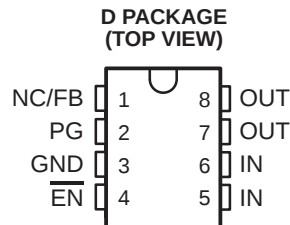


TPS76515, TPS76518, TPS76525, TPS76527
TPS76528, TPS76530, TPS76533, TPS76550, TPS76501

ULTRA-LOW QUIESCIENT CURRENT 150-mA LOW-DROPOUT VOLTAGE REGULATORS

SLVS236 – AUGUST 1999

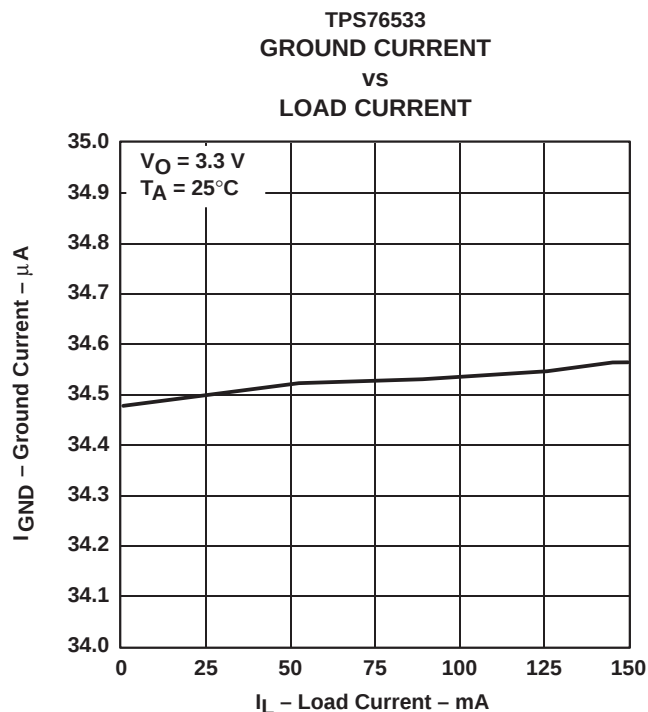
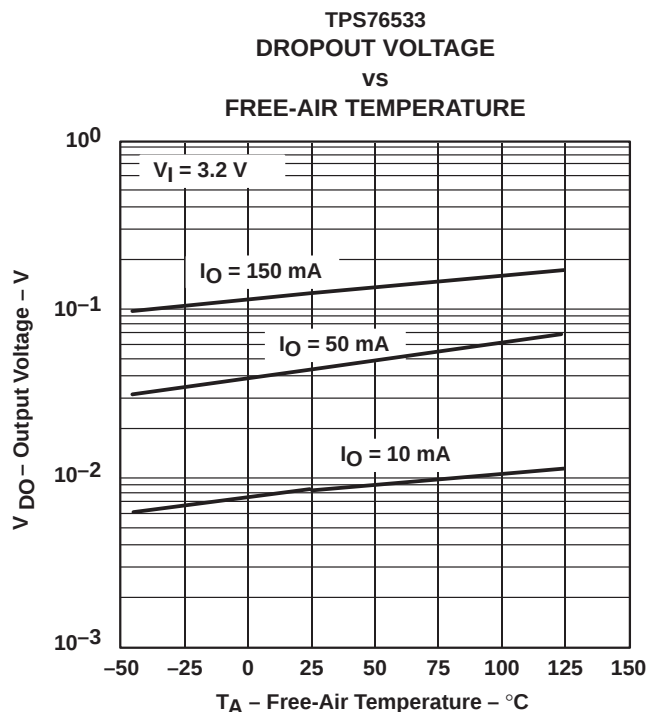
- 150-mA Low-Dropout Voltage Regulator
- Available in 1.5-V, 1.8-V, 2.5-V, 2.7-V, 2.8-V, 3.0-V, 3.3-V, 5.0-V Fixed Output and Adjustable Versions
- Dropout Voltage to 85 mV (Typ) at 150 mA (TPS76550)
- Ultra-Low 35- μ A Typical Quiescent Current
- 3% Tolerance Over Specified Conditions for Fixed-Output Versions
- Open Drain Power Good
- 8-Pin SOIC Package
- Thermal Shutdown Protection



description

This device is designed to have an ultra-low quiescent current and be stable with a 4.7- μ F capacitor. This combination provides high performance at a reasonable cost.

Because the PMOS device behaves as a low-value resistor, the dropout voltage is very low (typically 85 mV at an output current of 150 mA for the TPS76550) and is directly proportional to the output current. Additionally, since the PMOS pass element is a voltage-driven device, the quiescent current is very low and independent of output loading (typically 35 μ A over the full range of output current, 0 mA to 150 mA). These two key specifications yield a significant improvement in operating life for battery-powered systems. This LDO family also features a sleep mode; applying a TTL high signal to $\overline{\text{EN}}$ (enable) shuts down the regulator, reducing the quiescent current to less than 1 μ A (typ).



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.

**TEXAS
INSTRUMENTS**

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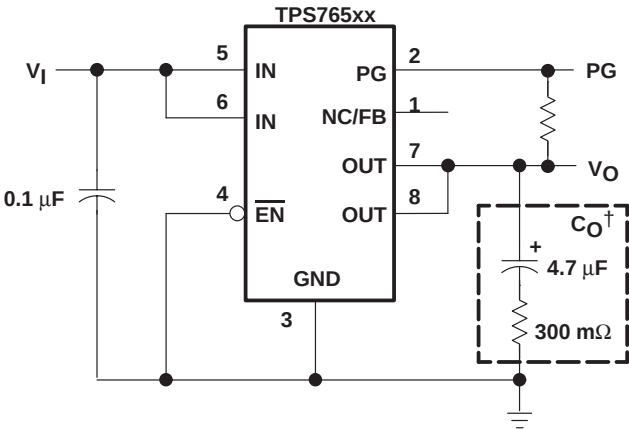
description (continued)

Power good (PG) is an active high output, which can be used to implement a power-on reset or a low-battery indicator.

The TPS765xx is offered in 1.5-V, 1.8-V, 2.5-V, 2.7-V, 2.8-V, 3.0-V, 3.3-V and 5.0-V fixed-voltage versions and in an adjustable version (programmable over the range of 1.25 V to 5.5 V). Output voltage tolerance is specified as a maximum of 3% over line, load, and temperature ranges. The TPS765xx family is available in 8 pin SOIC package.

AVAILABLE OPTIONS		
T _J	OUTPUT VOLTAGE (V)	PACKAGED DEVICES
	TYP	SOIC (D)
–40°C to 125°C	5.0	TPS76550D
	3.3	TPS76533D
	3.0	TPS76530D
	2.8	TPS76528D
	2.7	TPS76527D
	2.5	TPS76525D
	1.8	TPS76518D
	1.5	TPS76515D
	Adjustable 1.25 V to 5.5 V	TPS76501D

The TPS76501 is programmable using an external resistor divider (see application information). The D package is available taped and reeled. Add an R suffix to the device type (e.g., TPS76501DR).



† See application information section for capacitor selection details.

Figure 1. Typical Application Configuration for Fixed Output Options

[illegible]

Terminal Functions – SOIC Package

TERMINAL NAME	NO.	I/O	DESCRIPTION
$\overline{\text{EN}}$	4	I	Enable input
FB/NC	1	I	Feedback input voltage for adjustable device (no connect for fixed options)
GND	3		Regulator ground
IN	5	I	Input voltage
IN	6	I	Input voltage
OUT	7	O	Regulated output voltage
OUT	8	O	Regulated output voltage
PG	2	O	PG output

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)[†]

Input voltage range [‡] , V_I	–0.3 V to 13.5 V
Voltage range at $\overline{\text{EN}}$	–0.3 V to 16.5 V
Maximum PG voltage	16.5 V
Peak output current	Internally limited
Continuous total power dissipation	See dissipation rating tables
Output voltage, V_O (OUT, FB)	7 V
Operating virtual junction temperature range, T_J	–40°C to 125°C
Storage temperature range, T_{stg}	–65°C to 150°C
ESD rating, HBM	2 kV

[†] 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.

[‡] All voltage values are with respect to network terminal ground.

