TEXAS INSTRUMENTS

bq27532-G1 Battery Management Unit Impedance Track™ Fuel Gauge for bq2425x Charger

1 Features

- Battery Fuel Gauge and Charger Controller for 1-Cell Li-Ion Applications up to 14,500-mAh Capacity
- Resides on System Main Board
- Battery Fuel Gauge Based on Patented Impedance Track™ Technology
  - Models the Battery Discharge Curve for Accurate Remaining Capacity Predictions
  - Automatically Adjusts for Battery Aging, Battery Self-Discharge, and Temperature and Rate Inefficiencies
  - Low-value Sense Resistor (5 to 20 mΩ)
- Battery Charger Controller With Customizable Charge Profiles
  - Configurable Charge Voltage and Current Based on Temperature
  - Optional State-of-Health (SoH) and Multi-Level Based Charge Profiles
- Host-free Autonomous Battery Management System
  - Reduced Software Overhead Allows for Easy Portability Across Platforms and Shorter OEM Design Cycles
  - Higher Safety and Security
- Runtime Improvements
  - Longer Battery Runtime Leveraging Impedance Track™ Technology
  - Tighter Accuracy Controls for Charger Termination
  - Improved Recharge Thresholds
- Intelligent Charging – Customized and Adaptive Charging Profiles
  - Charger Control Based on SoH
  - Temperature Level Charging (TLC)
- Stand-alone Battery Charger Controller for bq2425x Single-Cell Switch-mode Battery Charger
- 400-kHz I^2C™ Interface for Connection to System Microcontroller Port

2 Applications

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

3 Description

The bq27532-G1 system-side, Li-Ion battery management unit is a microcontroller peripheral that provides Impedance Track™ fuel gauging and charging control for single-cell Li-Ion battery packs. The fuel gauge requires little system microcontroller firmware development. Together with bq2425x single-cell switch-mode charger, the fuel gauge manages an embedded battery (non-removable) or a removable battery pack.

The fuel gauge uses the patented Impedance Track algorithm for fuel gauging, and provides information, such as remaining battery capacity (mAh), state-of-charge (%), runtime-to-empty (minimum), battery voltage (mV), temperature (°C), and SoH (%).

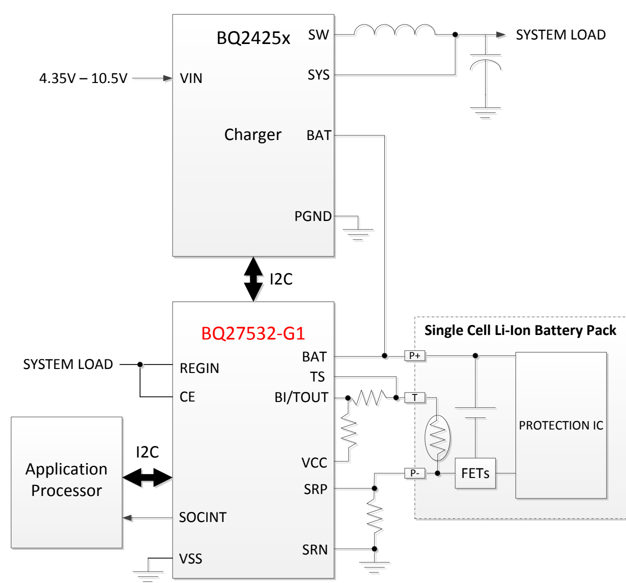
Battery fuel gauging with the device requires only PACK+ (P+), PACK– (P–), and thermistor (T) connections to a removable battery pack or embedded battery circuit. The 15-pin NanoFree™ (CSP) package has dimensions of 2.61 mm × 1.96 mm with 0.5-mm lead pitch. It is ideal for space-constrained applications.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
bq27532-G1	CSP (15)	2.61 mm × 1.96 mm

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

Simplified Schematic



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4 Revision History

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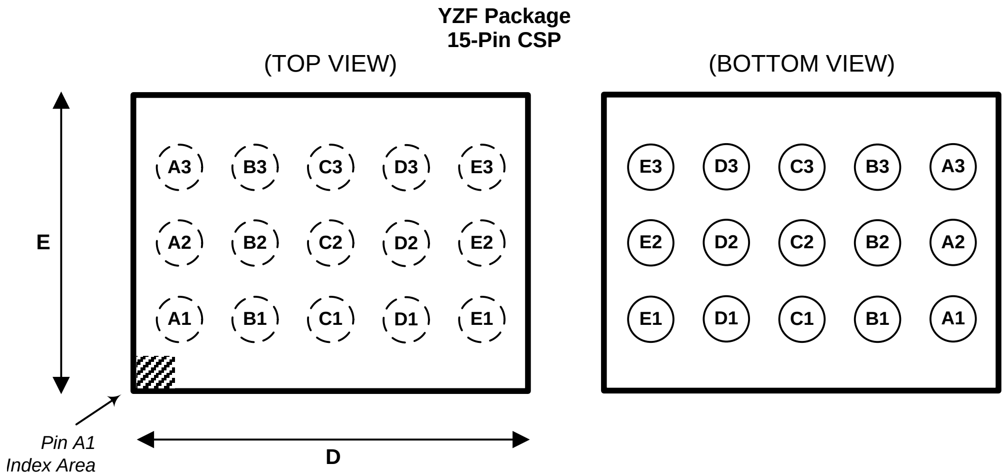
Changes from Revision A (October 2015) to Revision B	Page
• Changed *ESD Ratings*	4

5 Pin Configuration and Functions



DIM	MIN	TYP	MAX	UNITS
D	2580	2610	2640	µm
E	1926	1956	1986	

Pin Functions

PIN		TYPE(1)	DESCRIPTION
NAME	NUMBER		
BAT	E2	I	Cell-voltage measurement input. ADC input. TI recommends 4.8 V maximum for conversion accuracy.
BI/TOUT	E3	IO	Battery-insertion detection input. Power pin for pack thermistor network. Thermistor-multiplexer control pin. Use with pullup resistor > 1 MΩ (1.8 MΩ typical).
BSCL	B2	O	Battery charger clock output line for chipset communication. Use without external pullup resistor. Push-pull output.
BSDA	C3	IO	Battery charger data line for chipset communication. Use without external pullup resistor. Push-pull output.
CE	D2	I	Chip enable. Internal LDO is disconnected from REGIN when driven low. **Note:** CE has an internal ESD protection diode connected to REGIN. TI recommends maintaining $V_{CE} \leq V_{REGIN}$ under all conditions.
REGIN	E1	P	Regulator input. Decouple with 0.1-µF ceramic capacitor to V_{SS}.
SCL	A3	I	Slave I^2C serial communications clock input line for communication with system (master). Open-drain IO. Use with 10-kΩ pullup resistor (typical).
SDA	B3	IO	Slave I^2C serial communications data line for communication with system (master). Open-drain IO. Use with 10-kΩ pullup resistor (typical).
SOC_INT	A2	IO	SOC state interrupts output. Generates a pulse as described in *bq27532-G1 Technical Reference Manual,* SLUUB04. Open-drain output.
SRN	B1	AI	Analog input pin connected to the internal coulomb counter where SRN is nearest the V_{SS} connection. Connect to 5- to 20-mΩ sense resistor.
SRP	A1	AI	Analog input pin connected to the internal coulomb counter where SRP is nearest the PACK– connection. Connect to 5- to 20-mΩ sense resistor.
TS	D3	AI	Pack thermistor voltage sense (use 103AT-type thermistor). ADC input.
V_{CC}	D1	P	Regulator output and bq27532-G1 device power. Decouple with 1-µF ceramic capacitor to V_{SS}. Pin is not intended to power additional external loads.
V_{SS}	C1, C2	P	Device ground

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

6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
V_{REGIN}	Regulator input	–0.3	5.5	V
		–0.3	6 (2)	V
V_{CE}	CE input pin	–0.3	V_{REGIN} + 0.3	V
V_{CC}	Supply voltage	–0.3	2.75	V
V_{IOD}	Open-drain IO pins (SDA, SCL, SOC_INT)	–0.3	5.5	V
V_{BAT}	BAT input pin	–0.3	5.5	V
		–0.3	6 (2)	V
V_I	Input voltage to all other pins (BI/TOUT, TS, SRP, SRN, BSCL, BSDA)	–0.3	V_{CC} + 0.3	V
T_A	Operating free-air temperature	–40	85	°C
T_{stg}	Storage temperature	–65	150	°C

(1) Stresses beyond those listed as *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 as recommended operating conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Condition not to exceed 100 hours at 25°C lifetime.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001, BAT pin(1)	±1500	V
		Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001, All other pins(1)	±2000	
		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.

6.3 Recommended Operating Conditions

T_A = –40°C to 85°C, V_{REGIN} = V_{BAT} = 3.6 V (unless otherwise noted)

			MIN	NOM	MAX	UNIT
V_{REGIN}	Supply voltage	No operating restrictions	2.8		4.5	V
		No flash writes	2.45		2.8	
C_{REGIN}	External input capacitor for internal LDO between REGIN and V_{SS}	Nominal capacitor values specified. Recommend a 5% ceramic X5R-type capacitor located close to the device.		0.1		µF
C_{LDO25}	External output capacitor for internal LDO between V_{CC} and V_{SS}		0.47	1		µF
t_{PUCD}	Power-up communication delay			250		ms

6.4 Thermal Information

THERMAL METRIC(1)		bq27532-G1 YZF (CSP) 15 PINS	UNIT
$R_{θJA}$	Junction-to-ambient thermal resistance	70	°C/W
$R_{JC(top)}$	Junction-to-case (top) thermal resistance	17	°C/W
$R_{θJB}$	Junction-to-board thermal resistance	20	°C/W
$Ψ_{JT}$	Junction-to-top characterization parameter	1	°C/W
$Ψ_{JB}$	Junction-to-board characterization parameter	18	°C/W
$R_{θJC(bottom)}$	Junction-to-case (bottom) thermal resistance	n/a	°C/W

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

6.5 Electrical Characteristics: Supply Current

T_A = 25°C and V_{REGIN} = V_{BAT} = 3.6 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
I_{CC} (1)	Normal operating-mode current	Fuel gauge in NORMAL mode I_{LOAD} > ***Sleep current***		118		µA
I_{SLP+} (1)	Sleep+ operating-mode current	Fuel gauge in SLEEP+ mode I_{LOAD} < ***Sleep current***		62		µA
I_{SLP} (1)	Low-power storage-mode current	Fuel gauge in SLEEP mode I_{LOAD} < ***Sleep current***		23		µA
I_{HIB} (1)	Hibernate operating-mode current	Fuel gauge in HIBERNATE mode I_{LOAD} < ***Hibernate current***		8		µA

(1) Specified by design. Not production tested. Actual supply current consumption will vary slightly depending on firmware operation and dataflash configuration.

6.6 Digital Input and Output DC Electrical Characteristics

T_A = –40°C to 85°C, typical values at T_A = 25°C and V_{REGIN} = 3.6 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OL}	Output voltage, low (SCL, SDA, SOC_INT, BSDA, BSCL)	I_{OL} = 3 mA			0.4	V
$V_{OH(PP)}$	Output voltage, high (BSDA, BSCL)	I_{OH} = –1 mA	V_{CC} – 0.5			V
$V_{OH(OD)}$	Output voltage, high (SDA, SCL, SOC_INT)	External pullup resistor connected to V_{CC}	V_{CC} – 0.5			
V_{IL}	Input voltage, low (SDA, SCL)		–0.3		0.6	V
	Input voltage, low (BI/TOUT)	BAT INSERT CHECK MODE active	–0.3		0.6	
V_{IH}	Input voltage, high (SDA, SCL)		1.2			V
	Input voltage, high (BI/TOUT)	BAT INSERT CHECK MODE active	1.2		V_{CC} + 0.3	
$V_{IL(CE)}$	Input voltage, low (CE)	V_{REGIN} = 2.8 to 4.5 V			0.8	V
$V_{IH(CE)}$	Input voltage, high (CE)		2.65			
I_{lkg} (1)	Input leakage current (IO pins)				0.3	µA

(1) Specified by design. Not production tested.

