

### FEATURES

- Easy to use
- Internal cold junction compensation
- High impedance differential input
- Reference pin allows offset adjustment
- Thermocouple break detection
- Wide power supply range
  - Single supply: 2.7 V to 36 V
  - Dual supply:  $\pm 2.7$  V to  $\pm 18$  V
- RoHS compliant
- 180  $\mu$ A supply current
- 8-pin MSOP

### APPLICATIONS

- J or K type thermocouple measurement
- Oven measurements
- Exhaust gas temperature sensing

### GENERAL DESCRIPTION

The AD8494/AD8495/AD8496/AD8497 are easy to use amplifiers for J and K type thermocouples. These amplifiers convert the small voltage generated by a thermocouple junction into a signal that can easily be read by an analog-to-digital converter (ADC) or microcontroller. The gain from the thermocouple to the amplifier output is approximately 5 mV/ $^{\circ}$ C.

The AD8494/AD8495/AD8496/AD8497 perform cold junction compensation using an on-board temperature sensor. Thermocouple measurements stay accurate through a wide range of ambient temperatures.

The AD8494/AD8495/AD8496/AD8497 contain a high precision instrumentation amplifier. This amplifier has high common-mode rejection, to block common-mode noise that the long lead thermocouples may pick up. For additional protection, the high impedance inputs of the amplifier make it easy to add extra filtering.

The AD8494/AD8495/AD8496/AD8497 allow a wide variety of supply voltages. With a 5 V single supply, the devices can cover nearly 1000 degrees of a thermocouple's temperature range.

The AD8494/AD8495/AD8496/AD8497 work with 3 V supplies, allowing them to directly interface to lower supply ADCs. They can also work with supplies as large as  $\pm 18$  V in industrial systems that require a wide common-mode input range.

### FUNCTIONAL BLOCK DIAGRAM

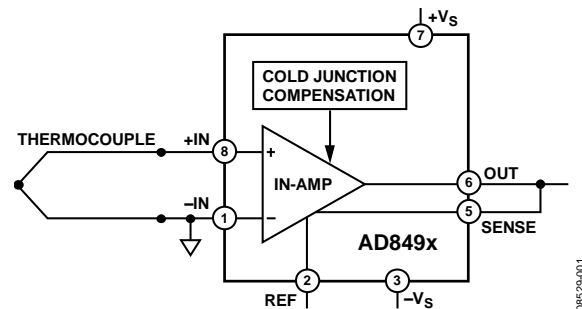


Figure 1.

Whatever the supply rails, the AD8494/AD8495/AD8496/AD8497 can easily measure negative temperatures. The 0 $^{\circ}$ C output can be adjusted with a voltage on the reference pin. This gives flexibility in adjusting the output range of the AD8494/AD8495/AD8496/AD8497 to fit the ADC.

The robust inputs are designed to handle real-world connection scenarios. The AD8494/AD8495/AD8496/AD8497 are robust to input voltages far beyond the supply rails. For example, with a  $\pm 5$  V supply, the parts are guaranteed to withstand  $\pm 35$  V at the input with no damage. Minimum and maximum input bias currents are specified to facilitate open thermocouple detection.

The AD8494/AD8495/AD8496/AD8497 are available in an 8-pin MSOP package and are fully RoHS compliant.

Table 1. Device Temperature Ranges

Part No.	Thermocouple Type	Optimized Temperature Range	
		Reference Junction	Measurement Junction
AD8494	J	0 $^{\circ}$ C to 50 $^{\circ}$ C	Full J type range
AD8495	K	0 $^{\circ}$ C to 50 $^{\circ}$ C	Full K type range
AD8496	J	25 $^{\circ}$ C to 100 $^{\circ}$ C	Full J type range
AD8497	K	25 $^{\circ}$ C to 100 $^{\circ}$ C	Full K type range

