# TPS56x209, 4.5V to 17 V Input, 2-A, 3-A Synchronous Step-Down Voltage Regulator in 6 pin SOT-23

## 1 Features

- TPS562209 - 2A converter with integrated 122-mΩ and 72-mΩ FETs
- TPS563209 - 3A converter with integrated 68-mΩ and 39-mΩ FETs
- D-CAP2™ Mode Control for Fast Transient Response
- Input Voltage Range: 4.5 V to 17 V
- Output Voltage Range: 0.76 V to 7 V
- 650 kHz Switching Frequency
- Low Shutdown Current Less than 10µA
- 1% Feedback Voltage Accuracy (25°C)
- Startup from Pre-Biased Output Voltage
- Cycle By Cycle Over-current Limit
- Hiccup-mode Under Voltage Protection
- Non-latch OVP, UVLO and TSD Protections
- Fixed Soft Start : 1.0ms

## 2 Applications

- Digital TV Power Supply
- High Definition Blu-ray Disc™ Players
- Networking Home Terminal
- Digital Set Top Box (STB)

## 3 Description

The TPS562209 and TPS563209 are simple, easy-to-use, 2-A and 3-A synchronous step-down converters in 6 pin SOT-23 package.

The devices are optimized to operate with minimum external component counts and also optimized to achieve low standby current.

These switch mode power supply (SMPS) devices employ D-CAP2™ mode control providing a fast transient response and supporting both low equivalent series resistance (ESR) output capacitors such as specialty polymer and ultra-low ESR ceramic capacitors with no external compensation components.

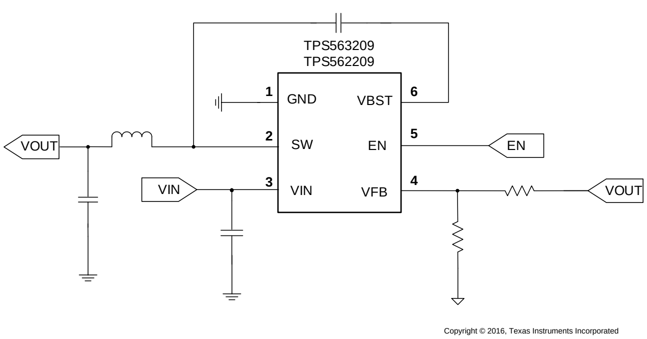
TPS562209 and TPS563209 always operate in continuous conduction mode, which reduces the output ripple voltage in light load compared to discontinous conduction mode. TPS56x209 are available in a 6-pin 1.6 × 2.9(mm) SOT (DDC) package, and specified from –40°C to 150°C of junction temperature.

**Device Information(1)**

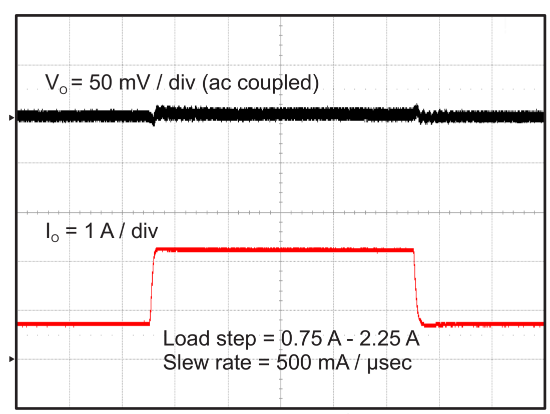
| PART NUMBER | PACKAGE | BODY SIZE (NOM) |
|---|---|---|
| TPS563209, TPS562209 | SOT (6) | 1.60 mm × 2.90 mm |

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

**Simplified Schematic**




**Transient Response**



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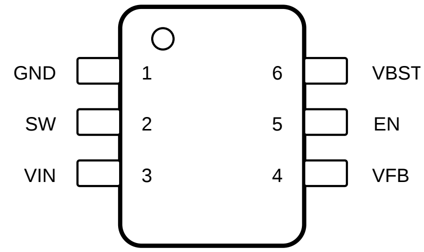
# 4 Revision History

| Changes from Original (September 2014) to Revision A | Page |
|---|---|
| • Updated the Pinout image in Pin Configuration and Functions | 3 |
| • Changed the "Handling Ratings" table to the ESD Ratings table | 4 |
| • Changed $R_{\theta JB}$ for TPS562209 From: 57.3 To: 13.4 in Thermal Information | 4 |
| • The Adaptive On-Time Control and PWM Operation, changed text From: "proportional to the converter input voltage, $V_{IN}$, and inversely proportional to the output voltage, $V_O$" To: "inversely proportional to the converter input voltage, $V_{IN}$, and proportional to the output voltage, $V_O$" | 11 |

# 5 Pin Configuration and Functions

**DDC Package**
**6 Pin (SOT)**
**Top View**




## Pin Functions

| PIN | | DESCRIPTION |
|---|---|---|
| NAME | NO. | |
| GND | 1 | Ground pin Source terminal of low-side power NFET as well as the ground terminal for controller circuit. Connect sensitive VFB to this GND at a single point. |
| SW | 2 | Switch node connection between high-side NFET and low-side NFET. |
| VIN | 3 | Input voltage supply pin. The drain terminal of high-side power NFET. |
| VFB | 4 | Converter feedback input. Connect to output voltage with feedback resistor divider. |
| EN | 5 | Enable input control. Active high and must be pulled up to enable the device. |
| VBST | 6 | Supply input for the high-side NFET gate drive circuit. Connect 0.1 µF capacitor between VBST and SW pins. |

# 6 Specifications

## 6.1 Absolute Maximum Ratings

$T_J$ = –40°C to 150°C (unless otherwise noted) (1)

| | | MIN | MAX | UNIT |
|---|---|---|---|---|
| Input voltage range | VIN, EN | –0.3 | 19 | V |
| | VBST | –0.3 | 25 | V |
| | VBST (10 ns transient) | –0.3 | 27.5 | V |
| | VBST (vs SW) | –0.3 | 6.5 | V |
| | VFB, | –0.3 | 6.5 | V |
| | SW | –2 | 19 | V |
| | SW (10 ns transient) | –3.5 | 21 | V |
| Operating junction temperature, $T_J$ | | –40 | 150 | °C |
| Storage temperature, $T_{stg}$ | | –55 | 150 | °C |

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

## 6.2 ESD Ratings

| | | | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{(ESD)}$ | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins(1) | | 2 | kV |
| | | Charged device model (CDM), per JEDEC specification JESD22-C101, all pins(2) | | 500 | V |

(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

$T_J$ = -40°C to 150°C (unless otherwise noted)

| | | | MIN | MAX | UNIT |
|---|---|---|---|---|---|
| $V_{IN}$ | Supply input voltage range | | 4.5 | 17 | V |
| $V_I$ | Input voltage range | VBST | –0.1 | 23 | V |
| | | VBST (10 ns transient) | –0.1 | 26 | |
| | | VBST(vs SW) | –0.1 | 6.0 | |
| | | EN | –0.1 | 17 | |
| | | VFB | –0.1 | 5.5 | |
| | | SW | –1.8 | 17 | |
| | | SW (10 ns transient) | –3.5 | 20 | |
| $T_A$ | Operating free-air temperature | | –40 | 85 | °C |

## 6.4 Thermal Information

| THERMAL METRIC(1) | | TPS562209 | TPS563209 | UNIT |
|---|---|---|---|---|
| | | DDC (6 PINS) | | |
| $R_{\theta JA}$ | Junction-to-ambient thermal resistance | 109.2 | 87.9 | °C/W |
| $R_{\theta JC(top)}$ | Junction-to-case (top) thermal resistance | 44.5 | 42.2 | |
| $R_{\theta JB}$ | Junction-to-board thermal resistance | 13.4 | 13.6 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 2.3 | 1.9 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 60.4 | 13.3 | |

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

## 6.5 Electrical Characteristics

$T_J$ = -40°C to 150°C, VIN = 12V (unless otherwise noted)

| PARAMETER | | TEST CONDITIONS | MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **SUPPLY CURRENT** | | | | | | |
| $I_{VIN}$ | Operating – non-switching supply current | $V_{IN}$ current, $T_A$ = 25°C, EN = 5V, VFB = 0.8 V | | 650 | 900 | µA<br>µA |
| $I_{VINSDN}$ | Shutdown supply current | $V_{IN}$ current, $T_A$ = 25°C, EN = 0 V | | 3.0 | 10 | µA |
| **LOGIC THRESHOLD** | | | | | | |
| $V_{ENH}$ | EN high-level input voltage | EN | 1.6 | | | V |
| $V_{ENL}$ | EN low-level input voltage | EN | | | 0.6 | V |
| $R_{EN}$ | EN pin resistance to GND | $V_{EN}$ = 12 V | 225 | 450 | 900 | kΩ |
| **$V_{FB}$ VOLTAGE AND DISCHARGE RESISTANCE** | | | | | | |
| $V_{FBTH}$ | $V_{FB}$ threshold voltage | $T_A$ = 25°C, $V_O$ = 1.05 V, continuous mode operation | 758 | 765 | 772 | mV |
| $I_{VFB}$ | $V_{FB}$ input current | $V_{FB}$ = 0.8V, $T_A$ = 25°C | | 0 | ±0.1 | mA |
| **MOSFET** | | | | | | |
| $R_{DS(on)h}$ | High side switch resistance | $T_A$ = 25°C, $V_{BST}$ – SW = 5.5 V (TPS562209) | | 122 | | mΩ |
| | | $T_A$ = 25°C, $V_{BST}$ – SW = 5.5 V (TPS563209) | | 68 | | |
| $R_{DS(on)l}$ | Low side switch resistance | $T_A$ = 25°C (TPS562209) | | 72 | | mΩ |
| | | $T_A$ = 25°C (TPS563209) | | 39 | | |
| **CURRENT LIMIT** | | | | | | |
| $I_{ocl}$ | Current limit(1) | DC current, VOUT = 1.05V , L1 = 2.2 µH | 2.5 | 3.2 | 4.3 | A |
| | | DC current, VOUT = 1.05V , L1 = 1.5 µH | 3.5 | 4.2 | 5.3 | |
| **THERMAL SHUTDOWN** | | | | | | |
| $T_{SDN}$ | Thermal shutdown threshold(1) | Shutdown temperature | | 155 | | °C |
| | | Hysteresis | | 35 | | |
| **ON-TIME TIMER CONTROL** | | | | | | |
| $t_{ON}$ | On time | VIN = 12 V, VO = 1.05 V | | 150 | | ns |
| $t_{OFF(MIN)}$ | Minimum off time | $T_A$ = 25°C, $V_{FB}$ = 0.5 V | | 260 | 310 | ns |
| **SOFT START** | | | | | | |
| $T_{ss}$ | Soft –start time | Internal soft-start time, $T_A$ = 25°C | 0.7 | 1.0 | 1.3 | ms |
| **OUTPUT UNDERVOLTAGE AND OVERVOLTAGE PROTECTION** | | | | | | |
| $V_{OVP}$ | Output OVP threshold | OVP Detect | | 125%x Vfbth | | |
| $V_{UVP}$ | Output UVP threshold | Hiccup detect | | 65%xVf bth | | |
| $T_{HiccupOn}$ | Hiccup Power On Time | Relative to soft start time | | 1 | | ms |
| $T_{HiccupOff}$ | Hiccup Power Off Time | Relative to soft start time | | 7 | | ms |
| **UVLO** | | | | | | |
| UVLO | UVLO threshold | Wake up VIN voltage | 3.45 | 3.75 | 4.05 | V |
| | | Hysteresis VIN voltage | 0.13 | 0.32 | 0.55 | |

