LT1635

Micropower Rail-to-Rail Op Amp and Reference

FEATURES

- **Guaranteed Operation at 1.2V**
- **Op Amp and Reference on Single Chip**
- **Micropower: 130µA Supply Current**
- Industrial Temperature Range SO-8 Packages
- Rail-to-Rail Output
- High Output Current: 20mA Min
- Output Drives 1000pF
- Capable of Floating Mode Operation
- Specified for 5V and ±5V Supplies
- Low Reference Drift: 30ppm/°C
- Industry Standard LM10 Pinout

APPLICATIONS

- Battery- or Solar-Powered Systems
  Portable Instrumentation
  Sensor Conditioning
- Precision Current Regulators
- Precision Voltage Regulators
- Battery Level Indicator
- Thermocouple Transmitter

DESCRIPTION

The LT®1635 is a new analog building block that includes a rail-to-rail output op amp, a precision reference and reference buffer. The device operates from supplies as low as a single 1.2V or up to ±5V, yet it consumes only 130µA of supply current.

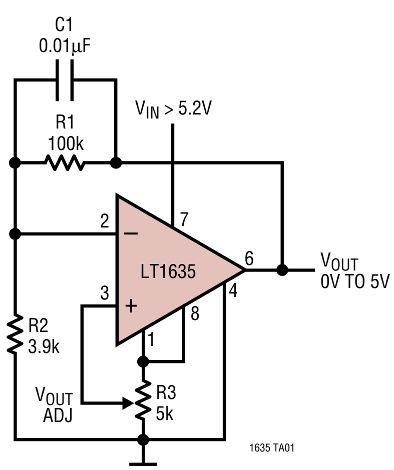
The input common mode range of the op amp includes ground and incorporates phase reversal protection to prevent false outputs from occurring when the input is below the negative supply. The rail-to-rail output stage can swing to within 15mV of each rail with no load and can swing to within 250mV of each rail while delivering 10mA of output current. The gain bandwidth of the op amp is 175kHz and it is unity-gain stable with up to 1000pF load capacitance.

The 0.2V reference is referred to V^- and includes a buffer amplifier to enhance flexibility. The reference and buffer combine to achieve a drift of 30ppm/°C, a line regulation of 20ppm/V and a load regulation of 150ppm/mA.

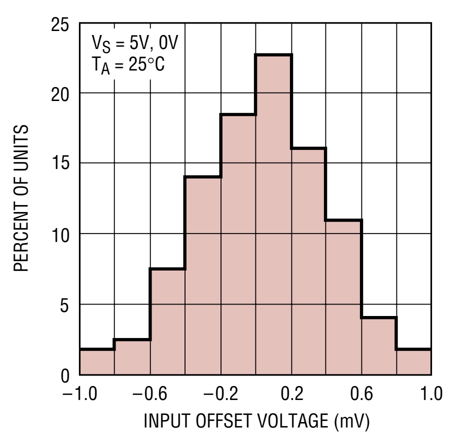
The LT1635 is available in 8-pin PDIP and SO packages, and has the industry standard LM10 pinout.

TYPICAL APPLICATION

0V to 5V Regulator



Typical Distribution of Input Offset Voltage

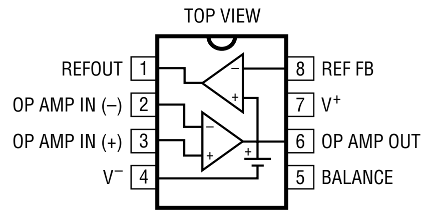


ABSOLUTE MAXIMUM RATINGS

(Note 1)

Total Supply Voltage (V^+ to V^-) 14V
Input Differential Voltage 14V
Input Current ....±25mA
Output Short-Circuit Duration ....Continuous
Operating Temperature Range
(Note 2) .... −40°C to 85°C
Junction Temperature .... 150°C
Storage Temperature Range .... −65°C to 150°C
Lead Temperature (Soldering, 10 sec) .... 300°C

PACKAGE/ORDER INFORMATION



N8 PACKAGE 8-LEAD PDIP | S8 PACKAGE 8-LEAD PLASTIC SO

T_{JMAX} = 150°C, θ_{JA} = 130°C/ W (N8)
T_{JMAX} = 150°C, θ_{JA} = 190°C/ W (S8)

ORDER PART NUMBER
LT1635CN8
LT1635CS8
LT1635IN8
LT1635IS8
S8 PART MARKING
1635 1635I

Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

5V OP AMP: The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = 5V, 0V; V_{CM} = V_{OUT} = 2.5V, unless otherwise noted. (Note 2)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage				0.3	1.3	mV
		0°C ≤ T_A ≤ 70°C	●		0.5	1.6	mV
		−40°C ≤ T_A ≤ 85°C	●			1.8	mV
	Input Offset Voltage Drift	−40°C ≤ T_A ≤ 85°C (Note 4)	●		3.0	7.0	µV/°C
V_{OS} ADJ	Offset Voltage Adjust Range	Positive Adjust	●	6	8		mV
		Negative Adjust	●	−1.4	−2		mV
I_{OS}	Input Offset Current		●		0.2	0.6	nA
I_B	Input Bias Current				2.0	4.5	nA
			●		2.5	5.5	nA
	Input Noise Voltage	0.1Hz to 10Hz			1		μV_{P-P}
e_n	Input Noise Voltage Density	f = 1kHz			50		$nV/\sqrt{Hz}$
i_n	Input Noise Current Density	f = 1kHz			0.05		$pA/\sqrt{Hz}$
R_{IN}	Input Resistance	Differential	●	7	25		MΩ
		Common Mode, V_{CM} = 0V to 4V			6		GΩ
	Input Voltage Range		●	0		4	V
CMRR	Common Mode Rejection Ratio	V_{CM} = 0V to 4V		92	110		dB
			●	85	97		dB
A_{VOL}	Large-Signal Voltage Gain	V_O = 200mV to 4.5V, No Load	●	100	450		V/mV
		V_O = 200mV to 4.5V, R_L = 1.1k	●	45	200		V/mV
		V_O = 200mV to 4.5V, R_L = 500Ω	●	35	150		V/mV
	Shunt Gain	I_{OUT} = 0.1mA to 5mA					V/mV
		V_O = 1.5V to 6.45V		15	25		V/mV
		(Note 5)	●	8	20		V/mV
V_{OL}	Output Voltage Swing Low	V_S = 5V, No Load	●		2	10	mV
		V_S = 5V, I_{SINK} = 5mA	●		125	250	mV
		V_S = 5V, I_{SINK} = 10mA	●		200	500	mV
V_{OH}	Output Voltage Swing High	V_S = 5V, No Load	●	4.975	4.985		V
		V_S = 5V, I_{SOURCE} = 5mA	●	4.65	4.8		V
		V_S = 5V, I_{SOURCE} = 10mA	●	4.55	4.75		V

