Oven-Compensated, Buried Zener, 7.05 V Voltage Reference

FEATURES

- 7.05 V ultrastable shunt reference
- Low temperature coefficient: 0.2 ppm/°C
- Available in 4-pin TO-46 and 8-terminal LCC
- Typical reference noise for 10 Hz < f < 1 kHz: 1.84 µV rms
- Initial accuracy range: −300 mV to +250 mV
- Low dynamic impedance: 0.04 Ω in TO-46, 0.011 Ω in LCC
- External thermal insulator provided for TO-46
- Upgrade path for legacy LM399, now also in surface-mount technology (SMT)

APPLICATIONS

- Precision voltage reference for multimeters
- Calibration equipment voltage standards
- Laboratory measurement equipment
- Industrial monitor and control instrumentation
- Ultrastable data convertors

GENERAL DESCRIPTION

The ADR1399 precision shunt reference features excellent temperature stability over a wide range of voltage, temperature, and quiescent current conditions. A temperature stabilizing loop is incorporated with the active Zener on a monolithic substrate, which nearly eliminates changes in voltage with temperature. The subsurface Zener circuit is fully specified at a quiescent current I_{REF} of 3 mA and offers minimal noise (1.44 µV p-p, 0.1 Hz to 10 Hz) and excellent long-term stability (7 ppm/√kHr). The ADR1399 offers a lower output dynamic impedance (0.08 Ω) than the LM399, reducing the effects of shunt resistor (R_{SHUNT}) and the supply voltage variation on the reference output.

Ideal applications for the ADR1399 include ultrastable digital voltmeters, precision calibration equipment, and ultrarepeatable analog-to-digital converters (ADCs). The simplicity of the basic pin configurations is shown in Figure 1. The 8-terminal LCC version offers force and sense pins for lower dynamic impedance and for Kelvin sensing.

Table 1. Related Products

Model	Output Voltage (V)	Initial Accuracy Range (mV)
ADR1399	7.05	−300 to +250
LTZ1000	7.2	−200 to +300
LM399	6.95	−200 to +350
LT1236	5 and 10	−2.5 to +2.5

PIN CONFIGURATIONS

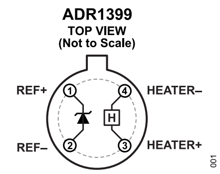

Figure 1. 4-Pin TO-46 Package

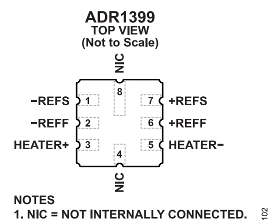

Figure 2. 8-Terminal LCC Package

DOCUMENT FEEDBACK

TECHNICAL SUPPORT

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REVISION HISTORY

3/2022—Rev. 0 to Rev. A

10/2021—Revision 0: Initial Version

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS

T_A = 25°C, unless otherwise noted.

Table 2.

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
ZENER REFERENCE VOLTAGE	V_Z	3 mA ≤ reference current (I_{REF}) ≤ 13 mA	6.75	7.05	7.30	V
CHANGE IN REFERENCE VOLTAGE WITH CURRENT	ΔV_Z	TO-46, 3 mA ≤ I_{REF} ≤ 13 mA		0.4	0.8	mV
		LCC		0.11	0.25	mV
DYNAMIC IMPEDANCE	R_Z	TO-46, 3 mA ≤ I_{REF} ≤ 13 mA		0.04	0.08	Ω
		LCC		0.011	0.025	Ω
TEMPERATURE COEFFICIENT	dV/dT	I_{REF} = 3 mA, heater voltage (V_H) = 30 V, T_A = 0ºC to 70°C		0.2	1[1]	ppm/°C
REFERENCE NOISE	$e_{N\ p\text{-}p}$	I_{REF} = 3 mA, 0.1 Hz < f < 10 Hz		0.2		ppm p-p
		I_{REF} = 3 mA, 0.1 Hz < f < 10 Hz		1.44		μV p-p
	$e_{N\ rms}$	10 Hz < f < 1 kHz		1.84		μV rms
	e_N	I_{REF} = 3 mA				
		Frequency = 0.1 Hz		200		nV/√Hz
		Frequency = 10 Hz		65		nV/√Hz
		Frequency = 1 kHz		58		nV/√Hz
LONG-TERM STABILITY	dV_Z /dt	V_H = 30 V, 22°C ≤ T_A ≤ 28°C, 1000 Hrs, I_{REF} = 3 mA		7		ppm/√kHr
HEATER SUPPLY CURRENT, STILL AIR[2]	I_H	TO-46, T_A = 25°C, V_H = 30 V, I_{REF} = 3 mA		8.5	15	mA
		T_A = –55°C		21	28[1]	mA
		LCC, T_A = 25°C, V_H = 30 V, I_{REF} = 3 mA		20	25	mA
		T_A = –55°C		40		mA
HEATER START-UP CURRENT	I_{HS}	V_H = 9.5 V to 30 V		110	140	mA
HEATER SUPPLY VOLTAGE	V_H		9.5		40	V
WARM-UP TIME	t_{HOT}	TO-46, LCC socketed, to ±0.05%, V_H = 30 V		0.1		sec
		To ±20 ppm		1		sec
		To ±10 ppm		5		sec

1 Guarantee by design, not 100% production tested.

2 Guarantee correlated to moving air production test.

ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
Temperature Stabilizer	40 V
Reverse Breakdown Current	20 mA
Forward Current	1 mA
Reference to Substrate Voltage	–0.1 V
Temperature	
Operating Range	0°C to 70°C
Storage Range	−65°C to +150°C
Lead, Soldering (10 sec)	300°C

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

THERMAL RESISTANCE

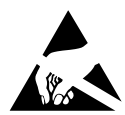
Thermal performance is directly linked to the printed circuit board (PCB) design and operating environment. Close attention to the PCB thermal design is required.

Table 4. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
TO-46			
2-Layer JEDEC Board	220	Not applicable[1]	°C/W
LCC			
2-Layer JEDEC Board	125	4	°C/W

[1] The TO-46 case is not accessible beneath the Valox enclosure.

