



Using the STC3100 battery monitor for gas gauge applications

Introduction

Handheld devices such as mobile phones, music and video players, as well as portable navigation devices, tend to integrate ever more multimedia functions, all of which have different power needs. As a consequence, it has become difficult to manage the battery's state-of-charge (SoC) and predict the remaining operating time with no dedicated gas gauge support. The STC3100 is a new device that includes battery monitoring features (voltage, current and temperature) and a Coulomb counter to implement a gas gauge system in existing or future applications.

This application note is intended to assist product designers by taking advantage of using the STC3100 in one-cell Li-Ion battery handheld applications to implement the gas gauge function. The document provides:

- a brief description of the STC3100 device and typical applications,
- information on how to use the battery monitoring functions of the STC3100,
- a general flow chart of the tasks needed to implement a simple gas gauge system.

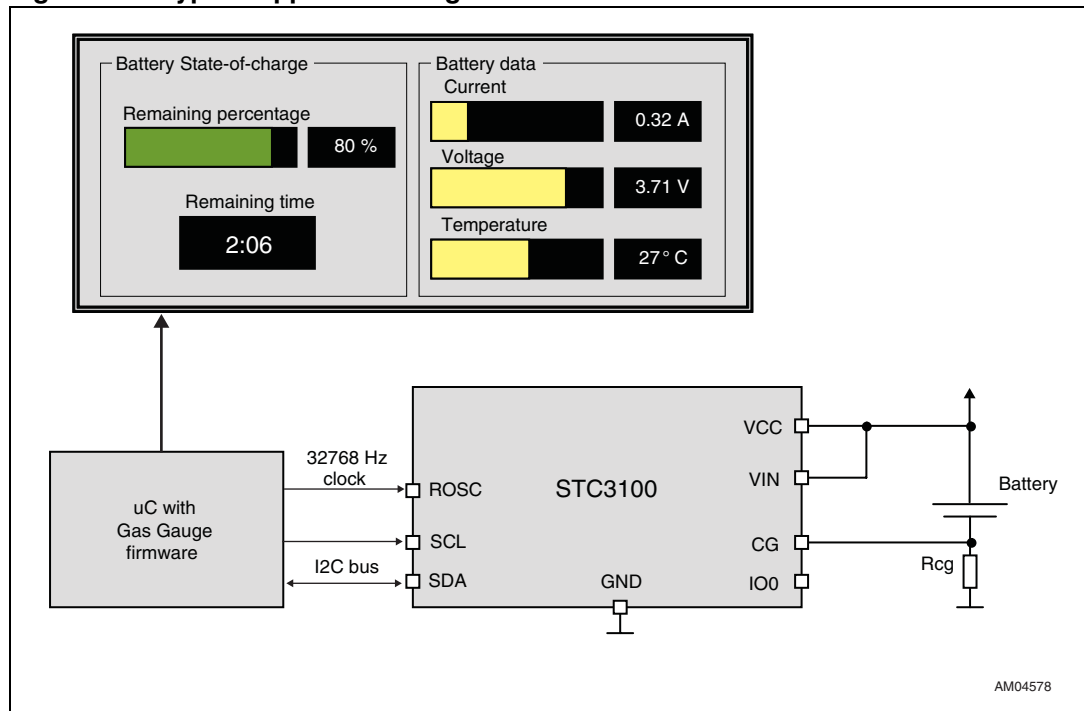
1 Using the STC3100

1.1 Brief description of the STC3100

The STC3100 battery monitoring function includes the measurement of the battery voltage and current, measurement of the IC’s die temperature and computation of the battery charge variation (Coulomb counter). An external sense resistor is used in series with the battery to adapt the current measurement to the application requirements.

Figure 1 shows a typical application using the STC3100.