DISSIPATION RATING TABLE 1 – FREE-AIR TEMPERATURES

PACKAGE	AIR FLOW (CFM)	$T_A < 25^\circ\text{C}$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25^\circ\text{C}$	$T_A = 70^\circ\text{C}$ POWER RATING	$T_A = 85^\circ\text{C}$ POWER RATING
D	0	568 mW	5.68 mW/°C	312 mW	227 mW
	250	904 mW	9.04 mW/°C	497 mW	361 mW

recommended operating conditions

	MIN	MAX	UNIT
Input voltage, V_I [☆]	2.7	10	V
Output voltage range, V_O	1.2	5.5	V
Output current, I_O (Note 1)	0	150	mA
Operating virtual junction temperature, T_J (Note 1)	–40	125	°C

[☆] To calculate the minimum input voltage for your maximum output current, use the following equation: $V_{I(\text{min})} = V_{O(\text{max})} + V_{\text{DO}(\text{max load})}$.

NOTE 1: Continuous 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.

**TPS76515, TPS76518, TPS76525, TPS76527
TPS76528, TPS76530, TPS76533, TPS76550, TPS76501**
ULTRA-LOW QUIESCIENT CURRENT 150-mA LOW-DROPOUT VOLTAGE REGULATORS

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**electrical characteristics over recommended operating free-air temperature range,
 $V_i = V_{O(typ)} + 1\text{ V}$, $I_O = 10\text{ }\mu\text{A}$, $\overline{\text{EN}} = 0\text{ V}$, $C_O = 4.7\text{ }\mu\text{F}$ (unless otherwise noted)**

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Output voltage (10 μA to 150 mA load) (see Note 2)	TPS76501	5.5 V ≥ V _O ≥ 1.25 V, T _J = 25°C		V _O			V
		5.5 V ≥ V _O ≥ 1.25 V, T _J = −40°C to 125°C		0.97V _O 1.03V _O			
	TPS76515	T _J = 25°C, 2.7 V < V _{IN} < 10 V		1.5			
		T _J = −40°C to 125°C, 2.7 V < V _{IN} < 10 V		1.455 1.545			
	TPS76518	T _J = 25°C, 2.8 V < V _{IN} < 10 V		1.8			
		T _J = −40°C to 125°C, 2.8 V < V _{IN} < 10 V		1.746 1.854			
	TPS76525	T _J = 25°C, 3.5 V < V _{IN} < 10 V		2.5			
		T _J = −40°C to 125°C, 3.5 V < V _{IN} < 10 V		2.425 2.575			
	TPS76527	T _J = 25°C, 3.7 V < V _{IN} < 10 V		2.7			
		T _J = −40°C to 125°C, 3.7 V < V _{IN} < 10 V		2.619 2.781			
	TPS76528	T _J = 25°C, 3.8 V < V _{IN} < 10 V		2.8			
		T _J = −40°C to 125°C, 3.8 V < V _{IN} < 10 V		2.716 2.884			
	TPS76530	T _J = 25°C, 4.0 V < V _{IN} < 10 V		3.0			
		T _J = −40°C to 125°C, 4.0 V < V _{IN} < 10 V		2.910 3.090			
	TPS76533	T _J = 25°C, 4.3 V < V _{IN} < 10 V		3.3			
		T _J = −40°C to 125°C, 4.3 V < V _{IN} < 10 V		3.201 3.399			
	TPS76550	T _J = 25°C, 6.0 V < V _{IN} < 10 V		5.0			
		T _J = −40°C to 125°C, 6.0 V < V _{IN} < 10 V		4.850 5.150			
Quiescent current (GND current) EN = 0V, (see Note 2)		10 μA < I _O < 150 mA, T _J = 25°C		35			μA
		I _O = 150 mA, T _J = −40°C to 125°C		50			
Output voltage line regulation (ΔV _O /V _O) (see Notes 2 and 3)		V _O + 1 V < V _I ≤ 10 V, T _J = 25°C		0.01			%/V
Load regulation		I _O = 10 μA to 150 mA		0.3%			
Output noise voltage		BW = 300 Hz to 50 kHz, C _O = 4.7 μF, T _J = 25°C		200			μVrms
Output current Limit		V _O = 0 V		0.8 1.2			A
Thermal shutdown junction temperature				150			°C
Standby current		EN = V _I , T _J = 25°C, 2.7 V < V _I < 10 V		1			μA
		EN = V _I , T _J = −40°C to 125°C 2.7 V < V _I < 10 V		10			μA
FB input current		TPS76501	FB = 1.5 V	2			nA
High level enable input voltage				2.0			V
Low level enable input voltage				0.8			V
Power supply ripple rejection (see Note 2)		f = 1 kHz, C _O = 4.7 μF, I _O = 10 μA, T _J = 25°C		63			dB
PG	Minimum input voltage for valid PG		I _O (PG) = 300μA	1.1			V
	Trip threshold voltage		V _O decreasing	92	98		%V _O
	Hysteresis voltage		Measured at V _O	0.5			%V _O
	Output low voltage		V _I = 2.7 V, I _O (PG) = 1mA	0.15	0.4		V
	Leakage current		V(PG) = 5 V	1			μA
Input current (EN)		EN = 0 V		−1	0	1	μA
		EN = V _I		−1	1		

NOTE: 2. Minimum IN operating voltage is 2.7 V or $V_{O(typ)} + 1\text{ V}$, whichever is greater. Maximum IN voltage 10 V.



electrical characteristics over recommended operating free-air temperature range,
 $V_i = V_{O(\text{typ})} + 1 \text{ V}$, $I_O = 10 \mu\text{A}$, $\overline{\text{EN}} = 0 \text{ V}$, $C_O = 4.7 \mu\text{F}$ (unless otherwise noted) (continued)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
Dropout voltage (See Note 4)	TPS76528	$I_O = 150 \text{ mA}$, $T_J = 25^\circ\text{C}$		190		mV
		$I_O = 150 \text{ mA}$, $T_J = -40^\circ\text{C to } 125^\circ\text{C}$			330	
	TPS76530	$I_O = 150 \text{ mA}$, $T_J = 25^\circ\text{C}$		160		
		$I_O = 150 \text{ mA}$, $T_J = -40^\circ\text{C to } 125^\circ\text{C}$			280	
	TPS76533	$I_O = 150 \text{ mA}$, $T_J = 25^\circ\text{C}$		140		
		$I_O = 150 \text{ mA}$, $T_J = -40^\circ\text{C to } 125^\circ\text{C}$			240	
	TPS76550	$I_O = 150 \text{ mA}$, $T_J = 25^\circ\text{C}$		85		
		$I_O = 150 \text{ mA}$, $T_J = -40^\circ\text{C to } 125^\circ\text{C}$			150	

NOTES: 3. If $V_O \leq 1.8 \text{ V}$ then $V_{\text{imin}} = 2.7 \text{ V}$, $V_{\text{imax}} = 10 \text{ V}$:

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

If $V_O \geq 2.5 \text{ V}$ then $V_{\text{imin}} = V_O + 1 \text{ V}$, $V_{\text{imax}} = 10 \text{ V}$:

$$\text{Line Reg. (mV)} = (\%/V) \times \frac{V_O(V_{\text{imax}} - (V_O + 1 \text{ V}))}{100} \times 1000$$

4. IN voltage equals $V_{O(\text{Typ})} - 100 \text{ mV}$; TPS76501 output voltage set to 3.3 V nominal with external resistor divider. TPS76515, TPS76518, TPS76525, and TPS76527 dropout voltage limited by input voltage range limitations (i.e., TPS76530 input voltage needs to drop to 2.9 V for purpose of this test).

