# TPS6124x 3.5-MHz High Efficiency Step-Up Converter

## 1 Features

- Efficiency > 90% at Nominal Operating Conditions
- Total DC Output Voltage Accuracy 5.0 V±2%
- Typical 30-µA Quiescent Current
- *Best in Class* Line and Load Transient
- Wide $V_{IN}$ Range From 2.3 V to 5.5 V
- Output Current up to 450 mA
- Automatic PFM/PWM Mode Transition
- Low Ripple Power Save Mode for Improved Efficiency at Light Loads
- Internal Softstart, 250-µs Typical Start-Up Time
- 3.5-MHz Typical Operating Frequency
- Load Disconnect During Shutdown
- Current Overload and Thermal Shutdown Protection
- Three Surface-Mount External Components Required (One MLCC Inductor, Two Ceramic Capacitors)
- Total Solution Size <13 $mm^2$
- Available in a 6-Pin DSBGA and 2-mm × 2-mm WSON Package

## 2 Applications

- USB-OTG Applications
- Portable HDMI Applications
- Cell Phones, Smart Phones
- PDAs, Pocket PCs
- Portable Media Players
- Digital Cameras

## 3 Description

The TPS6124x device is a highly efficient synchronous step-up DC-DC converter optimized for products powered by either a three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-Polymer battery. The TPS6124x supports output currents up to 450 mA. The TPS61240 has an input valley current limit of 500 mA, and the TPS61241 has an input valley current of 600 mA.

With an input voltage range of 2.3 V to 5.5 V, the device supports batteries with extended voltage range and are ideal to power portable applications like mobile phones and other portable equipment. The TPS6124x boost converter is based on a quasi-constant on-time valley current mode control scheme.

The TPS6124x presents a high impedance at the $V_{OUT}$ pin when shut down. This allows for use in applications that require the regulated output bus to be driven by another supply while the TPS6124x is shut down.

During light loads the device will automatically pulse skip allowing maximum efficiency at lowest quiescent currents. In the shutdown mode, the current consumption is reduced to less than 1 µA.

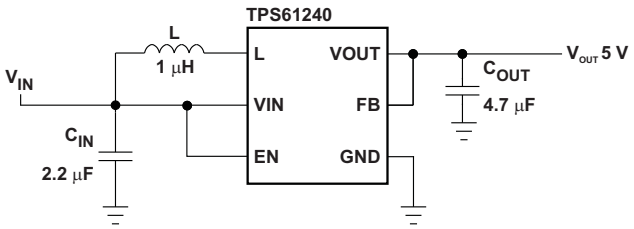
TPS6124x allows the use of small inductors and capacitors to achieve a small solution size. During shutdown, the load is completely disconnected from the battery. The TPS6124x is available in a 6-pin DSBGA and 2-mm × 2-mm WSON package.

**Device Information(1)**

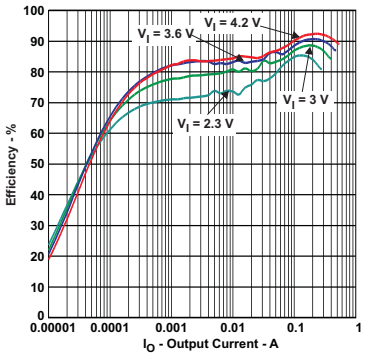
| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| TPS61240 | WSON (6) | 2.00 mm × 2.00 mm |
| | DSBGA (6) | 1.25 mm × 0.86 mm |
| TPS61241 | DSBGA (6) | 1.25 mm × 0.86 mm |

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

**Typical Application Schematic**




**Efficiency vs Output Current**

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## 4 Revision History

**Changes from Revision C (December 2014) to Revision D** **Page**

- Changed $V_{IH}$ Description From: High level input voltage, EN To: High level input voltage threshold, EN in the *Electrical Characteristics* ... 5
- Changed $V_{IL}$ Description From: Low level input voltage, EN To: Low level input voltage threshold, EN in the *Electrical Characteristics* ... 5

**Changes from Revision B (February 2012) to Revision C** **Page**

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


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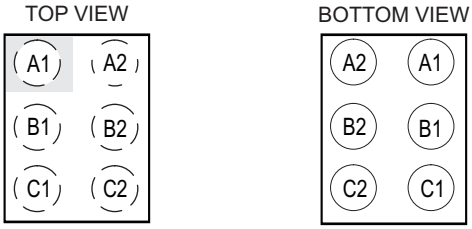
# 5 Device Options

| PART NUMBER(1) | OUTPUT VOLTAGE | DEVICE SPECIFIC FEATURES |
|---|---|---|
| TPS61240 | 5 V | Supports 5 V, up to 250 mA loading down to 3.2 V input voltage |
| | | Supports 5 V, up to 250 mA loading down to 3.2 V input voltage |
| TPS61241 | | Supports 5 V, up to 300 mA loading down to 3.2 V input voltage |
| TPS61242(2) | | Optimized to drive an inductive load |

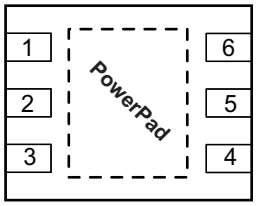
(1) See *Mechanical, Packaging, and Orderable Information* for ordering information.
(2) Product preview. Contact TI factory for more information.

# 6 Pin Configuration and Functions

**DSBGA Package**
**6 Pins**
**Top View**




**WSON Package**
**6 Pins**
**Top View**




## Pin Functions

| PIN | | | I/O | DESCRIPTION | REMARKS |
|---|---|---|---|---|---|
| NAME | WSON | DSGBA | | | |
| EN | 4 | C1 | I | Enable | Positive polarity. Low = IC shutdown. |
| FB | 3 | C2 | I | Feedback input | Feedback for regulation. |
| GND | 1 | A2 | — | Ground | Power ground and IC ground |
| L | 5 | B1 | I | Boost and rectifying switch input | Inductor connection to FETs |
| $V_{IN}$ | 6 | A1 | I | Supply voltage | Supply from battery |
| $V_{OUT}$ | 2 | B2 | O | Output | Connected to load |

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# 7 Specifications

## 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1) (2)

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| $V_I$ | Input voltage on $V_{IN}$, L, EN | –0.3 | 7 | V |
| | Voltage on $V_{OUT}$ | –2.0 | 7 | V |
| | Voltage on FB | –2.0 | 14 | V |
| | Peak output current | Internally limited | | A |
| $T_J$ | Maximum operating junction temperature | –40 | 125 | °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 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.
(2) The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.

## 7.2 ESD Ratings

| | | | VALUE | UNIT |
|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge(1) | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(2) | ±4000 | V |
| | | Charged-device model (CDM), per JEDEC specification JESD22-C101(3) | ±500 | |
| | | Machine model (MM) | ±200 | |

(1) The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.
(2) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 500-V HBM is possible with the necessary precautions.
(3) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process. Manufacturing with less than 250-V CDM is possible with the necessary precautions.

## 7.3 Recommended Operating Conditions

| | | | MIN | NOM | MAX | UNIT |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Input voltage range | | 2.3 | | 5.5 | V |
| L | Inductance | | 0.4 | 1 | 1.5 | µH |
| $C_O$ | Output capacitance | TPS61240 TPS61241 | 1 | | 20 | µF |
| | | TPS61242 | 0.8 | | 10 | µF |
| $T_A$ | Operating ambient temperature | | –40 | | 85 | °C |
| $T_J$ | Operating junction temperature | | –40 | | 125 | |

## 7.4 Thermal Information

| THERMAL METRIC(1) | | TPS6124x | | UNIT |
|---|---|---|---|---|
| | | YFF | DRV | |
| | | 6 PINS | 6 PINS | |
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 132.7 | 104.1 | °C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 1.2 | 97.1 | |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 22.4 | 74.0 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 5.2 | 4.5 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 22.4 | 74.4 | |
| $R_{\theta JC(bot)}$ | Junction-to-case (bottom) thermal resistance | — | 48.4 | |

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


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## 7.5 Electrical Characteristics

Over full operating ambient temperature range, typical values are at $T_A$ = 25°C. Unless otherwise noted, specifications apply for condition $V_{IN}$ = EN = 3.6V. External components $C_{IN}$ = 2.2µF, $C_{OUT}$ = 4.7µF 0603, L = 1µH, refer to Parameter Measurement Information section.

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **DC-DC STAGE** | | | | | | |
| $V_{IN}$ | Input voltage range | | 2.3 | | 5.5 | V |
| $V_{OUT}$ | Fixed output voltage range | 2.3 V ≤ $V_{IN}$ ≤ 5.5 V, 0 mA ≤ $I_{OUT}$ ≤ 200 mA | 4.9 | 5.0 | 5.1 | V |
| $V_{O_Ripple}$ | Ripple voltage, PWM mode | $I_{LOAD}$ = 150 mA | | | 20 | mVpp |
| $I_{SW}$ | Output current | $V_{IN}$ 2.3 V to 5.5 V | 200 | | | mA |
| | Switch valley current limit | $V_{OUT}$ = $V_{GS}$ = 5.0 V (TPS61240) | 500 | 600 | | mA |
| | | $V_{OUT}$ = $V_{GS}$ = 5.0 V (TPS61241, TPS61242) | 600 | 700 | | |
| | Short circuit current | $V_{OUT}$ = $V_{GS}$ = 5.0 V | 200 | 350 | | mApk |
| | High side MOSFET on-resistance(1) | $V_{IN}$ = $V_{GS}$ = 5.0 V, $T_A$ = 25°C(1) | | 290 | | mΩ |
| | Low Side MOSFET on-resistance(1) | $V_{IN}$ = $V_{GS}$ = 5.0 V, $T_A$ = 25°C (1) | | 250 | | mΩ |
| | Operating quiescent current | $I_{OUT}$ = 0 mA, Power save mode | | 30 | 40 | µA |
| | Shutdown current | EN = GND | | | 1.5 | µA |
| | Reverse leakage current $V_{OUT}$ | EN = 0, $V_{OUT}$ = 5 V | | | 2.5 | µA |
| | Leakage current from battery to $V_{OUT}$ | EN = GND | | | 2.5 | µA |
| | Line transient response | $V_{IN}$ 600 mVp-p AC square wave, 200 Hz, 12.5% DC at 50/200 mA load | | ±25 | ±50 | mVpk |
| | Load transient response | 0–50 mA, 50–0 mA $V_{IN}$ = 3.6V $T_{Rise}$ = $T_{Fall}$ = 0.1 µs | | 50 | | mVpk |
| | | 50–200 mA, 200–50 mA, $V_{IN}$ = 3.6 V, $T_{Rise}$ = $T_{Fall}$ = 0.1 µs | | 150 | | |
| $I_{IN}$ | Input bias current, EN | EN = GND or $V_{IN}$ | | 0.01 | 1.0 | µA |
| $V_{UVLO}$ | Undervoltage lockout threshold | Falling | | 2.0 | 2.1 | V |
| | | Rising | | 2.1 | 2.2 | V |
| **CONTROL STAGE** | | | | | | |
| $V_{IH}$ | High level input voltage threshold, EN | 2.3 V ≤ $V_{IN}$ ≤ 5.5 V | | | 1.0 | V |
| $V_{IL}$ | Low level input voltage threshold, EN | 2.3 V ≤ $V_{IN}$ ≤ 5.5 V | 0.4 | | | V |
| OVC | Input overvoltage threshold | Falling | | 5.9 | | V |
| | | Rising | | 6.0 | | |
| $t_{Start}$ | Start-up time | Time from active EN to start switching, no-load until $V_{OUT}$ is stable 5 V | | | 300 | µs |
| **DC-DC STAGE** | | | | | | |
| *f* | | See Figure 7 (Frequency Dependancy vs $I_{OUT}$) | | 3.5 | | MHz |
| $T_{SD}$ | Thermal shutdown | Increasing junction temperature | | 140 | | °C |
| | Thermal shutdown hysteresis | Decreasing junction temperature | | 20 | | °C |

(1) DRV package has an increased $R_{DSon}$ of about 40mΩ due to bond wire resistance.

