3.0A Low Dropout Linear Regulator with Programmable Soft-Start

Check for Samples: TPS749xx

FEATURES

- **V_{OUT} Range: 0.8V to 3.6V**
- **Ultralow V_{IN} Range: 0.8V to 5.5V**
- **V_{BIAS} Range: 2.7V to 5.5V**
- **Low Dropout: 120mV (typ) at 3.0A, V_{BIAS} = 5V**
- **Power-Good (PG) Output Allows Supply Monitoring or Provides a Sequencing Signal for Other Supplies**
- **2% Accuracy Over Line/Load/Temperature**
- **Programmable Soft-Start Provides Linear Voltage Startup**
- **V_{BIAS} Permits Low V_{IN} Operation with Good Transient Response**
- **Stable with Any Output Capacitor ≥ 2.2μF**
- **Available in 5mm × 5mm × 1mm QFN and DDPAK-7 Packages**
- **Open-Drain Power-Good**
- **Active High Enable**

APPLICATIONS

- **FPGA Applications**
- **DSP Core and I/O Voltages**
- **Post-Regulation Applications**
- **Applications with Special Start-Up Time or Sequencing Requirements**
- **Hot-Swap and Inrush Controls**

DESCRIPTION

The TPS749xx low-dropout (LDO) linear regulator provides an easy-to-use robust power management solution for a wide variety of applications. User-programmable soft-start minimizes stress on the input power source by reducing capacitive inrush current on start-up. The soft-start is monotonic and well-suited for powering many different types of processors and ASICs. The enable input and power-good output allow easy sequencing with external regulators. This complete flexibility permits the user to configure a solution that meets the sequencing requirements of FPGAs, DSPs, and other applications with special start-up requirements.

A precision reference and error amplifier deliver 2% accuracy over load, line, temperature, and process. The device is stable with any type of capacitor ≥ 2.2μF, and the device is fully specified from –40°C to +125°C. The TPS749xx is offered in a small (5mm × 5mm) QFN package, yielding a highly compact total solution size. It is also available in a DDPAK-7.

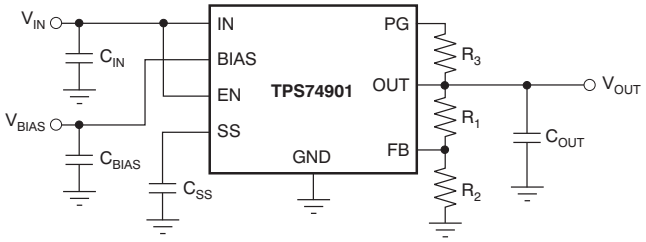


Figure 1. Typical Application Circuit (Adjustable)

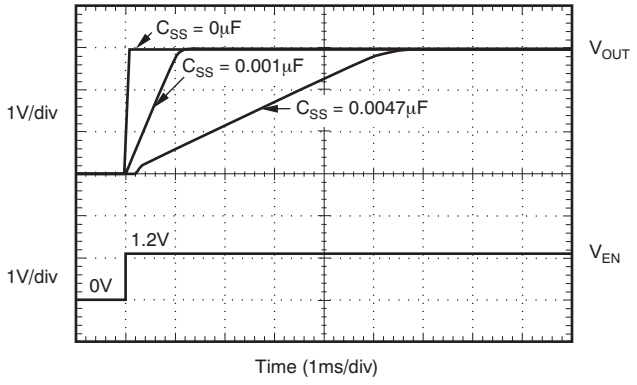


Figure 2. Turn-On Response

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This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ORDERING INFORMATION(1)

PRODUCT	V_{OUT} (2)
TPS749**xx** ***yyy z***	**XX** is nominal output voltage (for example, 12 = 1.2V, 15 = 1.5V, 01 = Adjustable).(3) **YYY** is package designator. **Z** is package quantity.

(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI website at www.ti.com.
(2) Fixed output voltages from 0.8V to 3.3V are available; minimum order quantities may apply. Contact factory for details and availability.
(3) For fixed 0.8V operation, tie FB to OUT.

ABSOLUTE MAXIMUM RATINGS(1)

At T_J = –40°C to +125°C, unless otherwise noted. All voltages are with respect to GND.

PARAMETER		TPS749xx	UNIT
V_{IN}, V_{BIAS}	Input voltage range	–0.3 to +6	V
V_{EN}	Enable voltage range	–0.3 to +6	V
V_{PG}	Power-good voltage range	–0.3 to +6	V
I_{PG}	PG sink current	0 to +1.5	mA
V_{SS}	SS pin voltage range	–0.3 to +6	V
V_{FB}	Feedback pin voltage range	–0.3 to +6	V
V_{OUT}	Output voltage range	–0.3 to V_{IN} + 0.3	V
I_{OUT}	Maximum output current	Internally limited	
	Output short-circuit duration	Indefinite	
P_{DISS}	Continuous total power dissipation	See *Thermal Information* Table	
T_J	Operating junction temperature range	–40 to +125	°C
T_{STG}	Storage junction temperature range	–55 to +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 conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

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THERMAL INFORMATION

THERMAL METRIC(1)		TPS74901(2)		UNITS
		RGW (20 PINS)	KTW (7 PINS)	
θ_{JA}	Junction-to-ambient thermal resistance(3)	30.5	20.1	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance(4)	27.6	2.1	
θ_{JB}	Junction-to-board thermal resistance(5)	N/A	N/A	
ψ_{JT}	Junction-to-top characterization parameter(6)	0.37	4.2	
ψ_{JB}	Junction-to-board characterization parameter(7)	10.6	6.1	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance(8)	4.1	1.4	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953A.
(2) Thermal data for the RGW and KTW packages are derived by thermal simulations based on JEDEC-standard methodology as specified in the JESD51 series. The following assumptions are used in the simulations:
  (a) i. RGW: The exposed pad is connected to the PCB ground layer through a 4x4 thermal via array.
  ii. KTW: The exposed pad is connected to the PCB ground layer through a 6x6 thermal via array.
  (b) Each of top and bottom copper layers has a dedicated pattern for 20% copper coverage.
  (c) These data were generated with only a single device at the center of a JEDEC high-K (2s2p) board with 3in × 3in copper area. To understand the effects of the copper area on thermal performance, refer to the *Power Dissipation* and *Estimating Junction Temperature* sections.
(3) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
(4) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the top of the package. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
(5) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
(6) The junction-to-top characterization parameter, ψ_{JT}, estimates the junction temperature of a device in a real system and is extracted from the simulation data to obtain θ_{JA} using a procedure described in JESD51-2a (sections 6 and 7).
(7) The junction-to-board characterization parameter, ψ_{JB}, estimates the junction temperature of a device in a real system and is extracted from the simulation data to obtain θ_{JA} using a procedure described in JESD51-2a (sections 6 and 7).
(8) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

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ELECTRICAL CHARACTERISTICS

At T_J = –40°C to +125°C, V_{EN} = 1.1V, V_{IN} = V_{OUT} + 0.3V, C_{BIAS} = 0.1µF, C_{IN} = C_{OUT} = 10µF, C_{NR} = 1nF, I_{OUT} = 50mA, and V_{BIAS} = 5.0V, unless otherwise noted. Typical values are at T_J = +25°C.

PARAMETER		TEST CONDITIONS	TPS74901			UNIT
			MIN	TYP	MAX	
V_{IN}	Input voltage range		V_{OUT} + V_{DO}		5.5	V
V_{BIAS}	Bias pin voltage range		2.7		5.5	V
V_{REF}	Internal reference (Adj.)	T_J = +25°C	0.798	0.802	0.806	V
V_{OUT}	Output voltage range	V_{IN} = 5V, I_{OUT} = 3.0V	V_{REF}		3.6	V
	Accuracy (RGW package)(1)	V_{OUT} + 2.2V ≤ V_{BIAS} ≤ 5.5V, 50mA ≤ I_{OUT} ≤ 3.0A	–2	±0.5	2	%
	Accuracy (KTW package)(1)	V_{OUT} + 2.4V ≤ V_{BIAS} ≤ 5.5V, 50mA ≤ I_{OUT} ≤ 3.0A	–2	±0.5	2	%
V_{OUT}/V_{IN}	Line regulation	$V_{OUT\ (NOM)}$ + 0.3 ≤ V_{IN} ≤ 5.5V		0.03		%/V
V_{OUT}/I_{OUT}	Load regulation	50mA ≤ I_{OUT} ≤ 3.0A		0.09		%/A
V_{DO}	V_{IN} dropout voltage(2)	I_{OUT} = 3.0A, V_{BIAS} – $V_{OUT\ (NOM)}$ ≥ 3.25V(3)		120	280	mV
	V_{BIAS} dropout voltage(2)	I_{OUT} = 3.0A, V_{IN} = V_{BIAS}		1.31	1.75	V
I_{CL}	Current limit	V_{OUT} = 80% × $V_{OUT\ (NOM)}$, RGW Package	3.9	4.6	5.5	A
		V_{OUT} = 80% × $V_{OUT\ (NOM)}$, KTW Package	3.8	4.6	5.5	
I_{BIAS}	Bias pin current			1	2	mA
I_{SHDN}	Shutdown supply current (I_{GND})	V_{EN} ≤ 0.4V		1	50	µA
I_{FB}	Feedback pin current		–1	0.150	1	µA
PSRR	Power-supply rejection (V_{IN} to V_{OUT})	1kHz, I_{OUT} = 1.5A, V_{IN} = 1.8V, V_{OUT} = 1.5V		60		dB
		300kHz, I_{OUT} = 1.5A, V_{IN} = 1.8V, V_{OUT} = 1.5V		30		
	Power-supply rejection (V_{BIAS} to V_{OUT})	1kHz, I_{OUT} = 1.5A, V_{IN} = 1.8V, V_{OUT} = 1.5V		50		dB
		300kHz, I_{OUT} = 1.5A, V_{IN} = 1.8V, V_{OUT} = 1.5V		30		
Noise	Output noise voltage	100Hz to 100kHz, I_{OUT} = 3.0A, C_{SS} = 0.001µF		25 × V_{OUT}		μV_{RMS}
t_{STR}	Minimum startup time	R_{LOAD} for I_{OUT} = 1.0A, C_{SS} = open		200		µs
I_{SS}	Soft-start charging current	V_{SS} = 0.4V		440		nA
$V_{EN,\ HI}$	Enable input high level		1.1		5.5	V
$V_{EN,\ LO}$	Enable input low level		0		0.4	V
$V_{EN,\ HYS}$	Enable pin hysteresis			50		mV
$V_{EN,\ DG}$	Enable pin deglitch time			20		µs
I_{EN}	Enable pin current	V_{EN} = 5V		0.1	1	µA
V_{IT}	PG trip threshold	V_{OUT} decreasing	85	90	94	$\%V_{OUT}$
V_{HYS}	PG trip hysteresis			3		$\%V_{OUT}$
$V_{PG,\ LO}$	PG output low voltage	I_{PG} = 1mA (sinking), V_{OUT} < V_{IT}			0.3	V
$I_{PG,\ LKG}$	PG leakage current	V_{PG} = 5.25V, V_{OUT} > V_{IT}		0.1	1	µA
T_J	Operating junction temperature		–40		+125	°C
T_{SD}	Thermal shutdown temperature	Shutdown, temperature increasing		+165		°C
		Reset, temperature decreasing		+140		

(1) Adjustable devices tested at 0.8V; resistor tolerance is not taken into account.
(2) Dropout is defined as the voltage from V_{IN} to V_{OUT} when V_{OUT} is 3% below nominal.
(3) *3.25V* is a test condition of this device and can be adjusted by referring to **Figure 8** .

