# TPS92541-Q1 65V Automotive Synchronous Boost Controller, and 2A Synchronous CC/CV Buck Converter

## 1 Features

- AEC-Q100 qualified for automotive applications
  - Grade 1: –40°C to 125°C ambient operating temperature
  - Device HBM classification level H1C
  - Device CDM classification level C5
- Functional Safety-Capable
  - Documentation available to aid functional safety system design
- 4.5V to 65V wide input voltage range
- Synchronous Buck with integrated switches
- Configurable Constant Voltage (CV) and Constant Current (CC) operation
  - Up to 2A continuous output current with 4% accuracy
  - 4% regulation accuracy (voltage and current mode)
- Synchronous BOOST controller
  - Programmable output voltage up to 65V
- BOOST and BUCK spread-spectrum for EMI mitigation
- BUCK switch thermal protection
- UART serial communication
  - Internal oscillator for system clock
  - LMM compatible
- Internal EEPROM
  - Default settings
  - Customer calibration data

## 2 Applications

- Automotive headlight and adaptive LED driving module

## 3 Description

The TPS92541-Q1 device contains a synchronous BOOST controller and a monolithic synchronous buck LED driver with a wide 4.5V to 65V operating BUCK input voltage range.

The synchronous BOOST controller implements a peak current-mode controller to operate in constant voltage mode. The Boost can be programmed to operate as dual-phase, or three-phase together with other TPS92541-Q1 devices. The output voltage can be programmed using a programmable 8-bit DAC. The BOOST controller incorporates programmable frequency modulation technique for EMI reduction.

The monolithic synchronous BUCK implements an adaptive on-time average current mode control and is designed to generate constant voltage (CV) or constant current (CC) output. In the CC mode, the BUCK is compatible with shunt FET dimming techniques and LED matrix manager-based dynamic beam headlamps. In CV mode, the adaptive on-time control enables high bandwidth operation with fast transient response. The adaptive on-time control provides near constant switching frequency that can be set between 100kHz and 1.0MHz. Inductor current sensing and closed-loop feedback enable better than ±4% accuracy over wide input voltage, output voltage and ambient temperature range. In CC mode, the BUCK can independently modulate LED current using both analog or PWM dimming techniques.

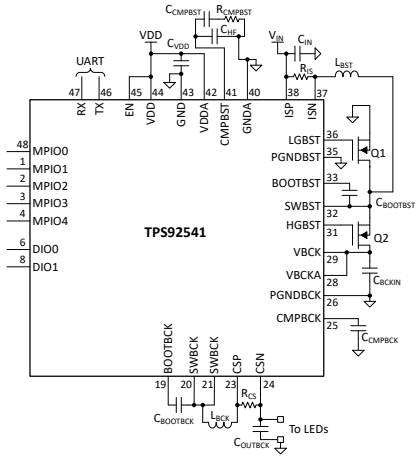
The TPS92541-Q1 includes an internal oscillator. The UART serial interface is compatible with TPS9266x, and TPS9254x devices. The internal EEPROM can store system defaults as well as calibration and lighting module data. The seven configurable MPIOs and DIOs can be set as digital inputs or outputs, or ADC inputs for applications with system temperature compensation, LED binning and coding, etc.

The TPS92541-Q1 is available in a 7.0mm × 7.0mm thermally-enhanced 48-pin HTQFP package with top-exposed pad.