(1) Not production tested.

## 6.6 Typical Characteristics TPS562209

$V_{IN}$ = 12V (unless otherwise noted)

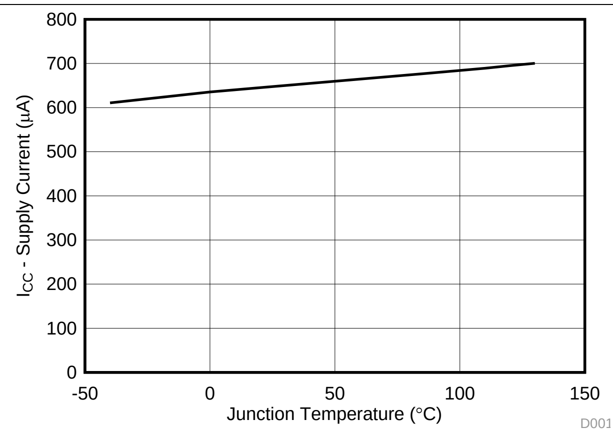



**Figure 1. Supply Current vs Junction Temperature**

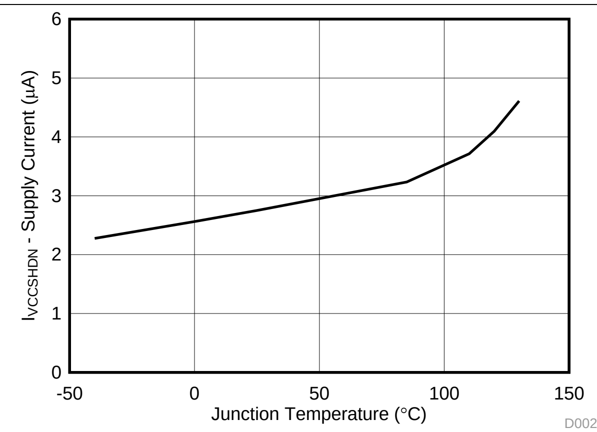



**Figure 2. VIN Shutdown Current vs Junction Temperature**

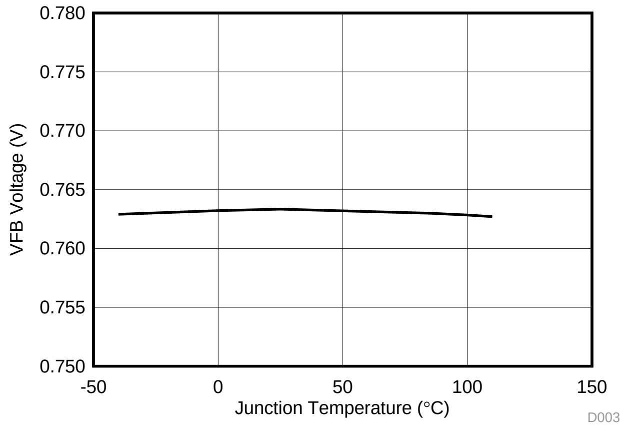



**Figure 3. VFB Voltage vs Junction Temperature**

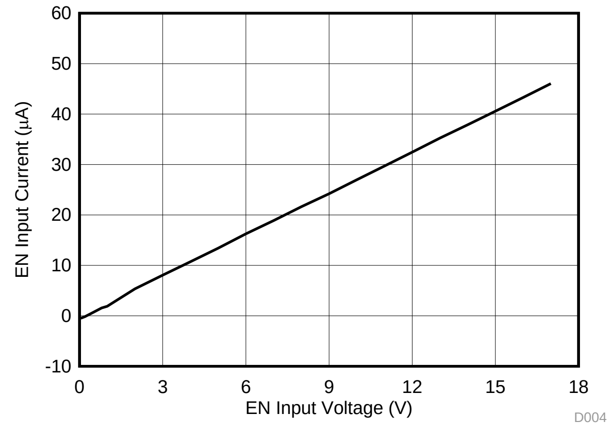



**Figure 4. EN Current vs EN Voltage**

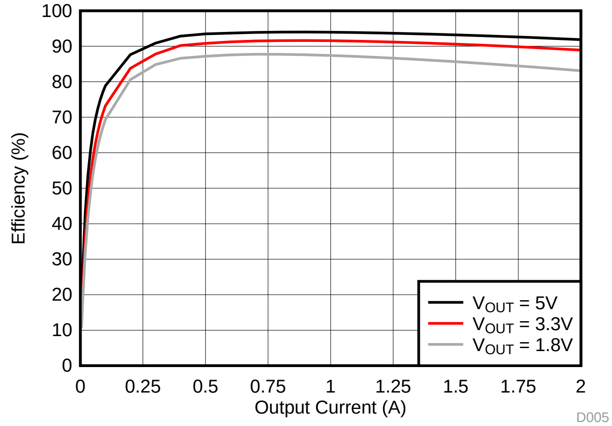



**Figure 5. Efficiency vs Output Current**

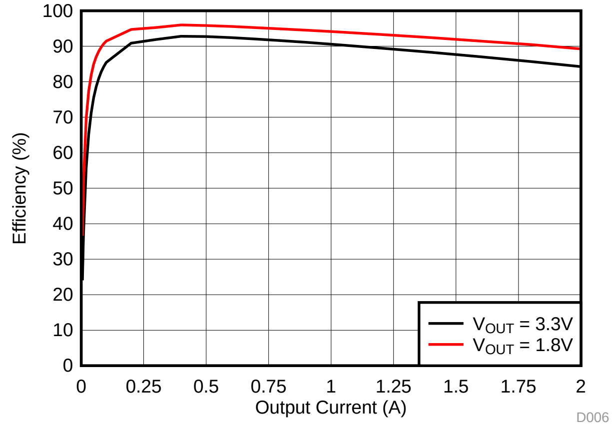



**Figure 6. Efficiency vs Output current ($V_I$ = 5 V)**

## Typical Characteristics TPS562209 (continued)

$V_{IN}$ = 12V (unless otherwise noted)

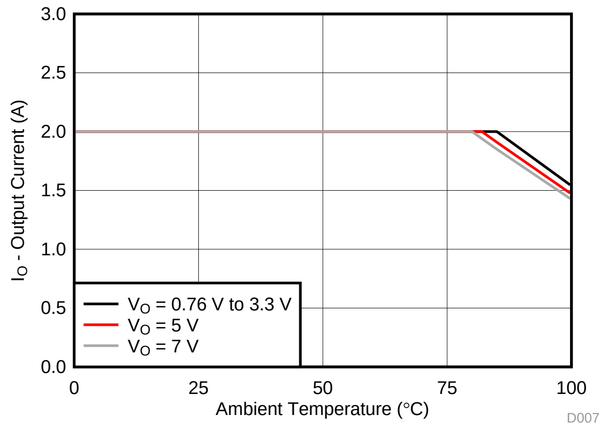



**Figure 7. Output Current vs Ambient Temperature**

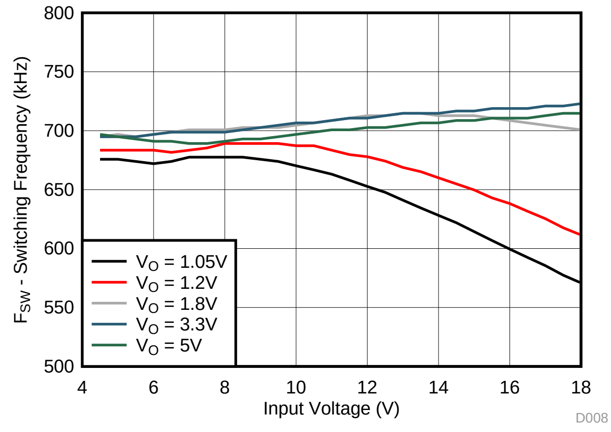



**Figure 8. Switching Frequency vs Input Voltage**

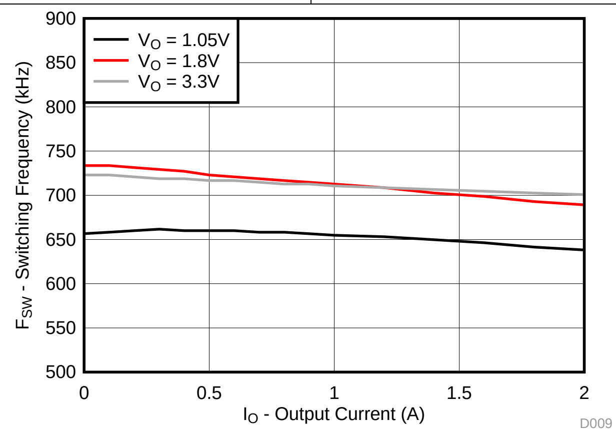



**Figure 9. Switching Frequency vs Output Current**

## 6.7 Typical Characteristics TPS563209

$V_{IN}$ = 12V (unless otherwise noted)