#### Rev. PrA

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## SPECIFICATIONS

+V<sub>S</sub> = 5 V, -V<sub>S</sub> = 0 V, V<sub>IN+</sub> = V<sub>IN-</sub> = 0 V, V<sub>REF</sub> = 0 V, T<sub>A</sub> = T<sub>R</sub> = 0°C to 100°C, R<sub>L</sub> = 100 kΩ, unless otherwise noted. Table does not include gain and offset errors of the thermocouple itself. T<sub>A</sub> is the ambient temperature at the AD849x; T<sub>R</sub> is the thermocouple reference junction temperature; T<sub>M</sub> is the thermocouple measurement junction temperature.

Table 2.

Parameter	Test Conditions/Comments	A Grade			B Grade			Unit
		Min	Typ	Max	Min	Typ	Max	
TEMPERATURE ACCURACY								
Initial Accuracy	AD8494/AD8495: T <sub>A</sub> = T <sub>R</sub> = T <sub>M</sub> = 25°C AD8496/AD8497: T <sub>A</sub> = T <sub>R</sub> = 60°C, T <sub>M</sub> = 25°C			3			1	°C
Ambient Temperature Rejection	AD8494/AD8495: T <sub>A</sub> = T <sub>R</sub> = 0°C to 50°C AD8496/AD8497: T <sub>A</sub> = T <sub>R</sub> = 25°C to 100°C			0.05			0.025	°C/°C
Gain Error <sup>1,2</sup>	AD8494/5: T <sub>M</sub> = -200°C to 1200°C AD8496/7: T <sub>M</sub> = -260°C to 1400°C			0.1			0.01	%
Nominal Transfer Function <sup>1</sup>				5			5	mV/°C
INPUTS								
Input Voltage Range		-V <sub>S</sub> - 0.2		+V <sub>S</sub> - 1.6	-V <sub>S</sub> - 0.2		+V <sub>S</sub> - 1.6	V
Overvoltage Range		+V <sub>S</sub> - 40		-V <sub>S</sub> + 40	+V <sub>S</sub> - 40		-V <sub>S</sub> + 40	V
Input Bias Current <sup>3</sup>			30			30		nA
Input Offset Current			0.5			0.5		nA
Common-Mode Rejection				0.2			0.1	°C/V
Power Supply Rejection				0.5			0.25	°C/V
NOISE								
Voltage Noise	f = 0.1 Hz to 10 Hz, T <sub>A</sub> = 25°C		0.5			0.5		μV p-p
Voltage Noise Density	f = 1 kHz, T <sub>A</sub> = 25°C		29			29		nV/√Hz
Current Noise Density	f = 1 kHz, T <sub>A</sub> = 25°C		100			100		fA/√Hz
REFERENCE INPUT								
R <sub>IN</sub>			50			50		kΩ
I <sub>IN</sub>			22			22		μA
Voltage Range		-V <sub>S</sub>		+V <sub>S</sub>	-V <sub>S</sub>		+V <sub>S</sub>	V
Gain to Output			1			1		V/V
OUTPUT								
Output Voltage Range	R <sub>L</sub> = 100 kΩ to opposite supply	-V <sub>S</sub> + 0.05		+V <sub>S</sub> - 0.1	-V <sub>S</sub> + 0.05		+V <sub>S</sub> - 0.1	V
Short-Circuit Current <sup>4</sup>								mA
DYNAMIC RESPONSE								
-3 dB Bandwidth								
AD8494/AD8496			31			31		kHz
AD8495/AD8497			25			25		kHz
Settling Time								μs
POWER SUPPLY								
Operating Voltage Range <sup>5</sup>								
Single Supply		2.7		36	2.7		36	V
Dual Supply		±2.7		±18	±2.7		±18	V
Quiescent Current			180			180		μA

Parameter	Test Conditions/Comments	A Grade		B Grade		Unit
TEMPERATURE RANGE ( $T_A$ )						
Specified Performance						$^{\circ}\text{C}$
AD8494/AD8495		0	50	0	50	$^{\circ}\text{C}/^{\circ}\text{C}$
AD8496/AD8497		25	100	25	100	$^{\circ}\text{C}/^{\circ}\text{C}$
Operational		-40	+125	-40	+125	$^{\circ}\text{C}$

<sup>1</sup> Error does not include thermocouple gain error or thermocouple nonlinearity.

