3μA I_Q, 20mA, 45V Low Dropout Fault Tolerant Linear Regulators

FEATURES

- **FMEA Fault Tolerant: Output Stays at or Below Regulation Voltage During Adjacent Pin Short or if a Pin Is Left Floating**
- **Ultralow Quiescent Current: 3μA**
- **Input Voltage Range: 2.0V to 45V**
- **Output Current: 20mA**
- **Dropout Voltage: 300mV**
- **Adjustable Output (V_{ADJ} = $V_{OUT(MIN)}$ = 600mV)**
- **Fixed Output Voltages: 1.2V, 1.5V, 1.8V, 2.5V, 3.3V, 5V**
- Output Tolerance: ±2% Over Load, Line and Temperature
- Stable with Low ESR, Ceramic Output Capacitors (2.2μF Minimum)
- Shutdown Current: <1μA
- Current Limit Protection
- Reverse-Battery Protection
- Thermal Limit Protection
- TSOT-23 Package

APPLICATIONS

- Automotive
- Low Current Battery-Powered Systems
- Keep-Alive Power Supplies
- Remote Monitoring
- Utility Meters
- Low Power Industrial Applications

DESCRIPTION

The LT®3007 series are micropower, low dropout voltage (LDO) linear regulators. The devices supply 20mA output current with a dropout voltage of 300mV. No-load quiescent current is 3μA. Ground pin current remains at less than 5% of output current as load increases. In shutdown, quiescent current is less than 1μA.

The LT3007 regulators optimize stability and transient response with low ESR ceramic capacitors, requiring a minimum of only 2.2μF. The regulators do not require the addition of ESR as is common with other regulators. Internal protection circuitry includes current limiting, thermal limiting, reverse-battery protection and reverse-current protection.

The LT3007 series are ideal for applications that require moderate output drive capability coupled with ultralow standby power consumption. The device is available in fixed output voltages of 1.2V, 1.5V, 1.8V, 2.5V, 3.3V and 5V, and an adjustable version with an output voltage range of 0.6V to 44.5V. The LT3007 is available in the thermally enhanced 8-lead TSOT-23 package.

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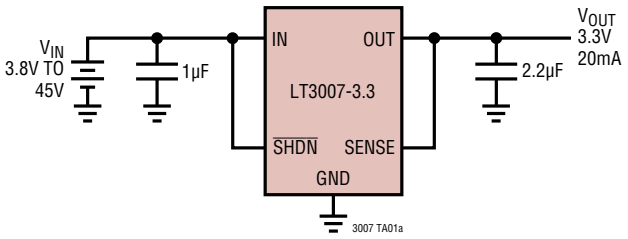
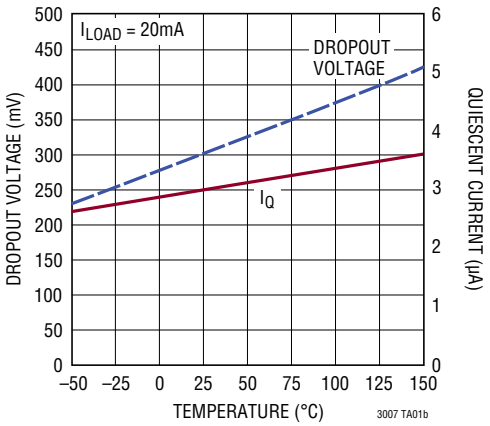
TYPICAL APPLICATION

3.3V, 20mA Supply with Shutdown



Dropout Voltage/Quiescent Current

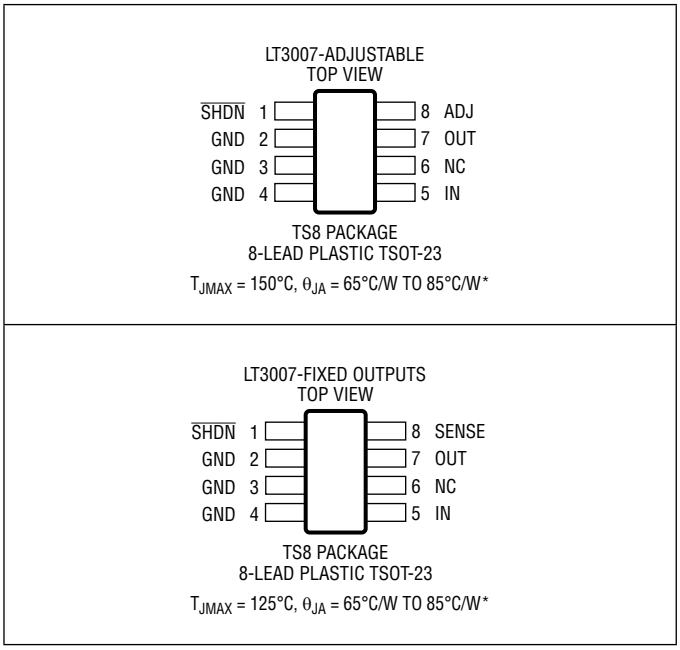


ABSOLUTE MAXIMUM RATINGS

(Note 1)

IN Pin Voltage ..... ±50V
OUT Pin Voltage ..... ±50V
Input-to-Output Differential Voltage ..... ±50V
ADJ Pin Voltage ..... ±50V
SENSE Pin Voltage ..... ±50V
$\overline{SHDN}$ Pin Voltage (Note 8) ..... ±50V
Output Short-Circuit Duration ..... Indefinite
Operating Junction Temperature Range (Notes 2, 4)
E-, I-Grades ..... –40°C to 125°C
H-Grade ..... –40°C to 150°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature: Soldering, 10 sec ..... 300°C

PIN CONFIGURATION



* See the Applications Information Section.

ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING*	PACKAGE DESCRIPTION	TEMPERATURE RANGE
LT3007ETS8#PBF	LT3007ETS8#TRPBF	LTGJW	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8#PBF	LT3007ITS8#TRPBF	LTGJW	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007HTS8#PBF	LT3007HTS8#TRPBF	LTGJW	8-Lead Plastic TSOT-23	–40°C to 150°C
LT3007ETS8-1.2#PBF	LT3007ETS8-1.2#TRPBF	LTGKB	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8-1.2#PBF	LT3007ITS8-1.2#TRPBF	LTGKB	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ETS8-1.5#PBF	LT3007ETS8-1.5#TRPBF	LTGKD	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8-1.5#PBF	LT3007ITS8-1.5#TRPBF	LTGKD	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ETS8-1.8#PBF	LT3007ETS8-1.8#TRPBF	LTGJZ	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8-1.8#PBF	LT3007ITS8-1.8#TRPBF	LTGJZ	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ETS8-2.5#PBF	LT3007ETS8-2.5#TRPBF	LTGJX	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8-2.5#PBF	LT3007ITS8-2.5#TRPBF	LTGJX	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ETS8-3.3#PBF	LT3007ETS8-3.3#TRPBF	LTGKC	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8-3.3#PBF	LT3007ITS8-3.3#TRPBF	LTGKC	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ETS8-5#PBF	LT3007ETS8-5#TRPBF	LTGJY	8-Lead Plastic TSOT-23	–40°C to 125°C
LT3007ITS8-5#PBF	LT3007ITS8-5#TRPBF	LTGJY	8-Lead Plastic TSOT-23	–40°C to 125°C

Consult LTC Marketing for parts specified with wider operating temperature ranges. *The temperature grade is identified by a label on the shipping container.

For more information on lead free part marking, go to: http://www.linear.com/leadfree/
For more information on tape and reel specifications, go to: http://www.linear.com/tapeandreel/

