



T-58-07 LT1021
Precision Reference

FEATURES

- Pin Compatible with Most Bandgap Reference Applications, Including Ref 01, Ref 02, LM368, MC1400, and MC1404, with Greatly Improved Stability, Noise, and Drift
- Ultra Low Drift—2ppm/°C Max Slope
- Trimmed Output Voltage
- Operates in Series or Shunt Mode
- Output Sinks and Sources in Series Mode
- Very Low Noise < 1ppm p-p (0.1Hz to 10Hz)
- > 100dB Ripple Rejection
- Minimum Input-Output Differential of 1V
- 100% Noise Tested

APPLICATIONS

- A to D and D to A Converters
- Precision Regulators
- Digital Voltmeters
- Inertial Navigation Systems
- Precision Scales
- Portable Reference Standard

DESCRIPTION

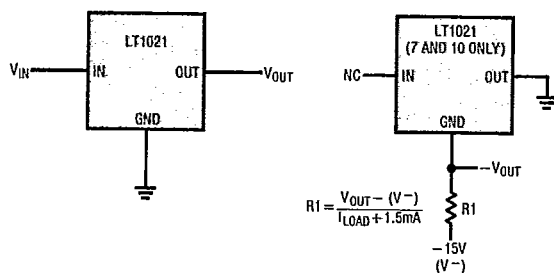
The LT1021 is a precision reference with ultra low drift and noise, extremely good long term stability, and almost total immunity to input voltage variations. The reference output will both source and sink up to 10mA. Three voltages are available; 5V, 7V and 10V. The 7V and 10V units can be used as shunt regulators (two terminal zeners) with the same precision characteristics as the three terminal connection. Special care has been taken to minimize thermal regulation effects and temperature induced hysteresis.

The LT1021 references are based on a buried zener diode structure which eliminates noise and stability problems associated with surface breakdown devices. Further, a subsurface zener exhibits better temperature drift and time stability than even the best band-gap references.

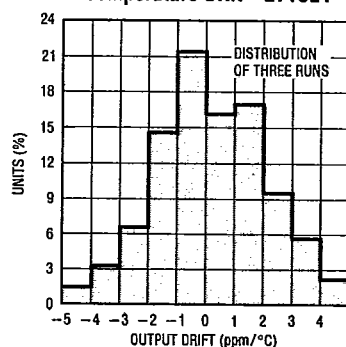
Unique circuit design makes the LT1021 the first IC reference to offer ultra low drift without the use of high power on-chip heaters.

The LT1021-7 uses no resistive divider to set output voltage, and therefore exhibits the best long term stability and temperature hysteresis. The LT1021-5 and LT1021-10 are intended for systems requiring a precise 5V or 10V reference, with an initial tolerance as low as $\pm 0.05\%$.

Basic Positive and Negative Connections



Typical Distribution of Temperature Drift—LT1021



LT1021

ABSOLUTE MAXIMUM RATINGS

Input Voltage	40V
Input-Output Voltage Differential	35V
Output to Ground Voltage (Shunt Mode Current Limit)	
LT1021-5	10V
LT1021-7	10V
LT1021-10	16V
Trim Pin to Ground Voltage	
Positive	Equal to V_{OUT}
Negative	-20V
Output Short Circuit Duration	
$V_{IN} = 35V$	10 sec
$V_{IN} \leq 20V$	Indefinite
Operating Temperature Range	
LT1021 Mil	-55°C to 125°C
LT1021 Comm	0°C to 70°C
Storage Temperature Range	
All Devices	-65°C to 150°C
Lead Temperature (Soldering, 10 sec.)	300°C

PACKAGE/ORDER INFORMATION

TOP VIEW	ORDER PART NUMBER	
	LT1021BMH-5	LT1021AMH-10
METAL CAN H PACKAGE *CONNECTED INTERNALLY. DO NOT CONNECT EXTERNAL CIRCUITRY TO THESE PINS. **NO TRIM PIN ON LT1021-7. DO NOT CONNECT EXTERNAL CIRCUITRY TO PIN 5 ON LT1021-7.	LT1021CMH-5	LT1021BMH-10
	LT1021DMH-5	LT1021CMH-10
	LT1021BCH-5	LT1021DMH-10
	LT1021CCH-5	LT1021ACH-10
	LT1021DCH-5	LT1021BCH-10
		LT1021CCH-10
PLASTIC DIP N8 PACKAGE *CONNECTED INTERNALLY. DO NOT CONNECT EXTERNAL CIRCUITRY TO THESE PINS. **NO TRIM PIN ON LT1021-7. DO NOT CONNECT EXTERNAL CIRCUITRY TO PIN 5 ON LT1021-7.	LT1021AMH-7	LT1021DCH-10
	LT1021BMH-7	
	LT1021DMH-7	
	LT1021ACH-7	
	LT1021BCH-7	
	LT1021DCH-7	
	LT1021BCN8-5	
	LT1021CCN8-5	
	LT1021DCN8-5	
	LT1021BCN8-7	
	LT1021DCN8-7	
	LT1021BCN8-10	
	LT1021CCN8-10	
	LT1021DCN8-10	

ELECTRICAL CHARACTERISTICS LT1021-5

 $V_{IN} = 10V$, $I_{OUT} = 0$, $T_A = 25^\circ C$, Mil or Comm version, unless otherwise noted

PARAMETER	CONDITIONS	LT1021-5			UNITS
		MIN	TYP	MAX	
Output Voltage (Note 1)	LT1021C-5 LT1021B-5, D-5	4.9975 4.95	5.000 5.00	5.0025 5.05	V V
Output Voltage Temperature Coefficient (Note 2)	$T_{MIN} \leq T_J \leq T_{MAX}$ LT1021B-5 LT1021C-5, D-5		2 3	5 20	ppm/°C ppm/°C
Line Regulation (Note 3)	$7.2V \leq V_{IN} \leq 10V$ $10V \leq V_{IN} \leq 40V$		4 2	12 6 10	ppm/V ppm/V ppm/V
Load Regulation (Sourcing Current)	$0 \leq I_{OUT} \leq 10mA$ (Note 3)		10	20 35	ppm/mA ppm/mA
Load Regulation (Sinking Current)	$0 \leq I_{OUT} \leq 10mA$ (Note 3)		60	100 150	ppm/mA ppm/mA
Supply Current			0.8	1.2 1.5	mA mA
Output Voltage Noise (Note 5)	$0.1Hz \leq f \leq 10Hz$ $10Hz \leq f \leq 1kHz$		3 2.2	3.5	$\mu Vp-p$ μV_{rms}
Long Term Stability of Output Voltage (Note 6)	$\Delta t = 1000$ Hrs Non-Cumulative		15		ppm
Temperature Hysteresis of Output	$\Delta T = \pm 25^\circ C$		10		ppm