## 7.6 Typical Characteristics

### 7.6.1 Table of Graphs

| | | Figure |
|---|---|---|
| **Maximum Output Current** | vs Input Voltage | Figure 1 |
| **Efficiency** | vs Output Current, $V_{out}$ = 5V, $V_{in}$ = [2.3 V; 3.0 V; 3.6 V; 4.2 V] | Figure 2 |
| | vs Input Voltage, $V_{out}$ = 5 V, $I_{out}$ = [100 µA; 1 mA; 10 mA; 100 mA; 200 mA] | Figure 3 |
| **Input Current** | at No Output Load, Device Disabled | Figure 4 |
| **Output Voltage** | vs Output Current, $V_{out}$ = 5 V, $V_{in}$ = [2.3 V; 3.0 V; 3.6 V; 4.2 V] | Figure 5 |
| | vs Input Voltage | Figure 6 |
| **Frequency** | vs Output Load, $V_{out}$ = 5 V, $V_{in}$ = [3.0 V; 4.0 V; 5.0 V] | Figure 7 |

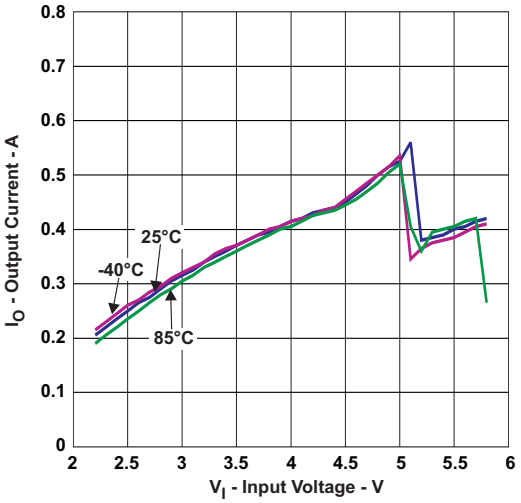


Figure 1. Maximum Output Current vs Input Voltage

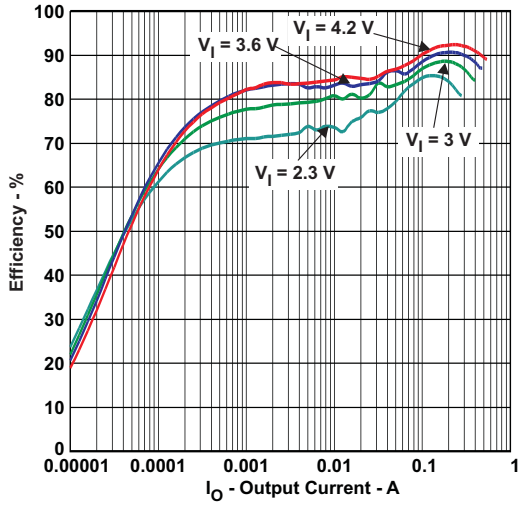


Figure 2. Efficiency vs Output Current

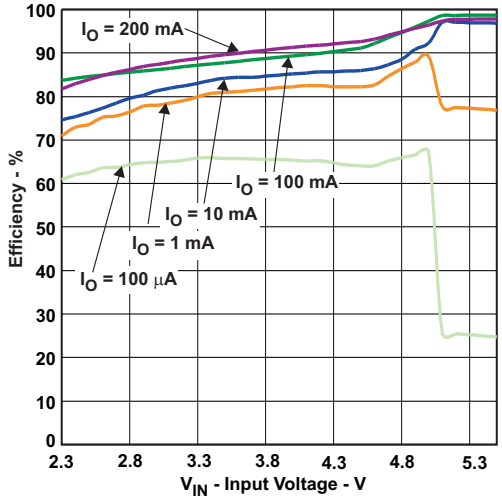


Figure 3. Efficiency vs Input Voltage

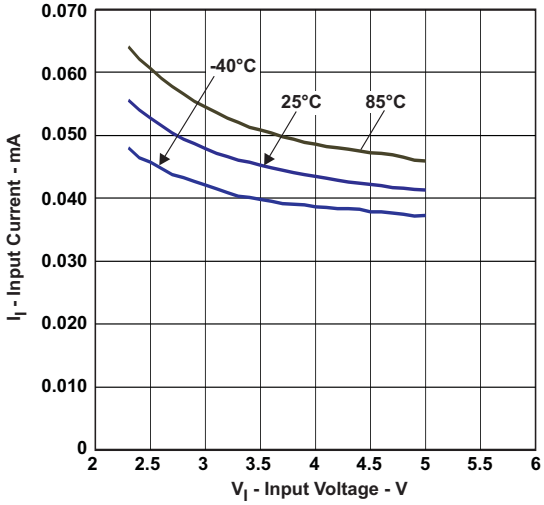


Figure 4. Input at No Output Load


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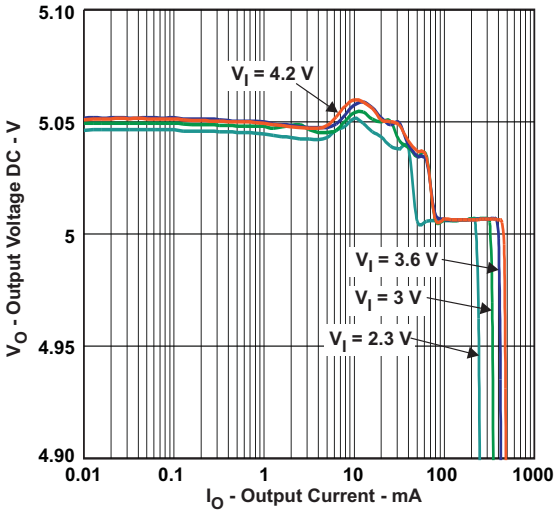


**Figure 5. Output Voltage vs Output Current**

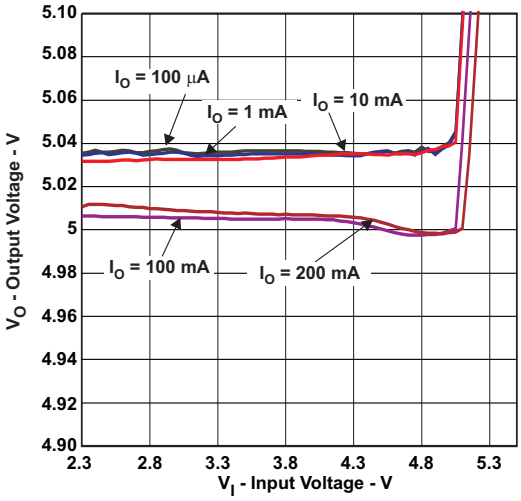


**Figure 6. Output Voltage vs Input Voltage**

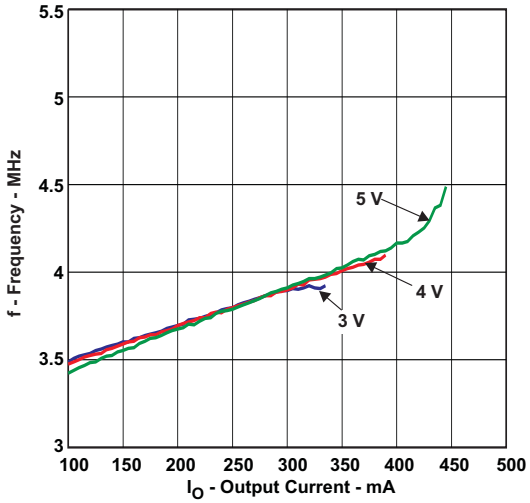


**Figure 7. Frequency vs Output Load**

# 8 Parameter Measurement Information

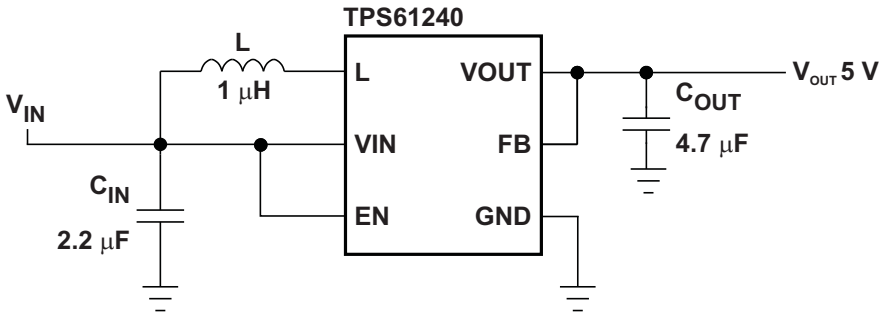


**Figure 8. Parameter Measurement Schematic**


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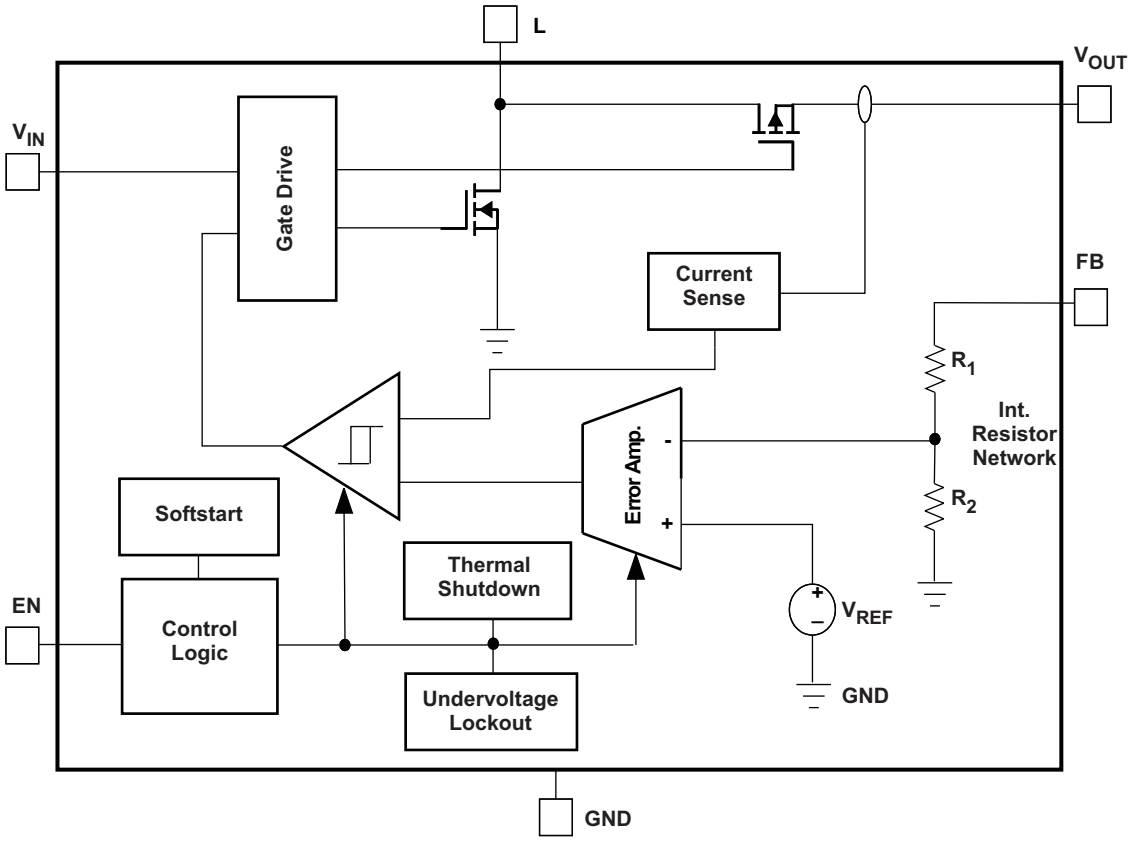
# 9 Detailed Description