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

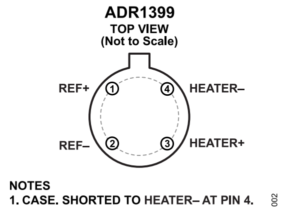


Figure 3. TO-46 Pin Configuration (The TO-46 Tab Is Indicated on the Plastic Enclosure by a Raised Ridge)

Table 5. TO-46 Pin Function Descriptions

Pin No.	Mnemonic	Description
1	REF+	Positive Side of the Zener Reference (Typically with a Pull-Up Resistor to the Input Voltage (V_{IN})).
2	REF−	Negative Side of the Zener Reference (Typically Grounded).
3	HEATER+	Positive Side of the Heater (Typically 15 V).
4	HEATER–	Negative Side of the Heater (Typically Grounded or –15 V).
Not applicable	CASE	CASE. Shorted to HEATER− at Pin 4.

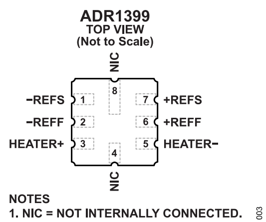


Figure 4. LCC Pin Configuration

Table 6. LCC Pin Function Descriptions

Pin No.	Mnemonic	Description
1	−REFS	Negative Side of the Reference, Sense Pin. 2.2 mA flows out of this pin. Sense the negative reference at the −REFS pin.
2	−REFF	Negative Side of the Reference, Force Pin. Typically, 0.8 mA of current flows out of this pin.
3	HEATER+	Heater Positive Supply Pin.
4	NIC	Not Internally Connected. This pin is not connected internally.
5	HEATER−	Heater Negative Supply Pin (Substrate). Keep this pin voltage at or lower than other pins.
6	+REFF	Positive Side of the Reference, Force Pin. Typically, 0.8 mA of current flows into +REFF at the nominal overall set current of I_{REF} = 3 mA.
7	+REFS	Positive Side of the Reference, Sense Pin. 2.2 mA flows in. Sense the positive reference at the +REFS pin.
8	NIC	Not Internally Connected. This pin is not connected internally.

TYPICAL PERFORMANCE CHARACTERISTICS

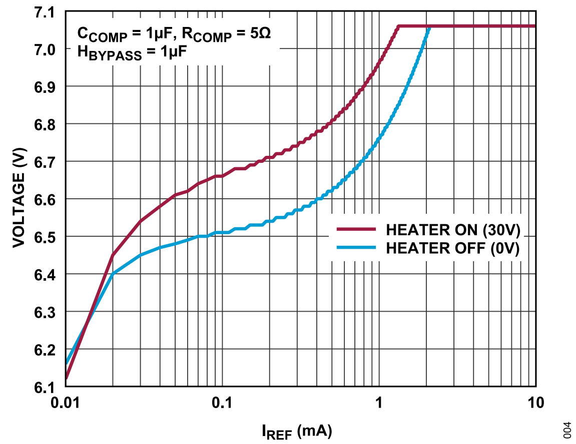


Figure 5. Zener Reverse Characteristic (C_{COMP} Is the Compensation Capacitor, R_{COMP} Is the Compensation Resistor, H_{BYPASS} Is the Capacitance Between HEATER+ and HEATER–, and I_{REF} Is the Reference Current.)

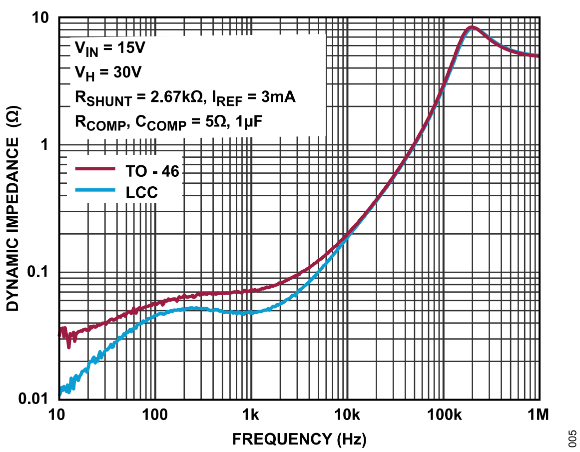


Figure 6. Dynamic Impedance vs. Frequency

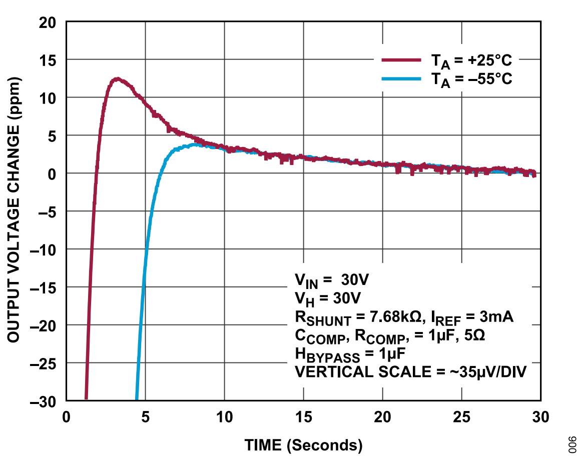


Figure 7. Stabilization Time, TO-46 (V_{REF} Is the Reference Voltage.)

