

# How to Maximize Temperature Measurement Accuracy

## INTRODUCTION

Thermocouples are the most versatile and widely used devices for temperature measurements. They are inexpensive, reliable, rugged, and can be used over a wide temperature range. These sensors require cold junction compensation and complex linearization algorithms to achieve good accuracy. The output voltage of thermocouples is very small (tenths of mV) and hence require high gain amplifiers before being fed to the ADC. Any errors and non-linearity in these areas of signal conditioning and amplification will lead to inaccurate measurements. Most test engineers are careful about the measurement errors caused by thermocouples, but not always about the measurement system. Measurement systems are calibrated regularly (typically once per year) at ambient room temperatures and are expected to perform throughout the year with the same accuracies.

What if the measurement system is placed where the temperature is not at ambient room temperature? Is the measured data accurate?

This application note focuses on this lesser known and important aspect called "Self-Calibration".

Measurement instruments will be highly accurate only when they are compensated for conditions like gain drifting, aging and temperature variations.

## PRIMARY SOURCES OF ERRORS WITH THERMOCOUPLE MEASUREMENTS

Let us look at the Primary Error Sources. They can be broadly categorized as:

- 1) Errors due to the measurement system
- 2) Errors due to the thermocouple

**CJC Errors:** CJC error is one of the single largest contributors to overall accuracy. CJC is responsible for compensating the voltage difference as cold junction is not maintained at an ideal zero temperature.



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## DID YOU KNOW?

The EX10xxA family implements IEEE-1588 precision time stamp protocol and the LXI wired trigger bus to precisely synchronize data and allow for distributed high-channel count systems.

[Find out more about the EX10xxA Series](#)



EX1048A: 48-Channel Precision Thermocouple Measurement Instrument



Find out more about how the EX1048A was used in combination with other VTI products to provide a mission-critical LXI DAQ system

The overall CJC error includes:

1. The error from the CJC temperature sensor (often a thermistor) used to sense the reference-junction temperature.
2. The error in measuring the CJC sensor.
3. The temperature gradient between the cold-junction and the CJC sensor.

Of these three errors, the temperature gradient between the cold-junction and the CJC sensor is generally the largest, and typically has the largest variation.

To overcome these errors the CJC sensor must be a precision thermistor and must be close to the isothermal plate. Furthermore, the CJC sensor to measurement channel ratio should be low, typically as low as one CJC for every four channels would give very good results.

**Offset & Gain Errors:** Since the measured voltage is in millivolts, offset errors also contribute to the overall accuracy. Gain errors are proportional to the input voltage and their impact will be felt while measuring temperatures at the edge of the supported range of the thermocouple. Measurement systems should have an auto-zero functionality for nulling these errors.

**Noise Errors:** Due to the millivolt range, thermocouples are more susceptible to noise. This could be due to the 50 & 60 Hz power line of the mounting of thermocouples on conductive materials like steel or water.

Measurement systems should have good "Low Pass Filter" capabilities for cancellation of noise caused by electrical and magnetic interference.

**Thermocouple Errors:** The voltage generated by the thermocouple is proportional to the temperature difference between the point where the temperature is measured and the point where it connects to the device. Temperature gradients across the thermocouple wire can introduce errors due to impurities in the metals, which can be largely relative to most measurement systems.

## DID YOU KNOW?

You can combine VTI's EMX series of "Smart" Dynamic Signal Analyzers and Test for IDEAS software from MAYA HTT to create a powerful, yet simple to use Noise and Vibration testing solution.

[View the Webinar to learn more!](#)

## EXAMPLE ILLUSTRATING THE IMPORTANCE OF SELF-CALIBRATION

Let us consider that the unit was calibrated at an ambient temperature of 23 °C. Typical accuracy specifications are valid within a range of +/- 5°C. Therefore, the published specifications will be valid between an ambient temperature range of 18°C and 28 °C.

Now let us consider that the instrument is presently working in a location with an ambient temperature of 33 °C. The typical Voltage Gain Stability error would be 25 ppm/ °C and typical Voltage Offset Stability error would be 2 µV/ °C.

A 10 °C rise in ambient temperature results in a 5 °C rise above the valid operating range. Therefore, we must consider the errors associated with temperature change. Calculating for the 5 °C increase, we see that:

Voltage Gain error for a 5 °C rise above the valid range equates to (25 ppm x 5) 0.0125 %.

Voltage Offset error for a 5 °C rise above the valid range equates to (2 µV x 5) 0.01 mV.

