# SINGLE-CHIP CHARGER AND DC/DC CONVERTER IC FOR PORTABLE APPLICATIONS

## FEATURES

- **Li-Ion Or Li-Pol Charge Management and Synchronous DC-DC Power Conversion In a Single Chip**
- **Charges and Powers the System from Either the AC Adapter or USB with Autonomous Power Source Selection**
- **Integrated USB Charge Control with Selectable 100 mA and 500 mA Charge Rates**
- **Integrated Power FET and Current Sensor for Up to 500 mA Charge Applications AND 300 mA DC-DC Controller with Integrated FETs**
- **Reverse Leakage Protection Prevents Battery Drainage**
- **Automatic Power Save Mode For High Efficiency at Low Current, or Forced PWM for Frequency Sensitive Applications**

## APPLICATIONS

- **MP3 Players**
- **PDAs, Smartphones**
- **Digital Cameras**

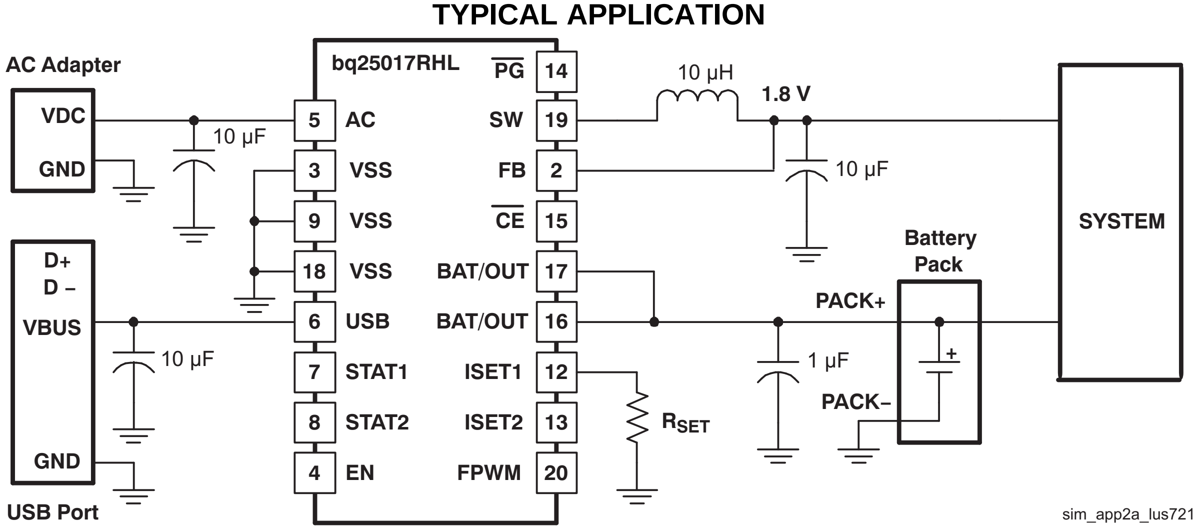
## DESCRIPTION

The bq25015/7 are highly integrated charge and power management devices targeted at space-limited bluetooth applications. The bq25015/7 devices offer integrated power FET and current sensor for charge control, reverse blocking protection, high accuracy current and voltage regulation, charge status, charge termination, and a highly efficient and low-power dc-dc converter in a small package.

The bq25015/7 devices charge the battery in three phases: conditioning, constant current and constant voltage. Charge is terminated based on minimum current. An internal charge timer provides a backup safety feature for charge termination. The bq25015/7 automatically re-starts the charge if the battery voltage falls below an internal threshold. The bq25015/7 automatically enters sleep mode when $V_{CC}$ supply is removed.

The integrated low-power high-efficiency dc-dc converter is designed to operate directly from a single-cell Li-ion or Li-Pol battery pack. The output voltage is either adjustable from 0.7 V to VBAT, or fixed at 1.8 V (bq25017) and is capable of delivering up to 300-mA of load current. The dc-dc converter operates at a synchronized 1 MHz switching frequency allowing for the use of small inductors.

### TYPICAL APPLICATION



## ELECTRICAL CHARACTERISTICS

## ELECTRICAL CHARACTERISTICS (continued)

over operating temperature range ($T_A$ = 0°C to 125°C) and recommended supply voltage range (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **FPWM – bq25015** | | | | | | |
| $V_{IH(FPWM)}$ | High-level input voltage | | 2.0 | | | |
| $V_{IL(FPWM)}$ | Low-level input voltage | | | | 0.4 | |
| **FPWM – bq25017** | | | | | | |
| $V_{IH(FPWM)}$ | High-level input voltage | | 1.3 | | | V |
| $V_{IL(FPWM)}$ | Low-level input voltage | | | | 0.4 | |
| $I_{FPWM}$ | Input bias current | $V_{EN}$ | | | | |

