DATAQ INSTRUMENTS · APPLICATION NOTE

Choosing a Data Logger for Thermocouple Measurements

How to choose a thermocouple, understand the limits of a general-purpose voltage logger, and adjust cold-junction compensation on the DI-2008

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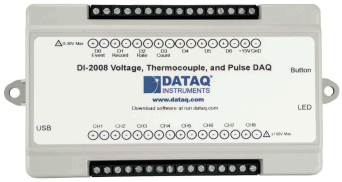
Overview



Thermocouples (TCs) are the most widely used temperature sensors: inexpensive, rugged, self-powered and available for anything from cryogenic tests to furnaces above 1700 °C. Getting an accurate reading from one, however, depends as much on the **data logger** as on the sensor. A thermocouple produces only microvolts per degree, its output depends on the temperature of the instrument's own terminals, and its voltage is not a straight-line function of temperature.

This note explains how to choose a thermocouple type, why a general-purpose voltage logger is not the best tool for the job, and how the **DI-2008** handles all three problems, with per-channel cold-junction calibration stored in the instrument itself.

How a Thermocouple Works

A thermocouple is two wires of different metals joined at the measuring point, the **hot junction**. Wherever a temperature gradient runs along the wires, a small voltage develops (the Seebeck effect). The measured voltage is the thermocouple's reference-table voltage at the measuring-junction temperature **minus** its voltage at the temperature of the instrument terminals, where the wires connect to the instrument: the **cold junction** (also called the reference junction).

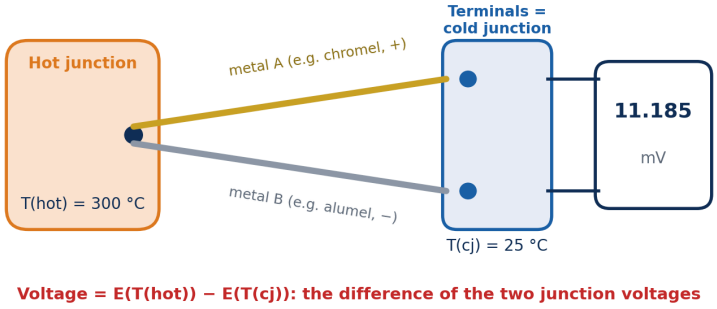


Figure 1. A Type K thermocouple at 300 °C with its terminals at 25 °C produces about 11.2 mV, the difference between the two junction voltages. E(T) is the Type K reference-table voltage at temperature T.

To recover the true hot-junction temperature, the instrument must therefore (1) measure the cold-junction temperature and add back its equivalent voltage, called **cold-junction compensation (CJC)**, and (2) convert the compensated voltage to temperature using the thermocouple's reference curve, called **linearization**.

Step 1: Choose the Thermocouple

Thermocouple types are identified by letter. Each combines a temperature range, a sensitivity (its Seebeck coefficient) and an environment it tolerates well. Figure 2 shows the range each type covers on the DI-2008, with its sensitivity near 0 °C.

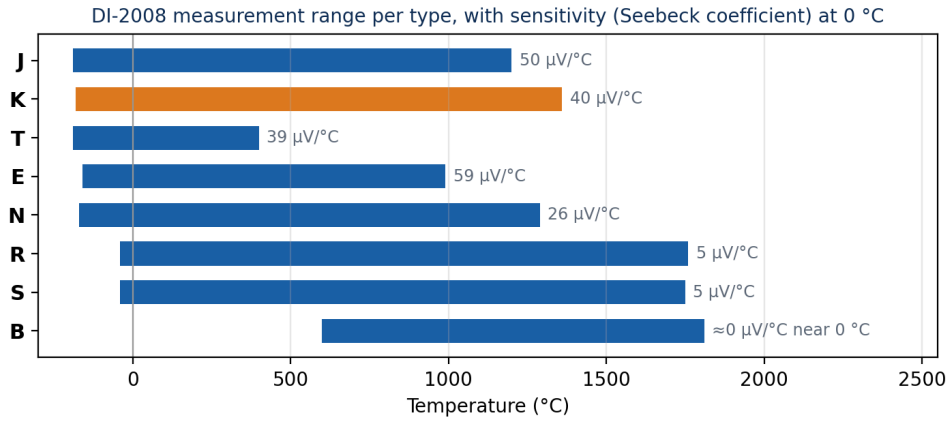


Figure 2. DI-2008 thermocouple measurement ranges (from the DI-2008 specifications) and approximate Seebeck coefficients at 0 °C.

Type	Typical use and notes
K	The general-purpose choice: wide range, good in oxidizing atmospheres, inexpensive and widely available. If nothing points elsewhere, start here.
T	Low and sub-zero temperatures, food and environmental testing. Good accuracy below about 350 °C (copper positive leg).
J	Older equipment and vacuum or reducing atmospheres. The iron leg oxidizes, so it is limited to lower temperatures than K.
E	Highest output per degree of the common types, useful for resolving small temperature changes and at low temperatures.
N	Similar range to K but more stable at high temperature, so less drift in long high-heat exposures.
R, S	Platinum-based, for high temperatures and laboratory work. Low sensitivity near 0 °C (about 5–6 µV/°C) and higher cost.
B	Highest temperatures. Output is almost zero near room temperature, so it is only usable well above ambient.

