

Battery Fuel Gauge
[Smart LiB Gauge]
for 1-Cell Lithium-ion/
Polymer (Li+) with Low Power
2 μ A Operation

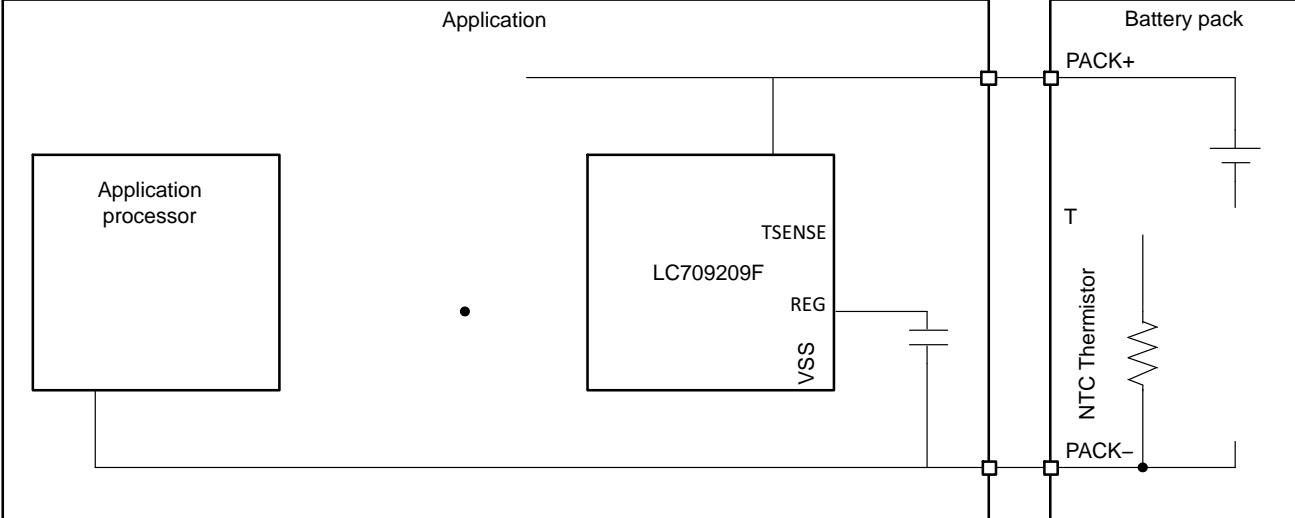
LC709209F

Overview

LC709209F is a Fuel Gauge (in other words, Fuel Gauge IC, Gas Gauge, Battery Monitor or Battery Gauge) for 1-Cell Lithium-ion/Polymer batteries. It is part of our **Smart LiB Gauge**

