

System-Side Impedance Track™ Fuel Gauge With Integrated LDO

Check for Samples: [bq27520-G3](#)

1 INTRODUCTION

1.1 FEATURES

- Battery Fuel Gauge for 1-Series Li-Ion Applications
- Resides on System Main Board
 - Works With Embedded or Removable Battery Packs
- Uses **PACK+**, **PACK-**, and **T** Battery Terminals
- Microcontroller Peripheral Provides:
 - Accurate Battery Fuel Gauging
 - Internal Temperature Sensor for Battery Temperature Reporting
 - **Battery Low** Interrupt Warning
 - **Battery Insertion** Indicator
 - **Configurable Level of State of Charge (SOC)** Interrupts
 - **State of Health** Indicator
 - Current Data Logging Buffer
 - 32 Bytes of Non-Volatile Scratch-Pad FLASH
- Battery Fuel Gauge Based on Patented Impedance Track™ Technology
 - Models the Battery Discharge Curve for Accurate Time-to-Empty Predictions
 - Automatically Adjusts for Battery Aging, Battery Self-Discharge, and Temperature/Rate Inefficiencies
 - Low-Value Sense Resistor (10 mΩ or Less)
- 400-kHz I²C™ Interface for Connection to System Microcontroller Port
- In a 15-Pin NanoFree™ (CSP) Packaging

1.2 APPLICATIONS

- Smartphones
- PDAs
- Digital Still and Video Cameras
- Handheld Terminals
- MP3 or Multimedia Players

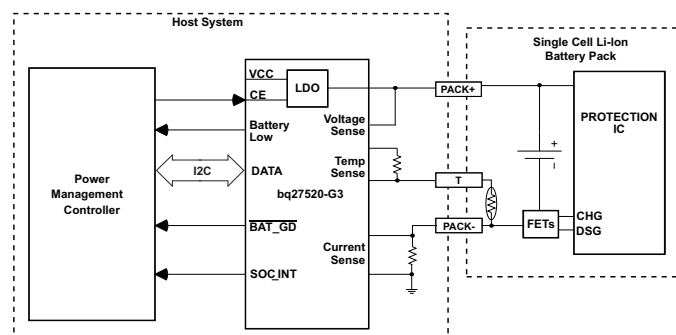
1.3 DESCRIPTION

The Texas Instruments bq27520-G3 system-side Li-Ion battery fuel gauge is a microcontroller peripheral that provides fuel gauging for single-cell Li-Ion battery packs. The device requires little system microcontroller firmware development. The resides on the system's main board and manages an embedded battery (non-removable) or a removable battery pack.

The bq27520-G3 uses the patented Impedance Track™ algorithm for fuel gauging, and provides information such as remaining battery capacity (mAh), state-of-charge (%), run-time to empty (min), battery voltage (mV), temperature (°C) and state of health (%).

Battery fuel gauging with the requires only **PACK+** (P+), **PACK-** (P-), and Thermistor (T) connections to a removable battery pack or embedded battery circuit. The CSP option is a 15-ball package in the [nominal dimensions of 2610 × 1956 μm](#) with 0,5 mm lead pitch. It is ideal for space constrained applications.

TYPICAL APPLICATION



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These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

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2 DEVICE INFORMATION

2.1 AVAILABLE OPTIONS

PART NUMBER	FIRMWARE VERSION	PACKAGE	T _A	COMMUNICATION FORMAT	TAPE and REEL QUANTITY
BQ27520YZFR-G3	3.24	CSP-15	–40°C to 85°C	I ² C	3000
BQ27520YZFT-G3					250

2.2 THERMAL INFORMATION

THERMAL METRIC		bq27520-G3 YZF(15 PINS)	UNITS
θ_{JA}	Junction-to-ambient thermal resistance	70	°C/W
θ_{JCTop}	Junction-to-case (top) thermal resistance	17	
θ_{JB}	Junction-to-board thermal resistance	20	
Ψ_{JT}	Junction-to-top characterization parameter	1	
Ψ_{JB}	Junction-to-board characterization parameter	18	
θ_{JCbott}	Junction-to-case (bottom) thermal resistance	n/a	

2.3 PIN ASSIGNMENT

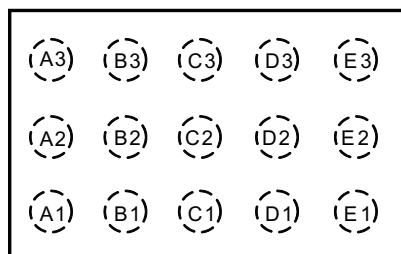
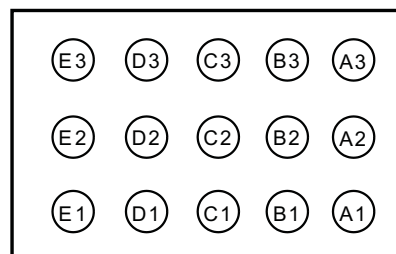
CSP-15
(TOP VIEW)

CSP-15
(BOTTOM VIEW)


Table 2-1. PIN FUNCTIONS

PIN		TYPE	DESCRIPTION
NAME	NO.		
SRP	A1	IA	Analog input pin connected to the internal coulomb counter with a Kelvin connection where SRP is nearest the PACK– connection. Connect to 5-mΩ to 20-mΩ sense resistor.
SRN	B1	IA	Analog input pin connected to the internal coulomb counter with a Kelvin connection where SRN is nearest the Vss connection. Connect to 5-mΩ to 20-mΩ sense resistor.
V _{SS}	C1, C2	P	Device ground
V _{CC}	D1	P	Regulator output and bq27520-G3 processor power. Decouple with 1μF ceramic capacitor to Vss.
REGIN	E1	P	Regulator input. Decouple with 0.1μF ceramic capacitor to Vss.
SOC_INT	A2	O	SOC state interrupts output. Generates a pulse under the conditions specified by Table 5-6 . Open drain output.
$\overline{\text{BAT_GD}}$	B2	O	Battery-good indicator. Active- <i>low</i> by default, though polarity can be configured through the [BATG_POL] bit of Operation Configuration . Push-pull output.
CE	D2	I	Chip Enable. Internal LDO is disconnected from REGIN when driven low.
BAT	E2	I	Cell-voltage measurement input. ADC input. Recommend 4.8V maximum for conversion accuracy.
SCL	A3	I	Slave I ² C serial communications clock input line for communication with system (Master). Open-drain I/O. Use with 10kΩ pull-up resistor (typical).
SDA	B3	I/O	Slave I ² C serial communications data line for communication with system (Master). Open-drain I/O. Use with 10kΩ pull-up resistor (typical).
BAT_LOW	C3	O	Battery Low output indicator. Active <i>high</i> by default, though polarity can be configured through the [BATL_POL] bit of Operation Configuration . Push-pull output.
TS	D3	IA	Pack thermistor voltage sense (use 103AT-type thermistor). ADC input.
BI/TOUT	E3	I/O	Battery-insertion detection input. Power pin for pack thermistor network. Thermistor-multiplexer control pin. Use with pull-up resistor >1MΩ (1.8 MΩ typical).

3 ELECTRICAL SPECIFICATIONS

3.1 ABSOLUTE MAXIMUM RATINGS

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

PARAMETER		VALUE	UNIT
V _{REGIN}	Regulator input range	–0.3 to 5.5	V
V _{CC}	Supply voltage range	–0.3 to 2.75	V
V _{IOD}	Open-drain I/O pins (SDA, SCL, SOC_INT)	–0.3 to 5.5	V
V _{BAT}	BAT input pin	–0.3 to 5.5	
V _I	Input voltage range to all other pins (BI/TOUT, TS, SRP, SRN, BAT_GD)	–0.3 to V _{CC} + 0.3	V
ESD	Human-body model (HBM), BAT pin	1.5	kV
	Human-body model (HBM), all other pins	2	
	Charged-Device model (CDM), all pins	500	V
T _A	Operating free-air temperature range	–40 to 85	°C
T _F	Functional temperature range	–40 to 100	°C
T _{stg}	Storage temperature range	–65 to 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.

3.2 RECOMMENDED OPERATING CONDITIONS

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V _{REGIN}	Supply voltage	No operating restrictions	2.7		4.5	V
		No FLASH writes	2.45		2.7	
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
I _{CC}	Normal operating-mode current ⁽¹⁾	Fuel gauge in NORMAL mode. I _{LOAD} > Sleep Current		118		μA
I _{SLP+}	Sleep+ operating mode current ⁽¹⁾	Fuel gauge in SLEEP+ mode. I _{LOAD} < Sleep Current		62		μA
I _{SLP}	Low-power storage-mode current ⁽¹⁾	Fuel gauge in SLEEP mode. I _{LOAD} < Sleep Current		23		μA
I _{HIB}	Hibernate operating-mode current ⁽¹⁾	Fuel gauge in HIBERNATE mode. I _{LOAD} < Hibernate Current		8		μA
V _{OL}	Output voltage, low (SCL, SDA, SOC_INT, BAT_LOW)	I _{OL} = 3 mA			0.4	V
V _{OH(PP)}	Output voltage, high (BAT_LOW, BAT_GD)	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
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(OD)}	Input voltage, high (SDA, SCL)		1.2		6	
	Input voltage, high (BI/TOUT)	BAT INSERT CHECK MODE active	1.2		V _{CC} + 0.3	
V _{A1}	Input voltage range (TS)		V _{SS} – 0.125		2	V
V _{A2}	Input voltage range (BAT)		V _{SS} – 0.125		5	V
V _{A3}	Input voltage range (SRP, SRN)		V _{SS} – 0.125		0.125	V
I _{ikg}	Input leakage current (I/O pins)				0.3	μA
t _{PUCD}	Power-up communication delay			250		ms

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

3.3 POWER-ON RESET

 $T_A = -40^{\circ}\text{C}$ to 85°C , typical values at $T_A = 25^{\circ}\text{C}$ and $V_{\text{REGIN}} = 3.6\text{ V}$ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{\text{IT+}}$ Positive-going battery voltage input at V_{CC}		2.09	2.20	2.31	V
V_{HYS} Power-on reset hysteresis		45	115	185	mV

3.4 2.5V LDO REGULATOR

 $T_A = 25^{\circ}\text{C}$, $C_{\text{LDO25}} = 1\mu\text{F}$, $V_{\text{REGIN}} = 3.6\text{V}$ (unless otherwise noted)

PARAMETER		TEST CONDITION		MIN	NOM	MAX	UNIT
2.5 V LDO REGULATOR ⁽¹⁾							
V _{REG25}	Regulator output voltage	2.7V ≤ V _{REGIN} ≤ 4.5V, I _{OUT} ≤ 16mA	T _A = −40°C to 85°C	2.4	2.5	2.6	V
		2.45V ≤ V _{REGIN} < 2.7V (low battery), I _{OUT} ≤ 3mA	T _A = −40°C to 85°C	2.4			V
V _{IH(CE)}	CE High-level input voltage	V _{REGIN} = 2.7 to 4.5V	T _A = −40°C to 85°C	2.65		0.8	V
V _{IL(CE)}	CE Low-level input voltage						
V _{DO}	Regulator dropout voltage	2.7V, I _{OUT} ≤ 16mA	T _A = −40°C to 85°C			325	mV
		2.45V, I _{OUT} ≤ 3mA	T _A = −40°C to 85°C			50	
ΔV _{REGTEMP}	Regulator output change with temperature	V _{REGIN} = 3.6V, I _{OUT} = 16mA	T _A = −40°C to 85°C	0.5%			
ΔV _{REGLINE}	Line regulation	2.7V ≤ V _{REGIN} ≤ 4.5V, I _{OUT} = 16mA		18		40	mV
ΔV _{REGLOAD}	Load regulation	0.2mA ≤ I _{OUT} ≤ 3mA, V _{REGIN} = 2.45 V		34		40	mV
		3mA ≤ I _{OUT} ≤ 16mA, V _{REGIN} = 2.7 V		31			
I _{SHORT} ⁽²⁾	Short circuit current limit	V _{REG25} = 0V	T _A = −40°C to 85°C			250	mA

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

(2) Specified by design. Not production tested.

3.5 INTERNAL TEMPERATURE SENSOR CHARACTERISTICS

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

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
G_{TEMP} Temperature sensor voltage gain			-2		mV/ $^{\circ}\text{C}$

3.6 HIGH-FREQUENCY OSCILLATOR

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

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{OSC} Operating frequency			2.097		MHz
f_{EIO} Frequency error ^{(1) (2)}	$T_A = 0^{\circ}\text{C}$ to 60°C	-2%	0.38%	2%	
	$T_A = -20^{\circ}\text{C}$ to 70°C	-3%	0.38%	3%	
	$T_A = -40^{\circ}\text{C}$ to 85°C	-4.5%	0.38%	4.5%	
t_{SXO} Start-up time ⁽³⁾			2.5	5	ms

(1) The frequency error is measured from 2.097 MHz.

(2) The frequency drift is included and measured from the trimmed frequency at $V_{\text{CC}} = 2.5\text{ V}$, $T_A = 25^{\circ}\text{C}$.

(3) The start-up time is defined as the time it takes for the oscillator output frequency to be within $\pm 3\%$ of typical oscillator frequency.

3.7 LOW-FREQUENCY OSCILLATOR

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

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
f_{LOSC} Operating frequency			32.768		kHz
f_{LEIO} Frequency error ^{(1) (2)}	$T_A = 0^{\circ}\text{C}$ to 60°C	–1.5%	0.25%	1.5%	
	$T_A = -20^{\circ}\text{C}$ to 70°C	–2.5%	0.25%	2.5%	
	$T_A = -40^{\circ}\text{C}$ to 85°C	–4%	0.25%	4%	
t_{LSXO} Start-up time ⁽³⁾				500	μs

(1) The frequency drift is included and measured from the trimmed frequency at $V_{CC} = 2.5\text{ V}$, $T_A = 25^{\circ}\text{C}$.

(2) The frequency error is measured from 32.768 kHz.

(3) The start-up time is defined as the time it takes for the oscillator output frequency to be within $\pm 3\%$ of typical oscillator frequency.