Table of Graphs

		FIGURE
Output voltage	vs Load current	2, 3
	vs Free-air temperature	4, 5
Ground current	vs Load current	6, 7
	vs Free-air temperature	8, 9
Power supply ripple rejection	vs Frequency	10
Output spectral noise density	vs Frequency	11
Output impedance	vs Frequency	12
Dropout voltage	vs Free-air temperature	13, 14
Line transient response		15, 17
Load transient response		16, 18
Output voltage	vs Time	19
Dropout voltage	vs Input voltage	20
Equivalent series resistance (ESR)	vs Output current	21 – 24
Equivalent series resistance (ESR)	vs Added ceramic capacitance	25, 26

TYPICAL CHARACTERISTICS

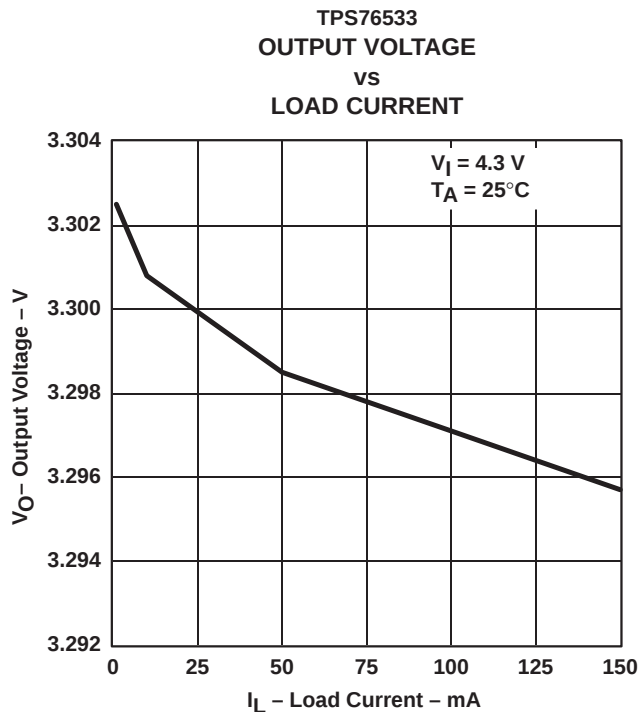


Figure 2

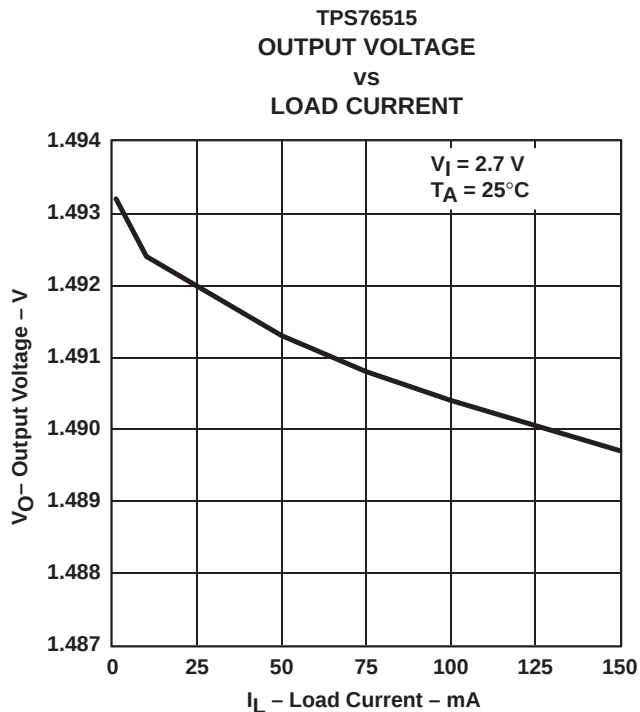


Figure 3

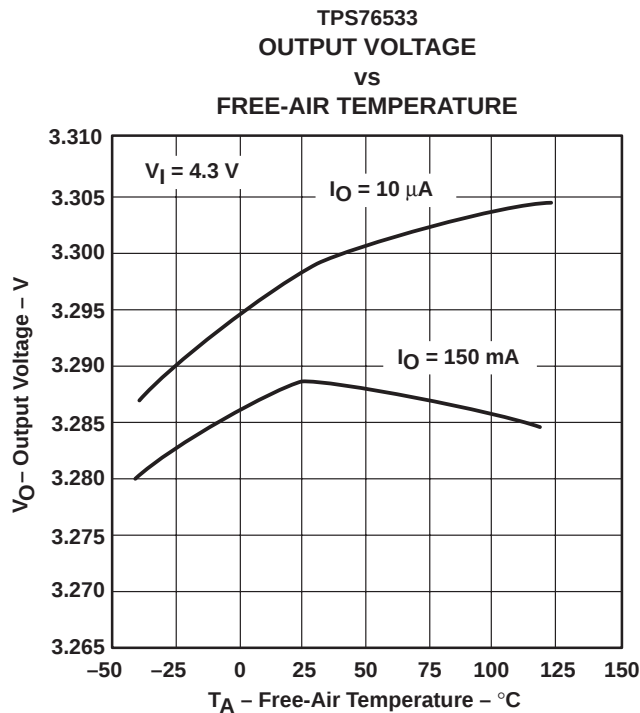


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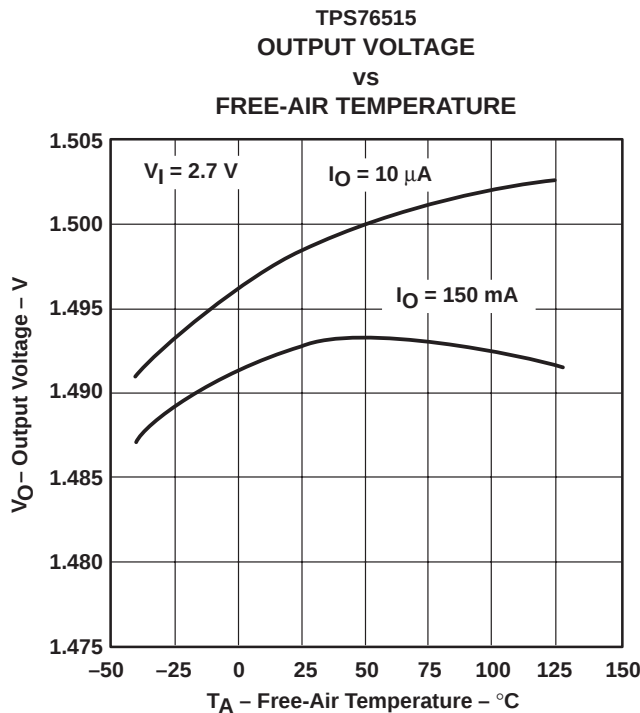