## 9.1 Overview

The TPS6124x device is a highly efficient synchronous step-up DC-DC converter optimized for products powered by either a three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-Polymer battery. The TPS6124x supports output currents up to 450 mA. The TPS61240 has an input valley current limit of 500 mA, and the TPS61241 has an input valley current of 600 mA. The TPS6124x boost converter is based on a quasi-constant on-time valley current mode control scheme. TPS6124x allows the use of small inductors and capacitors to achieve a small solution size. During shutdown, the load is completely disconnected from the battery.

## 9.2 Functional Block Diagram




## 9.3 Feature Description

### 9.3.1 Operation

The TPS6124x boost converter operates with typically 3.5-MHz fixed frequency pulse width modulation (PWM) at moderate to heavy load currents. At light load currents the converter will automatically enter power save mode and operates then in PFM (Pulse Frequency Modulation) mode. During PWM operation the converter uses a unique fast response quasi-constant on-time valley current mode controller scheme which allows “Best in Class” line and load regulation allowing the use of small ceramic input and output capacitors.

Based on the $V_{IN}/V_{OUT}$ ratio, a simple circuit predicts the required on-time. At the beginning of the switching cycle, the low-side N-MOS switch is turned-on and the inductor current ramps up to a defined peak current. In the second phase, once the peak current is reached, the current comparator trips, the on-timer is reset turning off the switch, and the current through the inductor then decays to an internally set valley current limit. Once this occurs, the on-timer is set to turn the boost switch back on again and the cycle is repeated.

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## Feature Description (continued)

### 9.3.2 Current Limit Operation

The current limit circuit employs a valley current sensing scheme. Current limit detection occurs during the off time through sensing of the voltage drop across the synchronous rectifier.

The output voltage is reduced as the power stage of the device operates in a constant current mode. The maximum continuous output current ($I_{OUT(CL)}$), before entering current limit operation, can be defined by Equation 1 as shown.

$$I_{OUT(CL)} = (1 - D) \times \left(I_{VALLEY} + \frac{1}{2}\Delta I_L\right) \quad \text{with } \Delta I_L = \frac{V_{IN}}{L} \times \frac{D}{f} \text{ and } D \approx \frac{V_{OUT} - V_{IN}}{V_{OUT}} \tag{1}$$

Figure 9 illustrates the inductor and rectifier current waveforms during current limit operation. The output current, $I_{OUT}$, is the average of the rectifier ripple current waveform. When the load current is increased such that the lower peak is above the current limit threshold, the off time is lengthened to allow the current to decrease to this threshold before the next on-time begins (so called frequency fold-back mechanism).

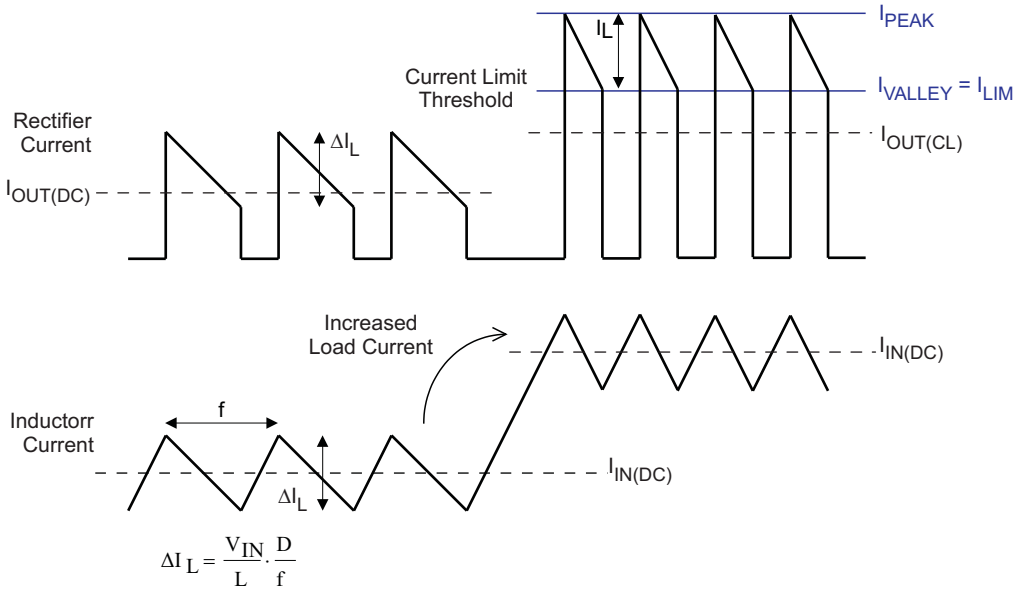


**Figure 9. Inductor/Rectifier Currents in Current Limit Operation**

### 9.3.3 Undervoltage Lockout

The undervoltage lockout circuit prevents the device from malfunctioning at low input voltages and from excessive discharge of the battery. It disables the output stage of the converter once the falling $V_{IN}$ trips the undervoltage lockout threshold $V_{UVLO}$. The undervoltage lockout threshold $V_{UVLO}$ for falling $V_{IN}$ is typically 2.0 V. The device starts operation once the rising VIN trips undervoltage lockout threshold $V_{UVLO}$ again at typically 2.1 V.

### 9.3.4 Input Overvoltage Protection

In the event of an overvoltage condition appearing on the input rail, the output voltage will also experience the overvoltage due to being in dropout condition. A input overvoltage protection feature has been implemented into the TPS6124x which has an input overvoltage threshold of 6.0 V. Once this level is triggered, the device will go into a shutdown mode to protect itself. If the voltage drops to 5.9 V or below, the device will startup once more into normal operation.

### 9.3.5 Enable

The device is enabled setting EN pin to high. At first, the internal reference is activated and the internal analog circuits are settled. Afterwards, the soft start is activated and the output voltage is ramped up. The output voltages reaches its nominal value in typically 250 µs after the device has been enabled.


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## Feature Description (continued)

The EN input can be used to control power sequencing in a system with various DC-DC converters. The EN pin can be connected to the output of another converter, to drive the EN pin high and getting a sequencing of supply rails. With EN = GND, the device enters shutdown mode.

### 9.3.6 Soft Start

The TPS6124x has an internal soft start circuit that controls the ramp up of the output voltage. The output voltages reaches its nominal value within $t_{Start}$ of typically 250µs after EN pin has been pulled to high level. The output voltage ramps up from 5% to its nominal value within $t_{RAMP}$ of typically 300 µs.

This limits the inrush current in the converter during start up and prevents possible input voltage drops when a battery or high impedance power source is used.

During soft start, the switch current limit is reduced to 300 mA until the output voltage reaches $V_{IN}$. Once the output voltage trips this threshold, the device operates with its nominal current limit $I_{LIMT}$.

### 9.3.7 Load Disconnect

Load disconnect electrically removes the output from the input of the power supply when the supply is disabled. This is especially important during shutdown. In shutdown of a boost converter, the load is still connected to the input through the inductor and catch diode. Since the input voltage is still connected to the output, a small current continues to flow, even when the supply is disabled. Even small leakage currents significantly reduce battery life during extended periods of off time.

The benefit of this implemented feature for the system design engineer is that the battery is not depleted during shutdown of the converter. No additional components must be added to the design to make sure that the battery is disconnected from the output of the converter.

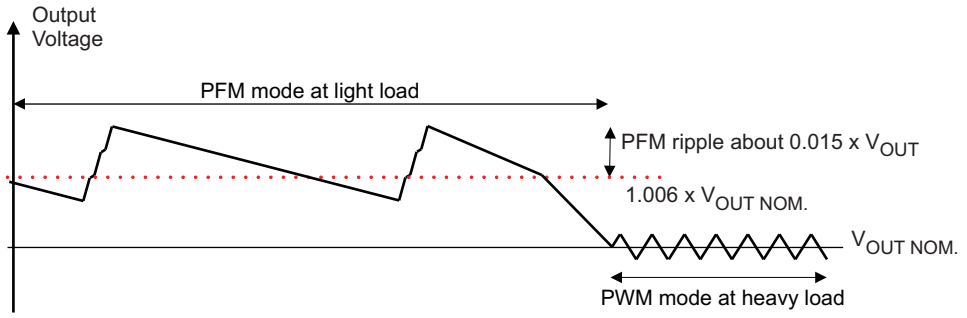
### 9.3.8 Thermal Shutdown

As soon as the junction temperature, $T_J$, exceeds 140°C (typical) the device goes into thermal shutdown. In this mode, the High Side and Low Side MOSFETs are turned-off. When the junction temperature falls below the thermal shutdown hysteresis, the device continuous operation.

## 9.4 Device Functional Modes

### 9.4.1 Power Save Mode

The TPS6124x family of devices integrates a power save mode to improve efficiency at light load. In power save mode the converter only operates when the output voltage trips below a set threshold voltage. It ramps up the output voltage with several pulses and goes into power save mode once the output voltage exceeds the set threshold voltage.




The PFM mode is left and PWM mode entered in case the output current can not longer be supported in PFM mode.

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# 10 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.

## 10.1 Application Information

The TPS6124x device is optimized for products powered by either a three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-Polymer battery. With an input voltage range of 2.3 V to 5.5 V, the device supports batteries with extended voltage range and are ideal to power portable applications like mobile phones and other portable equipment. The TPS6124x supports output currents up to 450 mA.

The TPS6124x presents a high impedance at the $V_{OUT}$ pin and the load is completely disconnected from the battery when shut down. This allows for use in applications that require the regulated output bus to be driven by another supply while the TPS6124x is shut down.

## 10.2 Typical Application

TPS61240 to output fixed 5.0 V for HDMI / USB-OTG applications.

