# Ways to Measure Temperature Using Thermocouples

**Introduction**

The thermocouple is a simple, widely used component for measuring temperature. This article provides a basic overview of thermocouples, describes common challenges encountered when designing with them, and suggests two signal conditioning solutions. The first solution combines both reference-junction compensation and signal conditioning in a single analog IC for convenience and ease of use; the second solution separates the reference-junction compensation from the signal conditioning to provide digital-output temperature sensing with greater flexibility and accuracy.

**Voltage Change vs. Temperature Rise (Seebeck Coefficient) for Various Thermocouple Types at 25° C.**

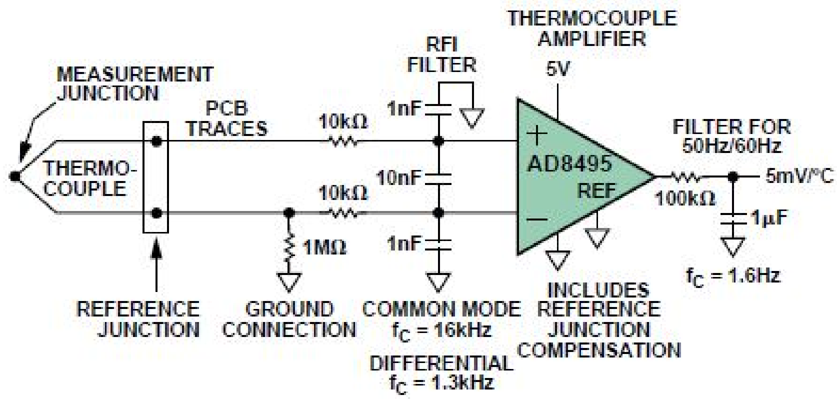
| Thermocouple Type | Seebeck Coefficient (µV/°C) |
|---|---|
| E | 61 |
| J | 52 |
| K | 41 |
| N | 27 |
| R | 9 |
| S | 6 |
| T | 41 |

Because the voltage signal is small, the signal-conditioning circuitry typically requires gains of about 100 or so—fairly straightforward signal conditioning. What can be more difficult is distinguishing the actual signal from the noise picked up on the thermocouple leads. Thermocouple leads are long and often run through electrically noisy environments. The noise picked up on the leads can easily overwhelm the tiny thermocouple signal. Two approaches are commonly combined to extract the signal from the noise. The first is to use a differential-input amplifier, such as an instrumentation amplifier, to amplify the signal. Because much of the noise appears on both wires (*common-mode*), measuring differentially eliminates it. The second is low-pass filtering, which removes out-of-band noise. The low-pass filter should remove both radio-frequency interference (above 1 MHz) that may cause rectification in the amplifier and 50 Hz/60 Hz (power-supply) *hum*.

It is important to place the filter for radio frequency interference ahead of the amplifier (or use an amplifier with filtered inputs). The location of the 50-Hz/60-Hz filter is often not critical—it can be combined with the RFI filter, placed between the amplifier and ADC, incorporated as part of a sigma-delta ADC, or it can be programmed in software as an averaging filter.

**Measurement Solution 1:**

It is based on using the AD8495 thermocouple amplifier, which is designed specifically to measure K-type thermocouples. This analog solution is optimized for minimum design time: It has a straightforward signal chain and requires no software coding.




**Measurement solution 1: optimized for simplicity.**

How does this simple signal chain address the signal conditioning requirements for K-type thermocouples?

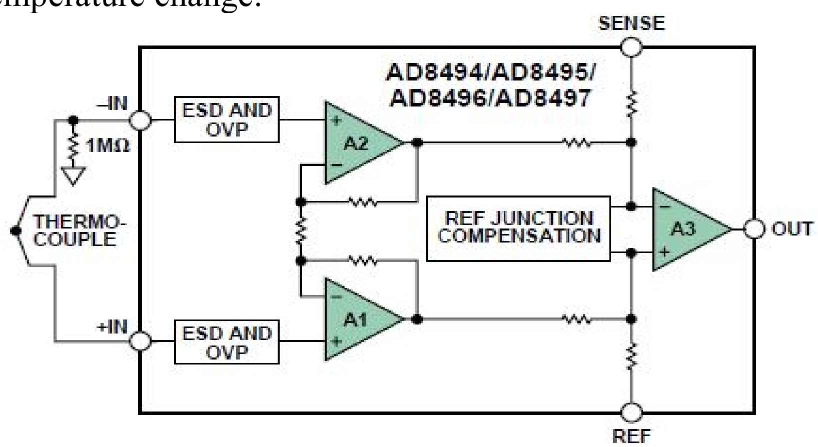
**Gain and output scale factor:** The small thermocouple signal is amplified by the AD8495's gain of 122, resulting in a 5-mV/°C output signal sensitivity (200°C/V).