ELECTRICAL CHARACTERISTICS LT1021-7 $V_{IN} = 12V$, $I_{OUT} = 0$, $T_A = 25^\circ C$, MII or Comm version, unless otherwise noted

PARAMETER	CONDITIONS	LT1021-7			UNITS
		MIN	TYP	MAX	
Output Voltage (Note 1)		6.95	7.00	7.05	V
Output Voltage Temperature Coefficient (Note 2)	$T_{MIN} \leq T_J \leq T_{MAX}$		1	2	ppm/ $^\circ C$
	LT1021A-7		2	5	ppm/ $^\circ C$
	LT1021B-7		3	20	ppm/ $^\circ C$
Line Regulation (Note 3)	$8.5V \leq V_{IN} \leq 12V$		1	4	ppm/V
			2	8	ppm/V
	$12V \leq V_{IN} \leq 40V$		0.5	2	ppm/V
			1	4	ppm/V
Load Regulation (Sourcing Current)	$0 \leq I_{OUT} \leq 10mA$ (Note 3)		12	25	ppm/mA
				40	ppm/mA
Load Regulation (Shunt Mode)	$1.2mA \leq I_{SHUNT} \leq 10mA$ (Notes 3, 4)		50	100	ppm/mA
				150	ppm/mA
Supply Current (Series Mode)			0.75	1.2	mA
				1.5	mA
Minimum Current (Shunt Mode)	V_{IN} is Open		0.7	1.0	mA
				1.2	mA
Output Voltage Noise (Note 5)	$0.1Hz \leq f \leq 10Hz$		4		$\mu Vp-p$
	$10Hz \leq f \leq 1kHz$		2.5	4	$\mu Vrms$
Long Term Stability of Output Voltage (Note 6)	$\Delta t = 1000$ Hrs Non-Cumulative		7		ppm
Temperature Hysteresis of Output	$\Delta T = \pm 25^\circ C$		3		ppm

ELECTRICAL CHARACTERISTICS LT1021-10 $V_{IN} = 15V$, $I_{OUT} = 0$, $T_A = 25^\circ C$, MII or Comm version, unless otherwise noted

PARAMETER	CONDITIONS	LT1021-10			UNITS
		MIN	TYP	MAX	
Output Voltage (Note 1)	LT1021C-10	9.995	10.00	10.005	V
	LT1021A-10, B-10, D-10	9.95	10.00	10.05	V
Output Voltage Temperature Coefficient (Note 2)	$T_{MIN} \leq T_J \leq T_{MAX}$		1	2	ppm/ $^\circ C$
	LT1021A-10		2	5	ppm/ $^\circ C$
	LT1021B-10		5	20	ppm/ $^\circ C$
Line Regulation (Note 3)	$11.5V \leq V_{IN} \leq 14.5V$		1	4	ppm/V
				6	ppm/V
	$14.5V \leq V_{IN} \leq 40V$		0.5	2	ppm/V
				4	ppm/V
Load Regulation (Sourcing Current)	$0 \leq I_{OUT} \leq 10mA$ (Note 3)		12	25	ppm/mA
				40	ppm/mA
Load Regulation (Shunt Mode)	$1.7mA \leq I_{SHUNT} \leq 10mA$ (Notes 3, 4)		50	100	ppm/mA
				150	ppm/mA
Series Mode Supply Current			1.2	1.7	mA
				2.0	mA
Shunt Mode Minimum Current	V_{IN} is Open		1.1	1.5	mA
				1.7	mA
Output Voltage Noise (Note 5)	$0.1Hz \leq f \leq 10Hz$		6		$\mu Vp-p$
	$0.1Hz \leq f \leq 1kHz$		3.5	6	$\mu Vrms$
Long Term Stability of Output Voltage (Note 6)	$\Delta t = 1000$ Hrs Non-Cumulative		15		ppm
Temperature Hysteresis of Output	$\Delta T = \pm 25^\circ C$		5		ppm

LT1021

The ● denotes the specifications which apply over the full operating temperature range.

Note 1: Output voltage is measured immediately after turn-on. Changes due to chip warm-up are typically less than 0.005%.

Note 2: Temperature coefficient is measured by dividing the change in output voltage over the temperature range by the change in temperature. Separate tests are done for hot and cold; T_{MIN} to 25°C, and 25°C to T_{MAX} . Incremental slope is also measured at 25°C. For the "A" version only, a box method is used from 0°C to 70°C with a height of 2ppm/°C $\times$ 70°C = 140ppm. Military "A" grades receive an additional -55°C to +125°C test to $\pm$ 5ppm/°C.

Note 3: Line and load regulation are measured on a pulse basis. Output changes due to die temperature change must be taken into account separately. Package thermal resistance is 150°C/W for TO-5 (H), and 130°C/W for N.

Note 4: Shunt mode regulation is measured with the input open. With the input connected, shunt mode current can be reduced to 0mA. Load regulation will remain the same.

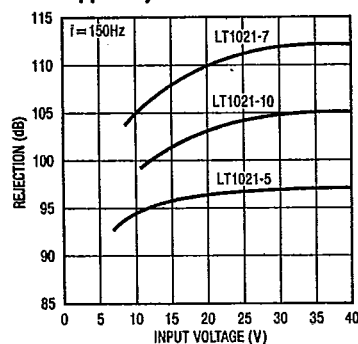
Note 5: RMS noise is measured with a single high pass filter at 10Hz and a 2-pole low pass filter at 1kHz. The resulting output is full wave rectified and then integrated for a fixed period, making the final reading an average as opposed to RMS. A correction factor of 1.1 is used to convert from average to RMS, and a second correction of 0.88 is used to correct for the non-ideal bandpass of the filters.

Peak-to-peak noise is measured with a single high pass filter at 0.1Hz and a 2-pole low pass filter at 10Hz. The unit is enclosed in a still-air environment to eliminate thermocouple effects on the leads. Test time is 10 seconds.

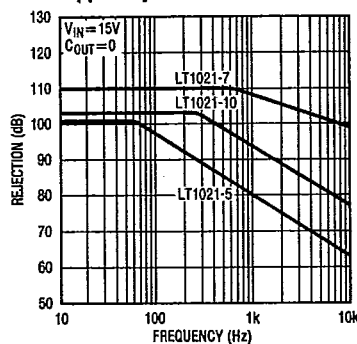
Note 6: Consult factory for units with long term stability data.

