TPS73101, TPS73115, TPS73118,
TPS73125, TPS73130, TPS73133,
TPS73150

SBVS034A – SEPTEMBER 2003 – REVISED NOVEMBER 2003

Cap-Free, NMOS, 150mA Low-Dropout Regulator with Reverse Current Protection

FEATURES

- No Output Capacitor Required for Stability
- Ultra-Low Dropout Voltage: 30mV typ
- Excellent Load Transient Response—with or without Optional Output Capacitor
- New NMOS Topology Delivers Low Reverse Leakage Current
- Low Noise: 30μV_{RMS} typ (10Hz to 100kHz)
- 1% Overall Accuracy Over Line, Load, and Temperature
- Less Than 1μA max I_Q in Shutdown Mode
- Thermal Shutdown and Current Limit Protection
- Available in Multiple Output Voltage Versions
  - Fixed Outputs of 1.5V, 1.8V, 2.5V, 3.0V, 3.3V, and 5.0V
  - Adjustable Outputs from 1.20V to 5.5V
  - Custom Outputs Available
- Small SOT23-5 Package

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

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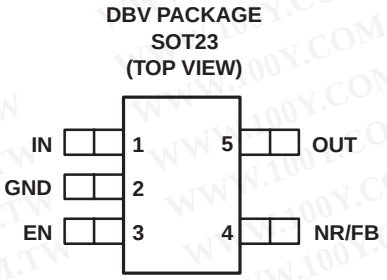
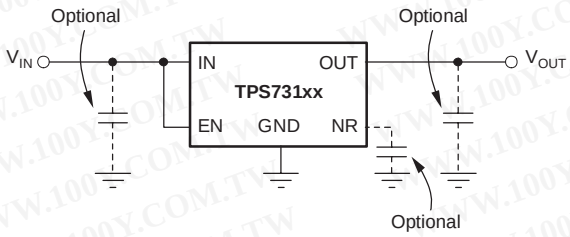
DESCRIPTION

The TPS731xx 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 even 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 TPS731xx uses an advanced BiCMOS process to yield high precision while delivering very low dropout voltages and low ground pin current. Current consumption, when not enabled, is under 1μA and ideal for portable applications. The extremely low output noise (30μV_{RMS} with 0.1μF C_{NR}) is ideal for powering VCOs. These devices are protected by thermal shutdown and foldback current limit.





Typical Application Circuit for Fixed Voltage Versions

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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.

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ORDERING INFORMATION

PRODUCT	V_{OUT}(1)	PACKAGE-LEAD (DESIGNATOR(2))	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
TPS73101	Adjustable	SOT23-5 (DBV)	−40°C to +125°C	PWYQ	TPS73101DBVT	Tape and Reel, 250
					TPS73101DBVR	Tape and Reel, 3000
TPS73115	1.5V	SOT23-5 (DBV)	−40°C to +125°C	T31	TPS73115DBVT	Tape and Reel, 250
					TPS73115DBVR	Tape and Reel, 3000
TPS73118	1.8V	SOT23-5 (DBV)	−40°C to +125°C	T32	TPS73118DBVT	Tape and Reel, 250
					TPS73118DBVR	Tape and Reel, 3000
TPS73125	2.5V	SOT23-5 (DBV)	−40°C to +125°C	PHWI	TPS73125DBVT	Tape and Reel, 250
					TPS73125DBVR	Tape and Reel, 3000
TPS73130	3.0V	SOT23-5 (DBV)	−40°C to +125°C	T33	TPS73130DBVT	Tape and Reel, 250
					TPS73130DBVR	Tape and Reel, 3000
TPS73133	3.3V	SOT23-5 (DBV)	−40°C to +125°C	T34	TPS73133DBVT	Tape and Reel, 250
					TPS73133DBVR	Tape and Reel, 3000
TPS73150	5.0V	SOT23-5 (DBV)	−40°C to +125°C	T35	TPS73150DBVT	Tape and Reel, 250
					TPS73150DBVR	Tape and Reel, 3000

(1) Custom output voltages from 1.3V to 4V in 100mV increments are available on a quick-turn basis for prototyping. Minimum order quantities apply; Contact factory for details and availability.
(2) For the most current specification and package information, refer to our web site at www.ti.com.

ABSOLUTE MAXIMUM RATINGS

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

	TPS731XX	UNIT
V_{IN} range	−0.3 to 6.0	V
V_{EN} range	−0.3 to 6.0	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 Rating table	
Junction temperature range, T_J	−55 to +150	°C
Storage temperature range	−65 to +150	°C
ESD rating, HBM	2	kV
ESD rating, 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.

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.

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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	3.9mW/°C	390mW	215mW	155mW
High K(3)	DBV	64°C/W	180°C/W	5.6mW/°C	560mW	310mW	225mW

(1) See Power Dissipation in the Applications section for more information related to thermal design.
(2) The JEDEC Low K (1s) board design used to derive this data was a 3inch x 3inch, 2-layer board with 2-ounce copper traces on top of the board.
(3) The JEDEC High K (2s2p) board design used to derive this data was a 3inch x 3inch, multilayer board with 1-ounce internal power and ground planes and 2-ounce copper traces on the top and bottom of the board.

ELECTRICAL CHARACTERISTICS

Over operating temperature range (T_J = −40°C to +125°C), V_{IN} = $V_{OUT(nom)}$ + 0.5V, I_{OUT} = 10mA, V_{EN} = 1.8V, and C_{OUT} = 0.1µF, unless otherwise noted. Typical values are at T_J = 25°C.

