

# System-Side Impedance Track™ Fuel Gauge With Integrated Sense Resistor

Check for Samples: [bq27425-G2](#)

## FEATURES

- **Single series cell Li-Ion battery fuel gauge**
  - Resides on system board
  - Supports embedded or removable batteries
  - Powered directly from battery with integrated LDO
  - Low-value integrated sense resistor (10 mΩ Typical)
- **Easy to configure fuel gauging based on patented Impedance Track™ technology**
  - Reports Remaining Capacity and State of Charge (SOC) with Smoothing Filter
  - Automatically adjusts for battery aging, self-discharge, temperature, and rate changes
  - Battery State of Health (aging) estimation
- **Microcontroller peripheral supports:**
  - 400-kHz I<sup>2</sup>C™ serial interface
  - Configurable SOC Interrupt, or Battery Low digital output warning
  - Internal temperature sensor, or Host reported temperature
- **15-pin 2.69 × 1.75 mm, 0.5 mm pitch CSP package**

## APPLICATIONS

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

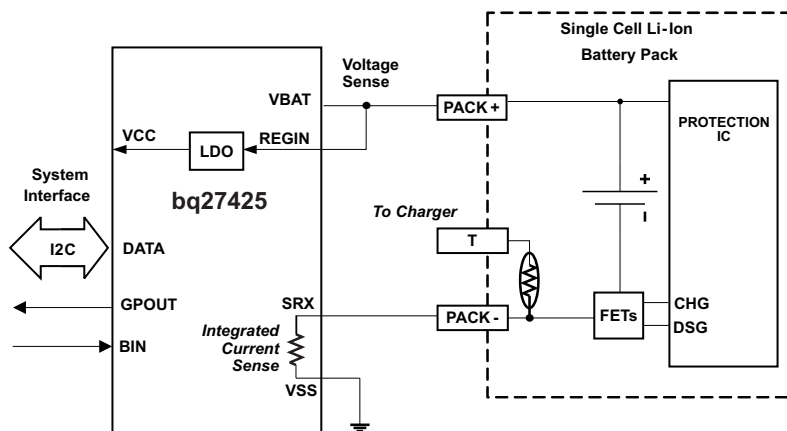
## DESCRIPTION

The Texas Instruments bq27425 is an easy to configure microcontroller peripheral that provides system-side fuel gauging for single-cell Li-Ion batteries. The device requires minimal user configuration and system microcontroller firmware development.

The bq27425 uses the patented Impedance Track™ algorithm for fuel gauging, and provides information such as remaining battery capacity (mAh), state-of-charge (%), and battery voltage (mV).

Battery fuel gauging with the bq27425 requires connections only to PACK+ (P+) and PACK– (P–) for a removable battery pack or embedded battery circuit. The 15-pin 2.69 × 1.75 mm, 0.5 mm pitch CSP package is ideal for space constrained applications.

## TYPICAL APPLICATION



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

Impedance Track is a trademark of Texas Instruments.  
is a trademark of ~NXP B.V. Corp Netherlands.



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.

## DEVICE INFORMATION

### AVAILABLE OPTIONS

PART NUMBER	BATTERY TYPE	CHEM_ID (1)	FIRMWARE VERSION (2)	PACKAGE (3)	T <sub>A</sub>	COMM. FORMAT	TAPE and REEL QUANTITY
bq27425YZFR-G2A	LiCoO <sub>2</sub> (4.2 V max charge)	0x128	2.05 (0x0205)	CSP-15	-40°C to 85°C	I <sup>2</sup> C	3000
bq27425YZFT-G2A							250
bq27425YZFR-G2B	LiMn <sub>2</sub> O <sub>4</sub> (4.3 - 4.35 V max charge)	0x312					3000
bq27425YZFT-G2B							250

(1) Refer to the [CHEM\\_ID](#) subcommand to confirm the battery chemistry type.

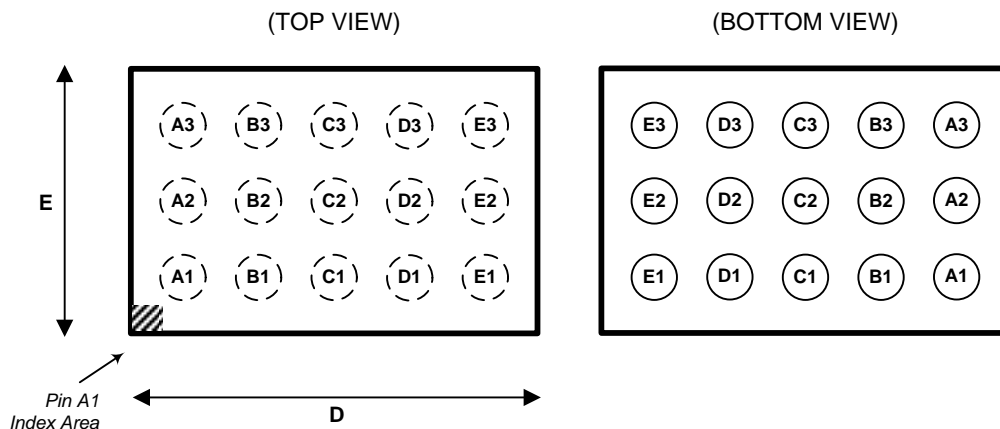
(2) Refer to the [FW\\_VERSION](#) subcommand to confirm the firmware version.

(3) For the most current package and ordering information see the Package Option Addendum at the end of this document; or, see the TI website at [www.ti.com](http://www.ti.com).

### THERMAL INFORMATION

THERMAL METRIC <sup>(1)</sup>		bq27425-G2	UNITS
		YZF (15-PINS)	
$\theta_{JA}$	Junction-to-ambient thermal resistance	70	°C/W
$\theta_{JTop}$	Junction-to-case (top) thermal resistance	17	
$\theta_{JB}$	Junction-to-board thermal resistance	20	
$\Psi_{JT}$	Junction-to-top characterization parameter	1	
$\Psi_{JB}$	Junction-to-board characterization parameter	18	
$\theta_{JBot}$	Junction-to-case (bottom) thermal resistance	n/a	

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

**PIN DIAGRAM AND PACKAGE DIMENSIONS**


DIM	MIN	TYP	MAX	UNITS
D	2660	2690	2720	μm
E	1720	1750	1780	

**PIN FUNCTIONS**

PIN		TYPE <sup>(1)</sup>	DESCRIPTION
NAME	NO.		
SRX	B1	IA	Integrated Sense Resistor and Coulomb Counter input typically connected to battery PACK- terminal. For best performance decouple with 0.1μF ceramic capacitor to V <sub>SS</sub> .
V <sub>SS</sub>	C1	P, IA	Device ground and Integrated Sense Resistor termination.
V <sub>CC</sub>	D1	P	Regulator output and bq27425 processor power. Decouple with 1μF ceramic capacitor to V <sub>SS</sub> .
REGIN	E1	P	Regulator input. Decouple with 0.1μF ceramic capacitor to V <sub>SS</sub> .
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 <sup>2</sup> C serial communications clock input line for communication with system (Master). Use with 10kΩ pull-up resistor (typical).
SDA	B3	I/O	Slave I <sup>2</sup> C serial communications data line for communication with system (Master). Open-drain I/O. Use with 10kΩ pull-up resistor (typical).
BIN	C3	I	Battery-insertion detection input. A logic high to low transition is detected as a battery insertion event. Recommend using a pull-up resistor >1MΩ (1.8 MΩ typical) to V <sub>CC</sub> for reduced power consumption. An internal pull-up resistor option is also available using the <b>Operation Configuration</b> [BI_PU_EN] register bit.
GPOUT	A2	O	General Purpose open-drain output. May be configured as a Battery Low indicator or perform SOC interrupt (SOC_INT) function.
NC	A1, B2	N/A	No internal connection. May be left floating.
	C2, D3, E3	I/O	Reserved for factory use. Must be left floating for proper operation.

(1) I/O = Digital input/output, IA = Analog input, P = Power connection

## ELECTRICAL SPECIFICATIONS

### ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

PARAMETER		VALUE	UNIT
V <sub>REGIN</sub>	Regulator input range	–0.3 to 6.0	V
V <sub>CC</sub>	Supply voltage range	–0.3 to 2.75	V
V <sub>IOD</sub>	Open-drain I/O pins (SDA, SCL, GPOUT)	–0.3 to 6.0	V
V <sub>BAT</sub>	BAT input pin	–0.3 to 6.0	V
V <sub>I</sub>	Input voltage range to all other pins (SRX, BIN)	–0.3 to V <sub>CC</sub> + 0.3	V
T <sub>A</sub>	Operating free-air temperature range	–40 to 85	°C
T <sub>stg</sub>	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.

