# bq24157S 1.55-A Fully Integrated Switch-Mode One-Cell Li-Ion Charger With Full USB Compliance and USB-OTG Support

***Not Recommended for New Designs***

## 1 Features

- Integrated Power FETs for up to 1.55-A Charge Rate
- Spread Spectrum Frequency Control for Improved EMI Performance
- High-Accuracy Voltage and Current Regulation
  - Input Current Regulation Accuracy: ±5% (100 mA and 500 mA)
  - Charge Voltage Regulation Accuracy: ±0.5% (25°C), ±1% (0°C to 125°C)
  - Charge Current Regulation Accuracy: ±5%
- Factory Test-Mode for GSM Calibration Without a Battery
- Input Voltage Based Dynamic Power Management (VIN DPM)
- Bad Adaptor Detection and Rejection
- Safety Limit Register for Maximum Charge Voltage and Current Limiting
- High-Efficiency Mini-USB/AC Battery Charger for Single-Cell Li-Ion and Li-Polymer Battery Packs
- 20-V Absolute Maximum Input Voltage Rating
- 6.5-V Maximum Operating Input Voltage
- Programmable Charge Parameters through $I^2C$ Compatible Interface (up to 3.4 Mbps):
  - Input Current Limit
  - VIN DPM Threshold
  - Fast-Charge/Termination Current
  - Charge Regulation Voltage (3.5 to 4.44 V)
  - Low Charge Current Mode Enable/Disable
  - Termination Enable/Disable
- Synchronous Fixed-Frequency PWM Controller Operating at 3 MHz With 0% to 99.5% Duty Cycle
- Automatic High Impedance Mode for Low Power Consumption
- Robust Protection
  - Reverse Leakage Protection Prevents Battery Drainage
  - Thermal Regulation and Protection
  - Input/Output Overvoltage Protection
- Status Output for Charging and Faults
- USB Friendly Boot-Up Sequence
- Automatic Charging
- Power Up System Without Battery
- Boost Mode Operation for USB OTG:
  - Input Voltage Range (from Battery): 3.2 to 4.5 V
  - Output for $V_{BUS}$: 5.05 V, 350 mA
- 2.1 × 2.0-mm, 20-Pin DSBGA Package
- Pin-to-Pin Compatible With bq24157 and bq24158

## 2 Applications

- Mobile and Smart Phones
- MP3 Players
- Handheld Devices

## 3 Description

The bq24157S is a compact, flexible, high-efficiency, USB-friendly switch-mode charge management device for single-cell Li-ion and Li-polymer batteries used in a wide range of portable applications. The charge parameters can be programmed through an $I^2C$ interface. The IC integrates a synchronous PWM controller, power MOSFETs, input current sensing, high-accuracy current and voltage regulation, and charge termination, into a small DSBGA package.

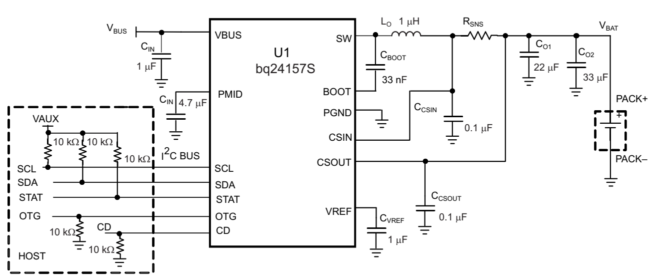
The IC charges the battery in three phases: conditioning, constant current, and constant voltage. The input current is automatically limited to the value set by the host.

**Device Information(1)**

| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| bq24157S | DSBGA (20) | 2.10 mm × 2.00 mm |

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

**Typical Application Circuit**




A. Use $R_{SNS}$ = 68 mΩ to program up to 1.25-A charge current, use $R_{SNS}$ = 55 mΩ to program up to 1.55-A charge current. For detailed instructions, refer to the *Detailed Design Procedure*.

## Table of Contents



# 4 Revision History

**Changes from Revision A (June 2014) to Revision B** **Page**

- Deleted "Safety Timer with Reset Control" from the Features .......... 1
- Changed the package *Features* From: 2.25 x 2.65 mm To: 2.1 x 2.0 mm .......... 1
- Changed the BODY SIZE values in the *Device Information* table .......... 1
- Moved $T_{stg}$ Storage Temperature From: *ESD Ratings* To: *Absolute Maximum Ratings*(1) (2) .......... 4
- Changed the title of Figure 3 From Battery Detection at Power Up To: Power Up in DEFAULT Mode .......... 8
- Changed "32S Mode" To: "HOST Mode" and 15 Minute Mode To: DEFAULT Mode in Figure 5 .......... 8
- Changed 32-second mode To: HOST mode in the *Overview* section .......... 11
- Changed 15-minute operation To: default mode in the *Overview* section .......... 11
- Changed 100-ms power-up delay From: No To: Yes in Table 1 .......... 11
- Changed Figure 19 .......... 14
- Changed text From: "During the normal charging process with HOST control..." To: "During the normal charging process with HOST control and termination enabled.." .......... 17
- Changed Title From: *15-Minute Safety Timer* To: *DEFAULT Mode* .......... 17
- Changed 32-second mode To: HOST mode in *USB Friendly Power Up* .......... 17
- Changed 15-minute mode To: DEFAULT mode and 32-s mode To: HOST mode in *Input Current Limiting at Power Up* .......... 17
- Added a NOTE to the *Application and Implementation* section .......... 29
- Changed Figure 30 .......... 33
- Changed Figure 31 .......... 33
- Added Figure 30 .......... 33

**Changes from Original (February 2013) to Revision A** **Page**

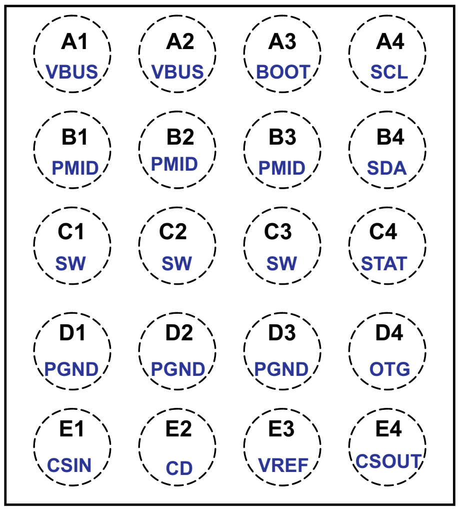
- Added the *Handling Ratings* table, *Detailed Description* section, *Feature Description* section, *Device Functional Modes* section, *Register Maps* section, *Application and Implementation* section. *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, *Mechanical, Packaging*, and *Orderable Information* section .......... 1

## 5 Description (continued)

Charge is terminated based on battery voltage and user-selectable minimum current level. During normal operation, the IC automatically restarts the charge cycle if the battery voltage falls below an internal threshold and automatically enters sleep mode or high impedance mode when the input supply is removed. The charge status can be reported to the host using the $I^2C$ interface. During the charging process, the IC monitors its junction temperature ($T_J$) and reduces the charge current after $T_J$ increases to about 125°C. To support a USB OTG device, bq24157S can provide VBUS (5.05 V) by boosting the battery voltage. The IC is available in 20-pin DSBGA package.

## 6 Pin Configuration and Functions

**20-Bump DSBGA Package**
**(Top View)**




### Pin Functions

| PIN | | I/O | DESCRIPTION |
|---|---|---|---|
| NAME | NUMBER | | |
| BOOT | A3 | I/O | Bootstrap capacitor connection for the high-side FET gate driver. Connect a 33-nF ceramic capacitor (voltage rating ≥10 V) from BOOT pin to SW pin. |
| CD | E2 | I | Charge disable control pin. CD = 0, charge is enabled. CD = 1, charge is disabled and VBUS pin is high impedance to GND. |
| CSIN | E1 | I | Charge current-sense input. Battery current is sensed across an external sense resistor. A 0.1-µF ceramic capacitor to PGND is required. |
| CSOUT | E4 | I | Battery voltage and current sense input. Bypass it with a ceramic capacitor (minimum 0.1 µF) to PGND if there are long inductive leads to battery. |
| OTG | D4 | I | Boost mode enable control or input current limiting selection pin. When OTG is in active status, the device is forced to operate in boost mode. It has higher priority over $I^2C$ control and can be disabled using the control register. At POR while in DEFAULT mode, the OTG pin is the default to be used as the input current limiting selection pin. The $I^2C$ register is ignored at startup. When OTG = High, $I_{IN\_LIMIT}$ = 500 mA and when OTG = Low, $I_{IN\_LIMIT}$ = 100 mA. |
| PGND | D1, D2, D3 | | Power ground |
| PMID | B1, B2, B3 | I/O | Connection point between reverse blocking FET and high-side switching FET. Bypass it with a minimum of 3.3-µF capacitor from PMID to PGND. |
| SCL | A4 | I | $I^2C$ interface clock. Connect a 10-kΩ pullup resistor to 1.8-V rail ($V_{AUX}$= $V_{CC\_HOST}$) |
| SDA | B4 | I/O | $I^2C$ interface data. Connect a 10-kΩ pullup resistor to 1.8-V rail ($V_{AUX}$= $V_{CC\_HOST}$) |
| STAT | C4 | O | Charge status pin. Pull low when charge in progress. Open drain for other conditions. During faults, a 128-µs pulse is sent out. STAT pin can be disabled by the EN_STAT bit in control register. STAT can be used to drive a LED or communicate with a host processor. |
| SW | C1, C2, C3 | O | Internal switch to output inductor connection |
| VBUS | A1, A2 | I/O | Charger input voltage. Bypass it with a 1-µF ceramic capacitor from VBUS to PGND. It also provides power to the load during boost mode. |
| VREF | E3 | O | Internal bias regulator voltage. Connect a 1-µF ceramic capacitor from this output to PGND. TI does not recommend an external load on VREF. |

# 7 Specifications

## 7.1 Absolute Maximum Ratings(1) (2)

over operating free-air temperature (unless otherwise noted)

| | | | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| | Supply voltage (with respect to PGND(3)) | VBUS; $V_{PMID} \geq V_{BUS}$ – 0.3 V | –2 | 20 | V |
| | Input voltage (with respect to PGND(3)) | SCL, SDA, OTG, SLRST, CSIN, CSOUT, CD | –0.3 | 7 | V |
| | Output voltage (with respect to PGND(3)) | PMID, STAT | –0.3 | 20 | V |
| | | VREF | -0.3 | 7 | V |
| | | SW, BOOT | –0.7 | 20 | V |
| | Voltage difference between CSIN and CSOUT inputs ($V_{(CSIN)} – V_{(CSOUT)}$) | | | ±7 | V |
| | Voltage difference between BOOT and SW inputs ($V_{(BOOT)} – V_{(SW)}$) | | –0.3 | 7 | V |
| | Voltage difference between VBUS and PMID inputs ($V_{(VBUS)} – V_{(PMID)}$) | | –7 | 0.7 | V |
| | Voltage difference between PMID and SW inputs ($V_{(PMID)} – V_{(SW)}$) | | –0.7 | 20 | V |
| | Output sink | STAT | 10 | 10 | mA |
| | Output current (average) | SW | | 1.55(2) | A |
| $T_A$ | Operating free-air temperature range | | –30 | 85 | °C |
| $T_{stg}$ | Storage temperature range | | –45 | 150 | °C |
| $T_J$ | Junction temperature | | –40 | 125 | °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. All voltage values are with respect to the network ground terminal unless otherwise noted.
(2) Duty cycle for output current should be less than 50% for 10-year lifetime when output current is above 1.5 A.
(3) All voltages are with respect to PGND if not specified. Currents are positive into, negative out of the specified terminal, if not specified. For thermal limitations and considerations of packages, see *Thermal Information* .

## 7.2 ESD Ratings

| | | | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1) | 0 | 2000 | V |
| | | Charged device model (CDM), per JEDEC specification JESD22-C101, all pins(2) | 0 | 500 | |

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

## 7.3 Recommended Operating Conditions

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{BUS}$ | Supply voltage, bq24157S | 4 | | 6(1) | V |
| $T_J$ | Operating junction temperature range | –40 | | 125 | °C |

(1) The inherent switching noise voltage spikes should not exceed the absolute maximum rating on either the BOOST or SW pins. A *tight* layout minimizes switching noise.

## 7.4 Thermal Information

| THERMAL METRIC(1) | | bq24157S | UNIT |
|---|---|---|---|
| | | YFF (20 PINS) | |
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 85 | °C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 25 | |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 55 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 4 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 50 | |
| $R_{\theta JC(bot)}$ | 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.

## 7.5 Electrical Characteristics

Circuit of Figure 28, VBUS = 5 V, HZ_MODE = 0, OPA_MODE = 0 (CD = 0), $T_J$ = –40°C to 125°C, $T_J$ = 25°C for typical values (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **INPUT CURRENTS** | | | | | | |
| $I_{(VBUS)}$ | VBUS supply current control | VBUS > VBUS(min), PWM switching | | 10 | | mA |
| | | VBUS > VBUS(min), PWM not switching | | | 5 | |
| | | 0°C < $T_J$ < 85°C, CD = 1 or HZ_MODE = 1 | | 15 | 23 | μA |
| $I_{lgk}$ | Leakage current from battery to VBUS pin | 0°C < $T_J$ < 85°C, $V_{(CSOUT)}$ = 4.2 V, high impedance mode, VBUS = 0 V | | | 5 | μA |
| | Battery discharge current in high impedance mode, (CSIN, CSOUT, SW pins) | 0°C < $T_J$ < 85°C, $V_{(CSOUT)}$ = 4.2 V, high impedance mode, V = 0 V, SCL, SDA, OTG = 0 V or 1.8 V | | | 23 | μA |
| **VOLTAGE REGULATION** | | | | | | |
| $V_{(OREG)}$ | Output regulation voltage programable range | Operating in voltage regulation, programmable | 3.5 | | 4.44 | V |
| | Voltage regulation accuracy | $T_A$ = 25°C | –0.5% | | 0.5% | |
| | | $T_A$ = -40°C to 125°C | –1% | | 1% | |
| **CURRENT REGULATION (FAST CHARGE)** | | | | | | |
| $I_{O(CHARGE)}$ | Output charge current programmable range | $V_{(LOWV)} \le V_{(CSOUT)} < V_{(OREG)}$, VBUS > $V_{(SLP)}$, $R_{(SNS)}$ = 68 mΩ, LOW_CHG = 0, Programmable | 550 | | 1250 | mA |
| | Low charge current (default after POR in 15 min mode) | $V_{LOWV} \le V_{CSOUT} < V_{OREG}$, VBUS > $V_{SLP}$, $R_{SNS}$= 68 mΩ, LOW_CHG = 1, OTG = High | | 325 | 350 | mA |
| | | $V_{LOWV} \le V_{CSOUT} < V_{OREG}$, VBUS > $V_{SLP}$, $R_{SNS}$= 68 mΩ, LOW_CHG = 0, OTG = High | | 550 | 569 | |
| | Regulation accuracy of the voltage across $R_{(SNS)}$ (for charge current regulation) $V_{(IREG)} = I_{O(CHARGE)} \times R_{(SNS)}$ | 37.4 mV ≤ $V_{(IREG)}$< 44.2 mV | –3.5% | | 3.5% | |
| | | 44.2 mV ≤ $V_{(IREG)}$ | –3% | | 3% | |
| **WEAK BATTERY DETECTION** | | | | | | |
| $V_{(LOWV)}$ | Weak battery voltage threshold programmable range2 (1) | Adjustable using $I^2C$ control | 3.4 | | 3.7 | V |
| | Weak battery voltage accuracy | | –5% | | 5% | |
| | Hysteresis for $V_{(LOWV)}$ | Battery voltage falling | | 100 | | mV |
| | Deglitch time for weak battery threshold | Rising voltage, 2-mV overdrive, $t_{RISE}$ = 100 ns | | 30 | | ms |
| **CD, OTG, AND SLRST PIN LOGIC LEVEL** | | | | | | |
| $V_{IL}$ | Input low threshold level | | | | 0.4 | V |
| $V_{IH}$ | Input high threshold level | | 1.3 | | | V |
| $I_{(bias)}$ | Input bias current | Voltage on control pin is 5 V | | | 1.0 | μA |
| **CHARGE TERMINATION DETECTION** | | | | | | |
| $I_{(TERM)}$ | Termination charge current programmable range | $V_{(CSOUT)} > V_{(OREG)} – V_{(RCH)}$, VBUS > $V_{(SLP)}$, $R_{(SNS)}$ = 68 mΩ, programmable | 50 | | 400 | mA |
| | Deglitch time for charge termination | Both rising and falling, 2-mV overdrive, $t_{RISE}$, $t_{FALL}$ = 100 ns | | 30 | | ms |
| | Regulation accuracy for termination current across $R_{(SNS)}$ $V_{(IREG\_TERM)} = I_{O(TERM)} \times R_{(SNS)}$ | 3.4 mV ≤ $V_{(IREG\_TERM)}$ ≤ 6.8 mV | –15% | | 15% | |
| | | 6.8 mV < $V_{(IREG\_TERM)}$ ≤ 17 mV | –10% | | 10% | |
| | | 17 mV < $V_{(IREG\_TERM)}$ ≤ 27.2 mV | –5.5% | | 5.5% | |
| **BAD ADAPTOR DETECTION** | | | | | | |
| $V_{IN}$(min) | Input voltage lower limit | Bad adaptor detection | 3.6 | 3.8 | 4.0 | V |
| | Deglitch time for VBUS rising above $V_{IN}$(min) | Rising voltage, 2-mV overdrive, $t_{RISE}$ = 100 ns | | 30 | | ms |
| | Hysteresis for $V_{IN}$(min) | Input voltage rising | 100 | | 200 | mV |
| $I_{SHORT}$ | Current source to GND | During bad adaptor detection | 20 | 30 | 40 | mA |
| $t_{INT}$ | Detection Interval | Input power source detection | | 2 | | s |
| **INPUT BASED DYNAMIC POWER MANAGEMENT** | | | | | | |
| $V_{IN\_DPM}$ | Input Voltage DPM threshold programmable range | | 4.2 | | 4.76 | V |
| | VIN DPM threshold accuracy | | –3% | | 1% | |

(1) While in DEFAULT mode, if a battery that is charged to a voltage higher than this voltage is inserted, the charger enters Hi-Z mode and awaits $I^2C$ commands.