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BLOCK DIAGRAM

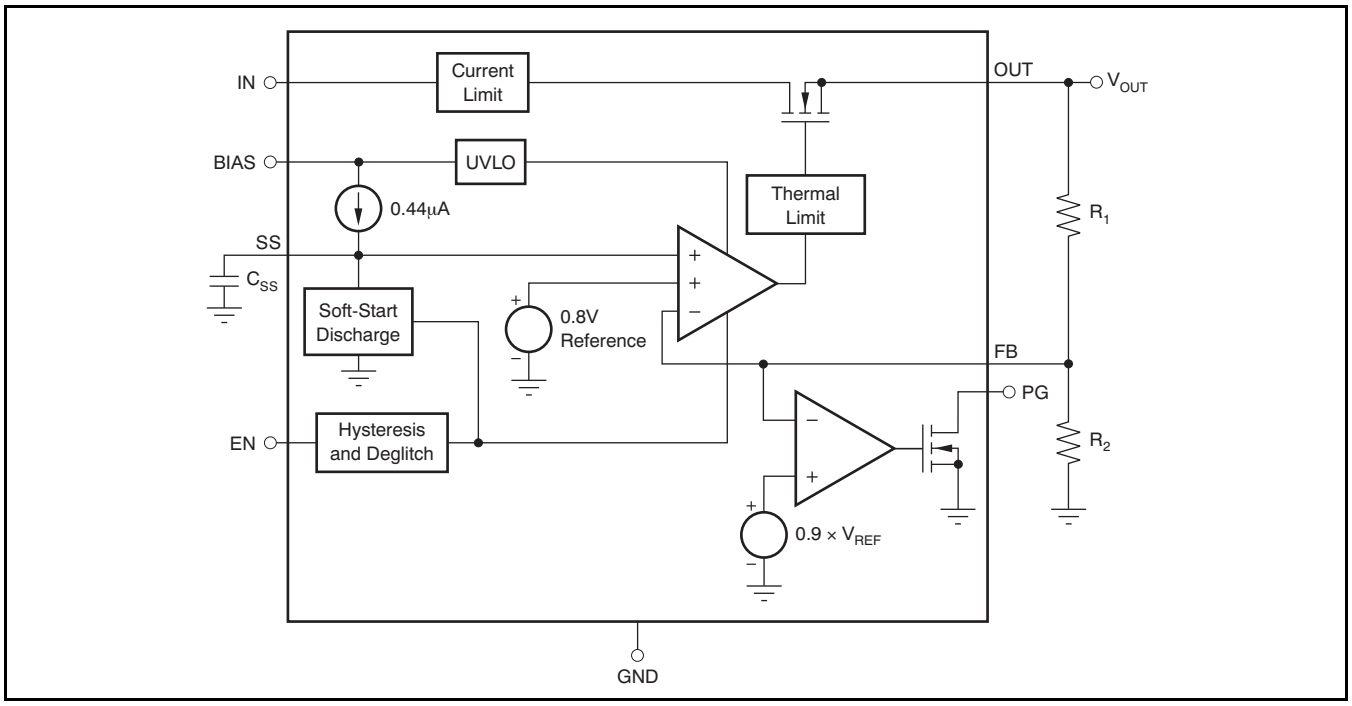


Table 1. Standard 1% Resistor Values for Programming the Output Voltage(1)

R_1 (kΩ)	R_2 (kΩ)	V_{OUT} (V)
Short	Open	0.8
0.619	4.99	0.9
1.13	4.53	1.0
1.37	4.42	1.05
1.87	4.99	1.1
2.49	4.99	1.2
4.12	4.75	1.5
3.57	2.87	1.8
3.57	1.69	2.5
3.57	1.15	3.3

(1) $V_{OUT} = 0.8 \times (1 + R_1/R_2)$

Table 2. Standard Capacitor Values for Programming the Soft-Start Time(1)

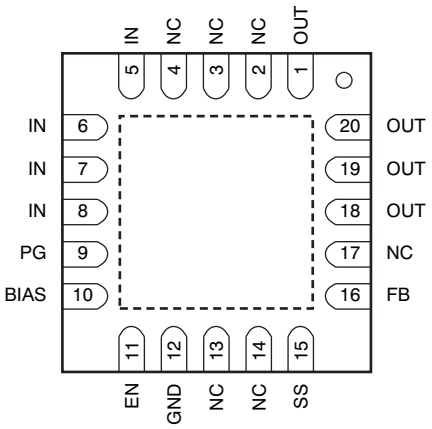
C_{SS}	SOFT-START TIME
Open	0.1ms
270pF	0.5ms
560pF	1ms
2.7nF	5ms
5.6nF	10ms
0.01μF	18ms

(1) $$t_{SS}(s) = \frac{V_{REF} \times C_{SS}}{I_{SS}} = \frac{0.8V \times C_{SS}(F)}{0.44\mu A}$$ where $t_{SS}(s)$ = soft-start time in seconds.

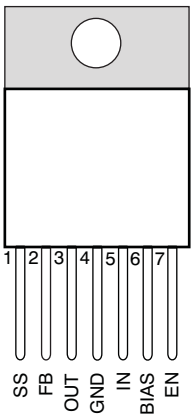
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PIN ASSIGNMENTS

RGW PACKAGE
QFN-20
(TOP VIEW)



KTW PACKAGE
DDPAK-7
(TOP VIEW)



PIN DESCRIPTIONS

NAME	KTW (DDPAK)	RGW (QFN)	DESCRIPTION
IN	5	5–8	Unregulated input to the device.
EN	7	11	Enable pin. Driving this pin high enables the regulator. Driving this pin low puts the regulator into shutdown mode. This pin must not be left floating.
SS	1	15	Soft-Start pin. A capacitor connected on this pin to ground sets the start-up time. If this pin is left floating, the regulator output soft-start ramp time is typically 100μs.
BIAS	6	10	Bias input voltage for error amplifier, reference, and internal control circuits.
PG	N/A	9	Power-Good (PG) is an open-drain, active-high output that indicates the status of V_{OUT}. When V_{OUT} exceeds the PG trip threshold, the PG pin goes into a high-impedance state. When V_{OUT} is below this threshold the pin is driven to a low-impedance state. A pull-up resistor from 10kΩ to 1MΩ should be connected from this pin to a supply up to 5.5V. The supply can be higher than the input voltage. Alternatively, the PG pin can be left floating if output monitoring is not necessary.
FB	2	16	This pin is the feedback connection to the center tap of an external resistor divider network that sets the output voltage. This pin must not be left floating.
OUT	3	1, 18–20	Regulated output voltage. A small capacitor (total typical capacitance ≥ 2.2μF, ceramic) is needed from this pin to ground to assure stability.
NC	N/A	2–4, 13, 14, 17	No connection. This pin can be left floating or connected to GND to allow better thermal contact to the top-side plane.
GND	4	12	Ground
PAD/TAB			Should be soldered to the ground plane for increased thermal performance.

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TYPICAL CHARACTERISTICS

At T_J = +25°C, V_{IN} = $V_{OUT(TYP)}$ + 0.3V, V_{BIAS} = 5V, I_{OUT} = 50mA, V_{EN} = V_{IN}, C_{IN} = 1µF, C_{BIAS} = 4.7µF, and C_{OUT} = 10µF, unless otherwise noted.

V_{IN} LINE REGULATION

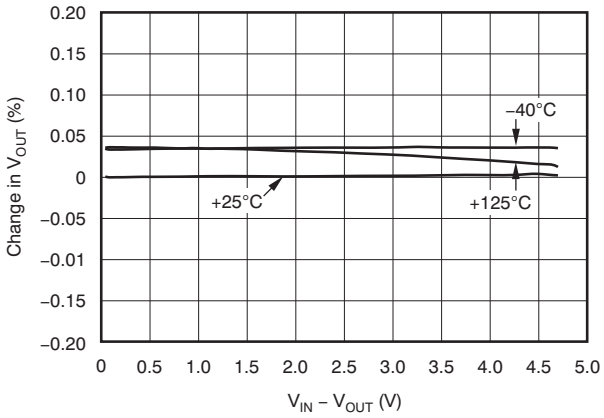


Figure 3.

V_{BIAS} LINE REGULATION

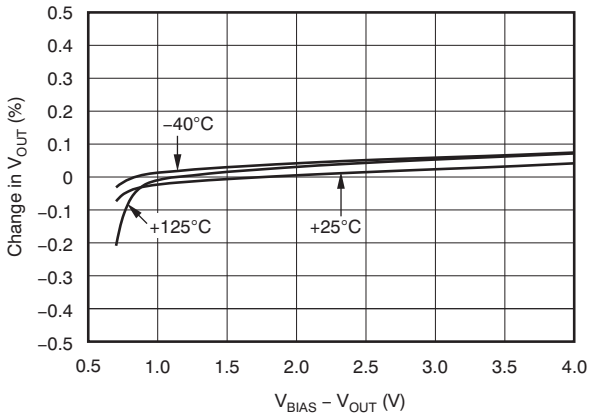


Figure 4.

LOAD REGULATION

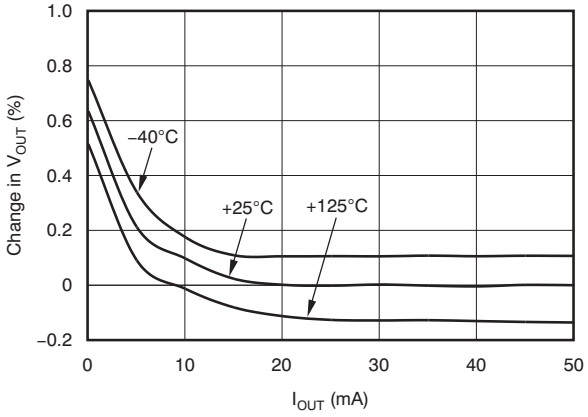


Figure 5.