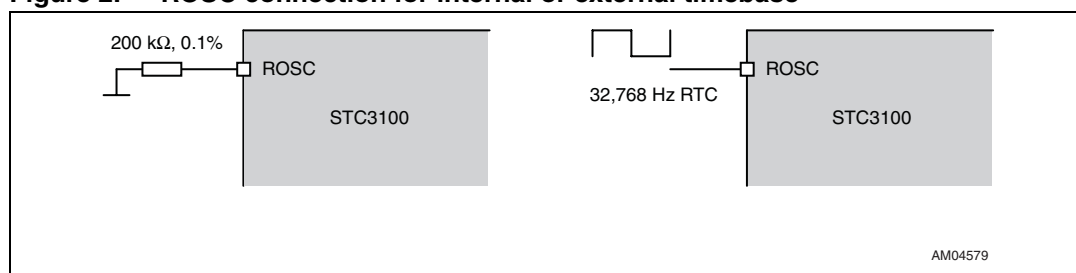
Figure 1. Typical application diagram for the STC3100



The STC3100 mode and operation are controlled through an I²C interface. SCL and SDA are the clock and data signals of the I²C interface.

1.2 Internal or external 32,768 Hz timebase

The Coulomb counter system needs an accurate 32,768 Hz timebase to compute the level of charge flowing from and to the battery. The STC3100 can operate from an internal oscillator or use an external RTC signal for highest accuracy. To use the internal oscillator, a 200 kΩ 0.1% resistor must be connected to the ROSC pin. The accuracy of the internal oscillator is 2.5% maximum over the supply voltage and temperature ranges. An external RTC signal can be applied to the ROSC pin (no resistor required in this case). The signal must be a square wave with a low level below 0.5 V and a high level above 1.5 V.

Figure 2. ROSC connection for internal or external timebase

The STC3100 automatically recognizes the presence of the external clock signal and uses it if present. The internal oscillator, however, can be inhibited to force the use of an external signal by setting the SEL_EXT_CLK bit in the REG_MODE register.

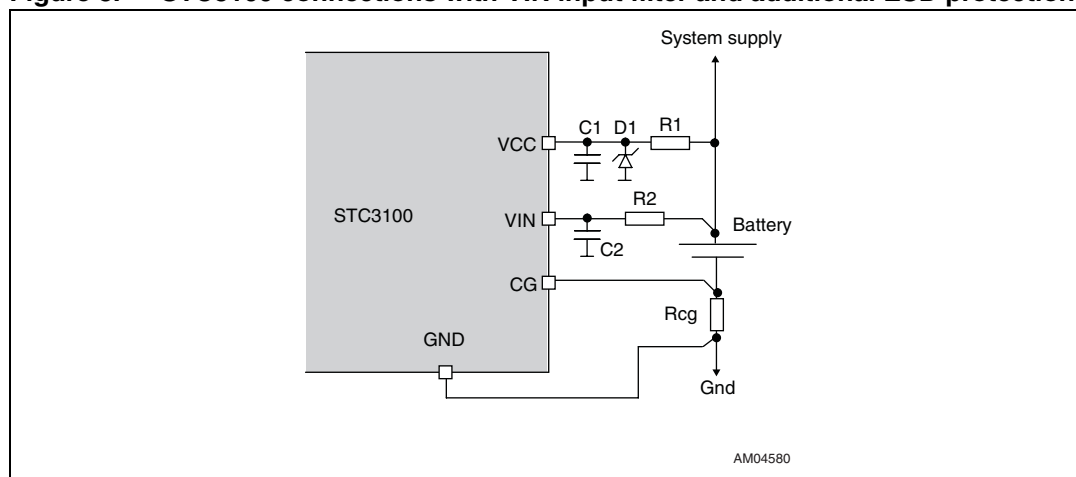
1.3 STC3100 external components

The Rcg resistor is used to sense the current flowing into or from the battery. The value of the Rcg resistor must be selected based on the maximum peak current in the application; the voltage drop across the Rcg resistor must not exceed +/-80 mV.

$$\text{Rcg resistance (Ohm)} \leq 0.08/\text{peak current (A)}.$$

For instance, a current of up to +/- 2 A can be monitored using a 33 mΩ resistor.

