

# Advances In ULTRA-Accurate Temperature Measurement Design

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**Abstract** – Temperature is the world’s most widely measured property. Most temperature measurement instruments deployed today rely on technology architectures developed when silicon-based devices were far more costly and DOS ran computers. New approaches to analog design have changed this paradigm. This paper describes how the latest techniques in analog technology can be applied to the development of ultra-accurate temperature measurement instruments.

**Keywords** – Temperature measurement, data acquisition, multiplexers, DC/DC converters, parallel instruments, galvanic isolation, USB, LXI, Ethernet

## I. Introduction

This paper describes how the latest techniques in analog technology can be applied to the development of ultra-accurate temperature measurement instruments. These new architectures leverage the dramatic increase in performance of silicon based devices such as 24-bit Delta-Sigma A/D converters. This architecture achieves 0.05% accuracy, 150dB common mode rejection, 1000V channel-to-channel isolation, and intuitive graphical interfaces. The three key instrument capabilities are accuracy, robustness, and ease of use.

## II. Traditional Approach

Traditional approaches for temperature measurement instrumentation rely on multiplexing to keep instrument cost and instrument size manageable. This typically means that as many as 20 or more inputs are multiplexed to a single A/D converter. Thermocouple instruments typically rely on a single CJC or a single reference junction – adding many error sources not captured in an instrument’s specifications.

Multiplexing leads to cross-talk due to A/D response times and makes channel-to-channel isolation problematic. Single reference junctions make isolation nearly impossible – and provide a means for mixing common-mode signals, which results in common-mode noise being transposed into a normal-mode error.

Further, the commonly deployed 16-bit A/D converter requires an amplifier due to the low voltage level readings required for thermocouples. 16-bit A/D converters provide 300uV resolution over the typical full scale of +/-10V input. By comparison, thermocouples typically output 30-50uV per degree C temperature change. These voltage levels render 16 bit A/D converters almost useless without the addition of an amplifier. And amplifiers add measurement noise.

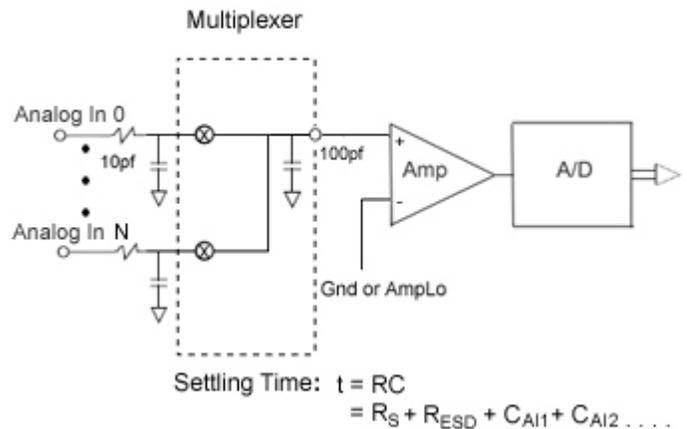


Figure 1. The traditional approach to A/D architecture uses a multiplexer to route X number of input channels through one A/D converter. This contributes to cross-talk between channels as well as the need for additional amplification.

Traditional instrument interfaces include data loggers with proprietary memory formats, push-button front panels, expensive chassis based systems, RS-232, and telnet interfaces. Today’s interface options offer easier interfacing and higher functionality.

### III. The Latest Technology

Applying the latest technology means fully leveraging the benefits of Moore’s Law in all aspects of instrument design – from analog front-end through firmware and interface to software. Moore’s Law underlies the remarkable improvement in the price/performance ratio of silicon based devices – A/D converters, DSPs, memory, ICs, etc.

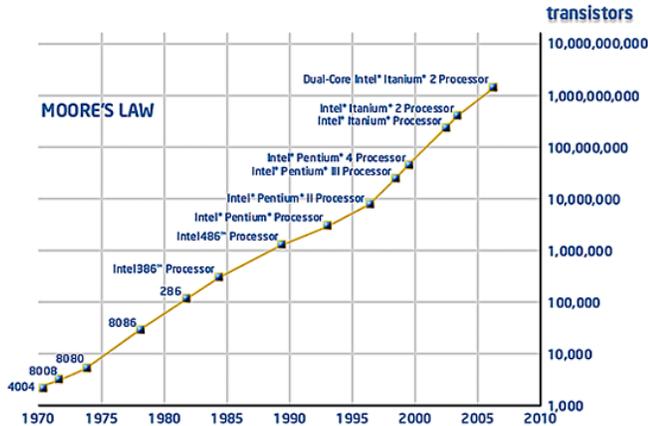


Figure 2 . In 1965 Gordon Moore of Intel famously predicted that the number of transistors would double every 2 years. “Moore’s Law” underlies the rapid improvement in price/performance of silicon based devices such as processors, memory, A/Ds, etc.