**Device Information**

| PART NUMBER(1) | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| TPS92541-Q1 | PKD (HTQFP, 48) | 7.0mm × 7.0mm |

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




**Simplified Schematic**

# Table of Contents

# 4 Pin Configuration and Functions

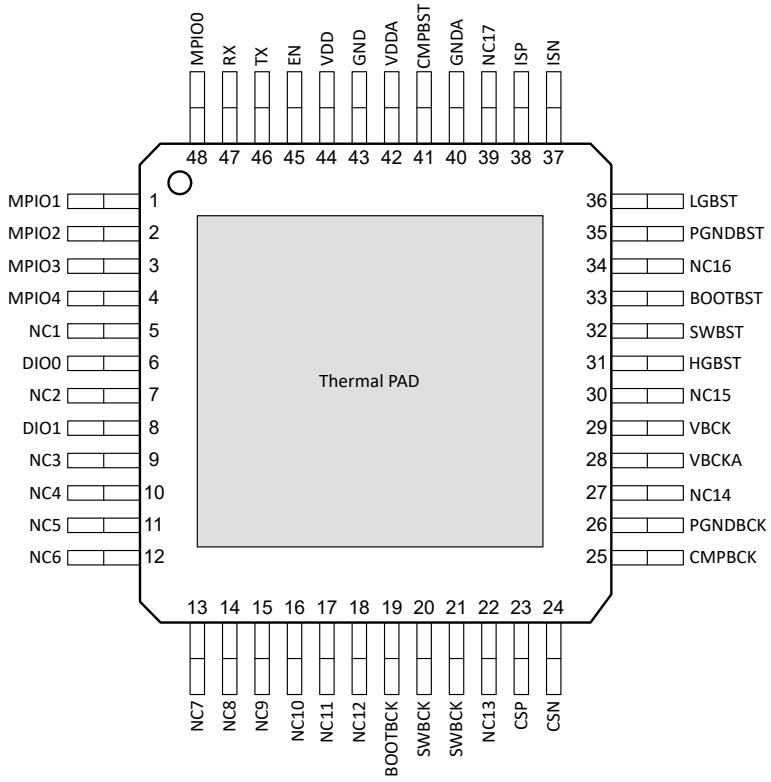



**Figure 4-1. PKD Package 48-Pin HTQFP (Top-Exposed PAD) Top View**

**Table 4-1. Pin Functions**

| PIN | | I/O | DESCRIPTION |
|---|---|---|---|
| NAME | NO. | | |
| | PKD | | |
| BOOTBCK | 19 | P | Supply input for BUCK high-side MOSFET gate drive circuit. Connect a ceramic capacitor between BOOTBCK and SWBCK pins. An internal diode is connected between VDD and BOOTBCK. |
| BOOTBST | 33 | P | Supply input for BOOST high-side MOSFET gate drive circuit. Connect a ceramic capacitor between BOOTBST and SWBST pins. An internal diode is connected between VDD and BOOTBST. |
| CMPBCK | 25 | I/O | Output of BUCK internal transconductance error amplifier. Connect an integral compensation network to ensure stability. |
| CMPBST | 41 | I/O | Output of BOOST internal transconductance error amplifier. Connect a proportional-integral compensation network to ensure stability. |
| CSN | 24 | I | Negative input (–) of internal rail-to-rail transconductance error amplifier. Connect directly to the negative node of the LED current sense resistor, $R_{CS}$. |
| CSP | 23 | I | Positive input (+) of internal rail-to-rail transconductance error amplifier. Connect directly to the positive node of the LED current sense resistor, $R_{CS}$. |
| DIO0 | 6 | I/O | Digital IO. The pin can be configured as digital input, or digital output. |
| DIO1 | 8 | I/O | |
| EN | 45 | I | Hardware enable. Pull this pin low to enter shutdown. |
| GND | 43 | G | Signal and analog ground. Return for the internal voltage reference and analog circuits. Connect to circuit ground to complete return path. |
| GNDA | 40 | | |
| HGBST | 31 | I/O | BOOST high side gate driver output. |

