



# TPS54228 4.5-V to 18-V Input, 2-A Synchronous Step-Down Converter With Eco-Mode™

## 1 Features

- D-CAP2™ Mode Enables Fast Transient Response
- Low Output Ripple and Allows Ceramic Output Capacitor
- Wide  $V_{IN}$  Input Voltage Range: 4.5 V to 18 V
- Output Voltage Range: 0.76 V to 7 V
- Highly Efficient Integrated FETs Optimized for Lower Duty Cycle Applications
  - 155 mΩ (High-Side) and 108 mΩ (Low-Side)
- High Efficiency, Less than 10  $\mu$ A at Shutdown
- High Initial Bandgap Reference Accuracy
- Adjustable Soft Start
- Prebiased Soft Start
- 700-kHz Switching Frequency ( $f_{SW}$ )
- Cycle-by-Cycle Overcurrent Limit
- Auto-Skip Eco-Mode™ for High Efficiency at Light Load

## 2 Applications

- Wide Range of Applications for Low Voltage System
  - Digital TV Power Supply
  - High Definition Blu-ray Disc™ Players
  - Networking Home Terminals
  - Digital Set Top Boxes (STB)

## 3 Description

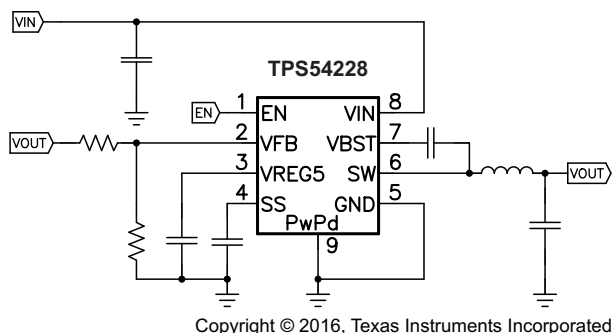
The TPS54228 device is an adaptive on-time D-CAP2™ mode synchronous buck converter. The TPS54228 enables system designers to complete the suite of various end-equipment power bus regulators with a cost effective, low component count, low standby current solution. The main control loop for the TPS54228 uses the D-CAP2™ mode control that provides a fast transient response with no external compensation components. The adaptive on-time control supports seamless transition between PWM mode at higher load conditions and Eco-Mode™ operation at light loads. Eco-Mode™ allows the TPS54228 to maintain high efficiency during lighter load conditions. The TPS54228 also has a proprietary circuit that enables the device to adopt to both low equivalent series resistance (ESR) output capacitors, such as POSCAP or SP-CAP, and ultra-low ESR ceramic capacitors. The device operates from 4.5-V to 18-V  $V_{IN}$  input. The output voltage can be programmed between 0.76 V and 7 V. The device also features an adjustable soft start time. The TPS54228 is available in 8-pin SO, 8-pin SOIC, and 10-pin VSON packages, and is designed to operate over the ambient temperature range of  $-40^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ .

### Device Information<sup>(1)</sup>

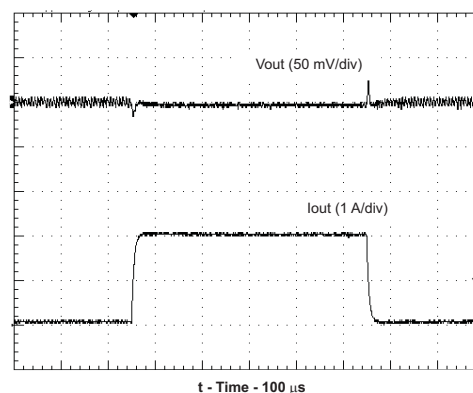
| PART NUMBER | PACKAGE   | BODY SIZE (NOM)   |
|-------------|-----------|-------------------|
| TPS54228    | HSOP (8)  | 4.89 mm × 3.90 mm |
|             | SOIC (8)  | 4.89 mm × 3.90 mm |
|             | VSON (10) | 3.00 mm × 3.00 mm |

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

### Simplified Schematic



### TPS54228 Transient Response



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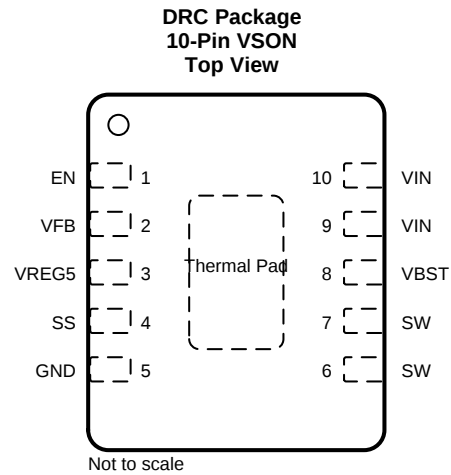
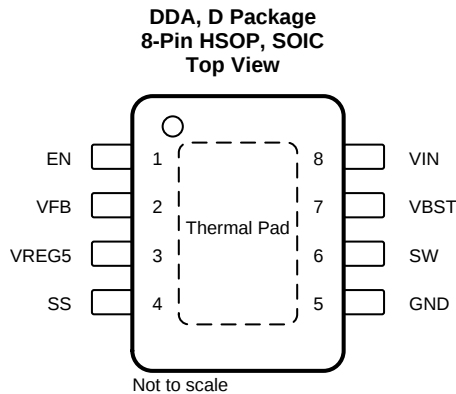
|                                                |          |                                                                  |           |
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## 4 Revision History

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

|                                                                                                                                                                                                                                                                                             |             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision D (January 2013) to Revision E</b>                                                                                                                                                                                                                                 | <b>Page</b> |
| • 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           |
| • Deleted Ordering Information table, see POA at the end of the data sheet.....                                                                                                                                                                                                             | 3           |
| <b>Changes from Revision C (March 2012) to Revision D</b>                                                                                                                                                                                                                                   | <b>Page</b> |
| • Added the 10-pin DRC package to the data sheet .....                                                                                                                                                                                                                                      | 1           |
| • Added the DRC package to the Device Information section .....                                                                                                                                                                                                                             | 3           |
| • Added <a href="#">Figure 20</a> .....                                                                                                                                                                                                                                                     | 16          |
| <b>Changes from Revision B (December 2011) to Revision C</b>                                                                                                                                                                                                                                | <b>Page</b> |
| • Removed SWIFT™ from the data sheet title.....                                                                                                                                                                                                                                             | 1           |
| <b>Changes from Revision A (October 2011) to Revision B</b>                                                                                                                                                                                                                                 | <b>Page</b> |
| • Added the 8-pin D package to the data sheet .....                                                                                                                                                                                                                                         | 1           |
| <b>Changes from Original (May 2011) to Revision A</b>                                                                                                                                                                                                                                       | <b>Page</b> |
| • Added R <sub>EN</sub> - EN pin resistance to GND to the LOGIC THRESHOLD section of the ELECTRICAL CHARACTERISTICS table .....                                                                                                                                                             | 5           |

## 5 Pin Configuration and Functions



### Pin Functions

| PIN                 |                          |           | I/O | DESCRIPTION                                                                                                                                                           |
|---------------------|--------------------------|-----------|-----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME                | HSOP, SOIC               | VSON      |     |                                                                                                                                                                       |
| EN                  | 1                        | 1         | I   | Enable input control. EN is active high and must be pulled up to enable the device.                                                                                   |
| VFB                 | 2                        | 2         | I   | Converter feedback input. Connect to output voltage with feedback resistor divider.                                                                                   |
| VREG5               | 3                        | 3         | O   | 5.5-V power supply output. A capacitor (typical 1 $\mu$ F) must be connected to GND. VREG5 is not active when EN is low.                                              |
| SS                  | 4                        | 4         | I   | Soft-start control. An external capacitor must be connected to GND.                                                                                                   |
| GND                 | 5                        | —         | —   | Ground pin. Power ground return for switching circuit. Connect sensitive SS and VFB returns to GND at a single point.                                                 |
| GND                 | —                        | 5         | —   | Ground pin. Connect sensitive SS and VFB returns to GND at a single point.                                                                                            |
| SW                  | 6                        | 6, 7      | O   | Switch node connection between high-side NFET and low-side NFET.                                                                                                      |
| VBST                | 7                        | 8         | I   | Supply input for the high-side FET gate drive circuit. Connect 0.1 $\mu$ F capacitor between VBST and SW pins. An internal diode is connected between VREG5 and VBST. |
| VIN                 | 8                        | 9, 10     | I   | Input voltage supply pin.                                                                                                                                             |
| Exposed Thermal Pad | Back side <sup>(1)</sup> | —         | —   | Thermal pad of the package. Must be soldered to achieve appropriate dissipation. Must be connected to GND.                                                            |
|                     | —                        | Back side | —   | Thermal pad of the package. PGND power ground return of internal low-side FET. Must be soldered to achieve appropriate dissipation.                                   |

(1) DDA package only

## 6 Specifications

### 6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                                                    |                         | MIN  | MAX | UNIT |
|----------------------------------------------------|-------------------------|------|-----|------|
| Input voltage                                      | VIN, EN                 | –0.3 | 20  | V    |
|                                                    | VBST                    | –0.3 | 26  |      |
|                                                    | VBST (transient, 10 ns) | –0.3 | 28  |      |
|                                                    | VBST (vs SW)            | –0.3 | 6.5 |      |
|                                                    | VFB, SS                 | –0.3 | 6.5 |      |
|                                                    | SW                      | –2   | 20  |      |
|                                                    | SW (transient, 10 ns)   | –3   | 22  |      |
| Output voltage                                     | VREG5                   | –0.3 | 6.5 | V    |
|                                                    | GND                     | –0.3 | 0.3 |      |
| Voltage from GND to thermal pad, V <sub>diff</sub> |                         | –0.2 | 0.2 | V    |
| Operating junction temperature, T <sub>J</sub>     |                         | –40  | 150 | °C   |
| Storage temperature, T <sub>stg</sub>              |                         | –55  | 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.

### 6.2 ESD Ratings

|                                            |                                                                                | VALUE | UNIT |
|--------------------------------------------|--------------------------------------------------------------------------------|-------|------|
| V <sub>(ESD)</sub> Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±2000 | V    |
|                                            | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±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.