Figure 5

TYPICAL CHARACTERISTICS

TPS76533
 GROUND CURRENT
 VS
 LOAD CURRENT

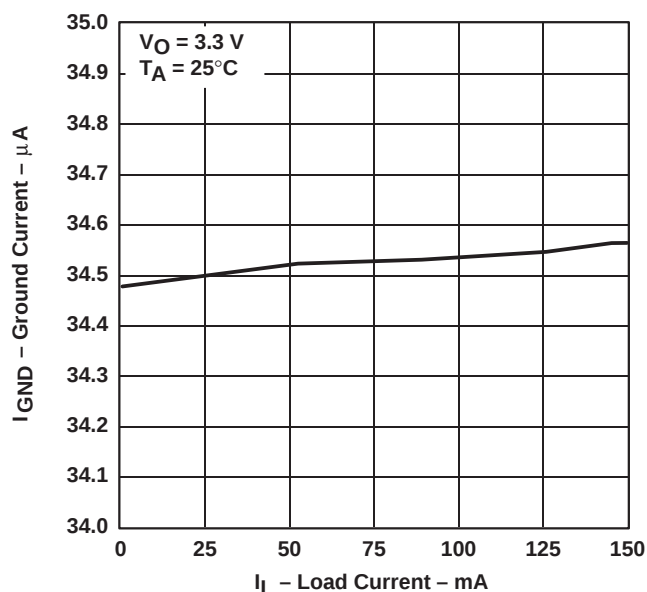


Figure 6

TPS76515
 GROUND CURRENT
 VS
 LOAD CURRENT

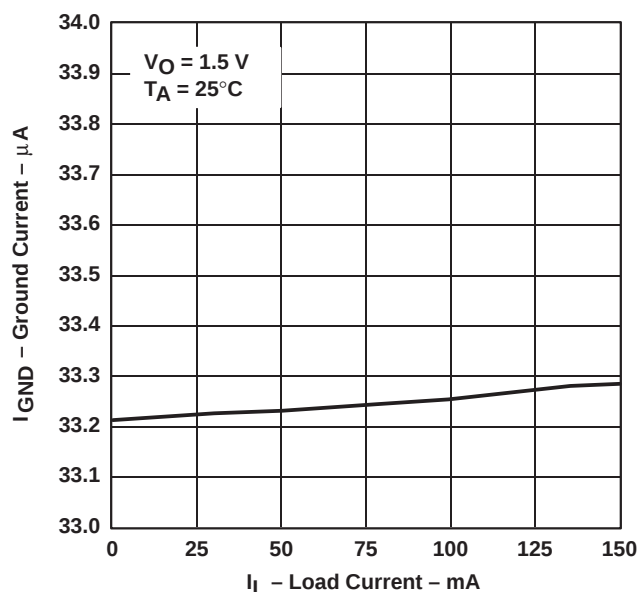


Figure 7

TPS76533
 GROUND CURRENT
 VS
 FREE-AIR TEMPERATURE

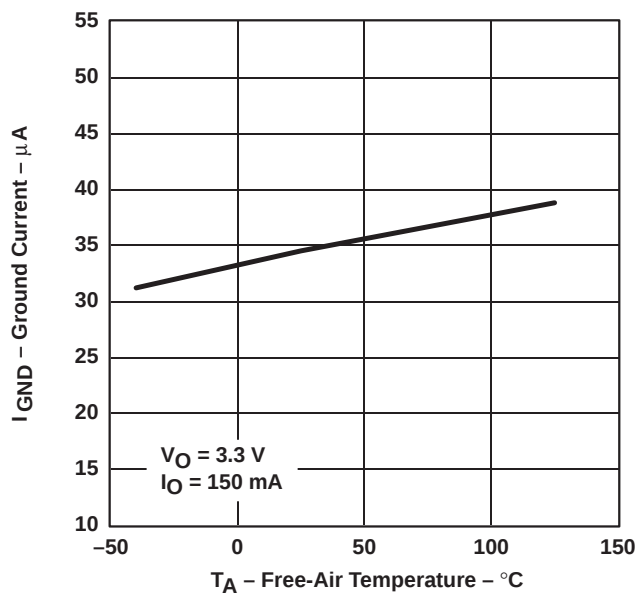


Figure 8

TPS76515
 GROUND CURRENT
 VS
 FREE-AIR TEMPERATURE

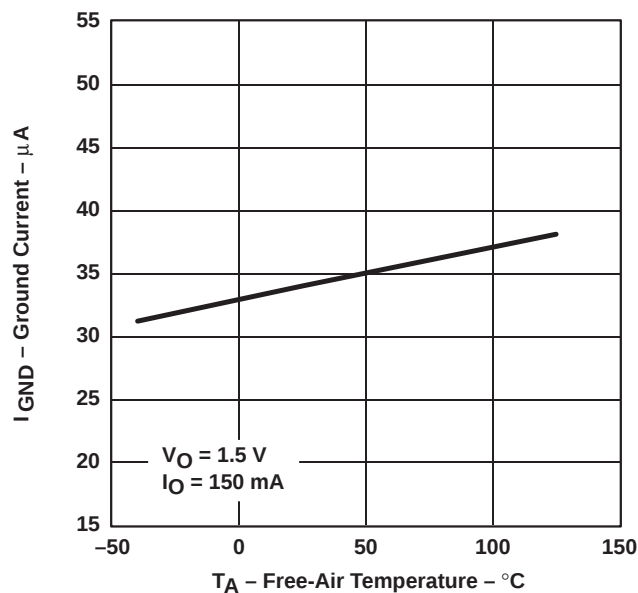


Figure 9

TYPICAL CHARACTERISTICS

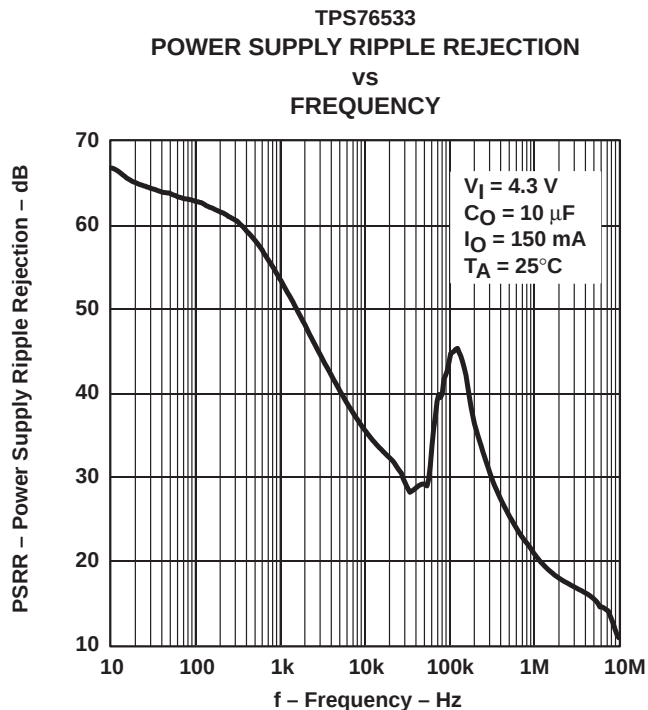


Figure 10

