4.5V to 17V Input, 500mA Synchronous Step Down SWIFT™ Converter with Advanced Eco-mode™

Check for Samples: TPS560200

FEATURES

- **Integrated Monolithic 0.95Ω High Side and 0.33Ω Low Side MOSFETs**
- **500mA Continuous Output Current**
- **Output Voltage Range: 0.8V to 6.5V**
- **0.8V Voltage Reference with ±1.3% Accuracy Over Temperature**
- **Advanced Auto-Skip Eco-mode™ for High Efficiency at Light Loads**
- **D-CAP2™ Mode Enables Fast Transient Responses**
- **No External Compensation Needed**
- **600 kHz Switching Frequency**
- **2 ms Internal Soft Start**
- **Safe Startup into Pre-biased VOUT**
- **Thermal Shutdown**
- **–40°C to 125°C Operating Junction Temperature Range**
- **Available in 5-Pin SOT23 Packages**

APPLICATIONS

- **Set Top Boxes**
- **Modems**
- **DTBs**
- **ASDLs**

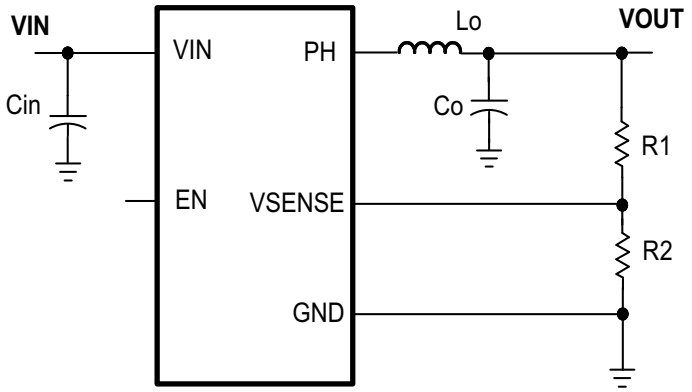
DESCRIPTION

The TPS560200 is an 17V, 500mA, low Iq, adaptive on-time D-CAP2™ mode synchronous monolithic buck converter with integrated MOSFETs in easy-to-use 5-pin SOT23 package.

The TPS560200 enables system designers to complete the suite of various end-equipment power bus regulators with a cost effective, low component count and low standby current solution. The main control loop for the device 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 advanced Eco-mode™ operation at light loads.

The TPS560200 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 17-V VIN input. The output voltage can be programmed between 0.8 V and 6.5 V. The device also features a fixed 2 ms soft start time. The device is available in the 5-pin SOT23 package.

SIMPLIFIED SCHEMATIC



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.

ORDERING INFORMATION(1)

T_J	PACKAGE	PART NUMBER
–40°C to +125°C	5 Pin SOT23	TPS560200DBVR/T

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

ABSOLUTE MAXIMUM RATINGS(1)

		MIN	MAX	UNIT
Input voltage	VIN	–0.3	20	V
	EN	–0.3	7	V
	VSENSE	–0.3	3	V
Output voltage	PH	–0.6	20	V
	PH 10ns Transient	–2	20	V
Source current	EN		±100	µA
	PH	Current Limit		A
Sink current	PH	Current Limit		A
Electrostatic Discharge	Human Body Model (HBM) QSS 009-105 (JESD22-A114A)		2	kV
	Charged Device Model (CDM) QSS 009-147 (JESD22-C101B.01)		500	V
Operating junction temperature		–40	125	°C
Storage temperature		–65	150	°C

(1) Stresses beyond those listed under absolute maximum ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under recommended operating conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

THERMAL INFORMATION

THERMAL METRIC		TPS560200 SOT23 (5 PINS)	UNITS
θ_{JA}		166.8	
θ_{JA}	Junction-to-ambient thermal resistance(1)	100	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	75.5	
θ_{JB}	Junction-to-board thermal resistance	29.2	
ψ_{JT}	Junction-to-top characterization parameter	3.7	
ψ_{JB}	Junction-to-board characterization parameter	28.7	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	N/A	

(1) Test boards conditions:
a. 2 inches x 2 inches, 2 layers, thickness: 0.062 inch
b. 2 oz. copper traces located on the top of the PCB
c. 2 oz. copper ground plane on the bottom of the PCB

ELECTRICAL CHARACTERISTICS

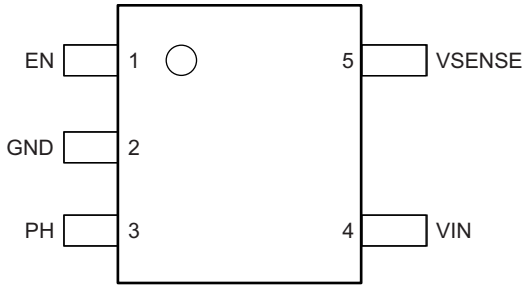
T_J = –40°C to +125°C, VIN = 4.5 V to 17 V (unless otherwise noted)

DESCRIPTION	CONDITIONS / SYMBOL	MIN	TYP	MAX	UNIT
SUPPLY VOLTAGE (VIN PIN)					
VIN Operating input voltage		4.5		17	V
VIN Internal UVLO threshold	VIN Rising	3.9	4.35	4.5	V
VIN Internal UVLO hysteresis			200		mV
VIN Shutdown supply current	EN = 0 V, VIN = 12 V	2.0	3.7	9	µA
VIN Operating– non switching supply current	VSENSE = 850 mV, VIN = 12V	35	60	95	µA
ENABLE (EN PIN)					
Enable threshold	Rising		1.16	1.29	V
	Falling	1.05	1.13		V
Internal soft start	VSENSE ramps from 0 V to 0.8 V		2		ms
OUTPUT VOLTAGE					
Voltage reference	25°C, VIN = 12 V, VOUT = 1.05 V, IOUT = 5 mA, Pulse Skipping	0.796	0.804	0.812	V
	25°C, VIN = 12 V, VOUT = 1.05 V, IOUT = 100mA, Continuous current mode	0.792	0.800	0.808	V
	VIN = 12 V, VOUT = 1.05 V, IOUT = 100mA, Continuous current mode	0.789	0.800	0.811	V
MOSFET					
High side switch resistance(1)	VIN = 12 V	0.50	0.95	1.50	Ω
Low side switch resistance(1)	VIN = 12 V	0.20	0.33	0.55	Ω
CURRENT LIMIT					
Low side switch sourcing current limit	LOUT = 10uH, Valley current, VOUT = 1.05V	550	650	775	mA
THERMAL SHUTDOWN					
Thermal shutdown			170		°C
Thermal shutdown hysteresis			10		°C
ON TIME TIMER CONTROL					
On time	VIN = 12 V	130	165	200	ns
Minimum off time	25°C, VSENSE = 0.5V		250	400	ns
OUTPUT UNDERVOLTAGE PROTECTION					
Output UVP threshold	Falling	56%	63%	69%	VREF
Hiccup time			15		ms