Sensor accuracy matters too. For Types J, K and N, ASTM E230 standard tolerance is ±2.2 °C or ±0.75% of the reading in °C, whichever is greater, over the applicable positive-temperature range. Special tolerance is ±1.1 °C or ±0.4%, whichever is greater. Both sensor tolerance and instrument accuracy contribute to measurement uncertainty.

Choose the wire insulation, too

The insulation on the thermocouple wire, not the junction, often sets the usable temperature. DATAQ's Type K thermocouple wire (24-gauge, beaded junction) comes with two coatings:

Coating	Max. operating temperature (insulation)	Best for
Teflon®-coated TC-KWB2-03 / -12 / -C	260 °C (500 °F)	Moist atmospheres, liquids and vapors: the insulation seals against liquid and vapor. Food, environmental, HVAC and general lab work below 260 °C.
High Temp Glassbraid TCH-KWB2-03 / -12 / -C	704 °C (1300 °F)	Hot, dry locations: ovens, kilns, heat treating, exhaust and engine surfaces. **Not for water submersion.**

Both are available in 3 ft, 12 ft and custom lengths. The DI-2008 measurement range is shown in Figure 2. For temperatures above the listed insulation rating, select a probe assembly rated for the highest temperature it will encounter. Source: dataq.com/products/accessories/thermocouple/tc_k.htm.

Practical tips: use extension wire and connectors matched to the thermocouple type all the way to the DI-2008. If you switch to copper leads at a remote terminal block, that block becomes the reference junction, and a temperature difference between the block and the logger terminals will introduce an error. Observe polarity: in the ANSI color code the **red** lead is negative. Choose an ungrounded (insulated) junction where the process or the probe sheath may be at a different potential.

Step 2: Why a Standard Voltage Logger Falls Short

It is tempting to wire a thermocouple to a general-purpose voltage data logger and scale the reading in software. That approach runs into three problems.

1. The signal is tiny

A Type K thermocouple produces about **41 µV per °C** near room temperature. On a typical ±10 V, 16-bit input, one count is 20 V / 65,536 ≈ **305 µV, about 7.5 °C** of Type K signal. To resolve fractions of a degree, the input needs millivolt-level ranges, low noise, and good common-mode rejection, because a thermocouple wire run is an efficient antenna for electrical noise.

2. No cold-junction compensation

Without CJC, every change in the temperature of the logger's terminals appears directly as a measurement error. In Figure 3, a Type K probe sits at a steady 100 °C. With the terminals at 25 °C, software that converts the measured voltage using a 0 °C reference reports about 75 °C; if the cabinet warms to 35 °C, the reading drops to about 65 °C, although nothing changed at the probe.

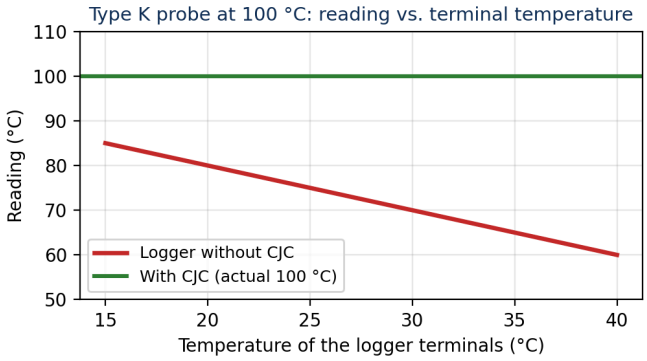


Figure 3. Reading of a Type K probe at 100 °C versus the temperature of the logger terminals, with and without CJC.

3. No linearization

The thermocouple voltage is not proportional to temperature. Scaling a voltage reading with one fixed factor, for example the 40.96 µV/°C average slope of Type K between 0 and 100 °C, is close only near the points where it was set. Using the NIST reference values for Type K, the straight-line scale reads about **8 °C high at 1000 °C**, about **20 °C low at 1300 °C**, and about **56 °C high at −200 °C** (Figure 4). Correct linearization uses the reference polynomial for each thermocouple type.