6.7 Power-on Reset

T_A = –40°C to 85°C, typical values at T_A = 25°C and V_{REGIN} = 3.6 V (unless otherwise noted)

PARAMETER		MIN	TYP	MAX	UNIT
V_{IT+}	Positive-going battery voltage input at V_{CC}	2.05	2.15	2.20	V
V_{HYS}	Power-on reset hysteresis		115		mV

6.8 2.5-V LDO Regulator

T_A = –40°C to 85°C, C_{LDO25} = 1 µF, V_{REGIN} = 3.6 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	NOM	MAX	UNIT
V_{REG25}	Regulator output voltage (V_{CC})	2.8 V ≤ V_{REGIN} ≤ 4.5 V, I_{OUT} ≤ 16 mA (1)	2.3	2.5	2.6	V
		2.45 V ≤ V_{REGIN} < 2.8 V (low battery), I_{OUT} ≤ 3 mA	2.3			V

(1) LDO output current, I_{OUT}, is the total load current. LDO regulator should be used to power internal fuel gauge only.

6.9 Internal Clock Oscillators

T_A = –40°C to 85°C, 2.4 V < V_{CC} < 2.6 V; typical values at T_A = 25°C and V_{CC} = 2.5 V (unless otherwise noted)

PARAMETER		MIN	TYP	MAX	UNIT
f_{OSC}	High-frequency oscillator		8.389		MHz
f_{LOSC}	Low-frequency oscillator		32.768		kHz

6.10 ADC (Temperature and Cell Measurement) Characteristics

T_A = –40°C to 85°C, 2.4 V < V_{CC} < 2.6 V; typical values at T_A = 25°C and V_{CC} = 2.5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{ADC1}	Input voltage range (TS)		V_{SS} – 0.125		2	V
V_{ADC2}	Input voltage range (BAT)		V_{SS} – 0.125		5	V
$V_{IN(ADC)}$	Input voltage range		0.05		1	V
G_{TEMP}	Internal temperature sensor voltage gain			–2		mV/°C
t_{ADC_CONV}	Conversion time				125	ms
	Resolution		14		15	bits
$V_{OS(ADC)}$	Input offset			1		mV
Z_{ADC1} (1)	Effective input resistance (TS)		8			MΩ
Z_{ADC2} (1)	Effective input resistance (BAT)	Device not measuring cell voltage	8			MΩ
		Device measuring cell voltage		100		kΩ
$I_{lkg(ADC)}$ (1)	Input leakage current				0.3	µA

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

6.11 Integrating ADC (Coulomb Counter) Characteristics

T_A = –40°C to 85°C, 2.4 V < V_{CC} < 2.6 V; typical values at T_A = 25°C and V_{CC} = 2.5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{SR}	Input voltage range, $V_{(SRP)}$ and $V_{(SRN)}$	$V_{SR} = V_{(SRP)} – V_{(SRN)}$	–0.125		0.125	V
t_{SR_CONV}	Conversion time	Single conversion		1		s
	Resolution		14		15	bits
$V_{OS(SR)}$	Input offset			10		µV
INL	Integral nonlinearity error			±0.007%	±0.034%	FSR
$Z_{IN(SR)}$ (1)	Effective input resistance		2.5			MΩ
$I_{lkg(SR)}$ (1)	Input leakage current				0.3	µA

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

6.12 Data Flash Memory Characteristics

T_A = –40°C to 85°C, 2.4 V < V_{CC} < 2.6 V; typical values at T_A = 25°C and V_{CC} = 2.5 V (unless otherwise noted)

PARAMETER		MIN	TYP	MAX	UNIT
t_{DR} (1)	Data retention	10			Years
	Flash-programming write cycles(1)	20,000			Cycles
$t_{WORDPROG}$ (1)	Word programming time			2	ms
I_{CCPROG} (1)	Flash-write supply current		5	10	mA
$t_{DFERASE}$ (1)	Data flash master erase time	200			ms
$t_{IFERASE}$ (1)	Instruction flash master erase time	200			ms
$t_{PGERASE}$ (1)	Flash page erase time	20			ms

(1) Specified by design. Not production tested

6.13 I²C-compatible Interface Communication Timing Requirements

T_A = –40°C to 85°C, 2.4 V < V_{CC} < 2.6 V; typical values at T_A = 25°C and V_{CC} = 2.5 V (unless otherwise noted)

		MIN	TYP	MAX	UNIT
t_r	SCL or SDA rise time			300	ns
t_f	SCL or SDA fall time			300	ns
$t_{w(H)}$	SCL pulse duration (high)	600			ns
$t_{w(L)}$	SCL pulse duration (low)	1.3			μs
$t_{su(STA)}$	Setup for repeated start	600			ns
$t_{d(STA)}$	Start to first falling edge of SCL	600			ns
$t_{su(DAT)}$	Data setup time	100			ns
$t_{h(DAT)}$	Data hold time	0			ns
$t_{su(STOP)}$	Setup time for stop	600			ns
$t_{(BUF)}$	Bus free time between stop and start	66			μs
f_{SCL}	Clock frequency (1)			400	kHz

(1) 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*).

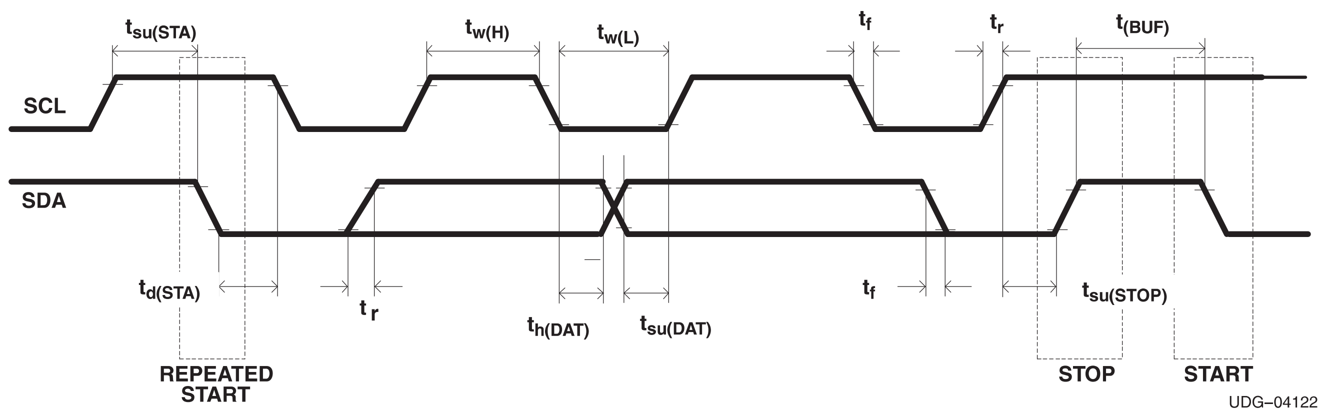


Figure 1. I²C-Compatible Interface Timing Diagrams

6.14 Typical Characteristics

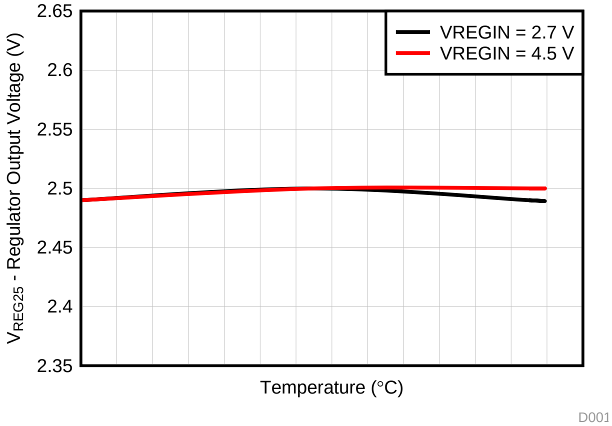


Figure 2. Regulator Output Voltage vs. Temperature

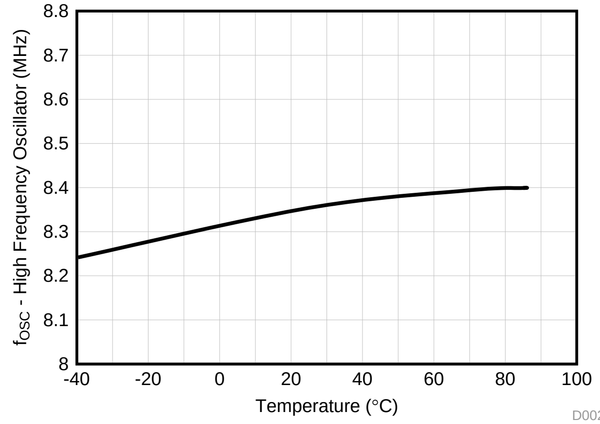


Figure 3. High-Frequency Oscillator Frequency vs. Temperature

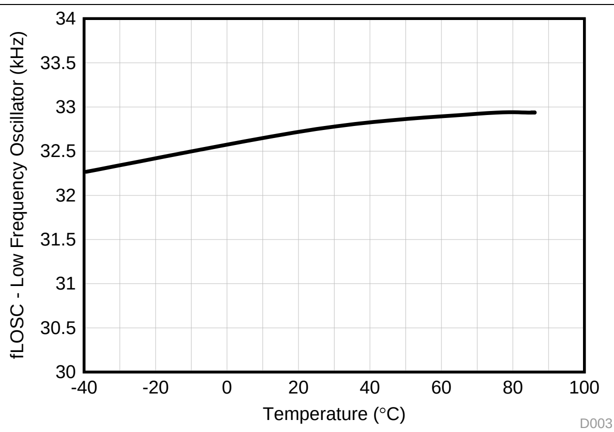


Figure 4. Low-Frequency Oscillator Frequency vs. Temperature

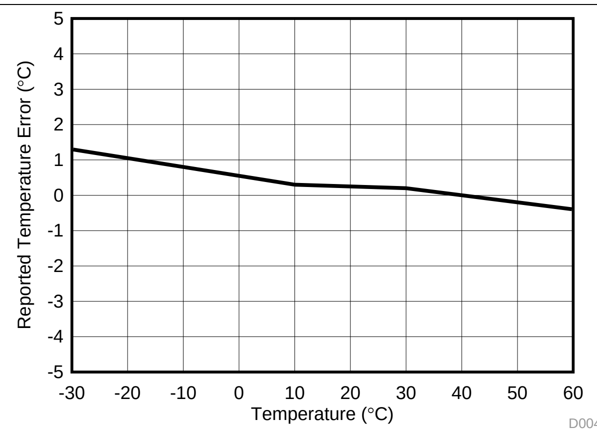


Figure 5. Reported Internal Temperature Measurement vs. Temperature

7 Detailed Description

7.1 Overview

The 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 remaining capacity and state-of-charge (SOC) as well as SOC interrupt signal to the host.

The fuel gauge can control a bq2425x Charger IC without the intervention from an application system processor. Using the bq27532-G1 and bq2425x chipset, batteries can be charged with the typical constant-current, constant-voltage (CCCV) profile or charged using a Multi-Level Charging (MLC) algorithm.

The fuel gauge can also be configured to suggest charge voltage and current values to the system so that the host can control a charger that is not part of the bq2425x charger family.