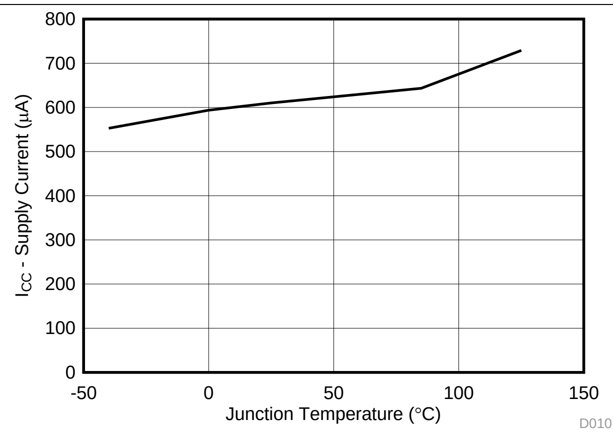



**Figure 10. Supply Current vs Junction Temperature**

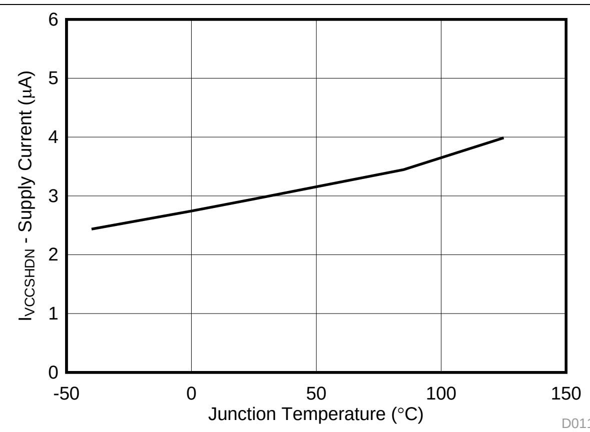



**Figure 11. VIN Shutdown Current vs Junction Temperature**

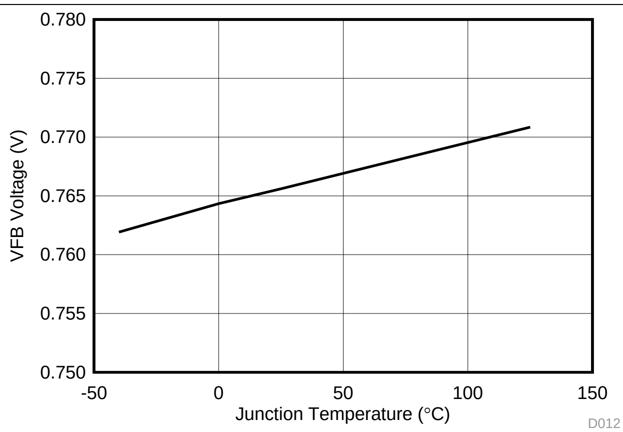



**Figure 12. VFB Voltage vs Junction Temperature**

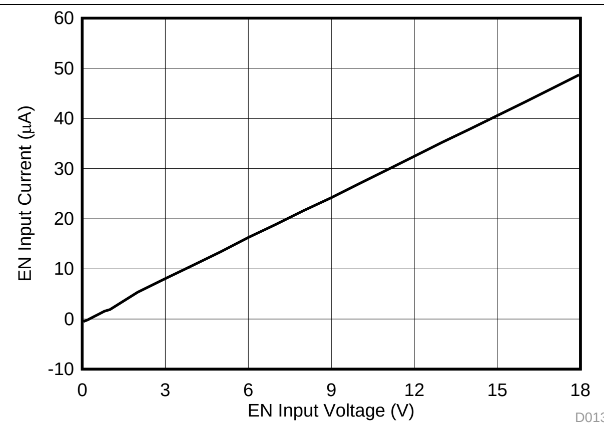



**Figure 13. EN Current vs EN Voltage**

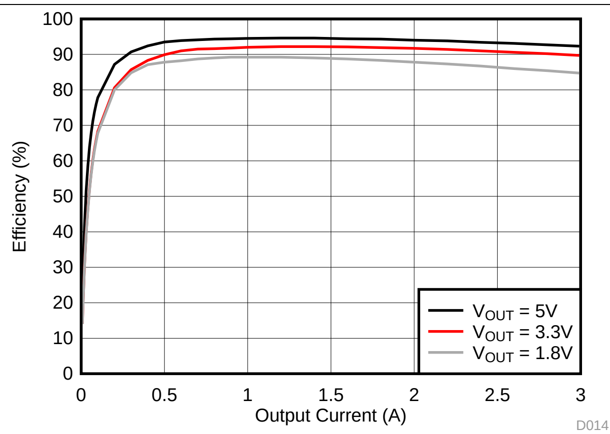



**Figure 14. Efficiency vs Output Current**

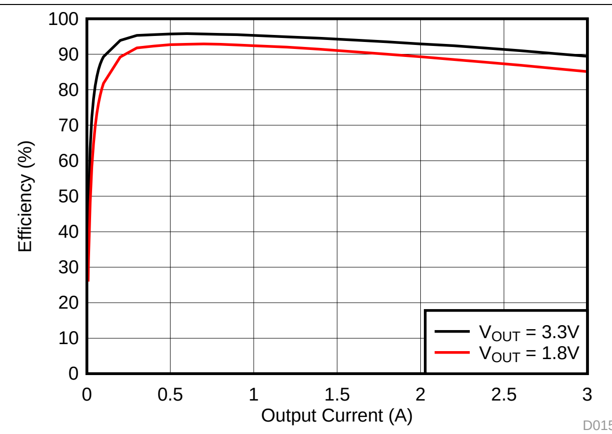



**Figure 15. Efficiency vs Output current ($V_I$ = 5 V)**

## Typical Characteristics TPS563209 (continued)

$V_{IN}$ = 12V (unless otherwise noted)

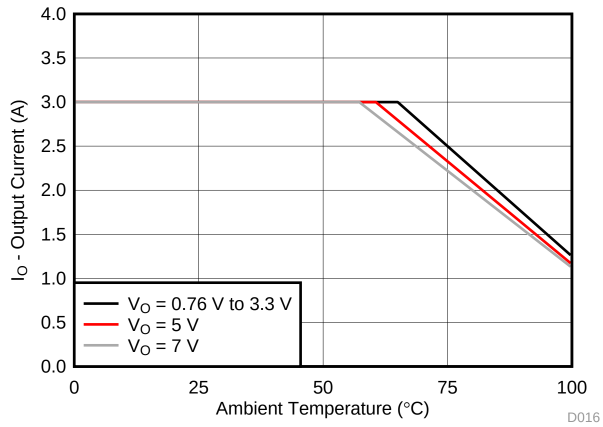



**Figure 16. Output Current vs Ambient Temperature**

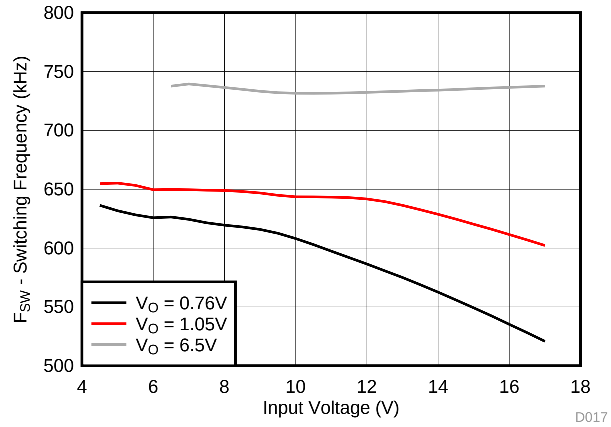



**Figure 17. Switching Frequency vs Input Voltage**

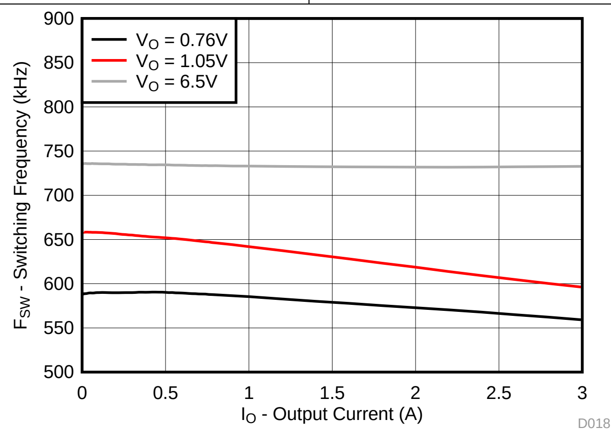



**Figure 18. Switching Frequency vs Output Current**

# 7 Detailed Description

## 7.1 Overview

The TPS562209 and TPS563209 are 2-A and 3-A synchronous step-down converters, respectively. The proprietary D-CAP2™ mode control supports low ESR output capacitors such as specialty polymer capacitors and multi-layer ceramic capacitors without complex external compensation circuits. The fast transient response of D-CAP2™ mode control can reduce the output capacitance required to meet a specific level of performance.