(1) Measured at pins

PIN ASSIGNMENTS

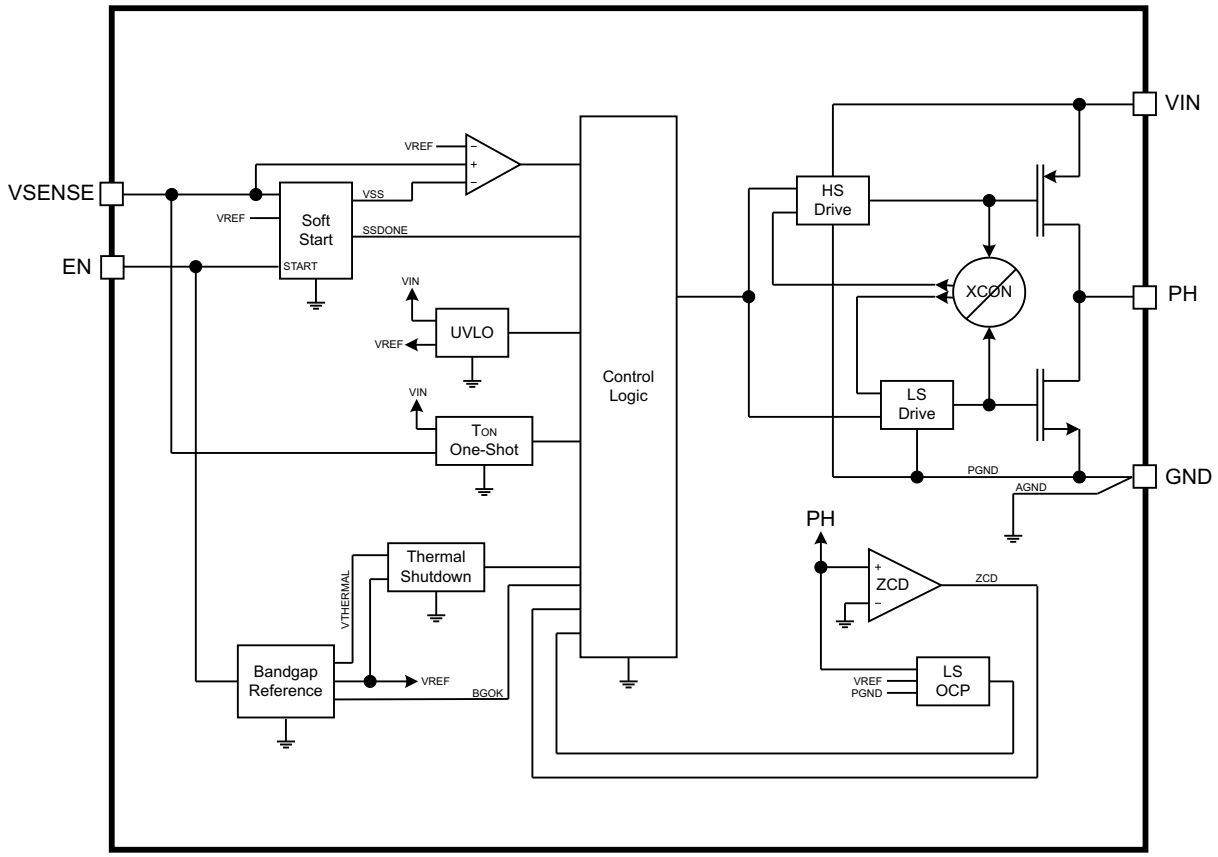
SOT23 PACKAGE
(TOP VIEW)



PIN FUNCTIONS

PIN		DESCRIPTION
NAME	NUMBER	
EN	1	Enable pin. Float to enable.
GND	2	Return for control circuitry and low side power MOSFET.
PH	3	The switch node.
VIN	4	Supplies the control circuitry of the power converter.
VSENSE	5	Converter feedback input. Connect to output voltage with feedback resistor divider.

FUNCTIONAL BLOCK DIAGRAM



OVERVIEW

The TPS560200 is a 500-mA 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.

DETAILED DESCRIPTION

PWM Operation

The main control loop of the TPS560200 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.

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, VIN, and the output voltage, VOUT, 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.

PWM Frequency and Adaptive On-Time Control

TPS560200 uses an adaptive on-time control scheme and does not have a dedicated on board oscillator. The TPS560200 runs with a pseudo-constant frequency of 600 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 VOUT/VIN, the frequency is constant.

Advanced Auto-Skip Eco-mode™ Control

The TPS560200 is designed with advanced auto-skip Eco-mode™ to increase higher light load efficiency. As the output current decreases from heavy load condition, the inductor current is also reduced. If the output current is reduced enough, the inductor current ripple valley reaches the zero level, which is the boundary between continuous conduction and discontinuous conduction modes. The rectifying low-side 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 approximately the same as is in continuous conduction mode. The off-time increases as it takes more time to discharge the output capacitor to the level of the reference voltage with smaller load current. The transition point to the light load operation $I_{OUT(LL)}$ current can be calculated in Equation 1

$$I_{OUT(LL)} = \frac{1}{2 \times L_{OUT} \times fsw} \times \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{V_{IN}} \quad (1)$$

Soft Start and Pre-Biased Soft Start

The TPS560200 has an internal 2ms soft-start. When the EN pin becomes high, internal soft-start function begins ramping up the reference voltage to the PWM comparator.