NOTE

Formatting conventions used in this document:

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

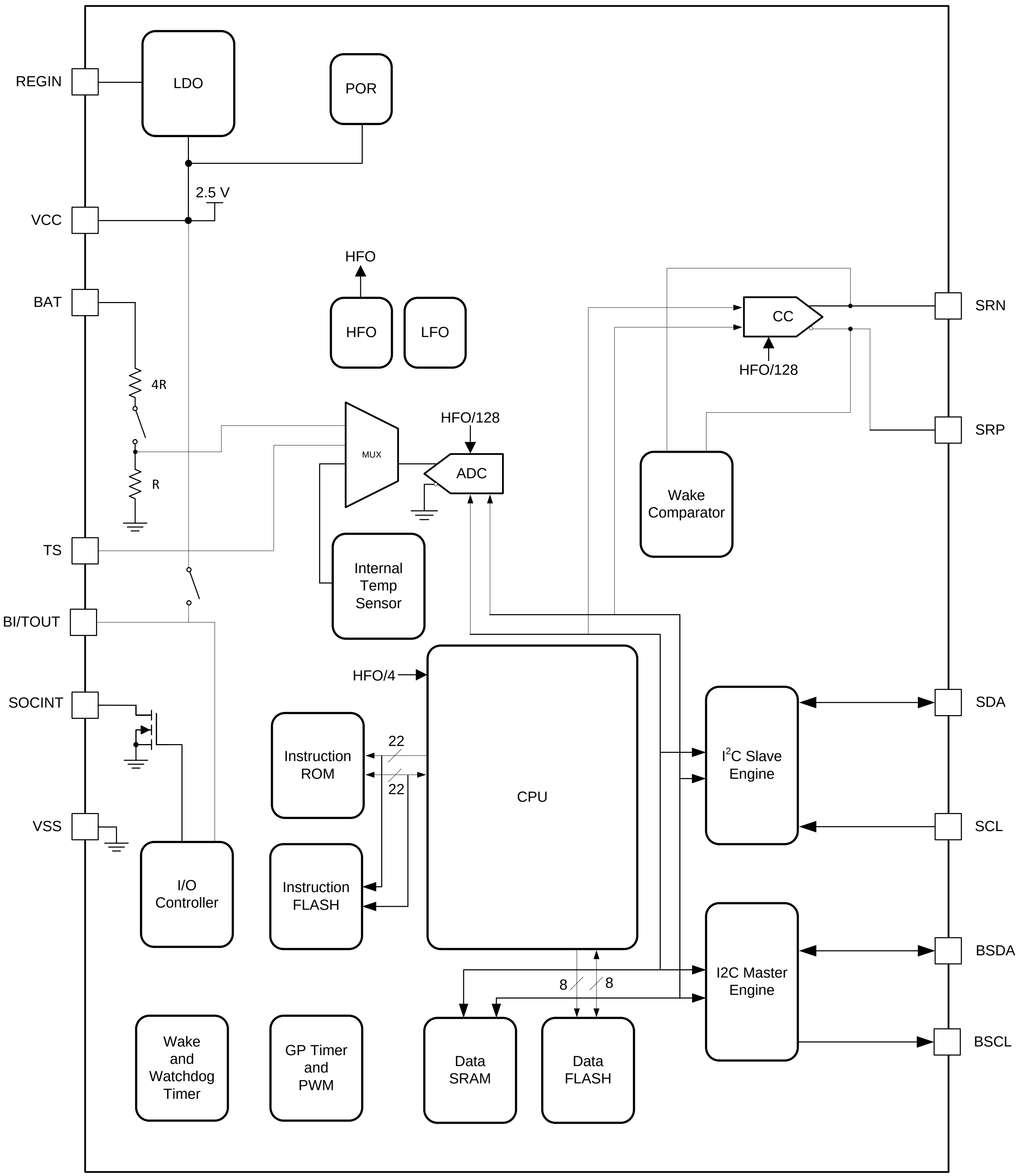
Data flash: *italics*, **bold**, and *breaking spaces*, for example, ***Design Capacity***

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

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

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

7.2 Functional Block Diagram



7.3 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 flash locations. Commands are sent from system to gauge using the I^2C serial communications engine, and can be executed during application development, pack manufacture, or end-equipment operation.

Cell information is stored in non-volatile flash memory. Many of these data flash locations are accessible during application development. They cannot, generally, be accessed directly during end-equipment operation. Access to these locations is achieved by either use of the companion evaluation software, through individual commands, or through a sequence of data-flash-access commands. To access a desired data flash location, the correct data flash subclass and offset must be known.

The key to the high-accuracy gas gauging prediction is the TI proprietary Impedance Track™ algorithm. This algorithm uses cell measurements, characteristics, and properties to create SOC predictions that can achieve less than 1% error across a wide variety of operating conditions and over the lifetime of the battery.

The fuel gauge measures the charging and discharging of the battery by monitoring the voltage across a small-value series sense resistor (5 to 20 mΩ, typical) located between the system V_{SS} and the battery PACK– terminal. 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 external temperature sensing is optimized with the use of a high-accuracy negative temperature coefficient (NTC) thermistor with R25 = 10.0 kΩ ±1%, B25/85 = 3435 K ± 1% (such as Semitec NTC 103AT). The fuel gauge can also be configured to use its internal temperature sensor. When an external thermistor is used, a 18.2-kΩ pullup resistor between the BI/TOUT and TS pins is also required. The fuel gauge uses temperature to monitor the battery-pack environment, which is used for fuel gauging and cell protection functionality.

To minimize power consumption, the fuel gauge has different power modes: NORMAL, SLEEP, SLEEP+, HIBERNATE, and BAT INSERT CHECK. 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 complete operational details, see *bq27532-G1 Technical Reference Manual,* SLUUB04.

7.3.1 Functional Description

The fuel gauge measures the cell voltage, temperature, and current to determine battery SOC. The fuel gauge monitors the charging and discharging of the battery by sensing the voltage across a small-value resistor (5 mΩ to 20 mΩ, typical) between the SRP and SRN pins and in series with the cell. By integrating charge passing through the battery, the battery SOC is adjusted during battery charge or discharge.

The total battery capacity is found by comparing states of charge before and after applying the load with the amount of charge passed. When an application load is applied, the impedance of the cell is measured by comparing the OCV obtained from a predefined function for present SOC with the measured voltage under load. Measurements of OCV and charge integration determine chemical SOC and chemical capacity (Qmax). The initial Qmax values are taken from a cell manufacturers' data sheet multiplied by the number of parallel cells. It is also used for the value in ***Design Capacity***. The fuel gauge acquires and updates the battery-impedance profile during normal battery usage. It uses this profile, along with SOC and the Qmax value, to determine *FullChargeCapacity( )* and *StateOfCharge( )*, specifically for the present load and temperature. *FullChargeCapacity( )* is reported as capacity available from a fully-charged battery under the present load and temperature until *Voltage( )* reaches the ***Terminate Voltage***. *NominalAvailableCapacity( )* and *FullAvailableCapacity( )* are the uncompensated (no or light load) versions of *RemainingCapacity( )* and *FullChargeCapacity( )*, respectively.

The fuel gauge has two flags accessed by the *Flags( )* function that warn when the battery SOC has fallen to critical levels. When *RemainingCapacity( )* falls below the first capacity threshold as specified in ***SOC1 Set Threshold***, the *[SOC1] (State of Charge Initial)* flag is set. The flag is cleared once *RemainingCapacity( )* rises above ***SOC1 Clear Threshold***.

When the voltage is discharged to ***Terminate Voltage***, the SOC will be set to 0.

7.4 Device Functional Modes

7.4.1 Power Modes

The fuel gauge has different power modes:

1. BAT INSERT CHECK: The BAT INSERT CHECK mode is a powered-up, but low-power halted, state where the fuel gauge resides when no battery is inserted into the system.
2. NORMAL: In NORMAL mode, the fuel gauge is fully powered and can execute any allowable task.
3. SLEEP: In SLEEP mode, the fuel gauge turns off the high-frequency oscillator and exists in a reducedpower state, periodically taking measurements and performing calculations.
4. SLEEP+: In SLEEP+ mode, both low-frequency and high-frequency oscillators are active. Although the SLEEP+ mode has higher current consumption than the SLEEP mode, it is also a reduced power mode.
5. HIBERNATE: In HIBERNATE mode, the fuel gauge is in a low power state, but can be woken up by communication or certain I/O activity.

The relationship between these modes is shown in Figure 6.

7.4.2 BAT INSERT CHECK Mode

This mode is a halted-CPU state that occurs when an adapter, or other power source, is present to power the fuel gauge (and system), yet no battery has been detected. When battery insertion is detected, a series of initialization activities begin, which include: OCV measurement, setting the Flags() [BAT_DET] bit, and selecting the appropriate battery profiles.

Some commands, issued by a system processor, can be processed while the fuel gauge is halted in this mode. The gauge wakes up to process the command, then returns to the halted state awaiting battery insertion.

7.4.3 NORMAL Mode

The fuel gauge is in NORMAL mode when not in any other power mode. During this mode, AverageCurrent(), Voltage(), and Temperature() measurements are taken, and the interface data set is updated. Decisions to change states are also made. This mode is exited by activating a different power mode.

Because the gauge consumes the most power in NORMAL mode, the Impedance Track™ algorithm minimizes the time the fuel gauge remains in this mode.

7.4.4 SLEEP Mode

SLEEP mode is entered automatically if the feature is enabled (Op Config [SLEEP] = 1) and AverageCurrent() is below the programmable level Sleep Current. Once entry into SLEEP mode has been qualified, but prior to entering it, the fuel gauge performs a coulomb counter autocalibration to minimize offset.

During SLEEP mode, the fuel gauge periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The fuel gauge exits SLEEP mode if any entry condition is broken, specifically when:

1. *AverageCurrent()* rises above **Sleep Current**, or
2. A current in excess of I_{WAKE} through R_{SENSE} is detected.

   In the event that a battery is removed from the system while a charger is present (and powering the gauge), Impedance Track™ updates are not necessary. Hence, the fuel gauge enters a state that checks for battery insertion and does not continue executing the Impedance Track™ algorithm.

7.4.5 SLEEP+ Mode

Compared to the SLEEP mode, SLEEP+ mode has the high-frequency oscillator in operation. The communication delay could be eliminated. The SLEEP+ mode is entered automatically if the feature is enabled (CONTROL_STATUS [SNOOZE] = 1) and AverageCurrent() is below the programmable level **Sleep Current**.

During SLEEP+ mode, the fuel gauge periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The fuel gauge exits SLEEP+ mode if any entry condition is broken, specifically when:

Device Functional Modes (continued)

1. Any communication activity with the gauge, or
2. *AverageCurrent()* rises above **Sleep Current**, or
3. A current in excess of I_{WAKE} through R_{SENSE} is detected.

7.4.6 HIBERNATE Mode

HIBERNATE mode should be used when the system equipment needs to enter a low-power state, and minimal gauge power consumption is required. This mode is ideal when system equipment is set to its own HIBERNATE, SHUTDOWN, or OFF mode.

Before the fuel gauge can enter HIBERNATE mode, the system must set the CONTROL_STATUS [HIBERNATE] bit. The gauge waits to enter HIBERNATE mode until it has taken a valid OCV measurement and the magnitude of the average cell current has fallen below Hibernate Current. The gauge can also enter HIBERNATE mode if the cell voltage falls below Hibernate Voltage and a valid OCV measurement has been taken. The gauge remains in HIBERNATE mode until the system issues a direct I^2C command to the gauge or a POR occurs. Any I^2C communication that is not directed to the gauge does not wake the gauge.

It is the responsibility of the system to wake the fuel gauge after it has gone into HIBERNATE mode. After waking, the gauge can proceed with the initialization of the battery information (OCV, profile selection, and so forth).