## Electrical Characteristics (continued)

Circuit of Figure 28, VBUS = 5 V, HZ_MODE = 0, OPA_MODE = 0 (CD = 0), $T_J$ = –40°C to 125°C, $T_J$ = 25°C for typical values (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|---|
| **INPUT CURRENT LIMITING** | | | | | | | |
| $I_{IN\_LIMIT}$ | Input current limiting threshold | $I_{IN}$ = 100 mA | $T_J$ = 0°C to 125°C | 88 | 93 | 98 | mA |
| | | | $T_J$ = –40°C to 125°C | 86 | 93 | 98 | |
| | | $I_{IN}$ = 500 mA | $T_J$ = 0°C to 125°C | 450 | 475 | 500 | mA |
| | | | $T_J$ = –40°C to 125°C | 440 | 475 | 500 | |
| **VREF BIAS REGULATOR** | | | | | | | |
| $V_{REF}$ | Internal bias regulator voltage | VBUS > $V_{IN}$(min) or $V_{(CSOUT)}$ > VBUS(min), $I_{(VREF)}$ = 1 mA, $C_{(VREF)}$ = 1 µF | | 2 | | 6.5 | V |
| | $V_{REF}$ output short current limit | | | | 30 | | mA |
| **BATTERY RECHARGE THRESHOLD** | | | | | | | |
| $V_{(RCH)}$ | Recharge threshold voltage | Below $V_{(OREG)}$ | | 100 | 120 | 150 | mV |
| | Deglitch time | $V_{(SCOUT)}$ decreasing below threshold, $t_{FALL}$ = 100 ns, 10-mV overdrive | | | 130 | | ms |
| **STAT OUTPUTS** | | | | | | | |
| $V_{OL(STAT)}$ | Low-level output saturation voltage, STAT pin | $I_O$ = 10 mA, sink current | | | | 0.55 | V |
| | High-level leakage current for STAT | Voltage on STAT pin is 5 V | | | | 1 | µA |
| **I²C BUS LOGIC LEVELS AND TIMING CHARACTERISTICS** | | | | | | | |
| $V_{OL}$ | Output low threshold level | $I_O$ = 10 mA, sink current | | | | 0.4 | V |
| $V_{IL}$ | Input low threshold level | $V_{(pullup)}$ = 1.8 V, SDA and SCL | | | | 0.4 | V |
| $V_{IH}$ | Input high threshold level | $V_{(pullup)}$ = 1.8 V, SDA and SCL | | 1.2 | | | V |
| $I_{(BIAS)}$ | Input bias current | $V_{(pullup)}$ = 1.8 V, SDA and SCL | | | | 1 | µA |
| $f_{(SCL)}$ | SCL clock frequency | | | | | 3.4 | MHz |
| **BATTERY DETECTION** | | | | | | | |
| $I_{(DETECT)}$ | Battery detection current before charge done (sink current) (2) | Begins after termination detected, $V_{(CSOUT)} \le V_{(OREG)}$ | | | –0.5 | | mA |
| $t_{DETECT}$ | Battery detection time | | | | 262 | | ms |
| **SLEEP COMPARATOR** | | | | | | | |
| $V_{(SLP)}$ | Sleep-mode entry threshold, VBUS – $V_{CSOUT}$ | 2.3 V ≤ $V_{(CSOUT)} \le V_{(OREG)}$, $V_{BUS}$ falling | | 0 | 40 | 100 | mV |
| $V_{(SLP\_EXIT)}$ | Sleep-mode exit hysteresis | 2.3 V ≤ $V_{(CSOUT)} \le V_{(OREG)}$ | | 140 | 200 | 260 | mV |
| | Deglitch time for VBUS rising above $V_{(SLP)}$ + $V_{(SLP\_EXIT)}$ | Rising voltage, 2-mV overdrive, $t_{RISE}$ = 100 ns | | | 30 | | ms |
| **UNDERVOLTAGE LOCKOUT (UVLO)** | | | | | | | |
| UVLO | IC active threshold voltage | $V_{BUS}$ rising – exits UVLO | | 3.05 | 3.3 | 3.55 | V |
| $UVLO_{(HYS)}$ | IC active hysteresis | $V_{BUS}$ falling below UVLO – enters UVLO | | 120 | 150 | | mV |
| | Power up delay | | | | 140 | | ms |
| **PWM** | | | | | | | |
| | Voltage from BOOT pin to SW pin | During charge or boost operation | | | | 6.5 | V |
| | Internal top reverse blocking MOSFET on-resistance | $I_{IN(LIMIT)}$ = 500 mA, measured from VBUS to PMID | | | 180 | 250 | mΩ |
| | Internal top N-channel switching MOSFET on-resistance | Measured from PMID to SW, $V_{BOOT} – V_{SW}$ = 4 V | | | 120 | 250 | |
| | Internal bottom N-channel MOSFET on-resistance | Measured from SW to PGND | | | 110 | 210 | |
| $f_{(OSC)}$ | Oscillator frequency | | | | 3.0 | | MHz |
| | Frequency accuracy | | | –10% | | 10% | |
| $D_{(MAX)}$ | Maximum duty cycle | | | | 99.5% | | |
| $D_{(MIN)}$ | Minimum duty cycle | | | 0 | | | |
| | Synchronous mode to non-synchronous mode transition current threshold (2) | Low-side MOSFET cycle-by-cycle current sensing | | | 100 | | mA |

(2) Bottom N-channel FET always turns on for approximately 30 ns, and then turns off if current is too low.

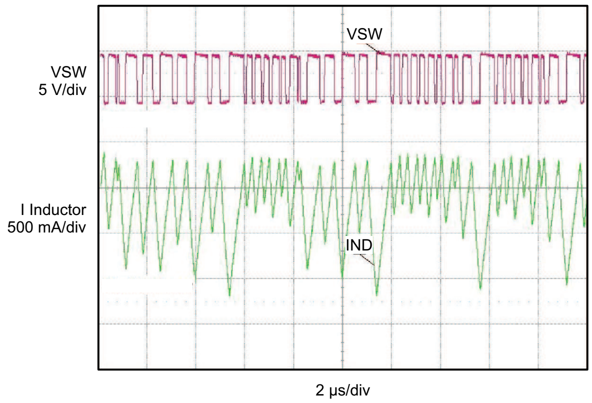
## Electrical Characteristics (continued)

Circuit of Figure 28, VBUS = 5 V, HZ_MODE = 0, OPA_MODE = 0 (CD = 0), $T_J$ = –40°C to 125°C, $T_J$ = 25°C for typical values (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **CHARGE MODE PROTECTION** | | | | | | |
| $V_{OVP\_IN\_USB}$ | Input VBUS OVP threshold voltage | VBUS threshold to turn off converter during charge | 6.3 | 6.5 | 6.7 | V |
| $V_{OVP}$ | Output OVP threshold voltage | $V_{(CSOUT)}$ threshold over $V_{(OREG)}$ to turn off charger during charge | 110 | 117 | 121 | $\%V_{OREG}$ |
| | $V_{(OVP)}$ hysteresis | Lower limit for $V_{(CSOUT)}$ falling from above $V_{(OVP)}$ | | 11 | | |
| $I_{LIMIT}$ | Cycle-by-cycle current limit for charge | Charge mode operation | 1.8 | 2.4 | 3.0 | A |
| $V_{SHORT}$ | Trickle to fast charge threshold | $V_{(CSOUT)}$ rising | 2.0 | 2.1 | 2.2 | V |
| | $V_{SHORT}$ hysteresis | $V_{(CSOUT)}$ falling below $V_{SHORT}$ | | 100 | | mV |
| $I_{SHORT}$ | Trickle charge charging current | $V_{(CSOUT)} \leq V_{SHORT)}$ | 20 | 30 | 40 | mA |
| **BOOST MODE OPERATION FOR $V_{BUS}$ (OPA_MODE = 1, HZ_MODE = 0)** | | | | | | |
| $V_{BUS\_B}$ | Boost output voltage (to VBUS pin) | 2.5 V < $V_{(CSOUT)}$ < 4.5 V | | 5.05 | | V |
| | Boost output voltage accuracy | Including line and load regulation | –3% | | 3% | |
| $I_{BO}$ | Maximum output current for boost | $V_{BUS\_B}$ = 5.05 V, 3.3 V < $V_{(CSOUT)}$ < 4.5 V, $T_J$= 0°C – 125°C | 350 | | | mA |
| $I_{BLIMIT}$ | Cycle by cycle current limit for boost | $V_{BUS\_B}$ = 5.05 V, 2.5 V < $V_{(CSOUT)}$ < 4.5 V | | 1.0 | | A |
| $V_{BUSOVP}$ | Overvoltage protection threshold for boost (VBUS pin) | Threshold over VBUS to turn off converter during boost | 5.8 | 6.0 | 6.2 | V |
| | $V_{BUSOVP}$ hysteresis | $V_{BUS}$ falling from above $V_{BUSOVP}$ | | 162 | | mV |
| $V_{BATMAX}$ | Maximum battery voltage for boost (CSOUT pin) | $V_{(CSOUT)}$ rising edge during boost | 4.75 | 4.9 | 5.05 | V |
| | $V_{BATMAX}$ hysteresis | $V_{(CSOUT)}$ falling from above $V_{BATMAX}$ | | 200 | | mV |
| $V_{BATMIN}$ | Minimum battery voltage for boost (CSOUT pin) | During boosting | | 2.5 | | V |
| | | Before boost starts | | 2.9 | 3.05 | V |
| | Boost output resistance at high-impedance mode (from VBUS to PGND) | CD = 1 or HZ_MODE = 1 | 217 | | | kΩ |
| **PROTECTION** | | | | | | |
| $T_{SHTDWN)}$ | Thermal trip | | | 165 | | °C |
| | Thermal hysteresis | | | 10 | | |
| $T_{CF}$ | Thermal regulation threshold | Charge current begins to reduce | | 120 | | |

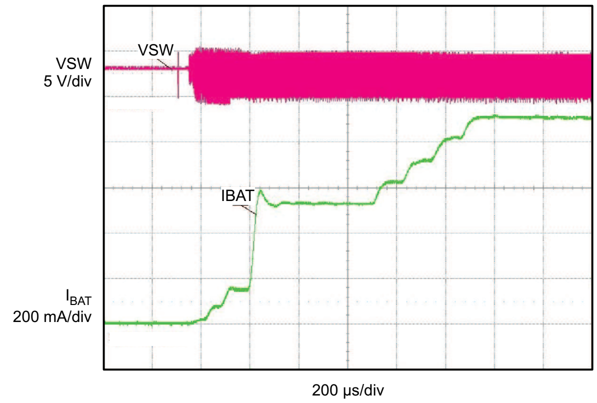
## 7.6 Typical Performance Characteristics

Using circuit shown in Figure 28, $T_A$ = 25°C, unless otherwise specified.



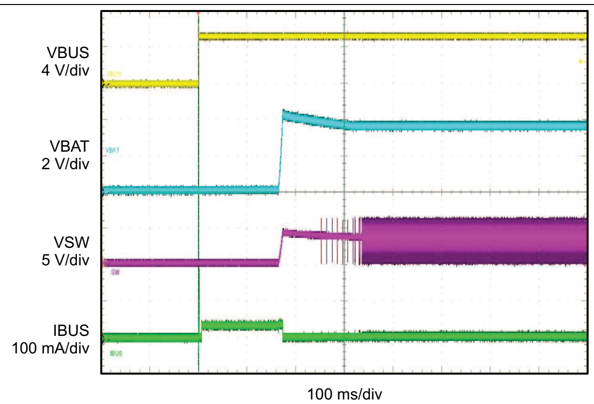

VBUS = 5 V $V_{BAT}$ = 3.5 V

**Figure 1. Cycle by Cycle Current Limiting In Charge Mode Overload Operation**



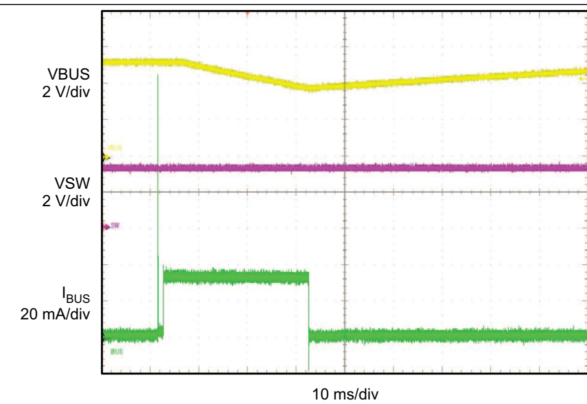

$V_{IN}$ = 5 V $V_{BAT}$ = 3.2 V $I_{CHG}$ = 950 mA

**Figure 2. Charge Current Ramp Up No Input Current Limit**



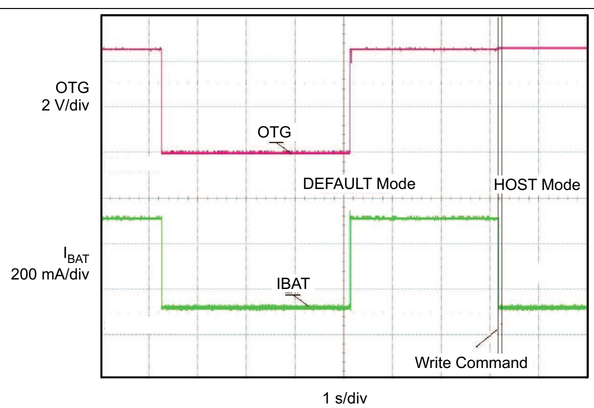

VBUS = 5 V No Battery Connected Termination Disabled

**Figure 3. Power Up in DEFAULT Mode**



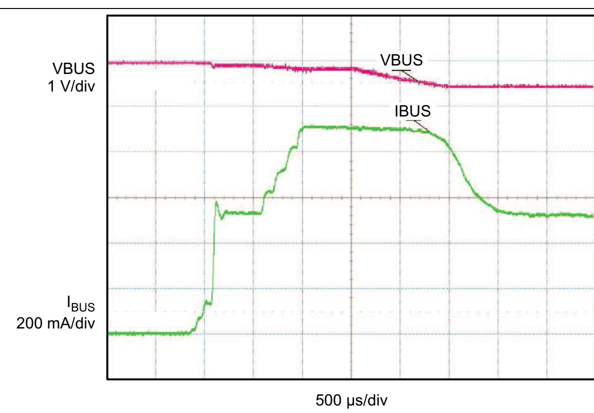

VBUS = 5 V at 8 mA $V_{BAT}$ = 3.2 V $I_{IN\_limit}$ = 100 mA
$I_{CHG}$ = 550 mA

**Figure 4. Poor Source Detection**




OTG Control, DEFAULT Mode: VBUS = 5 V, $V_{BAT}$ = 3.1 V, $I_{IN\_limit}$ = 100 and 500 mA
$I^2C$ Control, HOST Mode: $I_{IN\_limit}$ = 100 mA

**Figure 5. Input Current Control**




VBUS = 5 V at 500 mA $V_{BAT}$ = 3.5 V $I_{CHG}$ = 1550 mA
$V_{IN\_DPM}$ = 4.52 V

**Figure 6. VIN Based DPM**

## Typical Performance Characteristics (continued)

Using circuit shown in Figure 28, $T_A$ = 25°C, unless otherwise specified.

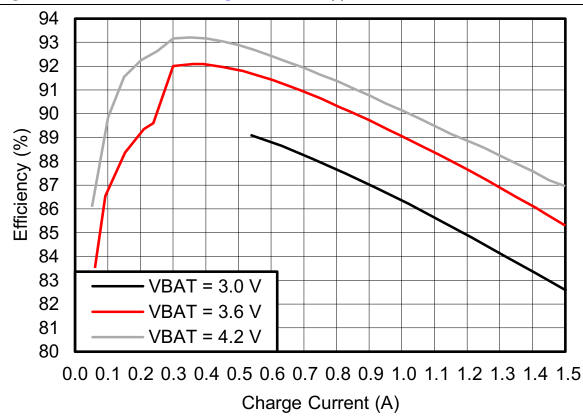
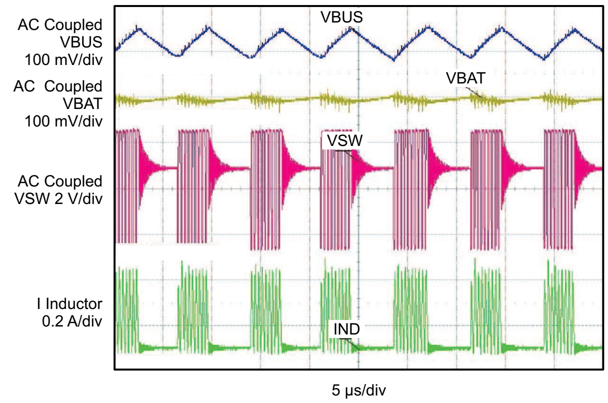
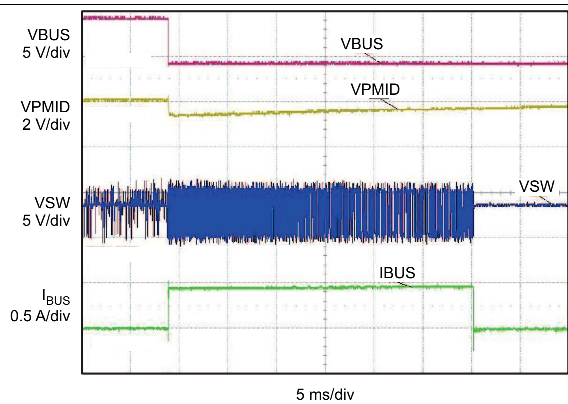