The TPS560200 contains a unique circuit to prevent current from being pulled from the output during startup if the output is pre-biased. When the soft-start commands a voltage higher than the pre-bias level (internal soft start becomes greater than feedback voltage V_{VSENSE}), 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 pre-bias output, and ensure that the out voltage (V_{OUT}) starts and ramps up smoothly into regulation and the control loop is given time to transition from pre-biased start-up to normal mode operation.

Current Protection

The output over-current 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 PH 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 Iout. The TPS560200 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 switching 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 cycle begins. In subsequent switching cycles, the on-time is set to a fixed value and the current is monitored in the same manner.

There are some important considerations for this type of over-current protection. The peak current is the average load current plus one half of the peak-to-peak inductor current. The valley current is the average load current minus one half of the peak-to-peak inductor current. Since the valley current is used to detect the overcurrent threshold, the load current is higher than the over-current 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 protection is non-latching. When the VSENSE voltage becomes lower than 63% of the target voltage, the UVP comparator detects it. After 7 µs detecting the UVP voltage, device shuts down and re-starts after hiccup time.

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

Thermal Shutdown

TPS560200 monitors the temperature of itself. If the temperature exceeds the threshold value (typically 170°C), the device is shut off. This is non-latch protection.

TYPICAL CHARACTERISTICS

V_{IN} = 12 V, T_A = 25°C (unless otherwise noted).

