TEXAS INSTRUMENTS

**bq27411-G1**

SLUSBN7D –JANUARY 2014–REVISED APRIL 2017

# bq27411-G1 Single-Cell Li-Ion Battery Fuel Gauge for Battery Pack Integration

## 1 Features

- Single-Cell Li-Ion Battery Fuel Gauge
  - Resides in Battery Pack
  - Low-Value External Sense Resistor (10 mΩ Typical)
  - One Time Programmable (OTP) Configuration Non-Volatile Memory (NVM)
  - Powered Directly from Battery with Integrated LDO
  - 400-kHz I2C™ Serial Interface
  - Internal Temperature Sensor or Host-reported Temperature
- Battery Fuel Gauging Based on Patented Impedance Track™ Technology
  - Reports Remaining Capacity and State of Charge (SOC) with Smoothing Filter
  - Automatically Adjusts for Battery Aging, Self-discharge, Temperature, and Rate Changes
  - Battery State of Health (Aging) Estimation

## 2 Applications

- Smartphones, Feature Phones, and Tablets
- Digital Still and Video Cameras
- Handheld Terminals
- MP3 or Multimedia Players

## 3 Description

The Texas Instruments bq27411-G1 device is a battery fuel gauging solution for single-cell Li-Ion battery packs. The device requires minimal configuration and uses One Time Programmable (OTP) Non-Volatile Memory (NVM) to avoid an initialization download by the system processor.

The fuel gauge uses the patented Impedance Track™ algorithm for fuel gauging, and provides information such as remaining battery capacity (mAh), state-of-charge (%), and battery voltage (mV).

The small, 12-pin, 2.50 mm × 4.00 mm, Small Outline No-Lead (SON) package is ideal for space-constrained applications.

### Device Information[1]

| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| bq27411-G1 | VSON (12) | 2.50 mm x 4.00 mm |

(1) For all available packages, see the orderable addendum at the end of the data sheet.
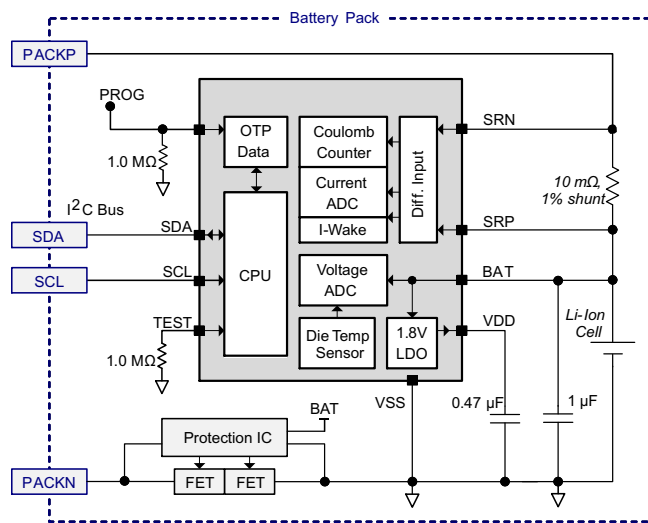
### Simplified Schematic



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# Table of Contents

## 4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

**Changes from Revision C (September 2015) to Revision D**               **Page**

# 5  Device Comparison Table

| PART NUMBER | BATTERY TYPE | CHEM_ID[1] | DM_CODE[2] | FIRMWARE VERSION[3] |
|---|---|---|---|---|
| bq27411DRZR-G1A | $LiCoO_2$ (4.2-V maximum charge) | 0x0128 | 0x80 | |
| bq27411DRZT-G1A | | | | |
| bq27411DRZR-G1B | $LiCoO_2$ (4.3-V maximum charge) | 0x0312 | 0x90 | 1.09 (0x0109) |
| bq27411DRZT-G1B | | | | |
| bq27411DRZR-G1C | $LiCoO_2$ (4.35-V maximum charge) | 0x0354 | 0xA0 | |
| bq27411DRZT-G1C | | | | |

(1)  Refer to the *CHEM_ID* subcommand to confirm the battery chemistry type.
(2)  Refer to the *DM_CODE* subcommand to confirm the Data Memory code.
(3)  Refer to the *FW_VERSION* subcommand to confirm the firmware version.

# 6  Pin Configuration and Functions



Not to scale
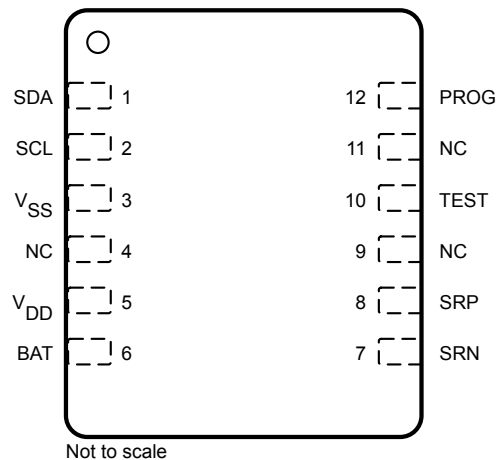
## Pin Functions

| NUMBER | NAME | TYPE[1] | DESCRIPTION |
|---|---|---|---|
| 1 | SDA | DIO | Slave I²C serial bus for communication with system (Master). Open-drain pins. Use with external 5- to 10-kΩ pullup resistors (typical) for each pin. If the external pullup resistors will be disconnected from these pins during normal operation, recommend using external 1.0-MΩ pulldown resistors to $V_{SS}$ at each pin to avoid floating inputs. |
| 2 | SCL | DIO | |
| 3 | $V_{SS}$ | PI | Ground pin |
| 4 | NC | — | No internal connection. May be left floating or tied to $V_{SS}$. |
| 5 | $V_{DD}$ | PO | 1.8-V Regulator Output. Decouple with 0.47-µF ceramic capacitor to $V_{SS}$. This pin is not intended to provide power for other devices in the system. |
| 6 | BAT | PI, AI | LDO regulator input, battery voltage input, and coulomb counter input typically connected to the PACK+ terminal. Connect a capacitor (1 µF) between BAT to $V_{SS}$. Place the capacitor close to gauge. |
| 7 | SRN | AI | Coulomb counter differential inputs expecting an external 10-mΩ, 1% sense resistor. Connect SRP to BAT (CELLP) and connect SRN to PACKP. Low-side current sensing can be enabled by connecting SRN to BATN and SRP to PACKN. Refer to the typical application diagrams in *Typical Applications*. |
| 8 | SRP | AI | |
| 9 | NC | — | No internal connection. May be left floating or tied to $V_{SS}$. |
| 10 | TEST | DI | This digital factory TEST pin must be pulled low for proper operation in customer's application. Recommend terminating with a 1.0-MΩ (typical) pulldown resistor to $V_{SS}$ for reduced power consumption. |
| 11 | NC | — | No internal connection. May be left floating or tied to $V_{SS}$. |
| 12 | PROG | DO | Programming voltage input for the One Time Programmable (OTP) memory to be used during customer factory configuration. To avoid a floating input condition, recommend terminating with a 1.0-MΩ (typical) pulldown resistor to $V_{SS}$ for reduced power consumption. If the device is in SHUTDOWN mode, toggling PROG causes the gauge exit SHUTDOWN. It is recommended to connect PROG to the SDA line through a 470-KΩ resistor, so that in case of any inadvertent shutdown condition, the gauge can be commanded to come out of SHUTDOWN. |

(1)  DIO = Digital input-output, AI = Analog input, P = Power connection

# 7 Specifications

## 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)[1]

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| $V_{BAT}$ | BAT pin input voltage range | –0.3 | 6 | V |
| $V_{SR}$ | SRP and SRN pins input voltage range | –0.3 | $V_{BAT}$ + 0.3 | V |
| | Differential voltage across SRP and SRN. ABS(SRP–SRN) | | 2 | V |
| $V_{DD}$ | $V_{DD}$ pin supply voltage range (LDO output) | –0.3 | 2 | V |
| $V_{IOD}$ | Open-drain IO pins (SDA, SCL) | –0.3 | 6 | V |
| $V_{PROG}$ | PROG (pin 12) | –0.3 | 7.8 | V |
| $V_{IOPP}$ | Push-pull IO pins (TEST, pin 10) | –0.3 | $V_{DD}$ + 0.3 | V |
| $T_A$ | Operating free-air temperature range | –40 | 85 | °C |
| $T_{stg}$ | Storage temperature | –65 | 150 | °C |

(1) Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

## 7.2 ESD Ratings

| | | | VALUE | UNIT |
|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001[1] | ±1500 | V |
| | | Charged-device model (CDM), per JEDEC specification JESD22-C101[2] | ±250 | |

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

## 7.3 Recommended Operating Conditions

$T_A$ = 30°C and $V_{REGIN}$ = $V_{BAT}$ = 3.6 V (unless otherwise noted)

| | | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|---|
| $C_{BAT}$[1] | External input capacitor for internal LDO between BAT and $V_{SS}$ | Nominal capacitor values specified. Recommend a 5% ceramic X5R type capacitor located close to the device. | | 0.1 | | µF |
| $C_{LDO18}$[1] | External output capacitor for internal LDO between $V_{DD}$ and $V_{SS}$ | | | 0.47 | | µF |
| $V_{PU}$[1] | External pull-up voltage for open-drain pins (SDA, SCL, PROG) | | 1.62 | | 3.6 | V |
| $V_{PV}$ | PROG Programming Voltage [RA0] | $T_A$ = 15°C to 35°C. OTP Programming mode only. | 7.3 | 7.4 | 7.5 | V |
| $I_{PV}$ | PROG Programming Current [RA0] | | | 4 | 5 | mA |

(1) Specified by design. Not production tested.