## 7.2 Functional Block Diagram

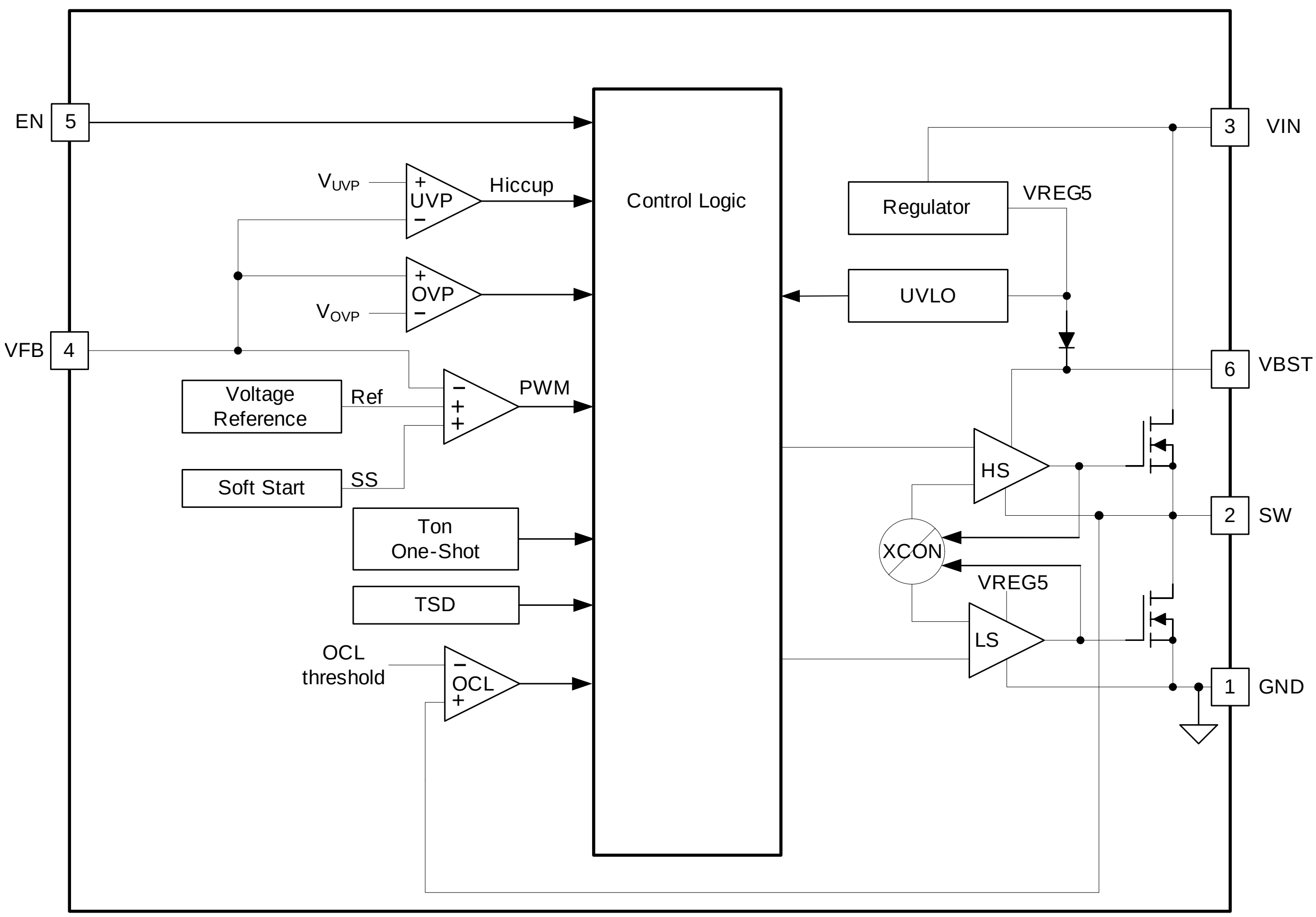





**Figure 19. TPS56x209**

## 7.3 Feature Description

### 7.3.1 The Adaptive On-Time Control and PWM Operation

The main control loop of the TPS56x209 are adaptive on-time pulse width modulation (PWM) controller that supports a proprietary D-CAP2™ mode control. The D-CAP2™ mode control combines adaptive 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.

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 duration is set inversely proportional to the converter input voltage, $V_{IN}$, and proportional to 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 Soft Start and Pre-Biased Soft Start

The TPS562209 and TPS563209 have an internal 1.0ms soft-start. When the EN pin becomes high, the internal soft-start function begins ramping up the reference voltage to the PWM comparator.

If the output capacitor is pre-biased at startup, the devices initiate switching and start ramping up only after the internal reference voltage becomes greater than the feedback voltage $V_{FB}$. This scheme ensures that the converters ramp up smoothly into regulation point.

### 7.3.3 Current Protection

The output over-current limit (OCL) is implemented using a cycle-by-cycle valley detect control circuit. The switch current is monitored during the OFF state by measuring the low-side FET drain to source voltage. 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 Vin, Vout, 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 Iout. If the monitored current is above the OCL level, the converter maintains low-side FET on and delays the creation of a new set pulse, even the voltage feedback loop requires one, until the current level becomes OCL level or lower. In subsequent switching cycles, the on-time is set to a fixed value and the current is monitored in the same manner. If the over current condition exists 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 threshold is returned to the higher value.

There are some important considerations for this type of over-current protection. The load current is higher than the over-current threshold by one half of the peak-to-peak inductor ripple current. 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 VFB voltage falls below the UVP threshold voltage, the UVP comparator detects it. And then, the device will shut down after the UVP delay time (typically 14µs) and re-start after the hiccup time (typically 12ms).

When the over current condition is removed, the output voltage returns to the regulated value.

### 7.3.4 Over Voltage Protection

TPS562209 and TPS563209 detect over voltage condition by monitoring the feedback voltage (VFB). When the feedback voltage becomes higher than 125% of the target voltage, the OVP comparator output goes high and both the high-side MOSFET and the low-side MOSFET turn off. This function is non-latch operation.

### 7.3.5 UVLO Protection

Under voltage lock out protection (UVLO) monitors the device input voltage. When the voltage is lower than UVLO threshold voltage, the device is shut off. This protection is non-latching.

## Feature Description (continued)

### 7.3.6 Thermal Shutdown

The device monitors the temperature of itself. If the temperature exceeds the threshold value (typically 155°C), the device is shut off. This is a 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 TPS562209 and TPS563209 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 TPS562209 and TPS563209 operate at a quasi-fixed frequency of 650 kHz.

### 7.4.2 Forced CCM Operation

When the TPS562209 and TPS563209 are in the normal CCM operating mode and the switch current falls below 0 A, the TPS562209 and TPS563209 begin operating in forced CCM.

### 7.4.3 Standby Operation

When the TPS562209 and TPS563209 are operating in either normal CCM or forced CCM, they 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 TPS562209 and TPS563209 are typically used as step down converters, which convert a voltage from 4.5V - 17V to a lower voltage. Webench software is available to aid in the design and analysis of circuits

## 8.2 Typical Applications

### 8.2.1 TPS562209 4.5-V to 17-V Input, 1.05-V Output Converter

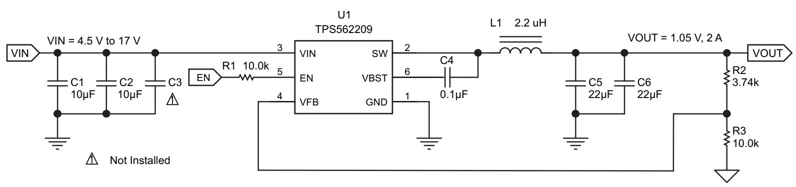





**Figure 20. TPS562209 1.05V/2A Reference Design**

#### *8.2.1.1 Design Requirements*

To begin the design process, you must know a few application parameters:

**Table 1. Design Parameters**

| PARAMETER | VALUE |
|---|---|
| Input voltage range | 4.5 V to 17 V |
| Output voltage | 1.05 V |
| Output current | 2 A |
| Output voltage ripple | 20 mVpp |

#### *8.2.1.2 Detailed Design Procedure*

##### 8.2.1.2.1 Output Voltage Resistors Selection

The output voltage is set with a resistor divider from the output node to the VFB pin. It is recommended to use 1% tolerance or better divider resistors. Start by using Equation 1 to calculate $V_{OUT}$.

To improve efficiency at very light loads consider using larger value resistors, too high of resistance will be more susceptible to noise and voltage errors from the VFB input current will be more noticeable.

$$V_{OUT} = 0.765 \times \left(1 + \frac{R2}{R3}\right) \quad (1)$$

##### 8.2.1.2.2 Output Filter Selection

The LC filter used as the output filter has double pole at:

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

At low frequencies, the overall loop gain is set by the output set-point resistor divider network and the internal gain of the device. The low frequency phase is 180 degrees. 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 degrees one decade above the zero frequency. The inductor and capacitor for the output filter must be selected so that the double pole of Equation 2 is located below the high frequency zero but close enough that the phase boost provided be 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) | R2 (kΩ) | R3 (kΩ) | L1 (µH) | | | C5 + C6 (µF) |
|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | |
| 1 | 3.09 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 1.05 | 3.74 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 1.2 | 5.76 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 1.5 | 9.53 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 1.8 | 13.7 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 2.5 | 22.6 | 10.0 | 2.2 | 3.3 | 4.7 | 20 - 68 |
| 3.3 | 33.2 | 10.0 | 2.2 | 3.3 | 4.7 | 20 - 68 |
| 5 | 54.9 | 10.0 | 3.3 | 4.7 | 4.7 | 20 - 68 |
| 6.5 | 75 | 10.0 | 3.3 | 4.7 | 4.7 | 20 - 68 |

The inductor peak-to-peak ripple current, peak current and RMS current are calculated using Equation 3, Equation 4 and Equation 5. 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 650 kHz for $f_{SW}$. Make sure the chosen inductor is rated for the peak current of Equation 4 and the RMS current of Equation 5.

$$Il_{P-P} = \frac{V_{OUT}}{V_{IN(MAX)}} \times \frac{V_{IN(MAX)} - V_{OUT}}{L_O \times f_{SW}} \tag{3}$$

$$Il_{PEAK} = I_O + \frac{Il_{P-P}}{2} \tag{4}$$

$$I_{LO(RMS)} = \sqrt{I_O^2 + \frac{1}{12} Il_{P-P}^2} \tag{5}$$

For this design example, the calculated peak current is 2.34 A and the calculated RMS current is 2.01 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 TPS562209 is intended for use with ceramic or other low ESR capacitors. Recommended values range from 20µF to 68µF. Use Equation 6 to determine the required RMS current rating for the output capacitor.

$$I_{CO(RMS)} = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\sqrt{12} \times V_{IN} \times L_O \times f_{SW}} \tag{6}$$

For this design two TDK C3216X5R0J226M 22µF output capacitors are used. The typical ESR is 2 mΩ each. The calculated RMS current is 0.199A and each output capacitor is rated for 4A.