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Application Circuit Example



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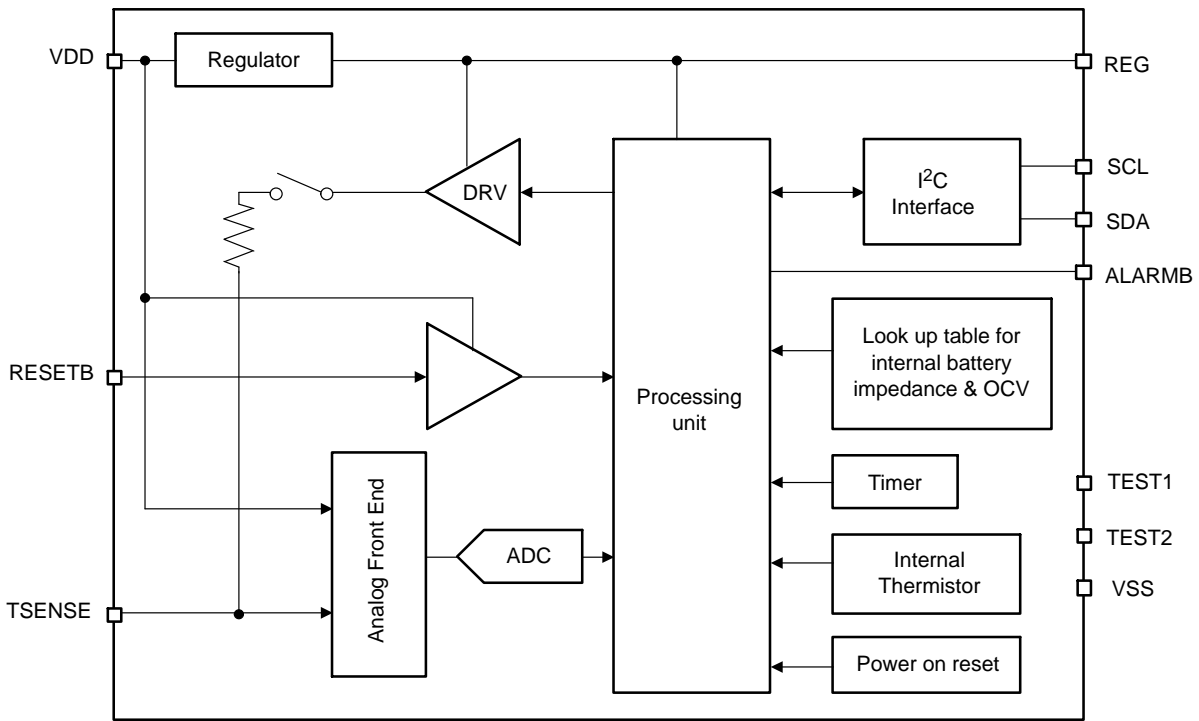
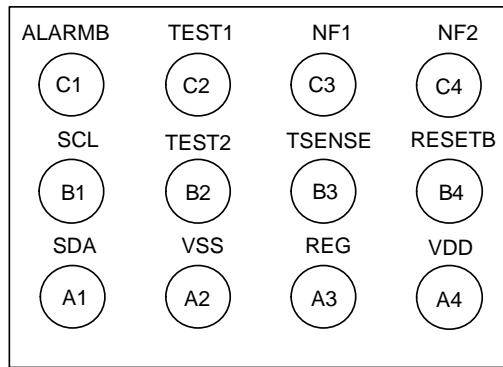


Figure 3. Block Diagram



(Bottom View)

Figure 4. Pin Assignment

Table 1. PIN FUNCTION

WLCSP12	Name
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Table 5. I²C SLAVE CHARACTERISTICS ($T_A = -40$ to $+85^\circ\text{C}$, $V_{SS} = 0$ V)

Parameter	Symbol	Pin/Remarks	Conditions	V _{DD} (V)	Specification		Unit
					Min	Max	
Clock Frequency	T _{SCL}	SCL		2.5 to 5.0	-	400	kHz
Bus Free Time between STOP Condition and START Condition	T _{BUF}	SCL, SDA					

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I²C Communication Protocol

Communication protocol type: I²C

Frequency: Supported up to 400 kHz

Slave Address: 0001011 (The first 8-bits after the Start Condition is 0x16 (WRITE) or 0x17 (READ).)

The device will stretch the clock.

Bus Protocols

S	:	Start Condition
Sr	:	Repeated Start Condition
Rd	:	Read (bit value of 1)
Wr	:	Write (bit value of 0)
A	:	ACK (bit value of 0)
N	:	NACK (bit value of 1)
P	:	Stop Condition
CRC-8	:	Slave Address to Last Data (CRC-8-ATM : ex.3778 mV : 0x16, 0x09, 0x17, 0xC2, 0x0E → 0x86)
	:	Master-to-Slave

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Table 6. FUNCTION OF REGISTERS