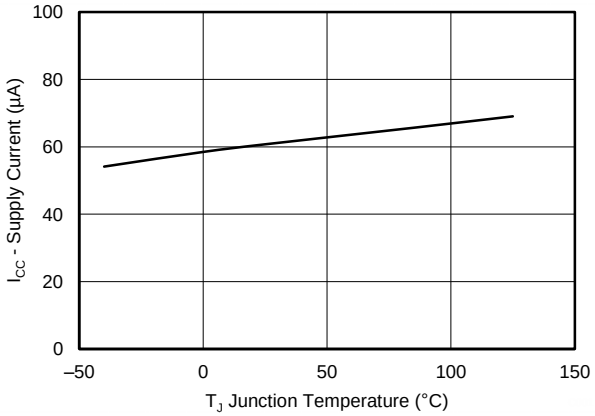


Figure 1. SUPPLY CURRENT vs JUNCTION TEMPERATURE

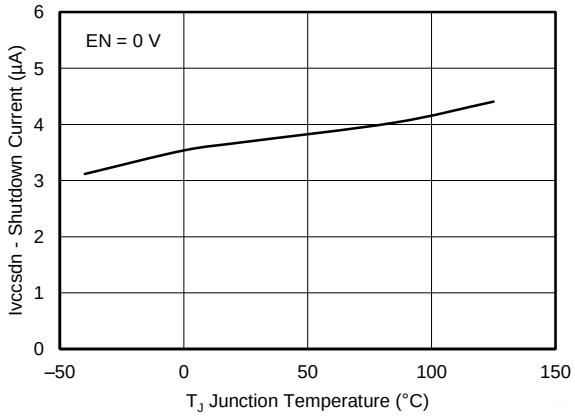


Figure 2. SHUTDOWN CURRENT vs JUNCTION TEMPERATURE

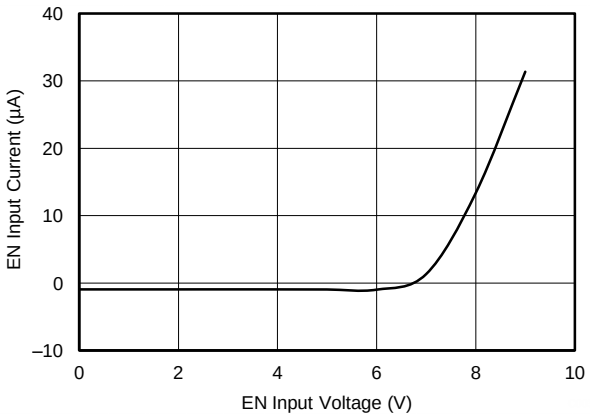


Figure 3. EN INPUT CURRENT vs EN INPUT VOLTAGE

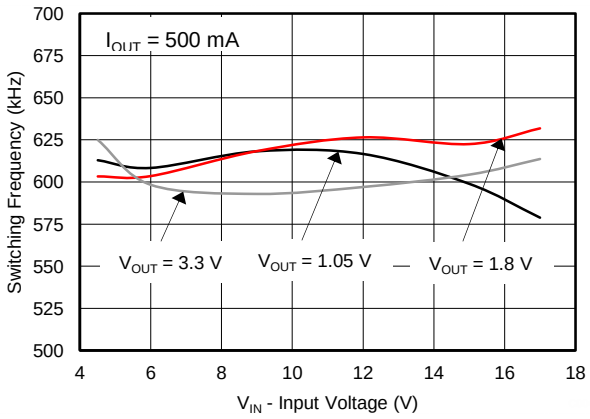


Figure 4. SWITCHING FREQUENCY vs INPUT VOLTAGE

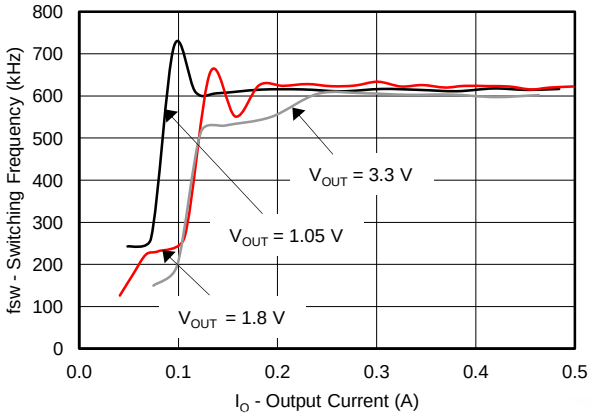


Figure 5. SWITCHING FREQUENCY vs OUTPUT CURRENT

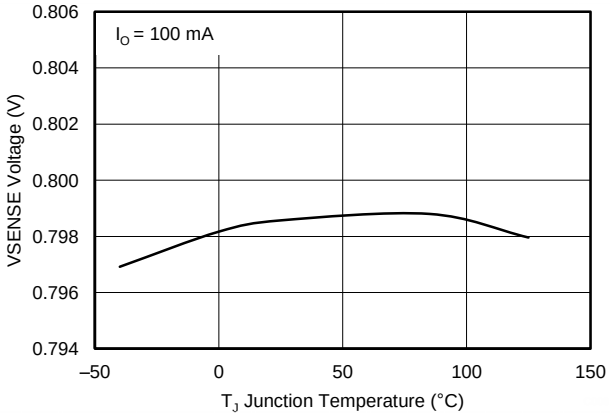


Figure 6. VSENSE VOLTAGE vs JUNCTION TEMPERATURE

APPLICATION INFORMATION

Design Guide

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

- Input voltage range
- Output voltage
- Output current
- Output voltage ripple
- Input voltage ripple

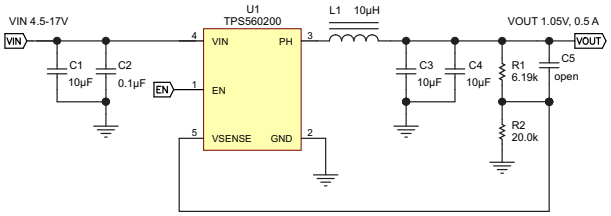


Figure 7. Typical Application Schematic

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 2 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 VSENSE input current are more noticeable.

$$R2 = \frac{R1 \times 0.8\ V}{V_{OUT} - 0.8V} \quad (2)$$

Output Filter Selection

The output filter used with the TPS560200 is an LC circuit. This LC filter has double pole at:

$$F_P = \frac{1}{2\pi\sqrt{L_{OUT} \times C_{OUT}}} \quad (3)$$

At low frequencies, the overall loop gain is set by the output set-point resistor divider network and the internal gain of the TPS560200. 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 selected for the output filter must be selected so that the double pole of Equation 3 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 1

Table 1. Recommended Component Values

Output Voltage (V)	R1 (kΩ)	R2 (kΩ)	C5 (pF)	L1 (µH)			C3 + C4 (µF)
				Min	Typ	Max	
1.0	4.99	20.0			10		10 + 10
1.05	6.19	20.0			10		10 + 10
1.2	10.0	20.0			10		10 + 10
1.5	17.4	20.0			10		10 + 10
1.8	24.9	20.0	optional		10		10 + 10
2.5	42.2	20.0	optional		10		10 + 10

Table 1. Recommended Component Values (continued)

Output Voltage (V)	R1 (kΩ)	R2 (kΩ)	C5 (pF)	L1 (µH)			C3 + C4 (µF)
				Min	Typ	Max	
3.3	61.9	20.0	optional		10		10 + 10
5.0	105	20.0	optional		10		10 + 10

Since the DC gain is dependent on the output voltage, the required inductor value increases as the output voltage increases. Additional phase boost can be achieved by adding a feed forward capacitor (C5) in parallel with R1. The feed forward capacitor is most effective for output voltages at or above 1.8 V.

The inductor peak-to-peak ripple current, peak current and RMS current are calculated using Equation 4, Equation 5 and Equation 6. 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 600 kHz for f_{SW}.

Use 600 kHz for f_{SW}. Make sure the chosen inductor is rated for the peak current of Equation 5 and the RMS current of Equation 6.

$$I_{LPP} = \frac{V_{OUT}}{V_{IN(max)}} \times \frac{V_{IN(max)} - V_{OUT}}{L_{OUT} \times fsw} \quad (4)$$

$$I_{LPEAK} = I_{OUT} + \frac{I_{LPP}}{2} \quad (5)$$

$$I_{L_{OUT}}(RMS) = \sqrt{I_{OUT}^2 + \frac{1}{12} I_{LPP}^2} \quad (6)$$

For this design example, the calculated peak current is 0.582 A and the calculated RMS current is 0.502 A. The inductor used is a Würth 744777910 with a peak current rating of 2.6 A and an RMS current rating of 2 A.

The capacitor value and ESR determines the amount of output voltage ripple. The TPS54628 is intended for use with ceramic or other low ESR capacitors. The recommended values are given in Table 1. Use Equation 7 to determine the required RMS current rating for the output capacitor.

$$I_{C_{OUT}}(RMS) = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{\sqrt{12} \times V_{IN} \times L_{OUT} \times fsw} \quad (7)$$

For this design two MuRata GRM32DR61E106KA12L 10µF output capacitors are used. The typical ESR is 2 mΩ each. The calculated RMS current is 0.047 A and each output capacitor is rated for 3A.

Input Capacitor Selection

The TPS560200 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 (C2) from pin 4 to ground is optional to provide additional high frequency filtering. The capacitor voltage rating needs to be greater than the maximum input voltage.

APPLICATION CURVES

V_{IN} = 12 V, V_{OUT} = 1.05 V, T_A = 25°C (unless otherwise noted).