**Figure 7. Charger Efficiency**




VBUS = 5.05 V $V_{BAT}$ = 3.5 V $I_{BUS}$ = 42 mA

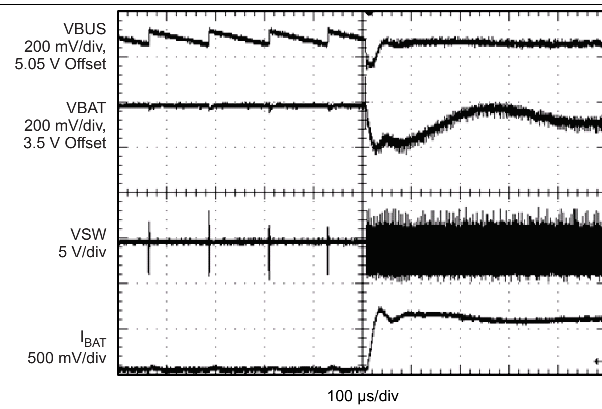
**Figure 8. Boost Waveform (PFM Mode)**




VBUS = 5.05 V $V_{BAT}$ = 3.5 V

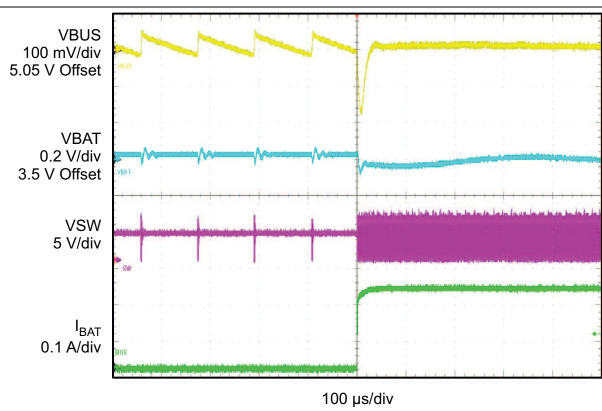
$I_{LOAD}$ (at VBUS) = 5 to 450 mA

**Figure 9. VBUS Overload Waveforms (Boost Mode)**



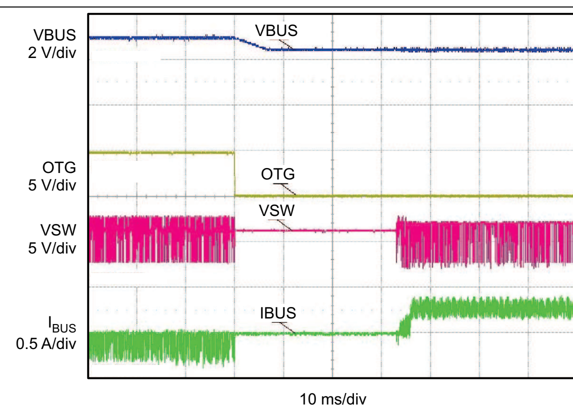

VBUS = 5.05 V $V_{BAT}$ = 3.5 V $I_{BUS}$ = 0 to 360 mA

**Figure 10. Load Step Up Response (Boost Mode)**




VBUS = 5.05 V $V_{BAT}$ = 3.5 V $I_{BUS}$ = 0 to 217 mA

**Figure 11. Load Step Up Response (Boost Mode)**




VBUS = 4.5 V (Charge Mode) VBUS = 5.1 V (Boost Mode)

$V_{BAT}$ = 3.5 V, $I_{IN\_LIM}$ = 500 mA, (HOST Mode)

**Figure 12. Boost to Charge Mode Transition (OTG Control)**

## Typical Performance Characteristics (continued)

Using circuit shown in Figure 28, $T_A$ = 25°C, unless otherwise specified.

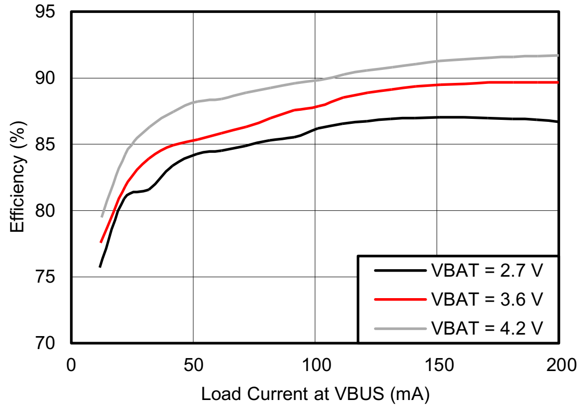



**Figure 13. Boost Efficiency**

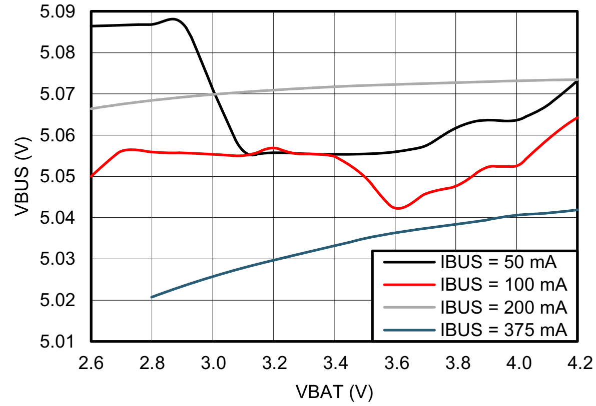



**Figure 14. Line Regulation For Boost**

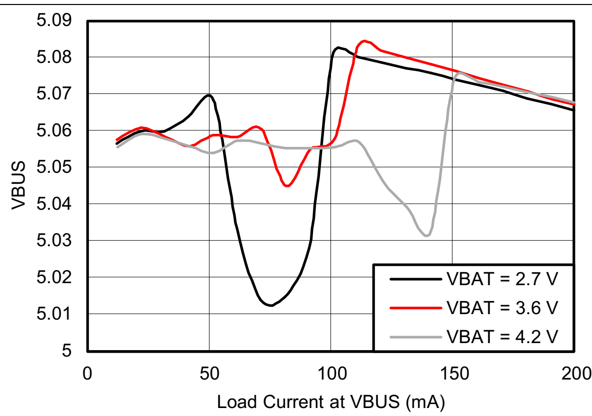



**Figure 15. Load Regulation for Boost**

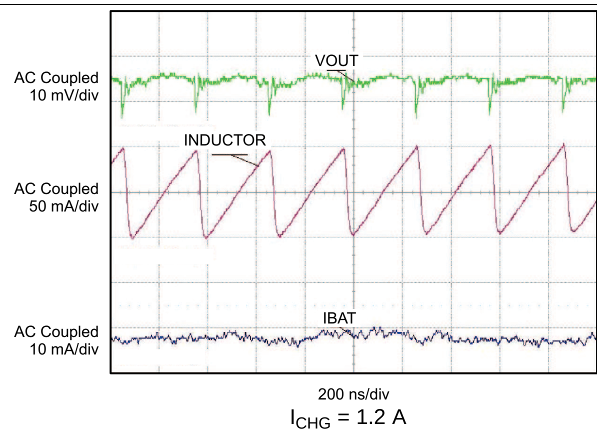



**Figure 16. Output Ripple for Voltage and Current**

# 8 Detailed Description

## 8.1 Overview

For a current-restricted power source, such as a USB host or hub, a high-efficiency converter is critical to fully use the input power capacity for quickly charging the battery. Due to the high efficiency for a wide range of input voltages and battery voltages, the switch mode charger is a good choice for high speed charging with less power loss and better thermal management than a linear charger.

The bq24157S includes highly integrated synchronous switch-mode chargers, featuring integrated FETs and small external components, targeted at extremely space-limited portable applications powered by 1-cell Li-Ion or Li-polymer battery pack. Furthermore, the device has bidirectional operation to achieve boost function for USB-OTG support.

The bq24157S has three operation modes: charge mode, boost mode, and high impedance mode. In charge mode, the IC supports a precision Li-ion or Li-polymer charging system for single-cell applications. In boost mode, the IC boosts the battery voltage to VBUS for powering attached OTG devices. In high impedance mode, the IC stops charging or boosting and operates in a mode with very-low current from VBUS or battery, to effectively reduce the power consumption when the portable device is in standby mode. Through $I^2C$ communication with a host (referred to as HOST mode), the IC achieves smooth transition among the different operation modes. During DEFAULT operation, the charger will still charge the battery but uses each register's default values.

**Table 1. Device Features**

| Features | bq24157S |
|---|---|
| VOVP (V) | 6.5 |
| D4 pin definition | OTG |
| $I_{CHARGE(MAX)}$ at POR in DEFAULT mode with $R_{(SNS)}$ = 68 mΩ and OTG = High | 550 mA |
| $I_{CHARGE(MAX)}$ in HOST mode with $R_{(SNS)}$ = 68 mΩ and safety limit register increased from default (A) | 1.5 |
| Output regulation voltage at POR (V) | 3.54 |
| Boost function | Yes |
| Input current limit in DEFAULT mode | 100 mA (OTG = Low);<br>500 mA (OTG = High) |
| Battery detection at power up | No |
| $I^2C$ address | 6AH |
| PN1 (bit4 of 03H) | 1 |
| PN0 (bit3 of 03H) | 0 |
| Safety timer and WD timer | Disabled |
| 100-ms power-up delay | Yes |
| Spread Spectrum | Yes |
| Factory test mode | Yes |