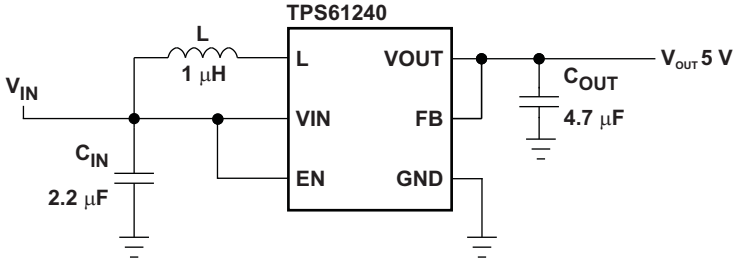


**Figure 10. TPS61240 Fixed 5.0 V for HDMI / USB-OTG Applications**

### 10.2.1 Design Requirements

In this example, the TPS61240 is used to design a 5-V output with 100-mA output current capability. The TPS61240 is powered by either a three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-Polymer battery. In this example, the input voltage range is from 3 V to 4.2 V for a one-cell Li-Ion battery input design.

**Table 1. TPS61240 5V Output Design Requirements**

| Parameters | Value |
|---|---|
| Input Voltage | 3 V to 4.2 V |
| Output Voltage | 5 V |
| Output Current | 100 mA |

### 10.2.2 Detailed Design Procedure

**Table 2. List of Components**

| COMPONENT REFERENCE | PART NUMBER | MANUFACTURER | VALUE |
|---|---|---|---|
| $C_{IN}$ | JMK105BJ225MV | Taiyo Yuden | 2.2 µF, X5R, 6.3 V, 0402 |
| $C_{OUT}$ | JDK105BJ475MV | Taiyo Yuden | 4.7 µF, X5R, 6.3 V, 0402 |
| L | MDT2012-CH1R0AN | TOKO | 1.0 µH, 900mA, 0805 |


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#### 10.2.2.1 Programming the Output Voltage

The output voltage is set by a resistor divider internally. The FB pin is used to sense the output voltage. So to configure the output properly, the FB pin needs to be connected directly to the output.

#### 10.2.2.2 Inductor Selection

To make sure that the TPS6124x devices can operate, an inductor must be connected between pin $V_{IN}$ and pin L. A boost converter normally requires two main passive components for storing energy during the conversion. A boost inductor and a storage capacitor at the output are required. To select the boost inductor, it is recommended to keep the possible peak inductor current below the current limit threshold of the power switch in the chosen configuration. The highest peak current through the inductor and the switch depends on the output load, the input ($V_{IN}$), and the output voltage ($V_{OUT}$). Estimation of the maximum average inductor current can be done using Equation 2.

$$I_{L_MAX} \approx I_{OUT} \times \frac{V_{OUT}}{\eta \times V_{IN}} \tag{2}$$

For example, for an output current of 200 mA at 5.0 V $V_{OUT}$, at least 540 mA of average current flows through the inductor at a minimum input voltage of 2.3 V.

The second parameter for choosing the inductor is the desired current ripple in the inductor. Normally, it is advisable to work with a ripple of less than 20% of the average inductor current. A smaller ripple reduces the magnetic hysteresis losses in the inductor, as well as output voltage ripple and EMI. But in the same way, regulation time at load changes rises. In addition, a larger inductor increases the total system size and cost. With these parameters, it is possible to calculate the value of the minimum inductance by using Equation 3.

$$L_{MIN} \approx \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f \times V_{OUT}} \tag{3}$$

Parameter f is the switching frequency and $\Delta I_L$ is the ripple current in the inductor, i.e., 20% x $I_L$. In this example, the desired inductor has the value of 1.7 µH. With this calculated value and the calculated currents, it is possible to choose a suitable inductor. In typical applications a 1.0-µH inductance is recommended. The device has been optimized to operate with inductance values between 1.0 µH and 2.2 µH. It is recommended that inductance values of at least 1.0 µH is used, even if Equation 3 yields something lower. Care has to be taken that load transients and losses in the circuit can lead to higher currents as estimated in Equation 3. Also, the losses in the inductor caused by magnetic hysteresis losses and copper losses are a major parameter for total circuit efficiency.

With the chosen inductance value, the peak current for the inductor in steady state operation can be calculated. Equation 4 shows how to calculate the peak current I.

$$I_{L(peak)} = \frac{V_{IN} \times D}{2 \times f \times L} + \frac{I_{OUT}}{(1 - D) \times \eta} \quad \text{with} \quad D = \frac{V_{OUT} - V_{IN}}{V_{OUT}} \tag{4}$$

This would be the critical value for the current rating for selecting the inductor. It also needs to be taken into account that load transients and error conditions may cause higher inductor currents.

**Table 3. List of Inductors**

| MANUFACTURER | SERIES | DIMENSIONS |
|---|---|---|
| TOKO | MDT2012-CH1R0AN | 2.0 x 1.2 x 1.0 max. height |
| | MDT1608-CH1R0N | 1.6 x 0.8 x 0.95 max. height |
| Hitachi Metals | KSLI-201210AG-1R0 | 2.0 x 1.2 x 1.0 max. height |
| | KSLI-201610AG-1R0 | 2.0 x 1.6 x 1.0 max. height |
| muRata | LQM21PN1R0MC0 | 2.0 x 1.2 x 0.55 max. height |
| FDK | MIPS2012D1R0-X2 | 2.0 x 1.2 x 1.0 max. height |

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#### 10.2.2.3 Input Capacitor

At least 2.2-µF input capacitor is recommended to improve transient behavior of the regulator and EMI behavior of the total power supply circuit. It is recommended to place a ceramic capacitor as close as possible to the VIN and GND pins.

#### 10.2.2.4 Output Capacitor

For the output capacitor, it is recommended to use small ceramic capacitors placed as close as possible to the $V_{OUT}$ and GND pins of the IC. If, for any reason, the application requires the use of large capacitors which can not be placed close to the IC, using a smaller ceramic capacitor in parallel to the large one is recommended. This small capacitor should be placed as close as possible to the $V_{OUT}$ and GND pins of the IC. To get an estimate of the recommended minimum output capacitance, Equation 5 can be used.

$$C_{min} = \frac{I_{OUT} \times (V_{OUT} - V_{IN})}{f \times \Delta V \times V_{OUT}} \quad (5)$$

where

- f is the switching frequency
- ΔV is the maximum allowed ripple

With a chosen ripple voltage of 10 mV, a minimum effective capacitance of 2.7 µF is needed. The total ripple is larger due to the ESR of the output capacitor. This additional component of the ripple can be calculated using $\Delta V_{ESR} = I_{OUT} \times R_{ESR}$.

A capacitor with a value in the range of the calculated minimum should be used. This is required to maintain control loop stability. There are no additional requirements regarding minimum ESR. There is no upper limit for the output capacitance value. Larger capacitors cause lower output voltage ripple as well as lower output voltage drop during load transients.

Note that ceramic capacitors have a DC Bias effect, which will have a strong influence on the final effective capacitance needed. Therefore the right capacitor value has to be chosen carefully. Package size and voltage rating in combination with material are responsible for differences between the rated capacitor value and the effective capacitance.

#### 10.2.2.5 Checking Loop Stability

The first step of circuit and stability evaluation is to look from a steady-state perspective at the following signals:

- Switching node, SW
- Inductor current, $I_L$
- Output ripple voltage, $V_{O(AC)}$

These are the basic signals that need to be measured when evaluating a switching converter. When the switching waveform shows large duty cycle jitter or the output voltage or inductor current shows oscillations, the regulation loop may be unstable. This is often a result of board layout and/or L-C combination.

As a next step in the evaluation of the regulation loop, the load transient response is tested. The time between the application of the load transient and the turn on of the P-channel MOSFET, the output capacitor must supply all of the current required by the load. $V_O$ immediately shifts by an amount equal to $\Delta I_{(LOAD)} \times$ ESR, where ESR is the effective series resistance of $C_O$. $\Delta I_{(LOAD)}$ begins to charge or discharge $C_O$ generating a feedback error signal used by the regulator to return $V_O$ to its steady-state value. The results are most easily interpreted when the device operates in PWM mode. During this recovery time, $V_O$ can be monitored for settling time, overshoot or ringing that helps judge the converter's stability. Without any ringing, the loop has usually more than 45° of phase margin. Because the damping factor of the circuitry is directly related to several resistive parameters (for example, MOSFET $r_{DS(on)}$) that are temperature dependant, the loop stability analysis has to be done over the input voltage range, load current range, and temperature range.


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### 10.2.3 Application Curves

| | FIGURE |
|---|---|
| Output Voltage Ripple, PFM Mode, $I_{out}$ = 10 mA | Figure 11 |
| Output Voltage Ripple, PWM Mode, $I_{out}$ = 150 mA | Figure 12 |
| Load Transient Response, $V_{in}$ = 3.6 V, 0 - 50 mA | Figure 13 |
| Load Transient Response, $V_{in}$ = 3.6 V, 50 - 200 mA | Figure 14 |
| Line Transient Response, $V_{in}$ = 3.6 V - 4.2 V, $I_{out}$ = 50 mA | Figure 15 |
| Line Transient Response, $V_{in}$ = 3.6 V - 4.2 V, $I_{out}$ = 200 mA | Figure 16 |
| Startup after Enable, $V_{in}$ = 3.6 V, $V_{out}$ = 5 V, Load = 5 KΩ | Figure 17 |
| Startup after Enable, $V_{in}$ = 3.6 V, $V_{out}$ = 5 V, Load = 16.5 Ω | Figure 18 |
| Startup and Shutdown, $V_{in}$ = 3.6 V, $V_{out}$ = 5 V, Load = 16.5 Ω | Figure 19 |