## 7.4 Thermal Information

| | THERMAL METRIC[1] | bq27411-G1 | UNIT |
|---|---|---|---|
| | | DRZ (12 PINS) | |
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 64.1 | °C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 59.8 | |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 52.7 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 0.3 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 28.3 | |
| $R_{\theta JC(bot)}$ | Junction-to-case (bottom) thermal resistance | 2.4 | |

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics Application Report*, SPRA953.

## 7.5   Supply Current

$T_A$ = 30°C and $V_{REGIN}$ = $V_{BAT}$ = 3.6 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $I_{CC}$[1] | NORMAL mode current | $I_{LOAD}$ > **Sleep Current**[2] | | 93 | | μA |
| $I_{SLP}$[1] | SLEEP mode current | $I_{LOAD}$ < **Sleep Current**[2] | | 21 | | μA |
| $I_{HIB}$[1] | HIBERNATE mode current | $I_{LOAD}$ < **Hibernate Current**[2] | | 9 | | μA |
| $I_{SD}$[1] | SHUTDOWN mode current | Fuel gauge in host-commanded SHUTDOWN mode. (LDO regulator output disabled) | | 0.6 | | μA |

(1)   Specified by design. Not production tested.
(2)   Wake Comparator Disabled

## 7.6   Digital Input and Output DC Characteristics

$T_A$ = –40°C to 85°C, typical values at $T_A$ = 30°C and $V_{REGIN}$ = 3.6 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{IH(OD)}$ | Input voltage, high[2] | External pullup resistor to $V_{PU}$ | $V_{PU}$ × 0.7 | | | V |
| $V_{IH(PP)}$ | Input voltage, high[3] | | 1.4 | | | V |
| $V_{IL}$ | Input voltage, low[2][3] | | | | 0.6 | V |
| $V_{OL}$ | Output voltage, low[2] | | | | 0.6 | V |
| $I_{OH}$ | Output source current, high[2] | | | | 0.5 | mA |
| $I_{OL(OD)}$ | Output sink current, low[2] | | | | –3 | mA |
| $C_{IN}$[1] | Input capacitance[2][3] | | | | 5 | pF |
| $I_{lkg}$ | Input leakage current[2][3] | SCL, SDA, and TEST pins | | | 0.1 | μA |
| | | PROG pin | | | 1.0 | |

(1)   Specified by design. Not production tested.
(2)   Open Drain pins: (SCL, SDA, PROG)
(3)   Push-pull pin: (TEST)

## 7.7   LDO Regulator, Wake-Up, and Auto-Shutdown DC Characteristics

$T_A$ = –40°C to 85°C, typical values at $T_A$ = 30°C and $V_{REGIN}$ = 3.6 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{BAT}$ | BAT pin regulator input | | 2.45 | | 4.5 | V |
| $V_{DD}$ | Regulator output voltage | | | 1.8 | | V |
| $UVLO_{IT+}$ | $V_{BAT}$ Undervoltage lockout LDO Wake-up rising threshold | | | 2 | | V |
| $UVLO_{IT-}$ | $V_{BAT}$ Undervoltage lockout LDO Auto-shutdown falling threshold | | | 1.95 | | V |

(1)   Specified by design. Not production tested.

## 7.8   ADC (Temperature and Cell Measurement) Characteristics

$T_A$ = –40°C to 85°C; typical values at $T_A$ = 30°C and $V_{REGIN}$ = 3.6 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{IN(BAT)}$ | BAT pin voltage measurement range | Voltage divider enabled | 2.45 | | 4.5 | V |
| $t_{ADC\_CONV}$ | Conversion time | | | 125 | | ms |
| | Effective Resolution | | | 15 | | bits |

(1)   Specified by design. Not tested in production.

## 7.9 Integrating ADC (Coulomb Counter) Characteristics

$T_A$ = –40°C to 85°C; typical values at $T_A$ = 30°C and $V_{REGIN}$ = 3.6 V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{SR}$ | Input voltage range from BAT to SRX pins | | | BAT ± 25 | | mV |
| $t_{SR\_CONV}$ | Conversion time | Single conversion | | 1 | | s |
| | Effective Resolution | Single conversion | | 16 | | bits |

(1)   Specified by design. Not tested in production.

## 7.10 I²C-Compatible Interface Communication Timing Characteristics

$T_A$ = –40°C to 85°C; typical values at $T_A$ = 30°C and $V_{REGIN}$ = 3.6 V (unless otherwise noted)

| | | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **Standard Mode (100 kHz)** | | | | | | |
| $t_{d(STA)}$ | Start to first falling edge of SCL | | 4 | | | µs |
| $t_{w(L)}$ | SCL pulse duration (low) | | 4.7 | | | µs |
| $t_{w(H)}$ | SCL pulse duration (high) | | 4 | | | µs |
| $t_{su(STA)}$ | Setup for repeated start | | 4.7 | | | µs |
| $t_{su(DAT)}$ | Data setup time | Host drives SDA | 250 | | | ns |
| $t_{h(DAT)}$ | Data hold time | Host drives SDA | 0 | | | ns |
| $t_{su(STOP)}$ | Setup time for stop | | 4 | | | µs |
| $t_{(BUF)}$ | Bus free time between stop and start | Includes command waiting time | 66 | | | µs |
| $t_f$ | SCL or SDA fall time [1] | | | | 300 | ns |
| $t_r$ | SCL or SDA rise time [1] | | | | 300 | ns |
| $f_{SCL}$ | Clock frequency [2] | | | | 100 | kHz |
| **Fast Mode (400 kHz)** | | | | | | |
| $t_{d(STA)}$ | Start to first falling edge of SCL | | 600 | | | ns |
| $t_{w(L)}$ | SCL pulse duration (low) | | 1300 | | | ns |
| $t_{w(H)}$ | SCL pulse duration (high) | | 600 | | | ns |
| $t_{su(STA)}$ | Setup for repeated start | | 600 | | | ns |
| $t_{su(DAT)}$ | Data setup time | Host drives SDA | 100 | | | ns |
| $t_{h(DAT)}$ | Data hold time | Host drives SDA | 0 | | | ns |
| $t_{su(STOP)}$ | Setup time for stop | | 600 | | | ns |
| $t_{(BUF)}$ | Bus free time between stop and start | Includes command waiting time | 66 | | | µs |
| $t_f$ | SCL or SDA fall time [1] | | | | 300 | ns |
| $t_r$ | SCL or SDA rise time [1] | | | | 300 | ns |
| $f_{SCL}$ | Clock frequency [2] | | | | 400 | kHz |

(1)   Specified by design. Not production tested.
(2)   If the clock frequency ($f_{SCL}$) is > 100 kHz, use 1-byte write commands for proper operation. All other transactions types are supported at 400 kHz. (See *I²C Interface* and *I²C Command Waiting Time*.)
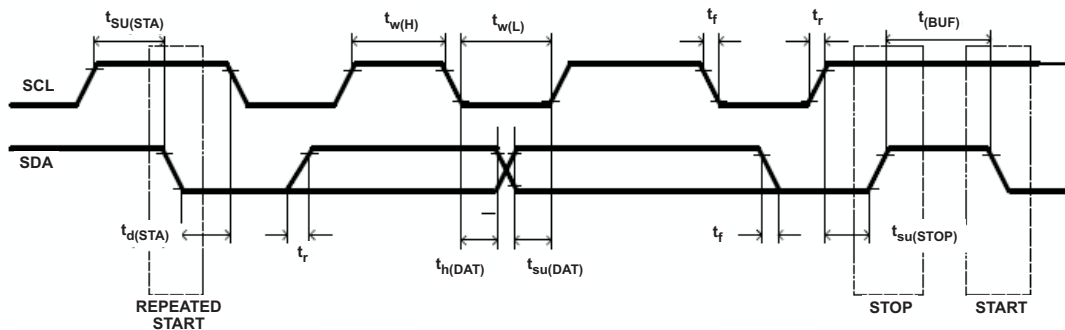
**Figure 1. I²C-Compatible Interface Timing Diagrams**
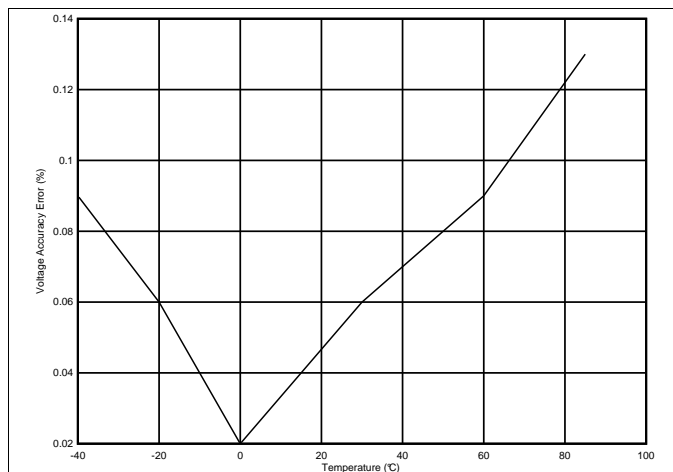
## 7.11 Typical Characteristics