### 6.3 Recommended Operating Conditions

over operating free-air temperature range and V<sub>IN</sub> = 12 V (unless otherwise noted)

|                  |                                         | MIN                     | NOM | MAX | UNIT |
|------------------|-----------------------------------------|-------------------------|-----|-----|------|
| V <sub>IN</sub>  | Supply input voltage                    | 4.5                     |     | 18  | V    |
| V <sub>I</sub>   | Input voltage                           | VBST                    |     | 24  | V    |
|                  |                                         | VBST (transient, 10 ns) |     | 27  |      |
|                  |                                         | VBST(vs SW)             |     | 5.7 |      |
|                  |                                         | SS                      |     | 5.7 |      |
|                  |                                         | EN                      |     | 18  |      |
|                  |                                         | VFB                     |     | 5.5 |      |
|                  |                                         | SW                      |     | 18  |      |
|                  |                                         | SW (transient, 10 ns)   |     | 21  |      |
|                  |                                         | GND                     |     | 0.1 |      |
| V <sub>O</sub>   | Output voltage, VREG5                   | –0.1                    |     | 5.7 | V    |
| I <sub>O</sub>   | Output current, I <sub>VREG5</sub>      | 0                       |     | 10  | mA   |
| I <sub>OUT</sub> | Operating output current <sup>(1)</sup> |                         |     | 2   | A    |
| T <sub>A</sub>   | Operating free-air temperature          | –40                     |     | 85  | °C   |

- (1) D package, V<sub>OUT</sub> > 5 V (see [Figure 9](#) for temperature derating)

## 6.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | TPS54228 |          |            | UNITS |
|-------------------------------|----------------------------------------------|----------|----------|------------|-------|
|                               |                                              | DDA (SO) | D (SOIC) | DRC (VSON) |       |
|                               |                                              | 8 PINS   | 8 PINS   | 10 PINS    |       |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 45.3     | 114.4    | 43.9       | °C/W  |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 54.8     | 60.8     | 55.4       | °C/W  |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 16.2     | 55.7     | 18.9       | °C/W  |
| ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 6.6      | 17.4     | 0.7        | °C/W  |
| ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 16       | 55.1     | 19.1       | °C/W  |
| R <sub>θJC(bot)</sub>         | Junction-to-case (bottom) thermal resistance | 8.5      | —        | 5.3        | °C/W  |

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

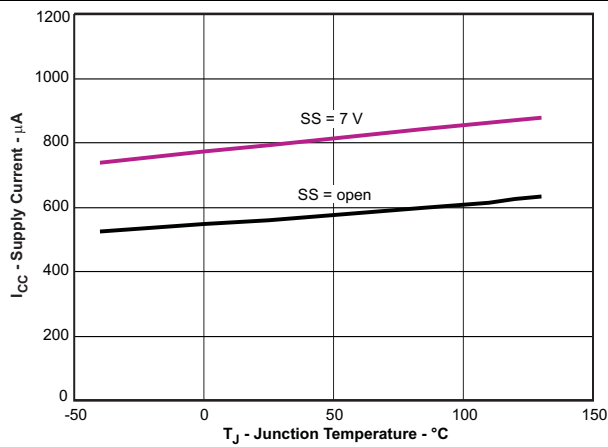
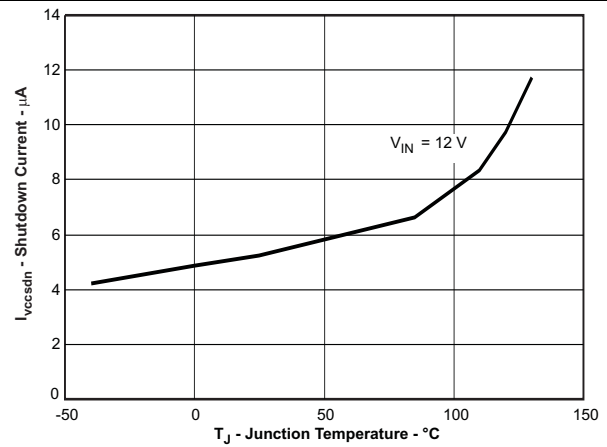
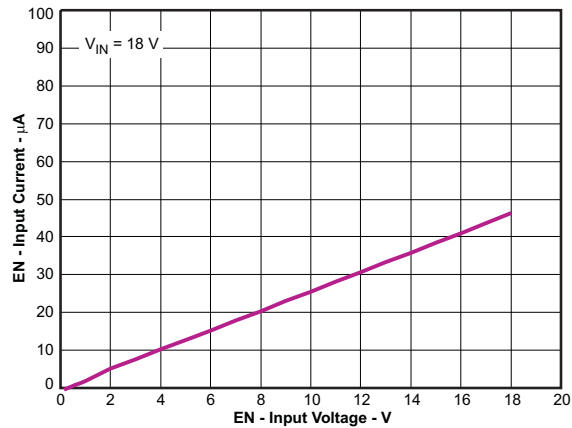
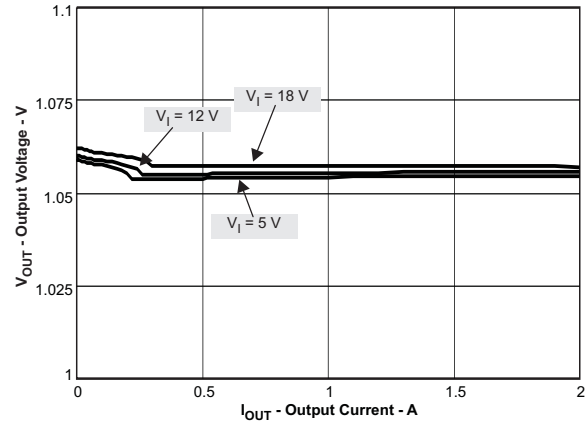
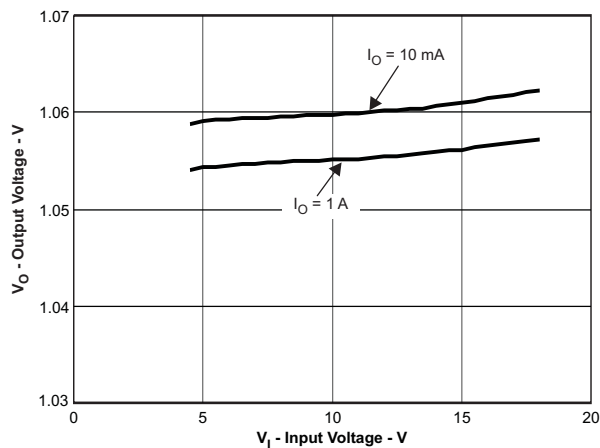
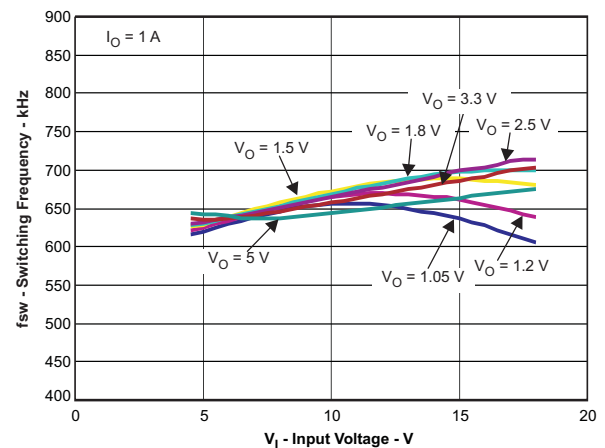
## 6.5 Electrical Characteristics

over operating free-air temperature range and V<sub>IN</sub> = 12 V (unless otherwise noted)

| PARAMETER                                              |                                         | TEST CONDITIONS                                                                             | MIN  | TYP  | MAX  | UNIT |
|--------------------------------------------------------|-----------------------------------------|---------------------------------------------------------------------------------------------|------|------|------|------|
| <b>SUPPLY CURRENT</b>                                  |                                         |                                                                                             |      |      |      |      |
| I <sub>VIN</sub>                                       | Operating, non-switching supply current | V <sub>IN</sub> current, T <sub>A</sub> = 25°C, EN = 5 V, V <sub>FB</sub> = 0.8 V           |      | 800  | 1200 | μA   |
| I <sub>VINSDN</sub>                                    | Shutdown supply current                 | V <sub>IN</sub> current, T <sub>A</sub> = 25°C, EN = 0 V                                    |      | 5    | 10   | μA   |
| <b>LOGIC THRESHOLD</b>                                 |                                         |                                                                                             |      |      |      |      |
| V <sub>EN</sub>                                        | EN high-level input voltage             | EN                                                                                          | 1.6  |      |      | V    |
|                                                        | EN low-level input voltage              | EN                                                                                          |      |      | 0.6  | V    |
| R <sub>EN</sub>                                        | EN pin resistance to GND                | V <sub>EN</sub> = 12 V                                                                      | 220  | 440  | 880  | kΩ   |
| <b>V<sub>FB</sub> VOLTAGE AND DISCHARGE RESISTANCE</b> |                                         |                                                                                             |      |      |      |      |
| V <sub>FBTH</sub>                                      | V <sub>FB</sub> threshold voltage       | T <sub>A</sub> = 25°C, V <sub>O</sub> = 1.05 V, I <sub>O</sub> = 10 mA, Eco-Mode™ operation |      | 770  |      | mV   |
|                                                        |                                         | T <sub>A</sub> = 25°C, V <sub>O</sub> = 1.05 V, continuous mode operation                   | 749  | 765  | 781  | mV   |
| I <sub>VFB</sub>                                       | V <sub>FB</sub> input current           | V <sub>FB</sub> = 0.8 V, T <sub>A</sub> = 25°C                                              |      | 0    | ±0.1 | μA   |
| <b>V<sub>REG5</sub> OUTPUT</b>                         |                                         |                                                                                             |      |      |      |      |
| V <sub>VREG5</sub>                                     | V <sub>REG5</sub> output voltage        | T <sub>A</sub> = 25°C, 6 V < V <sub>IN</sub> < 18 V, 0 < I <sub>VREG5</sub> < 5 mA          | 5.2  | 5.5  | 5.7  | V    |
| V <sub>LN5</sub>                                       | Line regulation                         | 6 V < V <sub>IN</sub> < 18 V, I <sub>VREG5</sub> = 5 mA                                     |      |      | 25   | mV   |
| V <sub>LD5</sub>                                       | Load regulation                         | 0 mA < I <sub>VREG5</sub> < 5 mA                                                            |      |      | 100  | mV   |
| I <sub>VREG5</sub>                                     | Output current                          | V <sub>IN</sub> = 6 V, V <sub>REG5</sub> = 4 V, T <sub>A</sub> = 25°C                       |      | 60   |      | mA   |
| <b>MOSFET</b>                                          |                                         |                                                                                             |      |      |      |      |
| R <sub>DS(on)</sub>                                    | High side switch resistance             | DDA and D packages 25°C, V <sub>BST</sub> – SW = 5.5 V                                      |      | 155  |      | mΩ   |
|                                                        |                                         | DRC package, 25°C, V <sub>BST</sub> – SW = 5.5 V                                            |      | 165  |      |      |
|                                                        | Low side switch resistance              | 25°C                                                                                        |      | 108  |      |      |
| I <sub>ocl</sub>                                       | Current limit                           | DDA and DRC packages, L out = 2.2 μH <sup>(1)</sup>                                         | 2.5  | 3.3  | 4.7  | A    |
|                                                        |                                         | D package, L out = 2.2 μH <sup>(1)</sup>                                                    | 2.3  | 3    | 4.5  | A    |
| T <sub>SDN</sub>                                       | Thermal shutdown threshold              | Shutdown temperature <sup>(1)</sup>                                                         |      | 165  |      | °C   |
|                                                        |                                         | Hysteresis <sup>(1)</sup>                                                                   |      | 35   |      |      |
| t <sub>ON</sub>                                        | On time                                 | V <sub>IN</sub> = 12 V, V <sub>O</sub> = 1.05 V                                             |      | 150  |      | ns   |
| t <sub>OFF(MIN)</sub>                                  | Minimum off time                        | T <sub>A</sub> = 25°C, V <sub>FB</sub> = 0.7 V                                              |      | 260  | 310  | ns   |
| I <sub>SS</sub>                                        | Soft-start charge current               | V <sub>SS</sub> = 1 V                                                                       | 1.4  | 2    | 2.6  | μA   |
|                                                        | Soft-start discharge current            | V <sub>SS</sub> = 0.5 V                                                                     | 0.1  | 0.2  |      | mA   |
| UVLO                                                   | Undervoltage lockout threshold          | Wake up V <sub>REG5</sub> voltage                                                           | 3.45 | 3.75 | 4.05 | V    |
|                                                        |                                         | Hysteresis V <sub>REG5</sub> voltage                                                        | 0.13 | 0.32 | 0.48 |      |

