

## 150-mA LOW-NOISE LDO WITH IN-RUSH CURRENT CONTROL FOR USB APPLICATION

### FEATURES

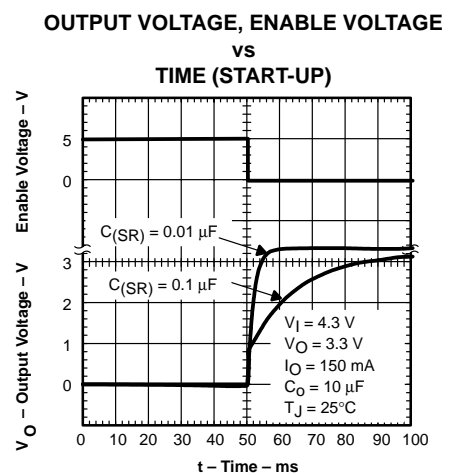
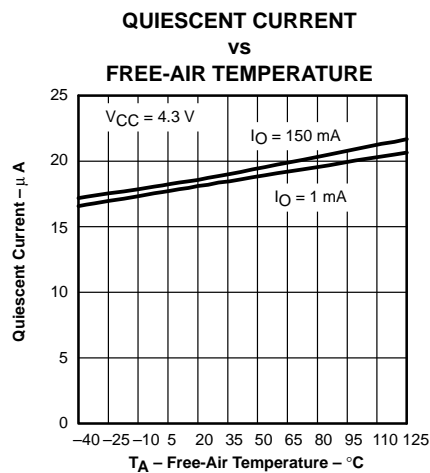
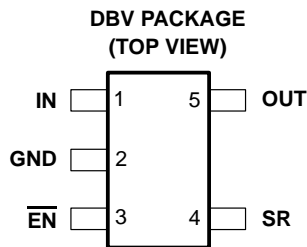
- 150-mA Low-Dropout Regulator
- Available in 2.5 V, 3.3 V
- Programmable Slew Rate Control
- Output Noise Typically 56  $\mu\text{V}_{\text{RMS}}$
- Only 17  $\mu\text{A}$  Quiescent Current at 150 mA
- 1  $\mu\text{A}$  Quiescent Current in Standby Mode
- Dropout Voltage Typically 150 mV at 150 mA (TPS78833)
- Over Current Limitation
- $-40^{\circ}\text{C}$  to  $125^{\circ}\text{C}$  Operating Junction Temperature Range
- 5-Pin SOT-23 (DBV) Package

### DESCRIPTION

The TPS78825 and TPS78833 are very small (SOT-23) package, low-noise LDOs that regulate the output voltage to 2.5 V and 3.3 V with input voltage ranging from 2.7 V to an absolute maximum of 13.5 V. These devices output 150 mA with a peak current of 350 mA (typ). The TPS788xx family uses the SR pin to program the output voltage slew rate to control the in-rush current. This is specifically used in the USB application where large load capacitance is present at start-up. The TPS788xx devices use only 17  $\mu\text{A}$  of quiescent current and exhibit only 56  $\mu\text{V}_{\text{RMS}}$  of output voltage noise using a 10  $\mu\text{F}$  output capacitor.

The usual PNP pass transistor has been replaced by a PMOS pass element. Because the PMOS pass element behaves as a low-value resistor, the dropout voltage is very low, typically 150 mV at 150 mA of load current, and is directly proportional to the load current.

The TPS788xx also features a logic-enabled sleep mode to shut down the regulator, reducing quiescent current to 1  $\mu\text{A}$  typical at  $T_J = 25^{\circ}\text{C}$ .