So, for just a 10 °C increase in the ambient temperature, the accuracy could be affected by as much as 0.3/0.4 °C. If there is more than a 15 °C variation in the ambient temperature, we could be seeing nearly a 1 °C error in the measured value.

## SELF-CALIBRATION

In order to achieve high measurement accuracy over a wide ambient operating temperature range, the measurement device should have the ability to perform an instrument self-calibration. VTI Instruments manufactures the EX10xxA series of thermocouple and voltage measurement instruments which has a "Self-Calibration" capability.

Self-calibration does not overwrite, modify, or take the place of the instrument's nonvolatile calibration constants generated by a full calibration or factory calibration. Instead, it generates an additional set of calibration constants that are applied to the measurement calculation after the full calibration constants. By default, self-calibration data is volatile, meaning that it is not saved through instrument resets or power cycles. This ensures that the instrument always initializes with calibration constants generated by a full calibration. This feature is particularly important when the instrument is being shared among multiple users. Each user is consequently sheltered from the actions of others.

Despite having the ability to conduct self-calibration at any time, there may be user applications that require the use of self-calibration, but demand that it create non-volatile data. The EX10xxA supports this operation as well. Once self-calibration is performed, the data can be stored to non-volatile memory through a separate function. Similarly, previously stored self-calibration data can be loaded or cleared from non-volatile memory.

Self-calibration should be conducted as often as is necessary. Especially if the ambient environment has changed significantly since the previous calibration. The self-calibration process completes quickly and does not require removal of the actual input connections, making it convenient to run often.

Similarly, self-calibration should only be performed after the EX10xxA has been allowed to warm-up from a cold start for at least 60 minutes. To protect the user, the instrument will return a warning if self-calibration is initiated prior to the completion of this warm-up period. However, it is only a warning, and it can be overridden by repeating the calibration function call. An override would be completely acceptable, for example, in cases where a) the unit is already fully warmed-up and is quickly moved from one physical location to another, or b) instrument line power is briefly lost due to a facility power outage.

Self-calibration operations can be performed through the embedded web page or instrument driver interfaces (Refer to Fig 1.). Once self-calibration is performed, the Thermocouple Accuracy (refer to the [EX10xxA Datasheet](#) for detailed accuracy Table) is valid for 7 days and over a  $\pm 5$  °C ambient temperature change. Note, however, that the unit must still undergo a full calibration at least once a year, regardless of the use of self-calibration.