PARAMETER			TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{IN}	Input voltage range(1)			1.8		5.5	V
V_{FB}	Internal reference		T_J = 25°C	1.198	1.20	1.210	V
V_{OUT}	Output voltage range (TPS73101)			V_{FB}		5.0	V
	Accuracy	Nominal	T_J = 25°C	−0.5		+0.5	%
		over V_{IN}, I_{OUT}, and T	V_{OUT} + 0.5V ≤ V_{IN} ≤ 5.5V; 10mA ≤ I_{OUT} ≤ 150mA;	−1	±0.5	+1	%
$\Delta V_O\%/\Delta V_I$	Line regulation		$V_{OUT(nom)}$ + 0.5V ≤ V_{IN} ≤ 5.5V		0.01		%/V
$\Delta V_O\%/\Delta I_O$	Load regulation		1mA ≤ I_{OUT} ≤ 150mA		0.002		%/mA
			10mA ≤ I_{OUT} ≤ 150mA		0.0005		%/mA
V_{DO}	Dropout voltage(2) (V_{IN} = $V_{OUT(nom)}$ − 0.1V)		I_{OUT} = 150mA		30	100	mV
Z_O(DO)	Output impedance in dropout		1.8V ≤ V_{IN} ≤ V_{OUT} + V_{DO}		0.25		Ω
I_{CL}	Output current limit		V_{OUT} = 0.9 × $V_{OUT(nom)}$	150	360	500	mA
I_{SC}	Short-circuit current		V_{OUT} = 0V		200		mA
I_{REV}	Reverse leakage current(3) (−I_{IN})		V_{EN} ≤ 0.5V, 0V ≤ V_{IN} ≤ V_{OUT}		0.1	10	µA
I_{GND}	Ground pin current		I_{OUT} = 10mA (I_Q)		400	550	µA
			I_{OUT} = 150mA		550	750	µA
I_{SHDN}	Shutdown current (I_{GND})		V_{EN} ≤ 0.5V, V_{OUT} ≤ V_{IN} ≤ 5.5		0.02	1	µA
I_{FB}	FB pin current (TPS73101)				100	300	nA
PSRR	Power-supply rejection ratio (ripple rejection)		f = 100Hz, I_{OUT} = 150mA		58		dB
			f = 10KHz, I_{OUT} = 150mA		37		dB
V_N	Output noise voltage BW = 10Hz – 100KHz		C_{OUT} = 10µF, No C_{NR}		27 × V_{OUT}		μV_{RMS}
			C_{OUT} = 10µF, C_{NR} = 0.01µF		8.5 × V_{OUT}		μV_{RMS}
t_{STR}	Startup time		V_{OUT} = 3V, R_L = 30Ω C_{OUT} = 1µF, C_{NR} = 0.01µF		600		µs
V_{EN}(HI)	Enable high (enabled)			1.8			V
V_{EN}(LO)	Enable low (shutdown)					0.5	V
I_{EN}(HI)	Enable pin current (enabled)		V_{EN} = 5.5V		0.02	0.1	µA
T_{SD}	Thermal shutdown temperature		Shutdown, temperature increasing		160		°C
			Reset, temperature decreasing		140		°C
T_J	Operating junction temperature			−40		125	°C

(1) Minimum V_{IN} = V_{OUT} +V_{DO} or 1.8V, whichever is greater.
(2) V_{DO} is not measured for the TPS73115 ($V_{O(nom)}$ = 1.5V) since minimum V_{IN} = 1.8V.
(3) Refer to Applications section for more information.