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

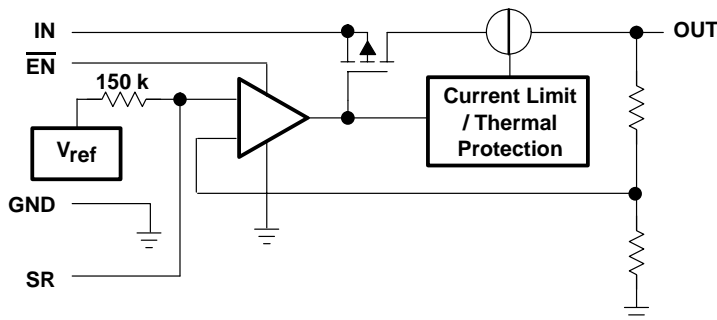
AVAILABLE OPTIONS

T <sub>J</sub>	VOLTAGE	PACKAGE	PART NUMBER		SYMBOL
-40°C to 125°C	2.5 V	SOT-23 (DBV)	TPS78825DBVT†	TPS78825DBVR‡	PGZI
	3.3 V		TPS78833DBVT	TPS78833DBVR	PGTI

† The DBVT indicates tape and reel of 250 parts.

‡ The DBVR indicates tape and reel of 3000 parts.

functional block diagram



Terminal Functions

TERMINAL NAME	NO.	I/O	DESCRIPTION
EN	3	I	Active low enable
GND	2		Regulator ground
IN	1	I	The IN terminal is the input to the device.
OUT	5	O	The OUT terminal is the regulated output of the device.
SR	4	I	The SR terminal is used to control the in-rush current.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)§

Input voltage range (see Note 1)	-0.3 V to 13.5 V
Voltage range at EN	-0.3 V to V <sub>I</sub> + 0.3 V
Voltage on OUT	7 V
Peak output current	Internally limited
ESD rating, HBM	2 kV
Continuous total power dissipation	See Dissipation Rating Table
Operating virtual junction temperature range, T <sub>J</sub>	-40°C to 150°C
Operating ambient temperature range, T <sub>A</sub>	-40°C to 85°C
Storage temperature range, T <sub>stg</sub>	-65°C to 150°C

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

NOTE 1: All voltage values are with respect to network ground terminal.

DISSIPATION RATING TABLE

BOARD	PACKAGE	R <sub>θJC</sub>	R <sub>θJA</sub>	DERATING FACTOR ABOVE T <sub>A</sub> = 25°C	T <sub>A</sub> ≤ 25°C POWER RATING	T <sub>A</sub> = 70°C POWER RATING	T <sub>A</sub> = 85°C POWER RATING
Low K†	DBV	65.8°C/W	259°C/W	3.9 mW/°C	386 mW	212 mW	154 mW
High K#	DBV	65.8°C/W	180°C/W	5.6 mW/°C	555 mW	305 mW	222 mW

† The JEDEC Low K (1s) board design used to derive this data was a 3 inch x 3 inch, two layer board with 2 ounce copper traces on top of the board.

# The JEDEC High K (2s2p) board design used to derive this data was a 3 inch x 3 inch, multilayer board with 1 ounce internal power and ground planes and 2 ounce copper traces on top and bottom of the board.