### RECOMMENDED OPERATING CONDITIONS

T<sub>A</sub> = 25°C and V<sub>REGIN</sub> = V<sub>BAT</sub> = 3.6V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>REGIN</sub>	Supply voltage	No operating restrictions	2.8		4.5	V
		No NVM writes	2.45		2.8	
C <sub>REGIN</sub>	External input capacitor for internal LDO between REGIN and V <sub>SS</sub>	Nominal capacitor values specified. Recommend a 5% ceramic X5R type capacitor located close to the device.		0.1		μF
C <sub>LDO25</sub>	External output capacitor for internal LDO between V <sub>CC</sub> and V <sub>SS</sub>		0.47	1		μF
I <sub>CC</sub>	NORMAL operating-mode current <sup>(1)</sup>	Fuel gauge in NORMAL mode. I <sub>LOAD</sub> > <b>Sleep Current</b>		118		μA
I <sub>SLEP</sub>	SLEEP mode operating mode current <sup>(1)</sup>	Fuel gauge in SLEEP mode. I <sub>LOAD</sub> < <b>Sleep Current</b>		23		μA
I <sub>HIB</sub>	HIBERNATE operating-mode current <sup>(1)</sup>	Fuel gauge in HIBERNATE mode. I <sub>LOAD</sub> < <b>Hibernate Current</b>		8		μA
I <sub>SHD</sub>	SHUTDOWN mode current <sup>(1)</sup>	Fuel gauge in SHUTDOWN mode. CE Pin < V <sub>IL(CE)</sub> max.		1		μA
V <sub>OL(OD)</sub>	Output low voltage on open-drain pins (SCL, SDA, GPOUT)	I <sub>OL</sub> = 1 mA			0.4	V
V <sub>OH(OD)</sub>	Output high voltage on open-drain pins (SDA, SCL, GPOUT)	External pullup resistor connected to V <sub>CC</sub>	V <sub>CC</sub> – 0.5			V
V <sub>IL</sub>	Input low voltage, all digital pins				0.6	V
V <sub>IH</sub>	Input high voltage (SDA, SCL)		1.2			V
	Input high voltage (BIN)		1.2			V
V <sub>A2</sub>	Input voltage range (BAT)		V <sub>SS</sub> – 0.125		5	V
V <sub>A3</sub>	Input voltage range (SRX) <sup>(1)(2)</sup>		V <sub>SS</sub> – 0.040		0.040	V
I <sub>lkg</sub>	Input leakage current (I/O pins)				0.3	μA
t <sub>PUCD</sub>	Power-up communication delay			250		ms

(1) Specified by design. Not production tested.

(2) Limited by I<sub>SRX</sub> maximum recommend input current with some margin for the Integrated Sense Resistor tolerance

### POWER-ON RESET

T<sub>A</sub> = –40°C to 85°C, typical values at T<sub>A</sub> = 25°C and V<sub>REGIN</sub> = 3.6 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V <sub>IT+</sub>	Positive-going voltage on V <sub>CC</sub> (Regulator output)		1.98	2.20	2.31	V
V <sub>HYS</sub>	Power-on reset hysteresis		43	115	185	mV

## 2.5V LDO REGULATOR

 $T_A = -40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ ,  $C_{LDO25} = 1\mu\text{F}$ ,  $V_{\text{REGIN}} = 3.6\text{ V}$  (unless otherwise noted)

PARAMETER	TEST CONDITION	MIN	NOM	MAX	UNIT			
$V_{\text{REG25}}$	Regulator output voltage	$2.7\text{V} \leq V_{\text{REGIN}} \leq 4.5\text{V}$ , $I_{\text{OUT}} \leq 5\text{mA}$			2.4	2.5	2.6	V
		$2.45\text{V} \leq V_{\text{REGIN}} < 2.7\text{V}$ (low battery), $I_{\text{OUT}} \leq 3\text{mA}$			2.4			V
$V_{\text{IH(CE)}}$	CE High-level input voltage	$V_{\text{REGIN}} = 2.7$ to $4.5\text{V}$			2.65			V
$V_{\text{IL(CE)}}$	CE Low-level input voltage					0.8		

## INTEGRATING ADC (COULOMB COUNTER) CHARACTERISTICS

 $T_A = -40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ ; 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		
$V_{\text{SR}}$	Input voltage range <sup>(1)(2)</sup>	$V_{\text{SR}} = V_{\text{(SRX)}} - V_{\text{SS}}$			-0.040	0.040	V
$t_{\text{SR\_CONV}}$	Conversion time	Single conversion				1	s
	Resolution		14	15			bits
$V_{\text{OS(SR)}}$	Input offset		10				$\mu\text{V}$
INL	Integral nonlinearity error		$\pm 0.007$	$\pm 0.034$			% FSR
$Z_{\text{IN(SR)}}$	Effective input resistance <sup>(1)</sup>	2.5					M $\Omega$
$I_{\text{lkq(SR)}}$	Input leakage current <sup>(1)</sup>	$T_A = 25^{\circ}\text{C}$				0.3	$\mu\text{A}$

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

(2) Limited by  $I_{\text{SRX}}$  maximum recommend input current with some margin for the Integrated Sense Resistor tolerance.

## INTEGRATED SENSE RESISTOR CHARACTERISTICS

 $T_A = -40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ ; 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		
$\text{SRX}_{\text{RES}}$	Resistance of Integrated Sense Resistor from SRX to VSS. <sup>(1)(2)</sup>	$T_A = 25^{\circ}\text{C}$				10	m $\Omega$
$I_{\text{SRX}}$	Recommended Sense Resistor input current. <sup>(1)(3)</sup>	Long term RMS, average device utilization.				2000	mA
		Peak RMS current, 10% device utilization. <sup>(3)</sup>				2500	mA
		Peak pulsed current, 250mS max, 1% device utilization. <sup>(3)</sup>				3500	mA

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

(2) Firmware compensation applied for temperature coefficient of resistor.

(3) Device utilization is the long term usage profile at a specific condition compared to the average condition.

## ADC (TEMPERATURE AND CELL MEASUREMENT) CHARACTERISTICS

 $T_A = -40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ ; 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	
$V_{\text{IN(ADC)}}$	Input voltage range	0.05		1	V	
$G_{\text{TEMP}}$	Temperature sensor voltage gain		-2		mV/ $^{\circ}\text{C}$	
$t_{\text{ADC\_CONV}}$	Conversion time			125	ms	
	Resolution	14		15	bits	
$V_{\text{OS(ADC)}}$	Input offset		1		mV	
$Z_{\text{ADC}}$	Effective input resistance (BAT) <sup>(1)</sup>	Not measuring cell voltage			8	M $\Omega$
		Measuring cell voltage			100	k $\Omega$
$I_{\text{lkq(ADC)}}$	Input leakage current <sup>(1)</sup>	$T_A = 25^{\circ}\text{C}$			0.3	$\mu\text{A}$

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

### EEPROM MEMORY CHARACTERISTICS

T<sub>A</sub> = -40°C to 85°C; typical values at T<sub>A</sub> = 25°C and V<sub>REGIN</sub> = 3.6 V (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Array Size			256		Bytes
Data retention <sup>(1)</sup>		10			Years
Programming write cycles <sup>(1)</sup>		100K			Cycles

(1) Specified by design. Not production tested

### I<sup>2</sup>C-COMPATIBLE INTERFACE COMMUNICATION TIMING CHARACTERISTICS

T<sub>A</sub> = -40°C to 85°C; typical values at T<sub>A</sub> = 25°C and V<sub>REGIN</sub> = 3.6 V (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t <sub>r</sub>	SCL/SDA rise time			300	ns
t <sub>f</sub>	SCL/SDA fall time			300	ns
t <sub>w(H)</sub>	SCL pulse duration (high)	600			ns
t <sub>w(L)</sub>	SCL pulse duration (low)	1.3			µs
t <sub>su(STA)</sub>	Setup for repeated start	600			ns
t <sub>d(STA)</sub>	Start to first falling edge of SCL	600			ns
t <sub>su(DAT)</sub>	Data setup time	100			ns
t <sub>h(DAT)</sub>	Data hold time	0			ns
t <sub>su(STOP)</sub>	Setup time for stop	600			ns
t <sub>(BUF)</sub>	Bus free time between stop and start	66			µs
f <sub>SCL</sub>	Clock frequency <sup>(1)</sup>			400	kHz

(1) If the clock frequency (f<sub>SCL</sub>) is > 100 kHz, use 1-byte write commands for proper operation. All other transactions types are supported at 400 kHz. (Refer to I<sup>2</sup>C INTERFACE and I<sup>2</sup>C Command Waiting Time)

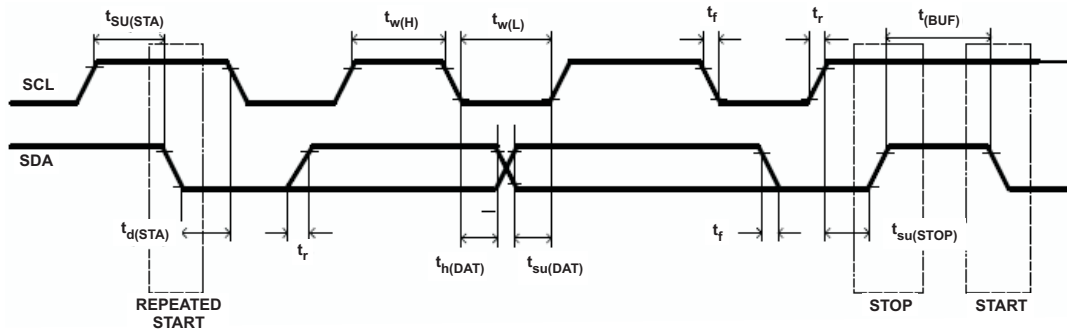


Figure 1. I<sup>2</sup>C-Compatible Interface Timing Diagrams

## GENERAL DESCRIPTION

The bq27425 accurately predicts the battery capacity and other operational characteristics of a single Li-based rechargeable cell. It can be interrogated by a system processor to provide cell information, such as state-of-charge (SOC).