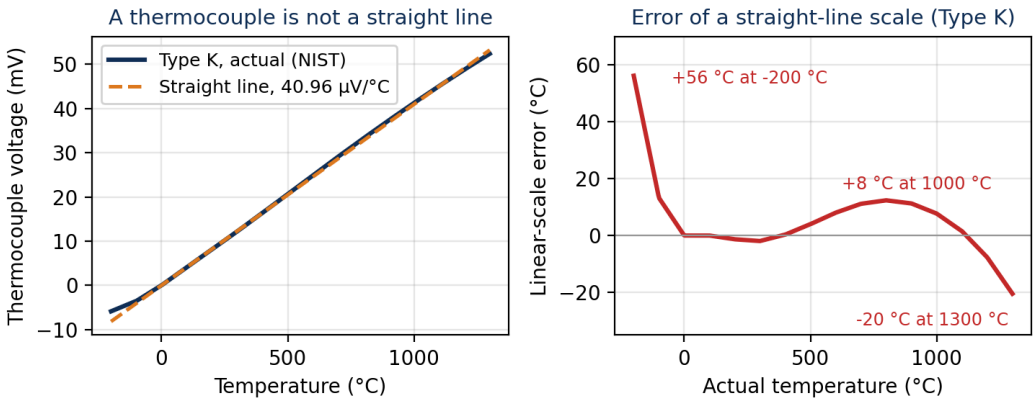


Figure 4. Left: Type K voltage (NIST) versus a straight line. Right: the resulting temperature error of a straight-line scale.

A thermocouple logger resolves microvolt-level signals, compensates for the temperature at the input terminals, and converts the corrected voltage to temperature using the reference curve for the selected thermocouple type.

Step 3: The DI-2008 Thermocouple and Voltage Data Logger

The **DI-2008** is a USB data acquisition system built for exactly this job, while still measuring ordinary voltages on the same instrument:

- **8 isolated differential inputs**, each individually programmable as a **voltage** input or a **Type J, K, T, B, R, S, E or N thermocouple**, so thermocouples and other sensors can be mixed on one unit.
- **Built-in cold-junction compensation and linearization**: thermocouple channels are reported directly in °C; no scaling is needed in software.
- **12 voltage ranges** from ±10 mV to ±50 V, **16-bit** resolution.
- **350 Vpp isolation** input-to-output and channel-to-channel, which helps limit ground-loop errors. Common-mode rejection exceeds **100 dB** from DC to 60 Hz.
- **Open-thermocouple detection**: WinDaq Studio flags a broken or disconnected thermocouple as “TC OPEN (burnout)” instead of showing a misleading value.
- USB-powered, with 7 digital I/O ports; maximum throughput is 2,000 samples/s with one channel enabled and 200 samples/s total with two or more channels enabled.
- Ships with WinDaq software; also works with WinDaq Direct in a web browser.

For thermocouple ranges and accuracy by type, see the DI-2008 specifications at dataq.com/products/di-2008/.

Step 4: Tune the Cold-Junction Compensation for Each Instrument

The DI-2008 lets you adjust **each channel** against a known temperature reference. The instrument **stores the correction**, so it stays with the unit when you connect it to another computer. The correction is an offset measured at one reference temperature and includes the probe and wiring, so verify it at the temperatures you actually measure.

Procedure in WinDaq Studio

1. Power the DI-2008 for at least **30 minutes** so the cold-junction sensor stabilizes.
2. For an ice-bath check, immerse each thermocouple's measuring junction, with the extension wire you will actually use, in a well-mixed bath of crushed ice and water (**0 °C**). Keep the DI-2008 terminals at ambient temperature. Set the sample rate to 1 sample/s, allow the readings to stabilize, and record each channel's reading. If using an electronic thermocouple calibrator, connect it to the input and follow the calibrator's instructions for thermocouple simulation and reference-junction compensation.
3. Open **Device > CJC Calibration** (shown when a DI-2008 is connected). A running scan pauses while the dialog is open and restarts afterwards; the dialog is unavailable while recording.
4. For each channel to correct, enter the **Last Reading** and the **Actual** temperature. Leave both at 0 for channels you don't want to change.
5. Click **OK**. WinDaq Studio converts the difference into a correction in 0.0625 °C steps and commits it to the instrument.
6. With the scan running, verify each adjusted channel against the reference.

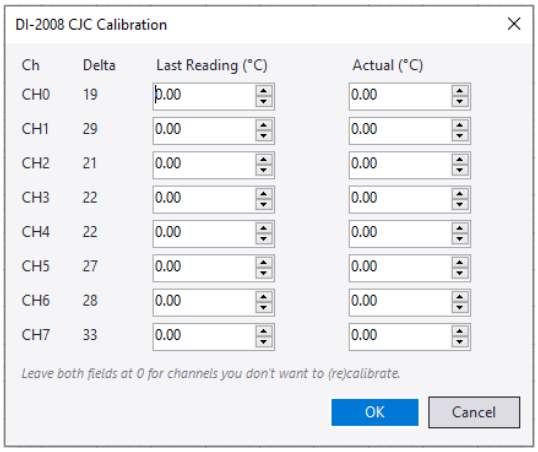


Figure 5. The DI-2008 CJC Calibration dialog in WinDaq Studio. For each channel to correct, enter its last reading and the actual temperature; leave both at 0 for the others.

Summary

- Choose the thermocouple type by temperature range and environment; Type K is the usual starting point.
- When evaluating a voltage logger for thermocouple measurements, check its input resolution, cold-junction compensation, and support for thermocouple reference curves.
- The DI-2008 provides all three on eight isolated channels, reports °C directly, detects open thermocouples, and lets you fine-tune CJC per channel with the correction stored in the instrument.