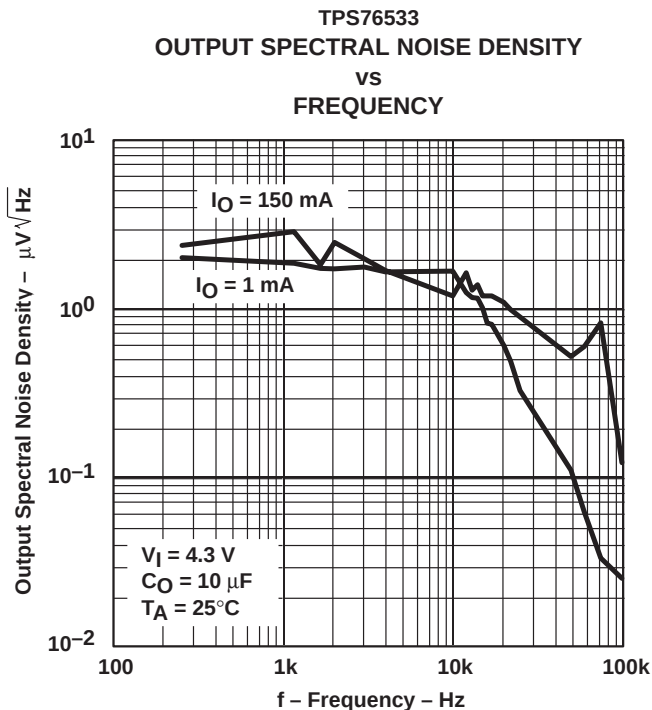


Figure 11

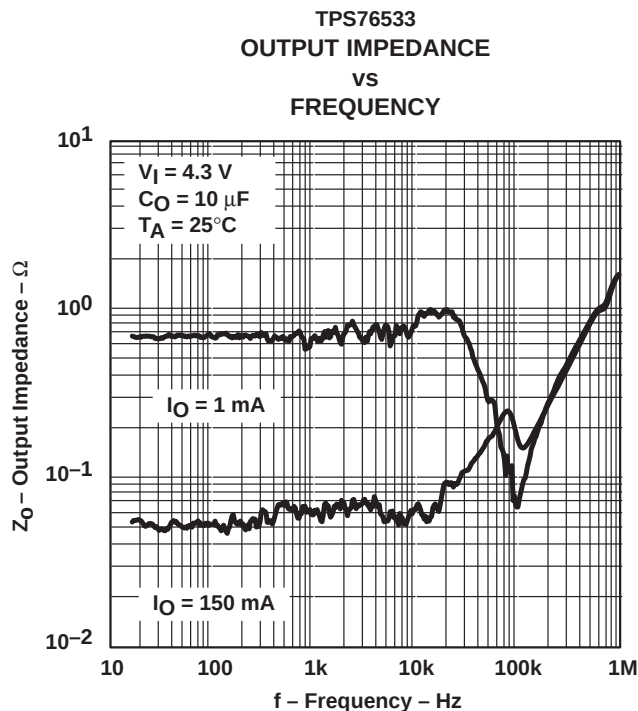


Figure 12

TYPICAL CHARACTERISTICS

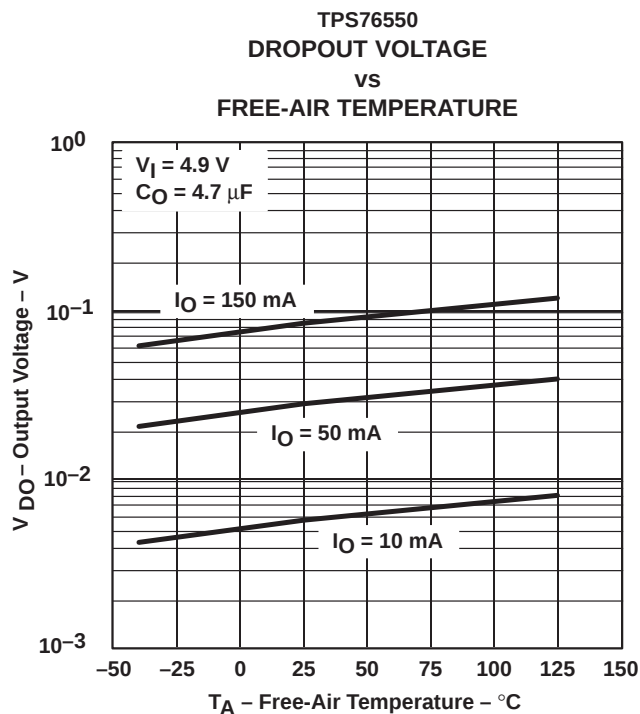


Figure 13

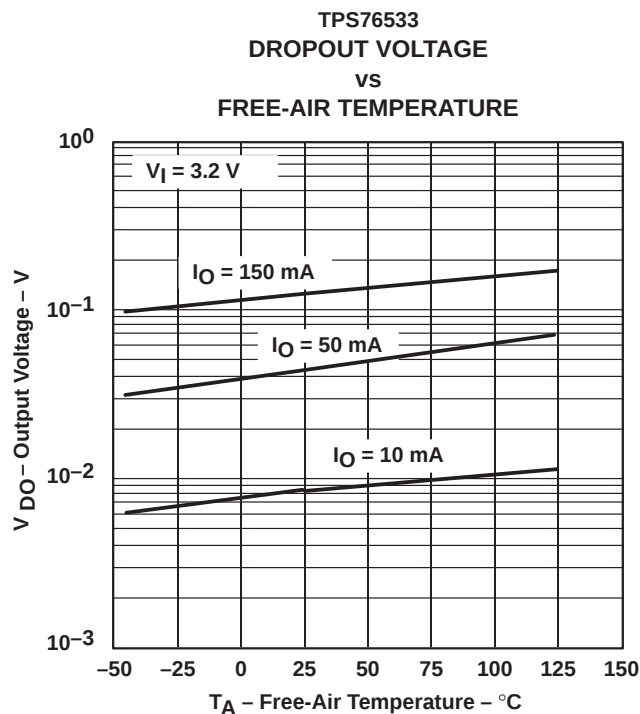


Figure 14

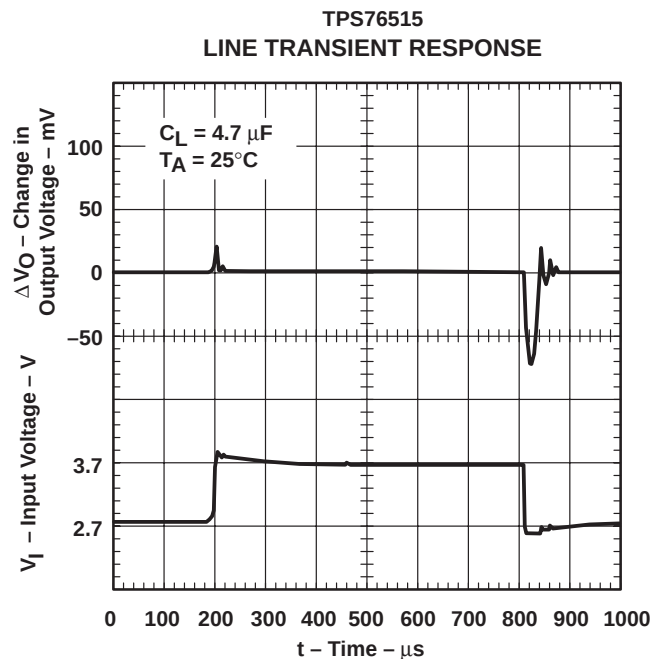


Figure 15

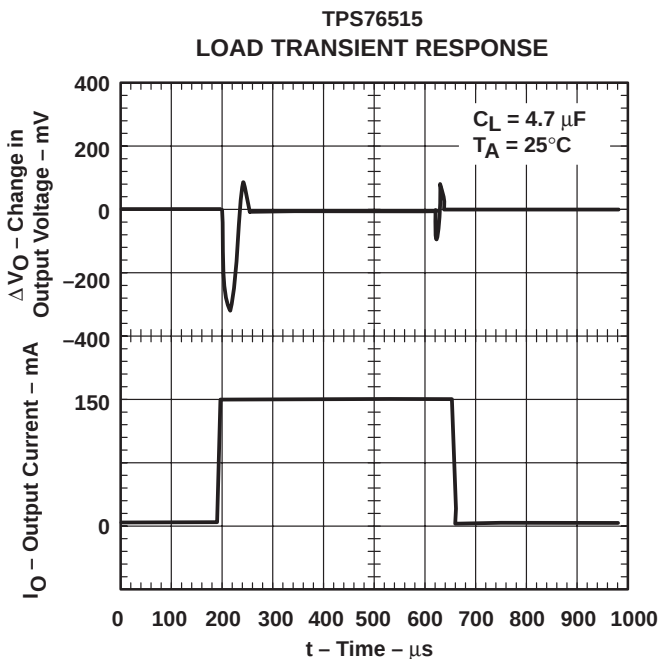


Figure 16

TYPICAL CHARACTERISTICS

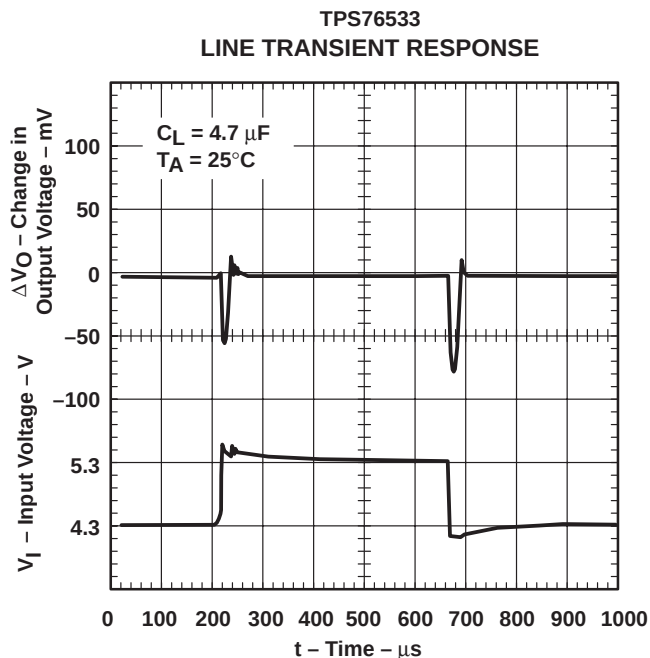


Figure 17

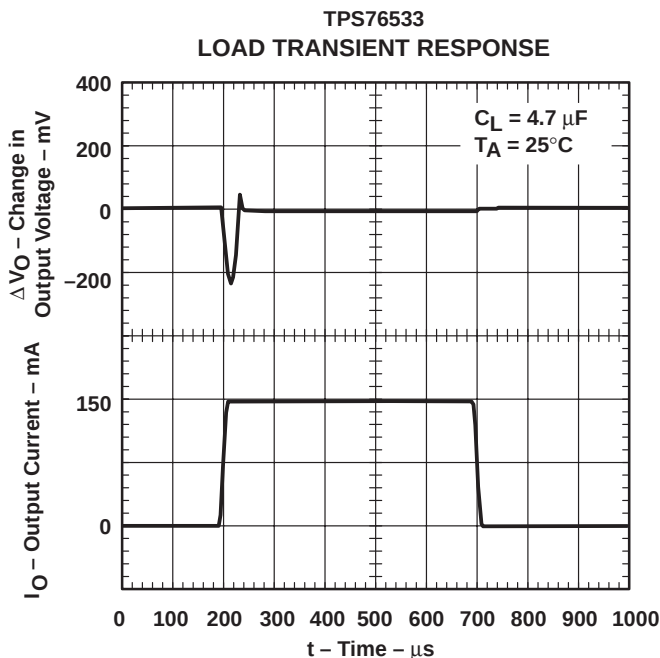


Figure 18

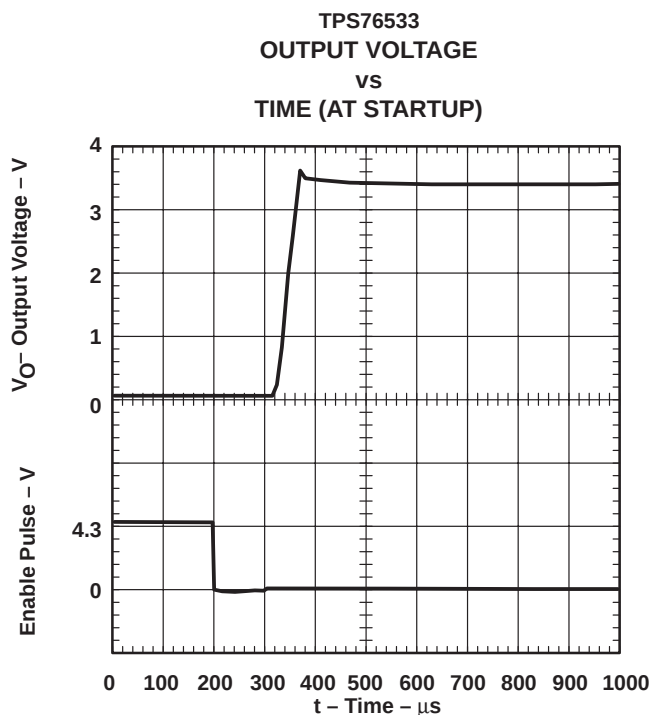