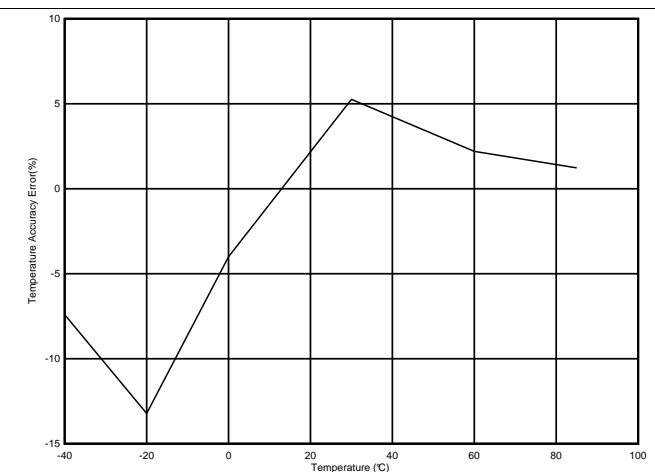**Figure 2. Voltage Accuracy**



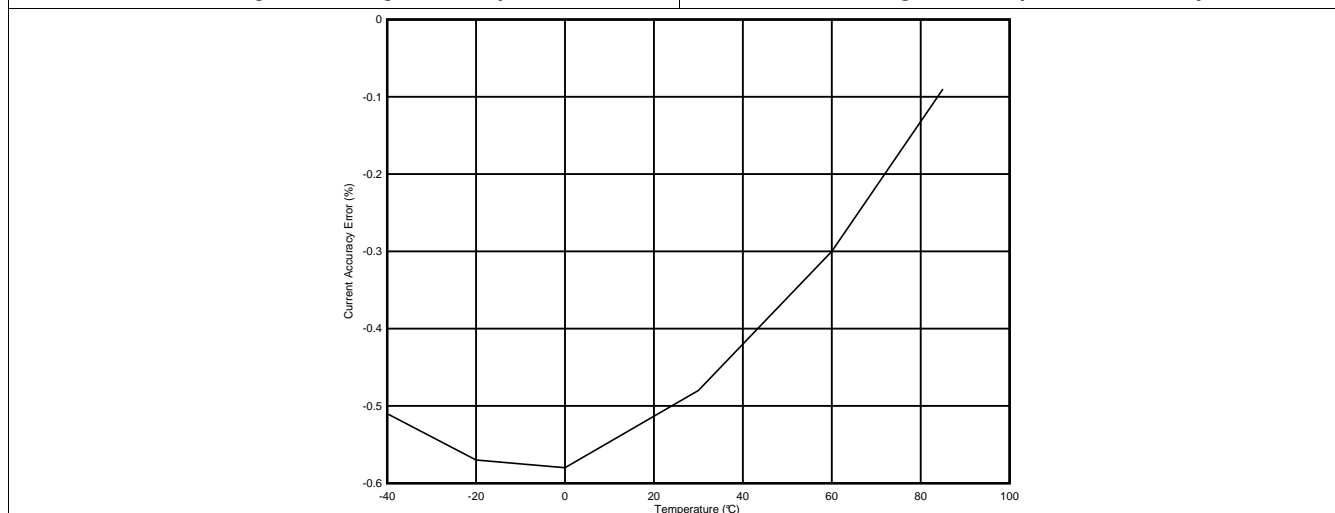**Figure 3. Temperature Accuracy**



**Figure 4. Current Accuracy**

# 8 Detailed Description

## 8.1 Overview

The bq27411-G1 fuel gauge accurately predicts the battery capacity and other operational characteristics of a single Li-based rechargeable cell. It can be interrogated by a system processor to provide cell information, such as state-of-charge (SOC). The fuel gauge is available in several options optimized for different battery cell chemistries (see *Device Comparison Table*). Configuration parameters unique to the customer's application are programmed in OTP memory at the customer's factory using a 7.4-V typical voltage applied to the PROG pin and a set of I$^2$C programming commands. More details are available in the *SmartFlash OTP Programming Application Report* (SLUA703).

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**NOTE**
**Formatting Conventions used in this Document:**

**Commands**: *italics* with parentheses() and no breaking spaces; for example, *Control()*

**Data Flash**: *italics*, **bold**, and breaking spaces; for example, ***Design Capacity***

**Register bits and flags**: *italics* with brackets [ ]; for example, *[TDA]*

**Data flash bits**: *italics*, **bold**, and brackets [ ]; for example, ***[LED1]***

**Modes and states**: ALL CAPITALS; for example, UNSEALED mode

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## 8.2 Functional Block Diagram



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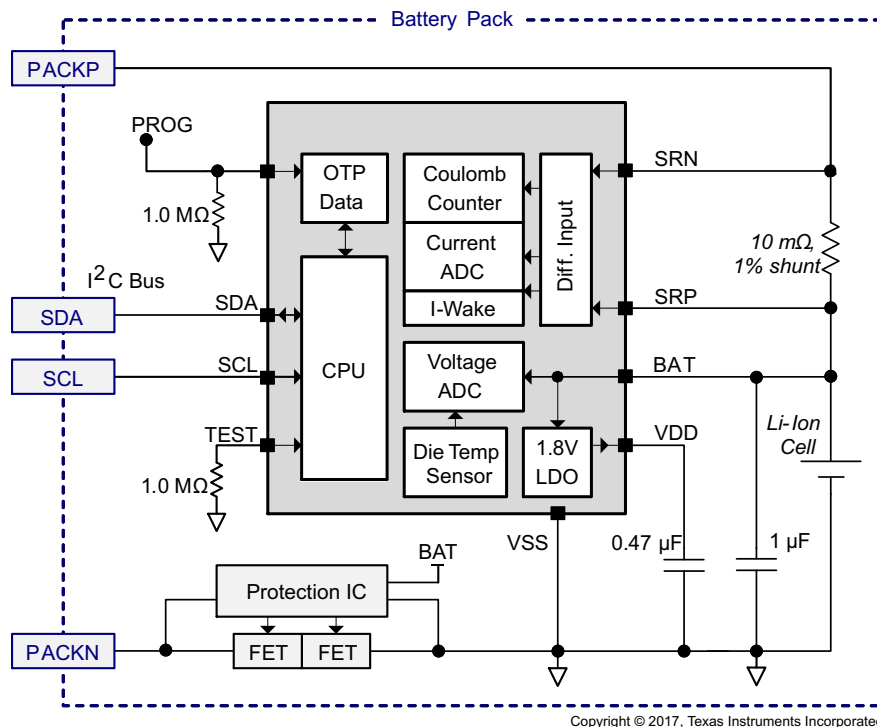
## 8.3 Feature Description

Information is accessed through a series of commands, called *Standard Commands*. Further capabilities are provided by the additional *Extended Commands* set. Both sets of commands, indicated by the general format *Command()*, are used to read and write information contained within the control and status registers, as well as its data locations.

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## Feature Description (continued)

The key to the high-accuracy gas gauging prediction is Texas Instruments proprietary Impedance Track algorithm. This algorithm uses cell measurements, characteristics, and properties to create state-of-charge predictions that can achieve high accuracy across a wide variety of operating conditions and over the lifetime of the battery.

The fuel gauge measures the charging or discharging of the battery by monitoring the voltage across a small-value sense resistor. When a cell is attached to the fuel gauge, cell impedance is computed, based on cell current, cell open-circuit voltage (OCV), and cell voltage under loading conditions.

The fuel gauge uses an integrated temperature sensor for estimating cell temperature. Alternatively, the host processor can provide temperature data for the fuel gauge.

For more details, see the *bq27411-G1 Technical Reference Manual* (SLUUAS7).

## 8.4  Device Functional Modes

To minimize power consumption, the fuel gauge has several power modes: INITIALIZATION, NORMAL, SLEEP, and HIBERNATE. The fuel gauge passes automatically between these modes, depending upon the occurrence of specific events, though a system processor can initiate some of these modes directly.

For more details, see the *bq27411-G1 Technical Reference Manual* (SLUUAS7).

## 8.5  Programming

### 8.5.1  Standard Data Commands

The bq27411-G1 fuel gauge uses a series of 2-byte standard commands to enable system reading and writing of battery information. Each standard command has an associated command-code pair, as indicated in Table 1. Because each command consists of two bytes of data, two consecutive I$^2$C transmissions must be executed both to initiate the command function, and to read or write the corresponding two bytes of data. For more details, see the *bq27411-G1 Technical Reference Manual* (SLUUAS7).