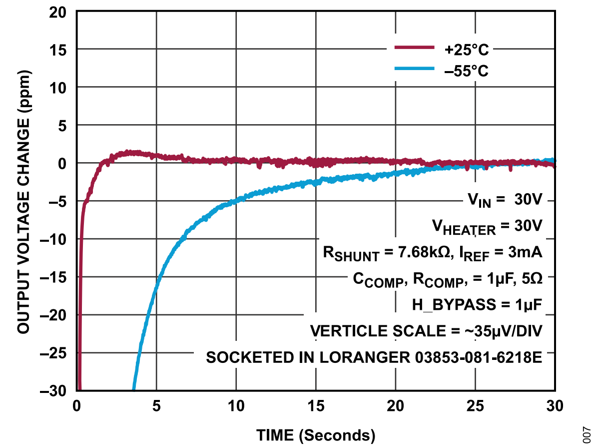


Figure 8. Stabilization Time, LCC

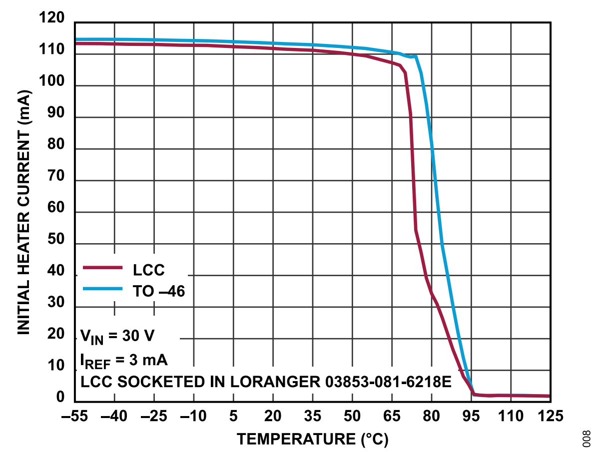


Figure 9. Initial Heater Current vs. Temperature

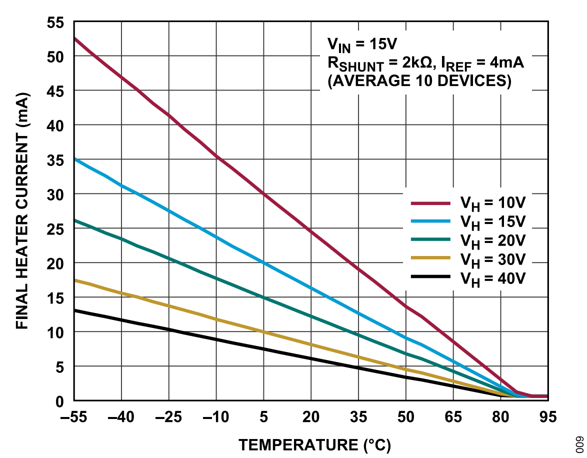


Figure 10. Final Heater Current vs. Temperature for Various Heater Voltages, TO-46

