CAP-FREE NMOS 400 mA LOW-DROPOUT REGULATORS WITH REVERSE CURRENT PROTECTION

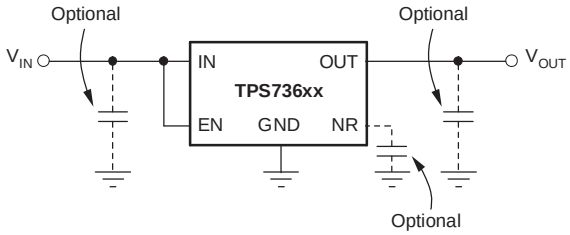
FEATURES

- **Controlled Baseline**
  - **One Assembly**
  - **One Test Site**
  - **One Fabrication Site**
- **Extended Temperature Performance of –55°C to 125°C**
- **Enhanced Diminishing Manufacturing Sources (DMS) Support**
- **Enhanced Product-Change Notification**
- **Qualification Pedigree** (1)
- **Stable With No Output Capacitor or Any Value or Type of Capacitor**
- **Input Voltage Range of 1.7 V to 5.5 V**
- **Ultra-Low Dropout Voltage: 75 mV Typical**
- **Excellent Load Transient Response—With or Without Optional Output Capacitor**
- **New NMOS Topology Delivers Low Reverse Leakage Current**
- **Low Noise: 30 μV_{RMS} Typical (10 Hz to 100 kHz)**
- **0.5% Initial Accuracy**
- **1% Overall Accuracy Over Line, Load, and Temperature**
- **Less Than 1-µA Max I_Q in Shutdown Mode**
- **Thermal Shutdown and Specified Min/Max Current Limit Protection**
- **Available in Multiple Output Voltage Versions**
  - **Fixed Outputs of 1.2 V to 3.3 V**
  - **Adjustable Output from 1.2 V to 5.5 V**
  - **Custom Outputs Available**

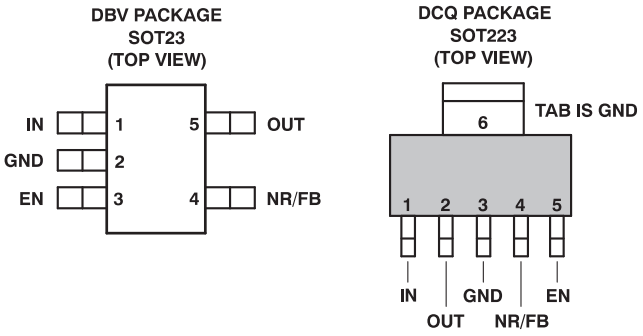
(1) Component qualification in accordance with JEDEC and industry standards to ensure reliable operation over an extended temperature range. This includes, but is not limited to, Highly Accelerated Stress Test (HAST) or biased 85/85, temperature cycle, autoclave or unbiased HAST, electromigration, bond intermetallic life, and mold compound life. Such qualification testing should not be viewed as justifying use of this component beyond specified performance and environmental limits.

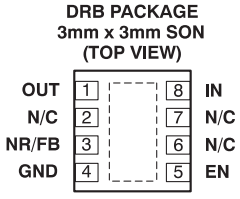
APPLICATIONS

- **Portable/Battery-Powered Equipment**
- **Post-Regulation for Switching Supplies**
- **Noise-Sensitive Circuitry Such as VCOs**
- **Point of Load Regulation for DSPs, FPGAs, ASICs, and Microprocessors**



Typical Application Circuit for Fixed-Voltage Versions





N/C - No internal connection

DESCRIPTION

The TPS736xx family of low-dropout (LDO) linear voltage regulators uses a new topology—an NMOS pass element in a voltage-follower configuration. This topology is stable using output capacitors with low ESR and allows operation without a capacitor. It also provides high reverse blockage (low reverse current) and ground-pin current that is nearly constant over all values of output current.

The TPS736xx uses an advanced BiCMOS process to yield high precision while delivering low dropout voltages and low ground-pin current. Current consumption, when not enabled, is under 1 µA and ideal for portable applications. The low output noise (30 μV_{RMS} with 0.1-µF C_{NR}) is ideal for powering VCOs. These devices are protected by thermal shutdown and foldback current limit.

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.

PRODUCT INFORMATION

PRODUCT	V_{OUT}(1)
TPS736xxMyyyREP	**xx** is normal output voltage (for example, 25 = 2.5 V, 01 = Adjustable(2)). ***yyy*** is package designator. ***z*** is package quantity.

(1) Additional output voltages from 1.25 V to 4.3 V in 100 mV increments are available on a quick-turn basis using innovative factory EEPROM programming. Minimum order quantities apply; contact TI for details and availability.
(2) For fixed 1.2-V operation, tie FB to OUT.

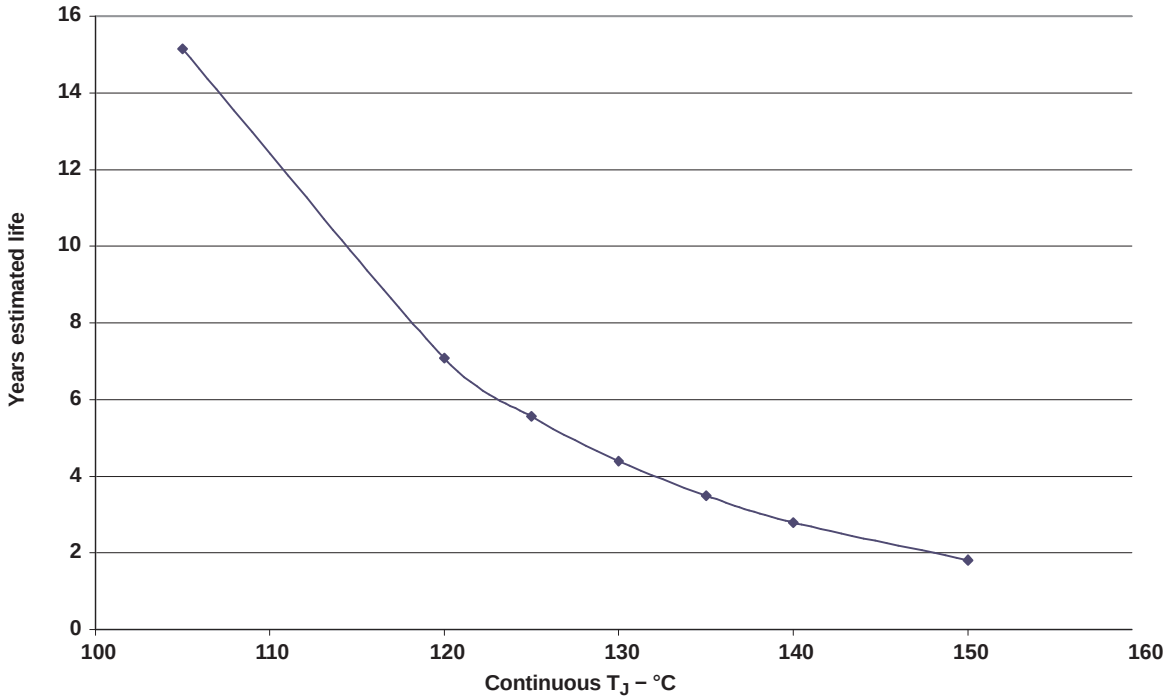
ORDERING INFORMATION(1)

T_A	PACKAGE(2)	ORDERABLE PART NUMBER	TOP-SIDE MARKING
–55°C to 125°C	SOT23 - DBV	TPS73601MDBVREP	PJRM
		TPS73615MDBVREP	T59
		TPS73618MDBVREP	T60
		TPS73625MDBVREP	T61
		TPS73630MDBVREP	T62
		TPS73632MDBVREP	T63
		TPS73633MDBVREP	T64
	SOT223 - DCQ	TPS73601MDCQREP	PWZM
	SON - DRB	TPS73601MDRBREP	PMNM

(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) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

TERMINAL FUNCTIONS

NAME	SOT23 (DBV) PIN NO.	SOT223 (DCQ) PIN NO.	3x3 SON (DRB) PIN NO.	DESCRIPTION
IN	1	1	8	Unregulated input supply
GND	2	3, 6	4, Pad	Ground
EN	3	5	5	Enable. Driving EN high turns on the regulator. Driving this pin low puts the regulator into shutdown mode. See the Shutdown section under Applications Information for more details. EN can be connected to IN if not used.
NR	4	4	3	Fixed-voltage versions only. Connecting an external capacitor to this pin bypasses noise generated by the internal bandgap, reducing output noise to low levels.
FB	4	4	3	Feedback. Adjustable-voltage version only. This is the input to the control loop error amplifier and is used to set the output voltage of the device.
OUT	5	2	1	Output of the regulator. There are no output capacitor requirements for stability.



A. $T_J = T_{JA} \times W + T_A$ (Standard. JESD 51 conditions)

Figure 1. TPS736xxDBVzEP Estimated Device Life at Elevated Temperatures Electromigration Fail Mode

ABSOLUTE MAXIMUM RATINGS

over operating free-air temperature range unless otherwise noted(1)

			UNIT
V_{IN} range		–0.3 to 6	V
V_{EN} range		–0.3 to 6	V
V_{OUT} range		–0.3 to 5.5	V
Peak output current		Internally limited	
Output short-circuit duration		Indefinite	
Continuous total power dissipation		See Dissipation Ratings Table	
Junction temperature range, T_J		–55 to 150	°C
Storage temperature range		–65 to 150	°C
ESD rating	Human-Body Model - HBM	2	kV
	Charged-Device Model - CDM	500	V

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

POWER DISSIPATION RATINGS(1)

BOARD	PACKAGE	$R_{\theta JC}$	$R_{\theta JA}$	DERATING FACTOR ABOVE T_A = 25°C	$T_A \le 25°C$ POWER RATING	T_A = 70°C POWER RATING	T_A = 85°C POWER RATING
Low-K(2)	DBV	64°C/W	255°C/W	3.9 mW/°C	390 mW	215 mW	155 mW
High-K(3)	DBV	64°C/W	180°C/W	5.6 mW/°C	560 mW	310 mW	225 mW
Low-K(2)	DCQ	15°C/W	53°C/W	18.9 mW/°C	1.89 mW	1.04 mW	0.76 mW
High-K(3)	DCQ	15°C/W	45°C/W	22.2 mW/°C	2.22 mW	1.22 mW	0.89 mW
High-K(3)(4)	DRB	1.2°C/W	40°C/W	25.0 mW/°C	2.50 mW	1.38 mW	1.0 mW

(1) See the Thermal Protection section for more information related to thermal design.
(2) The JEDEC Low-K (1s) board design used to derive this data was a 3 in × 3 in, two-layer board with 2 oz copper traces on top of the board.
(3) The JEDEC High-K (2s2p) board design used to derive this data was a 3 in × 3 in, multilayer board with 1 oz internal power and ground planes, and 2-oz copper traces on the top and bottom of the board.
(4) Based on preliminary thermal simulations.