electrical characteristics over recommended operating free-air temperature range  $\overline{EN} = 0$ ,  
 $T_J = -40$  to  $125$  °C,  $V_I = V_O(\text{typ}) + 1$  V,  $I_O = 1$  mA,  $C_O = 4.7$   $\mu\text{F}$ ,  $C(\text{SR}) = 0.01$   $\mu\text{F}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_I$	Input voltage (see Note 2)		2.7		10	V
$I_O$	Continuous output current (see Note 3)		0		150	mA
$T_J$	Operating junction temperature		-40		125	°C
Output voltage	TPS78825	$T_J = 25^\circ\text{C}$		2.5		V
		$10 \mu\text{A} < I_O < 150 \text{ mA}, 3.5 \text{ V} < V_I < 10 \text{ V}$	2.425		2.575	
	TPS78833	$T_J = 25^\circ\text{C}$		3.3		
		$10 \mu\text{A} < I_O < 150 \text{ mA}, 3.8 \text{ V} < V_I < 10 \text{ V}$	3.201		3.399	
Quiescent current (GND current)	$10 \mu\text{A} < I_O < 450 \text{ mA}, T_J = 25^\circ\text{C}$			17		$\mu\text{A}$
	$10 \mu\text{A} < I_O < 150 \text{ mA}$				28	
Load regulation	$10 \mu\text{A} < I_O < 200 \text{ mA}, T_J = 25^\circ\text{C}$			12		mV
Output voltage line regulation ( $\Delta V_O/V_O$ ) (see Note 5)	$V_O + 1 \text{ V} < V_I \leq 10 \text{ V}, T_J = 25^\circ\text{C}$			0.04		%V
	$V_O + 1 \text{ V} < V_I \leq 10 \text{ V}$				0.1	
Output noise voltage (TPS78833)	BW = 200 Hz to 100 kHz, $I_O = 150 \text{ mA}$ , $T_J = 25^\circ\text{C}$ , $C_O = 10 \mu\text{F}$ , $C(\text{SR}) = 0.47 \mu\text{F}$			56		$\mu\text{V}_{\text{RMS}}$
Time, start-up (TPS78833)	$R_L = 22 \Omega$ , $C_O = 10 \mu\text{F}$ , $T_J = 25^\circ\text{C}$	$C(\text{byp}) = 0.01 \mu\text{F}$		10		ms
		$C(\text{byp}) = 0.1 \mu\text{F}$		50		
		$C(\text{byp}) = 0.47 \mu\text{F}$		300		
Output current limit	$V_O = 0 \text{ V}$ (see Note 4)			350	750	mA
Standby current	$EN = 0 \text{ V}, 2.7 \text{ V} < V_I < 10 \text{ V}$			1	2	$\mu\text{A}$
High level enable input voltage	$2.7 \text{ V} < V_I < 10 \text{ V}$		1.7			V
Low level enable input voltage	$2.7 \text{ V} < V_I < 10 \text{ V}$				0.9	V
Input current (EN)	$EN = 0$		-1		1	$\mu\text{A}$
Power supply ripple rejection	TPS78833	$f = 1 \text{ kHz}$ , $T_J = 25^\circ\text{C}$ , $C_O = 10 \mu\text{F}$	$C(\text{SL}) = 0.01 \mu\text{F}$ , $I_O = 150 \text{ mA}$ ,	70		dB
Dropout voltage (see Note 6)	TPS78833	$I_O = 150 \text{ mA}, T_J = 25^\circ\text{C}$		150		mV
		$I_O = 150 \text{ mA}$			300	

NOTES: 2. To calculate the minimum input voltage for your maximum output current, use the following formula:

$$V_I(\text{min}) = V_O(\text{max}) + V_{\text{DO}}(\text{max load})$$

- Continuous output current and operating junction temperature are limited by internal protection circuitry, but it is not recommended that the device operate under conditions beyond those specified in this table for extended periods of time.
- The minimum IN operating voltage is 2.7 V or  $V_O(\text{typ}) + 1$  V, whichever is greater. The maximum IN voltage is 5.5 V. The maximum output current is 200 mA.
- If  $V_O \leq 2.5$  V then  $V_{\text{Imin}} = 2.7$  V,  $V_{\text{Imax}} = 5.5$  V:

$$\text{Line regulation (mV)} = (\%/V) \times \frac{V_O(V_{\text{Imax}} - 2.7 \text{ V})}{100} \times 1000$$

If  $V_O > 2.5$  V then  $V_{\text{Imin}} = V_O + 1$  V,  $V_{\text{Imax}} = 5.5$  V.