<sup>2</sup> With a 100 k $\Omega$  load, measurement junction temperatures beyond approximately 880 $^{\circ}\text{C}$  for the AD8494/AD8496 and 960 $^{\circ}\text{C}$  for the AD8495/AD8497 require supply voltages larger than 5 V or a negative voltage applied to the reference pin. Temperatures below 10 $^{\circ}\text{C}$  require either a positive offset voltage applied to the reference pin or a negative supply.

<sup>3</sup> Input stage uses pnp transistors, so bias current always flows out of the part.

<sup>4</sup> Large output currents can increase the internal temperature rise of the part and contribute to cold junction compensation (CJC) error.

<sup>5</sup> Unbalanced supplies can also be used. Care should be taken that the common-mode voltage of the thermocouple stays within the input voltage range of the part.

## ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Rating
Supply Voltage	$\pm 18\text{ V}$
Output Short-Circuit Current	Indefinite
Maximum Voltage at $-IN$ or $+IN$	$+V_S - 40\text{ V}$
Minimum Voltage at $-IN$ or $+IN$	$-V_S + 40\text{ V}$
REF Voltage	$\pm V_S$
Storage Temperature Range	$-65^\circ\text{C}$ to $+150^\circ\text{C}$
Specified Temperature Range	
AD8494/AD8495	$0^\circ\text{C}$ to $50^\circ\text{C}$
AD8496/AD8497	$25^\circ\text{C}$ to $100^\circ\text{C}$
Maximum IC Junction Temperature	$140^\circ\text{C}$

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

## THERMAL RESISTANCE

$\theta_{JA}$  is specified for a device in free air.

Table 4.

Package	$\theta_{JA}$	Unit
8-Lead MSOP, 4-Layer JEDEC Board	135	$^\circ\text{C}/\text{W}$

## 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 CONFIGURATION AND FUNCTION DESCRIPTIONS

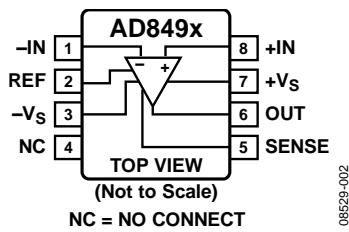


Figure 2. Pin Configuration

Table 5. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	-IN	Negative Input.
2	REF	Reference. This pin must be driven by low impedance.
3	-V <sub>S</sub>	Negative Supply.
4	NC	No Connect.
5	SENSE	Sense Pin. In measurement mode, connect to output; in setpoint mode, connect to setpoint voltage.
6	OUT	Output.
7	+V <sub>S</sub>	Positive Supply.
8	+IN	Positive Input.

## THEORY OF OPERATION

### THERMOCOUPLE THEORY

A thermocouple consists of two dissimilar metals. These metals are connected at one end to form the measurement junction, sometimes also called the hot junction. This measurement junction is at the temperature to be measured. The other end of the thermocouple is connected to the metal lines that lead to the measurement electronics. This connection also forms a junction: the reference junction, also called the cold junction.