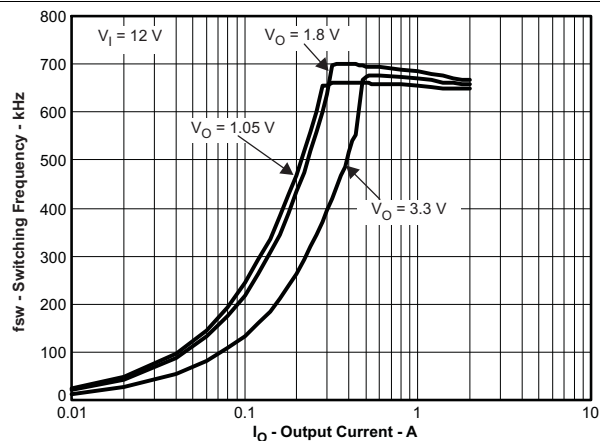
(1) Not production tested.

## 6.6 Typical Characteristics

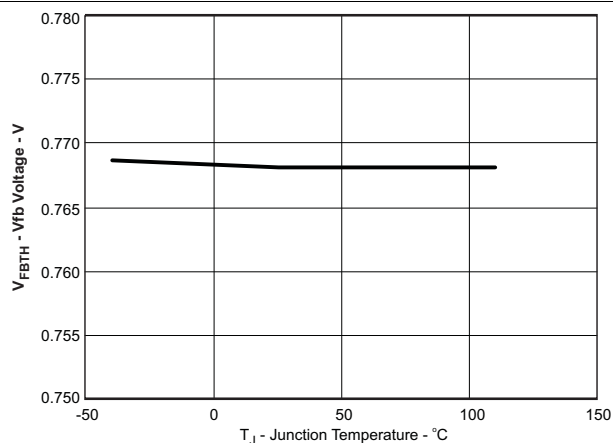
 $V_{IN} = 12\text{ V}$  and  $T_A = 25\text{ }^{\circ}\text{C}$  (unless otherwise noted)

**Figure 1. VIN Current vs Junction Temperature**

**Figure 2. VIN Shutdown Current vs Junction Temperature**

**Figure 3. EN Current vs EN Voltage**

**Figure 4. 1.05-V Output Voltage vs Output Current**

**Figure 5. 1.05-V Output Voltage vs Input Voltage**

**Figure 6. Switching Frequency vs Input Voltage**

## Typical Characteristics (continued)

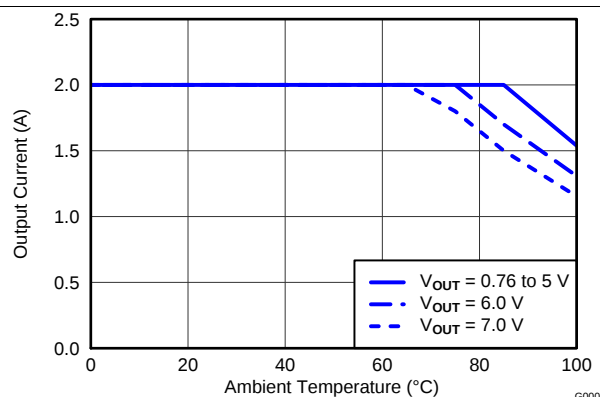
$V_{IN} = 12\text{ V}$  and  $T_A = 25\text{ }^{\circ}\text{C}$  (unless otherwise noted)



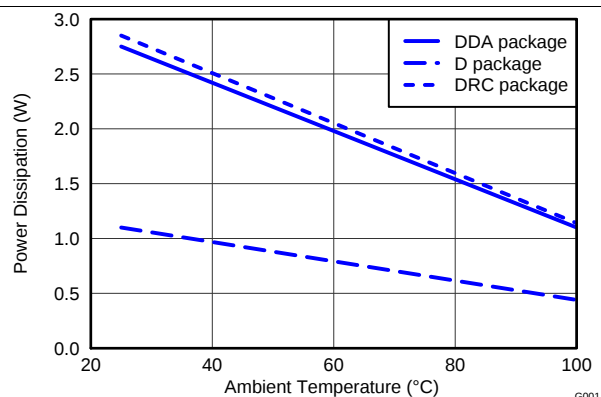
**Figure 7. Switching Frequency vs Output Current**



**Figure 8. Vfb Voltage vs Junction Temperature**



**Figure 9. D Package Output Current vs Ambient Temperature**



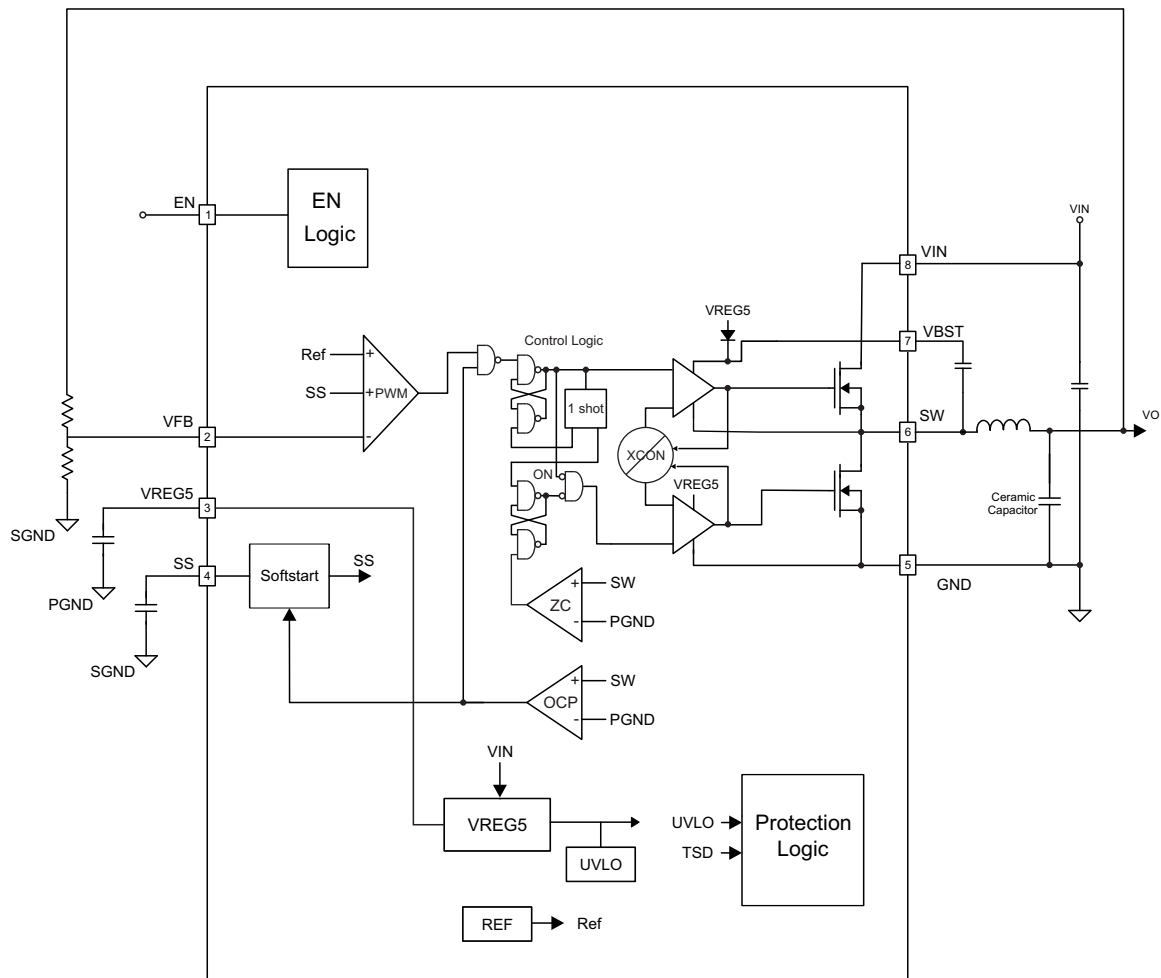
**Figure 10. Power Dissipation vs Ambient Temperature**

## 7 Detailed Description

### 7.1 Overview

The TPS54228 is a 2-A synchronous step-down (buck) converter with two integrated N-channel MOSFETs. It operates using D-CAP2™ mode control. The fast transient response of D-CAP2™ control reduces the output capacitance required to meet a specific level of performance. Proprietary internal circuitry allows the use of low-ESR output capacitors including ceramic and special polymer types.

### 7.2 Functional Block Diagram



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### 7.3 Feature Description

#### 7.3.1 PWM Operation

The main control loop of the TPS54228 is an adaptive on-time pulse width modulation (PWM) controller that supports a proprietary D-CAP2™ mode control. D-CAP2™ mode control combines constant on-time control with an internal compensation circuit for pseudo-fixed frequency and low external component count configuration with both low ESR and ceramic output capacitors. It is stable even with virtually no ripple at the output.

## Feature Description (continued)

At the beginning of each cycle, the high-side MOSFET is turned on. This MOSFET is turned off after internal one-shot timer expires. This one shot is set by the converter input voltage,  $V_{IN}$ , and the output voltage,  $V_O$ , to maintain a pseudo-fixed frequency over the input voltage range, hence it is called adaptive on-time control. The one-shot timer is reset and the high-side MOSFET is turned on again when the feedback voltage falls below the reference voltage. An internal ramp is added to reference voltage to simulate output ripple, eliminating the need for ESR induced output ripple from D-CAP2™ mode control.