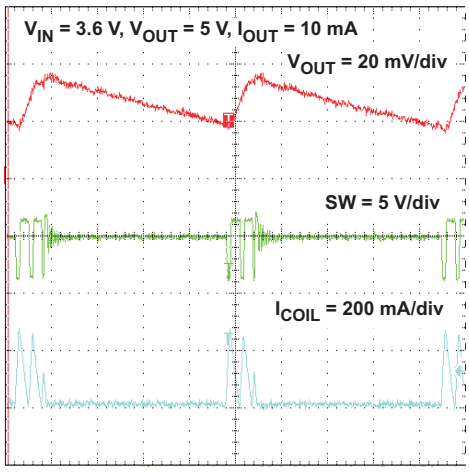


**Figure 11. Output Voltage Ripple – PFM Mode**

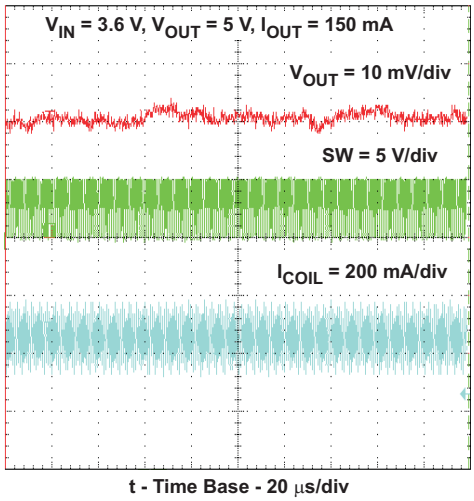


**Figure 12. Output Voltage Ripple – PWM Mode**

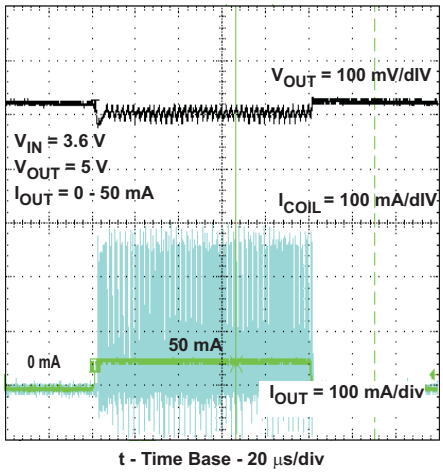


**Figure 13. Load Transient Response 0 mA – 50 mA and 50 mA – 0 mA**

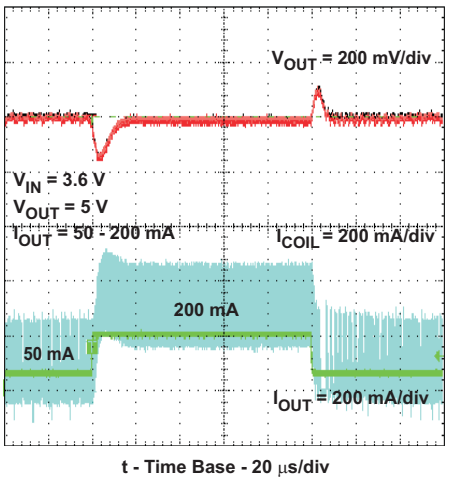


**Figure 14. Load Transient Response 0 mA – 200 mA and 200 mA – 0 mA**

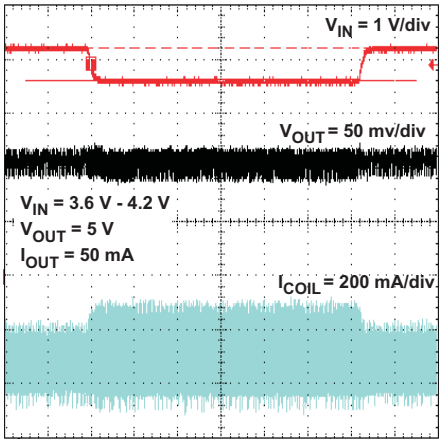


**Figure 15. Line Transient Response 3.6 V – 4.2 V at 50 mA Load**

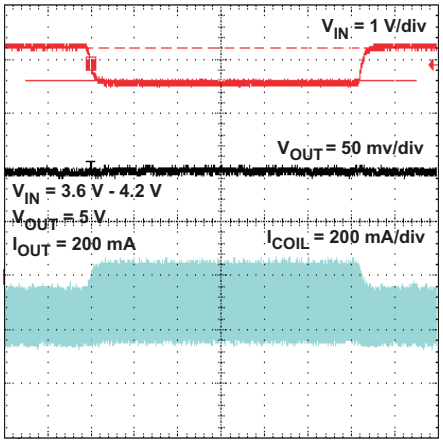


**Figure 16. Line Transient Response 3.6 V – 4.2 V at 200 mA Load**

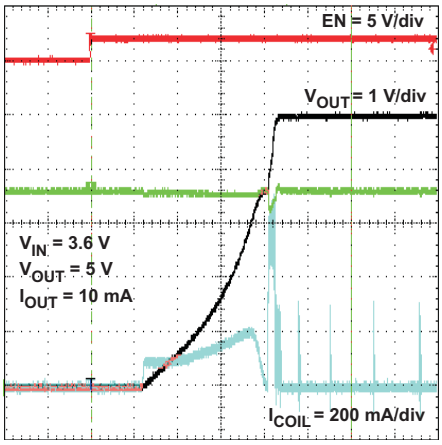


**Figure 17. Startup After Enable – No Load**

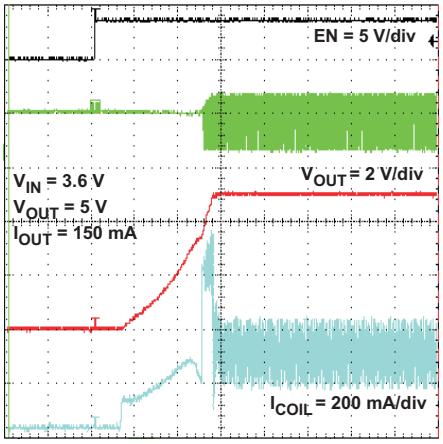


**Figure 18. Startup After Enable – With Load**

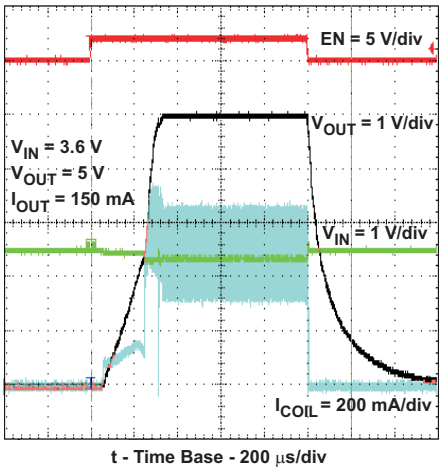


**Figure 19. Startup and Shutdown**


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## 10.3 System Examples

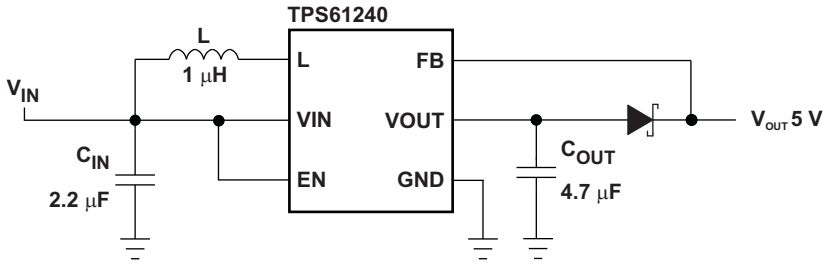


**Figure 20. TPS61240 Fixed 5.0 V With Schottky Diode for Output Overvoltage Protection**

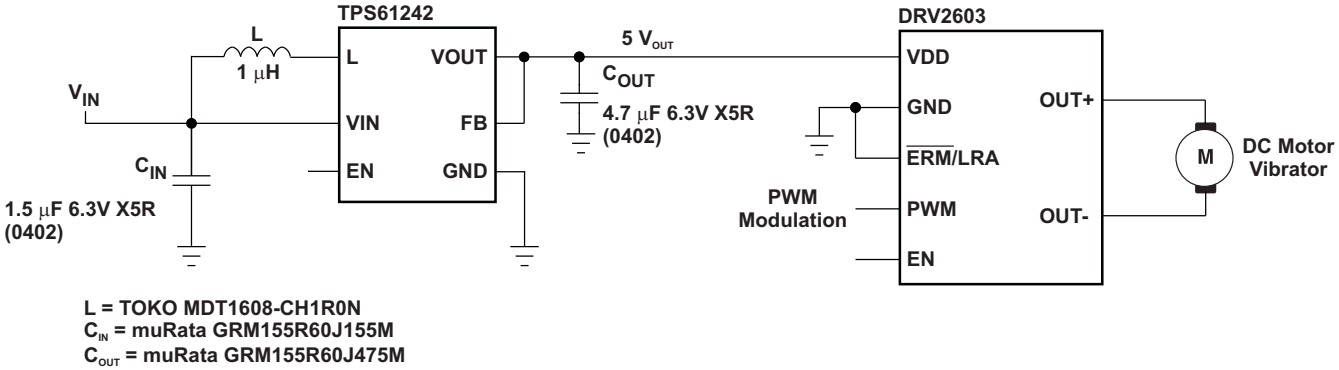


**Figure 21. DRV2603 + TPS61242 Haptic Driver Solution featuring PWM Modulation Control**

## 11 Power Supply Recommendations

The power supply can be a three-cell alkaline, NiCd or NiMH, or one-cell Li-Ion or Li-Polymer battery. The input supply should be well regulated with the rating of TPS6124x. If the input supply is located more than a few inches from the device, additional bulk capacitance may be required in addition to the ceramic bypass capacitors. An electrolytic or tantalum capacitor with a value of 47 µF is a typical choice.

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# 12 Layout

## 12.1 Layout Guidelines

As for all switching power supplies, the layout is an important step in the design, especially at high peak currents and high switching frequencies. If the layout is not carefully done, the regulator could show stability problems as well as EMI problems. Therefore, use wide and short traces for the main current path and for the power ground tracks. The input and output capacitor, as well as the inductor should be placed as close as possible to the IC.

Use a common ground node for power ground and a different one for control ground to minimize the effects of ground noise. Connect these ground nodes at any place close to one of the ground pins of the IC. The feedback divider should be placed as close as possible to the control ground pin of the IC. To lay out the control ground, it is recommended to use short traces as well, separated from the power ground traces. This avoids ground shift problems, which can occur due to superimposition of power ground current and control ground current.

## 12.2 Layout Example

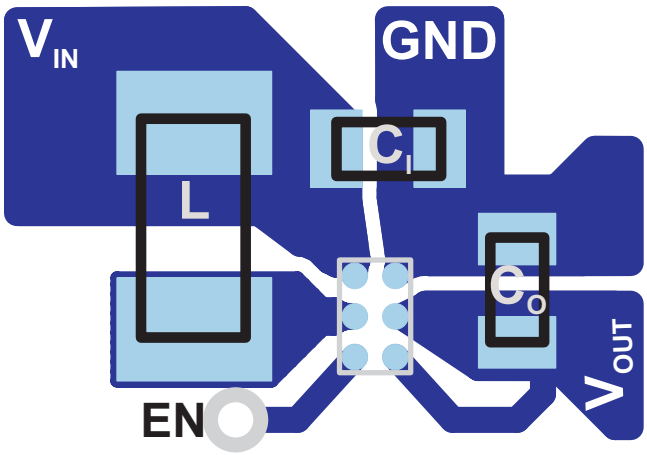


**Figure 22. Suggested Layout (Top)**

## 12.3 Thermal Considerations

Implementation of integrated circuits in low-profile and fine-pitch surface-mount packages typically requires special attention to power dissipation. Many system-dependant issues such as thermal coupling, airflow, added heat sinks, and convection surfaces, and the presence of other heat-generating components, affect the power-dissipation limits of a given component.

Three basic approaches for enhancing thermal performance are listed below:

- Improving the power dissipation capability of the PCB design
  - For example, increase of the GND plane on the top layer which is connected to the exposed thermal pad
  - Use thicker copper layer
- Improving the thermal coupling of the component to the PCB
- Introducing airflow in the system

The maximum recommended junction temperature ($T_J$) of the TPS6124x is 105°C. The thermal resistance of the 6-pin CSP package (YFF-6) is $R_{\theta JA}$ = 133 °C/W. Regulator operation is specified to a maximum steady-state ambient temperature $T_A$ of 85°C. Therefore, the maximum power dissipation is about 150 mW.

$$P_{D(Max)} = [T_{J\ (max)} - T_A\ ] / \theta_{JA} = [105°C - 85°C] / 133\ °C/W = 150\ mW \quad (6)$$


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# 13 Device and Documentation Support

## 13.1 Device Support

### 13.1.1 Third-Party Products Disclaimer

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## 13.2 Related Links

The table below lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

**Table 4. Related Links**

| PARTS | PRODUCT FOLDER | SAMPLE & BUY | TECHNICAL DOCUMENTS | TOOLS & SOFTWARE | SUPPORT & COMMUNITY |
|---|---|---|---|---|---|
| TPS61240 | Click here | Click here | Click here | Click here | Click here |
| TPS61241 | Click here | Click here | Click here | Click here | Click here |

## 13.3 Trademarks

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

## 13.4 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.

## 13.5 Glossary

SLYZ022 — *TI Glossary*.