## TYPICAL OPERATING CHARACTERISTICS

**EFFICIENCY**
**vs**
**LOAD CURRENT**

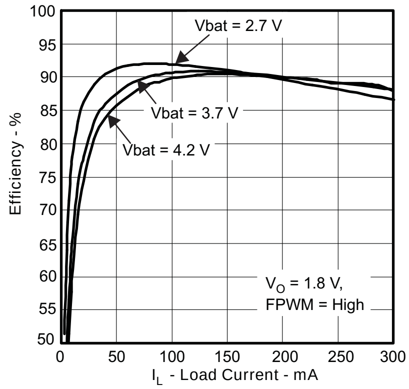



**Figure 1.**

**EFFICIENCY**
**vs**
**LOAD CURRENT**

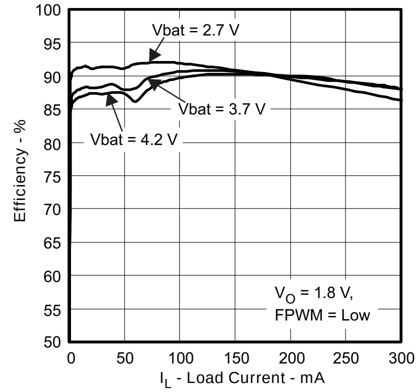



**Figure 2.**

**EFFICIENCY**
**vs**
**LOAD CURRENT**

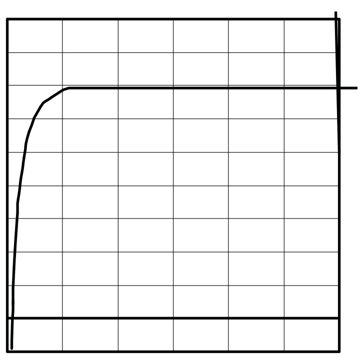


**Figure 3.**

**EFFICIENCY**
**vs**
**LOAD CURRENT**

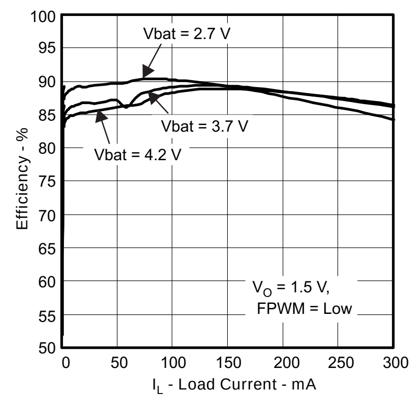



**Figure 4.**

**SHORT CIRCUIT INDUCTOR CURRENT**

**Figure 5.**

## TYPICAL OPERATING CHARACTERISTICS (continued)

**LOAD TRANSIENT, 3 mA TO 300 mA,
Vbat = 3.7 V, Vo = 1.8 V
FPWM = HIGH, FORCE PWM**

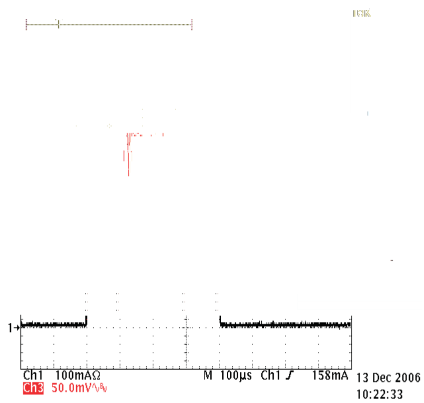



Figure 6.

**LOAD TRANSIENT, 3 mA TO 300 mA,
Vbat = 3.7 V, Vo = 1.8 V
FPWM = LOW, POWER SAVE MODE**

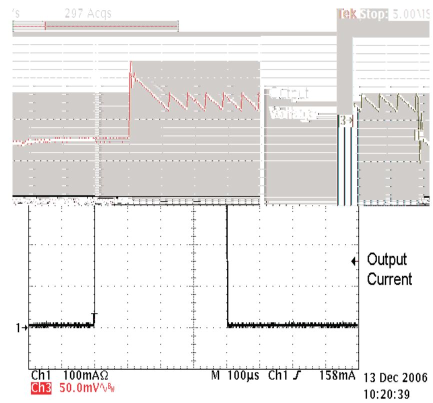



Figure 7.

**LIGHT LOAD WAVEFORM, Vbat = 3.7 V, Vo = 1.8 V
LOAD CURRENT = 36 mA,
FPWM = HIGH, FORCE PWM**

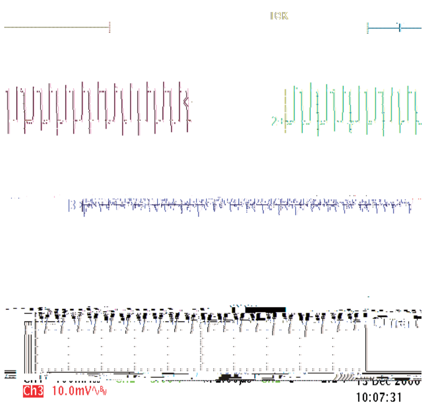



Figure 8.

**LIGHT LOAD WAVEFORM, Vbat = 3.7 V, Vo = 1.8 V
LOAD CURRENT = 36 mA,
FPWM = LOW, FORCE PWM**

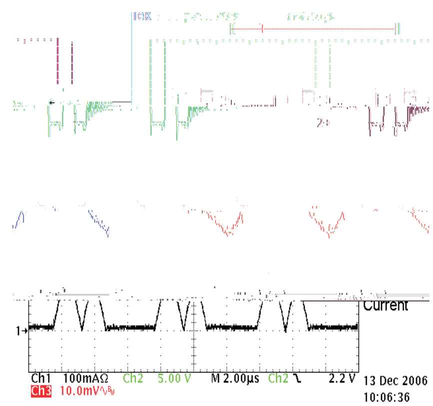



Figure 9.