## 8.2 Functional Block Diagrams

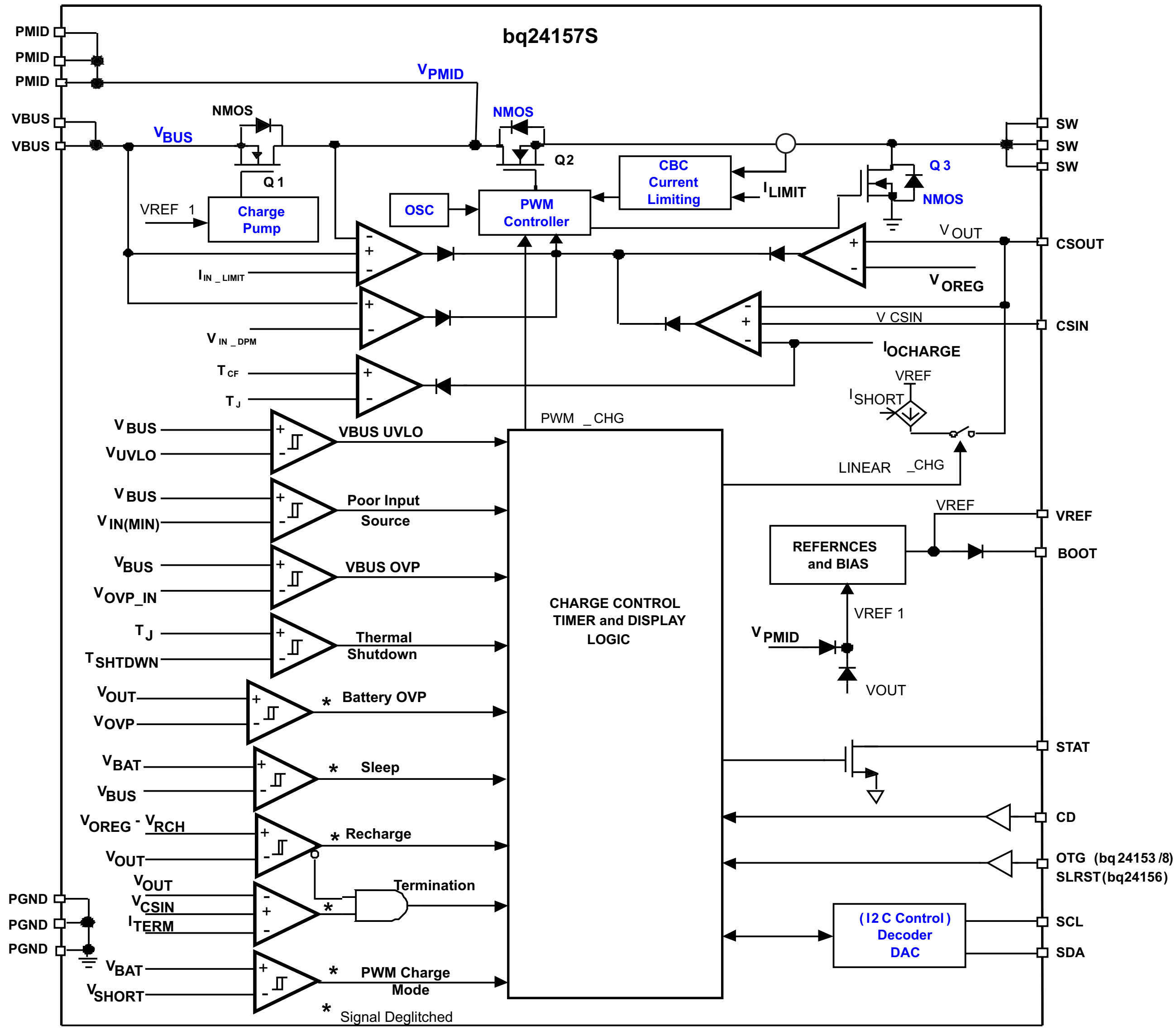



Figure 17. Function Block Diagram of bq24157S in Charge Mode

## Functional Block Diagrams (continued)

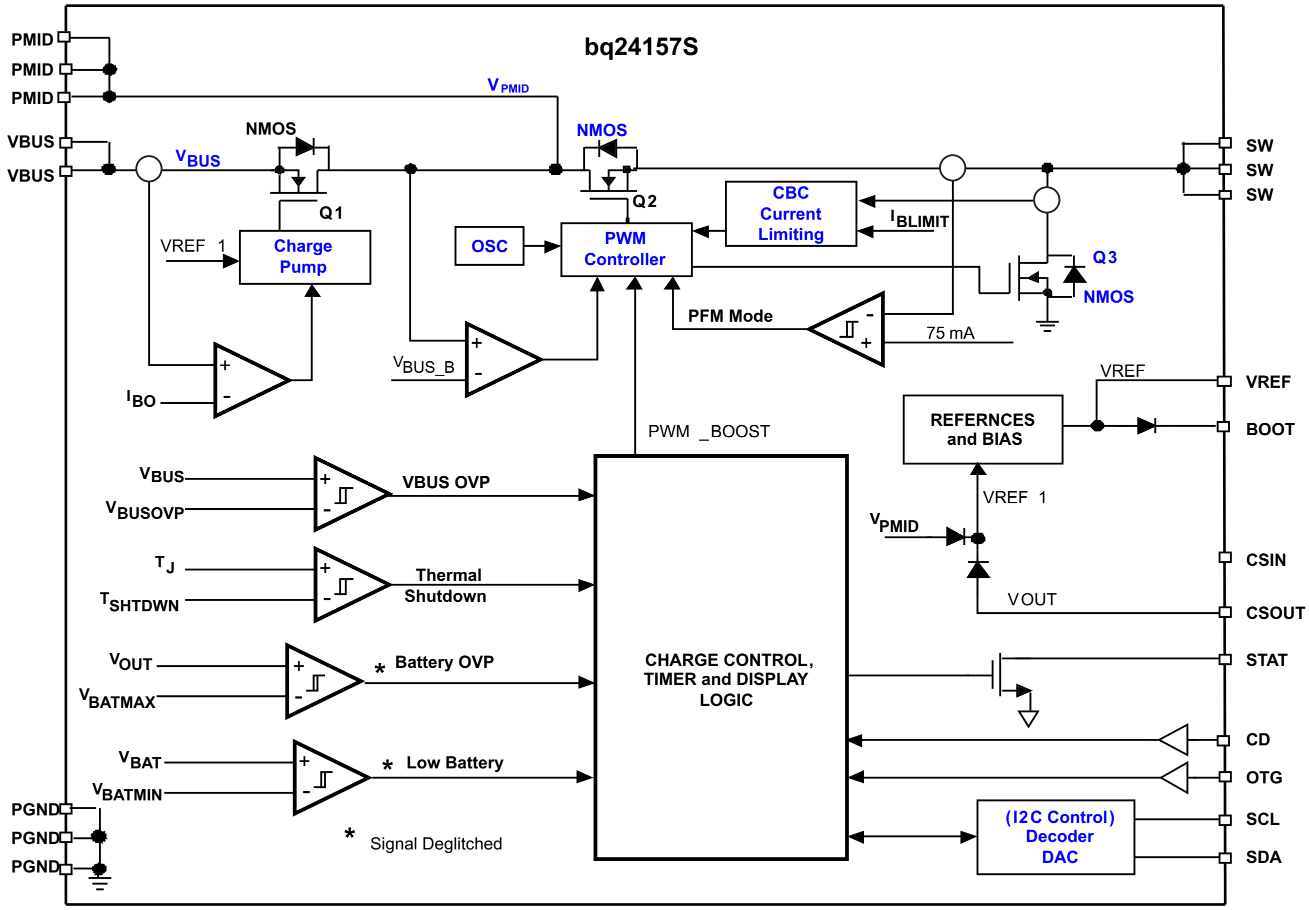



**Figure 18. Function Block Diagram of bq24157S in Boost Mode**

## Functional Block Diagrams (continued)

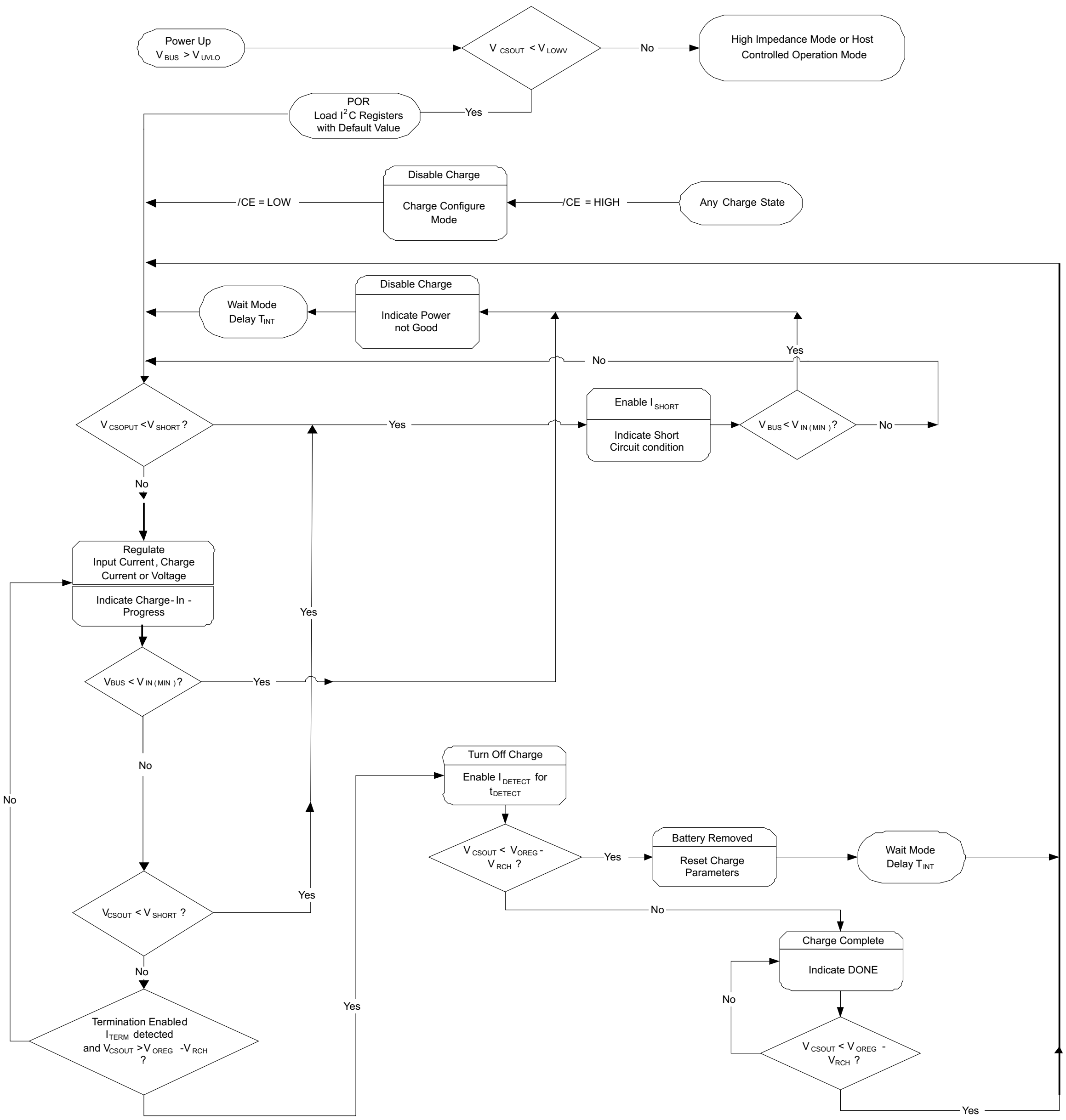



**Figure 19. Operational Flow Chart of bq24157S in Charge Mode**

## 8.3 Feature Description

### 8.3.1 Input Voltage Protection

#### *8.3.1.1 Input Overvoltage Protection*

The IC provides built-in input overvoltage protection to protect the device and other components against damage if the input voltage (voltage from VBUS to PGND) goes too high. When an input overvoltage condition is detected, the IC turns off the PWM converter, sets fault status bits, and sends out a fault pulse from the STAT pin. Once $V_{BUS}$ drops below the input overvoltage exit threshold, the fault is cleared and the charge process resumes.

#### *8.3.1.2 Bad Adaptor Detection/Rejection*

Although not shown in Figure 20, at power-on-reset (POR) of VBUS, the IC performs the bad adaptor detection by applying a current sink to VBUS. If the VBUS is higher than $V_{IN(MIN)}$ for 30 ms, the adaptor is good and the charge process begins. If the VBUS drops below $V_{IN(MIN)}$, a bad adaptor is detected. Then, the IC disables the current sink, sends a send fault pulse in FAULT pin, and sets the bad adaptor flag (B2 – B0 = 011 for register 00H). After a delay of $T_{INT}$, the IC repeats the adaptor detection process, as shown in Figure 20 and Figure 21.

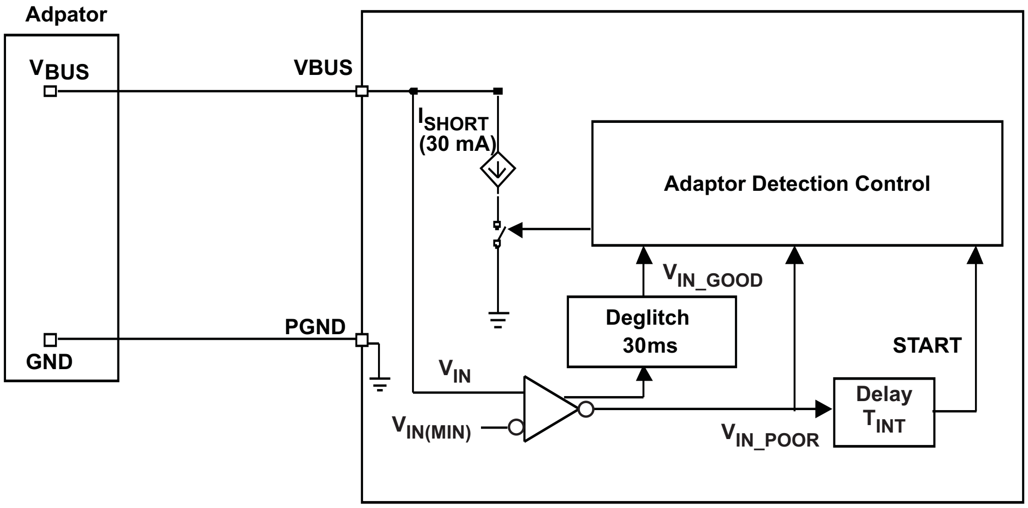



**Figure 20. Bad Adaptor Detection Circuit**

## Feature Description (continued)

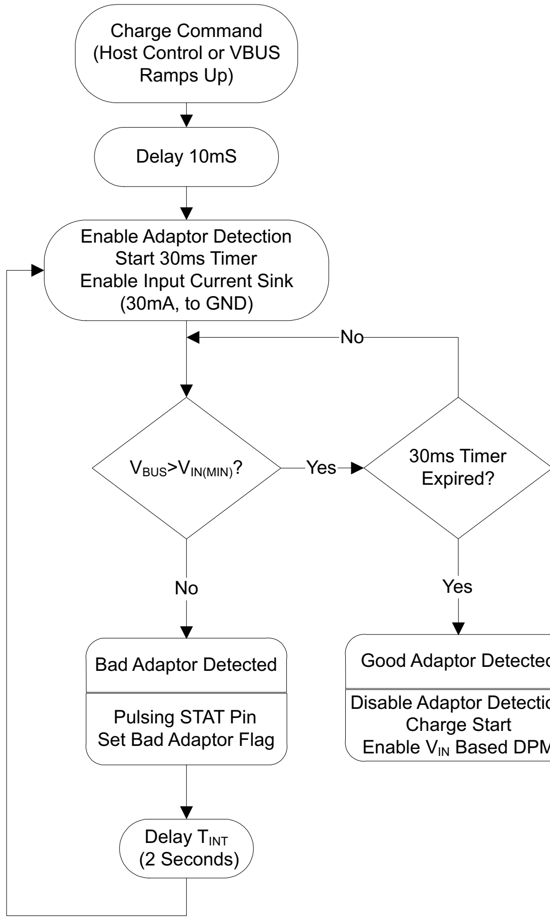



**Figure 21. Bad Adaptor Detection Scheme Flow Chart**

#### *8.3.1.3 Sleep Mode*

The IC enters the low-power sleep mode if the VBUS pin voltage falls below the sleep-mode entry threshold, $V_{CSOUT}$ + $V_{SLP}$, and VBUS is higher than the bad adaptor detection threshold, $V_{IN(MIN)}$. This feature prevents draining the battery during the absence of $V_{BUS}$. During sleep mode, both the reverse blocking switch Q1 and PWM are turned off.

#### *8.3.1.4 Input Voltage Based DPM (Special Charger Voltage Threshold)*

During the charging process, if the input power source is not able to support the programmed or default charging current, the VBUS voltage will decrease. After the VBUS drops to $V_{IN\_DPM}$ (default 4.52 V), the charge current begins to taper down to prevent any further drop of VBUS. When the IC enters this mode, the charge current is lower than the set value and the special charger bit is set (B4 in register 05H). This feature makes the IC compatible with adapters having different current capabilities.

### 8.3.2 Battery Protection

#### *8.3.2.1 Output Overvoltage Protection*

The IC provides a built-in overvoltage protection to protect the device and other components against damage if the battery voltage goes too high, as when the battery is suddenly removed. When an overvoltage condition is detected, the IC turns off the PWM converter, sets fault status bits, and sends out a fault pulse from the STAT pin. When $V_{(CSOUT)}$ drops to the battery overvoltage exit threshold, the fault is cleared and the charge process resumes.

## Feature Description (continued)

#### *8.3.2.2 Battery Short Protection*

During the normal charging process, if the battery voltage is lower than the short-circuit threshold, $V_{SHORT}$, the charger operates in short circuit mode with a lower charge rate of $I_{SHORT}$.

#### *8.3.2.3 Battery Detection in HOST Mode*

For applications with removable battery packs, the IC provides a battery absent detection scheme to reliably detect insertion or removal of battery packs.

During the normal charging process with HOST control and termination enabled, when the voltage at the CSOUT pin is above the battery recharge threshold, $V_{OREG} – V_{RCH}$, and the termination charge current is detected, the IC turns off the PWM charge and enables a discharge current, $I_{DETECT}$, for a period of $t_{DETECT}$, (262-ms typical), then checks the battery voltage. If the battery voltage is still above the recharge threshold after $t_{DETECT}$, the battery is present. On the other hand, if the battery voltage is below the battery recharge threshold, the battery is absent. Under this condition, the charge parameters (such as input current limit) are reset to the default values and charge resumes after a delay of $t_{INT}$. This function ensures that the charge parameters are reset whenever the battery is replaced.

### 8.3.3 DEFAULT Mode

After the battery and input bus voltages are removed from the IC and replaced, the bq24157S enters DEFAULT mode until $I^2C$ communication begins.

### 8.3.4 USB Friendly Power Up

Prior to POR, if the host continues to write the TMR_RST bit to 1, to stay in HOST mode, then at POR, the charger enters normal charge mode (using the desired control bits). If not in HOST mode at POR, the charge will operate with default bit values, until the host updates the control registers.

The default control bits set the charging current and regulation voltage low as a safety feature to avoid violating USB specifications and overcharging any of the Li-Ion chemistries, while the host has lost communication. The input current limiting is described in the following sections.

### 8.3.5 Input Current Limiting at Power Up

The input current sensing circuit and control loop are integrated into the IC. When operating in DEFAULT mode, the OTG pin logic level sets the input current limit to 100 mA for a logic low and 500 mA for a logic high. In HOST mode, the input current limit is set by the programmed control bits in register 01H.

### 8.3.6 Factory Mode

The factory mode can be enabled only when the battery is removed. This can be done through an $I^2C$ register 05 bit 6 (see Table 9). The purpose of the mode is to operate the phone in a GSM phone call with no-battery connected and do a calibration of the system. Setting the factory mode bit enables the following changes:

- 20X ICHG amp is disabled – that is, output current limit is disabled
- Cycle-by-cycle HS current limit threshold is doubled (current typical is 2.4 A, shifts to 4.8 A)
- CCM mode is always enabled (because the current could go from 0 to full GSM pulse)

### 8.3.7 Spread Spectrum Mode

The purpose of the spread spectrum clock modulation is to reduce EMI. In the spread spectrum mode, the switching frequency is not fixed to 3 MHz. It is instead shifted by ±10% from the fixed 3-MHz switching frequency. The shift is happening in eight steps, four steps in the upper range and four steps in the lower range every 170 µs. By modulating the clock frequency, the energy of the switching converter’s EMI is distributed over a wider range of frequencies thereby lowering the magnitude of EMI at 3 MHz ±10% as well as harmonic frequencies.

## Feature Description (continued)

### 8.3.8 PWM Controller in Charge Mode

The IC provides an integrated, fixed 3-MHz frequency voltage-mode controller to regulate charge current or voltage. This type of controller is used to improve line transient response, thereby, simplifying the compensation network used for both continuous and discontinuous current conduction operation. The voltage and current loops are internally compensated using a Type-III compensation scheme that provides enough phase margin for stable operation, allowing the use of small ceramic capacitors with a low ESR. The device operates between 0% to 99.5% duty cycles.

The IC has back-to-back common-drain N-channel FETs at the high side and one N-channel FET at the low side. The input N-FET (Q1) prevents battery discharge when VBUS is lower than $V_{CSOUT}$. The second high-side N-FET (Q2) is the switching control switch. A charge pump circuit is used to provide gate drive for Q1, while a bootstrap circuit with an external bootstrap capacitor is used to supply the gate drive voltage for Q2.

Cycle-by-cycle current limit is sensed through the FETs Q2 and Q3. The threshold for Q2 is set to a nominal 2.4-A peak current. The low-side FET (Q3) also has a current limit that decides if the PWM controller will operate in synchronous or non-synchronous mode. This threshold is set to 100 mA and it turns off the low-side N-channel FET (Q3) before the current reverses, preventing the battery from discharging. Synchronous operation is used when the current of the low-side FET is greater than 100 mA to minimize power losses.

### 8.3.9 Battery Charging Process

At the beginning of precharge, while battery voltage is below the $V_{(SHORT)}$ threshold, the IC applies a short-circuit current, $I_{(SHORT)}$, to the battery. When the battery voltage is above $V_{SHORT}$ and below $V_{OREG}$, the charge current ramps up to fast charge current, $I_{OCHARGE}$, or a charge current that corresponds to the input current of $I_{IN\_LIMIT}$. The slew rate for fast charge current is controlled to minimize the current and voltage overshoot during transient. Both the input current limit, $I_{IN\_LIMIT}$, and fast charge current, $I_{OCHARGE}$, can be set by the host. When the battery voltage reaches the regulation voltage, $V_{OREG}$, the charge current is tapered down, as shown in Figure 27. The voltage regulation feedback occurs by monitoring the battery-pack voltage between the CSOUT and PGND pins. In HOST mode, the regulation voltage is adjustable (3.5 to 4.44 V) and is programmed through $I^2C$ interface. In DEFAULT mode, the regulation voltage is fixed at 3.54 V.

The IC monitors the charging current during the voltage regulation phase. If termination is enabled, during the normal charging process with HOST control, after the voltage at the CSOUT pin is above the battery recharge threshold, $V_{OREG} – V_{RCH}$ for the 32-ms (typical) deglitch period, and the termination charge current $I_{TERM}$ is detected, the IC turns off the PWM charge and enables a discharge current, $I_{DETECT}$, for a period of $t_{DETECT}$ (262-ms typical), then checks the battery voltage. If the battery voltage is still above the recharge threshold after $t_{DETECT}$, the battery charging is complete. The battery detection routine is used to ensure termination did not occur because the battery was removed. After 40 ms (typical) for synchronization purposes of the EOC state and the counter, the status bit and pin are updated to indicate charging has completed. The termination current level is programmable. To disable the charge current termination, the host can set the charge termination bit (TE) of charge control register to 0, refer to *$I^2C$ Update Sequence* for details.

A new charge cycle is initiated when one of the following conditions is detected:

- The battery voltage falls below the $V_{(OREG)} – V_{(RCH)}$ threshold.
- VBUS POR, if battery voltage is below the $V_{(LOWV)}$ threshold.
- $\overline{CE}$ bit toggle or RESET bit is set (host controlled)

### 8.3.10 Thermal Regulation and Protection

To prevent overheating of the chip during the charging process, the IC monitors the junction temperature, $T_J$, of the die and begins to taper down the charge current after $T_J$ reaches the thermal regulation threshold, $T_{CF}$. The charge current is reduced to 0 when the junction temperature increases approximately 10°C above $T_{CF}$. In any state, if $T_J$ exceeds $T_{SHTDWN}$, the IC suspends charging. In thermal shutdown mode, PWM is turned off and all timers are frozen. Charging resumes when $T_J$ falls below $T_{SHTDWN}$ by approximately 10°C.

## Feature Description (continued)

### 8.3.11 Charge Status Output, STAT Pin

The STAT pin is used to indicate operation conditions. STAT is pulled low during charging when EN_STAT bit in control register (00H) is set to 1. Under other conditions, STAT pin behaves as a high impedance (open-drain) output. Under fault conditions, a 128-µs pulse will be sent out to notify the host. The status of STAT pin at different operation conditions is summarized in Table 2. The STAT pin can be used to drive an LED or communicate to the host processor.

**Table 2. STAT Pin Summary**

| Charge State | Stat |
|---|---|
| Charge in progress and EN_STAT = 1 | Low |
| Other normal conditions | Open-drain |
| Charge mode faults: Timer fault, sleep mode, VBUS or battery overvoltage, poor input source, VBUS UVLO, no battery, thermal shutdown | 128-µs pulse, then open-drain |
| Boost mode faults: Timer fault, over load, VBUS or battery overvoltage, low battery voltage, thermal shutdown | 128-µs pulse, then open-drain |

### 8.3.12 Control Bits in Charge Mode

#### *8.3.12.1 $\overline{CE}$ Bit (Charge Mode)*

The $\overline{CE}$ bit in the control register is used to disable or enable the charge process. A low logic level (0) on this bit enables the charge and a high logic level (1) disables the charge.

#### *8.3.12.2 RESET Bit*

The RESET bit in the Battery Termination/Fast Charge Current register is used to reset all the charge parameters. Writing 1 to the RESET bit will reset all the charge parameters to default values except the safety limit register, and RESET bit is automatically cleared to 0 when the charge parameters are reset. It is designed for charge parameter reset before charge starts and TI does not recommended to set the RESET bit while charging or boosting are in progress.

#### *8.3.12.3 OPA_MODE Bit*

OPA_MODE is the operation mode control bit. When OPA_MODE = 0, the IC operates as a charger; if HZ_MODE is set to 0, refer to Table 3 for details. When OPA_MODE = 1 and HZ_MODE = 0, the IC operates in boost mode.

**Table 3. Operation Mode Summary**

| OPA_MODE | HZ_MODE | Operation Mode |
|---|---|---|
| 0 | 0 | Charge (no fault)<br>Charge configure (fault, $V_{bus}$ > UVLO)<br>High impedance ($V_{bus}$ < UVLO) |
| 1 | 0 | Boost (no faults)<br>Any fault go to charge configure mode |
| X | 1 | High impedance |

### 8.3.13 Control Pins in Charge Mode

#### *8.3.13.1 CD Pin (Charge Disable)*

The CD pin is used to disable the charging process. When the CD pin is low, charge is enabled. When the CD pin is high, charge is disabled and the charger enters high impedance (Hi-Z) mode.