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FUNCTIONAL BLOCK DIAGRAMS

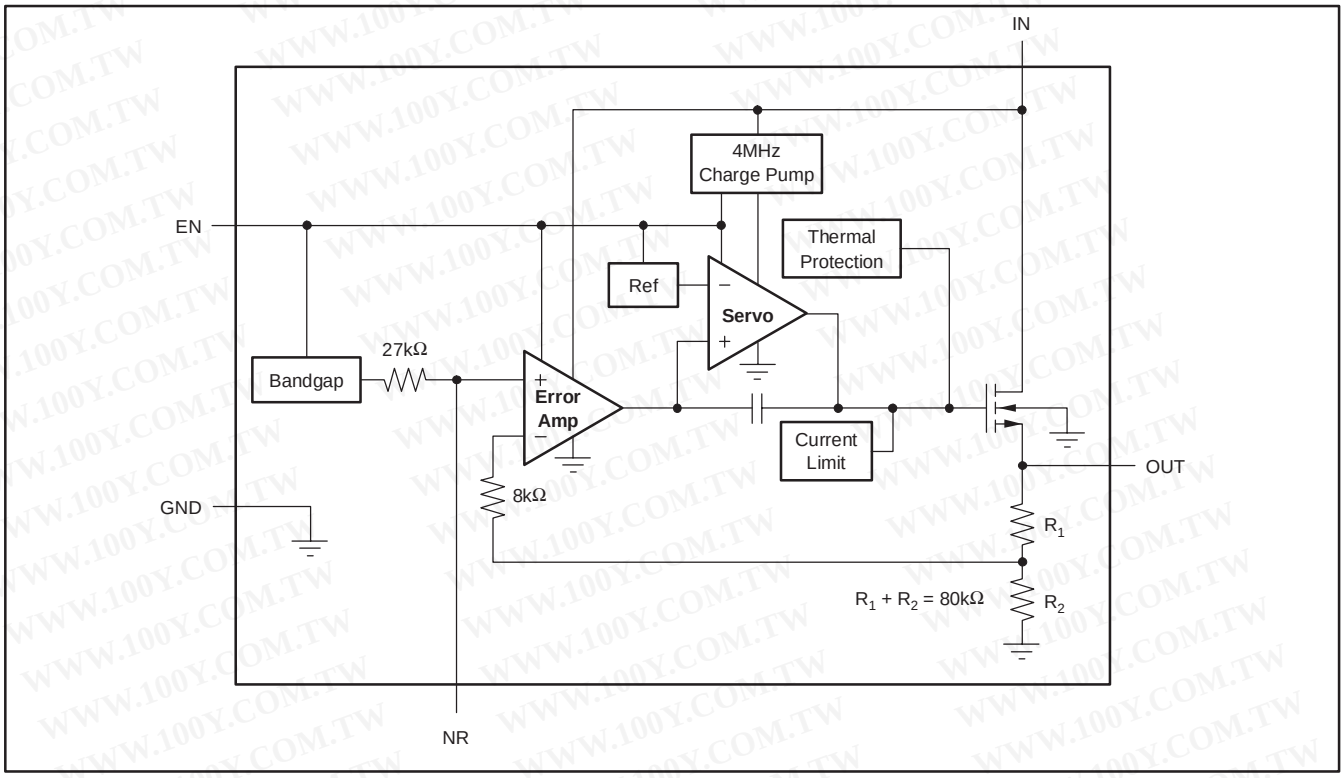


Figure 1. Fixed Voltage Version

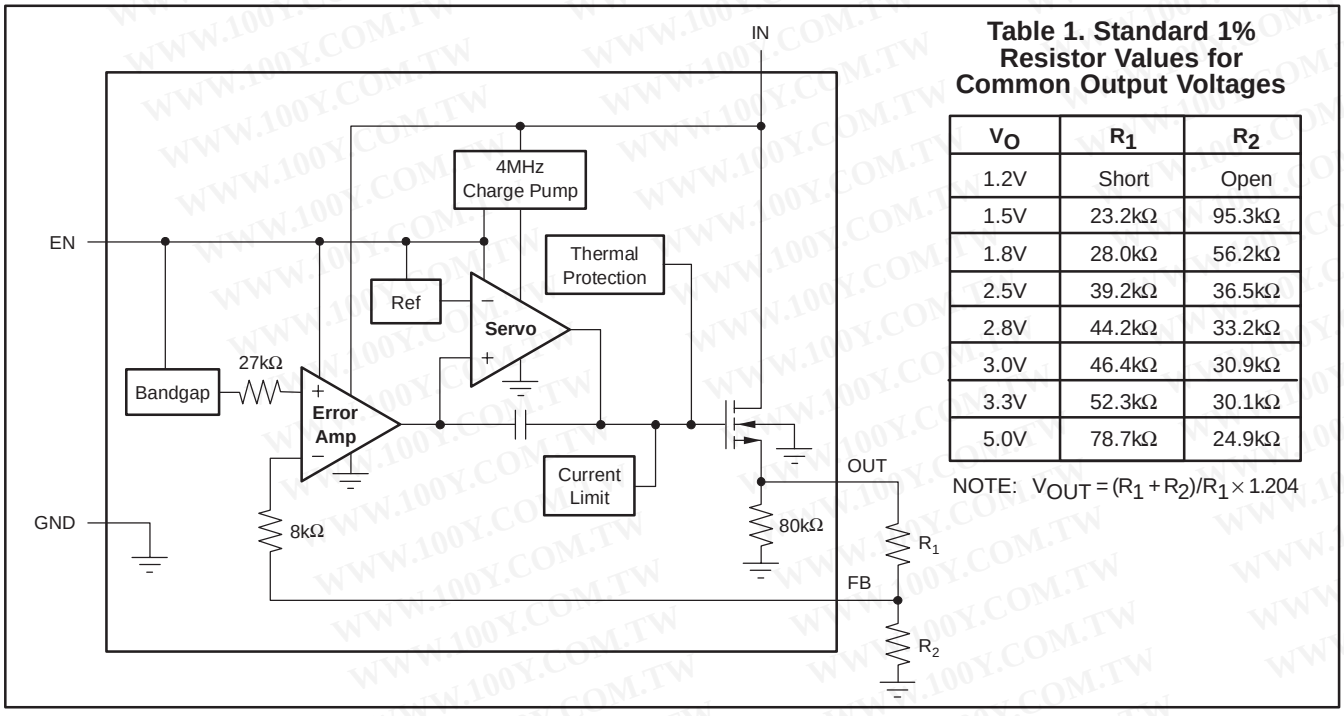


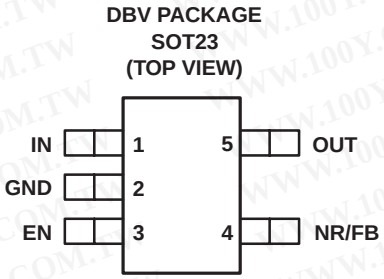
Figure 2. Adjustable Voltage Version

Table 1. Standard 1% Resistor Values for Common Output Voltages

V_O	R_1	R_2
1.2V	Short	Open
1.5V	23.2kΩ	95.3kΩ
1.8V	28.0kΩ	56.2kΩ
2.5V	39.2kΩ	36.5kΩ
2.8V	44.2kΩ	33.2kΩ
3.0V	46.4kΩ	30.9kΩ
3.3V	52.3kΩ	30.1kΩ
5.0V	78.7kΩ	24.9kΩ

NOTE: $V_{OUT} = (R_1 + R_2)/R_1 \times 1.204$

PIN ASSIGNMENTS



Terminal Functions

TERMINAL NAME	TERMINAL NO.	DESCRIPTION
IN	1	Unregulated input supply
GND	2	Ground
EN	3	Driving the enable pin (EN) high turns on the regulator. Driving this pin low puts the regulator into shutdown mode. Refer to the Shutdown section under Applications Information for more details. EN can be connected to IN if not used.
NR	4	Fixed voltage versions only—connecting an external capacitor to this pin bypasses noise generated by the internal bandgap, reducing output noise to very low levels.
FB	4	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	Output of the regulator. There are no output capacitor requirements for stability.

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TYPICAL CHARACTERISTICS

For all voltage versions, at T_J = +25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5V, I_{OUT} = 10mA, V_{EN} = 1.8V, and C_{OUT} = 0.1µF, unless otherwise noted.

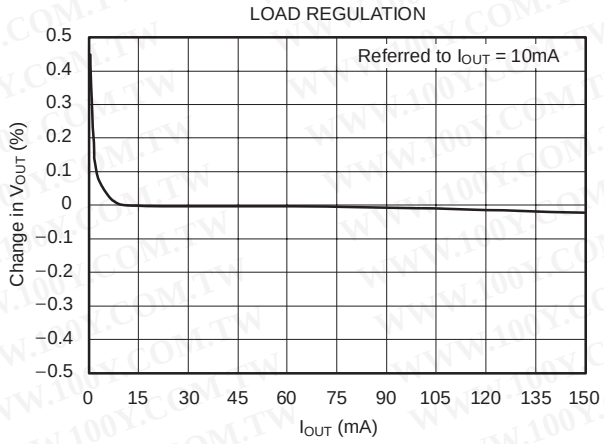


Figure 3

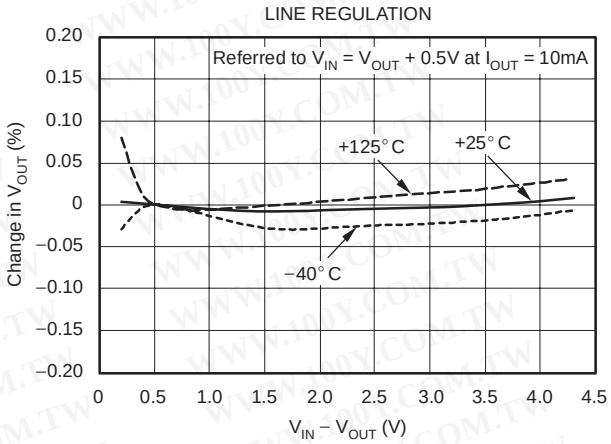
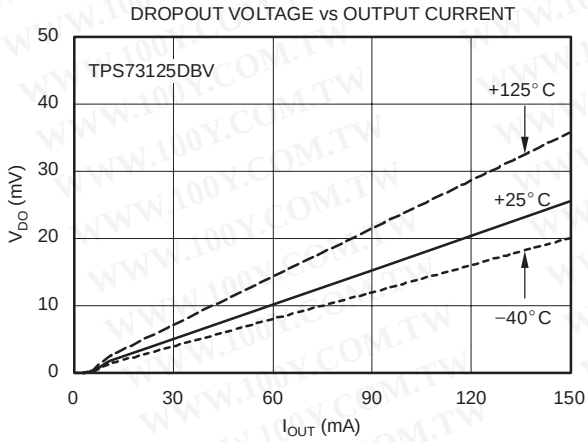