**Table 4-1. Pin Functions (continued)**

| PIN | | I/O | DESCRIPTION |
|---|---|---|---|
| NAME | NO. | | |
| | PKD | | |
| ISN | 37 | O | Negative input (–) of BOOST current sense amplifier. Connect directly to the current sense resistor, $R_{IS}$. |
| ISP | 38 | I | Positive input (+) of BOOST current sense amplifier. Connect directly to the current sense resistor, $R_{IS}$. |
| LGBST | 36 | I/O | BOOST low side gate driver output. |
| MPIO0 | 48 | I/O | Multi-purpose IO. The pin can be configured as an ADC input, digital input, or digital output. MPIO0 is used to enter CTM. |
| MPIO1 | 1 | I/O | Multi-purpose IO. The pin can be configured as an ADC input, digital input, or digital output. |
| MPIO2 | 2 | I/O | |
| MPIO3 | 3 | I/O | |
| MPIO4 | 4 | I/O | |
| NC1, NC2, NC3, NC4, NC5, NC6, NC7, NC8, NC9, NC10, NC11, NC12, NC13, NC14, NC15, NC16, NC17 | 5, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 22, 27, 30, 34, 39 | NC | Do not connect. Can be connected to ground. |
| PGNDBCK | 26 | G | Ground return for BUCK low-side MOSFET |
| PGNDBST | 35 | G | Ground return for BOOST high-side gate driver |
| RX | 47 | I | UART receive data input. Connect to RX of CAN transceiver. |
| SWBCK | 20, 21 | P | Switching output of the BUCK regulator. Internally connected to both power MOSFETs. Connect to the power inductor. |
| SWBST | 32 | P | Switch node of the BOOST controller. |
| TX | 46 | O | UART transmit data output. Connect to TX of CAN transceiver. |
| VBCK | 29 | P | Power inputs and connections to BUCK high-side MOSFET drain node. Connect to the BOOST output voltage and bypass capacitors $C_{IN}$. The path from the VBCK pin to high frequency bypass $C_{IN}$ and PGND must be as short as possible. |
| VBCKA | 28 | P | Power to internal analog block of BUCK regulator. Connect to VBCK pin and high frequency bypass capacitor. |
| VDD | 44 | P | Digital input supply voltage. Locally decouple to GND using a 2.2µF to 4.7µF ceramic capacitor located close to the device. |
| VDDA | 42 | P | Analog input supply voltage. Locally decouple to GND using a 100nF to 1µF ceramic capacitor located close to the device. |

## 5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| DATE | REVISION | NOTES |
|---|---|---|
| March 2025 | * | Initial Release |

## 6 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.

## 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) |
|---|---|---|---|---|---|---|---|---|---|
| TPS92541QPKDRQ1 | Active | Production | HTQFP (PKD) \| 48 | 1000 \| LARGE T&R | Yes | NIPDAU | Level-3-260C-168 HR | -40 to 125 | TPS92541 |

**(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.

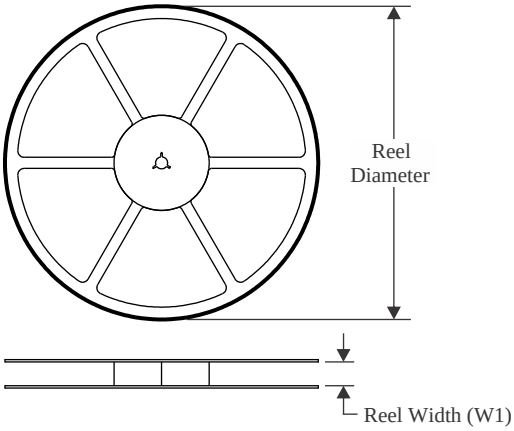
**(5) MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will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

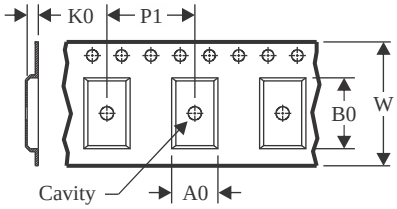
Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