The STC3100 has separate pins for the power supply (VCC) and voltage measurement (VIN) inputs, providing an easy way of implementing an input filter or additional ESD protection without affecting the accuracy of the voltage measurement.

Figure 3. STC3100 connections with VIN input filter and additional ESD protection

C1 is the normal recommended decoupling capacitor (1 μF).

R1 and D1 provide additional ESD protection to the STC3100's VCC pin. A typical value for R1 is 150 Ω and D1 is a 5.6 V Zener diode.

R2 provides additional ESD protection to the STC3100's VIN pin. A typical value for R2 is 1 kΩ. The input impedance of the VIN pin is approximately 500 kΩ; an R2 resistor value of 1 kΩ will not affect the accuracy of the battery voltage measurement. The VIN input must be connected directly (through the R2 resistor) to the battery's positive terminal.

The C2 capacitor is optional and can be used if additional filtering is required, with typical values of 47 to 220 nF.

The STC3100's ground connection (GND) is used as the reference input for the current measurement and must be connected to the ground side of the sense resistor by a dedicated track. No current, except the supply current of the STC3100 itself, must flow in this track to avoid creating an offset error in the current measurement.

2 Battery monitoring functions

The STC3100 includes the following battery monitoring functions.

- A Coulomb counter for automatic computation of the battery's charge variation: this is done by integrating the battery current versus the time and accumulating the resulting charge variation into the accumulator register. The last current measurement is always available.
- Automatic periodic measurement of the battery voltage.
- Automatic periodic measurement of the temperature using the STC3100's internal sensor.

The battery monitoring functions are controlled by the GG_RUN bit in the REG_MODE register. Since GG_RUN is reset at power-up, the battery monitoring functions are disabled, ensuring a low standby current when the battery is inserted until the application is started.

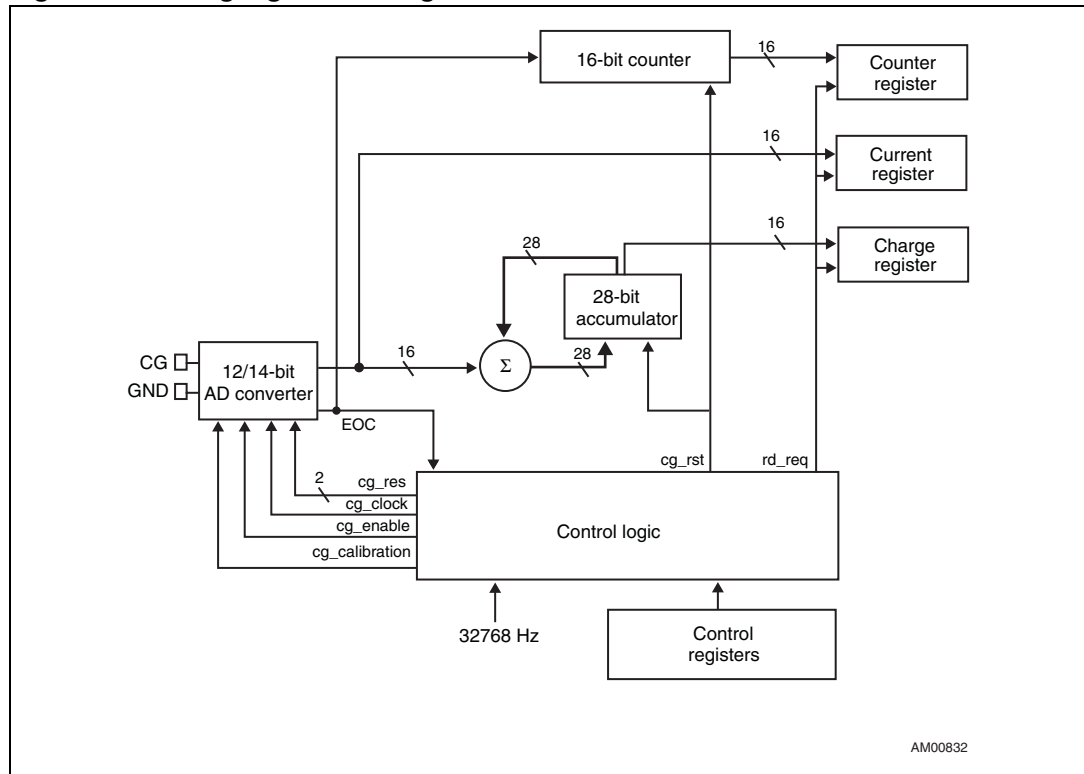
The Coulomb counter function uses a 12/14-bit ADC and runs continuously after it has been enabled by the GG_RUN bit.