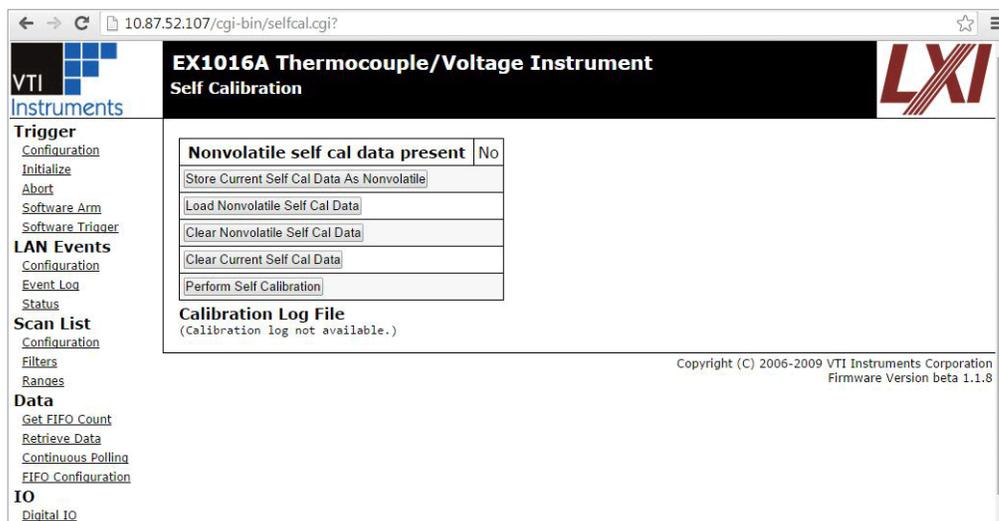


FIG 1: SELF-CALIBRATION WEBPAGE

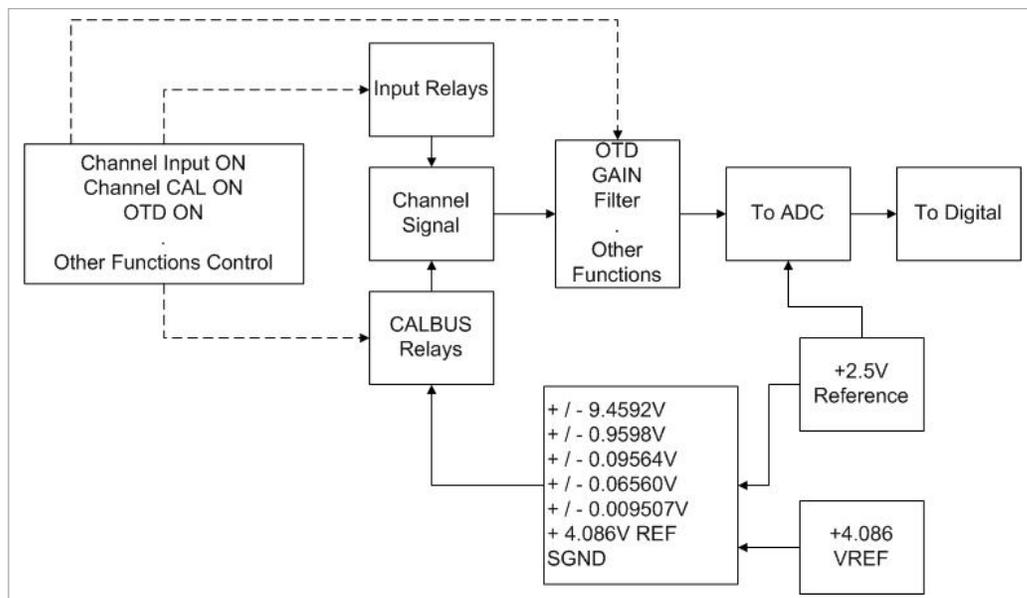


FIG 2: SELF-CALIBRATION BLOCK DIAGRAM

During Self-Calibration the input relays will be disconnected, thus disconnecting the input signals. They will then be connected to the CALBUS Relays. Self-Calibration will then load factory/full calibration data into the non-volatile memory and perform calibration for signal path, signal offsets, and CJC path. A highly accurate calibration source provides reference signals that are applied prior to analog filtering and gain circuits to compensate for drift, aging, or temperature variations. Thus, with the EX10xxA, VTI guarantees precision data, first time, every time.

## FEATURES OF EX10XXA

- Combined Thermocouple and Analog Inputs with sampling rates up to 1kSa/sec/ch.
- **End-to-End Self-Calibration** - Complete end-to-end self-calibration is provided for each signal path on a programmable basis. Self-calibration is simple and quick, and can be performed as often as desired.
- **Scalable for Synchronized High-Speed, High-Channel Count** - LXI™ compliant, features like a built-in Trigger Bus™ hardware trigger subsystem for easy integration and synchronization of multiple devices.

- **Open Thermocouple Detection (OTD)** – OTD LED for each channel that illuminates upon recognition of fault condition.
- **Cold Junction Compensation (CJC)** - Embedded isothermal input sections that are monitored by twelve precision thermistors. One for every four thermocouple channels.
- **Simplified Installation, Setup and Control** – Full LXI™ compliance makes the EX10xxA family of instruments ideal for distributed measurements throughout a facility – reducing cabling and installation expense. Connect directly to an Ethernet network using industry standard Ethernet cable and connections. With plug-and-play capability experience simplified installation and setup.
- **Channel Independence** - Each of the EX10xxA's 48 differential input channels is an independent signal conditioning path, complete with amplification, programmable hardware filtering, and continuous open transducer detection.
- **Measurement Range** – Supports all standard thermocouple types like J, K, T, E, S, R, B, N. For maximum flexibility, each channel can be independently configured with regards to its thermocouple conversion. Moreover, non-standard thermocouples are accommodated through the input of user defined thermocouple polynomial coefficients. In voltage mode it supports +/-10V.
- **Hardware Filter** - Each EX10xxA input channel can be individually configured with one of six low-pass hardware filters.
- **Input Connectors** - Mini-thermocouple female jacks as an input connector for fail-safe and easy installation for thermocouples. 50-pin D-sub connector for voltage input channels.
- **Digital I/O** - 8-channel digital I/O port for any handshake or trigger purpose.

## SUMMARY

For high accuracies in temperature measurements, especially in varying external temperatures, self-calibration is a very essential feature. With the help of Self-Calibration and other features present in the EX10xx series of instruments, VTI guarantees accuracies of +/-0.2 °C (Typical) for certain temperature ranges.