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 bq27425 control and status registers, as well as its data locations. Commands are sent from system to gauge using the bq27425's I<sup>2</sup>C serial communications engine, and can be executed during application development, system manufacture, or end-equipment operation.

The key to the bq27425'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 high accuracy across a wide variety of operating conditions and over the lifetime of the battery.

The bq27425 measures charge/discharge activity by monitoring the voltage across a small-value integrated sense resistor (10 mΩ typical) located between the system's V<sub>SS</sub> and the battery's PACK– terminal. When a cell is attached to the bq27425, cell impedance is computed, based on cell current, cell open-circuit voltage (OCV), and cell voltage under loading conditions.

The bq27425 uses an integrated temperature sensor for estimating cell temperature. Alternatively, the host processor can provide temperature data for the bq27425.

To minimize power consumption, the bq27425 has several power modes: INITIALIZATION, NORMAL, SLEEP, and HIBERNATE. The bq27425 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 Section *Power Modes*.

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### NOTE

#### FORMATTING CONVENTIONS IN THIS DOCUMENT:

Commands: *italics* with *parentheses* and no breaking spaces, that is, *RemainingCapacity( )*.

NVM Data: *italics*, **bold**, and *breaking spaces*, that is, **Design Capacity**.

Register bits and flags: brackets and *italics*, that is, [TDA]

NVM Data bits: brackets, *italics* and **bold**, that is: [LED1]

Modes and states: ALL CAPITALS, that is, UNSEALED mode.

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## DATA COMMANDS

### Standard Data Commands

The bq27425 uses a series of 2-byte standard commands to enable system reading and writing of battery information. Each standard command has an associated command-code pair, as indicated in [Table 1](#). Because each command consists of two bytes of data, two consecutive I<sup>2</sup>C 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, *I2C INTERFACE*. 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, refer to Section *Access Modes*.)

**Note:** Data values read by the host may be invalid during initialization for a period of up to 3 seconds.

**Table 1. Standard Commands**

NAME		COMMAND CODE	UNITS	SEALED ACCESS
<i>Control( )</i>	CNTL	0x00 / 0x01	N/A	R/W
<i>Temperature( )</i>	TEMP	0x02 / 0x03	0.1°K	R/W
<i>Voltage( )</i>	VOLT	0x04 / 0x05	mV	R
<i>Flags( )</i>	FLAGS	0x06 / 0x07	N/A	R
<i>NominalAvailableCapacity( )</i>		0x08 / 0x09	mAh	R
<i>FullAvailableCapacity( )</i>		0x0a / 0x0b	mAh	R
<i>RemainingCapacity( )</i>	RM	0x0c / 0x0d	mAh	R
<i>FullChargeCapacity( )</i>	FCC	0x0e / 0x0f	mAh	R
<i>AverageCurrent( )</i>		0x10 / 0x11	mA	R
<i>Debug1( )</i>		0x16 / 0x17	num	R
<i>AveragePower( )</i>		0x18 / 0x19	mW	R
<i>StateOfCharge( )</i>	SOC	0x1c / 0x1d	%	R
<i>IntTemperature( )</i>		0x1e / 0x1f	0.1°K	R
<i>StateOfHealth( )</i>	SOH	0x20 / 0x21	%	R
<i>Debug2( )</i>		0x2c / 0x2d	num	R
<i>Debug3( )</i>		0x32 / 0x33	num	R
<i>OperationConfiguration( )</i>	OpConfig	0x3a / 0x3b	N/A	R
<i>DesignCapacity( )</i>		0x3c / 0x3d	mAh	R



**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 bq27425 during normal operation and additional features when the bq27425 is in different access modes, as described in [Table 2](#).

**Table 2. Control() Subcommands**

CNTL FUNCTION	CNTL DATA	SEALED ACCESS	DESCRIPTION
CONTROL_STATUS	0x0000	Yes	Reports the status of device.
DEVICE_TYPE	0x0001	Yes	Reports the device type (0x0425).
FW_VERSION	0x0002	Yes	Reports the firmware version of the device.
PREV_MACWRITE	0x0007	Yes	Returns previous MAC command code.
CHEM_ID	0x0008	Yes	Reports the chemical identifier of the Impedance Track™ configuration
BAT_INSERT	0x000c	Yes	Forces the <i>[BAT_DET]</i> bit set when the <i>[BIE]</i> bit is 0.
BAT_REMOVE	0x000d	Yes	Forces the <i>[BAT_DET]</i> 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_CFGUPDATE	0x0013	No	Force CONTROL_STATUS [ <i>CFGUPMODE</i> ] to 1 and gauge enters CONFIG UPDATE mode.
SEALED	0x0020	No	Places the bq27425 in SEALED access mode.
RESET	0x0041	No	Performs a full device reset.
SOFT_RESET	0x0042	No	Gauge exits CONFIG UPDATE mode.

**CONTROL\_STATUS: 0x0000**

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

**Table 3. CONTROL\_STATUS Bit Definitions**

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High Byte	RSVD	RSVD	SS	CALMODE	CCA	BCA	QMAX_UP	RES_UP
Low Byte	RSVD	HIBERNATE	RSVD	SLEEP	LDMD	RUP_DIS	VOK	RSVD

RSVD = Reserved.

SS = Status bit indicating the bq27425 is in the SEALED State. Active when set.

CALMODE = Status bit indicating the bq27425 is in calibration mode. Active when set.

CCA = Status bit indicating the bq27425 Coulomb Counter Auto-Calibration routine is active. The CCA routine will take place approximately 3 minutes and 45 seconds after the initialization as well as periodically as conditions permit. Active when set.

BCA = Status bit indicating the bq27425 board calibration routine is active. Active when set.

QMAX\_UP = Status bit indicating Qmax has Updated. True when set. This bit is cleared after power on reset or when [BAT\_DET] bit is set. When this bit is cleared, it enables fast learning of battery Qmax.

RES\_UP = Status bit indicating that resistance has been updated. True when set. This bit is cleared after power on reset or when [BAT\_DET] bit is set. Also this bit can only be set after Qmax is updated. ([QMAX\_UP] set). When this bit is cleared, it enables fast learning of battery impedance.

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

SLEEP = Status bit indicating the bq27425 is in SLEEP mode. True when set.

LDMD = Status bit indicating the algorithm is using constant-power mode. True when set. Default is 1. Note: The bq27425 always uses constant-power mode.

RUP\_DIS = Status bit indicating the bq27425 Ra table updates are disabled. Updates are disabled when set.

VOK = Status bit indicating cell voltages are OK for Qmax updates. True when set.

**DEVICE\_TYPE: 0x0001**

Instructs the fuel gauge to return the device type to addresses 0x00/0x01. The value returned is 0x0425.

**FW\_VERSION: 0x0002**

Instructs the fuel gauge to return the firmware version to addresses 0x00/0x01. Refer to [AVAILABLE OPTIONS](#) for the expected data value.

**PREV\_MACWRITE: 0x0007**

Instructs the fuel gauge to return the previous command written to addresses 0x00/0x01. The value returned is limited to less than 0x0015.

**CHEM\_ID: 0x0008**

Instructs the fuel gauge to return the chemical identifier for the Impedance Track™ configuration to addresses 0x00/0x01. Refer to [AVAILABLE OPTIONS](#) for the expected data value.

**BAT\_INSERT: 0X000C**

This subcommand forces the *Flags()* [BAT\_DET] bit to set when the battery insertion detection is disabled via **OpConfig[BIE=0]**. In this case, the gauge does not detect battery insertion from the BIN pin's logic state, but relies on the BAT\_INSERT host subcommand to indicate battery presence in the system. This subcommand also starts Impedance Track™ gauging.

**BAT\_REMOVE: 0X000D**

This subcommand forces the *Flags()* [BAT\_DET] bit to clear when the battery insertion detection is disabled via **OpConfig[BIE=0]**. In this case, the gauge does not detect battery removal from the BIN pin's logic state, but relies on the BAT\_REMOVE host subcommand to indicate battery removal from the system.

**SET\_HIBERNATE: 0x0011**

Instructs the fuel gauge to force the *CONTROL\_STATUS[HIBERNATE]* bit to 1. If the necessary conditions are met, this enables the gauge to enter the HIBERNATE power mode after the transition to SLEEP power state is detected. The *[HIBERNATE]* bit is automatically cleared upon exiting from HIBERNATE mode.

**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 SLEEP power state is detected. It can also be used to force the gauge out of HIBERNATE mode.

**SET\_CFGUPDATE: 0x0013**

Instructs the fuel gauge to set the *Flags[CFGUPMODE]* bit to 1 and enter CONFIG UPDATE mode. This command is only available when the fuel gauge is UNSEALED. Note: A SOFT\_RESET subcommand is typically used to exit CONFIG UPDATE mode to resume normal gauging.

