



## 3.0-A ULTRA-LDO WITH PROGRAMMABLE SOFT-START

Check for Samples: [TPS74401-EP](#)

### FEATURES

- Soft-Start (SS) Pin Provides a Linear Startup with Ramp Time Set by External Capacitor
- 1% Accuracy Over Line, Load, and Temperature
- Supports Input Voltages as Low as 0.9 V with External Bias Supply
- Adjustable Output (0.8 V to 3.6 V)
- Ultra-Low Dropout: 115 mV at 3.0 A (typ)
- Stable with Any or No Output Capacitor
- Excellent Transient Response
- Available in 5 mm × 5 mm × 1 mm QFN Package
- Active High Enable

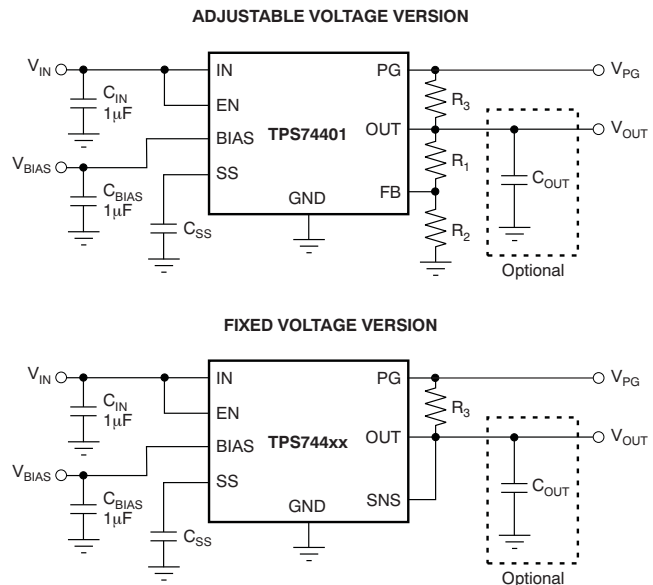
### SUPPORTS DEFENSE, AEROSPACE, AND MEDICAL APPLICATIONS

- Controlled Baseline
- One Assembly/Test Site
- One Fabrication Site
- Available in Military (–55°C/125°C) Temperature Ranges<sup>(1)</sup>
- Extended Product Life Cycle
- Extended Product-Change Notification
- Product Traceability

(1) Custom temperature ranges available

### 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



**Figure 1. Typical Application Circuit**



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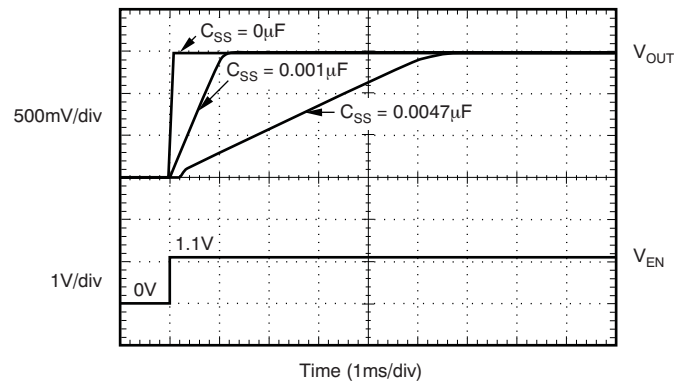
This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

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.

## DESCRIPTION

The TPS74401 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 will meet the sequencing requirements of FPGAs, DSPs, and other applications with specific start-up requirements.

A precision reference and error amplifier deliver 1% accuracy over load, line, temperature, and process. Each LDO is stable with low-cost ceramic output capacitors and the device is fully specified from  $-55^{\circ}\text{C}$  to  $125^{\circ}\text{C}$ .



**Figure 2. Turn-On Response**

**Table 1. ORDERING INFORMATION<sup>(1)</sup>**

$T_A$	PACKAGE <sup>(2)</sup>		ORDERABLE PART NUMBER	TOP-SIDE MARKING
$-55^{\circ}\text{C}$ to $125^{\circ}\text{C}$	QFN (RGW)	Reel of 3000	TPS74401MRGWREP	TPS74401EP

(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](http://www.ti.com).

(2) Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at [www.ti.com/sc/package](http://www.ti.com/sc/package).

## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

At  $T_J = -55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ , unless otherwise noted. All voltages are with respect to GND.

			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	
$T_J$	Operating junction temperature range	–55 to +125	$^{\circ}\text{C}$
$T_{STG}$	Storage junction temperature range	–65 to +150	$^{\circ}\text{C}$

- (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.

## THERMAL INFORMATION

THERMAL METRIC <sup>(1)(2)</sup>		TPS74401-EP	UNITS
		RGW (20 PINS)	
$\theta_{JA}$	Junction-to-ambient thermal resistance	36.3	$^{\circ}\text{C}/\text{W}$
$\theta_{JCTop}$	Junction-to-case (top) thermal resistance	34.3	
$\theta_{JB}$	Junction-to-board thermal resistance	10.8	
$\psi_{JT}$	Junction-to-top characterization parameter	0.3	
$\psi_{JB}$	Junction-to-board characterization parameter	11.9	
$\theta_{JCbott}$	Junction-to-case (bottom) thermal resistance	2.4	

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).  
(2) For thermal estimates of this device based on PCB copper area, see the [TI PCB Thermal Calculator](#).

## ELECTRICAL CHARACTERISTICS

At  $V_{EN} = 1.1\text{ V}$ ,  $V_{IN} = V_{OUT} + 0.3\text{ V}$ ,  $C_{IN} = C_{BIAS} = 0.1\text{ }\mu\text{F}$ ,  $C_{OUT} = 10\text{ }\mu\text{F}$ ,  $I_{OUT} = 50\text{ mA}$ ,  $V_{BIAS} = 5.0\text{ V}$ , and  $T_J = -55^\circ\text{C}$  to  $+125^\circ\text{C}$ , unless otherwise noted. Typical values are at  $T_J = +25^\circ\text{C}$ .

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{IN}$	Input voltage range		$V_{OUT} + V_{DO}$		5.5	V
$V_{BIAS}$	Bias pin voltage range		2.375		5.25	V
$V_{REF}$	Internal reference (Adj.)		0.792		0.808	V
$V_{OUT}$	Output voltage range	$V_{IN} = 5\text{ V}$ , $I_{OUT} = 1.5\text{ A}$ , $V_{BIAS} = 5\text{ V}$	$V_{REF}$		3.6	V
	Accuracy <sup>(1)</sup>	$2.97\text{ V} \leq V_{BIAS} \leq 5.25\text{ V}$ , $50\text{ mA} \leq I_{OUT} \leq 3.0\text{ A}$	-1	$\pm 0.2$	+1	%
$V_{OUT}/V_{IN}$	Line regulation	$V_{OUT}(\text{NOM}) + 0.3 \leq V_{IN} \leq 5.5\text{ V}$		0.0005	0.05	%/V
$V_{OUT}/I_{OUT}$	Load regulation	$0\text{ mA} \leq I_{OUT} \leq 50\text{ mA}$		0.013		%/mA
		$50\text{ mA} \leq I_{OUT} \leq 3.0\text{ A}$		0.03		%/A
$V_{DO}$	$V_{IN}$ dropout voltage <sup>(2)</sup>	$I_{OUT} = 3.0\text{ A}$ , $V_{BIAS} - V_{OUT}(\text{NOM}) \geq 1.62\text{ V}$		120	195	mV
	$V_{BIAS}$ dropout voltage <sup>(2)</sup>	$I_{OUT} = 3.0\text{ A}$ , $V_{IN} = V_{BIAS}$			1.62	V
$I_{CL}$	Current limit	$V_{OUT} = 80\% \times V_{OUT}(\text{NOM})$	3.7		6.0	A
$I_{BIAS}$	Bias pin current	$I_{OUT} = 0\text{ mA}$ to $3.0\text{ A}$		2	4	mA
$I_{SHDN}$	Shutdown supply current ( $V_{IN}$ )	$V_{EN} \leq 0.4\text{ V}$		0.4	1	$\mu\text{A}$
$I_{FB}$	Feedback pin current <sup>(3)</sup>	$I_{OUT} = 50\text{ mA}$ to $3.0\text{ A}$	-250	95	250	nA
PSRR <sup>(4)</sup>	Power-supply rejection ( $V_{IN}$ to $V_{OUT}$ )	1 kHz, $I_{OUT} = 1.5\text{ A}$ , $V_{IN} = 1.8\text{ V}$ , $V_{OUT} = 1.5\text{ V}$		73		dB
		800 kHz, $I_{OUT} = 1.5\text{ A}$ , $V_{IN} = 1.8\text{ V}$ , $V_{OUT} = 1.5\text{ V}$		42		
	Power-supply rejection ( $V_{BIAS}$ to $V_{OUT}$ )	1 kHz, $I_{OUT} = 1.5\text{ A}$ , $V_{IN} = 1.8\text{ V}$ , $V_{OUT} = 1.5\text{ V}$		62		dB
		800 kHz, $I_{OUT} = 1.5\text{ A}$ , $V_{IN} = 1.8\text{ V}$ , $V_{OUT} = 1.5\text{ V}$		50		
Noise	Output noise voltage	100 Hz to 100 kHz, $I_{OUT} = 1.5\text{ A}$ , $C_{SS} = 0.001\text{ }\mu\text{F}$		$16 \times V_{OUT}$		$\mu\text{V}_{\text{RMS}}$
$V_{TRAN}$	% $V_{OUT}$ droop during load transient	$I_{OUT} = 100\text{ mA}$ to $3.0\text{ A}$ at $1\text{ A}/\mu\text{s}$ , $C_{OUT} = 0\text{ }\mu\text{F}$		4		% $V_{OUT}$
$t_{STR}$	Minimum startup time	$I_{OUT} = 1.5\text{ A}$ , $C_{SS} = \text{open}$		100		$\mu\text{s}$
$I_{SS}$	Soft-start charging current	$V_{SS} = 0.4\text{ V}$	0.5	0.73	1	$\mu\text{A}$
$V_{EN, HI}$	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		$\mu\text{s}$
$I_{EN}$	Enable pin current	$V_{EN} = 5\text{ V}$		0.1	1	$\mu\text{A}$
$V_{IT}$	PG trip threshold	$V_{OUT}$ decreasing	86	90	93.5	% $V_{OUT}$
$V_{HYS}$	PG trip hysteresis			3		% $V_{OUT}$
$V_{PG, LO}$	PG output low voltage	$I_{PG} = 1\text{ mA}$ (sinking), $V_{OUT} < V_{IT}$			0.3	V
$I_{PG, LKG}$	PG leakage current	$V_{PG} = 5.25\text{ V}$ , $V_{OUT} > V_{IT}$		0.03	1	$\mu\text{A}$
$T_J$	Operating junction temperature		-55		+125	$^\circ\text{C}$
$T_{SD}$	Thermal shutdown temperature	Shutdown, temperature increasing		+155		$^\circ\text{C}$
		Reset, temperature decreasing		+140		