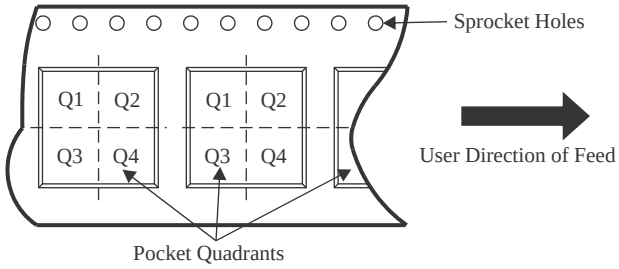



**TAPE DIMENSIONS**




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

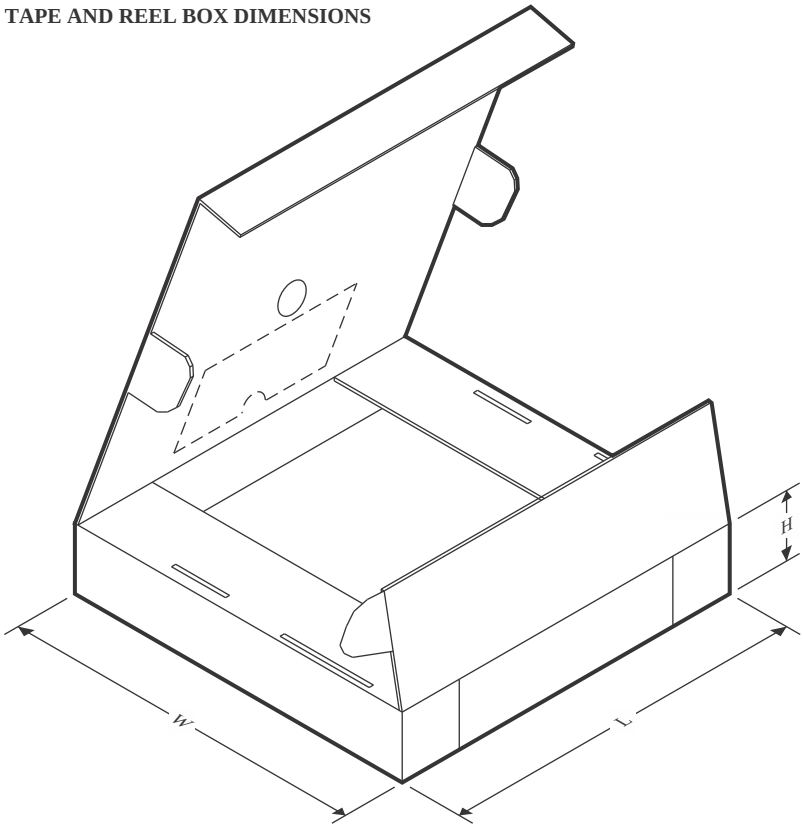
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS92541QPKDRQ1 | HTQFP | PKD | 48 | 1000 | 330.0 | 16.4 | 9.6 | 9.6 | 1.5 | 12.0 | 16.0 | Q2 |

TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| TPS92541QPKDRQ1 | HTQFP | PKD | 48 | 1000 | 336.6 | 336.6 | 31.8 |