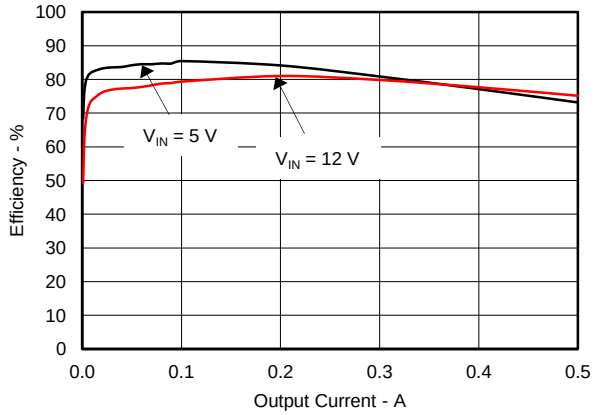


Figure 8. Efficiency

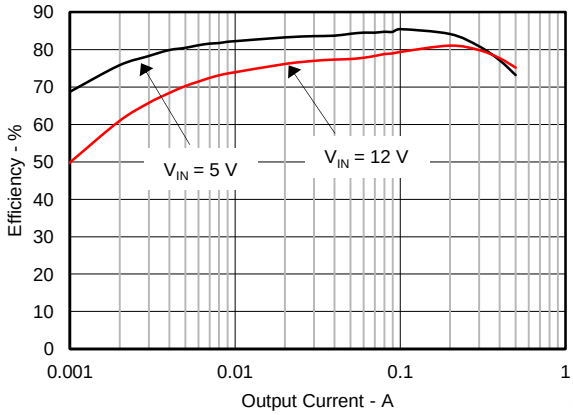


Figure 9. Light Load Efficiency

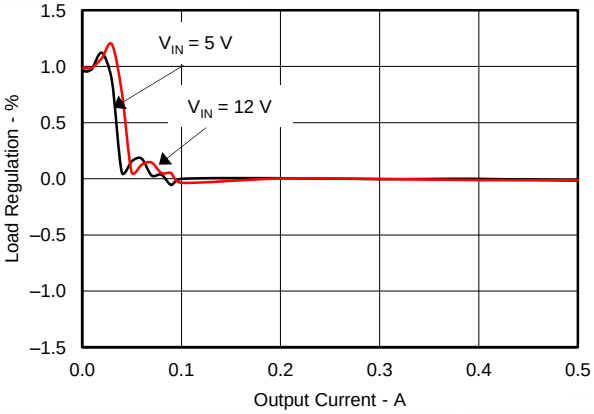


Figure 10. Load Regulation

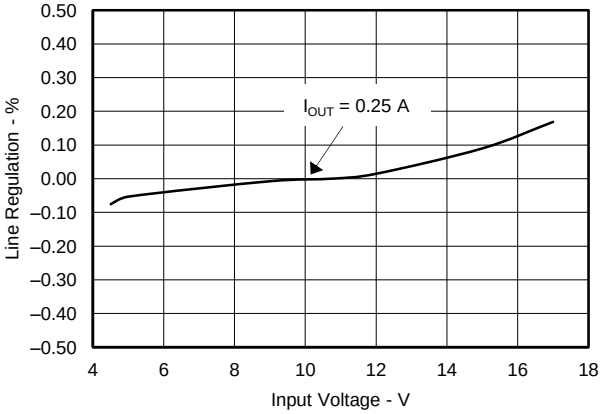


Figure 11. Line Regulation

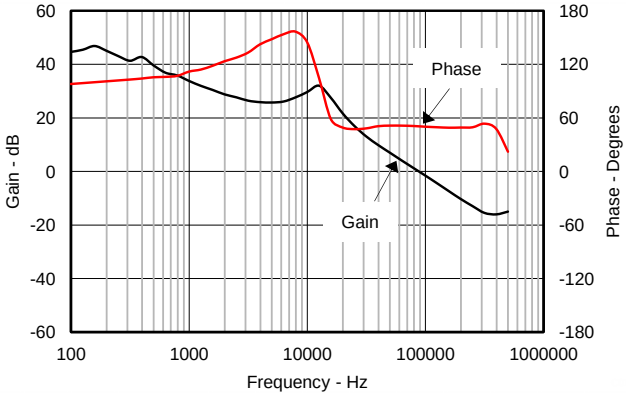
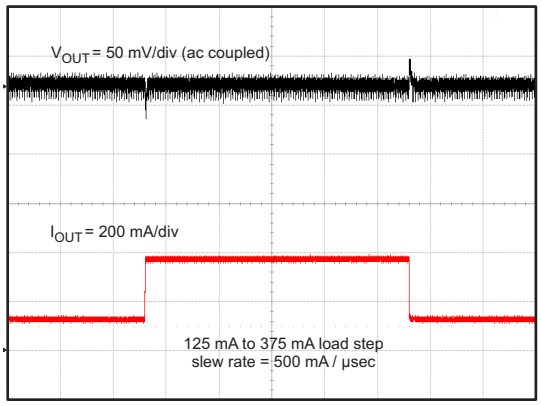


Figure 12. Loop Response, I_{OUT} = 0.25 A

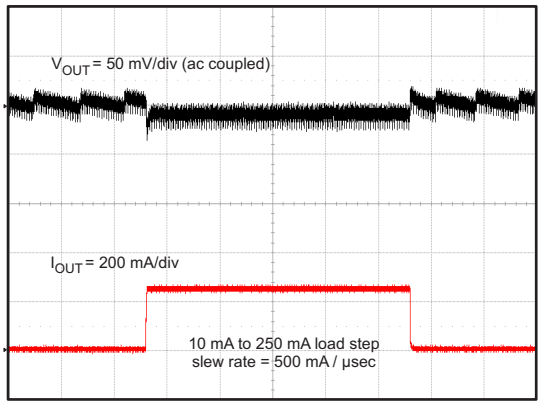


Time = 200 µs/div

Figure 13. Transient Response, 25% to 75% Load Step

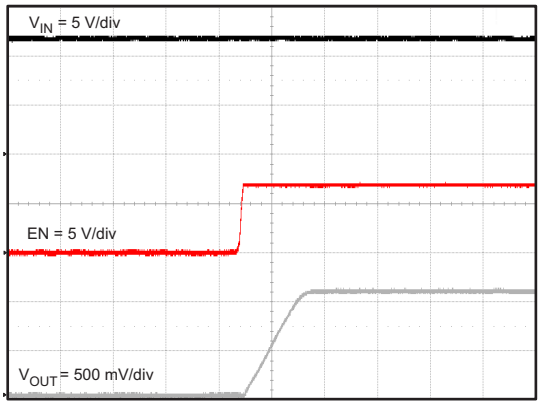
APPLICATION CURVES (continued)

V_{IN} = 12 V, V_{OUT} = 1.05 V, T_A = 25°C (unless otherwise noted).