**SEALED: 0x0020**

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

**RESET : 0x0041**

This command instructs the fuel gauge to perform a full device reset and reinitialize RAM data to the default values from ROM. The gauge sets the *Flags[ITPOR]* bit and enters the INITIALIZE mode. Refer to [Figure 2](#). This command is only available when the fuel gauge is UNSEALED.

**SOFT\_RESET : 0x0042**

This command instructs the fuel gauge to perform a partial (soft) reset from any mode with an OCV measurement. The *Flags[ITPOR, CFGUPMODE]* bits are cleared and a resimulation occurs to update *StateOfCharge( )*. Refer to [Figure 2](#). This command is only available when the fuel gauge is UNSEALED.

### Temperature( ): 0x02/0x03

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 *Op Config[TEMPS]* bit = 0 (default), a read command will return the internal temperature sensor value and write command will be ignored. If *Op Config[TEMPS]* bit = 1, a write command sets the temperature to be used for gauging calculations while a read command returns to temperature previously written.

### Voltage( ): 0x04/0x05

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

### Flags( ): 0x06/0x07

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

**Table 4. Flags Bit Definitions**

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
High Byte	OT	UT	RSVD	RSVD	RSVD	EEFAIL	FC	CHG
Low Byte	OCVTAKEN	RSVD	ITPOR	CFGUPMODE	BAT_DET	SOC1	SOCF	DSG

OT = Over-Temperature condition is detected. [OT] is set when *Temperature( )* ≥ **Over Temp** (default = 55 °C). [OT] is cleared when *Temperature( )* < **Over Temp - Temp Hys**.

UT = Under-Temperature condition is detected. [UT] is set when *Temperature( )* ≤ **Under Temp** (default = 0 °C). [UT] is cleared when *Temperature( )* > **Under Temp + Temp Hys**.

RSVD = Reserved.

RSVD = Reserved.

RSVD = Reserved.

EEFAIL = EEPROM Write Fail. True when set. This bit is set after a single EEPROM write failure. All subsequent EEPROM writes are disabled. A power on reset or RESET subcommand is required to clear the bit to re-enable EEPROM writes.

FC = Full-charge is detected. If the **FC Set%** (default = 100%) is a positive threshold, [FC] is set when SOC ≥ **FC Set %** and is cleared when SOC ≤ **FC Clear %** (default = 98%). Alternatively, if **FC Set%** = -1, [FC] is set when the fuel gauge has detected charge termination.

CHG = Fast charging allowed. If the **TCA Set%** (Terminate Charge Alarm Set %) is a positive threshold (default = 99%), [CHG] is cleared when SOC ≥ **TCA Set %** and is set when SOC ≤ **TCA Clear %** (default = 95%). Alternatively, if **TCA Set%** = -1, the TCA thresholds are disabled and the [CHG] bit is cleared when the fuel gauge has detected a taper condition.

OCVTAKEN = Cleared on entry to relax mode and Set to 1 when OCV measurement is performed in relax

RSVD = Reserved.

ITPOR = Indicates a Power On Reset or RESET subcommand has occurred. True when set. This bit is cleared after the SOFT\_RESET subcommand is received.

CFGUPMODE = Fuel gauge is in CONFIG UPDATE mode. True when set. Default is 0. Refer to CONFIG UPDATE Mode section for details.

BAT\_DET = Battery insertion detected. True when set. When **OpConfig[BIE]** is set, [BAT\_DET] is set by detecting a logic high to low transition at BIN pin. when **OpConfig[BIE]** is low, [BAT\_DET] is set when host issues BAT\_INSERT subcommand and clear when host issues BAT\_REMOVE subcommand.

SOC1 = If set, *StateOfCharge( )* ≤ **SOC1 Set Threshold**. The [SOC1] bit will remain set until *StateOfCharge( )* ≥ **SOC1 Clear Threshold**.

SOCF = If set, *StateOfCharge( )* ≤ **SOCF Set Threshold**. The [SOCF] bit will remain set until *StateOfCharge( )* ≥ **SOCF Clear Threshold**.

DSG = Discharging detected. True when set.

**NominalAvailableCapacity( ): 0x08/0x09**

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

**FullAvailableCapacity( ): 0x0a/0x0b**

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.

**RemainingCapacity( ): 0x0c/0x0d**

This read-only command pair returns the compensated battery capacity remaining. Units are mAh.

**FullChargeCapacity( ): 0x0e/0f**

This read-only command pair returns the compensated capacity of the battery when fully charged. Units are mAh. *FullChargeCapacity( )* is updated at regular intervals, as specified by the IT algorithm.

**AverageCurrent( ): 0x10/0x11**

This read-only command pair returns a signed integer value that is the average current flow through the sense resistor. In NORMAL mode, it is updated once per second and 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.

**AveragePower( ): 0x18/0x19**

This read-only function returns an 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.

**StateOfCharge( ): 0x1c/0x1d**

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%.

**IntTemperature( ): 0x1e/0x1f**

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. If **OpConfig[TEMPS]** = 0, this command will return the same value as *Temperature( )*.

**StateOfHealth( ): 0x20/0x21**

0x20 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 programmed in factory (default = -400mA). The range of the returned SOH percentage is 0x00 to 0x64, indicating 0 to 100% correspondingly.

0x21 SOH Status: this read-only function returns an unsigned integer value, indicating the status of the SOH percentage:

- 0x00: SOH not valid (initialization)
- 0x01: Instant SOH value ready
- 0x02: Initial SOH value ready
  - Calculation based on default Qmax
  - May not reflect SOH for currently inserted pack
- 0x03: SOH value ready
  - Calculation based on learned Qmax
  - Most accurate SOH for currently inserted pack following a Qmax update
- 0x04-0xFF: Reserved

### **OperationConfiguration( ): 0x3a/0x3b**

This read-only function returns the contents of the NVM **Operation Configuration (Op Config)** register and is most useful for system level debug to quickly determine device configuration.

### **DesignCapacity( ): 0x3c/0x3d**

This read-only function 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 and is used as an input for the algorithm to scale the normalized resistance tables and for the calculation of *StateOfHealth()*.

### **DebugX( ):**

Several read-only functions such as *Debug1( )*, *Debug2( )*, *Debug3( )* provide information useful for debug purposes. For factory use only.

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

**Table 5. Extended Commands**

NAME	COMMAND CODE	UNITS	SEALED ACCESS <sup>(1) (2)</sup>	UNSEALED ACCESS <sup>(1) (2)</sup>
<i>DataClass( )</i> <sup>(2)</sup>	0x3e	N/A	N/A	R/W
<i>DataBlock( )</i> <sup>(2)</sup>	0x3f	N/A	R/W	R/W
<i>BlockData( )</i>	0x40...0x5f	N/A	R	R/W
<i>BlockDataChecksum( )</i>	0x60	N/A	R/W	R/W
<i>BlockDataControl( )</i>	0x61	N/A	N/A	R/W
Reserved	0x62...0x7f	N/A	R	R

(1) SEALED and UNSEALED states are entered via commands to **Control( )** 0x00/0x01

(2) In sealed mode, data CANNOT be accessed through commands 0x3e and 0x3f.

### **OperationConfiguration( ): 0x3a/0x3b**

SEALED and UNSEALED Access: This command returns the **Operation Configuration** register setting

### **DesignCapacity( ): 0x3c/0x3d**

SEALED and UNSEALED Access: This command returns the value is stored in **Design Capacity** and is expressed in mAh. This is intended to be the theoretical or nominal capacity of a new pack and is used as an input for the algorithm to scale the normalized resistance tables.

### **DataClass( ): 0x3e**

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

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

### **DataBlock( ): 0x3f**

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

SEALED Access: Issuing a 0x01 instructs the *BlockData( )* command to transfer the **Manufacturer Info** block.

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

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

SEALED Access: This data block is used to access the **Manufacturer Info** block. No other NVM or RAM data blocks are accessible in SEALED mode.

***BlockDataChecksum( )*: 0x60**

UNSEALED Access: This byte contains the checksum on the 32 bytes of block data read or written. 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. For a block write, the correct complemented checksum must be written before the *BlockData( )* will be transferred to NVM or RAM.

SEALED Access: This byte contains the checksum for the 8 bytes of the **Manufacturer Info** block.

***BlockDataControl( )*: 0x61**

UNSEALED Access: This command is used to control the data access mode. Writing 0x00 to this command enables *BlockData( )* to access NVM and RAM.

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

***Reserved – 0x62 – 0x7f***

## BLOCK DATA INTERFACE

### Accessing Block Data

The bq27425 contains both re-writable EEPROM non-volatile memory (NVM) and ROM-based data blocks. Upon device RESET, the ROM-based data blocks are copied to associated volatile RAM space to initialize default configuration and data constants to be used by the fuel gauging algorithm. Re-writable NVM-based data blocks contain information expected to change such as: calibration, customer data and Impedance Track fuel gauging data tables. If the application requires a change to the NVM or RAM configuration data, the host can update the data blocks in CONFIG UPDATE mode. RAM-based data changes are temporary and must be applied by the host using CONFIG UPDATE mode after each device RESET; while changes to the NVM data blocks are permanent. The data blocks can be accessed in several different ways, depending on the access mode and what data is being accessed.

Commonly accessed data block locations, frequently read by a system, are conveniently accessed through specific instructions, already described in Section *Data Commands*. These commands are available when the bq27425 is either in UNSEALED or SEALED modes.