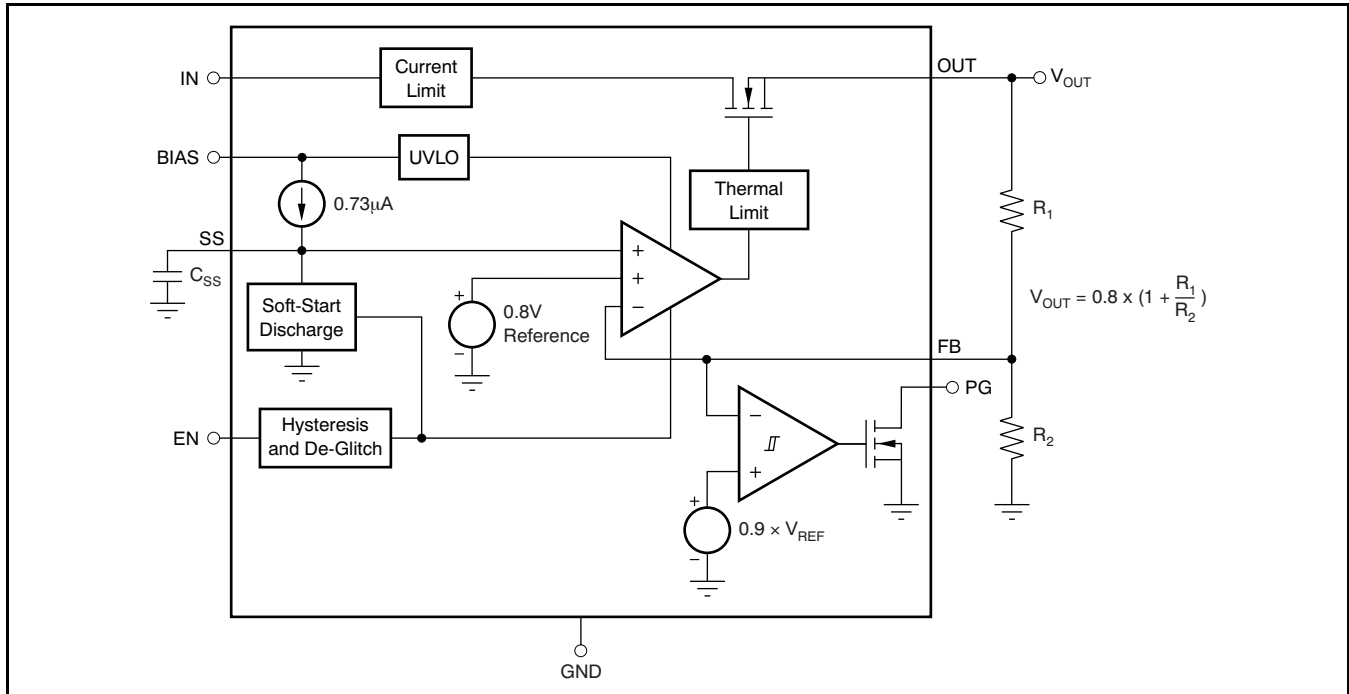
(1) Adjustable devices tested at 0.8 V; external resistor tolerance is not taken into account.

(2) Dropout is defined as the voltage from the input to  $V_{OUT}$  when  $V_{OUT}$  is 2% below nominal.

(3)  $I_{FB}$  current flow is out of the device.

(4) See Figure 10 to Figure 13 for PSRR at different conditions.

## BLOCK DIAGRAM



**Table 2. Standard 1% Resistor Values for Programming the Output Voltage<sup>(1)</sup>**

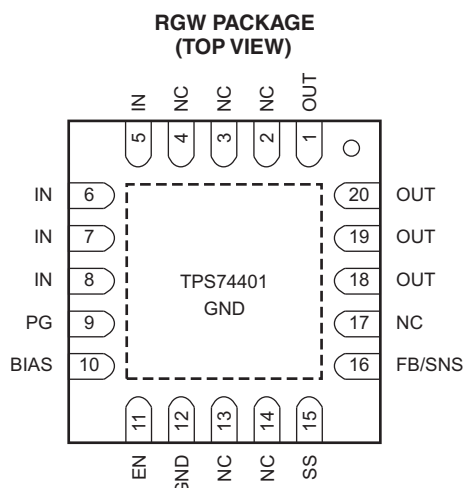
R <sub>1</sub> (kΩ)	R <sub>2</sub> (kΩ)	V <sub>OUT</sub> (V)
Short	Open	0.8
0.619	4.99	0.9
1.13	4.53	1.0
1.37	4.42	1.05
1.87	4.99	1.1
2.49	4.99	1.2
4.12	4.75	1.5
3.57	2.87	1.8
3.57	1.69	2.5
3.57	1.15	3.3

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

**Table 3. Standard Capacitor Values for Programming the Soft-Start Time<sup>(1)</sup>**

C <sub>SS</sub>	SOFT-START TIME
Open	0.1 ms
470 pF	0.5 ms
1000 pF	1 ms
4700 pF	5 ms
0.01 µF	10 ms
0.015 µF	16 ms

(1)  $t_{SS}(s) = 0.8 \times C_{SS}(F)/7.3 \times 10^{-7}$



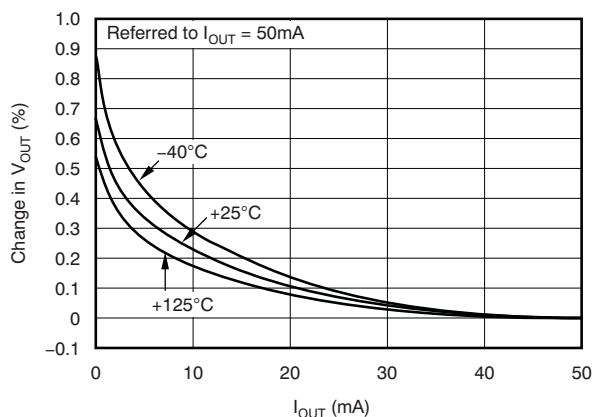
### PIN DESCRIPTIONS

NAME	NO.	DESCRIPTION
IN	5–8	Unregulated input to the device.
EN	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	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	10	Bias input voltage for error amplifier, reference, and internal control circuits.
PG	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	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	1, 18–20	Regulated output voltage. No capacitor is required on this pin for stability.
NC	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	12	Ground
PAD/TAB		Should be soldered to the ground plane for increased thermal performance.

## TYPICAL CHARACTERISTICS

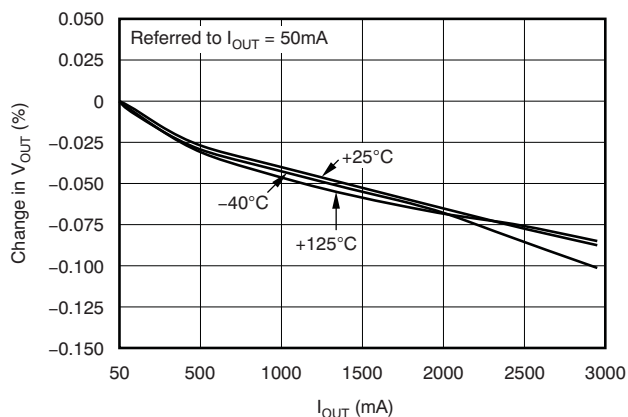
At  $T_J = +25^\circ\text{C}$ ,  $V_{OUT} = 1.5\text{ V}$ ,  $V_{IN} = V_{OUT(TYP)} + 0.3\text{ V}$ ,  $V_{BIAS} = 3.3\text{ V}$ ,  $I_{OUT} = 50\text{ mA}$ ,  $C_{IN} = 1\text{ }\mu\text{F}$ ,  $C_{BIAS} = 1\text{ }\mu\text{F}$ ,  $C_{SS} = 0.01\text{ }\mu\text{F}$ , and  $C_{OUT} = 10\text{ }\mu\text{F}$ , unless otherwise noted.