TYPICAL PERFORMANCE CHARACTERISTICS

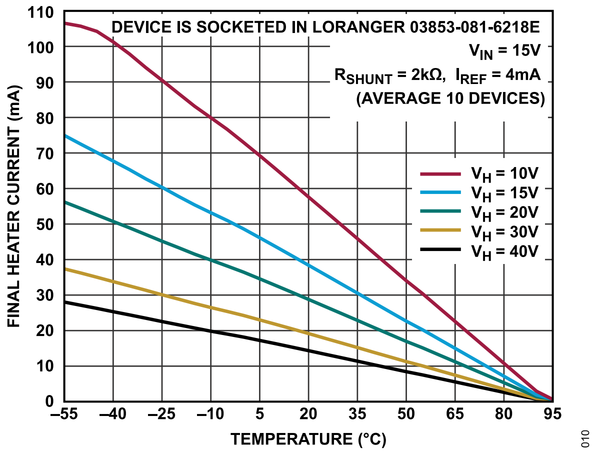


Figure 11. Final Heater Current vs. Temperature for Various Heater Voltages, LCC

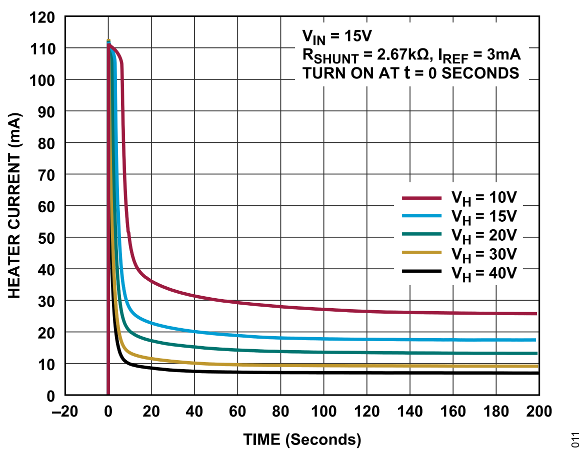


Figure 12. Heater Current vs. Time, TO-46

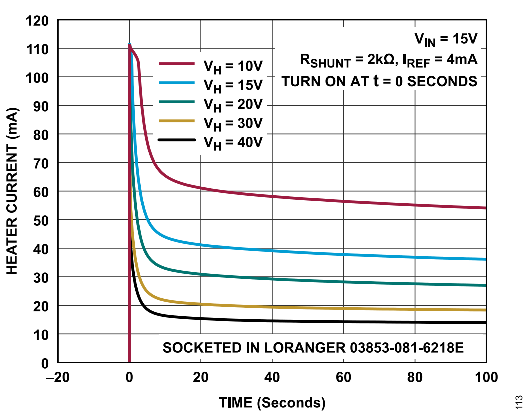


Figure 13. Heater Current vs. Time, LCC

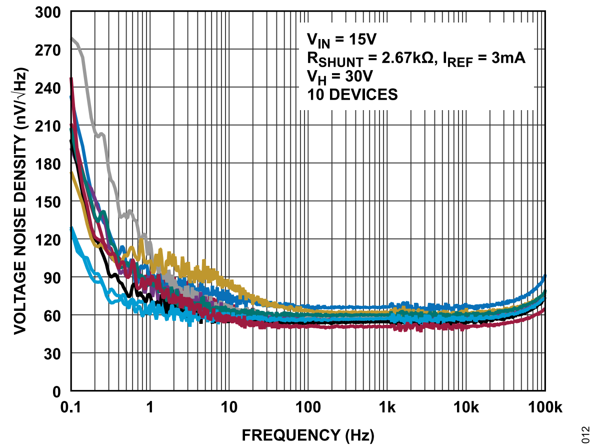


Figure 14. Zener Spectral Noise with the Heater On

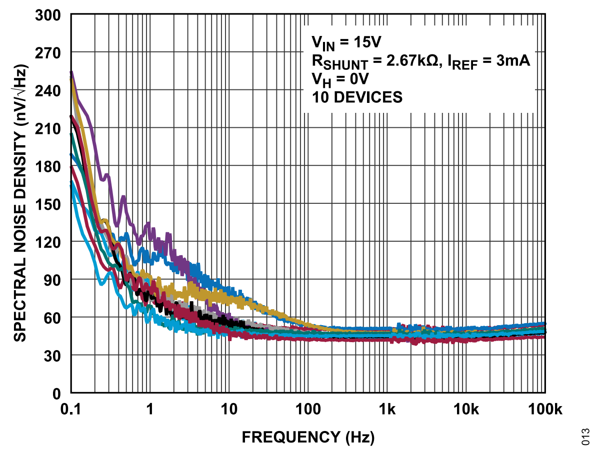


Figure 15. Zener Spectral Noise with the Heater Off

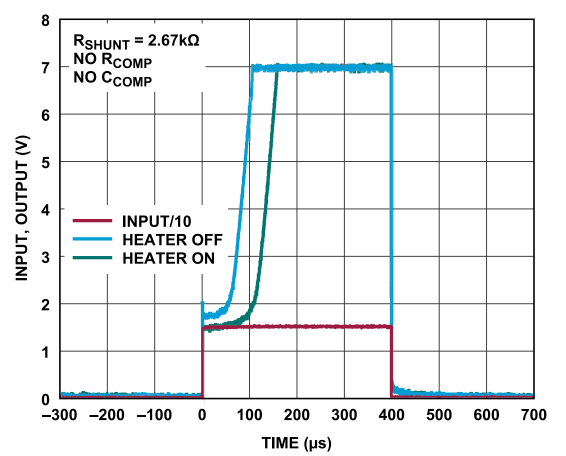


Figure 16. Response Time, No R_{COMP} or C_{COMP}

TYPICAL PERFORMANCE CHARACTERISTICS

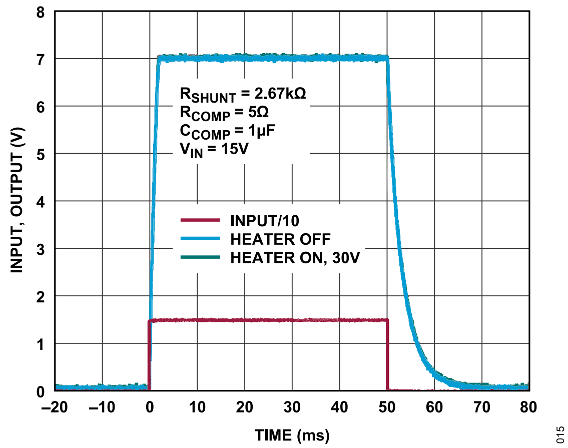


Figure 17. Response Time with R_{COMP} and C_{COMP}

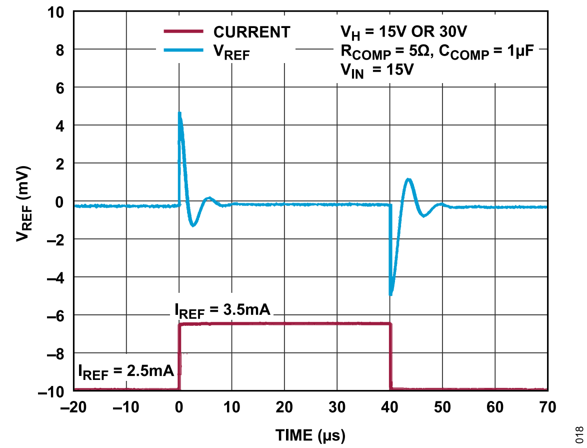


Figure 20. 1 mA Load Step Response, R_{COMP} = 5 Ω, C_{COMP} = 1 μF

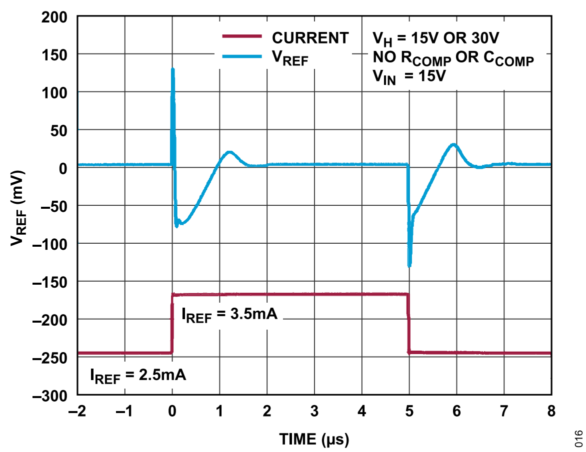


Figure 18. 1 mA Load Step Response, No R_{COMP} or C_{COMP}

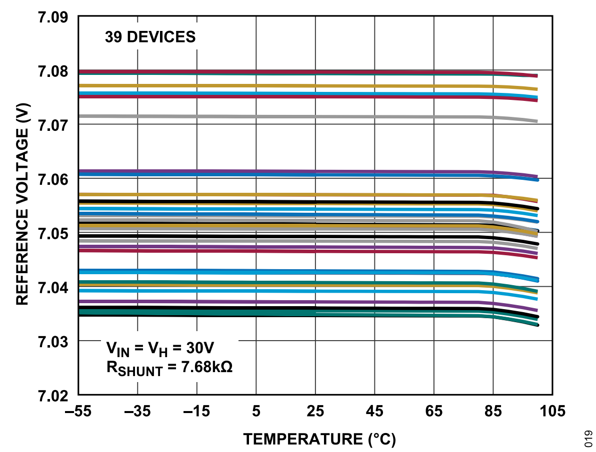


Figure 21. Reference Voltage vs. Temperature for 39 Devices, TO-46

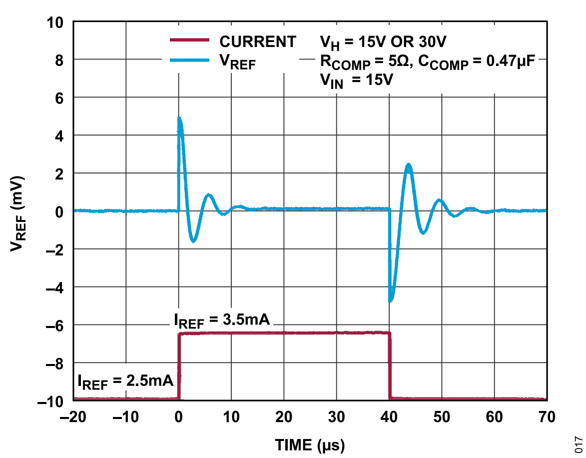


Figure 19. 1 mA Load Step Response, R_{COMP} = 5 Ω, C_{COMP} = 0.47 μF

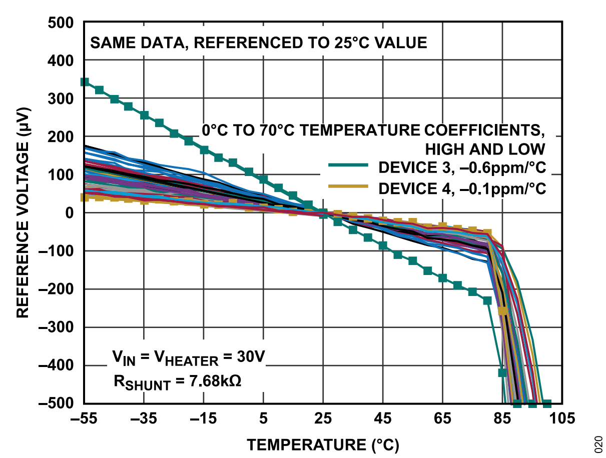


Figure 22. Reference Voltage vs. Temperature for 39 Devices, TO-46, Referenced to 25°C Value