ELECTRICAL CHARACTERISTICS

5V OP AMP: The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = 5V, 0V; V_{CM} = V_{OUT} = 2.5V, unless otherwise noted. (Note 2)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
I_{SC}	Short-Circuit Current	V_S = 5V, Short to GND V_S = 5V, Short to V_{CC}	● ●	20 20	40 40		mA mA
PSRR	Power Supply Rejection Ratio	V_S = 1.2V to 12V, V_{CM} = V_O = 0.2V	 ●	93 90	100 97		dB dB
	Minimum Operating Supply Voltage	(Note 3)	●		1.1	1.2	V
I_S	Supply Current		 ●		130 150	200 260	μA μA
GBW	Gain Bandwidth Product	f = 1kHz			175		kHz
SR	Slew Rate	A_V = –1, R_L = ∞			0.045		V/μs

5V REFERENCE: The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = 5V, 0V, unless otherwise noted. (Note 2)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{REF}	Feedback Sense Voltage	Voltage at Pin 1 with Pin 1 Connected to Pin 8 (Note 6)	●	189	200	211	mV
TC V_{REF}	Reference Drift	(Note 4)	●		30	100	ppm/°C
	Feedback Current	Current into Pin 8	 ●		3.5 5.0	10 15	nA nA
	Line Regulation	0 ≤ I_{REF} ≤ 1mA, V_{REF} = 200mV V_S = 1.2V to 5V V_S = 1.3V to 5V (Note 3)	 ●		 20 30	 100 200	 ppm/V ppm/V
	Load Regulation	I_{REF} = 0 to 1mA	 ●		150 200	300 500	ppm/mA ppm/mA
	Reference Amplifier Gain	V_O = 0.2V to 3.5V	 ●	45 25	90 50		V/mV V/mV

±5V OP AMP: The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = ±5V; V_{CM} = V_{OUT} = 0V, unless otherwise noted. (Note 2)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	 0°C ≤ T_A ≤ 70°C –40°C ≤ T_A ≤ 85°C	 ● ●		0.3 0.5	1.5 1.9 2.1	mV mV mV
	Input Offset Voltage Drift	0°C ≤ T_A ≤ 85°C (Note 4)	●		4.5	10.0	μV/°C
V_{OS} ADJ	Offset Voltage Adjust Range	Positive Adjust Negative Adjust	● ●	6 –1.4	8 –2		mV mV
I_{OS}	Input Offset Current		●		0.2	0.6	nA
I_B	Input Bias Current		 ●		2.0 2.5	4.5 5.5	nA nA
	Input Noise Voltage	0.1Hz to 10Hz			1		μV_{P-P}
e_n	Input Noise Voltage Density	f = 1kHz			50		$nV/\sqrt{Hz}$
i_n	Input Noise Current Density	f = 1kHz			0.05		$pA/\sqrt{Hz}$
R_{IN}	Input Resistance	Differential Common Mode, V_{CM} = –5V to 4V	●	7	35 9		MΩ GΩ
	Input Voltage Range		●	–5		4	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –5V to 4V	 ●	94 91	115 110		dB dB

ELECTRICAL CHARACTERISTICS

±5V OP AMP: The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = ±5V; V_{CM} = V_{OUT} = 0V, unless otherwise noted. (Note 2)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
A_{VOL}	Large-Signal Voltage Gain	V_O = −4.5V to 4.5V, No Load V_O = −4.5V to 4.5V, R_L = 1.1k V_O = −4.5V to 4.5V, R_L = 500Ω	● ● ●	175 15 10	300 100 60		V/mV V/mV V/mV
V_O	Output Voltage Swing	V_S = ±5V, No Load V_S = ±5V, I_{SINK} = 5mA V_S = ±5V, I_{SINK} = 10mA	● ● ●	±4.975 ±4.65 ±4.5	±4.985 ±4.75 ±4.6		mV mV mV
I_{SC}	Short-Circuit Current	V_S = ±5V		±20	±40		mA
PSRR	Power Supply Rejection Ratio	V_S = ±1V to ±6V, V_{CM} = V_O = 0V	 ●	90 88	100 98		dB dB
I_S	Supply Current		 ●		135 160	215 280	µA µA
GBW	Gain Bandwidth Product	f = 1kHz			175		kHz
SR	Slew Rate	A_V = −1, R_L = ∞			0.05		V/µs

±5V REFERENCE: The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = ±5V, unless otherwise noted. (Note 2)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{REF}	Feedback Sense Voltage	Voltage at Pin 1 with Pin 1 Connected to Pin 8 (Note 6)	●	189	200	211	mV
TC V_{REF}	Reference Drift	(Note 4)	●		40	120	ppm/°C
	Feedback Current	Current into Pin 8	 ●		3.5 5.0	10 15	nA nA
	Line Regulation	0 ≤ I_{REF} ≤ 1mA, V_{REF} = 200mV V_S = ±0.6V to ±5V V_S = ±0.65V to ±5V (Note 3)	 ●		 20 30	 100 200	 ppm/V ppm/V
	Load Regulation	I_{REF} = 0 to 1mA	 ●		150 200	300 500	ppm/mA ppm/mA
	Reference Amplifier Gain	V_O = 0.2V to 8.5V V_S = 10V, 0V	 ●	45 25	90 50		V/mV V/mV

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: The LT1635C is guaranteed to operate over the commercial temperature range of 0°C to 70°C. It is designed, characterized and expected to meet these extended temperature limits, but is not tested at −40°C and 85°C. The LT1635I is guaranteed to meet the industrial temperature range.