Command Code	Register Name	R/W	Range	Unit	Description	Initial Value
BATTERY PROFILE-RELATED REGISTERS						
0x12	Change of the Parameter	R/W	0x0000 to 0x0004		Selects a battery profile.	0x0000 (Note 3)
0x1A	Number of the Parameter	R	0x0000 to 0xFFFF		Displays the battery profile code.	–
0x0B	APA	R/W	0x0000 to 0xFFFF		Sets an adjustment parameter.	– (Note 3)
0x1C	Termination Current Rate	R/W	0x0002 to 0x001E: Threshold (0.02C to 0.3C)	0.01C	Sets termination current rate.	0x0002 (Note 3)
0x1D	Empty Cell Voltage	R/W	0x0000: Disable 0x09C4 to 0x1388: Threshold (2.5 V to 5V)	mV	Sets empty cell voltage.	0x0000 (Note 3)
0x1E	ITE Offset	R/W	0x0000 to 0x03E8 (0.0% to 100.0%)	0.1%	Sets ITE corresponding to 0% RSOC.	0x0000 (Note 3)
THERMISTOR-RELATED REGISTERS						
0x16	Status Bit	R/W	0x0000: I ² C mode 0x0001: Thermistor mode		Selects I ² C or Thermistor mode.	0x0000 (Note 3)
0x06	TSENSE Thermistor B	R/W	0x0000 to 0xFFFF	K	Sets B-constant of the TSENSE thermistor.	0x0D34 (3380 K) (Note 3)
0x0C	APT	R/W	0x0000 to 0xFFFF		Delays temperature measurement timing.	0x001E (Note 3)
0x08	Cell Temperature (TSENSE)	R	0x0980 to 0x0DCC (–30°C to +80°C)	0.1K (0.0°C = 0x0AAC)	Displays Cell Temperature.	0x0BA6 (25°C)
		W			Sets Cell Temperature in I ² C mode.	
CONTROL REGISTERS						
0x15	IC Power Mode	R/W	0x0001: Operational mode 0x0002: Sleep mode		Selects Operational or Sleep mode.	0x0002 (Note 3)
0x0A	Current Direction	R/W	0x0000: Auto mode 0x0001: Charge mode 0xFFFF: Discharge mode		Selects Auto, Charge or Discharge mode.	0x0000
0x04	Before RSOC	W	0xAA55: 1 st sampling 0xAA56: 2 nd sampling 0xAA57: 3 rd sampling 0xAA58: 4 th sampling		Optional Command, especially for obtaining the voltage with intentional timing after power on reset.	–
0x07	Initial RSOC	W	0xAA55: Initialize RSOC		Initializes RSOC with current voltage when 0xAA55 is set.	–
REPORTING REGISTERS						
0x09	Cell Voltage	R	0x09C4 to 0x1388 (2.5V to 5V)	mV	Displays cell voltage.	

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Table 9. DESIGN CAPACITY TO TYPICAL APA CONVERSION TABLE

BITS	Register Name
APA[15:8]	APA value for charging adjustment
APA[7:0]	APA value for discharging adjustment

The Smart LiB Gauge Automatic Support Tool automatically evaluates the optimum APA by measuring the target battery. The evaluated APA will improve the RSOC accuracy more than the APA from the conversion table. For the evaluation, the tool discharges a target battery using the on-board programmable load and measures the cell voltage and temperature. The tool works in the Strata Developer Studio. Please refer to the documents in the Strata Developer Studio for further details about the tool.

Termination Current Rate (0x1C)

This register contains the termination current rate in 0.01C. (i.e. the set value is 0x02 for 3000 mAh design capacity and 60 mA termination current.) This termination current rate is used to adjust RSOC report so that 100% is reported at the end of the charging period, or even before the charger finishes charging.

When this value is the default 0.02C, there is no offset at full charge state (RSOC (0x0D) is 100%) between ITE (0x0F) and RSOC (0x0D). When the value exceeds 0x02, there will be an offset between them, as shown in Figure 9. This corresponds to a decrease in the full charged capacity as an increase in the termination current. As the result, the RSOC will reach 100% faster. This offset value is calculated automatically according to the battery profile and this register value.