TYPICAL PERFORMANCE CHARACTERISTICS

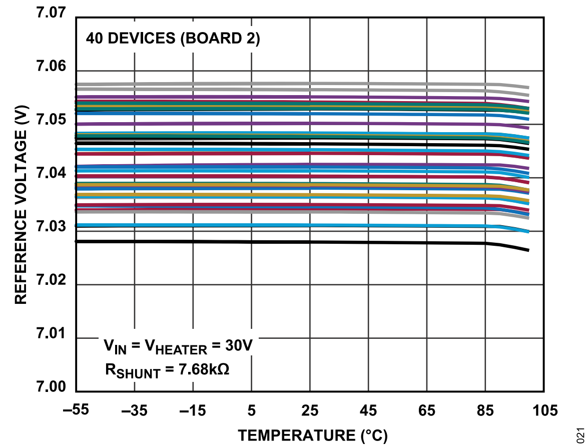


Figure 23. Reference Voltage vs. Temperature for 40 Devices, LCC

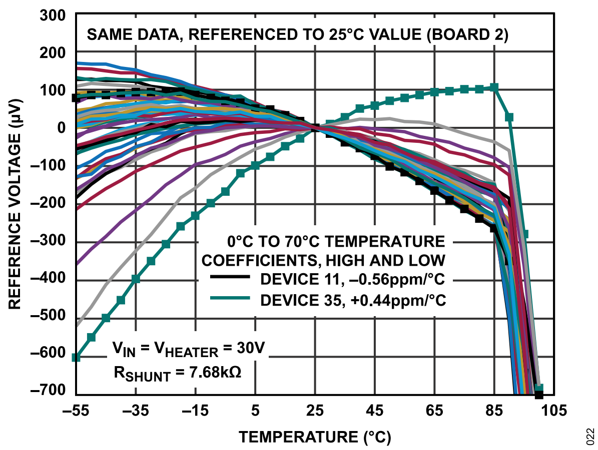


Figure 24. Reference Voltage vs. Temperature for 40 Devices, LCC, Referenced to 25°C Value

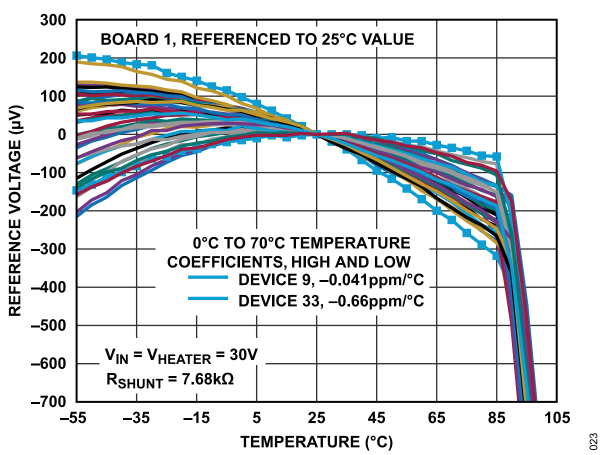


Figure 25. Reference Voltage vs. Temperature for 40 Devices, LCC, Referenced to 25°C Value (Board 1)

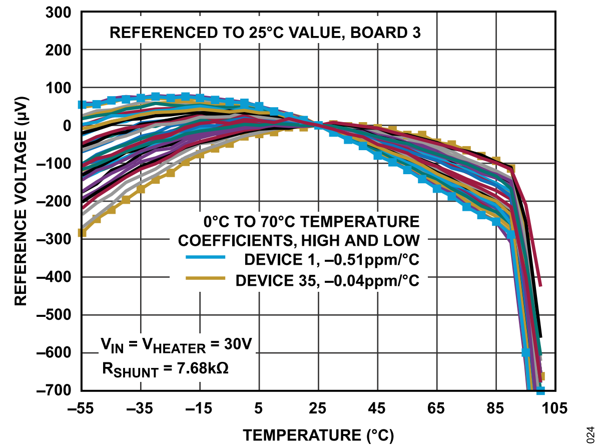


Figure 26. Reference Voltage vs. Temperature for 40 Devices, LCC, Referenced to 25°C Value (Board 3)