3.8 INTEGRATING ADC (COULOMB COUNTER) CHARACTERISTICS

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

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

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

3.9 ADC (TEMPERATURE AND CELL MEASUREMENT) CHARACTERISTICS

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

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{\text{IN}(\text{ADC})}$ Input voltage range		0.05		1	V
$t_{\text{ADC_CONV}}$ Conversion time				125	ms
Resolution		14		15	bits
$V_{\text{OS}(\text{ADC})}$ Input offset			1		mV
Z_{ADC1} Effective input resistance (TS) ⁽¹⁾		8			M Ω
Z_{ADC2} Effective input resistance (BAT) ⁽¹⁾	bq27520-G3 not measuring cell voltage	8			M Ω
	bq27520-G3 measuring cell voltage		100		k Ω
$I_{\text{lk}(\text{ADC})}$ Input leakage current ⁽¹⁾				0.3	μA

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

3.10 DATA FLASH MEMORY CHARACTERISTICS

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

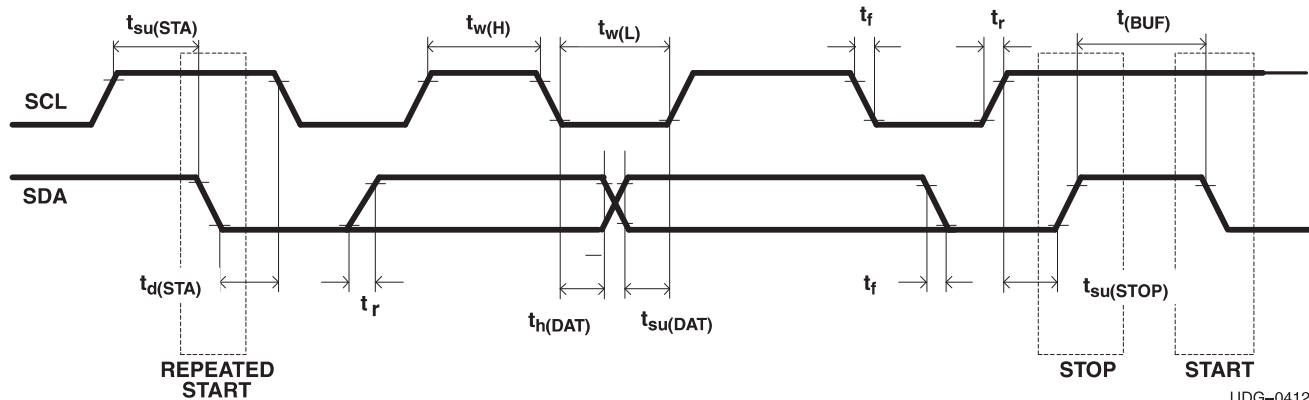
PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{DR} Data retention ⁽¹⁾		10			Years
Flash-programming write cycles ⁽¹⁾		20,000			Cycles
$t_{WORDPROG}$ Word programming time ⁽¹⁾				2	ms
I_{CCPROG} Flash-write supply current ⁽¹⁾			5	10	mA
$t_{DFERASE}$ Data flash master erase time ⁽¹⁾		200			ms
$t_{IFERASE}$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

(1) Specified by design. Not production tested

3.11 I²C-COMPATIBLE INTERFACE COMMUNICATION TIMING CHARACTERISTICS

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

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_r SCL/SDA rise time				300	ns
t_f SCL/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				400	kHz



UDG-04122

Figure 3-1. I²C-Compatible Interface Timing Diagrams

4 GENERAL DESCRIPTION

The bq27520-G3 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 time-to-empty (TTE), time-to-full (TTF) and state-of-charge (SOC) as well as SOC interrupt signal to the host.

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 device control and status registers, as well as its data flash locations. Commands are sent from system to gauge using the bq27520-G3's I²C serial communications engine, and can be executed during application development, pack manufacture, or end-equipment operation.

Cell information is stored in the device 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 bq27520-G3's 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 bq27520-G3 provides a 32-byte user-programmable data flash **Manufacturer Info Block**. This data space is accessed through a data flash interface. For specifics on accessing the data flash, see Section 4.3: [MANUFACTURER INFORMATION BLOCK](#).

The key to the bq27520-G3's high-accuracy gas gauging prediction is Texas Instrument's proprietary Impedance Track™ algorithm. This algorithm uses cell measurements, characteristics, and properties to create state-of-charge predictions that can achieve less than 1% error across a wide variety of operating conditions and over the lifetime of the battery.

The device measures charge/discharge activity by monitoring the voltage across a small-value series sense resistor (5 mΩ to 20 mΩ typ.) located between the system's V_{SS} and the battery's PACK- terminal. When a cell is attached to the device, cell impedance is computed, based on cell current, cell open-circuit voltage (OCV), and cell voltage under loading conditions.

The device external temperature sensing is optimized with the use of a high accuracy negative temperature coefficient (NTC) thermistor with R₂₅ = 10.0kΩ ±1%. B_{25/85} = 3435K ± 1% (such as Semitec NTC 103AT). Alternatively, the bq27520-G3 can also be configured to use its internal temperature sensor or receive temperature data from the host processor. When an external thermistor is used, a 18.2k pull up resistor between BT/TOUT and TS pins is also required. The bq27520-G3 uses temperature to monitor the battery-pack environment, which is used for fuel gauging and cell protection functionality.

To minimize power consumption, the device has different power modes: NORMAL, SLEEP+, SLEEP, HIBERNATE, and BAT INSERT CHECK. The bq27520-G3 passes automatically between these modes, depending upon the occurrence of specific events, though a system processor can initiate some of these modes directly. More details can be found in see Section 5.7: [POWER MODES](#).

NOTE

FORMATTING CONVENTIONS IN THIS DOCUMENT:

Commands: *italics* with parentheses and no breaking spaces, e.g., *RemainingCapacity()*

Data flash: *italics*, **bold**, and *breaking spaces*, e.g., **Design Capacity**

Register bits and flags: brackets and *italics*, e.g., *[TDA]*

Data flash bits: brackets, *italics* and **bold**, e.g., **[LED1]**

Modes and states: ALL CAPITALS, e.g., UNSEALED mode.

4.1 DATA COMMANDS

4.1.1 STANDARD DATA COMMANDS

The bq27520-G3 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 4-1](#). Because each command consists of two bytes of data, two consecutive I²C transmissions must be executed both to initiate the command function, and to read or write the corresponding two bytes of data. Additional options for transferring data, such as spooling, are described in Section of **Communication**. Standard commands are accessible in NORMAL operation. Read/Write permissions depend on the active access mode, SEALED or UNSEALED (for details on the SEALED and UNSEALED states, see [Section 4.4](#) , Access Modes.)

Table 4-1. Standard Commands

NAME		COMMAND CODE	UNITS	SEALED ACCESS
<i>Control()</i>	CNTL	0x00 / 0x01	N/A	R/W
<i>AtRate()</i>	AR	0x02 / 0x03	mA	R/W
<i>AtRateTimeToEmpty()</i>	ARTTE	0x04 / 0x05	Minutes	R
<i>Temperature()</i>	TEMP	0x06 / 0x07	0.1 K	R/W
<i>Voltage()</i>	VOLT	0x08 / 0x09	mV	R
<i>Flags()</i>	FLAGS	0x0a / 0x0b	N/A	R
<i>NominalAvailableCapacity()</i>	NAC	0x0c / 0x0d	mAh	R
<i>FullAvailableCapacity()</i>	FAC	0x0e / 0x0f	mAh	R
<i>RemainingCapacity()</i>	RM	0x10 / 0x11	mAh	R
<i>FullChargeCapacity()</i>	FCC	0x12 / 0x13	mAh	R
<i>AverageCurrent()</i>	AI	0x14 / 0x15	mA	R
<i>TimeToEmpty()</i>	TTE	0x16 / 0x17	Minutes	R
<i>TimeToFull()</i>	TTF	0x18 / 0x19	Minutes	R
<i>StandbyCurrent()</i>	SI	0x1a / 0x1b	mA	R
<i>StandbyTimeToEmpty()</i>	STTE	0x1c / 0x1d	Minutes	R
<i>MaxLoadCurrent()</i>	MLI	0x1e / 0x1f	mA	R
<i>MaxLoadTimeToEmpty()</i>	MLTTE	0x20 / 0x21	Minutes	R
<i>AvailableEnergy()</i>	AE	0x22 / 0x23	mWh	R
<i>AveragePower()</i>	AP	0x24 / 0x25	mW	R
<i>TTEatConstantPower()</i>	TTECP	0x26 / 0x27	Minutes	R
<i>StateOfHealth()</i>	SOH	0x28 / 0x29	% / num	R
<i>CycleCount()</i>	CC	0x2a / 0x2b	num	R
<i>StateOfCharge()</i>	SOC	0x2c / 0x2d	%	R
<i>NormalizedImpedanceCal()</i>	NIC	0x2e / 0x2f	mohm	R
<i>InstantaneousCurrent Reading()</i>	ICR	0x30 / 0x31	mA	R
<i>DataLogIndex()</i>	DLI	0x32 / 0x33	N/A	R
<i>DataLogBuffer()</i>	DLB	0x34 / 0x35	mA	R
<i>InternalTemperature()</i>	ITEMP	0x36 / 0x37	0.1 K	R
<i>OperationConfiguration()</i>	OPCFG	0x3a / 0x3b	N/A	R

4.1.1.1 *Control()*: 0x00/0x01

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 bq27520-G3 during normal operation and additional features when the device is in different access modes, as described in [Table 4-2](#).

Table 4-2. *Control()* Subcommands

CNTL FUNCTION	CNTL DATA	SEALED ACCESS	DESCRIPTION
CONTROL_STATUS	0x0000	Yes	Reports the status of DF checksum, hibernate, IT, etc.
DEVICE_TYPE	0x0001	Yes	Reports the device type (eg: 0x0520)
FW_VERSION	0x0002	Yes	Reports the firmware version on the device type
PREV_MACWRITE	0x0007	Yes	Returns previous MAC subcommand code
CHEM_ID	0x0008	Yes	Reports the chemical identifier of the Impedance Track™ configuration
OCV_CMD	0x000c	Yes	Request the gauge to take a OCV measurement
BAT_INSERT	0x000d	Yes	Forces the BAT_DET bit set when the <i>[BIE]</i> bit is 0
BAT_REMOVE	0x000e	Yes	Forces the BAT_DET bit clear when the <i>[BIE]</i> bit is 0
SET_HIBERNATE	0x0011	Yes	Forces CONTROL_STATUS <i>[HIBERNATE]</i> to 1
CLEAR_HIBERNATE	0x0012	Yes	Forces CONTROL_STATUS <i>[HIBERNATE]</i> to 0
SET_SLEEP+	0x0013	Yes	Forces CONTROL_STATUS <i>[SNOOZE]</i> to 1
CLEAR_SLEEP+	0x0014	Yes	Forces CONTROL_STATUS <i>[SNOOZE]</i> to 0
FACTORY_RESTORE	0x0015	No	Forces a Factory Restore of learned resistance and Qmax to defaults
ENABLE_DLOG	0x0018	Yes	Commands the device to start coulomb counter Data Logging Mode.
DISABLE_DLOG	0x0019	Yes	Commands the device to stop Data Logging Mode.
DF_VERSION	0x001F	Yes	Returns the Data Flash Version code
SEALED	0x0020	No	Places the bq27520-G3 in SEALED access mode
IT_ENABLE	0x0021	No	Enables the Impedance Track™ algorithm
IT_DISABLE	0x0023	No	Disables the Impedance Track™ algorithm
RESET	0x0041	No	Forces a full reset of the bq27520-G3

4.1.1.1.1 **CONTROL_STATUS: 0x0000**

Instructs the fuel gauge to return status information to control addresses 0x00/0x01. The status word includes the following information.

Table 4-3. CONTROL_STATUS Bit Definitions

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High byte	DLOGEN	FAS	SS	CSV	CCA	BCA	OCVCMDCOMP	OCVFAIL
Low byte	INITCOMP	HIBERNATE	SNOOZE	SLEEP	LDMD	RUP_DIS	VOK	QEN

DLOGEN = Status bit indicating the bq27520-G3 is in current Data Logging Mode. True when set.

FAS = Status bit indicating the bq27520-G3 is in FULL ACCESS SEALED state. Active when set.

SS = Status bit indicating the bq27520-G3 is in SEALED state. Active when set.

CSV = Status bit indicating a valid data flash checksum has been generated. Active when set.

CCA = Status bit indicating the bq27520-G3 Coulomb Counter Calibration routine is active. The CCA routine will take place approximately 1 minute after the initialization. Active when set.

BCA = Status bit indicating the bq27520-G3 board calibration routine is active. Active when set.

OCVCMDCOMP = Status bit indicating the bq27520-G3 has executed the OCV command. This bit can only be set with battery's presence. True when set.

OCVFAIL = Status bit indicating bq27520-G3 OCV reading failed due to the current. This bit can only be set with battery's presence. True when set.

INITCOMP = Initialization completion bit indicating the initialization completed. This bit can only be set with battery's presence and can be monitored to determine when gauge values are valid. True when set.

HIBERNATE = Status bit indicating a request for entry into HIBERNATE from SLEEP mode. True when set. Default is 0.

SNOOZE = Status bit indicating the bq27520-G3 SLEEP+ mode is enabled. True when set.

SLEEP = Status bit indicating the bq27520-G3 is in SLEEP mode. True when set.

LDMD = Status bit indicating the bq27520-G3 Impedance Track™ algorithm is using constant-power mode. True when set. Default is 0 (constant-current mode).

RUP_DIS = Status bit indicating the bq27520-G3 Ra table updates are disabled. Updates disabled when set.

VOK = Status bit indicating the bq27520-G3 voltages are okay for Qmax updates and calculations. True when set.

QEN = Status bit indicating the bq27520-G3 Qmax updates enabled. True when set.

4.1.1.1.2 **DEVICE_TYPE: 0x0001**

Instructs the fuel gauge to return the device type to addresses 0x00/0x01. The bq27520-G3 device type returned is 0x0520.

4.1.1.1.3 **FW_VERSION: 0x0002**

Instructs the fuel gauge to return the firmware version to addresses 0x00/0x01. The bq27520-G3 firmware version returned is 0x0322.

4.1.1.1.4 **PREV_MACWRITE: 0x0007**

Instructs the fuel gauge to return the previous subcommand written to addresses 0x00/0x01. **Note:** This subcommand is only supported for previous subcommand codes 0x0000 through 0x0014. For subcommand codes greater than 0x0009, a value of 0x0007 is returned.

4.1.1.1.5 **CHEM_ID: 0x0008**

Instructs the fuel gauge to return the chemical identifier for the Impedance Track™ configuration to addresses 0x00/0x01.

4.1.1.1.6 **OCV_CMD: 0x000C**

This command is to request the gauge to take an Open Circuit Voltage (OCV) reading. This command can only be issued after the [INITCOMP] has been set, indicating the initialization has been completed. The OCV measurement takes place at the beginning of the next repeated 1s firmware synchronization clock and the SOC_INT pin will pulse for approximately 165mS to indicate the measurement window. For a valid OCV reading, the host should reduce the system load current below a C/20 rate within 8ms after the leading edge of SOC_INT assertion and maintain the reduced load for the remaining 165mS window. The OCV command [OCVFAIL] bit will be set if the OCV_CMD is issued when [CHG_INH] is set.

4.1.1.1.7 **BAT_INSERT: 0X000D**

This command is to force the BAT_DET bit to be set when the battery insertion detection is disabled (BIE=0). When the BIE is set to 0, the battery insertion detection is disabled. The gauge relies on the host to inform it of the battery insertion with this command to set the BAT_DET bit. Alternatively, battery insertion can be detected by the gauge by using the external thermistor network when BIE is set to 1.

4.1.1.1.8 **BAT_REMOVE: 0X000E**

This command is to force the BAT_DET bit to be clear when the battery insertion detection is disabled. When the BIE is set to 0, the battery insertion detection is disabled. The gauge relies on the host to inform it of the battery removal with this command to clear the BAT_DET bit.

4.1.1.1.9 **SET_HIBERNATE: 0x0011**

Instructs the fuel gauge to force the CONTROL_STATUS [HIBERNATE] bit to 1. This will allow the gauge to enter the HIBERNATE power mode after the transition to SLEEP power state is detected and required conditions are met. The [HIBERNATE] bit is automatically cleared upon exiting from HIBERNATE mode.

4.1.1.1.10 **CLEAR_HIBERNATE: 0x0012**

Instructs the fuel gauge to force the CONTROL_STATUS [HIBERNATE] bit to 0. This prevents the gauge from entering the HIBERNATE power mode after the transition to the SLEEP power state is detected. It can also be used to force the gauge out of HIBERNATE mode.

