# TPS61088 10-A Fully-Integrated Synchronous Boost Converter

## 1 Features

- Input Voltage Range: 2.7 to 12 V
- Output Voltage Range: 4.5 to 12.6 V
- 10-A Switch Current
- Up to 91% Efficiency at $V_{IN}$ = 3.3 V, $V_{OUT}$ = 9 V, and $I_{OUT}$ = 3 A
- Mode Selection Between PFM Mode and Forced PWM Mode at Light Load
- 1.0 µA Current into VIN Pin during Shutdown
- Resistor-Programmable Switch Peak Current Limit
- Adjustable Switching Frequency: 200 kHz to 2.2 MHz
- Programmable Soft Start
- Output Overvoltage Protection at 13.2 V
- Cycle-by-Cycle Overcurrent Protection
- Thermal Shutdown
- 4.50-mm × 3.50-mm 20-Pin VQFN Package

## 2 Applications

- Portable POS terminal
- Bluetooth™ Speaker
- E-Cigarette
- Thunderbolt Interface
- Quick Charge Power Bank

## 3 Description

The TPS61088 is a high power density, fully integrated synchronous boost converter with a 11-mΩ power switch and a 13-mΩ rectifier switch to provide a high efficiency and small size solution in portable systems. The TPS61088 has wide input voltage range from 2.7 V to 12 V to support applications with single cell or two cell Lithium batteries. The device has 10-A switch current capability and is capable of providing an output voltage up to 12.6 V.

The TPS61088 uses adaptive constant off-time peak current control topology to regulate the output voltage. In moderate to heavy load condition, the TPS61088 works in the pulse width modulation (PWM) mode. In light load condition, the device has two operation modes selected by the MODE pin. One is the pulse frequency modulation (PFM) mode to improve the efficiency and another one is the forced PWM mode to avoid application problems caused by low switching frequency. The switching frequency in the PWM mode is adjustable ranging from 200 kHz to 2.2 MHz by an external resistor. The TPS61088 also implements a programmable soft-start function and an adjustable switching peak current limit function. In addition, the device provides 13.2-V output overvoltage protection, cycle-by-cycle overcurrent protection, and thermal shutdown protection.

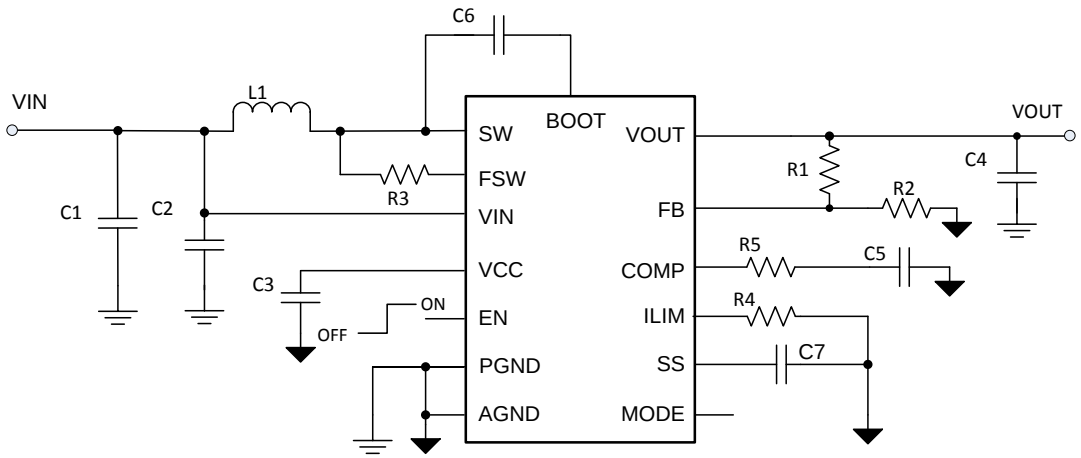
The TPS61088 is available in a 4.50-mm × 3.50-mm 20-pin VQFN package.

**Device Information**[1]

| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| TPS61088 | VQFN (20) | 4.50 mm × 3.50 mm |

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

## 4 Typical Application Circuit




An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.

# Table of Contents

**1 Features** ... 1
**2 Applications** ... 1
**3 Description** ... 1
**4 Typical Application Circuit** ... 1
**5 Revision History** ... 2
**6 Pin Configuration and Functions** ... 3
**7 Specifications** ... 4
7.1 Absolute Maximum Ratings ... 4
7.2 ESD Ratings ... 4
7.3 Recommended Operating Conditions ... 4
7.4 Thermal Information ... 4
7.5 Electrical Characteristics ... 5
7.6 Typical Characteristics ... 6
**8 Detailed Description** ... 8
8.1 Overview ... 8
8.2 Functional Block Diagram ... 9
8.3 Feature Description ... 9
8.4 Device Functional Modes ... 11
**9 Application and Implementation** ... 13
9.1 Application Information ... 13
9.2 Typical Application ... 13
**10 Power Supply Recommendations** ... 20
**11 Layout** ... 20
11.1 Layout Guidelines ... 20
11.2 Layout Example ... 20
11.3 Thermal Considerations ... 21
**12 Device and Documentation Support** ... 22
12.1 Device Support ... 22
12.2 Community Resources ... 22
12.3 Trademarks ... 22
12.4 Electrostatic Discharge Caution ... 22
12.5 Glossary ... 22
**13 Mechanical, Packaging, and Orderable Information** ... 22

## 5 Revision History

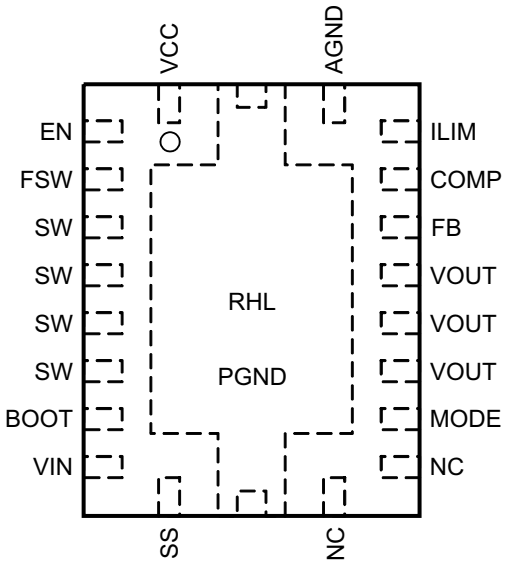
**Changes from Original (May 2015) to Revision A** **Page**

- Updated device status to production data ... 1
- Updated $V_{CCLPH}$ and $V_{CCLPL}$ typical voltage ... 5
- Fixed legend of Figure 2 and Figure 4 from input to output ... 6


Copyright © 2015, Texas Instruments Incorporated

# 6 Pin Configuration and Functions

**RHL Package**
**20 Pin VQFN With Thermal Pad**
**Top View**




**Pin Functions**

| PIN | | I/O | DESCRIPTION |
|---|---|---|---|
| NAME | NUMBER | | |
| VCC | 1 | O | Output of the internal regulator. A ceramic capacitor of more than 1.0 µF is required between this pin and ground. |
| EN | 2 | I | Enable logic input. Logic high level enables the device. Logic low level disables the device and turns it into shutdown mode. |
| FSW | 3 | I | The switching frequency is programmed by a resister between this pin and the SW pin. |
| SW | 4, 5, 6, 7 | I | The switching node pin of the converter. It is connected to the drain of the internal low-side power MOSFET and the source of the internal high-side power MOSFET. |
| BOOT | 8 | O | Power supply for high-side MOSFET gate driver. A ceramic capacitor of 0.1 µF must be connected between this pin and the SW pin |
| VIN | 9 | I | IC power supply input |
| SS | 10 | O | Soft-start programming pin. An external capacitor sets the ramp rate of the internal error amplifier's reference voltage during soft-start |
| NC | 11, 12 | — | No connection inside the device. Connect these two pins to ground plane on the PCB for good thermal dissipation |
| MODE | 13 | I | Operation mode selection pin for the device in light load condition. When this pin is connected to ground, the device works in PWM mode. When this pin is left floating, the device works in PFM mode. |
| VOUT | 14, 15, 16 | O | Boost converter output |
| FB | 17 | I | Voltage feedback. Connect to the center tape of a resistor divider to program the output voltage. |
| COMP | 18 | O | Output of the internal error amplifier, the loop compensation network should be connected between this pin and the AGND pin. |
| ILIM | 19 | O | Adjustable switch peak current limit. An external resister should be connected between this pin and the AGND pin. |
| AGND | 20 | — | Signal ground of the IC |
| PGND | 21 | — | Power ground of the IC. It is connected to the source of the low-side MOSFET. |

Copyright © 2015, Texas Instruments Incorporated

# 7 Specifications

## 7.1 Absolute Maximum Ratings

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

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| Voltage(2) | BOOT | –0.3 | SW + 7 | V |
| | VIN, SW, FSW, VOUT | –0.3 | 14.5 | |
| | EN, VCC, SS, COMP, MODE | –0.3 | 7 | |
| | ILIM, FB | –0.3 | 3.6 | |
| $T_J$ | Operating junction temperature | –40 | 150 | °C |
| $T_{stg}$ | Storage temperature | –65 | 150 | °C |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) All voltage values are with respect to network ground terminal.