**Noise reduction:** High-frequency common-mode and differential noise are removed by the external RFI filter. Low frequency common mode noise is rejected by the AD8495's instrumentation amplifier. Any remaining noise is addressed by the external post filter.

**Reference junction compensation:** The AD8495, which includes a temperature sensor to compensate for changes in ambient temperature, must be placed near the reference junction to maintain both at the same temperature for accurate reference junction compensation.

**Nonlinearity correction:** The AD8495 is calibrated to give a 5 mV/°C output on the linear portion of the K-type thermocouple curve, with less than 2°C of linearity error in the –25°C to +400°C temperature range. If temperatures beyond this range are needed, Analog Devices Application Note AN-1087 describes how a lookup table or equation could be used in a microprocessor to extend the temperature range.

**More about the AD8495:** Amplifiers A1, A2, and A3—and the resistors shown—form an instrumentation amplifier that amplifies the K-type thermocouple's output with a gain appropriate to produce an output voltage of 5 mV/°C. Inside the box labeled "Ref junction compensation" is an ambient temperature sensor. With the measurement junction temperature held constant, the differential voltage from the thermocouple will decrease if the reference junction temperature rises for anyreason. If the tiny (3.2 mm × 3.2 mm × 1.2 mm) AD8495 is in close thermal proximity to the reference junction, the reference junction compensation circuitry injects additional voltage into the amplifier, so that the output voltage stays constant, thus compensating for the reference temperature change.

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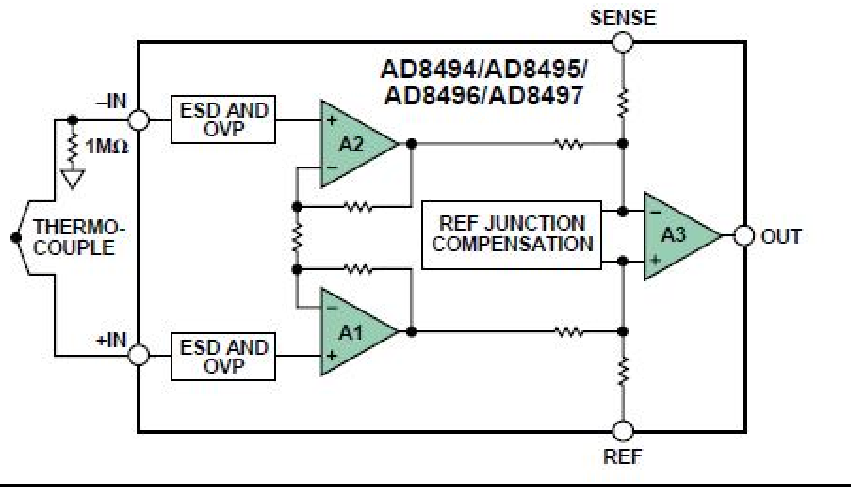
**Measurement Solution 2: Optimized for Accuracy and Flexibility**

This circuit includes a high-precision ADC to measure the small-signal thermocouple voltage and a high-accuracy temperature sensor to measure the reference junction temperature. Both devices are controlled using an SPI interface from an external microcontroller.

**Remove noise and amplify voltage:** The AD7793, shown in detail in Figure — a high-precision, low-power analog front end—is used to measure the thermocouple voltage. The thermocouple output is filtered externally and connects to a set of differential inputs, AIN1(+) and AIN1(–). The signal is then routed through a multiplexer, a buffer, and an instrumentation amplifier—which amplifies the small thermocouple signal—and to an ADC, which converts the signal to digital.




AD8495 functional block diagram.

**Compensate for reference junction temperature:**

The ADT7320 (detailed in Figure 10), if placed close enough to the reference junction, can measure the reference-junction temperature accurately, to ±0.2°C, from –10°C to +85°C. An on-chip temperature sensor generates a voltage proportional to absolute temperature, which is compared to an internal voltage reference and applied to a precision digital modulator. The digitized result from the modulator updates a 16-bit temperature value register. The temperature value register can then be read back from a microcontroller, using an SPI interface, and combined with the temperature reading from the ADC to effect the compensation.

**Correct nonlinearity:**

The ADT7320 provides excellent linearity over its entire rated temperature range (–40°C to +125°C), requiring no correction or calibration by the user. Its digital output can thus be considered an accurate representation of the reference-junction state. To determine the actual thermocouple temperature, this reference temperature measurement must be converted into an equivalent thermoelectric voltage using equations provided by the National Institute of Standards and Technology (NIST). This voltage then gets added to the thermocouple voltage measured by the AD7793; and the summation is then translated back into a thermocouple temperature, again using NIST equations..