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

# 14 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.

## 14.1 Chip Scale Package Dimensions

The TPS6124x device is available in a 6-bump chip scale package (YFF, NanoFree™). The package dimensions are given as:

| D | E |
|---|---|
| Max = 1280 µm | Max = 890 µm |
| Min = 1220 µm | Min = 830 µm |

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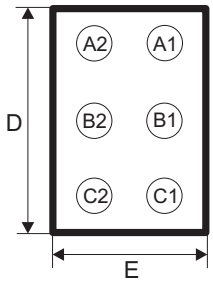
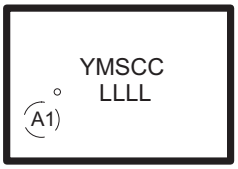
Chip Scale Package
(Bottom View)




Chip Scale Package
(Top View)




Code:
- YM - Year Month date code
- S - Assembly site code
- CC - Chip Code
- LLLL - Lot trace code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## PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package \| Pins | Package qty \| Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---|---|---|---|---|---|---|---|---|---|
| TPS61240DRVR | Active | Production | WSON (DRV) \| 6 | 3000 \| LARGE T&R | Yes | NIPDAU \| NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240DRVR.A | Active | Production | WSON (DRV) \| 6 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240DRVR.B | Active | Production | WSON (DRV) \| 6 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240DRVRG4.A | Active | Production | WSON (DRV) \| 6 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240DRVRG4.B | Active | Production | WSON (DRV) \| 6 | 3000 \| LARGE T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240DRVT | Active | Production | WSON (DRV) \| 6 | 250 \| SMALL T&R | Yes | NIPDAU \| NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240DRVT.B | Active | Production | WSON (DRV) \| 6 | 250 \| SMALL T&R | Yes | NIPDAU | Level-1-260C-UNLIM | -40 to 125 | OCJ |
| TPS61240YFFR | Active | Production | DSBGA (YFF) \| 6 | 3000 \| LARGE T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | GM |
| TPS61240YFFR.A | Active | Production | DSBGA (YFF) \| 6 | 3000 \| LARGE T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | GM |
| TPS61240YFFR.B | Active | Production | DSBGA (YFF) \| 6 | 3000 \| LARGE T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | GM |
| TPS61240YFFT | Active | Production | DSBGA (YFF) \| 6 | 250 \| SMALL T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | GM |
| TPS61240YFFT.A | Active | Production | DSBGA (YFF) \| 6 | 250 \| SMALL T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | GM |
| TPS61240YFFT.B | Active | Production | DSBGA (YFF) \| 6 | 250 \| SMALL T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | GM |
| TPS61241YFFR | Active | Production | DSBGA (YFF) \| 6 | 3000 \| LARGE T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | NF |
| TPS61241YFFR.A | Active | Production | DSBGA (YFF) \| 6 | 3000 \| LARGE T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | NF |
| TPS61241YFFR.B | Active | Production | DSBGA (YFF) \| 6 | 3000 \| LARGE T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | NF |
| TPS61241YFFT | Active | Production | DSBGA (YFF) \| 6 | 250 \| SMALL T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | NF |
| TPS61241YFFT.A | Active | Production | DSBGA (YFF) \| 6 | 250 \| SMALL T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | NF |
| TPS61241YFFT.B | Active | Production | DSBGA (YFF) \| 6 | 250 \| SMALL T&R | Yes | SNAGCU | Level-1-260C-UNLIM | -40 to 125 | NF |

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

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

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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**OTHER QUALIFIED VERSIONS OF TPS61240 :**

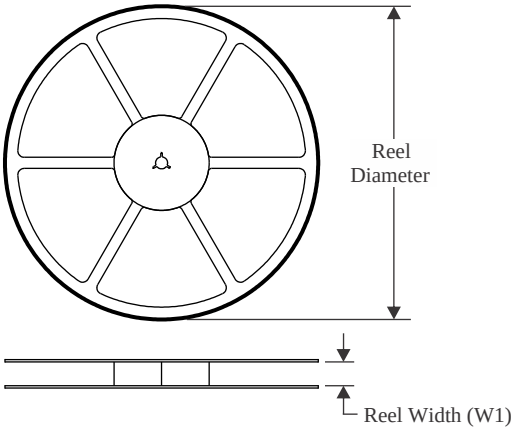
- Automotive : TPS61240-Q1

NOTE: Qualified Version Definitions:

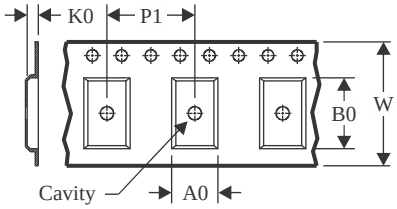
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

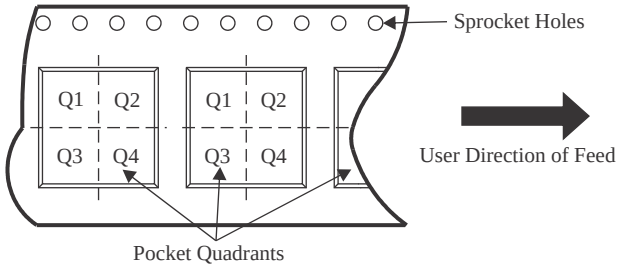



**TAPE DIMENSIONS**




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

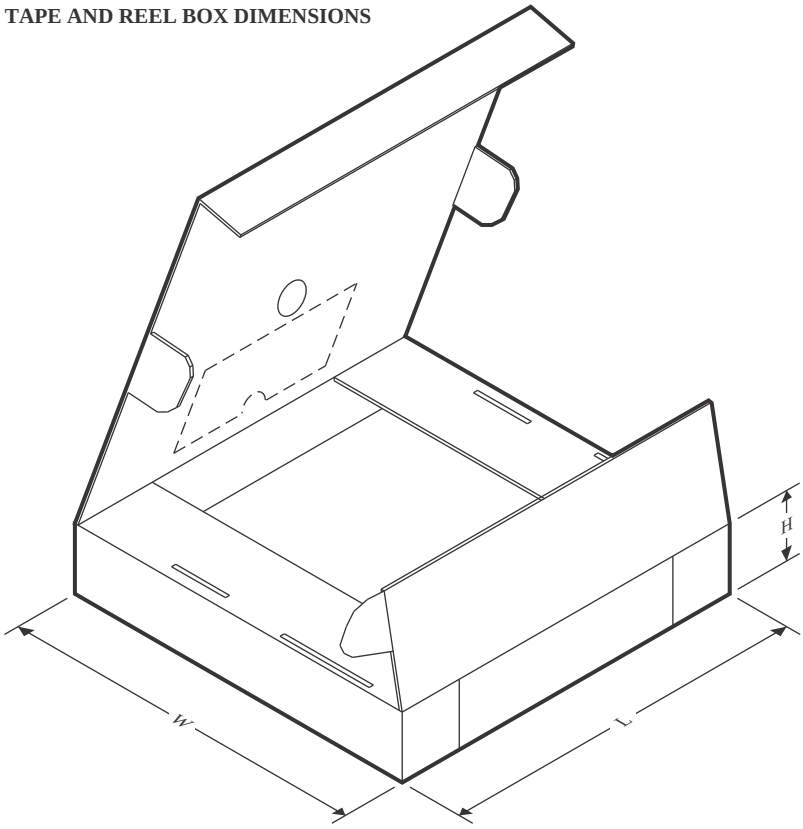
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS61240DRVR | WSON | DRV | 6 | 3000 | 180.0 | 8.4 | 2.3 | 2.3 | 1.15 | 4.0 | 8.0 | Q2 |
| TPS61240DRVT | WSON | DRV | 6 | 250 | 179.0 | 8.4 | 2.2 | 2.2 | 1.2 | 4.0 | 8.0 | Q2 |
| TPS61240DRVT | WSON | DRV | 6 | 250 | 180.0 | 8.4 | 2.3 | 2.3 | 1.15 | 4.0 | 8.0 | Q2 |
| TPS61240YFFR | DSBGA | YFF | 6 | 3000 | 180.0 | 8.4 | 0.98 | 1.41 | 0.69 | 4.0 | 8.0 | Q1 |
| TPS61240YFFT | DSBGA | YFF | 6 | 250 | 180.0 | 8.4 | 0.98 | 1.41 | 0.69 | 4.0 | 8.0 | Q1 |
| TPS61241YFFR | DSBGA | YFF | 6 | 3000 | 180.0 | 8.4 | 0.98 | 1.41 | 0.69 | 4.0 | 8.0 | Q1 |
| TPS61241YFFT | DSBGA | YFF | 6 | 250 | 180.0 | 8.4 | 0.98 | 1.41 | 0.69 | 4.0 | 8.0 | Q1 |