TYPICAL PERFORMANCE CHARACTERISTICS

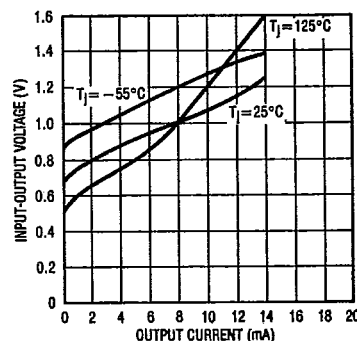
Ripple Rejection



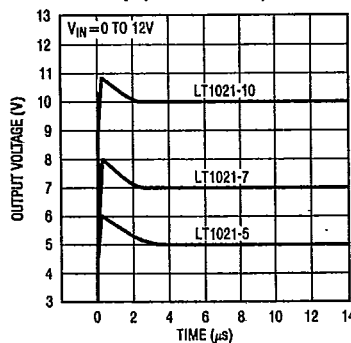
Ripple Rejection



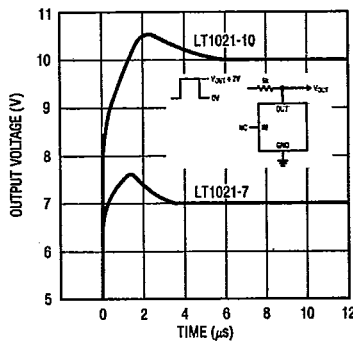
Minimum Input-Output Differential LT1021-7 and LT1021-10



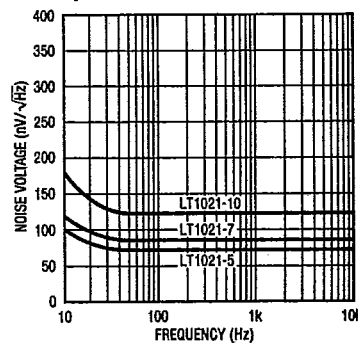
Start-Up (Series Mode)



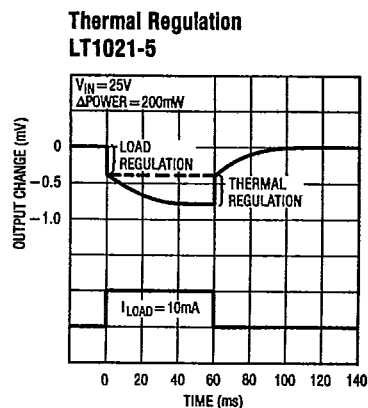
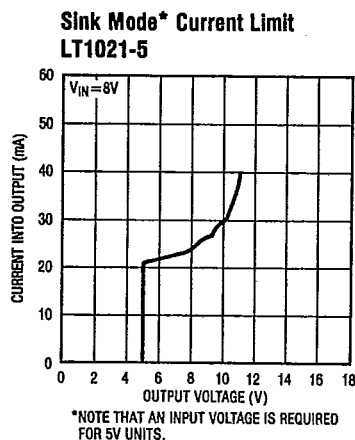
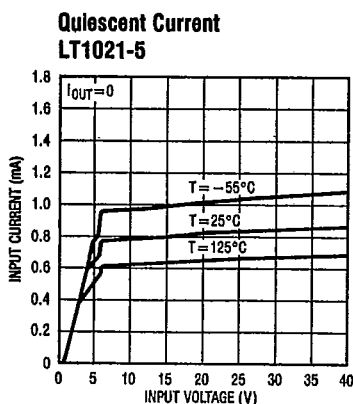
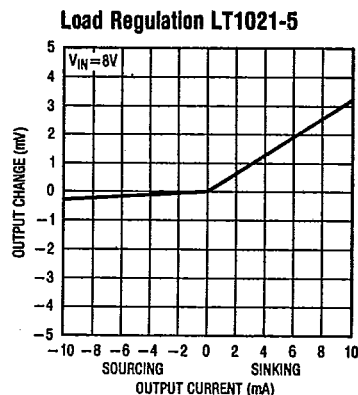
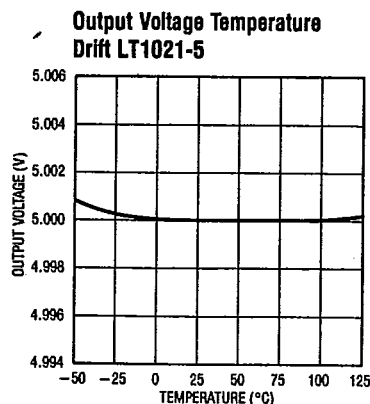
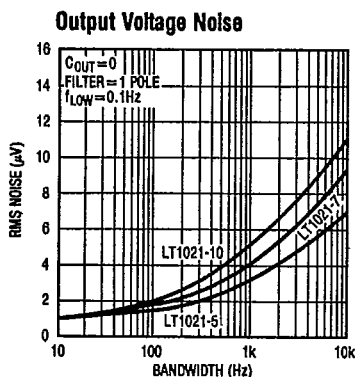
Start-Up (Shunt Mode) LT1021-7 and LT1021-10



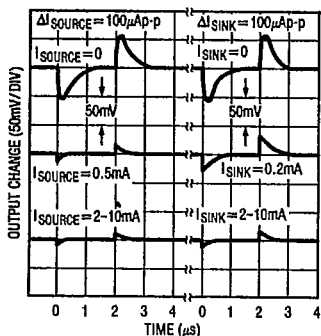
Output Voltage Noise Spectrum



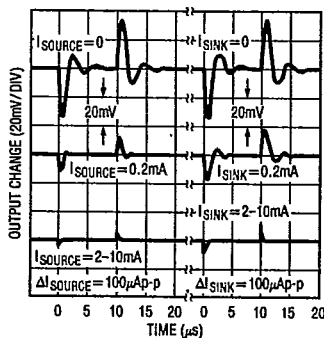
TYPICAL PERFORMANCE CHARACTERISTICS



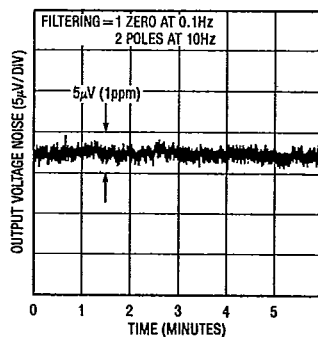
Load Transient Response LT1021-5, $C_{LOAD}=0$