Note 3: The LT1635 op amp operates on a 1.2V supply over the full industrial temperature range with an input common mode voltage of 0V to 0.2V. The minimum supply voltage for the reference to operate properly over this temperature range is 1.3V.

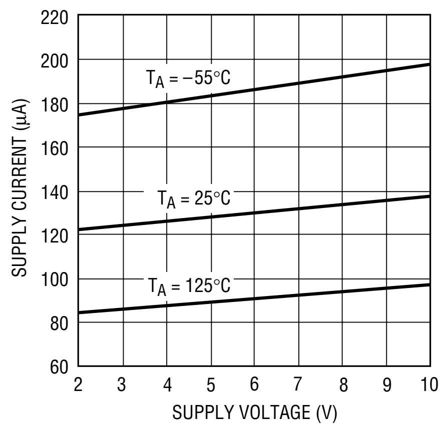
Note 4: This parameter is not 100% tested. Temperature coefficient is measured by dividing the change in output voltage by specified temperature range.

Note 5: Shunt gain defines the operation in floating applications when the output is connected to the V^+ terminal and input common mode is referred to V^-.

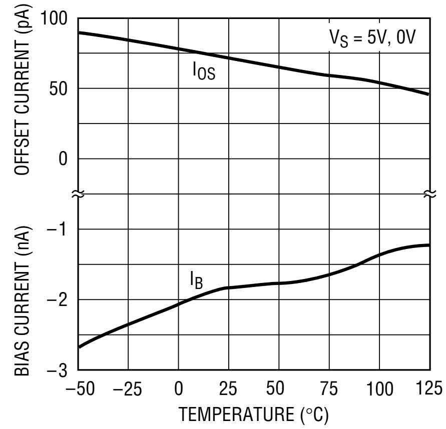
Note 6: If part is stored outside of the specified temperature range, the output may shift due to hysteresis.

TYPICAL PERFORMANCE CHARACTERISTICS Op Amp

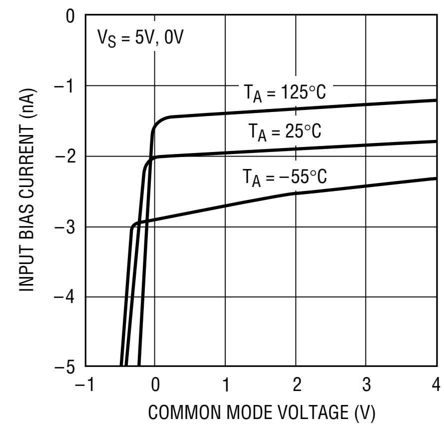
Supply Current vs Supply Voltage



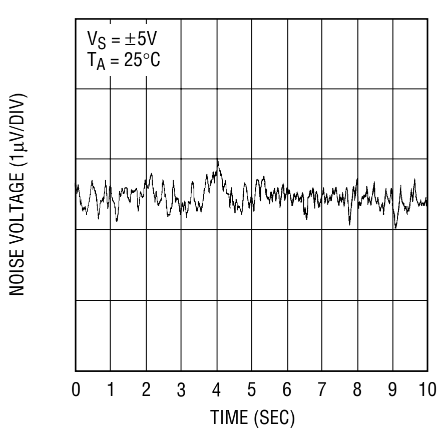
Input Bias and Offset Currents vs Temperature



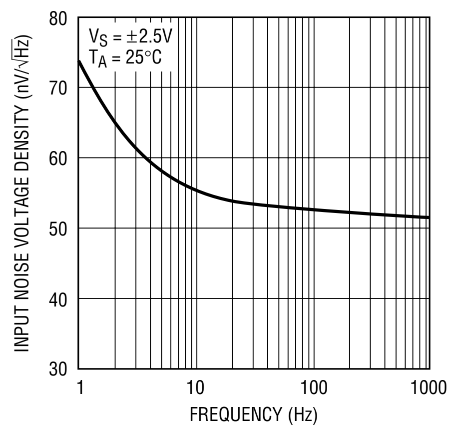
Input Bias Current vs Common Mode Voltage



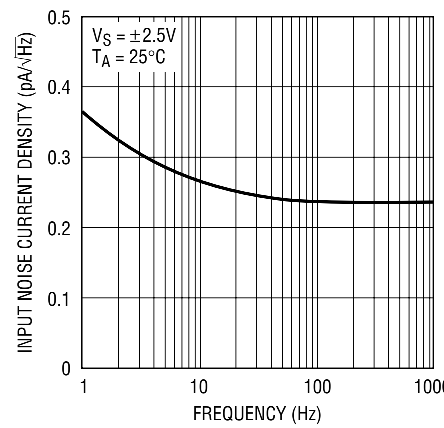
0.1Hz to 10Hz Noise Voltage



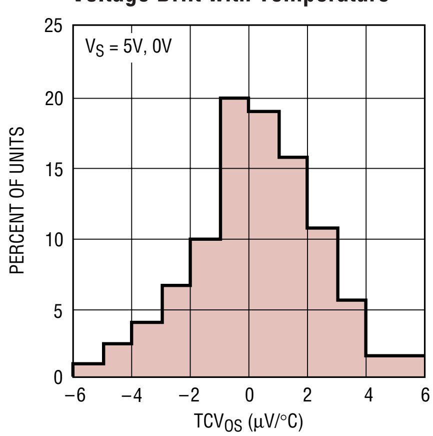
Noise Voltage Density vs Frequency



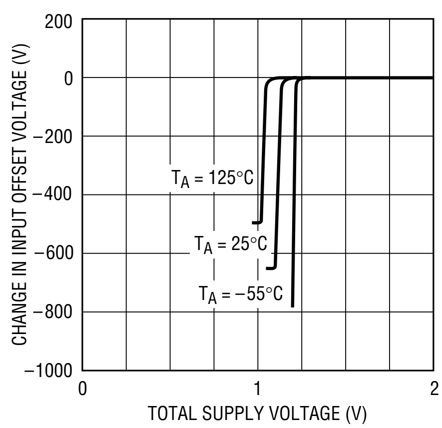
Input Noise Current vs Frequency



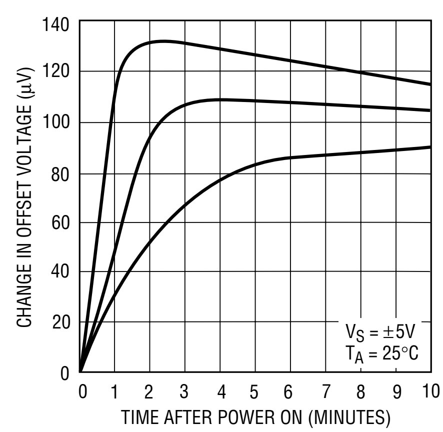
Typical Distribution of Offset Voltage Drift with Temperature