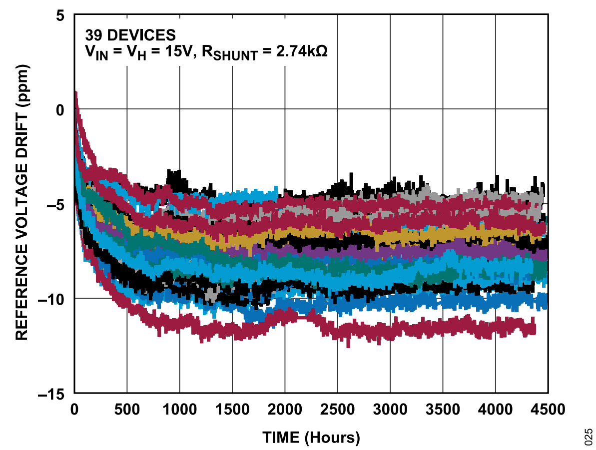


Figure 27. Reference Voltage Long-Term Drift

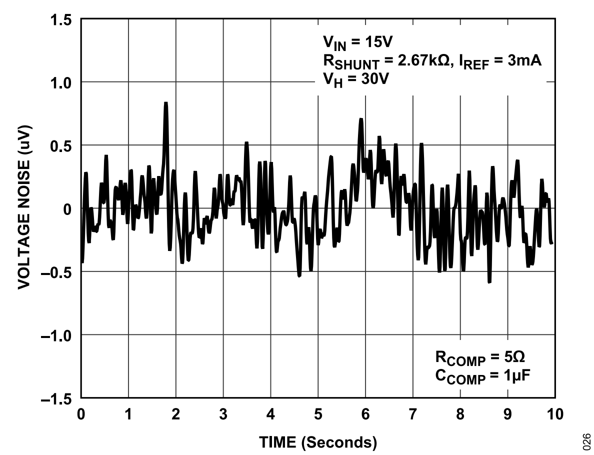


Figure 28. 0.1 Hz to 10 Hz Peak-to-Peak Noise

TYPICAL PERFORMANCE CHARACTERISTICS

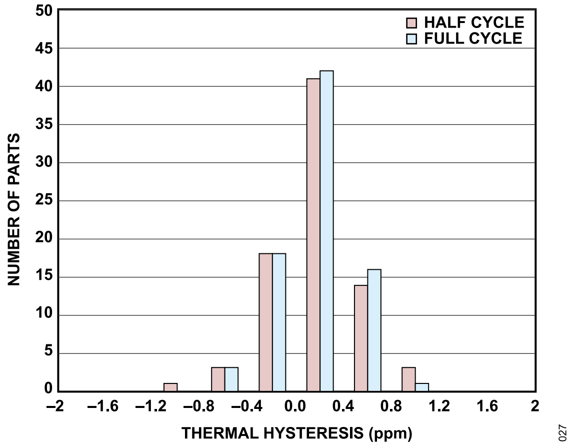


Figure 29. TO-46 Hysteresis, 0°C to 70°C, Heater On

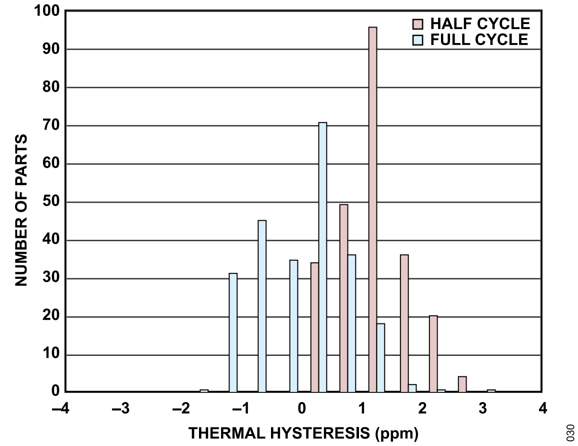


Figure 32. LCC Hysteresis, 0°C to 70°C, Heater On

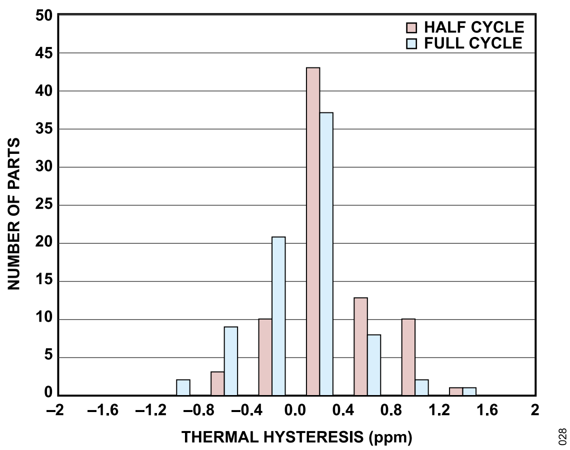


Figure 30. TO-46 Hysteresis, 0°C to 70°C, Heater Off

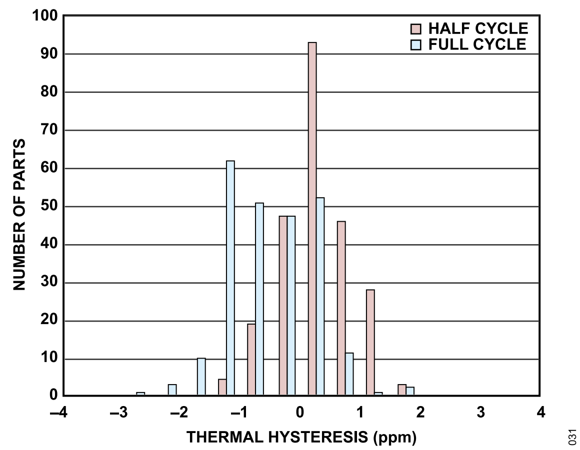


Figure 33. LCC Hysteresis, 0°C to 70°C, Heater Off

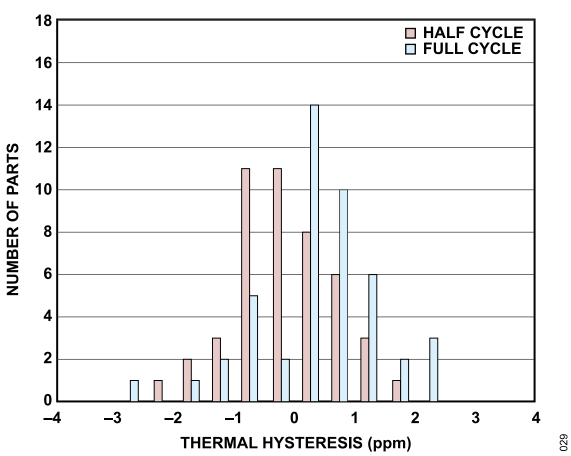


Figure 31. TO-46 Hysteresis, −40°C to +125°C, Heater Off

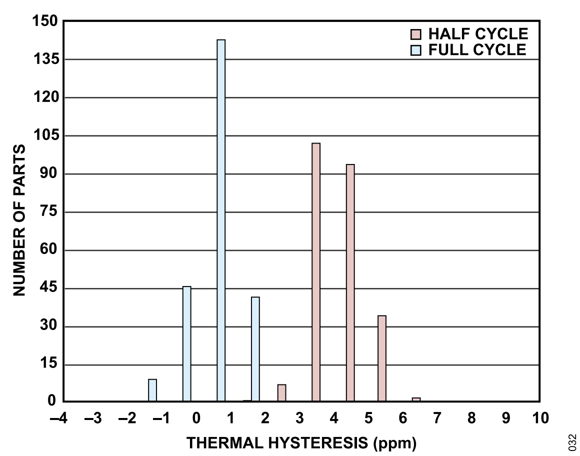


Figure 34. LCC Hysteresis, −40°C to +125°C, Heater Off

THEORY OF OPERATION

OPERATING SET TEMPERATURE

The ADR1399 contains a buried Zener diode with an approximate +2 mV/°C temperature coefficient, in series with an NPN, base emitter voltage (V_{BE}) with an approximate –2 mV/°C temperature coefficient. The combined positive and negative temperature coefficients sum to a nominal 0 mV/°C overall temperature coefficient. There are two op-amp servo loops inside the ADR1399. One op-amp loop maintains a fixed ratio of Zener and V_{BE} currents, with the total current set by an externally applied pull-up resistor or current source. Another op-amp loop maintains the device die at a nonadjustable set temperature of approximately 95°C, precluding the external ambient temperature fluctuations from affecting operating temperature. The entire system is provided in a simple 4-pin, hermetically sealed, TO-46 package and placed inside a plastic thermal insulator, which further keeps ambient fluctuations at bay and reduces the required heater power. If the ambient temperature exceeds the set temperature, the chip temperature control becomes open loop, and the temperature rejection of the device degrades while the excess ambient temperature condition persists.