- IN voltage equals  $V_O(\text{typ}) - 100$  mV

TYPICAL CHARACTERISTICS

OUTPUT VOLTAGE  
vs  
LOAD CURRENT

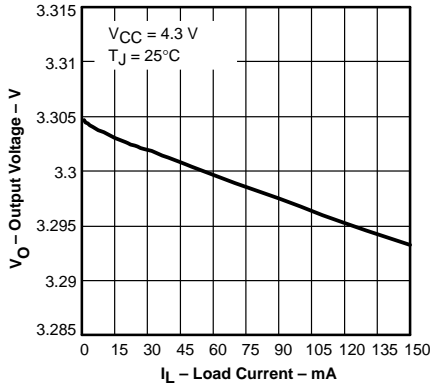


Figure 1

OUTPUT VOLTAGE  
vs  
FREE-AIR TEMPERATURE

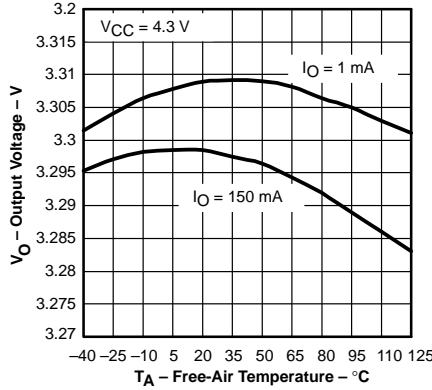


Figure 2

QUIESCENT CURRENT  
vs  
FREE-AIR TEMPERATURE

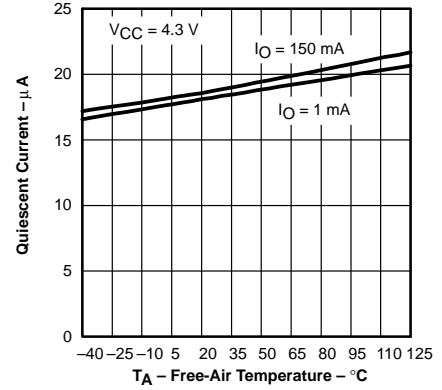


Figure 3

OUTPUT SPECTRAL NOISE DENSITY  
vs  
FREQUENCY

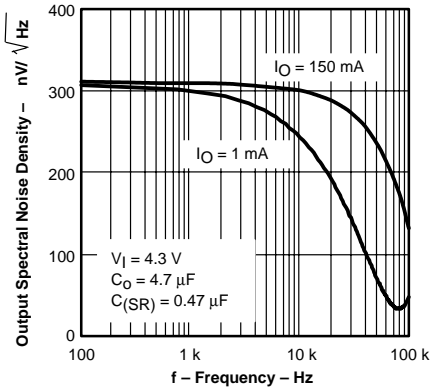


Figure 4

ROOT MEAN SQUARED OUTPUT NOISE  
vs  
SLEW RATE CAPACITANCE