ELECTRICAL CHARACTERISTICS

over operating temperature range (T_A = –55°C to 125°C), V_{IN} = $V_{OUT(nom)}$ + 0.5 V(1), I_{OUT} = 10 mA, V_{EN} = 1.7 V, and C_{OUT} = 0.1 µF (unless otherwise noted). Typical values are at T_J = 25°C.

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IN}	Input voltage range(1) (2)			1.7		5.5	V
V_{FB}	Internal reference (TPS73601)		T_J = 25°C	1.198	1.2	1.21	V
V_{OUT}	Output voltage range (TPS73601)			V_{FB}		5.5 – V_{DO}	V
	Accuracy(1)	Nominal	T_J = 25°C	–0.5%		0.5%	
		Over V_{IN}, I_{OUT}, and T	V_{OUT} + 0.5 V ≤ V_{IN} ≤ 5.5 V, 10 mA ≤ I_{OUT} ≤ 400 mA	–1%	±0.5%	1%	
$\Delta V_{OUT}\%/\Delta V_{IN}$	Line regulation(1)		$V_{O(nom)}$ + 0.5 V ≤ V_{IN} ≤ 5.5 V		0.01		%/V
$\Delta V_{OUT}\%/\Delta I_{OUT}$	Load regulation		1 mA ≤ I_{OUT} ≤ 400 mA		0.002		%/mA
			10 mA ≤ I_{OUT} ≤ 400 mA		0.0005		
V_{DO}	Dropout voltage(3) (V_{IN} = $V_{OUT(nom)}$ – 0.1 V)		I_{OUT} = 400 mA		75	200	mV
Z_O(DO)	Output impedance in dropout		1.7 V ≤ V_{IN} ≤ V_{OUT} + V_{DO}		0.25		Ω
I_{CL}	Output current limit		V_{OUT} = 0.9 × $V_{OUT(nom)}$	400	650	800	mA
I_{SC}	Short-circuit current		V_{OUT} = 0 V		450		mA
I_{REV}	Reverse leakage current(4) (–I_{IN})		V_{EN} ≤ 0.5 V, 0 V ≤ V_{IN} ≤ V_{OUT}		0.1	15	µA
I_{GND}	Ground-pin current		I_{OUT} = 10 mA (I_Q)		400	550	µA
			I_{OUT} = 400 mA		800	1000	
I_{SHDN}	Shutdown current (I_{GND})		V_{EN} ≤ 0.5 V, V_{OUT} ≤ V_{IN} ≤ 5.5 V		0.02	1	µA
I_{FB}	FB pin current (TPS73601)				0.1	0.45	µA
PSRR	Power-supply rejection ratio (ripple rejection)		f = 100 Hz, I_{OUT} = 400 mA		58		dB
			f = 10 kHz, I_{OUT} = 400 mA		37		
V_N	Output noise voltage BW = 10 Hz to 100 kHz		C_{OUT} = 10 µF, No C_{NR}		27 × V_{OUT}		μV_{RMS}
			C_{OUT} = 10 µF, C_{NR} = 0.01 µF		8.5 × V_{OUT}		
t_{STR}	Startup time		V_{OUT} = 3 V, R_L = 30 Ω, C_{OUT} = 1 µF, C_{NR} = 0.01 µF		600		µs
V_{EN}(HI)	Enable high (enabled)			1.7		V_{IN}	V
V_{EN}(LO)	Enable low (shutdown)			0		0.5	V
I_{EN}(HI)	Enable pin current (enabled)		V_{EN} = 5.5 V		0.02	0.1	µA
T_{SD}	Thermal shutdown temperature		Shutdown, temperature increasing		160		°C
			Reset, temperature decreasing		140		
T_A	Operating ambient temperature			-55		125	°C

(1) Minimum V_{IN} = V_{OUT} + V_{DO} or 1.7 V, whichever is greater.
(2) For $V_{OUT(nom)}$ < 1.6 V, when V_{IN} ≤ 1.6 V, the output locks to V_{IN} and may result in a damaging over-voltage level on the output. To avoid this situation, disable the device before powering down the V_{IN}.
(3) V_{DO} is not measured for the TPS73615 ($V_{OUT(nom)}$ = 1.5 V) since minimum V_{IN} = 1.7 V.
(4) See the ***Applications*** section for more information.

FUNCTIONAL BLOCK DIAGRAMS

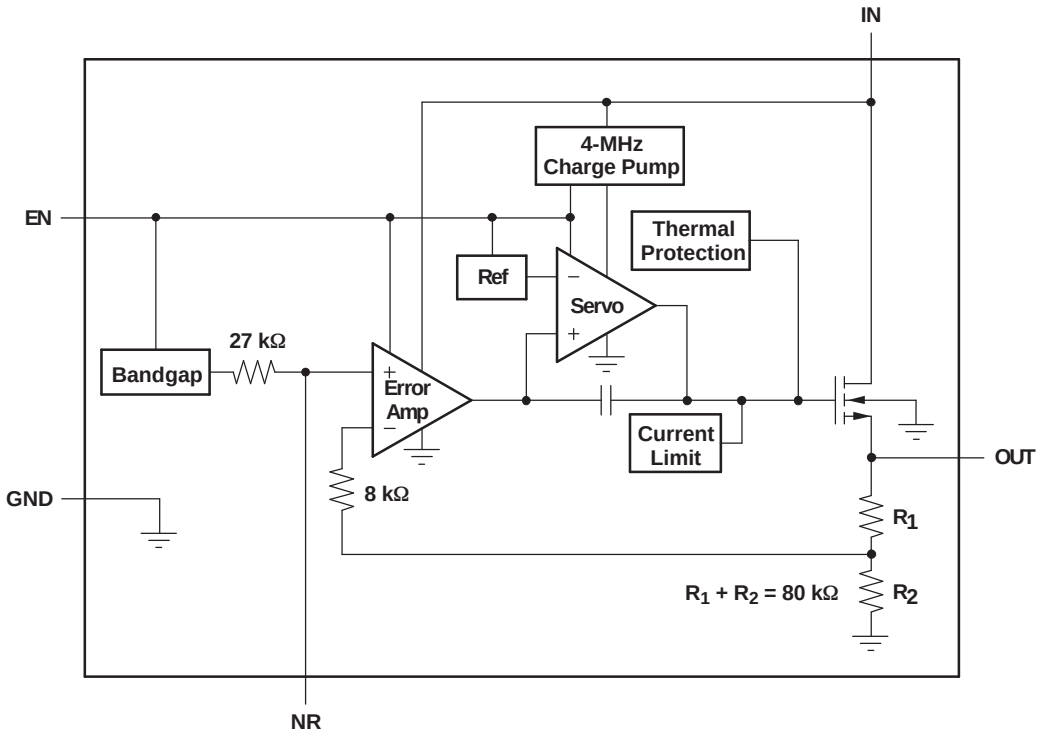
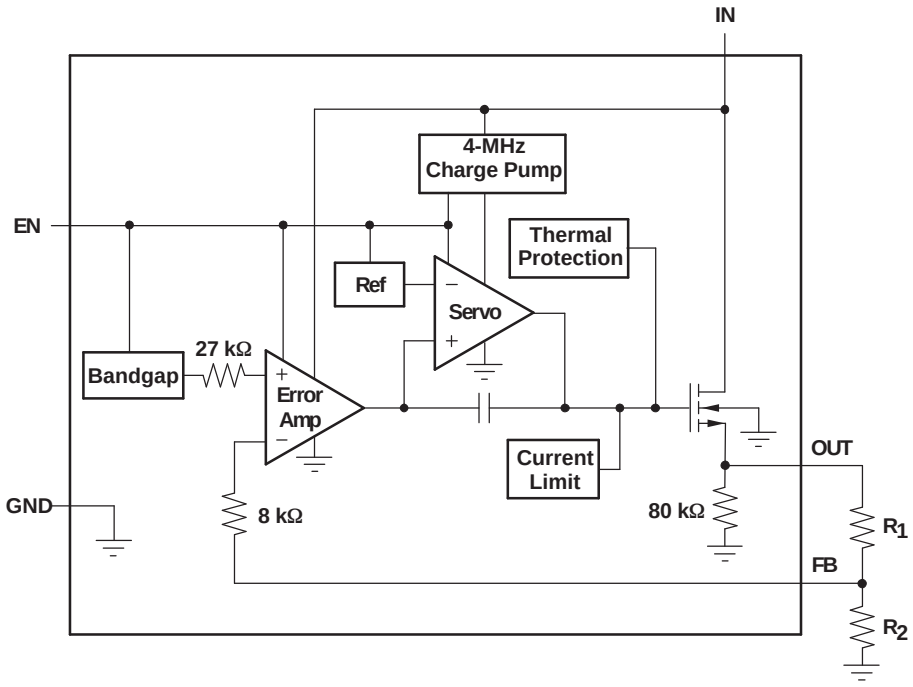