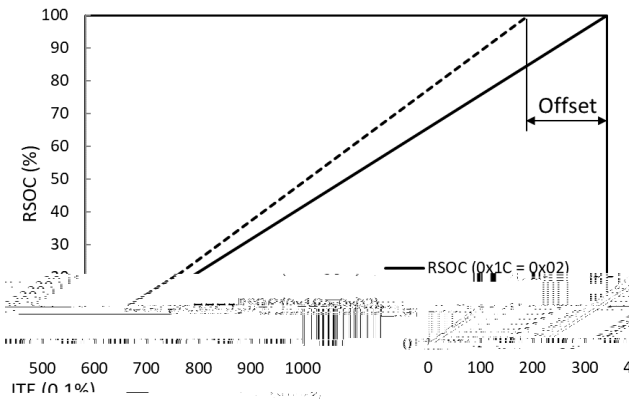


Figure 9. Rescaled RSOC with Termination Current Rate

ITE Of. As 543Vsi)

THERMISTOR-RELATED REGISTERS

Status Bit (0x16)

This register controls the cell temperature measurement. The bit selection details is shown in Table 10. Set the bit0 to 1 to measure the temperature using a thermistor connected to the TSENSE pin. If the thermistor is not connected to the device, set the bit0 to 0. Refer to Cell Temperature (0x08) section to see the details on using the I²C mode.

Charge or Discharge mode, the decrease or increase is prohibited, as shown in Figure 14 and 15.

Generally, RSOC may increase slightly without charging due to the difference in usable battery capacity at each cell temperature. However, if an application cannot allow such an RSOC increase without charging, you can use the Discharge mode to prevent the increase. Note that if the Discharge mode is set during charging, the RSOC register value will deviate significantly from the actual RSOC.

Table 11. CURRENT DIRECTION

Data	Mode	Description
0x0000	Auto mode	RSOC is not restricted.
0x0001	Charge mode	Decrease of RSOC is restricted.
0xFFFF	Discharge mode	Increase of RSOC is restricted.



Figure 14. Discharge Mode
(An example with increasing in temperature. A warm cell has more capacity than a cold cell. Therefore RSOC increases without charging in Auto mode).



Figure 15. Charge Mode
(An example with decreasing in temperature. A cold cell has less capacity than a warm cell. Therefore RSOC decreases without discharging in Auto mode).

Before RSOC (0x04)

This register is used to execute “Before RSOC” command. This command obtains the initial RSOC using

one of the automatically measured cell voltages after battery insertion as shown in Figure 16. These cell voltages are measured four times every 10 ms after the battery insertion. This is an optional command, because the device obtains the initial RSOC automatically using the first sampling cell voltage. However, if the first RSOC does not satisfy the requirements for the target battery, this command can initialize the RSOC again using the second, the third or the fourth sampling cell voltage.

The cell voltage is used as Open Circuit Voltage (OCV) to obtain the initial RSOC. Therefore, in order to obtain the RSOC accurately, it is desirable that the battery current at the voltage measurement is smaller. It is recommended that the current is less than 0.025C. (i.e. less than 75 mA for 3000 mAh design capacity battery.) If the battery is not charged, “Before RSOC” command to give the maximum RSOC with the maximum cell voltage is estimated to be suitable for more accurate initial RSOC.

To execute this command, write one of the data shown in Table 12 into this register. The data selects a sampling cell voltage to initial RSOC.

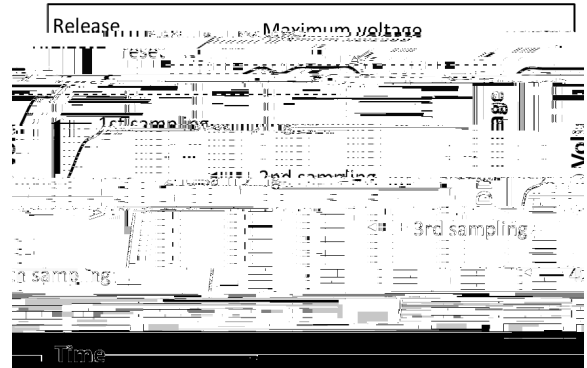


Figure 16. Sampling Order for Before RSOC Command

Table 12. BEFORE RSOC COMMAND

Command Code	DATA	Sampling order of battery voltage for RSOC initialization
0x04	0xAA55	1 st sampling
	0xAA56	2 nd sampling
	0xAA57	3 rd sampling
	0xAA58	4 th sampling