Minimum Supply Voltage

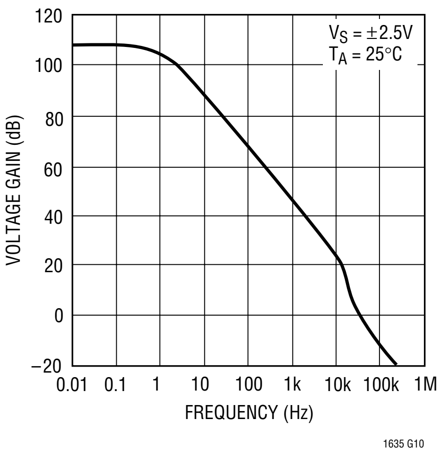


Turn-On Drift of Three Typical Units

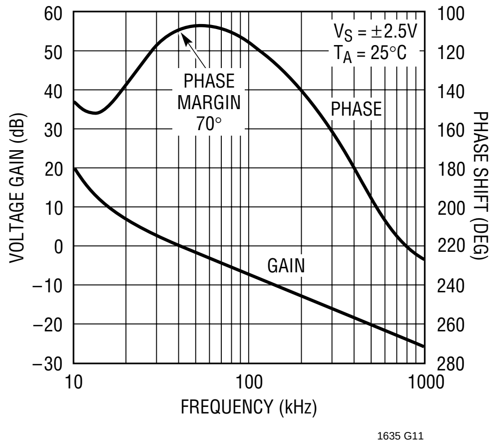


TYPICAL PERFORMANCE CHARACTERISTICS Op Amp

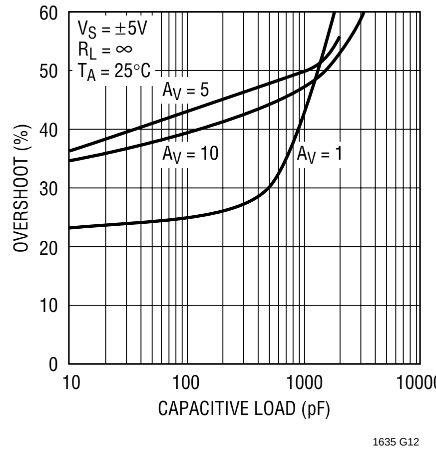
Voltage Gain vs Frequency



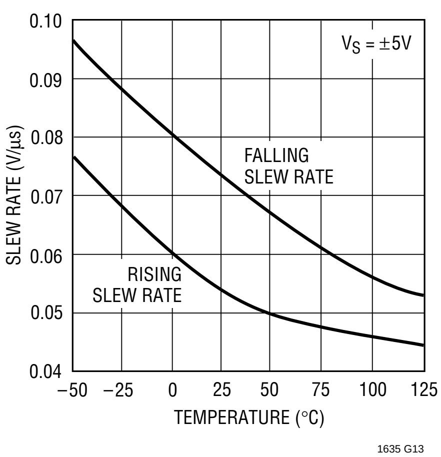
Gain Phase vs Frequency



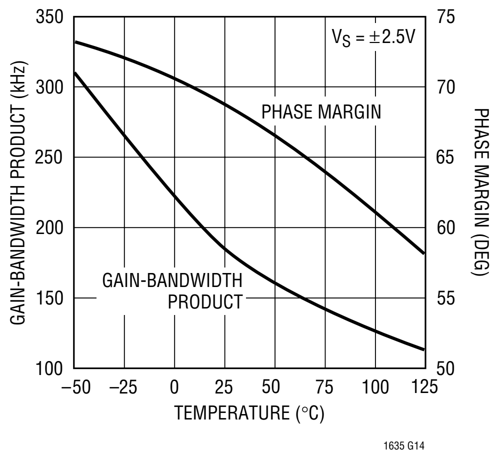
Capacitive Load Handling



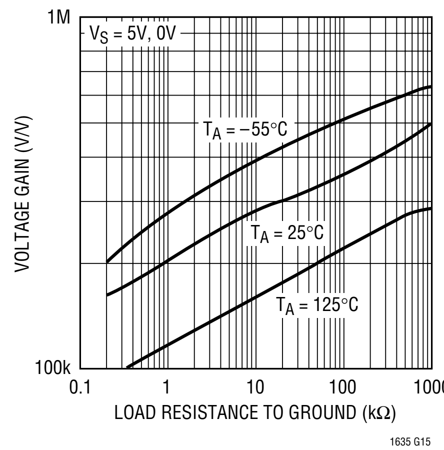
Slew Rate vs Temperature



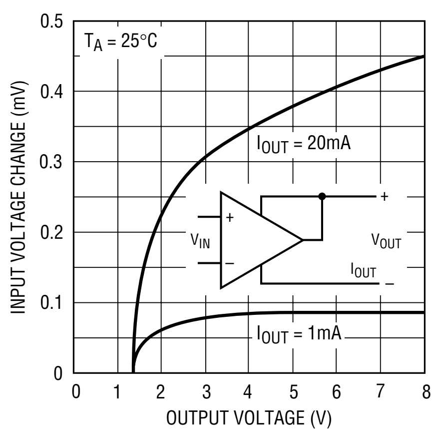
Gain-Bandwidth Product and Phase Margin vs Temperature