### 8.3.14 Boost Mode Operation

In HOST mode, when OTG pin is high (and OTG_EN bit is high thereby enabling OTG functionality) or the operation mode bit (OPA_MODE) is set to 1, the device operates in boost mode and delivers the power to VBUS from the battery. In normal boost mode, the device converts the battery voltage to $V_{BUS-B}$ (about 5.05 V) and delivers a current as much as $I_{BO}$ (about 375 mA for bq24157S) to support other USB OTG devices connected to the USB connector.

#### *8.3.14.1 PWM Controller in Boost Mode*

Similar to charge mode operation, in boost mode, the IC provides an integrated, fixed 3-MHz frequency voltage-mode controller to regulate output voltage at PMID pin ($V_{PMID}$). The voltage control loop is internally compensated using a Type-III compensation scheme that provides enough phase margin for stable operation with a wide load range and battery voltage range.

In boost mode, the input N-FET (Q1) prevents battery discharge when VBUS pin is over loaded. Cycle-by-cycle current limit is sensed through the internal sense FET for Q3. The cycle-by-cycle current limit threshold for Q3 is set to a nominal 1.0-A peak current. Synchronous operation is used in PWM mode to minimize power losses.

#### *8.3.14.2 Boost Start Up*

To prevent the inductor saturation and limit the inrush current, a soft-start control is applied during the boost start up.

#### *8.3.14.3 PFM Mode at Light Load*

In boost mode, under light load conditions, the IC operates in pulse skipping mode (PFM mode) to reduce the power loss and improve the converter efficiency. During boosting, the PWM converter is turned off when the inductor current is less than 75 mA, and the PWM is turned back on only when the voltage at PMID pin drops to about 99.5% of the rated output voltage. A unique pre-set circuit is used to make the smooth transition between PWM and PFM mode.

#### *8.3.14.4 Protection in Boost Mode*

##### 8.3.14.4.1 Output Overvoltage Protection

The IC provides built-in overvoltage protection to protect the device and other components against damage if the VBUS voltage goes too high. When an overvoltage condition is detected, the IC turns off the PWM converter, resets OPA_MODE bit to 0, sets fault status bits, and sends out a fault pulse from the STAT pin. When VBUS drops to the normal level, the boost starts after host sets OPA_MODE to 1 or OTG pin stays in active status.

##### 8.3.14.4.2 Output Overload Protection

The IC provides built-in overload protection to prevent the device and battery from damage when VBUS is overloaded. After the overload condition is detected, Q1 operates in linear mode to limit the output current. If the overload condition lasts for more than 30 ms, the overload fault is detected. When an overload condition is detected, the IC turns off the PWM converter, resets OPA_MODE bit to 0, sets fault status bits, and sends out fault pulse in STAT pin. The boost will not start until the host clears the fault register.

##### 8.3.14.4.3 Battery Overvoltage Protection

During boosting, when the battery voltage is above the battery overvoltage threshold, $V_{BATMAX}$, or below the minimum battery voltage threshold, $V_{BATMIN}$, the IC turns off the PWM converter, resets OPA_MODE bit to 0, sets fault status bits, and sends out fault pulse in STAT pin. After the battery voltage goes above $V_{BATMIN}$, the boost will start after the host sets OPA_MODE to 1 or OTG pin stays in active status.

#### *8.3.14.5 STAT Pin in Boost Mode*

During normal boosting operation, the STAT pin behaves as a high impedance (open-drain) output. Under fault conditions, a 128-µs pulse is sent out to notify the host.

### 8.3.15 High Impedance (Hi-Z) Mode

In Hi-Z mode, the charger stops charging and enters a low quiescent current state to conserve power. Taking the CD pin high causes the charger to enter Hi-Z mode. When in DEFAULT mode and the CD pin is low, the charger automatically enters Hi-Z mode if either:

- VBUS > UVLO and a battery with $V_{BAT} > V_{LOWV}$ is inserted, or
- VBUS falls below UVLO.

When in HOST mode and the CD is low, the charger can be placed into Hi-Z mode if the HZ-MODE control bit is set to 1 and OTG pin is not in active status.

To exit Hi-Z mode, the CD pin must be low, VBUS must be higher than UVLO, and the HOST must write a 0 to the HZ-MODE control bit.

### 8.3.16 Serial Interface Description

$I^2C$ is a 2-wire serial interface developed by Philips Semiconductor (see $I^2C$-Bus Specification, Version 2.1, January 2000). The bus consists of a data line (SDA) and a clock line (SCL) with pullup structures. When the bus is idle, both SDA and SCL lines are pulled high. All the $I^2C$ compatible devices connect to the $I^2C$ bus through open drain I/O pins, SDA and SCL. A master device, usually a microcontroller or a digital signal processor, controls the bus. The master is responsible for generating the SCL signal and device addresses. The master also generates specific conditions that indicate the START and STOP of data transfer. A slave device receives and/or transmits data on the bus under control of the master device.

The IC works as a slave and is compatible with the following data transfer modes, as defined in the $I^2C$-Bus Specification: standard mode (100 kbps), fast mode (400 kbps), and high-speed mode (up to 3.4 Mbps in write mode). The interface adds flexibility to the battery charge solution, enabling most functions to be programmed to new values depending on the instantaneous application requirements. Register contents remain intact as long as supply voltage remains above 2.2 V (typical). $I^2C$ is asynchronous, which means that it runs off of SCL. The device has no noise or glitch filtering on SCL, so SCL input needs to be clean. Therefore, TI recommends that SDA changes while SCL is low.

The data transfer protocol for standard and fast modes is the same; therefore, they are referred to as F/S-mode in this document. The protocol for high-speed mode is different from the F/S-mode, and it is referred to as HS-mode. The bq24157S device supports 7-bit addressing only. The device 7-bit address is defined as 1101010 (6AH).

#### *8.3.16.1 F/S Mode Protocol*

The master initiates data transfer by generating a start condition. The start condition is when a high-to-low transition occurs on the SDA line while SCL is high, as shown in Figure 22. All $I^2C$-compatible devices should recognize a start condition.

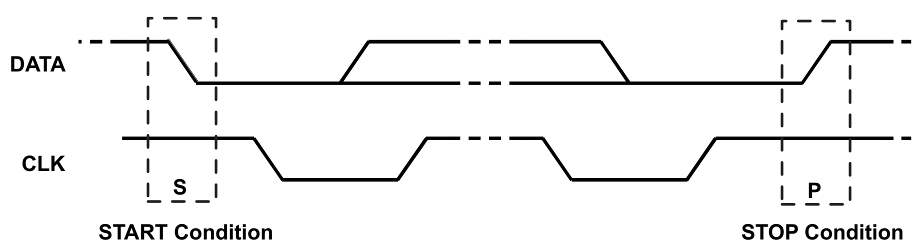



**Figure 22. Start and Stop Condition**

The master then generates the SCL pulses, and transmits the 8-bit address and the Read or Write direction bit R/W on the SDA line. During all transmissions, the master ensures that data is valid. A valid data condition requires the SDA line to be stable during the entire high period of the clock pulse (see Figure 23). All devices recognize the address sent by the master and compare it to their internal fixed addresses. Only the slave device with a matching address generates an acknowledge (see Figure 23) by pulling the SDA line low during the entire high period of the ninth SCL cycle. Upon detecting this acknowledge, the master knows that communication link with a slave has been established.

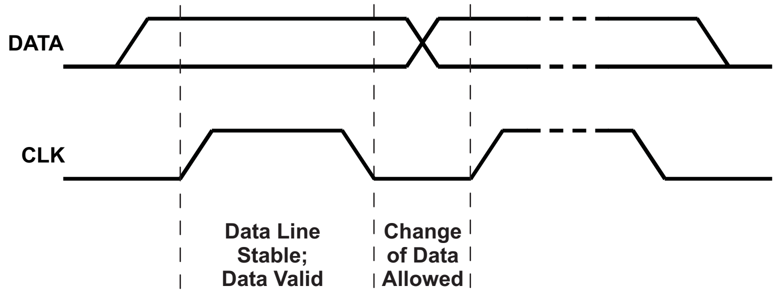



**Figure 23. Bit Transfer on the Serial Interface**

The master generates further SCL cycles to either transmit data to the slave (R/W bit 1) or receive data from the slave (R/W bit 0). In either case, the receiver needs to acknowledge the data sent by the transmitter. So an acknowledge signal can either be generated by the master or by the slave, depending on which one is the receiver. The 9-bit valid data sequences consisting of 8-bit data and 1-bit acknowledge can continue as long as necessary. To signal the end of the data transfer, the master generates a STOP condition by pulling the SDA line from low to high while the SCL line is high (see Figure 25). This releases the bus and stops the communication link with the addressed slave. All $I^2C$ compatible devices must recognize the stop condition. Upon the receipt of a stop condition, all devices know that the bus is released, and they wait for a start condition followed by a matching address. If a transaction is terminated prematurely, the master needs to send a STOP condition to prevent the slave $I^2C$ logic from getting stuck in a bad state. Attempting to read data from register addresses not listed in this section will result in FFh being read out.

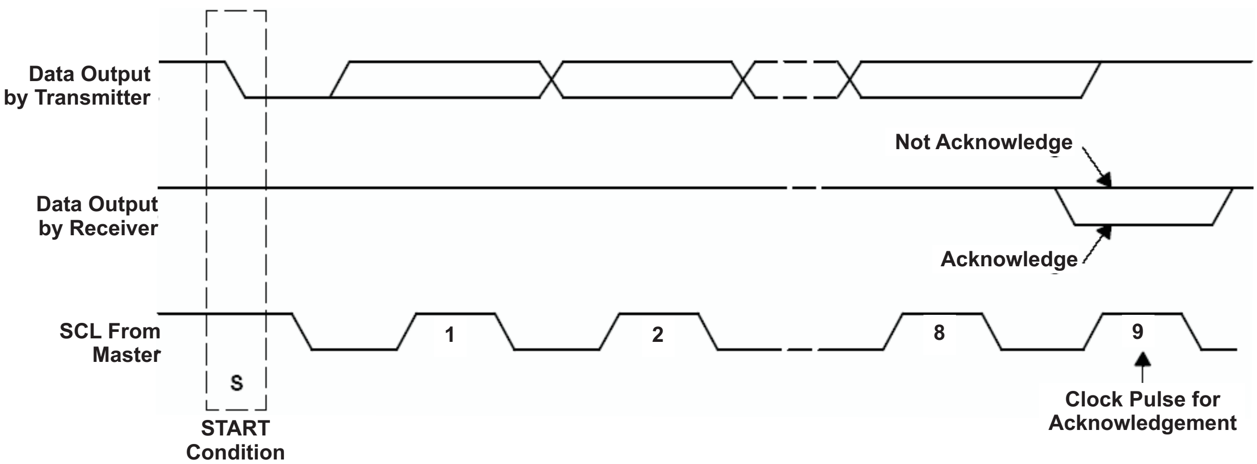



**Figure 24. Acknowledge on the $I^2C$ Bus**

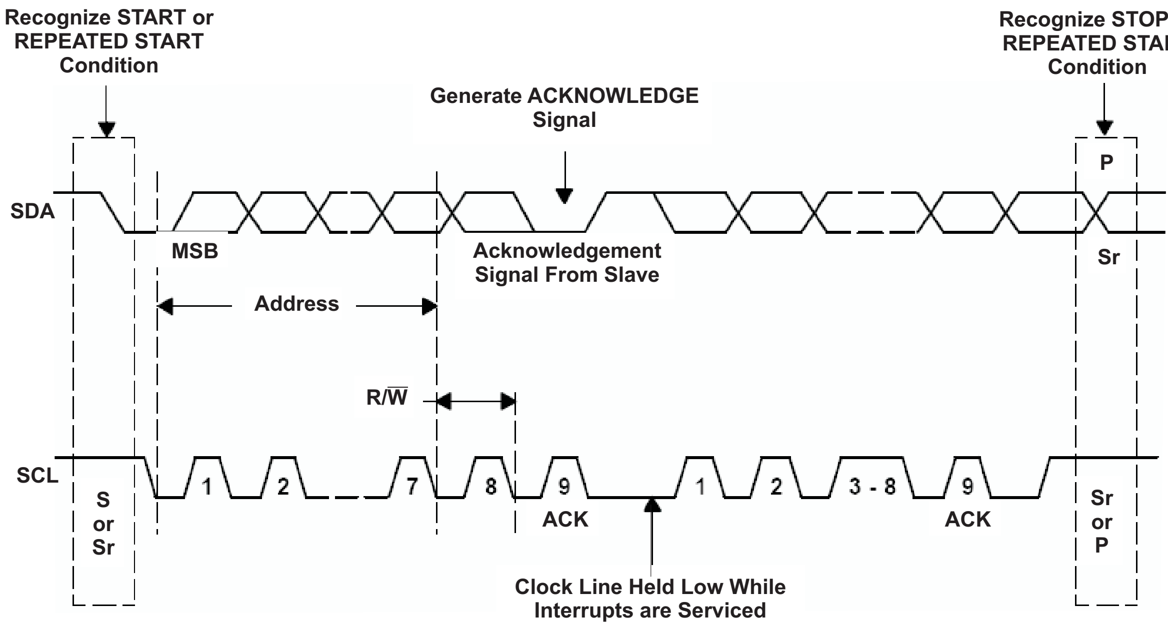



**Figure 25. Bus Protocol**

### *8.3.16.2 HS Mode Protocol*

When the bus is idle, both SDA and SCL lines are pulled high by the pullup devices.

The master generates a START condition followed by a valid serial byte containing HS master code 00001XXX. This transmission is made in F/S-mode at no more than 400 Kbps. No device is allowed to acknowledge the HS master code, but all devices must recognize it and switch their internal setting to support 3.4-Mbps operation.

The master then generates a repeated START condition (a repeated START condition has the same timing as the start condition). After this repeated START condition, the protocol is the same as F/S-mode, except that transmission speeds up to 3.4 Mbps are allowed. A STOP condition ends the HS-mode and switches all the internal settings of the slave devices to support the F/S-mode. Instead of using a STOP condition, repeated START conditions should be used to secure the bus in HS-mode. If a transaction is terminated prematurely, the master needs to send a STOP condition to prevent the slave $I^2C$ logic from getting stuck in a bad state.

Attempting to read data from register addresses not listed in this section results in FFh being read out.

### *8.3.16.3 $I^2C$ Update Sequence*

The IC requires a start condition, a valid $I^2C$ address, a register address byte, and a data byte for a single update. After the receipt of each byte, the IC acknowledges by pulling the SDA line low during the high period of a single clock pulse. A valid $I^2C$ address selects the IC. The IC performs an update on the falling edge of the acknowledge signal that follows the LSB byte.

For the first update, the IC requires a START condition, a valid $I^2C$ address, a register address byte, and a data byte. For all consecutive updates, the IC needs a register address byte and a data byte. When a STOP condition is received, the IC releases the $I^2C$ bus and awaits new start conditions.

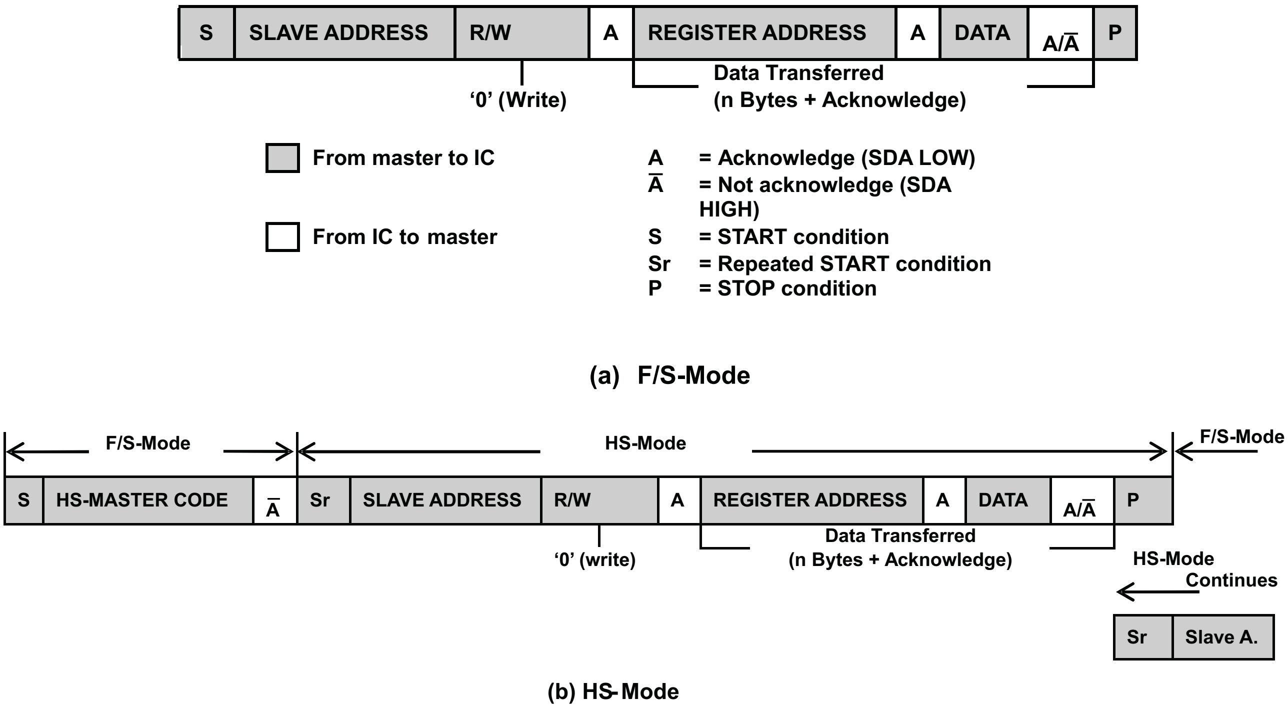



**Figure 26. Data Transfer Format In F/S Mode And HS Mode**

#### *8.3.16.4 Slave Address Byte*

The slave address byte is the first byte received following the START condition from the master device.

| MSB | | | | | | | LSB |
|---|---|---|---|---|---|---|---|
| X | 1 | 1 | 0 | 1 | 0 | 1 | 1 |

#### *8.3.16.5 Register Address Byte*

Following the successful acknowledgment of the slave address, the bus master will send a byte to the IC, which contains the address of the register to be accessed. The IC contains five 8-bit registers accessible through a bidirectional $I^2C$-bus interface. Among them, four internal registers have read and write access; and one has only read access.

| MSB | | | | | | | LSB |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | D2 | D1 | D0 |

## 8.4 Device Functional Modes

### 8.4.1 Charge Mode Operation

#### *8.4.1.1 Charge Profile*

When a good battery with voltage below the recharge threshold has been inserted and a good adapter is attached, the bq24157S enters charge mode. In charge mode, the IC has five control loops to regulate input voltage, input current, charge current, charge voltage, and device junction temperature. During the charging process, all five loops are enabled and the one that is dominant takes control. The IC supports a precision Li-ion or Li-polymer charging system for single-cell applications. Figure 27 (a) indicates a typical charge profile without input current regulation loop. It is the traditional CC/CV charge curve, while Figure 27 (b) shows a typical charge profile when input current limiting loop is dominant during the constant current mode. In this case, the charge current is higher than the input current, so the charge process is faster than the linear chargers. The input voltage threshold for DPM loop, input current limits, charge current, termination current, and charge voltage are all programmable using $I^2C$ interface.