Values held in consecutive registers (such as the charge value in the REG_CHARGE_LOW and REG_CHARGE_HIGH registers) must be read with a single I²C access to ensure data integrity. Multiple values can be read in one I²C access; all values will then be consistent, that is, will be relative to the same time.

2.1 Coulomb counter operation

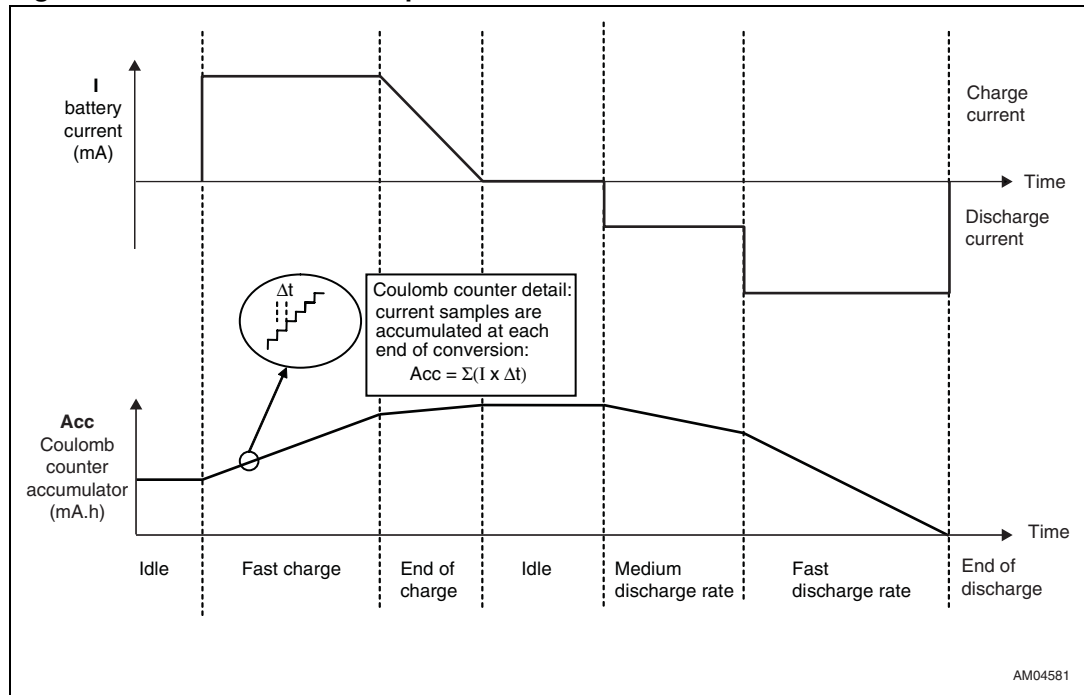
The voltage drop between the CG and GND pins is integrated during a conversion period and input to a 12- to 14-bit AD converter. The output conversion is accumulated into a 28-bit accumulator. The system controller can control the Coulomb counter and read the data (upper 16 bits of the accumulator) through the I²C control registers.

Figure 4. Gas gauge block diagram



The A/D converter's output is a signed value in two's complement format. It is positive when the battery is charging and negative when the battery is discharging. When a conversion cycle is completed, the result is added to the charge accumulator and the 16-bit conversion counter is incremented.