Load Transient Response LT1021-5, $C_{LOAD}=1000pF$



Output Noise 0.1Hz to 10Hz LT1021-5

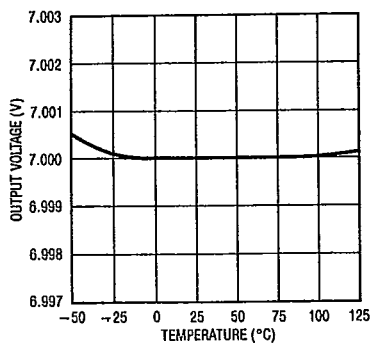


LT1021

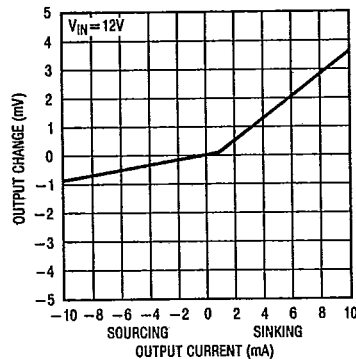
T-58-07

TYPICAL PERFORMANCE CHARACTERISTICS

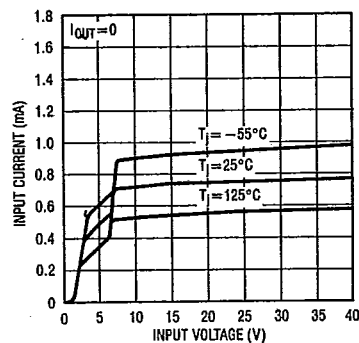
Output Voltage Temperature Drift LT1021-7



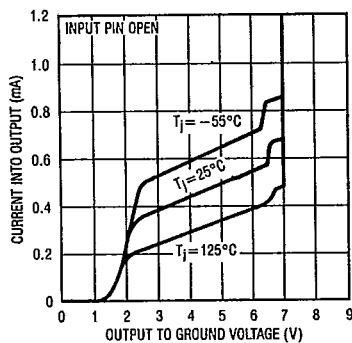
Load Regulation LT1021-7, 10



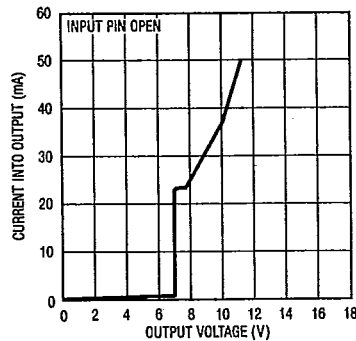
Quiescent Current LT1021-7



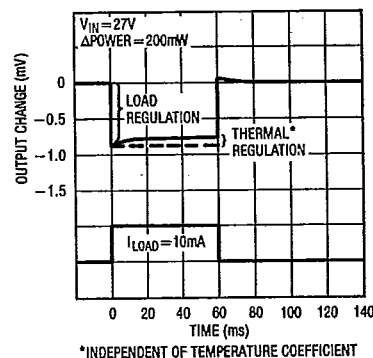
Shunt Characteristics LT1021-7



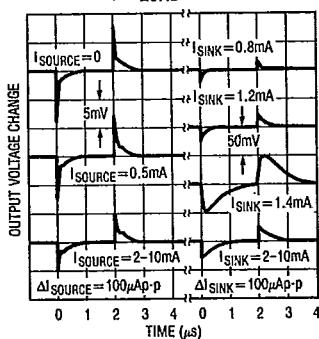
Shunt Mode Current Limit LT1021-7



Thermal Regulation LT1021-7

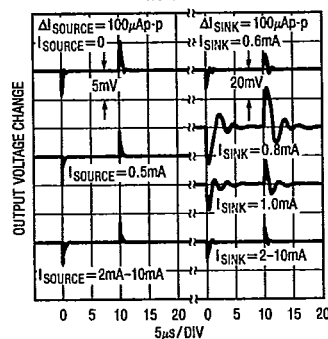


Load Transient Response LT1021-7, C_{LOAD} = 0



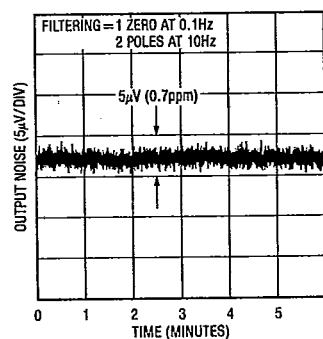
NOTE VERTICAL SCALE CHANGE BETWEEN SOURCING AND SINKING

Load Transient Response LT1021-7, C_{LOAD} = 1000pF



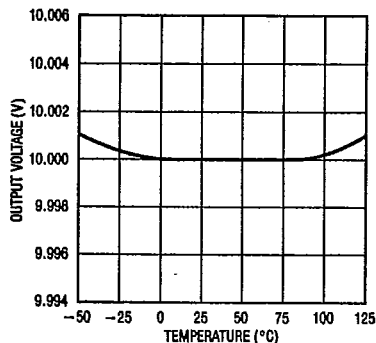
NOTE VERTICAL SCALE CHANGE BETWEEN SOURCING AND SINKING

Output Noise 0.1Hz to 10Hz LT1021-7

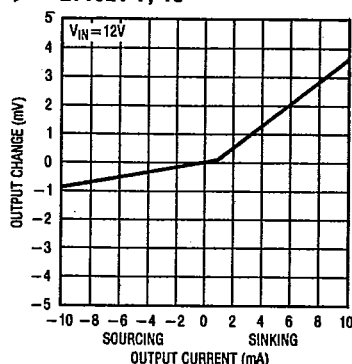


TYPICAL PERFORMANCE CHARACTERISTICS

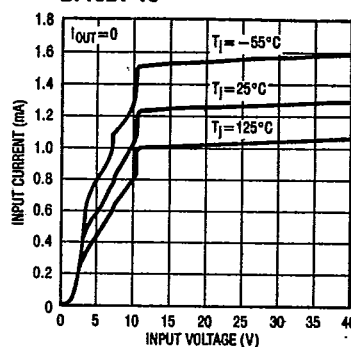
Output Voltage Temperature Drift LT1021-10