Most data block locations, however, are only accessible in UNSEALED mode by use of the bq27425 evaluation software or by data block transfers. These locations should be optimized and/or fixed during the development and manufacture processes. Once established, the values generally remain unchanged during end-equipment operation.

To access data locations individually, the block containing the desired data NVM 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 the associated data block, once the correct checksum for the whole block is written to *BlockDataChecksum( )* (0x60).

Occasionally, a data CLASS will be larger than the 32-byte block size. In this case, the *DataBlock( )* command is used to designate which 32-byte block the desired locations reside in. The correct command address is then given by  $0x40 + \text{offset} \text{ modulo } 32$ . For example, to access **Sleep Current** in the *Gas Gauging* class, the *DataClass( )* is issued 82 (0x52) to set the class. Because the offset is 34, it resides in the second 32-byte block. Hence, *DataBlock( )* is issued 0x01 to set the block offset, and the offset used to index into the *BlockData( )* memory area is  $0x40 + 34 \text{ modulo } 32 = 0x40 + 2 = 0x40 + 2 = 0x42$ .

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 bq27425, 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 data written to NVM blocks is persistent, so a power-on reset does not resolve the fault.

## ACCESS MODES

The bq27425 supports SEALED and UNSEALED access modes to control data NVM access permissions according to [Table 6](#).

**Table 6. Data NVM Access**

Security Mode	Data NVM	Manufacturer Info
UNSEALED	R/W	R/W
SEALED	None	R

## SEALING/UNSEALING DATA BLOCKS

The bq27425 implements a key-access security scheme to transition from a SEALED state to the UNSEALED state. Devices are shipped from the factory in the UNSEALED state and should be SEALED prior to use in end-equipment. The **Sealed to Unseal** key can only be updated in the UNSEALED state.

**To SEAL from UNSEALED:** The host sends the SEALED subcommand 0x0020 to the *Control( )* register. After receiving the SEALED command, the *CONTROL\_STATUS[SS]* bit is set within 2 seconds.

**To UNSEAL from SEALED:** Host sends the keys to the *Control( )* register. The keys must be sent consecutively, with no other data written to *Control( )*. Note: To avoid conflict with normal subcommands, the keys must be different from the codes presented in the CNTL DATA column of the [Table 2](#) table. The first word is Key 0 and the second word is Key 1. The order of the keys sent are Key 1 followed by Key 0. The order of the bytes for each key entered through the *Control( )* command is the reverse of what is read from the part. For an example, if the 4-byte **Sealed to Unseal** key is 0x56781234, key 1 is 0x1234 and key 0 is 0x5678. So, the host should write 0x3412 followed by 0x7856 to unseal the part. After receiving the correct key sequence the *CONTROL\_STATUS[SS]* bit is cleared.



**DATA BLOCK SUMMARY**
**Table 7. Data Block Summary**

Class	Subclass ID	Subclass	Offset	Name	Data Type	Min Value	Max Value	Default Value (-G2B)	Units (EVSU Units)*
Configuration [RAM]	2	Safety [RAM]	0	Over Temp	I2	-1200	1200	550	0.1°C (°C)
			2	Under Temp	I2	-1200	1200	0	0.1°C (°C)
			4	Temp Hys	U1	0	255	50	0.1°C (°C)
	36	Charge Termination [RAM]	3	TCA Set %	I1	-1	100	99	%
			4	TCA Clear %	I1	-1	100	95	%
			5	FC Set %	I1	-1	100	100	%
			6	FC Clear %	I1	-1	100	98	%
	49	Discharge [RAM]	0	SOC1 Set Threshold	U1	0	255	10	%
			1	SOC1 Clear Threshold	U1	0	255	15	%
			2	SOCF Set Threshold	U1	0	255	2	%
			3	SOCF Clear Threshold	U1	0	255	5	%
	68	Power [RAM]	9	Hibernate I	I2	0	700	3	mA
11			Hibernate V	I2	2400	3000	2550	mV	
System Data [NVM]	58	Manufacturer Info [NVM]	0 - 7	Block A 0 - 7	H1	0x00	0xff	0x00	-
Gas Gauging [NVM/RAM]	80	IT Cfg [RAM]	55	Max Delta Voltage	I2	-32000	32000	200	mV
			57	TermV Valid t	U1	0	255	2	sec
	81	Current Thresholds [RAM]	0	Dsg Current Threshold	I2	0	2000	167	0.1 h
			2	Chg Current Threshold	I2	0	2000	133	0.1 h
			4	Quit Current	I2	0	1000	250	0.1 h
	82	State [NVM]	2	Update Status	H1	0x00	0xFF	0x04 (0x34)	-
			3	Reserve Cap-mAh	I2	0	9000	0	mAh
			5	Op Config	H2	0x0000	0xffff	0x89f8	-
			12	Design Capacity	I2	0	32767	1340 (1000)	mAh
			14	Design Energy	I2	0	32767	4960 (3800)	mWh
			18	Terminate Voltage	I2	2800	3700	3200	mV
			22	SOHLoadI	I2	-32767	0	50	mA
			29	SOCI Delta	U1	0	100	1	%
			30	Taper Current	I2	0	1000	75	mA
			32	Taper Voltage	I2	0	5000	4100 (4200)	mV
			34	Sleep Current	I2	0	100	10	mA
			36	V at Chg Term	I2	0	5000	4190 (4290)	mV
			38	Transient Factor Charge	U1	0	255	179	num
			39	Transient Factor Discharge	U1	0	255	179	num
			40	RDL Tempco	F4	1.0e-20	4.0e+1	0.000393	num
Ra Tables [NVM/RAM]	88	R_a NVM [NVM]	0 - 28	Cell0 R_a 0 - 14	I2	183	183	[Table]	2 <sup>-10</sup> Ω (num)
	89	R_a RAM [RAM]	0 - 28	Cell0 R_a 0 - 14	I2	183	183	[Table]	2 <sup>-10</sup> Ω (num)
Calibration [NVM]	104	Data [NVM]	0	CC Offset	I2	-32768	32767	-1312	mV
			2	Board Offset	I1	-128	127	0	uV
			3	Int Temp Offset	I1	-128	127	0	°0.1°C (°C)
			4	Pack V Offset	I1	-128	127	0	mV
	105	CC Cal [NVM]	0	CC Gain	F4	1.0e-1	4.0e+1	0.47095	num (2 <sup>-10</sup> Ω)
			4	CC Cal Temp	I2	0	32767	2982	0.1K

**Table 7. Data Block Summary (continued)**

Class	Subclass ID	Subclass	Offset	Name	Data Type	Min Value	Max Value	Default Value (-G2B)	Units (EVSW Units)*
	107	Current [RAM]	19	CC Delta	F4	2.9826e+4	1.193046e+6	559538.8	num (2 <sup>-10</sup> Ω)
Security	112	Codes [RAM]	0	Sealed to Unsealed	H4	0x00000000	0xffffffff	0x36720414	-

## FUNCTIONAL DESCRIPTION

### FUEL GAUGING

The bq27425 is an easy to configure fuel gauge that measures the cell voltage, temperature, and current to determine battery state of charge (SOC). The bq27425 monitors charge and discharge activity by sensing the voltage across an integrated small-value resistor (10 mΩ typ.) between the SRX and VSS 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 the **Design Capacity**. The bq27425 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.

### FUEL GAUGING CONFIGURATIONS

The bq27425 features easy to configure data NVM to speed-up fuel gauging design. Users are required to configure **Design Capacity**, **Termination Voltage**, and **Operation Configuration** (see [The Operation Configuration Register](#) section for details) to achieve optimal performance. The Impedance Track™ algorithm uses these parameters along with built-in parameters to achieve accurate battery fuel gauging.

Several built-in parameters are used in the Impedance Track™ algorithm to identify different modes of battery:

- Charging : **Chg Current Threshold** (default = **DesignCapacity** /13.3 ),
- Discharging: **Dsg Current Threshold** (default = **DesignCapacity** /16.7 )
- Relax: **Quit Current Threshold** (default = **DesignCapacity** /25.0 )

To achieve accurate fuel gauging, the bq27425 uses a Constant Power Model for fuel gauging. This model uses the average discharge power from the beginning of the discharge cycle until present time to compute load-compensated capacity such as *RemainingCapacity( )* and *FullChargeCapacity( )* in the Impedance Track™ algorithm.

### SOC Smoothing Feature

Rapid changes in operating conditions, such as temperature or discharge current, can lead to sudden changes in the algorithm's immediate calculation of *RemainingCapacity( )*, *FullChargeCapacity( )* and *StateOfCharge( )*. SOC Smoothing provides filtered data to the host resulting in more gradual changes to SOC-related data when conditions vary and can provide a better end-user experience. The feature is enabled via **Op Config [SMOOTHEN]**.

## The Operation Configuration (Op Config) Register

Gauge operation is configured via the **Operation Configuration** (Op Config) data NVM register, as indicated in [Table 8](#). This register is programmed/read via the methods described in *Section Accessing the Data NVM*.