### 7.3.2 PWM Frequency and Adaptive On-Time Control

TPS54228 uses an adaptive on-time control scheme and does not have a dedicated on board oscillator. The TPS54228 runs with a pseudo-constant frequency of 700 kHz by using the input voltage and output voltage to set the on-time, one-shot timer. The on-time is inversely proportional to the input voltage and proportional to the output voltage; therefore, when the duty ratio is  $V_{OUT}/V_{IN}$ , the frequency is constant.

### 7.3.3 Auto-Skip Eco-Mode™ Control

The TPS54228 is designed with Auto-Skip Eco-Mode™ to increase light load efficiency. As the output current decreases from heavy load condition, the inductor current is also reduced and eventually comes to point that its rippled valley touches zero level, which is the boundary between continuous conduction and discontinuous conduction modes. The rectifying MOSFET is turned off when its zero inductor current is detected. As the load current further decreases the converter run into discontinuous conduction mode. The on-time is kept almost the same as is was in the continuous conduction mode so that it takes longer time to discharge the output capacitor with smaller load current to the level of the reference voltage. The transition point to the light load operation  $I_{OUT(LL)}$  current can be calculated in [Equation 1](#)

$$I_{OUT(LL)} = \frac{1}{2 \cdot L \cdot f_{sw}} \cdot \frac{(V_{IN} - V_{OUT}) \cdot V_{OUT}}{V_{IN}} \quad (1)$$

### 7.3.4 Soft Start and Prebiased Soft Start

The soft-start function is adjustable. When the EN pin becomes high, 2-μA current begins charging the capacitor which is connected from the SS pin to GND. Smooth control of the output voltage is maintained during start-up. The equation for the slow start time is [Equation 2](#). VFB voltage is 0.765 V and SS pin source current is 2 μA.

$$t_{SS}(ms) = \frac{C6(nF) \times V_{REF} \times 1.1}{I_{SS}(\mu A)} = \frac{C6(nF) \times 0.765 \times 1.1}{2} \quad (2)$$

The TPS54228 contains a unique circuit to prevent current from being pulled from the output during start-up if the output is prebiased. When the soft start commands a voltage higher than the prebias level (internal soft start becomes greater than feedback voltage  $V_{FB}$ ), the controller slowly activates synchronous rectification by starting the first low-side FET gate driver pulses with a narrow on-time. It then increments that on-time on a cycle-by-cycle basis until it coincides with the time dictated by  $(1-D)$ , where  $D$  is the duty cycle of the converter. This scheme prevents the initial sinking of the prebias output, and ensure that the out voltage ( $V_O$ ) starts and ramps up smoothly into regulation and the control loop is given time to transition from prebiased start-up to normal mode operation.

### 7.3.5 Current Protection

The output overcurrent protection (OCP) is implemented using a cycle-by-cycle valley detect control circuit. The switch current is monitored by measuring the low-side FET switch voltage between the SW pin and GND. This voltage is proportional to the switch current. To improve accuracy, the voltage sensing is temperature compensated.

During the on-time of the high-side FET switch, the switch current increases at a linear rate determined by  $V_{IN}$ ,  $V_{OUT}$ , the on-time and the output inductor value. During the on-time of the low-side FET switch, this current decreases linearly. The average value of the switch current is the load current,  $I_{OUT}$ . The TPS54228 constantly monitors the low-side FET switch voltage, which is proportional to the switch current, during the low-side on-time. If the measured voltage is above the voltage proportional to the current limit, an internal counter is incremented per each SW cycle and the converter maintains the low-side switch on until the measured voltage is below the voltage corresponding to the current limit at which time the switching cycle is terminated and a new switching

## Feature Description (continued)

cycle begins. In subsequent switching cycles, the on-time is set to a fixed value and the current is monitored in the same manner. If the overcurrent condition exists for 7 consecutive switching cycles, the internal OCL threshold is set to a lower level, reducing the available output current. When a switching cycle occurs where the switch current is not above the lower OCL threshold, the counter is reset and the OCL limit is returned to the higher value.

There are some important considerations for this type of overcurrent protection. The load current one half of the peak-to-peak inductor current higher than the overcurrent threshold. Also when the current is being limited, the output voltage tends to fall as the demanded load current may be higher than the current available from the converter. This may cause the output voltage to fall. When the overcurrent condition is removed, the output voltage returns to the regulated value. This protection is non-latching.

### 7.3.6 UVLO Protection

Undervoltage lockout protection (UVLO) monitors the voltage of the  $V_{REG5}$  pin. When the  $V_{REG5}$  voltage is lower than UVLO threshold voltage, the TPS54228 is shut off. This protection is non-latching.

### 7.3.7 Thermal Shutdown

TPS54228 monitors the temperature of itself. If the temperature exceeds the threshold value (typically 165°C), the device is shut off. This is non-latch protection.

## 7.4 Device Functional Modes

### 7.4.1 Normal Operation

When the input voltage is above the UVLO threshold and the EN voltage is above the enable threshold, the TPS54228 can operate in their normal switching modes. Normal continuous conduction mode (CCM) occurs when the minimum switch current is above 0 A. In CCM, the TPS54228 operates at a quasi-fixed frequency of 700 kHz.

### 7.4.2 Standby Operation

When the TPS54228 is operating in either normal CCM or forced CCM, it may be placed in standby by asserting the EN pin low.

## 8 Application and Implementation

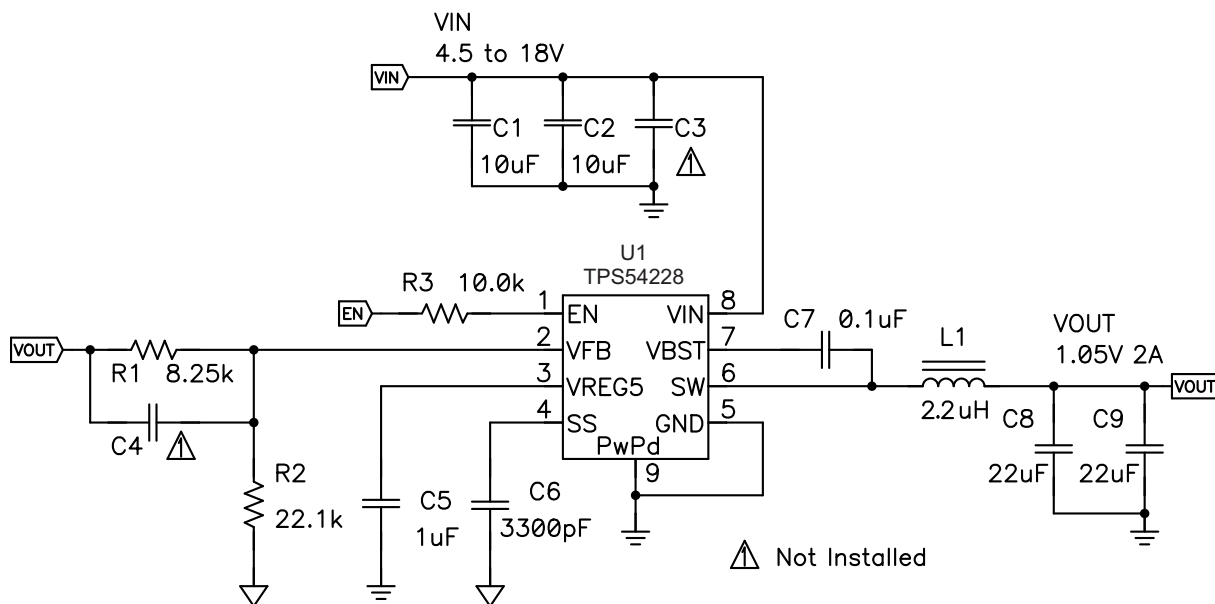
### NOTE

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.

### 8.1 Application Information

The TPS54228 is typically used as step-down converters, which convert a voltage to a lower voltage, 4.5 V to 18 V. WEBENCH™ software is available to aid in the design and analysis of circuits.

### 8.2 Typical Application



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**Figure 11. Example Design Schematic**

#### 8.2.1 Design Requirements

Table 1 shows the parameters for this design example.

**Table 1. Design Parameters**

| PARAMETER             | VALUE         |
|-----------------------|---------------|
| Input voltage         | 4.5 V to 18 V |
| Output voltage        | 1.05 V        |
| Output current        | 2 A           |
| Output voltage ripple | 20 mVpp       |

## 8.2.2 Detailed Design Procedure

### 8.2.2.1 Output Voltage Resistors Selection

The output voltage is set with a resistor divider from the output node to the VFB pin. TI recommends using 1% tolerance or better divider resistors. Start by using [Equation 3](#) to calculate  $V_{OUT}$ .

To improve efficiency at light loads, consider using larger value resistors. High resistance is more susceptible to noise, and the voltage errors from the VFB input current are more noticeable.

$$V_{OUT} = 0.765 \times \left( 1 + \frac{R1}{R2} \right) \quad (3)$$

### 8.2.2.2 Output Filter Selection

The output filter used with the TPS54228 is an LC circuit. This LC filter has double pole at:

$$F_P = \frac{1}{2\pi\sqrt{L_{OUT} \times C_{OUT}}} \quad (4)$$

At low frequencies, the overall loop gain is set by the output set-point resistor divider network and the internal gain of the TPS54228. The low frequency phase is 180°. At the output filter pole frequency, the gain rolls off at a –40 dB per decade rate and the phase drops rapidly. D-CAP2™ introduces a high frequency zero that reduces the gain roll off to –20 dB per decade and increases the phase to 90° one decade above the zero frequency. The inductor and capacitor selected for the output filter must be selected so that the double pole of [Equation 4](#) is located below the high frequency zero but close enough that the phase boost provided by the high frequency zero provides adequate phase margin for a stable circuit. To meet this requirement use the values recommended in [Table 2](#).

**Table 2. Recommended Component Values**

| OUTPUT VOLTAGE (V) | R1 (kΩ) | R2 (kΩ) | C4 (pF) <sup>(1)</sup> | L1 (μH)    | C8 + C9 (μF) |
|--------------------|---------|---------|------------------------|------------|--------------|
| 1                  | 6.81    | 22.1    | —                      | 1.5 to 2.2 | 22 to 68     |
| 1.05               | 8.25    | 22.1    | —                      | 1.5 to 2.2 | 22 to 68     |
| 1.2                | 12.7    | 22.1    | —                      | 2.2        | 22 to 68     |
| 1.5                | 21.5    | 22.1    | —                      | 2.2        | 22 to 68     |
| 1.8                | 30.1    | 22.1    | 5 to 22                | 3.3        | 22 to 68     |
| 2.5                | 49.9    | 22.1    | 5 to 22                | 3.3        | 22 to 68     |
| 3.3                | 73.2    | 22.1    | 5 to 22                | 3.3        | 22 to 68     |
| 5                  | 124     | 22.1    | 5 to 22                | 4.7        | 22 to 68     |
| 6.5                | 165     | 22.1    | 5 to 22                | 4.7        | 22 to 68     |

(1) Optional

Because the DC gain is dependent on the output voltage, the required inductor value increases as the output voltage increases. For higher output voltages at or above 1.8 V, additional phase boost can be achieved by adding a feedforward capacitor (C4) in parallel with R1.