Initial RSOC (0x07)

This register is used to execute “Initial RSOC” command. The command obtains the initial RSOC using the cell voltage at which it is executed, as shown in Figure 17. When this command is executed, it is desirable for battery current to be less than 0.025C like “Before RSOC” command. However, an application processor and other devices may be operating and consuming the battery current at this time. Therefore it is generally recommended to use the RSOC that

was automatically obtained after the battery insertion without using this command.

To execute this command, mode 0xAA55 data into this register.

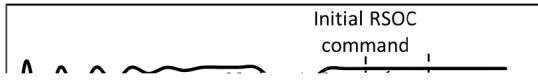


Figure 17. Initial RSOC Command

REPORTING REGISTERS

Cell Voltage (0x09)

This register contains the V_{DD} voltage in mV.

RSOC (0x0D)

This register contains RSOC of a battery in 1% unit. The RSOC is updated automatically as a result of battery gauging in Operational mode. The RSOC is the same as ITE (0x0F) when Termination current rate (0x1C) and Empty Cell Voltage (0x1D) are default values.

Although this register is writable, it is not recommended for general use. If a value which differs from the actual battery RSOC is written, it will gradually converge itself to an actual battery RSOC in Operational mode. Refer to Automatic Convergence of the Error section about the convergence.

Indicator to Empty (0x0F)

This register contains RSOC in 0.1% increments. It is updated automatically throughout the battery gauging process.

TimeToEmpty (0x03)

This register contains estimated time to empty in minutes. The empty condition is defined as the state that RSOC (0x0D) is 0%.

TimeToFull (0x05)

This register contains estimated time to full in minutes. The full condition is defined as the state that RSOC (0x0D) is 100%.

SOH- RELATED REGISTERS

State of Health (0x32)

This register contains SOH of a battery in 1% unit. The SOH is updated automatically according to battery aging. The initial value after reset or power on is 100% (0x0064).

LOG REGISTERS

Cycle Count (0x17)

This register contains the number of charging and discharging cycles of a battery. The cycle is counted as “1” when the total “Decrement of RSOC” reaches 100%. The count is started with 0 after battery insertion. Figure 18 shows an example where the Cycle Count is set to 1 when one full discharge cycle is completed.

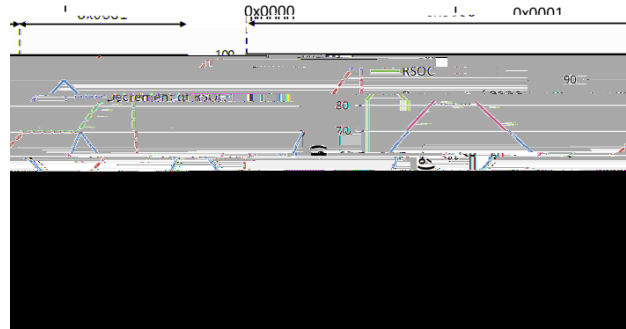


Figure 18. CycleCount

Total Runtime (0x24, 0x25)

This register contains an elapsed time of Operational mode after battery insertion in minutes. The device stops the counting when it reaches 0xFFFFFFFF. When this register is written it starts counting from the written value. It doesn't count in Sleep mode.

Accumulated Temperature (0x26, 0x27)

In Operational mode this register accumulates Cell Temperature (0x08) value per a minute shown in eq. 6.

$$\text{AccumulatedTemperature} = \text{AccumulatedTemperature} + \frac{\text{CellTemperature}}{20} \quad (\text{eq. 6})$$

You can calculate averaged cell temperature using this register and TotalRuntime register. The initial value after power on reset is 0. When this register reaches 0xFFFFFFFF or the device is in Sleep mode, it will stop accumulating. If this register is written it will start accumulating from the written value.