4.1.1.1.11 **ENABLE_SLEEP+ MODE: 0X0013**

Instructs the fuel gauge to set the CONTROL_STATUS [SNOOZE] bit to 1. This will enable the SLEEP+ mode. The gauge will enter SLEEP+ power mode after the transition conditions are met.

4.1.1.1.12 **DISABLE_SLEEP+ MODE: 0X0014**

Instructs the fuel gauge to set the CONTROL_STATUS [SNOOZE] bit to 0. This will disable the SLEEP+ mode. The gauge will exit from the SLEEP+ power mode after the SNOOZE bit is cleared.

4.1.1.1.13 **FACTORY RESTORE: 0X0015**

Instructs the fuel gauge to reset learned resistance tables and Qmax values to the default values. If **Operation Configuration B [INDFACRES]** is set, SOC_INT is asserted while the restore is in progress. This command is only available when the fuel gauge is UNSEALED.

4.1.1.1.14 **ENABLE_DLOG: 0x0018**

Commands the fuel gauge to set the CONTROL_STATUS[DLOGEN] bit to 1, clear the data FIFO, and begin recording coulomb counter data logging. While in Data Logging Mode, the device will not enter Sleep mode.

4.1.1.1.15 **DISABLE_DLOG: 0x0019**

Commands the fuel gauge to clear the CONTROL_STATUS[DLOGEN] bit to 0 and stop recording coulomb counter data. The previous data stored in the FIFO is not cleared.

4.1.1.1.16 **DF_VERSION: 0x001F**

Instructs the fuel gauge to return the 16-bit data flash revision code to addresses 0x00/0x01. The code is stored in **Data Flash Version** and provides a simple method for the customer to control data flash revisions. The default DF_VERSION is 0x0000 as configured in data flash.

4.1.1.1.17 **SEALED: 0x0020**

Instructs the fuel gauge to transition from the UNSEALED state to the SEALED state. The fuel gauge must always be set to the SEALED state for use in end equipment.

4.1.1.1.18 **IT_ENABLE: 0x0021**

This command forces the fuel gauge to begin the Impedance Track™ algorithm, sets the **IT Enable** to 0x01 and causes the [VOK] and [QEN] flags to be set in the CONTROL_STATUS register. [VOK] is cleared if the voltages are not suitable for a Qmax update. This command is only available when the fuel gauge is UNSEALED and is typically enabled at the last step of production after system test is completed.

4.1.1.1.19 **IT_DISABLE: 0x0023**

This command disables the fuel gauge the Impedance Track™ algorithm, clears the **IT Enable** to 0x00 and causes the [QEN] flags to be cleared in the CONTROL_STATUS register. This command is only available when the fuel gauge is UNSEALED.

4.1.1.1.20 **RESET: 0x0041**

This command instructs the fuel gauge to perform a full reset. This command is only available when the fuel gauge is UNSEALED.

4.1.1.2 **AtRate(): 0x02/0x03**

The *AtRate()* read-/write-word function is the first half of a two-function command set used to set the *AtRate* value used in calculations made by the *AtRateTimeToEmpty()* function. The *AtRate()* units are in mA.

The *AtRate()* value is a signed integer, with negative values interpreted as a discharge current value. The *AtRateTimeToEmpty()* function returns the predicted operating time at the *AtRate* value of discharge. The default value for *AtRate()* is zero and forces *AtRateTimeToEmpty()* to return 65,535. Both the *AtRate()* and *AtRateTimeToEmpty()* commands must only be used in NORMAL mode.

4.1.1.3 **AtRateTimeToEmpty(): 0x04/0x05**

This read-word function returns an unsigned integer value of the predicted remaining operating time if the battery is discharged at the *AtRate()* value in minutes with a range of 0 to 65,534. A value of 65,535 indicates *AtRate()* = 0. The fuel gauge updates *AtRateTimeToEmpty()* within 1 s after the system sets the *AtRate()* value. The fuel gauge automatically updates *AtRateTimeToEmpty()* based on the *AtRate()* value every 1 s. Both the *AtRate()* and *AtRateTimeToEmpty()* commands must only be used in NORMAL mode.

4.1.1.4 **Temperature(): 0x06/0x07**

This read-/write-word function returns an unsigned integer value of the temperature in units of 0.1 K measured by the fuel gauge. If [WRTEMP] bit = 1, a write command sets the temperature to be used for gauging calculations while a read command returns to temperature previously written. If [WRTEMP] bit = 0 and [TEMPS] bit = 0, a read command will return the internal temperature sensor value.

4.1.1.5 **Voltage(): 0x08/0x09**

This read-word function returns an unsigned integer value of the measured cell-pack voltage in mV with a range of 0 to 6000 mV.

4.1.1.6 **Flags(): 0x0a/0x0b**

This read-word function returns the contents of the fuel-gauge status register, depicting the current operating status.

Table 4-4. Flags Bit Definitions

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High byte	OTC	OTD	–	–	CHG_INH	XCHG	FC	CHG
Low byte	–	–	OCV_GD	WAIT_ID	BAT_DET	SOC1	SYSDOWN	DSG

OTC = Overtemperature in charge condition is detected. True when set. [SOC_INT will toggle once if set.](#)

OTD = Overtemperature in discharge condition is detected. True when set. [SOC_INT will toggle once if set.](#)

CHG_INH = Charge inhibit: unable to begin charging (temperature outside the range [*Charge Inhibit Temp Low, Charge Inhibit Temp High*]). True when set.

XCHG = Charge suspend alert (temperature outside the range [*Suspend Temperature Low, Suspend Temperature High*]). True when set.

FC = Full-charged is detected. FC is set when charge termination is reached and *FC Set%* = -1 (See the Charging and Charge Termination Indication section for details) or State of Charge is larger than *FC Set%* and *FC Set%* is not -1. True when set.

CHG = (Fast) charging allowed. True when set.

OCV_GD = Good OCV measurement taken. True when set.

WAIT_ID = Waiting to identify inserted battery. True when set.

BAT_DET = Battery detected. True when set.

SOC1 = State-of-charge threshold 1 (**SOC1 Set**) reached. The flag is enabled when BL_INT bit in **Operation Configuration B** is set. True when set.

SysDown = SystemDown bit indicating the system should shut down. [Refer to the Data Flash SysDown parameters for threshold settings.](#)

True when set. [SOC_INT will toggle once if set.](#)

DSG = Discharging detected. True when set.

4.1.1.7 **NominalAvailableCapacity()**: 0x0c/0x0d

This read-only command pair returns the uncompensated (less than C/20 load) battery capacity remaining. Units are mAh.

4.1.1.8 **FullAvailableCapacity()**: 0x0e/0x0f

This read-only command pair returns the uncompensated (less than C/20 load) capacity of the battery when fully charged. Units are mAh. *FullAvailableCapacity()* is updated at regular intervals, as specified by the IT algorithm.

4.1.1.9 **RemainingCapacity()**: 0x10/0x11

This read-only command pair returns the remaining battery capacity which is compensated for the present conditions of load, temperature and battery age. *RemainingCapacity()* is typically lower than the uncompensated *NominalAvailableCapacity()*. Units are mAh.

4.1.1.10 **FullChargeCapacity()**: 0x12/13

This read-only command pair returns the capacity of the battery when fully charged with compensation for the present conditions of temperature and battery age. *FullChargeCapacity()* is updated at regular intervals, as specified by the IT algorithm typically lower than the uncompensated *FullAvailableCapacity()*. Units are mAh.

4.1.1.11 **AverageCurrent()**: 0x14/0x15

This read-only command pair returns a signed integer value that is the average current flow through the sense resistor. *AverageCurrent()* is calculated by dividing the 1 second change in coulomb counter data by 1 second. Large current spikes of short duration will be averaged out in this measurement. Units are mA.

4.1.1.12 **TimeToEmpty()**: 0x16/0x17

This read-only function returns an unsigned integer value of the predicted remaining battery life at the present rate of discharge, in minutes. A value of 65,535 indicates battery is not being discharged.

4.1.1.13 **TimeToFull()**: 0x18/0x19

This read-only function returns an unsigned integer value of predicted remaining time until the battery reaches full charge, in minutes, based upon *AverageCurrent()*. The computation accounts for the taper current time extension from the linear TTF computation based on a fixed *AverageCurrent()* rate of charge accumulation. A value of 65,535 indicates the battery is not being charged.

4.1.1.14 **StandbyCurrent()**: 0x1a/0x1b

This read-only function returns a signed integer value of the measured standby current through the sense resistor. The *StandbyCurrent()* is an adaptive measurement. Initially it reports the standby current programmed in **Initial Standby**, and after spending several seconds in standby, reports the measured standby current.

The register value is updated every 1 second when the measured current is above the **Deadband** and is less than or equal to $2 \times \text{Initial Standby}$. The first and last values that meet this criteria are not averaged in, since they may not be stable values. To approximate a 1 minute time constant, each new *StandbyCurrent()* value is computed by taking approximate 93% weight of the last standby current and approximate 7% of the current measured average current.

4.1.1.15 **StandbyTimeToEmpty()**: 0x1c/0x1d

This read-only function returns an unsigned integer value of the predicted remaining battery life at the standby rate of discharge, in minutes. The computation uses *Nominal Available Capacity* (NAC), the uncompensated remaining capacity, for this computation. A value of 65,535 indicates battery is not being discharged.

4.1.1.16 **MaxLoadCurrent()**: 0x1e/0x1f

This read-only function returns a signed integer value, in units of mA, of the maximum load conditions. The *MaxLoadCurrent()* is an adaptive measurement which is initially reported as the maximum load current programmed in *Initial Max Load Current*. If the measured current is ever greater than *Initial Max Load Current*, then *MaxLoadCurrent()* updates to the new current. *MaxLoadCurrent()* is reduced to the average of the previous value and *Initial Max Load Current* whenever the battery is charged to full after a previous discharge to an SOC less than 50%. This prevents the reported value from maintaining an unusually high value.

4.1.1.17 **MaxLoadTimeToEmpty()**: 0x20/0x21

This read-only function returns an unsigned integer value of the predicted remaining battery life at the maximum load current discharge rate, in minutes. A value of 65,535 indicates that the battery is not being discharged.

4.1.1.18 **AvailableEnergy()**: 0x22/0x23

This read-only function returns an unsigned integer value of the predicted charge or energy remaining in the battery. The value is reported in units of mWh.

4.1.1.19 **AveragePower()**: 0x24/0x25

This read-only function returns a signed integer value of the average power during battery charging and discharging. It is negative during discharge and positive during charge. A value of 0 indicates that the battery is not being discharged. The value is reported in units of mW.

4.1.1.20 **TimeToEmptyAtConstantPower()**: 0x26/0x27

This read-only function returns an unsigned integer value of the predicted remaining operating time if the battery is discharged at the *AveragePower()* value in minutes. A value of 65,535 indicates *AveragePower()* = 0. The fuel gauge automatically updates *TimeToEmptyatContantPower()* based on the *AveragePower()* value every 1 s.

4.1.1.21 **StateOfHealth()**: 0x28/0x29

0x28 SOH percentage: this read-only function returns an unsigned integer value, expressed as a percentage of the ratio of predicted *FCC(25°C, SOH LoadI)* over the *DesignCapacity()*. The *FCC(25°C, SOH LoadI)* is the calculated full charge capacity at 25°C and the *SOH LoadI* which is specified in the data flash. The range of the returned SOH percentage is 0x00 to 0x64, indicating 0 to 100% correspondingly.

0x29 SOH Status: this read-only function returns an unsigned integer value, indicating the status of the SOH percentage. The meanings of the returned value are:

- 0x00: SOH not valid before initialization
- 0x01: Instant SOH value ready
- 0x02: Initial SOH value ready. The calculation is based on uncompensated Qmax and is updated at first grid point during discharge after cell insertion.
- 0x03: SOH value ready. The calculation is based on updated compensated Qmax value. The updated Qmax value is measured after charge/relaxation or Fast Qmax conditions are met.
- 0x04-0xFF: Reserved

4.1.1.22 **CycleCount()**: 0x2a/0x2b

This read-only function returns an unsigned integer value of the number of cycles that the active cell has experienced with a range of 0 to 65535. One cycle occurs when accumulated discharge \geq **CC Threshold**. The gauge maintains a separate cycle counter for both cell profiles and will reset to zero if the insertion of a new pack has been detected.

4.1.1.23 **StateOfCharge()**: 0x2c/0x2d

This read-only function returns an unsigned integer value of the predicted remaining battery capacity expressed as a percentage of *FullChargeCapacity()*, with a range of 0 to 100%.

4.1.1.24 **NormalizedImpedanceCal()**: 0x2e/0x2f

This read-only function returns an unsigned integer value of the calculated normalized impedance to 0°C at the current Depth of Discharge, with the unit of mΩ.

4.1.1.25 **InstantaneousCurrent Reading()** 0x30/0x31

This read-only function returns a signed integer value that is the instantaneous current flow through the sense resistor. The conversion time is 125ms. It is updated every 1 second. Units are mA.

4.1.1.26 **DataLogIndex()**: 0x32/0x33

In Data Logging Mode, this read-only register returns an unsigned integer that increments for every new coulomb counter sample placed in the data FIFO and decrements for each sample read by the host from *DataLogBuffer()*. The index saturates at 30 counts to prevent rollover of the FIFO and subsequent data samples are discarded. Data logging is controlled by the *ENABLE_DLOG* and *DISABLE_DLOG* subcommands while status is provided by the *CONTROL_STATUS[DLOGEN]* bit.

4.1.1.27 **DataLogBuffer()**: 0x34/0x35

In Data Logging Mode, this read-only register returns a 16-bit signed coulomb counter value in mA. Access to data is provided by a 30 sample FIFO with the number of samples available from *DataLogIndex()*. If the FIFO is empty, this value returned is 0x7FFF.

4.1.1.28 **InternalTemperature()**: 0x36/0x37

This read-only function returns an unsigned integer value of the internal temperature sensor in units of 0.1 K measured by the fuel gauge. This function can be useful as an additional system-level temperature monitor if the main *Temperature()* function is configured for external or host reported temperature.

4.1.1.29 OperationConfiguration(): 0x3A/0x3B

This read-only function returns the contents of the data flash **Operation Configuration** register and is most useful for system level debug to quickly determine device configuration.

4.1.2 EXTENDED DATA COMMANDS

Extended 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 commands bytes for a given extended command ranges in size from single to multiple bytes, as specified in [Table 4-5](#).

Table 4-5. Extended Data Commands

NAME		COMMAND CODE	UNITS	SEALED ACCESS	UNSEALED ACCESS
Reserved	RSVD	0x34...0x3b	N/A	R	R
DesignCapacity()	DCAP	0x3c / 0x3d	mAh	R	R
DataFlashClass() ⁽²⁾	DFCLS	0x3e	N/A	N/A	R/W
DataFlashBlock() ⁽²⁾	DFBLK	0x3f	N/A	R/W	R/W
BlockData()	DFD	0x40...0x5f	N/A	R	R/W
BlockDataCheckSum()	DFDCKS	0x60	N/A	R/W	R/W
BlockDataControl()	DFDCNTL	0x61	N/A	N/A	R/W
ApplicationStatus()	APPSTAT	0x6a	N/A	R	R
Reserved	RSVD	0x6b...0x7f	N/A	R	R

4.1.2.1 DesignCapacity(): 0x3c/0x3d

SEALED and UNSEALED Access: This command returns the value stored in **Design Capacity** and is expressed in mAh. This is intended to be the theoretical or nominal capacity of a new pack, but has no bearing on the operation of the fuel gauge functionality except for the calculation of *StateOfHealth()*.