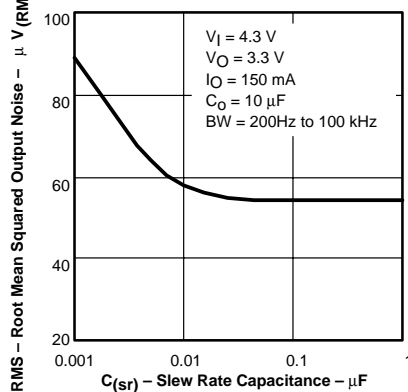


Figure 5

OUTPUT IMPEDANCE  
vs  
FREQUENCY

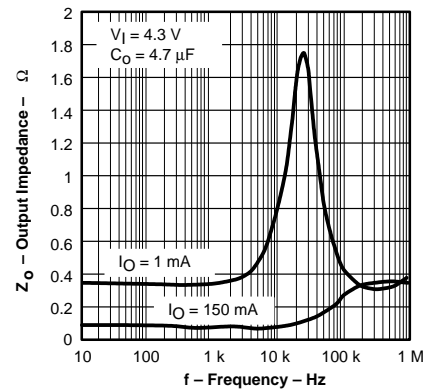


Figure 6

DROPOUT VOLTAGE  
vs  
FREE-AIR TEMPERATURE

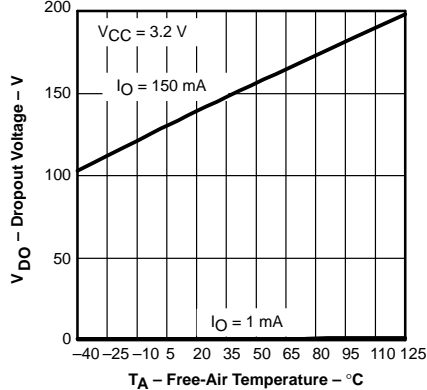


Figure 7

RIPPLE REJECTION  
vs  
FREQUENCY

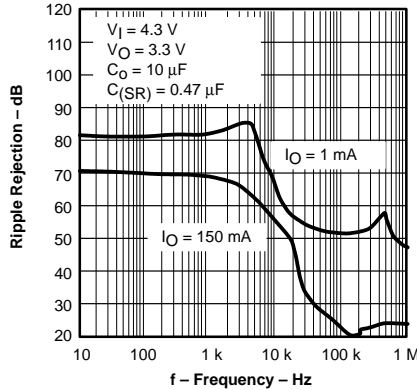


Figure 8

OUTPUT VOLTAGE, ENABLE VOLTAGE  
vs  
TIME (START-UP)

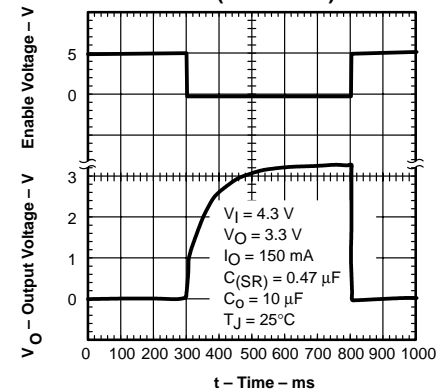


Figure 9

TYPICAL CHARACTERISTICS

OUTPUT VOLTAGE, ENABLE VOLTAGE  
vs  
TIME (START-UP)