Figure 2. Fixed-Voltage Version



Standard 1% Resistor Values for Common Output Voltages

V_O	R_1	R_2
1.2 V	Short	Open
1.5 V	23.2 kΩ	95.3 kΩ
1.8 V	28 kΩ	56.2 kΩ
2.5 V	39.2 kΩ	36.5 kΩ
2.8 V	44.2 kΩ	33.2 kΩ
3 V	46.4 kΩ	30.9 kΩ
3.3 V	52.3 kΩ	30.1 kΩ

NOTE: $V_{OUT} = (R_1 + R_2)/R_2 \times 1.204$; $R_1 || R_2 \cong 19$ kΩ for best accuracy

Figure 3. Adjustable-Voltage Version

TYPICAL CHARACTERISTICS

For all voltage versions, T_J = 25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5 V, I_{OUT} = 10 mA, V_{EN} = 1.7 V, and C_{OUT} = 0.1 µF (unless otherwise noted)

LOAD REGULATION

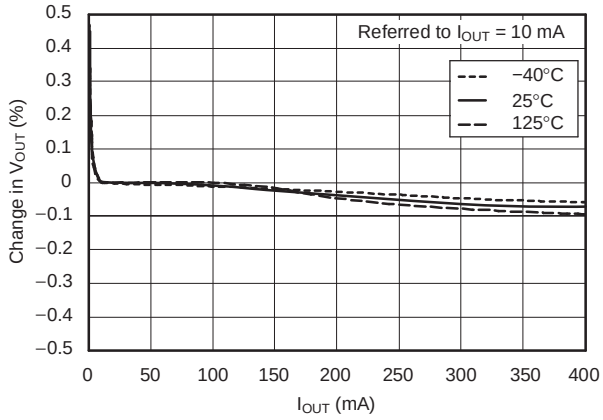


Figure 4.

LINE REGULATION

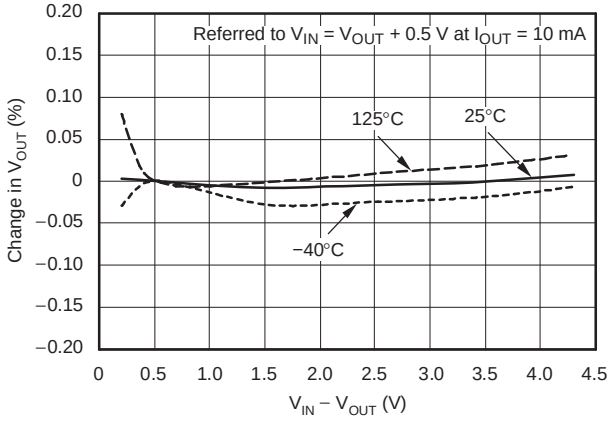


Figure 5.

DROPOUT VOLTAGE vs OUTPUT CURRENT

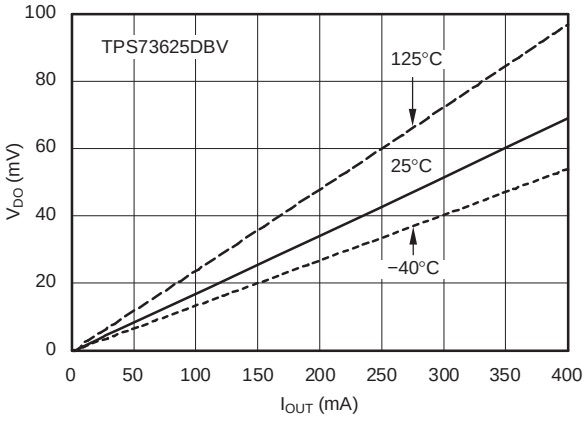


Figure 6.

DROPOUT VOLTAGE vs TEMPERATURE

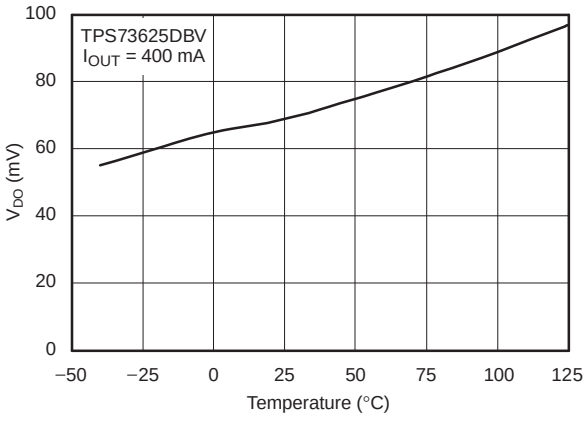


Figure 7.

OUTPUT VOLTAGE ACCURACY HISTOGRAM

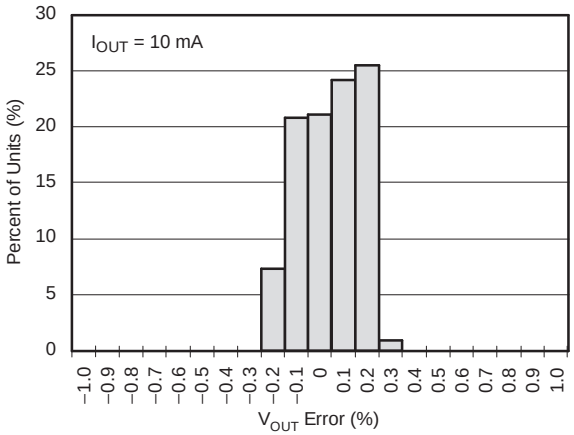


Figure 8.

OUTPUT VOLTAGE DRIFT HISTOGRAM

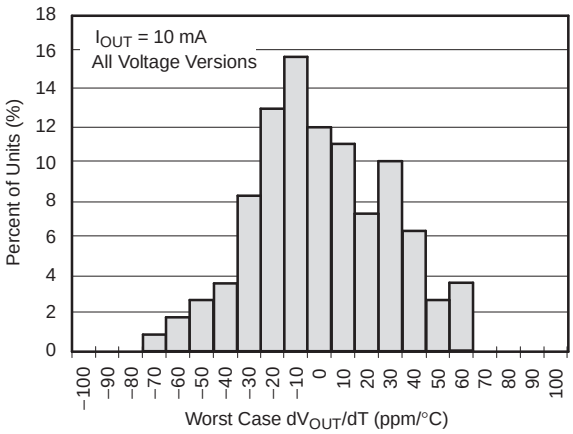


Figure 9.

TYPICAL CHARACTERISTICS (continued)

For all voltage versions, T_J = 25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5 V, I_{OUT} = 10 mA, V_{EN} = 1.7 V, and C_{OUT} = 0.1 µF (unless otherwise noted)

GROUND-PIN CURRENT vs OUTPUT CURRENT

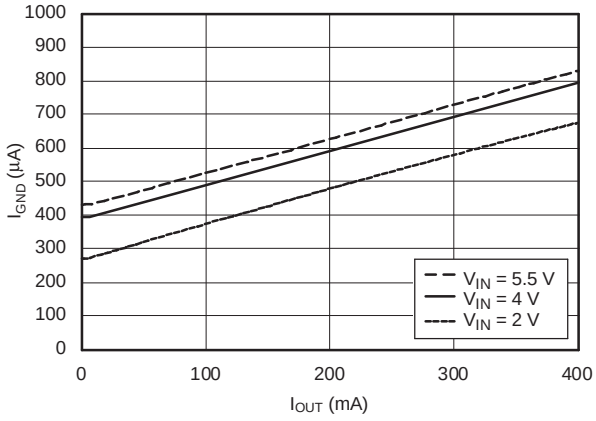


Figure 10.

GROUND PIN CURRENT vs TEMPERATURE

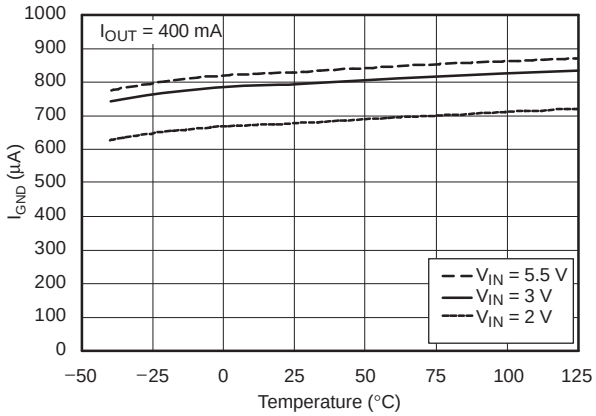


Figure 11.

CURRENT LIMIT vs V_{OUT} (FOLDBACK)

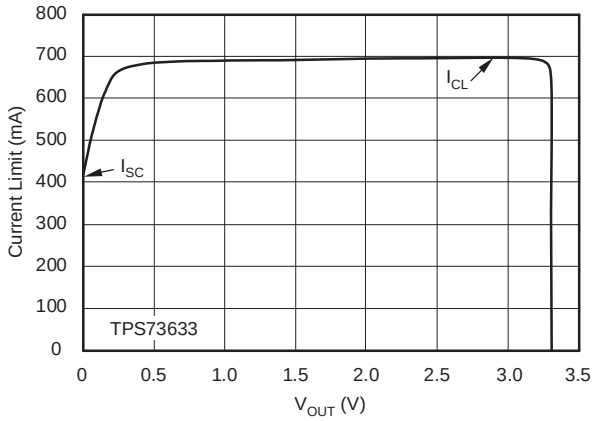


Figure 12.

GROUND PIN CURRENT in SHUTDOWN vs TEMPERATURE

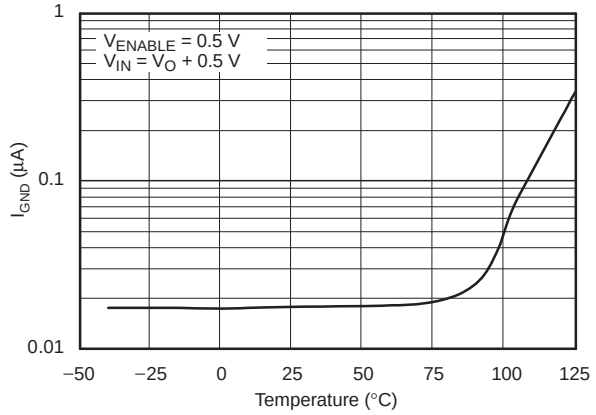


Figure 13.