4.1.2.2 DataFlashClass(): 0x3e

UNSEALED Access: This command sets the data flash class to be accessed. The class to be accessed must be entered in hexadecimal.

SEALED Access: This command is not available in SEALED mode.

4.1.2.3 DataFlashBlock(): 0x3f

UNSEALED Access: This command sets the data flash block to be accessed. When 0x00 is written to *BlockDataControl()*, *DataFlashBlock()* holds the block number of the data flash to be read or written. Example: writing a 0x00 to *DataFlashBlock()* specifies access to the first 32-byte block, a 0x01 specifies access to the second 32-byte block, and so on.

SEALED Access: This command directs which data flash block is accessed by the *BlockData()* command. Writing a 0x01 or 0x02 instructs the *BlockData()* command to transfer the **Manufacturer Info Block**. All other *DataFlashBlock()* values are reserved.

4.1.2.4 BlockData(): 0x40...0x5f

UNSEALED Access: This data block is the remainder of the 32 byte data block when accessing data flash.

SEALED Access: This data block is the remainder of the 32 byte data block when accessing **Manufacturer Block Info**.

4.1.2.5 *BlockDataChecksum()*: 0x60

UNSEALED Access: This byte contains the checksum on the 32 bytes of block data read or written to data flash. The least-significant byte of the sum of the data bytes written must be complemented ($[255 - x]$, for x the least-significant byte) before being written to 0x60.

SEALED Access: This byte contains the checksum for the 32 bytes of block data written to **the Manufacturer Info Block**. The least-significant byte of the sum of the data bytes written must be complemented ($[255 - x]$, for x the least-significant byte) before being written to 0x60.

4.1.2.6 *BlockDataControl()*: 0x61

UNSEALED Access: This command is used to control data flash access mode. Writing 0x00 to this command enables *BlockData()* to access general data flash. Writing a 0x01 to this command enables SEALED mode operation of *DataFlashBlock()*.

SEALED Access: This command is not available in SEALED mode.

4.1.2.7 *ApplicationStatus()*: 0x6a

This byte function allows the system to read the bq27520-G3 **Application Status** data flash location. See [Table 6-1](#) for specific bit definitions.

4.1.2.8 Reserved — 0x6b–0x7f

4.2 DATA FLASH INTERFACE

4.2.1 ACCESSING THE DATA FLASH

The bq27520-G3 data flash is a non-volatile memory that contains bq27520-G3 initialization, default, cell status, calibration, configuration, and user information. The data flash can be accessed in several different ways, depending on what mode the bq27520-G3 is operating in and what data is being accessed.

Commonly accessed data flash memory locations, frequently read by a system, are conveniently accessed through specific instructions, already described in [Section 4.1, DATA COMMANDS](#). These commands are available when the bq27520-G3 is either in UNSEALED or SEALED modes.

Most data flash locations, however, are only accessible in UNSEALED mode by use of the bq27520-G3 evaluation software or by data flash block transfers. These locations should be optimized and/or fixed during the development and manufacture processes. They become part of a golden image file and can then be written to multiple battery packs. Once established, the values generally remain unchanged during end-equipment operation.

To access data flash locations individually, the block containing the desired data flash location(s) must be transferred to the command register locations, where they can be read to the system or changed directly. This is accomplished by sending the set-up command *BlockDataControl()* (0x61) with data 0x00. Up to 32 bytes of data can be read directly from the *BlockData()* (0x40...0x5f), externally altered, then rewritten to the *BlockData()* command space. Alternatively, specific locations can be read, altered, and rewritten if their corresponding offsets are used to index into the *BlockData()* command space. Finally, the data residing in the command space is transferred to data flash, once the correct checksum for the whole block is written to *BlockDataChecksum()* (0x60).

Occasionally, a data flash CLASS will be larger than the 32-byte block size. In this case, the *DataFlashBlock()* command is used to designate which 32-byte block the desired locations reside in. The correct command address is then given by $0x40 + \text{offset modulo } 32$. For example, to access **Terminate Voltage** in the *Gas Gauging* class, *DataFlashClass()* is issued 80 (0x50) to set the class. Because the offset is 45, it must reside in the second 32-byte block. Hence, *DataFlashBlock()* is issued 0x01 to set the block offset, and the offset used to index into the *BlockData()* memory area is $0x40 + 45 \text{ modulo } 32 = 0x40 + 13 = 0x40 + 0x0d = 0x4d$.

Reading and writing subclass data are block operations up to 32 bytes in length. If during a write the data length exceeds the maximum block size, then the data is ignored.

None of the data written to memory are bounded by the bq27520-G3 – the values are not rejected by the fuel gauge. Writing an incorrect value may result in hardware failure due to firmware program interpretation of the invalid data. The written data is persistent, so a power-on reset does resolve the fault.

4.3 MANUFACTURER INFORMATION BLOCK

The bq27520-G3 contains 32 bytes of user programmable data flash storage called the **Manufacturer Info Block**. The method for accessing these memory locations is slightly different, depending on whether the device is in UNSEALED or SEALED modes.

When in UNSEALED mode and when 0x00 has been written to *BlockDataControl()*, accessing the manufacturer information blocks is identical to accessing general data flash locations. First, a *DataFlashClass()* command is used to set the subclass, then a *DataFlashBlock()* command sets the offset for the first data flash address within the subclass. The *BlockData()* command codes contain the referenced data flash data. When writing the data flash, a checksum is expected to be received by *BlockDataChecksum()*. Only when the checksum is received and verified is the data actually written to data flash.

When in SEALED mode or when 0x01 *BlockDataControl()* does not contain 0x00, data flash is no longer available in the manner used in UNSEALED mode. Rather than issuing subclass information, a designated Manufacturer Information Block is selected with the *DataFlashBlock()* command. Issuing a 0x01 or 0x02 with this command causes the corresponding information block to be transferred to the command space 0x40...0x5f for editing or reading by the system. Upon successful writing of checksum information to *BlockDataChecksum()*, the modified block is returned to data flash. **Note:** *The Manufacturer Info Block* is read-only when in SEALED mode.

4.4 ACCESS MODES

The bq27520-G3 provides three security modes (FULL ACCESS, UNSEALED, and SEALED) that control data flash access permissions, according to [Table 4-6](#). *Data Flash* refers to those data flash locations, specified in [Table 4-7](#), that are accessible to the user.

Table 4-6. Data Flash Access

Security Mode	Data Flash	Manufacture Info Block
FULL ACCESS	R/W	R/W
UNSEALED	R/W	R/W
SEALED	None	R

Although FULL ACCESS and UNSEALED modes appear identical, only FULL ACCESS allows the bq27520-G3 to write access-mode transition keys.

4.5 SEALING/UNSEALING DATA FLASH

The bq27520-G3 implements a key-access scheme to transition between SEALED, UNSEALED, and FULL-ACCESS modes. Each transition requires that a unique set of two keys be sent to the bq27520-G3 via the *Control()* control command. The keys must be sent consecutively, with no other data being written to the *Control()* register in between. Note that to avoid conflict, the keys must be different from the codes presented in the *CNTL DATA* column of [Table 4-2](#) subcommands.

When in SEALED mode, the *CONTROL_STATUS [SS]* bit is set, but when the UNSEAL keys are correctly received by the bq27520-G3, the *[SS]* bit is cleared. When the full-access keys are correctly received, then the *CONTROL_STATUS [FAS]* bit is cleared.

Both the sets of keys for each level are 2 bytes each in length and are stored in data flash. The UNSEAL key (stored at **Unseal Key 0** and **Unseal Key 1**) and the FULL-ACCESS key (stored at **Full-Access Key 0** and **Full-Access Key 1**) can only be updated when in FULL-ACCESS mode. The order of the keys is **Key 1** followed by **Key 0**. The order of the bytes entered through the *Control()* command is the reverse of what is read from the part. For example, if the **Key 1** and **Key 0** of the **Unseal Keys** returns 0x1234 and 0x5678, then the *Control()* should supply 0x3412 and 0x7856 to unseal the part.

4.6 DATA FLASH SUMMARY

Table 4-7 summarizes the data flash locations available to the user, including their default, minimum, and maximum values.

Table 4-7. Data Flash Summary

Class	Subclass ID	Subclass	Offset	Name	Data Type	Min Value	Max Value	Default Value	Units
Configuration	2	Safety	0	OT Chg	I2	0	1200	550	0.1°C
Configuration	2	Safety	2	OT Chg Time	U1	0	60	2	s
Configuration	2	Safety	3	OT Chg Recovery	I2	0	1200	500	0.1°C
Configuration	2	Safety	5	OT Dsg	I2	0	1200	600	0.1°C
Configuration	2	Safety	7	OT Dsg Time	U1	0	60	2	s
Configuration	2	Safety	8	OT Dsg Recovery	I2	0	1200	550	0.1°C
Configuration	32	Charge Inhibit Temp Low	0	Charge Inhibit Temp Low	I2	–400	1200	0	0.1°C
Configuration	32	Charge Inhibit Temp High	2	Charge Inhibit Temp High	I2	–400	1200	450	0.1°C
Configuration	32	Temp Hysteresis	4	Temp Hys	I2	0	100	50	0.1°C
Configuration	34	Charge	2	Charging Voltage	I2	0	4600	4200	mV
Configuration	34	Charge	4	Delta Temp	I2	0	500	50	0.1°C
Configuration	34	Charge	6	Suspend Low Temp	I2	–400	1200	–50	0.1°C
Configuration	34	Charge	8	Suspend High Temp	I2	–400	1200	550	0.1°C
Configuration	36	Charge Termination	2	Taper Current	I2	0	1000	100	mA
Configuration	36	Charge Termination	4	Min Taper Capacity	I2	0	1000	25	0.01mAh
Configuration	36	Charge Termination	6	Taper Voltage	I2	0	1000	100	mV
Configuration	36	Charge Termination	8	Current Taper Window	U1	0	60	40	s
Configuration	36	Charge Termination	11	FC Set %	I1	–1	100	100	%
Configuration	36	Charge Termination	12	FC Clear %	I1	–1	100	98	%
Configuration	36	Charge Termination	13	DOD at EOC	I2	0	1000	100	0.1°C
Configuration	48	Data	4	Initial Standby Current	I1	–128	0	–10	mA
Configuration	48	Data	5	Initial Max Load Current	I2	–32,767	0	–500	mA
Configuration	48	Data	7	CC Threshold	I2	100	32,767	900	mAh
Configuration	48	Data	10	Design Capacity	I2	0	65,535	1000	mAh
Configuration	48	Data	12	SOH Load	I2	–32,767	0	–400	mA
Configuration	48	Data	14	Default Temp	I2	0	1000	250 ⁽¹⁾	0.1°C
Configuration	48	Data	16	Device name	S8	x	x	bq27520	–
Configuration	48	Data	24	Data Flash Version	H2	0x00	0xFF	0x00	–
Configuration	49	Discharge	0	SOC1 Set Threshold	U1	0	255	150	mAh
Configuration	49	Discharge	1	SOC1 Clear Threshold	U1	0	255	175	mAh
Configuration	49	Discharge	5	SysDown Set Volt Threshold	I2	0	4200	3150	mV
Configuration	49	Discharge	7	SysDown Set Volt Time	U1	0	60	2	s
Configuration	49	Discharge	8	SysDown Clear Volt Threshold	I2	0	4200	3400	mV
Configuration	49	Discharge	15	Final Voltage	U2	0	4200	3000	mV
Configuration	49	Discharge	17	Def Cell 0 DOD at EOC	I2	0	16384	0	num
Configuration	49	Discharge	19	Def Cell 1 DOD at EOC	I2	0	16384	0	num
Configuration	49	Discharge	21	Def Avg I Last Run	I2	–32768	32767	–299	mA

(1) Display as the value EVSW displayed. Data Flash value is different.

Table 4-7. Data Flash Summary (continued)

Class	Subclass ID	Subclass	Offset	Name	Data Type	Min Value	Max Value	Default Value	Units
Configuration	49	Discharge	23	Def Avg PLast Run	I2	-32768	32767	-1131	mW
System Data	57	Manufacturer Info	0–31	Block [0 – 31]	H1	0x00	0xff	0x00	–
Configuration	64	Registers	0	Operation Configuration	H2	0x0000	0xffff	0x0973	–
Configuration	64	Registers	7	SOC Delta	U1	0	25	1	%
Configuration	64	Registers	8	I ² C Timeout	U1	0	7	4	num
Configuration	64	Registers	9	DFWrlndWaitTime	U2	0	65535	0	5μs
Configuration	64	Registers	11	OpConfigB	H1	0x00	0xff	0x4B	–
Configuration	64	Registers	12	OpConfigC	H1	0x00	0xff	0x2C	–
Configuration	64	Registers	13	Clock Control Register	H1	0x00	0xff	0x09	–
Configuration	68	Power	0	Flash Update OK Voltage	I2	0	4200	2800	mV
Configuration	68	Power	4	Sleep Current	I2	0	100	10	mA
Configuration	68	Power	13	Hibernate Current	U2	0	700	8	mA
Configuration	68	Power	15	Hibernate Voltage	U2	2400	3000	2550	mV
Gas Gauging	80	IT Cfg	0	Load Select	U1	0	255	1	–
Gas Gauging	80	IT Cfg	1	Load Mode	U1	0	255	0	–
Gas Gauging	80	IT Cfg	21	Max Res Factor	U1	0	255	20	num
Gas Gauging	80	IT Cfg	22	Min Res Factor	U1	0	255	5	num
Gas Gauging	80	IT Cfg	24	Ra Filter	U2	0	1000	500	num
Gas Gauging	80	IT Cfg	40	Min % Passed Charge for Qmax	U1	1	100	37	%
Gas Gauging	80	IT Cfg	44	Qmax Filter	U1	0	255	96	num
Gas Gauging	80	IT Cfg	45	Terminate Voltage	I2	–32,768	32,767	3400	mV
Gas Gauging	80	IT Cfg	47	Term V Delta	I2	0	4200	200	mV
Gas Gauging	80	IT Cfg	50	ResRelax Time	U2	0	65534	500	s
Gas Gauging	80	IT Cfg	54	User Rate-mA	I2	–2000	–100	0	mA
Gas Gauging	80	IT Cfg	56	User Rate-mW	I2	–7200	–350	0	mW
Gas Gauging	80	IT Cfg	58	Reserve Cap-mAh	I2	0	9000	0	mAh
Gas Gauging	80	IT Cfg	60	Reserve Cap-mWh	I2	0	14,000	0	mWh
Gas Gauging	80	IT Cfg	65	Min Delta Voltage	I2	–32,000	32,000	0	mV
Gas Gauging	80	IT Cfg	67	Max Sim Rate	U1	0	255	2	C/rate
Gas Gauging	80	IT Cfg	68	Min Sim Rate	U1	0	255	20	C/rate
Gas Gauging	80	IT Cfg	69	Ra MΔx Delta	U2	0	65,535	44	mΩ
Gas Gauging	80	IT Cfg	71	Qmax MΔx Delta%	U1	0	255	5	%
Gas Gauging	80	IT Cfg	72	ΔV Max dV	U2	0	65,535	10	mV
Gas Gauging	80	IT Cfg	74	Max Res Scale	U2	0	32767	5000	num
Gas Gauging	80	IT Cfg	76	Min Res Scale	U2	0	32767	200	num
Gas Gauging	80	IT Cfg	78	Fast Scale Start SOC	U1	0	100	10	%
Gas Gauging	81	Current Thresholds	0	Dsg Current Threshold	I2	0	2000	60	mA
Gas Gauging	81	Current Thresholds	2	Chg Current Threshold	I2	0	2000	75	mA
Gas Gauging	81	Current Thresholds	4	Quit Current	I2	0	1000	40	mA
Gas Gauging	81	Current Thresholds	6	Dsg Relax Time	U2	0	8191	60	s
Gas Gauging	81	Current Thresholds	8	Chg Relax Time	U1	0	255	60	s
Gas Gauging	81	Current Thresholds	9	Quit Relax Time	U1	0	63	1	s
Gas Gauging	81	Current Thresholds	10	Transient Factor Charge	U1	0	255	255	num