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_J = 25°C. (Note 2)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Operating Voltage		●	2		45	V
Regulated Output Voltage	LT3007-1.2: V_{IN} = 2V, I_{LOAD} = 100µA		1.188	1.2	1.212	V
	2V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA	●	1.176	1.2	1.224	V
	LT3007-1.5: V_{IN} = 2.05V, I_{LOAD} = 100µA		1.485	1.5	1.515	V
	2.05V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA	●	1.47	1.5	1.53	V
	LT3007-1.8: V_{IN} = 2.35V, I_{LOAD} = 100µA		1.782	1.8	1.818	V
	2.35V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA	●	1.764	1.8	1.836	V
	LT3007-2.5: V_{IN} = 3.05V, I_{LOAD} = 100µA		2.475	2.5	2.525	V
	3.05V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA	●	2.45	2.5	2.55	V
	LT3007-3.3: V_{IN} = 3.85V, I_{LOAD} = 100µA		3.267	3.3	3.333	V
	3.85V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA	●	3.234	3.3	3.366	V
	LT3007-5: V_{IN} = 5.55V, I_{LOAD} = 100µA		4.95	5	5.05	V
	5.55V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA	●	4.9	5	5.1	V
ADJ Pin Voltage (Notes 3, 4)	V_{IN} = 2V, I_{LOAD} = 100µA		594	600	606	mV
	2V < V_{IN} < 45V, 1µA < I_{LOAD} < 20mA (E-, I-Grades)	●	588	600	612	mV
	2V < V_{IN} < 45V, 20µA < I_{LOAD} < 20mA (H-Grade)	●	582		612	mV
Line Regulation (Note 3)	LT3007-1.2: ΔV_{IN} = 2V to 45V, I_{LOAD} = 1mA	●		1.2	6	mV
	LT3007-1.5: ΔV_{IN} = 2.05V to 45V, I_{LOAD} = 1mA	●		1.5	7.5	mV
	LT3007-1.8: ΔV_{IN} = 2.35V to 45V, I_{LOAD} = 1mA	●		1.8	9	mV
	LT3007-2.5: ΔV_{IN} = 3.05V to 45V, I_{LOAD} = 1mA	●		2.5	12.5	mV
	LT3007-3.3: ΔV_{IN} = 3.85V to 45V, I_{LOAD} = 1mA	●		3.3	16.5	mV
	LT3007-5: ΔV_{IN} = 5.55V to 45V, I_{LOAD} = 1mA	●		5	25	mV
	LT3007 (E-, I-Grades): ΔV_{IN} = 2V to 45V, I_{LOAD} = 1mA	●		0.6	3	mV
	LT3007 (H-Grade): ΔV_{IN} = 2V to 45V, I_{LOAD} = 1mA	●		0.6	9	mV
Load Regulation (Note 3)	LT3007-1.2: V_{IN} = 2V, I_{LOAD} = 1µA to 10mA	●		0.8	4	mV
	V_{IN} = 2V, I_{LOAD} = 1µA to 20mA	●		1	10	mV
	LT3007-1.5: V_{IN} = 2.05V, I_{LOAD} = 1µA to 10mA	●		1	5	mV
	V_{IN} = 2.05V, I_{LOAD} = 1µA to 20mA	●		1.3	13	mV
	LT3007-1.8: V_{IN} = 2.35V, I_{LOAD} = 1µA to 10mA	●		1.2	6	mV
	V_{IN} = 2.35V, I_{LOAD} = 1µA to 20mA	●		1.5	15	mV
	LT3007-2.5: V_{IN} = 3.05V, I_{LOAD} = 1µA to 10mA	●		1.7	8.3	mV
	V_{IN} = 3.05V, I_{LOAD} = 1µA to 20mA	●		2.1	21	mV
	LT3007-3.3: V_{IN} = 3.85V, I_{LOAD} = 1µA to 10mA	●		2.2	11	mV
	V_{IN} = 3.85V, I_{LOAD} = 1µA to 20mA	●		2.8	28	mV
	LT3007-5: V_{IN} = 5.55V, I_{LOAD} = 1µA to 10mA	●		3.4	17	mV
	V_{IN} = 5.55V, I_{LOAD} = 1µA to 20mA	●		4.2	42	mV
	LT3007 (E-, I-Grades): V_{IN} = 2V, I_{LOAD} = 1µA to 10mA	●		0.4	2	mV
	V_{IN} = 2V, I_{LOAD} = 1µA to 20mA	●		0.5	5	mV
	LT3007 (H-Grade): V_{IN} = 2V, I_{LOAD} = 20µA to 10mA	●		0.4	5	mV
	V_{IN} = 2V, I_{LOAD} = 20µA to 20mA	●		0.5	9	mV
Dropout Voltage	I_{LOAD} = 100µA			115	180	mV
V_{IN} = $V_{OUT(NOMINAL)}$ (Notes 5, 6)	I_{LOAD} = 100µA (E-, I-Grades)	●			250	mV
	I_{LOAD} = 100µA (H-Grade)	●			290	mV
	I_{LOAD} = 1mA			170	250	mV
	I_{LOAD} = 1mA (E-, I-Grades)	●			350	mV
	I_{LOAD} = 1mA (H-Grade)	●			390	mV
	I_{LOAD} = 10mA			270	340	mV
	I_{LOAD} = 10mA (E-, I-Grades)	●			470	mV
	I_{LOAD} = 10mA (H-Grade)	●			510	mV
	I_{LOAD} = 20mA			300	365	mV
	I_{LOAD} = 20mA (E-, I-Grades)	●			500	mV
	I_{LOAD} = 20mA (H-Grade)	●			540	mV

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_J = 25°C. (Note 2)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Quiescent Current (Notes 6, 7)	I_{LOAD} = 0µA (E-, I-Grades) I_{LOAD} = 0µA (H-Grade)	● ●		3	6 7	µA µA
GND Pin Current V_{IN} = $V_{OUT(NOMINAL)}$ + 0.5V (Notes 6, 7)	I_{LOAD} = 0µA (E-, I-Grades) I_{LOAD} = 0µA (H-Grade) I_{LOAD} = 100µA (E-, I-Grades) I_{LOAD} = 100µA (H-Grade) I_{LOAD} = 1mA I_{LOAD} = 10mA I_{LOAD} = 20mA	● ● ● ● ● ● ●		3 6 21 160 350	6 7 12 14 50 500 1200	µA µA µA µA µA µA µA
Output Voltage Noise (Note 9)	C_{OUT} = 2.2µF, I_{LOAD} = 20mA, BW = 10Hz to 100kHz			92		μV_{RMS}
ADJ Pin Bias Current			–10	0.4	10	nA
Shutdown Threshold	V_{OUT} = Off to On V_{OUT} = On to Off	● ●	 0.25	0.67 0.61	1.5	V V
$\overline{SHDN}$ Pin Current	$V_{\overline{SHDN}}$ = 0V, V_{IN} = 45V $V_{\overline{SHDN}}$ = 45V, V_{IN} = 45V	● ●		 0.65	±1 2	µA µA
Quiescent Current in Shutdown	V_{IN} = 6V, $V_{\overline{SHDN}}$ = 0V (E-, I-Grades) V_{IN} = 6V, $V_{\overline{SHDN}}$ = 0V (H-Grade)	● ●		<1 <9		µA µA
Ripple Rejection (Note 3)	V_{IN} – V_{OUT} = 2V, V_{RIPPLE} = 0.5V_{P-P}, f_{RIPPLE} = 120Hz, I_{LOAD} = 20mA LT3007 LT3007-1.2 LT3007-1.5 LT3007-1.8 LT3007-2.5 LT3007-3.3 LT3007-5		 58 54 53 52 49 47 42	 70 66 65 64 61 59 54		 dB dB dB dB dB dB dB
Current Limit (Note 3)	V_{IN} = 45V, V_{OUT} = 0 V_{IN} = $V_{OUT(NOMINAL)}$ + 1V, ΔV_{OUT} = –5%	 ●	 22	75		mA mA
Input Reverse-Leakage Current	V_{IN} = –45V, V_{OUT} = 0	●		1	30	µA
Reverse-Output Current	V_{OUT} = 1.2V, V_{IN} = 0			0.6	10	µA

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: The LT3007 is tested and specified under pulse load conditions such that $T_J \cong T_A$. The LT3007E regulators are 100% tested at T_A = 25°C and performance is guaranteed from 0°C to 125°C. Performance at –40°C to 125°C is assured by design, characterization and correlation with statistical process controls. The LT3007I regulators are guaranteed over the full –40°C to 125°C operating junction temperature range. The LT3007H regulator is 100% tested at the 150°C operating junction temperature. High junction temperatures degrade operating lifetimes. Operating lifetime is derated at junction temperature greater than 125°C. H-grade is available only in the adjustable version.

Note 3: The LT3007 adjustable version is tested and specified for these conditions with the ADJ pin connected to the OUT pin.

Note 4: Operating conditions are limited by maximum junction temperature. The regulated output voltage specification will not apply for all possible combinations of input voltage and output current. When operating at the maximum input voltage, the output current range must be limited. When operating at the maximum output current, the input voltage must be limited.

Note 5: Dropout voltage is the minimum input to output voltage differential needed to maintain regulation at a specified output current. In dropout, the output voltage equals (V_{IN} – $V_{DROPOUT}$). For the LT3007-1.2 and LT3007-1.5, dropout voltage will be limited by the minimum input voltage.

Note 6: To satisfy minimum input voltage requirements, the LT3007 adjustable version is tested and specified for these conditions with an external resistor divider (61.9k bottom, 280k top) which sets V_{OUT} to 3.3V. The external resistor divider adds 9.69µA of DC load on the output. This external current is not factored into GND pin current.

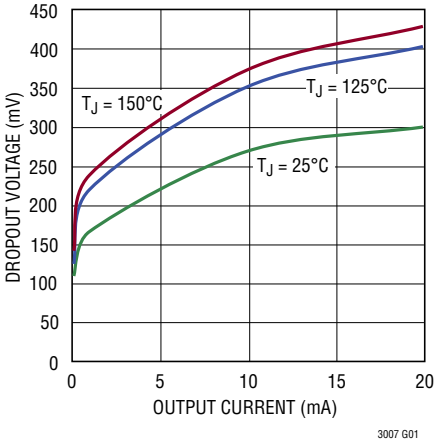
Note 7: GND pin current is tested with V_{IN} = $V_{OUT(NOMINAL)}$ + 0.55V and a current source load. GND pin current will increase in dropout. For the fixed output voltage versions, an internal resistor divider will add about 1µA to the GND pin current. See the GND Pin Current curves in the Typical Performance Characteristics section.

Note 8: The $\overline{SHDN}$ pin can be driven below GND only when tied to the IN pin directly or through a pull-up resistor. If the $\overline{SHDN}$ pin is driven below GND by more than –0.3V while IN is powered, the output will turn on.

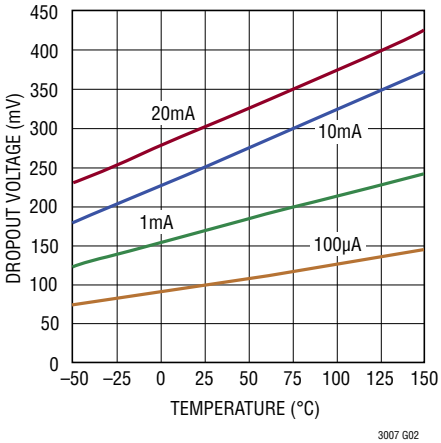
Note 9: Output noise is listed for the adjustable version with the ADJ pin connected to the OUT pin. See the RMS Output Noise vs Load Current curve in the Typical Performance Characteristics Section.

TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

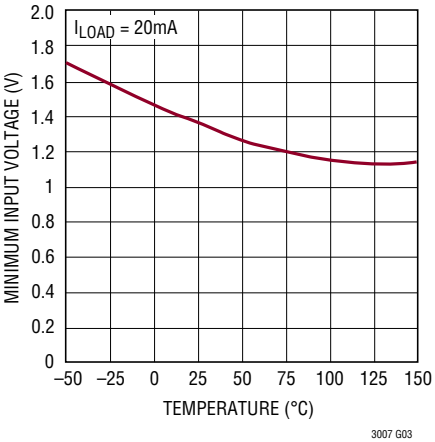
Dropout Voltage



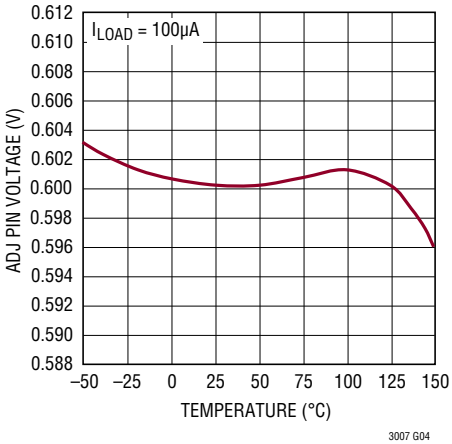
Dropout Voltage



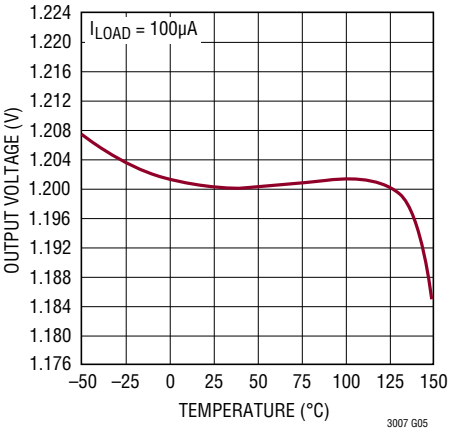
Minimum Input Voltage



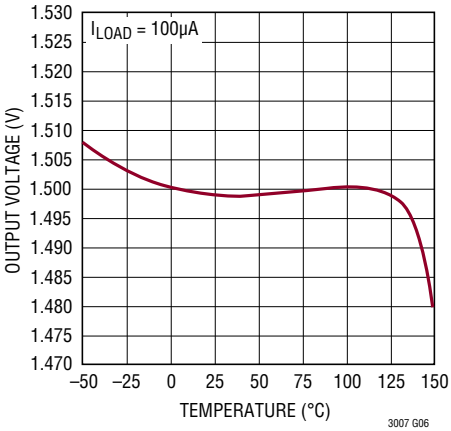
ADJ Pin Voltage



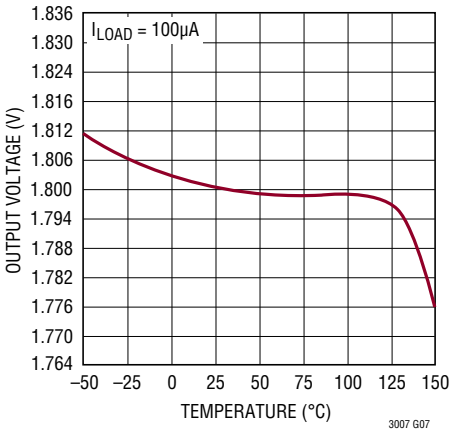
Output Voltage LT3007-1.2



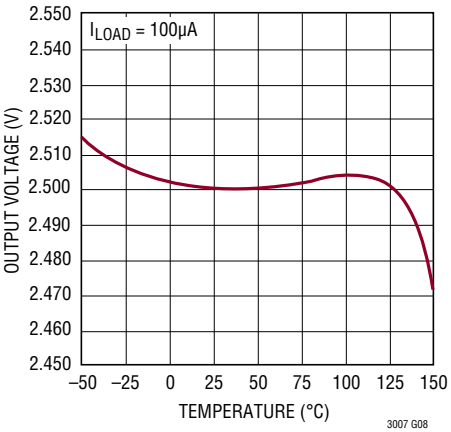
Output Voltage LT3007-1.5



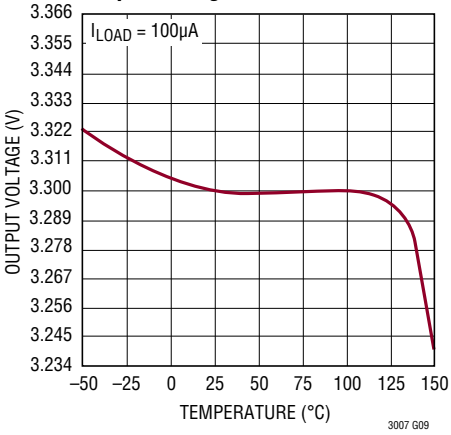
Output Voltage LT3007-1.8



Output Voltage LT3007-2.5

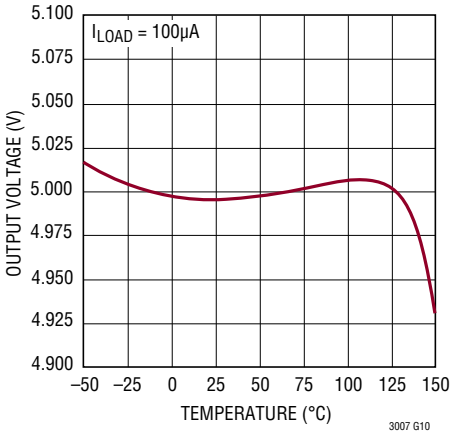


Output Voltage LT3007-3.3

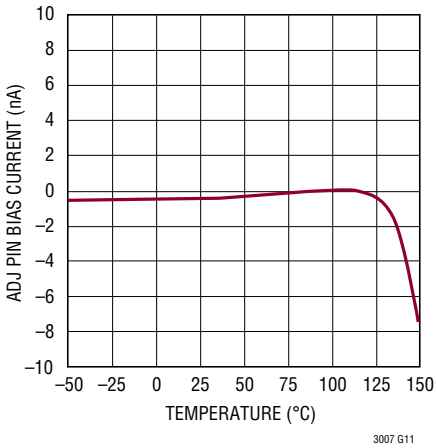


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

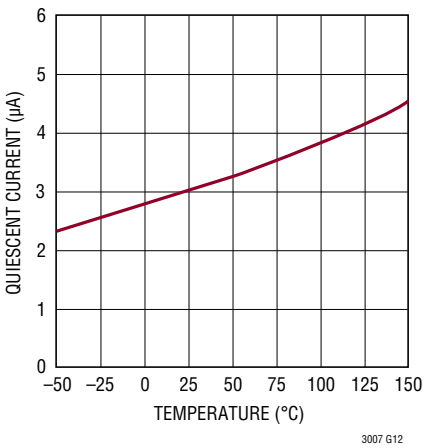
Output Voltage LT3007-5



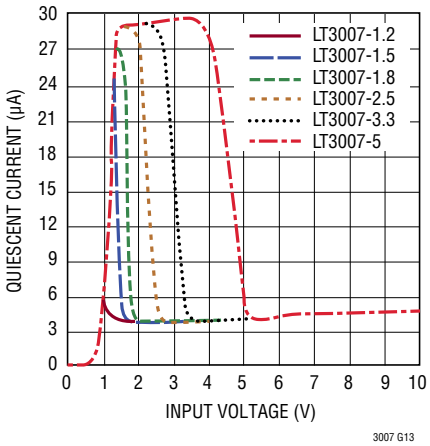
ADJ Pin Bias Current



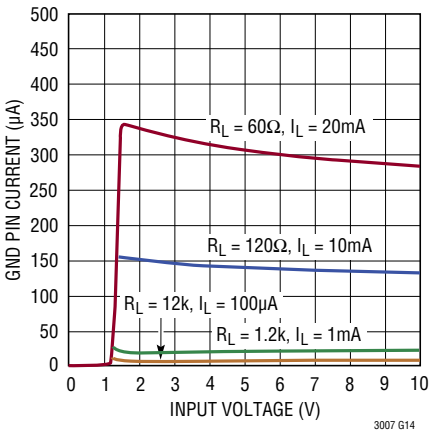
Adjustable Quiescent Current



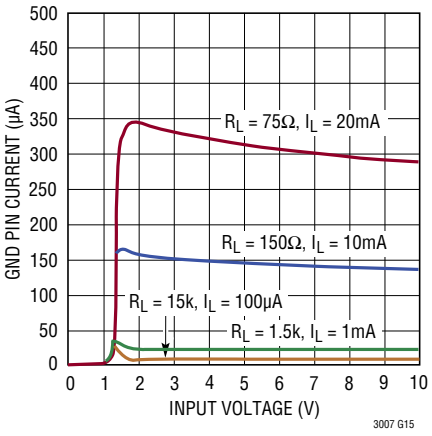
Quiescent Current



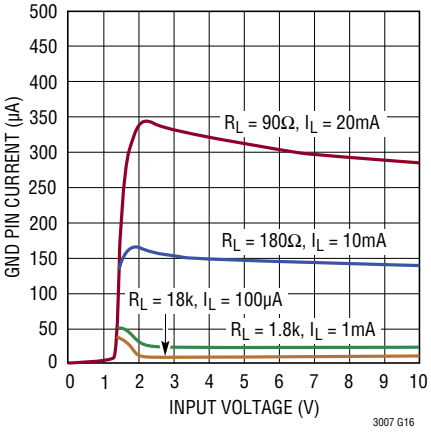
GND Pin Current LT3007-1.2