#### 8.2.1.2.3 Input Capacitor Selection

The TPS562209 and TPS563209 require 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 3 to ground is optional to provide additional high frequency filtering. The capacitor voltage rating needs to be greater than the maximum input voltage.

#### 8.2.1.2.4 Bootstrap Capacitor Selection

A 0.1µF ceramic capacitor must be connected between the VBST to SW pin for proper operation. It is recommended to use a ceramic capacitor.

### *8.2.1.3 Application Curves*

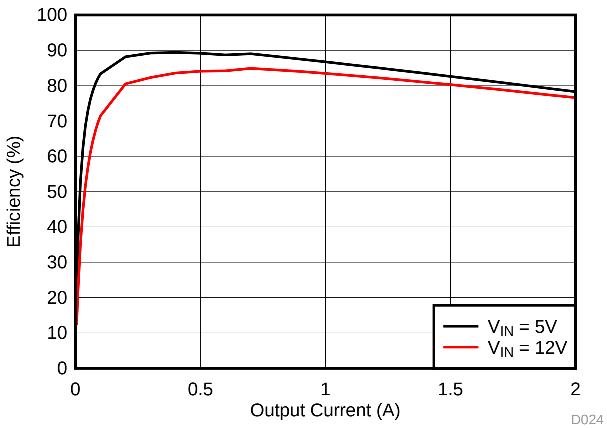



**Figure 21. TPS562209 Efficiency**

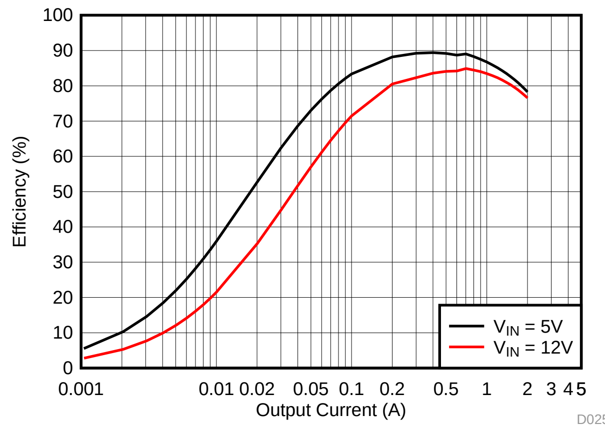



**Figure 22. TPS562209 Light Load Efficiency**

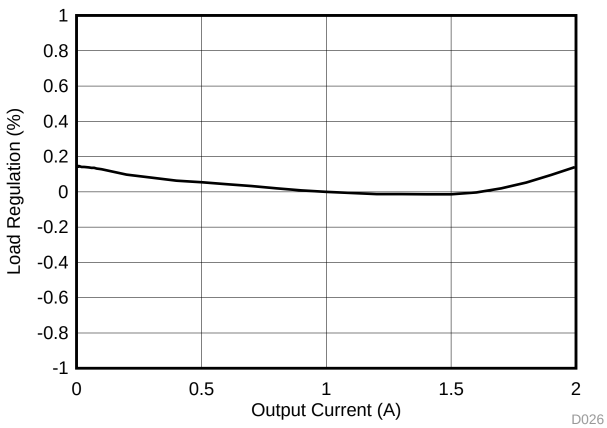



**Figure 23. TPS562209 Load Regulation, $V_I$ = 5 V**

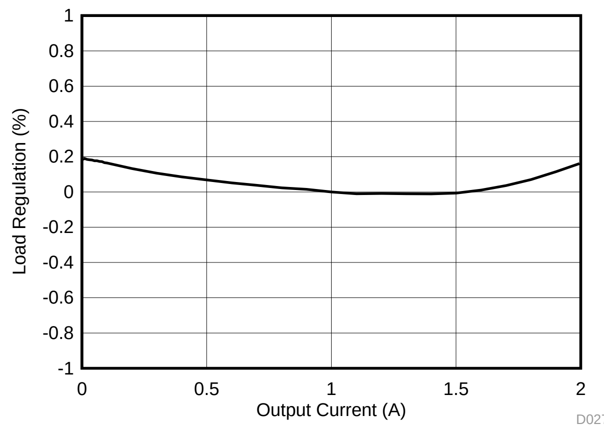



**Figure 24. TPS562209 Load Regulation, $V_I$ = 12 V**

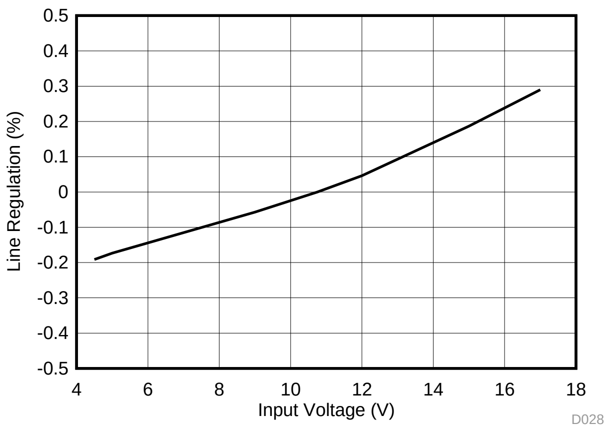



**Figure 25. TPS562209 Line Regulation**

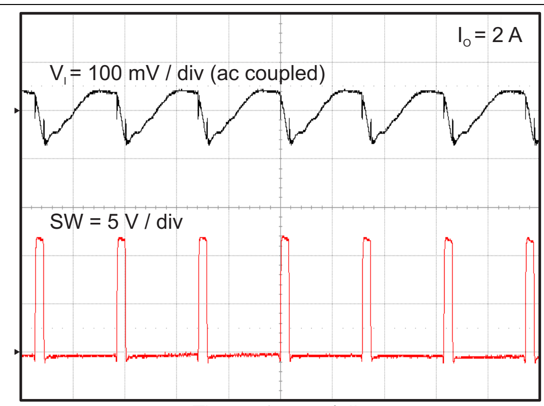



**Figure 26. TPS562209 Input Voltage Ripple**

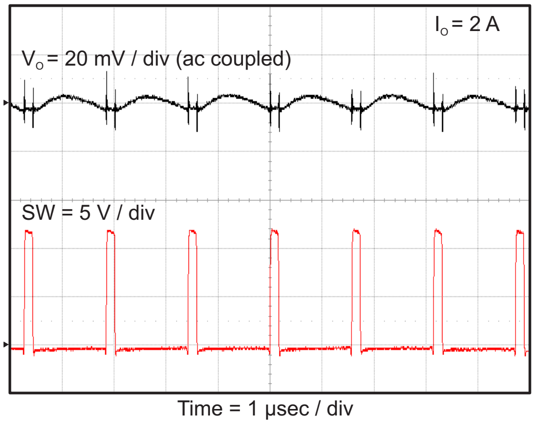



**Figure 27. TPS562209 Output Voltage Ripple**

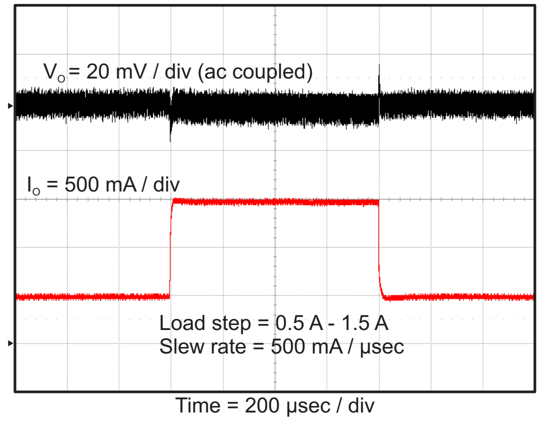



**Figure 28. TPS562209 Transient Response**

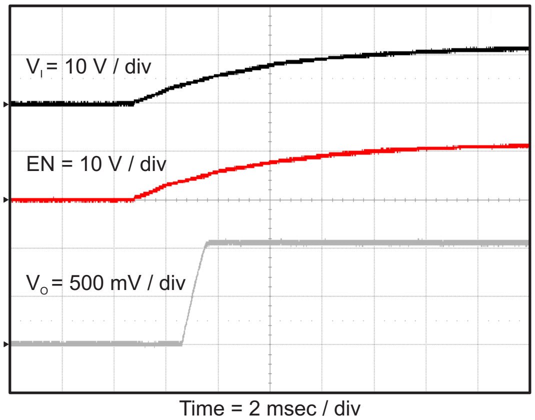



**Figure 29. TPS562209 Start Up Relative to $V_I$**

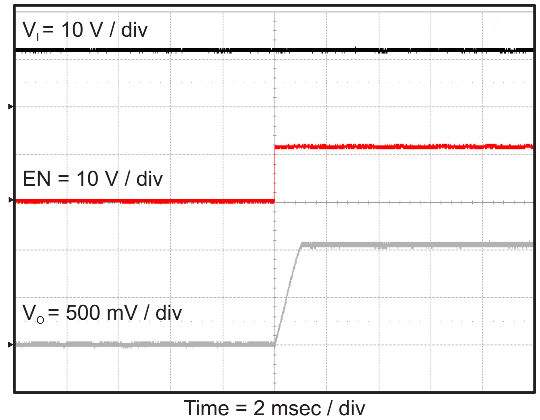



**Figure 30. TPS562209 Start Up Relative to EN**

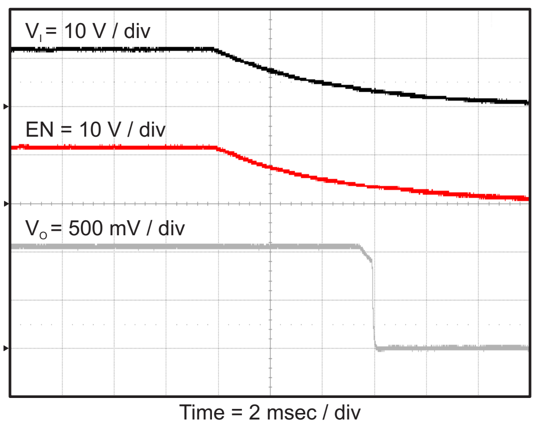



**Figure 31. TPS562209 Shut Down Relative to $V_I$**

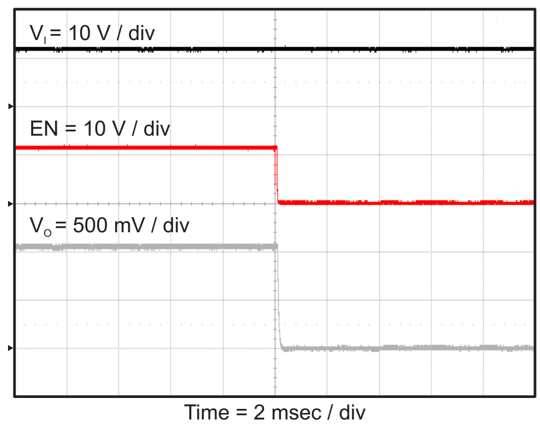



**Figure 32. TPS562209 Shut Down Relative to EN**

### 8.2.2 TPS563209 4.5-V to 17-V Input, 1.05-V Output Converter

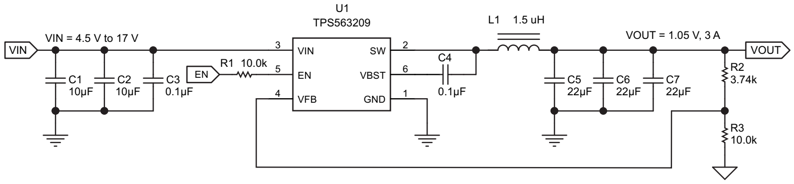





**Figure 33. TPS563209 1.05V/3A Reference Design**

#### *8.2.2.1 Design Requirements*

To begin the design process, the user must know a few application parameters:

**Table 3. Design Parameters**

| PARAMETER | VALUE |
|---|---|
| Input voltage range | 4.5 V to 17 V |
| Output voltage | 1.05 V |
| Output current | 3 A |
| Output voltage ripple | 20 mVpp |

#### *8.2.2.2 Detailed Design Procedures*

The detailed design procedure for TPS563209 is the same as for TPS562209 except for inductor selection.

##### 8.2.2.2.1 Output Filter Selection

**Table 4. Recommended Component Values**

| OUTPUT VOLTAGE (V) | R2 (kΩ) | R3 (kΩ) | L1 (µH) | | | C5 +C6 + C7 (µF) |
|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | |
| 1 | 3.09 | 10.0 | 1.0 | 1.5 | 4.7 | 20 - 68 |
| 1.05 | 3.74 | 10.0 | 1.0 | 1.5 | 4.7 | 20 - 68 |
| 1.2 | 5.76 | 10.0 | 1.0 | 1.5 | 4.7 | 20 - 68 |
| 1.5 | 9.53 | 10.0 | 1.0 | 1.5 | 4.7 | 20 - 68 |
| 1.8 | 13.7 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 2.5 | 22.6 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 3.3 | 33.2 | 10.0 | 1.5 | 2.2 | 4.7 | 20 - 68 |
| 5 | 54.9 | 10.0 | 2.2 | 3.3 | 4.7 | 20 - 68 |
| 6.5 | 75 | 10.0 | 2.2 | 3.3 | 4.7 | 20 - 68 |

The inductor peak-to-peak ripple current, peak current and RMS current are calculated using Equation 7, Equation 8 and Equation 9. 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 650 kHz for $f_{SW}$.

Use 650 kHz for $f_{SW}$. Make sure the chosen inductor is rated for the peak current of Equation 8 and the RMS current of Equation 9.

$$Il_{P-P} = \frac{V_{OUT}}{V_{IN(MAX)}} \times \frac{V_{IN(MAX)} - V_{OUT}}{L_O \times f_{SW}} \quad (7)$$

$$Il_{PEAK} = I_O + \frac{Il_{P-P}}{2} \quad (8)$$

$$I_{LO(RMS)} = \sqrt{I_O^2 + \frac{1}{12} I_{P-P}^2} \quad (9)$$

For this design example, the calculated peak current is 3.505 A and the calculated RMS current is 3.014 A. The inductor used is a TDK CLF7045T-1R5N with a peak current rating of 7.3-A and an RMS current rating of 4.9-A

The capacitor value and ESR determines the amount of output voltage ripple. The TPS563209 is intended for use with ceramic or other low ESR capacitors. Recommended values range from 20µF to 68µF. Use Equation 6 to determine the required RMS current rating for the output capacitor.

$$I_{CO(RMS)} = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\sqrt{12} \times V_{IN} \times L_O \times f_{SW}} \quad (10)$$

For this design three TDK C3216X5R0J226M 22µF output capacitors are used. The typical ESR is 2 mΩ each. The calculated RMS current is 0.292A and each output capacitor is rated for 4A.