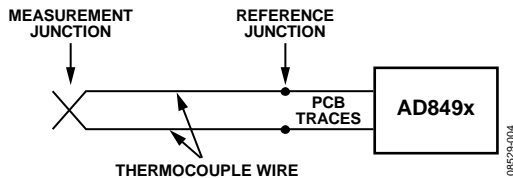


Figure 3. Thermocouple Junctions

Thermocouples create a differential voltage based on the temperature difference between the hot and cold junctions. The thermocouple voltage depends on both junction temperatures. Therefore, to derive the temperature at the measurement junction, the user must know two pieces of information: the differential voltage created by the thermocouple and the reference junction temperature. The use of the reference junction temperature, along with the thermocouple voltage reading, is typically called “cold junction compensation,” because the electronics must compensate for any changes in temperature at the reference (cold) junction. Table 6 shows an example of a K type thermocouple voltage for various combinations of 0°C and 50°C on the reference and measurement junctions.

Table 6. K Type Thermocouple Voltages and AD8495 Readings

Measurement Junction Temperature	Reference Junction Temperature	Thermocouple Voltage	AD8495 Reading
50°C	0°C	2.023 mV	250 mV
50°C	50°C	0 mV	250 mV
0°C	0°C	0 mV	0 mV
0°C	50°C	-2.023 mV	0 mV

The voltage generated by a thermocouple is quite small. At room temperature, a K type thermocouple changes about 41  $\mu\text{V}/^\circ\text{C}$ , and a J type thermocouple changes about 52  $\mu\text{V}/^\circ\text{C}$ . Because the voltages generated are so small, thermocouple measurements are susceptible to interference.

The designer can take several steps to minimize possible interference.

- Measure thermocouples differentially to avoid ground loops.
- Filtering is typically recommended to remove high frequency noise and to protect against RFI interference.

- The signal conditioning circuitry should include a large amount of gain so that the small thermocouple signal can be read accurately by the components later in the signal chain.

Real-world thermocouples have variability in their metallurgical properties. These properties are reflected in specifications from the manufacturer for maximum error. Thermocouples are typically specified with an absolute temperature error, as well as with an error vs. temperature.

The voltage generated by a thermocouple is nonlinear. For example, whereas a J type thermocouple changes 52  $\mu\text{V}/^\circ\text{C}$  at +25°C, it changes by 47  $\mu\text{V}/^\circ\text{C}$  at -50°C, and by +55  $\mu\text{V}/^\circ\text{C}$  at 150°C. K type thermocouples tend to be more linear, staying fairly near 41  $\mu\text{V}/^\circ\text{C}$  when temperatures are above 0  $\mu\text{V}/^\circ\text{C}$ . Whether a thermocouple needs linearization depends on the thermocouple type chosen and the required system accuracy.

### Thermocouple Tips

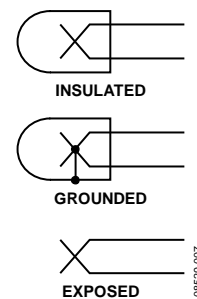


Figure 4. Thermocouple Measurement Junction Types

Thermocouple manufacturers offer three different styles for their measurement junctions:

- Insulated tip: The thermocouple manufacturer places a sheath around the thermocouple tip. The thermocouple tip is electrically isolated from the sheath, so that there is no electrical connection between the material being measured and the thermocouple. This thermocouple type is the most popular type on the market and is the easiest to use, but it has the slowest response time.
- Grounded: The thermocouple manufacturer places a sheath around the thermocouple tip, but the sheath is electrically connected to the thermocouple. Therefore, the thermocouple makes an electrical connection with the material being measured.
- Exposed: There is no protective sheath around the thermocouple tip, but there is an electrical connection between the thermocouple and the substance being measured. This type of thermocouple is the least robust but provides the fastest response time.

The type of thermocouple tip determines whether a ground connection should be made to the thermocouple in the signal conditioning system (see the Ground Connection section).

affecting the measurement. The AD849x also has low input bias currents, which allows for easy filtering at the inputs.

## THERMOCOUPLE AMPLIFIER ARCHITECTURE

Figure 5 shows a block diagram of the AD849x circuitry. The AD849x consists of a low offset instrumentation amplifier and a temperature sensor. Figure 6 shows a simplified schematic with more detail.