## 7.2 ESD Ratings

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

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

| | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{IN}$ | Input voltage range | 2.7 | | 12 | V |
| $V_{OUT}$ | Output voltage range | 4.5 | | 12.6 | V |
| L | Inductance, effective value | 0.47 | 2.2 | 10 | µH |
| $C_I$ | Input capacitance, effective value | 10 | | | µF |
| $C_O$ | Output capacitance, effective value | 6.8 | 47 | 1000 | µF |
| $T_J$ | Operating junction temperature | –40 | | 125 | °C |

## 7.4 Thermal Information

| THERMAL METRIC(1) | | TPS61088 RHL (VQFN) 20 PINS | UNIT |
|---|---|---|---|
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 38.8 | °C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 39.8 | °C/W |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 15.5 | °C/W |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 0.6 | °C/W |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 15.5 | °C/W |
| $R_{\theta JC(bot)}$ | Junction-to-case (bottom) thermal resistance | 3.1 | °C/W |

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


Copyright © 2015, Texas Instruments Incorporated

## 7.5 Electrical Characteristics

Minimum and maximum values are at $V_{IN}$ = 2.7 V to 5.5 V and $T_J$ = -40°C to 125°C. Typical values are at $V_{IN}$ = 3.6 V and $T_J$ = 25°C

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **POWER SUPPLY** | | | | | | |
| $V_{IN}$ | Input voltage range | | 2.7 | | 12 | V |
| $V_{IN_UVLO}$ | Undervoltage lockout (UVLO) threshold | $V_{IN}$ rising | | | 2.7 | V |
| | | $V_{IN}$ falling | | 2.4 | 2.5 | V |
| $V_{IN_HYS}$ | VIN UVLO hysteresis | | | 200 | | mV |
| $V_{CC_UVLO}$ | UVLO threshold | $V_{CC}$ falling | | 2.1 | | V |
| $I_Q$ | Operating quiescent current from the VIN pin | IC enabled, $V_{EN}$ = 2 V, no load, $R_{ILIM}$ = 100 kΩ , $V_{FB}$ = 1.3 V, $V_{OUT}$ = 12 V, $T_J$ up to 85°C | | 1 | 3 | µA |
| | Operating quiescent current from the VOUT pin | | | 110 | 250 | µA |
| $I_{SD}$ | Shutdown current into the VIN pin | IC disabled, $V_{EN}$ = 0 V, no load, no feedback resistor divider connected to the VOUT pin, $T_J$ up to 85°C | | 1 | 3 | µA |
| $V_{CC}$ | VCC regulation | $I_{VCC}$ = 5 mA, $V_{IN}$ = 8 V | | 5.8 | | V |
| **EN AND MODE INPUT** | | | | | | |
| $V_{ENH}$ | EN high threshold voltage | $V_{CC}$ = 6 V | | | 1.2 | V |
| $V_{ENL}$ | EN low threshold voltage | $V_{CC}$ = 6 V | 0.4 | | | V |
| $R_{EN}$ | EN internal pull-down resistance | $V_{CC}$ = 6 V | | 800 | | kΩ |
| $V_{MODEH}$ | MODE high threshold voltage | $V_{CC}$ = 6 V | | | 4.0 | V |
| $V_{MODEL}$ | MODE low threshold voltage | $V_{CC}$ = 6 V | 1.5 | | | V |
| $R_{MODE}$ | MODE internal pull-up resistance | $V_{CC}$ = 6 V | | 800 | | kΩ |
| **OUTPUT** | | | | | | |
| $V_{OUT}$ | Output voltage range | | 4.5 | | 12.6 | V |
| $V_{REF}$ | Reference voltage at the FB pin | PWM mode | 1.186 | 1.204 | 1.222 | V |
| | | PFM mode | | 1.212 | | |
| $I_{LKG_FB}$ | FB pin leakage current | $V_{FB}$ = 1.2 V | | | 100 | nA |
| $I_{SS}$ | Soft-start charging current | | | 5 | | µA |
| **ERROR AMPLIFIER** | | | | | | |
| $I_{SINK}$ | COMP pin sink current | $V_{FB}$ = $V_{REF}$ +200 mV, $V_{COMP}$ = 1.5 V | | 20 | | µA |
| $I_{SOURCE}$ | COMP pin source current | $V_{FB}$ = $V_{REF}$ –200 mV, $V_{COMP}$ = 1.5 V | | 20 | | µA |
| $V_{CCLPH}$ | High clamp voltage at the COMP pin | $V_{FB}$ = 1 V, $R_{ILIM}$ = 100 kΩ | | 2.3 | | V |
| $V_{CCLPL}$ | Low clamp voltage at the COMP pin | $V_{FB}$ = 1.5 V, $R_{ILIM}$ = 100 kΩ, MODE pin floating | | 1.4 | | |
| $G_{EA}$ | Error amplifier transconductance | $V_{COMP}$ = 1.5 V | | 190 | | µA/V |
| **POWER SWITCH** | | | | | | |
| $R_{DS(on)}$ | High-side MOSFET on-resistance | VCC = 6 V | | 13 | 18 | mΩ |
| | Low-side MOSFET on-resistance | VCC = 6 V | | 11 | 16.5 | mΩ |
| **CURRENT LIMIT** | | | | | | |
| $I_{LIM}$ | Peak switch current limit in PFM mode | $R_{ILIM}$ = 100 kΩ, $V_{CC}$ = 6 V, MODE pin floating | 10.6 | 11.9 | 13 | A |
| | Peak switch current limit in FPWM mode | $R_{ILIM}$ = 100 kΩ, $V_{CC}$ = 6 V, MODE pin short to ground | 9.0 | 10.3 | 11.4 | A |
| $V_{ILIM}$ | Reference voltage at the ILIM pin | | | 1.204 | | V |
| **SWITCHING FREQUENCY** | | | | | | |
| $f_{SW}$ | Switching frequency | $R_{FREQ}$ = 301 kΩ, $V_{IN}$ = 3.6 V, $V_{OUT}$ = 12 V | | 500 | | kHz |
| $t_{ON_min}$ | Minimum on-time | $R_{FREQ}$ = 301 kΩ, $V_{IN}$ = 3.6 V, $V_{OUT}$ = 12 V | | 90 | 180 | ns |
| **PROTECTION** | | | | | | |
| $V_{OVP}$ | Output overvoltage protection threshold | $V_{OUT}$ rising | 12.7 | 13.2 | 13.6 | V |

Copyright © 2015, Texas Instruments Incorporated

## Electrical Characteristics (continued)

Minimum and maximum values are at $V_{IN}$ = 2.7 V to 5.5 V and $T_J$ = -40°C to 125°C. Typical values are at $V_{IN}$ = 3.6 V and $T_J$ = 25°C

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{OVP_HYS}$ | Output overvoltage protection hysteresis | $V_{OUT}$ falling below $V_{OVP}$ | | 0.25 | | V |
| **THERMAL SHUTDOWN** | | | | | | |
| $T_{SD}$ | Thermal shutdown threshold | $T_J$ rising | | 150 | | °C |
| $T_{SD_HYS}$ | Thermal shutdown hysteresis | $T_J$ falling below $T_{SD}$ | | 20 | | °C |