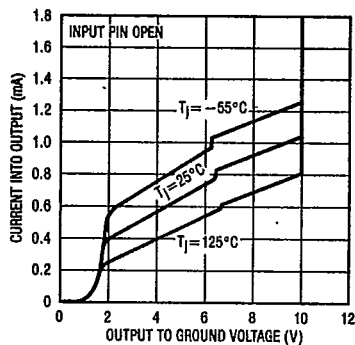
Load Regulation LT1021-7, 10



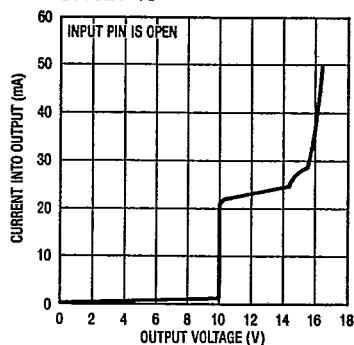
Input Supply Current LT1021-10



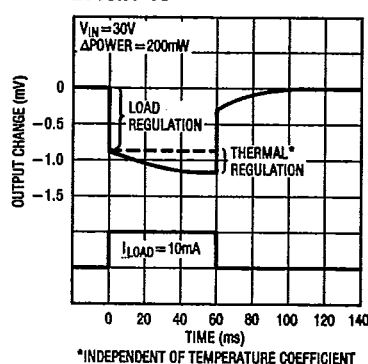
Shunt Characteristics LT1021-10



Shunt Mode Current Limit LT1021-10

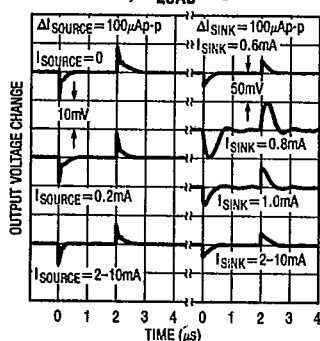


Thermal Regulation LT1021-10



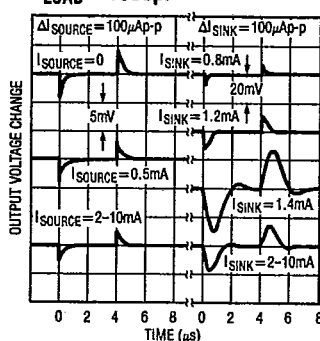
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Load Transient Response LT1021-10, C_LOAD = 0



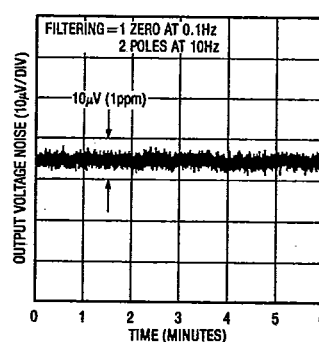
NOTE VERTICAL SCALE CHANGE BETWEEN SOURCING AND SINKING

Load Transient Response LT1021-10, C_LOAD = 1000pF



NOTE VERTICAL SCALE CHANGE BETWEEN SOURCING AND SINKING

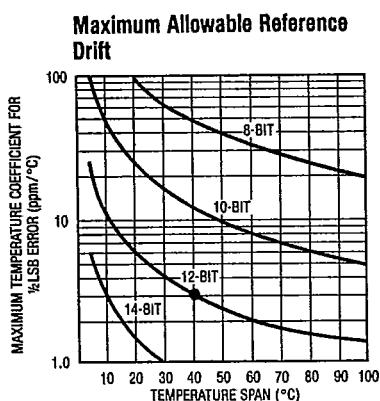
Output Noise 0.1Hz to 10Hz LT1021-10



APPLICATIONS INFORMATION

Effect of Reference Drift on System Accuracy

A large portion of the temperature drift error budget in many systems is the system reference voltage. This graph indicates the maximum temperature coefficient allowable if the reference is to contribute no more than $\frac{1}{2}$ LSB error to the overall system performance. The example shown is a 12-bit system designed to operate over a temperature range from 25°C to 65°C. Assuming the system calibration is performed at 25°C, the temperature span is 40°C. It can be seen from the graph that the temperature coefficient of the reference must be no worse than 3ppm/°C if it is to contribute less than $\frac{1}{2}$ LSB error. For this reason, the LT1021 family has been optimized for low drift.



Trimming Output Voltage

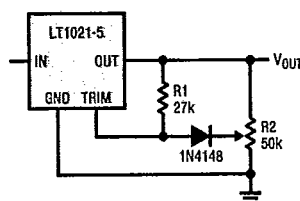
LT1021-10

The LT1021-10 has a trim pin for adjusting output voltage. The impedance of the trim pin is about 12k Ω with a nominal open circuit voltage of 5V. It is designed to be driven from a source impedance of 3k Ω or less to minimize changes in the LT1021 TC with output trimming. Attenuation between the trim pin and the output is 70:1. This allows ± 70 mV trim range when the trim pin is tied to the wiper of a potentiometer connected between the output and ground. A 10k Ω potentiometer is recommended, preferably a 20 turn cermet type with stable characteristics over time and temperature.

The LT1021-10 "C" version is pre-trimmed to ± 5 mV and therefore can utilize a restricted trim range. A 75k Ω resistor in series with a 20k Ω potentiometer will give ± 10 mV trim range. Effect on output TC will be only 1ppm/°C for the ± 5 mV trim needed to set the "C" device to 10.000V.

LT1021-5

The LT1021-5 does have an output voltage trim pin, but the TC of the nominal 4V open circuit voltage at this pin is about -1.7 mV/°C. For the voltage trimming not to affect reference output TC, the external trim voltage must track the voltage on the trim pin. Input impedance of the trim pin is about 100k Ω and attenuation to the output is 13:1. The technique shown below is suggested for trimming the output of the LT1021-5 while maintaining minimum shift in output temperature coefficient. The R1/R2 ratio is chosen to minimize interaction of trimming and TC shifts, so the exact values shown should be used.

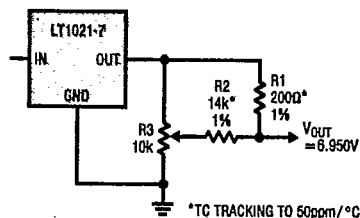


LT1021-7

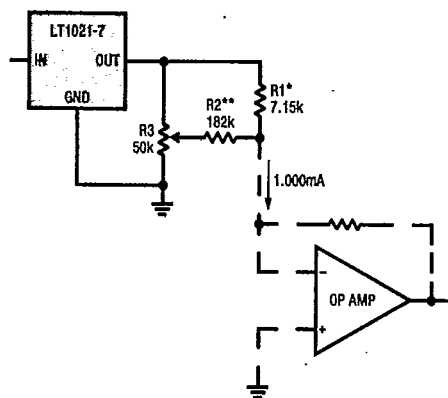
The 7V version of the LT1021 has no trim pin because the internal architecture does not have a point which could be driven conveniently from the output. Trimming must therefore be done externally, as is the case with ordinary reference diodes. Unlike these diodes, however, the output of the LT1021 can be loaded with a trim potentiometer. The following trim techniques are suggested; one for voltage output, and one for current output. The voltage output is trimmed for 6.95V. Current output is 1mA, as shown, into a summing junction, but all resistors may be scaled for currents up to 10mA.