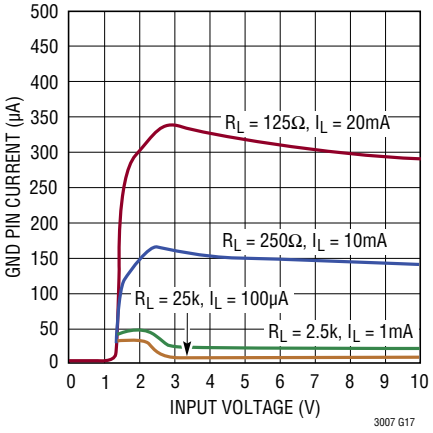
GND Pin Current LT3007-1.5



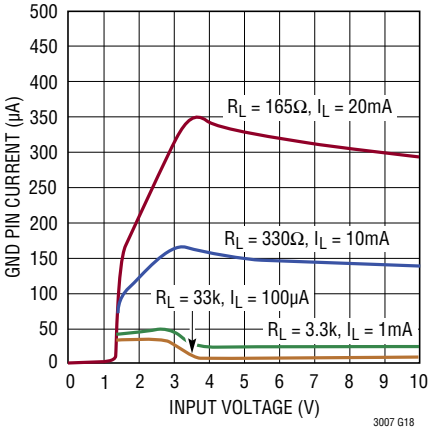
GND Pin Current LT3007-1.8



GND Pin Current LT3007-2.5

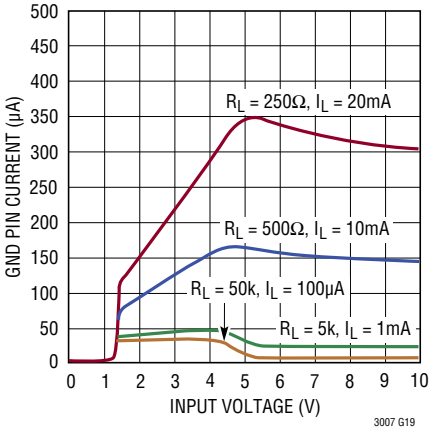


GND Pin Current LT3007-3.3

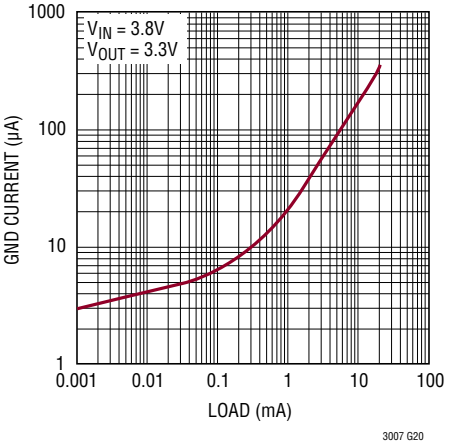


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

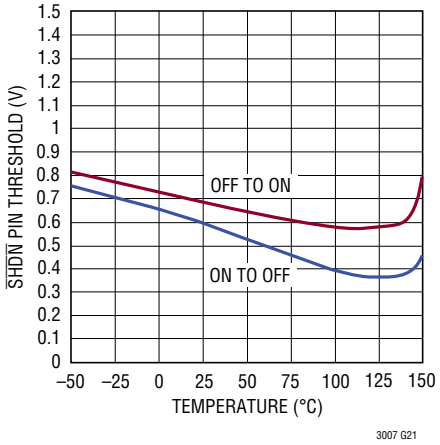
GND Pin Current LT3007-5



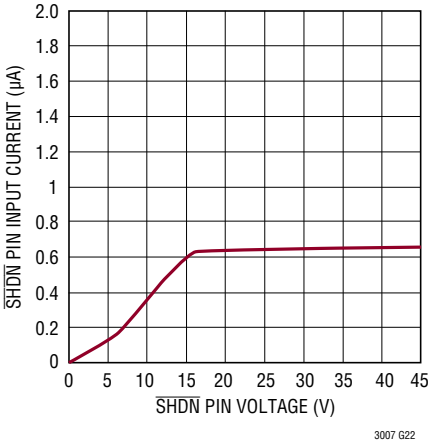
GND Pin Current vs I_{LOAD}



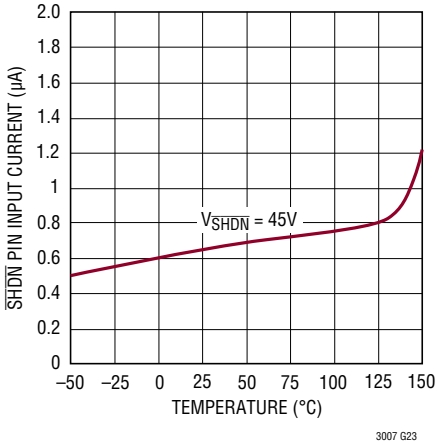
$\overline{SHDN}$ Pin Thresholds



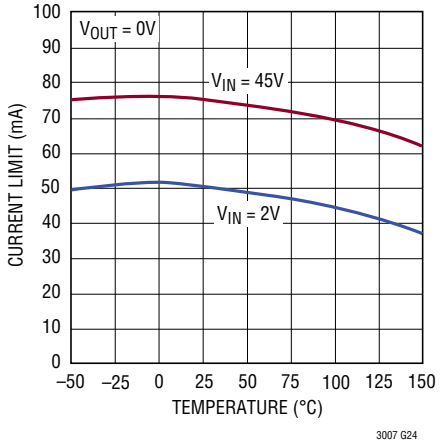
$\overline{SHDN}$ Pin Input Current



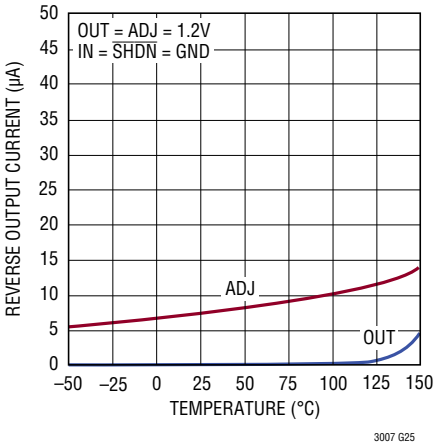
$\overline{SHDN}$ Pin Input Current



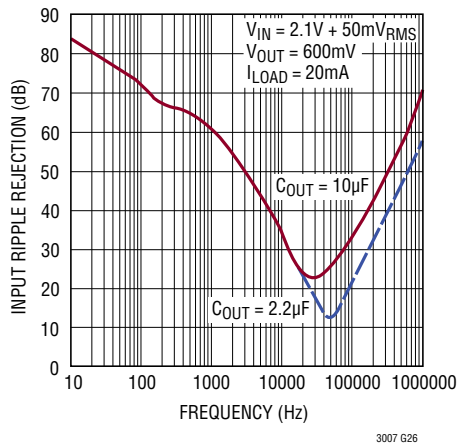
Current Limit



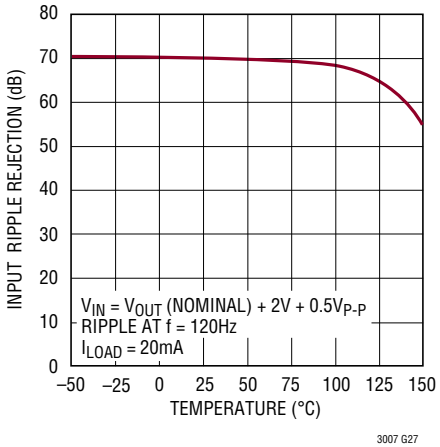
Reverse-Output Current



Input Ripple Rejection

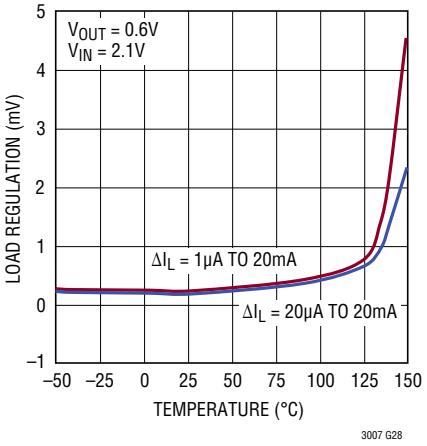


Input Ripple Rejection

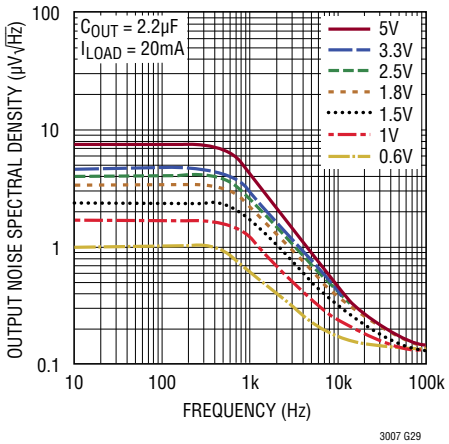


TYPICAL PERFORMANCE CHARACTERISTICS T_A = 25°C, unless otherwise noted.