## 7.6 Typical Characteristics

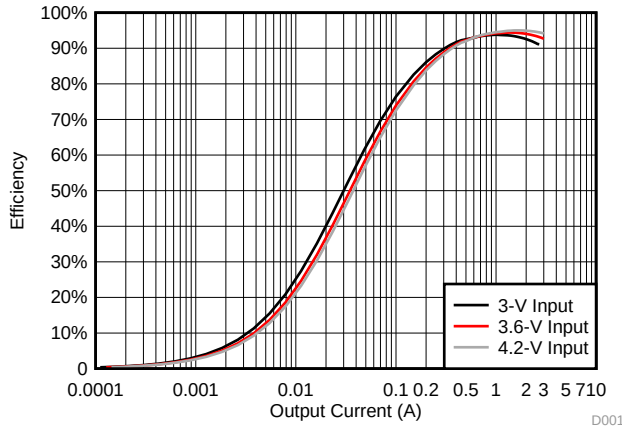



**Figure 1. Efficiency vs Output Current, $V_{OUT}$ = 9 V, FPWM**

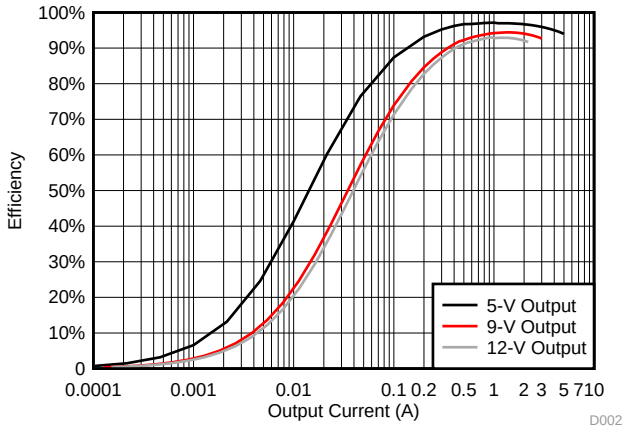



**Figure 2. Efficiency vs Output Current, $V_{IN}$ = 3.6 V, FPWM**

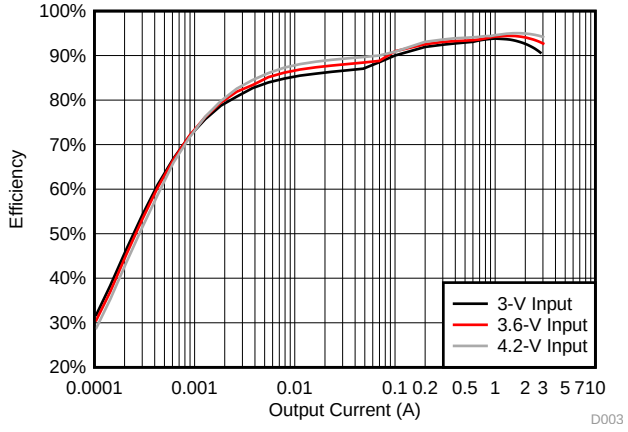



**Figure 3. Efficiency vs Output Current, $V_{OUT}$ = 9 V, PFM**

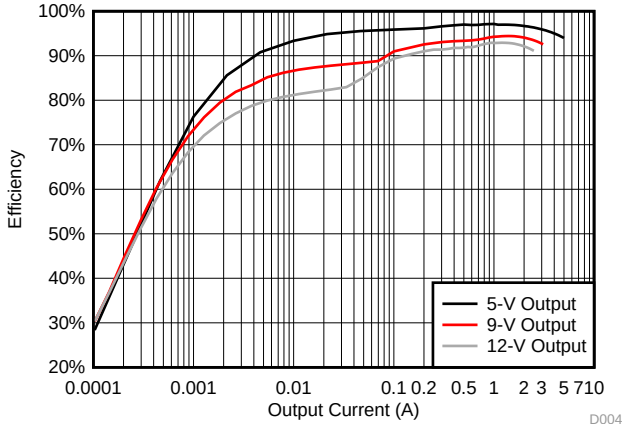



**Figure 4. Efficiency vs Output Current, $V_{IN}$ = 3.6 V, PFM**


Copyright © 2015, Texas Instruments Incorporated

## Typical Characteristics (continued)

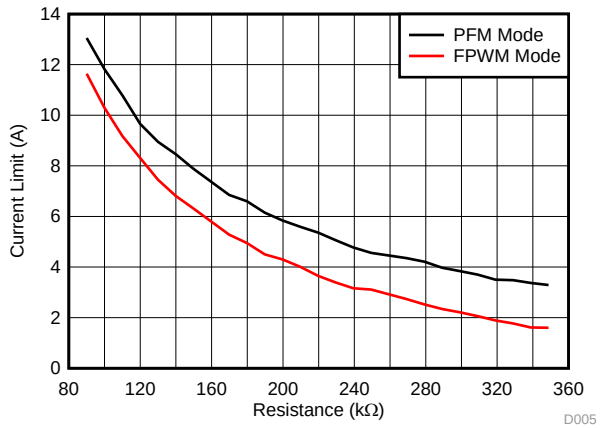



**Figure 5. Current Limit vs Setting Resistance**

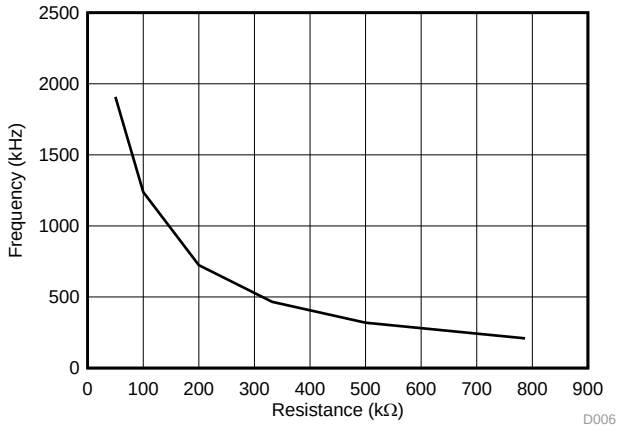



**Figure 6. Switching Frequency vs Setting Resistance**

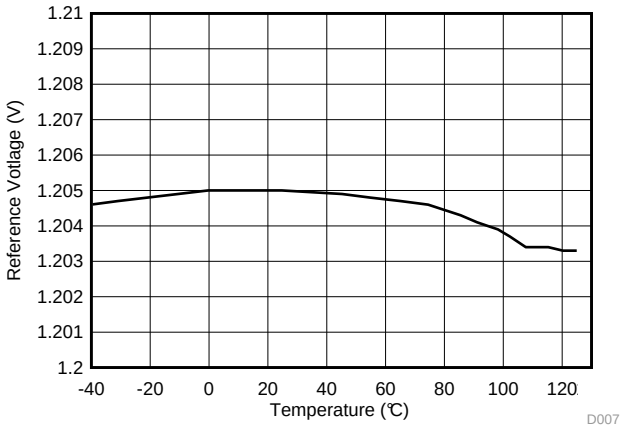



**Figure 7. Reference Voltage vs Temperature**

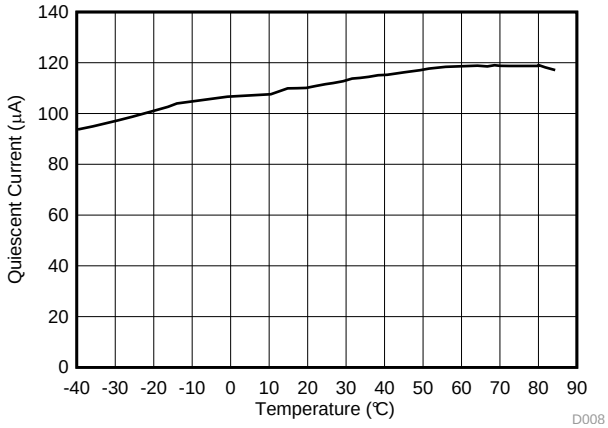



**Figure 8. Quiescent Current vs Temperature**

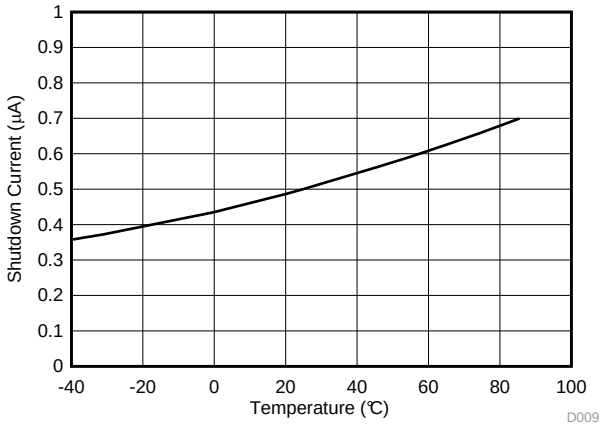



**Figure 9. Shutdown Current vs Temperature**

# 8 Detailed Description

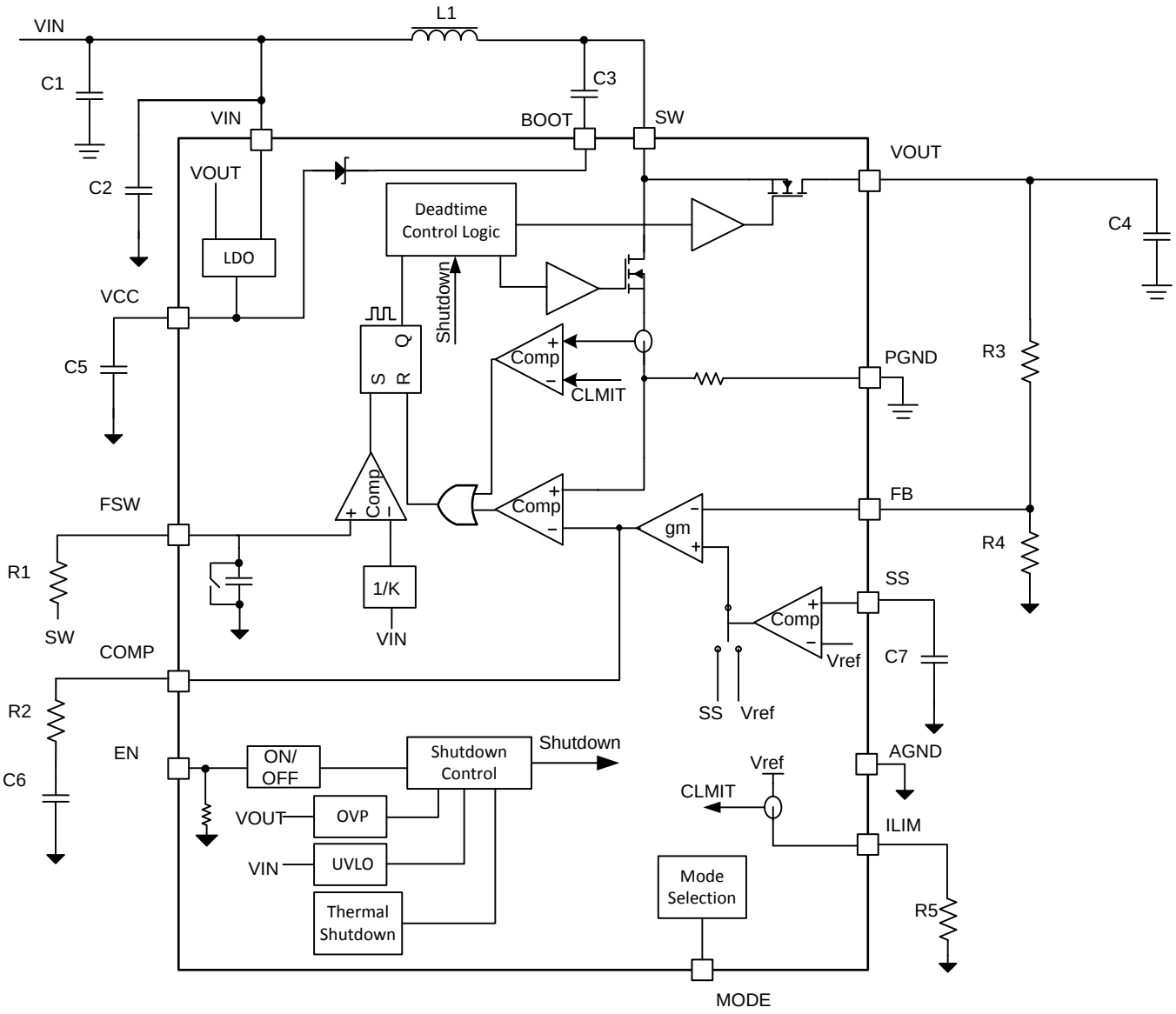
## 8.1 Overview

The TPS61088 is a fully-integrated synchronous boost converter with a 11-mΩ power switch and a 13-mΩ rectifier switch to output high power from a single cell or two-cell Lithium batteries. The device is capable of providing an output voltage of 12.6 V and delivering up to 30-W power from a single cell Lithium battery.

The TPS61088 uses adaptive constant off-time peak current control topology to regulate the output voltage. In moderate to heavy load condition, the TPS61088 works in the quasi-constant frequency pulse width modulation (PWM) mode. The switching frequency in the PWM mode is adjustable ranging from 200 kHz to 2.2 MHz by an external resistor. In light load condition, the device has two operation modes selected by the MODE pin. When the MODE pin is left floating, the TPS61088 works in the pulse frequency modulation (PFM) mode. The PFM mode brings high efficiency at the light load. When the MODE pin is short to ground, the TPS61088 works in the forced PWM mode (FPWM). The FPWM mode can avoid the acoustic noise and other problems caused by the low switching frequency. The TPS61088 implements cycle-by-cycle current limit to protect the device from overload conditions during boost switching. The switch peak current limit is programmable by an external resistor. The TPS61088 uses external loop compensation, which provides flexibility to use different inductors and output capacitors. The adaptive off-time peak current control scheme gives excellent transient line and load response with minimal output capacitance.