Figure 4



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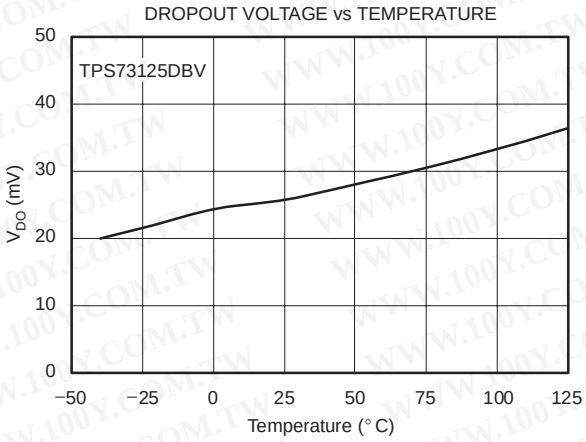

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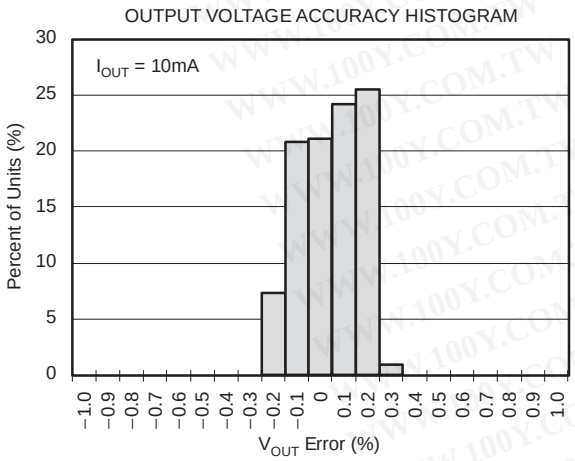

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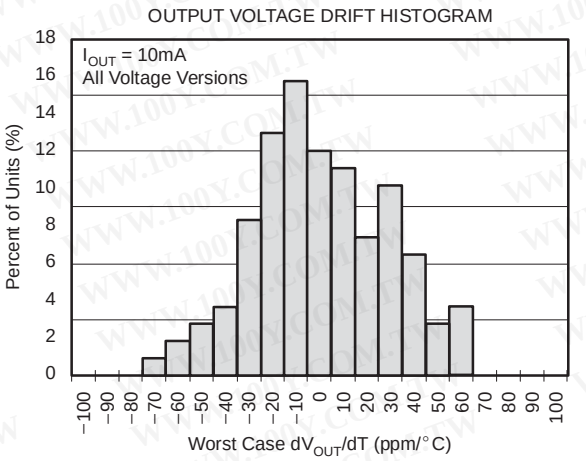

Figure 8

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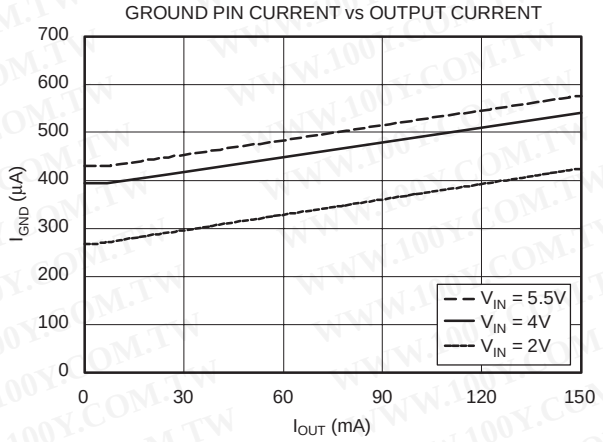
TYPICAL CHARACTERISTICS (continued)

For all voltage versions, at T_J = +25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5V, I_{OUT} = 10mA, V_{EN} = 1.8V, and C_{OUT} = 0.1µF, unless otherwise noted.



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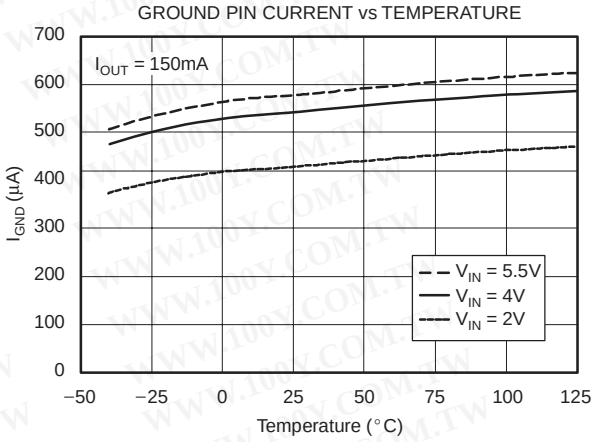

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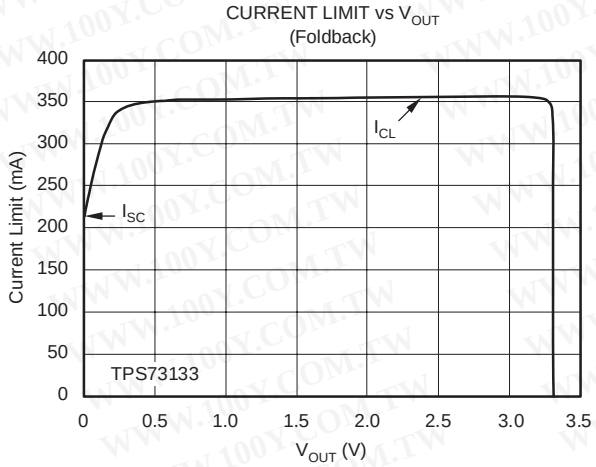

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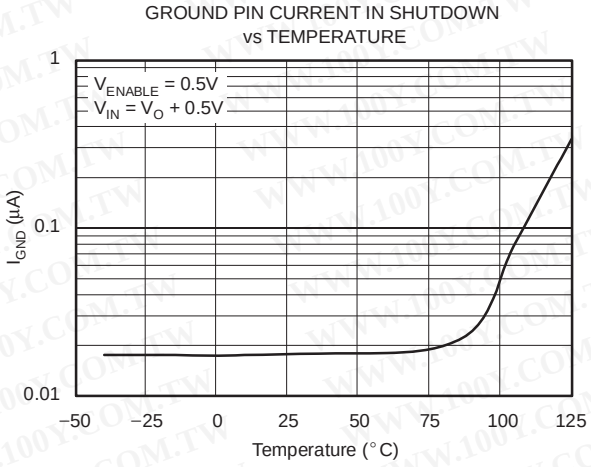