LOAD REGULATION

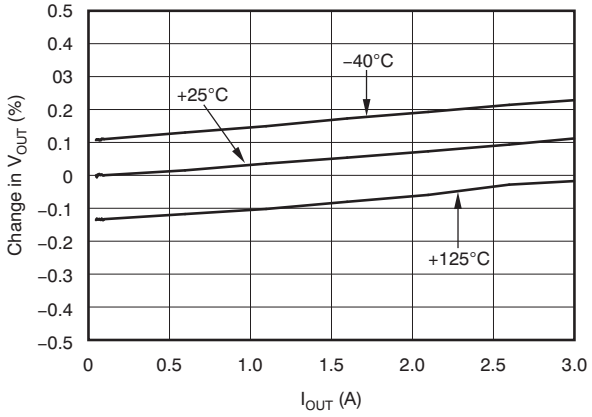


Figure 6.

V_{IN} DROPOUT VOLTAGE vs i_{OUT} AND TEMPERATURE (T_J)

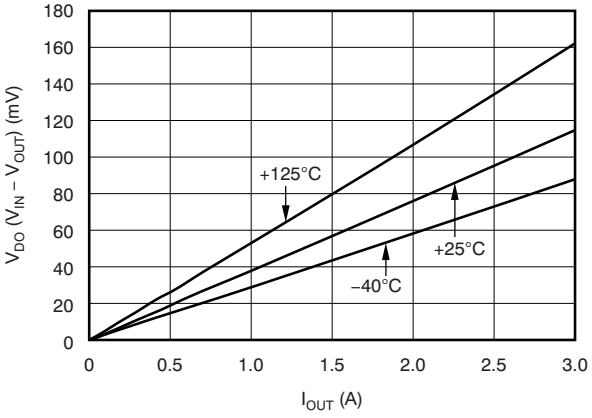


Figure 7.

V_{IN} DROPOUT VOLTAGE vs V_{IN} DROPOUT VOLTAGE vs I_{OUT} AND TEMPERATURE (T_J)

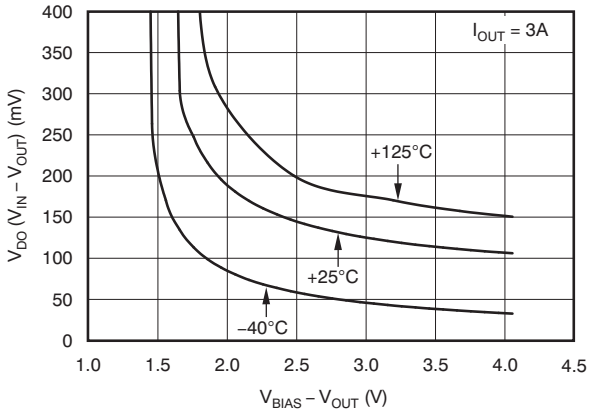


Figure 8.

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TYPICAL CHARACTERISTICS (continued)

At T_J = +25°C, V_{IN} = $V_{OUT(TYP)}$ + 0.3V, V_{BIAS} = 5V, I_{OUT} = 50mA, V_{EN} = V_{IN}, C_{IN} = 1µF, C_{BIAS} = 4.7µF, and C_{OUT} = 10µF, unless otherwise noted.

V_{IN} DROPOUT VOLTAGE vs (V_{BIAS} – V_{OUT}) AND TEMPERATURE (T_J)

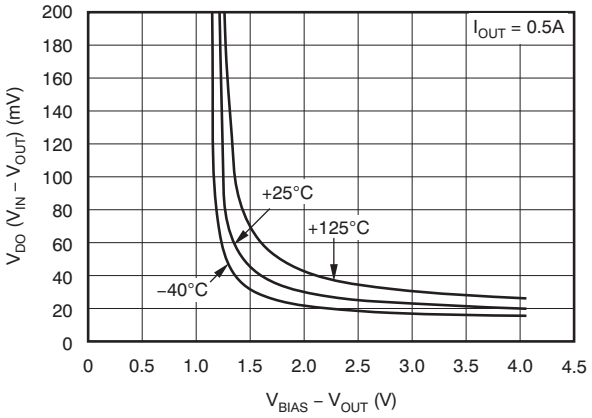


Figure 9.

V_{BIAS} DROPOUT VOLTAGE vs I_{OUT} AND TEMPERATURE (T_J)

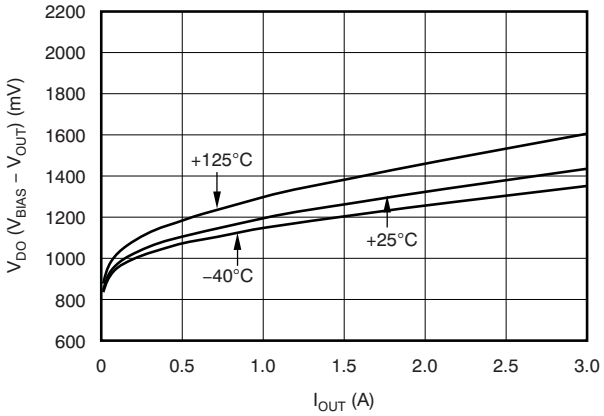


Figure 10.

V_{BIAS} PSRR vs FREQUENCY

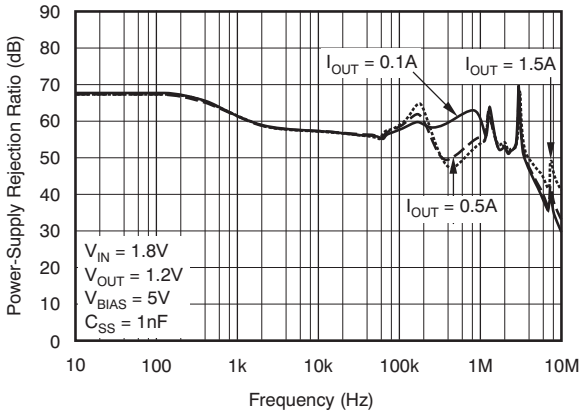


Figure 11.

V_{IN} PSRR vs FREQUENCY

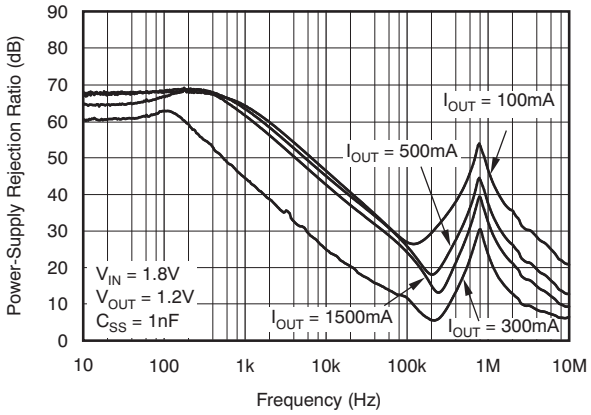


Figure 12.

V_{IN} PSRR vs (V_{IN} – V_{OUT})

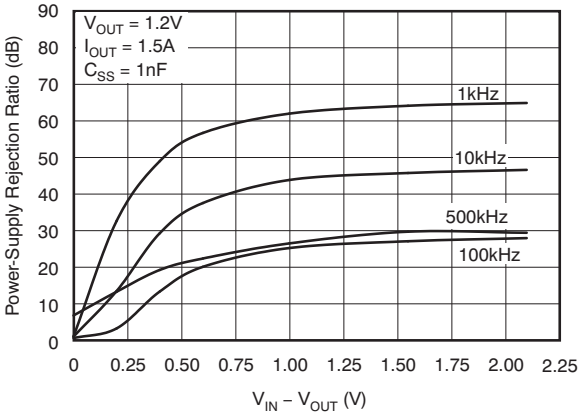


Figure 13.

NOISE SPECTRAL DENSITY

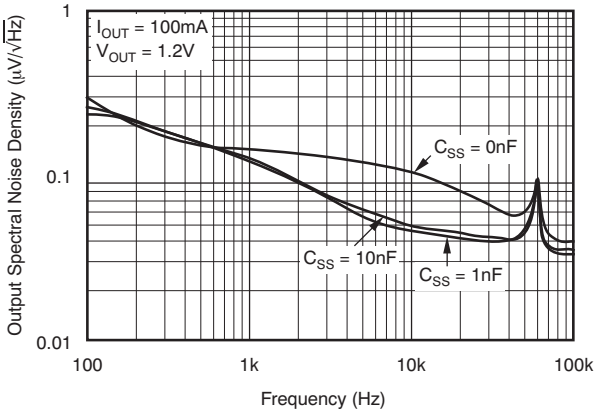


Figure 14.

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TYPICAL CHARACTERISTICS (continued)

At T_J = +25°C, V_{IN} = $V_{OUT(TYP)}$ + 0.3V, V_{BIAS} = 5V, I_{OUT} = 50mA, V_{EN} = V_{IN}, C_{IN} = 1µF, C_{BIAS} = 4.7µF, and C_{OUT} = 10µF, unless otherwise noted.

BIAS PIN CURRENT vs I_{OUT} AND TEMPERATURE (T_J)

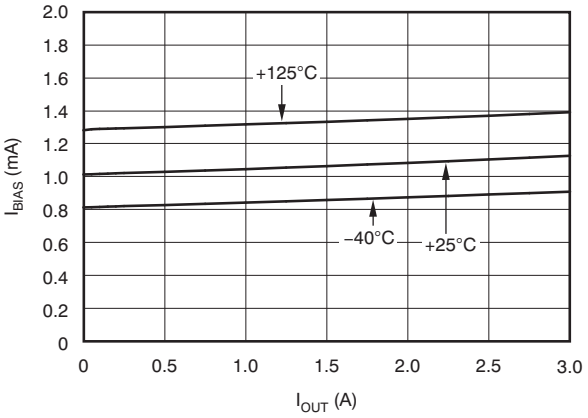


Figure 15.

BIAS PIN CURRENT vs V_{BIAS} AND TEMPERATURE (T_J)

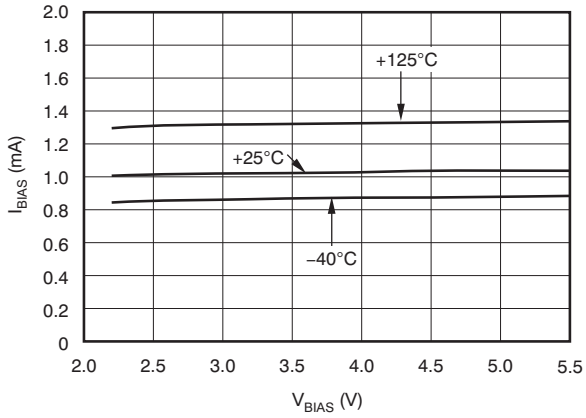


Figure 16.