**LOAD REGULATION**



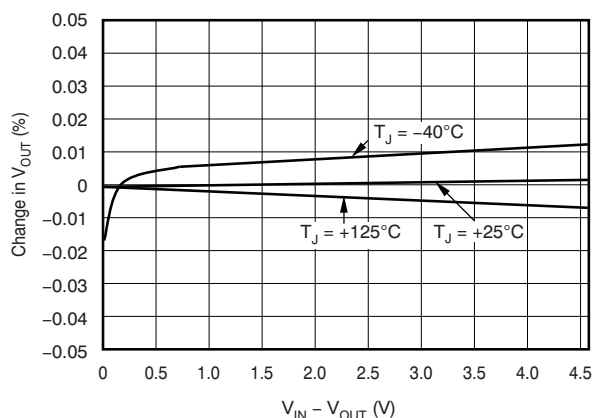
**Figure 3.**

**LOAD REGULATION**



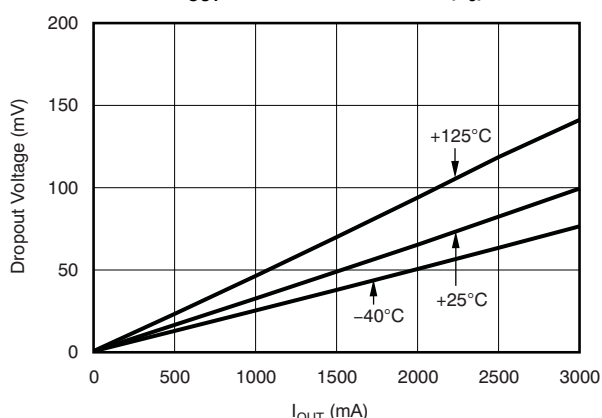
**Figure 4.**

**LINE REGULATION**



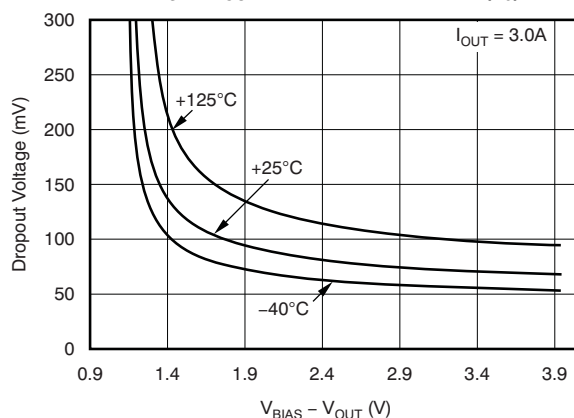
**Figure 5.**

**VIN DROPOUT VOLTAGE vs  
IOUT AND TEMPERATURE (TJ)**



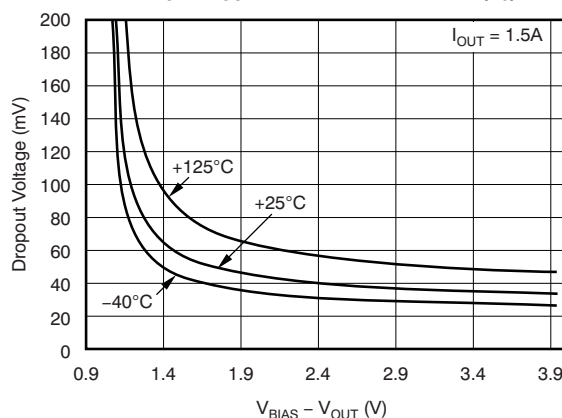
**Figure 6.**

**VIN DROPOUT VOLTAGE vs  
VBIAS - VOUT AND TEMPERATURE (TJ)**



**Figure 7.**

**VIN DROPOUT VOLTAGE vs  
VBIAS - VOUT AND TEMPERATURE (TJ)**

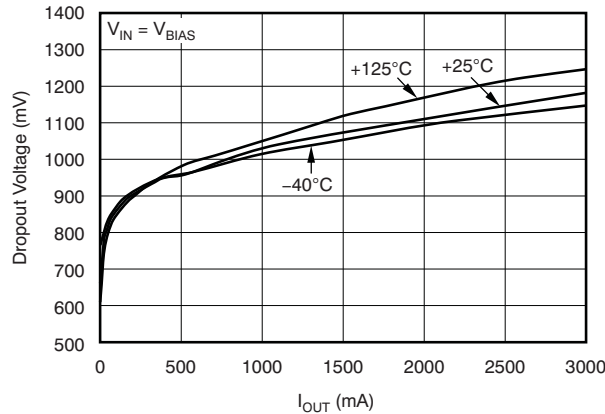


**Figure 8.**

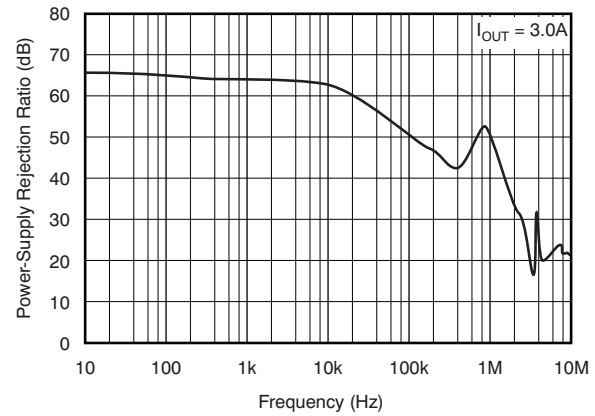
**TYPICAL CHARACTERISTICS (continued)**

At  $T_J = +25^\circ\text{C}$ ,  $V_{OUT} = 1.5\text{ V}$ ,  $V_{IN} = V_{OUT(TYP)} + 0.3\text{ V}$ ,  $V_{BIAS} = 3.3\text{ V}$ ,  $I_{OUT} = 50\text{ mA}$ ,  $C_{IN} = 1\text{ }\mu\text{F}$ ,  $C_{BIAS} = 1\text{ }\mu\text{F}$ ,  $C_{SS} = 0.01\text{ }\mu\text{F}$ , and  $C_{OUT} = 10\text{ }\mu\text{F}$ , unless otherwise noted.

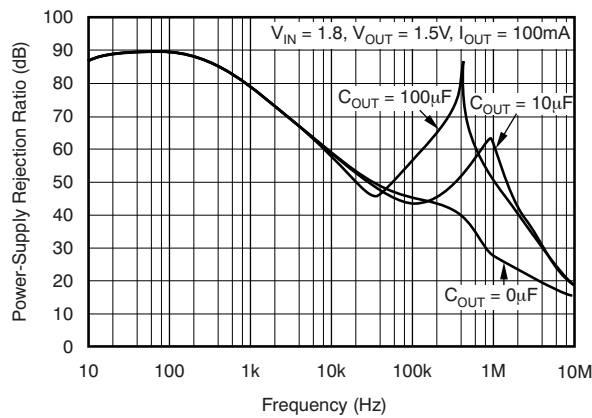
**$V_{BIAS}$  DROPOUT VOLTAGE vs  
 $I_{OUT}$  AND TEMPERATURE ( $T_J$ )**

**Figure 9.**

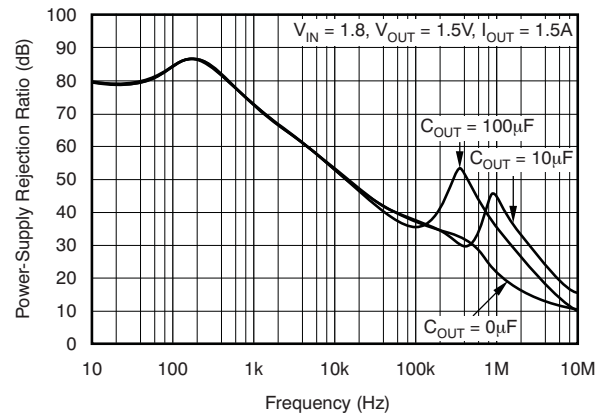
**$V_{BIAS}$  PSRR vs FREQUENCY**

**Figure 10.**

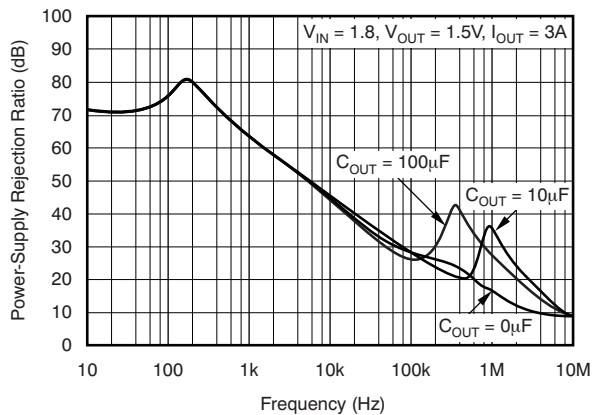
**$V_{IN}$  PSRR vs FREQUENCY**

**Figure 11.**

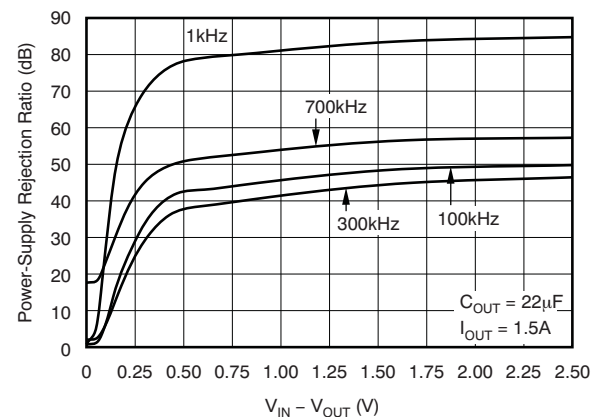
**$V_{IN}$  PSRR vs FREQUENCY**

**Figure 12.**

**$V_{IN}$  PSRR vs FREQUENCY**

**Figure 13.**

**$V_{IN}$  PSRR vs  $V_{IN} - V_{OUT}$**

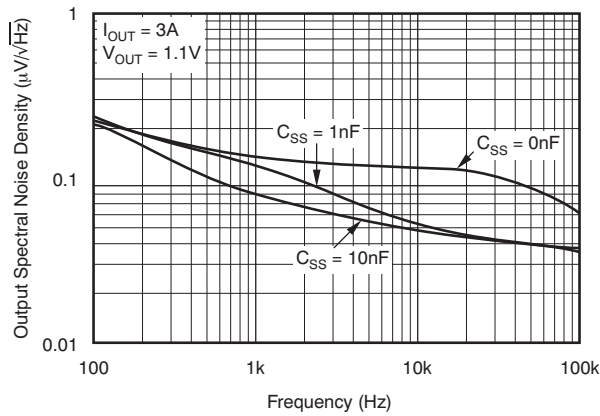
**Figure 14.**



## TYPICAL CHARACTERISTICS (continued)

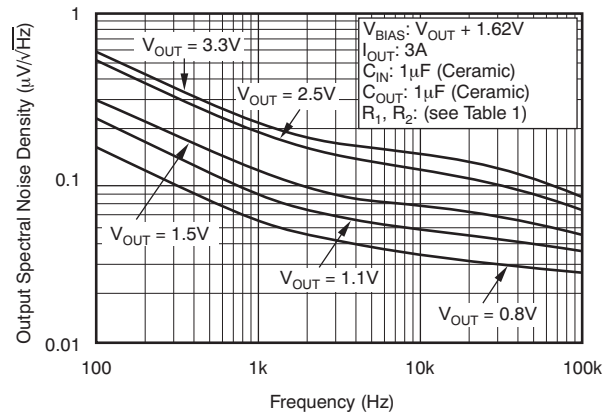
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**NOISE SPECTRAL DENSITY**