# GENERIC PACKAGE VIEW

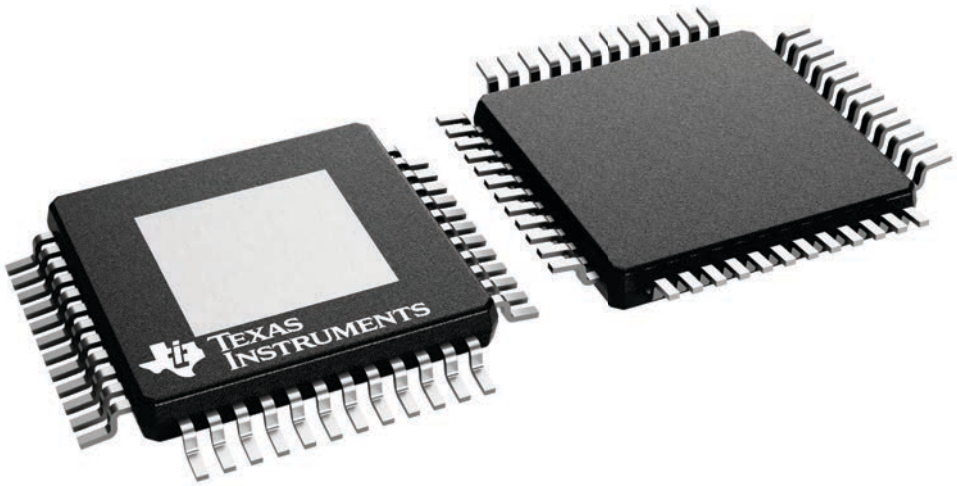
## PKD 48

## PowerPAD™ HTQFP - 1.15 mm max height

**7 x 7, 0.5 mm pitch**

PLASTIC QUAD FLATPACK

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



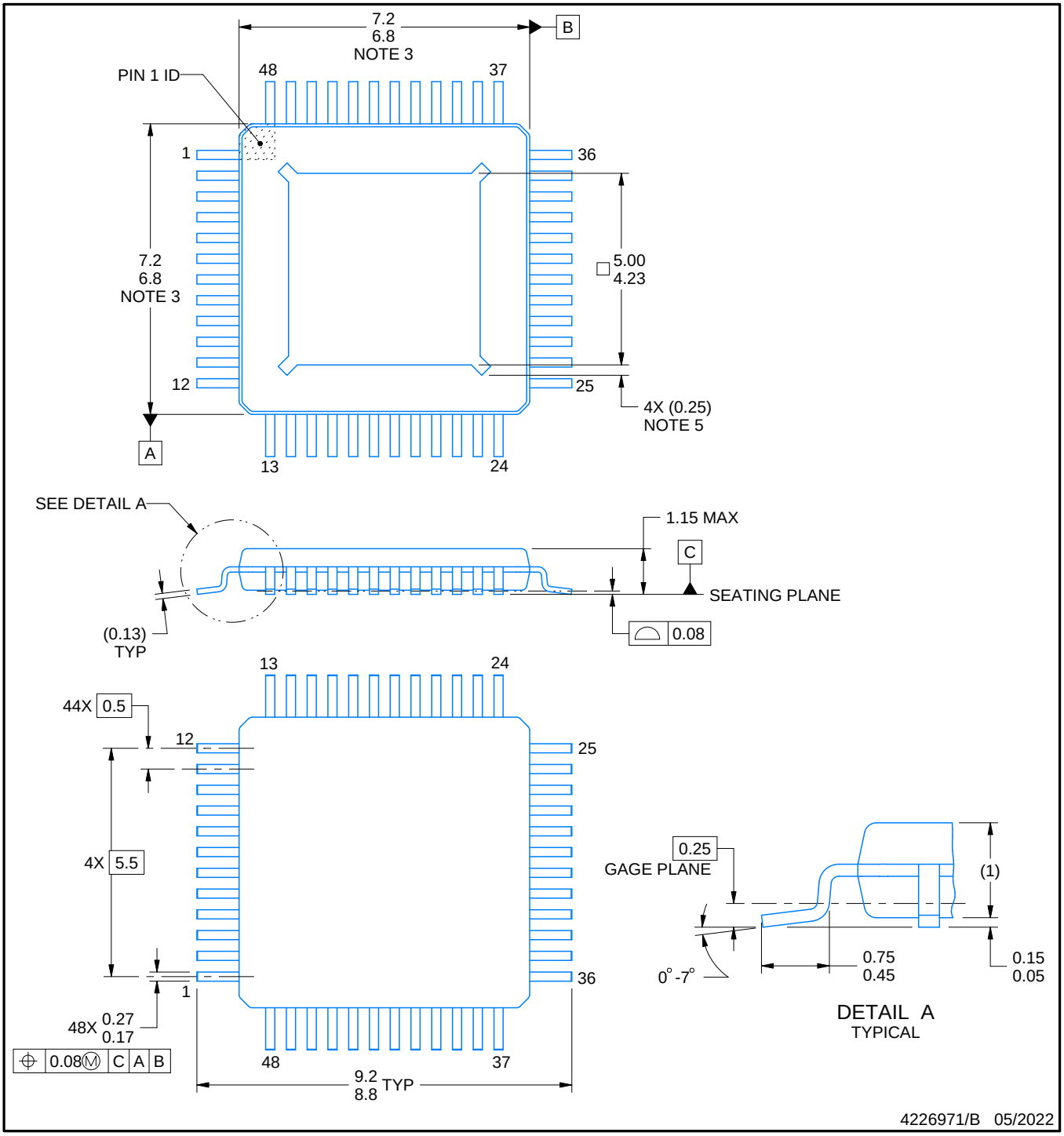

4231748/A

# PACKAGE OUTLINE

## PKD0048A

## PowerPAD ™HTQFP - 1.15 mm max height

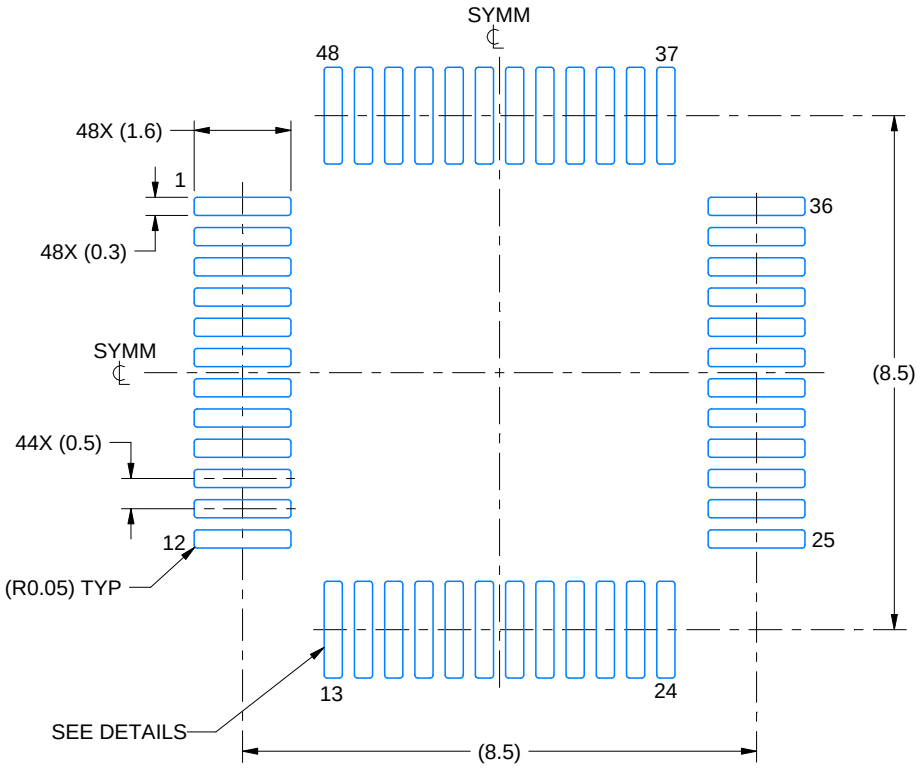
PLASTIC QUAD FLATPACK



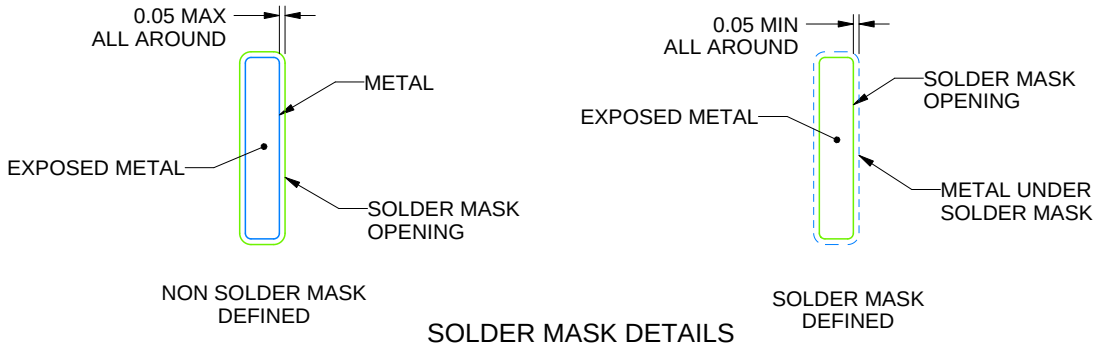

PowerPAD is a trademark of Texas Instruments.