#### 8.2.2.3 Application Curves

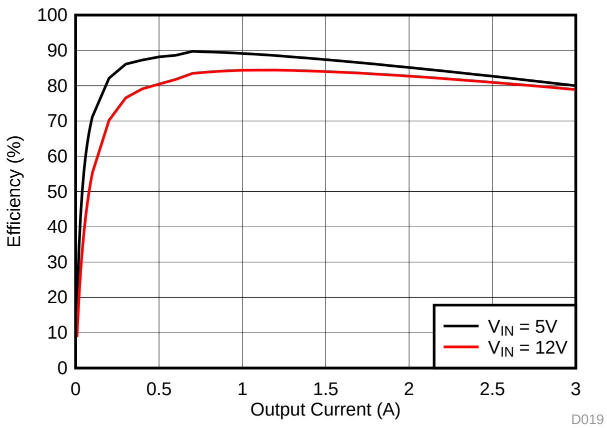



**Figure 34. TPS563209 Efficiency**

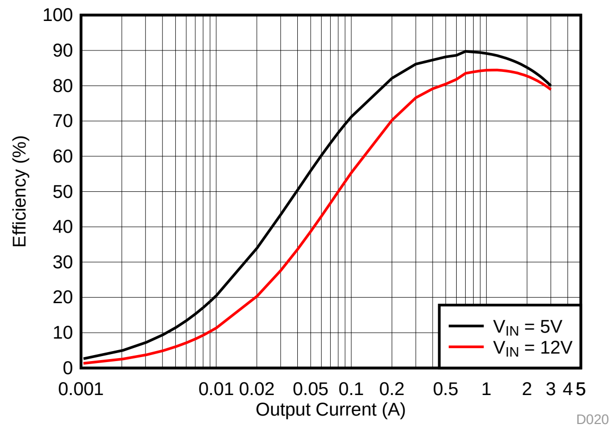



**Figure 35. TPS563209 Light Load Efficiency**

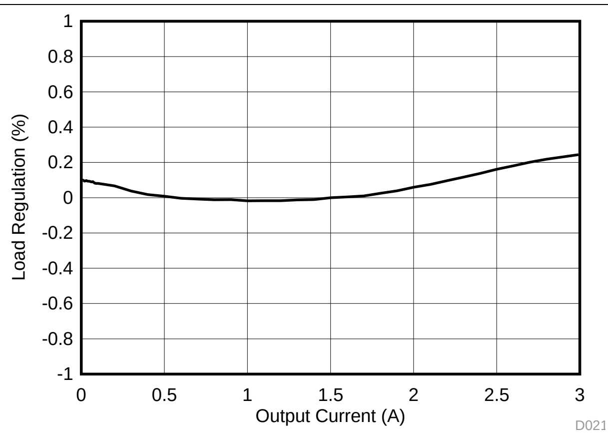



**Figure 36. TPS563209 Load Regulation, $V_I$ = 5 V**

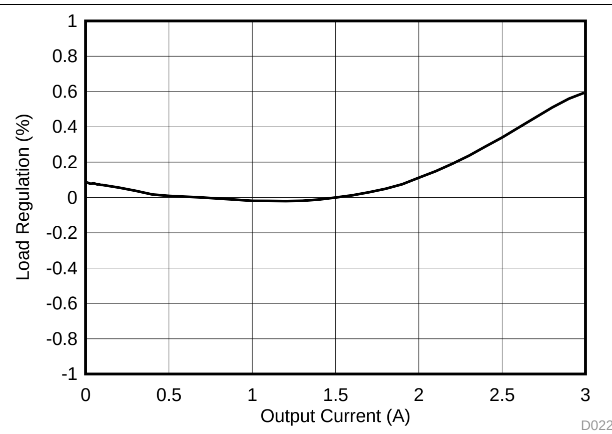



**Figure 37. TPS563209 Load Regulation, $V_I$ = 12 V**

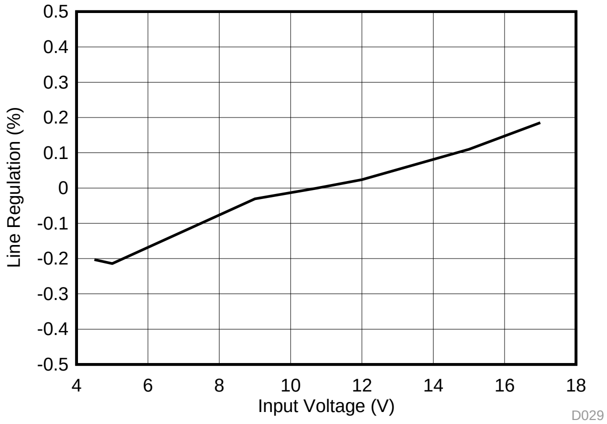



Figure 38. TPS563209 Line Regulation

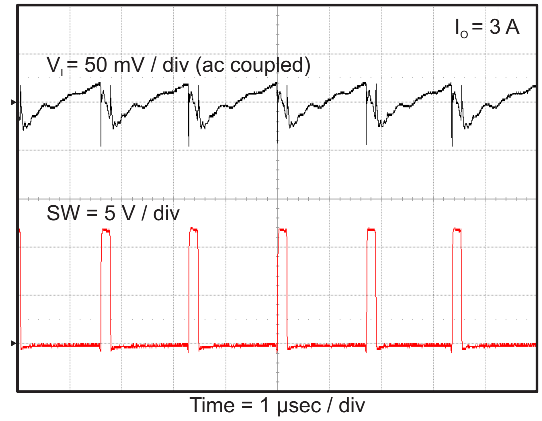



Figure 39. TPS563209 Input Voltage Ripple

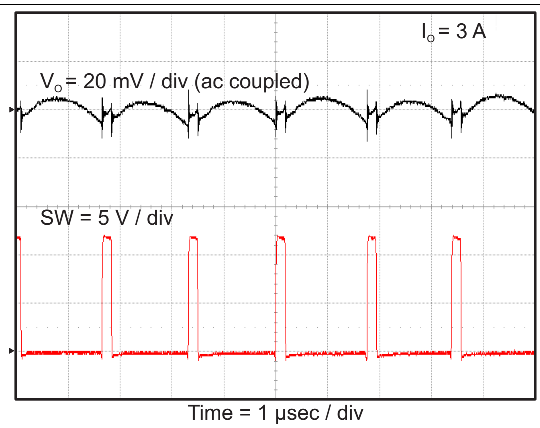



Figure 40. TPS563209 Output Voltage Ripple

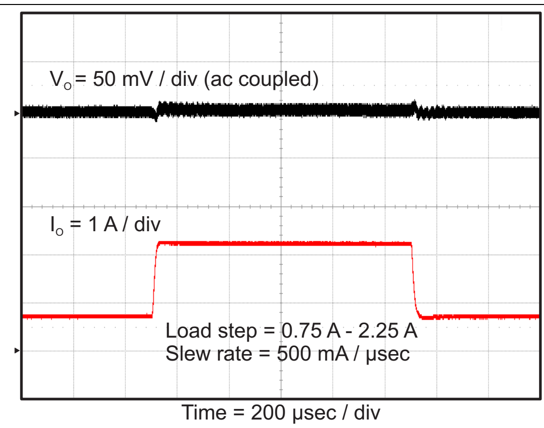



Figure 41. TPS563209 Transient Response

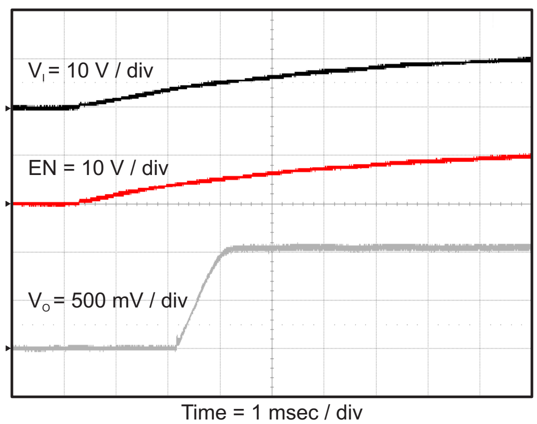



Figure 42. TPS563209 Start Up Relative to $V_I$

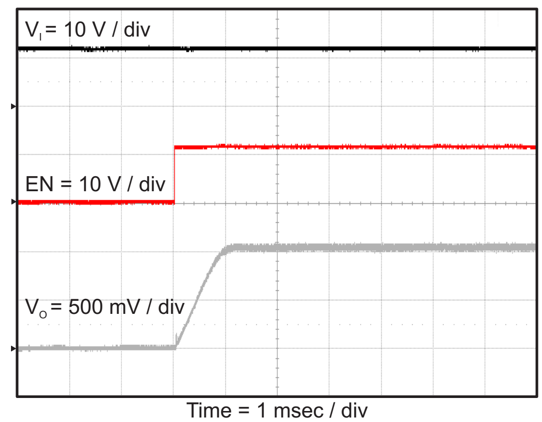



Figure 43. TPS563209 Start Up Relative to EN

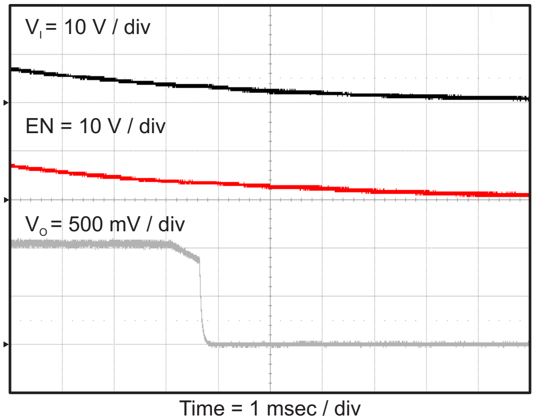



**Figure 44. TPS563209 Shut Down Relative to $V_I$**

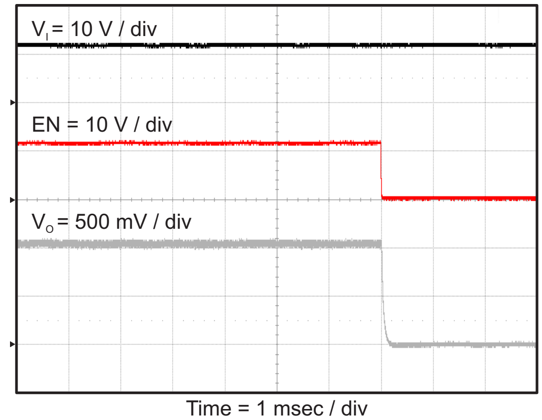



**Figure 45. TPS563209 Shut Down Relative to EN**

## 9 Power Supply Recommendations

The TPS562209 and TPS563209 are designed to operate from input supply voltage in the range of 4.5V to 17V. 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. VIN and GND traces should be as wide as possible to reduce trace impedance. The wide areas are also of advantage from the view point of heat dissipation.