CURRENT LIMIT vs V_{IN}

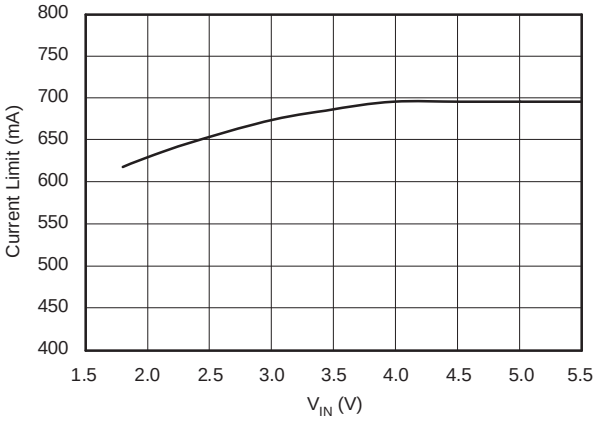


Figure 14.

CURRENT LIMIT vs TEMPERATURE

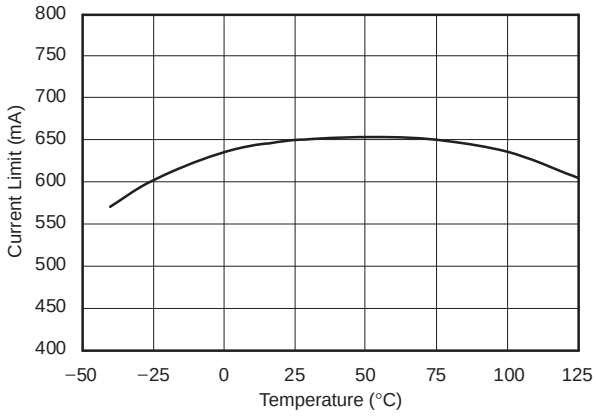


Figure 15.

TYPICAL CHARACTERISTICS (continued)

For all voltage versions, T_J = 25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5 V, I_{OUT} = 10 mA, V_{EN} = 1.7 V, and C_{OUT} = 0.1 µF (unless otherwise noted)

PSRR (RIPPLE REJECTION) vs FREQUENCY

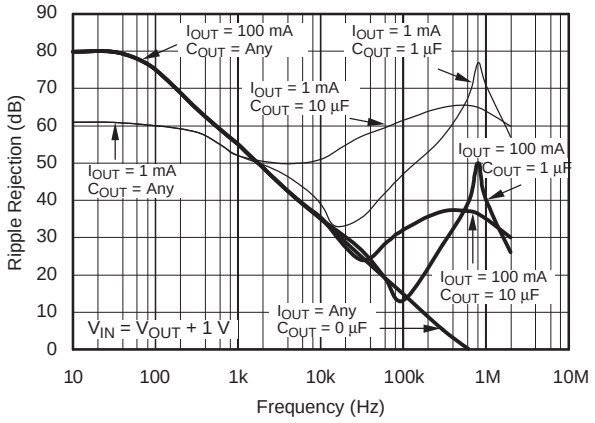


Figure 16.

PSRR (RIPPLE REJECTION) vs V_{IN} − V_{OUT}

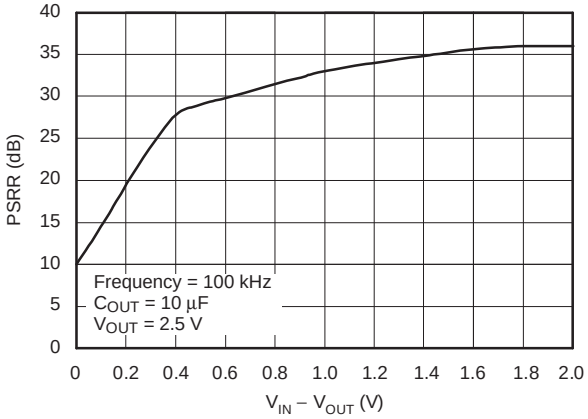


Figure 17.

NOISE SPECTRAL DENSITY
C_{NR} = 0 µF

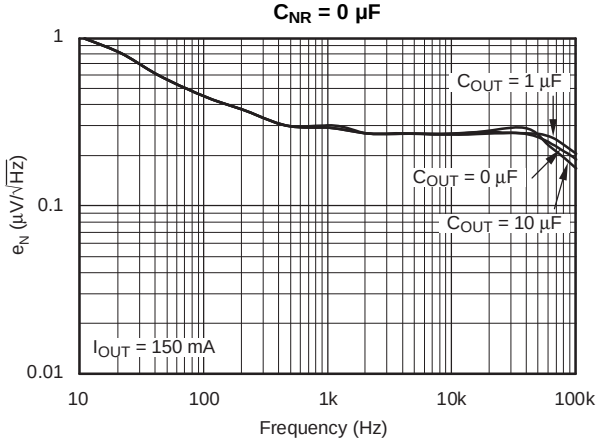


Figure 18.

NOISE SPECTRAL DENSITY
C_{NR} = 0.01 µF

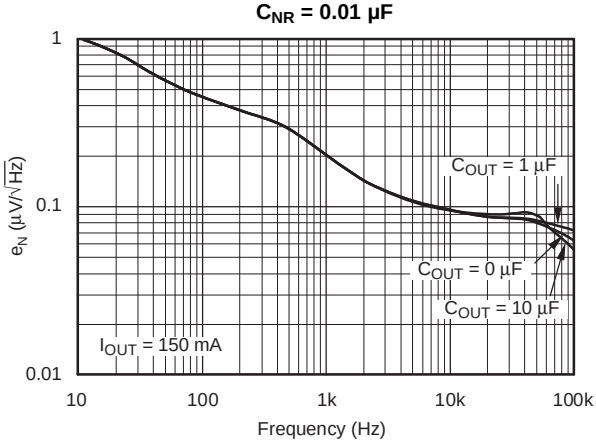


Figure 19.

RMS NOISE VOLTAGE vs C_{OUT}

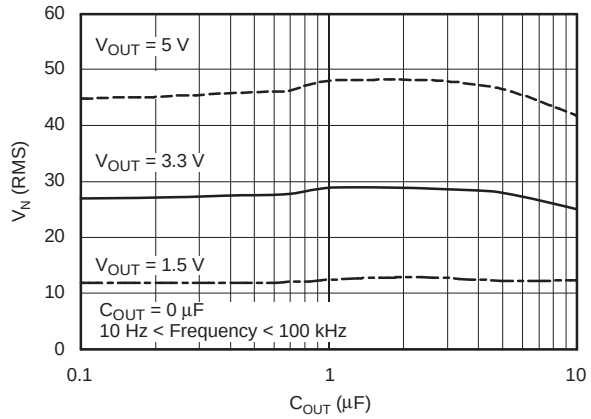


Figure 20.

RMS NOISE VOLTAGE vs C_{NR}

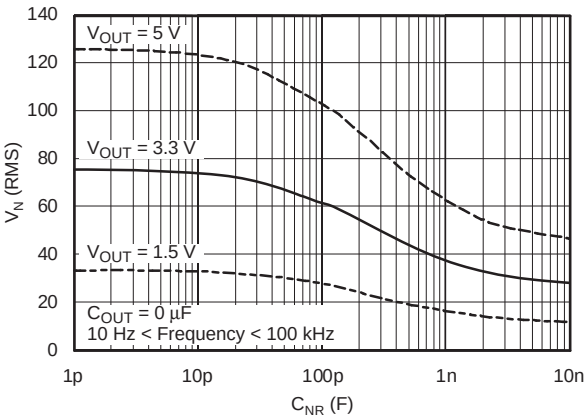


Figure 21.

TYPICAL CHARACTERISTICS (continued)

For all voltage versions, T_J = 25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5 V, I_{OUT} = 10 mA, V_{EN} = 1.7 V, and C_{OUT} = 0.1 µF (unless otherwise noted)

TPS73633
LOAD TRANSIENT RESPONSE

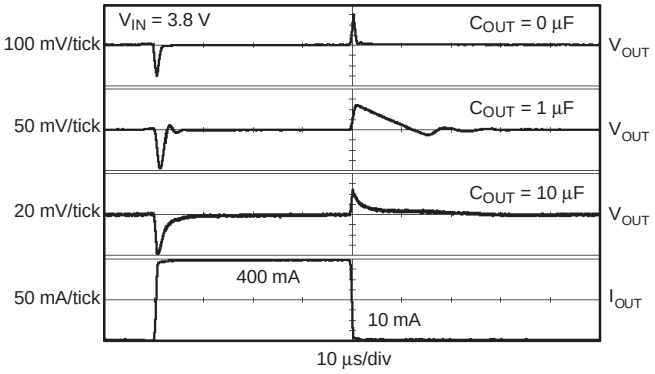


Figure 22.

TPS73633
LINE TRANSIENT RESPONSE

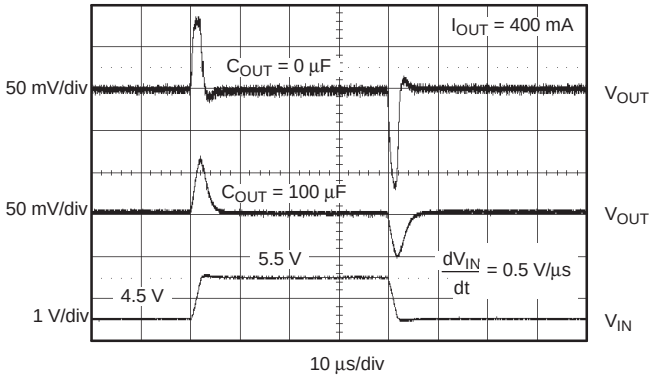


Figure 23.