TAPE AND REEL BOX DIMENSIONS

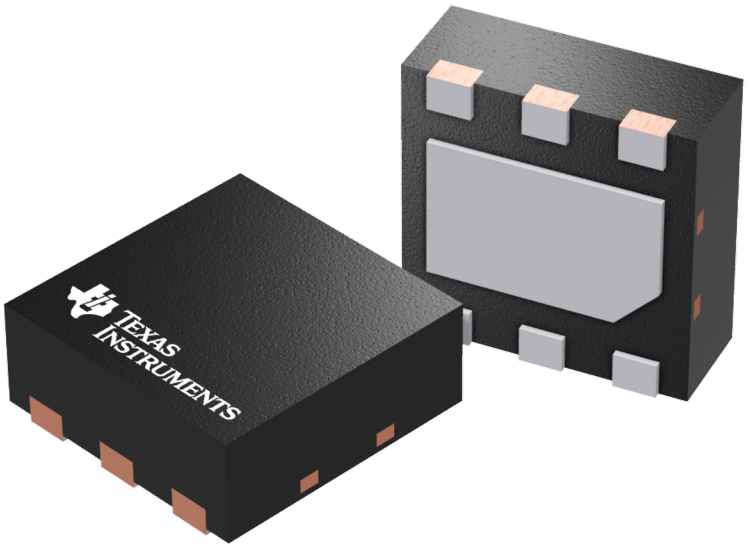



*All dimensions are nominal

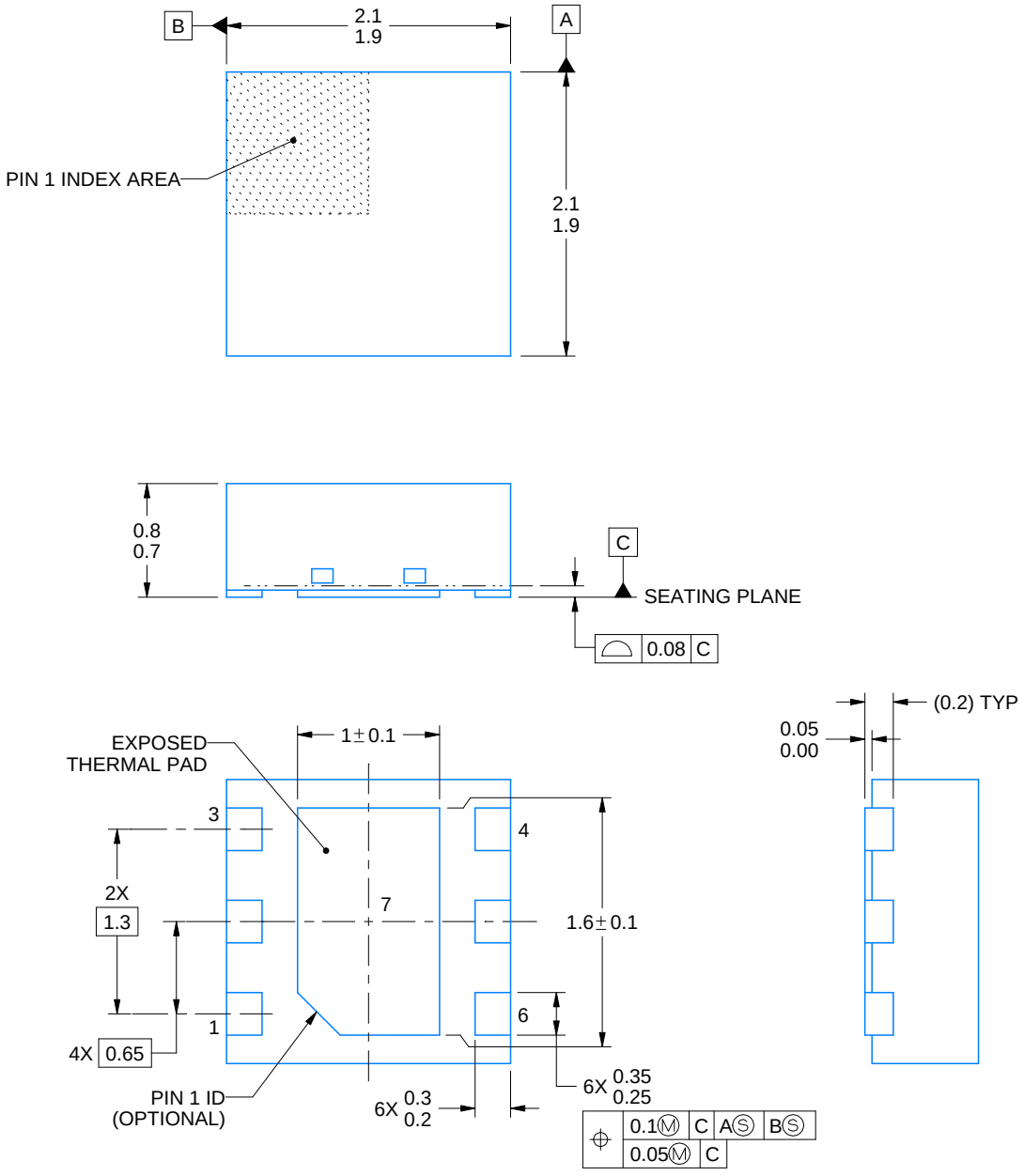
| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| TPS61240DRVR | WSON | DRV | 6 | 3000 | 210.0 | 185.0 | 35.0 |
| TPS61240DRVT | WSON | DRV | 6 | 250 | 200.0 | 183.0 | 25.0 |
| TPS61240DRVT | WSON | DRV | 6 | 250 | 210.0 | 185.0 | 35.0 |
| TPS61240YFFR | DSBGA | YFF | 6 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS61240YFFT | DSBGA | YFF | 6 | 250 | 182.0 | 182.0 | 20.0 |
| TPS61241YFFR | DSBGA | YFF | 6 | 3000 | 182.0 | 182.0 | 20.0 |
| TPS61241YFFT | DSBGA | YFF | 6 | 250 | 182.0 | 182.0 | 20.0 |

# DRV 6 WSON - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD

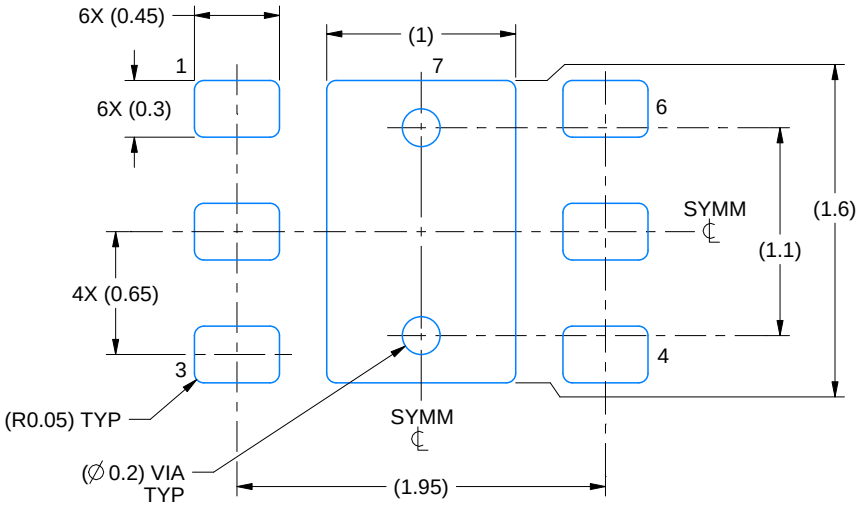



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

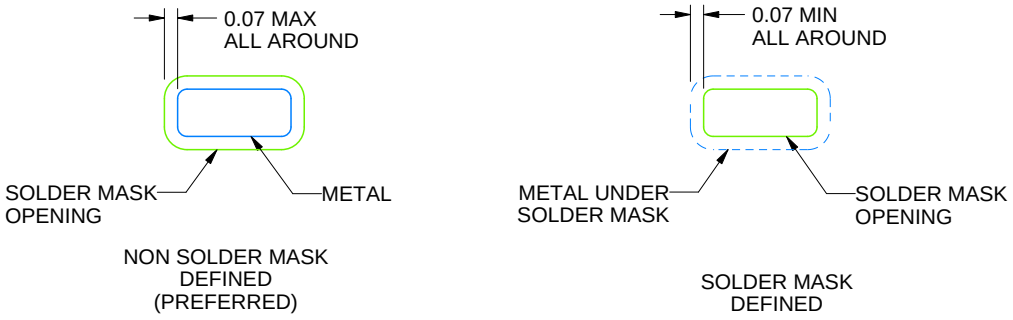



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.




LAND PATTERN EXAMPLE
SCALE:25X

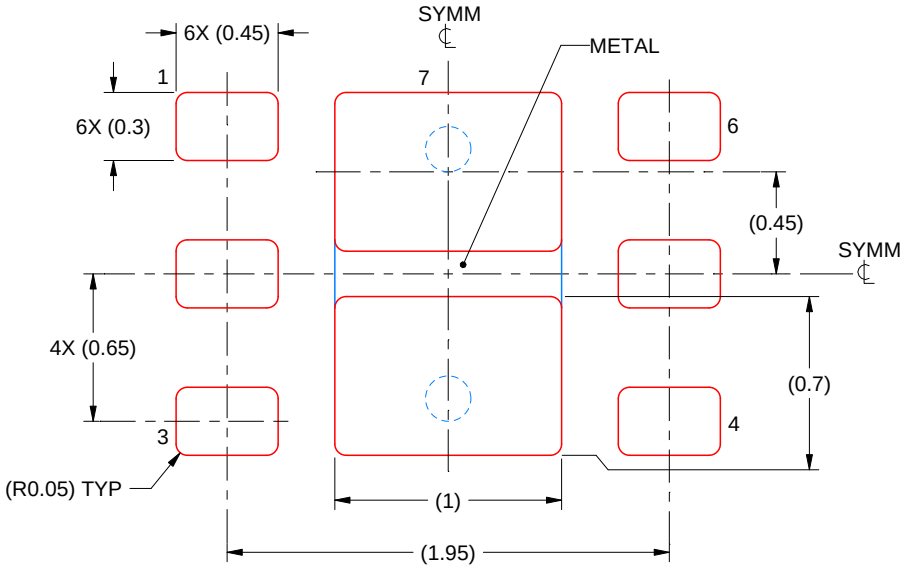



SOLDER MASK DETAILS

4222173/B 04/2018

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If some or all are implemented, recommended via locations are shown.




SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD #7
88% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:30X

4222173/B 04/2018

NOTES: (continued)

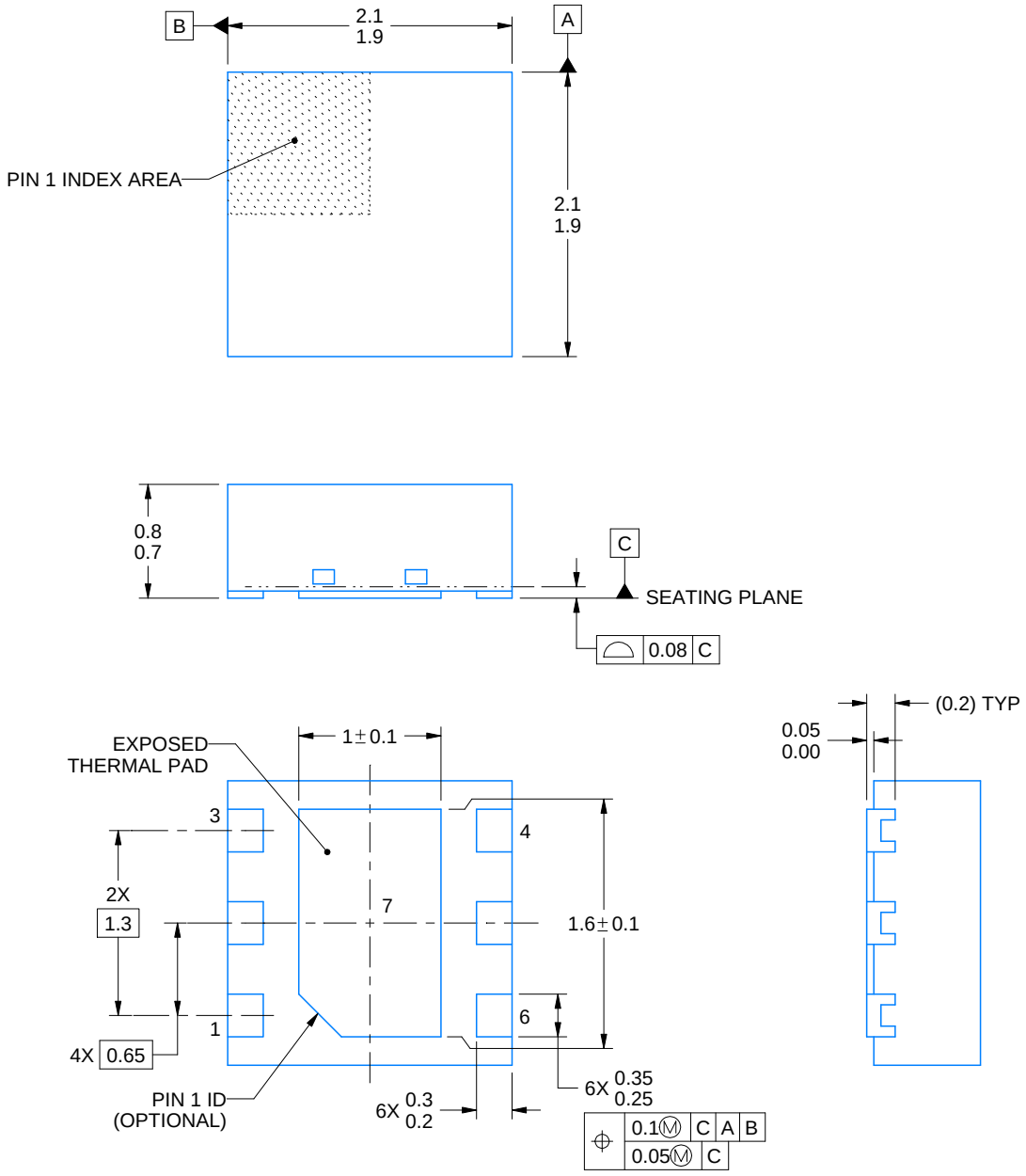
6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