Figure 5. Coulomb counter operation



2.2 Coulomb counter reading

The charge data as well as the conversion count can be read at any time by the system controller. The recommended procedure is to read the locations REG_CHARGE (2 bytes) and REG_COUNTER (2 bytes) in one go using a single I²C block read to ensure data consistency between the accumulator and counter.

Table 1. REG_CHARGE_LOW. address 2 (02h)

| Name | Pos. | Type | Power-up | Description |
|------------|--------|------|----------|----------------------|
| DATA[7..0] | [7..0] | R | 00 | Coulomb counter data |

Table 2. REG_CHARGE_HIGH. address 3 (03h)

| Name | Pos. | Type | Power-up | Description |
|-------------|--------|------|----------|----------------------|
| DATA[15..8] | [7..0] | R | 00 | Coulomb counter data |

The charge code is a 16-bit binary number using the two's complement binary format. Bit 15 is the sign bit and the LSB value is 6.70 μV.h. To convert the charge data into mA.h, the external resistance *R_{sense}* must be taken into account:

$$\text{charge data (mA.h)} = 6.70 * \text{charge_code} / R_{\text{sense}} \text{ (m}\Omega\text{)}.$$

When the result of an accumulation exceeds the limits of a signed binary number (below 0x8000 or above 0x7FFFF), the carry bit is lost, no overflow is generated and the accumulator continues to accumulate.

Table 3. REG_COUNTER_LOW. address 4 (04h)

| Name | Pos. | Type | Power-up | Description |
|------------|--------|------|----------|--------------------------|
| DATA[7..0] | [7..0] | R | 00 | Conversion counter data. |

Table 4. REG_COUNTER_HIGH. address 5 (05h)

| Name | Pos. | Type | Power-up | Description |
|-------------|--------|------|----------|-------------------------|
| DATA[15..8] | [7..0] | R | 00 | Conversion counter data |

The counter code is an unsigned 16-bit binary number.

When the conversion counter reaches its maximum value (binary code = $2^{16}-1 = 0xFFFF$), it wraps to 0 and continues counting. Both the accumulator and the counter can be reset with the GG_RST bit.

The CG_EOC bit in the REG_CTRL register can be used to check that at least one new current measurement has been done and accumulated since the last reading of the REG_CTRL register.

2.3 Battery current reading

The last measured value of the current is available in the REG_CURRENT locations (two bytes) and is updated at each conversion.

Table 5. REG_CURRENT_LOW. address 6 (06h)

| Name | Pos. | Type | Power-up | Description |
|------------|--------|------|----------|----------------------|
| DATA[7..0] | [7..0] | R | 00 | Battery current data |

Table 6. REG_CURRENT_HIGH. address 7 (07h)

| Name | Pos. | Type | Power-up | Description |
|--------------|--------|------|----------|----------------------|
| DATA[13..8] | [5..0] | R | 00 | Battery current data |
| DATA[15, 14] | [7,6] | R | 0 | Unused |

The current code is a 14-bit binary number using the two's complement binary format. Bit 13 is the sign bit and bits 0 to 12 are the data bits. The LSB value (bit 0) is 11.77 μ V.h, irrespective of the current conversion resolution. However, bit 0 is always zero in 12- and 13-bit resolution modes, and bit 1 is always zero in 12-bit resolution mode. To convert the current data into mA, the external resistance *R_{sense}* must be taken into account.

$$\text{current (mA)} = \text{current_code} * 11.77 / R_{\text{sense}} \text{ (m}\Omega\text{)}$$

2.4 Battery voltage and temperature reading

The battery voltage and chip temperature (close to the battery temperature) are measured by means of an A/D converter and a multiplexer. This function takes place concurrently to the Coulomb counter function with a dedicated A/D converter, which means that it does not affect the performance of the Coulomb counter. To reduce the power consumption, a conversion takes place every two seconds only, alternating between the battery voltage and temperature (so each value is refreshed every four seconds).