Copyright © 2015, Texas Instruments Incorporated

## 8.2 Functional Block Diagram




## 8.3 Feature Description

### 8.3.1 Enable and Startup

The TPS61088 has an adjustable soft start function to prevent high inrush current during start-up. To minimize the inrush current during start-up, an external capacitor, connected to the SS pin and charged with a constant current, is used to slowly ramp up the internal positive input of the error amplifier. When the EN pin is pulled high, the soft-start capacitor $C_{SS}$ (C7 in the *Typical Application Circuit*) is charged with a constant current of 5 µA typically. During this time, the SS pin voltage is compared with the internal reference (1.204 V), the lower one is fed into the internal positive input of the error amplifier. The output of the error amplifier (which determines the inductor peak current value) ramps up slowly as the SS pin voltage goes up. The soft-start phase is completed after the SS pin voltage exceeds the internal reference (1.204 V). The larger the capacitance at the SS pin, the slower the ramp of the output voltage and the longer the soft-start time. A 47-nF capacitor is usually sufficient for most applications. When the EN pin is pulled low, the voltage of the soft-start capacitor is discharged to ground.

Use Equation 1 to calculate the soft-start time.

Copyright © 2015, Texas Instruments Incorporated

## Feature Description (continued)

$$t_{SS} = \frac{V_{REF} \times C_{SS}}{I_{SS}}$$

where

- $t_{SS}$ is the soft start time.
- $V_{REF}$ is the internal reference voltage of 1.204 V.
- $C_{SS}$ is the capacitance between the SS pin and ground.
- $I_{SS}$ is the soft-start charging current of 5 µA. (1)

### 8.3.2 Undervoltage Lockout (UVLO)

The UVLO circuit prevents the device from malfunctioning at low input voltage and the battery from excessive discharge. The TPS61088 has both VIN UVLO function and VCC UVLO function. It disables the device from switching when the falling voltage at the VIN pin trips the UVLO threshold $V_{IN_UVLO}$ , which is typically 2.4 V. The device starts operating when the rising voltage at the VIN pin is 200-mV above the $V_{IN_UVLO}$. It also disables the device when the falling voltage at the VCC pin trips the UVLO threshold $V_{CC_UVLO}$, which is typically 2.1 V.

### 8.3.3 Adjustable Switching Frequency

This device features a wide adjustable switching frequency ranging from 200 kHz to 2.2 MHz. The switching frequency is set by a resistor connected between the FSW pin and the SW pin of the TPS61088. A resistor must always be connected from the FSW pin to SW pin for proper operation. The resistor value required for a desired frequency can be calculated using Equation 2.

$$R_{FREQ} = \frac{4 \times \left(\frac{1}{f_{SW}} - t_{DELAY} \times \frac{V_{OUT}}{V_{IN}}\right)}{C_{FREO}}$$

where

- $R_{FREQ}$ is the resistance connected between the FSW pin and the SW pin.
- $C_{FREQ}$ = 23 pF
- $f_{SW}$ is the desired switching frequency.
- $t_{DELAY}$ = 89 ns
- $V_{IN}$ is the input voltage.
- $V_{OUT}$ is the output voltage. (2)

### 8.3.4 Adjustable Peak Current Limit

To avoid an accidental large peak current, an internal cycle-by-cycle current limit is adopted. The low-side switch is turned off immediately as soon as the switch current touches the limit. The peak switch current limit can be set by a resistor at the ILIM pin to ground. The relationship between the current limit and the resistance depends on the status of the MODE pin.

When the MODE pin is floating, namely the TPS61088 is set to work in the PFM mode at light load, use Equation 3 to calculate the resistor value:

$$I_{LIM} = \frac{1190000}{R_{ILIM}}$$

where

- $R_{ILIM}$ is the resistance between the ILIM pin and ground.
- $I_{LIM}$ is the switch peak current limit. (3)

When the resistor value is 100 kΩ, the typical current limit is 11.9 A.

When the MODE pin is connected to ground, namely the TPS61088 is set to work in the forced PWM mode at light load, use Equation 4 to calculate the resistor value.

$$I_{LIM} = \frac{1190000}{R_{ILIM}} - 1.6 \quad (4)$$


Copyright © 2015, Texas Instruments Incorporated

## Feature Description (continued)

When the resistor value is 100 kΩ. the typical current limit is 10.3 A.

Considering the device variation and the tolerance over temperature, the minimum current limit at the worst case can be 1.3 A lower than the value calculated by above equations.

### 8.3.5 Overvoltage Protection

If the output voltage at the VOUT pin is detected above 13.2 V (typical value), the TPS61088 stops switching immediately until the voltage at the VOUT pin drops the hysteresis value lower than the output overvoltage protection threshold. This function prevents overvoltage on the output and secures the circuits connected to the output from excessive overvoltage.

### 8.3.6 Thermal Shutdown

A thermal shutdown is implemented to prevent damages due to excessive heat and power dissipation. Typically, the thermal shutdown happens at a junction temperature of 150°C. When the thermal shutdown is triggered, the device stops switching until the junction temperature falls below typically 130°C, then the device starts switching again.

## 8.4 Device Functional Modes

### 8.4.1 Operation

The synchronous boost converter TPS61088 operates at a quasi-constant frequency pulse width modulation (PWM) in moderate to heavy load condition. Based on the $V_{IN}$ to $V_{OUT}$ ratio, a circuit predicts the required off-time of the switching cycle. At the beginning of each switching cycle, the low-side N-MOSFET switch, shown in *Functional Block Diagram*, is turned on, and the inductor current ramps up to a peak current that is determined by the output of the internal error amplifier. After the peak current is reached, the current comparator trips, and it turns off the low-side N-MOSFET switch and the inductor current goes through the body diode of the high-side N-MOSFET in a dead-time duration. After the dead-time duration, the high-side N-MOSFET switch is turned on. Because the output voltage is higher than the input voltage, the inductor current decreases. The high-side switch is not turned off until the fixed off-time is reached. After a short dead-time duration, the low-side switch turns on again and the switching cycle is repeated.

In light load condition, the TPS61088 implements two operation modes, PFM mode and forced PWM mode, to meet different application requirements. The operation mode is set by the status of the MODE pin. When the MODE pin is connected to ground, the device works in the forced PWM mode. When the MODE pin is left floating, the device works in the PFM mode.

#### *8.4.1.1 PWM Mode*

In the forced PWM mode, the TPS61088 keeps the switching frequency unchanged in light load condition. When the load current decreases, the output of the internal error amplifier decreases as well to keep the inductor peak current down, delivering less power from input to output. When the output current further reduces, the current through the inductor will decrease to zero during the off-time. The high-side N-MOSFET is not turned off even if the current through the MOSFET is zero. Thus, the inductor current changes its direction after it runs to zero. The power flow is from output side to input side. The efficiency will be low in this mode. But with the fixed switching frequency, there is no audible noise and other problems which might be caused by low switching frequency in light load condition.

#### *8.4.1.2 PFM Mode*

The TPS61088 improves the efficiency at light load with the PFM mode. When the converter operates in light load condition, the output of the internal error amplifier decreases to make the inductor peak current down, delivering less power to the load. When the output current further reduces, the current through the inductor will decrease to zero during the off-time. Once the current through the high side N-MOSFET is zero, the high-side MOSFET is turned off until the beginning of the next switching cycle. When the output of the error amplifier continuously goes down and reaches a threshold with respect to the peak current of $I_{LIM}$ / 12, the output of the error amplifier is clamped at this value and does not decrease any more. If the load current is smaller than what

Copyright © 2015, Texas Instruments Incorporated

## Device Functional Modes (continued)

the TPS61088 delivers, the output voltage increases above the nominal setting output voltage. The TPS61088 extends its off time of the switching period to deliver less energy to the output and regulate the output voltage to 0.7% higher than the nominal setting voltage. With the PFM operation mode, the TPS61088 keeps the efficiency above 80% even when the load current decreases to 1 mA. In addition, the output voltage ripple is much smaller at light load due to low peak current. Refer to Figure 10.

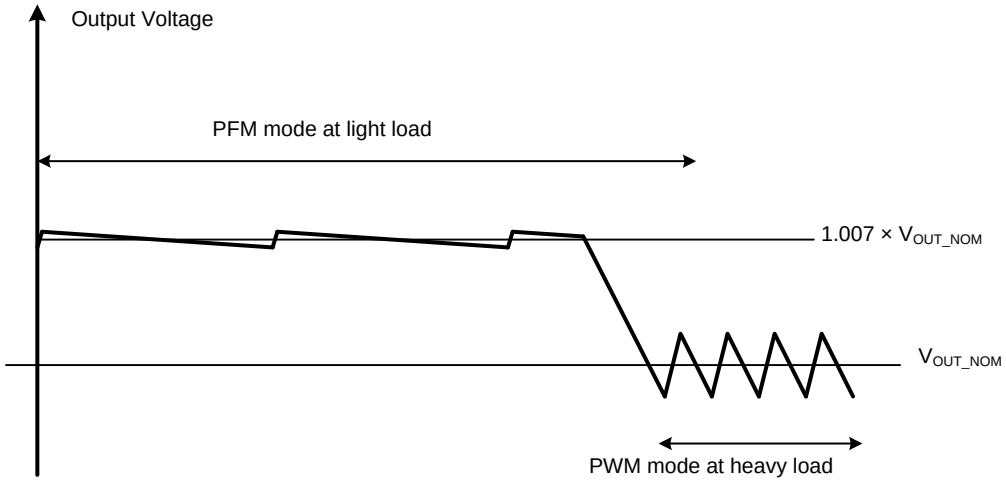



**Figure 10. PFM Mode Diagram**


Copyright © 2015, Texas Instruments Incorporated

# 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 TPS61088 is designed for outputting voltage up to 12.6 V with 10-A switch current capability to deliver more than 30-W power. The TPS61088 operates at a quasi-constant frequency pulse-width modulation (PWM) in moderate to heavy load condition. In light load condition, the converter can either operate in the PFM mode or in the forced PWM mode according to the mode selection. The PFM mode brings high efficiency over entire load range, but the PWM mode can avoid the acoustic noise as the switching frequency is fixed. The converter uses the adaptive constant off-time peak current control scheme, which provides excellent transient line and load response with minimal output capacitance. The TPS61088 can work with different inductor and output capacitor combination by external loop compensation. It also supports adjustable switching frequency ranging from 200 kHz to 2.2 MHz.