**Table 1. Standard Commands**

| NAME | | COMMAND CODE | UNIT | SEALED ACCESS |
|---|---|---|---|---|
| *Control()* | CNTL | 0x00 and 0x01 | NA | R/W |
| *Temperature()* | TEMP | 0x02 and 0x03 | 0.1°K | R/W |
| *Voltage()* | VOLT | 0x04 and 0x05 | mV | R |
| *Flags()* | FLAGS | 0x06 and 0x07 | NA | R |
| *NominalAvailableCapacity()* | | 0x08 and 0x09 | mAh | R |
| *FullAvailableCapacity()* | | 0x0A and 0x0B | mAh | R |
| *RemainingCapacity()* | RM | 0x0C and 0x0D | mAh | R |
| *FullChargeCapacity()* | FCC | 0x0E and 0x0F | mAh | R |
| *AverageCurrent()* | | 0x10 and 0x11 | mA | R |
| *StandbyCurrent()* | | 0x12 and 0x13 | mA | R |
| *MaxLoadCurrent()* | | 0x14 and 0x15 | mA | R |
| *AveragePower()* | | 0x18 and 0x19 | mW | R |
| *StateOfCharge()* | SOC | 0x1C and 0x1D | % | R |
| *InternalTemperature()* | | 0x1E and 0x1F | 0.1°K | R |
| *StateOfHealth()* | SOH | 0x20 and 0x21 | num / % | R |
| *RemainingCapacityUnfiltered()* | | 0x28 and 0x29 | mAh | R |
| *RemainingCapacityFiltered()* | | 0x2A and 0x2B | mAh | R |
| *FullChargeCapacityUnfiltered()* | | 0x2C and 0x2D | mAh | R |
| *FullChargeCapacityFiltered()* | | 0x2E and 0x2F | mAh | R |
| *StateOfChargeUnfiltered()* | | 0x30 and 0x31 | % | R |

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Product Folder Links: *bq27411-G1*

### 8.5.2 *Control()*: 0x00 and 0x01

Issuing a *Control()* command requires a subsequent 2-byte subcommand. These additional bytes specify the particular control function desired. The *Control()* command allows the system to control specific features of the fuel gauge during normal operation and additional features when the device is in different access modes, as described in Table 2. For additional details, see the *bq27411-G1 Technical Reference Manual* (SLUUAS7).

**Table 2. *Control()* Subcommands**

| CONTROL FUNCTION | CONTROL DATA | SEALED ACCESS | DESCRIPTION |
|---|---|---|---|
| CONTROL_STATUS | 0x0000 | Yes | Reports the status of device |
| DEVICE_TYPE | 0x0001 | Yes | Reports the device type (0x0421) |
| FW_VERSION | 0x0002 | Yes | Reports the firmware version of the device |
| DM_CODE | 0x0004 | Yes | Reports the Data Memory Code number stored in OTP memory |
| PREV_MACWRITE | 0x0007 | Yes | Returns previous MAC command code |
| CHEM_ID | 0x0008 | Yes | Reports the chemical identifier of the battery profile currently used by the Impedance Track configuration |
| SET_HIBERNATE | 0x0011 | Yes | Forces CONTROL_STATUS [*HIBERNATE*] to 1 |
| CLEAR_HIBERNATE | 0x0012 | Yes | Forces CONTROL_STATUS [*HIBERNATE*] to 0 |
| SET_CFGUPDATE | 0x0013 | No | Forces CONTROL_STATUS [*CFGUPMODE*] to 1 and gauge enters CONFIG UPDATE mode |
| SEALED | 0x0020 | No | Places the device in SEALED access mode |
| RESET | 0x0041 | No | Performs a full device reset |
| SOFT_RESET | 0x0042 | No | Gauge exits CONFIG UPDATE mode |

### 8.5.3 Extended Data Commands

Extended data commands offer additional functionality beyond the standard set of commands. They are used in the same manner; however, unlike standard commands, extended commands are not limited to 2-byte words. The number of command bytes for a given extended command ranges in size from single to multiple bytes, as specified in Table 3.

**Table 3. Extended Commands**

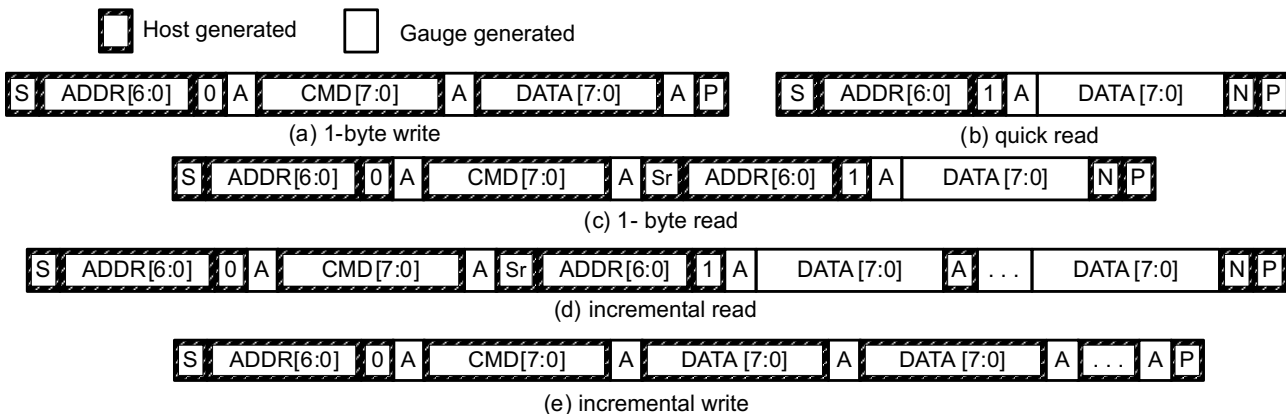| Name | Command Code | Unit | SEALED Access[1] [2] | UNSEALED Access[1] [2] |
|---|---|---|---|---|
| *OpConfig()* | 0x3A and 0x3B | NA | R | R |
| *DesignCapacity()* | 0x3C and 0x3D | mAh | R | R |
| *DataClass()* [2] | 0x3E | NA | NA | RW |
| *DataBlock()* [2] | 0x3F | NA | RW | RW |
| *BlockData()* | 0x40 through 0x5F | NA | R | RW |
| *BlockDataCheckSum()* | 0x60 | NA | RW | RW |
| *BlockDataControl()* | 0x61 | NA | NA | RW |
| Reserved | 0x62 through 0x7F | NA | R | R |

(1) SEALED and UNSEALED states are entered via commands to *Control()* 0x00 and 0x01
(2) In SEALED mode, data cannot be accessed through commands 0x3E and 0x3F.

### 8.5.4 Communications

#### 8.5.4.1 $I^2C$ Interface

The bq27411-G1 fuel gauge supports the standard $I^2C$ read, incremental read, quick read, one-byte write, and incremental write functions. The 7-bit device address (ADDR) is the most significant 7 bits of the hex address and is fixed as 1010101. The first 8 bits of the $I^2C$ protocol are, therefore, 0xAA or 0xAB for write or read, respectively.

☐ Host generated    ☐ Gauge generated

| S | ADDR[6:0] | 0 | A | CMD[7:0] | A | DATA [7:0] | A | P |    | S | ADDR[6:0] | 1 | A | DATA [7:0] | N | P |

(a) 1-byte write                                                          (b) quick read

| S | ADDR[6:0] | 0 | A | CMD[7:0] | A | Sr | ADDR[6:0] | 1 | A | DATA [7:0] | N | P |

(c) 1- byte read

| S | ADDR[6:0] | 0 | A | CMD[7:0] | A | Sr | ADDR[6:0] | 1 | A | DATA [7:0] | A | . . . | DATA [7:0] | N | P |

(d) incremental read

| S | ADDR[6:0] | 0 | A | CMD[7:0] | A | DATA [7:0] | A | DATA [7:0] | A | . . . | A | P |

(e) incremental write

(S = Start, Sr = Repeated Start, A = Acknowledge, N = No Acknowledge , and P = Stop).

The quick read returns data at the address indicated by the address pointer. The address pointer, a register internal to the I$^2$C communication engine, increments whenever data is acknowledged by the fuel gauge or the I$^2$C master. "Quick writes" function in the same manner and are a convenient means of sending multiple bytes to consecutive command locations (such as two-byte commands that require two bytes of data).