The inductor peak-to-peak ripple current, peak current and RMS current are calculated using [Equation 5](#), [Equation 6](#), and [Equation 7](#). The inductor saturation current rating must be greater than the calculated peak current, and the RMS or heating current rating must be greater than the calculated RMS current.

Use 700 kHz for  $f_{SW}$ . Make sure the chosen inductor is rated for the peak current of [Equation 6](#) and the RMS current of [Equation 7](#).

$$I_{IPP} = \frac{V_{OUT}}{V_{IN(max)}} \times \frac{V_{IN(max)} - V_{OUT}}{L_O \times f_{SW}} \quad (5)$$

$$I_{Ipeak} = I_O + \frac{I_{IPP}}{2} \quad (6)$$

$$I_{Lo(RMS)} = \sqrt{I_O^2 + \frac{1}{12} I_{IPP}^2} \quad (7)$$

For this design example, the calculated peak current is 2.311 A and the calculated RMS current is 2.008 A. The inductor used is a TDK CLF7045T-2R2N with a peak current rating of 5.5 A and an RMS current rating of 4.3 A.

The capacitor value and ESR determines the amount of output voltage ripple. The TPS54228 is intended for use with ceramic or other low-ESR capacitors. Recommended values range from 22 µF to 68 µF. Use [Equation 8](#) to determine the required RMS current rating for the output capacitor.

$$I_{Co(RMS)} = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\sqrt{12} \times V_{IN} \times L_O \times f_{SW}} \quad (8)$$

For this design, two TDK C3216X5R0J226M 22-µF output capacitors are used. The typical ESR is 2 mΩ each. The calculated RMS current is 0.18 A and each output capacitor is rated for 4 A.

### 8.2.2.3 Input Capacitor Selection

The TPS54228 requires an input decoupling capacitor and a bulk capacitor is needed depending on the application. A ceramic capacitor over 10 µF is recommended for the decoupling capacitor. An additional 0.1-µF capacitor (C3) from pin 8 to ground is optional to provide additional high frequency filtering. The capacitor voltage rating must be greater than the maximum input voltage.

### 8.2.2.4 Bootstrap Capacitor Selection

A 0.1-µF ceramic capacitor must be connected between the VBST to SW pin for proper operation. TI recommends using a ceramic capacitor.

### 8.2.2.5 VREG5 Capacitor Selection

A 1-µF ceramic capacitor must be connected between the VREG5 to GND pin for proper operation. TI recommends using a ceramic capacitor.

## 8.2.3 Application Curves

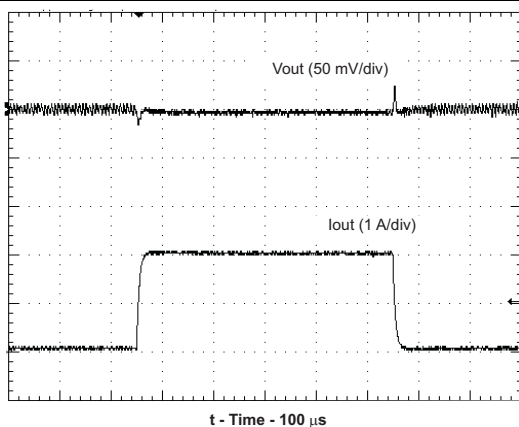


Figure 12. 1.05-V, Load Transient Response

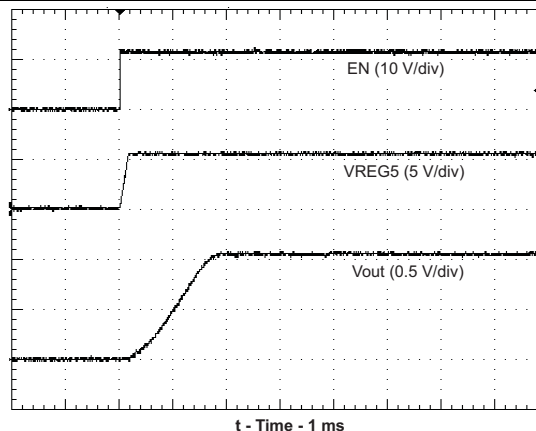
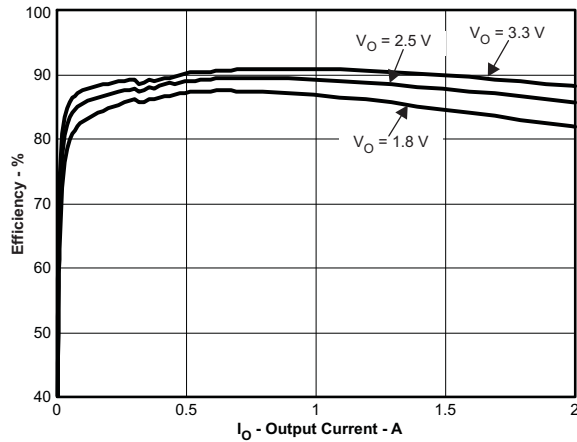
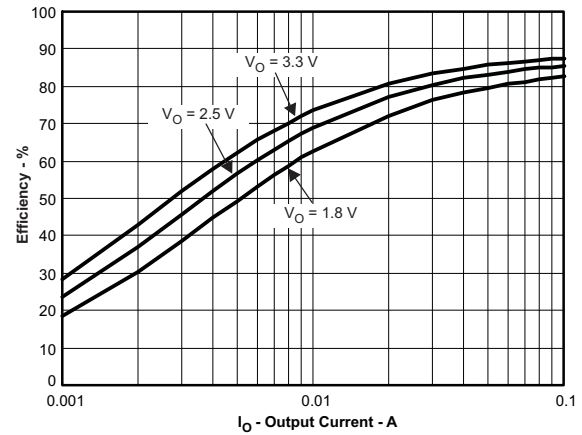
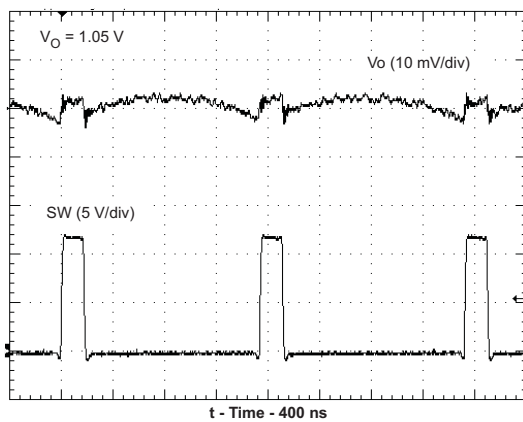
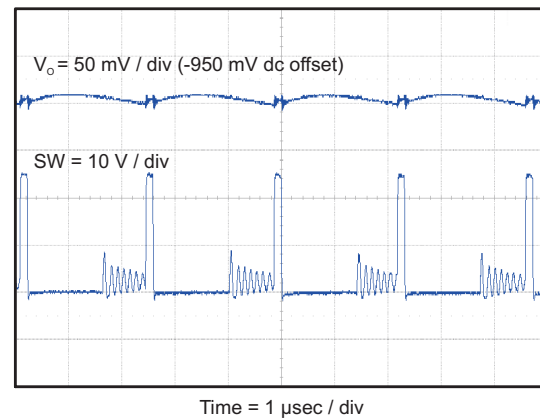
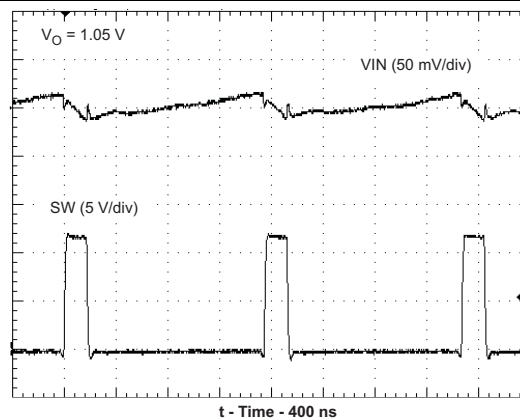


Figure 13. Start-Up Wave Form


**Figure 14. Efficiency vs Output Current**

**Figure 15. Light Load Efficiency vs Output Current**

**Figure 16. Voltage Ripple at Output ( $I_O = 2$  A)**

**Figure 17. DCM Voltage Ripple at Output ( $I_O = 30$  mA)**

**Figure 18. Voltage Ripple at Input ( $I_O = 2$  A)**

## 9 Power Supply Recommendations

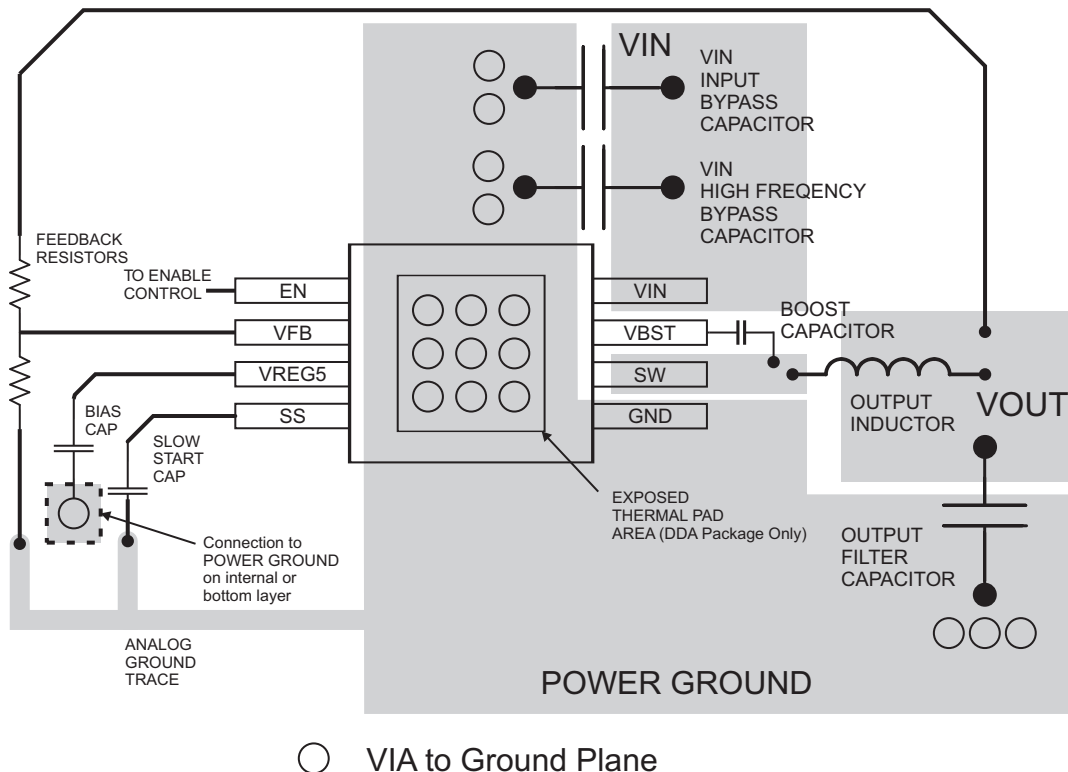
The TPS54228 is designed to operate from input supply voltage in the range of 4.5 V to 18 V. Buck converters require the input voltage to be higher than the output voltage for proper operation. The maximum recommended operating duty cycle is 65%. Using that criteria, the minimum recommended input voltage is  $V_O / 0.65$ .