Table 4-7. Data Flash Summary (continued)

Class	Subclass ID	Subclass	Offset	Name	Data Type	Min Value	Max Value	Default Value	Units
Gas Gauging	81	Current Thresholds	11	Transient Factor Discharge	U1	0	255	255	num
Gas Gauging	81	Current Thresholds	12	Max IR Correct	U2	0	1,000	400	mV
Gas Gauging	82	State	0	IT Enable	H1	0x00	0x03	0x00	–
Gas Gauging	82	State	1	Application Status	H1	0x00	0xff	0x00	–
Gas Gauging	82	State	2	Qmax 0	I2	0	32,767	1000	mAh
Gas Gauging	82	State	4	Cycle Count 0	U2	0	65,535	0	–
Gas Gauging	82	State	6	Update Status 0	H1	0x00	0x03	0x00	–
Gas Gauging	82	State	7	Qmax 1	I2	0	32767	1000	mAh
Gas Gauging	82	State	9	Cycle Count 1	U2	0	65,535	0	Count
Gas Gauging	82	State	11	Update Status 1	H1	0x00	0x03	0x00	–
Gas Gauging	82	State	12	Cell0 Chg DOD at EoC	I2	0	16384	0	–
Gas Gauging	82	State	14	Cell1 Chg DOD at EoC	I2	0	16384	0	–
Gas Gauging	82	State	16	Avg I Last Run	I2	–32,768	32,767	–299	mA
Gas Gauging	82	State	18	Avg P Last Run	I2	–32,768	32,767	–1131	mAh
Gas Gauging	82	State	20	Delta Voltage	I2	–32,768	32,768	2	mV
Gas Gauging	82	State	24	T Rise	U2	0	65535	2	num
Gas Gauging	82	State	26	T Time Constant	U2	0	65535	1000	num
OCV Table	83	OCVa0 Table	0	Chem ID 0	H2	0x0	0xffff	0x100	num
OCV Table	83	OCVa0 Table	2	Qmax Cell 0	I2	0	32767	1000	mAh
OCV Table	83	OCVa0 Table	4	Update Status	H1	0x00	0x03	0x00	–
OCV Table	84	OCVa1 Table	0	Chem ID 1	H2	0x0	0xffff	0x100	num
OCV Table	84	OCVa1 Table	2	Qmax Cell 1	I2	0	32767	1000	mAh
OCV Table	84	OCVa1 Table	4	Update Status 1	H1	0x00	0x03	0x00	–
Default Ra	87	Def0 Ra	0	Def0 Ra Status	H1	0x00	0x00	0xff	–
Default Ra	87	Def0 Ra	1	Def0 Ra Flag	H1	0x00	0x00	0x55	–
Default Ra	87	Def0 Ra	2-18	Def0 Ra	H1	0x00	0xff	–	–
Default Ra	88	Def1 Ra	0	Def1 Ra Status	H1	0x00	0x00	0xff	–
Default Ra	88	Def1 Ra	1	Def1 Ra Flag	H1	0x00	0x00	0x55	–
Default Ra	88	Def1 Ra	2-18	Def1 Ra	H1	0x00	0xff	–	–
Ra Table	91	Pack0 Ra	0	Pack0 Ra Status	H1	0x00	0x00	0xff	–
Ra Table	91	Pack0 Ra	1	Pack0 Ra Flag	H1	0x00	0x00	0x55	–
Ra Table	91	Pack0 Ra	2-18	Pack0 Ra	H1	0x00	0xff	–	–
Ra Table	92	Pack1 Ra	0	Pack1 Ra Status	H1	0x00	0x00	0xff	–
Ra Table	92	Pack1 Ra	1	Pack1 Ra Flag	H1	0x00	0x00	0x55	–
Ra Table	92	Pack1 Ra	2-18	Pack1 Ra	H1	0x00	0xff	–	–
Ra Table	93	Pack0 Rax	0	Pack0 Rax Status	H1	0x00	0x00	0xff	–
Ra Table	93	Pack0 Rax	1	Pack0 Rax Flag	H1	0x00	0x00	0x55	–
Ra Table	93	Pack0 Rax	2-18	Pack0 Rax	H1	0x00	0xff	–	–
Ra Table	94	Pack1 Rax	0	Pack1 Rax Status	H1	0x00	0x00	0xff	–
Ra Table	94	Pack1 Rax	1	Pack1 Rax Flag	H1	0x00	0x00	0x55	–
Ra Table	94	Pack1 Rax	2-18	Pack1 Rax	H1	0x00	0xff	–	–
Calibration	104	Data	0	CC Gain	F4 ⁽²⁾	0.1	47	10 ⁽³⁾	mohm
Calibration	104	Data	4	CC Delta	F4 ⁽²⁾	4.7	188	10 ⁽³⁾	mohm
Calibration	104	Data	8	CC Offset	I2	–2.4	2.4	–0.58 ⁽³⁾	mV

(2) Not IEEE floating point.

(3) Display as the value EVSW displayed. Data Flash value is different.

Table 4-7. Data Flash Summary (continued)

Class	Subclass ID	Subclass	Offset	Name	Data Type	Min Value	Max Value	Default Value	Units
Calibration	104	Data	10	ADC Offset	I2	–500	500	0	mV
Calibration	104	Data	12	Board Offset	I1	–128	127	0	mV
Calibration	104	Data	13	Int Temp Offset	I1	–128	127	0	0.1°C
Calibration	104	Data	14	Ext Temp Offset	I1	–128	127	0	0.1°C
Calibration	104	Data	15	Pack V Offset	I1	–128	127	0	mV
Temp Model	106	Data	0	Ext a Coef 1	I2	–32768	32767	–11130	num
Temp Model	106	Data	2	Ext a Coef 2	I2	–32768	32767	19142	num
Temp Model	106	Data	4	Ext a Coef 3	I2	–32768	32767	–19262	num
Temp Model	106	Data	6	Ext a Coef 4	I2	–32768	32767	28203	num
Temp Model	106	Data	8	Ext a Coef 5	I2	–32768	32767	892	num
Temp Model	106	Data	10	Ext b Coef 1	I2	–32768	32767	328	num
Temp Model	106	Data	12	Ext b Coef 2	I2	–32768	32767	–605	num
Temp Model	106	Data	14	Ext b Coef 3	I2	–32768	32767	–2443	num
Temp Model	106	Data	16	Ext b Coef 4	I2	–32768	32767	4696	num
Calibration	107	Current	1	Deadband	U1	0	255	5	mA
Security	112	Codes	0	Unseal Key 0	H2	0x0000	0xffff	0x3672	–
Security	112	Codes	2	Unseal Key 1	H2	0x0000	0xffff	0x0414	–
Security	112	Codes	4	Unsealed to Full 0	H2	0x0000	0xffff	0xffff	–
Security	112	Codes	6	Unsealed to Full 1	H2	0x0000	0xffff	0xffff	–
Security	112	Codes	8	FactRestorkey 0	H2	0x0000	0xffff	0x0DEF	–
Security	112	Codes		FactRestorkey 1	H2	0x0000	0xffff	0x0FAC	–

5 FUNCTIONAL DESCRIPTION

5.1 FUEL GAUGING

The bq27520-G3 measures the cell voltage, temperature, and current to determine battery SOC. The bq27520-G3 monitors charge and discharge activity by sensing the voltage across a small-value resistor (5 mΩ to 20 mΩ typ.) between the SRP and SRN pins and in series with the cell. By integrating charge passing through the battery, the battery's 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 state of charge 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 bq27520-G3 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 bq27520-G3 has two flags accessed by the *Flags()* function that warns when the battery's SOC has fallen to critical levels. When *RemainingCapacity()* falls below the first capacity threshold, specified in **SOC1 Set Threshold**, the [SOC1] (*State of Charge Initial*) flag is set. The flag is cleared once *RemainingCapacity()* rises above SOC1 Set Threshold. The bq27520-G3's BAT_LOW pin automatically reflects the status of the [SOC1] flag. This flag is enabled when BL_INT bit in **Operation Configuration B** is set. All units are in mAh.

When *Voltage()* falls below the system shut down threshold voltage, **SysDown Set Volt Threshold**, the *[SYSDOWN]* flag is set, serving as a final warning to shut down the system. The SOC_INT also signals. When *Voltage()* rises above **SysDown Clear Voltage** and the *[SYSDOWN]* flag has already been set, the *[SYSDOWN]* flag is cleared. The SOC_INT also signals such change. All units are in mV.

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

5.2 IMPEDANCE TRACK™ VARIABLES

The bq27520-G3 has several data flash variables that permit the user to customize the Impedance Track™ algorithm for optimized performance. These variables are dependent upon the power characteristics of the application as well as the cell itself.

5.2.1 Load Mode

Load Mode is used to select either the constant-current or constant-power model for the Impedance Track™ algorithm as used in **Load Select** (see **Load Select**). When **Load Mode** is 0, the *Constant Current Model* is used (default). When 1, the *Constant Power Model* is used. The *[LDMD]* bit of CONTROL_STATUS reflects the status of **Load Mode**.

5.2.2 Load Select

Load Select defines the type of power or current model to be used to compute load-compensated capacity in the Impedance Track™ algorithm. If **Load Mode** = 0 (*Constant-Current*) then the options presented in [Table 5-1](#) are available.

Table 5-1. Constant-Current Model Used When Load Mode = 0

LoadSelect Value	Current Model Used
0	Average discharge current from previous cycle: There is an internal register that records the average discharge current through each entire discharge cycle. The previous average is stored in this register.
1(default)	Present average discharge current: This is the average discharge current from the beginning of this discharge cycle until present time.
2	Average current: based on AverageCurrent()
3	Current: based off of a low-pass-filtered version of AverageCurrent() ($\tau = 14$ s)
4	Design capacity / 5: C Rate based off of Design Capacity /5 or a C/5 rate in mA.
5	AtRate (mA): Use whatever current is in AtRate()
6	User_Rate-mA: Use the value in <i>User_Rate-mA</i> . This mode provides a completely user-configurable method.

If **Load Mode** = 1 (*Constant Power*) then the following options shown in [Table 5-2](#) are available

Table 5-2. Constant-Power Model Used When Load Mode = 1

LoadSelect Value	Power Model Used
0	Average discharge power from previous cycle: There is an internal register that records the average discharge power through each entire discharge cycle. The previous average is stored in this register.
1(default)	Present average discharge power: This is the average discharge power from the beginning of this discharge cycle until present time.
2	Average current × voltage: based off the AverageCurrent() and Voltage() .
3	Current × voltage: based off of a low-pass-filtered version of AverageCurrent() ($\tau=14$ s) and Voltage() .
4	Design energy / 5: C Rate based off of Design Energy /5 or a C/5 rate in mA.
5	AtRate (10 mW): Use whatever value is in AtRate() .
6	User_Rate-10mW: Use the value in User_Rate-10mW . This mode provides a completely user-configurable method.

5.2.3 Reserve Cap-mAh

Reserve Cap-mAh determines how much actual remaining capacity exists after reaching 0 **RemainingCapacity()**, before **Terminate Voltage** is reached. A no-load rate of compensation is applied to this reserve.

5.2.4 Reserve Cap-mWh

Reserve Cap-mWh determines how much actual remaining capacity exists after reaching 0 **AvailableEnergy()**, before **Terminate Voltage** is reached. A no-load rate of compensation is applied to this reserve capacity.

5.2.5 Dsg Current Threshold

This register is used as a threshold by many functions in the bq27520-G3 to determine if significant discharge current is flowing into or out of the cell. The default for this register is in [Table 4-7](#), which should be sufficient for most applications. This threshold should be set low enough to be below any normal application load current but high enough to prevent noise or drift from affecting the measurement.

5.2.6 Chg Current Threshold

This register is used as a threshold by many functions in the bq27520-G3 to determine if significant charge current is flowing into or out of the cell. The default for this register is in [Table 4-7](#), which should be sufficient for most applications. This threshold should be set low enough to be below any normal charge current but high enough to prevent noise or drift from affecting the measurement.

5.2.7 Quit Current, DSG Relax Time, CHG Relax Time, and Quit Relax Time

The **Quit Current** is used as part of the Impedance Track™ algorithm to determine when the bq27520-G3 enters relaxation mode from a current-flowing mode in either the charge direction or the discharge direction. The value of **Quit Current** is set to a default value in [Table 4-7](#) and should be above the standby current of the system.

Either of the following criteria must be met to enter relaxation mode:

- $| \text{AverageCurrent}() | < | \text{Quit Current} |$ for **Dsg Relax Time**
- $| \text{AverageCurrent}() | < | \text{Quit Current} |$ for **Chg Relax Time**

After about 5 minutes in relaxation mode, the bq27520-G3 attempts to take accurate OCV readings. An additional requirement of $dV/dt < 1 \mu V/s$ is required for the to perform Qmax updates. These updates are used in the Impedance Track™ algorithms. It is critical that the battery voltage be relaxed during OCV readings to and that the current is not be higher than C/20 when attempting to go into relaxation mode.

Quit Relax Time specifies the minimum time required for **AverageCurrent()** to remain above the **Dsg or Chg Current Threshold** before exiting relaxation mode.

5.2.8 *Qmax 0 and Qmax 1*

Generically called *Qmax*, these dynamic variables contain the respective maximum chemical capacity of the active cell profiles, and are determined by comparing states of charge before and after applying the load with the amount of charge passed. They also correspond to capacity at a low rate of discharge, such as the C/20 rate. For high accuracy, this value is periodically updated by the bq27520-G3 during operation. Based on the battery cell capacity information, the initial value of chemical capacity should be entered in the **Qmax n** field for each default cell profile. The Impedance Track™ algorithm updates these values and maintains the associated actual cell profiles.

5.2.9 *Update Status 0 and Update Status 1*

Bit 0 (0x01) of the **Update Status n** registers is updated as needed by the bq27520-G3 to indicate that new *Qmax* parameters have been learned. The **Update Status n** registers are modified automatically by the bq27520-G3 and TI's evaluation software during the process of creating a golden Data Flash file. The remaining bits are reserved.

5.2.10 *Avg I Last Run*

The bq27520-G3 logs the current averaged from the beginning to the end of each discharge cycle. It stores this average current from the previous discharge cycle in this register. This register should not be modified. It is only updated by the bq27520-G3 when required.