SOFT-START CHARGING CURRENT (I_{SS}) vs TEMPERATURE (T_J)

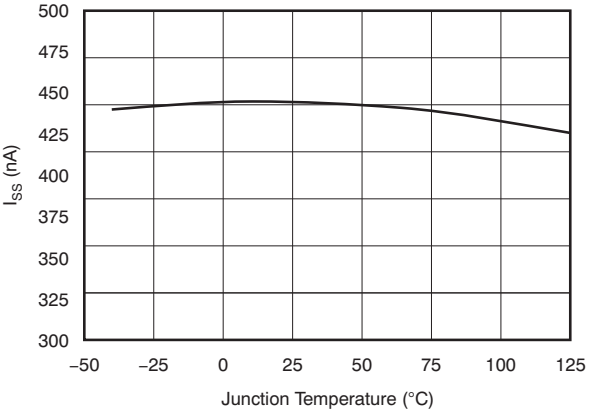


Figure 17.

LOW-LEVEL PG VOLTAGE vs CURRENT

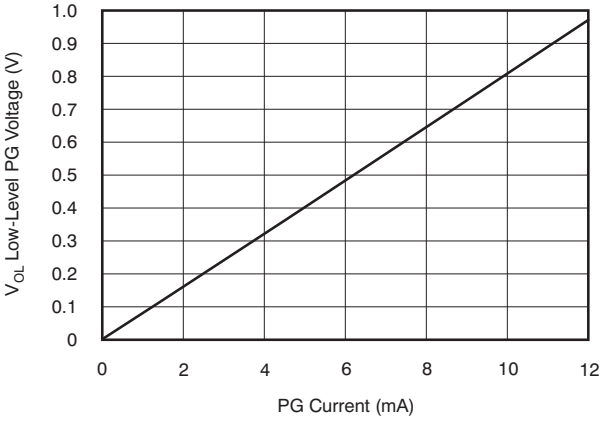


Figure 18.

CURRENT LIMIT vs (V_{BIAS} – V_{OUT})

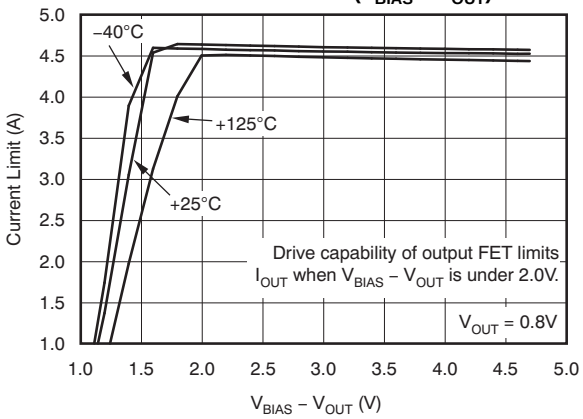


Figure 19.

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TYPICAL CHARACTERISTICS

At T_J = +25°C, V_{IN} = $V_{OUT(TYP)}$ + 0.3V, V_{BIAS} = 5V, I_{OUT} = 1A, V_{EN} = V_{IN} = 1.8V, V_{OUT} = 1.5V, C_{IN} = 1µF, C_{BIAS} = 4.7µF, and C_{OUT} = 10µF, unless otherwise noted.

V_{BIAS} LINE TRANSIENT

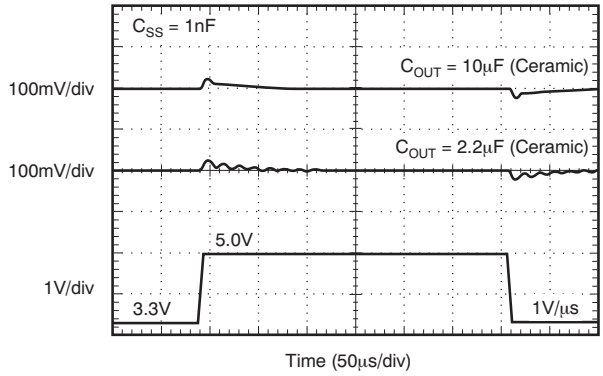


Figure 20.

V_{IN} LINE TRANSIENT

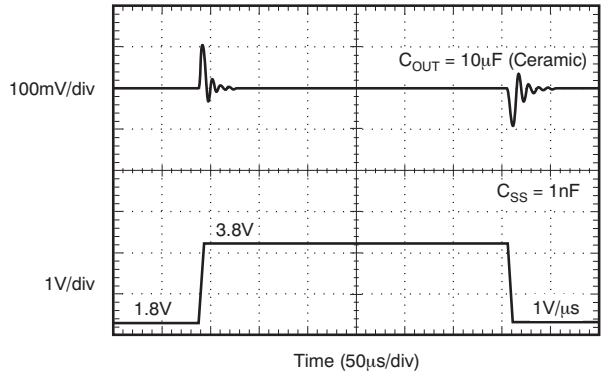


Figure 21.

OUTPUT LOAD TRANSIENT RESPONSE

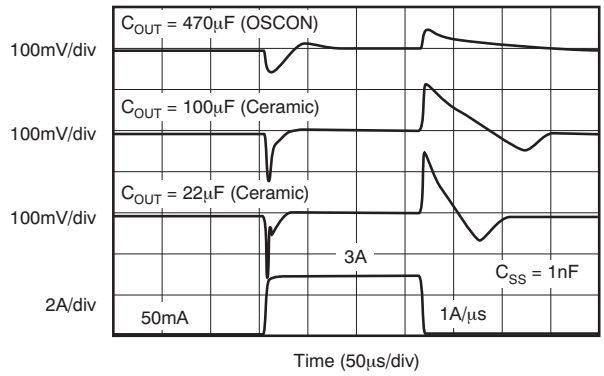


Figure 22.

TURN-ON RESPONSE

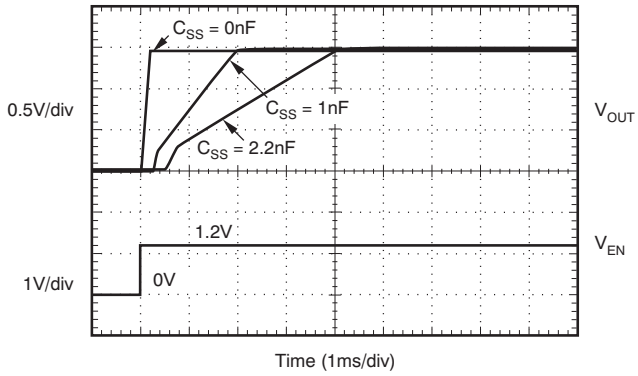


Figure 23.

POWER-UP/POWER-DOWN

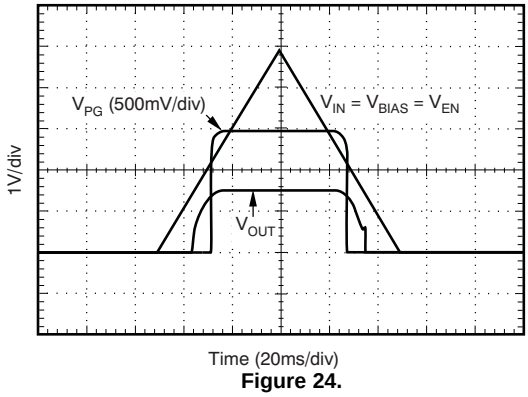


Figure 24.

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APPLICATION INFORMATION

The TPS749xx belongs to a family of low dropout regulators that feature soft-start capabilities. These regulators use a low current bias input to power all internal control circuitry, allowing the NMOS pass transistor to regulate very low input and output voltages.

The use of an NMOS-pass FET offers several critical advantages for many applications. Unlike a PMOS topology device, the output capacitor has little effect on loop stability. This architecture allows the TPS749xx to be stable with any capacitor type of value 2.2μF or greater. Transient response is also superior to PMOS topologies, particularly for low V_{IN} applications.

The TPS749xx features a programmable voltage-controlled soft-start circuit that provides a smooth, monotonic start-up and limits startup inrush currents that may be caused by large capacitive loads. A power-good (PG) output is available to allow supply monitoring and sequencing of other supplies. An enable (EN) pin with hysteresis and deglitch allows slow-ramping signals to be used for sequencing the device. The low V_{IN} and V_{OUT} capability allows for inexpensive, easy-to-design, and efficient linear regulation between the multiple supply voltages often present in processor intensive systems.

Figure 25 illustrates the typical application circuit for the TPS749xx adjustable output device.

R_1 and R_2 can be calculated for any output voltage using the formula shown in Figure 25. Refer to Table 1 for sample resistor values of common output voltages. In order to achieve the maximum accuracy specifications, R_2 should be ≤ 4.99kΩ.

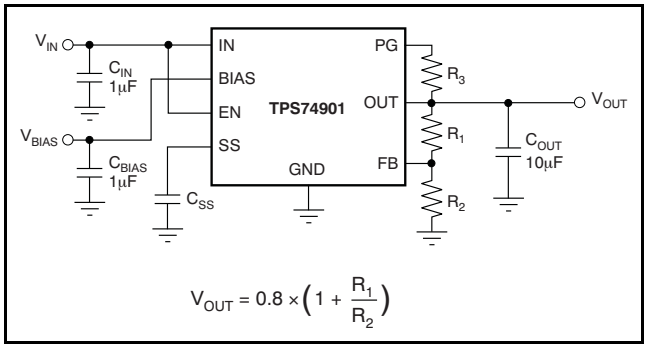


Figure 25. Typical Application Circuit for the TPS749xx (Adjustable)

INPUT, OUTPUT, AND BIAS CAPACITOR REQUIREMENTS

The device is designed to be stable for all available types of and values of output capacitors ≥ 2.2μF. The device is also stable with multiple capacitors in parallel, which can be of any type or value.

The capacitance required on the IN and BIAS pin strongly depends on the input supply source impedance. To counteract any inductance in the input, the minimum recommended capacitor for V_{IN} and V_{BIAS} is 1μF. If V_{IN} and V_{BIAS} are connected to the same supply, the recommended minimum capacitor for V_{BIAS} is 4.7μF. Good quality, low ESR capacitors should be used on the input; ceramic X5R and X7R capacitors are preferred. These capacitors should be placed as close the pins as possible for optimum performance.