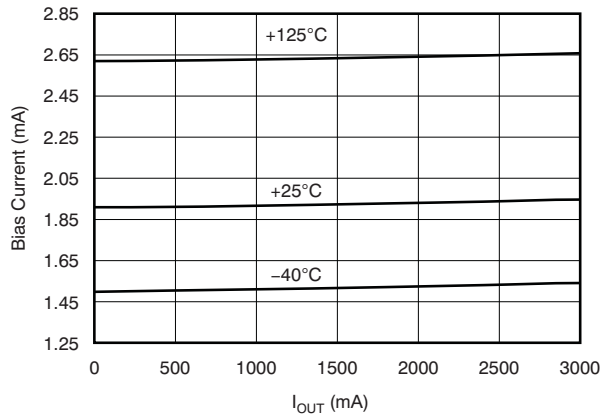
**Figure 15.**

**NOISE SPECTRAL DENSITY**



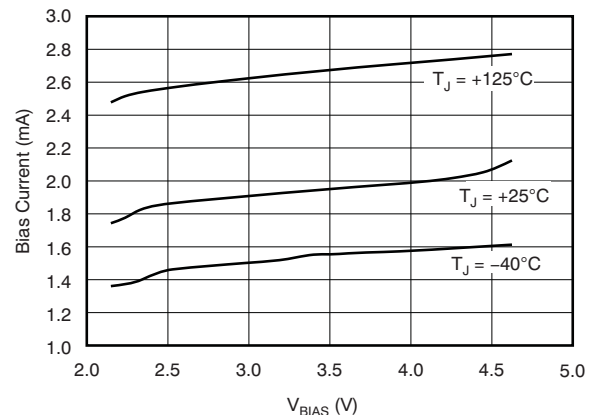
**Figure 16.**

**I<sub>BIAS</sub> vs I<sub>OUT</sub> AND TEMPERATURE**



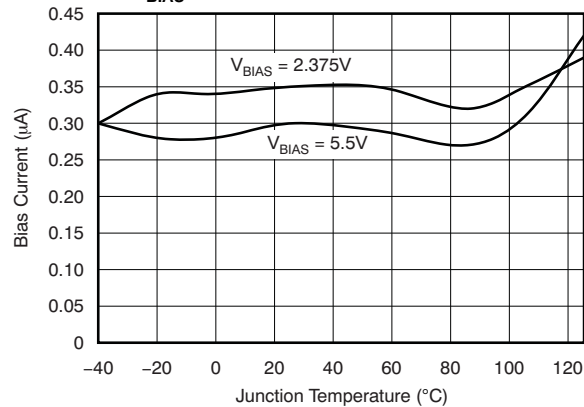
**Figure 17.**

**I<sub>BIAS</sub> vs V<sub>BIAS</sub> AND V<sub>OUT</sub>**



**Figure 18.**

**I<sub>BIAS</sub> SHUTDOWN vs TEMPERATURE**



**Figure 19.**

### TYPICAL CHARACTERISTICS (continued)

At  $T_J = +25^\circ\text{C}$ ,  $V_{OUT} = 1.5\text{ V}$ ,  $V_{IN} = V_{OUT(TYP)} + 0.3\text{ V}$ ,  $V_{BIAS} = 3.3\text{ V}$ ,  $I_{OUT} = 50\text{ mA}$ ,  $C_{IN} = 1\text{ }\mu\text{F}$ ,  $C_{BIAS} = 1\text{ }\mu\text{F}$ ,  $C_{SS} = 0.01\text{ }\mu\text{F}$ , and  $C_{OUT} = 10\text{ }\mu\text{F}$ , unless otherwise noted.

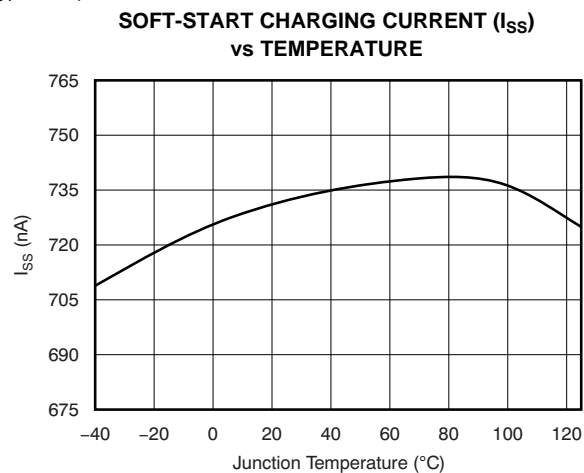


Figure 20.

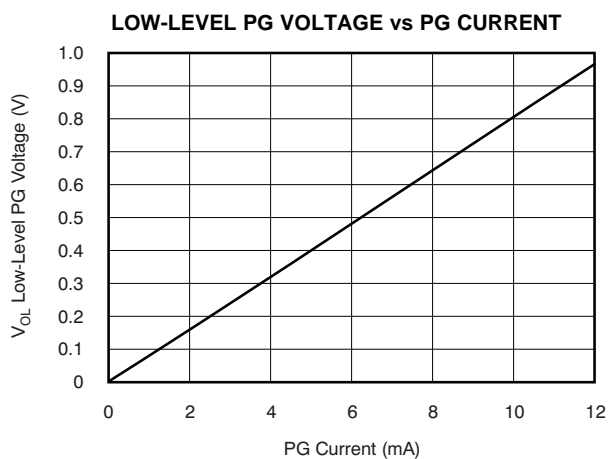


Figure 21.

## TYPICAL CHARACTERISTICS (continued)

At  $T_J = +25^\circ\text{C}$ ,  $V_{OUT} = 1.5\text{ V}$ ,  $V_{IN} = V_{OUT(TYP)} + 0.3\text{ V}$ ,  $V_{BIAS} = 3.3\text{ V}$ ,  $I_{OUT} = 50\text{ mA}$ ,  $C_{IN} = 1\text{ }\mu\text{F}$ ,  $C_{BIAS} = 1\text{ }\mu\text{F}$ ,  $C_{SS} = 0.01\text{ }\mu\text{F}$ , and  $C_{OUT} = 10\text{ }\mu\text{F}$ , unless otherwise noted.

### LOAD TRANSIENT RESPONSE

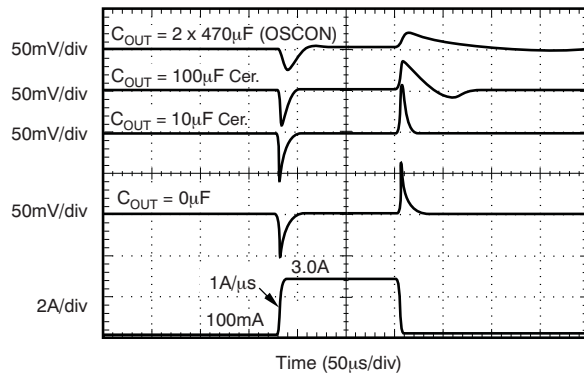


Figure 22.

### $V_{BIAS}$ LINE TRANSIENT (3A)

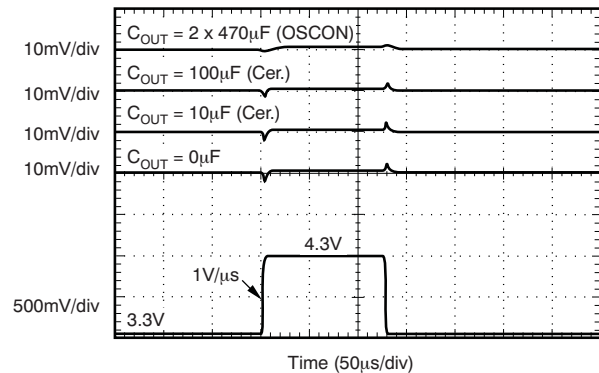


Figure 23.

### $V_{IN}$ LINE TRANSIENT (3A)

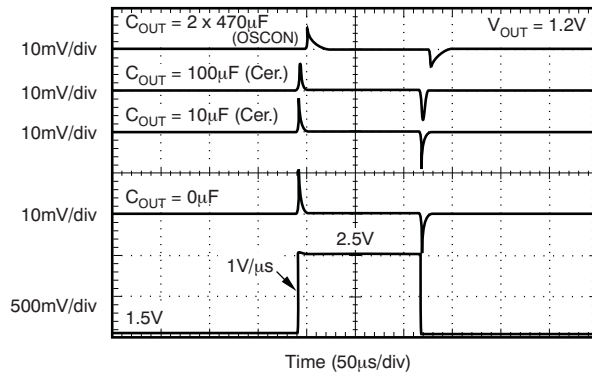


Figure 24.

### TURN-ON RESPONSE

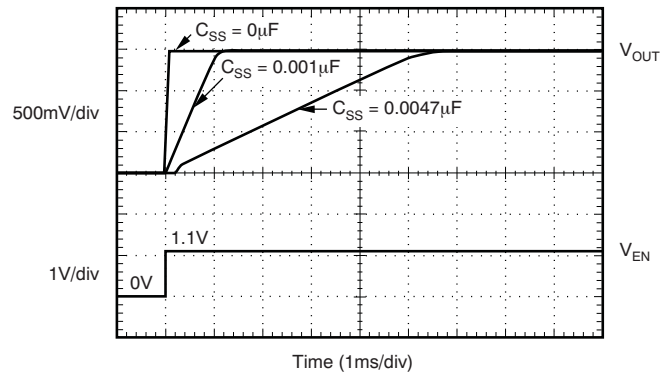


Figure 25.