The following command sequences are not supported:

Attempt to write a read-only address (NACK after data sent by master):

| S | ADDR[6:0] | 0 | A | CMD[7:0] | A | DATA[7:0] | N | P |
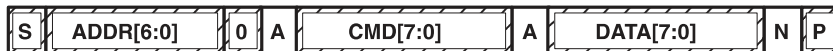
Attempt to read an address above 0x6B (NACK command):

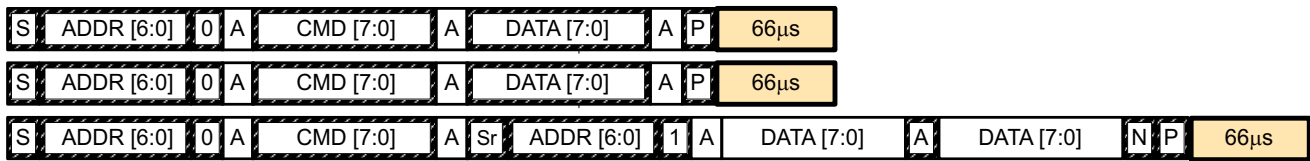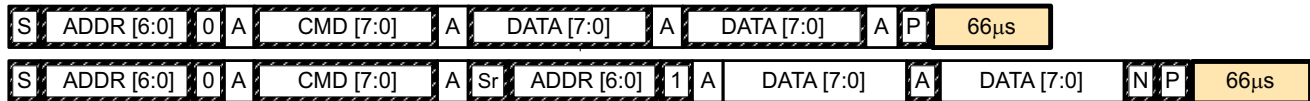| S | ADDR[6:0] | 0 | A | CMD[7:0] | N | P |

### 8.5.4.2  I$^2$C Time Out

The I$^2$C engine releases both SDA and SCL if the I$^2$C bus is held low for 2 seconds. If the fuel gauge is holding the lines, releasing them frees them for the master to drive the lines. If an external condition is holding either of the lines low, the I$^2$C engine enters the low-power SLEEP mode.
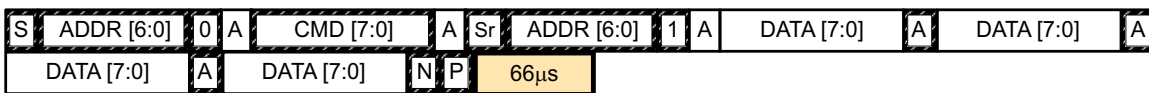
### 8.5.4.3  I$^2$C Command Waiting Time

To ensure proper operation at 400 kHz, a $t_{(BUF)}$ ≥ 66-µs bus-free waiting time must be inserted between all packets addressed to the fuel gauge. In addition, if the SCL clock frequency ($f_{SCL}$) is > 100 kHz, use individual 1-byte write commands for proper data flow control. The following diagram shows the standard waiting time required between issuing the control subcommand the reading the status result. For read-write standard command, a minimum of 2 seconds is required to get the result updated. For read-only standard commands, there is no waiting time required, but the host must not issue any standard command more than two times per second. Otherwise, the gauge could result in a reset issue due to the expiration of the watchdog timer.

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | DATA [7:0] | A | P | 66μs |

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | DATA [7:0] | A | P | 66μs |

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | Sr | ADDR [6:0] | 1 | A | DATA [7:0] | A | DATA [7:0] | N | P | 66μs |

Waiting time inserted between two 1-byte write packets for a subcommand and reading results
(required for 100 kHz < $f_{SCL}$ ≤ 400 kHz)

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | DATA [7:0] | A | DATA [7:0] | A | P | 66μs |

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | Sr | ADDR [6:0] | 1 | A | DATA [7:0] | A | DATA [7:0] | N | P | 66μs |

Waiting time inserted between incremental 2-byte write packet for a subcommand and reading results
(acceptable for $f_{SCL}$ ≤ 100 kHz)

| S | ADDR [6:0] | 0 | A | CMD [7:0] | A | Sr | ADDR [6:0] | 1 | A | DATA [7:0] | A | DATA [7:0] | A |
| DATA [7:0] | A | DATA [7:0] | N | P | 66μs |

Waiting time inserted after incremental read

### 8.5.4.4  $I^2C$ Clock Stretching

A clock stretch of up to 4 ms can occur during all modes of fuel gauge operation. In SLEEP and HIBERNATE modes, a short ≤ 100-μs clock stretch occurs on all I2C traffic as the device must wake-up to process the packet. In the other modes (INITIALIZATION, NORMAL) a ≤ 4-ms clock stretching period may occur within packets addressed for the fuel gauge. The majority of clock stretch periods are small while the I2C interface performs normal data flow control.

# 9 Applications and Implementation

**NOTE**

Information in the following application section is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

## 9.1 Application Information

The bq27411-G1 device is a fuel gauging solution for single-cell Li-Ion battery packs. The device requires minimal configuration and uses One Time Programmable (OTP) Non-Volatile Memory (NVM) to avoid an initialization download by the system processor. To allow for optimal performance in the end application, special considerations must be taken to ensure minimization of measurement error through proper printed circuit board (PCB) board layout. Such requirements are detailed in *Design Requirements*.
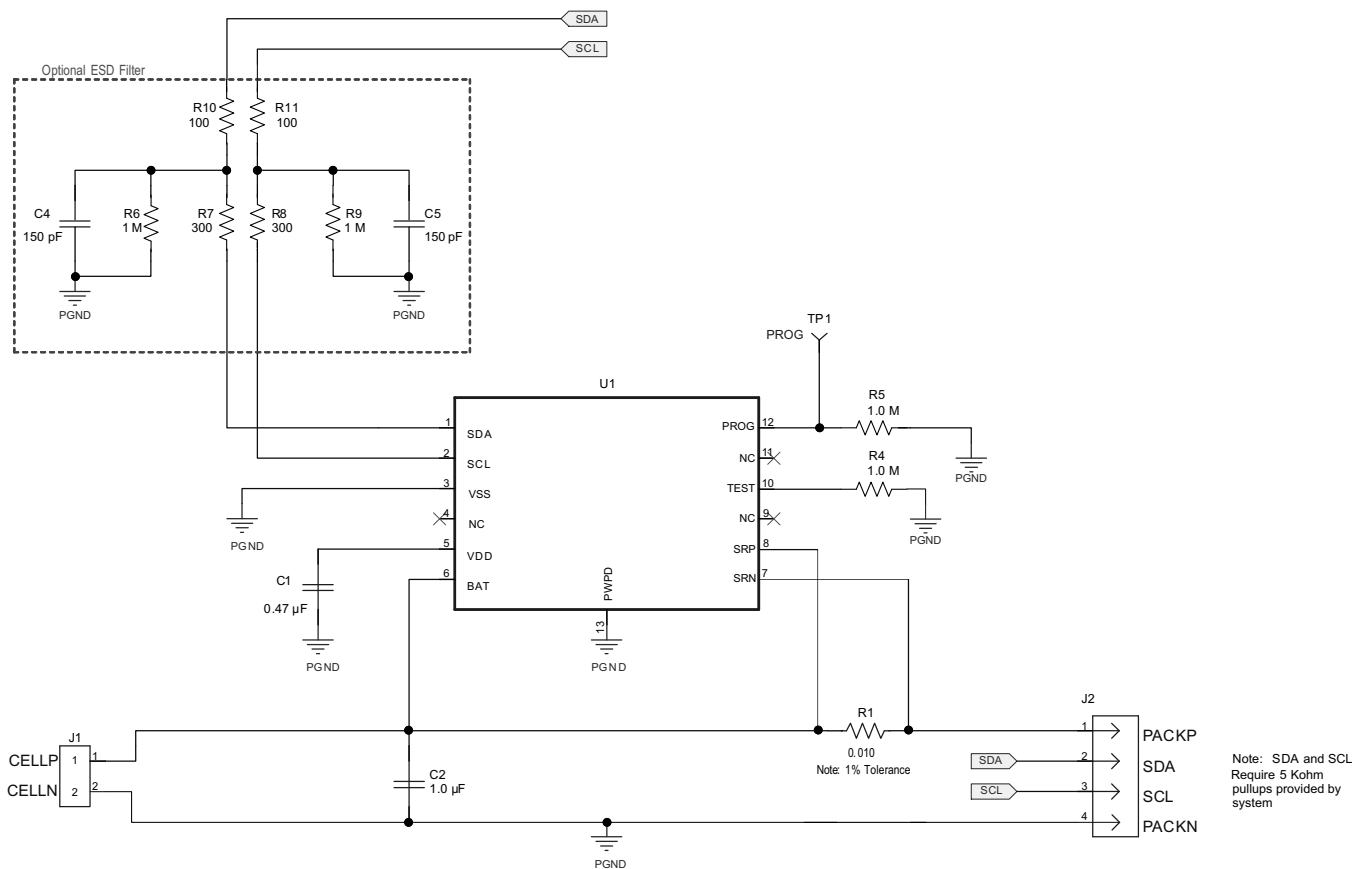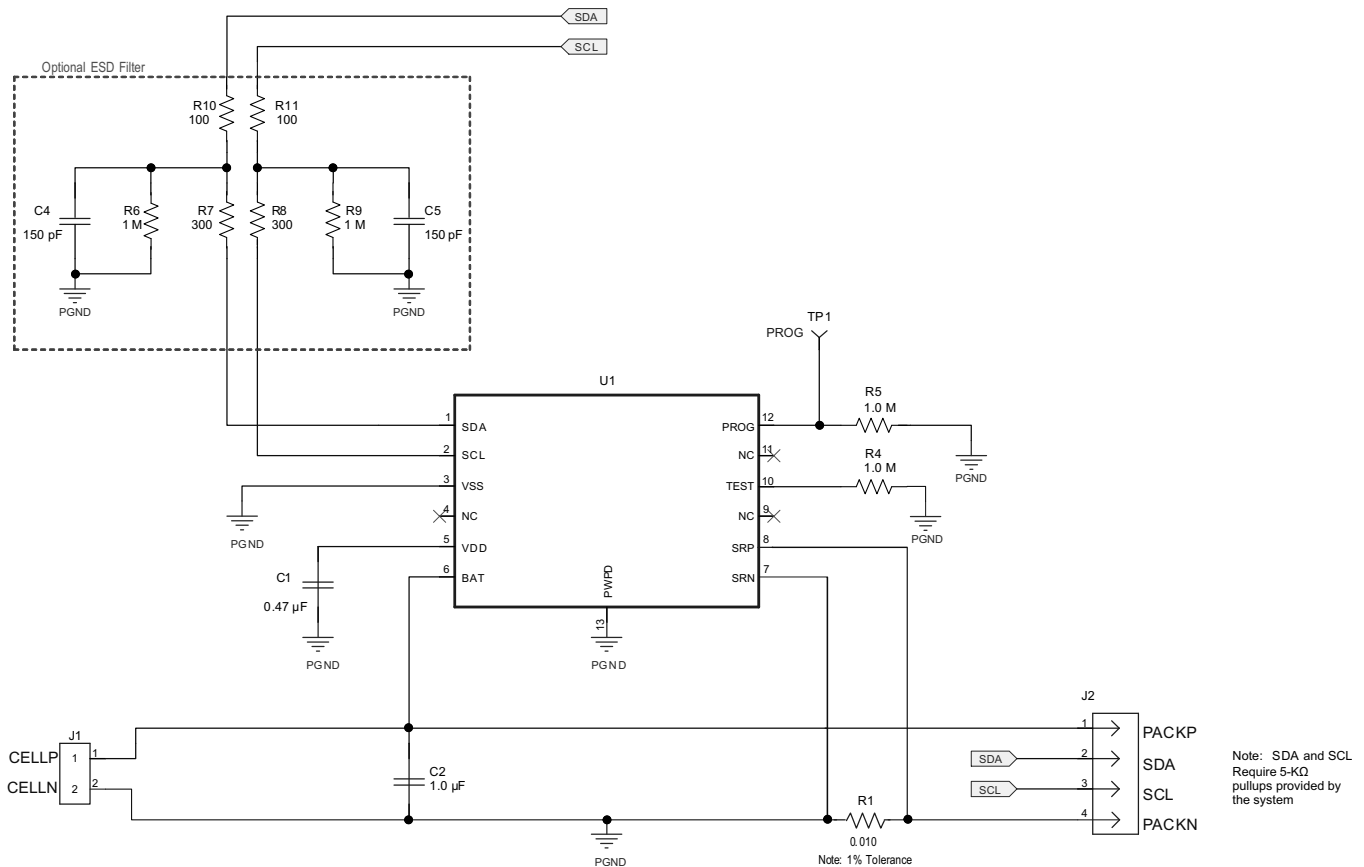
## 9.2 Typical Applications