Figure 19

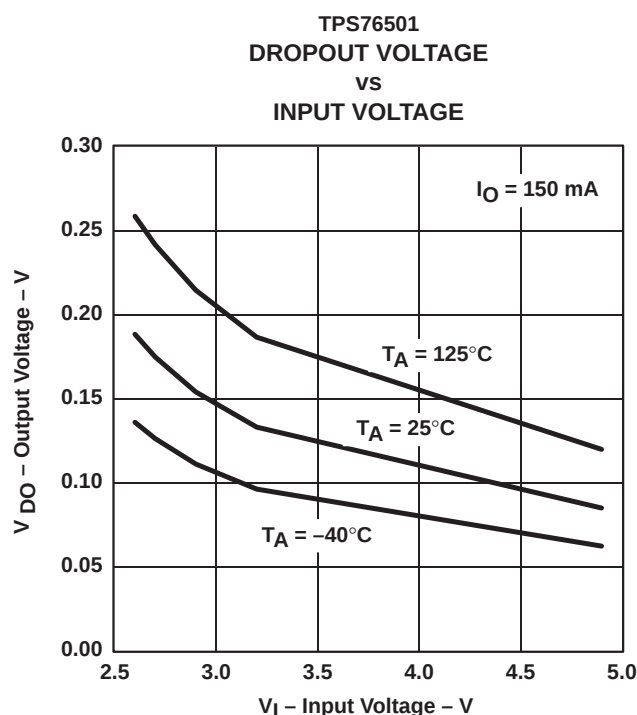


Figure 20

TYPICAL CHARACTERISTICS

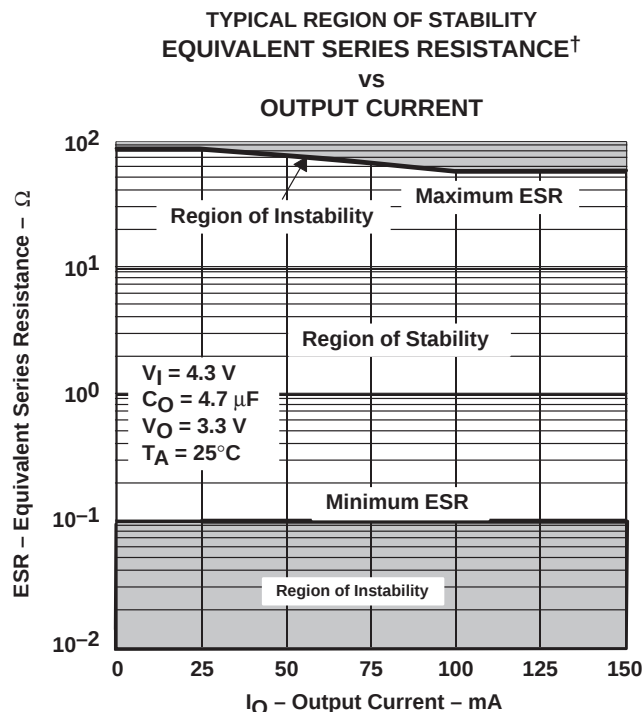


Figure 21

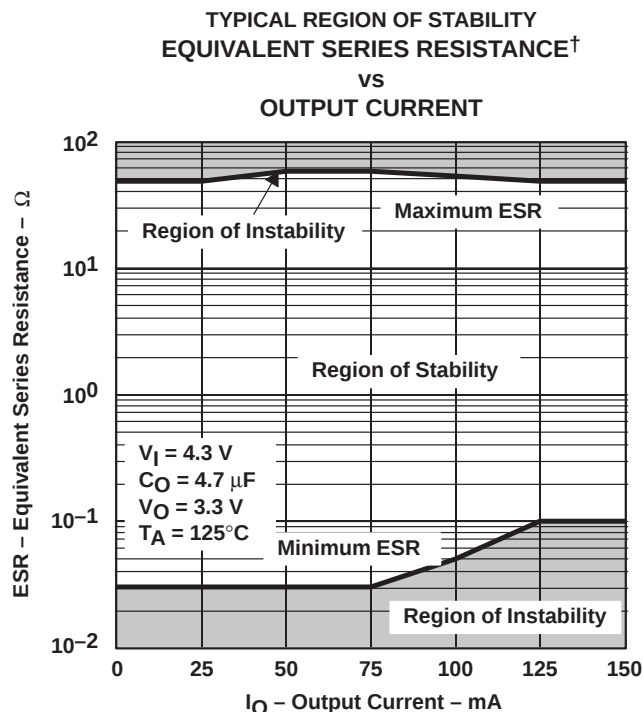


Figure 22

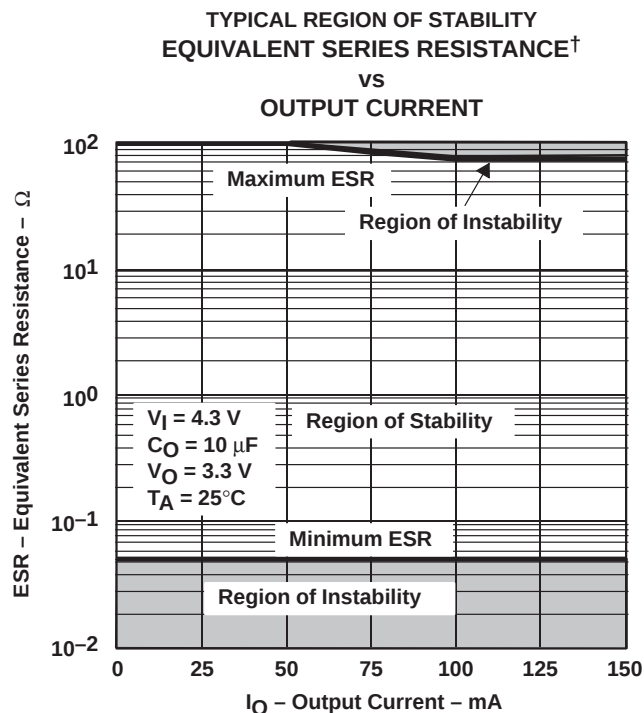


Figure 23

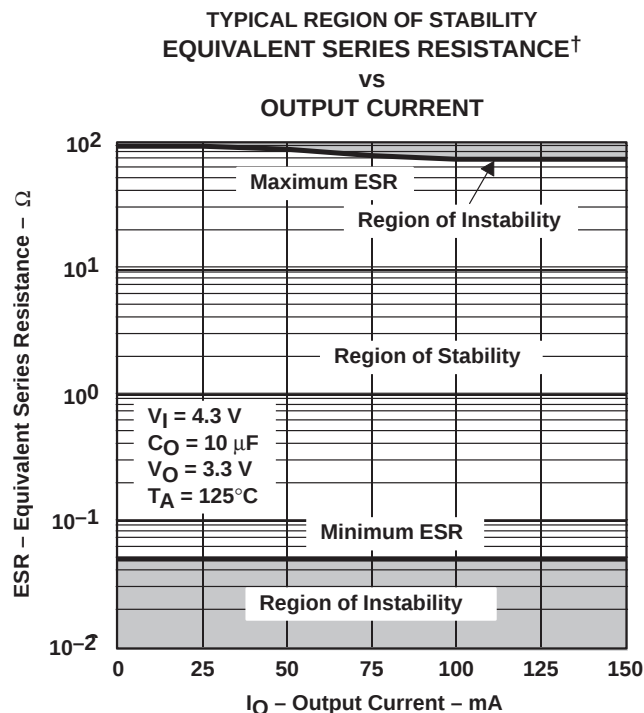


Figure 24

[†] Equivalent series resistance (ESR) refers to the total series resistance, including the ESR of the capacitor, any series resistance added externally, and PWB trace resistance to C_O .