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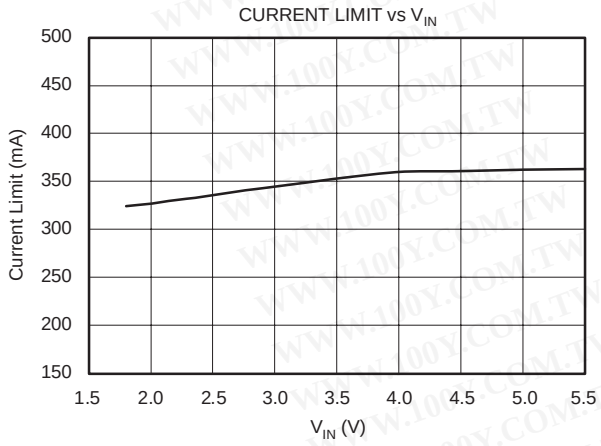

Figure 13

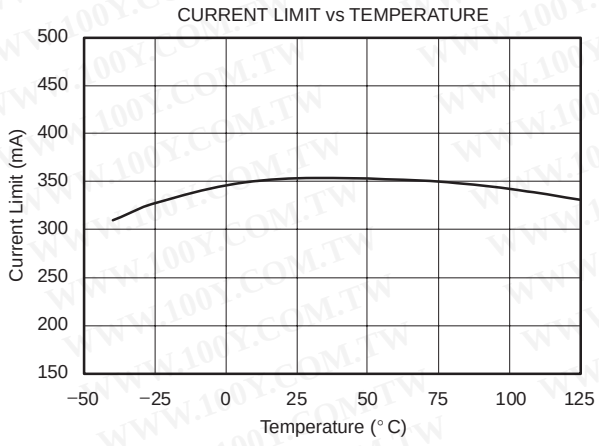

Figure 14

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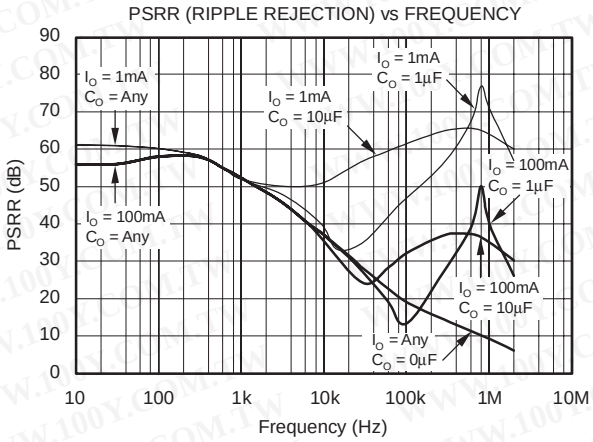


Figure 15

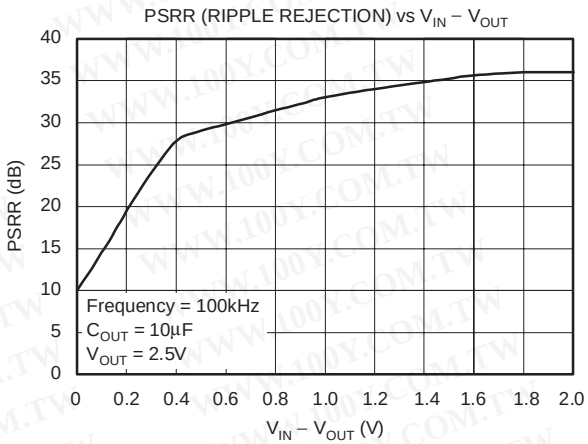
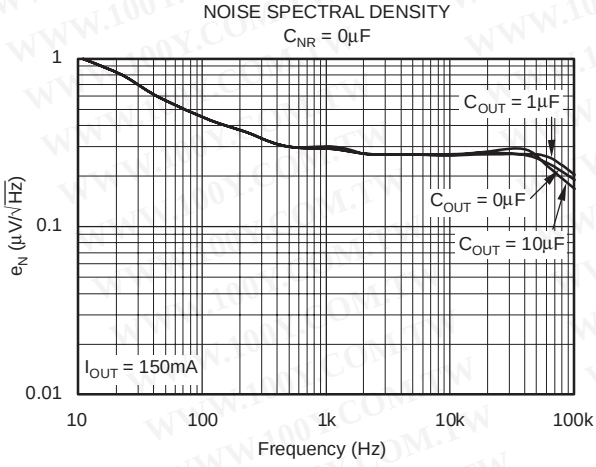


Figure 16



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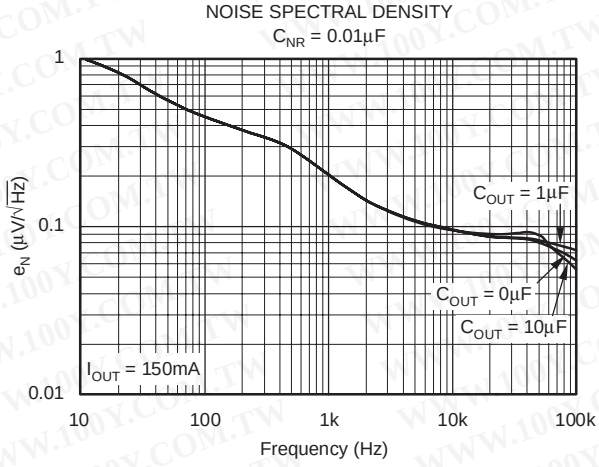