**Figure 5. Typical Application with High-Side Current Sense Resistor**

## Typical Applications (continued)



**Figure 6. Typical Application with Low-Side Current Sense Resistor**

### 9.2.1 Design Requirements

As shipped from the Texas Instruments factory, many bq27411-G1 parameters in OTP NVM are left in the unprogrammed state (zero) while some parameters directly associated with the CHEMID are preprogrammed. This partially programmed configuration facilitates customization for each end application. Upon device reset, the contents of OTP are copied to associated volatile RAM-based Data Memory blocks. For proper operation, all parameters in RAM-based Data Memory require initialization—either by updating Data Memory parameters in a lab/evaluation situation or by programming the OTP for customer production. Chapter 5 in the *bq27411-G1 Technical Reference Manual* (SLUUAS7) shows the default value and a typically expected value appropriate for most applications.

### 9.2.2 Detailed Design Procedure

#### 9.2.2.1 High-Side or Low-Side Sense Resistor

The bq27411-G1 device can be used with a high-side current resistor, as shown in Figure 5 or a low-side current resistor, as shown in Figure 6.

#### 9.2.2.2 BAT Voltage Sense Input

A ceramic capacitor at the input to the BAT pin is used to bypass AC voltage ripple to ground, greatly reducing its influence on battery voltage measurements. It proves most effective in applications with load profiles that exhibit high-frequency current pulses (that is, cell phones) but is recommended for use in all applications to reduce noise on this sensitive high-impedance measurement node.

## Typical Applications (continued)

### 9.2.2.3  Sense Resistor Selection

Any variation encountered in the resistance present between the SRP and SRN pins of the fuel gauge will affect the resulting differential voltage, and derived current, it senses. As such, it is recommended to select a sense resistor with minimal tolerance and temperature coefficient of resistance (TCR) characteristics. The standard recommendation based on best compromise between performance and price is a 1% tolerance, 50-ppm drift sense resistor with a 1-W power rating.

### 9.2.2.4  Communication Interface Lines

A protection network composed of resistors and capacitors is recommended on each of the serial communication inputs to protect the fuel gauge from dangerous ESD transients.

### 9.2.3  Application Curves



**Figure 7. Voltage Accuracy**



**Figure 8. Temperature Accuracy**



**Figure 9. Current Accuracy**
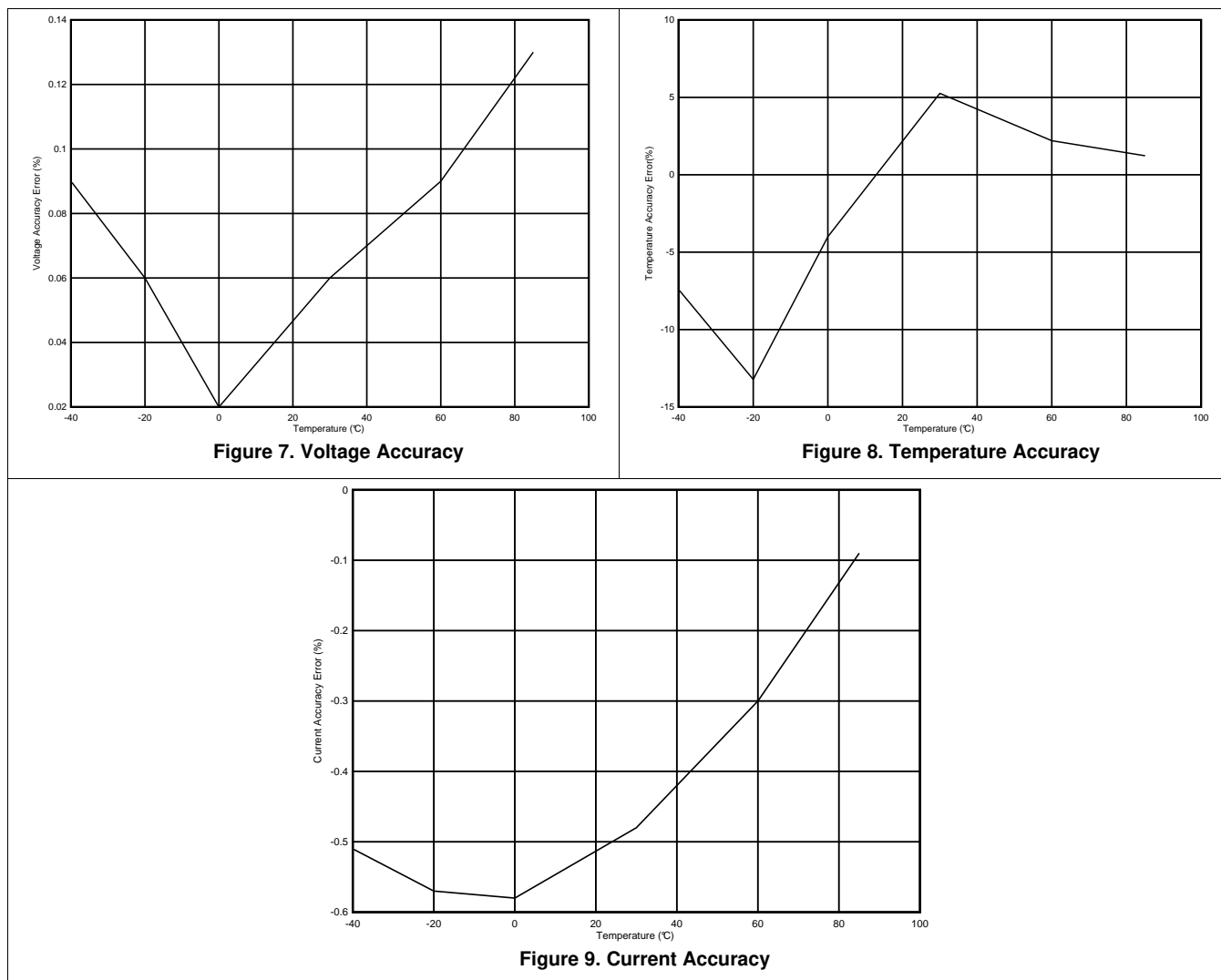
## 10 Power Supply Recommendation

### 10.1 Power Supply Decoupling

The battery connection on the BAT pin is used for two purposes:
- To supply power to the fuel gauge
- As an input for voltage measurement of the battery

A capacitor of value of at least 1 µF should be connected between BAT and $V_{SS}$. The capacitor should be placed close to the gauge IC and have short traces to both the $V_{DD}$ pin and $V_{SS}$.

The fuel gauge has an integrated LDO with an output on the $V_{DD}$ pin of approximately 1.8 V. A capacitor of value at least 0.47 µF should be connected between the $V_{DD}$ pin and $V_{SS}$. The capacitor should be placed close to the gauge IC and have short traces to both the $V_{DD}$ pin and $V_{SS}$.

