating Average Current

The processor does not communicate with the battery monitor on a continuous basis. The microcontroller spends most of its time controlling other system components. However, when the battery monitor is accessed, one of the values the processor microcontroller can calculate is average current during the last time period.

The average current during the last time period:

$$IAVG\ (A) = IACC/\Delta t \quad (3)$$

Where:

IACC is calculated from Equation 2 and Δt is calculated from Equation 1.

A negative IAVG indicates discharge and a positive IAVG indicates charge.

This value can be used to calculate the time to empty at the discharge rate calculated.

After the calculation for IAVG or IACC is complete, the processor must store CC_ACCUM1 to CC_ACCUM0 for the next time period.

12 Calculating the Remaining Capacity

Remaining capacity is the entire goal of gas gauging. This value can be manipulated in a number of ways to display for the end user. It can be presented as a percentage of total capacity, which is either the design value or the learned value, or used to calculate time to empty, which is detailed in Section 13, *Calculating the Time to Empty @ Rate*. The remaining capacity calculation is:

$$RM1\ (As) = RM0 + IACC \quad (4)$$

IACC is calculated from Equation 2 and RM0 is the last calculated remaining capacity.

After the calculating for remaining capacity, the processor must store RM1 to RM0 for the next time period.

13 Calculating the Time to Empty @ Rate

The basic assumption behind this calculation is that the user is interested in the time to empty at the average current consumption during some time period. This might require that IAVG, calculated in Equation 3, be calculated at a longer time period than IACC. More accurate average current results in a more accurate time-to-empty calculation. The time-to-empty at IAVG rate calculation is:

$$TTE@RATE\ (s) = RM1/IAVG \quad (5)$$

IAVG is calculated from Equation 3 and RM1 is the remaining capacity calculated in Equation 4.

14 Other Battery Parameters

Other battery parameters include the battery temperature and voltage.

The TWL6030 monitors the battery voltage through an ADC channel and can monitor the battery temperature through a second ADC channel using an NTC resistor. Both these parameters can be used in conjunction with the battery discharge characteristic data to create a more sophisticated capacity monitoring algorithm.

By measuring the battery voltage, the processor can signal the end user when the battery reaches its end of discharge voltage. This voltage, which varies from design to design and by cell type, is the absolute minimum at which the battery should be operated to maintain cell life.

15 Summary

This application note provides an overview of the components necessary for gas-gauging a battery with the TWL6030 battery monitor. A very simple system and understanding of some basic equations allow a basic gas-gauging application to be built.

This application note does not cover other steps required to create a more sophisticated gas-gauging algorithm, including capacity-learn cycles, charge-efficiency correction, self-discharge correction, and battery-temperature reporting, which are a function of the type of battery used. The proper handling of these topics results in a remaining capacity calculation that is extremely accurate across the system temperature and voltage range.

16 Revision History

The following table summarizes the TWL6030 Gas Gauging Basics versions.

Note: Numbering may vary from previous verisons.

Version	Literature Number	Date	Notes
*	SWCA095	April 2011	See [1]
A	SWCA095A	July 2011	See [2]

(1) TWL6030 Gas Gauging Basics Application Note, (SWCA095) - initial release.

(2) TWL6030 Gas Gauging Basics Application Note, (SWCA095A):

- Remove NDA statement

Appendix A Registers

The following registers are used to properly configure the gas gauge.

A.1 FG_REG_00 Register

CC_ACTIVE_MODE [1:0]	00 = 250-ms update rate 01 = 62.5-ms update rate 10 = 15.6-ms update rate 11 = 3.9-ms update rate
CC_AUTOCLEAR	Register bit self-clears on completion of clearing function 0 = no action 1 = Clears the values in the CC_OFFSETx, CC_SAMPLE_CNTRx, and CC_ACCUMx registers
CC_CAL_EN	0 = Calibration mode disabled 1 = Enables calibration sequence
CC_PAUSE	0 = Analog updates to registers allowed 1 = Analog updates to registers inhibited

A.2 FG_REG_01 Register

CC_SAMPLE_CNTR [7:0]	24-bit unsigned sample counter value

A.3 FG_REG_02 Register

CC_SAMPLE_CNTR [15:8]	24-bit unsigned sample counter value

A.4 FG_REG_03 Register

CC_SAMPLE_CNTR [23:16]	24-bit unsigned sample counter value

A.5 FG_REG_04 Register

CC_ACCUM [7:0]	32-bit signed accumulator value 2s complement

A.6 FG_REG_05 Register

CC_ACCUM [15:9]	32-bit signed accumulator value 2s complement

A.7 FG_REG_06 Register

CC_ACCUM [23:16]	32-bit signed accumulator value 2s complement

A.8 FG_REG_07 Register

CC_ACCUM [31:24]	32-bit signed accumulator value 2s complement

NOTE: With a 14-bit measurement result and 18-bits number of samples, selecting the 250-ms integration period mode, the accumulator can store up to 18 hours with a 6A maximum current, which typically gives 108 Ah. Nevertheless, the maximum time is also limited by the 24 bits sample counter, which gives 48 days with a 250-ms integration period.

A.9 FG_REG_08 Register

CC_OFFSET [7:0]	10-bit signed offset value 2s complement

A.10 FG_REG_09 Register

CC_OFFSET [9:8]	10 bit signed offset value 2’s complement

A.11 FG_REG_10 Register

CC_INTEG [7:0]	14-bit signed integrator value 2s complement

A.12 FG_REG_11 Register

CC_INTEG [13:8]	14-bit signed integrator value 2s complement

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