APPLICATIONS INFORMATION

Both of these circuits use the trimmers in a true potentiometric mode to reduce the effects of trimmer TC. The voltage output has a 200Ω impedance, so loading must be minimized. In the current output circuit, R_1 determines output current. It should have a TC commensurate with the LT1021 or track closely with the feedback resistor around the op amp.



*TC TRACKING TO 50ppm/°C



*RESISTOR TC DETERMINES I_{OUT} TC

**TC $\leq 10 \times R_1$ TC. R_2 AND R_3 SCALE WITH R_1 FOR DIFFERENT OUTPUT CURRENTS.

Capacitive Loading and Transient Response

The LT1021 is stable with all capacitive loads, but for optimum settling with load transients, output capacitance should be under 1000pF. The output stage of the reference is class AB with a fairly low idling current. This makes transient response worst-case at light load currents. Because of

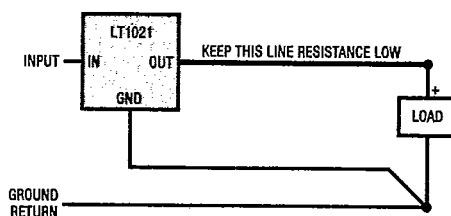
internal current drain on the output, actual worst-case occurs at $I_{LOAD} = 0$ on LT1021-5, $I_{LOAD} = -0.8\text{mA}$ (sinking) on LT1021-7, and $I_{LOAD} = 1.4\text{mA}$ (sinking) on LT1021-10. Significantly better load transient response is obtained by moving slightly away from these points. See Load Transient Response curves for details. In general, best transient response is obtained when the output is sourcing current. In critical applications, a $10\mu\text{F}$ solid tantalum capacitor with several ohms in series provides optimum output bypass.

Kelvin Connections

Although the LT1021 does not have true force/sense capability at its outputs, significant improvements in ground loop and line loss problems can be achieved with proper hook-up. In series mode operation, the ground pin of the LT1021 carries only $\approx 1\text{mA}$ and can be used as a sense line, greatly reducing ground loop and loss problems on the low side of the reference. The high side supplies load current so line resistance must be kept low. Twelve feet of #22 gauge hook up wire or 1 foot of 0.025 inch printed circuit trace will create 2mV loss at 10mA output current. This is equivalent to 1LSB in a 10V, 12-bit system.

The circuits below show proper hook up to minimize errors due to ground loops and line losses. Losses in the output lead can be greatly reduced by adding a PNP boost transistor if load currents are 5mA or higher. R_2 can be added to further reduce current in the output sense lead.

Standard Series Mode

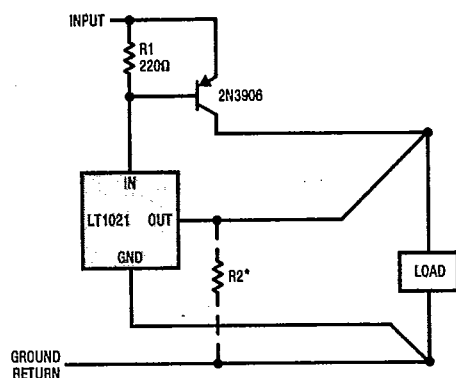


LT1021

T-58-07

APPLICATIONS INFORMATION

Series Mode with Boost Transistor



*OPTIONAL—REDUCES CURRENT IN OUTPUT SENSE LEAD
 $R2 = 2.4k$ (LT1021-5), $3k$ (LT1021-7), $5.6k$ (LT1021-10)

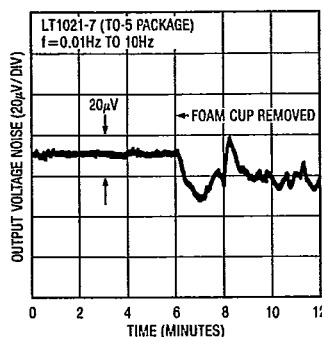
shielded from ambient air with a small foam cup. The cup was then removed for the second half of the trace. Ambient in both cases was a lab environment with no excessive air turbulence from air conditioners, opening/closing doors, etc. Removing the foam cup increases the output noise by almost an order of magnitude in the 0.01Hz to 1Hz band! The kovar leads of the TO-5 (H) package are the primary culprit. Alloy 42 and copper lead frames used on dual-in-line packages are not nearly as sensitive to thermally generated noise because they are intrinsically matched.

There is nothing magical about foam cups—any enclosure which blocks air flow from the reference will do. Smaller enclosures are better since they do not allow the build-up of internally generated air movement. Naturally, heat generating components external to the reference itself should not be included inside the enclosure.

Effects of Air Movement on Low Frequency Noise

The LT1021 has very low noise because of the buried zener used in its design. In the 0.1Hz to 10Hz band, peak-to-peak noise is about 0.5ppm of the DC output. To achieve this low noise, however, care must be taken to shield the reference from ambient air turbulence. Air movement can create noise because of thermoelectric differences between IC package leads (especially kovar lead TO-5) and printed circuit board materials and/or sockets. Power dissipation in the reference, even though it rarely exceeds 20mW, is enough to cause small temperature gradients in the package leads. Variations in thermal resistance, caused by uneven air flow, create differential lead temperatures, thereby causing thermoelectric voltage noise at the output of the reference. The XY plotter trace shown below dramatically illustrates this effect. The first half of the plot was done with the LT1021

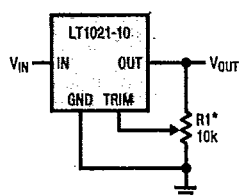
Noise Induced by Air Turbulence (TO-5 Package)



LT1021

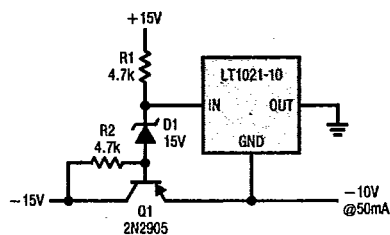
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APPLICATION CIRCUITS

LT1021-10 Full Trim Range ($\pm 0.7\%$)