5.2.11 *Avg P Last Run*

The bq27520-G3 logs the power averaged from the beginning to the end of each discharge cycle. It stores this average power from the previous discharge cycle in this register. To get a correct average power reading the bq27520-G3 continuously multiplies instantaneous current times *Voltage()* to get power. It then logs this data to derive the average power. This register should not be modified. It is only updated by the bq27520-G3 when required.

5.2.12 *Delta Voltage*

The bq27520-G3 stores the maximum difference of *Voltage()* during short load spikes and normal load, so the Impedance Track™ algorithm can calculate remaining capacity for pulsed loads. It is not recommended to change this value.

5.2.13 *Default Ra and Ra Tables*

These tables contain encoded data and, with the exception of the **Default Ra Tables**, are automatically updated during device operation. No user changes should be made except for reading/writing the values from a pre-learned pack (part of the process for creating golden image files).

5.3 DETAILED PIN DESCRIPTION

5.3.1 *The Operation Configuration Register*

Some bq27520-G3 pins are configured via the **Operation Configuration** data flash register, as indicated in [Table 5-3](#). This register is programmed/read via the methods described in [Section 4.2.1](#), Accessing the Data Flash. The register is located at subclass = 64, offset = 0.

Table 5-3. Operation Configuration Bit Definition

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High byte	RESCAP	BATG_OVR	INT_BREM	PFC_CFG1	PFC_CFG0	IWAKE	RSNS1	RSNS0
Low byte	INT_FOCV	IDSELEN	SLEEP	RMFCC	SOCI_POL	BATG_POL	BATL_POL	TEMPS

RESCAP = No-load rate of compensation is applied to the reserve capacity calculation. True when set. Default is 0.

BATG_OVR = BAT_GD override bit. If the gauge enters Hibernate only due to the cell voltage, the BAT_GD pin will not negate. True when set. Default is 0.

INT_BREM = Battery removal interrupt bit. The SOC_INT pulses 1ms when the battery removal interrupt is enabled. True when set. The default is 0.

PFC_CFG1/PFC_CFG0 = Pin function code (PFC) mode selection: PFC 0, 1, or 2 selected by 0/0, 0/1, or 1/0, respectively. Default is PFC 1 (0/1).

IWAKE/RSNS1/RSNS0 = These bits configure the current wake function (see Table 5-7). Default is 0/0/1.

INT_FOCV = Indication of the measurement of the OCV during the initialization. The SOC_INT will pulse during the first measurement if this bit is set. True when set. Default is 0.

IDSELEN = Enables cell profile selection feature. True when set. Default is 1.

SLEEP = The fuel gauge can enter sleep, if operating conditions allow. True when set. Default is 1.

RMFCC = RM is updated with the value from FCC, on valid charge termination. True when set. Default is 1.

SOCI_POL = SOC interrupt polarity is active-low. True when cleared. Default is 0.

BATG_POL = BAT_GD pin is active-low. True when cleared. Default is 0.

BATL_POL = BAT_LOW pin is active-high. True when set. Default is 1.

TEMPS = Selects external thermistor for Temperature() measurements. True when set. Default is 1.

Some bq27520-G3 pins are configured via the **Operation Configuration B** data flash register, as indicated in Table 5-4. This register is programmed/read via the methods described in Section 4.2.1: Accessing the Data Flash. The register is located at subclass = 64, offset = 11.

Table 5-4. Operation Configuration B Bit Definition

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
WRTEMP	BIE	BL_INT	GNDSEL	FCE	DFWrIndBL	RFACTSTEP	INDFACRES

WRTEMP = Enables the temperature write. The temperature is expected to be written by the host and is used for gauging. Neither the external thermistor of internal temperature sensor is used. True when set. Default is 0.

BIE = Battery insertion detection enable. When the battery insertion detection is disabled, the gauge relies on the host command to set and clear the BAT_DET bit. True when set. Default is 1.

BL_INT = Battery low interrupt enable. True when set. Default is 0.

GNDSEL = The ADC ground select control. The Vss (Pin D1) is selected as ground reference when the bit is clear. Pin A1 is selected when the bit is set. Default is 0.

FCE = Fast Convergence Enable. Configures algorithm to use fast convergence method. Default is 1 and is the recommended setting for all applications.

DFWrIndBL = DataFlash Write Indication. SOC_INT is used for indication if the bit is clear. BAT_LOW is used for indication if the bit is set. Default is 0.

RFACTSTEP = Enables Ra Step up/down to Min/Max Res Factor before disabling Ra updates. Default is 1.

INDFACRES = Enables SOC_INT pin to assert during FACTORY_RESTORE subcommand execution. Default is 1.

Table 5-5. Operation Configuration C Bit Definition

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
BATGSPUEN	BATGWPUEN	BATLSPUEN	BATLWPUEN	RSVD	SlpWkChg	DeltaVOpt1	DeltaVOpt0

BATGSPUEN = BAT_GD pin strong pull-up enable. Default is 0.

BATGWPUEN = BAT_GD pin weak pull-up enable. Default is 0.

BATLSPUEN = BAT_LOW pin strong pull-up enable. Default is 1.

BATLWPUEN = BAT_LOW pin weak pull-up enable. Default is 0.

SlpWkChg = Enables compensation for the passed charge missed when waking from SLEEP mode. Default is 1.

DeltaVOpt[1:0] = Configures options for determination of **Delta Voltage** which is defined as the maximum difference in Voltage() during normal load and short load spikes. **Delta Voltage** is used as a compensation factor for calculating for RemainingCapacity() under pulsed loads. Default is 0/0.

0/0 = Standard DeltaV. Average variance from steady state voltage used to determine end of discharge voltage. (Default)

0/1 = No Averaging. The last instantaneous change in Voltage() from steady state is used to determine the end of discharge voltage.

1/0 = Use the value in **Min Delta Voltage**.

1/1 = Not used.

5.3.2 Pin Function Code Descriptions

The bq27520-G3 has three possible pin-function variations that can be selected in accordance with the circuit architecture of the end application. Each variation has been assigned a pin function code, or PFC.

When the PFC is set to 0, only the bq27520-G3 measures battery temperature under discharge and relaxation conditions. The charger does not receive any information from the bq27520-G3 about the temperature readings, and therefore operates open-loop with respect to battery temperature.

A PFC of 1 is like a PFC of 0, except temperature is also monitored during battery charging. If charging temperature falls outside of the preset range defined in data flash, a charger can be disabled via the $\overline{\text{BAT_GD}}$ pin until cell temperature recovers. See [Section 5.6.2, Charge Inhibit and Suspend](#), for additional details.

Finally when the PFC is set to 2, the battery thermistor can be shared between the fuel gauge and the charger. The charger has full usage of the thermistor during battery charging, while the fuel gauge uses the thermistor exclusively during discharge and battery relaxation.

When PFC = 0 or 2, the bq27520-G3 must be queried by the system in order to determine the battery temperature. At that time, the bq27520-G3 samples the temperature. This saves battery energy when operating from battery, as periodic temperature updates are avoided during charging mode. Note: Due to thermistor sharing limitations, temperature data is not available during battery charging with PFC = 2.

The PFC is specified in **Operation Configuration [PFC_CFG1, PFC_CFG0]**. The default is PFC = 1.

5.3.3 BAT_LOW Pin

The BAT_LOW pin provides a system processor with an electrical indicator of battery status. The signaling on the BAT_LOW pin follows the status of the [SOC1] bit in the *Flags()* register. Note that the polarity of the BAT_LOW pin can be inverted via the [BATL_POL] bit of **Operation Configuration**.

5.3.4 Power Path Control With the $\overline{\text{BAT_GD}}$ Pin

The bq27520-G3 must operate in conjunction with other electronics in a system appliance, such as chargers or other ICs and application circuits that draw appreciable power. After a battery is inserted into the system, it is preferable that there should be no charging current or discharging current higher than C/20, so that an accurate OCV can be read. The OCV is used for helping determine which battery profile to use, as it constitutes part of the battery impedance measurement and to determine initial SOC.

When a battery is inserted into a system, the Impedance Track™ algorithm requires that no charging of the battery takes place and that any discharge is limited to less than C/20—these conditions are sufficient for the fuel gauge to take an accurate OCV reading. To disable these functions, the $\overline{\text{BAT_GD}}$ pin is merely negated from the default setting. Once an OCV reading has been made, the $\overline{\text{BAT_GD}}$ pin is asserted, thereby enabling battery charging and regular discharge of the battery. The **Operation Configuration [BATG_POL]** bit can be used to set the polarity of the battery good signal, should the default configuration need to be changed.

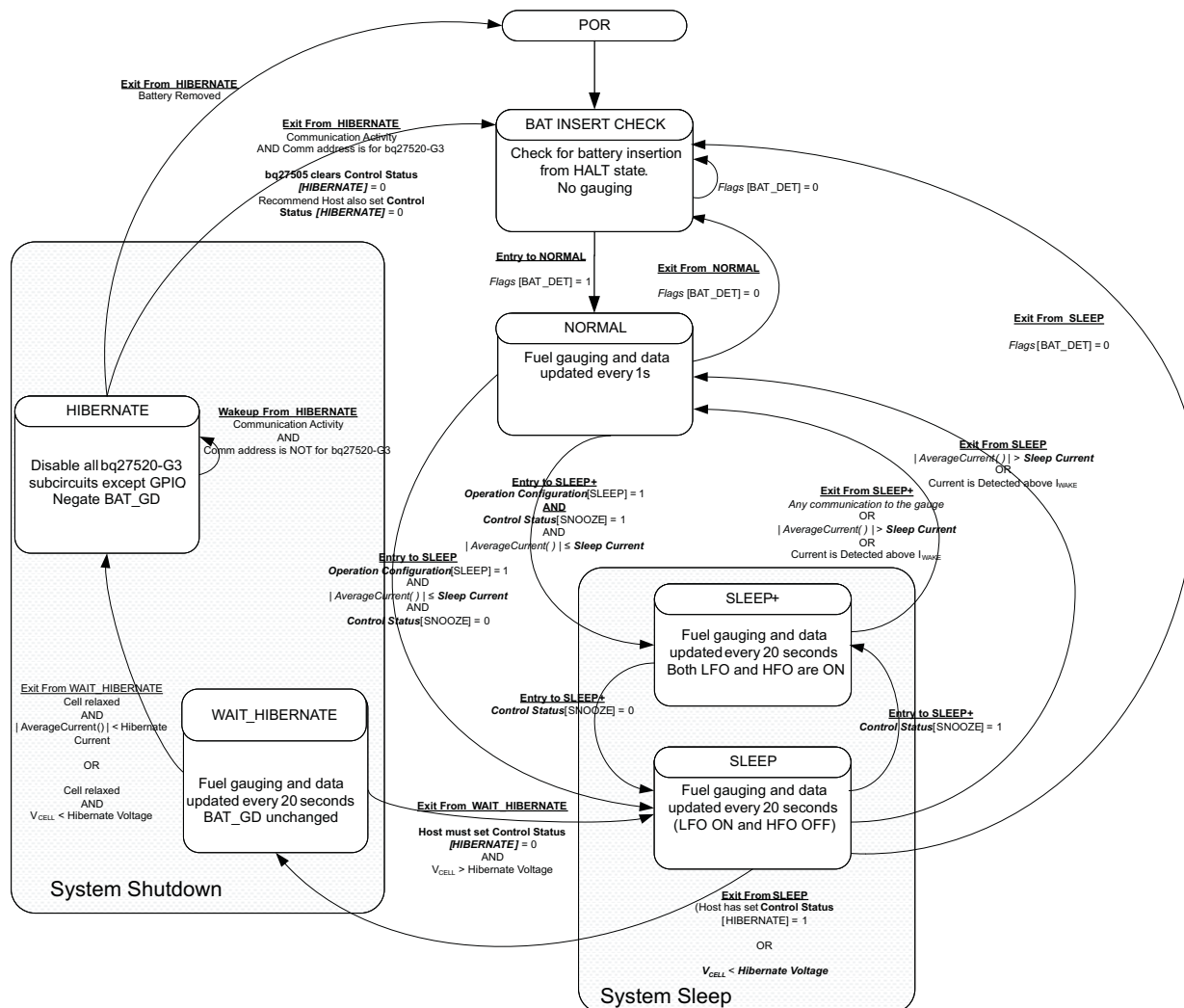


Figure 5-1. Power Mode Diagram

Figure 5-1 details how the `BAT_GD` pin functions in the context of battery insertion and removal, as well as NORMAL vs. SLEEP modes.

In PFC 1, the `BAT_GD` pin is also used to disable battery charging when the bq27520-G3 reads battery temperatures outside the range defined by **[Charge Inhibit Temp Low, Charge Inhibit Temp High]**. The `BAT_GD` line is asserted once temperature falls within the range **[Charge Inhibit Temp Low + Temp Hys, Charge Inhibit Temp High – Temp Hys]**.

5.3.5 Battery Detection Using the BI/TOUT Pin

During power-up or hibernate activities, or any other activity where the bq27520-G3 needs to determine whether a battery is connected or not, the fuel gauge applies a test for battery presence. First, the BI/TOUT pin is put into high-Z status. The weak 1.8M Ω pull-up resistor will keep the pin high while no battery is present. When a battery is inserted (or is already inserted) into the system device, the BI/TOUT pin will be pulled low. This state is detected by the fuel gauge, which polls this pin every second when the gauge has power. A *battery-disconnected* status is assumed when the bq27520-G3 reads a thermistor voltage that is near 2.5V.

When a thermistor is not used by the system for the gauge to detect battery insertion there are two options. First, the BI/TOUT pin can be tied to VSS with a resistor so the gauge will always consider a battery to be present if it has power. Second, the *[BIE]* bit can be cleared and the host can use the BAT_INSERT and BAT_REMOVE commands to inform the gauge of the battery status.

5.3.6 SOC_INT pin

The SOC_INT pin generates a pulse of different pulse widths under various conditions as indicated by the table below. After initialization only one SOC_INT pulse will be generated within any given one second time slot and therefore, may indicate multiple event conditions.

Table 5-6. SOC_INT Pulse Condition and Width

	Enable Condition	Pulse Width	Comment
SOC_Delta Point	SOC_Delta \neq 0	1 ms	During charge, when the SOC is greater than ($>$) the points, $100\% - n \times \text{SOC_Delta}$ and 100% ; During discharge, when the SOC reaches (\leq) the points $100\% - n \times \text{SOC_Delta}$ and 0% ; where n is an integer starting from 0 to the number generating SOC no less than 0%
SOC1 Set	Always	1 ms	When RSOC reached the SOC1 Set or Clear threshold set in the Data Flash and BL_INT bit in Operation Configuration B is set.
SOC1 Clear	Always	1 ms	
SysDown Set	Always	1 ms	When the Battery Voltage reached the SysDown Set or Clear threshold set in the Data Flash
SysDown Clear	Always	1 ms	
State Change	SOC_Delta \neq 0	1 ms	When there is a state change including charging, discharging and relaxation. This function is disabled when SOC_Delta is set to 0.
Battery Removal	INT_BREM bit is set in OpConfig AND BIE bit is set	1 ms	This function is disabled when BIE is cleared.
OCV Command	After Initialization	About 165ms. Same as the OCV command execution time period	SOC_INT pulses for the OCV command after the initialization.
OCV Command	INT_FOCV bit is set in OpConfig	About 165ms. Same as the OCV command execution time period	This command is to generate the SOC_INT pulse during the initialization.
Data Flash Write	After Initialization AND DFWrIndWaitTime \neq 0	Programmable pulse width flash (see comment)	SOC_INT is used to indicate the data flash update. The gauge will wait DFWrIndWaitTime times $5\mu\text{s}$ after the SOC_INT signal to start the data flash update. This function is disabled if DFWrIndWaitTime is set to 0.
OTC or OTD Flags	Always	1 ms	Upon first assertion of Flags[OTC] or Flags[OTD] over temperature conditions.
Factory Restore	INDFACRES bit is set in OpConfig B	About 450 ms	The Factory Restore command instructs the fuel gauge to reset learned resistance tables and Qmax values to the default values.