Figure 18

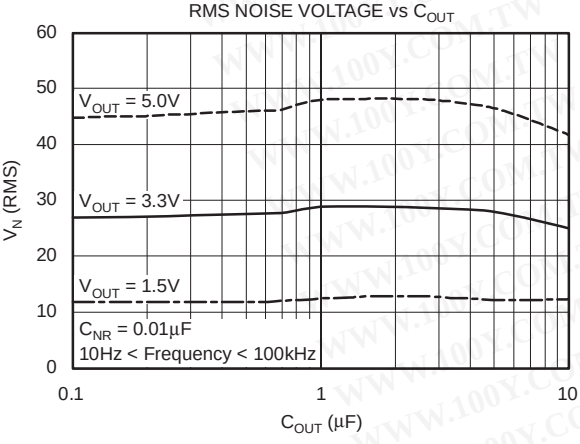

Figure 19

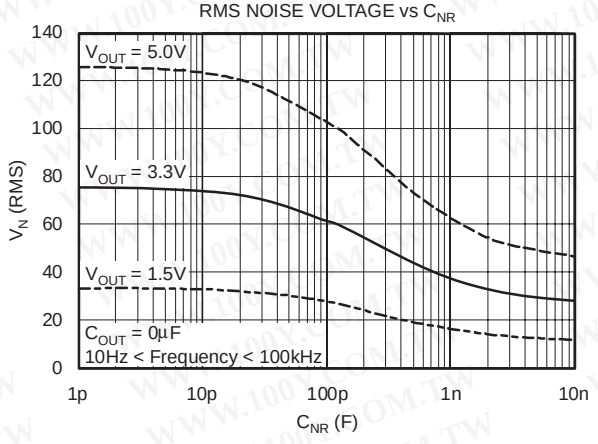

Figure 20

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TPS73133
LOAD TRANSIENT RESPONSE

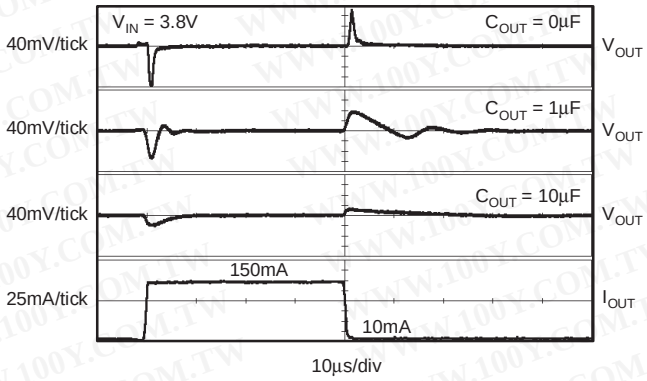

Figure 21

TPS73133
LINE TRANSIENT RESPONSE

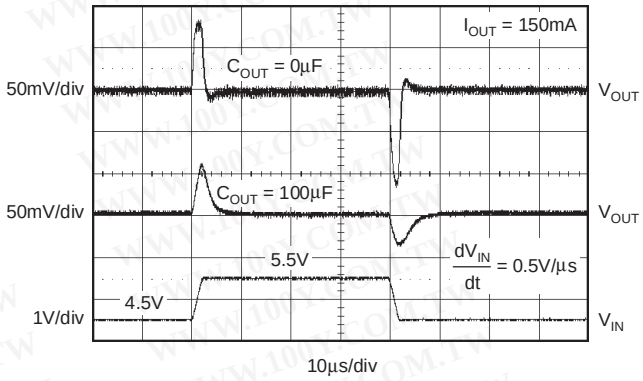

Figure 22

TPS73133
TURN-ON RESPONSE

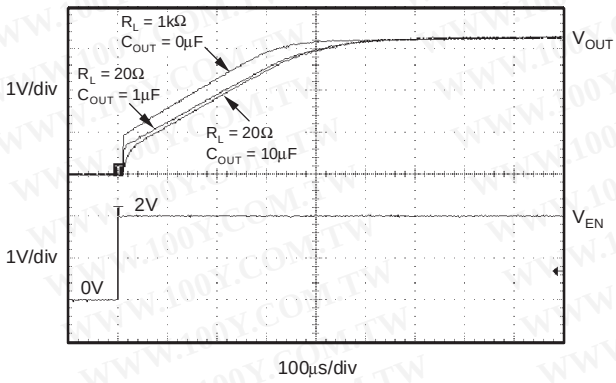

Figure 23

TPS73133
TURN-OFF RESPONSE

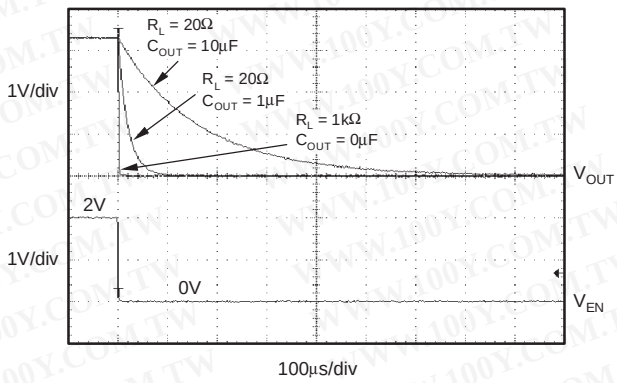

Figure 24

TPS73133
POWER UP/POWER DOWN

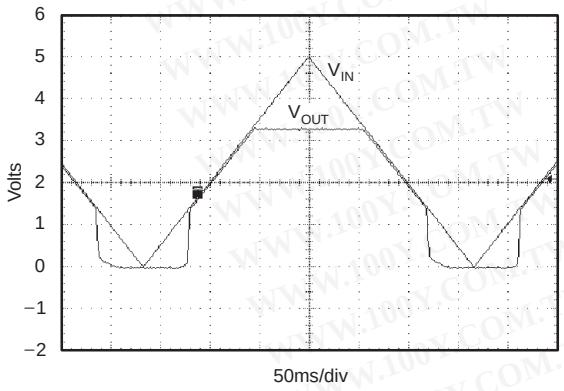

Figure 25

I_{ENABLE} vs TEMPERATURE

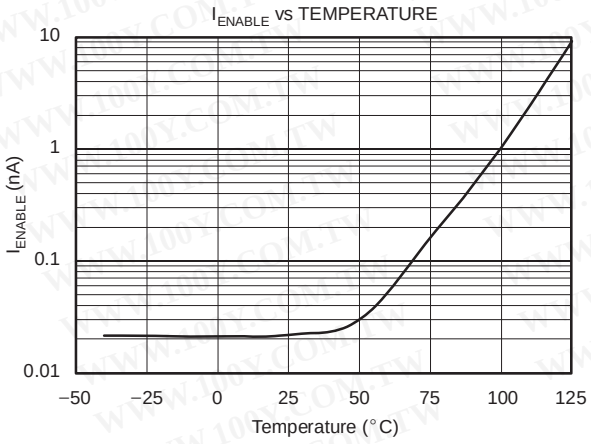

Figure 26

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TYPICAL CHARACTERISTICS (continued)

For all voltage versions, at T_J = +25°C, V_{IN} = $V_{OUT(nom)}$ + 0.5V, I_{OUT} = 10mA, V_{EN} = 1.8V, and C_{OUT} = 0.1µF, unless otherwise noted.