**Table 8. Op Config Register Definition**

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
<b>High Byte</b>	SMOOTHEN	RSVD0	BIE	BI_PU_EN	RSVD1	RSVD0	RSVD0	RSVD1
<b>Default =</b>	1	0	0	0	1	0	0	1
	<b>0x89</b>							
<b>Low Byte</b>	RSVD1	RSVD1	SLEEP	RMFCC	RSVD1	BATLOWEN	GPIOPOL	TEMPS
<b>Default =</b>	1	1	1	1	1	0	0	0
	<b>0xF8</b>							

SMOOTHEN = Enables the SOC smoothing feature. (See [SOC Smoothing Feature](#).) True when set.

BIE = Battery Insertion Enable. If set, the battery insertion is detection via BIN pin input. If cleared, the detection relies on the host to issue BAT\_INSERT subcommand to indicate battery presence in the system.

BI\_PU\_EN = Enables internal weak pull-up on BIN pin. True when set. If false, an external pull-up resistor is expected.

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

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

BATLOWEN = If set, the BAT\_LOW function for GPOUT pin is selected. If cleared, the SOC\_INT function is selected for GPOUT.

GPIO\_POL = GPOUT pin is active-high if set or active-low if cleared.

TEMPS = Selects the temperature source. Enables the host to write *Temperature( )* if set. If cleared, the internal temperature sensor is used for *Temperature( )*.

RSVD0 = Reserved. Default is 0. (Set to 0 for proper operation)

RSVD1 = Reserved. Default is 1. (Set to 1 for proper operation)

## DETAILED PIN DESCRIPTIONS

### GPOUT Pin

The GPOUT Pin is a multiplex pin and the polarity of the pin output can be selected via the *[GPIO\_POL]* bit of the **Operation Configuration**. The function is defined by *[BATLOWEN]*. If set, the Battery Low Indicator (BAT\_LOW) function for GPOUT pin is selected. If cleared, the SOC interrupt (SOC\_INT) function is selected for GPOUT.

When the BAT\_LOW function is activated, the signaling on the multiplexed pin follows the status of the *[SOC1]* bit in the *Flags( )* register. The bq27425 has two flags accessed by the *Flags( )* function that warns when the battery's SOC has fallen to critical levels. When *StateOfCharge( )* 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 *StateOfCharge( )* rises above **SOC1 Set Threshold**. The bq27425's GPOUT pin automatically reflects the status of the *[SOC1]* flag when **OpConfig[BATLOWEN=0]**.

When *StateOfCharge( )* falls below the second capacity threshold, **SOCF Set Threshold**, the *[SOCF]* (*State of Charge Final*) flag is set, serving as a final discharge warning. Similarly, when *StateOfCharge( )* rises above **SOCF Clear Threshold** and the *[SOCF]* flag has already been set, the *[SOCF]* flag is cleared.

When the SOC\_INT function is activated, the GPOUT pin generates 1ms pulse width under various conditions as described in [Table 9](#).

**Table 9. SOC\_INT Function Definition**

	Enable Condition	Pulse Width	Description
Change in SOC	( <b>SOCI Delta</b> ) ≠ 0	1ms	During charge, when the SOC is greater than (>) the points, 100% - n × ( <b>SOCI Delta</b> ) and 100%; During discharge, when the SOC reaches (≤) the points 100% - n × ( <b>SOCI Delta</b> ) and 0%; where n is an integer starting from 0 to the number generating SOC no less than 0% Examples: For <b>SOCI Delta</b> = 1% (default), the SOC_INT intervals are 0%, 1%, 2%, ..... 99%, and 100%. For <b>SOCI Delta</b> = 10%, the SOC_INT intervals are 0%, 10%, 20%, ..... 90%, and 100%.
State Change	( <b>SOCI Delta</b> ) ≠ 0	1ms	Upon detection of entry to a charge or a discharge state.. Relaxation is not included.
Battery Removal	[BIE] bit is set in OpConfig	1ms	When battery removal is detected by BIN pin.

## Battery Detection (BIN)

The function of *OpConfig[BIE]* bit is described in the [Table 10](#) table below. When battery insertion is detected and INITIALIZATION mode is completed, the bq27425 transitions to NORMAL mode to start Impedance Track™ fuel gauging. When battery insertion is not detected, the bq27425 remains in INITIALIZATION mode.

**Table 10. Battery Detection**

<i>OpConfig[BIE]</i>	Battery Insertion Requirement	Battery Removal Requirement
1	(1) Host drives BIN pin from logic high to low to signal battery insertion. or (2) A weak pull-up resistor can be used (between BIN and VCC pin). When battery pack with pull-down is connected, it can generate a logic low to signal battery insertion.	(1) Host drives BIN pin from logic low to high to signal battery removal. or (2) When battery pack with pull-down is removed, the weak pull-up resistor can generate a logic high to signal battery removal.
0	Host sends BAT_INSERT subcommand to signal battery insertion.	Host sends BAT_REMOVE subcommand to signal battery removal.

## DETECTING CHARGE TERMINATION

The bq27425 detects charge termination when (1) *AverageCurrent( )* < **Taper Current** (default = 75 mA) for 80 seconds, (2) during the same 80 seconds, the accumulated change in capacity > 0.25mAh / 40 seconds, and (3) *Voltage( )* > (**Charging Voltage** – 100mV). When this occurs, the *Flags( )*[CHG] bit is cleared. Also, if the **[RMFCC]** bit of **Operation Configuration** is set, then *RemainingCapacity( )* is set equal to *FullChargeCapacity( )*.

## OPERATING MODES

The bq27425 has different operating modes: POR, INITIALIZATION, NORMAL, CONFIG UPDATE, SLEEP, and HIBERNATE. Upon power up from OFF or SHUTDOWN, a Power On Reset (POR) occurs and the fuel gauge begins INITIALIZATION. In NORMAL mode, the bq27425 is fully powered and can execute any allowable task. Configuration data in RAM and NVM can be updated by the host using the CONFIG UPDATE mode. In SLEEP mode the fuel gauge turns off the high frequency oscillator clock to enter a reduced-power state, periodically taking measurements and performing calculations. In HIBERNATE mode the fuel gauge is in a very low power state, but can be woken up by communication or certain I/O activity.

In SHUTDOWN mode, the LDO is disabled so internal power and all volatile data is lost. Since no gauging occurs in SHUTDOWN mode, additional gauging error can be introduced if the system has significant battery charge/discharge activity prior to re-INITIALIZATION.