### POWER-UP/POWER-DOWN

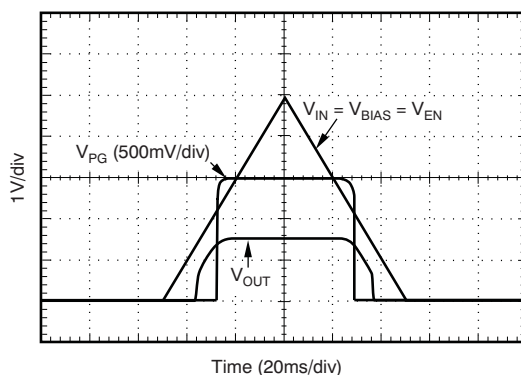


Figure 26.

### OUTPUT SHORT-CIRCUIT RECOVERY

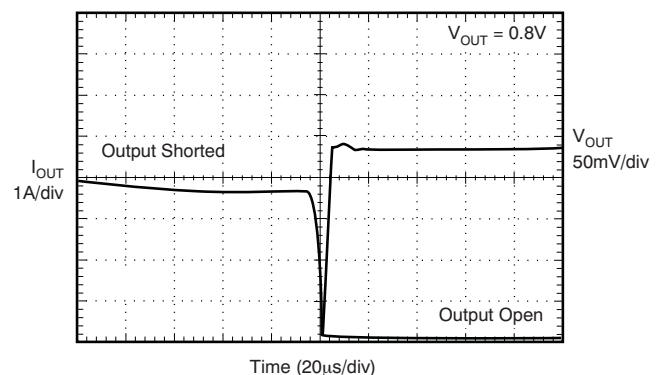


Figure 27.

## APPLICATION INFORMATION

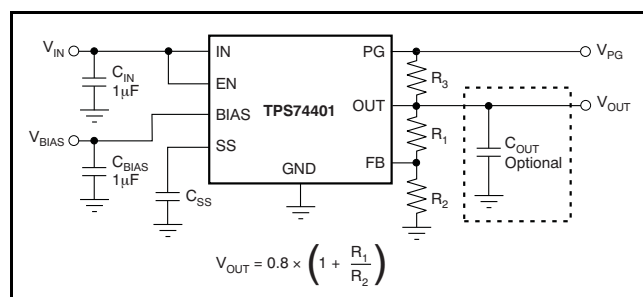
The TPS74401 belongs to a family of new generation ultra-low dropout regulators that feature soft-start and tracking capabilities. These regulators use a low current bias input to power all internal control circuitry, allowing the NMOS pass transistor to regulate very low input and output voltages.

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 TPS74401 to be stable with any or even no output capacitor. Transient response is also superior to PMOS topologies, particularly for low  $V_{IN}$  applications.

The TPS74401 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 28 illustrates a typical application circuit for the TPS74401 adjustable output device.

$R_1$  and  $R_2$  can be calculated for any output voltage using the formula shown in Figure 28. Refer to Table 2 for sample resistor values of common output voltages. In order to achieve the maximum accuracy specifications,  $R_2$  should be  $\leq 4.99 \text{ k}\Omega$ .



**Figure 28. Typical Application Circuit for the TPS74401 (Adjustable)**

## INPUT, OUTPUT, AND BIAS CAPACITOR REQUIREMENTS

The device does not require any output capacitor for stability. If an output capacitor is needed, the device is designed to be stable for all available types and values of output capacitance. The device is also stable with multiple capacitors in parallel, of any type or value.

The capacitance required on the IN and BIAS pins 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  $1 \mu\text{F}$ . If  $V_{IN}$  and  $V_{BIAS}$  are connected to the same supply, the recommended minimum capacitor for  $V_{BIAS}$  is  $4.7 \mu\text{F}$ . 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.

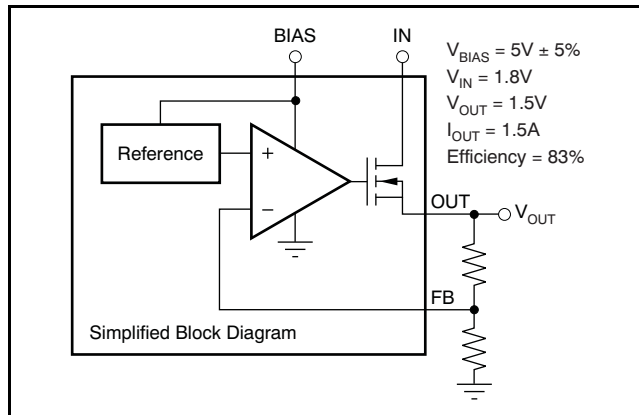
## TRANSIENT RESPONSE

The TPS74401 was designed to have transient response within 5% for most applications without any output capacitor. 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 300 mV. In this case, adding additional input capacitance improves the transient response much more than just adding additional output capacitance. With a solid input supply, adding additional output capacitance reduces undershoot and overshoot during a transient at the expense of a slightly longer  $V_{OUT}$  recovery time. Refer to Figure 22 in the Typical Characteristics section. Since the TPS74401 is stable without an output capacitor, many applications may allow for little or no capacitance at the LDO output. For these applications, local bypass capacitance for the device under power 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.

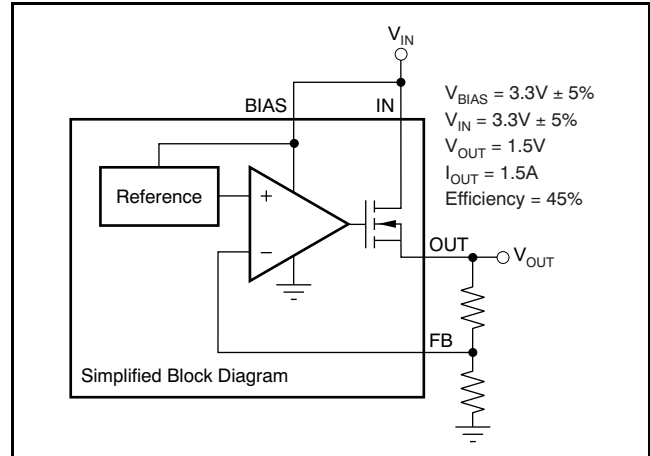
## DROPOUT VOLTAGE

The TPS74401 offers industry-leading dropout performance, making it well-suited for high-current low  $V_{IN}$ /low  $V_{OUT}$  applications. The extremely low dropout of the TPS74401 allows the device to be used in place of a DC/DC converter and still achieve good efficiencies. This efficiency allows users to rethink 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 TPS74401. The first specification (see Figure 29) is referred to as  $V_{IN}$  Dropout and is for users that wish to apply an external bias voltage to achieve low dropout. This specification assumes that  $V_{BIAS}$  is at least 1.62 V above  $V_{OUT}$ , which is the case for  $V_{BIAS}$  when powered by a 3.3-V rail with 5% tolerance and with  $V_{OUT} = 1.5V$ . If  $V_{BIAS}$  is higher than  $3.3V \times 0.95$  or  $V_{OUT}$  is less than 1.5 V,  $V_{IN}$  dropout is less than specified.



The second specification (see Figure 30) is referred to as  $V_{BIAS}$  Dropout and is for users that wish to tie IN and BIAS 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 and therefore must be 1.62 V 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.



**Figure 30. Typical Application of the TPS74401 Without an Auxiliary Bias**

## PROGRAMMABLE SOFT-START

The TPS74401 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 transients to the input power bus.

To achieve a linear and monotonic soft-start, the TPS74401 error amplifier tracks the voltage ramp of the external soft-start capacitor until the voltage exceeds the internal reference. The soft-start ramp time depends on the soft-start charging current ( $I_{SS}$ ), the 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:

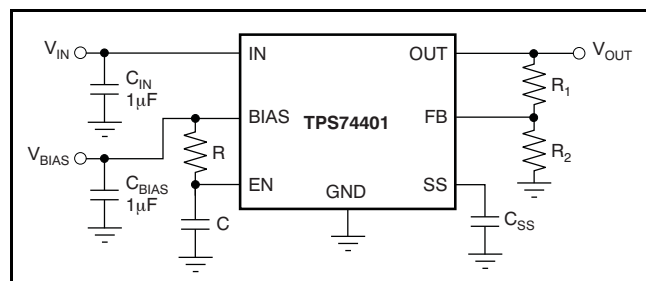
$$t_{SSCL} = \frac{(V_{OUT(NOM)} \times C_{OUT})}{I_{CL(MIN)}} \quad (2)$$

$V_{OUT(NOM)}$  is the nominal set output voltage as set by the user,  $C_{OUT}$  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.

The maximum recommended soft-start capacitor is 0.015  $\mu\text{F}$ . 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 re-enabled. Soft-start capacitors larger than 0.015  $\mu\text{F}$  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.  $C_{\text{SS}}$  must be low-leakage; X7R, X5R, or C0G dielectric materials are preferred. Refer to [Table 3](#) for suggested soft-start capacitor values.

## SEQUENCING REQUIREMENTS

The device can have  $V_{\text{IN}}$ ,  $V_{\text{BIAS}}$ , and  $V_{\text{EN}}$  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. Enabling the device after  $V_{\text{IN}}$  and  $V_{\text{BIAS}}$  are present is preferred, and can be accomplished using a digital output from a processor or supply supervisor. An analog signal from an external RC circuit, as shown in [Figure 31](#), can also be used as long as the delay time is long enough for  $V_{\text{IN}}$  and  $V_{\text{BIAS}}$  to be present.