2. The input capacitor and output capacitor should be placed as close to the device as possible to minimize trace impedance.
3. Provide sufficient vias for the input capacitor and output capacitor.
4. Keep the SW trace as physically short and wide as practical to minimize radiated emissions.
5. Do not allow switching current to flow under the device.
6. A separate VOUT path should be connected to the upper feedback resistor.
7. Make a Kelvin connection to the GND pin for the feedback path.
8. Voltage feedback loop should be placed away from the high-voltage switching trace, and preferably has ground shield.
9. The trace of the VFB node should be as small as possible to avoid noise coupling.
10. The GND trace between the output capacitor and the GND pin should be as wide as possible to minimize its trace impedance.

## 10.2 Layout Example

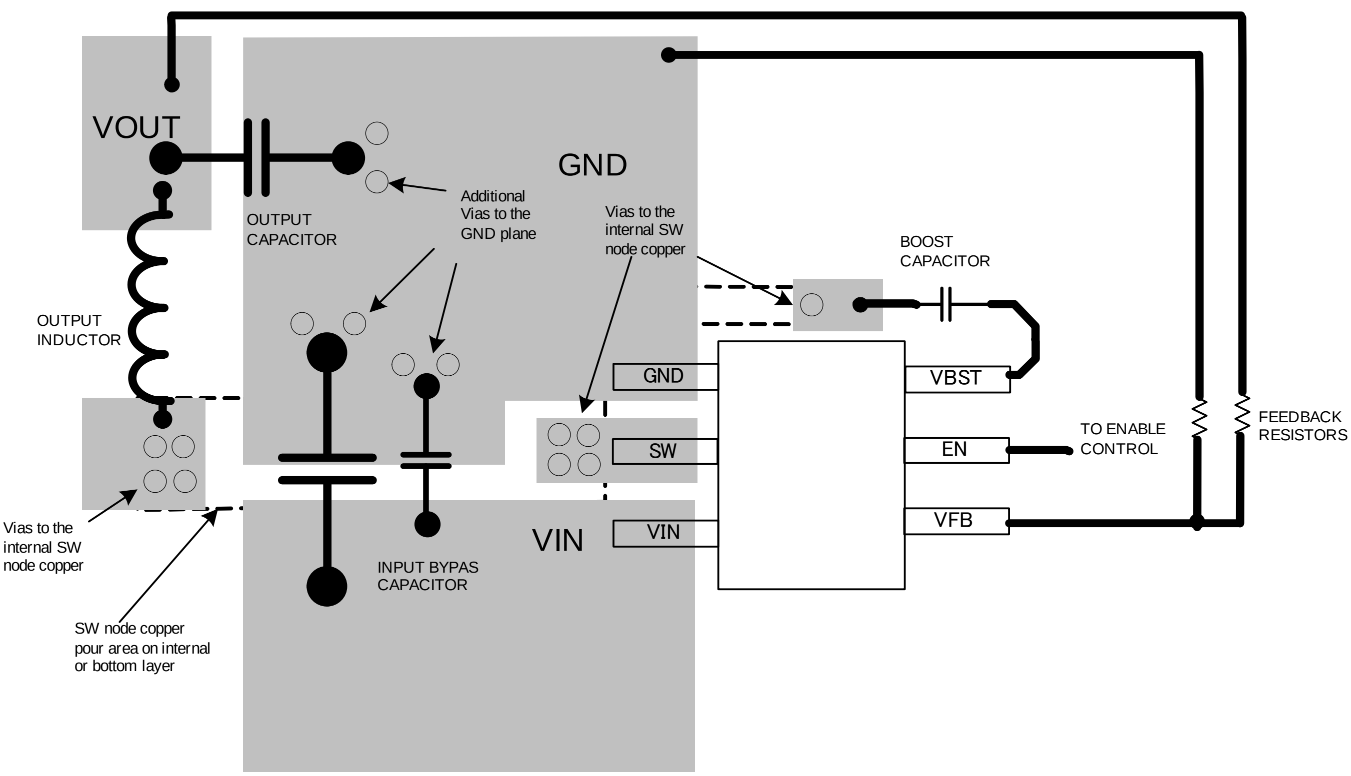



**Figure 46. TPS562209 and TPS563209 Layout**

# 11 Device and Documentation Support

## 11.1 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 5. Related Links**

| PARTS | PRODUCT FOLDER | SAMPLE & BUY | TECHNICAL DOCUMENTS | TOOLS & SOFTWARE | SUPPORT & COMMUNITY |
|---|---|---|---|---|---|
| TPS563209 | Click here | Click here | Click here | Click here | Click here |
| TPS562209 | Click here | Click here | Click here | Click here | Click here |

## 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, E2E are trademarks of Texas Instruments.
Blu-ray Disc is a trademark of Blu-ray Disc Association.