TPS73633
TURNON RESPONSE

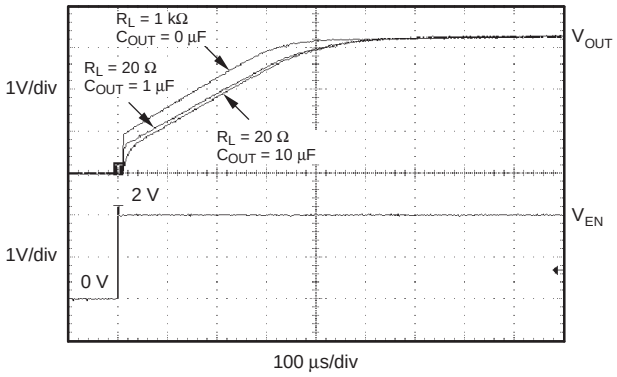


Figure 24.

TPS73633
TURNOFF RESPONSE

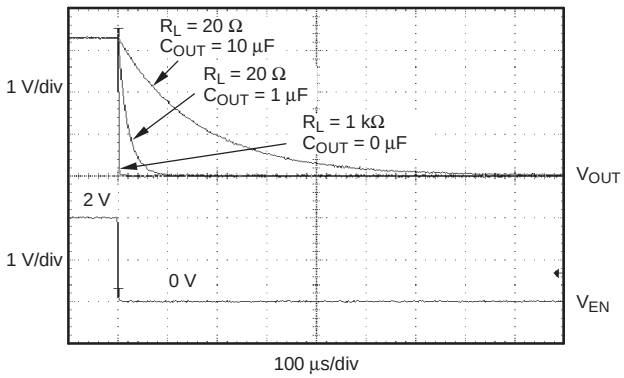


Figure 25.

TPS73633
POWER UP/POWER DOWN

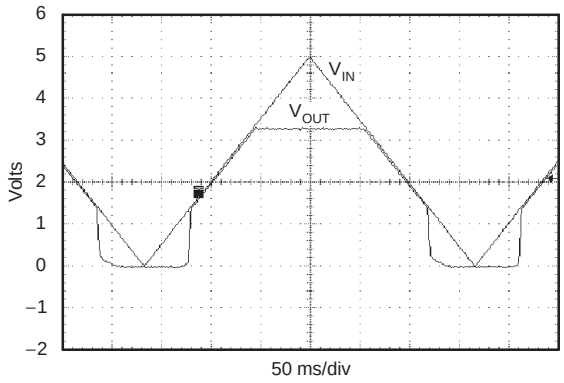


Figure 26.

I_{ENABLE} vs TEMPERATURE

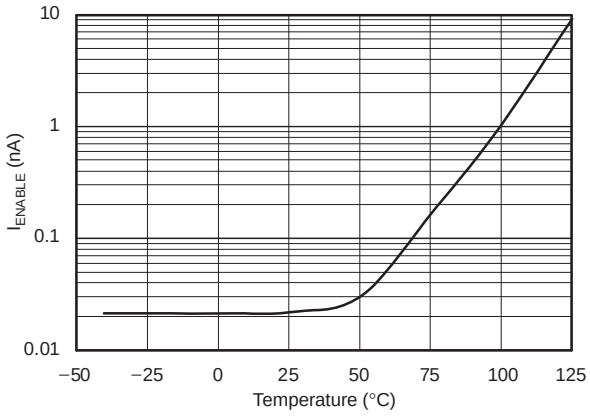


Figure 27.

TYPICAL CHARACTERISTICS (continued)

For all voltage versions, T_J = 25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5 V, I_{OUT} = 10 mA, V_{EN} = 1.7 V, and C_{OUT} = 0.1 µF (unless otherwise noted)

TPS73601
RMS NOISE VOLTAGE vs C_{ADJ}

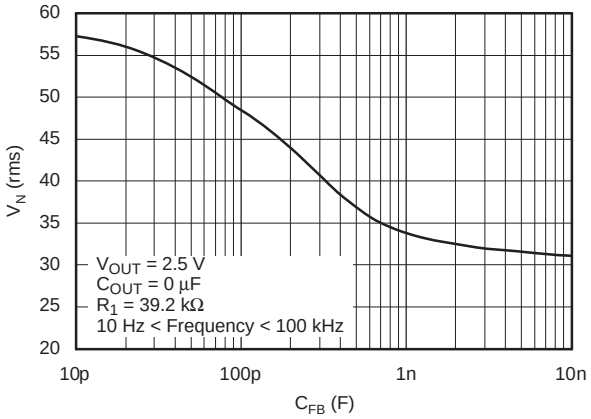


Figure 28.

TPS73601
I_{FB} vs TEMPERATURE

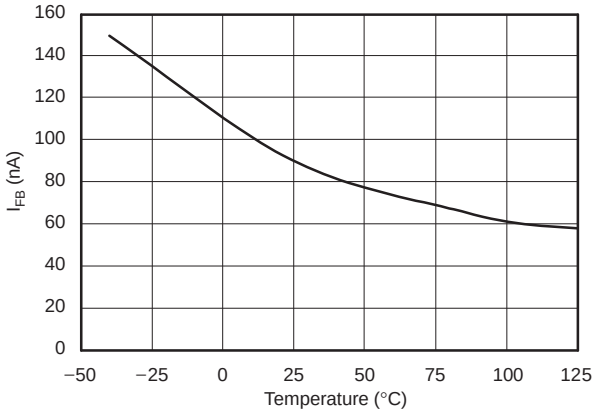


Figure 29.

TPS73601
LOAD TRANSIENT, ADJUSTABLE VERSION

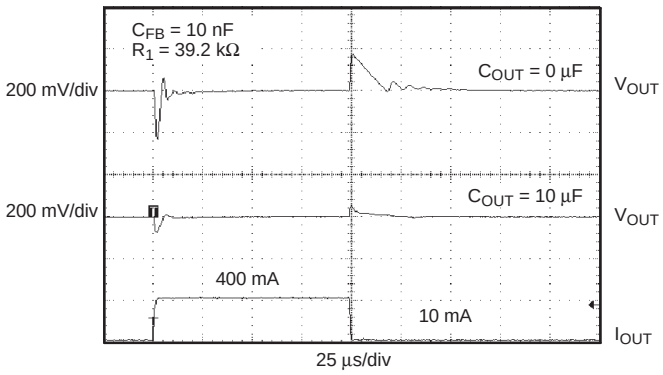


Figure 30.

TPS73601
LINE TRANSIENT, ADJUSTABLE VERSION

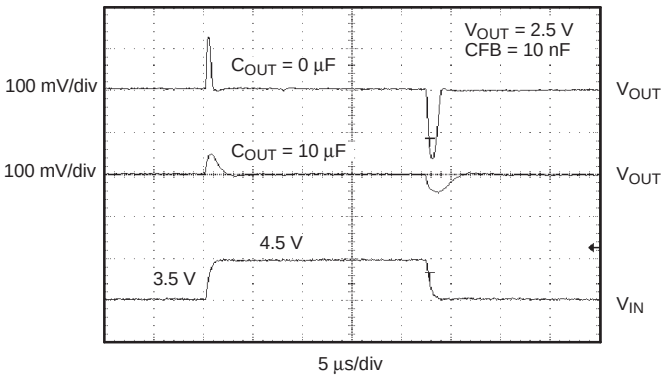


Figure 31.

APPLICATION INFORMATION

The TPS736xx belongs to a family of new-generation LDO regulators that use an NMOS pass transistor to achieve ultra-low-dropout performance, reverse current blockage, and freedom from output capacitor constraints. These features, combined with low noise and an enable input, make the TPS736xx ideal for portable applications. This regulator family offers a wide selection of fixed-output voltage versions and an adjustable-output version. All versions have thermal and overcurrent protection, including foldback current limit.

Figure 32 shows the basic circuit connections for the fixed-voltage models. Figure 33 shows the connections for the adjustable-output version (TPS73601). R_1 and R_2 can be calculated for any output voltage using the formula in Figure 33. Sample resistor values for common output voltages are shown in Figure 3. For the best accuracy, make the parallel combination of R_1 and R_2 approximately 19 kΩ.

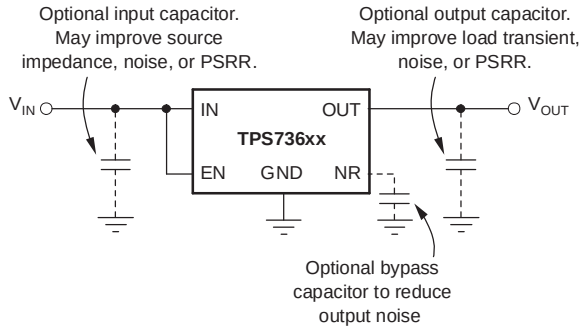


Figure 32. Typical Application Circuit for Fixed-Voltage Versions

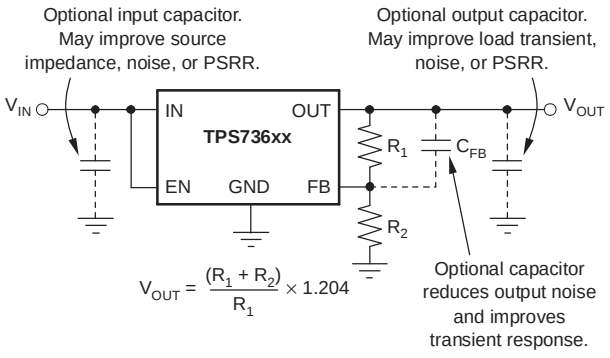


Figure 33. Typical Application Circuit for Adjustable-Voltage Versions

Input and Output Capacitor Requirements

Although an input capacitor is not required for stability, it is good analog design practice to connect a 0.1-µF to 1-µF low ESR capacitor across the input supply near the regulator. This counteracts reactive input sources and improves transient response, noise rejection, and ripple rejection. A higher-value capacitor may be necessary if large, fast rise-time load transients are anticipated, or the device is located several inches from the power source.