# DRV0006D

# PACKAGE OUTLINE

## WSON - 0.8 mm max height

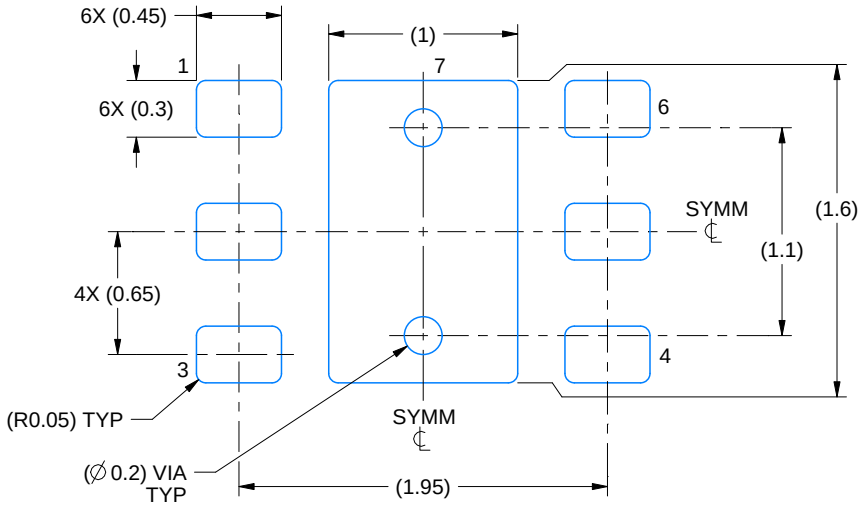
PLASTIC SMALL OUTLINE - NO LEAD



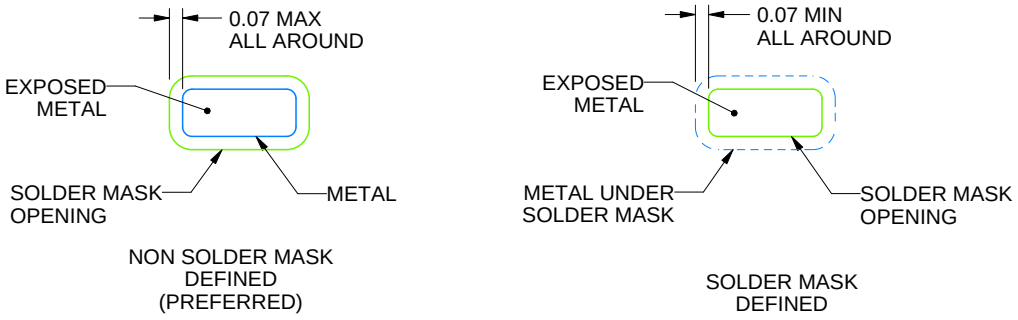

4225563/A 12/2019

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:25X

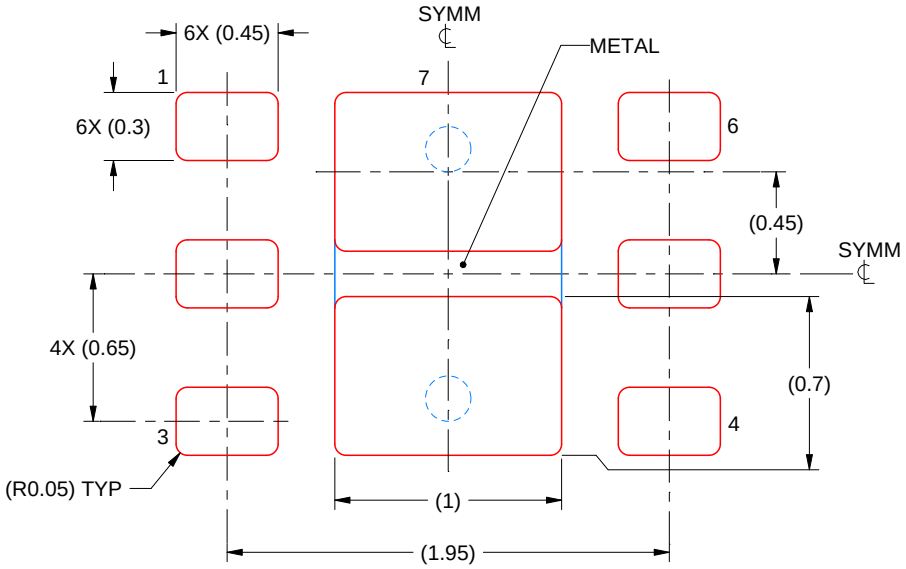



SOLDER MASK DETAILS

4225563/A 12/2019

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If some or all are implemented, recommended via locations are shown.




SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD #7
88% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:30X

4225563/A 12/2019

NOTES: (continued)

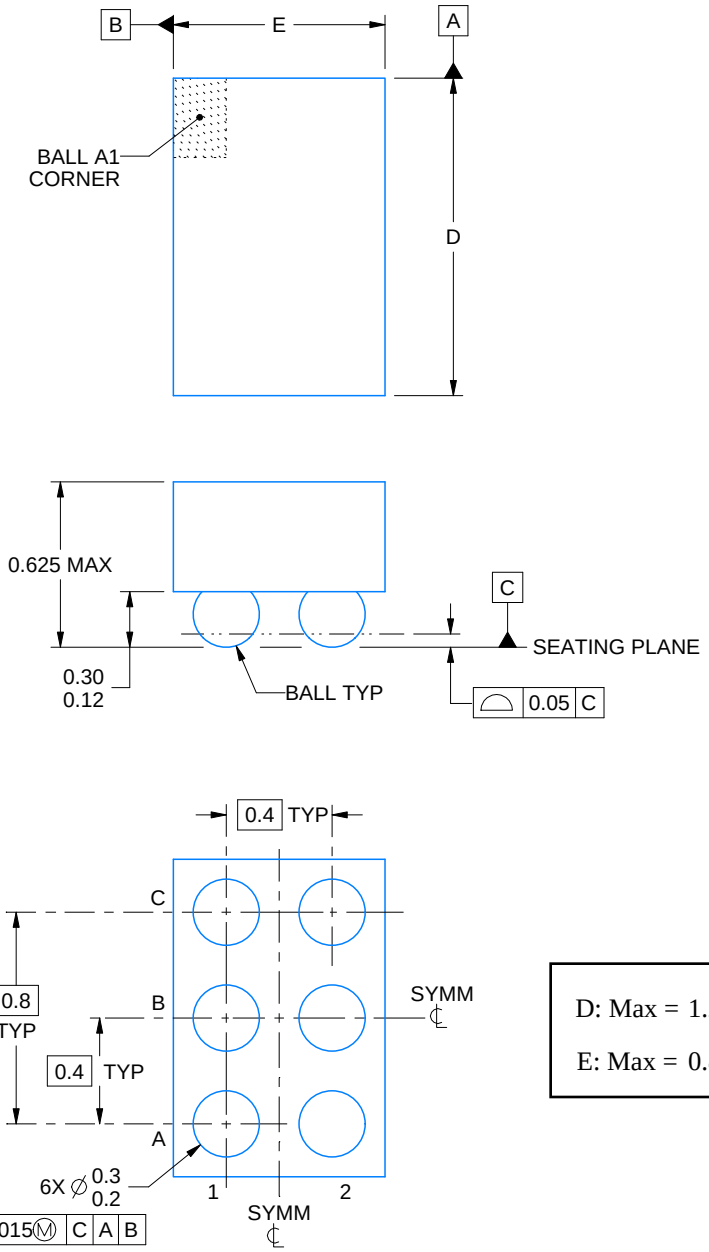
6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

# PACKAGE OUTLINE

## YFF0006

## DSBGA - 0.625 mm max height

DIE SIZE BALL GRID ARRAY



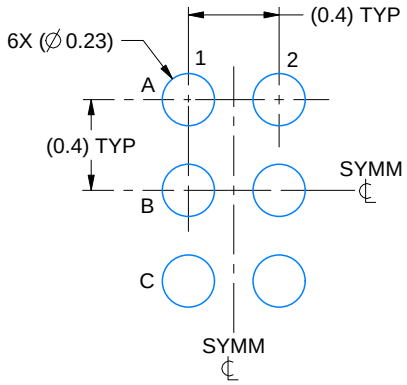

D: Max = 1.288 mm, Min =1.228 mm

E: Max = 0.886 mm, Min =0.826 mm

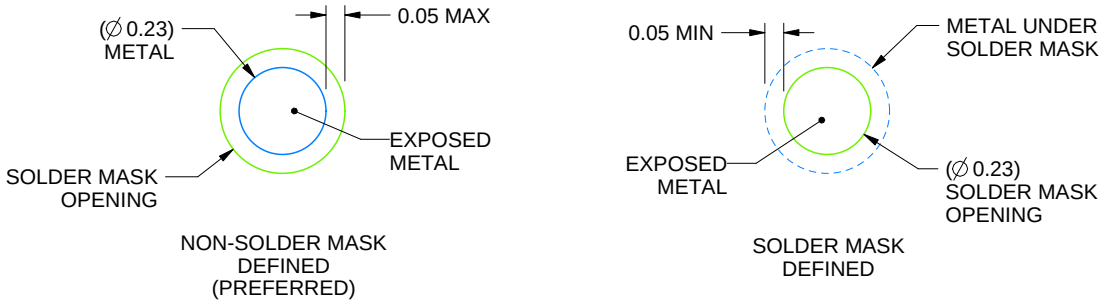
4223785/A 06/2017

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:30X

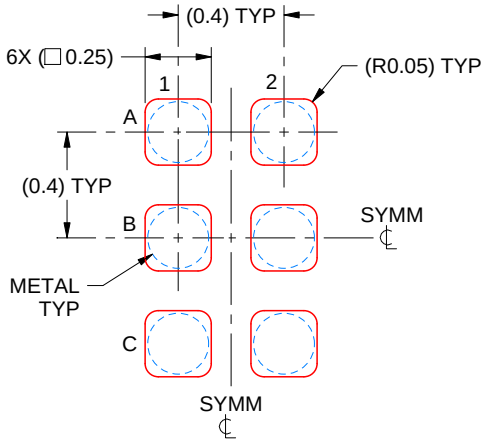



SOLDER MASK DETAILS
NOT TO SCALE

4223785/A 06/2017

NOTES: (continued)

3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints. For more information, see Texas Instruments literature number SNVA009 (www.ti.com/lit/snva009).




SOLDER PASTE EXAMPLE
BASED ON 0.1 mm THICK STENCIL
SCALE:35X

4223785/A 06/2017

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

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