TYPICAL CHARACTERISTICS

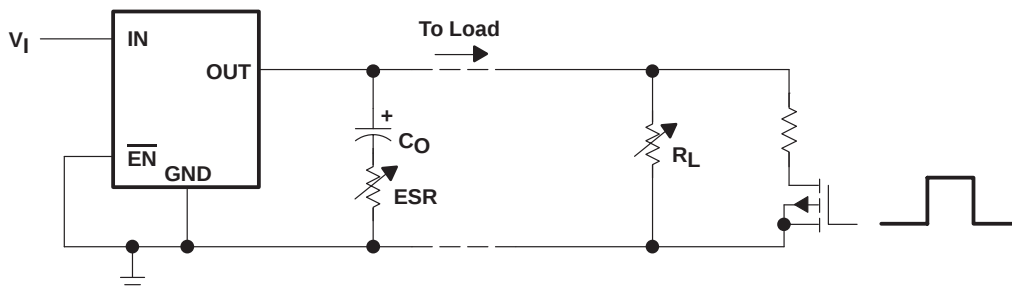
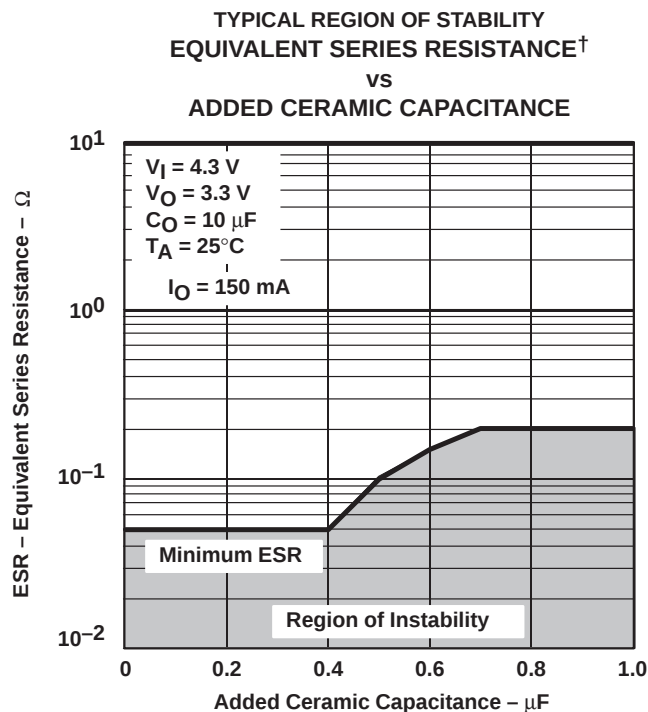
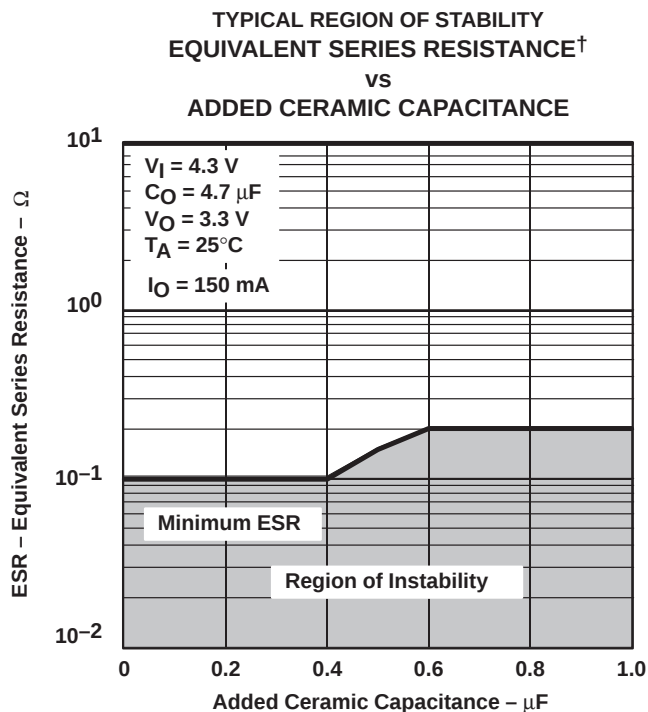


Figure 27. Test Circuit for Typical Regions of Stability (Figures 20 through 23) (Fixed Output Options)

[†] Equivalent series resistance (ESR) refers to the total series resistance, including the ESR of the capacitor, any series resistance added externally, and PWB trace resistance to C_O .

APPLICATION INFORMATION

The TPS765xx family includes eight fixed-output voltage regulators (1.5 V, 1.8 V, 2.5 V, 2.7 V, 2.8 V, 3.0 V, 3.3 V, and 5.0 V), and an adjustable regulator, the TPS76501 (adjustable from 1.25 V to 5.5 V).

device operation

The TPS765xx features very low quiescent current, which remains virtually constant even with varying loads. Conventional LDO regulators use a pnp pass element, the base current of which is directly proportional to the load current through the regulator ($I_B = I_C/\beta$). The TPS765xx uses a PMOS transistor to pass current; because the gate of the PMOS is voltage driven, operating current is low and invariable over the full load range.

Another pitfall associated with the pnp-pass element is its tendency to saturate when the device goes into dropout. The resulting drop in β forces an increase in I_B to maintain the load. During power up, this translates to large start-up currents. Systems with limited supply current may fail to start up. In battery-powered systems, it means rapid battery discharge when the voltage decays below the minimum required for regulation. The TPS765xx quiescent current remains low even when the regulator drops out, eliminating both problems.

The TPS765xx family also features a shutdown mode that places the output in the high-impedance state (essentially equal to the feedback-divider resistance) and reduces quiescent current to 1 μ A (typ). If the shutdown feature is not used, $\overline{EN}$ should be tied to ground. Response to an enable transition is quick; regulated output voltage is reestablished in typically 160 μ s.

minimum load requirements

The TPS765xx family is stable even at zero load; no minimum load is required for operation.

FB - pin connection (adjustable version only)

The FB pin is an input pin to sense the output voltage and close the loop for the adjustable option. The output voltage is sensed through a resistor divider network to close the loop as it is shown in Figure 29. Normally, this connection should be as short as possible; however, the connection can be made near a critical circuit to improve performance at that point. Internally, FB connects to a high-impedance wide-bandwidth amplifier and noise pickup feeds through to the regulator output. Routing the FB connection to minimize/avoid noise pickup is essential.

external capacitor requirements

An input capacitor is not usually required; however, a ceramic bypass capacitor (0.047 μ F or larger) improves load transient response and noise rejection if the TPS765xx is located more than a few inches from the power supply. A higher-capacitance electrolytic capacitor may be necessary if large (hundreds of milliamps) load transients with fast rise times are anticipated.

Like all low dropout regulators, the TPS765xx requires an output capacitor connected between OUT and GND to stabilize the internal control loop. The minimum recommended capacitance value is 4.7 μ F and the ESR (equivalent series resistance) must be between 300-m Ω and 20- Ω . Capacitor values 4.7 μ F or larger are acceptable, provided the ESR is less than 20 Ω . Solid tantalum electrolytic, aluminum electrolytic, and multilayer ceramic capacitors are all suitable, provided they meet the requirements described previously.