The TPS736xx does not require an output capacitor for stability and has maximum phase margin with no capacitor. It is designed to be stable for all available types and values of capacitors. In applications where $V_{IN} - V_{OUT} < 0.5$ V and multiple low ESR capacitors are in parallel, ringing may occur when the product of C_{OUT} and total ESR drops below 50 Ω. Total ESR includes all parasitic resistance, including capacitor ESR and board, socket, and solder-joint resistance. In most applications, the sum of capacitor ESR and trace resistance meets this requirement.

Output Noise

A precision band-gap reference is used to generate the internal reference voltage, V_{REF}. This reference is the dominant noise source within the TPS736xx and it generates approximately 32 μV_{RMS} (10 Hz to 100 kHz) at the reference output (NR). The regulator control loop gains up the reference noise with the same gain as the reference voltage, so that the noise voltage of the regulator is approximately given by:

$$V_N = 32\ \mu V_{RMS} \times \frac{(R_1 + R_2)}{R_2} = 32\ \mu V_{RMS} \times \frac{V_{OUT}}{V_{REF}} \quad (1)$$

Since the value of V_{REF} is 1.2 V, this relationship reduces to:

$$V_N(\mu V_{RMS}) = 27\left(\frac{\mu V_{RMS}}{V}\right) \times V_{OUT}(V) \quad (2)$$

for the case of no C_{NR}.

An internal 27-kΩ resistor in series with the noise reduction pin (NR) forms a low-pass filter for the voltage reference when an external noise reduction capacitor, C_{NR}, is connected from NR to ground. For C_{NR} = 10 nF, the total noise in the 10-Hz to 100-kHz bandwidth is reduced by a factor of ~3.2, giving the approximate relationship:

$$V_N(\mu V_{RMS}) = 8.5\left(\frac{\mu V_{RMS}}{V}\right) \times V_{OUT}(V) \quad (3)$$

for C_{NR} = 10 nF.

This noise reduction effect is shown as RMS Noise Voltage vs C_{NR} in Figure 21.

The TPS73601 adjustable version does not have the noise-reduction pin available. However, connecting a feedback capacitor, C_{FB}, from the output to the FB pin reduces output noise and improves load transient performance.

The TPS736xx uses an internal charge pump to develop an internal supply voltage sufficient to drive the gate of the NMOS pass element above V_{OUT}. The charge pump generates ~250 μV of switching noise at ~4 MHz; however, charge-pump noise contribution is negligible at the output of the regulator for most values of I_{OUT} and C_{OUT}.

Board Layout Recommendation to Improve PSRR and Noise Performance

To improve ac performance such as PSRR, output noise, and transient response, it is recommended that the board be designed with separate ground planes for V_{IN} and V_{OUT}, with each ground plane connected only at the GND pin of the device. In addition, the ground connection for the bypass capacitor should connect directly to the GND pin of the device.

Internal Current Limit

The TPS736xx internal current limit helps protect the regulator during fault conditions. Foldback helps to protect the regulator from damage during output short-circuit conditions by reducing current limit when V_{OUT} drops below 0.5 V. See Figure 12 for a graph of I_{OUT} vs V_{OUT}.

Shutdown

The enable (EN) pin is active high and is compatible with standard TTL-CMOS levels. V_{EN} below 0.5 V (max) turns the regulator off and drops the ground-pin current to approximately 10 nA. When shutdown capability is not required, EN can be connected to V_{IN}. When a pullup resistor is used, and operation down to 1.8 V is required, use pullup resistor values below 50 kΩ.

Dropout Voltage

The TPS736xx uses an NMOS pass transistor to achieve extremely low dropout. When ($V_{IN} – V_{OUT}$) is less than the dropout voltage (V_{DO}), the NMOS pass device is in its linear region of operation and the input-to-output resistance is the R_{DS-ON} of the NMOS pass element.

For large step changes in load current, the TPS736xx requires a larger voltage drop from V_{IN} to V_{OUT} to avoid degraded transient response. The boundary of this transient dropout region is approximately twice the dc dropout. Values of $V_{IN} – V_{OUT}$ above this line ensure normal transient response.

Operating in the transient dropout region can cause an increase in recovery time. The time required to recover from a load transient is a function of the magnitude of the change in load current rate, the rate of change in load current, and the available headroom (V_{IN} to V_{OUT} voltage drop). Under worst-case conditions [full-scale instantaneous load change with ($V_{IN} – V_{OUT}$) close to dc dropout levels], the TPS736xx can take a couple of hundred microseconds to return to the specified regulation accuracy.

Transient Response

The low open-loop output impedance provided by the NMOS pass element in a voltage-follower configuration allows operation without an output capacitor for many applications. As with any regulator, the addition of a capacitor (nominal value 1 μF) from the output pin to ground reduces undershoot magnitude but increases duration. In the adjustable version, the addition of a capacitor, C_{FB}, from the output to the adjust pin also improves the transient response.

The TPS736xx does not have active pulldown when the output is overvoltage. This allows applications that connect higher voltage sources, such as alternate power supplies, to the output. This also results in an output overshoot of several percent if load current quickly drops to zero when a capacitor is connected to the output. The duration of overshoot can be reduced by adding a load resistor. The overshoot decays at a rate determined by output capacitor C_{OUT} and the internal/external load resistance. The rate of decay is given by:

Fixed-voltage version:

$$dV/dt = \frac{V_{OUT}}{C_{OUT} \times 80\ k\Omega \parallel R_{LOAD}} \quad (4)$$

Adjustable-voltage version:

$$dV/dt = \frac{V_{OUT}}{C_{OUT} \times 80\ k\Omega \parallel (R_1 + R_2) \parallel R_{LOAD}} \quad (5)$$

Reverse Current

The NMOS pass element of the TPS736xx provides inherent protection against current flow from the output of the regulator to the input when the gate of the pass device is pulled low. To ensure that all charge is removed from the gate of the pass element, EN must be driven low before the input voltage is removed. If this is not done, the pass element may be left on due to stored charge on the gate.

After EN is driven low, no bias voltage is needed on any pin for reverse current blocking. Note that reverse current is specified as the current flowing out of the IN pin due to voltage applied on the OUT pin. There is additional current flowing into the OUT pin due to the 80-kΩ internal resistor divider to ground (see Figure 2 and Figure 3).

For the TPS73601, reverse current may flow when V_{FB} is more than 1 V above V_{IN}.

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 again enabled. Depending on power dissipation, thermal resistance, and ambient temperature, the thermal protection circuit may cycle on and off. This limits the dissipation of the regulator, protecting it from damage due to overheating.

Any tendency to activate the thermal protection circuit indicates excessive power dissipation or an inadequate heatsink. 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 the thermal protection is triggered; use worst-case loads and signal conditions. For good reliability, thermal protection should trigger at least 35°C above the maximum expected ambient condition of the application. This 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 TPS736xx has been designed to protect against overload conditions. It was not intended to replace proper heatsinking. Continuously running the TPS736xx into thermal shutdown degrades reliability.

Power Dissipation

The ability to remove heat from the die is different for each package type, presenting different considerations in the PCB layout. The PCB area around the device that is free of other components moves the heat from the device to the ambient air. Performance data for JEDEC low- and high-K boards are shown in the *Power Dissipation Ratings* table. Using heavier copper increases the effectiveness in removing heat from the device. The addition of plated through-holes to heat-dissipating layers also improves the heatsink effectiveness.

Power dissipation depends on input voltage and load conditions. Power dissipation is equal to the product of the output current times the voltage drop across the output pass element (V_{IN} to V_{OUT}):

$$P_D = (V_{IN} - V_{OUT}) \times I_{OUT} \quad (6)$$

Power dissipation can be minimized by using the lowest-possible input voltage necessary to ensure the required output voltage.

Package Mounting

Solder-pad footprint recommendations for the TPS736xx are presented in application bulletin *Solder Pad Recommendations for Surface-Mount Devices* (AB-132), available from the TI web site at www.ti.com.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
TPS73601MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS73601MDCQREP	ACTIVE	SOT-223	DCQ	6	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS73601MDRBREP	ACTIVE	SON	DRB	8	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
TPS73615MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS73618MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS73625MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS73630MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS73632MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
TPS73633MDBVREP	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-01XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-01YE	ACTIVE	SOT-223	DCQ	6	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
V62/06626-01ZE	ACTIVE	SON	DRB	8	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
V62/06626-02XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-03XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-04XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-05XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-06XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM
V62/06626-07XE	ACTIVE	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM

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

OTHER QUALIFIED VERSIONS OF TPS73601-EP, TPS73615-EP, TPS73618-EP, TPS73625-EP, TPS73630-EP, TPS73632-EP, TPS73633-EP :

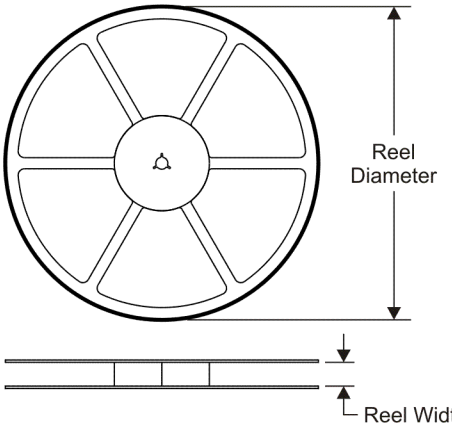
- Catalog: TPS73601, TPS73615, TPS73618, TPS73625, TPS73630, TPS73632, TPS73633

NOTE: Qualified Version Definitions:

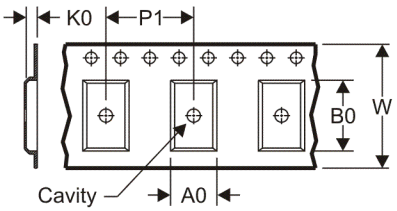
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