## Device Functional Modes (continued)

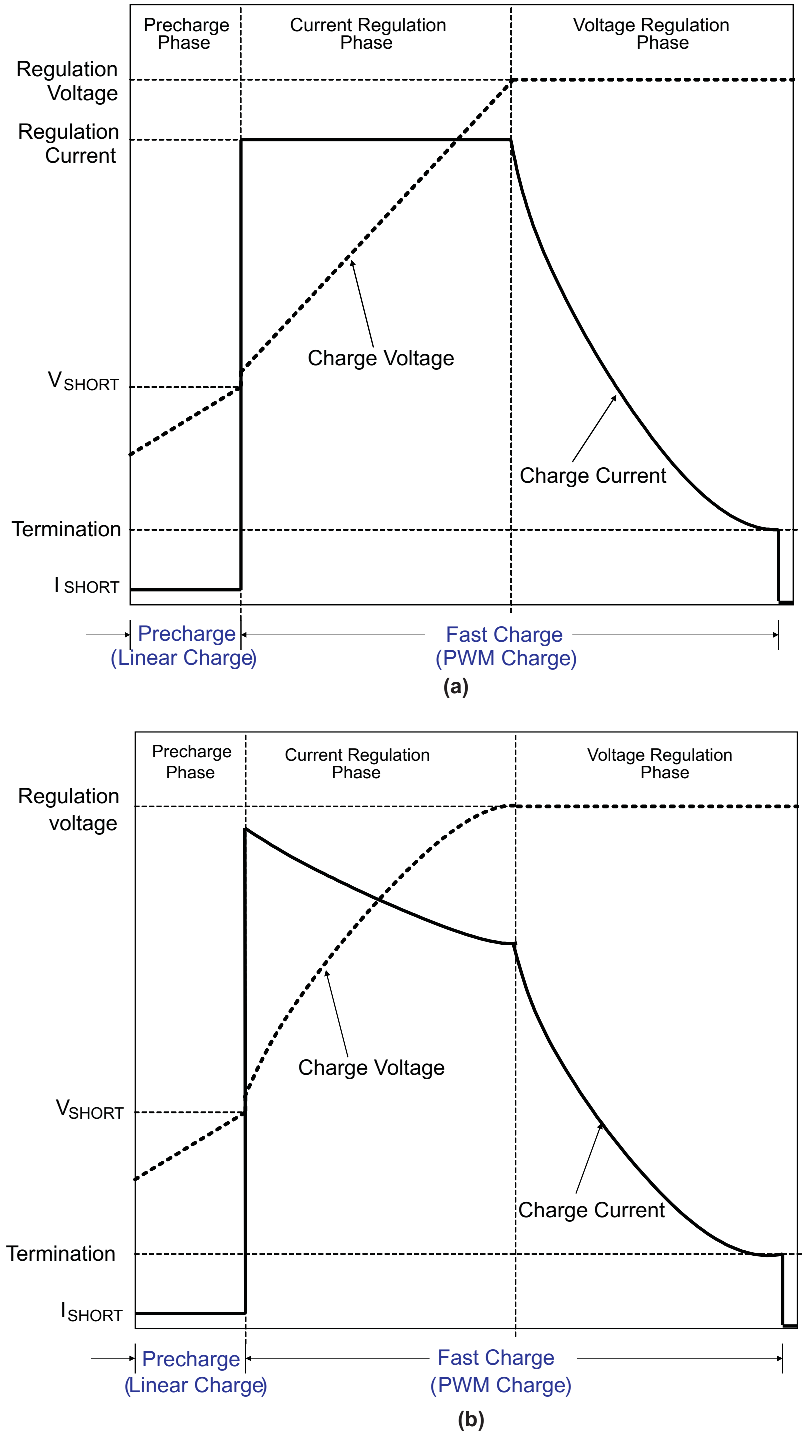



**Figure 27. Typical Charging Profile:**
**(a) Without Input Current Limit**
**(b) With Input Current Limit**

## 8.5 Register Maps

**Table 4. Status/Control Register (Read or Write)**
**Memory Location: 00, Reset State: x1xx 0xxx**

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | TMR_RST/OTG | Read or Write | Write: TMR_RST function, write 1 to reset the safety timer (auto clear)<br>Read: OTG pin status<br>0 – OTG pin at low level<br>1 – OTG pin at high level |
| B6 | EN_STAT | Read or Write | 0 – Disable STAT pin function<br>1 – Enable STAT pin function (default 1) |
| B5 | STAT2 | Read only | 00 – Ready<br>01 – Charge in progress<br>10 – Charge done<br>11 – Fault |
| B4 | STAT1 | Read only | |
| B3 | BOOST | Read only | 1 – Boost mode, 0 – Not in boost mode |
| B2 | FAULT_3 | Read only | **Charge mode:**<br>000 – Normal<br>001 – VBUS OVP<br>010 – Sleep mode<br>011 – Bad Adaptor or $V_{BUS} < V_{UVLO}$<br>100 – Output OVP<br>101 – Thermal shutdown<br>110 – Timer fault<br>111 – No battery<br>**Boost mode:**<br>000 – Normal<br>001 – VBUS OVP<br>010 – Overload<br>011 – Battery voltage is too low<br>100 – Battery OVP<br>101 – Thermal shutdown<br>110 – Timer fault<br>111 – N/A |
| B1 | FAULT_2 | Read only | |
| B0 (LSB) | FAULT_1 | Read only | |

**Table 5. Control Register (Read or Write)**
**Memory Location: 01, Reset State: 0011 0000**

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | Iin_Limit_2 | Read or Write | 00 – USB host with 100-mA current limit<br>01 – USB host with 500-mA current limit<br>10 – USB host/charger with 800-mA current limit<br>11 – No input current limit |
| B6 | Iin_Limit_1 | Read or Write | |
| B5 | $V_{(LOWV\_2)}$ (1) | Read or Write | Weak battery voltage threshold: 200-mV step (default 1) |
| B4 | $V_{(LOWV\_1)}$ (1) | Read or Write | Weak battery voltage threshold: 100-mV step (default 1) |
| B3 | TE | Read or Write | 1 – Enable charge current termination<br>0 – Disable charge current termination (default 0) |
| B2 | $\overline{CE}$ | Read or Write | 1 – Charger is disabled<br>0 – Charger enabled (default 0) |
| B1 | HZ_MODE | Read or Write | 1 – High impedance mode<br>0 – Not high impedance mode (default 0) |
| B0 (LSB) | OPA_MODE | Read or Write | 1 – Boost mode<br>0 – Charger mode (default 0) |

(1) The range of the weak battery voltage threshold ($V_{(LOWV)}$) is 3.4 to 3.7 V with an offset of 3.4 V and steps of 100 mV (default 3.7 V, using bits B4 to B5).

### Table 6. Control/Battery Voltage Register (Read or Write) Memory Location: 02, Reset State: 0000 1010(1)

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | $V_{O(REG5)}$ | Read or Write | Battery Regulation Voltage: 640-mV step (default 0) |
| B6 | $V_{O(REG4)}$ | Read or Write | Battery Regulation Voltage: 320-mV step (default 0) |
| B5 | $V_{O(REG3)}$ | Read or Write | Battery Regulation Voltage: 160-mV step (default 0) |
| B4 | $V_{O(REG2)}$ | Read or Write | Battery Regulation Voltage: 80-mV step (default 0) |
| B3 | $V_{O(REG1)}$ | Read or Write | Battery Regulation Voltage: 40-mV step (default 1) |
| B2 | $V_{O(REG0)}$ | Read or Write | Battery Regulation Voltage: 20-mV step (default 0) |
| B1 | OTG_PL | Read or Write | 1 – OTG boost enable with high level<br>0 – OTG boost enable with low level (default 1); not applicable to OTG pin control of current limit at POR in DEFAULT mode |
| B0 (LSB) | OTG_EN | Read or Write | 1 – Enable OTG Pin in HOST mode<br>0 – Disable OTG pin in HOST mode (default 0), not applicable to OTG pin control of current limit at POR in DEFAULT mode |

(1) Charge voltage range is 3.5 to 4.44 V with the offset of 3.5 V and steps of 20 mV (default 3.54 V), using bits B2 to B7.

### Table 7. Vender/Part/Revision Register (Read only) Memory Location: 03, Reset State: 0101 000x

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | Vender2 | Read only | Vender Code: bit 2 (default 0) |
| B6 | Vender1 | Read only | Vender Code: bit 1 (default 1) |
| B5 | Vender0 | Read only | Vender Code: bit 0 (default 0) |
| B4 | PN1 | Read only | For I2C Address 6AH:<br>01–N/A<br>10–bq24157S<br>11–N/A |
| B3 | PN0 | Read only | |
| B2 | Revision2 | Read only | 011: Revision 1.0;<br>001: Revision 1.1;<br>100 – 111: Future Revisions |
| B1 | Revision1 | Read only | |
| B0 (LSB) | Revision0 | Read only | |

### Table 8. Battery Termination/Fast Charge Current Register (Read or Write) Memory Location: 04, Reset State: 0000 0001(1)

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | Reset | Read or Write | Write:<br>1 – Charger in reset modes<br>0 – No effect, Read: always get 0 |
| B6 | $V_{I(CHRG3)}$ (2) | Read or Write | Charge current sense voltage: 27.2-mV step |
| B5 | $V_{I(CHRG2)}$ (2) | Read or Write | Charge current sense voltage: 13.6-mV step |
| B4 | $V_{I(CHRG1)}$ (2) | Read or Write | Charge current sense voltage: 6.8-mV step |
| B3 | $V_{I(CHRG0)}$ (2) | Read or Write | N/A |
| B2 | $V_{I(TERM2)}$ (3) | Read or Write | Termination current sense voltage: 13.6-mV step (default 0) |
| B1 | $V_{I(TERM1)}$ (3) | Read or Write | Termination current sense voltage: 6.8-mV step (default 0) |
| B0 (LSB) | $V_{I(TERM0)}$ (3) | Read or Write | Termination current sense voltage: 3.4-mV step (default 1) |

(1) Charge current sense voltage offset is 37.4 mV and default charge current is 550 mA, if 68-mΩ sensing resistor is used and LOW_CHG = 0.
(2) See Table 13
(3) See Table 12

**Table 9. Special Charger Voltage/Enable Pin Status Register Memory Location: 05, Reset state: 000X X100[1] [2]**

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | NA | Read or Write | NA |
| B6 | FAC_MODE | Read or Write | 0 – Disables factory test mode<br>1 – Enables the factory test mode |
| B5 | LOW_CHG | Read or Write | 0 – Normal charge current sense voltage at 04H,<br>1 – Low charge current sense voltage of 22.1 mV (default 0) |
| B4 | DPM_STATUS | Read only | 0 – DPM mode is not active,<br>1 – DPM mode is active |
| B3 | CD_STATUS | Read only | 0 – CD pin at LOW level,<br>1 – CD pin at HIGH level |
| B2 | VSREG2 | Read or Write | Special charger voltage: 320mV step (default 1) |
| B1 | VSREG1 | Read or Write | Special charger voltage: 160mV step (default 0) |
| B0 (LSB) | VSREG0 | Read or Write | Special charger voltage: 80mV step (default 0) |

(1) Special charger voltage offset is 4.2 V and default special charger voltage is 4.52 V.
(2) Default charge current will be 550 mA, if 68-mΩ sensing resistor is used, since default LOW_CHG = 0.

**Table 10. Safety Limit Register (Read or Write, Write Only One Time After Reset) Memory Location: 06, Reset State: 01000000**

| BIT | NAME | Read or Write | FUNCTION |
|---|---|---|---|
| B7 (MSB) | $V_{MCHRG3}$ [1] | Read or Write | Maximum charge current sense voltage: 54.4-mV step (default 0) [2] |
| B6 | $V_{MCHRG2}$ [1] | Read or Write | Maximum charge current sense voltage: 27.2-mV step (default 1) |
| B5 | $V_{MCHRG1}$ [1] | Read or Write | Maximum charge current sense voltage: 13.6-mV step (default 0) |
| B4 | $V_{MCHRG0}$ [1] | Read or Write | Maximum charge current sense voltage: 6.8-mV step (default 0) |
| B3 | $V_{MREG3}$ | Read or Write | Maximum battery regulation voltage: 160-mV step (default 0) |
| B2 | $V_{MREG2}$ | Read or Write | Maximum battery regulation voltage: 80-mV step (default 0) |
| B1 | $V_{MREG1}$ | Read or Write | Maximum battery regulation voltage: 40-mV step (default 0) |
| B0 (LSB) | $V_{MREG0}$ | Read or Write | Maximum battery regulation voltage: 20-mV step (default 0) |

(1) Refer to Table 13

- Maximum charge current sense voltage offset is 37.4 mV (550 mA), default at 64.6 mV (950 mA) and the maximum charge current option is 1.55 A (105.4 mV), if 55-mΩ sensing resistor is used.
- Maximum battery regulation voltage offset is 4.2 V (default at 4.2 V) and maximum battery regulation voltage option is 4.44 V.
- Memory location 06H resets only when $V_{(CSOUT)}$ drops below either 1) $V_{(SHORT)}$ threshold (typical 2.05 V) if VBUS>V(UVLO) or 2) the digital reset threshold (typ 2.4V) if VBUS<V(UVLO). After reset, the maximum values for battery regulation voltage and charge current can be programmed until any writing to other register locks the safety limits. Programmed values exclude higher values from memory locations 02 (battery regulation voltage), and from memory location 04 (fast charge current).
- If host accesses (write command) to some other register before safety limit register, the safety default values are used.

# 9 Application and Implementation

**NOTE**

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

## 9.1 Application Information

The bq24157S is a compact, flexible, high-efficiency, USB-friendly, switch-mode charge management solution for single-cell Li-ion and Li-polymer batteries used in a wide range of portable applications. The bq24157S integrates a synchronous PWM controller, power MOSFETs, input current sensing, high-accuracy current and voltage regulation, and charge termination, into a small DSBGA package. The charge parameters can be programmed through an $I^2C$ interface.

## 9.2 Typical Application

$V_{BUS}$ = 5 V, $I_{CHARGE}$ = 1250 mA, VBAT = 3.5 to 4.44 V (adjustable).

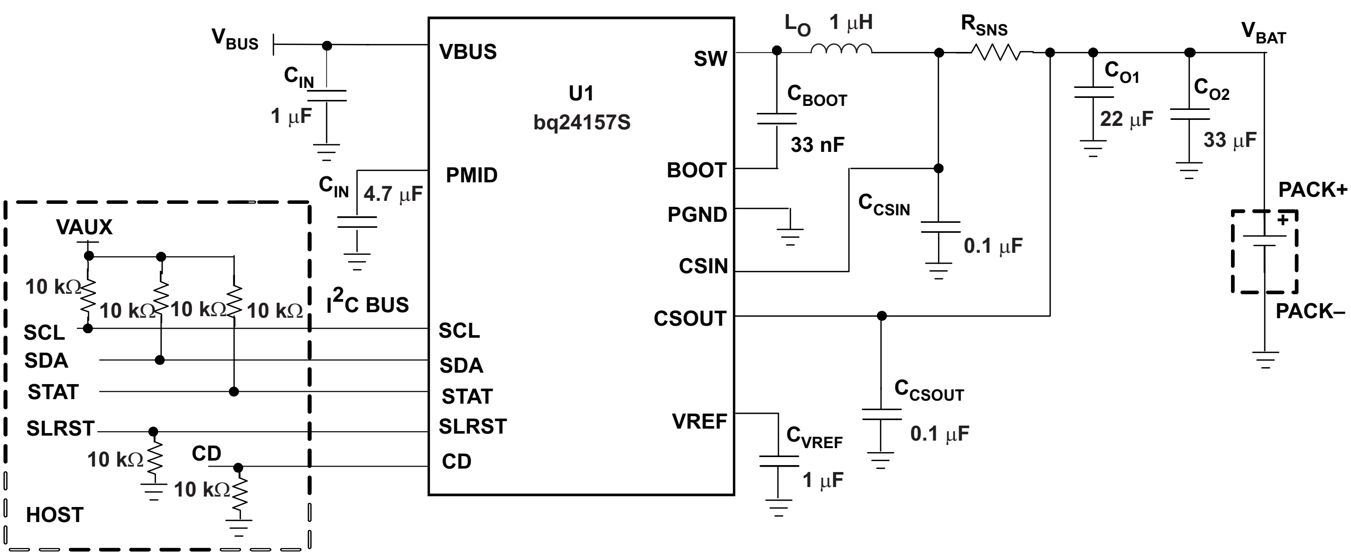



**Figure 28. $I^2C$ Controlled 1-Cell USB Charger Application Circuit With USB-OTG Support**

### 9.2.1 Design Requirements

Use the following typical application design procedure to select external components values for the bq24157S device.

| Specification | Test Condition | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|
| Input DC voltage, VIN | Input voltage from AC adapter input | 4 | 5 | 6 | V |
| Input current | Maximum input current from AC adapter input | 0.1 | 0.1 to 0.5 | 1.5 | A |
| Charge current | Battery charge current | 0.325 | 0.7 | 1.55 | A |
| Output regulation voltage | Voltage applied at VBAT | 0 | 3 to 4.2 | 4.44 | V |
| Operating junction temperature range, $T_J$ | | 0 | | 125 | °C |

### 9.2.2 Detailed Design Procedure

Systems design specifications:

- VBUS = 5 V
- $V_{BAT}$ = 4.2 V (1 cell)
- $I_{(charge)}$ = 1.25 A
- Inductor ripple current = 30% of fast charge current

1. Determine the inductor value ($L_{OUT}$) for the specified charge current ripple:

$$L_{OUT} = \frac{VBAT \times (VBUS - VBAT)}{VBUS \times f \times \Delta I_L}$$

, the worst case is when battery voltage is as close as to half of the input voltage.

$$L_{OUT} = \frac{2.5 \times (5 - 2.5)}{5 \times (3 \times 10^6) \times 1.25 \times 0.3} \quad (1)$$

$L_{OUT}$ = 1.11 μH

Select the output inductor to standard 1 μH. Calculate the total ripple current with using the 1-μH inductor:

$$\Delta I_L = \frac{VBAT \times (VBUS - VBAT)}{VBUS \times f \times L_{OUT}} \quad (2)$$

$$\Delta I_L = \frac{2.5 \times (5 - 2.5)}{5 \times (3 \times 10^6) \times (1 \times 10^{-6})} \quad (3)$$

$\Delta I_L$ = 0.42 A

Calculate the maximum output current:

$$I_{LPK} = I_{OUT} + \frac{\Delta I_L}{2} \quad (4)$$

$$I_{LPK} = 1.25 + \frac{0.42}{2} \quad (5)$$

$I_{LPK}$ = 1.46 A

Select 2.5-mm by 2-mm, 1-μH, 1.5-A surface mount multi-layer inductor. The suggested inductor part numbers are shown in Table 11.