5.4 TEMPERATURE MEASUREMENT

The bq27520-G3 measures battery temperature via its TS input, in order to supply battery temperature status information to the fuel gauging algorithm and charger-control sections of the gauge. Alternatively, it can also measure internal temperature via its on-chip temperature sensor, but only if the **[TEMPS]** bit of the **Operation Configuration** register is cleared. The **[GNDSEL]** bit of Operation Configuration B register selects the ground reference of the ADC converter for temperature measurement. A third option is enabled if the **[WRTEMP]** bit of Operation Configuration B is set. This allows a host processor to write the temperature measurement directly to the bq27520-G3 instead of the gauge making its own temperature measurements.

Regardless of which sensor is used for measurement, a system processor can request the current battery temperature by calling the *Temperature()* function (see [Section 4.1.1, Standard Data Commands](#), for specific information).

The thermistor circuit requires the use of an external NTC 103AT-type thermistor. Additional circuit information for connecting this thermistor to the bq27520-G3 is shown in [Section 8, Reference Schematic](#).

5.5 OVERTEMPERATURE INDICATION

5.5.1 Overtemperature: Charge

If during charging, *Temperature()* reaches the threshold of **OT Chg** for a period of **OT Chg Time** and *AverageCurrent()* > **Chg Current Threshold**, then the **[OTC]** bit of *Flags()* is set. When *Temperature()* falls to **OT Chg Recovery**, the **[OTC]** of *Flags()* is reset.

If **OT Chg Time** = 0, then the feature is completely disabled.

5.5.2 Overtemperature: Discharge

If during discharging, *Temperature()* reaches the threshold of **OT Dsg** for a period of **OT Dsg Time**, and *AverageCurrent()* ≤ **-Dsg Current Threshold**, then the **[OTD]** bit of *Flags()* is set. When *Temperature()* falls to **OT Dsg Recovery**, the **[OTD]** bit of *Flags()* is reset.

If **OT Dsg Time** = 0, then feature is completely disabled.

5.6 CHARGING AND CHARGE-TERMINATION INDICATION

5.6.1 Detecting Charge Termination

For proper bq27520-G3 operation, the cell charging voltage must be specified by the user. The default value for this variable is **Charging Voltage** [Table 4-7](#).

The bq27520-G3 detects charge termination when (1) during 2 consecutive periods of **Current Taper Window**, the *AverageCurrent()* is < **Taper Current**, (2) during the same periods, the accumulated change in capacity > **Min Taper Capacity / Current Taper Window**, and (3) *Voltage()* > **Charging Voltage – Taper Voltage**. When this occurs, the **[CHG]** bit of *Flags()* is cleared. Also, if the **[RMFCC]** bit of **Operation Configuration** is set, then *RemainingCapacity()* is set equal to *FullChargeCapacity()*.

5.6.2 Charge Inhibit and Suspend

The bq27520-G3 can indicate when battery temperature has fallen below or risen above predefined thresholds **Charge Inhibit Temp Low** or **Charge Inhibit Temp High**, respectively. In this mode, the **[CHG_INT]** bit is set and the $\overline{\text{BAT_GD}}$ pin is deserted to indicate this condition. The **[CHG_INT]** bit is cleared and the $\overline{\text{BAT_GD}}$ pin is asserted once the battery temperature returns to the range **[Charge Inhibit Temp Low + Temp Hys, Charge Inhibit Temp High – Temp Hys]**.

When $PFC = 1$, the bq27520-G3 can indicate when battery temperature has fallen below or risen above predefined thresholds **Suspend Low Temp** or **Suspend High Temp**, respectively. In this mode, the [XCHG] bit is set to indicate this condition. The [XCHG] bit is cleared once the battery temperature returns to the range [**Charge Inhibit Temp Low + Temp Hys**, **Charge Inhibit Temp High – Temp Hys**].

The charging should not start when the temperature is below the Charge Inhibit Temp Low or above the Charge Inhibit Temp High. The charging can continue if the charging starts inside the window [Charge Inhibit Temp Low, Charge Inhibit Temp High] until the temperature is either below Suspend Low Temp or above the Suspend Low Temp. Therefore, the window [Charge Inhibit Temp Low, Charge Inhibit Temp High] must be inside the window of [Suspend Low Temp, Suspend High Temp].

5.7 POWER MODES

The bq27520-G3 has different power modes: BAT INSERT CHECK, NORMAL, SLEEP+, SLEEP and HIBERNATE. In NORMAL mode, the bq27520-G3 is fully powered and can execute any allowable task. In SLEEP+ mode, both low frequency and high frequency oscillators are active. Although the SLEEP+ has higher current consumption than the SLEEP mode, it is also a reduced power mode. In SLEEP mode, the fuel gauge turns off the high frequency oscillator and exists in a reduced-power state, periodically taking measurements and performing calculations. In HIBERNATE mode, the fuel gauge is in a low power state, but can be woken up by communication or certain I/O activity. Finally, the BAT INSERT CHECK mode is a powered-up, but low-power halted, state, where the bq27520-G3 resides when no battery is inserted into the system.

The relationship between these modes is shown in [Figure 5-1](#).

5.7.1 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 bq27520-G3 (and system), yet no battery has been detected. Depending on the setting of the **[BIE]** bit in the Operation Configuration B dataflash register, the bq27520-G3 will detect battery insertion either through use of the thermistor network and BI/TOUT pin, or the host can use the BAT_INSERT and BAT_REMOVE commands to inform the battery presence status. When battery insertion is detected, a series of initialization activities begin, which include: OCV measurement, setting the **BAT_GD** pin, and selecting the appropriate battery profiles.

Some commands, issued by a system processor, can be processed while the bq27520-G3 is halted in this mode. The gauge will wake up to process the command, then return to the halted state awaiting battery insertion.

5.7.2 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.

5.7.3 SLEEP MODE

SLEEP mode is entered automatically if the feature is enabled (**Operation Configuration [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 bq27520-G3 performs an coulomb counter autocalibration to minimize offset.

During SLEEP mode, the bq27520-G3 periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The bq27520-G3 exits SLEEP 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.

5.7.4 SLEEP+ MODE

Compared to the SLEEP mode, SLEEP+ mode has the high frequency oscillator in operation. The communication delay associated with waking from SLEEP mode is therefore eliminated since the HFO is not turned off in SLEEP+ mode.. The SLEEP+ 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 bq27520-G3 periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The bq27520-G3 exits SLEEP+ if any entry condition is broken, specifically when (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.

5.7.5 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 a system equipment is set to its own HIBERNATE, SHUTDOWN, or OFF modes.

Before the fuel gauge can enter HIBERNATE mode, the system must set the *[HIBERNATE]* bit of the CONTROL_STATUS register. 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 will remain in HIBERNATE mode until the system issues a direct I²C command to the gauge or a POR occurs. I²C Communication that is not directed to the gauge will not wake the gauge.

It is important that $\overline{BAT_GD}$ be de-asserted status status (no battery charging/discharging). This prevents a charger application from inadvertently charging the battery before an OCV reading can be taken. It is the system's responsibility to wake the bq27520-G3 after it has gone into HIBERNATE mode. After waking, the gauge can proceed with the initialization of the battery information (OCV, profile selection, etc.)

5.8 POWER CONTROL

5.8.1 WAKE-UP COMPARATOR

The wake up comparator is used to indicate a change in cell current while the bq27520-G3 is in SLEEP mode. **Operation Configuration** uses bits **[RSNS1–RSNS0]** to set the sense resistor selection. **Operation Configuration** also uses the **[IWAKE]** bit to select one of two possible voltage threshold ranges for the given sense resistor selection. An internal interrupt is generated when the threshold is breached in either the charge or discharge direction. Setting both **[RSNS1]** and **[RSNS0]** to 0 disables this feature.

Table 5-7. I_{WAKE} Threshold Settings⁽¹⁾

RSNS1	RSNS0	IWAKE	Vth(SRP–SRN)
0	0	0	Disabled
0	0	1	Disabled
0	1	0	1.0 mV or –1.0 mV
0	1	1	2.2 mV or –2.2 mV
1	0	0	2.2 mV or –2.2 mV
1	0	1	4.6 mV or –4.6 mV
1	1	0	4.6 mV or –4.6 mV
1	1	1	9.8 mV or –9.8 mV

(1) The actual resistance value vs the setting of the sense resistor is not important, just the actual voltage threshold when calculating the configuration. The voltage thresholds are typical values under room temperature.

5.8.2 FLASH UPDATES

Data Flash can only be updated if $Voltage() \geq \text{Flash Update OK Voltage}$. Flash programming current can cause an increase in LDO dropout. The value of **Flash Update OK Voltage** should be selected such that the bq27520-G3 V_{CC} voltage does not fall below its minimum of 2.4 V during Flash write operations.

5.9 AUTOCALIBRATION

The bq27520-G3 provides an autocalibration feature that measures the voltage offset error across SRP and SRN as operating conditions change. It subtracts the resulting offset error from normal sense resistor voltage, V_{SR} , for maximum measurement accuracy.

Autocalibration of the coulomb counter begins on entry to SLEEP mode, except if $Temperature()$ is $\leq 5^{\circ}\text{C}$ or $Temperature() \geq 45^{\circ}\text{C}$.

The fuel gauge also performs a single offset when (1) the condition of $AverageCurrent() \leq 100 \text{ mA}$ and (2) {voltage change since last offset calibration $\geq 256 \text{ mV}$ } or {temperature change since last offset calibration is greater than 8°C for $\geq 60 \text{ s}$ }.

Capacity and current measurements continue at the last measured rate during the offset calibration when these measurements cannot be performed. If the battery voltage drops more than 32 mV during the offset calibration, the load current has likely increased; hence, the offset calibration is aborted.

6 APPLICATION-SPECIFIC INFORMATION

6.1 BATTERY PROFILE STORAGE AND SELECTION

6.1.1 Common Profile Aspects

The bq27520-G3 supports only one type of battery profile. This profile is stored in both the **Def0** and **Def1** profiles. When a battery pack is inserted for the first time, the default profile is copied into the **Packn** profiles. Then the Impedance Track™ algorithm begins gas gauging, regularly updating **Packn** as the battery is used.

In addition to the default profiles, the fuel gauge maintains two profiles PACK0 and PACK1. These tables hold dynamic battery data, and keep track of the status for up to two of the most recent batteries used. In most cases, the fuel gauge can manage the information on two removable battery packs. When a battery pack is removed from host equipment, the bq27520-G3 maintains some of the battery information in case the battery is re-inserted. This way, the Impedance Track™ algorithm has a means of recovering battery-status information, thereby maintaining good state-of-charge (SOC) estimates.

When an existing pack is removed from the bq27520-G3 and a different (or same) pack is inserted, cell impedance is measured immediately after battery detection (see Section 6.1.2.1., *First OCV and Impedance Measurement*). The bq27520-G3 chooses the profile which is closest to the measured impedance, starting with the **Packn** profiles. That is, if the measured impedance matches **Pack0**, then the **Pack0** profile is used. If the measured impedance matches **Pack1**, then the **Pack1** profile is used. If the measured impedance does not match the impedance stored in either **Pack0** or **Pack1**, the battery pack is deemed new (none of the previously used packs). Either **Def0/Def1** profile is copied into either the **Pack0** or **Pack1** profile, overwriting the oldest **Packn** profile.

6.1.2 Activities Upon Pack Insertion

6.1.2.1 First OCV and Impedance Measurement

At power-up the $\overline{\text{BAT_GD}}$ pin is inactive, so that the system might not obtain power from the battery (this depends on actual implementation). In this state, the battery should be put in a condition with load current less than $C/20$. Next, the bq27520-G3 measures its first open-circuit voltage (OCV) via the BAT pin. The $[\text{OCVCMDCOMP}]$ bit will set once the OCV measurement is completed. Depending on the load current, the $[\text{OCVFAIL}]$ bit indicates whether the OCV reading is valid. From the OCV(SOC) table, the SOC of the inserted battery is found. Then the $\overline{\text{BAT_GD}}$ pin is made active, and the impedance of the inserted battery is calculated from the measured voltage and the load current: $Z(\text{SOC}) = (\text{OCV}(\text{SOC}) - V) / I$. This impedance is compared with the impedance of the dynamic profiles, **Packn**, and the default profiles, **Defn**, for the same SOC (the letter *n* depicts either a **0** or **1**). The $[\text{INITCOMP}]$ bit will be set afterwards and the OCV command could be issued

6.1.3 Reading Application Status

The **Application Status** data flash location contains cell profile status information, and can be read using the *ApplicationStatus*() extended command (0x6a). The bit configuration of this function/location is shown in Table 6-1.

Table 6-1. ApplicationStatus() Bit Definitions.

Application Configuration	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Byte	—	—	—	—	—	—	—	LU_PROF

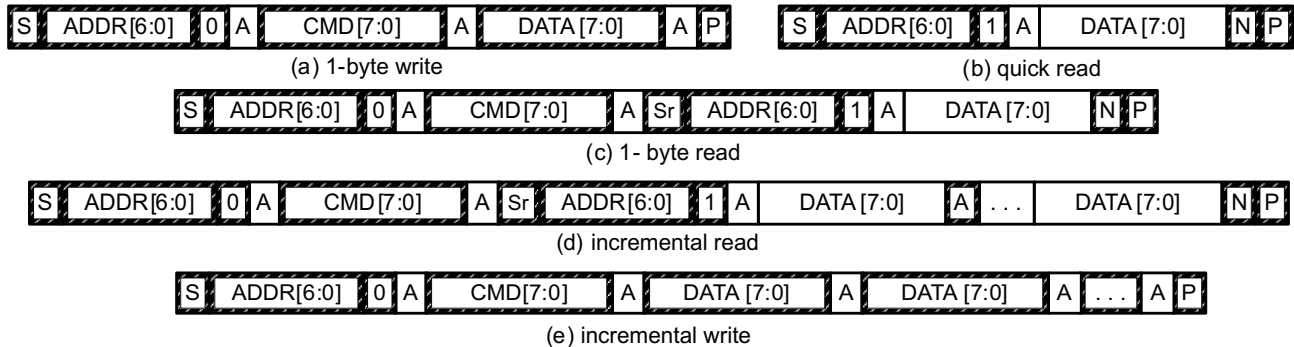
LU_PROF = Last profile used by fuel gauge. *Cell0* last used when cleared. *Cell1* last used when set. Default is 0.

7 COMMUNICATIONS

7.1 I²C INTERFACE

The bq27520-G3 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 will; therefore, be 0xAA or 0xAB for write or read, respectively.