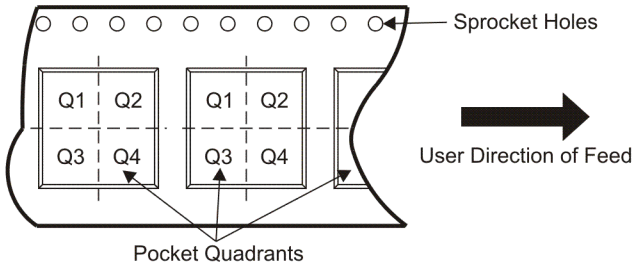


TAPE DIMENSIONS



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

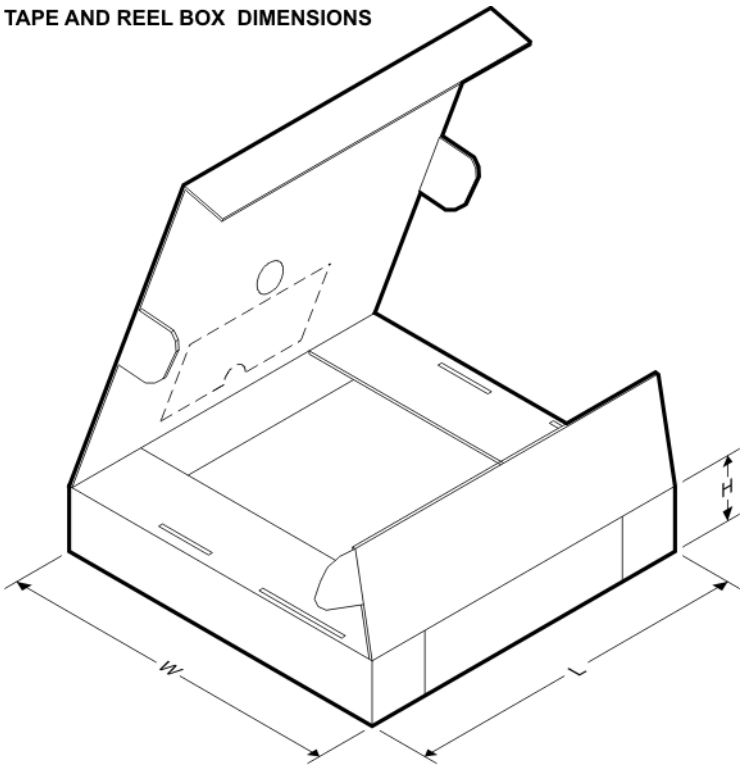
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS73601MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS73601MDCQREP	SOT-223	DCQ	6	2500	330.0	12.4	6.8	7.3	1.88	8.0	12.0	Q3
TPS73601MDRBREP	SON	DRB	8	3000	330.0	12.4	3.3	3.3	1.0	8.0	12.0	Q2
TPS73615MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS73618MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS73625MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS73630MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS73632MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
TPS73633MDBVREP	SOT-23	DBV	5	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3

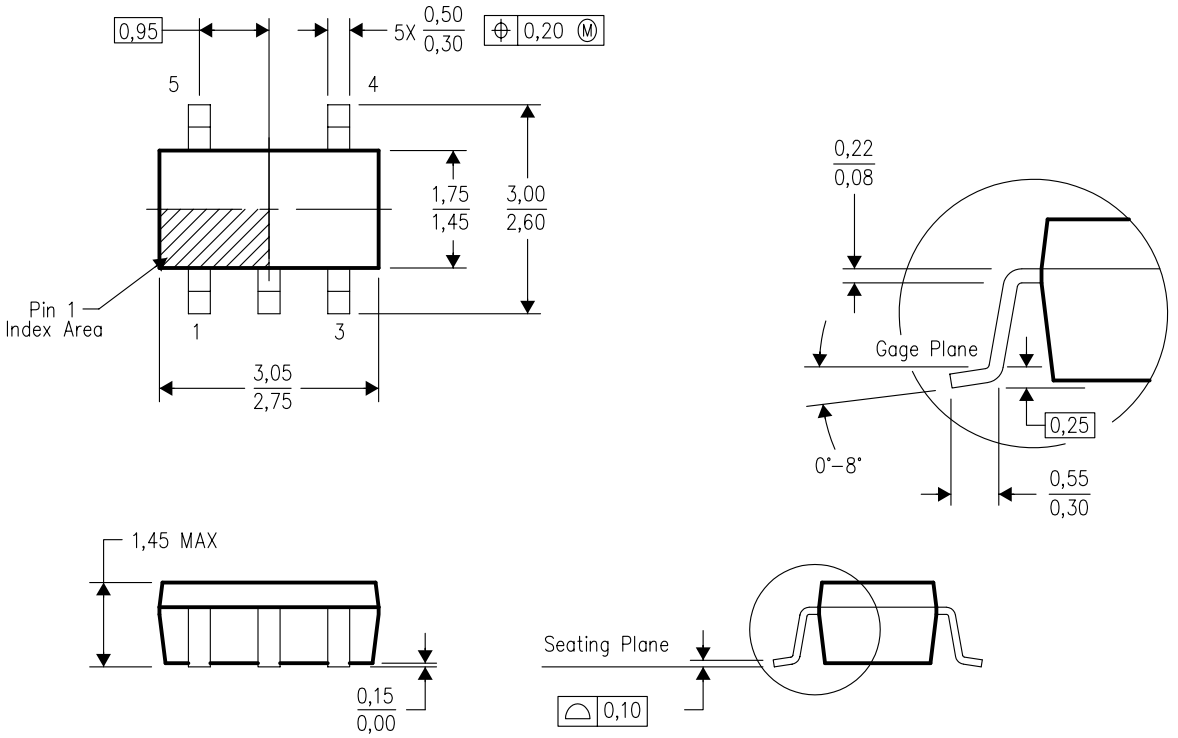
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS73601MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0
TPS73601MDCQREP	SOT-223	DCQ	6	2500	358.0	335.0	35.0
TPS73601MDRBREP	SON	DRB	8	3000	370.0	355.0	55.0
TPS73615MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0
TPS73618MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0
TPS73625MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0
TPS73630MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0
TPS73632MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0
TPS73633MDBVREP	SOT-23	DBV	5	3000	195.0	200.0	45.0

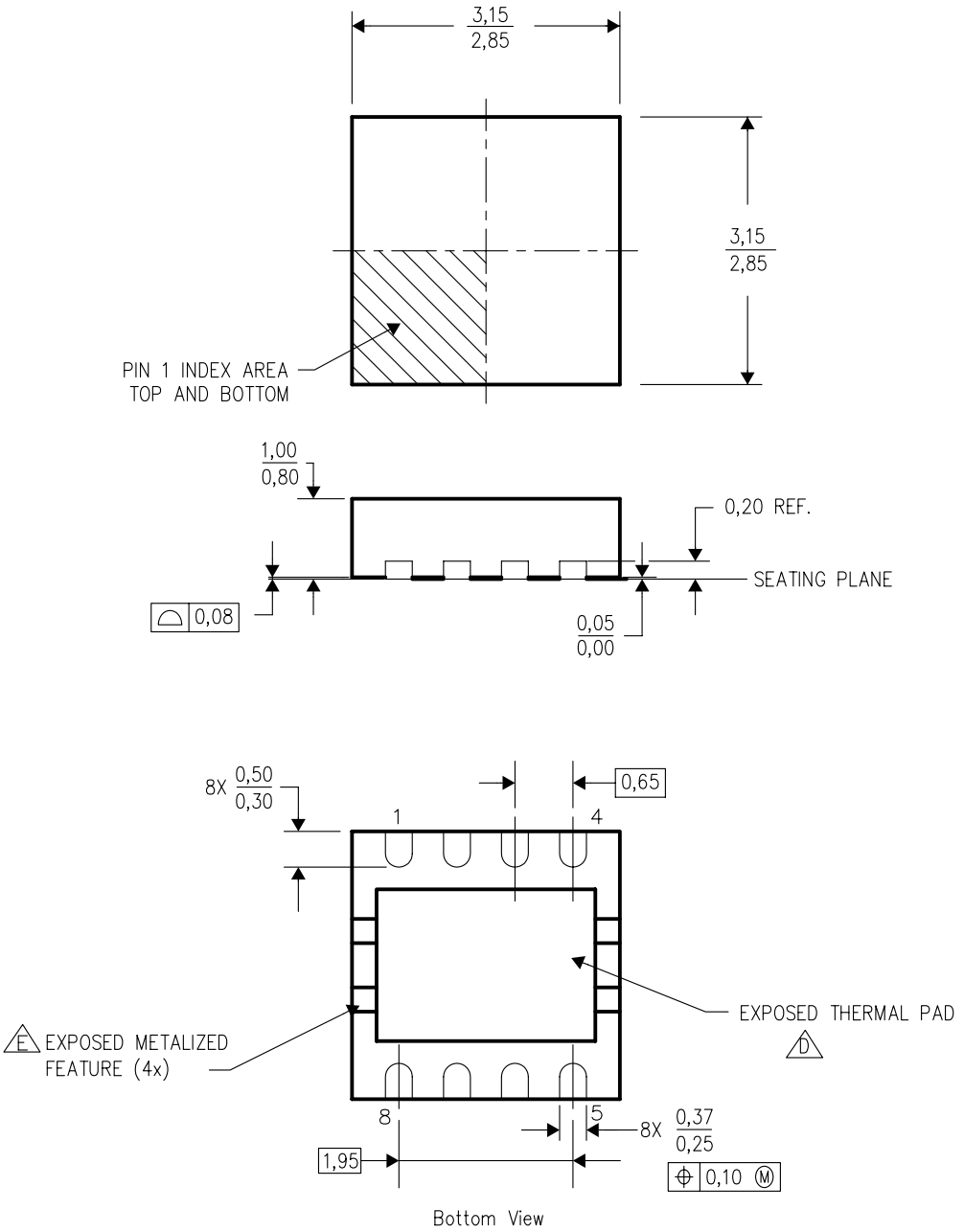
DBV (R–PDSO–G5) PLASTIC SMALL–OUTLINE PACKAGE



4073253–4/K 03/2006

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

DRB (S–PDSO–N8) PLASTIC SMALL OUTLINE



4203482/G 11/04

NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Small Outline No–Lead (SON) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
E. Metalized features are supplier options and may not be on the package.