## 10 Layout

### 10.1 Layout Guidelines

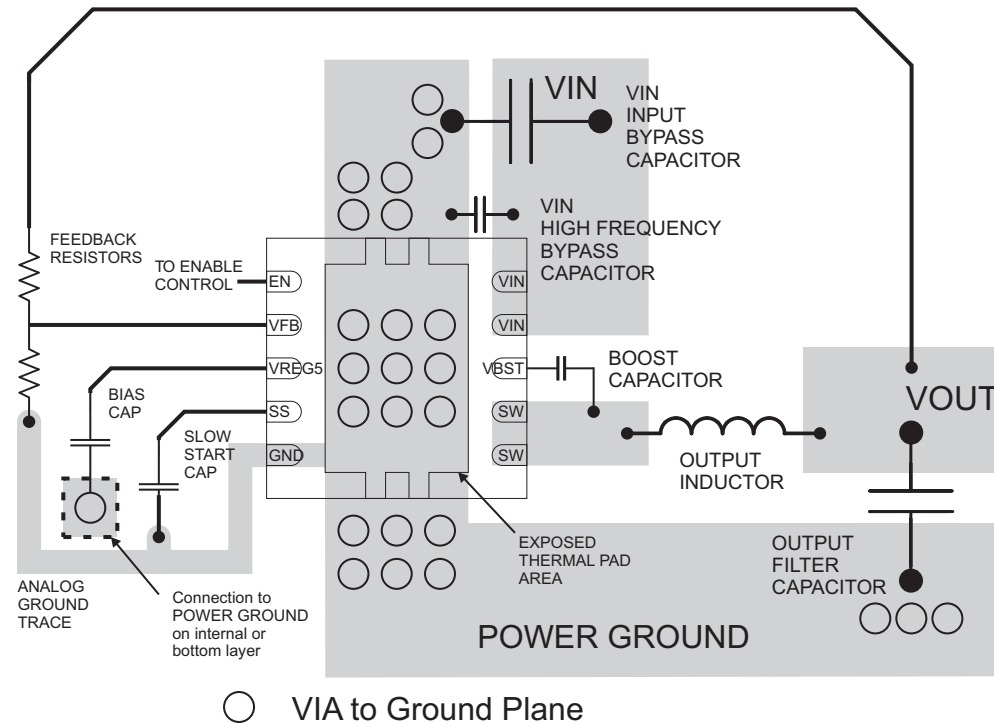
1. Keep the input switching current loop as small as possible.
2. Keep the SW node as physically small and short as possible to minimize parasitic capacitance and inductance and to minimize radiated emissions. Kelvin connections must be brought from the output to the feedback pin of the device.
3. Keep analog and non-switching components away from switching components.
4. Make a single point connection from the signal ground to power ground.
5. Do not allow switching current to flow under the device.
6. Keep the pattern lines for VIN and PGND broad.
7. Exposed pad of device must be connected to PGND with solder (DDA package only).
8. VREG5 capacitor must be placed near the device, and connected PGND.
9. Output capacitor must be connected to a broad pattern of the PGND.
10. Voltage feedback loop must be as short as possible, and preferably with ground shield.
11. Lower resistor of the voltage divider, which is connected to the VFB pin, must be tied to SGND.
12. Providing sufficient via is preferable for VIN, SW and PGND connection.
13. PCB pattern for VIN, SW, and PGND must be as broad as possible.
14. VIN capacitor must be placed as near as possible to the device.

### 10.2 Layout Examples



**Figure 19. PCB Layout**

## Layout Examples (continued)



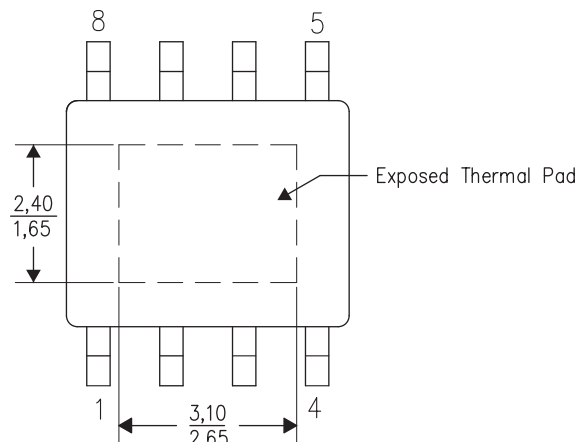
**Figure 20. DRC Package PCB Layout**

## 10.3 Thermal Considerations

This 8-pin DDA package incorporates an exposed thermal pad that is designed to be 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 additional information on the exposed thermal pad and how to use the advantage of its heat dissipating abilities, see [PowerPAD™ Thermally Enhanced Package](#) (SLMA002) and [PowerPAD™ Made Easy](#) (SMLA004).

[Figure 21](#) shows the exposed thermal pad dimensions for this package.



**Figure 21. Thermal Pad Dimensions**

## 11 Device and Documentation Support

### 11.1 Documentation Support

#### 11.1.1 Related Documentation

For related documentation see the following:

- [PowerPAD™ Thermally Enhanced Package](#) (SLMA002)
- [PowerPAD™ Made Easy](#) (SLMA004)

### 11.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 11.3 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.

### 11.4 Trademarks

D-CAP2, Eco-Mode, WEBENCH, E2E are trademarks of Texas Instruments.

Blu-ray Disc is a trademark of Blu-ray Disc Association.

All other trademarks are the property of their respective owners.

### 11.5 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.

### 11.6 Glossary

[SLYZ022](#) — *TI Glossary*.

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

## 12 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 Device | Status<br>(1) | Package Type | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| TPS54228D        | ACTIVE        | SOIC         | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAUAG             | Level-1-260C-UNLIM   | -40 to 85    | 54228                   | <a href="#">Samples</a> |
| TPS54228DDA      | ACTIVE        | SO PowerPAD  | DDA                | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU   CU SN       | Level-2-260C-1 YEAR  | -40 to 85    | 54228                   | <a href="#">Samples</a> |
| TPS54228DDAR     | ACTIVE        | SO PowerPAD  | DDA                | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU   CU SN       | Level-2-260C-1 YEAR  | -40 to 85    | 54228                   | <a href="#">Samples</a> |
| TPS54228DR       | ACTIVE        | SOIC         | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAUAG             | Level-1-260C-UNLIM   | -40 to 85    | 54228                   | <a href="#">Samples</a> |
| TPS54228DRCR     | ACTIVE        | VSON         | DRC                | 10   | 3000           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-2-260C-1 YEAR  | -40 to 85    | 54228                   | <a href="#">Samples</a> |
| TPS54228DRCT     | ACTIVE        | VSON         | DRC                | 10   | 250            | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-2-260C-1 YEAR  | -40 to 85    | 54228                   | <a href="#">Samples</a> |

(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.

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

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**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

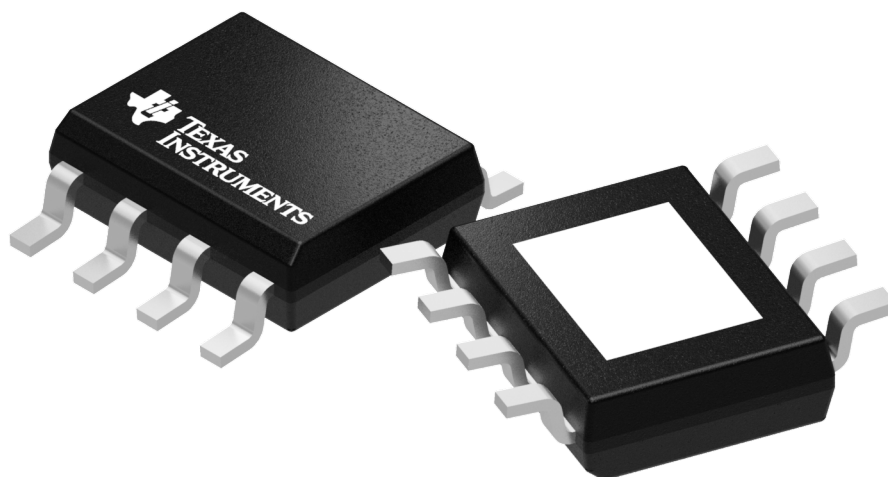
| Device       | Package Type | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| TPS54228DDAR | SO Power PAD | DDA             | 8    | 2500 | 330.0              | 12.8               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| TPS54228DR   | SOIC         | D               | 8    | 2500 | 330.0              | 12.8               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| TPS54228DRCR | VSON         | DRC             | 10   | 3000 | 330.0              | 12.4               | 3.3     | 3.3     | 1.1     | 8.0     | 12.0   | Q2            |
| TPS54228DRCT | VSON         | DRC             | 10   | 250  | 180.0              | 12.4               | 3.3     | 3.3     | 1.1     | 8.0     | 12.0   | Q2            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