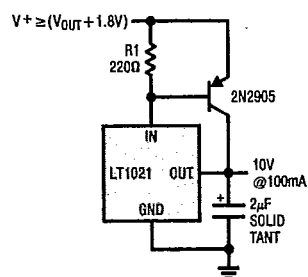
*CAN BE RAISED TO
20kΩ FOR LESS
CRITICAL APPLICATIONS

Negative Series Reference

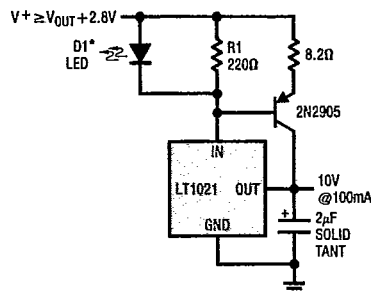


3

Boosted Output Current With No Current Limit



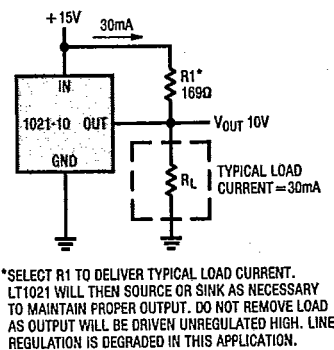
Boosted Output Current With Current Limit



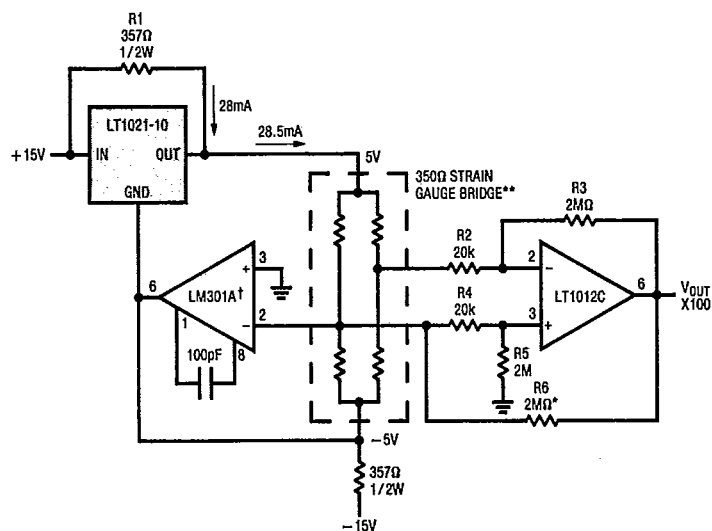
*GLOWS IN CURRENT LIMIT.
DO NOT OMIT.

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Handling Higher Load Currents



Strain Gauge Conditioner for 350Ω Bridge

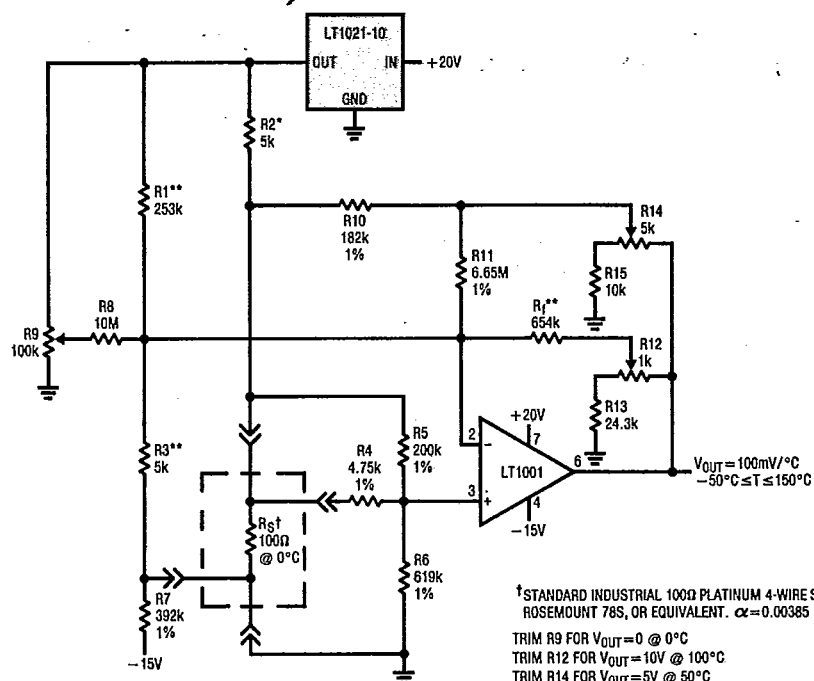


†OFFSET AND DRIFT OF LM301A ARE VIRTUALLY ELIMINATED BY DIFFERENTIAL CONNECTION OF LT1012C.

APPLICATION CIRCUITS

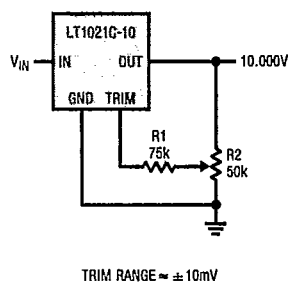
T-58-07

Ultra Linear Platinum Temperature Sensor*

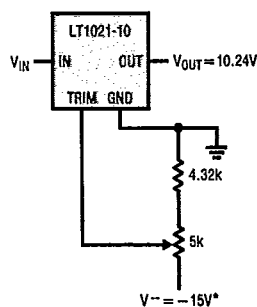


3

Restricted Trim Range for Improved Resolution, 10V, "C" Version Only



Trimming 10V Units to 10.24V



*MUST BE WELL REGULATED

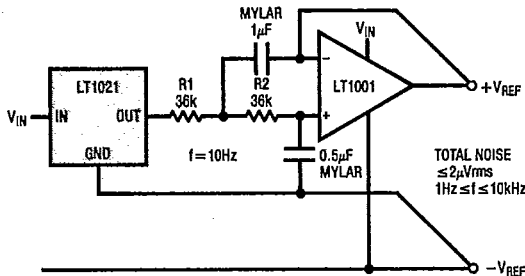
$$\frac{dV_{OUT}}{dV} = \frac{15\text{mV}}{V}$$