**Figure 31. Soft-Start Delay Using an RC Circuit on Enable**

If a signal is not available to enable the device after  $V_{\text{IN}}$  and  $V_{\text{BIAS}}$ , simply connecting  $V_{\text{EN}}$  to  $V_{\text{IN}}$  is acceptable for most applications as long as  $V_{\text{IN}}$  is greater than 1.1 V and the ramp rate of  $V_{\text{IN}}$  and  $V_{\text{BIAS}}$  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 will track the slower supply minus the dropout voltage until it reaches the set output voltage. If  $V_{\text{EN}}$  is connected to  $V_{\text{BIAS}}$ , the device will soft-start as programmed provided that  $V_{\text{IN}}$  is present before  $V_{\text{BIAS}}$ . If  $V_{\text{BIAS}}$  and  $V_{\text{EN}}$  are present before  $V_{\text{IN}}$  is applied and the set soft-start time has expired then  $V_{\text{OUT}}$  will track  $V_{\text{IN}}$ .

**NOTE:** When  $V_{\text{BIAS}}$  and  $V_{\text{EN}}$  are present and  $V_{\text{IN}}$  is not supplied, this device outputs approximately 50  $\mu\text{A}$  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 10 k $\Omega$ .

## OUTPUT NOISE

The TPS74401 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 0.001- $\mu\text{F}$  soft-start capacitor, the output noise is reduced by half and is typically 19  $\mu\text{V}_{\text{RMS}}$  for a 1.2-V output (100 Hz to 100 kHz). 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 0.001- $\mu\text{F}$  soft-start capacitor is given in [Equation 3](#).

$$V_{\text{N}}(\mu\text{V}_{\text{RMS}}) = 16 \left( \frac{\mu\text{V}_{\text{RMS}}}{V} \right) \times V_{\text{OUT}}(\text{V}) \quad (3)$$

The low output noise of the TPS74401 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.  $V_{\text{EN}}$  below 0.4 V turns the regulator off, while  $V_{\text{EN}}$  above 1.1 V turns the regulator on. Unlike many regulators, the enable circuitry has hysteresis and deglitching for use with relatively slow-ramping analog signals. This configuration allows the TPS74401 to be enabled by connecting the output of another supply to the EN pin. The enable circuitry typically has 50 mV of hysteresis and a deglitch circuit to help avoid on-off cycling because of small glitches in the  $V_{\text{EN}}$  signal.

The enable threshold is typically 0.8 V and varies with temperature and process variations. Temperature variation is approximately  $-1 \text{ mV}/^\circ\text{C}$ ; therefore, process variation accounts for most of the variation in the enable threshold. If precise turn-on timing is required, a fast rise-time signal should be used to enable the TPS74401.

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 (QFN Package Only)

The power-good (PG) pin is an open-drain output and can be connected to any 5.5 V or lower rail through an external pull-up resistor. This pin requires at least 1.1 V on  $V_{\text{BIAS}}$  in order to have a valid output. The PG output is high-impedance when  $V_{\text{OUT}}$  is greater than  $V_{\text{IT}} + V_{\text{HYS}}$ . If  $V_{\text{OUT}}$  drops below  $V_{\text{IT}}$  or if  $V_{\text{BIAS}}$  drops below 1.9 V, 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 condition of PG pin sink current is up to 1 mA, so the



pull-up resistor for PG should be in the range of 10 kΩ to 1 MΩ. The pull-up resistor for PG should be in the range of 10 kΩ to 1 MΩ. 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 TPS74401 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 3.5 A and maintain regulation. The current limit responds in about 10 μs to reduce the current during a short-circuit fault. Recovery from a short-circuit condition is well-controlled and results in very little output overshoot when the load is removed. See [Figure 27](#) in the Typical Characteristics section for short-circuit recovery performance.

The internal current limit protection circuitry of the TPS74401 is designed to protect against overload conditions. It is not intended to allow operation above the rated current of the device. Continuously running the TPS74401 above the rated current degrades device reliability.

## THERMAL PROTECTION

Thermal protection disables the output when the junction temperature rises to approximately +155°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 +30°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 TPS74401 is designed to protect against overload conditions. It is not intended to replace proper heatsinking. Continuously running the TPS74401 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<sub>1</sub> in [Figure 28](#) 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](#):

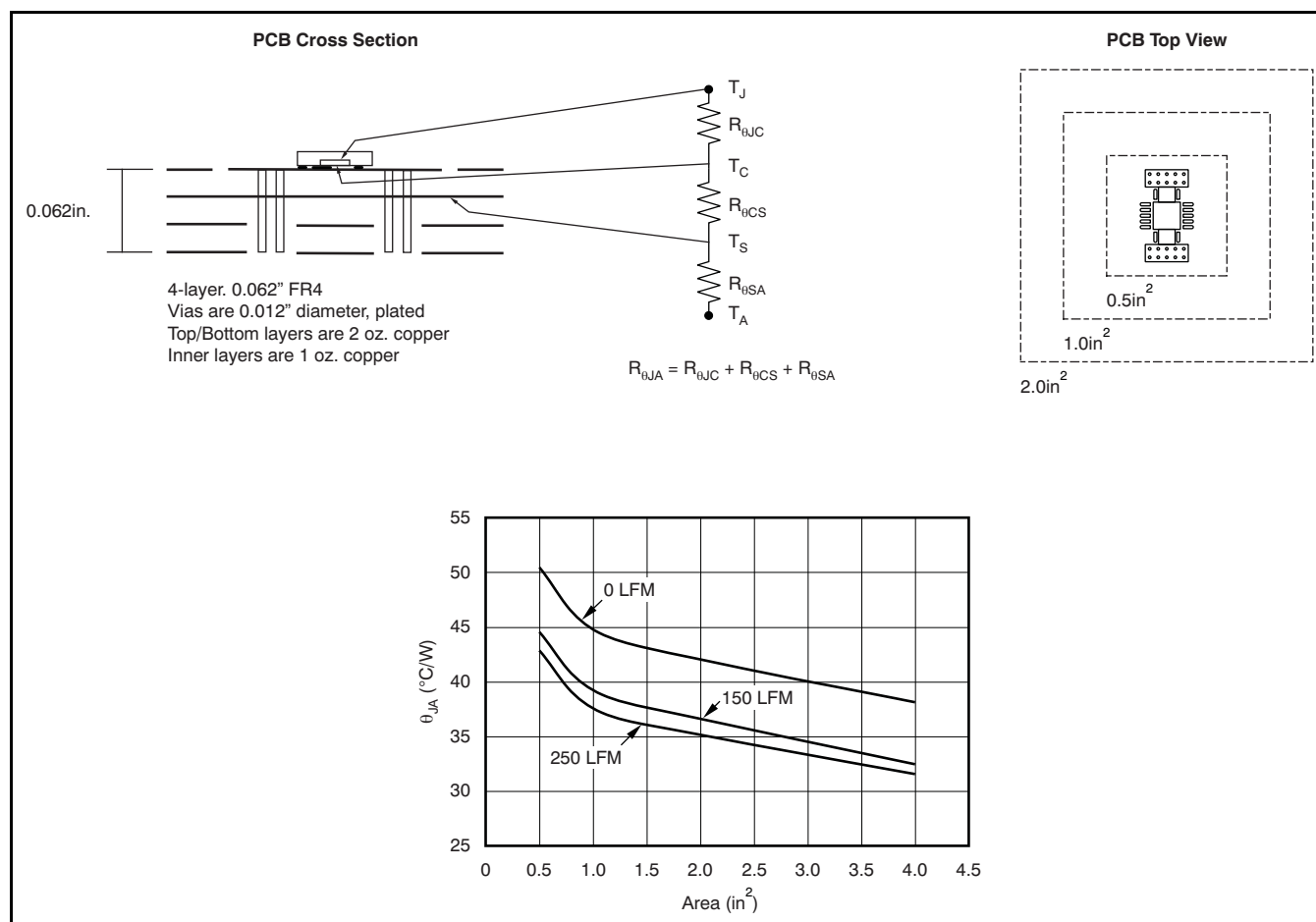
$$P_D = (V_{IN} - V_{OUT}) \times I_{OUT} \quad (4)$$

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.

The primary conduction path for heat is through the exposed pad or tab to the printed circuit board (PCB). The pad or tab 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 does not overheat. 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](#):

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

Knowing the maximum R<sub>θJA</sub> and system air flow, the minimum amount of PCB copper area needed for appropriate heatsinking can be calculated using [Figure 32](#) through [Figure 34](#).