With only an external supply and a pull-up resistor required for operation, the ADR1399 is simple to use. However, because it is so extremely stable, care must be taken to avoid degrading overall performance with external thermocouples and/or IR drops. For example, the heater current can be quite high; therefore, avoid sharing the heater current path with the Zener sense path. In addition, wherever metallurgic junctions are formed, such as where the device pins enter the board or where the reference voltage may be connectorized, try to ensure that junctions are paired and with similar thermal gradients. Parasitic thermocouples can simply add temperature dependencies from 1 µV/°C up to 40 µV/°C. See Application Note 86, *A Standards Lab Grade 20-Bit DAC with 0.1ppm/°C Drift* for additional information on thermoelectric potentials.

THERMAL RESISTANCE

The ADR1399 has an on-chip automated heater set to approximately 95°C. The TO-46 comes from the factory provided with a small plastic shield to keep air flow away from the reference. The factory included plastic air shield around the TO-46 reduces the effective net thermal resistance compared to a TO-46 without a shield. Techniques to increase thermal resistance include reducing solid copper planes in proximity to the device and elevating the device on its leads, approximately 1 cm above the board surface.

A hatch ground on the bottom side of the board increases thermal resistance compared to a solid ground plane. The heater power for the LCC version is about 3× to 4× greater than the TO-46 version. To reduce heater power, keep copper away from the inner layers near the device and use a hatch ground on the bottom layer. The slotting method (Application Note 82, *Understanding and Applying Voltage References*), which was originally intended to isolate references from externally applied flexing on the board, helps to increase thermal resistance. Combining a copper keepout area, hatching the bottom side ground layer, and extreme slotting or isothermal islands keeps the PCB from drawing excessive heat from the ovenized reference. After assembly, an external enclosure or insulation can further reduce the heat loss and consequent power draw.

FORCE AND SENSE PINS

The LCC version adds four pins, two of which are not internally connected (NIC) and the other two split the active reference into force and sense action on the top and bottom of the shunt. The force pins (+REFF and −REFF) are similar to op amp outputs, and the sense pins (+REFS and −REFS) are similar to the feedback pins of an op amp in that they sense the output to close the feedback loop. However, they differ from op amps because the sense pins have 2.2 mA of bias current, which is orders of magnitude more than any op amp input, for example. Additionally, whereas an op amp is often designed in to have the output node at the correct voltage, the ADR1399 is designed to have the sense node at the most accurate voltage. For example, when some resistance is placed between the +REFF and +REFS pins, all the IR drop induced in the resistance, including the IR noise induced by approximately 10 pA/rtHz of current noise, is transferred to the +REFF pin and does not appear at the +REFS pin. For the most accurate reading of the reference voltage, sense the reference voltage at the +REFS and −REFS pins, and not at the force pins.

The ADR1399 is characterized typically at 3 mA, and between 3 mA and 10 mA. Of the 3 mA, 2.2 mA is allocated to the ±REFS pins. 2.2 mA flows into the +REFS pin, and 2.2 mA flows out of the −REFS pin. The typical 3 mA is composed of an additional 0.8 mA flowing in and out of the +REFF and −REFF pins, respectively. At 10 mA, the sense pins remain at 2.2 mA and the extra 7.8 mA is regulated by the force pins.

THEORY OF OPERATION

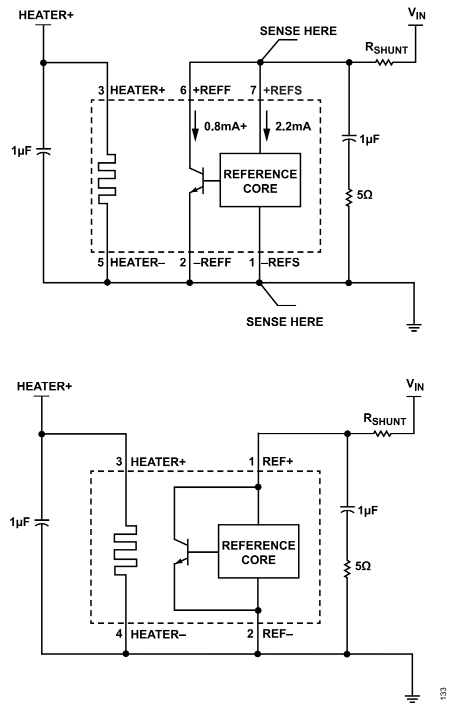


Figure 35. LCC vs. TO-46 Block Diagrams

APPLICATIONS INFORMATION

AVOIDING THERMOCOUPLE ERRORS

Thermocouples occur whenever two dissimilar metals form a junction. For example, the TO-46 package leads are made of Kovar™ and are usually soldered to a copper trace in a PCB design. Kovar copper junctions are known to cause thermocouple voltages of 35 µV/°C, which is about 25 times higher than the typical temperature coefficient of the ADR1399. To minimize thermocouple induced voltage errors, ensure that junctions in series with critical pins always see the same temperature as the corresponding junction in the return path. For the TO-46 of the ADR1399, this results in the need to avoid temperature gradients at the two points where the Zener pins contact the PCB.

SHUNT DYNAMIC IMPEDANCE AND CAPACITIVE LOAD

The ADR1399 offers reduced output shunt dynamic impedance over the LM399, which is often dismissed as an advancement that is not critical. However, considering the need for high stability in the presence of supply fluctuations and R_{SHUNT} drift, the low dynamic impedance of the ADR1399 is advantageous.

Consider, for example, the effect of a 0.1% change in supply voltage on a 15 V supply running 3 mA into an ADR1399 through a 2.67 kΩ R_{SHUNT}. The extra supply voltage causes an extra 5.6 µA to flow, which, on the 40 mΩ dynamic impedance of the TO-46 version of the ADR1399, increases the reference voltage by 0.22 µV. The same supply shift onto an LM399 design and into its typical 0.5 Ω dynamic impedance induces a considerable 2.8 µV of reference shift. Therefore, the improvement in dynamic impedance allows a better opportunity for maintaining high stability in the most critical shunt reference output voltage. Similarly, one can calculate for the effects due to changes in the R_{SHUNT} value.