## 9.2 Typical Application

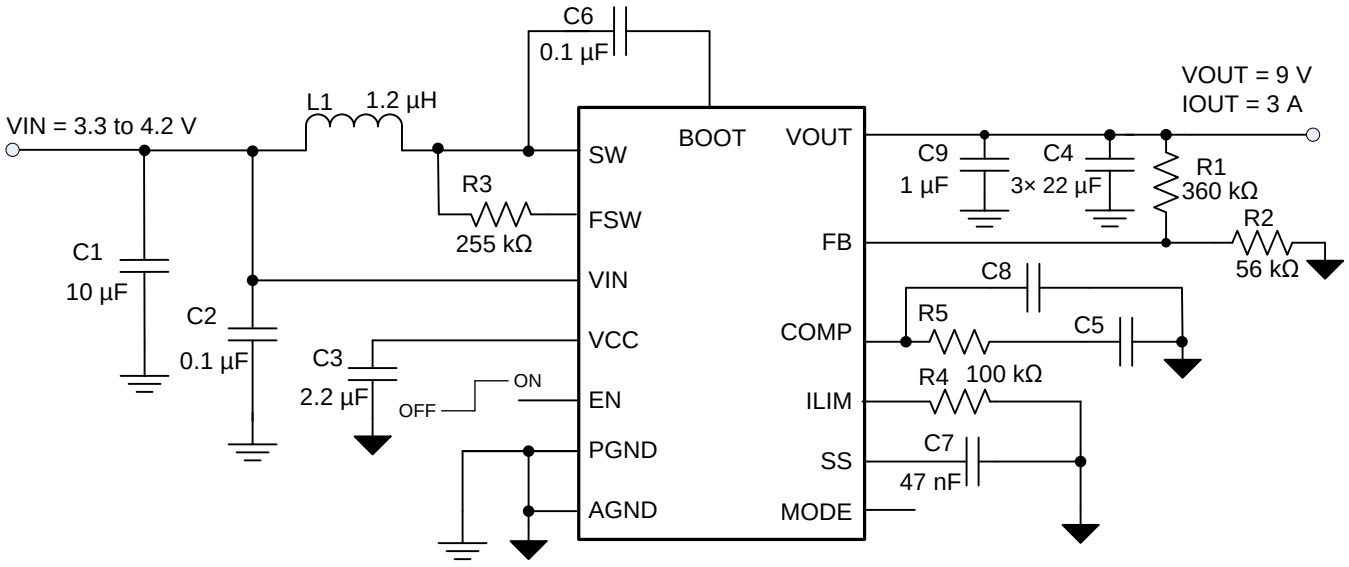



**Figure 11. TPS61088 3.3 V to 9-V/3-A Output Converter**

### 9.2.1 Design Requirements

**Table 1. Design Parameters**

| Design Parameters | Example Values |
|---|---|
| Input voltage range | 3.3 to 4.2 V |
| Output voltage | 9 V |
| Output voltage ripple | 100 mV peak to peak |
| Output current rating | 3 A |
| Operating frequency | 600 kHz |
| Operation mode at light load | PFM |

### 9.2.2 Detailed Design Procedure

#### 9.2.2.1 Setting Switching Frequency

The switching frequency is set by a resistor connected between the FSW pin and the SW pin of the TPS61088. The resistor value required for a desired frequency can be calculated using Equation 5.

$$R_{FREQ} = \frac{4 \times \left( \frac{1}{f_{SW}} - t_{DELAY} \times \frac{V_{OUT}}{V_{IN}} \right)}{C_{FREQ}}$$

where

- $R_{FREQ}$ is the resistance connected between the FSW pin and the SW pin.
- $C_{FREQ}$ = 23 pF
- $f_{SW}$ is the desired switching frequency.
- $t_{DELAY}$ = 89 ns
- $V_{IN}$ is the input voltage.
- $V_{OUT}$ is the output voltage. (5)

#### 9.2.2.2 Setting Peak Current Limit

The peak input current is set by selecting the correct external resistor value correlating to the required current limit. Because the TPS61088 is configured to work in the PFM mode in light load condition, use Equation 6 to calculate the correct resistor value:

$$I_{LIM} = \frac{1190000}{R_{ILIM}}$$

where

- $R_{ILIM}$ is the resistance connected between the ILIM pin and ground.
- $I_{LIM}$ is the switching peak current limit. (6)

For a typical current limit of 11.9 A, the resistor value is 100 kΩ. Considering the device variation and the tolerance over temperature, the minimum current limit at the worst case can be 1.3 A lower than the value calculated by Equation 6. The minimum current limit must be higher than the required peak switch current at the lowest input voltage and the highest output power to make sure the TPS61088 does not hit the current limit and still can regulate the output voltage in these conditions.

#### 9.2.2.3 Setting Output Voltage

The output voltage is set by an external resistor divider (R1, R2 in the *Typical Application Circuit*). Typically, a minimum current of 20 µA flowing through the feedback divider gives good accuracy and noise covering. A standard 56-kΩ resistor is typically selected for low-side resister R2.

The value of R1 is then calculated as:

$$R_1 = \frac{(V_{OUT} - V_{REF}) \times R_2}{V_{REF}} \quad (7)$$

#### 9.2.2.4 Inductor Selection

Because the selection of the inductor affects the power supply's steady state operation, transient behavior, loop stability, and boost converter efficiency, the inductor is the most important component in switching power regulator design. Three most important specifications to the performance of the inductor are the inductor value, DC resistance, and saturation current.

The TPS61088 is designed to work with inductor values between 0.47 and 10 µH. A 0.47-µH inductor is typically available in a smaller or lower-profile package, while a 10-µH inductor produces lower inductor current ripple. If the boost output current is limited by the peak current protection of the IC, using a 10-µH inductor can maximize the controller's output current capability.


Copyright © 2015, Texas Instruments Incorporated

Inductor values can have ±20% or even ±30% tolerance with no current bias. When the inductor current approaches saturation level, its inductance can decrease 20% to 35% from the value at 0-A current depending on how the inductor vendor defines saturation. When selecting an inductor, make sure its rated current, especially the saturation current, is larger than its peak current during the operation.

Follow Equation 8 to Equation 10 to calculate the peak current of the inductor. To calculate the current in the worst case, use the minimum input voltage, maximum output voltage, and maximum load current of the application. To leave enough design margin, TI recommends using the minimum switching frequency, the inductor value with –30% tolerance, and a low-power conversion efficiency for the calculation.

In a boost regulator, calculate the inductor DC current as in Equation 8 .

$$I_{DC} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta} \quad (8)$$

where

- $V_{OUT}$ is the output voltage of the boost regulator.
- $I_{OUT}$ is the output current of the boost regulator.
- $V_{IN}$ is the input voltage of the boost regulator.
- $\eta$ is the power conversion efficiency.

Calculate the inductor current peak-to-peak ripple as in Equation 9.

$$I_{PP} = \frac{1}{L \times \left(\frac{1}{V_{OUT} - V_{IN}} + \frac{1}{V_{IN}}\right) \times f_{SW}} \quad (9)$$

where

- $I_{PP}$ is the inductor peak-to-peak ripple.
- L is the inductor value.
- $f_{SW}$ is the switching frequency.
- $V_{OUT}$ is the output voltage.
- $V_{IN}$ is the input voltage.

Therefore, the peak current, $I_{Lpeak}$, seen by the inductor is calculated with Equation 10.

$$I_{Lpeak} = I_{DC} + \frac{I_{PP}}{2} \quad (10)$$

Set the current limit of the TPS61088 higher than the peak current $I_{Lpeak}$. Then select the inductor with saturation current higher than the setting current limit.

Boost converter efficiency is dependent on the resistance of its current path, the switching loss associated with the switching MOSFETs, and the inductor's core loss. The TPS61088 has optimized the internal switch resistance. However, the overall efficiency is affected significantly by the inductor's DC resistance (DCR), equivalent series resistance (ESR) at the switching frequency, and the core loss. Core loss is related to the core material and different inductors have different core loss. For a certain inductor, larger current ripple generates higher DCR and ESR conduction losses and higher core loss. Usually, a data sheet of an inductor does not provide the ESR and core loss information. If needed, consult the inductor vendor for detailed information. Generally, TI would recommend an inductor with lower DCR and ESR. However, there is a tradeoff among the inductor's inductance, DCR and ESR resistance, and its footprint. Furthermore, shielded inductors typically have higher DCR than unshielded inductors. Table 2 lists recommended inductors for the TPS61088. Verify whether the recommended inductor can support the user's target application with the previous calculations and bench evaluation. In this application, the Sumida's inductor CDMC8D28NP-1R2MC is selected for its small size and low DCR.

Copyright © 2015, Texas Instruments Incorporated

**Table 2. Recommended Inductors**

| Part Number | L (µH) | DCR Max (mΩ) | Saturation Current / Heat Rating Current (A) | Size Max (L × W × H mm) | Vendor |
|---|---|---|---|---|---|
| CDMC8D28NP-1R2MC | 1.2 | 7.0 | 12.2 / 12.9 | 9.5 x 8.7 x 3.0 | Sumida |
| 744311150 | 1.5 | 7.2 | 14.0 / 11.0 | 7.3 x 7.2 x 4.0 | Wurth |
| PIMB104T-2R2MS | 2.2 | 7.0 | 18 / 12 | 11.2 × 10.3 × 4.0 | Cyntec |
| PIMB103T-2R2MS | 2.2 | 9.0 | 16 / 13 | 11.2 × 10.3 × 3.0 | Cyntec |
| PIMB065T-2R2MS | 2.2 | 12.5 | 12 / 10.5 | 7.4 × 6.8 × 5.0 | Cyntec |

#### 9.2.2.5 Input Capacitor Selection

For good input voltage filtering, TI recommends low-ESR ceramic capacitors. The VIN pin is the power supply for the TPS61088. A 0.1-µF ceramic bypass capacitor is recommended as close as possible to the VIN pin of the TPS61088. The VCC pin is the output of the internal LDO. A ceramic capacitor of more than 1.0 µF is required at the VCC pin to get a stable operation of the LDO.

For the power stage, because of the inductor current ripple, the input voltage changes if there is parasite inductance and resistance between the power supply and the inductor. It is recommended to have enough input capacitance to make the input voltage ripple less than 100mV. Generally, 10-µF input capacitance is sufficient for most applications.