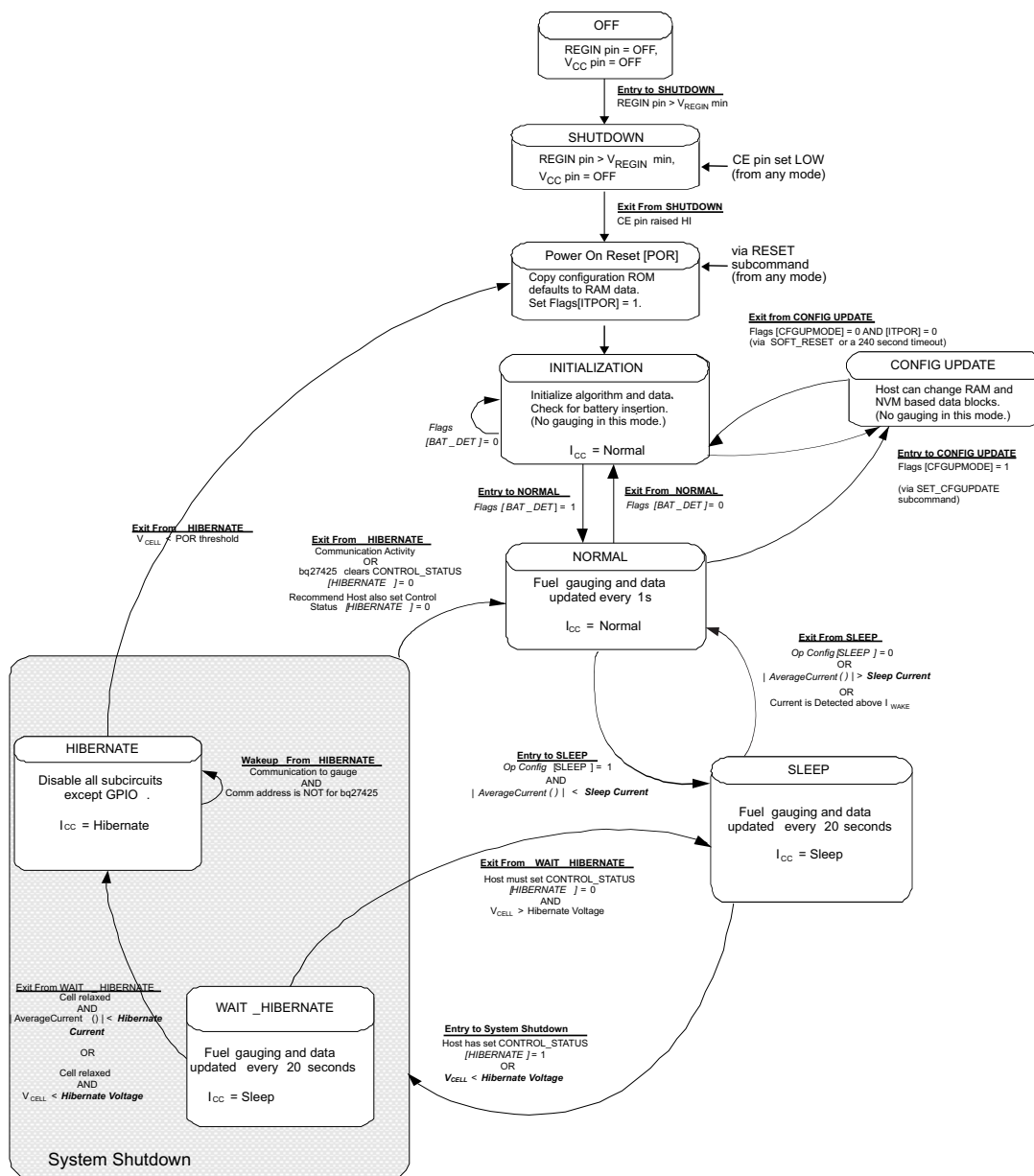


Figure 2. Power Mode Diagram

## POR and INITIALIZATION Modes

Upon Power On Reset (POR), the fuel gauge copies ROM-based configuration defaults to RAM and begins INITIALIZATION mode where essential data is initialized and will remain in INITIALIZATION mode as halted-CPU state when an adapter, or other power source is present to power the bq27425 (and system), yet no battery has been detected. The occurrence of POR or a *Control( )* RESET subcommand will set the *Flags( )* [ITPOR] status bit to indicate that RAM has returned to ROM default data. When battery insertion is detected, a series of initialization activities begin including an OCV measurement. In addition CONTROL\_STATUS[QMAX\_UP] and [RES\_UP] bits are cleared to allow fast learning of Qmax and impedance.

Some commands, issued by a system processor, can be processed while the bq27425 is halted in this mode. The gauge will wake up to process the command, and then return to the halted state awaiting battery insertion. The current consumption of INITIALIZATION mode is similar to NORMAL mode.

## CONFIG UPDATE Mode

If the application requires different configuration data for the bq27425. The host can update both NVM and RAM based parameters using the *Control( )* SET\_CFGUPDATE subcommand to enter CONFIG UPDATE mode as indicated by the *Flags( )* [CFGUPMODE] status bit. In this mode, fuel gauging is suspended while the host uses the Extended Data Commands to modify the configuration data blocks. To resume fuel gauging, the host sends a *Control( )* SOFT\_RESET subcommand to exit CONFIG UPDATE mode and clear both *Flags( )* [ITPOR] and [CFGUPMODE] bits. After a timeout of approximately 240 seconds (4 minutes), the gauge will automatically exit CONFIG UPDATE mode if it has not received a SOFT\_RESET subcommand from the host.

## 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 once per second, 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.

## 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** (default = 10mA). Once entry into SLEEP mode has been qualified, but prior to entering it, the bq27425 performs an ADC autocalibration to minimize offset.

During SLEEP mode, the bq27425 periodically takes data measurements and updates its data set. However, a majority of its time is spent in an idle condition.

The bq27425 exits SLEEP if any entry condition is broken, specifically when: *AverageCurrent( )* rises above **Sleep Current** (default = 10mA).

## HIBERNATE Mode

HIBERNATE mode could be used when the system equipment needs to enter a very 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**. The gauge will remain in HIBERNATE mode until the system issues a direct I<sup>2</sup>C command to the gauge. I<sup>2</sup>C communication that is not directed to the gauge will only briefly wake it up and the gauge immediately returns to HIBERNATE mode.

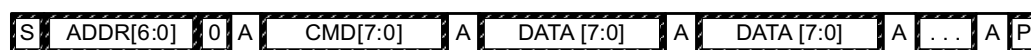
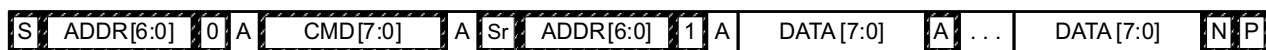
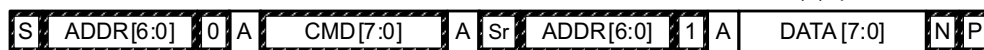
It is the system's responsibility to wake the bq27425 after it has gone into HIBERNATE mode and to prevent a charger from charging the battery before the [OCVTAKEN] bit is set which signals an OCV reading is taken. After waking, the gauge can proceed with the initialization of the battery information.



## I<sup>2</sup>C INTERFACE

The bq27425-G2 supports the standard I<sup>2</sup>C read, incremental read, quick read, one-byte write, and incremental write functions. The 7-bit device address (ADDR) is the most significant 7 bits of the hex address and is fixed as 1010101. The first 8 bits of the I<sup>2</sup>C protocol are, therefore, 0xAA or 0xAB for write or read, respectively.

Host generated       Gauge generated

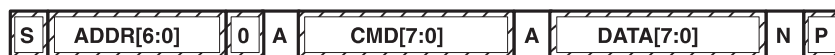


(S = Start, Sr = Repeated Start, A = Acknowledge, N = No Acknowledge, and P = Stop).

The quick read returns data at the address indicated by the address pointer. The address pointer, a register internal to the I<sup>2</sup>C communication engine, increments whenever data is acknowledged by the bq27425-G2 or the I<sup>2</sup>C master. "Quick writes" function in the same manner and are a convenient means of sending multiple bytes to consecutive command locations (such as two-byte commands that require two bytes of data).

The following command sequences are not supported:

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



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

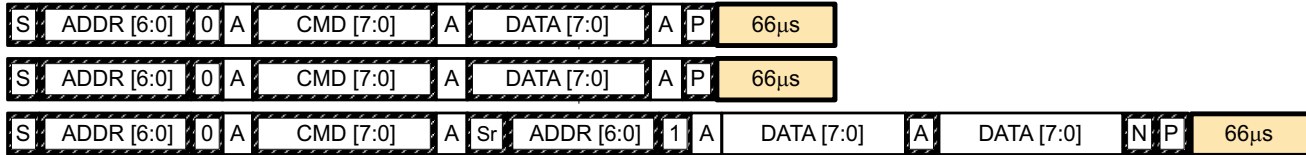


## I<sup>2</sup>C Time Out

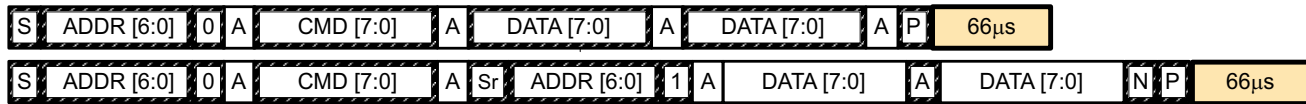
The I<sup>2</sup>C engine releases both SDA and SCL if the I<sup>2</sup>C bus is held low for 2 seconds. If the bq27425-G2 is holding the lines, releasing them frees them for the master to drive the lines. If an external condition is holding either of the lines low, the I<sup>2</sup>C engine enters the low-power sleep mode.

### I<sup>2</sup>C Command Waiting Time

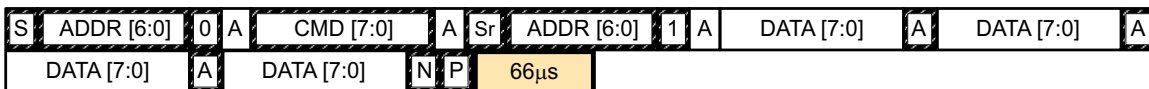
To ensure proper operation at 400 kHz, a  $t_{(BUF)} \geq 66 \mu s$  bus-free waiting time must be inserted between all packets addressed to the bq27425-G2. In addition, if the SCL clock frequency ( $f_{SCL}$ ) is  $> 100 \text{ kHz}$ , use individual 1-byte write commands for proper data flow control. The following diagram shows the standard waiting time required between issuing the control subcommand and the reading the status result. For read-write standard command, a minimum of 2 seconds is required to get the result updated. For read-only standard commands, there is no waiting time required, but the host must not issue any standard command more than two times per second. Otherwise, the gauge could result in a reset issue due to the expiration of the watchdog timer.