 Host generated  bq27520-G3 generated

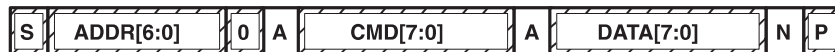


(S = Start, Sr = Repeated Start, A = Acknowledge, N = No Acknowledge, and P = Stop).

The “quick read” returns data at the address indicated by the address pointer. The address pointer, a register internal to the I²C communication engine, will increment whenever data is acknowledged by the bq27520-G3 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):



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

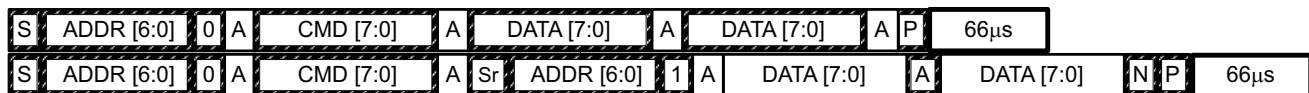


7.2 I²C Time Out

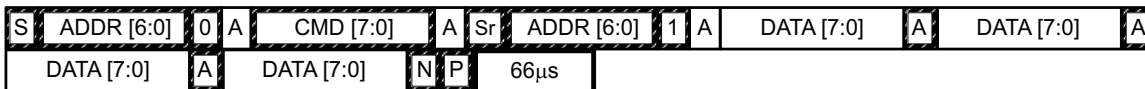
The I²C engine will release both SDA and SCL if the I²C bus is held low for the time defined by *I²C Timeout* times 0.5 second. If the bq27520-G3 was holding the lines, releasing them will free them for the master to drive the lines. If an external condition is holding either of the lines low, the I²C engine will enter the low power sleep mode.

7.3 I²C Command Waiting Time

To make sure the correct results of a command with the 400KHz I²C operation, a proper waiting time should be added between issuing command and reading results. For subcommands, the following diagram shows the waiting time required between issuing the control command the reading the status with the exception of checksum and OCV commands. A 100ms waiting time is required between the checksum command and reading result, and a 1.2 second waiting time is required between the OCV command and 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 should not issue all standard commands more than two times per second. Otherwise, the gauge could result in a reset issue due to the expiration of the watchdog timer.



Waiting time between control subcommand and reading results



Waiting time between continuous reading results

7.4 I²C Clock Stretching

I²C clock stretches can occur during all modes of fuel gauge operation. In the SLEEP and HIBERNATE modes, a short clock stretch will occur on all I2C traffic as the device must wake-up to process the packet. In NORMAL and SLEEP+ modes, clock stretching will only occur for packets addressed for the fuel gauge. The timing of stretches will vary as interactions between the communicating host and the gauge are asynchronous. The I²C clock stretches may occur after start bits, the ACK/NAK bit and first data bit transmit on a host read cycle. The majority of clock stretch periods are small ($\leq 4\text{mSec}$) as the I2C interface peripheral and CPU firmware perform normal data flow control. However, less frequent but more significant clock stretch periods may occur when data flash (DF) is being written by the CPU to update the resistance (Ra) tables and other DF parameters such as Qmax. Due to the organization of DF, updates need to be written in data blocks consisting of multiple data bytes.

An Ra table update requires erasing a single page of DF, programming the updated Ra table and a flag. The potential I²C clock stretching time is 24ms max. This includes 20ms page erase and 2ms row programming time (x2 rows). The Ra table updates occur during the discharge cycle and at up to 15 resistance grid points that occur during the discharge cycle.

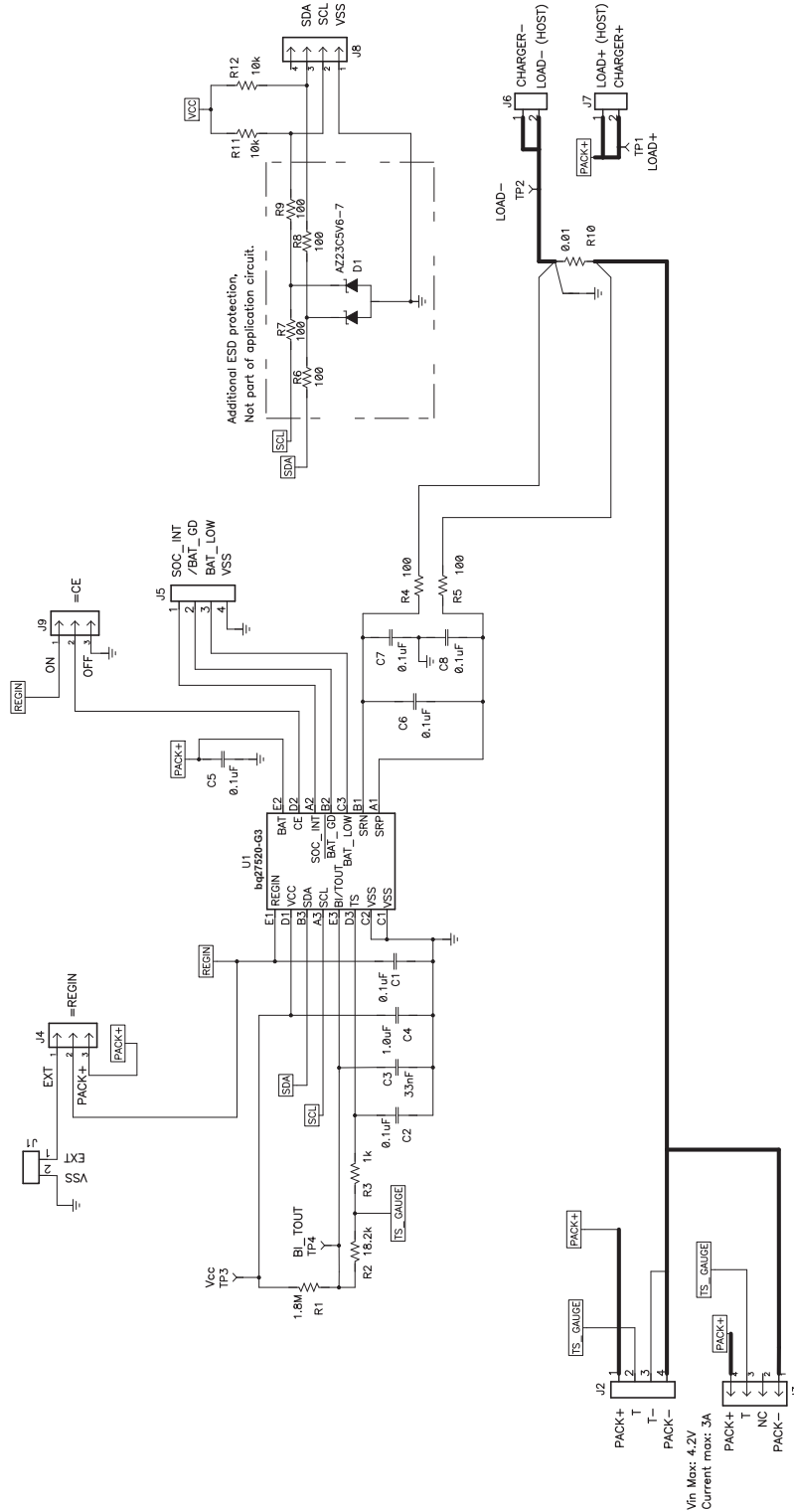
A DF block write typically requires a max of 72ms. This includes copying data to a temporary buffer and updating DF. This temporary buffer mechanism is used to protect from power failure during a DF update. The first part of the update requires 20ms time to erase the copy buffer page, 6 ms time to write the data into the copy buffer and the program progress indicator (2ms for each individual write). The second part of the update is writing to the DF and requires 44ms DF block update time. This includes a 20ms each page erase for two pages and 2ms each row write for two rows.

In the event that a previous DF write was interrupted by a power failure or reset during the DF write, an additional 44ms max DF restore time is required to recover the data from a previously interrupted DF write. In this power failure recovery case, the total I²C clock stretching is 116ms max.

Another case where I²C clock stretches is at the end of discharge. The update to the last discharge data will go through the DF block update twice because two pages are used for the data storage. The clock stretching in this case is 144ms max. This occurs if there has been a Ra table update during the discharge.

8 REFERENCE SCHEMATICS

8.1 SCHEMATIC



8.2 Package Dimensions

D	E
Max = 2640μm	Max = 1986μm
Min = 2580μm	Min = 1926μm

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/ Ball Finish	MSL Peak Temp ⁽³⁾	Samples (Requires Login)
BQ27520YZFR-G3	ACTIVE	DSBGA	YZF	15	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	
BQ27520YZFT-G3	ACTIVE	DSBGA	YZF	15	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	

⁽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⁾ Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

TBD: The Pb-Free/Green conversion plan has not been defined.

Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

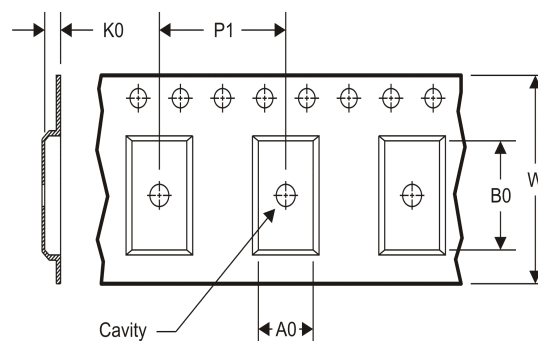
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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TAPE AND REEL INFORMATION
REEL DIMENSIONS

TAPE DIMENSIONS


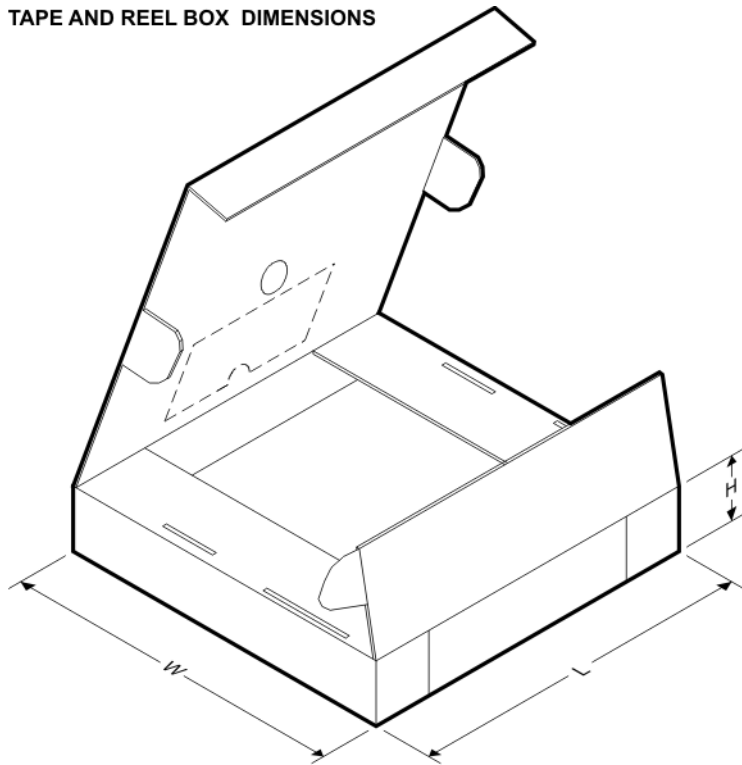
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

TAPE AND REEL INFORMATION

*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
BQ27520YZFR-G3	DSBGA	YZF	15	3000	180.0	8.4	2.1	2.76	0.73	4.0	8.0	Q1
BQ27520YZFT-G3	DSBGA	YZF	15	250	180.0	8.4	2.1	2.76	0.73	4.0	8.0	Q1

TAPE AND REEL BOX DIMENSIONS

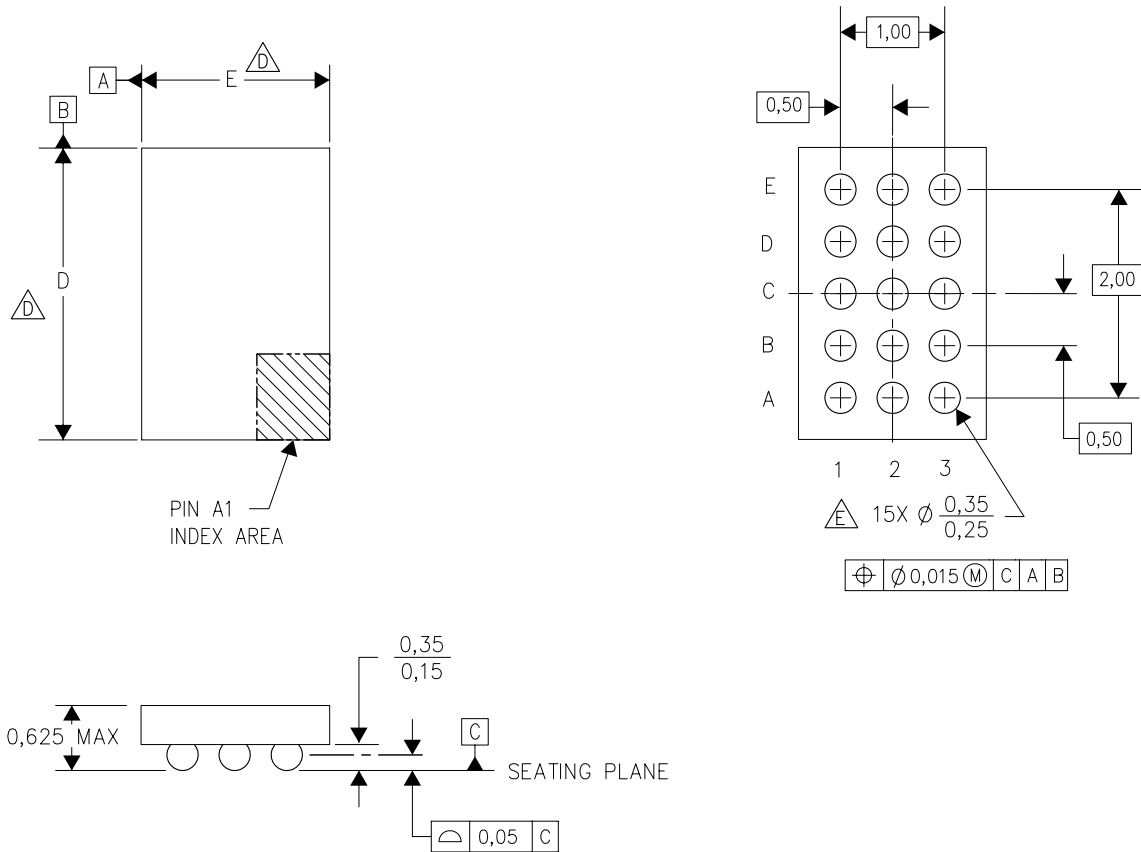


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ27520YZFR-G3	DSBGA	YZF	15	3000	210.0	185.0	35.0
BQ27520YZFT-G3	DSBGA	YZF	15	250	210.0	185.0	35.0

YZF (R-XBGA-N15)

DIE-SIZE BALL GRID ARRAY



4205058-5/M 09/11

- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
 - B. This drawing is subject to change without notice.
 - C. NanoFree™ package configuration.
 - The package size (Dimension D and E) of a particular device is specified in the device Product Data Sheet version of this drawing, in case it cannot be found in the product data sheet please contact a local TI representative.
 - Reference Product Data Sheet for array population.
3 x 5 matrix pattern is shown for illustration only.
 - F. This package contains Pb-free balls.

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