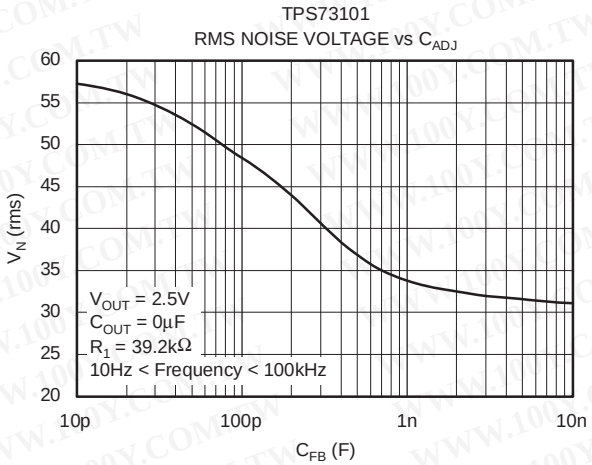

Figure 27

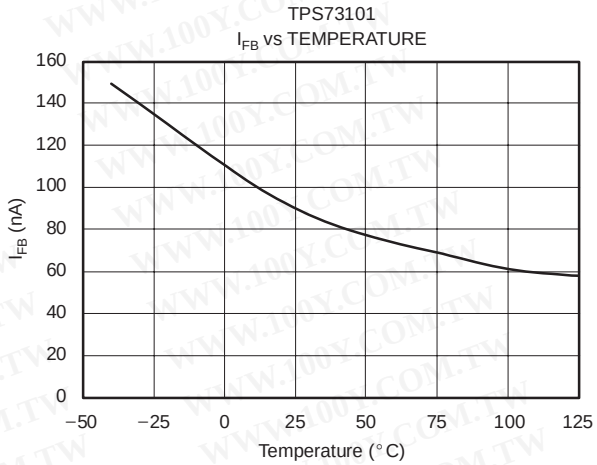

Figure 28

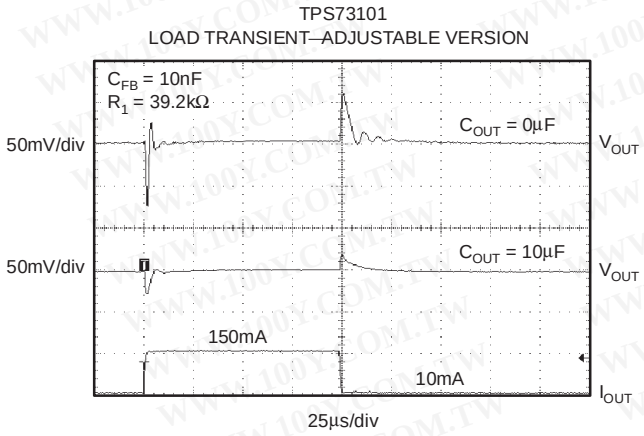

Figure 29

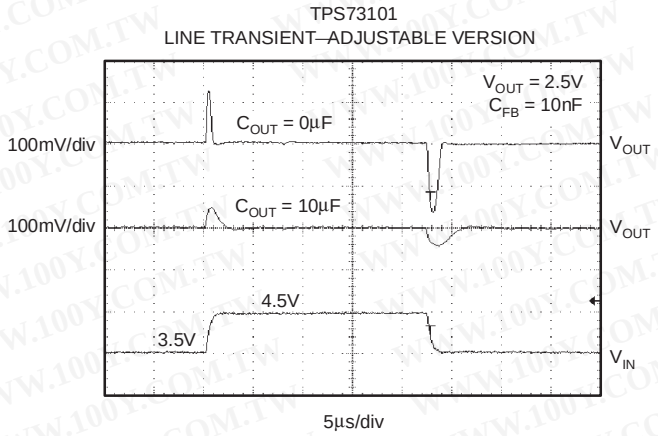

Figure 30

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APPLICATION INFORMATION

The TPS731xx 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 TPS731xx 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 over-current protection, including foldback current limit.

Figure 31 shows the basic circuit connections for the fixed voltage models. Figure 32 gives the connections for the adjustable output version (TPS73101). R_1 and R_2 can be calculated for any output voltage using the formula shown in Figure 32. Sample resistor values for common output voltages are shown in Figure 2.

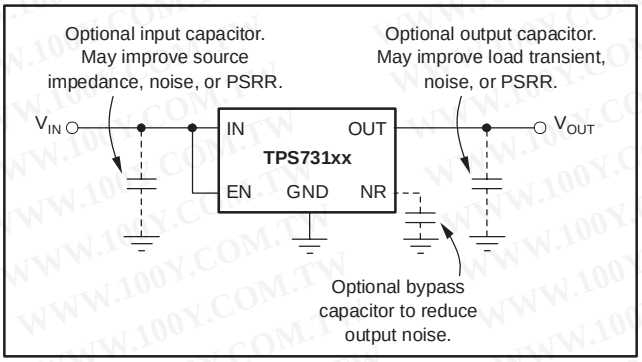

Figure 31. Typical Application Circuit for Fixed-Voltage Versions

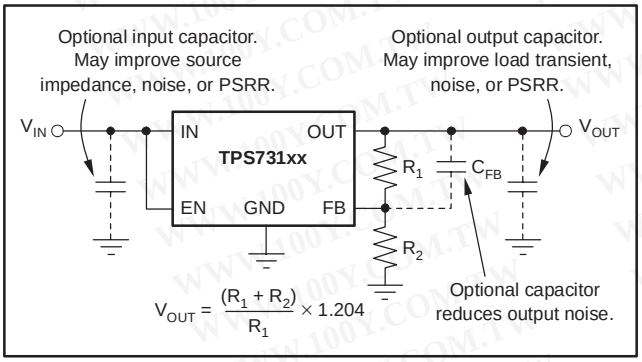

Figure 32. Typical Application Circuit for Adjustable-Voltage Versions

INPUT AND OUTPUT CAPACITOR REQUIREMENTS

Although an input capacitor is not required for stability, it is good analog design practice to connect a 0.1µF to 1µF low ESR capacitor across the input supply near the regulator. This will counteract reactive input sources and improve 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 TPS732xx does not require an output capacitor for stability. As with any regulator, some combinations of source impedance, board capacitance, trace inductance, and load capacitance and ESR can result in instability or ringing during transient response. If ringing or stability is seen to be an issue in a given application, the following should eliminate it:

- Using C_{OUT} values smaller than 10µF
- Keeping effective output ESR greater than 0.05Ω, including capacitor ESR and parasitic resistance in traces, solder joints, and sockets
- Making sure supply impedance is low (capacitors from IN to ground can ensure this)
- Minimize capacitance from FB to ground for the adjustable version (TPS73101)
- For light loads (I_{OUT} < 10mA) add a load resistor of value < 1kΩ

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 TPS731xx and it generates approximately $32\mu V_{RMS}$ (10Hz to 100kHz) 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 1.2V, 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 27kΩ 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} = 10nF, the total noise in the 10Hz to 100kHz 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} = 10nF.