**Table 11. Inductor Part Numbers**

| Part Number | Inductance | Size | Manufacturer |
|---|---|---|---|
| LQM2HPN1R0MJ0 | 1 μH | 2.5 × 2.0 mm | Murata |
| MIPS2520D1R0 | 1 μH | 2.5 × 2.0 mm | FDK |
| MDT2520-CN1R0M | 1 μH | 2.5 × 2.0 mm | TOKO |
| CP1008 | 1 μH | 2.5 × 2.0 mm | Inter-Technical |

2. Determine the output capacitor value ($C_{OUT}$) using 40 kHz as the resonant frequency:

$$f_o = \frac{1}{2\pi \times \sqrt{L_{OUT} \times C_{OUT}}} \quad (6)$$

$$C_{OUT} = \frac{1}{4\pi^2 \times f_0^2 \times L_{OUT}} \quad (7)$$

$$C_{OUT} = \frac{1}{4\pi^2 \times (40 \times 10^3)^2 \times (1 \times 10^{-6})} \quad (8)$$

$C_{OUT}$ = 15.8 µF

Select two 0603 X5R 6.3-V 10-µF ceramic capacitors in parallel, that is, Murata GRM188R60J106M.

3. Determine the sense resistor using Equation 9:

$$R_{(SNS)} = \frac{V_{(RSNS)}}{I_{(CHARGE)}} \quad (9)$$

The maximum sense voltage across the sense resistor is 85 mV. To get a better current regulation accuracy, $V_{(RSNS)}$ should equal 85 mV, and calculate the value for the sense resistor.

$$R_{(SNS)} = \frac{85mV}{1.25A} \quad (10)$$

$R_{(SNS)}$ = 68 mΩ

This is a standard value. If it is not a standard value, then choose the next close value and calculate the real charge current. Calculate the power dissipation on the sense resistor:

$P_{(RSNS)} = I_{(CHARGE)}{}^{2} \times R_{(SNS)}$

$P_{(RSNS)} = 1.25^{2} \times 0.068$

$P_{(RSNS)}$ = 0.106 W

Select 0402 0.125-W 68-mΩ 2% sense resistor, that is, Panasonic ERJ2BWGR068.

For 1.5A application, $R_{(SNS)}$= 85mV/1.55A = 55 mΩ

4. Measured efficiency and total power loss with different inductors are shown in Figure 29. SW node and inductor current waveform are shown in Figure 37.

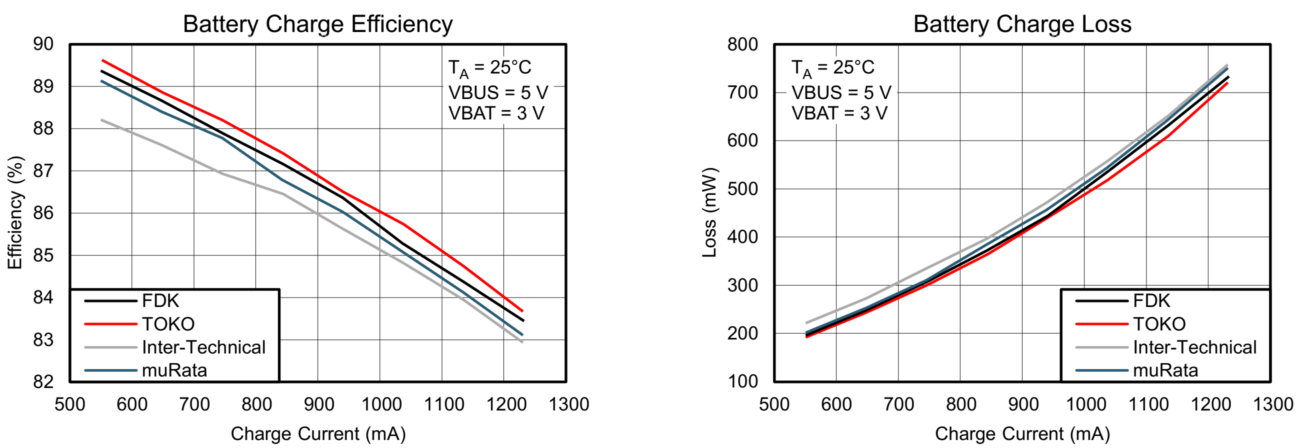



**Figure 29. Measured Efficiency and Power Loss**

#### 9.2.2.1 Charge Current Sensing Resistor Selection Guidelines

Both the termination current range and charge current range depend on the sensing resistor ($R_{SNS}$). The termination current step ($I_{OTERM\_STEP}$) can be calculated using Equation 11.

$$I_{O(TERM\_STEP)} = \frac{V_{I(TERM0)}}{R_{(SNS)}} \quad (11)$$

Table 12 shows the termination current settings for three sensing resistors.

**Table 12. Termination Current Settings for 55-mΩ, 68-mΩ, and 100-mΩ Sense Resistors**

| BIT | $V_{I(TERM)}$ (mV) | $I_{(TERM)}$ (mA) $R_{(SNS)}$ = 55 mΩ | $I_{(TERM)}$ (mA) $R_{(SNS)}$ = 68 mΩ | $I_{(TERM)}$ (mA) $R_{(SNS)}$ = 100 mΩ |
|---|---|---|---|---|
| $V_{I(TERM2)}$ | 13.6 | 247 | 200 | 136 |
| $V_{I(TERM1)}$ | 6.8 | 124 | 100 | 68 |
| $V_{I(TERM0)}$ | 3.4 | 62 | 50 | 34 |
| Offset | 3.4 | 62 | 50 | 34 |

For example, with a 68-mΩ sense resistor, $V_{(ITERM2)}$ = 1, $V_{(ITERM1)}$ = 0, and $V_{(ITERM0)}$ = 1, $I_{TERM}$ = [(13.6 mV × 1) + (6.8 mV × 0) + (3.4 mV × 1) + 3.4 mV] / 68 mΩ = 200 mA + 0 + 50 mA + 50 mA = 300 mA.

The charge current step ($I_{O(CHARGE\_STEP)}$) is calculated using Equation 12.

$$I_{O(CHARGE\_STEP)} = \frac{V_{I(CHRG0)}}{R_{(SNS)}} \quad (12)$$

Table 13 shows the charge current settings for three sensing resistors.

**Table 13. Charge Current Settings for 55-mΩ, 68-mΩ, and 100-mΩ Sense Resistors**

| BIT | $V_{I(REG)}$ (mV) | $I_{O(CHARGE)}$ (mA) $R_{(SNS)}$ = 55 mΩ | $I_{O(CHARGE)}$ (mA) $R_{(SNS)}$ = 68 mΩ | $I_{O(CHARGE)}$ (mA) $R_{(SNS)}$ = 100 mΩ |
|---|---|---|---|---|
| $V_{I(CHRG3)}$ | 54.4 | 989 | 800 | 544 |
| $V_{I(CHRG2)}$ | 27.2 | 495 | 400 | 272 |
| $V_{I(CHRG1)}$ | 13.6 | 247 | 200 | 136 |
| $V_{I(CHRG0)}$ | 6.8 | 124 | 100 | 68 |
| Offset | 37.4 | 680 | 550 | 374 |

For example, with a 68-mΩ sense resistor, $V_{(CHRG3)}$ = 1, $V_{(CHRG2)}$ = 0, $V_{(ICHRG1)}$ = 0, and $V_{(ICHRG0)}$ = 1, $I_{TERM}$ = [(54.4 mV × 1) + (27.2 mV × 0) + (13.6 mV × 0) + (6.8 mV × 1) + 37.4 mV] / 68 mΩ = 800 mA + 0 + 0 + 100 mA = 900 mA.

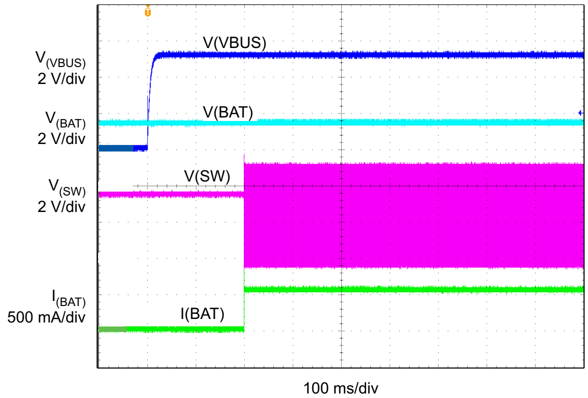
#### 9.2.2.2 Output Inductor and Capacitance Selection Guidelines

The IC provides internal loop compensation. With the internal loop compensation, the highest stability occurs when the LC resonant frequency, $f_o$, is approximately 40 kHz (20 to 80 kHz). Equation 13 can be used to calculate the value of the output inductor, $L_{OUT}$, and output capacitor, $C_{OUT}$.

$$f_o = \frac{1}{2\pi \times \sqrt{L_{OUT} \times C_{OUT}}} \quad (13)$$

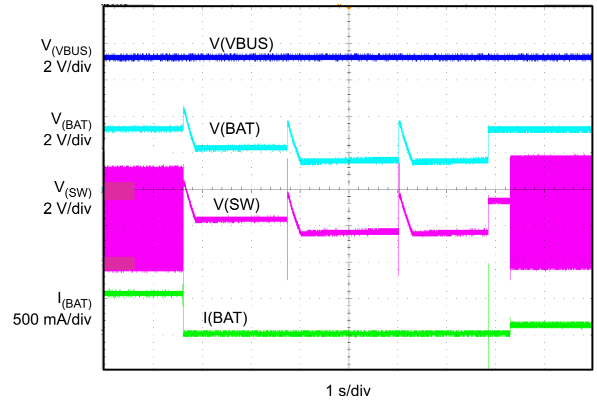
To reduce the output voltage ripple, TI recommends a ceramic capacitor with the capacitance between 4.7 to 47 μF for $C_{OUT}$. See previous sections in the *Detailed Design Procedure* for components selection.

### 9.2.3 Application Curves



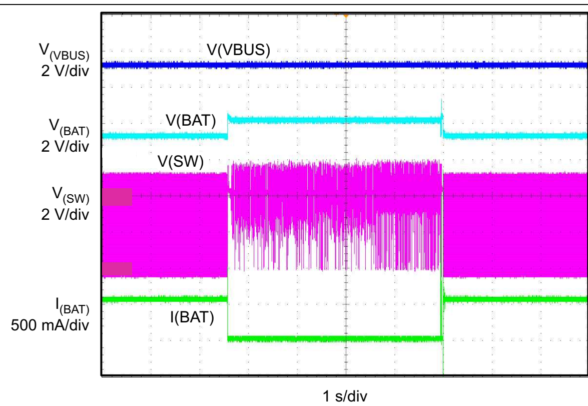

VBUS = 0 to 5 V $I_{IN\_limit}$ = 500 mA $V_{BATREG}$ = 4.2 V
VBAT = 3.5 V $I_{CHG}$ = 550 mA

**Figure 30. Adapter Insertion (HOST Mode)**



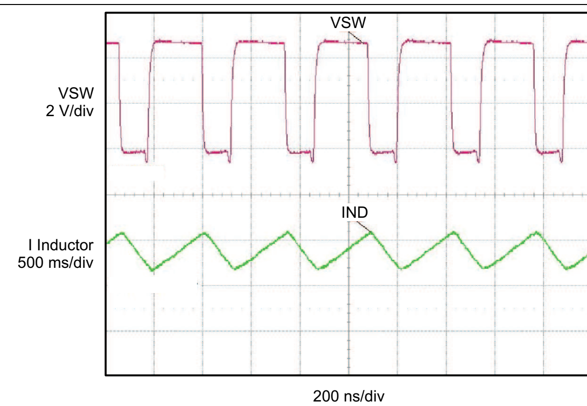

VBUS = 5 V $V_{BAT}$ = 3.5 V $I_{IN\_limit}$ = 500 mA
$V_{BATREG}$ = 4.2 V $I_{CHG}$ = 550 mA
Termination Enabled

**Figure 31. Battery Insertion/Removal Termination Enabled (HOST Mode)**



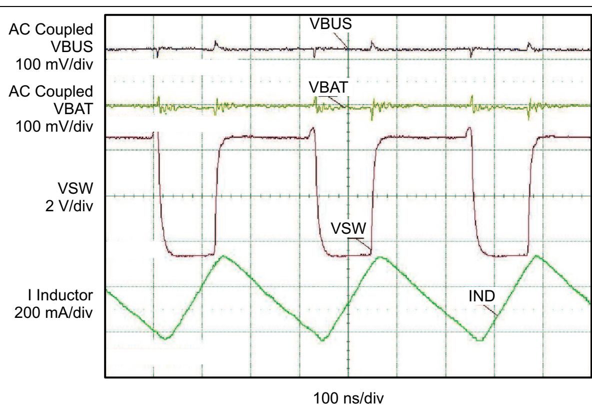

VBUS = 5 V $V_{BAT}$ = 3.5 V $I_{IN\_limit}$ = 500 mA
$V_{BATREG}$ = 4.2 V $I_{CHG}$ = 550 mA Termination Enabled

**Figure 32. Battery Insertion/Removal Termination Disabled (HOST Mode)**



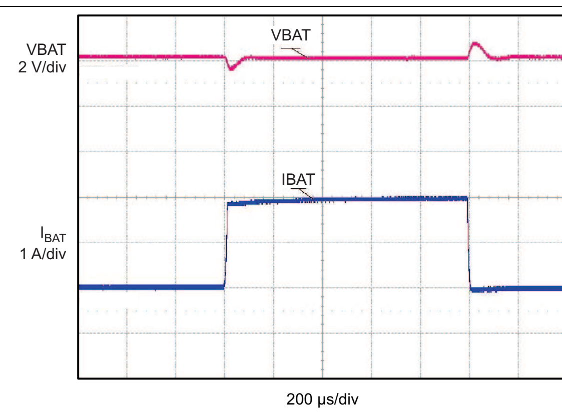

VBUS = 5 V $V_{BAT}$ = 2.6 V $V_{OREG}$ = 4.2 V
$I_{CHG}$ = 950 mA

**Figure 33. PWM Charging Waveforms**




VBUS = 5.05 V $V_{BAT}$ = 3.5 V $I_{BUS}$ = 217 mA

**Figure 34. Boost Waveform (PWM Mode)**




5.5-V input voltage

**Figure 35. Step Load from 0 to 2 A During Factory Mode**

# 10 Power Supply Recommendations

## 10.1 System Load After Sensing Resistor

One of the simpler high-efficiency topologies connects the system load directly across the battery pack, as shown in Figure 36. The input voltage has been converted to a usable system voltage with good efficiency from the input. When the input power is on, it supplies the system load and charges the battery pack at the same time. When the input power is off, the battery pack powers the system directly.

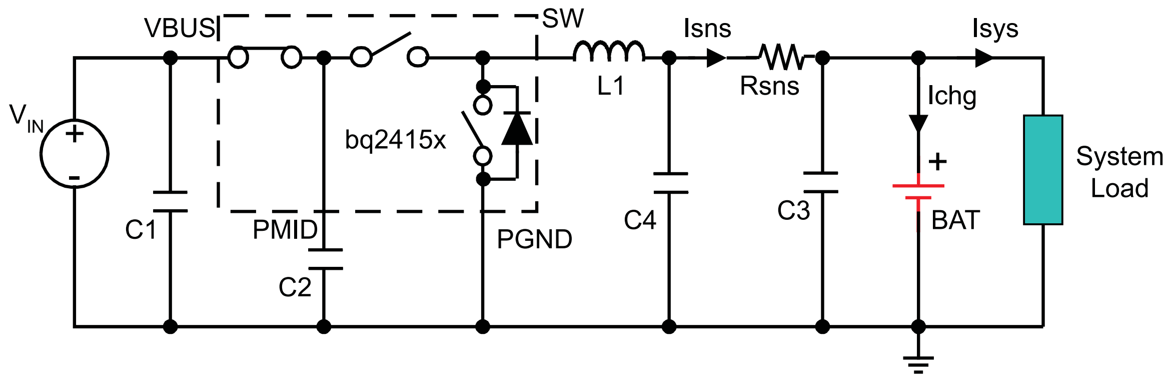



**Figure 36. System Load After Sensing Resistor**

The advantages:

1. When the AC adapter is disconnected, the battery pack powers the system load with minimum power dissipation. Consequently, the time that the system runs on the battery pack can be maximized.
2. It reduces the number of external path selection components and offers a low-cost solution.
3. Dynamic power management (DPM) can be achieved. The total of the charge current and the system current can be limited to a desired value by setting the charge current value. When the system current increases, the charge current drops by the same amount. As a result, no potential overcurrent or overheating issues are caused by excessive system load demand.
4. The total input current can be limited to a desired value by setting the input current limit value. USB specifications can be met easily.
5. The supply voltage variation range for the system can be minimized.
6. The input current soft-start can be achieved by the generic soft-start feature of the IC.