One of the trade-offs of achieving the reduced dynamic impedance, however, is an increased sensitivity to direct capacitive loading. The LM399 is stable with a wide range of capacitive load. The ADR1399 starts to ring with direct capacitive loads of more than a few hundred pF, and oscillates with 10 nF directly. The ADR1399 is optimized for an external compensation series network of ~5 Ω and 1 µF, as shown in Figure 36 to Figure 41 (see the Typical Applications section). If updating a legacy design with excessive capacitance for the ADR1399, and there is nowhere to add a series 5 Ω, reduce the capacitance to less than 1 nF if possible. Another single element passive that works directly with the ADR1399 is a 10 µF tantalum capacitor, even though the series resistance can measure less than 5 Ω on an impedance analyzer.

With the 8-terminal LCC version of the ADR1399, including new force and sense pins, the dynamic impedance is lower. With the +REFF and +REFS shorted together, and the −REFF and −REFS shorted together, and sensing across the ±REFS pins, the dynamic impedance is 11 mΩ in magnitude, with 180 degrees of phase at low frequency, or −11 mΩ at DC.

TYPICAL APPLICATIONS

Figure 36 through Figure 41 show basic connections for single-supply, split supply, buffered references, negative heater supply with positive reference, and parallel references for lower noise operation.

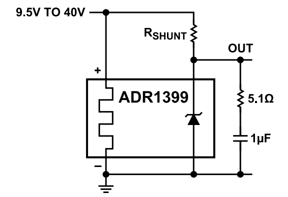


Figure 36. Single-Supply Operation

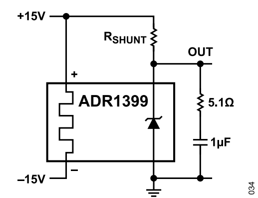


Figure 37. Split Supply Operation

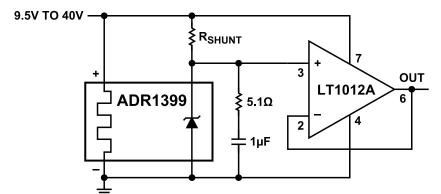


Figure 38. Buffered Operation

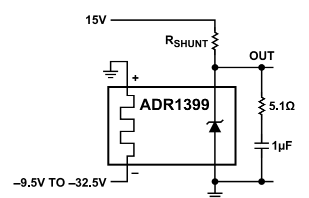


Figure 39. Negative Heater Supply with Positive Reference

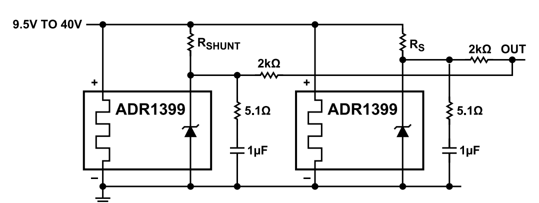


Figure 40. Parallel References for Lower Noise

APPLICATIONS INFORMATION

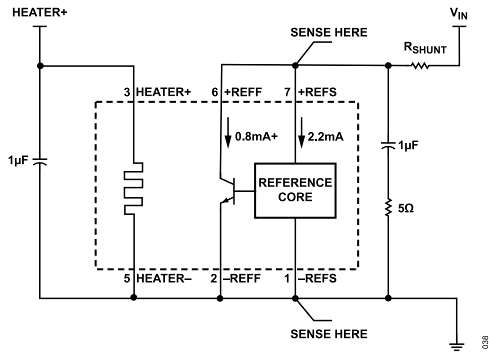


Figure 41. Basic Connections Using LCC with Force/Sense Pins

OUTLINE DIMENSIONS

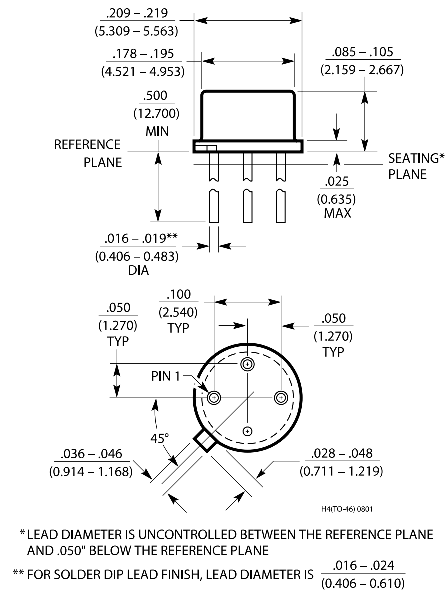


Figure 42. 4-Pin Metal Header Package [TO-46]
(05-08-1341)
Dimensions Shown in Inches (Millimeters), Side and Bottom Views

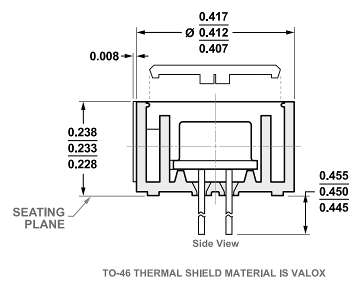


Figure 43. 4-Pin TO-46 Thermal Shield
Dimensions Shown in Inches

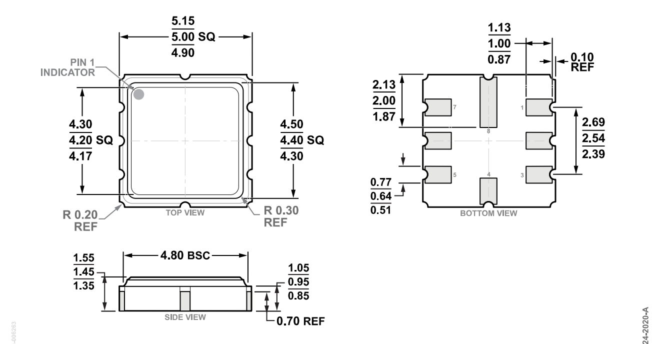


Figure 44. 8-Terminal Ceramic Leadless Chip Carrier LCC
(E-8-2)
Dimensions Shown in Millimeters

OUTLINE DIMENSIONS

Updated: December 11, 2021

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option
ADR1399KHZ	0°C to +70°C	4-Lead TO-46	05-08-1341
ADR1399KEZ	0°C to +70°C	8-Terminal LCC	E-8-2

[1] Z = RoHS Compliant Part.

EVALUATION BOARDS

Model[1]	Description
ADR1399E-EBZ	Evaluation Board for the ADR1399, LCC Package
ADR1399H-EBZ	Evaluation Board for the ADR1399, TO Package

[1] Z = RoHS Compliant Part.