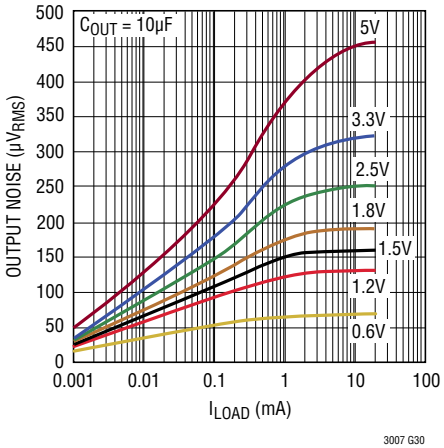
Load Regulation



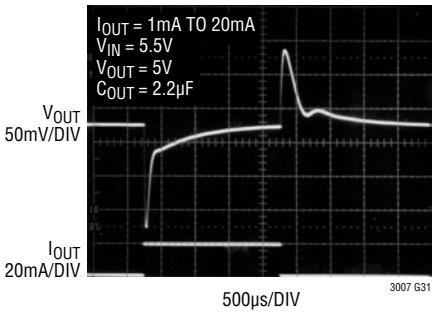
Output Noise Spectral Density



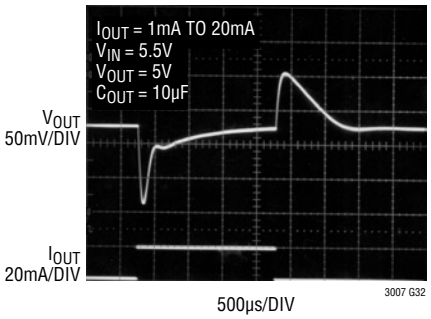
RMS Output Noise vs Load Current



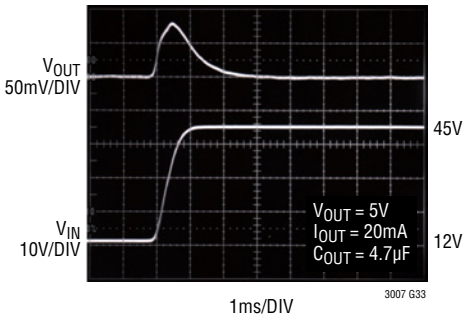
Transient Response



Transient Response



Transient Response (Load Dump)



PIN FUNCTIONS

$\overline{SHDN}$ (Pin 1): Shutdown. Pulling the $\overline{SHDN}$ pin low puts the LT3007 into a low power state and turns the output off. If unused, tie the $\overline{SHDN}$ pin to V_{IN}. The LT3007 does not function if the $\overline{SHDN}$ pin is not connected. The $\overline{SHDN}$ pin cannot be driven below GND unless tied to the IN pin. If the $\overline{SHDN}$ pin is driven below GND while IN is powered, the output will turn on. $\overline{SHDN}$ pin logic cannot be referenced to a negative rail.

GND (Pins 2, 3, 4): Ground. Connect the bottom of the resistor divider that sets output voltage directly to GND for the best regulation.

IN (Pin 5): Input. The IN pin supplies power to the device. The LT3007 requires a bypass capacitor at IN if the device is more than six inches away from the main input filter capacitor. In general, the output impedance of a battery rises with frequency, so it is advisable to include a bypass capacitor in battery-powered circuits. A bypass capacitor in the range of 0.1µF to 10µF will suffice. The LT3007 withstands reverse voltages on the IN pin with respect to ground and the OUT pin. In the case of a reversed input, which occurs with a battery plugged in backwards, the LT3007 acts as if a blocking diode is in series with its input. No reverse current flows into the LT3007 and no reverse voltage appears at the load. The device protects both itself and the load.

NC (Pin 6): No Connect. Pin 6 is an NC pin in the TSOT-23 package. This pin is not tied to any internal circuitry. LTC recommends that the NC pin be floated for fault tolerant operation.

OUT (Pin 7): Output. This pin supplies power to the load. Use a minimum output capacitor of 2.2µF to prevent oscillations. Large load transient applications require larger output capacitors to limit peak voltage transients. See the Applications Information section for more information on output capacitance and reverse-output characteristics.

ADJ (Pin 8): Adjust. This pin is the error amplifier's inverting terminal. Its 400pA typical input bias current flows out of the pin (see curve of ADJ Pin Bias Current vs Temperature in the Typical Performance Characteristics section). The ADJ pin voltage is 600mV referenced to GND and the output voltage range is 600mV to 44.5V.

SENSE (Pin 8): Sense. For fixed voltage versions of the LT3007 (LT3007-1.2, LT3007-1.5, LT3007-1.8, LT3007-2.5, LT3007-3.3, LT3007-5), the SENSE pin is the input to the error amplifier. Optimum regulation is obtained at the point where the SENSE pin is connected to the OUT pin of the regulator. In critical applications, small voltage drops are caused by the resistance (RP) of PC traces between the regulator and the load. These may be eliminated by connecting the SENSE pin to the output at the load as shown in Figure 1 (Kelvin Sense Connection). Note that the voltage drop across the external PC traces add to the dropout voltage of the regulator. The SENSE pin bias current is 1µA at the nominal rated output voltage. The SENSE pin can be pulled below ground (as in a dual supply system where the regulator load is returned to a negative supply) and still allow the device to start and operate.

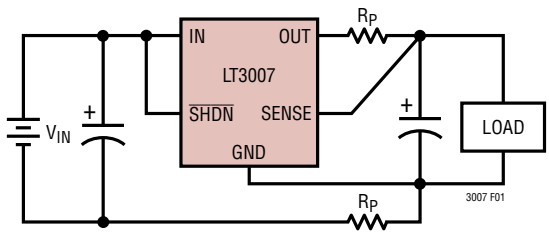


Figure 1. Kelvin Sense Connection

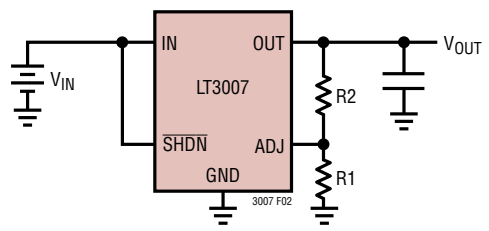
APPLICATIONS INFORMATION

The LT3007 is a low dropout linear regulator with ultra-low quiescent current and shutdown. Quiescent current is extremely low at 3µA and drops well below 1µA in shutdown. The device supplies up to 20mA of output current. Dropout voltage at 20mA is typically 300mV. The LT3007 incorporates several protection features, making it ideal for use in battery-powered systems. The device protects itself against both reverse-input and reverse-output voltages. In battery backup applications, where a backup battery holds up the output when the input is pulled to ground, the LT3007 acts as if a blocking diode is in series with its output and prevents reverse current flow. In applications where the regulator load returns to a negative supply, the output can be pulled below ground by as much as 50V without affecting start-up or normal operation.

Care must be taken when designing LT3007 applications to operate at temperatures greater than 125°C. See the High Temperature Operation Section for more information.

Adjustable Operation

The LT3007 has an output voltage range of 0.6V to 44.5V. Figure 2 shows that output voltage is set by the ratio of two external resistors. The IC regulates the output to maintain the ADJ pin voltage at 600mV referenced to ground. The current in R1 equals 600mV/R1 and the current in R2 is the current in R1 minus the ADJ pin bias current. The ADJ pin bias current, typically 400pA at 25°C, flows out of the pin. Calculate the output voltage using the formula in Figure 2. An R1 value of 619k sets the divider current to 0.97µA. Do not make R1's value any greater than 619k to minimize output voltage errors due to the ADJ pin bias current and to insure stability under minimum load conditions. In shutdown, the output turns off and the divider current is zero. Curves of ADJ Pin Voltage vs Temperature and ADJ Pin Bias Current vs Temperature appear in the Typical Performance Characteristics.



V_{OUT} = 600mV • (1 + R2/R1) – (I_{ADJ} • R2)
V_{ADJ} = 600mV
I_{ADJ} = 0.4nA at 25°C
OUTPUT RANGE = 0.6V to 44.5V

Figure 2. Adjustable Operation

Specifications for output voltages greater than 0.6V are proportional to the ratio of the desired output voltage to 0.6V: V_{OUT}/0.6V. For example, load regulation for an output current change of 100µA to 20mA is –0.5mV typical at V_{OUT} = 0.6V. At V_{OUT} = 5V, load regulation is:

$$\frac{5V}{0.6V} \bullet (-0.5mV) = -4.17mV$$

Table 1 shows resistor divider values for some common output voltages with a resistor divider current of about 1µA.

Table 1. Output Voltage Resistor Divider Values

V_{OUT}	R1	R2
1V	604k	402k
1.2V	590k	590k
1.5V	590k	887k
1.8V	590k	1.18M
2.5V	590k	1.87M
3V	590k	2.37M
3.3V	619k	2.8M
5V	590k	4.32M

Because the ADJ pin is relatively high impedance (depending on the resistor divider used), stray capacitances at this pin should be minimized. Special attention should be given to any stray capacitances that can couple external signals onto the ADJ pin, producing undesirable output transients or ripple.

Extra care should be taken in assembly when using high valued resistors. Small amounts of board contamination can lead to significant shifts in output voltage. Appropriate post-assembly board cleaning measures should be implemented to prevent board contamination. If the board is to be subjected to humidity cycling or if board cleaning measures cannot be guaranteed, consideration should be given to using resistors an order of magnitude smaller than in Table 1 to prevent contamination from causing unwanted shifts in the output voltage. A fixed voltage option in the LT3007 series does not need these special considerations.

APPLICATIONS INFORMATION

Output Capacitance and Transient Response

The LT3007 is stable with a wide range of output capacitors. The ESR of the output capacitor affects stability, most notably with small capacitors. Use a minimum output capacitor of 2.2µF with an ESR of 3Ω or less to prevent oscillations. The LT3007 is a micropower device and output load transient response is a function of output capacitance. Larger values of output capacitance decrease the peak deviations and provide improved transient response for larger load current changes.

Give extra consideration to the use of ceramic capacitors. Manufacturers make ceramic capacitors with a variety of dielectrics, each with different behavior across temperature and applied voltage. The most common dielectrics are specified with EIA temperature characteristic codes of Z5U, Y5V, X5R and X7R. The Z5U and Y5V dielectrics provide high C-V products in a small package at low cost, but exhibit strong voltage and temperature coefficients as shown in Figures 3 and 4. When used with a 5V regulator, a 16V 10µF Y5V capacitor can exhibit an effective value as low as 1µF to 2µF for the DC bias voltage applied and over the operating temperature range. The X5R and X7R dielectrics yield more stable characteristics and are more suitable for use as the output capacitor. The X7R type has better stability across temperature, while the X5R is less expensive and is available in higher values. One must still exercise care when using X5R and X7R capacitors; the X5R and X7R codes only specify operating temperature range and maximum capacitance change over temperature. Capacitance change due to DC bias with X5R and X7R capacitors is better than Y5V and Z5U capacitors, but can still be significant enough to drop capacitor values below appropriate levels. Capacitor DC bias characteristics tend to improve as component case size increases, but expected capacitance at operating voltage should be verified.