Device Functional Modes (continued)

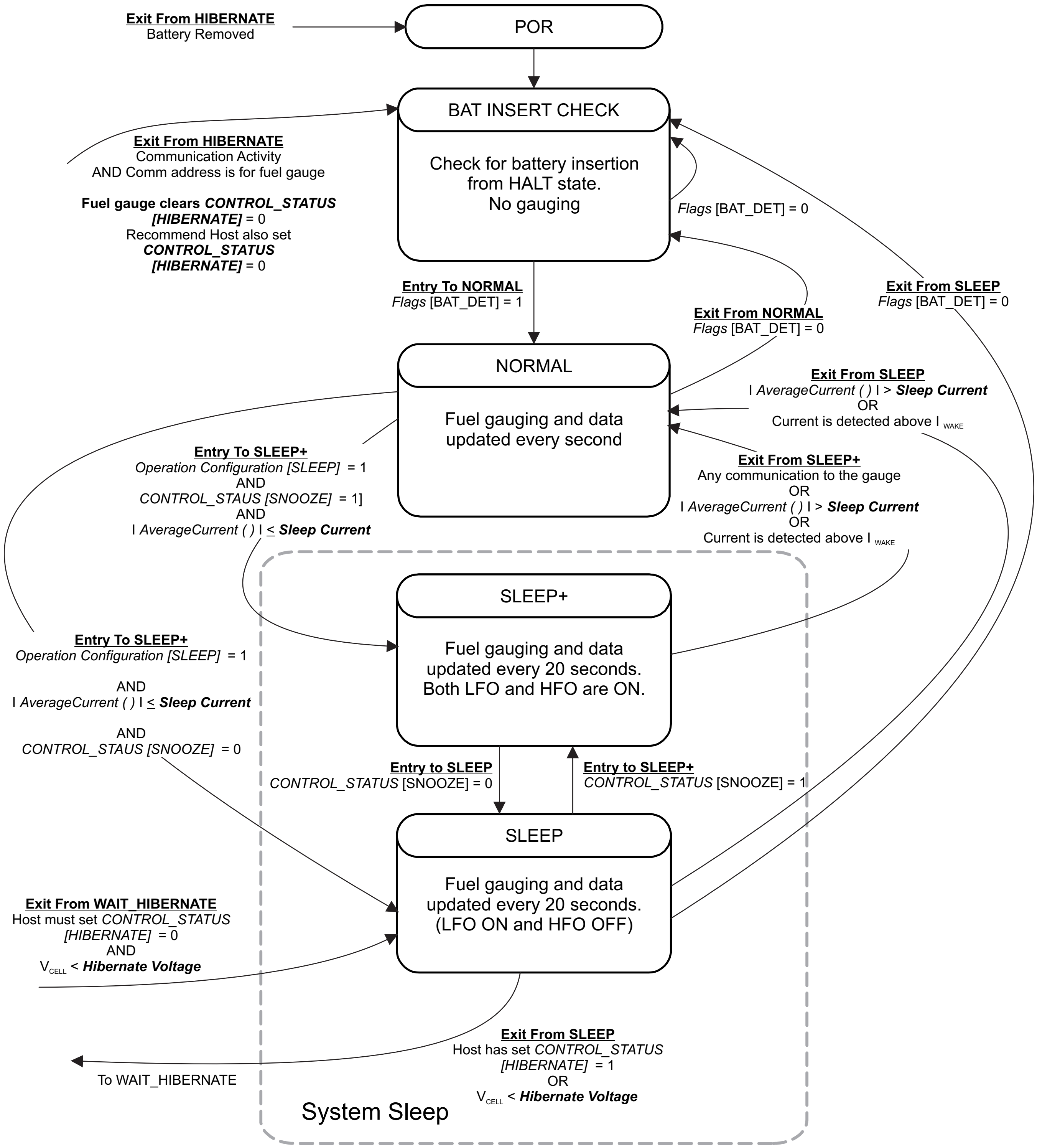


Figure 6. Power Mode Diagram—System Sleep

Device Functional Modes (continued)

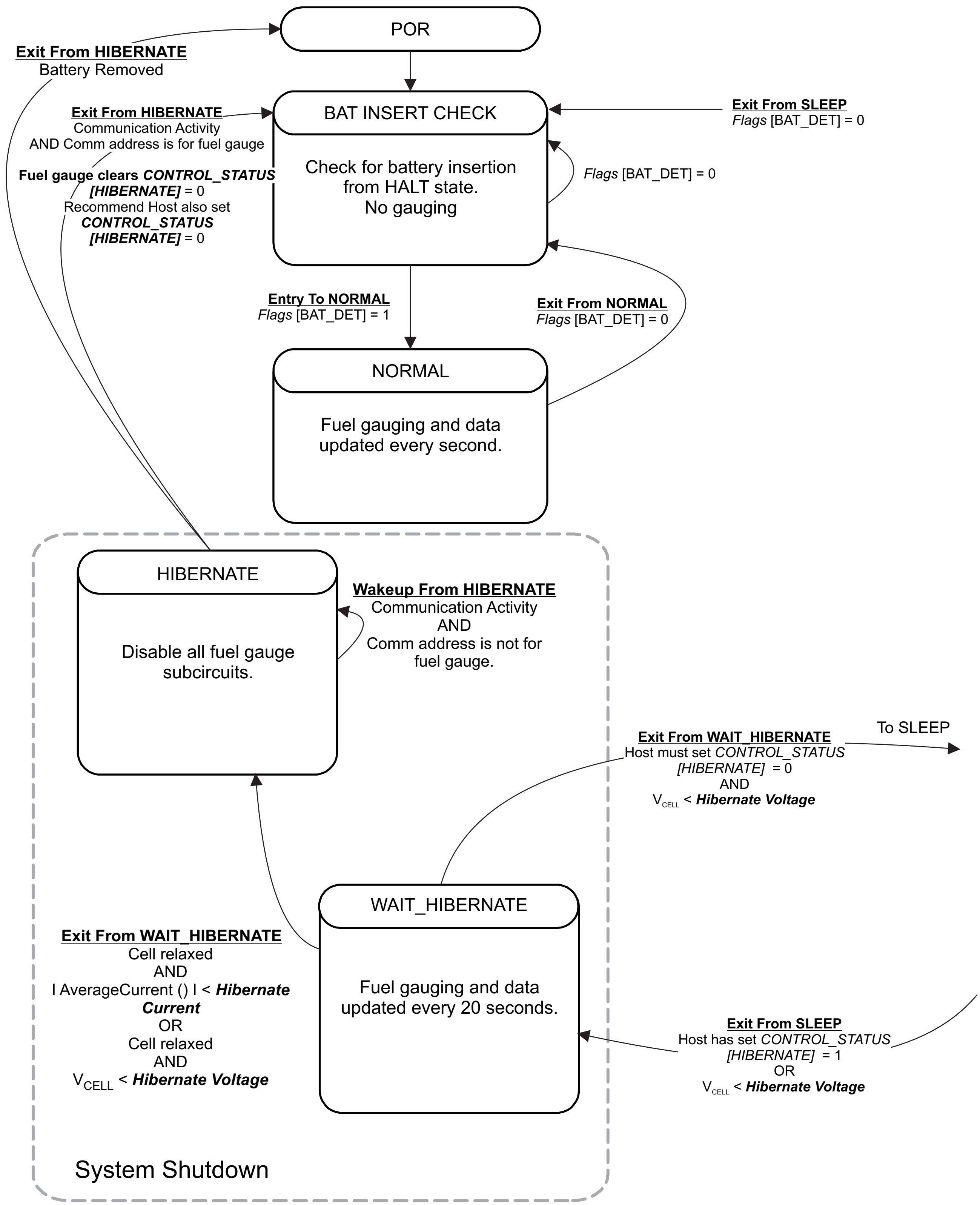


Figure 7. Power Mode Diagram—System Shutdown

7.5 Programming

7.5.1 Standard Data Commands

The 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. Because each command consists of two bytes of data, two consecutive I^2C transmissions must be executed both to initiate the command function, and to read or write the corresponding two bytes of data. Additional details are found in the *bq27532-G1 Technical Reference Manual,* SLUUB04.

Table 1. Standard Commands

NAME	COMMAND CODE	UNIT	SEALED ACCESS	UNSEALED ACCESS
Control( )	0x00 and 0x01	NA	RW	RW
AtRate( )	0x02 and 0x03	mA	RW	RW
AtRateTimeToEmpty( )	0x04 and 0x05	Minutes	R	RW
Temperature( )	0x06 and 0x07	0.1 K	RW	RW
Voltage( )	0x08 and 0x09	mV	R	RW
Flags( )	0x0A and 0x0B	Hex	R	RW
NominalAvailableCapacity( )	0x0C and 0x0D	mAh	R	RW
FullAvailableCapacity( )	0x0E and 0x0F	mAh	R	RW
RemainingCapacity( )	0x10 and 0x11	mAh	R	RW
FullChargeCapacity( )	0x12 and 0x13	mAh	R	RW
AverageCurrent( )	0x14 and 0x15	mA	R	RW
InternalTemperature( )	0x16 and 0x17	0.1 K	R	RW
ResScale( )	0x18 and 0x19	Num	R	RW
ChargingLevel( )	0x1A and 0x1B	Num	R	RW
StateOfHealth( )	0x1C and 0x1D	% / num	R	RW
CycleCount( )	0x1E and 0x1F	Counters	R	R
StateOfCharge( )	0x20 and 0x21	%	R	R
InstantaneousCurrentReading( )	0x22 and 0x23	mA	R	RW
FineQPass( )	0x24 and 0x25	mAh	R	RW
FineQPassFract( )	0x26 and 0x27	num	R	RW
ProgChargingCurrent( )	0x28 and 0x29	mA	R	RW
ProgChargingVoltage( )	0x2A and 0x2B	mV	R	RW
LevelTaperCurrent( )	0x2C and 0x2D	mA	R	RW
CalcChargingCurrent( )	0x2E and 0x2F	mA	R	RW
CalcChargingVoltage( )	0x30 and 0x31	mV	R	RW
ChargerStatus( )	0x32	Hex	R	RW
ChargReg0( )	0x33	Hex	RW	RW
ChargReg1( )	0x34	Hex	RW	RW
ChargReg2( )	0x35	Hex	RW	RW
ChargReg3( )	0x36	Hex	RW	RW
ChargReg4( )	0x37	Hex	RW	RW
ChargReg5( )	0x38	Hex	RW	RW
ChargReg6( )	0x39	Hex	RW	RW
RemainingCapacityUnfiltered( )	0x6C and 0x6D	mAh	R	RW
RemainingCapacityFiltered( )	0x6E and 0x6F	mAh	R	RW
FullChargeCapacityUnfiltered( )	0x70 and 0x71	mAh	R	RW
FullChargeCapacityFiltered( )	0x72 and 0x73	mAh	R	RW
TrueSOC( )	0x74 and 0x75	%	R	RW
MaxCurrent( )	0x76 and 0x77	mA	R	RW

7.5.2 *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 fuel gauge is in different access modes, as described in Device Functional Modes. Additional details are found in the *bq27532-G1 Technical Reference Manual,* SLUUB04.