# 11 Layout

## 11.1 Layout Guidelines

- A capacitor, of value at least 0.47 µF, is connected between the $V_{DD}$ pin and $V_{SS}$. The capacitor should be placed close to the gauge IC and have short traces to both the $V_{DD}$ pin and $V_{SS}$.
- It is required to have a capacitor, at least 1.0 µF, connect between the BAT pin and $V_{SS}$ if the connection between the battery pack and the gauge BAT pin has the potential to pick up noise. The capacitor should be placed close to the gauge IC and have short traces to both the $V_{DD}$ pin and $V_{SS}$.
- If the external pullup resistors on the SCL and SDA lines will be disconnected from the host during low-power operation, it is recommended to use external 1-M$\Omega$ pulldown resistors to $V_{SS}$ to avoid floating inputs to the I2C engine.
- The value of the SCL and SDA pullup resistors should take into consideration the pullup voltage and the bus capacitance. Some recommended values, assuming a bus capacitance of 10 pF, can be seen in Table 4.

**Table 4. Recommended Values for SCL and SDA Pullup Resistors**

| VPU | 1.8 V | | 3.3 V | |
|---|---|---|---|---|
| | **Range** | **Typical** | **Range** | **Typical** |
| $R_{PU}$ | 400 $\Omega$ ≤ $R_{PU}$ ≤ 37.6 k$\Omega$ | 10 k$\Omega$ | 900 $\Omega$ ≤ $R_{PU}$ ≤ 29.2 k$\Omega$ | 5.1 k$\Omega$ |

- If the GPOUT pin is not used by the host, the pin should still be pulled up to $V_{DD}$ with a 4.7-k$\Omega$ or 10-k$\Omega$ resistor. After the OTP has been programmed, it is recommended that PROG be connected to the SDA line with a 470-K$\Omega$ resistor so that in cases where the device is in SHUTDOWN, toggling PROG can wake the gauge up from the SHUTDOWN state.
- If the battery pack thermistor is not connected to the BIN pin, the BIN pin should be pulled down to $V_{SS}$ with a 10-k$\Omega$ resistor.
- The BIN pin should not be shorted directly to $V_{DD}$ or $V_{SS}$.
- The actual device ground is the center pin (B2). The C1 pin is floating internally and can be used as a bridge to connect the board ground plane to the device ground (B2).
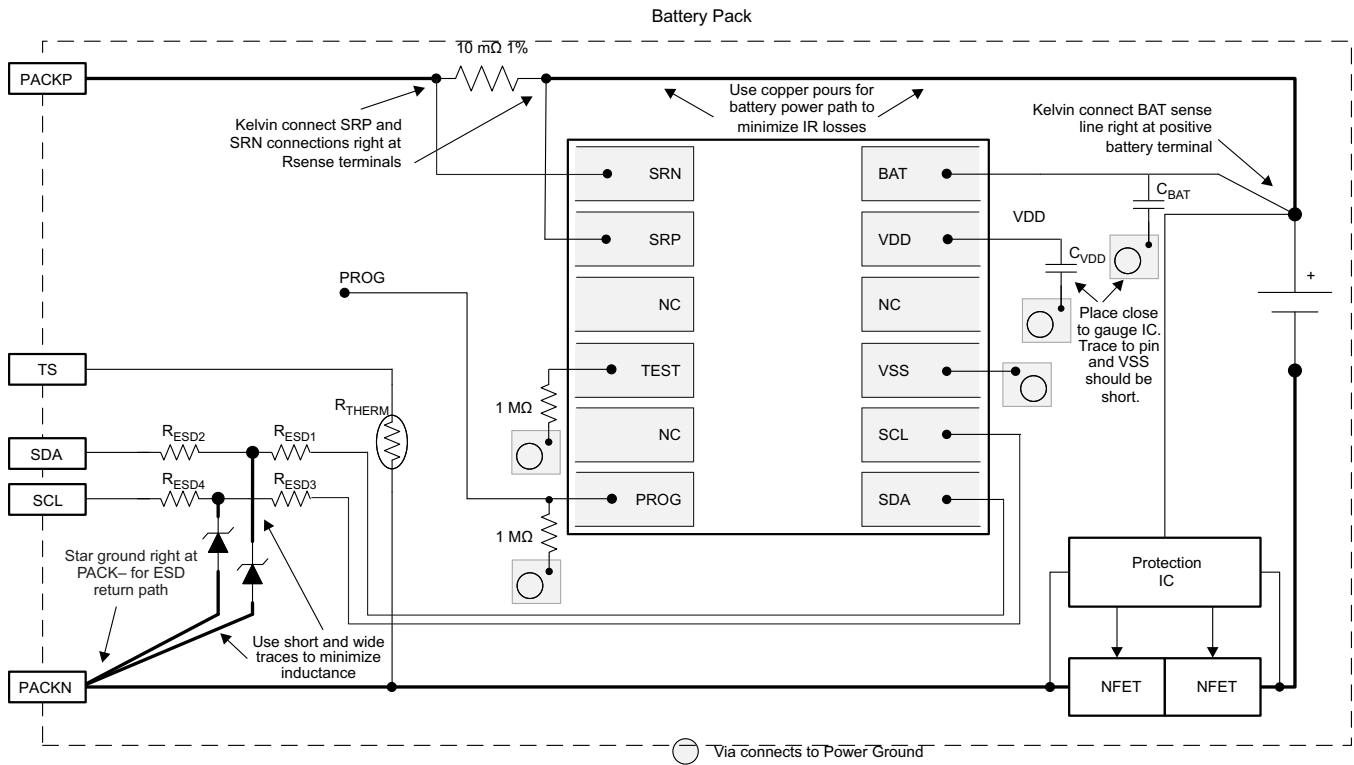
## 11.2 Layout Example



**Figure 10. bq27411-G1 Board Layout**

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Product Folder Links: *bq27411-G1*

## 12   Device and Documentation Support

### 12.1   Documentation Support

#### 12.1.1   Related Documentation

- *bq27411-G1 Technical Reference Manual* (SLUUAS7)
- *bq27411 EVM: Single-Cell Technology User's Guide* (SLUUAP3)
- *SmartFlash OTP Programming* (SLUA703)
- *Quickstart Guide for bq27411-G1* (SLUUAP6)
- *Single Cell Gas Gauge Circuit Design* (SLUA456)
- *Key Design Considerations for the bq27500 and bq27501* (SLUA439)
- *Single Cell Impedance Track Printed-Circuit Board Layout Guide* (SLUA457)
- *ESD and RF Mitigation in Handheld Battery Electronics* (SLUA460)

#### 12.1.2   Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community.* Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 12.2   Trademarks

Impedance Track, E2E are trademarks of Texas Instruments.
$I^2C$ is a trademark of NXP B.V. Corporation.
All other trademarks are the property of their respective owners.

### 12.3   Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

### 12.4   Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 13   Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead finish/ Ball material (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BQ27411DRZR-G1A | ACTIVE | SON | DRZ | 12 | 3000 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | BQ27 411A | Samples |
| BQ27411DRZR-G1C | ACTIVE | SON | DRZ | 12 | 3000 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | BQ27 411C | Samples |
| BQ27411DRZT-G1A | ACTIVE | SON | DRZ | 12 | 250 | RoHS & Green | NIPDAU | Level-1-260C-UNLIM | -40 to 85 | BQ27 411A | Samples |
| BQ27411DRZT-G1C | ACTIVE | SON | DRZ | 12 | 250 | RoHS & Green | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | BQ27 411C | Samples |

**(1)** The marketing status values are defined as follows:
**ACTIVE:** Product device recommended for new designs.
**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.
**OBSOLETE:** TI has discontinued the production of the device.

**(2) RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

**(3)** MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

**(4)** There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

**(5)** Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

**(6)** Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**



**TAPE DIMENSIONS**



| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**



*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BQ27411DRZR-G1A | SON | DRZ | 12 | 3000 | 330.0 | 12.4 | 2.8 | 4.3 | 1.2 | 4.0 | 12.0 | Q2 |
| BQ27411DRZR-G1C | SON | DRZ | 12 | 3000 | 330.0 | 12.4 | 2.8 | 4.3 | 1.2 | 4.0 | 12.0 | Q2 |
| BQ27411DRZT-G1A | SON | DRZ | 12 | 250 | 180.0 | 12.4 | 2.8 | 4.3 | 1.2 | 4.0 | 12.0 | Q2 |
| BQ27411DRZT-G1C | SON | DRZ | 12 | 250 | 180.0 | 12.4 | 2.8 | 4.3 | 1.2 | 4.0 | 12.0 | Q2 |

**TAPE AND REEL BOX DIMENSIONS**

*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| BQ27411DRZR-G1A | SON | DRZ | 12 | 3000 | 346.0 | 346.0 | 33.0 |
| BQ27411DRZR-G1C | SON | DRZ | 12 | 3000 | 346.0 | 346.0 | 33.0 |
| BQ27411DRZT-G1A | SON | DRZ | 12 | 250 | 182.0 | 182.0 | 20.0 |
| BQ27411DRZT-G1C | SON | DRZ | 12 | 250 | 210.0 | 185.0 | 35.0 |