TRANSIENT RESPONSE

The TPS749xx is designed to have excellent transient response for most applications with a small amount of output capacitance. In some cases, the transient response may be limited by the transient response of the input supply. This limitation is especially true in applications where the difference between the input and output is less than 300mV. In this case, adding additional input capacitance improves the transient response much more than just adding additional output capacitance would do. With a solid input supply, adding additional output capacitance reduces undershoot and overshoot during a transient event; refer to Figure 22 in the Typical Characteristics section. Because the TPS749xx is stable with output capacitors as low as 2.2μF, many applications may need very little capacitance at the LDO output. For these applications, local bypass capacitance for the powered device may be sufficient to meet the transient requirements of the application. This design reduces the total solution cost by avoiding the need to use expensive high-value capacitors at the LDO output.

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DROPOUT VOLTAGE

The TPS749xx offers very low dropout performance, making it well-suited for high-current low V_{IN}/low V_{OUT} applications. The low dropout of the TPS749xx allows the device to be used in place of a DC/DC converter and still achieve good efficiencies. This provides designers with the power architecture for their applications to achieve the smallest, simplest, and lowest cost solution.

There are two different specifications for dropout voltage with the TPS749xx. The first specification (see Figure 26) is referred to as *V_{IN} Dropout* and is used when an external bias voltage is applied to achieve low dropout. This specification assumes that V_{BIAS} is at least 3.25V(1) above V_{OUT}, which is the case for V_{BIAS} when powered by a 5.0V rail with 5% tolerance and with V_{OUT} = 1.5V. If V_{BIAS} is higher than V_{OUT} + 3.25V, V_{IN} dropout is less than specified(1).

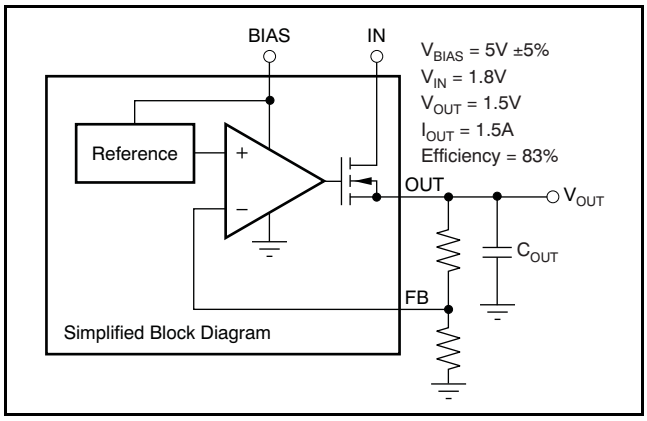


Figure 26. Typical Application of the TPS749xx Using an Auxiliary Bias Rail

The second specification (shown in Figure 27) is referred to as *V_{BIAS} Dropout* and applied to applications where IN and BIAS are tied together. This option allows the device to be used in applications where an auxiliary bias voltage is not available or low dropout is not required. Dropout is limited by BIAS in these applications because V_{BIAS} provides the gate drive to the pass FET; therefore, V_{BIAS} must be 1.75V above V_{OUT}. Dropout is limited by BIAS in these applications because V_{BIAS} provides the gate drive to the pass FET; therefore, V_{BIAS} must be 1.75V above V_{OUT}. Because of this usage, IN and BIAS tied together easily consume huge power. Pay attention not to exceed the power rating of the IC package.

(1) *3.25V* is a test condition of this device and can be adjusted by referring to **Figure 8** .

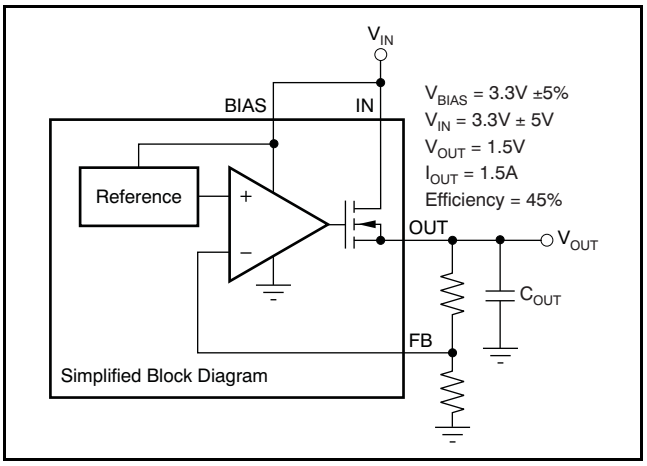


Figure 27. Typical Application of the TPS749xx Without an Auxiliary Bias

PROGRAMMABLE SOFT-START

The TPS749xx features a programmable, monotonic, voltage-controlled soft-start that is set with an external capacitor (C_{SS}). This feature is important for many applications because it eliminates power-up initialization problems when powering FPGAs, DSPs, or other processors. The controlled voltage ramp of the output also reduces peak inrush current during start-up, minimizing start-up transient events to the input power bus.

To achieve a linear and monotonic soft-start, the TPS749xx error amplifier tracks the voltage ramp of the external soft-start capacitor until the voltage exceeds the internal reference. The soft-start ramp time is dependent on the soft-start charging current (I_{SS}), soft-start capacitance (C_{SS}), and the internal reference voltage (V_{REF}), and can be calculated using Equation 1:

$$t_{SS} = \frac{(V_{REF} \times C_{SS})}{I_{SS}} \quad (1)$$

If large output capacitors are used, the device current limit (I_{CL}) and the output capacitor may set the start-up time. In this case, the start-up time is given by Equation 2:

$$t_{SSCL} = \frac{(V_{OUT(NOM)} \times C_{OUT})}{I_{CL(MIN)}} \quad (2)$$

where:

$V_{OUT(NOM)}$ is the nominal set output voltage,
C_{OUT} is the output capacitance, and
$I_{CL(MIN)}$ is the minimum current limit for the device.

In applications where monotonic startup is required, the soft-start time given by Equation 1 should be set to be greater than Equation 2.

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The maximum recommended soft-start capacitor is 0.015μF. Larger soft-start capacitors can be used and will not damage the device; however, the soft-start capacitor discharge circuit may not be able to fully discharge the soft-start capacitor when enabled. Soft-start capacitors larger than 0.015μF could be a problem in applications where the user needs to rapidly pulse the enable pin and still requires the device to soft-start from ground. C_{SS} must be low-leakage; X7R, X5R, or C0G dielectric materials are preferred. Refer to Table 2 for suggested soft-start capacitor values.

SEQUENCING REQUIREMENTS

V_{IN}, V_{BIAS}, and V_{EN} can be sequenced in any order without causing damage to the device. However, for the soft-start function to work as intended, certain sequencing rules must be applied. Connecting EN to IN is acceptable for most applications as long as V_{IN} is greater than 1.1V and the ramp rate of V_{IN} and V_{BIAS} is faster than the set soft-start ramp rate. If the ramp rate of the input sources is slower than the set soft-start time, the output tracks the slower supply minus the dropout voltage until it reaches the set output voltage. If EN is connected to BIAS, the device will soft-start as programmed, provided that V_{IN} is present before V_{BIAS}. If V_{BIAS} and V_{EN} are present before V_{IN} is applied and the set soft-start time has expired, then V_{OUT} tracks V_{IN}. If the soft-start time has not expired, the output tracks V_{IN} until V_{OUT} reaches the value set by the charging soft-start capacitor. Figure 28 shows the use of an RC-delay circuit to hold off V_{EN} until V_{BIAS} has ramped. This technique can also be used to drive EN from V_{IN}. An external control signal can also be used to enable the device after V_{IN} and V_{BIAS} are present.

NOTE: When V_{BIAS} and V_{EN} are present and V_{IN} is not supplied, this device outputs approximately 50μA of current from OUT. Although this condition will not cause any damage to the device, the output current may charge up the OUT node if total resistance between OUT and GND (including external feedback resistors) is greater than 10kΩ.

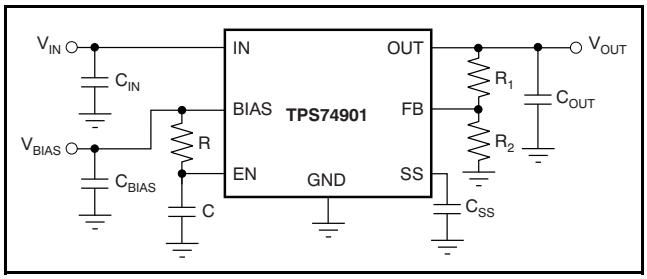


Figure 28. Soft-Start Delay Using an RC Circuit on Enable

OUTPUT NOISE

The TPS749xx provides low output noise when a soft-start capacitor is used. When the device reaches the end of the soft-start cycle, the soft-start capacitor serves as a filter for the internal reference. By using a 0.001μF soft-start capacitor, the output noise is reduced by half and is typically $30\mu V_{RMS}$ for a 1.2V output (10Hz to 100kHz). Further increasing C_{SS} has little effect on noise, Because most of the output noise is generated by the internal reference, the noise is a function of the set output voltage. The RMS noise with a 0.001μF soft-start capacitor is given in Equation 3.

$$V_N(\mu V_{RMS}) = 25 \left(\frac{\mu V_{RMS}}{V}\right) \times V_{OUT}(V) \quad (3)$$

The low output noise of the TPS749xx makes it a good choice for powering transceivers, PLLs, or other noise-sensitive circuitry.

ENABLE/SHUTDOWN

The enable (EN) pin is active high and is compatible with standard digital signaling levels. V_{EN} below 0.4V turns the regulator off, while V_{EN} above 1.1V turns the regulator on. Unlike many regulators, the enable circuitry has hysteresis and deglitching for use with relatively slowly ramping analog signals. This configuration allows the TPS749xx to be enabled by connecting the output of another supply to the EN pin. The enable circuitry typically has 50mV of hysteresis and a deglitch circuit to help avoid on-off cycling because of small glitches in the V_{EN} signal.

The enable threshold is typically 0.8V and varies with temperature and process variations. Temperature variation is approximately –1mV/°C; process variation accounts for most of the rest of the variation to the 0.4V and 1.1V limits. If precise turn-on timing is required, a fast rise-time signal must be used to enable the TPS749xx.

If not used, EN can be connected to either IN or BIAS. If EN is connected to IN, it should be connected as close as possible to the largest capacitance on the input to prevent voltage droops on that line from triggering the enable circuit.

POWER-GOOD

The power-good (PG) pin is an open-drain output and can be connected to any 5.5V or lower rail through an external pull-up resistor. This pin requires at least 1.1V on V_{BIAS} in order to have a valid output. The PG output is high-impedance when V_{OUT} is greater than $V_{IT} + V_{HYS}$. If V_{OUT} drops below V_{IT} or if V_{BIAS} drops below 1.9V, the open-drain output turns on and pulls the PG output low. The PG pin also asserts when the device is disabled. The recommended operating

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condition of PG pin sink current is up to 1mA, so the pull-up resistor for PG should be in the range of 10kΩ to 1MΩ. PG is only provided on the QFN package. If output voltage monitoring is not needed, the PG pin can be left floating.