THERMAL PAD MECHANICAL DATA

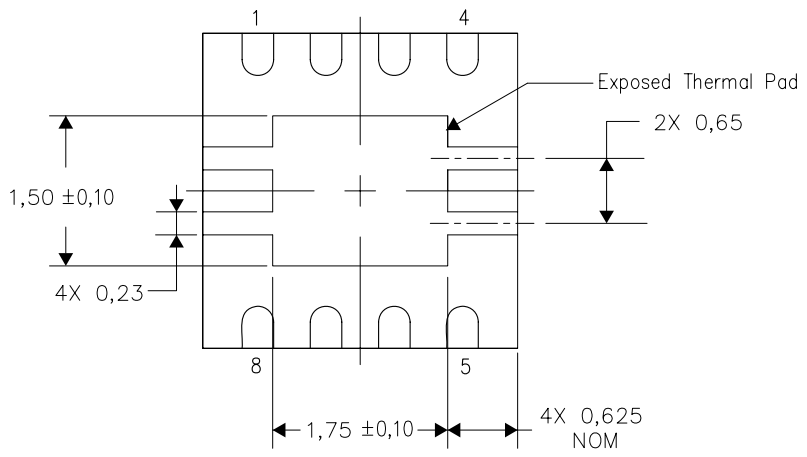
DRB (S–VSON–N8)

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, Quad Flatpack No–Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at www.ti.com.

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

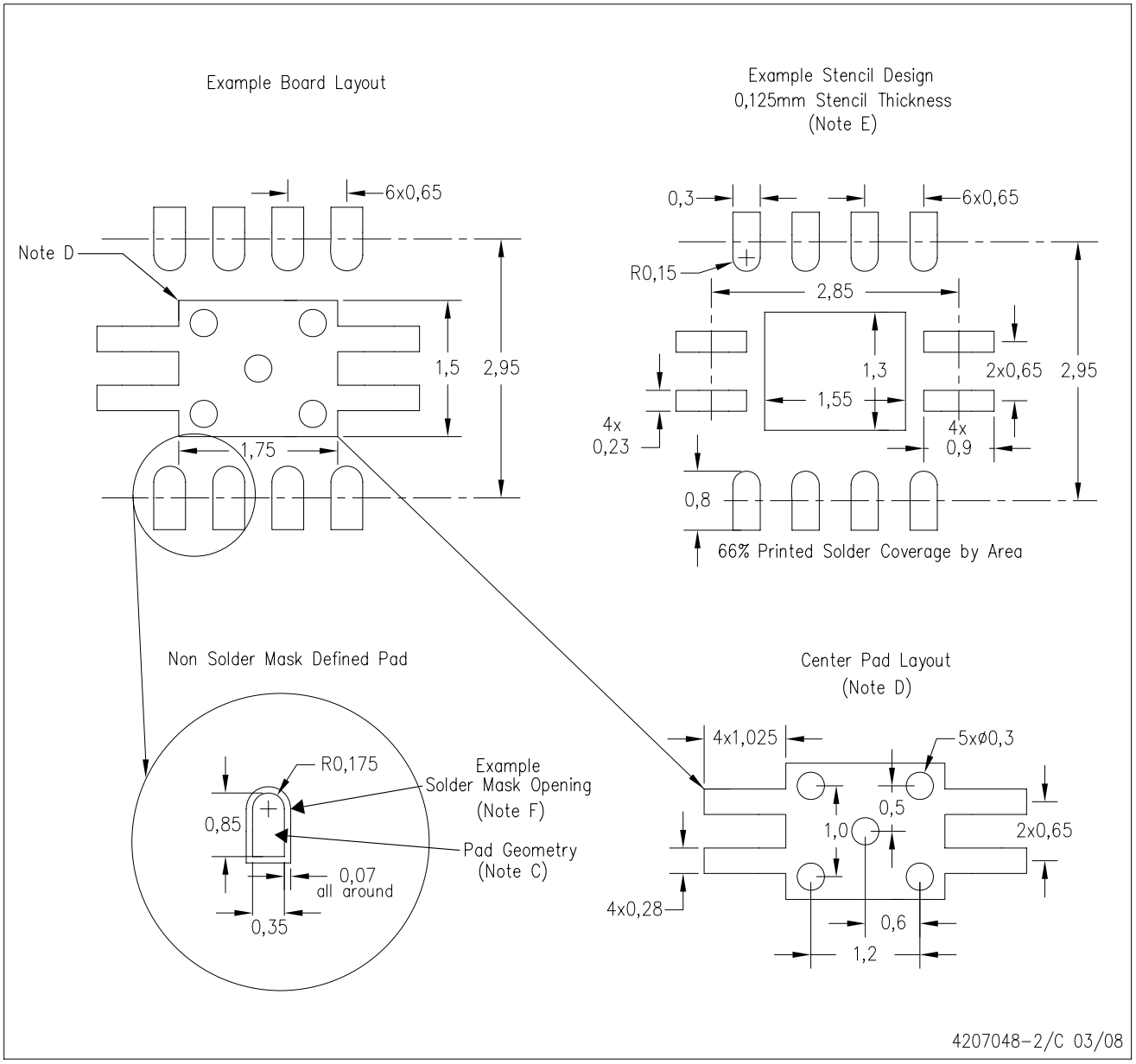


Bottom View

NOTE: All linear dimensions are in millimeters

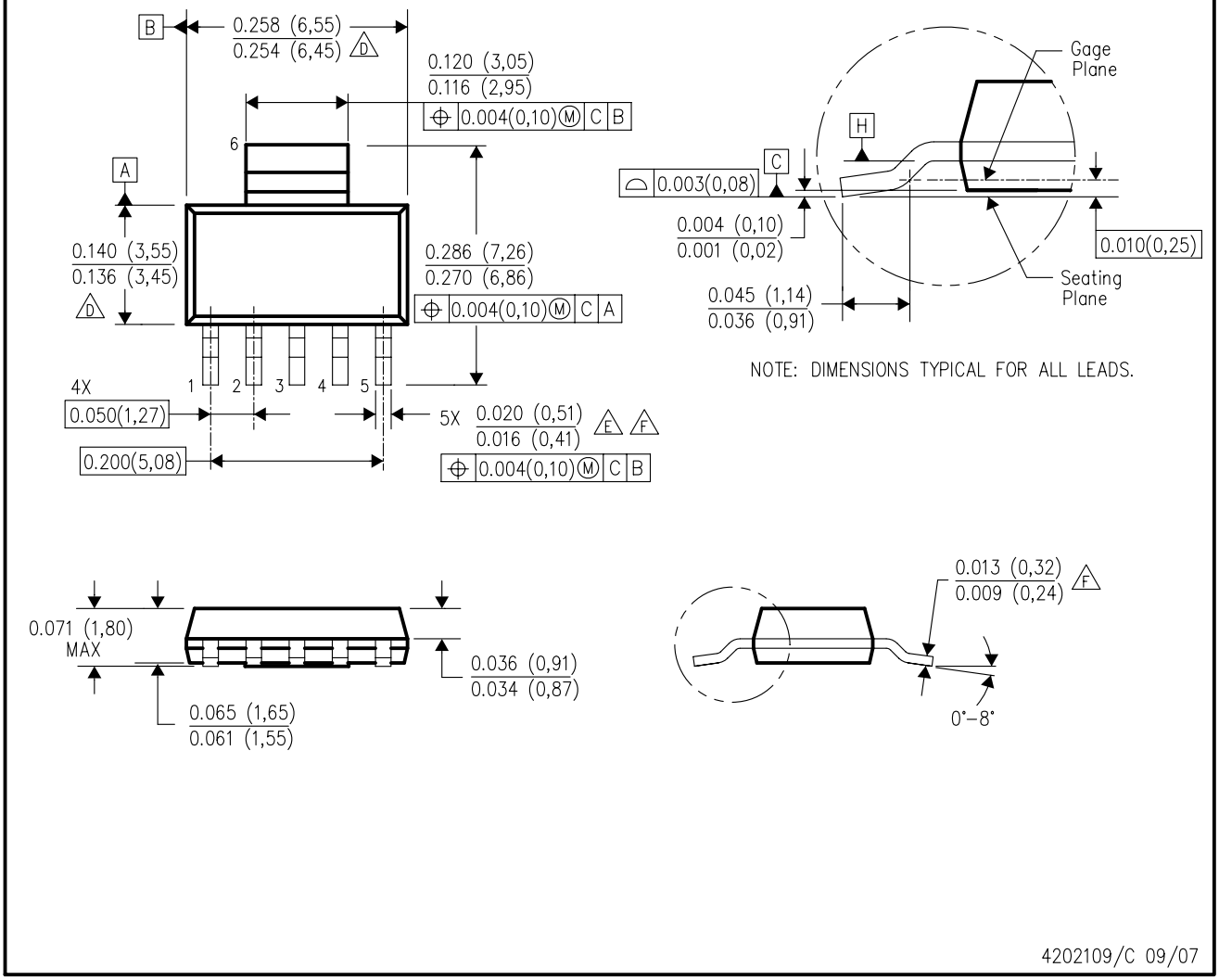
Exposed Thermal Pad Dimensions

DRB (S–VSON–N8)



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. SCBA017, 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.

DCQ (R–PDSO–G6) PLASTIC SMALL–OUTLINE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Controlling dimension in inches.
- D. Body length and width dimensions are determined at the outermost extremes of the plastic body exclusive of mold flash, tie bar burrs, gate burrs, and interlead flash, but including any mismatch between the top and the bottom of the plastic body.
- E. Lead width dimension does not include dambar protrusion.
- F. Lead width and thickness dimensions apply to solder plated leads.
- G. Interlead flash allow 0.008 inch max.
- H. Gate burr/protrusion max. 0.006 inch.
- I. Datums A and B are to be determined at Datum H.

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