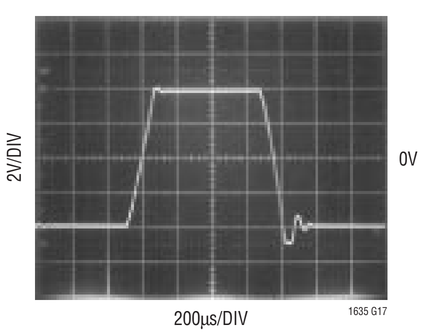
Voltage Gain vs Load Resistance



Shunt Gain

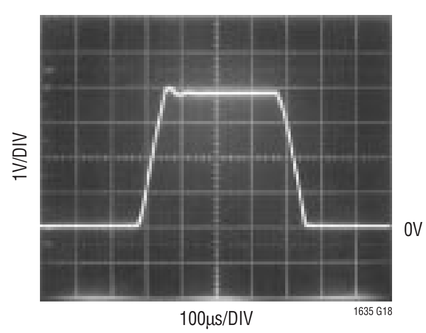


Large-Signal Transient Response $V_S = \pm5V$



$A_V = 1$, NO LOAD
INPUT $8V_{P-P}$

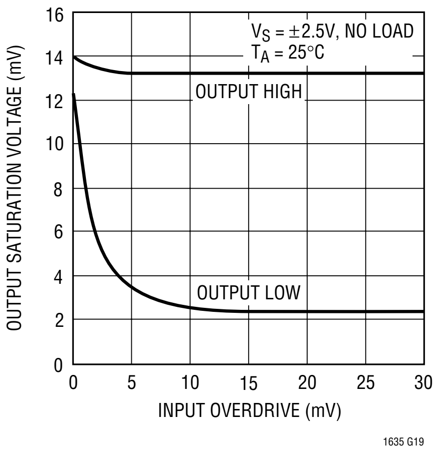
Large-Signal Transient Response $V_S = 5V, 0V$



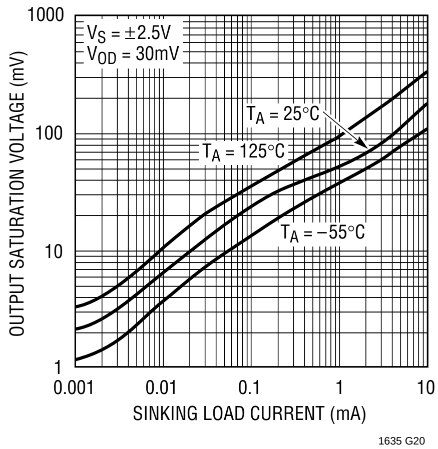
$A_V = 1$, NO LOAD
INPUT PULSE 0V TO 4V

TYPICAL PERFORMANCE CHARACTERISTICS Op Amp

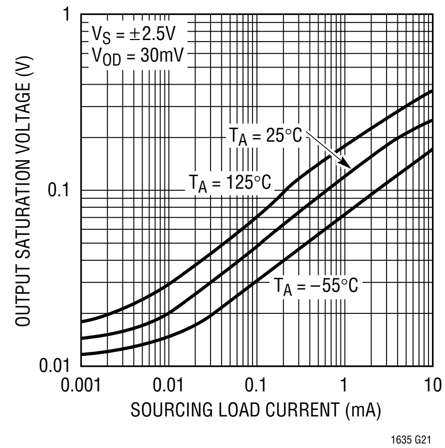
Output Saturation Voltage vs Input Overdrive



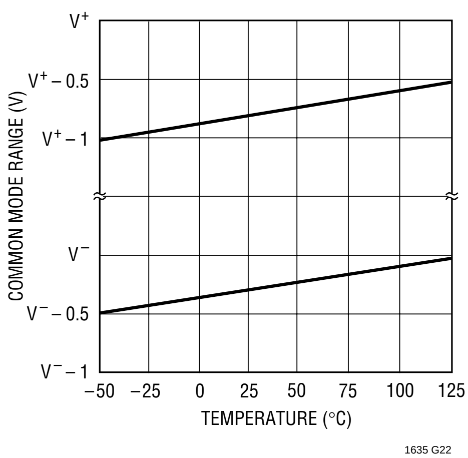
Output Saturation Voltage vs Load Current (Output Low)



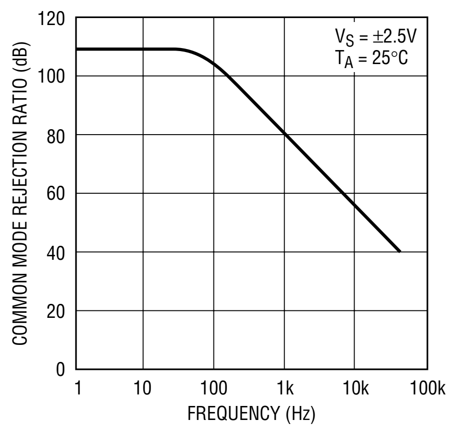
Output Saturation Voltage vs Load Current (Output High)



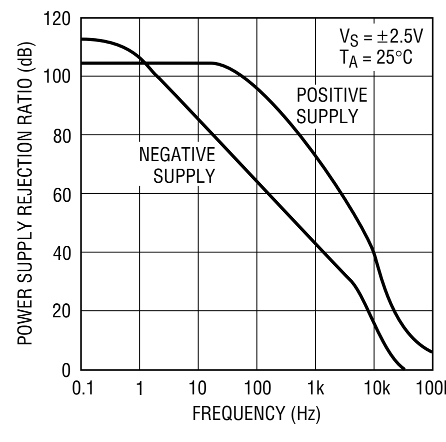
Common Mode Range vs Temperature



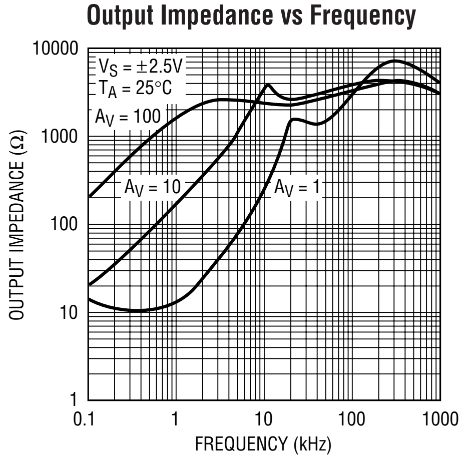
Common Mode Rejection Ratio vs Frequency