Table 7. REG_VOLTAGE_LOW. address 8 (08h)

| Name | Pos. | Type | Power-up | Description |
|------------|--------|------|----------|----------------------|
| DATA[7..0] | [7..0] | R | 00 | Battery voltage data |

Table 8. REG_VOLTAGE_HIGH. address 9 (09h)

| Name | Pos. | Type | Power-up | Description |
|--------------|--------|------|----------|----------------------|
| DATA[11..8] | [3..0] | R | 0 | Battery voltage data |
| DATA[15..12] | [7..4] | R | 0 | unused |

The voltage code is a 12-bit binary number using the two's complement binary format. Bit 11 is the sign bit and bits 0 to 10 are the data bits. The LSB value (bit 0) is 2.44 mV. Note that although the input voltage range is limited to a positive voltage, negative voltage codes can be read when the input voltage is close to 0 V due to internal offset effects.

Table 9. REG_TEMPERATURE_LOW. address 10 (0Ah)

| Name | Pos. | Type | Power-up | Description |
|------------|--------|------|----------|------------------|
| DATA[7..0] | [7..0] | R | 00 | Temperature data |

Table 10. REG_TEMPERATURE_HIGH. address 11 (0Bh)

| Name | Pos. | Type | Power-up | Description |
|--------------|--------|------|----------|------------------|
| DATA[11..8] | [3..0] | R | 0 | Temperature data |
| DATA[15..12] | [7..4] | R | 0 | unused |

The temperature code is a 12-bit binary number using the two's complement binary format. Bit 11 is the sign bit and bits 0 to 10 are the data bits. The LSB value (bit 0) is 0.125° C.

The actual values of the voltage and temperature are:

- voltage (mV) = Voltage_code * 2.44.
- temperature (°C) = Temperature_code * 0.125.

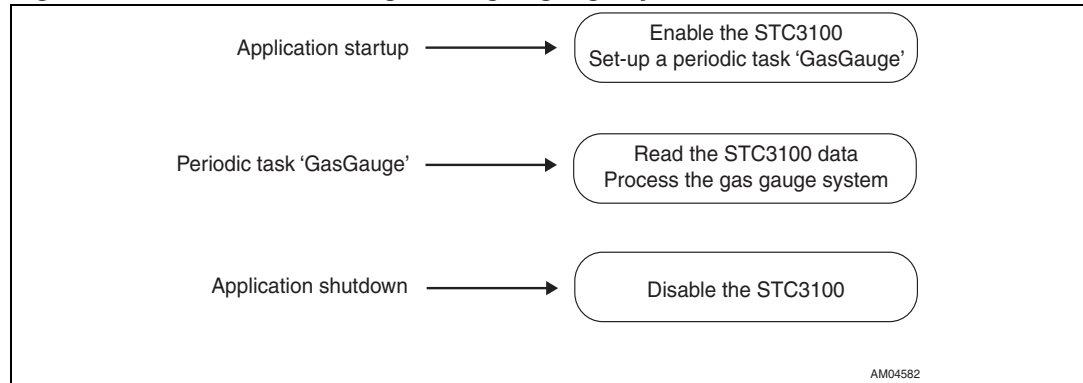
The VTM_EOC bit in the REG_CTRL register can be used to check that at least one new measurement of the voltage or temperature has been done since the last reading of the REG_CTRL register.

3 Controller tasks for gas gauge implementation

The system controller manages the following tasks.

- At start-up, it enables the STC3100's battery monitoring functions.
- It periodically reads the battery voltage, temperature, current and charge accumulator and uses this information to estimate the state of charge.
- At power-down, it disables the STC3100.

Figure 6. Flow chart of the general gas gauge system



3.1 Application start-up

A typical startup code writes 0x02 (hex value) into the REG_CTRL register to reset the accumulator and counter and clear the PORDET bit, and then 0x10 into the REG_MODE register to start the STC3100 in 14-bit resolution mode.

The startup code then sets a periodic *GasGauge* task that will be called every 5 seconds.

3.2 Periodic *GasGauge* task

A simple periodic *GasGauge* task will do the following.