**Figure 32. PCB Layout and Corresponding  $R_{\theta JA}$  Data, Buried Thermal Plane, No Vias Under Thermal Pad**



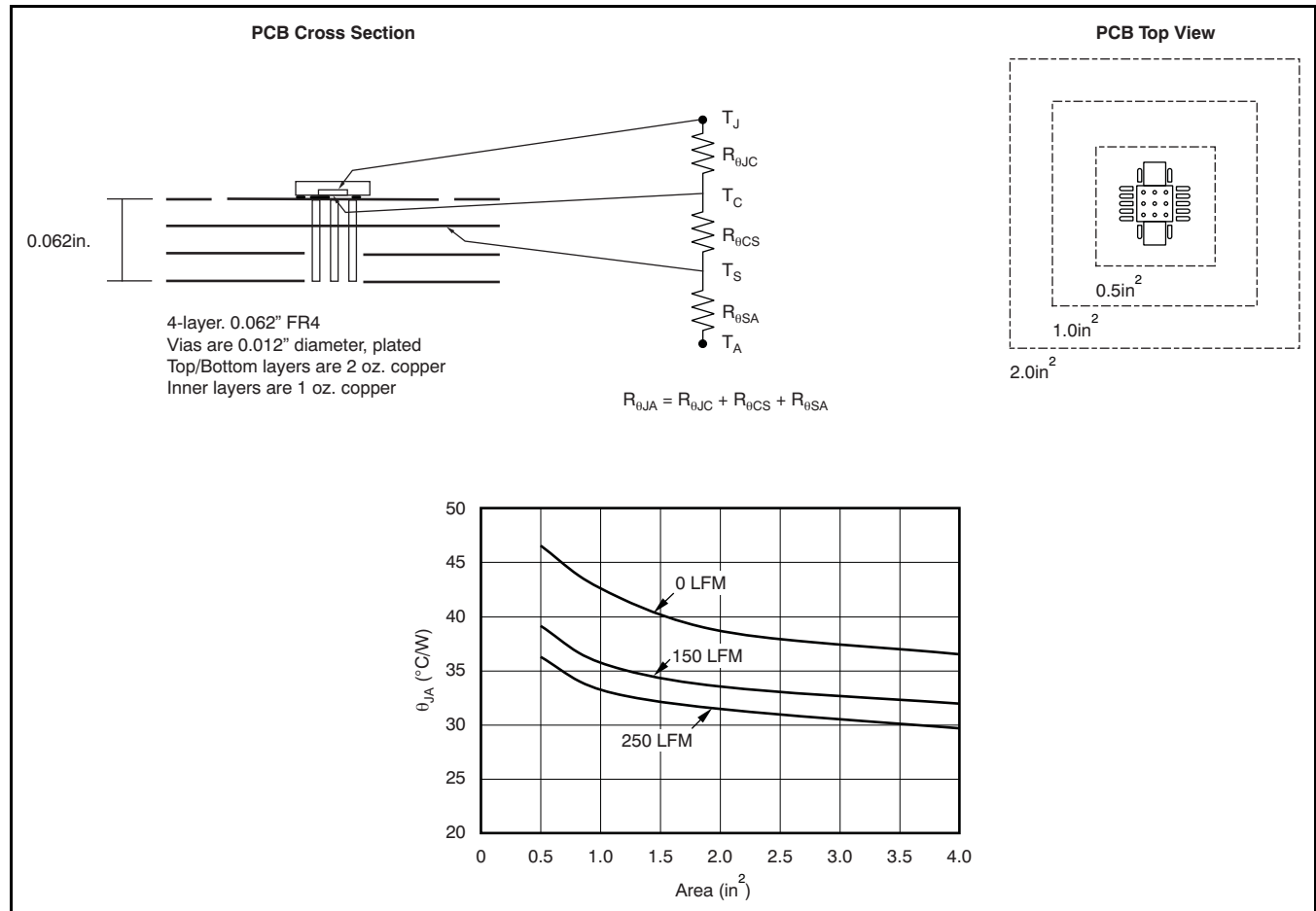
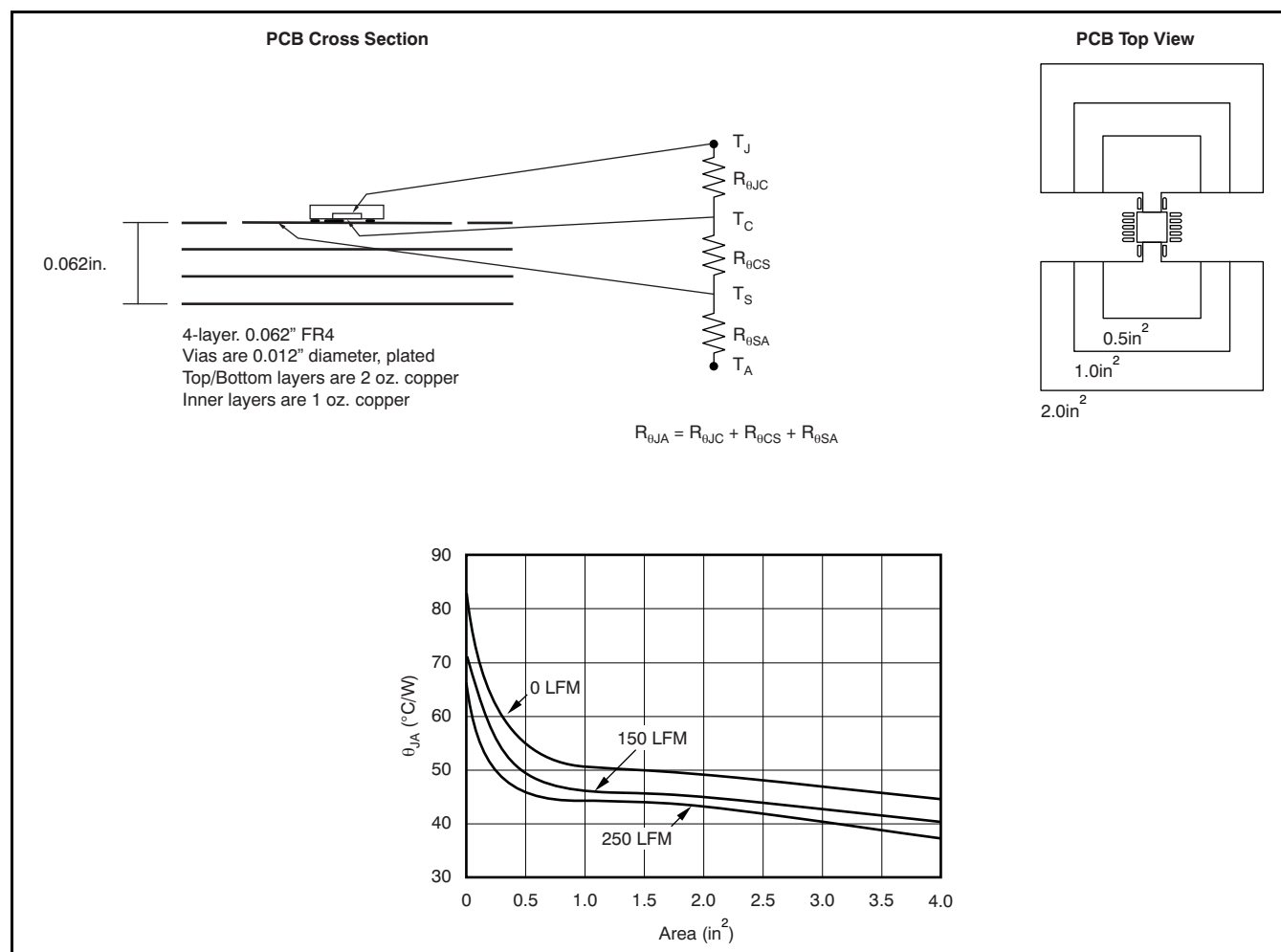


Figure 33. PCB Layout and Corresponding  $R_{\theta JA}$  Data, Buried Thermal Plane, Vias Under Thermal Pad

Figure 34. PCB Layout and Corresponding  $R_{\theta JA}$  Data, Top Layer Thermal Plane

## PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package   Pins	Package qty   Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
<a href="#">TPS74401MRGWREP</a>	Active	Production	VQFN (RGW)   20	3000   LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-55 to 125	TPS 74401EP
TPS74401MRGWREP.A	Active	Production	VQFN (RGW)   20	3000   LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-55 to 125	TPS 74401EP
<a href="#">V62/10611-01XE</a>	Active	Production	VQFN (RGW)   20	3000   LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-55 to 125	TPS 74401EP

(1) **Status:** For more details on status, see our [product life cycle](#).

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

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

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

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

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

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**OTHER QUALIFIED VERSIONS OF TPS74401-EP :**

- Catalog : [TPS74401](#)

NOTE: Qualified Version Definitions:

- Catalog - TI's standard catalog product

## 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
TPS74401MRGWREP	VQFN	RGW	20	3000	330.0	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)
TPS74401MRGWREP	VQFN	RGW	20	3000	353.0	353.0	32.0