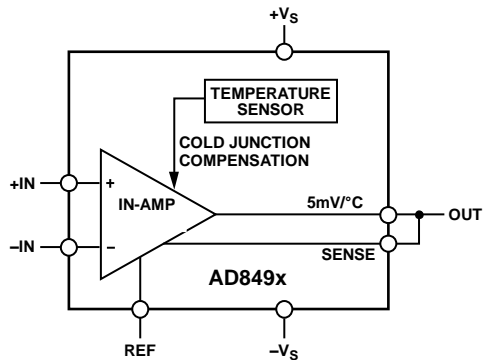


Figure 5. Block Diagram

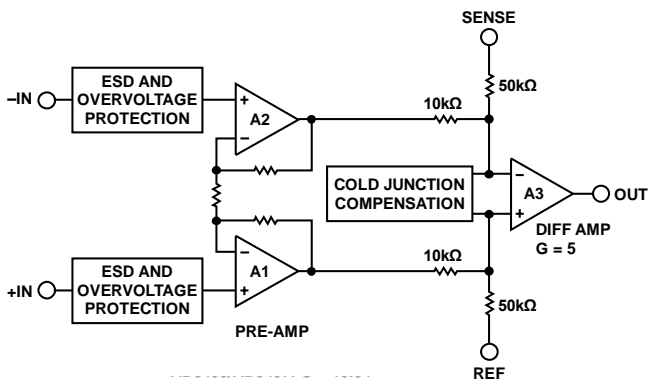


Figure 6. Simplified Schematics

### Instrumentation Amplifier

As noted in the Thermocouple Theory section, the small thermocouple voltages require considerable gain before they can be sampled by typical ADCs. The gain for the instrumentation amplifier in each of the AD8494/AD8495/AD8496/AD8497 was chosen to provide a transfer function of approximately 5 mV/°C for the J and K thermocouple types.

The small signal strength means that thermocouple voltages are quite vulnerable to interference, especially when measured with single-ended amplifiers. The AD849x addresses this issue in several ways. The differential inputs of the device make grounding much more straightforward for thermocouples with insulated tips and is essential for thermocouples with grounded or exposed tips. The AD849x has excellent common-mode rejection, which prevents variations in ground potential from



**Cold Junction Compensation**

The AD849x also includes a temperature sensor for cold junction compensation. This temperature sensor is used to measure the reference junction temperature of the thermocouple. This information is then fed into the instrumentation amplifier and is used to compensate the final output voltage. The cold junction compensation is optimized for 25°C in the AD8494/AD8495 for measurement systems typically at room temperature. It is optimized at 60°C in the AD8496/AD8497 for oven systems where the reference junction and signal conditioning circuitry typically sit at an elevated temperature.

**Open Thermocouple Detection**

The AD849x offers open thermocouple detection. The input bias current of the AD849x drives any unconnected input high and, therefore, rails the output. Whether the amplifier rails high or low depends on where the ground is connected: grounding the negative input causes the AD849x to rail high, whereas grounding the positive input causes the part to rail low. Note that this feature assumes no electrical connection at the thermocouple tip (see the Ground Connection section).

**Transfer Function**

The result of all this signal conditioning is an AD849x output voltage that is proportional to the temperature at the measurement junction ( $T_M$ ). The AD849x has the following nominal transfer function.

$$V_{OUT} = (T_M \times 5 \text{ mV}/^\circ\text{C}) + V_{REF}$$

For more accuracy, full details on the complete transfer functions of the AD8494/AD8495/AD8496/AD8497 will be provided in the final datasheet.

**Input Voltage Protection**

The AD849x has very robust inputs. Input voltages can be up to 40 V from the opposite supply rail. For example, with a +5 V positive supply and a -3 V negative supply, the part can safely withstand voltages at the inputs from -35 V to +37 V. Voltage at the reference and sense pins should not go beyond 0.3 V of the supply rails.