Accumulated RSOC (0x28, 0x29)

In Operational mode this register accumulates RSOC (0x0D) value per minute shown in eq. 7.

You can calculate averaged RSOC using this register and TotalRuntime register. The initial value after power on reset is 0.

$$\text{AccumulatedRSOC} = \text{AccumulatedRSOC} + \text{RSOC} \quad (\text{eq. 7})$$

When this register reaches 0xFFFFFFFF or the device is in Sleep mode, it will stop accumulating. If this register is written it will start accumulating from the written value.

Maximum Cell Voltage (0x2A)

The maximum Cell Voltage (0x09) is stored. This register will be updated whenever the higher voltage is detected. If the lower voltage is written it can detect the higher voltage than the written voltage again.

Minimum Cell Voltage (0x2B)

The minimum Cell Voltage (0x09) is stored. This register will be updated whenever the lower voltage is detected. If the higher voltage is written it can detect the lower voltage than the written voltage again.

Maximum Cell Temperature (TSENSE) (0x2C)

The maximum Cell Temperature (0x08) is stored. This register will be updated whenever the higher temperature is detected. If the lower temperature is written it can detect the higher temperature than the written temperature again.

Minimum Cell Temperature (TSENSE) (0x2D)

The minimum Cell Temperature (0x08) is stored. This register will be updated whenever the lower temperature is detected. If the higher temperature is written it can detect the lower temperature than the written temperature again.

ALARM THRESHOLD AND STATUS REGISTERS

Battery Status (0x19)

This register contains different alarms and estimated states of the battery. See Table 13. Each alarm bit is set to 1 when its alarm condition is reached. The bits which are set to 1 will remain at 1 even if their corresponding alarm conditions are resolved. Set the alarm bits to 0 manually after having confirmed the cause of the alarm.

Status bit 6, Discharging, reports on the current state of the battery. When it is 1, it means that the battery is discharged; and when it is 0, the battery is charged.

Status bit 7, INITIALIZED, helps an application processor to detect the power-on reset of the device. The bit is automatically set to 1 after power-on reset.

Table 13. BATTERY STATUS

	BIT	Function	ALARMB control	Initial value
ALARM	15	High Cell Voltage	✓	0
	14	Reserved	-	0
	13	Reserved	-	

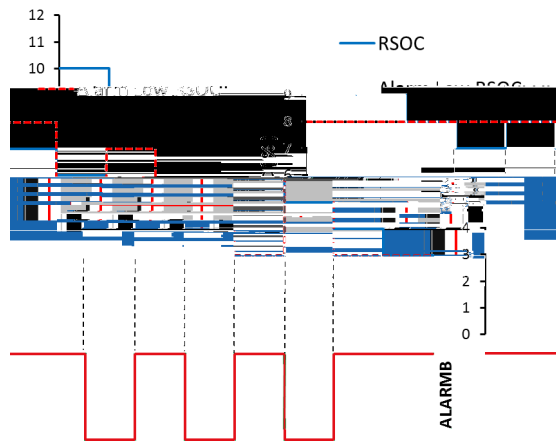


Figure 20. Alarm Low RSOC

Alarm Low Temperature (0x20)

This register contains the threshold in 0.1K of the alarm low cell temperature. When Cell Temperature (0x18) falls below this value, ALARMB pin outputs low level and bit 8 of the Battery Status register (0x19) is set to 1. When the Cell Temperature rises above this value, ALARMB is released. Set this register to 0 or I²C mode to disable this function.

Alarm High Temperature (0x21)

This register contains the threshold in 0.1K of the alarm high cell temperature. When Cell Temperature (0x18) rises above this value, ALARMB pin outputs low level and bit 12 of the Battery Status register (0x19) is set to 1. When the Cell Temperature falls below this value, ALARMB is released. Set this register to 0 or I²C mode to disable this function.