**START-UP AND SHUT-DOWN, Vbat = 3.7 V, Vo = 1.8 V
LOAD CURRENT = 300 mA,
FPWM = HIGH, FORCE PWM**

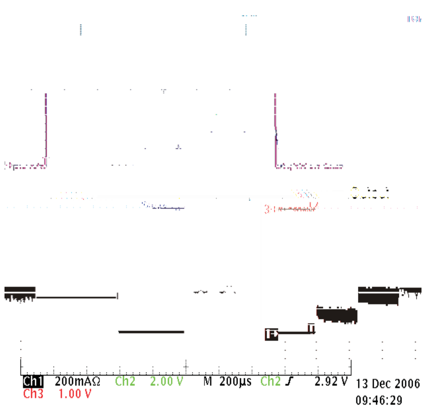



Figure 10.

**START-UP AND SHUT-DOWN, Vbat = 3.7 V, Vo = 1.8 V
LOAD CURRENT = 300 mA,
FPWM = LOW, POWER SAVE MODE**

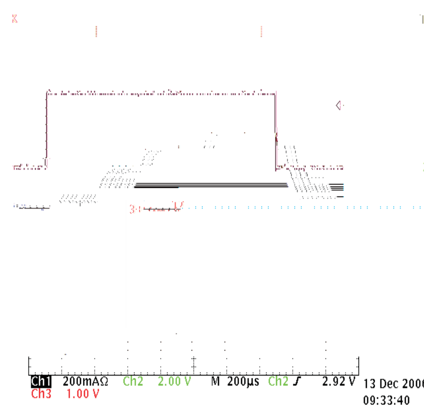
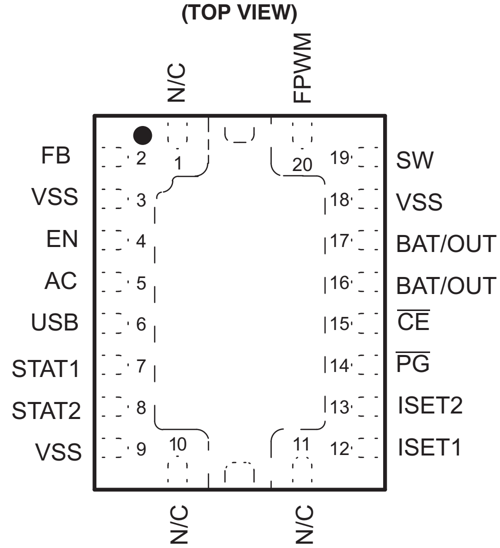


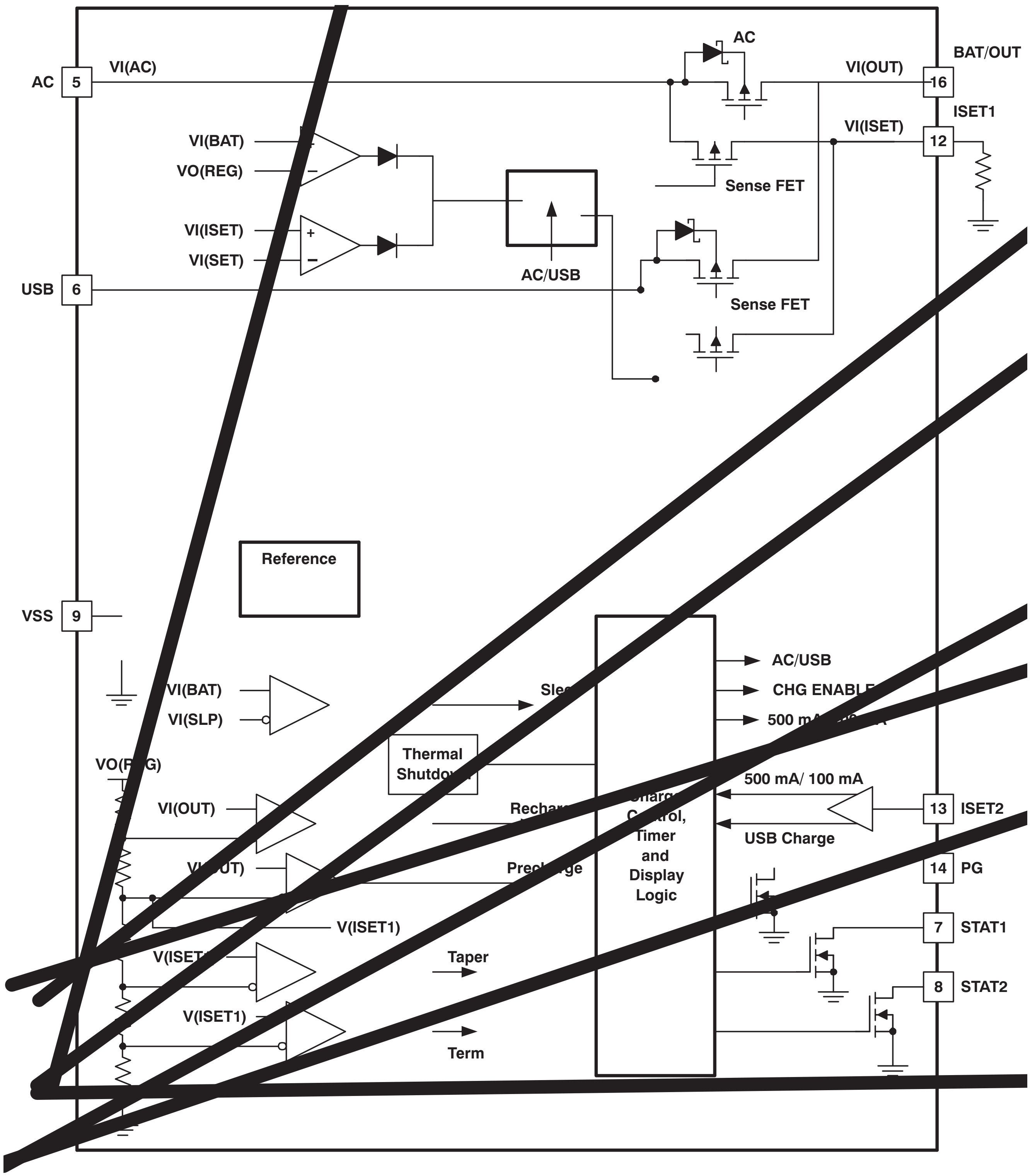

Figure 11.