## 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 (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/Ball Finish (6) | MSL Peak Temp (3) | Op Temp (°C) | Device Marking (4/5) | Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS562209DDCR | ACTIVE | SOT-23-THIN | DDC | 6 | 3000 | Green (RoHS & no Sb/Br) | CU SN | Level-1-260C-UNLIM | -40 to 125 | 209 | Samples |
| TPS562209DDCT | ACTIVE | SOT-23-THIN | DDC | 6 | 250 | Green (RoHS & no Sb/Br) | CU SN | Level-1-260C-UNLIM | -40 to 125 | 209 | Samples |
| TPS563209DDCR | ACTIVE | SOT-23-THIN | DDC | 6 | 3000 | Green (RoHS & no Sb/Br) | CU SN | Level-1-260C-UNLIM | -40 to 125 | 309 | Samples |
| TPS563209DDCT | ACTIVE | SOT-23-THIN | DDC | 6 | 250 | Green (RoHS & no Sb/Br) | CU SN | Level-1-260C-UNLIM | -40 to 125 | 309 | Samples |

(1) The marketing status values are defined as follows:
**ACTIVE:** Product device recommended for new designs.
**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.
**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

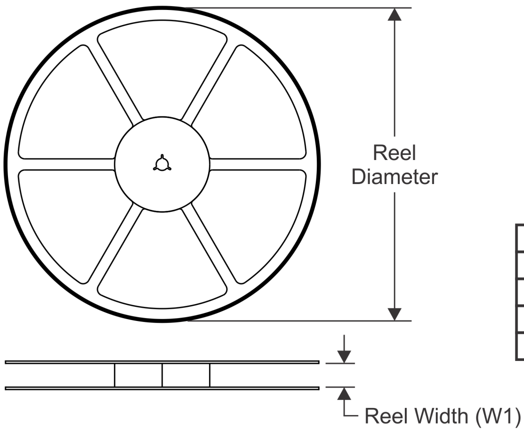
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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

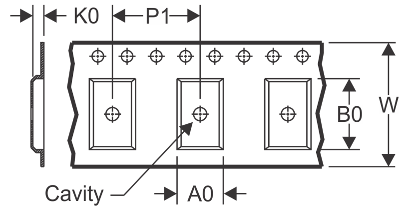
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

## TAPE AND REEL INFORMATION

### REEL DIMENSIONS

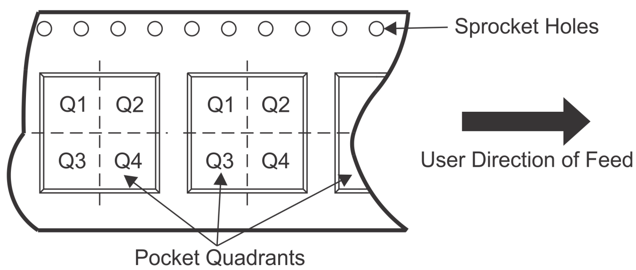



### TAPE DIMENSIONS




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

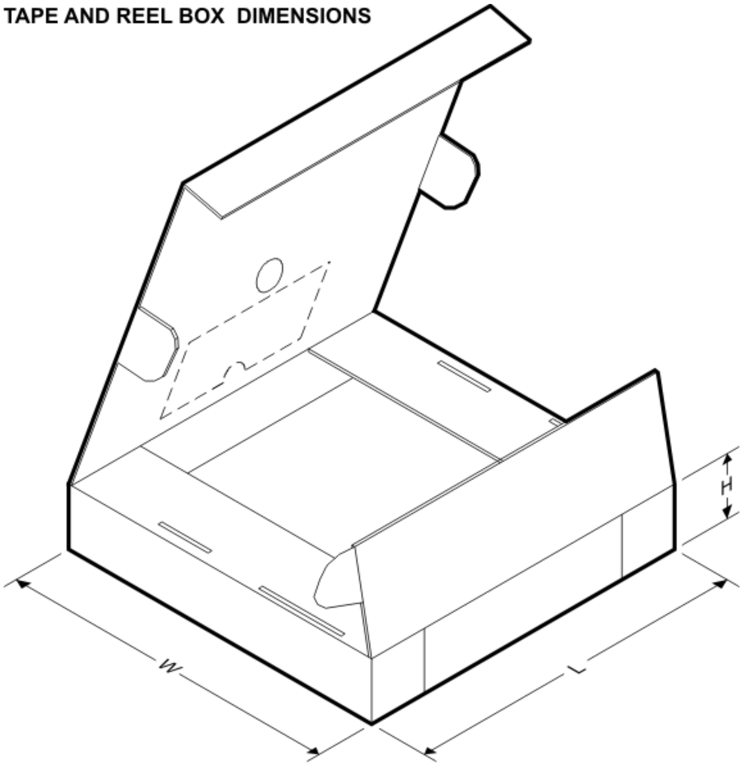
### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS562209DDCR | SOT-23-THIN | DDC | 6 | 3000 | 180.0 | 9.5 | 3.17 | 3.1 | 1.1 | 4.0 | 8.0 | Q3 |
| TPS562209DDCT | SOT-23-THIN | DDC | 6 | 250 | 180.0 | 9.5 | 3.17 | 3.1 | 1.1 | 4.0 | 8.0 | Q3 |
| TPS563209DDCR | SOT-23-THIN | DDC | 6 | 3000 | 180.0 | 9.5 | 3.17 | 3.1 | 1.1 | 4.0 | 8.0 | Q3 |
| TPS563209DDCT | SOT-23-THIN | DDC | 6 | 250 | 180.0 | 9.5 | 3.17 | 3.1 | 1.1 | 4.0 | 8.0 | Q3 |

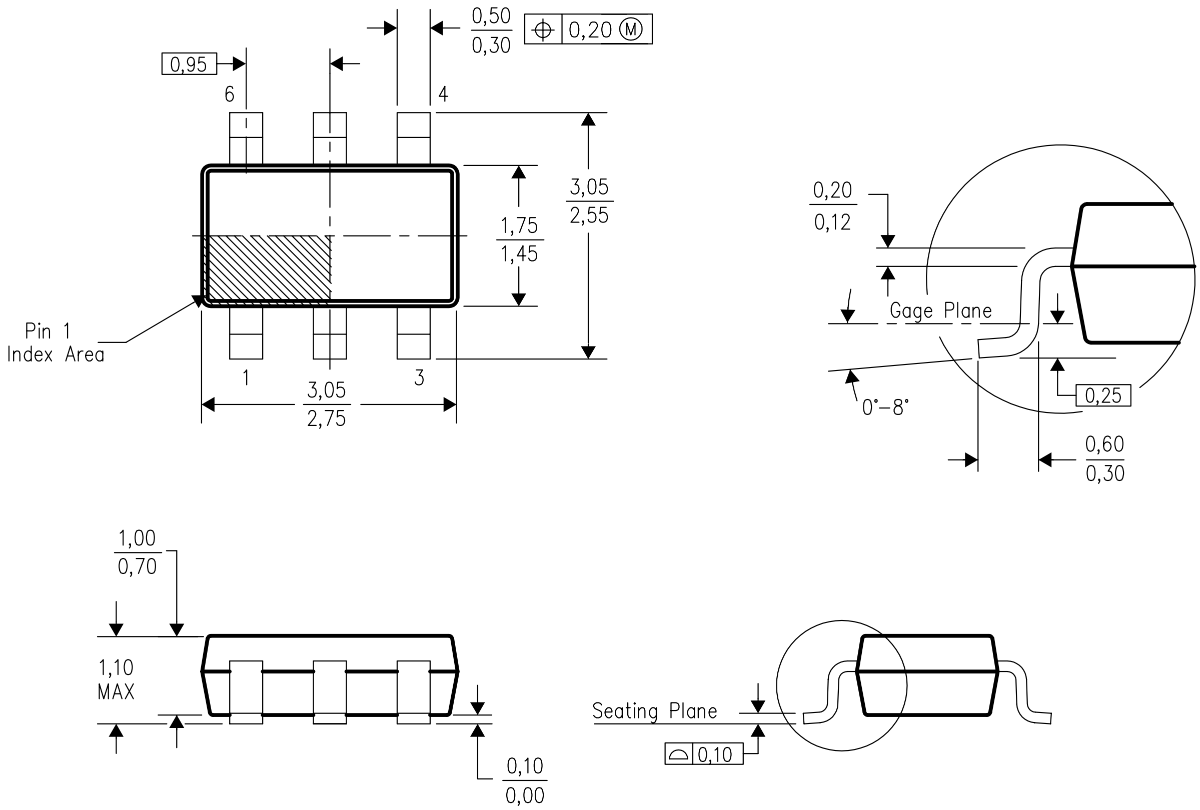
## TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| TPS562209DDCR | SOT-23-THIN | DDC | 6 | 3000 | 184.0 | 184.0 | 19.0 |
| TPS562209DDCT | SOT-23-THIN | DDC | 6 | 250 | 184.0 | 184.0 | 19.0 |
| TPS563209DDCR | SOT-23-THIN | DDC | 6 | 3000 | 184.0 | 184.0 | 19.0 |
| TPS563209DDCT | SOT-23-THIN | DDC | 6 | 250 | 184.0 | 184.0 | 19.0 |

DDC (R–PDSO–G6) PLASTIC SMALL–OUTLINE




4204403–3/E 06/05

NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body dimensions do not include mold flash or protrusion.
- D. Falls within JEDEC MO–193 variation AA (6 pin).

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