INTERNAL CURRENT LIMIT

The TPS749xx features a factory-trimmed, accurate current limit that is flat over temperature and supply voltage. The current limit allows the device to supply surges of up to 4A and maintain regulation. The current limit responds in about 10μs to reduce the current during a short-circuit fault.

The internal current limit protection circuitry of the TPS749xx is designed to protect against overload conditions. It is not intended to allow operation above the rated current of the device. Continuously running the TPS749xx above the rated current degrades device reliability.

THERMAL PROTECTION

Thermal protection disables the output when the junction temperature rises to approximately +160°C, allowing the device to cool. When the junction temperature cools to approximately +140°C, the output circuitry is enabled. Depending on power dissipation, thermal resistance, and ambient temperature the thermal protection circuit may cycle on and off. This cycling limits the dissipation of the regulator, protecting it from damage as a result of overheating.

Activation of the thermal protection circuit indicates excessive power dissipation or inadequate heatsinking. For reliable operation, junction temperature should be limited to +125°C maximum. To estimate the margin of safety in a complete design (including heatsink), increase the ambient temperature until thermal protection is triggered; use worst-case loads and signal conditions. For good reliability, thermal protection should trigger at least +40°C above the maximum expected ambient condition of the application. This condition produces a worst-case junction temperature of +125°C at the highest expected ambient temperature and worst-case load.

The internal protection circuitry of the TPS749xx is designed to protect against overload conditions. It is not intended to replace proper heatsinking. Continuously running the TPS749xx into thermal shutdown degrades device reliability.

LAYOUT RECOMMENDATIONS AND POWER DISSIPATION

An optimal layout can greatly improve transient performance, PSRR, and noise. To minimize the voltage droop on the input of the device during load transients, the capacitance on IN and BIAS should be connected as close as possible to the device. This capacitance also minimizes the effects of parasitic inductance and resistance of the input source and can therefore improve stability. To achieve optimal transient performance and accuracy, the top side of R_1 in Figure 25 should be connected as close as possible to the load. If BIAS is connected to IN it is recommended to connect BIAS as close to the sense point of the input supply as possible. This connection minimizes the voltage droop on BIAS during transient conditions and can improve the turn-on response.

Knowing the device power dissipation and proper sizing of the thermal plane that is connected to the tab or pad is critical to avoiding thermal shutdown and ensuring reliable operation. Power dissipation of the device depends on input voltage and load conditions and can be calculated using Equation 4:

$$P_D = (V_{IN} - V_{OUT}) \times I_{OUT} \quad (4)$$

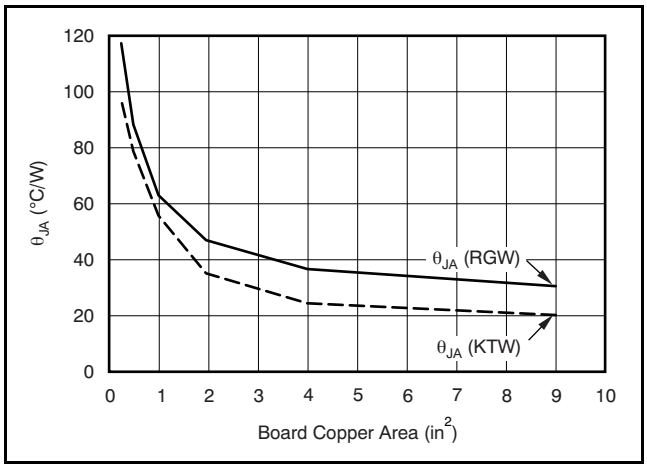
Power dissipation can be minimized and greater efficiency can be achieved by using the lowest possible input voltage necessary to achieve the required output voltage regulation.

On the QFN (RGW) package, the primary conduction path for heat is through the exposed pad to the printed circuit board (PCB). The pad can be connected to ground or be left floating; however, it should be attached to an appropriate amount of copper PCB area to ensure the device will not overheat. On the DDPAK (KTW) package, the primary conduction path for heat is through the tab to the PCB. That tab should be connected to ground. The maximum junction-to-ambient thermal resistance depends on the maximum ambient temperature, maximum device junction temperature, and power dissipation of the device and can be calculated using Equation 5:

$$R_{\theta JA} = \frac{(+125°C - T_A)}{P_D} \quad (5)$$

Knowing the maximum $R_{\theta JA}$, the minimum amount of PCB copper area needed for appropriate heatsinking can be estimated using Figure 29.

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Note: θ_{JA} value at board size of 9in^2 (that is, 3in × 3in) is a JEDEC standard.

Figure 29. θ_{JA} vs Board Size

Figure 29 shows the variation of θ_{JA} as a function of ground plane copper area in the board. It is intended only as a guideline to demonstrate the effects of heat spreading in the ground plane and should not be used to estimate actual thermal performance in real application environments.

NOTE: When the device is mounted on an application PCB, it is strongly recommended to use Ψ_{JT} and Ψ_{JB}, as explained in the *Estimating Junction Temperature* section.

ESTIMATING JUNCTION TEMPERATURE

Using the thermal metrics Ψ_{JT} and Ψ_{JB}, shown in the *Thermal Information* table, the junction temperature can be estimated with corresponding formulas (given in Equation 6). For backwards compatibility, an older $\theta_{JC,Top}$ parameter is listed as well.

$$\Psi_{JT}: \quad T_J = T_T + \Psi_{JT} \bullet P_D$$

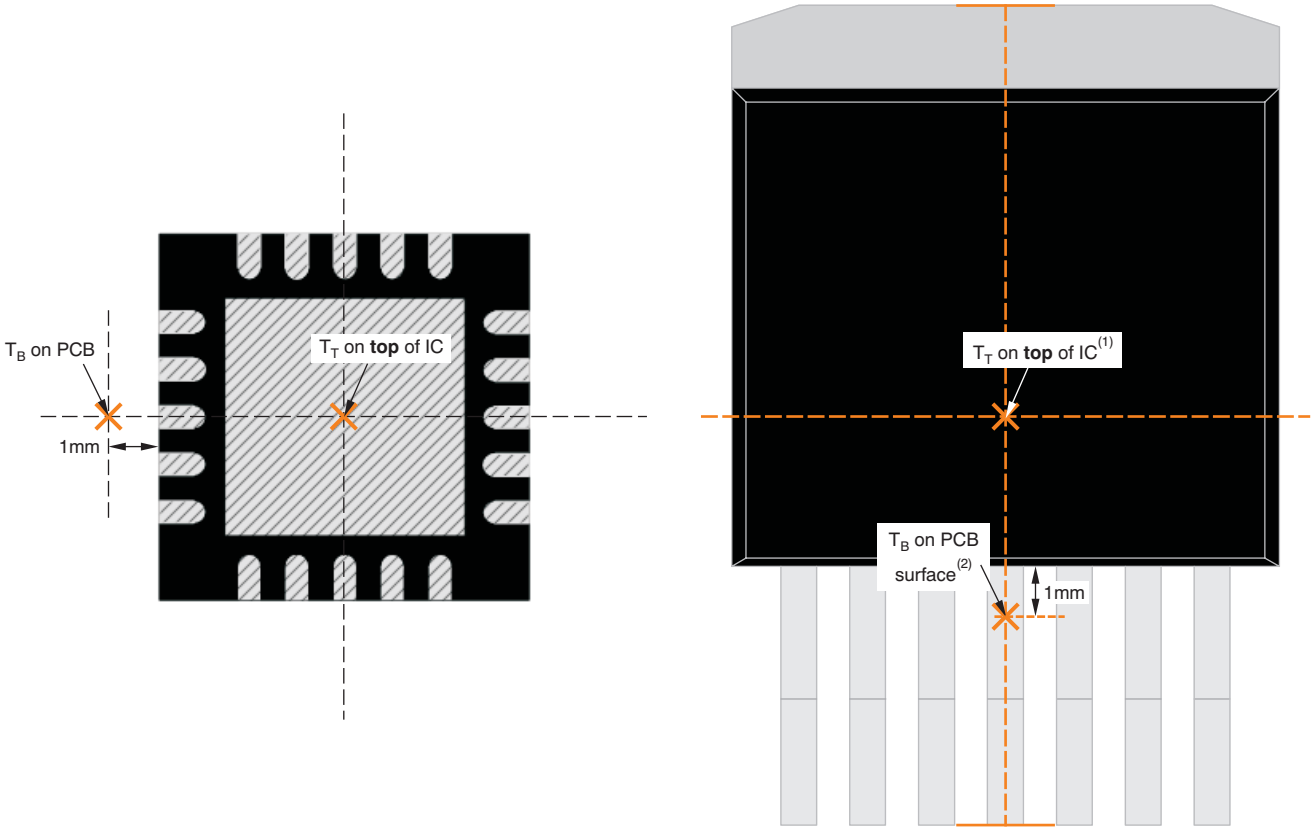
$$\Psi_{JB}: \quad T_J = T_B + \Psi_{JB} \bullet P_D \tag{6}$$

Where P_D is the power dissipation shown by Equation 4, T_T is the temperature at the center-top of the IC package, and T_B is the PCB temperature measured 1mm away from the IC package *on the PCB surface* (refer to Figure 30).

NOTE: Both T_T and T_B can be measured on actual application boards using a thermo-gun (an infrared thermometer).

For more information about measuring T_T and T_B, see the application note *Using New Thermal Metrics* (SBVA025), available for download at www.ti.com.

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(a) Example RGW (QFN) Package Measurement **(b) Example KTW (DDPAK) Package Measurement**

(1) T_T is measured at the center of both the X- and Y-dimensional axes.

(2) T_B is measured ***below*** the package lead **on the PCB surface**.

Figure 30. Measuring Points for T_T and T_B

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Compared with θ_{JA}, the new thermal metrics Ψ_{JT} and Ψ_{JB} are less independent of board size, but they do have a small dependency. Figure 31 shows characteristic performance of Ψ_{JT} and Ψ_{JB} versus board size.

Looking at Figure 31, the RGW package thermal performance has negligible dependency on board size. The KTW package, however, does have a measurable dependency on board size. This dependency exists because the package shape is not point-symmetric to an IC center. In the KTW package, for example (see Figure 30), silicon is not beneath the measuring point of T_T which is the center of the X and Y dimension, so that Ψ_{JT} has a dependency. Also, because of that non-point-symmetry, device heat distribution on the PCB is not point-symmetric, either, so that Ψ_{JB} has a dependency.