B

4.15
3.85

A

PIN 1 INDEX AREA

2.65
2.35

1
0.8

0.05
0

C

SEATING PLANE

0.08 C

2.55
2.35

2X (0.2)

(0.2) TYP

6

7

SYMM
℄

13

2X 2

2.05
1.85

10X 0.4

1

12

PIN 1 ID
(OPTIONAL)

SYMM
℄

12X 0.3
0.1

12X 0.5
0.3

0.1 Ⓜ C A B
0.05 Ⓜ C

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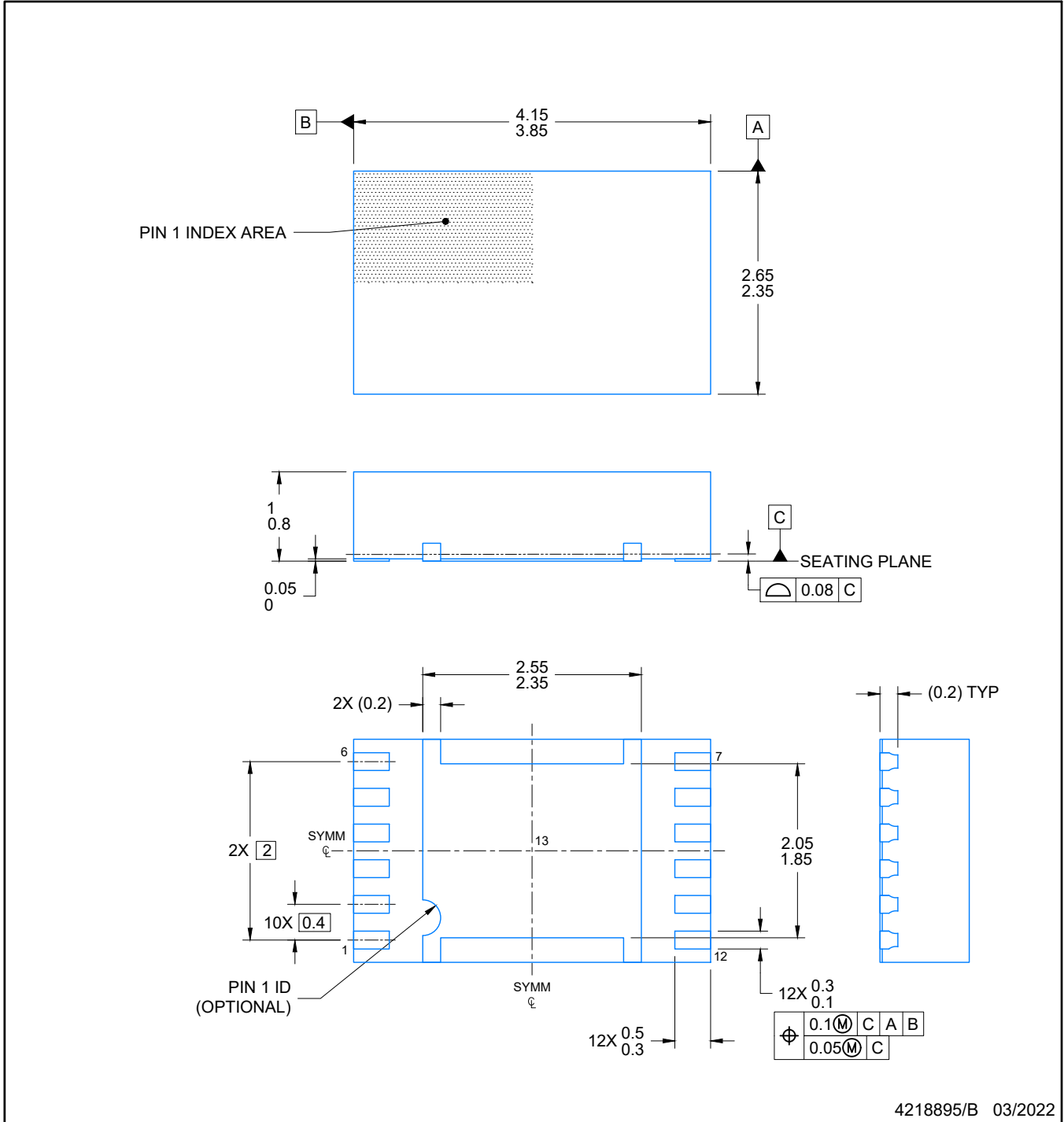
NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical performance.

PLASTIC QUAD FLATPACK- NO LEAD

12X (0.6)

12X (0.2)

2X (2.25)

2X (0.975)

1

10X (0.4)

SYMM

2X (2)

(Ø0.2) VIA
TYP

13

6

(R0.05) TYP

SYMM

12

(1.95)

(2.9)

2X (0.725)

7

4X (0.2)

(2.45)

(3.8)

## LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 20X

0.05 MAX
ALL AROUND

EXPOSED
METAL

METAL

SOLDER MASK
OPENING

NON SOLDER MASK
DEFINED
(PREFERRED)

0.05 MIN
ALL AROUND

EXPOSED
METAL

METAL UNDER
SOLDER MASK

SOLDER MASK
OPENING

SOLDER MASK
DEFINED

## SOLDER MASK DETAILS
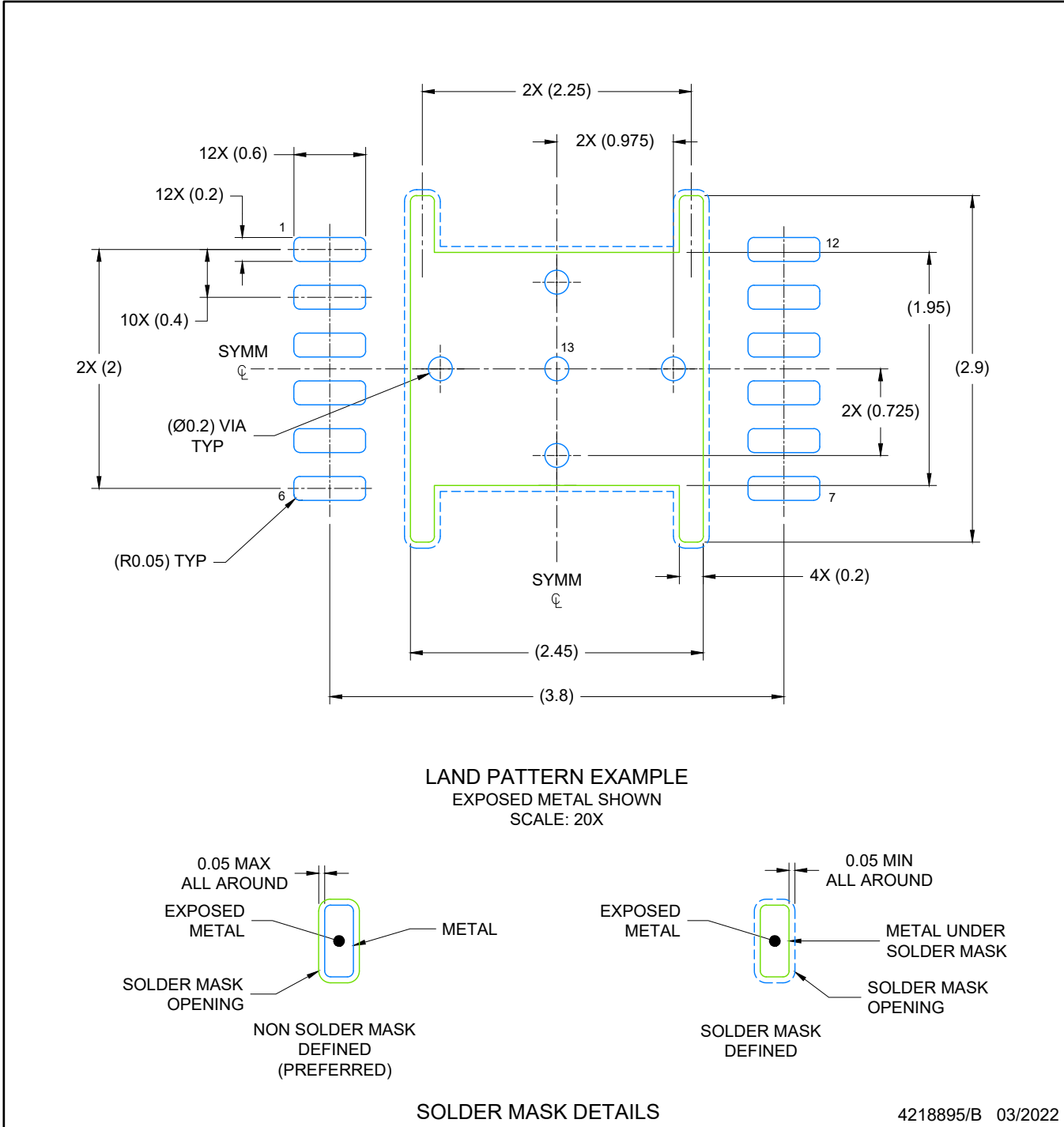
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NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL

EXPOSED PAD
79% PRINTED COVERAGE BY AREA
SCALE: 20X

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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