This noise reduction effect is shown as RMS Noise Voltage vs C_{NR} in the Typical Characteristics section.

The TPS73101 adjustable version does not have the noise-reduction pin available. However, connecting a feedback capacitor, C_{FB} , from the output to the FB pin will reduce output noise and improve load transient performance.

The TPS731xx 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 ~250µV of switching noise at ~4MHz; 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 TPS731xx internal current limit helps protect the regulator during fault conditions. Foldback current limit helps to protect the regulator from damage during output short-circuit conditions by reducing current limit when V_{OUT} drops below 0.5V. See Figure 11 in the Typical Characteristics section for a graph of I_{OUT} vs V_{OUT}.

SHUTDOWN

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

DROPOUT VOLTAGE

The TPS731xx 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 TPS731xx requires a larger voltage drop across it 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 insure 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 TPS731xx 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 1µF) from the output pin to ground will reduce undershoot magnitude but increase duration. In the adjustable version, the addition of a capacitor, C_{FB}, from the output to the adjust pin will also improve the transient response.

The TPS731xx does not have active pull-down when the output is over-voltage. 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 the 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)

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

(Adjustable Voltage Version)

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

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REVERSE CURRENT

The NMOS pass element of the TPS731xx 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, the enable pin 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 the enable pin 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 will be additional current flowing into the OUT pin due to the 80kΩ internal resistor divider to ground (see Figure 1 and Figure 2).

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 heat sink. For reliable operation, junction temperature should be limited to 125°C maximum. To estimate the margin of safety in a complete design (including heat sink), 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 your 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 TPS731xx has been designed to protect against overload conditions. It was not intended to replace proper heat sinking. Continuously running the TPS731xx into thermal shutdown will degrade reliability.

POWER DISSIPATION

The ability to remove heat from the die is different for each package type, presenting different considerations in the printed circuit-board 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 will increase the effectiveness in removing heat from the device. The addition of plated through-holes to heat-dissipating layers will improve the heat-sink 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 assure the required output voltage.

PACKAGE MOUNTING

Solder pad footprint recommendations for the TPS731xx are presented in Application Bulletin *Solder Pad Recommendations for Surface-Mount Devices* (AB-132), available from the Texas Instruments web site at www.ti.com.

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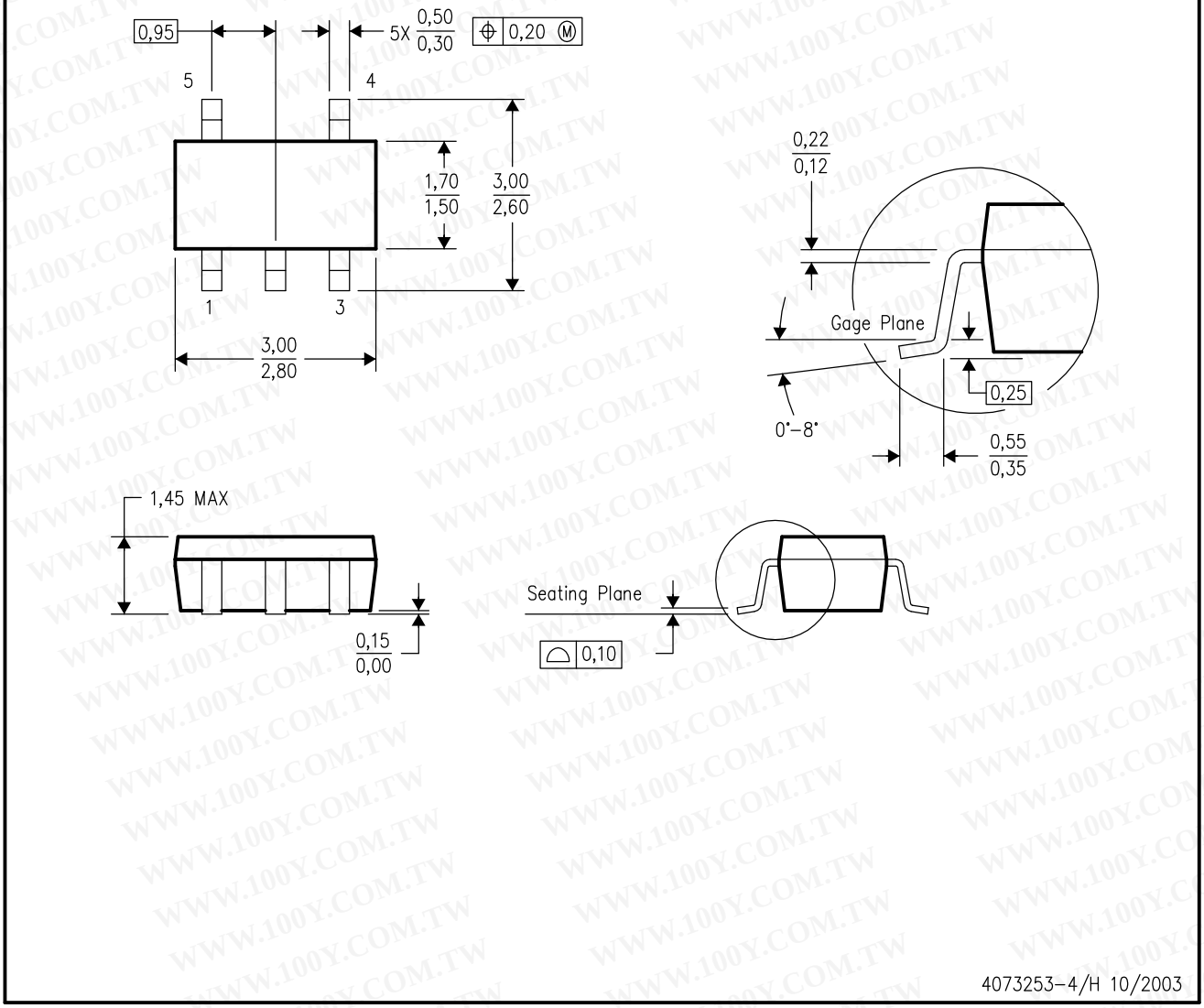
DBV (R–PDSO–G5) PLASTIC SMALL–OUTLINE PACKAGE



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

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