## RECOMMENDATIONS FOR BEST CIRCUIT PERFORMANCE

### Keeping the AD849x at the Same Temperature as the Reference Junction

The AD849x compensates for thermocouple reference junction temperature by using an internal temperature sensor. Any difference in temperature between the AD849x and the reference junction shows up directly as temperature error. Temperature difference may occur if the AD849x is not physically close to the reference junction or if the AD849x is required to supply large amounts of output current, especially on larger supplies.

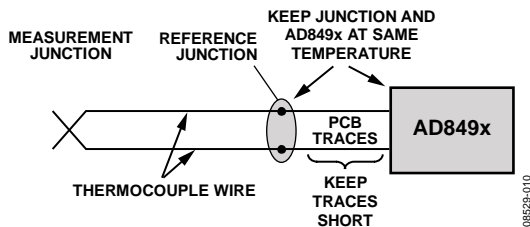


Figure 7. Compensating for Thermocouple Reference Junction Temperature

### Driving the Reference Pin

The AD849x comes with a reference pin, which can be used to offset the output voltage. This is particularly useful when reading a negative temperature in a single-supply system.

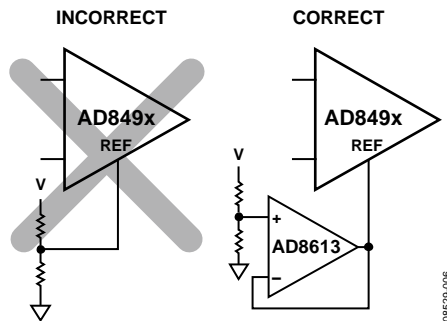


Figure 8. Driving the Reference Pin

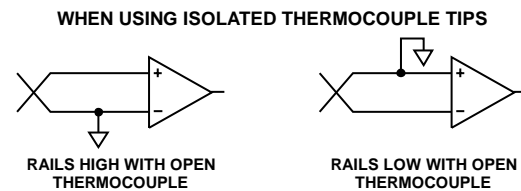
For best performance, the reference pin should be driven with a low output impedance source, not a resistor divider. The AD8613 and the OP777 are good choices for the buffer amplifier.

### Ground Connection

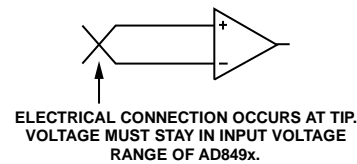
The thermocouple measurement junction tip determines how the ground should be connected to the thermocouple. The AD849x requires one, and only one, source of common-mode voltage. For thermocouples with insulated tips, a voltage connection (typically ground) must be provided. For thermocouples with grounded or exposed tips, no extra ground connection should be provided: the measurement junction itself sets the common-mode voltage. A ground at the grounded or exposed tip is detrimental to performance, because ground loops can form.

Connecting the ground to the negative input terminal causes the AD849x to rail high in an open thermocouple condition. The AD849x rails low if the ground is connected to the positive input.

If the thermocouple tip type is unknown, a 1 M $\Omega$  resistor to ground can be used. This solution works well regardless of whether there is an electrical connection at the measurement junction. If there is no electrical connection at the measurement junction, the resistor is small enough to create a common-mode voltage for the AD849x. If there is an electrical connection, the value is large enough so that any current from the measurement tip to ground is very small, preventing measurement errors.



### WHEN USING EXPOSED OR GROUNDED THERMOCOUPLE TIPS



### WHEN THERMOCOUPLE TIP TYPE IS UNKNOWN

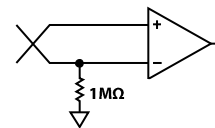


Figure 9. Grounding Options When Using Different Tip Types

### Input Filter

A low-pass filter before the input of the AD849x is highly recommended when operating in an electrically noisy environment. Long thermocouple leads can function as an excellent antenna and pick up many unwanted signals.