## DEVICE INFORMATION

**bq25015, bq25017**
**RHL PACKAGE**
**(TOP VIEW)**



## FUNCTIONAL BLOCK DIAGRAM



## FUNCTIONAL DESCRIPTIONS

### BATTERY CHARGER

The bq2501x supports a precision Li-Ion or Li-Pol charging system suitable for single-cell battery packs and a low-power DC-DC converter for providing power to system processor. See a typical charge profile, application circuit and an operational flow chart in Figure 12 through Figure 14 respectively. Figure 13 is the typical application circuit for a high-current application (300 mA). Here the battery charge current is 500 mA, input voltage range of 4.5V – 6.5V.

**Figure 12. Typical Charger Profile**

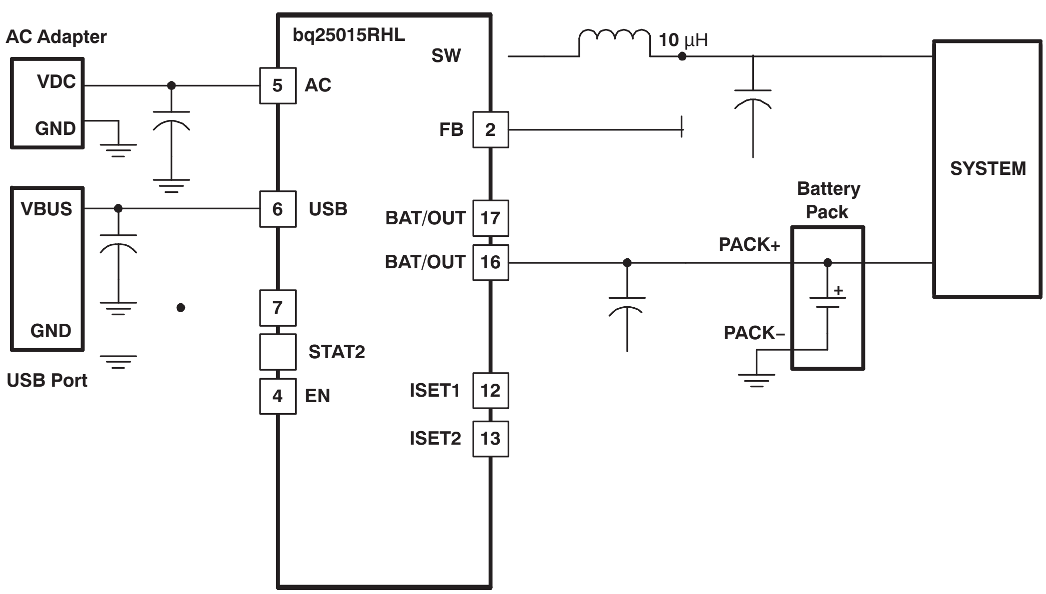



**Figure 13. Typical Application Circuit**

## FUNCTIONAL DESCRIPTIONS (continued)

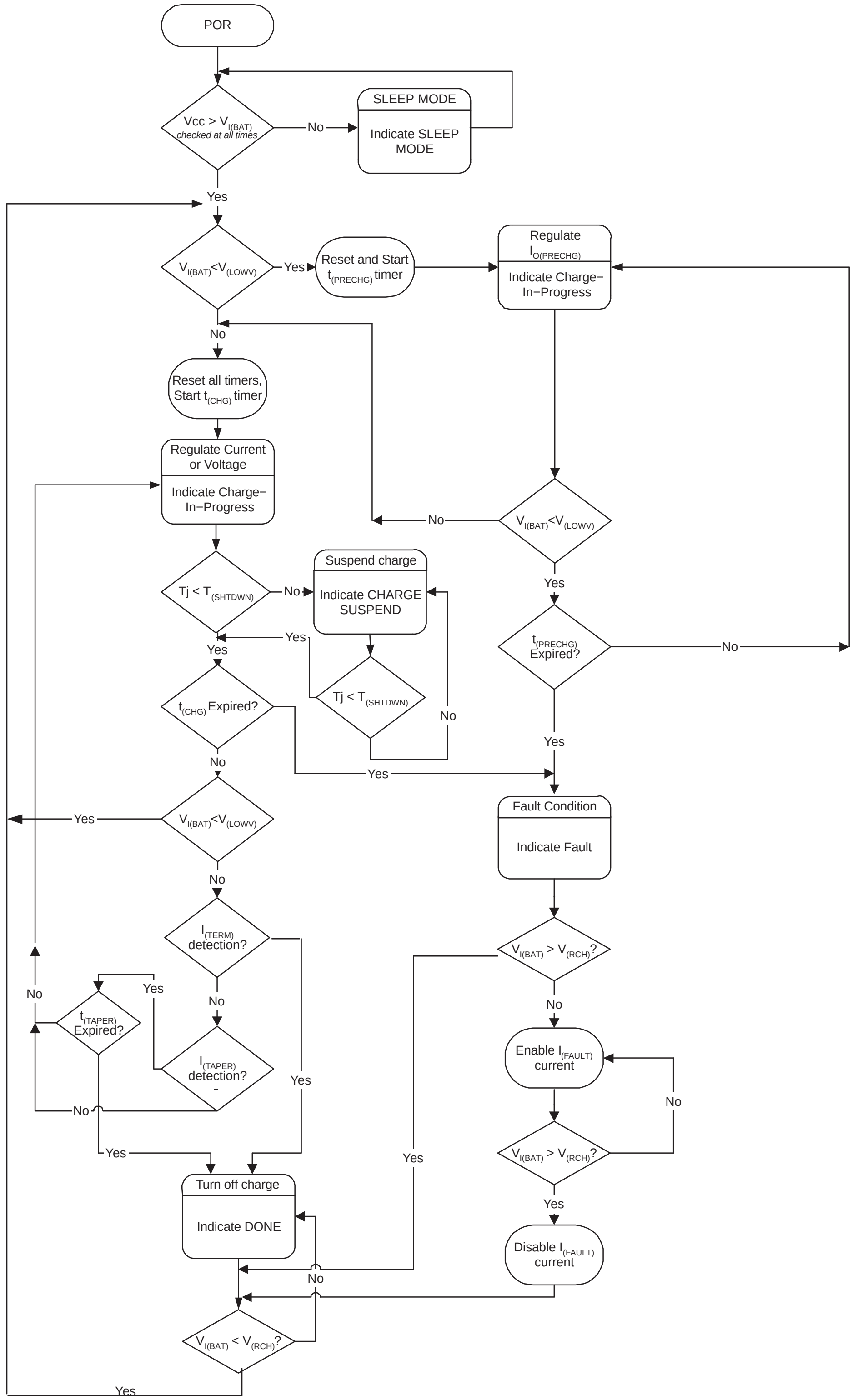
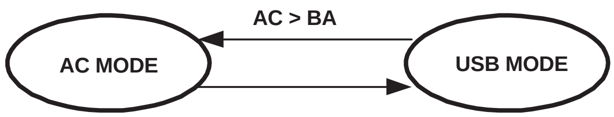



**Figure 14. Operational Flow Chart**

### Autononous Power Source Selection




### Battery Pre-Conditioning

$$I_{O\,(PRECHG)} \square \frac{V_{(PRECHG)} \square K_{(SET)}}{R_{SET}} \qquad (1)$$

### Battery Charge Current

$$I_{O\,(OUT)} \square \frac{V_{(SET)} \square K_{(SET)}}{R_{SET}} \qquad (2)$$

### Battery Voltage Regulation

### Charge Taper Detection, Termination and Regharge

$$I_{(TERM)} = \frac{V_{(TERM)} \times K_{(SET)}}{R_{SET}} \qquad (4)$$

### Sleep Mode for Charger

### Operation Modes

### Thermal Shutdown and Protection

The bq25015/7 monitors the junction temperature, $T_J$, of the die and suspends charging if $T_J$ exceeds $T_{(SHTDWN)}$. Charging resumes when $T_J$ falls below $T_{(SHTDWN)}$ by approximately 15°C.

### TImer Fault Recovery

As shown in Figure 14, bq25015/7 provides a recovery method to deal with timer fault conditions. The following summarizes this method:

**Condition 1**: Charge voltage above recharge threshold ($V_{(RCH)}$) and timeout fault occurs.

Recovery method: bq25015/7 waits for the battery voltage to fall below the recharge threshold. This could happen as a result of a load on the battery, self-discharge or battery removal. Once the battery falls below the recharge threshold, the bq25015/7 clears the fault and starts a new charge cycle. A POR or $\overline{CE}$ toggle also clears the fault.

**Condition 2:** Charge voltage below recharge threshold ($V_{(RCH)}$) and timeout fault occurs.

Recovery method: Under this scenario, the bq25015/7 applies the $I_{(FAULT)}$ current. This small current is used to detect a battery removal condition and remains on as long as the battery voltage stays below the recharge threshold. If the battery voltage goes above the recharge threshold, then the bq25015/7 disables the $I_{(FAULT)}$ current and executes the recovery method described for Condition 1. Once the battery falls below the recharge threshold, the bq25015/7 clears the fault and starts a new charge cycle. A POR or $\overline{CE}$ toggle also clears the fault.

## DC-DC CONVERTER

The bq25015/7 provides a low quiescent-current synchronous DC-DC converter. The internally compensated converter is designed to operate over the entire voltage range of a single-cell Li-Ion or Li-Pol battery. Under nominal load current, the device operates with a fixed PWM switching frequency of typically 1 MHz. At light load currents, the device enters the power save mode of operation; the switching frequency is reduced and the quiescent current drawn by the converter from the BAT/OUT pin is typically only 15 µA.