Table 2. *Control( )* Subcommands

CONTROL FUNCTION	CONTROL DATA	SEALED ACCESS	DESCRIPTION
CONTROL_STATUS	0x0000	Yes	Reports the status of HIBERNATE, IT, and so on
DEVICE_TYPE	0x0001	Yes	Reports the device type (for example, 0x0532 for bq27532-G1)
FW_VERSION	0x0002	Yes	Reports the firmware version on the device type
HW_VERSION	0x0003	Yes	Reports the hardware version of the device type
MLC_ENABLE	0x0004	Yes	Charge profile is based on MaxLife profile
MLC_DISABLE	0x0005	Yes	Charge profile is solely based on charge temperature tables and, if enabled, State of Health
CLEAR_IMAX_INT	0x0006	Yes	Clears the IMAX status bit and the interrupt signal from SOC_INT pin.
PREV_MACWRITE	0x0007	Yes	Returns previous MAC subcommand code
CHEM_ID	0x0008	Yes	Reports the chemical identifier of the Impedance Track™ configuration
BOARD_OFFSET	0x0009	No	Forces the device to measure and store the board offset
CC_OFFSET	0x000A	No	Forces the device to measure the internal CC offset
CC_OFFSET_SAVE	0x000B	No	Forces the device to store the internal CC offset
OCV_CMD	0x000C	Yes	Request the gauge to take a OCV measurement
BAT_INSERT	0x000D	Yes	Forces the BAT_DET bit set when the *[BIE]* bit is 0
BAT_REMOVE	0x000E	Yes	Forces the BAT_DET bit clear when the *[BIE]* bit is 0
SET_HIBERNATE	0x0011	Yes	Forces *CONTROL_STATUS [HIBERNATE]* to 1
CLEAR_HIBERNATE	0x0012	Yes	Forces *CONTROL_STATUS [HIBERNATE]* to 0
SET_SLEEP+	0x0013	Yes	Forces *CONTROL_STATUS [SNOOZE]* to 1
CLEAR_SLEEP+	0x0014	Yes	Forces *CONTROL_STATUS [SNOOZE]* to 0
ILIMIT_LOOP_ENABLE	0x0015	Yes	When the gauge is not connected to the charger through I^2C, this command indicates to the gauge that there is a charger input current limiting loop active. Disables charge termination detection by the gauge.
ILIMIT_LOOP_DISABLE	0x0016	Yes	When the gauge is not connected to the charger through I^2C, this command indicates to the gauge that battery charge current is not limited. Allows charge termination detection by the gauge.
SHIPMODE_ENABLE	0x0017	Yes	Commands the bq2425x to turn off BATFET after a delay time programmed in data flash so that system load does not draw power from the battery
SHIPMODE_DISABLE	0x0018	Yes	Commands the bq2425x to disregard turning off BATFET before the delay time or commands BATFET to turn on if a VIN had power during the SHIPMODE enabling process
CHG_ENABLE	0x001A	Yes	Enable charger. Charge will continue as dictated by the gauge charging algorithm.
CHG_DISABLE	0x001B	Yes	Disable charger (Set $\overline{CE}$ bit of bq2425x)
GG_CHGRCTL_ENABLE	0x001C	Yes	Enables the gas gauge to control the charger while continuously resetting the charger watchdog
GG_CHGRCTL_DISABLE	0x001D	Yes	The gas gauge stops resetting the charger watchdog
SMOOTH_SYNC	0x001E	Yes	Synchronizes *RemainingCapacityFiltered( )* and *FullChargeCapacityFiltered( )* with *RemainingCapacityUnfiltered( )* and *FullChargeCapacityUnfiltered( )*
DF_VERSION	0x001F	Yes	Returns the Data Flash Version
SEALED	0x0020	No	Places device in SEALED access mode
IT_ENABLE	0x0021	No	Enables the Impedance Track™ algorithm
RESET	0x0041	No	Forces a full reset of the bq27532-G1 device

7.5.3 Charger Data Commands

The charger registers are mapped to a series of single-byte Charger Data Commands to enable system reading and writing of battery charger registers. During charger power up, the registers are initialized to Charger Reset State. The fuel gauge can change the values of these registers during the System Reset State.

Each of the bits in the Charger Data Commands can be read or write. Note that System Access can be different from the read or write access as defined in bq2425x charger hardware. The fuel gauge may block write access to the charger hardware when the bit function is controlled by the fuel gauge exclusively. For example, the *[VBATREGx]* bits of *Chrgr_Reg2* are controlled by the fuel gauge and cannot be modified by system.

The fuel gauge reads the corresponding registers of *Chrgr_Reg0( )* and *Chrgr_Reg2( )* every second to mirror the charger status. Other registers in the bq2425x device are read when registers are modified by the fuel gauge.

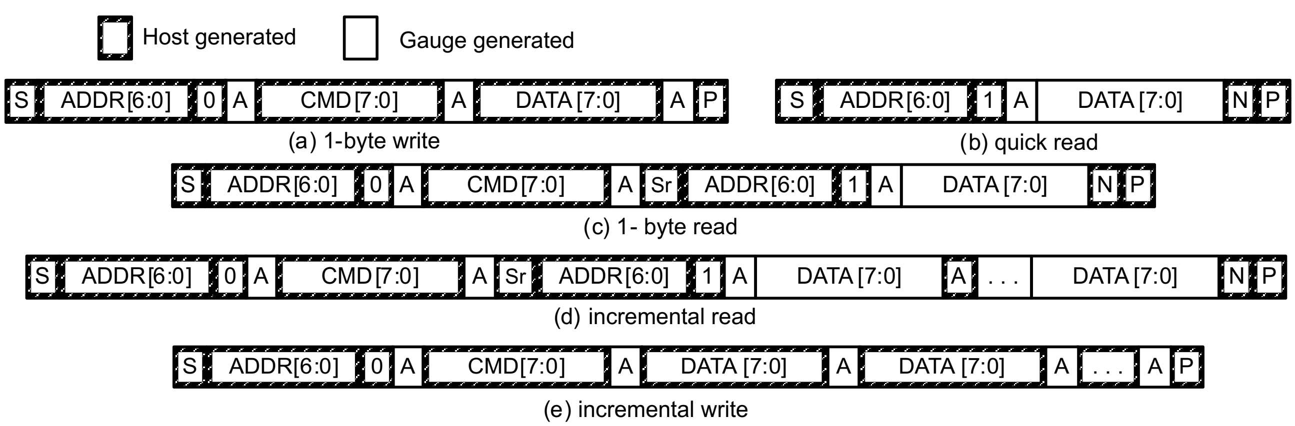
Table 3. Charger Data Commands

NAME		COMMAND CODE	bq2425x CHARGER MEMORY LOCATION	SEALED ACCESS	UNSEALED ACCESS	REFRESH RATE
ChargerStatus( )	CHGRSTAT	0x32	NA	R	R	Every second
Chrgr_Reg0( )	CHGR0	0x33	0x00	RW	RW	Every second
Chrgr_Reg1( )	CHGR1	0x34	0x01	RW	RW	Data change
Chrgr_Reg2( )	CHGR2	0x35	0x02	RW	RW	Every second
Chrgr_Reg3( )	CHGR3	0x36	0x03	RW	RW	Data change
Chrgr_Reg4( )	CHGR4	0x37	0x04	RW	RW	Every second
Chrgr_Reg5( )	CHGR5	0x38	0x05	RW	RW	Data change
Chrgr_Reg6( )	CHGR6	0x39	0x06	RW	RW	Data change

7.5.4 Communications

7.5.4.1 I²C Interface

The fuel gauge supports the standard I²C 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 I²C protocol are, therefore, 0xAA or 0xAB for write or read, respectively.



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

Figure 8. I²C Interface

The quick read returns data at the address indicated by the address pointer. The address pointer, a register internal to the I²C communication engine, increments whenever data is acknowledged by the fuel gauge or the I²C 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):

Figure 9. Invalid Write

Attempt to read an address above 0x6B (NACK command):

Figure 10. Invalid Read

7.5.4.2 I²C Time Out

The I²C engine releases both SDA and SCL if the I²C 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 I²C engine enters the low-power SLEEP mode.

7.5.4.3 I²C Command Waiting Time

To ensure proper operation at 400 kHz, a $t_{(BUF)} \geq 66$ 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 to 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.

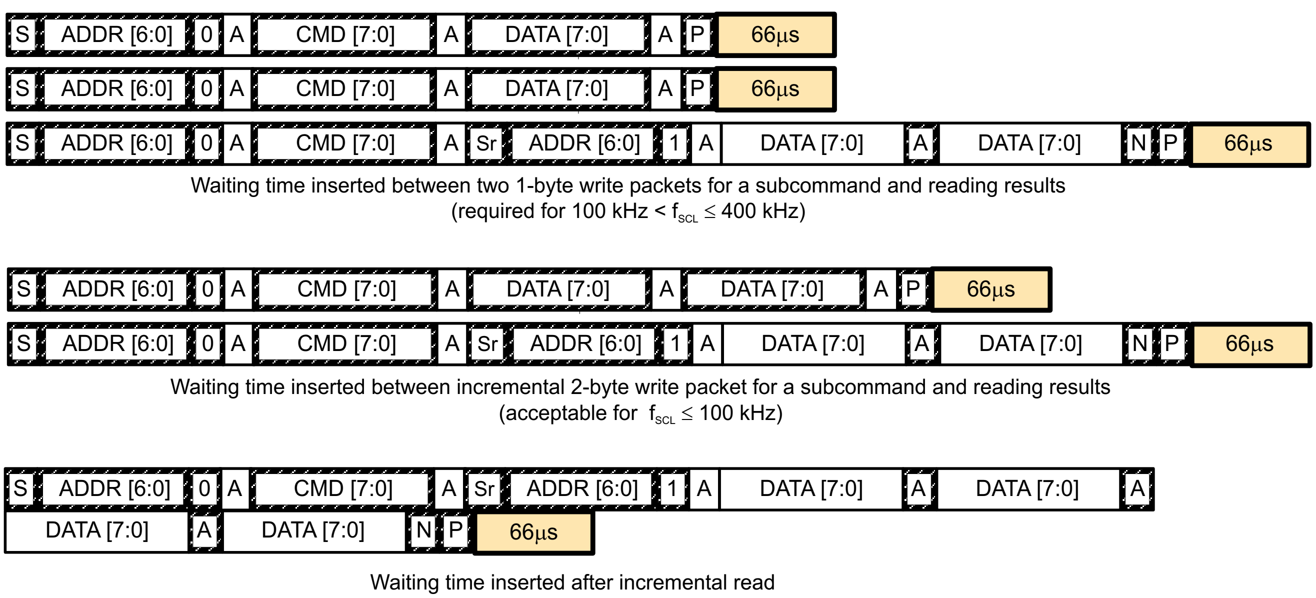


Figure 11. I²C Command Waiting Time

7.5.4.4 I^2C Clock Stretching

A clock stretch can occur during all modes of fuel gauge operation. In SLEEP and HIBERNATE modes, a short clock stretch occurs on all I^2C traffic as the device must wake-up to process the packet. In the other modes (INITIALIZATION, NORMAL) clock stretching only occurs for packets addressed for the fuel gauge. The majority of clock stretch periods are small as the I^2C interface performs normal data flow control. However, less frequent yet more significant clock stretch periods may occur as blocks of data flash are updated. The following table summarizes the approximate clock stretch duration for various fuel gauge operating conditions.

Table 4. Approximate Clock Stretch Duration

GAUGING MODE	OPERATING CONDITION / COMMENT	APPROXIMATE DURATION
SLEEP HIBERNATE	Clock stretch occurs at the beginning of all traffic as the device wakes up.	≤ 4 ms
INITIALIZATION NORMAL	Clock stretch occurs within the packet for flow control (after a start bit, ACK or first data bit).	≤ 4 ms
	Normal Ra table data flash updates.	24 ms
	Data flash block writes.	72 ms
	Restored data flash block write after loss of power.	116 ms
	End of discharge Ra table data flash update.	144 ms

8 Application and Implementation

NOTE

Information in the following applications sections 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.

8.1 Application Information

The fuel gauge can control a bq2425x Charger IC without the intervention from an application system processor. Using the bq27532-G1 and bq2425x chipset, batteries can be charged with the typical constant-current, constant-voltage (CCCV) profile or charged using a Multi-Level Charging (MLC) algorithm.