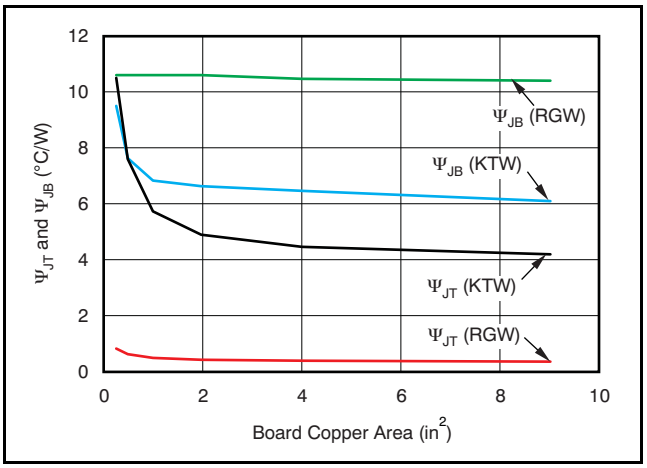


Figure 31. Ψ_{JT} and Ψ_{JB} vs Board Size

For a more detailed discussion of why TI does not recommend using θ_{JC},Top to determine thermal characteristics, refer to the application note *Using New Thermal Metrics* (SBVA025), available for download at www.ti.com. Also, refer to the application note *IC Package Thermal Metrics* (SPRA953) (also available on the TI web site) for further information.

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REVISION HISTORY

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

Changes from Revision F (August, 2010) to Revision G **Page**

- Corrected equation for and updated values for Table 2 5

Changes from Revision E (January, 2010) to Revision F **Page**

- Replaced the *Dissipation Ratings* table with the *Thermal Information* table 3
- Revised *Layout Recommendations and Power Dissipation* section 14
- Added *Estimating Junction Temperature* 15
- Deleted (previously numbered) Figure 29 through Figure 33 17

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PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
TPS74901KTWR	ACTIVE	DDPAK	KTW	7	500	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	
TPS74901KTWRG3	ACTIVE	DDPAK	KTW	7	500	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	
TPS74901KTWT	ACTIVE	DDPAK	KTW	7	50	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	
TPS74901KTWTG3	ACTIVE	DDPAK	KTW	7	50	Green (RoHS & no Sb/Br)	CU SN	Level-2-260C-1 YEAR	
TPS74901RGWR	ACTIVE	VQFN	RGW	20	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	
TPS74901RGWRG4	ACTIVE	VQFN	RGW	20	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	
TPS74901RGWT	ACTIVE	VQFN	RGW	20	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	
TPS74901RGWTG4	ACTIVE	VQFN	RGW	20	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	

(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)

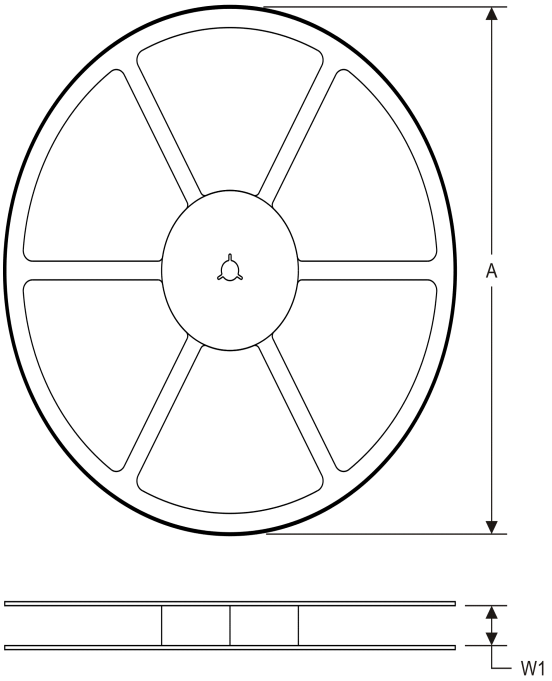
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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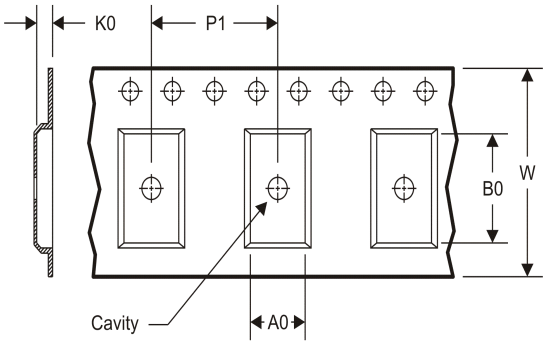
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TAPE AND REEL INFORMATION

REEL DIMENSIONS



TAPE DIMENSIONS



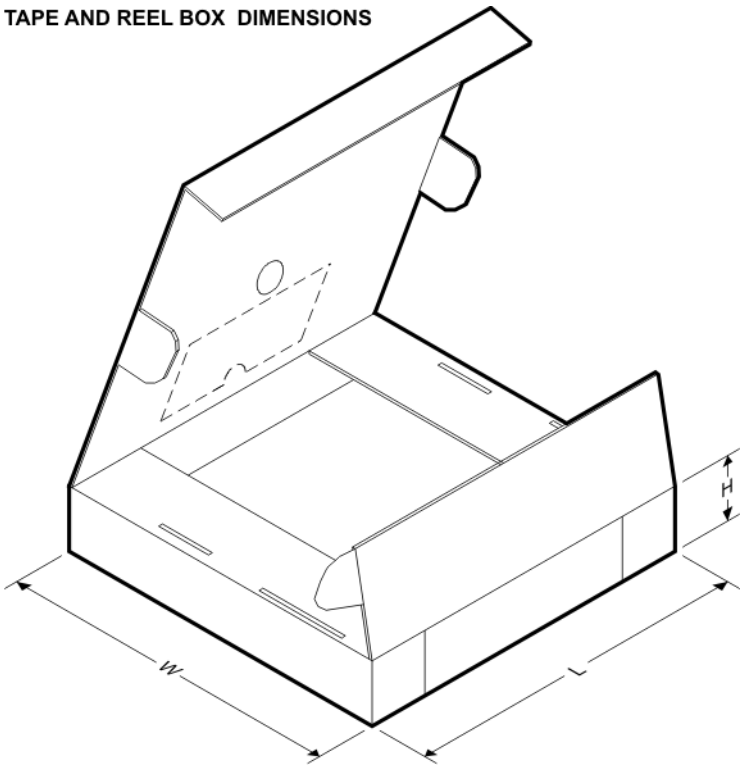
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

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
TPS74901KTWR	DDPAK	KTW	7	500	330.0	24.4	10.6	15.6	4.9	16.0	24.0	Q2
TPS74901KTWT	DDPAK	KTW	7	50	330.0	24.4	10.6	15.6	4.9	16.0	24.0	Q2
TPS74901RGWR	VQFN	RGW	20	3000	330.0	12.4	5.3	5.3	1.5	8.0	12.0	Q2
TPS74901RGWT	VQFN	RGW	20	250	180.0	12.4	5.3	5.3	1.5	8.0	12.0	Q2

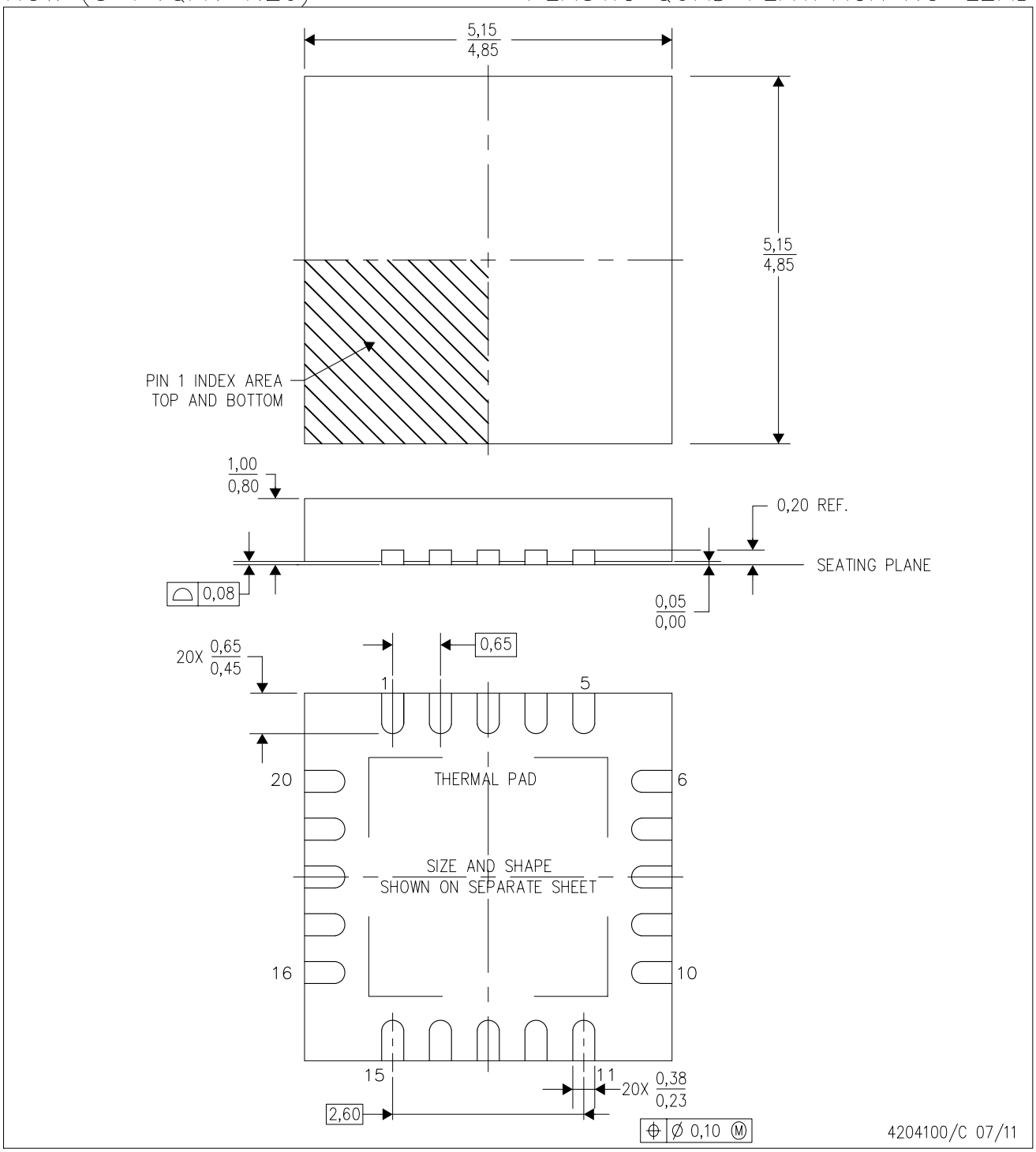
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS74901KTWR	DDPAK	KTW	7	500	367.0	367.0	45.0
TPS74901KTWT	DDPAK	KTW	7	50	367.0	367.0	45.0
TPS74901RGWR	VQFN	RGW	20	3000	367.0	367.0	35.0
TPS74901RGWT	VQFN	RGW	20	250	210.0	185.0	35.0

RGW (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD



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. Quad Flat pack, No–leads (QFN) package configuration
D. The package thermal pad must be soldered to the board for thermal and mechanical performance.
E. See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
F. Falls within JEDEC MO–220.