LT1021

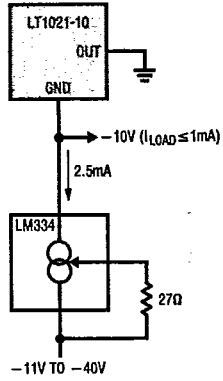
APPLICATION CIRCUITS

T-58-07

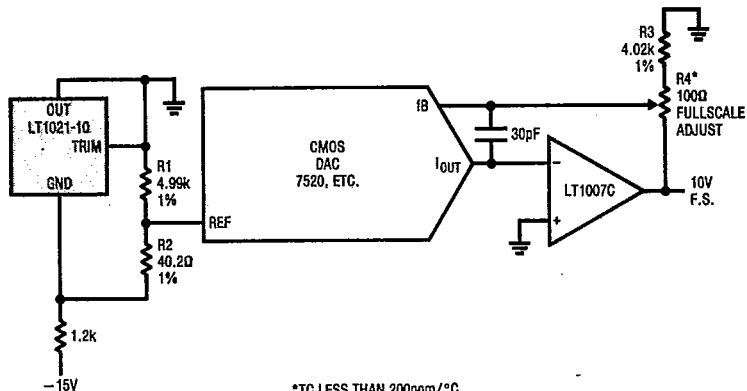
2-Pole Low Pass Filtered Reference



Negative Shunt Reference Driven by Current Source



CMOS DAC with Low-Drift Full Scale Trimming**

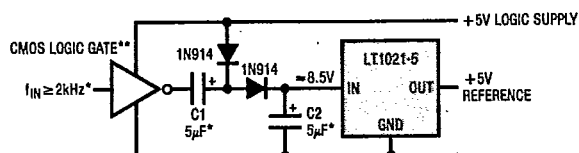


*TC LESS THAN 200ppm/°C
**NO ZERO ADJUST REQUIRED WITH LT1007 (VOS ≤ 60µV)

APPLICATION CIRCUITS

T-58-07

Operating 5V Reference from 5V Supply

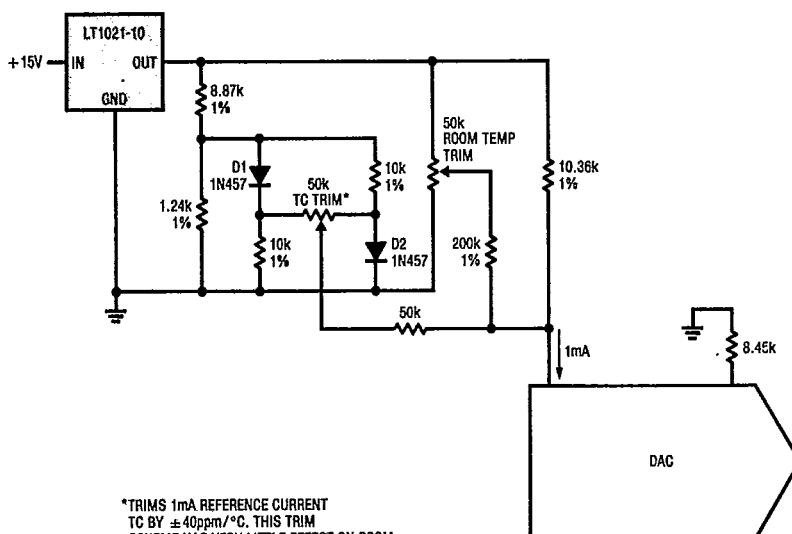


*FOR HIGHER FREQUENCIES C1 AND C2 MAY BE DECREASED.

****PARALLEL GATES FOR HIGHER REFERENCE CURRENT LOADING.**

3

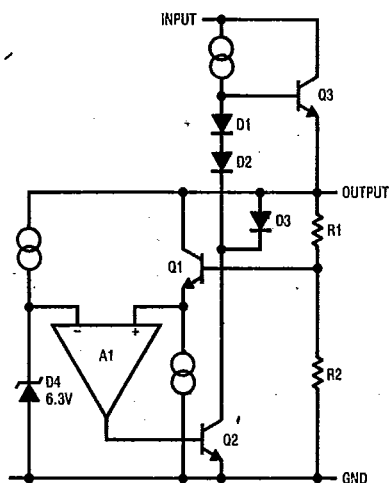
Precision DAC Reference with System TC Trim



*TRIMS 1mA REFERENCE CURRENT
TC BY $\pm 40\text{ppm}/^\circ\text{C}$. THIS TRIM
SCHEME HAS VERY LITTLE EFFECT ON ROOM
TEMPERATURE CURRENT TO MINIMIZE ITERATIVE
TRIMMING.

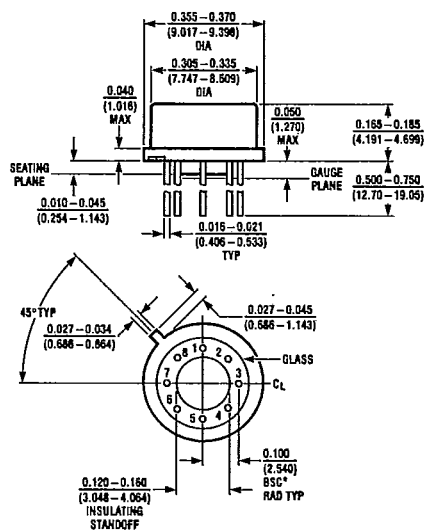
T-58-07

...and the



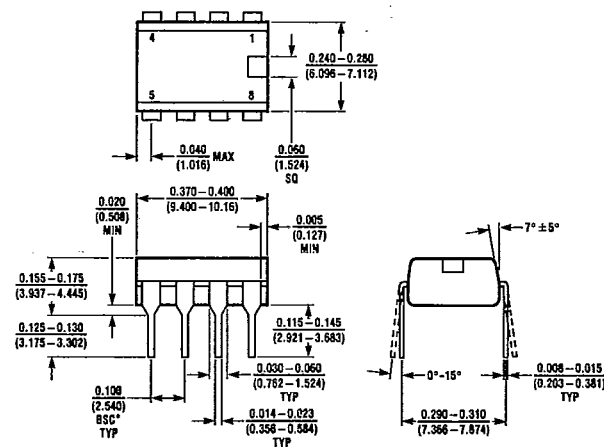
10

**N8 Package
8 Lead Plastic**



NOTE: DIMENSIONS IN INCHES (MILLIMETERS)

T_{jmax} 150°C	$\theta_{j\alpha}$ 150°C/W	θ_{jc} 45°C/W
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NOTE: DIMENSIONS IN INCHES UNLESS OTHERWISE NOTED
*LEADS WITHIN 0.007 OF TRUE POSITION (TP) AT GAUGE PLANE

T_{jmax}	θ_{ja}
100°C	130°C/W