8.2 Typical Application

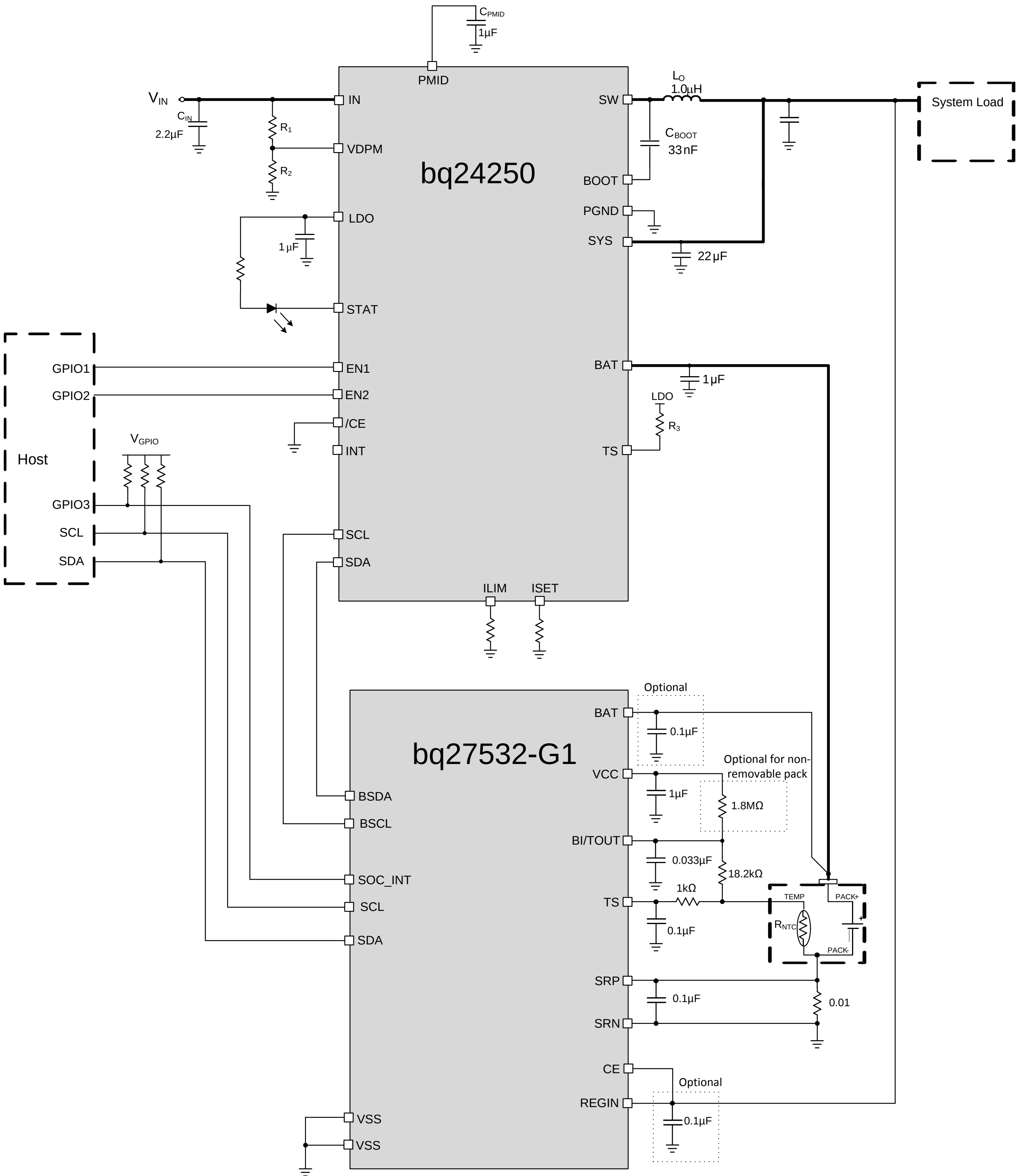


Figure 12. Typical Application Schematic

Typical Application (continued)

8.2.1 Design Requirements

Several key parameters must be updated to align with a given application's battery characteristics. For highest accuracy gauging, it is important to follow-up this initial configuration with a learning cycle to optimize resistance and maximum chemical capacity (Qmax) values prior to sealing and shipping systems to the field. Successful and accurate configuration of the fuel gauge for a target application can be used as the basis for creating a "golden" gas gauge (.fs) file that can be written to all gauges, assuming identical pack design and Li-ion cell origin (chemistry, lot, and so on). Calibration data is included as part of this golden GG file to cut down on system production time. If going this route, it is recommended to average the voltage and current measurement calibration data from a large sample size and use these in the golden file. Table 5, *Key Data Flash Parameters for Configuration*, shows the items that should be configured to achieve reliable protection and accurate gauging with minimal initial configuration.

Table 5. Key Data Flash Parameters for Configuration

NAME	DEFAULT	UNIT	RECOMMENDED SETTING
Design Capacity	1000	mAh	Set based on the nominal pack capacity as interpreted from cell manufacturer's datasheet. If multiple parallel cells are used, should be set to N × Cell Capacity.
Design Energy Scale	1	-	Set to 10 to convert all power values to cWh or to 1 for mWh. ***Design Energy*** is divided by this value.
Reserve Capacity-mAh	0	mAh	Set to desired runtime remaining (in seconds / 3600) × typical applied load between reporting 0% SOC and reaching ***Terminate Voltage***, if needed.
Cycle Count Threshold	900	mAh	Set to 90% of configured ***Design Capacity***.
Chem ID	0100	hex	Should be configured using TI-supplied Battery Management Studio software. Default open-circuit voltage and resistance tables are also updated in conjunction with this step. Do not attempt to manually update reported Device Chemistry as this does not change all chemistry information! Always update chemistry using the appropriate software tool (that is, bqStudio).
Load Mode	1	-	Set to applicable load model, 0 for constant current or 1 for constant power.
Load Select	1	-	Set to load profile which most closely matches typical system load.
Qmax Cell 0	1000	mAh	Set to initial configured value for Design Capacity. The gauge will update this parameter automatically after the optimization cycle and for every regular Qmax update thereafter.
Cell0 V at Chg Term	4200	mV	Set to nominal cell voltage for a fully charged cell. The gauge will update this parameter automatically each time full charge termination is detected.
Terminate Voltage	3200	mV	Set to empty point reference of battery based on system needs. Typical is between 3000 and 3200 mV.
Ra Max Delta	44	mΩ	Set to 15% of Cell0 R_a 4 resistance after an optimization cycle is completed.
Charging Voltage	4200	mV	Set based on nominal charge voltage for the battery in normal conditions (25°C, etc). Used as the reference point for offsetting by ***Taper Voltage*** for full charge termination detection.
Taper Current	100	mA	Set to the nominal taper current of the charger + taper current tolerance to ensure that the gauge will reliably detect charge termination.
Taper Voltage	100	mV	Sets the voltage window for qualifying full charge termination. Can be set tighter to avoid or wider to ensure possibility of reporting 100% SOC in outer JEITA temperature ranges that use derated charging voltage.
Dsg Current Threshold	60	mA	Sets threshold for gauge detecting battery discharge. Should be set lower than minimal system load expected in the application and higher than ***Quit Current***.
Chg Current Threshold	75	mA	Sets the threshold for detecting battery charge. Can be set higher or lower depending on typical trickle charge current used. Also should be set higher than ***Quit Current***.
Quit Current	40	mA	Sets threshold for gauge detecting battery relaxation. Can be set higher or lower depending on typical standby current and exhibited in the end system.
Avg I Last Run	–299	mA	Current profile used in capacity simulations at onset of discharge or at all times if ***Load Select*** = 0. Should be set to nominal system load. Is automatically updated by the gauge every cycle.
Avg P Last Run	–1131	mW	Power profile used in capacity simulations at onset of discharge or at all times if ***Load Select*** = 0. Should be set to nominal system power. Is automatically updated by the gauge every cycle.

Typical Application (continued)

Table 5. Key Data Flash Parameters for Configuration (continued)

NAME	DEFAULT	UNIT	RECOMMENDED SETTING
Sleep Current	15	mA	Sets the threshold at which the fuel gauge enters SLEEP mode. Take care in setting above typical standby currents else entry to SLEEP may be unintentionally blocked.
Charge T0	0	°C	Sets the boundary between charging inhibit and charging with T0 parameters.
Charge T1	10	°C	Sets the boundary between charging with T0 and T1 parameters.
Charge T2	45	°C	Sets the boundary between charging with T1 and T2 parameters.
Charge T3	50	°C	Sets the boundary between charging with T2 and T3 parameters.
Charge T4	60	°C	Sets the boundary between charging with T3 and T4 parameters.
Charge Current T0	50	% Des Cap	Sets the charge current parameter for T0.
Charge Current T1	50	% Des Cap	Sets the charge current parameter for T1.
Charge Current T2	50	% Des Cap	Sets the charge current parameter for T2.
Charge Current T3	50	% Des Cap	Sets the charge current parameter for T3.
Charge Current T4	0	% Des Cap	Sets the charge current parameter for T4.
Charge Voltage T0	210	20-mV	Sets the charge voltage parameter for T0.
Charge Voltage T1	210	20-mV	Sets the charge voltage parameter for T1.
Charge Voltage T2	207	20-mV	Sets the charge voltage parameter for T2.
Charge Voltage T3	205	20-mV	Sets the charge voltage parameter for T3.
Charge Voltage T4	0	20-mV	Sets the charge voltage parameter for T4.
Chg Temp Hys	5	°C	Adds temperature hysteresis for boundary crossings to avoid oscillation if temperature is changing by a degree or so on a given boundary.
Chg Disabled Regulation V	4200	mV	Sets the voltage threshold for voltage regulation to system when charge is disabled. It is recommended to program to same value as Charging Voltage and maximum charge voltage that is obtained from Charge Voltage Tn parameters.
CC Gain	10	mohms	Calibrate this parameter using TI-supplied bqStudio software and calibration procedure in the TRM. Determines conversion of coulomb counter measured sense resistor voltage to current.
CC Delta	10	mohms	Calibrate this parameter using TI-supplied bqStudio software and calibration procedure in the TRM. Determines conversion of coulomb counter measured sense resistor voltage to passed charge.
CC Offset	–1418	Counts	Calibrate this parameter using TI-supplied bqStudio software and calibration procedure in the TRM. Determines native offset of coulomb counter hardware that should be removed from conversions.
Board Offset	0	Counts	Calibrate this parameter using TI-supplied bqStudio software and calibration procedure in the TRM. Determines native offset of the printed circuit board parasitics that should be removed from conversions.
Pack V Offset	0	mV	Calibrate this parameter using TI-supplied bqStudio software and calibration procedure in the TRM. Determines voltage offset between cell tab and ADC input node to incorporate back into or remove from measurement, depending on polarity.

8.2.2 Detailed Design Procedure

8.2.2.1 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.

8.2.2.2 SRP and SRN Current Sense Inputs

The filter network at the input to the coulomb counter is intended to improve differential mode rejection of voltage measured across the sense resistor. These components should be placed as close as possible to the coulomb counter inputs and the routing of the differential traces length-matched to best minimize impedance mismatch-induced measurement errors.

8.2.2.3 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, 100 ppm drift sense resistor with a 1-W power rating.

8.2.2.4 TS Temperature Sense Input

Similar to the BAT pin, a ceramic decoupling capacitor for the TS pin is used to bypass AC voltage ripple away from the high-impedance ADC input, minimizing measurement error. Another helpful advantage is that the capacitor provides additional ESD protection since the TS input to system may be accessible in systems that use removable battery packs. It should be placed as close as possible to the respective input pin for optimal filtering performance.

8.2.2.5 Thermistor Selection

The fuel gauge temperature sensing circuitry is designed to work with a negative temperature coefficient-type (NTC) thermistor with a characteristic 10-kΩ resistance at room temperature (25°C). The default curve-fitting coefficients configured in the fuel gauge specifically assume a 103AT-2 type thermistor profile and so that is the default recommendation for thermistor selection purposes. Moving to a separate thermistor resistance profile (for example, JT-2 or others) requires an update to the default thermistor coefficients in data flash to ensure highest accuracy temperature measurement performance.

8.2.2.6 REGIN Power Supply Input Filtering

A ceramic capacitor is placed at the input to the fuel gauge internal LDO to increase power supply rejection (PSR) and improve effective line regulation. It ensures that voltage ripple is rejected to ground instead of coupling into the internal supply rails of the fuel gauge.

8.2.2.7 V_{CC} LDO Output Filtering

A ceramic capacitor is also needed at the output of the internal LDO to provide a current reservoir for fuel gauge load peaks during high peripheral utilization. It acts to stabilize the regulator output and reduce core voltage ripple inside of the fuel gauge.