**NOTE**

DC bias effect: High-capacitance ceramic capacitors have a DC bias effect, which has a strong influence on the final effective capacitance. Therefore, the right capacitor value must be chosen carefully. The differences between the rated capacitor value and the effective capacitance result from package size and voltage rating in combination with material. A 10-V rated 0805 capacitor with 10 µF can have an effective capacitance of less 5 µF at an output voltage of 5 V.

#### 9.2.2.6 Output Capacitor Selection

For small output voltage ripple, TI recommends a low-ESR output capacitor like a ceramic capacitor. Typically, three 22-µF ceramic output capacitors work for most applications. Higher capacitor values can be used to improve the load transient response. Take care when evaluating a capacitor's derating under DC bias. The bias can significantly reduce capacitance. Ceramic capacitors can lose most of their capacitance at rated voltage. Therefore, leave margin on the voltage rating to ensure adequate effective capacitance. From the required output voltage ripple, use the following equations to calculate the minimum required effective caapctance $C_{OUT}$:

$$V_{ripple_dis} = \frac{(V_{OUT} - V_{IN_MIN}) \times I_{OUT}}{V_{OUT} \times f_{SW} \times C_{OUT}} \quad (11)$$

$$V_{ripple_ESR} = I_{Lpeak} \times R_{C_ESR}$$

where

- $V_{ripple_dis}$ is output voltage ripple caused by charging and discharging of the output capacitor.
- $V_{ripple_ESR}$ is output voltage ripple caused by ESR of the output capacitor.
- $V_{IN_MIN}$ is the minimum input voltage of boost converter.
- $V_{OUT}$ is the output voltage.
- $I_{OUT}$ is the output current.
- $I_{Lpeak}$ is the peak current of the inductor.
- $f_{SW}$ is the converter switching frequency.
- $R_{C_ESR}$ is the ESR of the output capacitors. (12)

#### 9.2.2.7 Loop Stability

The TPS61088 requires external compensation, which allows the loop response to be optimized for each application. The COMP pin is the output of the internal error amplifier. An external compensation network comprised of resister R5, ceramic capacitors C5 and C8 is connected to the COMP pin.


Copyright © 2015, Texas Instruments Incorporated

The power stage small signal loop response of constant off time (COT) with peak current control can be modeled by Equation 13.

$$G_{PS}(S) = \frac{R_O \times (1-D)}{2 \times R_{sense}} \times \frac{\left(1 + \frac{S}{2 \times \pi \times f_{ESRZ}}\right)\left(1 - \frac{S}{2 \times \pi \times f_{RHPZ}}\right)}{1 + \frac{S}{2 \times \pi \times f_P}} \quad (13)$$

where

- D is the switching duty cycle.
- $R_O$ is the output load resistance.
- $R_{sense}$ is the equivalent internal current sense resistor, which is 0.08 Ω.

$$f_P = \frac{2}{2\pi \times R_O \times C_O} \quad (14)$$

where

- $C_O$ is output capacitor.

$$f_{ESRZ} = \frac{1}{2\pi \times R_{ESR} \times C_O} \quad (15)$$

where

- $R_{ESR}$ is the equivalent series resistance of the output capacitor.

$$f_{RHPZ} = \frac{R_O \times (1-D)^2}{2\pi \times L} \quad (16)$$

The COMP pin is the output of the internal transconductance amplifier. Equation 17 shows the small signal transfer function of compensation network.

$$Gc(S) = \frac{G_{EA} \times R_{EA} \times V_{REF}}{V_{OUT}} \times \frac{\left(1 + \frac{S}{2 \times \pi \times f_{COMZ}}\right)}{\left(1 + \frac{S}{2 \times \pi \times f_{COMP1}}\right)\left(1 + \frac{S}{2 \times \pi \times f_{COMP2}}\right)} \quad (17)$$

where

- $G_{EA}$ is the amplifier's transconductance
- $R_{EA}$ is the amplifier's output resistance
- $V_{REF}$ is the refernce voltage at the FB pin
- $V_{OUT}$ is the output voltage
- $f_{COMP1}$, $f_{COMP2}$ are the poles' frequency of the compensation network.
- $f_{COMZ}$ is the zero's frequency of the compensation network.

The next step is to choose the loop crossover frequency, $f_C$. The higher in frequency that the loop gain stays above zero before crossing over, the faster the loop response is. It is generally accepted that the loop gain cross over no higher than the lower of either 1/10 of the switching frequency, $f_{SW}$, or 1/5 of the RHPZ frequency, $f_{RHPZ}$.

Then set the value of R5, C5, and C8 (in Figure 11) by following these equations.

$$R5 = \frac{2\pi \times V_{OUT} \times R_{sense} \times f_C \times C_O}{(1-D) \times V_{REF} \times G_{EA}} \quad (18)$$

where

- $f_C$ is the selected crossover frequency.

The value of C5 can be set by Equation 19.

$$C5 = \frac{R_O \times C_O}{2R5} \quad (19)$$

The value of C8 can be set by Equation 20.

$$C8 = \frac{R_{ESR} \times C_O}{R5} \tag{20}$$

If the calculated value of C8 is less than 10 pF, it can be left open.

Designing the loop for greater than 45° of phase margin and greater than 10-dB gain margin eliminates output votlage ringing during the line and load transient.