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. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. Reference JEDEC registration MS-026.
5. Feature may not be present.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X

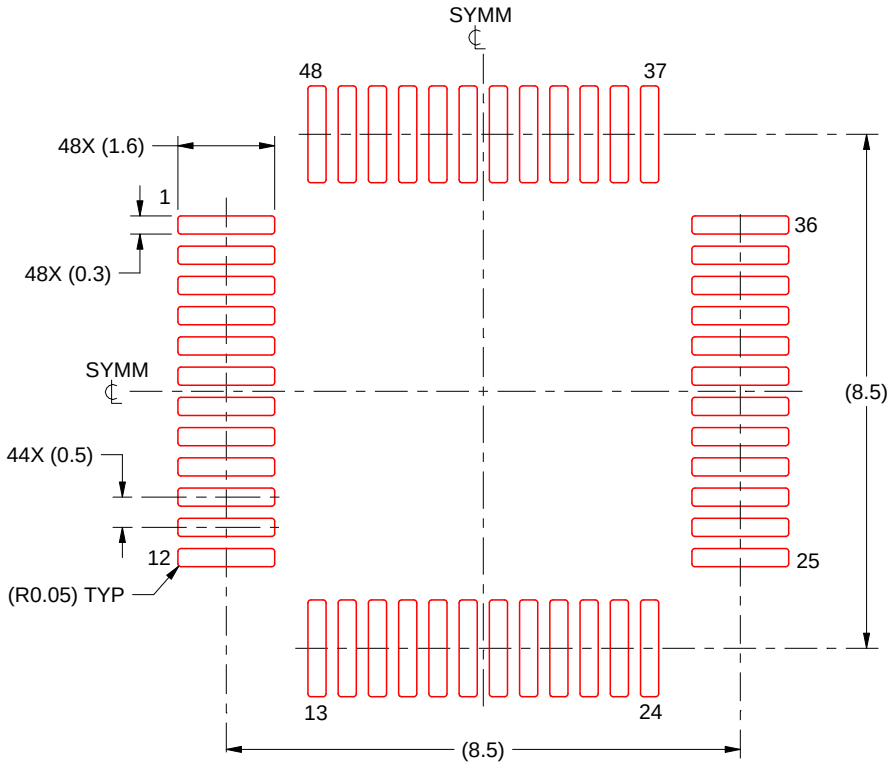



SOLDER MASK DETAILS

4226971/B 05/2022

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. This package is designed to be soldered to a thermal pad on the board. See technical brief, Powerpad thermally enhanced package, Texas Instruments Literature No. SLMA002 (www.ti.com/lit/slma002) and SLMA004 (www.ti.com/lit/slma004).
9. Vias are optional depending on application, refer to device data sheet. It is recommended that vias under paste be filled, plugged or tented.
10. Size of metal pad may vary due to creepage requirement.




SOLDER PASTE EXAMPLE
SCALE:8X

4226971/B 05/2022

NOTES: (continued)

11. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
12. Board assembly site may have different recommendations for stencil design.

# IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

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