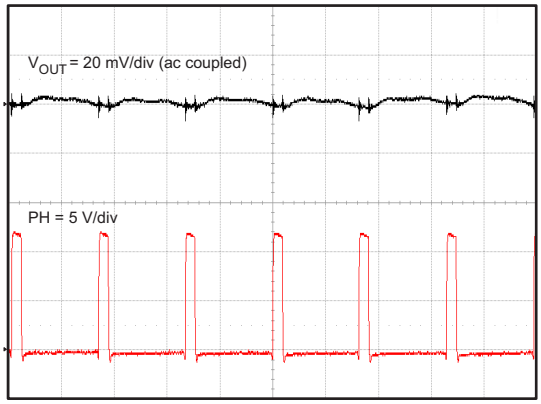
Time = 200 µs/div

Figure 14. Transient Response, 2% to 50% Load Step



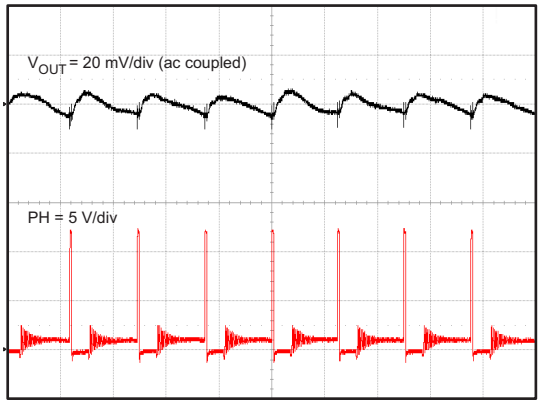
Time = 2 ms/div

Figure 15. Start Up Relative to EN



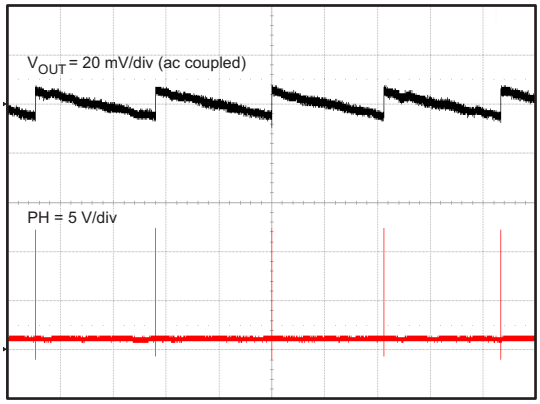
Time = 1 µs/div

Figure 16. Output Ripple, I_{OUT} = 500 mA



Time = 5 µs/div

Figure 17. Output Ripple, I_{OUT} = 30 mA



Time = 2 ms/div

Figure 18. Output Ripple, I_{OUT} = 0 mA

LAYOUT GUIDELINES

The VIN pin should be bypassed to ground with a low ESR ceramic bypass capacitor. Care should be taken to minimize the loop area formed by the bypass capacitor connection. the VIN pin, and the GND pin of the IC. The typical recommended bypass capacitance is 10-µF ceramic with a X5R or X7R dielectric and the optimum placement is closest to the VIN and GND pins of the device. An additional high frequency bypass capacitor may be added. See Figure 19 for a PCB layout example. The GND pin should be tied to the PCB ground plane at the pin of the IC. The PH pin should be routed to a small copper area directly adjacent to the pin. Make the circulating loop from PH to the output inductor, output capacitors and back to GND as tight as possible while preserving adequate etch width to reduce conduction losses in the copper. Connect the exposed thermal pad to bottom or internal layer ground plane using vias as shown. Additional vias may be used adjacent to the IC to tie top side copper to the internal or bottom layer copper. The additional external components can be placed approximately as shown. It may be possible to obtain acceptable performance with alternate layout schemes, however this layout has been shown to produce good results and is intended as a guideline.

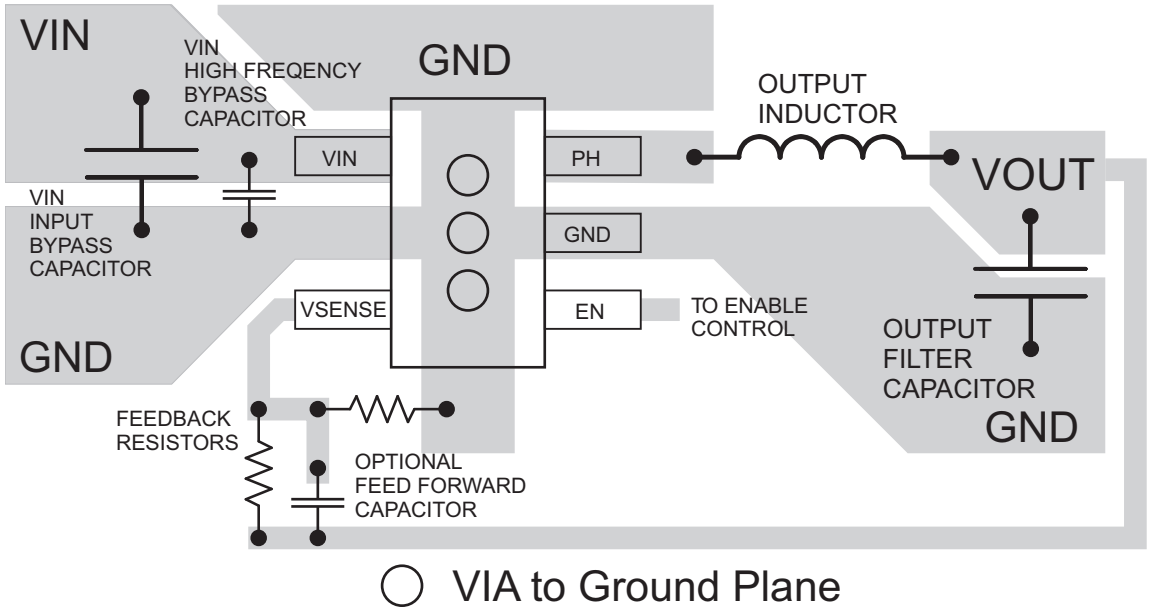


Figure 19. Typical Layout

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS560200DBVR	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L562	Samples
TPS560200DBVT	ACTIVE	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	L562	Samples