- Read the battery voltage, temperature, current and charge accumulator.
- At first call, use the battery voltage to estimate the battery's state-of-charge and save it in a RAM location of the STC3100 as a reference value.
- During subsequent calls, use the saved reference value and the present charge register content to calculate the present battery capacity:
battery capacity = reference value + charge register content.
- Trigger a "low battery" alarm if the battery's voltage is low (typically less than 3.1 V).
- Calculate the remaining operating time from the remaining battery capacity and current consumption when the battery is not charging (negative current).

3.3 Application power-down

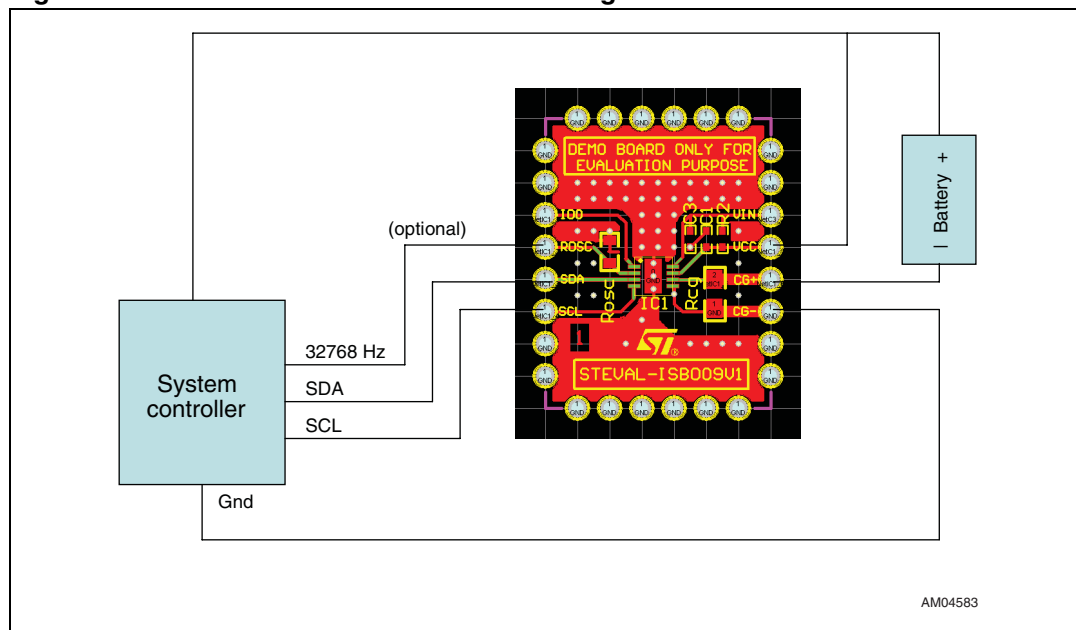
The shutdown code puts the STC3100 in standby mode by writing 0 into the REG_MODE register.

Appendix A STC3100 demonstration board

The STC3100 demonstration board is convenient to evaluate the charge and battery monitoring functions and quickly obtain a working prototype or design reference.

Figure 7 shows the basic connections to use the STC3100 demonstration board.

Figure 7. STC3100 demonstration board usage



The sense resistor is on the board and the resistance value is 33 mΩ

The digital interface comprises the SDA and SCL pads (I²C bus signals). An external 32,768 Hz clock can be applied to the ROOSC pad. It is not necessary to physically remove the ROOSC resistor. The digital levels are: <0.5 V for low level, >1.5 V for high level.

Appendix B STC3100 register map

[Table 11](#) details the mapping of the battery monitoring registers.