OTHER REGISTERS

CRC32 (0x38, 0x39)

This register contains CRC-32 result calculated from the registers shown in Table 13. The CRC-32 specifications are defined by the following Polynomial, Normal and Bit Reverse values.

Polynomial :

$$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x^1$$

Normal : 0x4C11DB7

BitReverse : 0xEDB88320

HG-CVR2**Hybrid Gauging by Current-Voltage Tracking with Internal Resistance**

HG-CVR2 is onsemi's unique method which is used to calculate accurate RSOC. **HG-CVR2** first measures battery voltage and temperature. Precise reference voltage is essential for accurate voltage measurement. LC709209F has accurate internal reference voltage circuit with little temperature dependency.

It also uses the measured battery voltage and internal impedance and Open Circuit Voltage (OCV) of a battery for the current measurement. OCV is battery voltage without load current. The measured battery voltage is separated into OCV and varied voltage by load current. The varied voltage is the product of load current and internal impedance. Then the current is determined by the following formulas.

$$V(\text{VARIED}) = V(\text{MEASURED}) - \text{OCV} \quad (\text{eq. 8})$$

$$I = \frac{V(\text{VARIED})}{R(\text{INTERNAL})} \quad (\text{eq. 9})$$

Where V(VARIED) is varied voltage by load current, V(MEASURED) is measured voltage, R(INTERNAL) is internal impedance of a battery. Detailed information about the internal impedance and OCV is installed in the LSI. The internal impedance is affected by remaining capacity, load-current, temperature, and more. The device has built-in look up tables for such variable conditions

HG-CVR2

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Table 16. REGISTERS FOR INITIAL SETTING

Command Code	Register Name	Mandatory or Optional	Initial Value is Stored in NVM
0x06	TSENSE Thermistor B	Mandatory (Thermistor Mode)	✓
0x0B	APA	Mandatory	✓
0x0C	APT	Optional	✓
0x12	Change of the Parameter	Mandatory	✓
0x13	Alarm Low RSOC	Optional	✓
0x14	Alarm Low Cell Voltage	Optional	✓
0x15	IC Power Mode	Mandatory	✓
0x16	Status Bit	Mandatory (Thermistor Mode)	✓
0x1C	Termination Current Rate	Optional	✓
0x1D	Empty Cell Voltage	Optional	✓
0x1E	ITE Offset	Optional	✓
0x1F	Alarm High Cell Voltage	Optional	✓
0x20	Alarm Low Temperature	Optional	✓
0x21	Alarm High Temperature	Optional	✓

Initial Setting with I²C Communication

If the required initial values of the registers in Table 16 is not programmed in the built-in NVM preliminarily, an application processor must write them with I²C