Figure 10 and Figure 11 show filtering options for different grounding configurations. To prevent input offset currents from influencing the measurement accuracy, resistors should be kept below 50 k $\Omega$ .

Although these low-pass filters can filter out noise within the bandwidth of the AD849x, their primary purpose is to filter out noise outside the frequency range of the AD849x. In particular, these filters remove RF signals, which, if allowed to reach the AD849x, could be rectified and appear as temperature fluctuations.

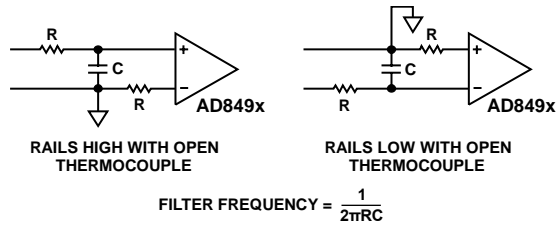


Figure 10. Filter Options for Isolated Thermocouple Tips

08529-008

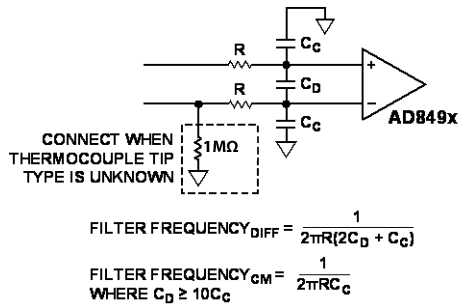


Figure 11. Filter Options for Exposed, Grounded, or Unknown Thermocouple Tips

08529-011

**Thermocouple Nonlinearity**

Thermocouples are nonlinear. The AD849x does not compensate for this nonlinearity. This nonlinearity can lead to unacceptable errors, especially at very low or very high temperatures.

When operating near 25°C for the AD8494/AD8495, or near 60°C for the AD8496/AD8497, linearity correction may not be needed. For operation far from these calibration points, linearity correction is recommended.

Thermocouple nonlinearity is typically corrected with a microcontroller in the digital domain.

**Debugging Tip**

If the AD849x is not providing the expected performance, a useful debugging step is to implement the ambient temperature configuration in Figure 13. If the ambient temperature sensor does not work as expected, the problem is likely with the AD849x or with the downstream circuitry. If the ambient temperature sensor configuration is working correctly, the problem typically lies with how the thermocouple is connected to the AD849x. A common error is an incorrect grounding configuration or lack of filtering.

## APPLICATIONS INFORMATION

For the sake of simplicity, the input connections in this section are shown with the negative input grounded and with no other input circuitry. This setup is appropriate for an insulated tip thermocouple in an electrically quiet environment. See the Ground Connection and Input Filter sections for information about additional input circuitry that may be required.

### BASIC CONNECTION

Figure 12 shows an example of a basic connection for the AD849x.

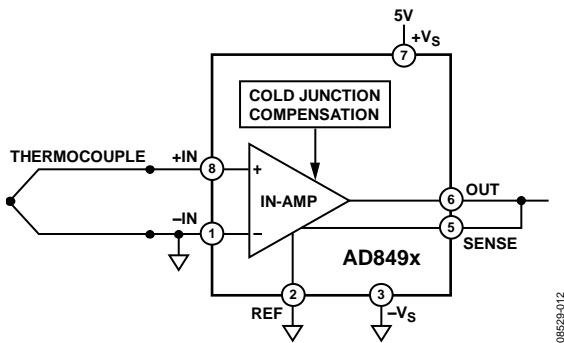


Figure 12. Basic Connection for the AD849x

The SENSE pin should be connected to the output pin of the AD849x. To measure negative temperatures, apply a voltage at the reference pin to offset the output voltage at 0°C.

### AMBIENT TEMPERATURE SENSOR

The AD849x can be configured as a standalone Celsius thermometer, as shown in Figure 13. The thermocouple sensing functionality is disabled by shorting both AD849x inputs to ground; the AD849x simply outputs the value from the on-board temperature sensor.