8.2.3 Application Curves

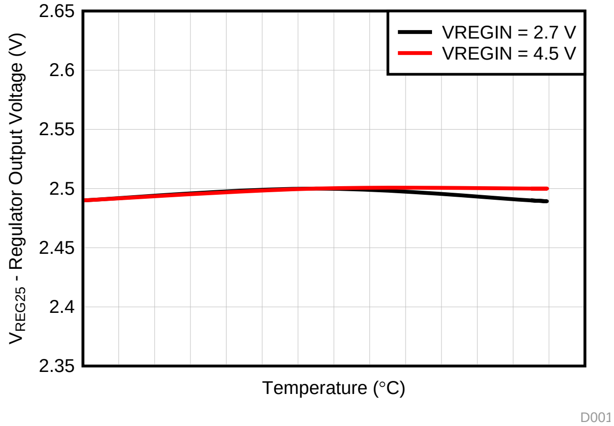


Figure 13. Regulator Output Voltage vs. Temperature

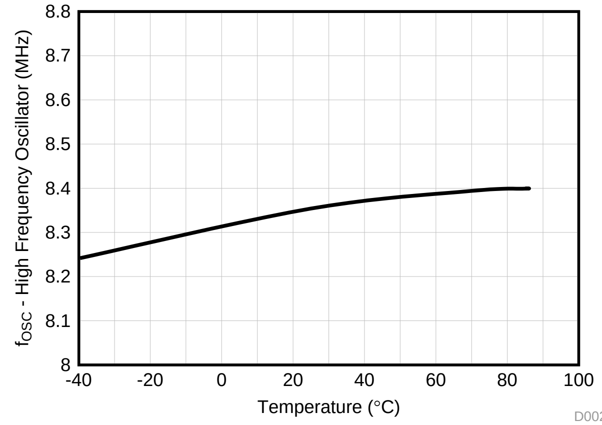


Figure 14. High-Frequency Oscillator Frequency vs. Temperature

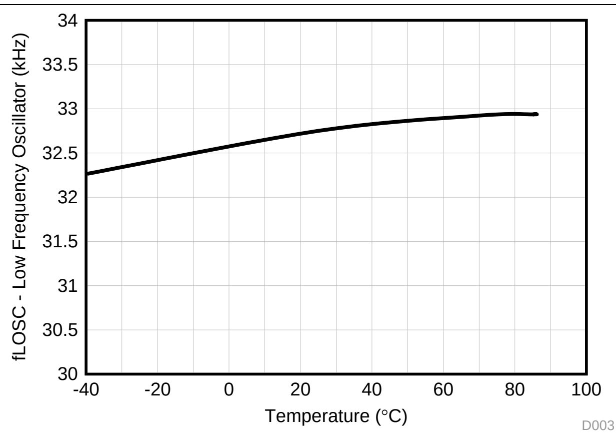


Figure 15. Low-Frequency Oscillator Frequency vs. Temperature

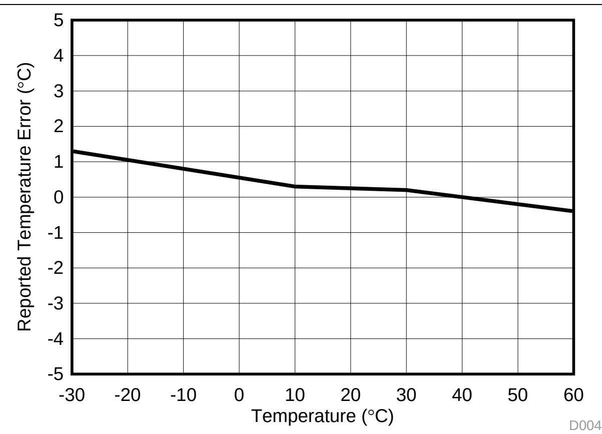


Figure 16. Reported Internal Temperature Measurement vs. Temperature

9 Power Supply Recommendations

9.1 Power Supply Decoupling

Both the REGIN input pin and the V_{CC} output pin require low equivalent series resistance (ESR) ceramic capacitors placed as closely as possible to the respective pins to optimize ripple rejection and provide a stable and dependable power rail that is resilient to line transients. A 0.1-µF capacitor at the REGIN and a 1-µF capacitor at V_{CC} will suffice for satisfactory device performance.

10 Layout

10.1 Layout Guidelines

10.1.1 Sense Resistor Connections

Kelvin connections at the sense resistor are just as critical as those for the battery terminals themselves. The differential traces should be connected at the inside of the sense resistor pads and not anywhere along the high-current trace path to prevent false increases to measured current that could result when measuring between the sum of the sense resistor and trace resistance between the tap points. In addition, the routing of these leads from the sense resistor to the input filter network and finally into the SRP and SRN pins needs to be as closely matched in length as possible else additional measurement offset could occur. It is further recommended to add copper trace or pour-based "guard rings" around the perimeter of the filter network and coulomb counter inputs to shield these sensitive pins from radiated EMI into the sense nodes. This prevents differential voltage shifts that could be interpreted as real current change to the fuel gauge. All of the filter components need to be placed as close as possible to the coulomb counter input pins.

10.1.2 Thermistor Connections

The thermistor sense input should include a ceramic bypass capacitor placed as close to the TS input pin as possible. The capacitor helps to filter measurements of any stray transients as the voltage bias circuit pulses periodically during temperature sensing windows.

10.1.3 High-Current and Low-Current Path Separation

For best possible noise performance, it is extremely important to separate the low-current and high-current loops to different areas of the board layout. The fuel gauge and all support components should be situated on one side of the boards and tap off of the high-current loop (for measurement purposes) at the sense resistor. Routing the low-current ground around instead of under high-current traces will further help to improve noise rejection.

10.2 Layout Example

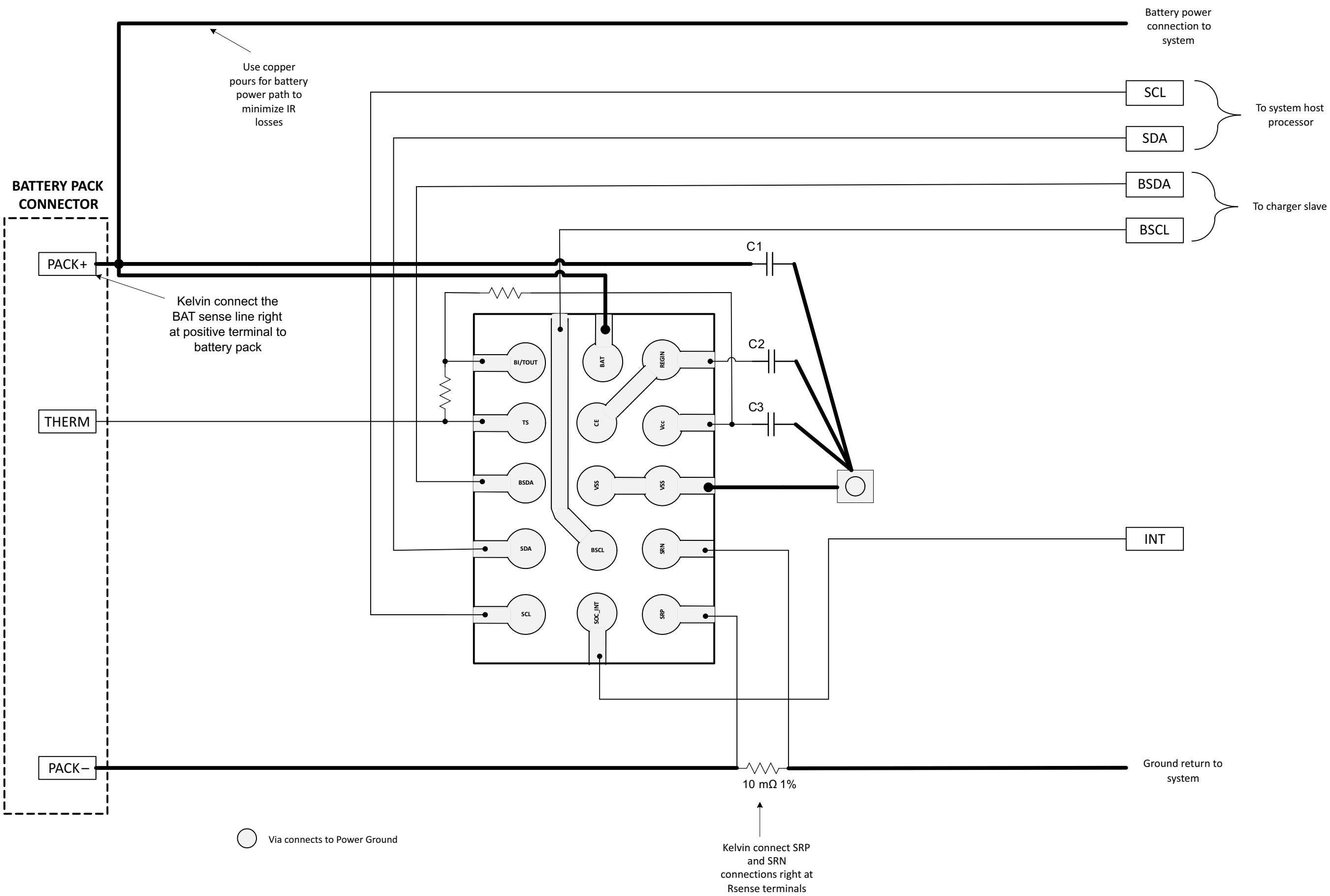


Figure 17. bq27532-G1 Layout Schematic

11 Device and Documentation Support

11.1 Documentation Support

11.1.1 Related Documentation

For related documentation, see the following:

1. *bq27532-G1 Technical Reference Manual* User's Guide (SLUUB04)
2. *bq27532EVM with bq27532 Battery Management Unit Impedance Track™ Fuel Gauge and bq24250 2.0-A, Switch-Mode Battery Charger for Single-Cell Applications* User's Guide (SLUUB58)

11.2 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.

11.3 Trademarks

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

11.4 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.

11.5 Glossary

SLYZ022 — *TI Glossary*.

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

12 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 part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
BQ27532YZFR-G1	Active	Production	DSBGA (YZF) | 15	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27532
BQ27532YZFR-G1.B	Active	Production	DSBGA (YZF) | 15	3000 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27532
BQ27532YZFT-G1	Active	Production	DSBGA (YZF) | 15	250 | SMALL T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27532
BQ27532YZFT-G1.B	Active	Production	DSBGA (YZF) | 15	250 | SMALL T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27532

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts 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.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

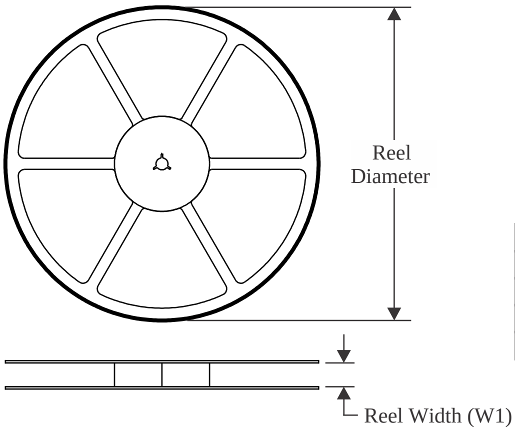
Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and 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.