Voltage and temperature coefficients are not the only sources of problems. Some ceramic capacitors have a piezoelectric response. A piezoelectric device generates voltage across its terminals due to mechanical stress, similar to the way a piezoelectric accelerometer or microphone works. For a ceramic capacitor, the stress can be induced by vibrations in the system or thermal transients.

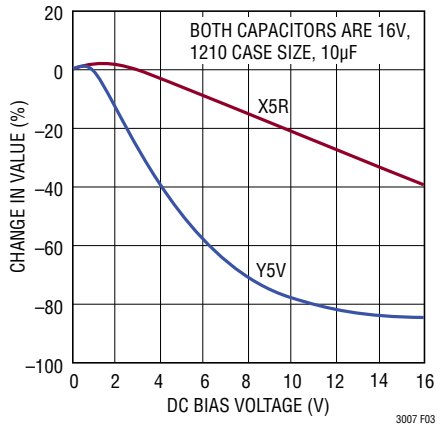


Figure 3. Ceramic Capacitor DC Bias Characteristics

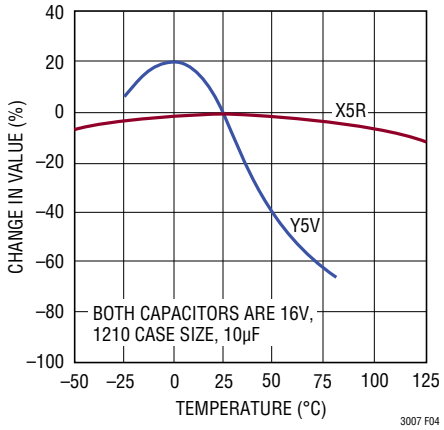


Figure 4. Ceramic Capacitor Temperature Characteristics

APPLICATIONS INFORMATION

The resulting voltages produced can cause appreciable amounts of noise, especially when a ceramic capacitor is used for noise bypassing. A ceramic capacitor produced Figure 5's trace in response to light tapping from a pencil. Similar vibration induced behavior can masquerade as increased output voltage noise.

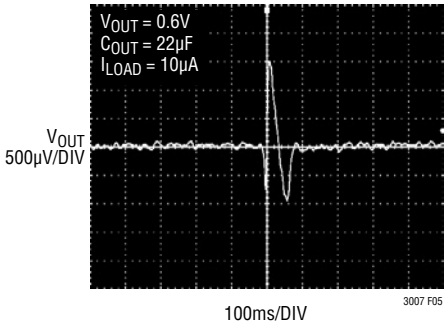


Figure 5. Noise Resulting from Tapping on a Ceramic Capacitor

Feedforward Capacitance

Using a feedforward capacitor (C_{FF}) from V_{OUT} to the ADJ pin of the LT3007 improves transient response for output voltages greater than 0.6V. With no feedforward capacitor, the settling time will increase as the output voltage is raised above 0.6V. A 4.7µF minimum output capacitor with an ESR of no more than 3Ω is required when using a feedforward capacitor. Use Table 2 to determine the recommended value of C_{FF} to achieve optimal transient response while maintaining stability. Round up to the nearest standard capacitor value.

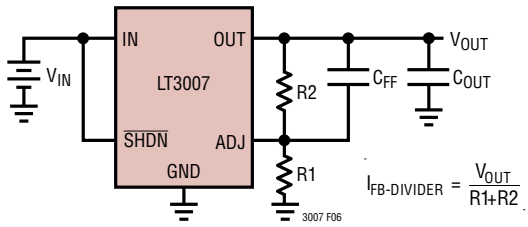


Figure 6. Feedforward Capacitor

Table 2. Feedforward Capacitor Values

NOMINAL V_{OUT}	FEEDFORWARD CAPACITANCE
$1.2 < V_{OUT} \leq 2.5$	470pF/µA • $I_{FB-DIVIDER}$ (µA)
$2.5 < V_{OUT} \leq 7.5$	220pF/µA • $I_{FB-DIVIDER}$ (µA)
$V_{OUT} > 7.5$	100pF/µA • $I_{FB-DIVIDER}$ (µA)

For example, a 5V output with a 1µA current flowing in the feedback resistor divider:

C_{FF} = 220pF/µA • 1µA = 220pF

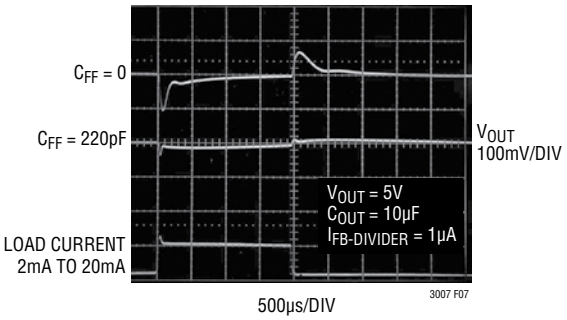


Figure 7. Transient Response with Feedforward Capacitor

Start-up time is affected by the use of a feedforward capacitor. Start-up time is directly proportional to the size of the feedforward capacitor and output voltage, and is inversely proportional to the feedback resistor divider current.

The use of a feedforward capacitor is required for operation at junction temperatures above 135°C in order to ensure good transient response.

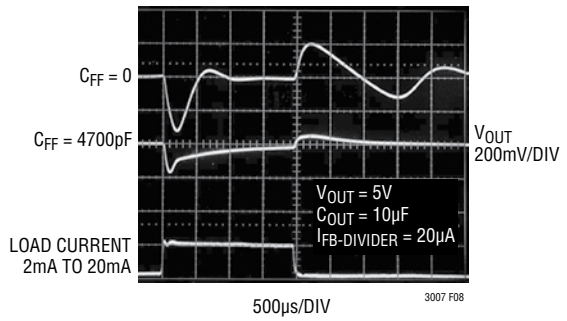


Figure 8. Transient Response with Feedforward Capacitor at 150°C

APPLICATIONS INFORMATION

Thermal Considerations

The LT3007's maximum rated junction temperature of 125°C limits its power-handling capability. Two components comprise the power dissipated by the device:

1. Output current multiplied by the input/output voltage differential: $I_{OUT} \bullet (V_{IN} - V_{OUT})$
2. GND pin current multiplied by the input voltage: $I_{GND} \bullet V_{IN}$

GND pin current is found by examining the GND Pin Current curves in the Typical Performance Characteristics section. Power dissipation is equal to the sum of the two components listed prior.

The LT3007 regulator has internal thermal limiting designed to protect the device during overload conditions. For continuous normal conditions, do not exceed the maximum junction temperature rating of 125°C. Carefully consider all sources of thermal resistance from junction to ambient including other heat sources mounted in proximity to the LT3007. For surface mount devices, heat sinking is accomplished by using the heat spreading capabilities of the PC board and its copper traces. Copper board stiffeners and plated through-holes can also be used to spread the heat generated by power devices.

The following tables list thermal resistance for several different board sizes and copper areas. All measurements were taken in still air on 3/32" FR-4 two-layer boards with one ounce copper.

PCB layers, copper weight, board layout and thermal vias affect the resultant thermal resistance. Although Table 2 provides thermal resistance numbers for 2-layer boards with 1 ounce copper, modern multilayer PCBs provide better performance than found in these tables. For example, a 4-layer, 1 ounce copper PCB board with three thermal vias from the three fused TSOT-23 GND pins to inner layer GND planes achieves 45°C/W thermal resistance. This is approximately a 30% improvement over the lowest numbers shown in Table 3.

Table 3: Measured Thermal Resistance for TSOT-23 Package

COPPER AREA		BOARD AREA	THERMAL RESISTANCE (JUNCTION-TO-AMBIENT)
TOPSIDE*	BACKSIDE		
2500mm^2	2500mm^2	2500mm^2	65°C/W
1000mm^2	2500mm^2	2500mm^2	67°C/W
225mm^2	2500mm^2	2500mm^2	70°C/W
100mm^2	2500mm^2	2500mm^2	75°C/W
50mm^2	2500mm^2	2500mm^2	85°C/W

*Device is mounted on the topside.

Calculating Junction Temperature

Example: Given an output voltage of 3.3V, an input voltage range of 12V ±5%, an output current range of 0mA to 20mA and a maximum ambient temperature of 85°C, what will the maximum junction temperature be?

The power dissipated by the device is equal to:

$$I_{OUT(MAX)} (V_{IN(MAX)} - V_{OUT}) + I_{GND} (V_{IN(MAX)})$$

where,

$I_{OUT(MAX)} = 20mA$

$V_{IN(MAX)} = 12.6V$

I_{GND} at ($I_{OUT} = 20mA$, $V_{IN} = 12.6V$) = 0.3mA

So,

$P = 20mA(12.6V - 3.3V) + 0.3mA(12.6V) = 189.8mW$

The thermal resistance ranges from 65°C/W to 85°C/W depending on the copper area. So, the junction temperature rise above ambient approximately equals:

0.1898W(75°C/W) = 14.2°C

APPLICATIONS INFORMATION

The maximum junction temperature equals the maximum junction temperature rise above ambient plus the maximum ambient temperature or:

$$T_{J(MAX)} = 85°C + 14.2°C = 99.2°C$$

High Temperature Operation

Care must be taken when designing LT3007 applications to operate at high ambient temperatures. The LT3007 works at elevated temperatures but erratic operation can occur due to unforeseen variations in external components. Some tantalum capacitors are available for high temperature operation, but ESR is often several Ohms; capacitor ESR above 3Ω is unsuitable for use with the LT3007. Ceramic capacitor manufacturers (Murata, AVX, TDK, and Vishay at the time of this writing) now offer ceramic capacitors that are rated to 150°C using an X8R dielectric. Device instability will occur if the output capacitor value and ESR are outside design limits at elevated temperature and operating DC voltage bias (see information on capacitor characteristics under Output Capacitance and Transient Response). Check each passive component for absolute value and voltage ratings over the operating temperature range.