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

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

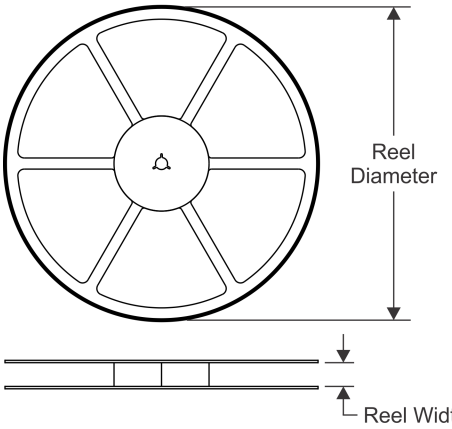
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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

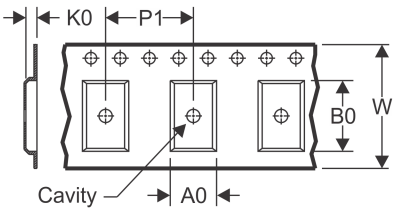
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

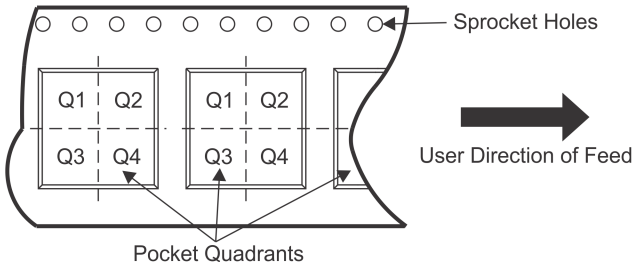


TAPE DIMENSIONS



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

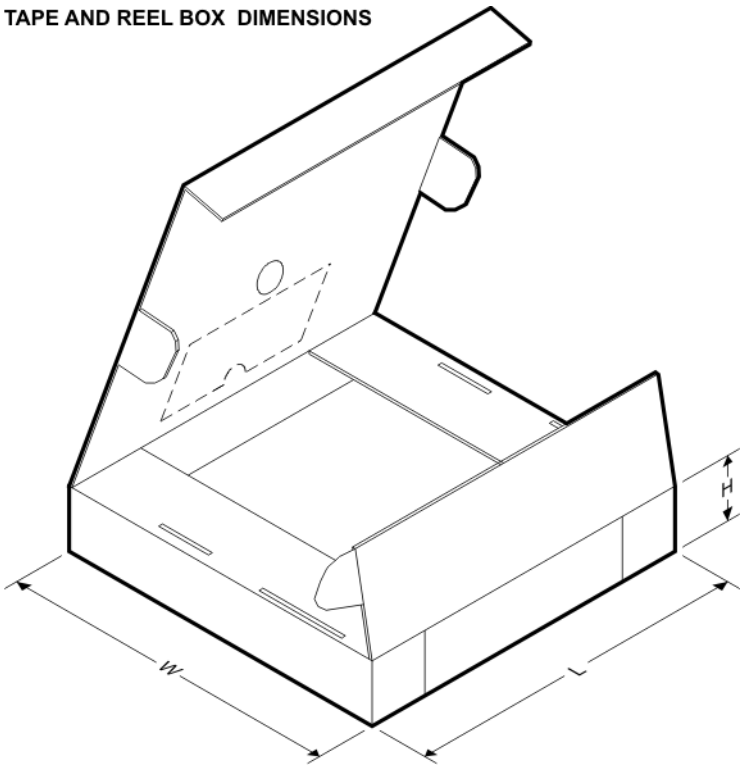
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TPS560200DBVR	SOT-23	DBV	5	3000	178.0	9.0	3.23	3.17	1.37	4.0	8.0	Q3
TPS560200DBVT	SOT-23	DBV	5	250	178.0	9.0	3.23	3.17	1.37	4.0	8.0	Q3