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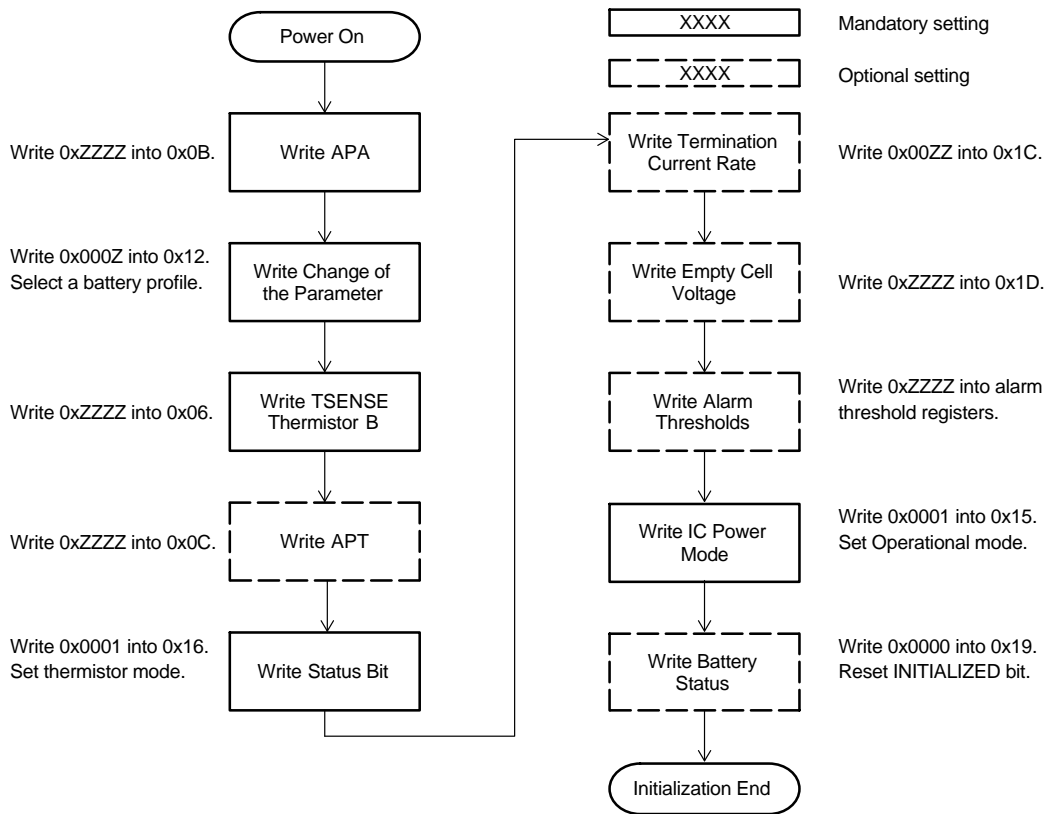


Figure 24. Starting Flow at Thermistor Mode

Mandatory setting

Optional setting

Write 0xZZZZ into alarm threshold registers.

Write 0xZZZZ into 0x0B.

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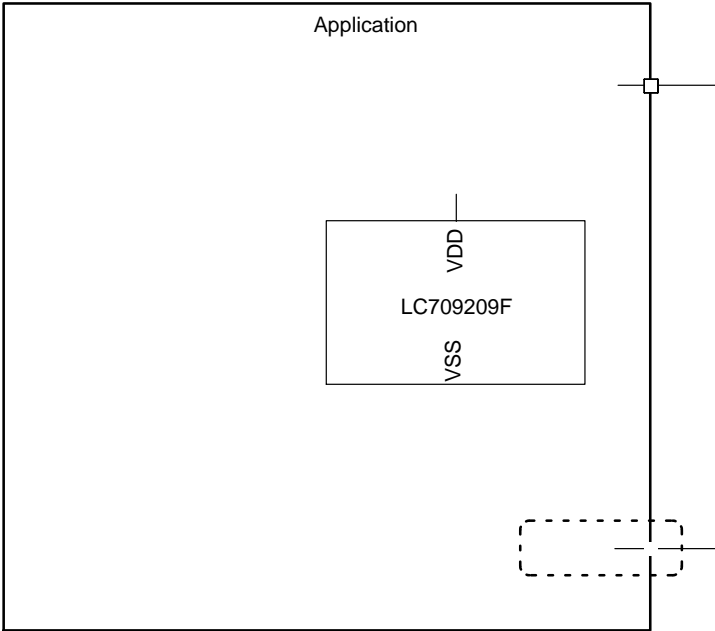
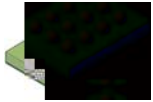
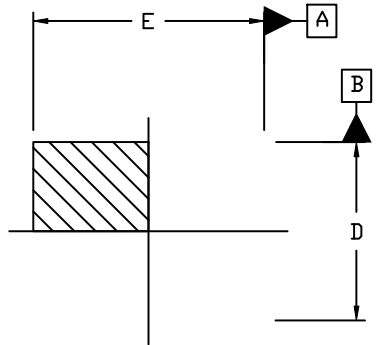


Figure 27. Position to Connect LC709209F on Power Supply Lines



WLCSP12, 1.48x1.91x0.51



+
12X ϕb

BOTTO

GENERIC
MARKING DIAGRAM*



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