Table 11. Register map

| Name | Address (dec.) | Type | Description |
|----------------------------|----------------|------|----------------------------------|
| Control registers | | | |
| REG_MODE | 0 | R/W | Mode register |
| REG_CTRL | 1 | R/W | Control and status register |
| REG_CHARGE_LOW | 2 | R | Coulomb counter data, bits 0-7 |
| REG_CHARGE_HIGH | 3 | R | Coulomb counter data, bits 8-15 |
| REG_COUNTER_LOW | 4 | R | Conversion counter, bits 0-7 |
| REG_COUNTER_HIGH | 5 | R | Conversion counter, bits 8-15 |
| REG_CURRENT_LOW | 6 | R | Battery current value, bits 0-7 |
| REG_CURRENT_HIGH | 7 | R | Battery current value, bits 8-15 |
| REG_VOLTAGE_LOW | 8 | R | Battery voltage value, bits 0-7 |
| REG_VOLTAGE_HIGH | 9 | R | Battery voltage value, bits 8-15 |
| REG_TEMPERATURE_LOW | 10 | R | Temperature value, bits 0-7 |
| REG_TEMPERATURE_HIGH | 11 | R | Temperature value, bits 8-15 |
| Device ID registers | | | |
| REG_ID0 | 24 | R | Part type ID = 10h |
| REG_ID1 | 25 | R | Unique part ID, bits 0-7 |
| REG_ID2 | 26 | R | Unique part ID, bits 8-15 |
| REG_ID3 | 27 | R | Unique part ID, bits 16-23 |
| REG_ID4 | 28 | R | Unique part ID, bits 24-31 |
| REG_ID5 | 29 | R | Unique part ID, bits 32-39 |
| REG_ID6 | 30 | R | Unique part ID, bits 40-47 |
| REG_ID7 | 31 | R | Device ID CRC |
| RAM registers | | | |
| REG_RAM0 | 32 | R/W | General-purpose RAM register 0 |
| ... | ... | | ... |
| REG_RAM31 | 63 | R/W | General-purpose RAM register 31 |

The REG_MODE and REG_CTRL registers are described in detail in [Table 12](#) and [Table 13](#).

Table 12. REG_MODE. address 0 (00h)

| Name | Pos. | Type | Power-up | Description |
|-------------|--------|------|----------|--|
| SEL_EXT_CLK | 0 | R/W | 0 | 32,768 Hz clock source: 0: auto-detect, 1: external clock |
| GG_RES | [2,1] | R/W | 00 | Current/Coulomb counter ADC resolution: 00: 14 bits, 01: 13 bits, 10: 12 bits |
| GG_CAL | 3 | R/W | 0 | 0: no effect 1: used to calibrate the AD converters |
| GG_RUN | 4 | R/W | 0 | 0: standby mode. Accumulator and counter registers are frozen, battery monitoring functions are in standby. 1: operating mode |
| | [7..5] | | | Unused |

Table 13. REG_CTRL. address 1 (01h)

| Name | Pos. | Type | Power-up | Description |
|---------|--------|------|----------|--|
| IO0DATA | 0 | R | X | Port IO0 data status: 0 = IO0 input is low, 1 = IO0 input is high |
| | | W | 1 | Port IO0 data output drive: 0 = IO0 output is driven low, 1 = IO0 output is open |
| GG_RST | 1 | W | 0 | 0: no effect 1: resets the charge accumulator and conversion counter. GG_RST is a self-clearing bit. |
| GG_EOC | 2 | R | 1 | Set at the end of a battery current conversion cycle. Clears upon reading. |
| VTM_EOC | 3 | R | 1 | Set at the end of a battery voltage or temperature conversion cycle. Clears upon reading. |
| PORDET | 4 | R | 1 | Power-on reset (POR) detection bit: 0 = no POR event occurred 1 = POR event occurred |
| | | W | 0 | Soft reset: 0 = releases the soft-reset and clears the POR detection bit 1 = asserts the soft-reset and sets the POR detection bit |
| | [7..5] | R/W | | Unused |

References

Table 14. Document references

| Document |
|--|
| STC3100 datasheet: <i>Battery monitor IC with Coulomb counter/gas gauge.</i> |

Revision history

Table 15. Document revision history

| Date | Revision | Changes |
|-------------|----------|------------------|
| 19-Oct-2009 | 1 | Initial release. |

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