Operation of the LT3007 at temperatures above 125°C requires careful selection of external components to ensure output regulation, stability and optimal transient response. Figures 9 and 10 have curves showing power device leakage (from IN to OUT) for the LT3007 in both active and shutdown states. The minimum external load must be greater than this leakage to prevent the OUT pin from rising out of regulation due to power device leakage. Power device leakage decreases if the LT3007 is active; if IN is tied directly to $\overline{SHDN}$, the minimum required load is reduced. The recommended minimum external load is 20µA. The use of a feedforward capacitor is required for operation at temperatures above 135°C (see Feedforward Capacitance section). For output voltages of 1.2V and above, the feedforward capacitor ensures good transient response. Use of the LT3007 at temperatures above 135°C and output voltages under 1.2V is not advised.

Leakage in capacitors, or from solder flux left after insufficient board cleaning, adversely affects the low quiescent current operation. Consider junction temperature increase due to power dissipation in both the junction and nearby components to ensure maximum specifications are not violated for the LT3007 or external components.

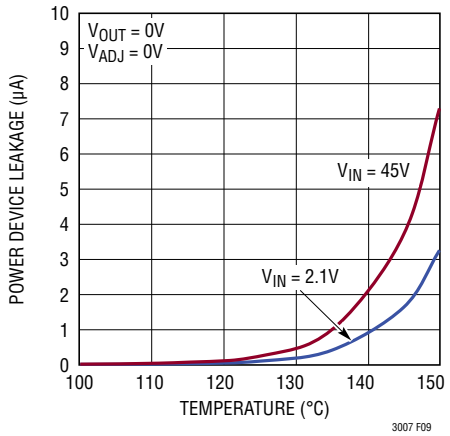


Figure 9. Power Device Leakage, $\overline{SHDN}$ = 0V

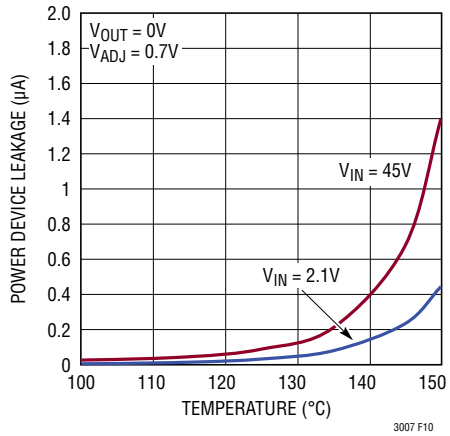


Figure 10. Power Device Leakage, $\overline{SHDN}$ = 1.5V

APPLICATIONS INFORMATION

Protection Features

The LT3007 incorporates several protection features that make it ideal for use in battery-powered circuits. In addition to the normal protection features associated with monolithic regulators, such as current limiting and thermal limiting, the device also protects against reverse-input voltages, reverse-output voltages and reverse output-to-input voltages.

Current limit protection and thermal overload protection protect the device against current overload conditions at the output of the device. For normal operation, do not exceed a junction temperature of 125°C. The typical thermal shutdown circuitry temperature threshold is 160°C.

The IN pin withstands reverse voltages of 50V. The device limits current flow to less than 30µA (typically less than 1µA) and no negative voltage appears at OUT. The device protects both itself and the load against batteries that are plugged in backwards.

The $\overline{SHDN}$ pin cannot be driven below GND unless tied to the IN pin. If the $\overline{SHDN}$ pin is driven below GND while IN is powered, the output will turn on. $\overline{SHDN}$ pin logic cannot be referenced to a negative rail.

The LT3007 incurs no damage if OUT is pulled below ground. If IN is left open circuit or grounded, OUT can be pulled below ground by 50V. No current flows from the pass transistor connected to OUT. However, current flows in (but is limited by) the resistor divider that sets output voltage. Current flows from the bottom resistor in the divider and from the ADJ pin's internal clamp through the top resistor in the divider to the external circuitry pulling OUT below ground. If IN is powered by a voltage source, OUT sources current equal to its current limit capability and the LT3007 protects itself by thermal limiting if necessary. In this case, grounding the $\overline{SHDN}$ pin turns off the LT3007 and stops OUT from sourcing current.

The LT3007 incurs no damage if the ADJ pin is pulled above or below ground by 50V. If IN is left open circuit or grounded, ADJ acts like a 100k resistor in series with a diode when pulled above or below ground.

In circuits where a backup battery is required, several different input/output conditions can occur. The output voltage may be held up while the input is either pulled to ground, pulled to some intermediate voltage or is left open circuit. Current flow back into the output follows the curve shown in Figure 11.

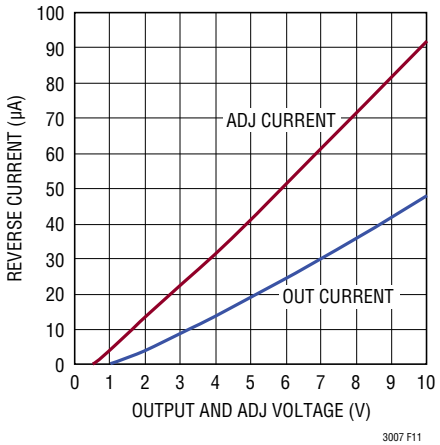


Figure 11. Reverse-Output Current

APPLICATIONS INFORMATION

If the LT3007 IN pin is forced below the OUT pin or the OUT pin is pulled above the IN pin, input current typically drops to less than 1µA. This occurs if the LT3007 input is connected to a discharged (low voltage) battery and either a backup battery or a second regulator circuit holds up the output. The state of the $\overline{SHDN}$ pin has no effect in the reverse current if OUT is pulled above IN.

Fault Tolerance

The LT3007 regulators tolerate single fault conditions. Shorting two adjacent pins together or leaving one single pin floating does not increase V_{OUT} above its regulated value or cause damage to the LT3007 regulators. However, the application circuit must meet the requirements discussed in this section to achieve this tolerance level. Tables 4 and 5 show the effects that result from shorting adjacent pins or from a floating pin, respectively.

Table 4: Effects of Pin-to-Pin Shorts

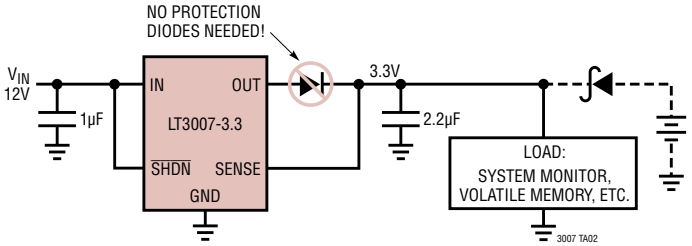
PIN NUMBERS	PIN NAMES	EFFECT	COMMENT
1-2	SHDN-GND	LT3007 is in Micropower Shutdown, V_{OUT} is Off	
2-3	GND-GND	No Effect. Pins 2, 3 and 4 are Normally Tied to GND	
3-4	GND-GND	No Effect. Pins 2, 3 and 4 are Normally Tied to GND	
5-6	IN-NC	No Effect as Long as NC is Floating	
6-7	NC-OUT	No Effect as Long as NC is Floating	
7-8	OUT-ADJ	V_{OUT} Decreases to 600mV as the Top Resistor in the V_{OUT} Divider is Shorted	LT3007 Adjustable Version
7-8	OUT-SENSE	No Effect as These Two Pins are Normally Shorted Together	LT3007 Fixed Voltage version.

Table 5: Effects of Floating Pins

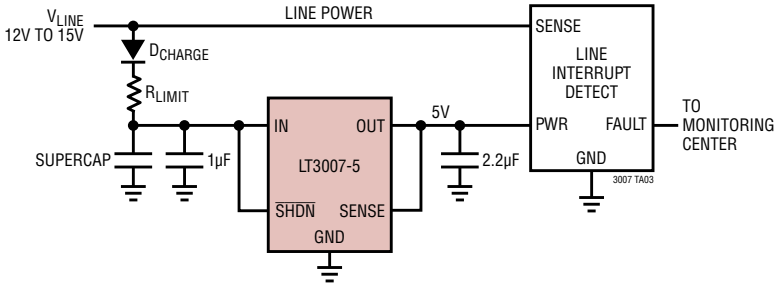
PIN NUMBER	PIN NAME	EFFECT	COMMENT
1	SHDN	LT3007 is in Micropower Shutdown, V_{OUT} is Off	
2	GND	No Effect as Long as Pins 3 or 4 are Tied to GND	
3	GND	No Effect as Long as Pins 2 or 4 are Tied to GND	
4	GND	No Effect as Long as Pins 2 or 3 are Tied to GND	
5	IN	LT3007 Has No Input Power, V_{OUT} is Off	
6	NC	No Effect	
7	OUT	V_{OUT} Internal to LT3007 is $\cong V_{IN}$. V_{OUT} Externally Decreases to 0V	
8	ADJ	V_{OUT} Decreases to Less Than Regulated V_{OUT}	LT3007 Adjustable Version
8	SENSE	V_{OUT} Increases to $\cong V_{IN}$ Unless an External Clamp is Added	LT3007 Fixed Voltage version.