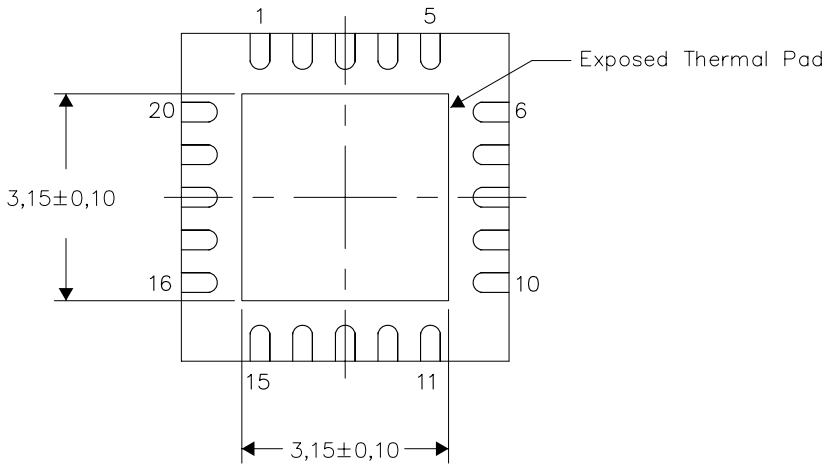
RGW (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached 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 information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

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



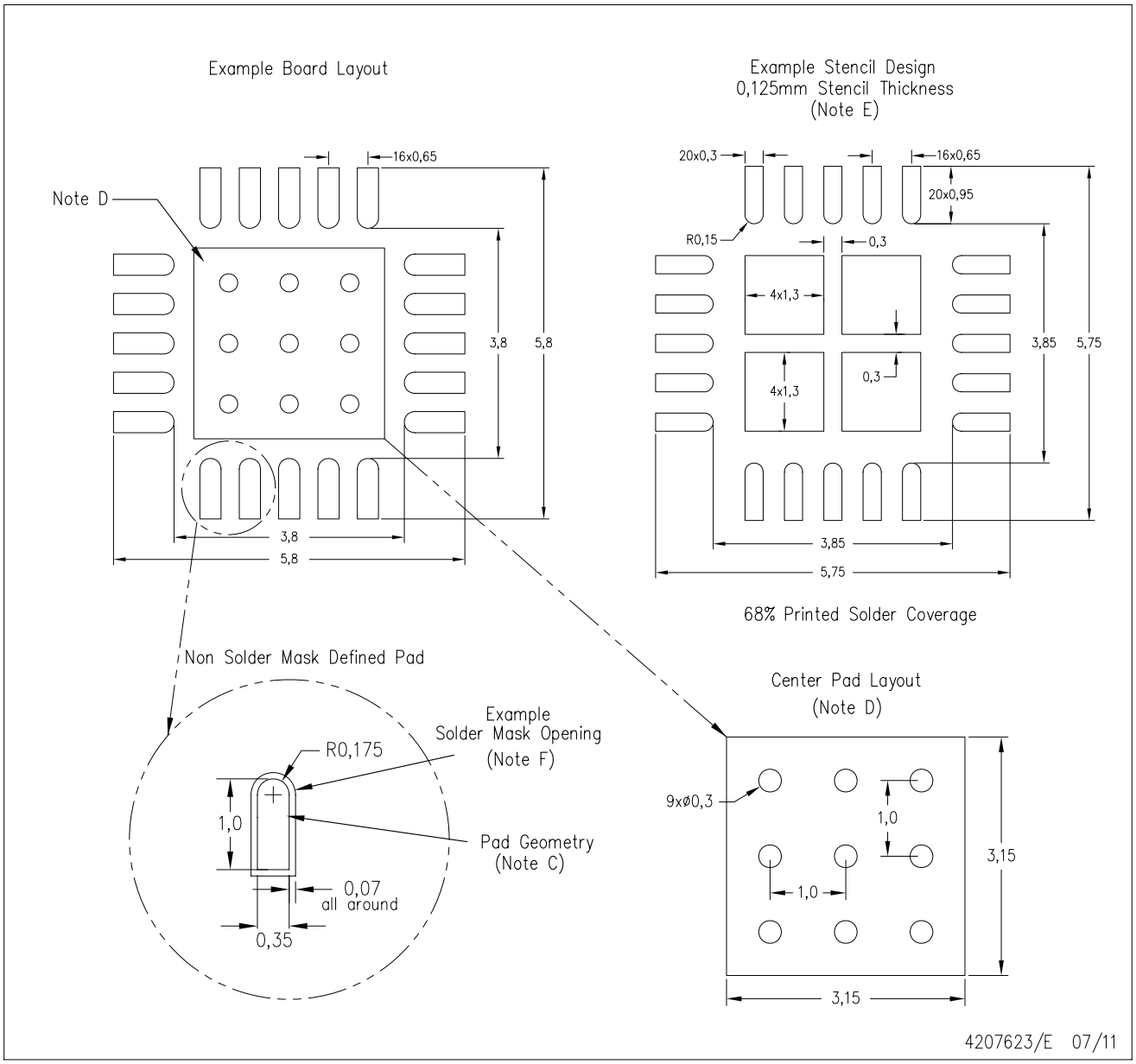
Bottom View

Exposed Thermal Pad Dimensions

4206352–2/J 07/11

NOTE: All linear dimensions are in millimeters

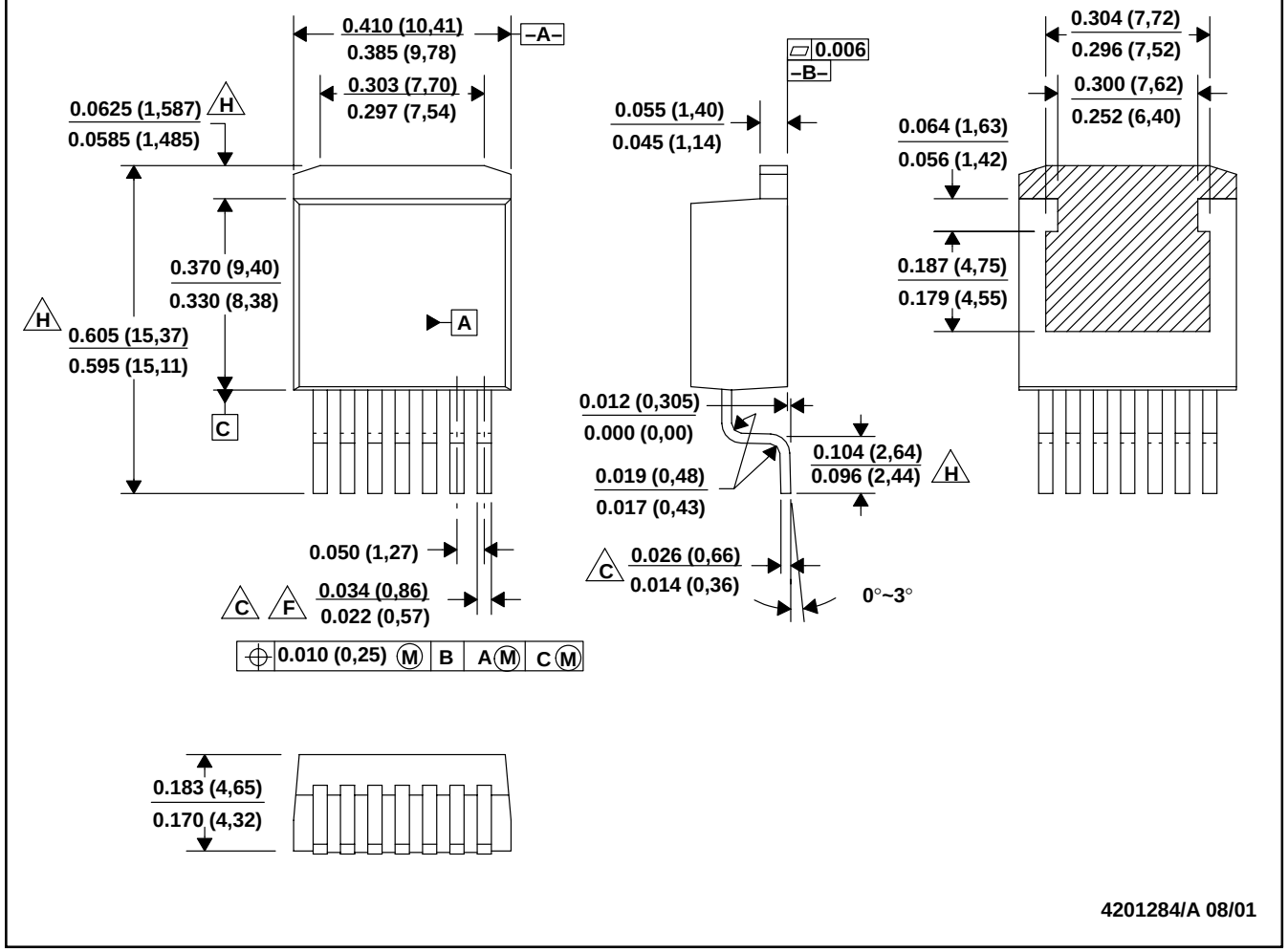
RGW (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, QFN Packages, Texas Instruments Literature No. SLUA271, 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>.
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. Refer to IPC 7525 for stencil design considerations.
F. Customers should contact their board fabrication site for solder mask tolerances.

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KTW (R-PSFM-G7) **PLASTIC FLANGE-MOUNT**



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Lead width and height dimensions apply to the plated lead.
D. Leads are not allowed above the Datum B.
E. Stand–off height is measured from lead tip with reference to Datum B.
F. Lead width dimension does not include dambar protrusion. Allowable dambar protrusion shall not cause the lead width to exceed the maximum dimension by more than 0.003”.
G. Cross–hatch indicates exposed metal surface.
H. Falls within JEDEC MO–169 with the exception of the dimensions indicated.

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