### 9.2.3 Application Curves

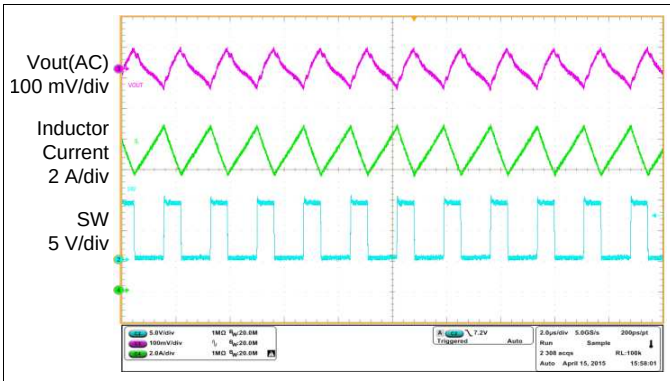



**Figure 12. Switching Waveforms in CCM**

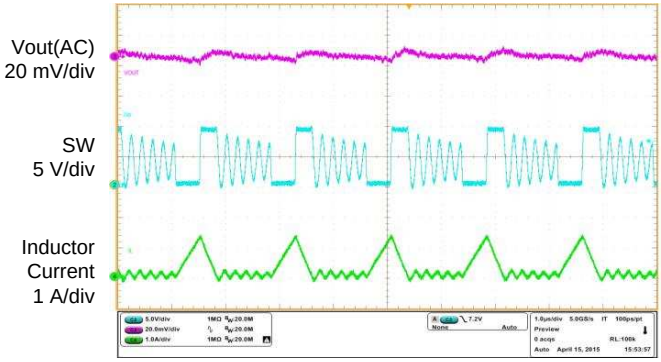



**Figure 13. Switching Waveforms in DCM**

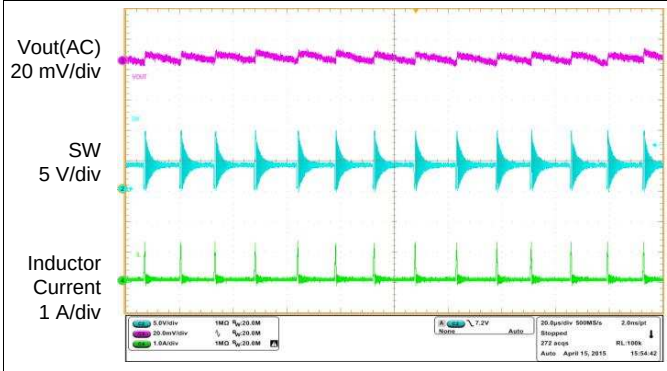



**Figure 14. Switching Waveforms in PFM Mode**

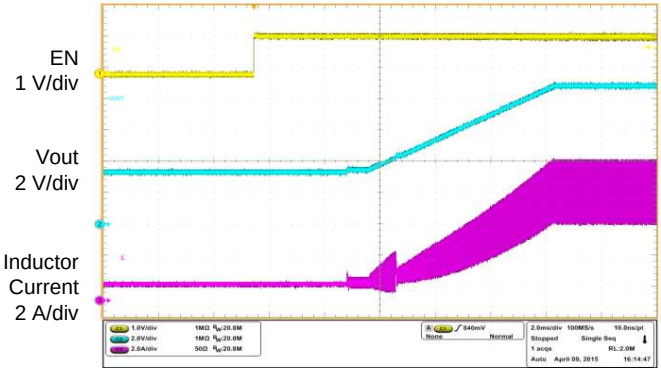



**Figure 15. Startup Waveforms**

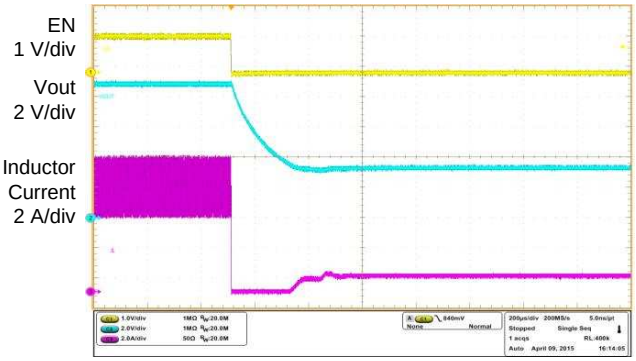



**Figure 16. Shutdown Waveforms**

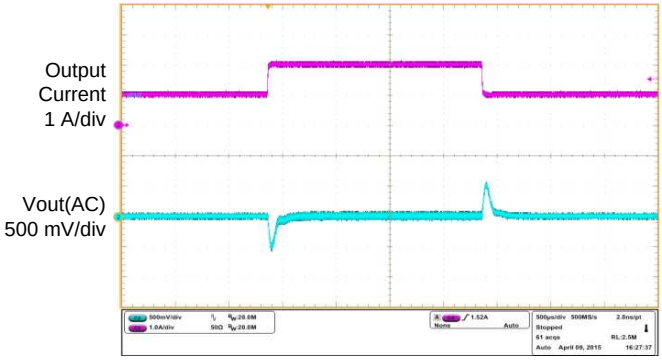



**Figure 17. Load Transient ($V_{OUT}$ = 9 V, $I_{OUT}$ = 1 to 2 A)**


Copyright © 2015, Texas Instruments Incorporated

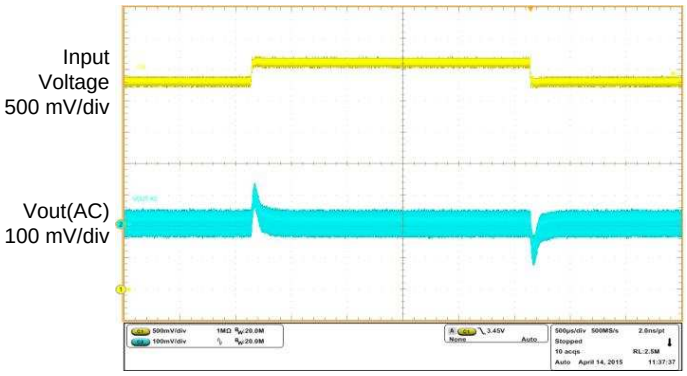



**Figure 18. Line Transient ($V_{OUT}$ = 9 V,$V_{IN}$ = 3.3 to 3.6 V)**

# 10 Power Supply Recommendations

The device is designed to operate from an input voltage supply range between 2.7 V to 12 V. This input supply must be well regulated. If the input supply is located more than a few inches from the converter, additional bulk capacitance may be required in addition to the ceramic bypass capacitors. A typical choice is an electrolytic or tantalum capacitor with a value of 47 µF.

# 11 Layout

## 11.1 Layout Guidelines

As for all switching power supplies, especially those running at high switching frequency and high currents, layout is an important design step. If layout is not carefully done, the regulator could suffer from instability and noise problems. To maximize efficiency, switch rise and fall times are very fast. To prevent radiation of high-frequency noise (for example, EMI), proper layout of the high-frequency switching path is essential. Minimize the length and area of all traces connected to the SW pin, and always use a ground plane under the switching regulator to minimize interplane coupling.

The input capacitor needs to be close to the VIN pin and GND pin in order to reduce the $I_{input}$ supply ripple.

The layout should also be done with well consideration of the thermal as this is a high power density device. A thermal pad that improves the thermal capabilities of the package should be soldered to the large ground plate, using thermal vias underneath the thermal pad.

## 11.2 Layout Example

The bottom layer is a large ground plane connected to the PGND plane and AGND plane on top layer by vias.

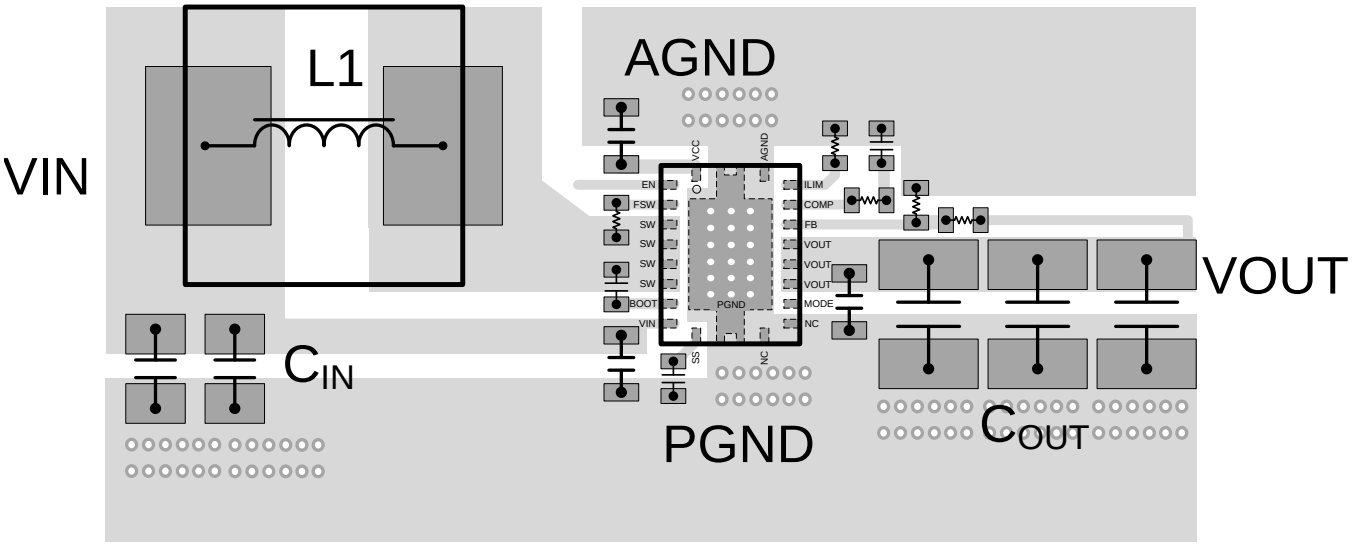



**Figure 19. Bottom Layer**


Copyright © 2015, Texas Instruments Incorporated

## 11.3 Thermal Considerations

The maximum IC junction temperature should be restricted to 125°C under normal operating conditions. Calculate the maximum allowable dissipation, $P_{D(max)}$, and keep the actual power dissipation less than or equal to $P_{D(max)}$. The maximum-power-dissipation limit is determined using Equation 21.

$$P_{D(max)} = \frac{125 - T_A}{R_{\theta JA}} \quad (21)$$

where

- $T_A$ is the maximum ambient temperature for the application.
- $R_{\theta JA}$ is the junction-to-ambient thermal resistance given in the *Thermal Information* table.

The TPS61088 comes in a thermally-enhanced VQFN package. This package includes a thermal pad that improves the thermal capabilities of the package. The real junction-to-ambient thermal resistance of the package greatly depends on the PCB type, layout, and thermal pad connection. Using thick PCB copper and soldering the thermal pad to a large ground plate enhance the thermal performance. Using more vias connects the ground plate on the top layer and bottom layer around the IC without solder mask also improves the thermal capability.

Copyright © 2015, Texas Instruments Incorporated

# 12 Device and Documentation Support

## 12.1 Device Support

### 12.1.1 Third-Party Products Disclaimer

TI'S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

## 12.2 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of Use.

**TI E2E™ Online Community** ***TI's Engineer-to-Engineer (E2E) Community.*** Created to foster collaboration among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** ***TI's Design Support*** Quickly find helpful E2E forums along with design support tools and contact information for technical support.

## 12.3 Trademarks

E2E is a trademark of Texas Instruments.
Bluetooth is a trademark of Bluetooth SIG.
All other trademarks are the property of their respective owners.

## 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.


Copyright © 2015, Texas Instruments Incorporated

## 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS61088RHLR | ACTIVE | VQFN | RHL | 20 | 3000 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | S61088A | Samples |
| TPS61088RHLT | ACTIVE | VQFN | RHL | 20 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | S61088A | Samples |

(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.

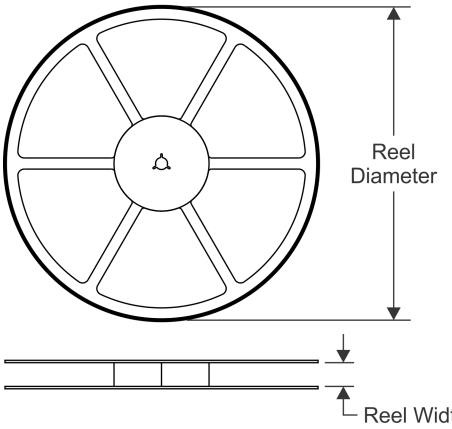
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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

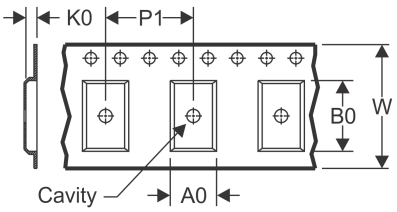
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

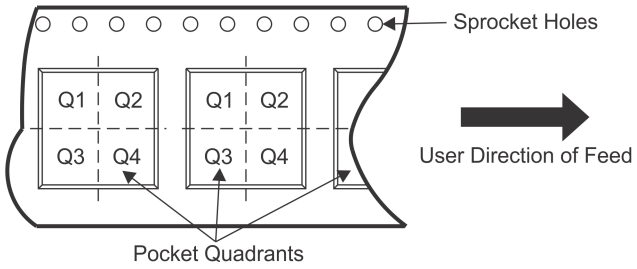



**TAPE DIMENSIONS**




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

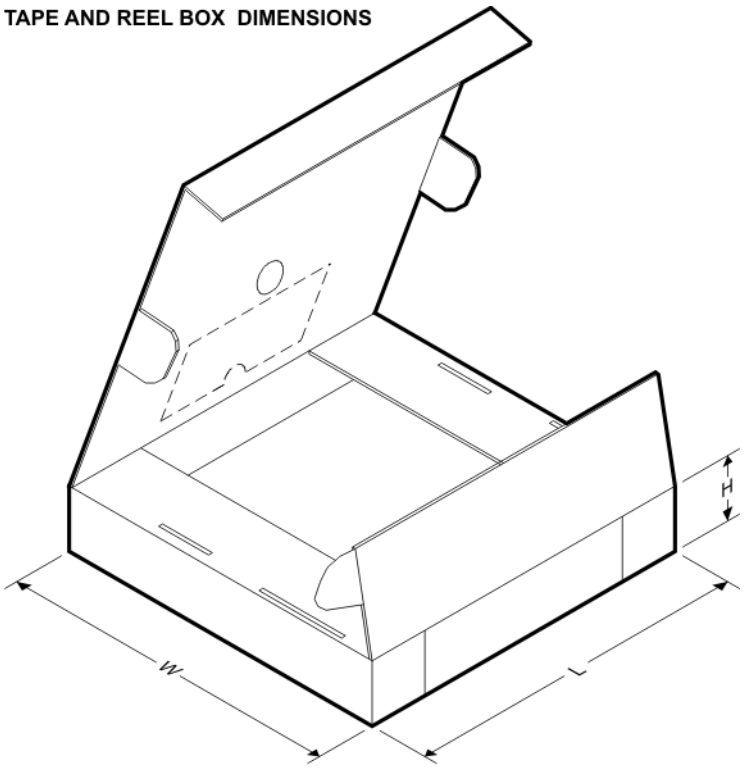
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS61088RHLR | VQFN | RHL | 20 | 3000 | 330.0 | 12.4 | 3.71 | 4.71 | 1.1 | 8.0 | 12.0 | Q1 |
| TPS61088RHLT | VQFN | RHL | 20 | 250 | 180.0 | 12.4 | 3.71 | 4.71 | 1.1 | 8.0 | 12.0 | Q1 |