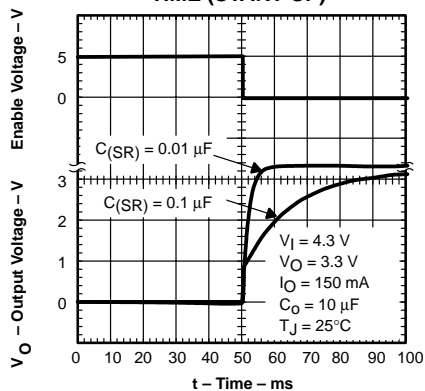


Figure 10

LINE TRANSIENT RESPONSE

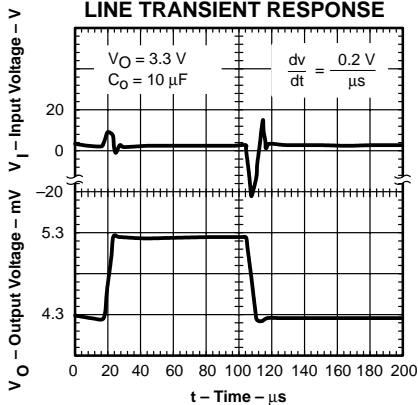


Figure 11

LOAD TRANSIENT RESPONSE

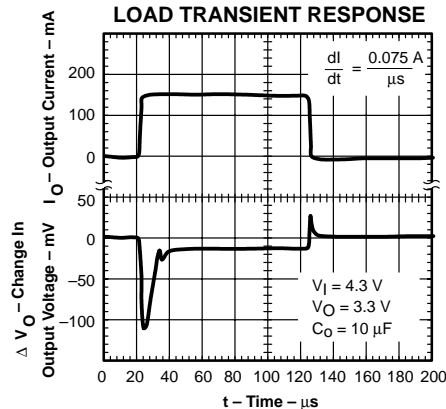


Figure 12

TYPICAL REGIONS OF STABILITY  
EQUIVALENT SERIES RESISTANCE (ESR)  
vs

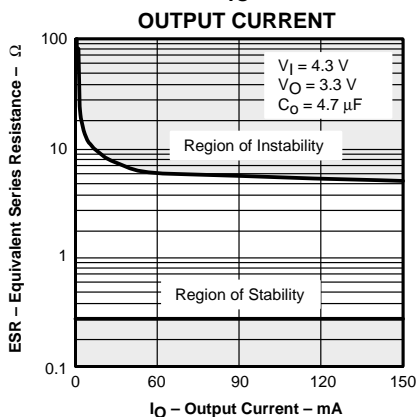


Figure 13

TYPICAL REGIONS OF STABILITY  
EQUIVALENT SERIES RESISTANCE (ESR)  
vs

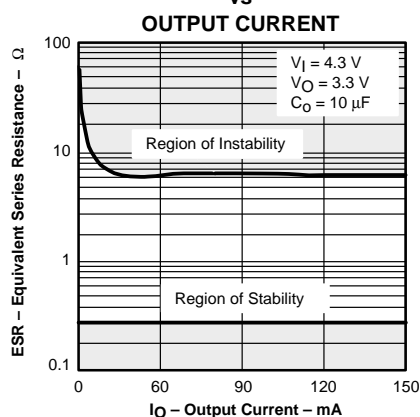
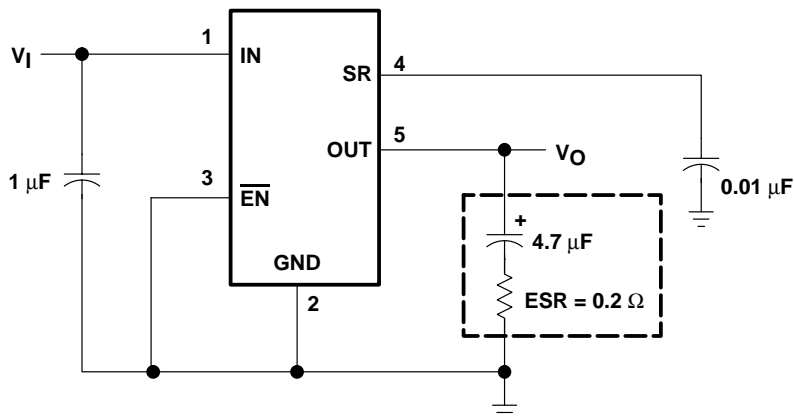


Figure 14

**APPLICATION INFORMATION**

The TPS788xx family of low-dropout (LDO) regulators has been optimized for use in battery-operated equipment. It features extremely low dropout voltages, low output noise, low quiescent current (17  $\mu$ A typically), and enable inputs to reduce supply currents to 1  $\mu$ A when the regulator is turned off. A typical application circuit is shown in Figure 15.



**Figure 15. Typical Application Circuit**

**external capacitor requirements**

Although not required, a 0.047- $\mu$ F or larger ceramic input bypass capacitor, connected between IN and GND and located close to the TPS788xx, is recommended to improve transient response and noise rejection. A higher-value electrolytic input capacitor may be necessary if large, fast-rise-time load transients are anticipated and the device is located several inches from the power source.

Like all low dropout regulators, the TPS788xx requires an output capacitor connected between OUT and GND to stabilize the internal control loop. The minimum recommended capacitance is 4.7  $\mu$ F. The ESR (equivalent series resistance) of the capacitor should be between 0.2  $\Omega$  and 10  $\Omega$ . to ensure stability. Capacitor values larger than 4.7  $\mu$ F are acceptable, and allow the use of smaller ESR values. Capacitances less than 4.7  $\mu$ F are not recommended because they require careful selection of ESR to ensure stability. Solid tantalum electrolytic, aluminum electrolytic, and multilayer ceramic capacitors are all suitable, provided they meet the requirements described above. Most of the commercially available 4.7  $\mu$ F surface-mount solid tantalum capacitors, including devices from Sprague, Kemet, and Nichico, meet the ESR requirements stated above. Multilayer ceramic capacitors may have very small equivalent series resistances and may thus require the addition of a low value series resistor to ensure stability.