Design considerations and potential issues:

1. If the system always demands a high current (but lower than the regulation current), the battery charging never terminates. Thus, the battery is always charged, and its lifetime may be reduced.
2. Because the total current regulation threshold is fixed and the system always demands some current, the battery may not be charged with a full-charge rate and thus may lead to a longer charge time.
3. If the system load current is large after the charger has been terminated, the IR drop across the battery impedance may cause the battery voltage to drop below the refresh threshold and start a new charge cycle. The charger would then terminate due to low charge current. Therefore, the charger would cycle between charging and terminating. If the load is smaller, the battery has to discharge down to the refresh threshold, resulting in a much slower cycling.
4. In a charger system, the charge current is typically limited to about 30 mA, if the sensed battery voltage is below the 2-V short circuit protection threshold. This results in low power availability at the system bus. If an external supply is connected and the battery is deeply discharged below the short circuit protection threshold, the charge current is clamped to the short circuit current limit. This then is the current available to the system during the power-up phase. Most systems cannot function with such limited supply current, and the battery supplements the additional power required by the system. Note that the battery pack is already at the depleted condition, and it discharges further until the battery protector opens, resulting in a system shutdown.
5. If the battery is below the short circuit threshold and the system requires a bias current budget lower than the short circuit current limit, the end-equipment will be operational, but the charging process can be affected

## System Load After Sensing Resistor (continued)

depending on the current left to charge the battery pack. Under extreme conditions, the system current is close to the short circuit current levels and the battery may not reach the fast-charge region in a timely manner. As a result, the safety timers flag the battery pack as defective, terminating the charging process. Because the safety timer cannot be disabled, the inserted battery pack must not be depleted to make the application possible.

6. If the battery pack voltage is too low, highly depleted, totally dead or even shorted, the system voltage is clamped by the battery and it cannot operate even if the input power is on.

# 11 Layout

## 11.1 Layout Guidelines

Give special attention to the PCB layout. The following list provides guidelines:

- To obtain optimal performance, the power input capacitors, connected from input to PGND, should be placed as close as possible to the pin. The output inductor should be placed close to the IC and the output capacitor connected between the inductor and PGND of the IC. The intent is to minimize the current path loop area from the SW pin through the LC filter and back to the PGND pin. To prevent high frequency oscillation problems, proper layout to minimize high frequency current path loop is critical (see Figure 37). The sense resistor should be adjacent to the junction of the inductor and output capacitor. Route the sense leads connected across the RSNS back to the IC, close to each other (minimize loop area) or on top of each other on adjacent layers (do not route the sense leads through a high-current path, see Figure 38).
- Place all decoupling capacitors close to their respective IC pins and close to PGND (do not place components such that routing interrupts power stage currents). All small control signals should be routed away from the high current paths.
- The PCB should have a ground plane (return) connected directly to the return of all components through vias (two vias per capacitor for power-stage capacitors, two vias for the IC PGND, and one via per capacitor for small-signal components). A star ground design approach is typically used to keep circuit block currents isolated (high-power/low-power small-signal), which reduces noise-coupling and ground-bounce issues. A single ground plane for this design gives good results. With this small layout and a single ground plane, there is no ground-bounce issue, and having the components segregated minimizes coupling between signals.
- The high-current charge paths into VBUS, PMID, and from the SW pins must be sized appropriately for the maximum charge current in order to avoid voltage drops in these traces. The PGND pins should be connected to the ground plane to return current through the internal low-side FET.
- Place 4.7-μF input capacitor as close to PMID pin and PGND pin as possible to make the high frequency current loop area as small as possible. Place 1-μF input capacitor as close to VBUS pin and PGND pin as possible to make high frequency current loop area as small as possible (see Figure 39).

## 11.2 Layout Example

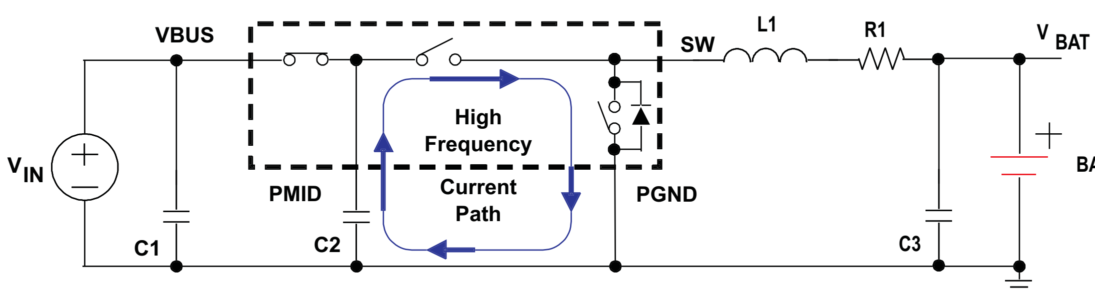



**Figure 37. High Frequency Current Path**

## Layout Example (continued)

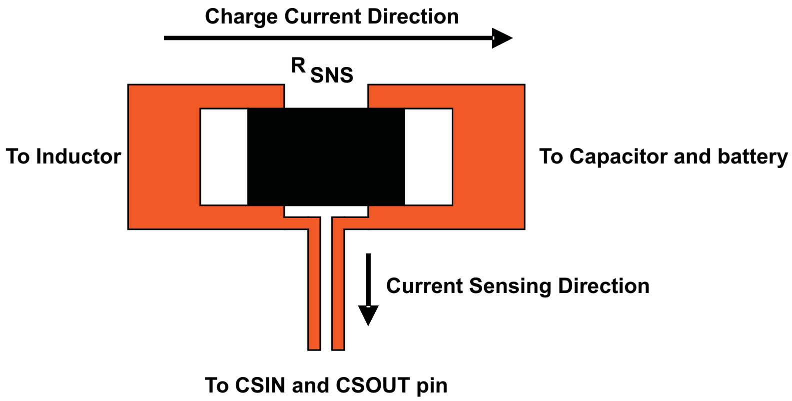



**Figure 38. Sensing Resistor PCB Layout**

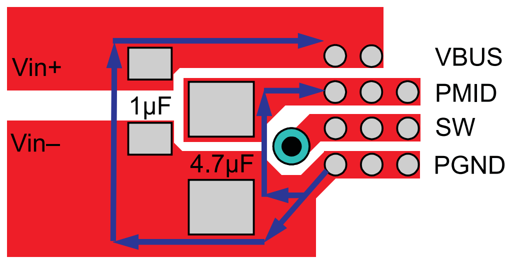



**Figure 39. Input Capacitor Position and PCB Layout Example**

# 12 Device and Documentation Support

## 12.1 Device Support

### 12.1.1 Third-Party Products Disclaimer

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## 12.2 Documentation Support

### 12.2.1 Related Documentation

bq24157S User's Guide (SLUU453)

## 12.3 Trademarks

NanoFree is a trademark of Texas Instruments.

## 12.4 Electrostatic Discharge Caution

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.

## 12.5 Glossary

SLYZ022 — *TI Glossary*.

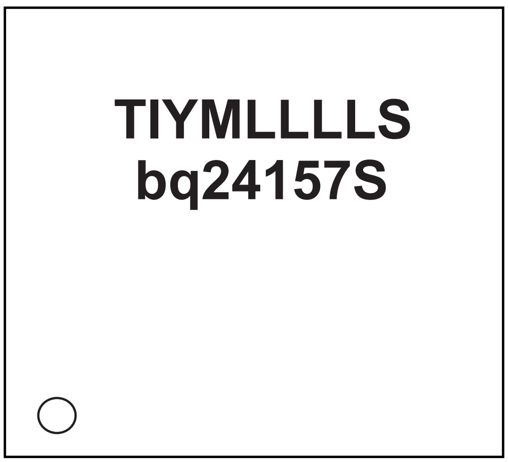
This glossary lists and explains terms, acronyms, and definitions.

# 13 Mechanical, Packaging, and Orderable Information

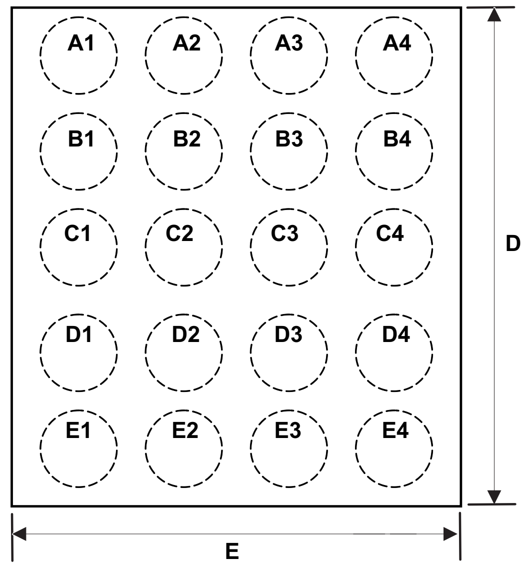
The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand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

## 13.1 Package Summary

Chip Scale Package
(Top Side Symbol)




DSBGA Package
(Top View)




0-Pin A1 Marker , TI-TI Letters, YM = Year Month Date Code, LLLL = Lot T race Code, S = Assembly Site Code

### 13.1.1 Chip Scale Packaging Dimensions

The bq24157S device is available in a 20-bump chip scale package (DSBGA, NanoFree™).

The package dimensions are:

| D | E |
|---|---|
| Max = 2.17 mm | Max = 2.03 mm |
| Min = 2.11 mm | Min = 1.97 mm |

## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BQ24157SYFFR | NRND | DSBGA | YFF | 20 | 3000 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | | BQ24157S | |
| BQ24157SYFFT | NRND | DSBGA | YFF | 20 | 250 | Green (RoHS & no Sb/Br) | SNAGCU | Level-1-260C-UNLIM | | BQ24157S | |

(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.

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

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

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

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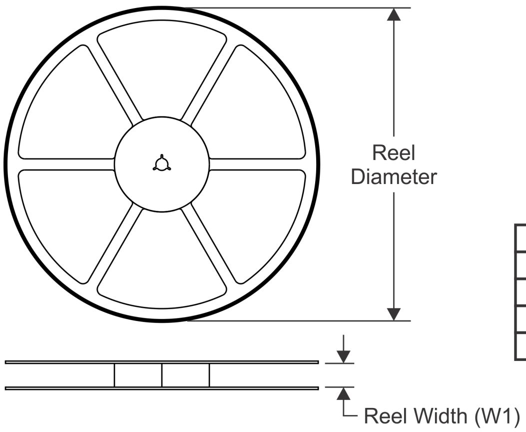
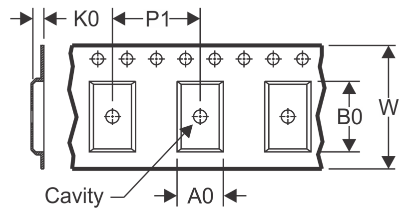
## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

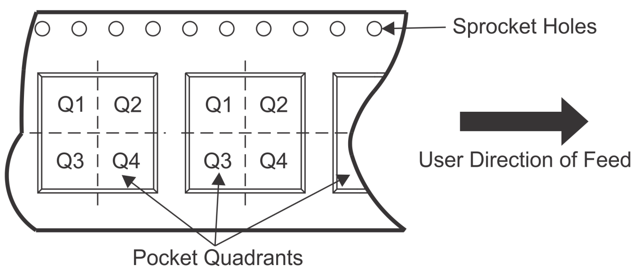



**TAPE DIMENSIONS**




| | |
|---|---|
| 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 |

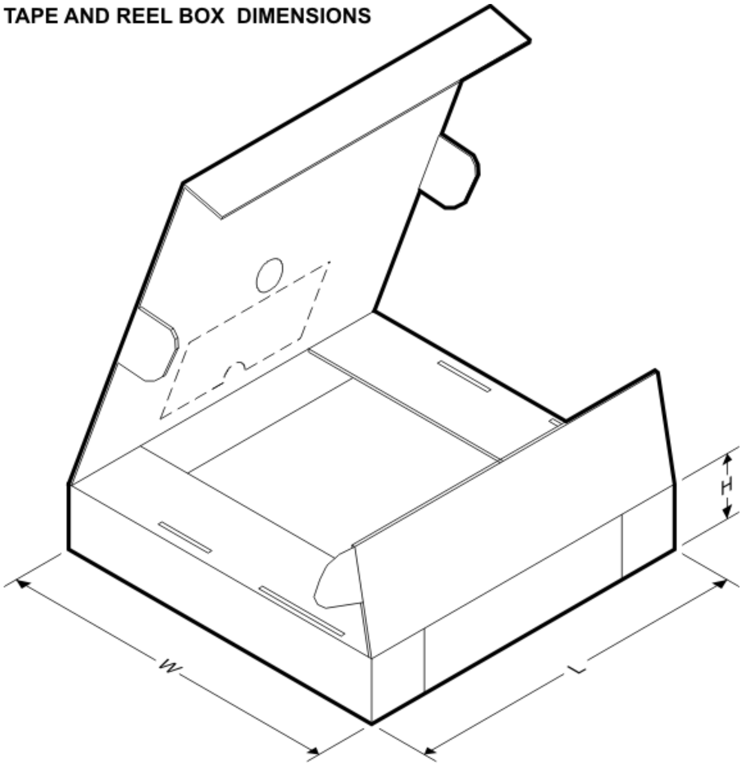
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BQ24157SYFFR | DSBGA | YFF | 20 | 3000 | 180.0 | 8.4 | 2.2 | 2.35 | 0.8 | 4.0 | 8.0 | Q1 |
| BQ24157SYFFT | DSBGA | YFF | 20 | 250 | 180.0 | 8.4 | 2.2 | 2.35 | 0.8 | 4.0 | 8.0 | Q1 |

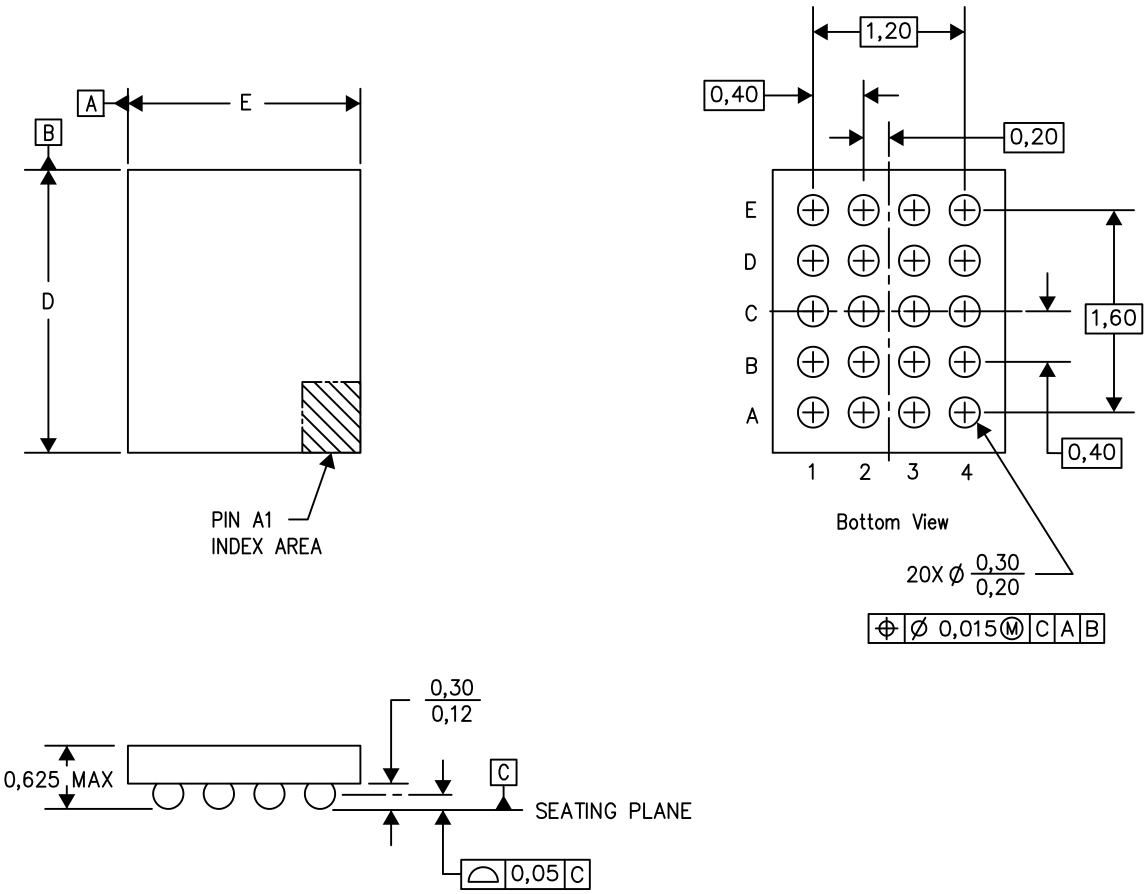
**TAPE AND REEL BOX DIMENSIONS**




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| BQ24157SYFFR | DSBGA | YFF | 20 | 3000 | 182.0 | 182.0 | 20.0 |
| BQ24157SYFFT | DSBGA | YFF | 20 | 250 | 182.0 | 182.0 | 20.0 |

YFF (R–XBGA–N20) DIE–SIZE BALL GRID ARRAY




| |
|---|
| D: Max = 2.172 mm, Min =2.112 mm |
| E: Max = 2.03 mm, Min = 1.97 mm |

4207625–9/A0 12/13

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.

NanoFree is a trademark of Texas Instruments.

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