Dur1

### Power Save Mode Operation

$$I_{SKIP} \square 66\ mA \square \frac{V_{IN}}{160\ \Omega} \tag{5}$$

$$I_{PEAK} \square 66\ mA \square \frac{V_{IN}}{80\ \Omega} \tag{6}$$

The N-channel rectifier is turned on and the inductor current ramps down. As the inductor current approaches zero the N-channel rectifier is turned off and the P-channel switch is turned on again starting the next pulse. The converter continues these pulses until the comp high threshold (set to typically 1.6% above VOUT nominal) is reached. The converter enters a sleep mode, reducing the quiescent current to a minimum. The converter wakes up again as the output voltage falls below the comp low threshold again. This control method reduces the quiescent current to typically to 15 µA and the switching frequency to a minimum, thereby achieving high converter efficiency. Setting the skip current thresholds to typically 0.8% and 1.6% above the nominal output voltage at light load current results in a dynamic output voltage achieving lower absolute voltage drops during heavy load transient changes. This allows the converter to operate with a small output capacitor of only 10 µF and still have a low absolute voltage drop during heavy load transient changes. Refer to Figure 16 as well for detailed operation of the power save mode.

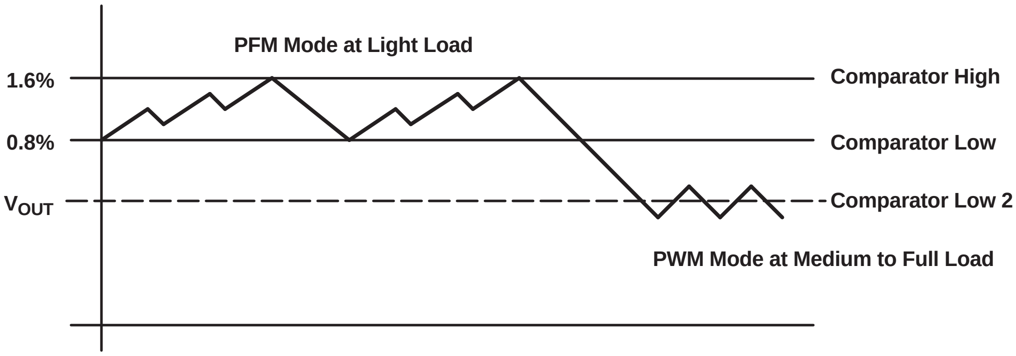



**Figure 16. Power Save Mode Thresholds and Dynamic Voltage Positioning**

The converter enters the fixed-frequency PWM mode again as soon as the output voltage drops below the comp low 2 threshold.

### Dynamic Voltage Positioning

As described in the power save mode operation section and as detailed in Figure 16, the output voltage is typically 0.8% above the nominal output voltage at light load currents as the device is in power save mode. This gives additional headroom for the voltage drop during a load transient from light load to full load. During a load transient from full load to light load the voltage overshoot is also minimized due to active regulation turning on the N-Channel rectifier switch.

### Soft-Start

The bq25015/7 has an internal soft-start circuit that limits the inrush current during startup. This soft-start is implemented as a digital circuit increasing the switch current in steps of typically 60 mA, 120 mA, 240 mA and then the typical switch current limit of 480 mA. Therefore the starup time depends mainly on the output capacitor and load current. Typical startup time with a 10-µF output capacitor and a 100-mA load current is 1.6 ms.

### 100% Duty Cycle Low Dropout Operation

The bq2501 offers a low input-to-output voltage difference while still maintaining operation with the use of the 100% duty cycle mode. In this mode the P-channel switch is constantly turned on. This is particularly useful in battery-powered applications to achieve longest operation time by taking full advantage of the whole battery voltage range. The minimum input voltage to maintain regulation depends on the load current and output voltage and can be calculated as:

$$V_{IN(min)} = V_{OUT(max)} + I_{OUT(max)} \times \left(R_{DS(on)MAX} + R_L\right) \quad (7)$$

where

$I_{OUT(max)}$ = maximum output current plus indicator ripple current
$R_{DS(on)MAX}$ = maximum P-channel switch $R_{DS(on)}$
$R_L$ = DC resistance of the inductor
$V_{OUT(max)}$ = nominal output voltage plus maximum output voltage tolerance

### Enable

Pulling the enable pin (EN) low forces the DC-DC converter into shutdown mode, with a shutdown quiescent current of typically 0.1 µA. In this mode the P-channel switch and N-channel rectifier are turned off, the internal resistor feedback divider is disconnected, and the converter enters shutdown mode. If an output voltage, which could be an external voltage source or a super capacitor, is present during shut down, the reverse leakage current is specified under electrical characteristics. For proper operation the EN pin must be terminated and should not be left floating.

Pulling the EN pin high starts up the DC-DC converter with the soft-start as previously described.

### Undervoltage Lockout

The undervoltage lockout circuit prevents the converter from turning on the switch or rectifier MOSFET at low input voltages or under undefined conditions.

### Forced PWM Mode

The FPWM input pin allows the host system to override the power save mode by driving the FPWM pin high. In this state, the DC-DC converter remains in the PWM mode of operation with continuous current conduction regardless of the load conditions. Tying the FPWM pin low allows the device to enter power save mode automatically as previously described.

## APPLICATION INFORMATION

### ADJUSTABLE OUTPUT VOLTAGE VERSIONOPf 1 2ERSI4 1 2ET1Tf (OPf 1 2ERSI1 Tf (ADJUADJUADJUADJ

## APPLICATION INFORMATION (continued)

If ceramic output capacitors are used, the capacitor RMS ripple current rating ensures the application requirements. For completeness, the RMS ripple current is calculated as:

$$I_{RMS} = I_{OUT(max)} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The worst case RMS ripple current occurs at D=0.5 and is calculated as:

$$I_{RMS} = \frac{I_{OUT}}{2} \qquad (12)$$

Ceramic capacitors perform well because of the low ESR value, and they are less sensitive to voltage transients and spikes compared to tantalum capacitors. The input capacitor should be placed as close as possible to the BAT/OUT pin of the device for best performance. Refer to Table 1for recommended components.