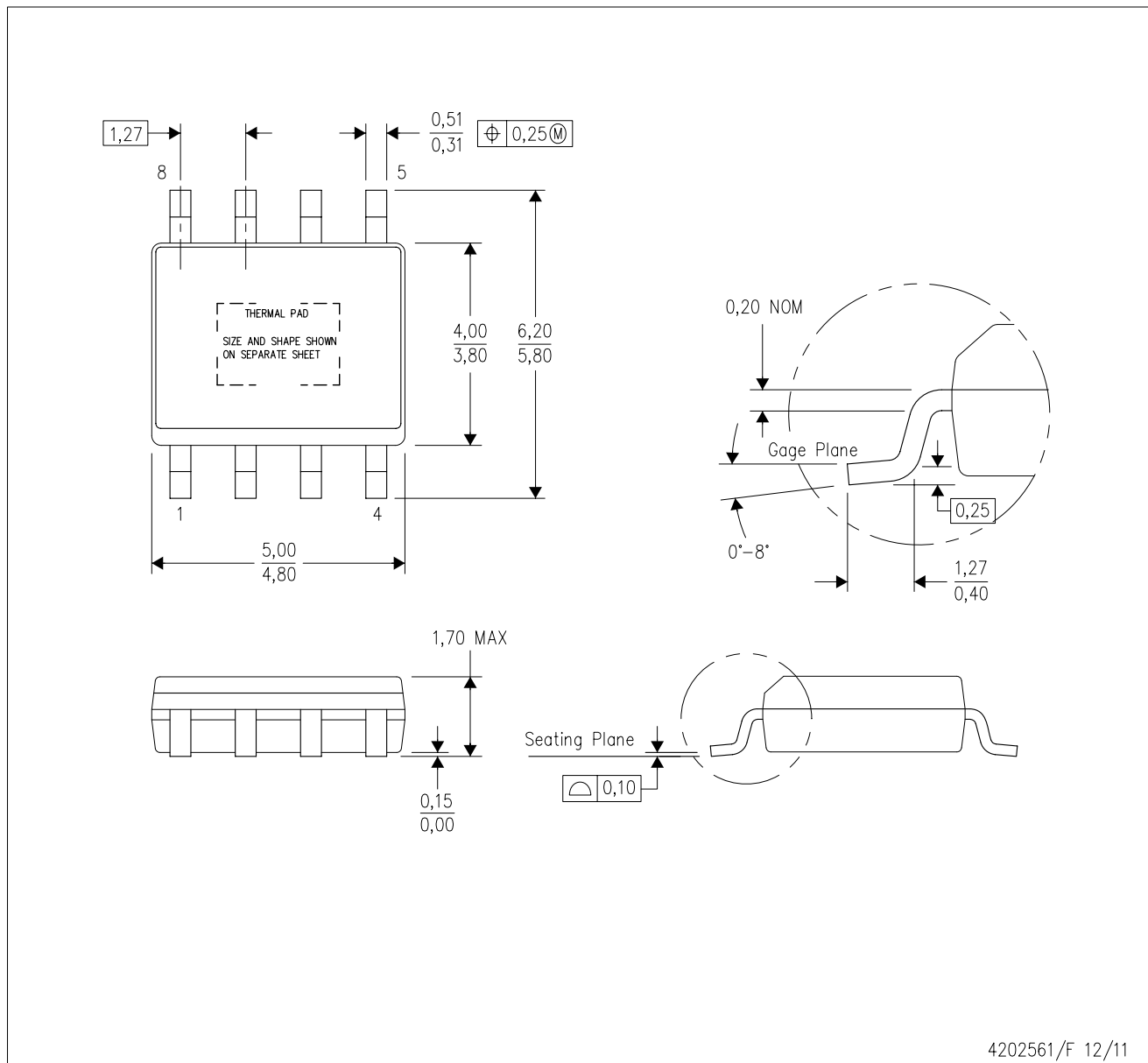
| Device       | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|--------------|-----------------|------|------|-------------|------------|-------------|
| TPS54228DDAR | SO PowerPAD  | DDA             | 8    | 2500 | 366.0       | 364.0      | 50.0        |
| TPS54228DR   | SOIC         | D               | 8    | 2500 | 364.0       | 364.0      | 27.0        |
| TPS54228DRCR | VSON         | DRC             | 10   | 3000 | 367.0       | 367.0      | 35.0        |
| TPS54228DRCT | VSON         | DRC             | 10   | 250  | 210.0       | 185.0      | 35.0        |



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

DDA (R-PDSO-G8)

PowerPAD™ PLASTIC SMALL-OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5-1994.
  - B. This drawing is subject to change without notice.
  - C. Body dimensions do not include mold flash or protrusion not to exceed 0,15.
  - D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at [www.ti.com](http://www.ti.com) <<http://www.ti.com>>.
  - E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
  - F. This package complies to JEDEC MS-012 variation BA

PowerPAD is a trademark of Texas Instruments.

DDA (R-PDSO-G8)

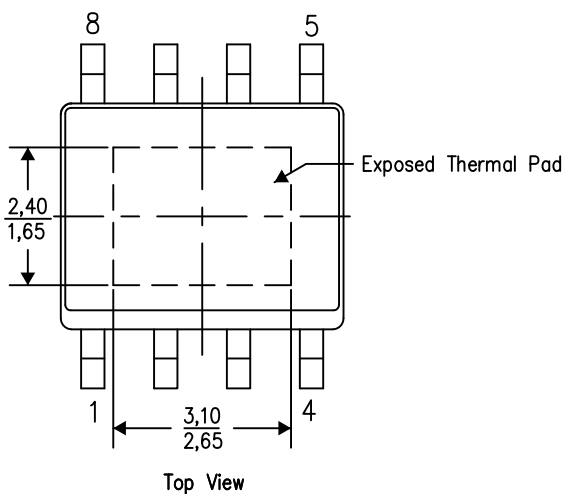
PowerPAD™ PLASTIC SMALL OUTLINE

## THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the 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 additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at [www.ti.com](http://www.ti.com).

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



Exposed Thermal Pad Dimensions

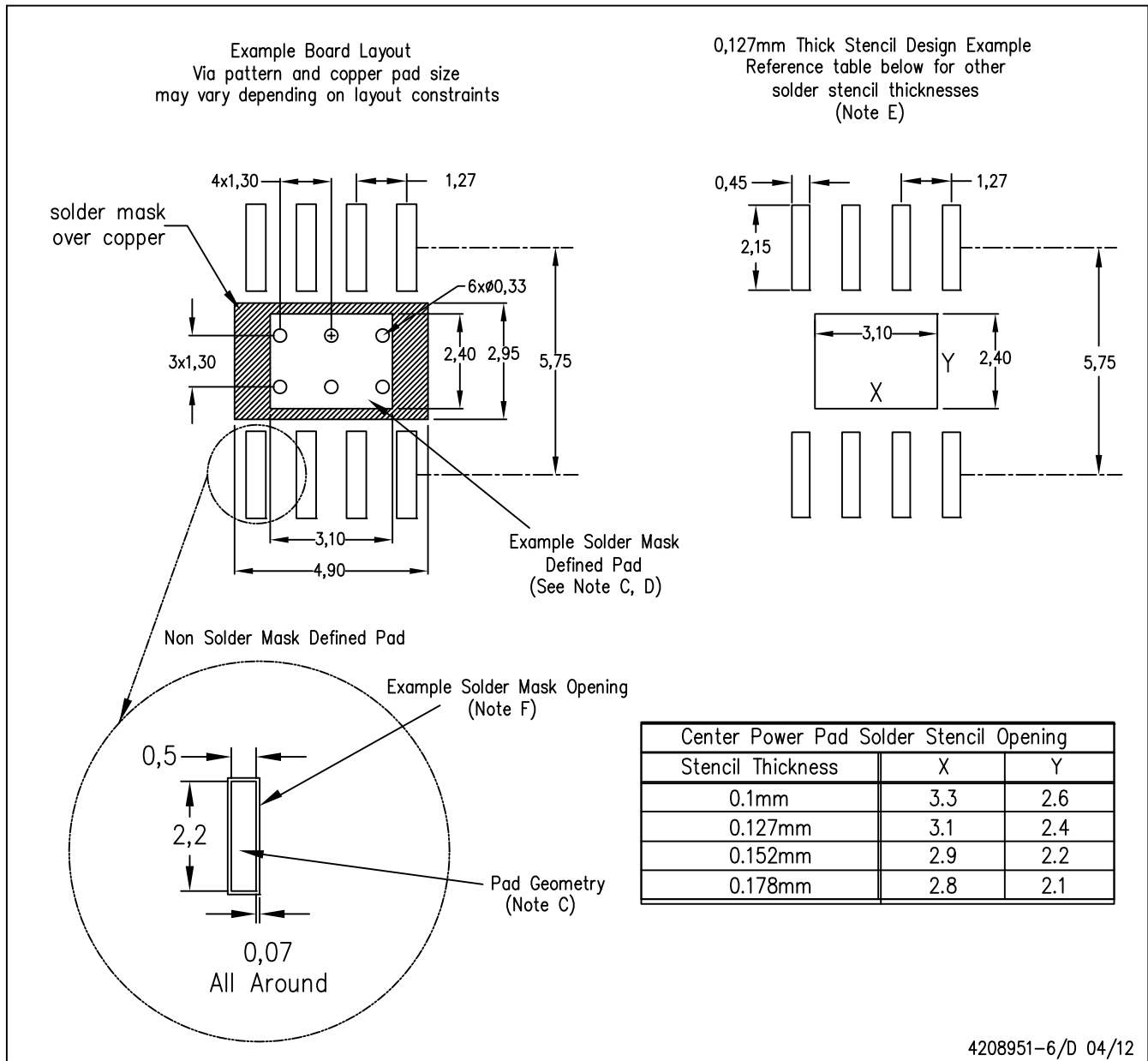
4206322-6/L 05/12

NOTE: A. All linear dimensions are in millimeters

PowerPAD is a trademark of Texas Instruments

DDA (R-PDSO-G8)

PowerPAD™ PLASTIC SMALL OUTLINE



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002, SLMA004, 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) <<http://www.ti.com>>. Publication IPC-7351 is recommended for alternate designs.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.
  - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

PowerPAD is a trademark of Texas Instruments.

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



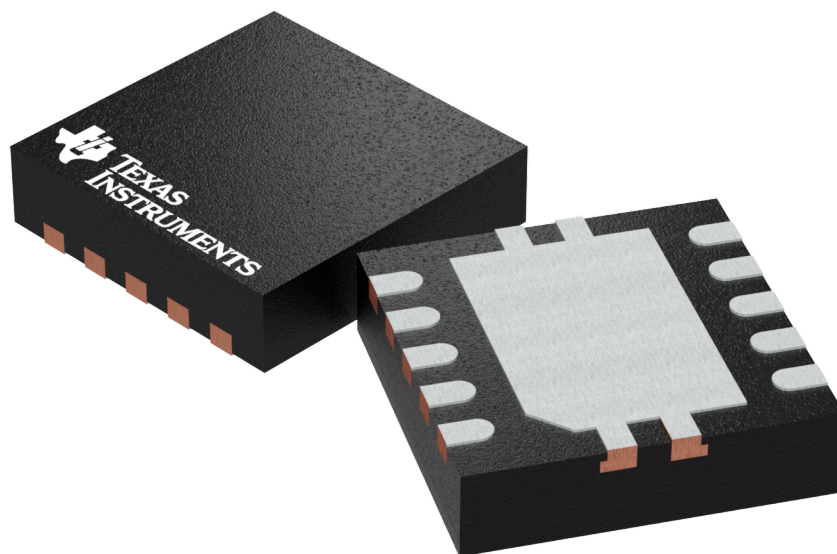
- NOTES:
- A. All linear dimensions are in inches (millimeters).
  - B. This drawing is subject to change without notice.
  - $\triangle C$  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
  - $\triangle D$  Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
  - E. Reference JEDEC MS-012 variation AA.