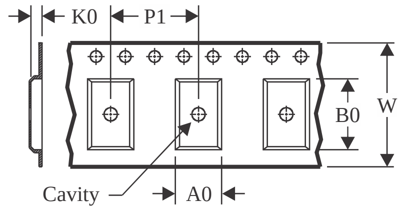
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

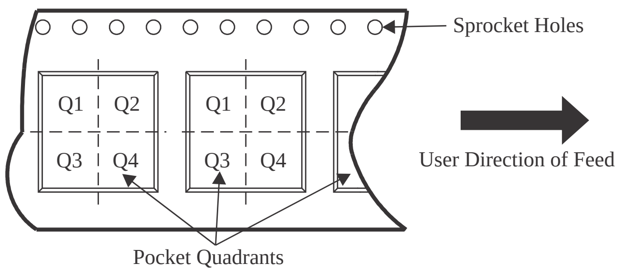


TAPE DIMENSIONS



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

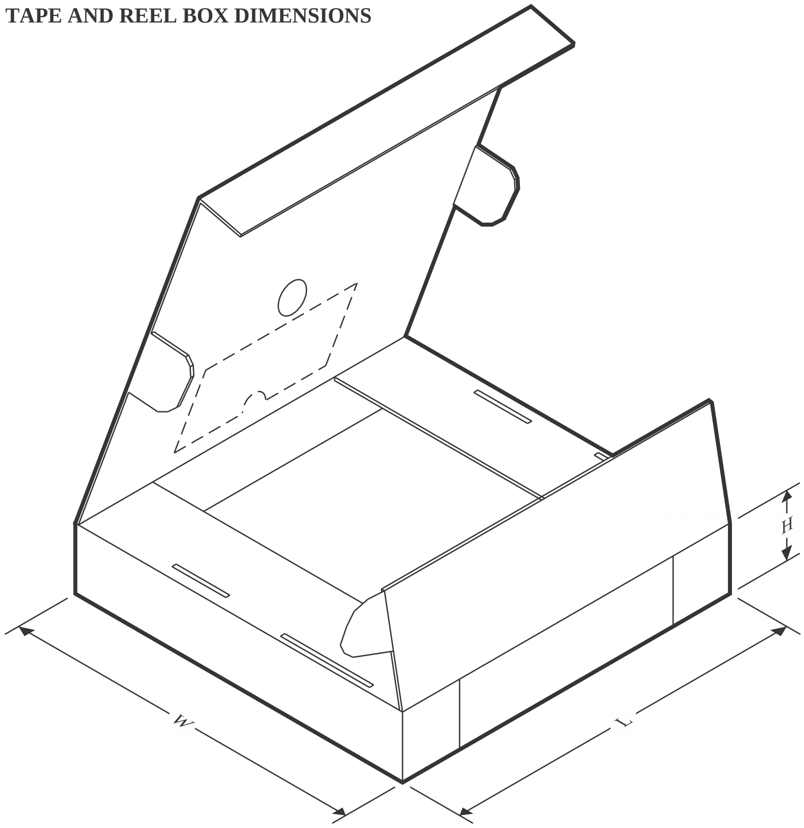
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

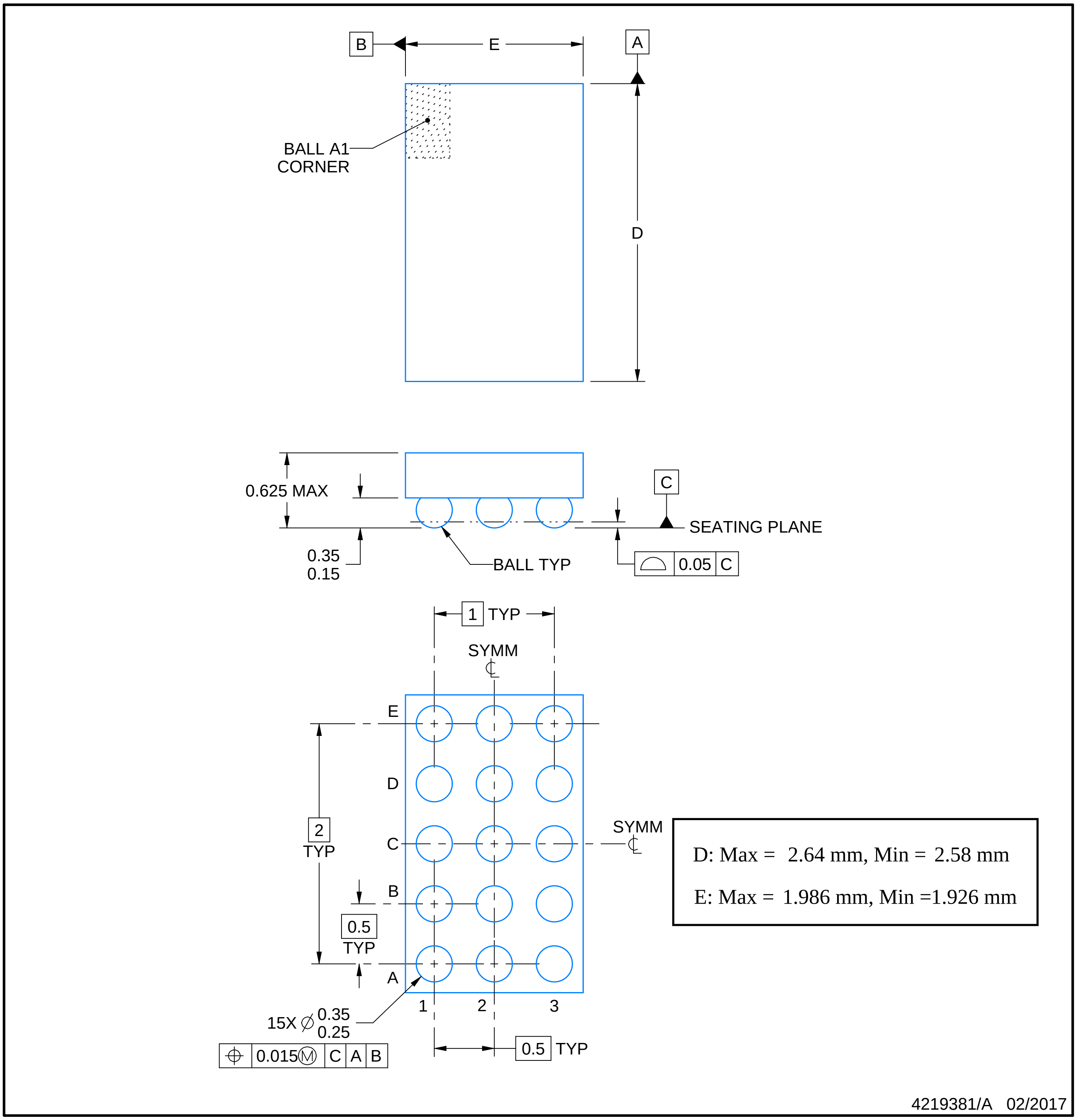
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
BQ27532YZFR-G1	DSBGA	YZF	15	3000	180.0	8.4	2.1	2.76	0.81	4.0	8.0	Q1
BQ27532YZFT-G1	DSBGA	YZF	15	250	180.0	8.4	2.1	2.76	0.81	4.0	8.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

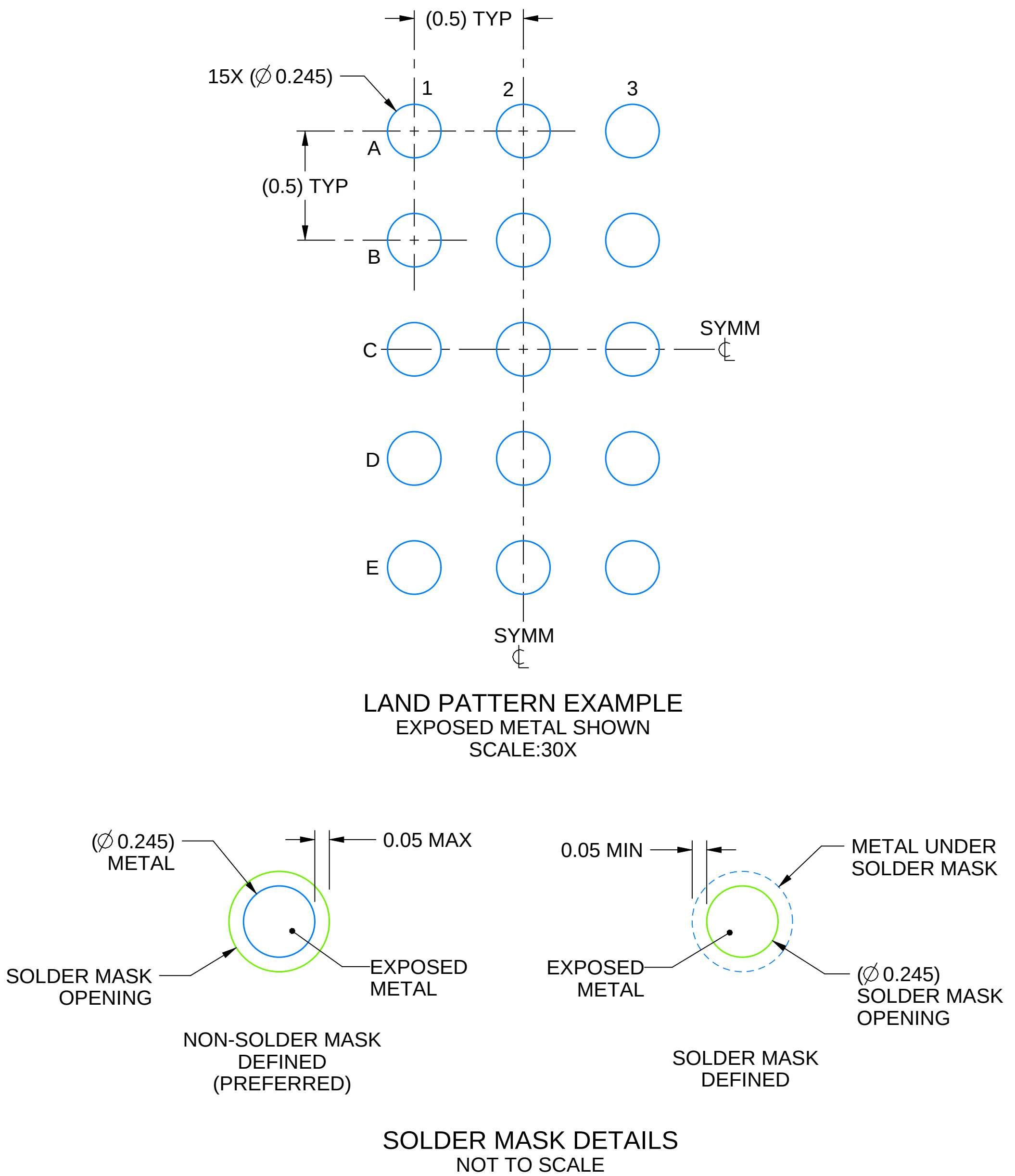
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ27532YZFR-G1	DSBGA	YZF	15	3000	182.0	182.0	20.0
BQ27532YZFT-G1	DSBGA	YZF	15	250	182.0	182.0	20.0



NOTES:

NanoFree Is a trademark of Texas Instruments.

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. NanoFree™ package configuration.



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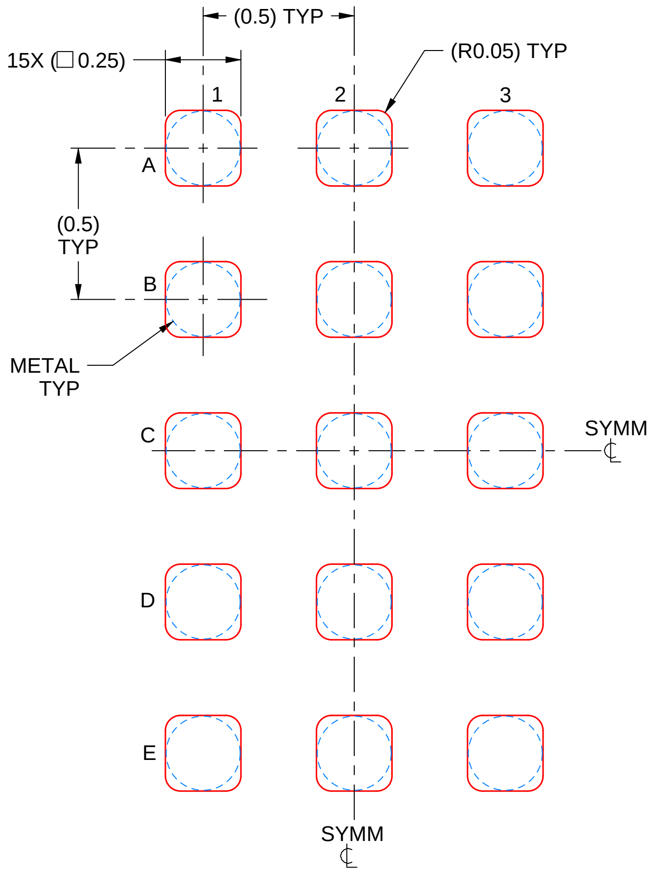
NOTES: (continued)

4. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints. For more information, see Texas Instruments literature number SNVA009 (www.ti.com/lit/snva009).



SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE:40X

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NOTES: (continued)

5. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

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