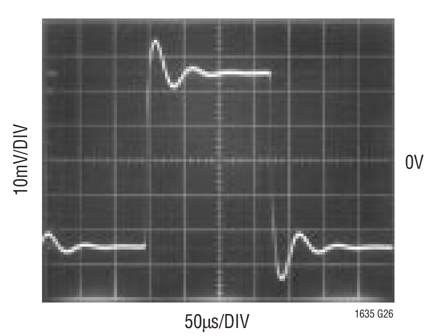
Power Supply Rejection Ratio vs Frequency



Output Impedance vs Frequency

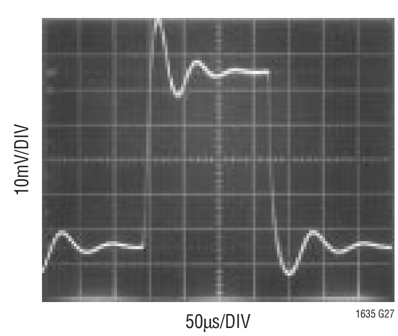


Small-Signal Transient Response $V_S = \pm5V$



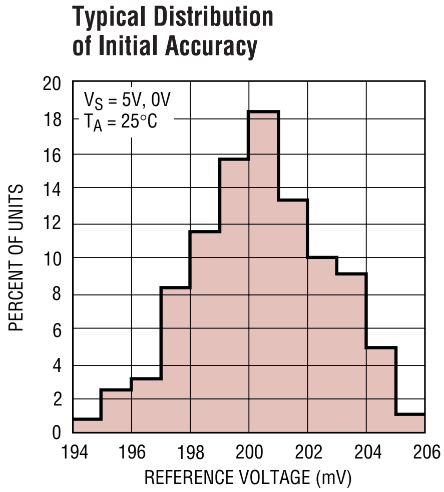
$A_V = 1$
$C_L = 15pF$

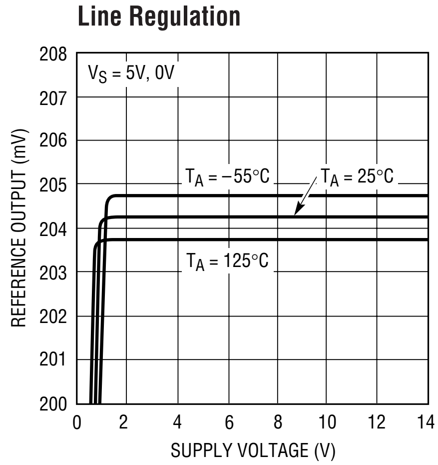
Small-Signal Transient Response $V_S = 5V, 0V$

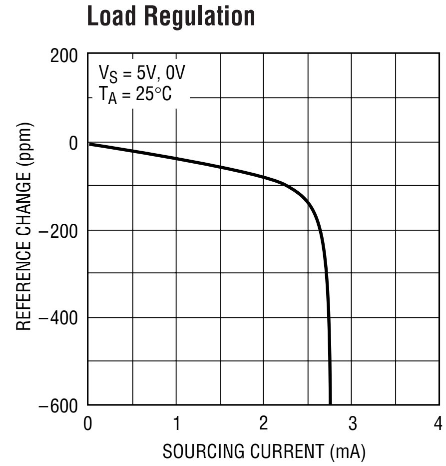


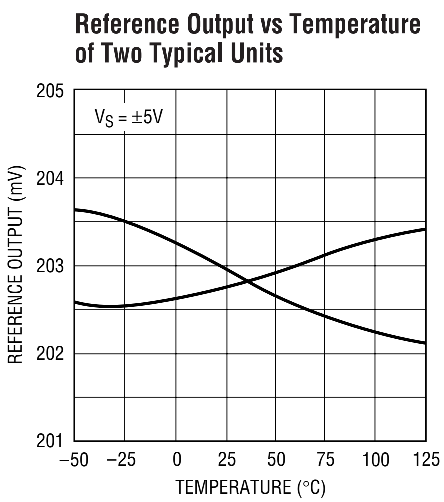
$A_V = 1$
$C_L = 15pF$
INPUT 50mV TO 100mV

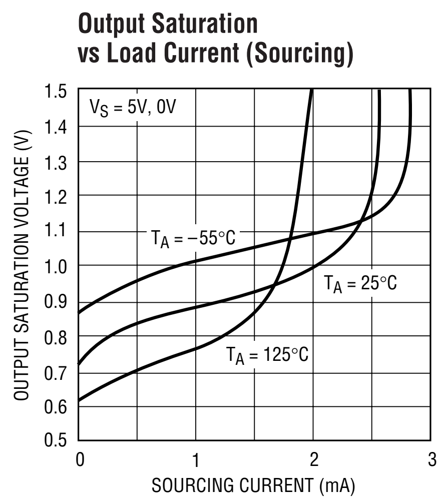
TYPICAL PERFORMANCE CHARACTERISTICS Reference

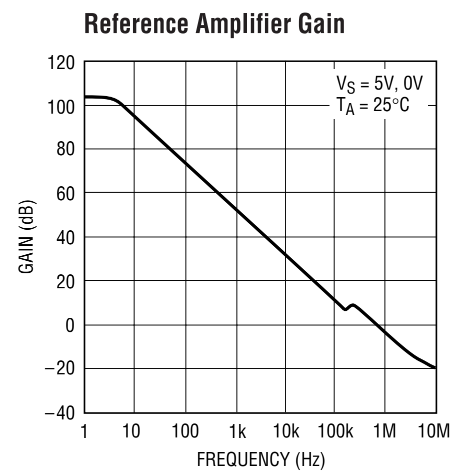




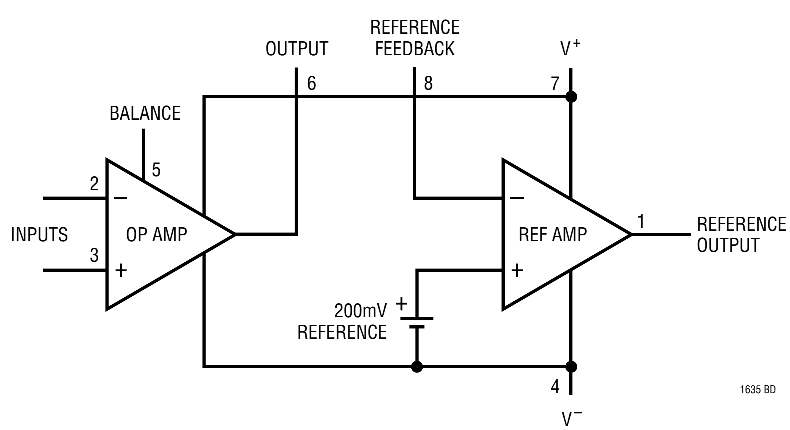








BLOCK DIAGRAM



APPLICATIONS INFORMATION

The LT1635 is fully specified with $V^+ = 5V$, $V^- = 0V$ and $V_{CM} = 2.5V$. The op amp offset voltage is internally trimmed to a minimum value at these supply voltages. A unique feature of this device is that it operates from a single 1.2V supply up to ±5V. A full set of specifications is provided at ±5V supply voltages. The positive supply pin of the LT1635 should be bypassed with a small capacitor (about 0.1µF), as well as the negative supply pin when using split supplies.