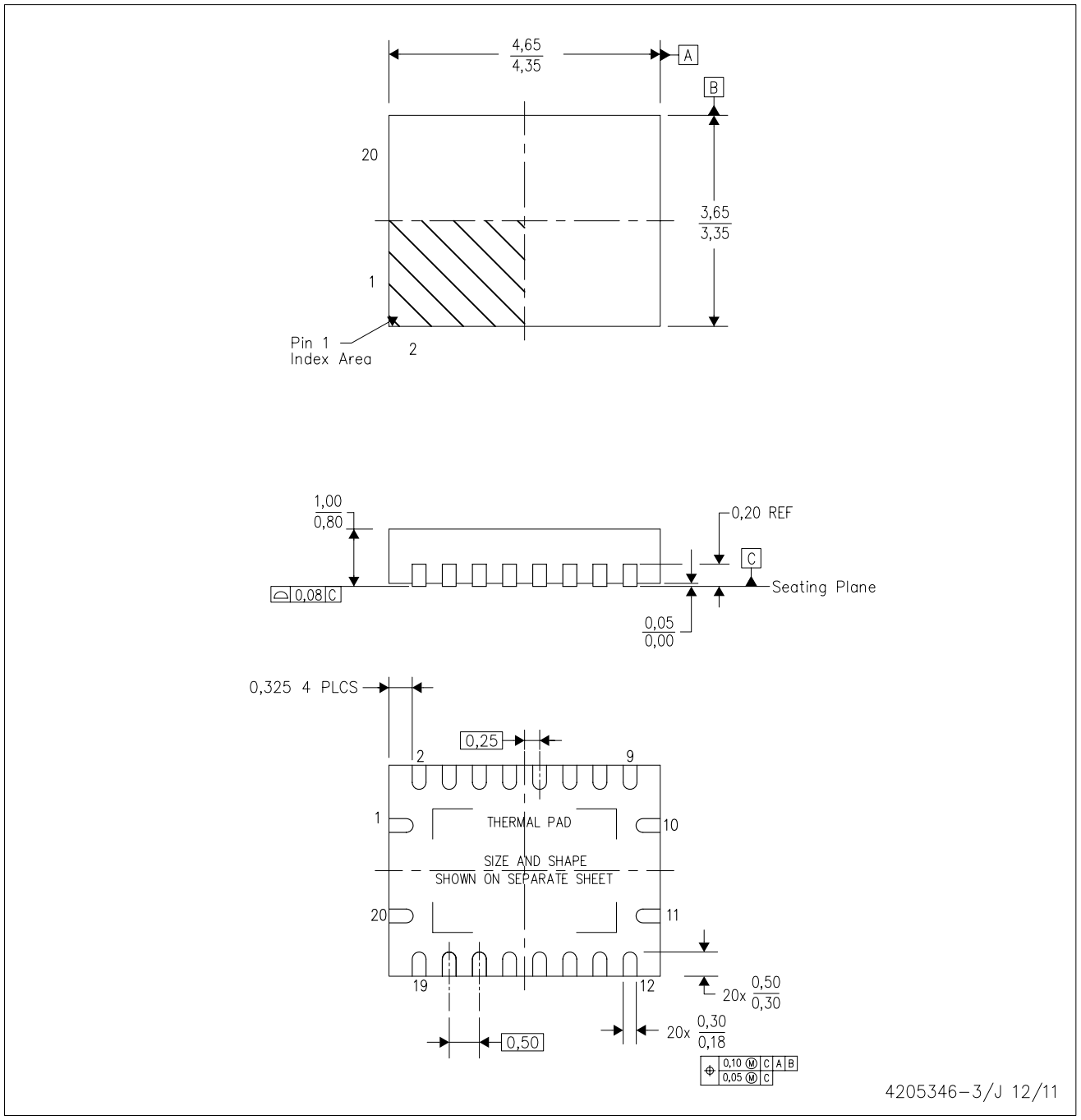
**TAPE AND REEL BOX DIMENSIONS**




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| TPS61088RHLR | VQFN | RHL | 20 | 3000 | 367.0 | 367.0 | 35.0 |
| TPS61088RHLT | VQFN | RHL | 20 | 250 | 210.0 | 185.0 | 35.0 |

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




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. QFN (Quad Flatpack No–Lead) Package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.

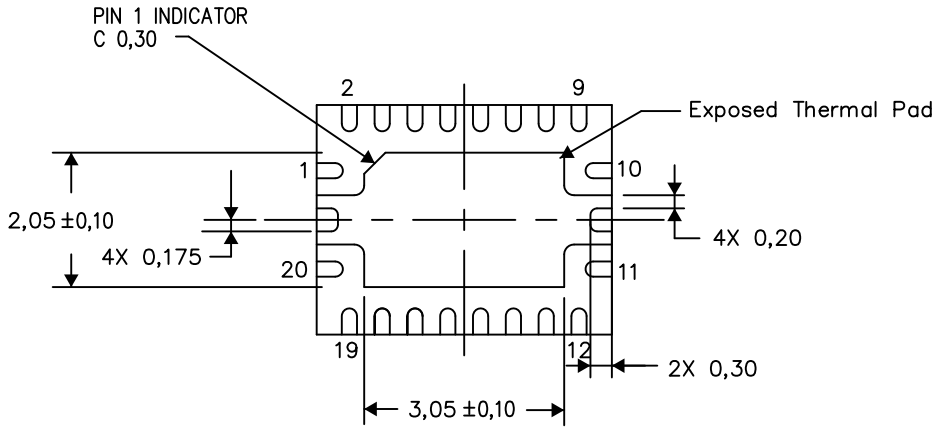
RHL (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



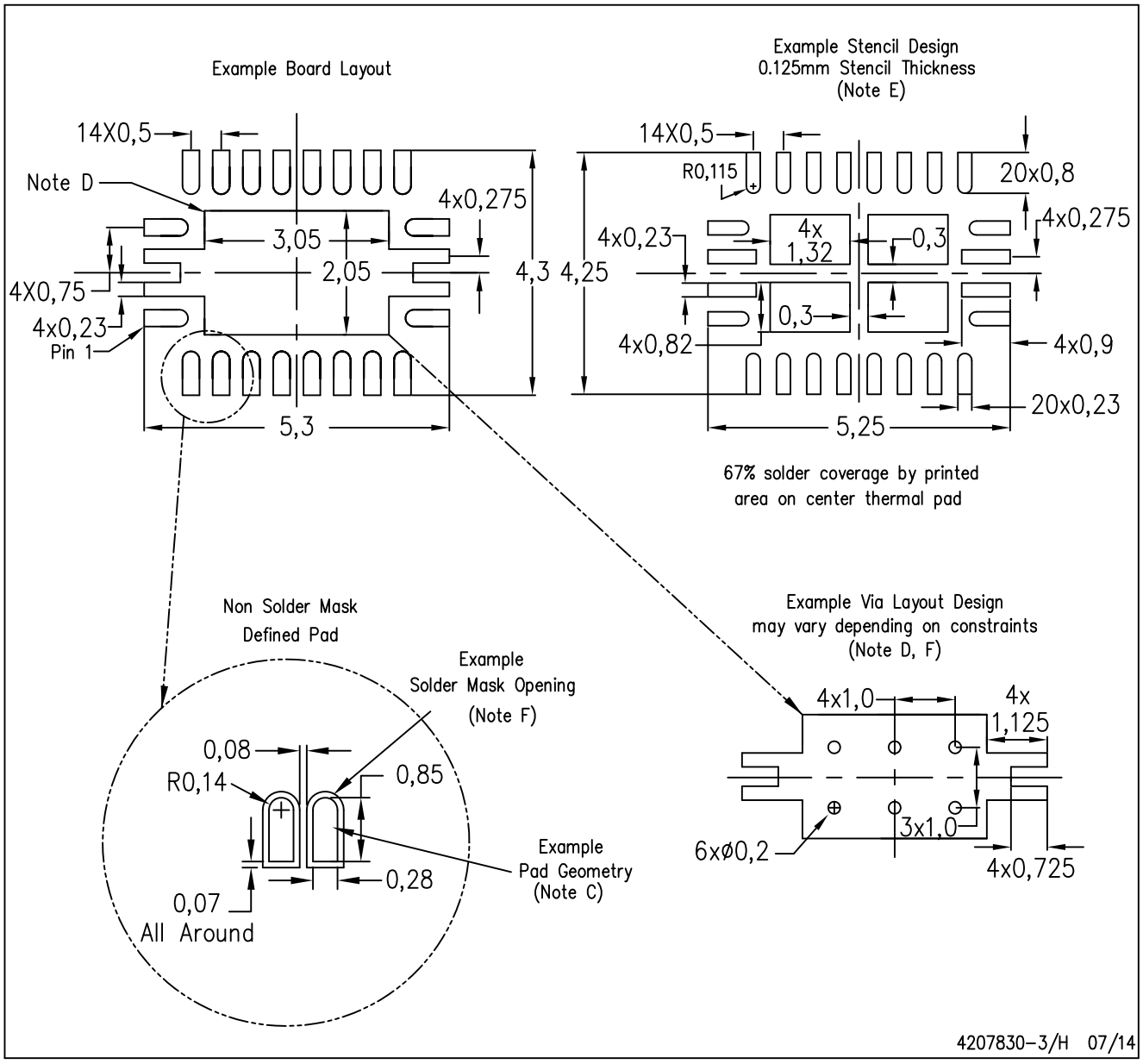

Bottom View

Exposed Thermal Pad Dimensions

4206363–3/N 07/14

NOTE: All linear dimensions are in millimeters

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




NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http://www.ti.com>.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
F. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

| **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
Copyright © 2015, Texas Instruments Incorporated