## GENERIC PACKAGE VIEW

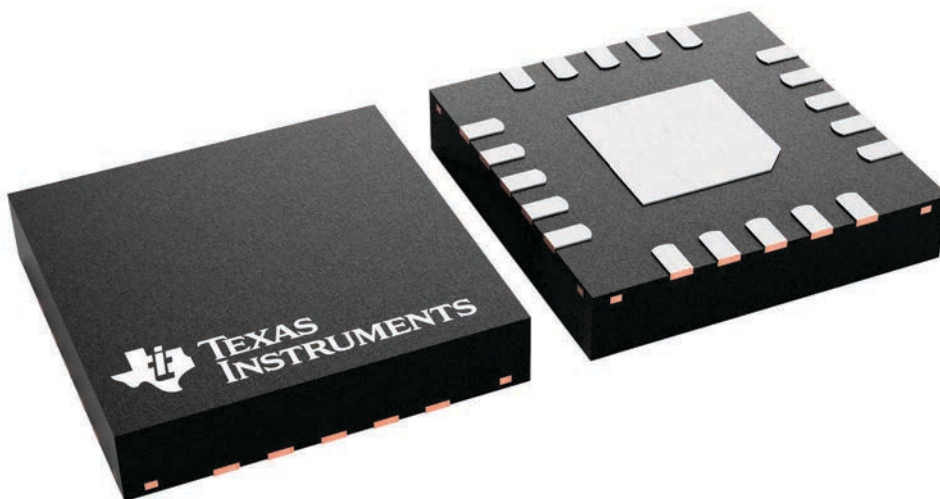
**RGW 20**

**VQFN - 1 mm max height**

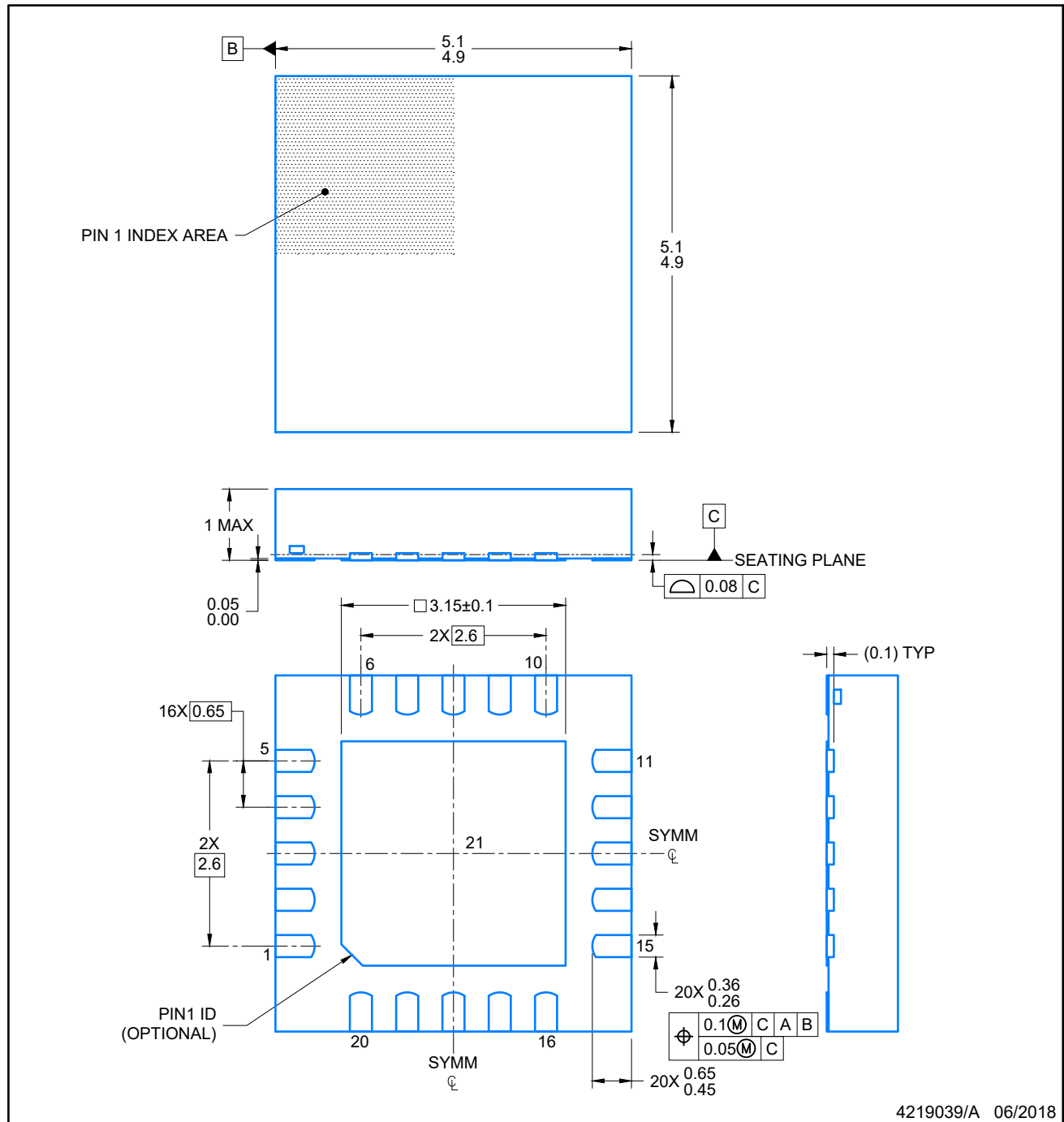
5 x 5, 0.65 mm pitch

PLASTIC QUAD FLATPACK - NO LEAD

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



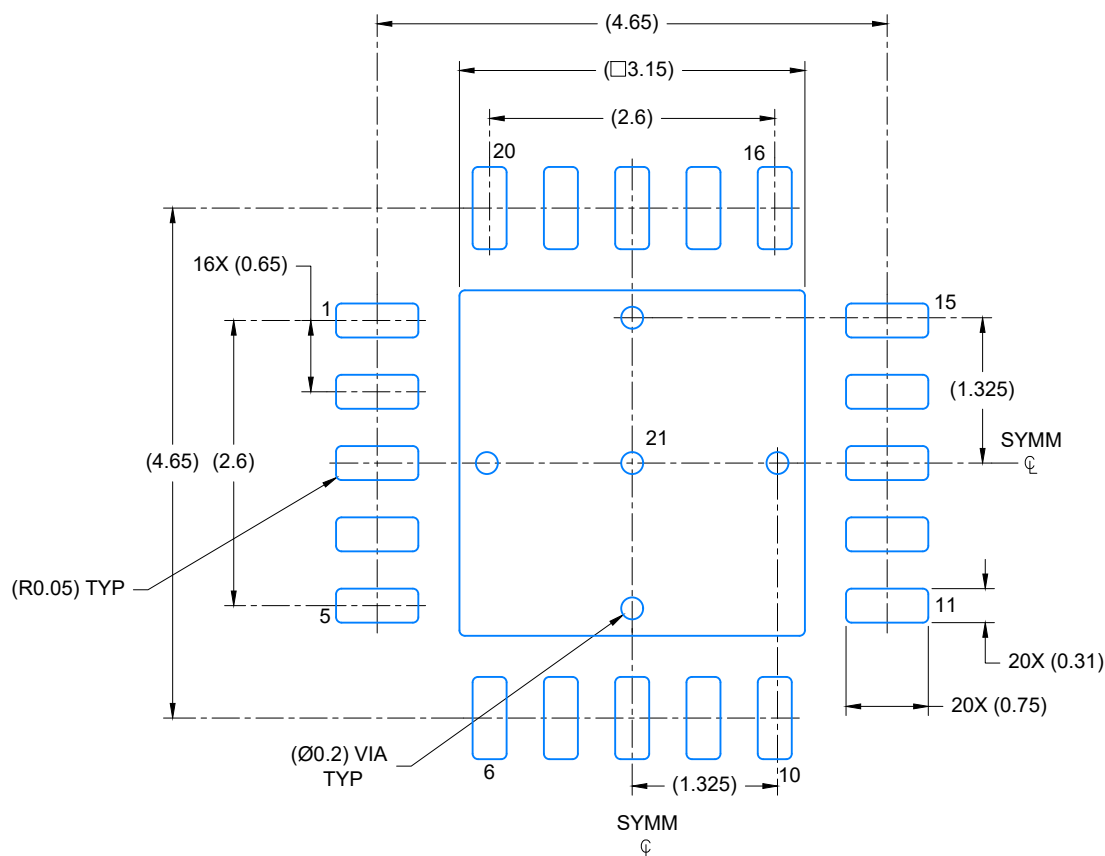
4227157/A



## NOTES:

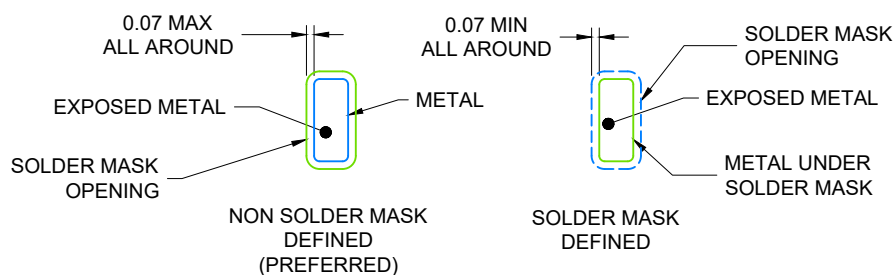
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical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





## LAND PATTERN EXAMPLE

SCALE: 15X

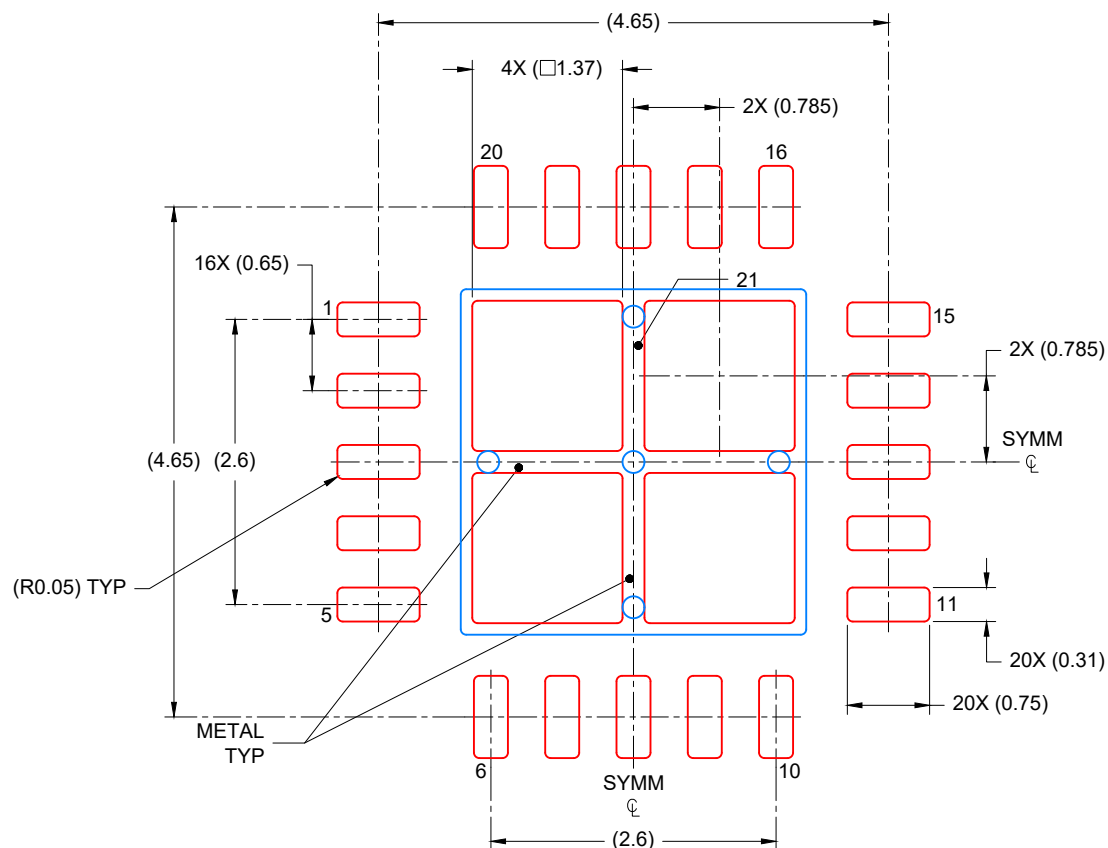


## SOLDER MASK DETAILS

4219039/A 06/2018

NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/sluea271](http://www.ti.com/lit/sluea271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD  
75% PRINTED COVERAGE BY AREA  
SCALE: 15X

4219039/A 06/2018

NOTES: (continued)

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

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