## DC-DC CONVERTER OUTPUT CAPACITOR SELECTION

The advanced fast response voltage mode control scheme of the bq25015/7 allows the use of tiny ceramic capacitors without having large output voltage under and overshoots during heavy load transients. Ceramic capacitors having low ESR values have the lowest output voltage ripple and are therefore recommended. If required, tantalum capacitors may be used as well (refer to Table 1 for recommended components). If ceramic output capacitors are used, the capacitor RMS ripple current rating always meets the application requirements. For completeness, the RMS ripple current is calculated as:

$$I_{RMS(Cout)} = V_{OUT} \times \frac{\left(1 - \frac{V_{OUT}}{V_{IN}}\right)}{L \times f} \times \frac{1}{2 \times \sqrt{3}} \qquad (13)$$

At nominal load current the device operates in PWM mode and the overall output voltage ripple is the sum of the voltage spike 0 Tf 110 5 device

$$\Delta V_{OUT} = V_{OUT} \times \frac{\left(1 - \frac{V_{OUT}}{V_{IN}}\right)}{L \times f} \times \left(\frac{1}{8 \times C_{OUT} \times f} + ESR\right) \qquad (14)$$

## APPLICATION INFORMATION (continued)

## DC-DC CONVERTER OUTPUT INDUCTOR SELECTION

For high efficiencies, the inductor should have a low DC resistance to minimize conduction losses. Although the inductor core material has less effect on efficiency than its DC resistance, an appropriate inductor core material must be used. The inductor value determines the inductor ripple current. The larger the inductor value, the

$$\Delta I_L = V_{OUT} \times \frac{\left(1 - \frac{V_{OUT}}{V_{IN}}\right)}{L \times f} \qquad (15)$$

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

## CHARGING WHILE UNDER LOAD

## THERMAL CONSIDERATIONS

$$\theta_{JA} = \frac{T_J - T_A}{P} \qquad (16)$$

where

$T_J$ = chip junction temperature

$T_A$ = ambient temperature

P = device power dissipation

Factors that can greatly influence the measurement and calculation of $\theta_{JA}$ include:

- Whether or not the device is board mounted
- Trace size, composition, thickness, and geometry
- Orientation of the device (horizontal or vertical)
- Volume of the ambient air surrounding the device under test and airflow
- Whether other surfaces are in close proximity to the device being tested

The device power dissipation (P) is a function of the charge rate and the voltage drop across the internal power FET. It can be calculated from the following equation:

$$P = \left(V_{IN} - V_{IN(BAT)}\right) \times I_{OUT(OUT)} \quad (17)$$

Due to the charge profile of Li-xx batteries, the maximum power dissipation is typically seen at the beginning of the charge cycle when the battery voltage is at its lowest.

## PCB LAYOUT CONSIDERATIONS

For all switching power supplies, the layout is an important step in the design, especially at high peak currents and switching frequencies. If the layout is not carefully done the regulator could exhibit stability problems as well as EMI problems. With this in mind, one should lay out the PCB using wide, short traces for the main current paths. The input capacitor, as well as the inductor and output capacitors, should be placed as close as possible to the IC pins.

The feedback resistor network must be routed away from the inductor and switch node to minimize noise and magnetic interference. To further minimize noise from coupling into the feedback network and feedback pin, the ground plane or ground traces must be used for shielding. This becomes very important especially at high switching frequencies.

The following are some additional guidelines that should be observed:

- To obtain optimal performance, the decoupling capacitor from AC to VSS (and from USB to VSS) and the output filter capacitors from BAT/OUT to VSS should be placed as close as possible to the bq25015/7, with short trace runs to both signal and VSS pins.
- All low-current VSS connections should be kept separate from the high-current charge or discharge paths from the battery. Use a single-point ground technique incorporating both the small signal ground path and the power ground path.
- The BAT/OUT pin provides voltage feedback to the IC for the charging function and should be connected with its trace as close to the battery pack as possible.
- The high current charge paths into AC and USB and from the BAT/OUT and SW pins must be sized appropriately for the maximum charge or output current in order to avoid voltage drops in these traces.
- The bq25015/7 deviecs are packaged in a thermally enhanced MLP package. The package includes a thermal pad to provide an effective thermal contact between the IC and the printed circuit board (PCB). Full PCB design guidelines for this package are provided in the application note *QFN/SON PCB Attachment* (SLUA271).

## PACKAGING INFORMATION

[4] Only one of markings shown within the brackets will appear on the physical device.