This mode can be particularly useful for debugging a misbehaving circuit. If the basic connection is not working, disconnect the thermocouple and short both inputs to ground. If the system reads the ambient temperature correctly, the problem is related to the thermocouple. If the system does not read the ambient temperature correctly, the problem is with the electronics.

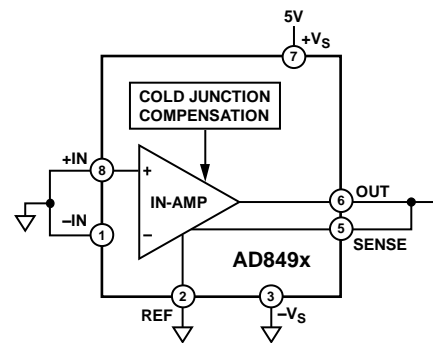
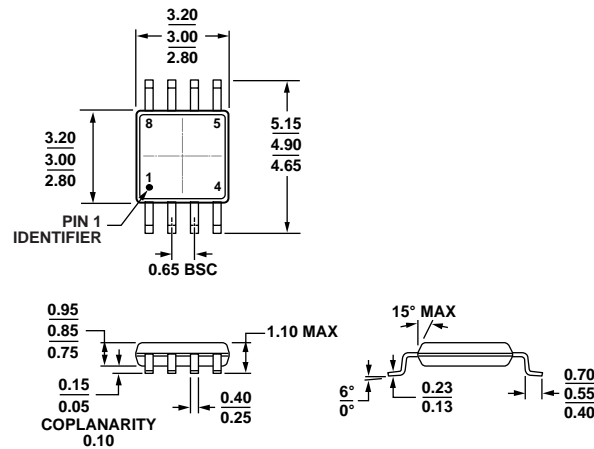


Figure 13. Ambient Temperature Sensor

# OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-187-AA

Figure 14. 8-Lead Mini Small Outline Package [MSOP] (RM-8)

Dimensions shown in millimeters

091709-A

## ORDERING GUIDE

Model <sup>1</sup>	Temperature Range	Package Description	Package Option
AD8494ARMZ	0°C to 50°C	8-Lead MSOP	RM-8
AD8494ARMZ-RL	0°C to 50°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8494ARMZ-R7	0°C to 50°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8494BRMZ	0°C to 50°C	8-Lead MSOP	RM-8
AD8494BRMZ-RL	0°C to 50°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8494BRMZ-R7	0°C to 50°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8495ARMZ	0°C to 50°C	8-Lead MSOP	RM-8
AD8495ARMZ-RL	0°C to 50°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8495ARMZ-R7	0°C to 50°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8495BRMZ	0°C to 50°C	8-Lead MSOP	RM-8
AD8495BRMZ-RL	0°C to 50°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8495BRMZ-R7	0°C to 50°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8496ARMZ	25°C to 100°C	8-Lead MSOP	RM-8
AD8496ARMZ-RL	25°C to 100°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8496ARMZ-R7	25°C to 100°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8496BRMZ	25°C to 100°C	8-Lead MSOP	RM-8
AD8496BRMZ-RL	25°C to 100°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8496BRMZ-R7	25°C to 100°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8497ARMZ	25°C to 100°C	8-Lead MSOP	RM-8
AD8497ARMZ-RL	25°C to 100°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8497ARMZ-R7	25°C to 100°C	8-Lead MSOP, 7" Tape and Reel	RM-8
AD8497BRMZ	25°C to 100°C	8-Lead MSOP	RM-8
AD8497BRMZ-RL	25°C to 100°C	8-Lead MSOP, 13" Tape and Reel	RM-8
AD8497BRMZ-R7	25°C to 100°C	8-Lead MSOP, 7" Tape and Reel	RM-8

<sup>1</sup> Z = RoHS Compliant Part.

**NOTES**

## NOTES