Op Amp

The LT1635 is fully specified for single supply operation, i.e., when the negative supply is 0V. Input common mode range of the op amp includes ground and the output swings within a few millivolts of ground while sinking current. The input stage of the op amp incorporates phase reversal protection to prevent false outputs from occurring when the input is below the negative supply. Protective resistors have been included in the input leads so that current does not become excessive when the inputs are forced below the negative supply.

The op amp also includes an offset nulling feature, this is accomplished by connecting the BALANCE pin (Pin 5) to a variable voltage derived from the reference output. The offset adjust range is asymmetrical, typically –2mV to 8mV. At room temperature the input offset voltage of the LT1635 is within the null range, thus the offset voltage can be adjusted to zero. Figure 1 shows the standard offset adjustment.

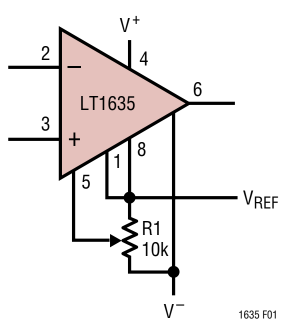


Figure 1. Standard Offset Adjustment

Output

The output voltage swing of the LT1635 is a function of input overdrive as shown in the typical performance curves. When monitoring voltages within 15mV of either rail, gain should be taken to keep the output from saturating. For example, a 1mV input signal will cause the amplifier to set up in its linear region in the gain 100 configuration as shown in Figure 2a. However, 1mV is not enough to make the amplifier function properly in the voltage follower mode (Figure 2b).

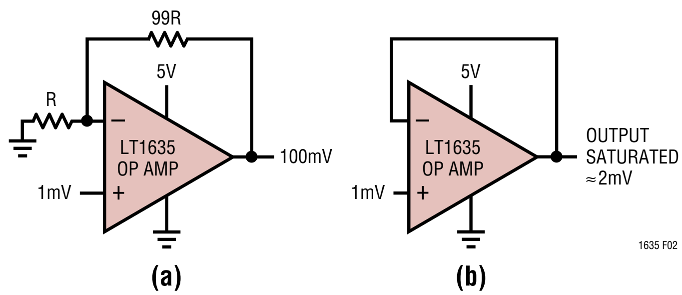


Figure 2. Gain 100 Amplifier and Voltage Follower

Distortion

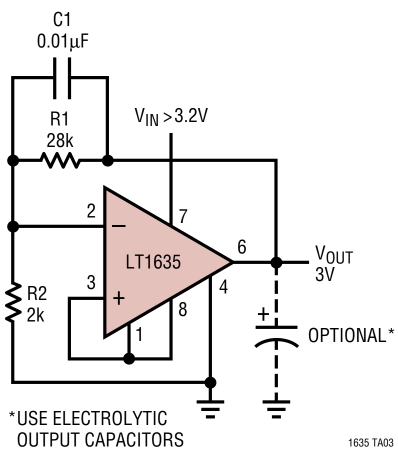
There are two main contributors of distortion in op amps: distortion caused by nonlinear common mode rejection and output crossover distortion as the output transitions from sourcing to sinking current. The common mode rejection ratio of the LT1635 is very good, typically 110dB. Therefore, as long as the input operates in normal common mode range, there will be very little common mode induced distortion. Crossover distortion will increase as the output load resistance decreases. For the lowest distortion, the LT1635 should be operated with the output always sourcing current.

Reference

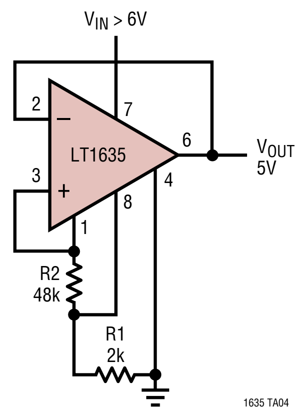
The reference of the LT1635 consists of a 200mV precision bandgap and a reference amplifier. As shown in the block diagram, the 0.2V precision bandgap is referred to V^- and is internally connected to the noninverting input of the reference amplifier. This configuration offers great flexibility in that the reference voltage can be amplified or the reference amplifier can be used as a comparator. Unlike the op amp, the output of the reference amplifier can only swing within 0.8V (typ) of the positive rail. To guarantee that the reference amplifier does not saturate over the industrial temperature range, the minimum operating supply should be 1.3V. The reference amplifier can source 2mA of load current and can sink 10µA over the industrial temperature range.