TYPICAL APPLICATIONS

Keep-Alive Power Supply



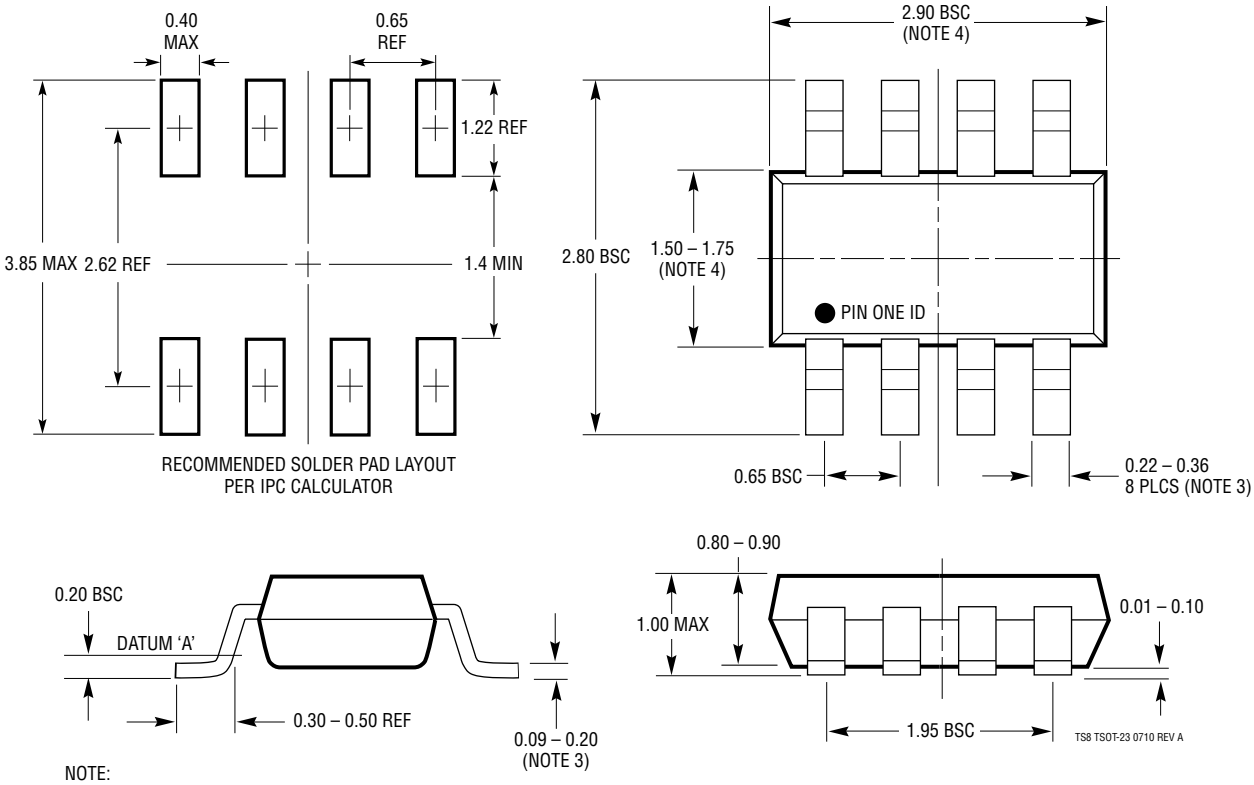
Last-Gasp Circuit



PACKAGE DESCRIPTION

Please refer to http://www.linear.com/designtools/packaging/ for the most recent package drawings.

TS8 Package
8-Lead Plastic TSOT-23
(Reference LTC DWG # 05-08-1637 Rev A)



NOTE:
1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. JEDEC PACKAGE REFERENCE IS MO-193

REVISION HISTORY

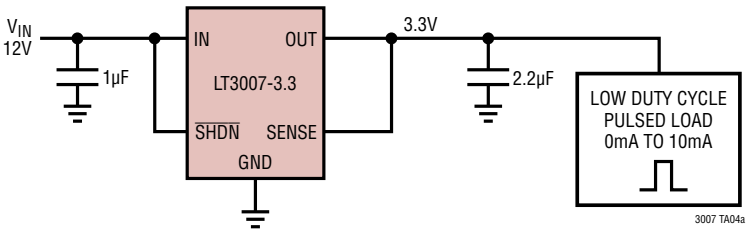
REV	DATE	DESCRIPTION	PAGE NUMBER
A	11/14	Added H-grade	2 to 5
		Modified Conditions for Current Limit graph	7
		Updated Load Regulation graph	8
		Modified High Temperature section in Applications Information	10
		Added Feedforward Capacitance section	12
		Added High Temperature Operation section	14

LINEAR TECHNOLOGY

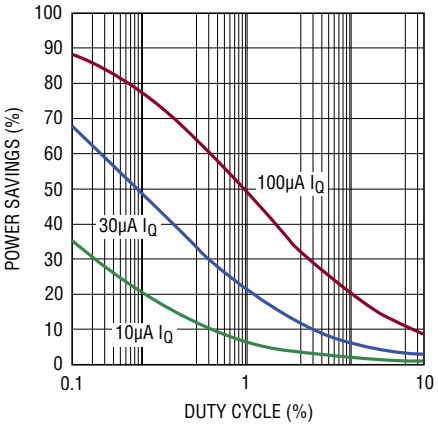
Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

TYPICAL APPLICATION

Low Duty Cycle Applications



Average Power Savings for Low Duty Cycle Applications
0mA to 10mA Pulsed Load, IN = 12V



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1761	100mA, Low Noise Micropower LDO	V_{IN}: 1.8V to 20V, V_{OUT} = 1.22V, V_{DO} = 0.3V, I_Q = 20µA, I_{SD} < 1µA, Low Noise: < 20µV_{RMS}, Stable with 1µF Ceramic Capacitors, ThinSOT™ Package
LT1762	150mA, Low Noise Micropower LDO	V_{IN}: 1.8V to 20V, V_{OUT} = 1.22V, V_{DO} = 0.3V, I_Q = 25µA, I_{SD} < 1µA, Low Noise: < 20µV_{RMS}, MS8 Package
LT1763	500mA, Low Noise Micropower LDO	V_{IN}: 1.8V to 20V, V_{OUT} = 1.22V, V_{DO} = 0.3V, I_Q = 30µA, I_{SD} < 1µA, Low Noise: < 20µV_{RMS}, S8 Package
LT1764/LT1764A	3A, Low Noise, Fast Transient Response LDOs	V_{IN}: 2.7V to 20V, V_{OUT} = 1.21V, V_{DO} = 0.34V, I_Q = 1mA, I_{SD} < 1µA, Low Noise: < 40µV_{RMS}, LT1764A Version Stable with Ceramic Capacitors, DD and TO220-5 Packages
LT1962	300mA, Low Noise Micropower LDO	V_{IN}: 1.8V to 20V, $V_{OUT(MIN)}$ = 1.22V, V_{DO} = 0.27V, I_Q = 30µA, I_{SD} < 1µA, Low Noise: < 20µV_{RMS}, MS8 Package
LT1963/LT1963A	1.5A, Low Noise, Fast Transient Response LDOs	V_{IN}: 2.1V to 20V, $V_{OUT(MIN)}$ = 1.21V, V_{DO} = 0.34V, I_Q = 1mA, I_{SD} < 1µA, Low Noise: < 40µV_{RMS}, LT1963A Version Stable with Ceramic Capacitors, DD, TO220-5, SOT223 and S8 Packages
LT3008	20mA, 45V, 3µA I_Q Micropower LDO	300mV Dropout Voltage, Low I_Q: 3µA, V_{IN}: 2V to 45V, V_{OUT}: 0.6V to 39.5V, ThinSOT and 2mm × 3mm DFN-6 Packages
LT3009	20mA, 3µA I_Q Micropower LDO	V_{IN}: 1.6V to 20V, Low I_Q: 3µA, V_{DO} = 0.28V, 2mm × 2mm DFN and SC70-8 Packages
LT3020	100mA, Low Voltage VLDO	V_{IN}: 0.9V to 10V, $V_{OUT(MIN)}$ = 0.20V, V_{DO} = 0.15V, I_Q = 120µA, I_{SD} < 1µA, 3mm × 3mm DFN and MS8 Packages
LT3021	500mA, Low Voltage VLDO	V_{IN}: 0.9V to 10V, $V_{OUT(MIN)}$ = 0.20V, V_{DO} = 0.16V, I_Q = 120µA, I_{SD} < 3µA, 5mm × 5mm DFN and SO8 Packages
LT3080/LT3080-1	1.1A, Parallelable, Low Noise, Low Dropout Linear Regulator	300mV Dropout Voltage (2-Supply Operation), Low Noise: 40µV_{RMS}, V_{IN}: 1.2V to 36V, V_{OUT}: 0V to 35.7V, Current-Based Reference with 1-Resistor V_{OUT} Set; Directly Parallelable (No Op Amp Required), Stable with Ceramic Caps, TO-220, SOT-223, MSOP and 3mm × 3mm DFN Packages; LT3080-1 Version Has Integrated Internal Ballast Resistor
LT3085	500mA, Parallelable, Low Noise, Low Dropout Linear Regulator	275mV Dropout Voltage (2-Supply Operation), Low Noise: 40µV_{RMS}, V_{IN}: 1.2V to 36V, V_{OUT}: 0V to 35.7V, Current-Based Reference with 1-Resistor V_{OUT} Set; Directly Parallelable (No Op Amp Required), Stable with Ceramic Caps, MSOP-8 and 2mm × 3mm DFN Packages

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