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



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



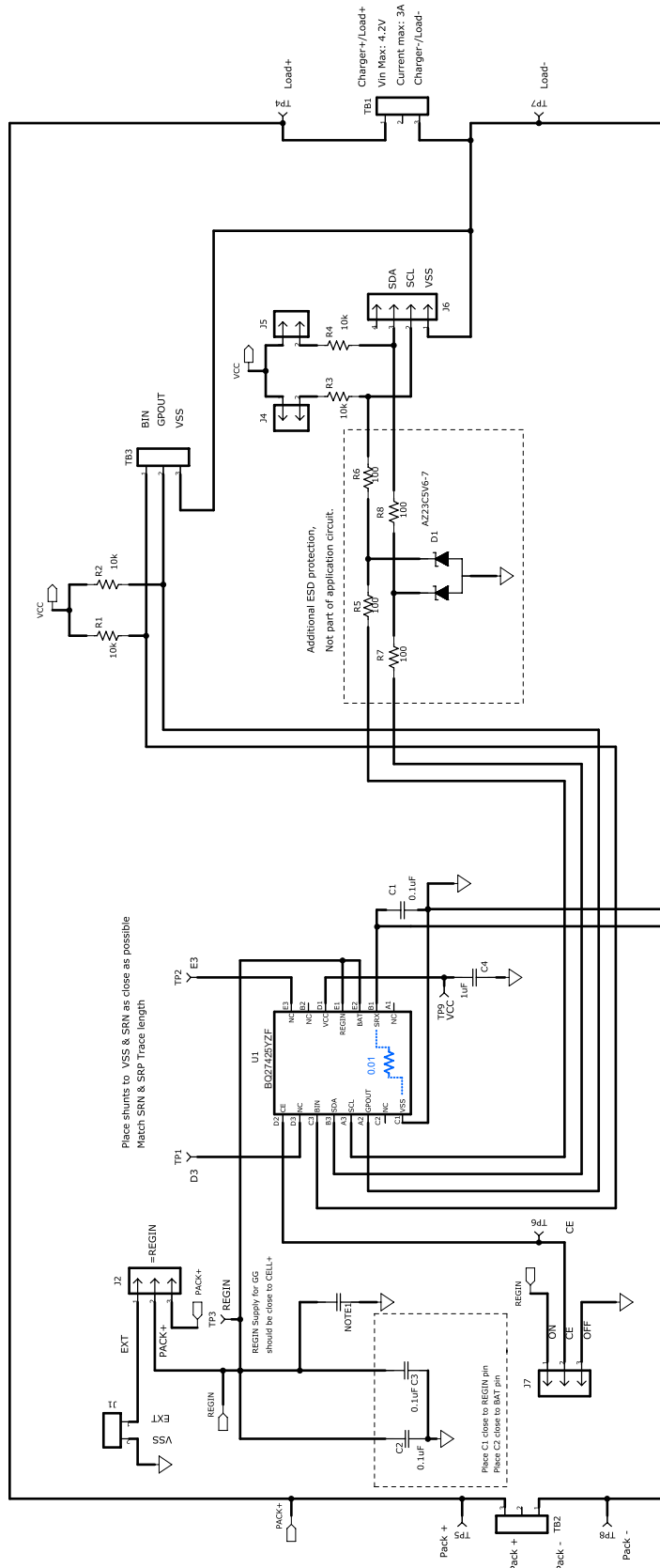
Waiting time inserted after incremental read

### I<sup>2</sup>C Clock Stretching

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

Gauging Mode	Operating Condition / Comment	Approximate Duration
SLEEP HIBERNATE	Clock stretch occurs at the beginning of all traffic as the device wakes up.	$\leq 4 \text{ ms}$
INITIALIZATION NORMAL	Clock stretch occurs within the packet for flow control (after a start bit, ACK or first data bit).	$\leq 4 \text{ ms}$
	Normal Ra table NVM updates.	24 ms
	NVM block writes.	72 ms
	Restored NVM block write after loss of power.	116 ms
	End of discharge Ra table NVM update.	144 ms

REFERENCE (EVM) SCHEMATIC



## REVISION HISTORY

Changes from Original (October 2012) to Revision A	Page
• AVAILABLE OPTIONS table: Replaced "Contact Factory" with orderable quantities for bq27425YZFR-G2A and bq27425YZFT-G2B .....	2
• AVAILABLE OPTIONS table: Added CHEM_ID column .....	2
• RECOMMENDED OPERATING CONDITIONS: Added SHUTDOWN mode specifications .....	4
• Changed the CHEM_ID subcommand section: (CHEM_ID: 0x0008) .....	10
• DATA BLOCK SUMMARY: Updated Default Value column to show -G2B version differences in (Green Text) .....	17
• DATA BLOCK SUMMARY: Changed Units value from Reserve Cap-mAh and Design Capacity from "mA" to "mAh" ....	17
• DATA BLOCK SUMMARY: Updated several Class/Subclass descriptions to correct [RAM] vs [NVM] indication. ....	17
• OPERATING MODES: Added text "In SHUTDOWN mode, ...." .....	23
• Changed <a href="#">Figure 2</a> , POWER MODE DIAGRAM. Added OFF and SHUTDOWN modes to diagram. ....	23

## PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
BQ27425YZFR-G2A	ACTIVE	DSBGA	YZF	15	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27425	<a href="#">Samples</a>
BQ27425YZFR-G2B	ACTIVE	DSBGA	YZF	15	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27425 G2B	<a href="#">Samples</a>
BQ27425YZFT-G2A	ACTIVE	DSBGA	YZF	15	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27425	<a href="#">Samples</a>
BQ27425YZFT-G2B	ACTIVE	DSBGA	YZF	15	250	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM	-40 to 85	BQ27425 G2B	<a href="#">Samples</a>

(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.

**OBSELETE:** 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.

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**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.

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

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

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## TAPE AND REEL INFORMATION



### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
BQ27425YZFR-G2A	DSBGA	YZF	15	3000	180.0	8.4	2.0	2.8	0.7	4.0	8.0	Q1
BQ27425YZFT-G2A	DSBGA	YZF	15	250	180.0	8.4	2.0	2.8	0.7	4.0	8.0	Q1

**TAPE AND REEL BOX DIMENSIONS**

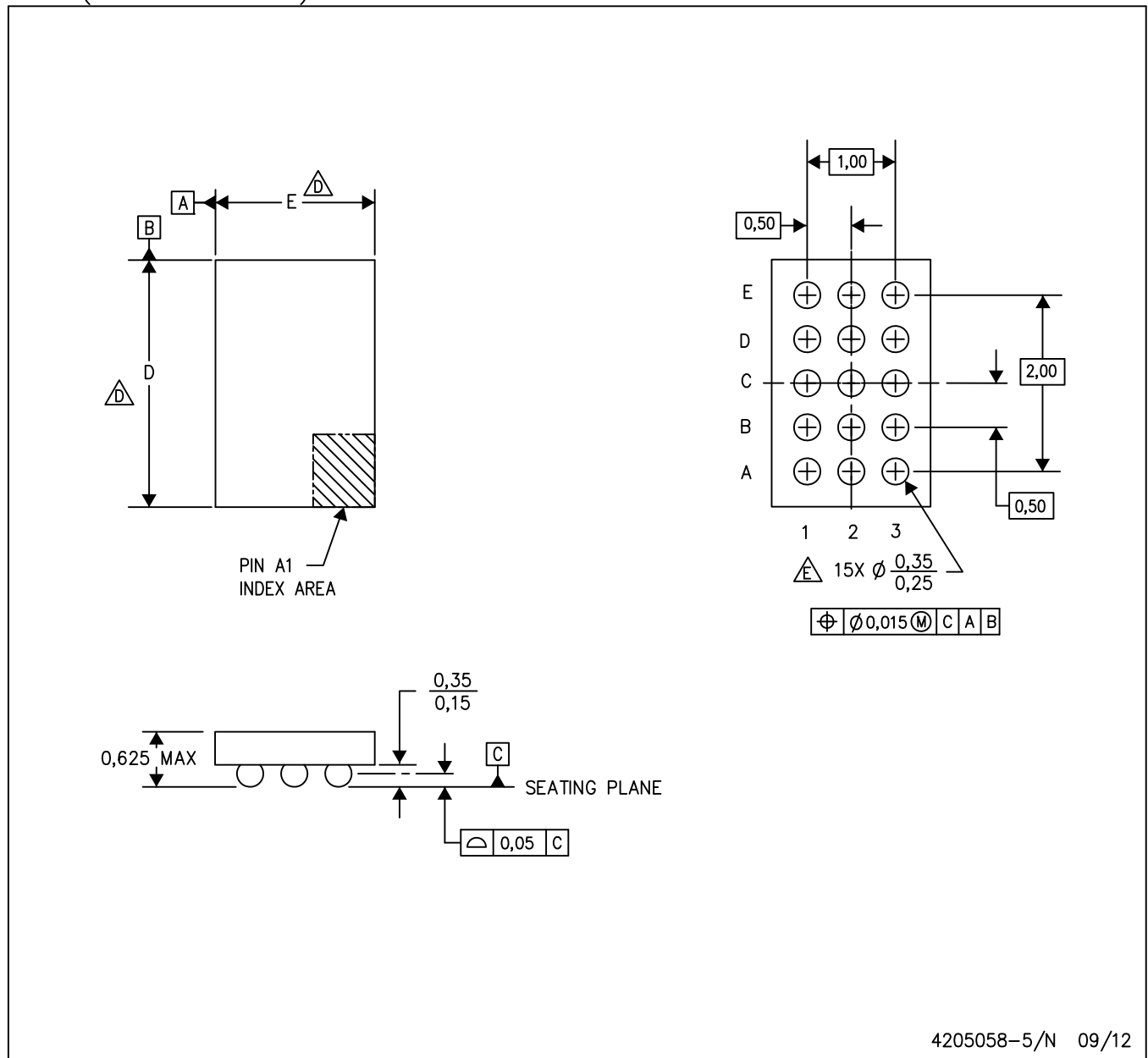

\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ27425YZFR-G2A	DSBGA	YZF	15	3000	210.0	185.0	35.0
BQ27425YZFT-G2A	DSBGA	YZF	15	250	210.0	185.0	35.0



YZF (R-XBGA-N15)

DIE-SIZE BALL GRID ARRAY



- 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.
  - $\triangle D$  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.
  - $\triangle E$  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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Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
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Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
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