APPLICATION INFORMATION

external capacitor requirements (continued)

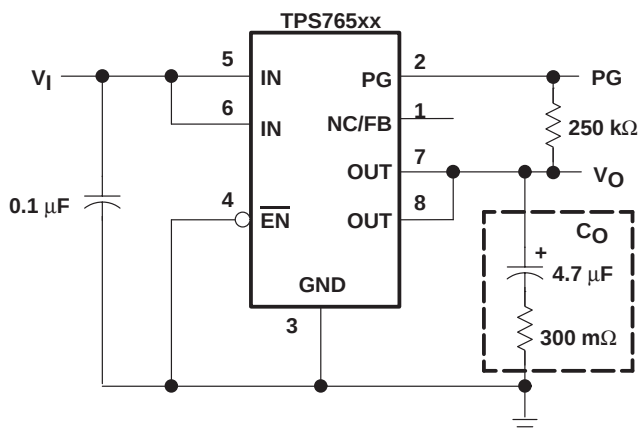


Figure 28. Typical Application Circuit (Fixed Versions)

programming the TPS76501 adjustable LDO regulator

The output voltage of the TPS76501 adjustable regulator is programmed using an external resistor divider as shown in Figure 29. The output voltage is calculated using:

$$V_O = V_{ref} \times \left(1 + \frac{R1}{R2}\right) \quad (1)$$

Where

$V_{ref} = 1.224 \text{ V typ}$ (the internal reference voltage)

Resistors R1 and R2 should be chosen for approximately 7-μA divider current. Lower value resistors can be used but offer no inherent advantage and waste more power. Higher values should be avoided as leakage currents at FB increase the output voltage error. The recommended design procedure is to choose R2 = 169 kΩ to set the divider current at 7 μA and then calculate R1 using:

$$R1 = \left(\frac{V_O}{V_{ref}} - 1\right) \times R2 \quad (2)$$

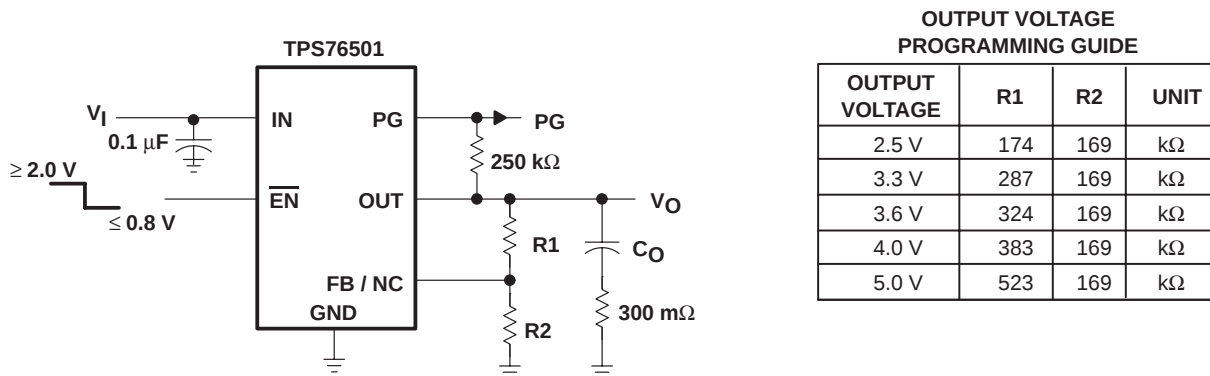


Figure 29. TPS76501 Adjustable LDO Regulator Programming

APPLICATION INFORMATION

power-good indicator

The TPS765xx features a power-good (PG) output that can be used to monitor the status of the regulator. The internal comparator monitors the output voltage: when the output drops to between 92% and 98% of its nominal regulated value, the PG output transistor turns on, taking the signal low. The open-drain output requires a pullup resistor. If not used, it can be left floating. PG can be used to drive power-on reset circuitry or used as a low-battery indicator.

regulator protection

The TPS765xx PMOS-pass transistor has a built-in back diode that conducts reverse currents 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. When extended reverse voltage is anticipated, external limiting may be appropriate.

The TPS765xx also features internal current limiting and thermal protection. During normal operation, the TPS765xx limits output current to approximately 0.8 A. 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 150°C(typ), thermal-protection circuitry shuts it down. Once the device has cooled below 130°C(typ), regulator operation resumes.

power dissipation and junction temperature

Specified regulator operation is assured to a junction temperature of 125°C; the maximum junction temperature should be restricted to 125°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, $P_{D(max)}$, and the actual dissipation, P_D , which must be less than or equal to $P_{D(max)}$.

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

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

Where

T_{Jmax} is the maximum allowable junction temperature

$R_{\theta JA}$ is the thermal resistance junction-to-ambient for the package, i.e., 176°C/W for the 8-terminal SOIC.

T_A is the ambient temperature.

The regulator dissipation is calculated using:

$$P_D = (V_I - V_O) \times I_O$$

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

TPS76515, TPS76518, TPS76525, TPS76527
 TPS76528, TPS76530, TPS76533, TPS76550, TPS76501
 ULTRA-LOW QUIESCIENT CURRENT 150-mA LOW-DROPOUT VOLTAGE REGULATORS

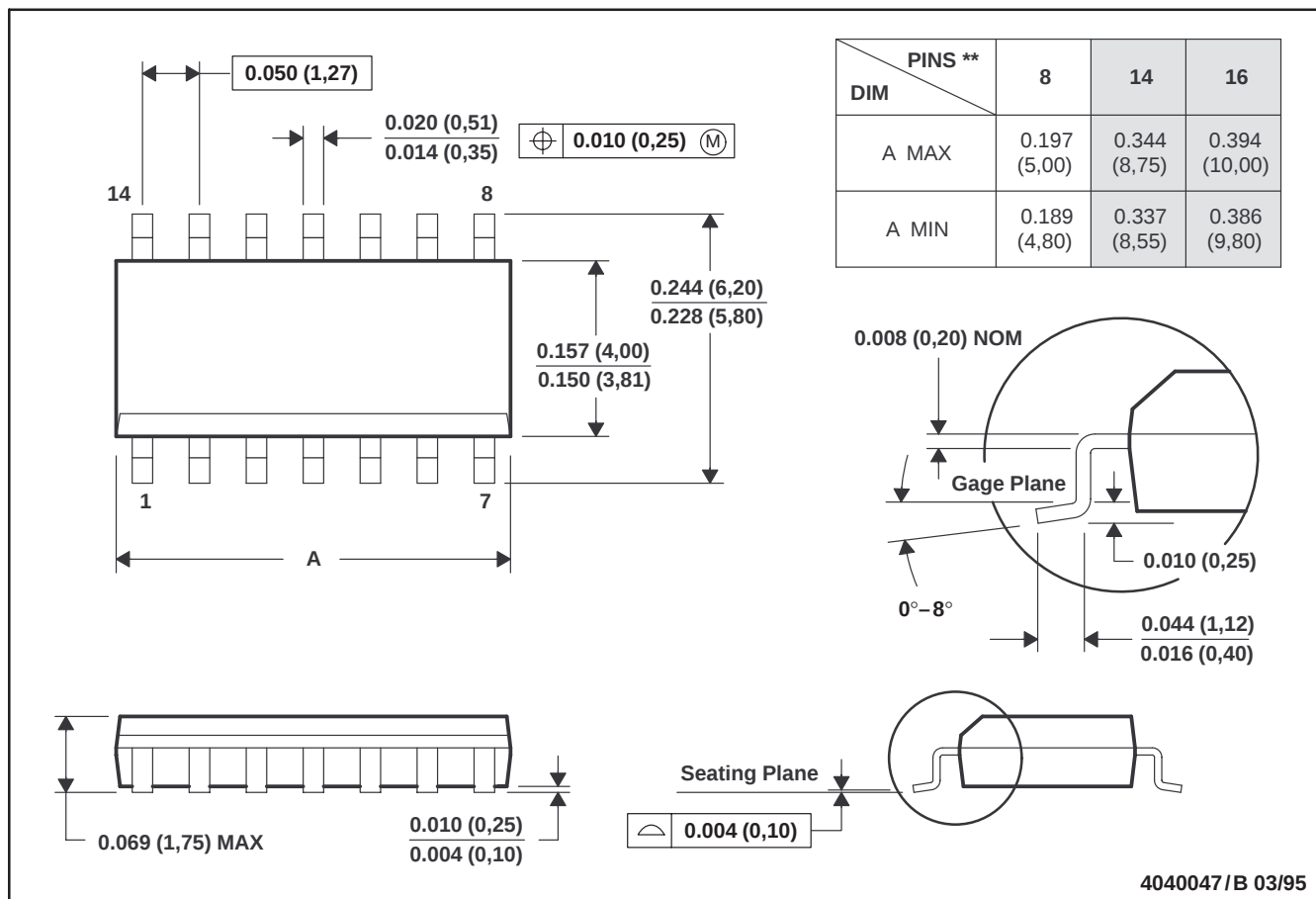
SLVS236 – AUGUST 1999

MECHANICAL DATA

D (R-PDSO-G**)

PLASTIC SMALL-OUTLINE PACKAGE

14 PIN SHOWN



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
 - D. Four center pins are connected to die mount pad.
 - E. Falls within JEDEC MS-012

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