**Important Information and Disclaimer:**The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

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

## TAPE AND REEL INFORMATION

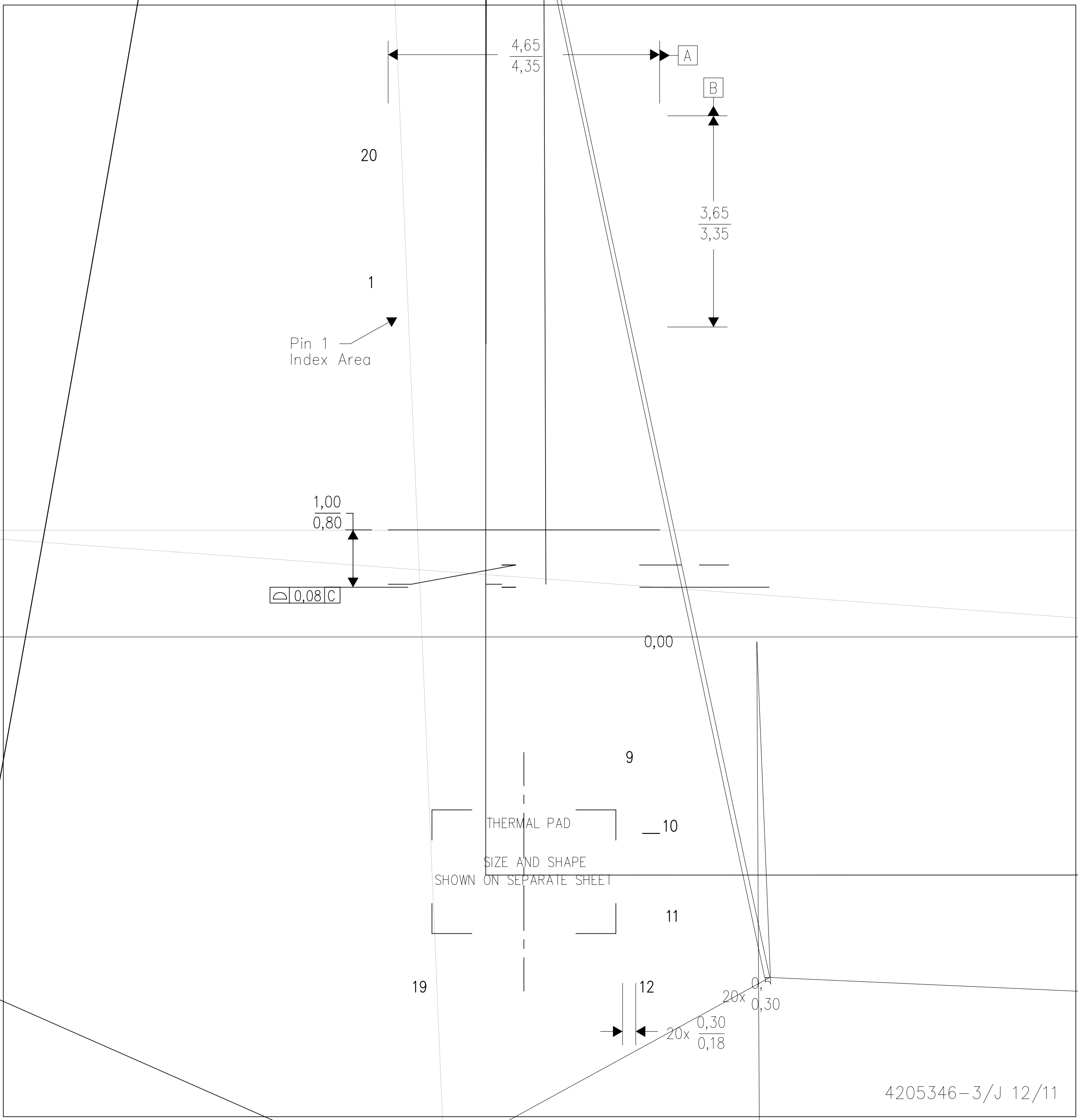

*All dimensions are nominal

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BQ25015RHLR | QFN | RHL | 20 | 3000 | 330.0 | 12.4 | 3.8 | 4.8 | 1.6 | 8.0 | 12.0 | Q1 |
| BQ25015RHLT | QFN | RHL | 20 | 250 | 180.0 | 12.4 | 3.8 | 4.8 | 1.6 | 8.0 | 12.0 | Q1 |
| BQ25017RHLR | QFN | RHL | 20 | 3000 | 330.0 | 12.4 | 3.8 | 4.8 | 1.6 | 8.0 | 12.0 | Q1 |
| BQ25017RHLT | QFN | RHL | 20 | 250 | 180.0 | 12.4 | 3.8 | 4.8 | 1.6 | 8.0 | 12.0 | Q1 |

[redacted]

*All dimensions are nominal

RHL (R-PVQFN-N20) PLASTIC QUAD FLATPACK NO-LEAD




NOTES: cnd tolerancing per ASME Y14.5M–1994.

B. This drawing is subject to change without notice.

420630

.NSTRUMENTS

C. Publication IPC–7351 is recommended for alternate designs.

Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should conl

## IMPORTANT NOTICE



| **Products** | | **Applications** | |
|---|---|---|---|
| Audio | www.ti.com/audio | Automotive and Transportation | www.ti.com/automotive |
| Amplifiers | amplifier.ti.com | Communications and Telecom | www.ti.com/communications |
| Data Converters | dataconverter.ti.com | Computers and Peripherals | www.ti.com/computers |
| DLP® Products | www.dlp.com | Consumer Electronics | www.ti.com/consumer-apps |
| DSP | dsp.ti.com | Energy and Lighting | www.ti.com/energy |
| Clocks and Timers | www.ti.com/clocks | Industrial | www.ti.com/industrial |
| Interface | interface.ti.com | Medical | www.ti.com/medical |
| Logic | logic.ti.com | Security | www.ti.com/security |
| Power Mgmt | power.ti.com | Space, Avionics and Defense | www.ti.com/space-avionics-defense |
| Microcontrollers | microcontroller.ti.com | Video and Imaging | www.ti.com/video |
| RFID | www.ti-rfid.com | | |
| OMAP Applications Processors | www.ti.com/omap | **TI E2E Community** | e2e.ti.com |
| Wireless Connectivity | www.ti.com/wirelessconnectivity | | |

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265