TYPICAL APPLICATIONS

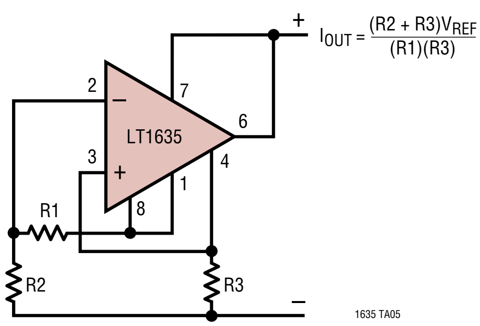
Low Voltage Regulator



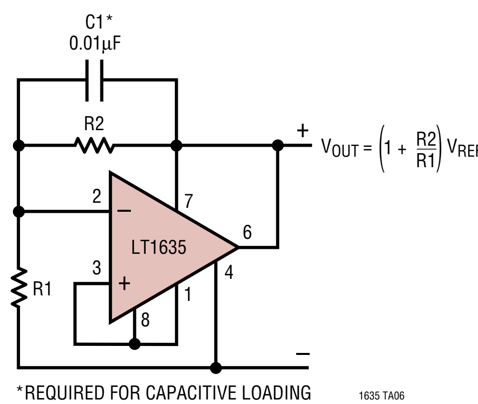
Best Regulation



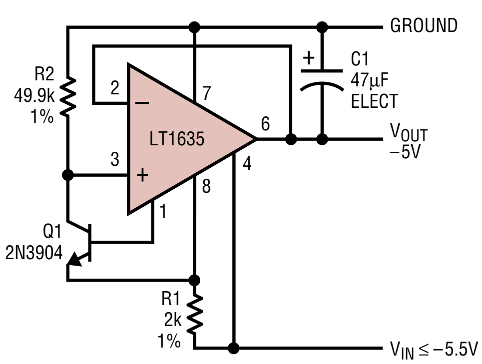
2-Terminal Current Regulator



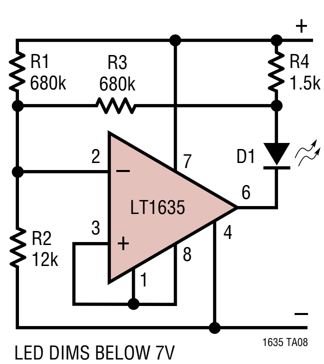
Shunt Regulator



Negative Regulator

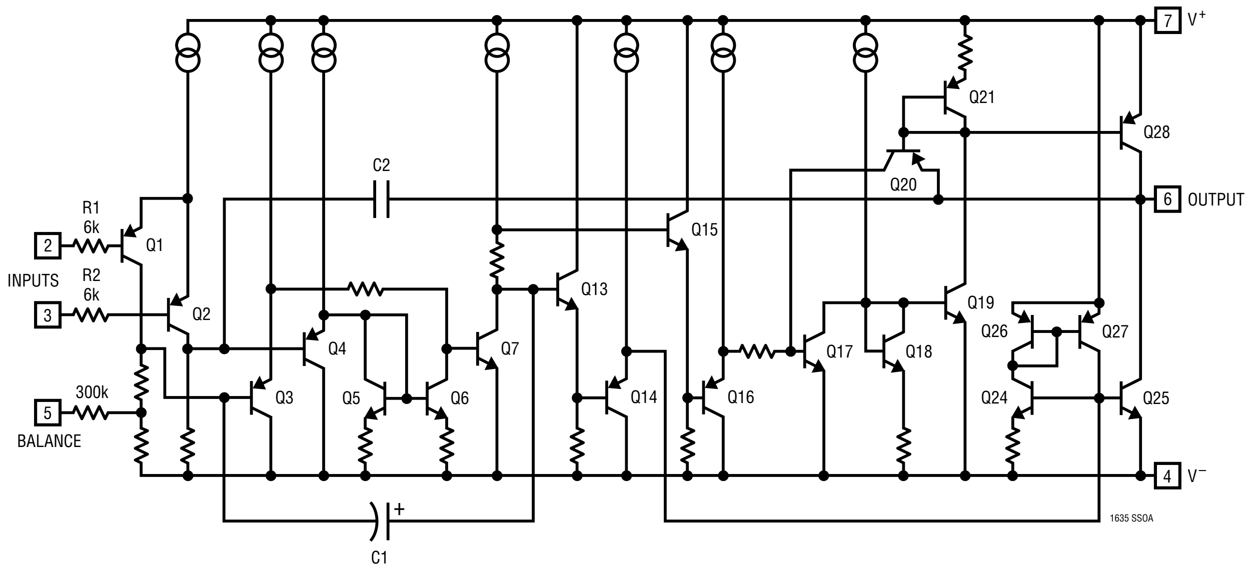


6V Battery-Level Indicator

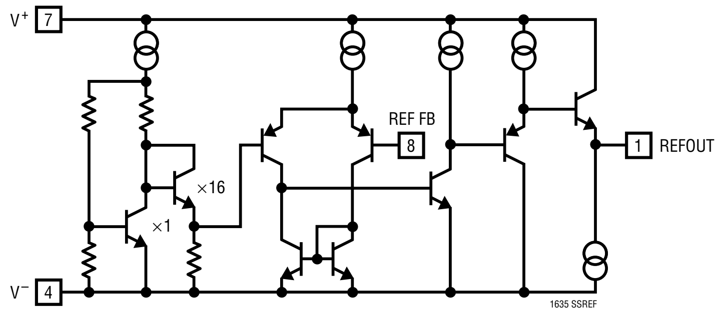


SIMPLIFIED SCHEMATICS

Op Amp

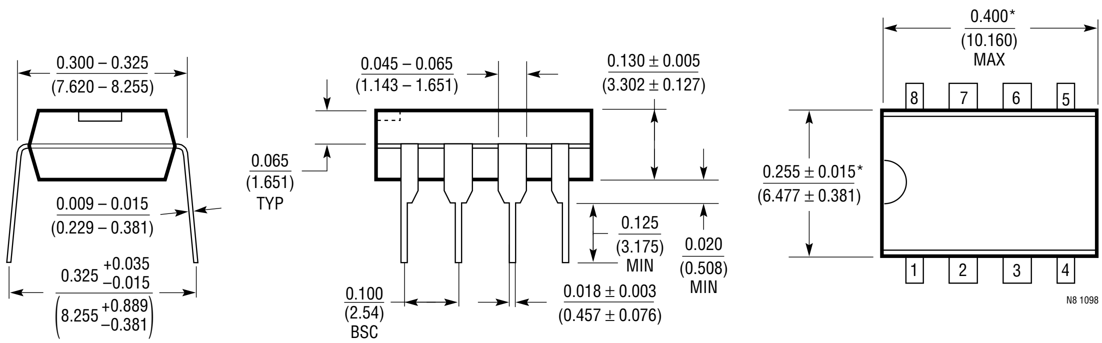


Reference



PACKAGE DESCRIPTION

N8 Package
8-Lead PDIP (Narrow .300 Inch)
(Reference LTC DWG # 05-08-1510)



*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)