**CAPACITOR SELECTION**

PART NO.	MFR.	VALUE	MAX ESR†	SIZE (H × L × W)†
T494B475K016AS	Kemet	4.7 $\mu$ F	1.5 $\Omega$	1.9 × 3.5 × 2.8
195D106x0016x2T	Sprague	10 $\mu$ F	1.5 $\Omega$	1.3 × 7.0 × 2.7
695D106x003562T	Sprague	10 $\mu$ F	1.3 $\Omega$	2.5 × 7.6 × 2.5
TPSC475K035R0600	AVX	4.7 $\mu$ F	0.6 $\Omega$	2.6 × 6.0 × 3.2

† Size is in mm. The ESR maximum resistance is in Ohms at 100 kHz and  $T_A = 25^\circ\text{C}$ . Contact the manufacturer for the minimum ESR values.

---

## APPLICATION INFORMATION

### external capacitor requirements (continued)

The external bypass capacitor, used in conjunction with an internal resistor to form a low-pass filter, should be a low ESR ceramic capacitor. For example, the TPS78833 exhibits only  $56 \mu\text{V}_{\text{RMS}}$  of output voltage noise using a  $0.01 \mu\text{F}$  ceramic bypass capacitor and a  $10\text{-}\mu\text{F}$  ceramic output capacitor. Note that the output will start up slower as the bypass capacitance increases due to the RC time constant at the bypass pin that is created by the internal  $150\text{-k}\Omega$  resistor and external capacitor.

### power dissipation and junction temperature

Specified regulator operation is assured to a junction temperature of  $125^\circ\text{C}$ ; the maximum junction temperature should be restricted to  $125^\circ\text{C}$  under normal operating conditions. This restriction limits the power dissipation the regulator can handle in any given application. To ensure the junction temperature is within acceptable limits, calculate the maximum allowable dissipation,  $P_{\text{D(max)}}$ , and the actual dissipation,  $P_{\text{D}}$ , which must be less than or equal to  $P_{\text{D(max)}}$ .

The maximum-power-dissipation limit is determined using the following equation:

$$P_{\text{D(max)}} = \frac{T_{\text{Jmax}} - T_{\text{A}}}{R_{\theta\text{JA}}}$$

Where:

$T_{\text{Jmax}}$  is the maximum allowable junction temperature.

$R_{\theta\text{JA}}$  is the thermal resistance junction-to-ambient for the package, see the dissipation rating table.

$T_{\text{A}}$  is the ambient temperature.

The regulator dissipation is calculated using:

$$P_{\text{D}} = (V_{\text{I}} - V_{\text{O}}) \times I_{\text{O}}$$

Power dissipation resulting from quiescent current is negligible. Excessive power dissipation will trigger the thermal protection circuit.

### regulator protection

The TPS788xx PMOS-pass transistor has a built-in back diode that conducts reverse current when the input voltage drops below the output voltage (e.g., during power down). Current is conducted from the output to the input and is not internally limited. If extended reverse voltage operation is anticipated, external limiting might be appropriate.

The TPS788xx features internal current limiting and thermal protection. During normal operation, the TPS78833 limits output current to approximately  $350 \text{ mA}$ . When current limiting engages, the output voltage scales back linearly until the overcurrent condition ends. While current limiting is designed to prevent gross device failure, care should be taken not to exceed the power dissipation ratings of the package. If the temperature of the device exceeds approximately  $165^\circ\text{C}$ , thermal-protection circuitry shuts it down. Once the device has cooled down to below approximately  $140^\circ\text{C}$ , regulator operation resumes.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<b>Products</b>		<b>Applications</b>	
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>	Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>	Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>	Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>	Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>	Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>	Energy	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>	Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>	Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>	Space, Avionics & Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
RF/IF and ZigBee® Solutions	<a href="http://www.ti.com/lprf">www.ti.com/lprf</a>	Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>
		Wireless	<a href="http://www.ti.com/wireless-apps">www.ti.com/wireless-apps</a>