## GENERIC PACKAGE VIEW

DRC 10

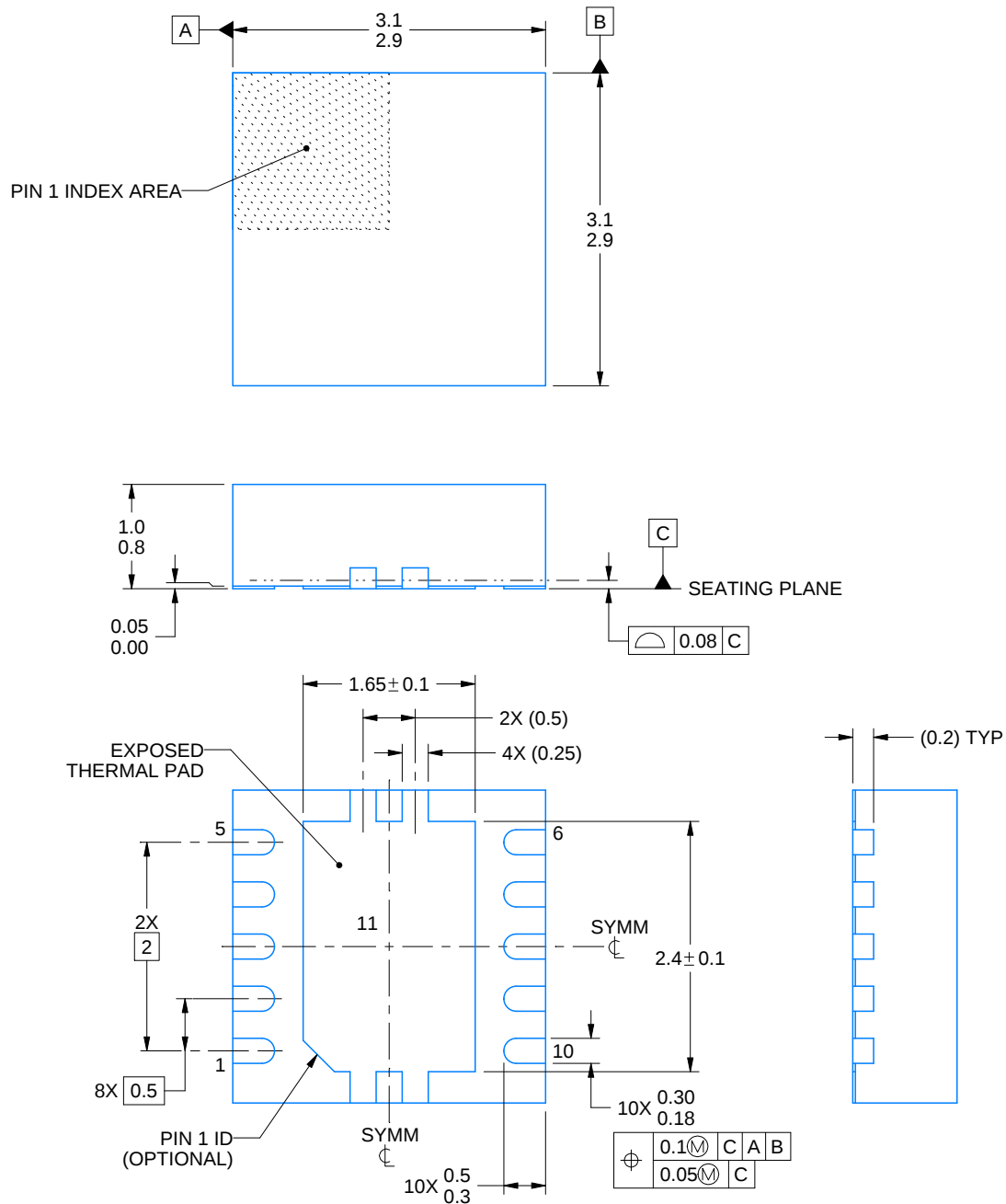
VSON - 1 mm max height

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.

4204102-3/M



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## NOTES:

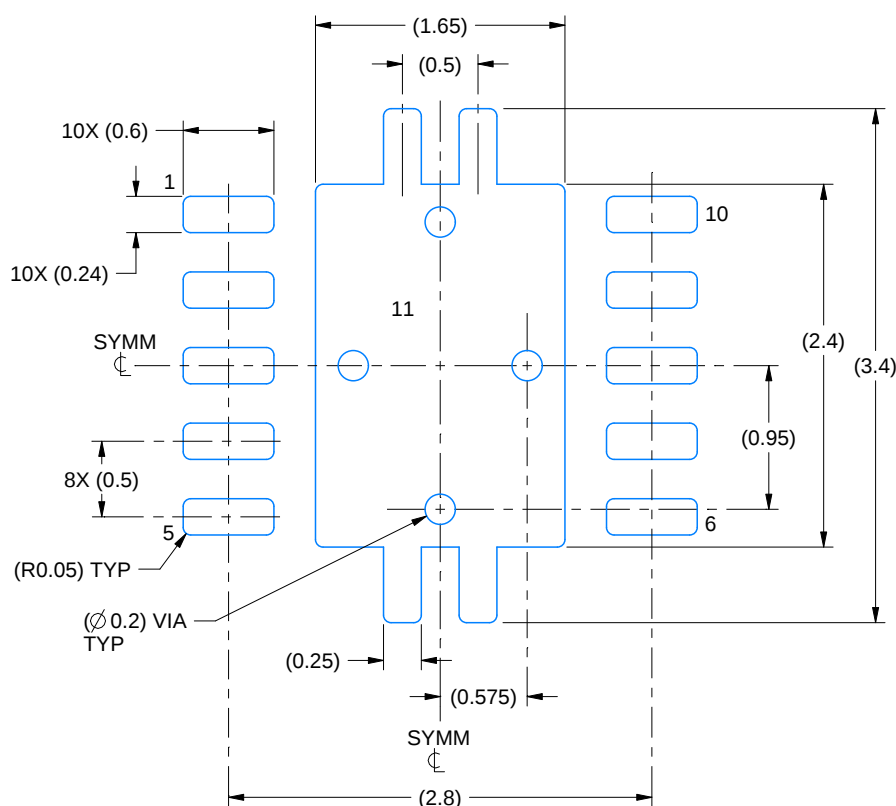
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical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

# EXAMPLE BOARD LAYOUT

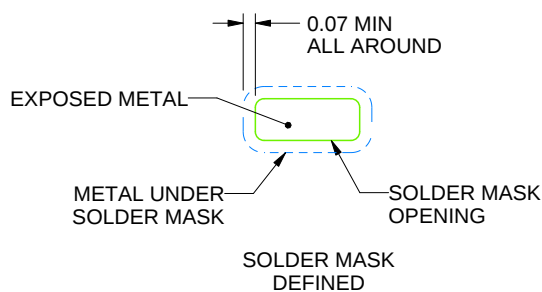
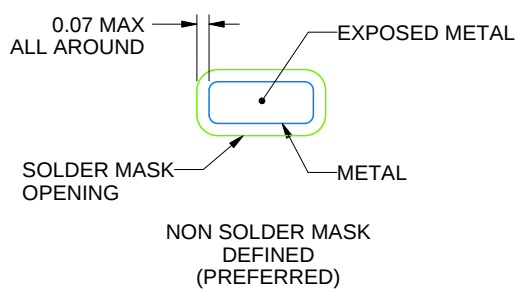
DRC0010J

VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:20X



SOLDER MASK DETAILS

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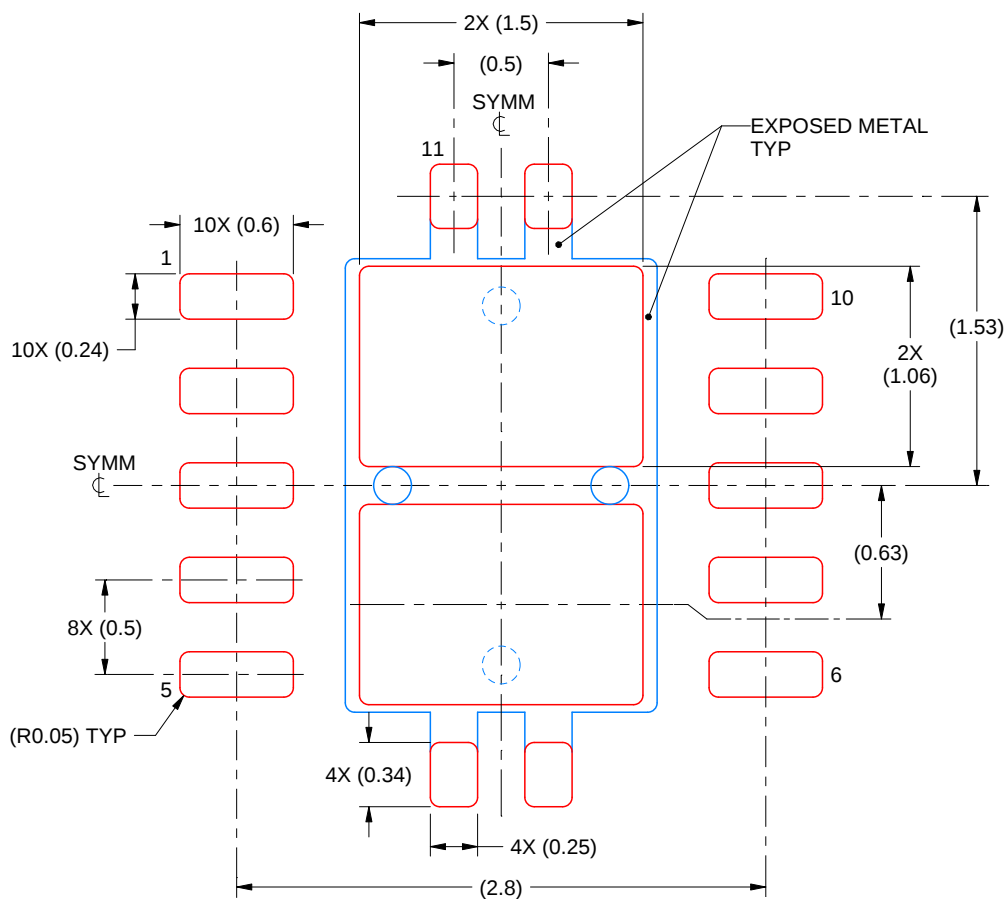
NOTES: (continued)

- 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/sluea271](http://www.ti.com/lit/sluea271)).
- Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

**DRC0010J**

**VSON - 1 mm max height**

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 11:  
80% PRINTED SOLDER COVERAGE BY AREA  
SCALE:25X

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NOTES: (continued)

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

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