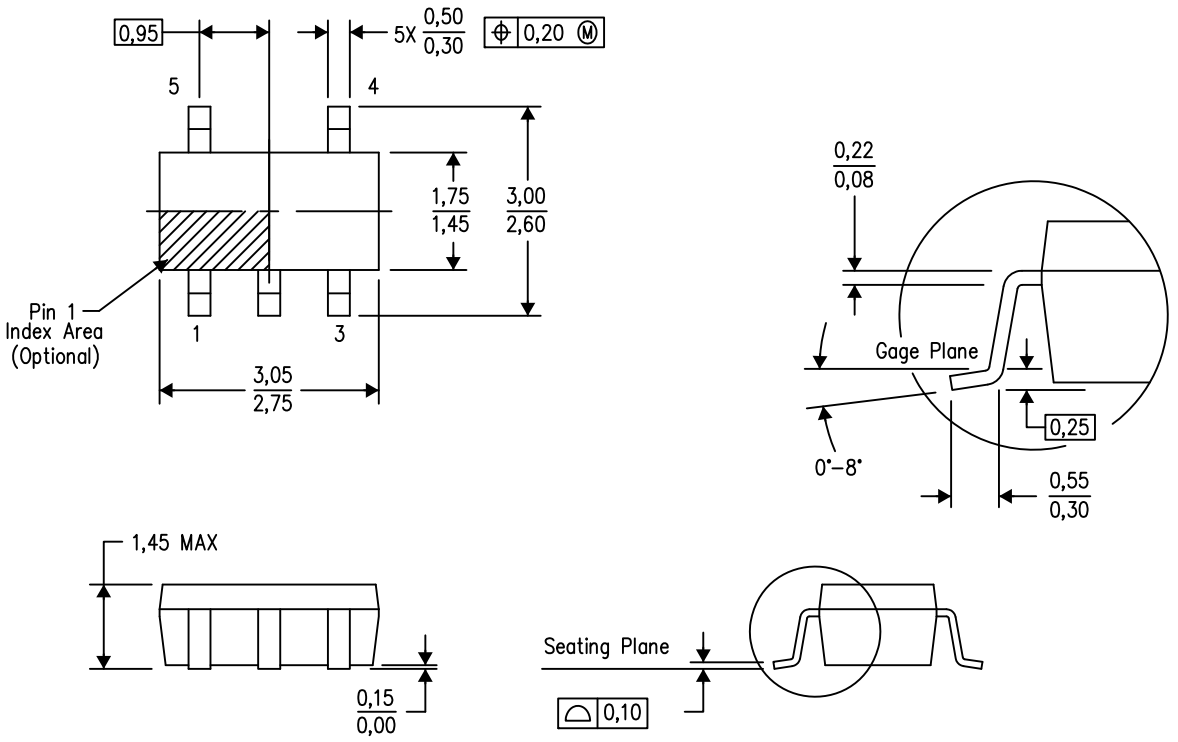
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS560200DBVR	SOT-23	DBV	5	3000	180.0	180.0	18.0
TPS560200DBVT	SOT-23	DBV	5	250	180.0	180.0	18.0

DBV (R–PDSO–G5) PLASTIC SMALL–OUTLINE PACKAGE



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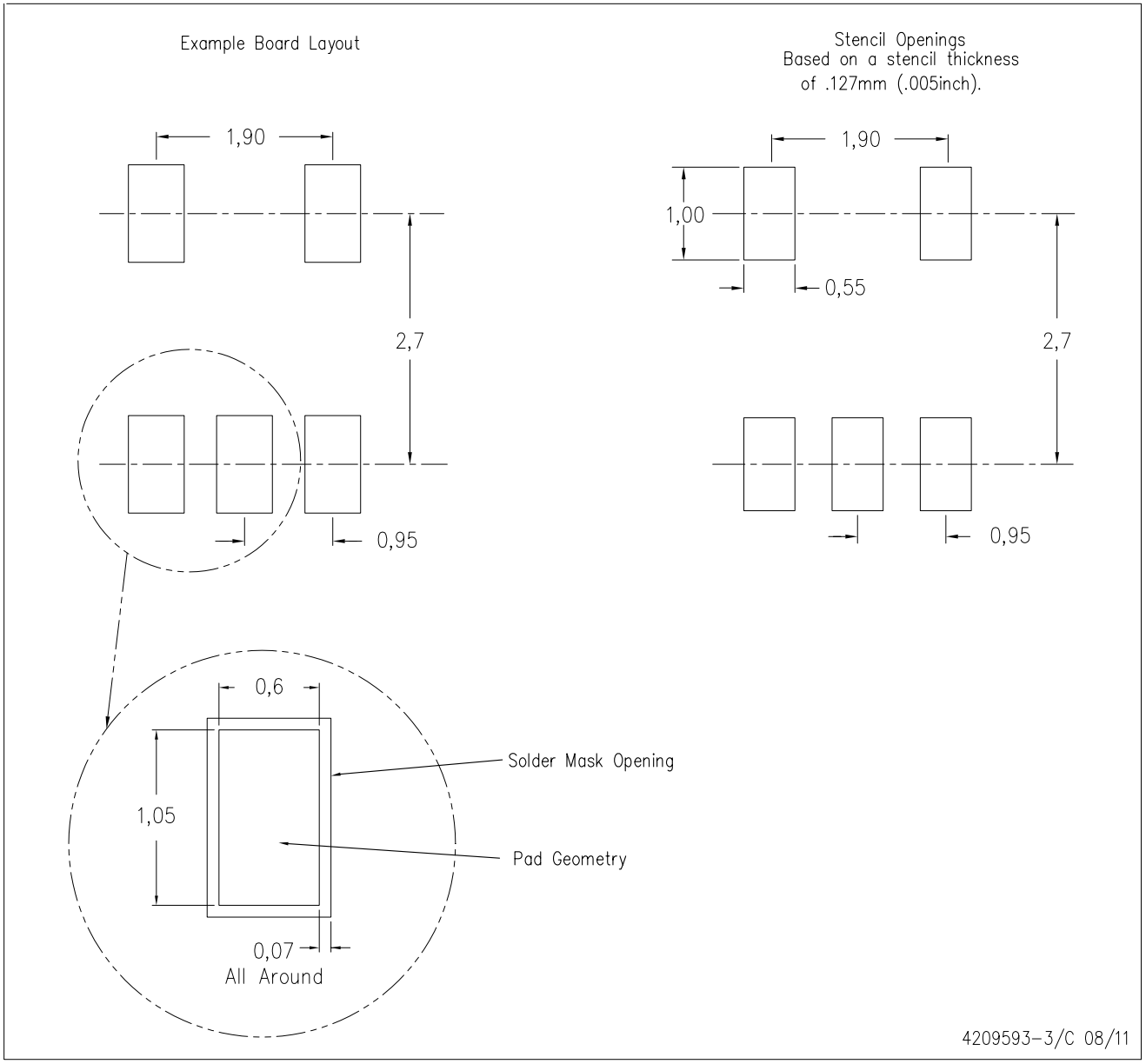
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Falls within JEDEC MO–178 Variation AA.

DBV (R–PDSO–G5) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. Publication IPC–7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.

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