In a temperature measurement instrument this means:

- Dedicated Components/Channel so there are really a number of “Parallel Instruments” operating within the same instrument. This leads to high common mode rejection and high channel-to-channel isolation

This design approach has been deployed in the TEMPpoint instrument from Data Translation. With the “Parallel Instrument” approach, each TEMPpoint channel has the following dedicated components:

- 24 bit Delta-Sigma A/D converter with built-in anti-aliasing filters
- CJC for thermocouple instruments / precision current source for RTD instruments
- DC-DC converter
- High stability reference

### IV. 48 Parallel Instruments Design Approach

High channel count instruments typically multiplex critical components as a means of cost reduction – i.e. A/D, CJC (thermocouples), DC-DC converter, reference voltage. The limitation of this approach is that data is easily corrupted by noise in the environment.

A “Parallel Instrument” approach, by contrast, has dedicated components on each and every channel. This approach eliminates cross talk and settling errors that are associated with multiplexed approaches. Additionally, each channel is galvanically isolated from adjacent channels by 1000V (and 2000V between any 2 channels).

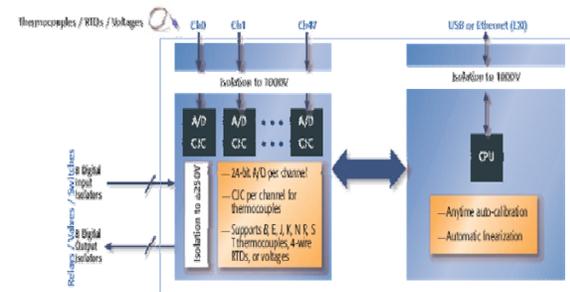


Figure 3 . Parallel Instrument design architecture deploys dedicated high accuracy components per channel and 1000V isolation channel to channel. This approach results in very high accurate measurements without cross-talk.

### V. 24-bit A/D per Channel

Deploying the latest 24-bit A/D converters on each channel leads to a number of advantages. First, the native resolution of a 24-bit A/D converter eliminates the need for an amplifier – the 24-bit A/D has 2uV native resolution operated over its nominal range compared with 300uV for the typical 16-bit

A/D. Eliminating the amplifier is significant because it removes a source of noise and drift, and the presence of amplifiers makes channel to channel isolation more difficult.

Delta-Sigma A/D converters provide the following advantages:

- Noise is reduced and accuracy is improved by oversampling the signal.
- Errors that result from aliasing and high frequency noise are eliminated.

- Excellent low-level signal-to-noise performance is provided, which improves dynamic accuracy on low-level signals.
- Excellent differential linearity is attained which ensures consistently accurate data conversion across the full input range.

Further, each A/D is calibrated for zero-point, gain, and offset on NIST traceable instrumentation at Data Translation. The zero point values are stored in ROM to enable re-zeroing the A/D at any time with a software command.

- Highest performance components such as 24-bit Delta-Sigma A/D converters.
- Engineering Units over Common Interfaces – Temperature units over USB and LXI Ethernet
- Graphical software which is easy to use and intuitive.

The result is an instrument that is accurate, robust, and easy to use – and most importantly an instrument that gives engineers confidence in their data.

#### VI. CJC or Reference Current/Channel

Thermocouples and RTDs are the most commonly deployed temperature sensors in test and measurement applications.

- Thermocouples output voltage indicating the temperature difference between the probe and instrument. A “cold junction compensation” or “reference junction” at the instrument is required to determine absolute temperature at the sensor.
- RTDs output resistance which correlates with absolute temperature at the sensor. Because A/D based instruments read voltage, a precision reference current is required to determine resistance of the RTD and thus determine temperature at the sensor probe.

Each TEMPpoint channel has a dedicated CJC for thermocouple instruments or dedicated reference current for RTD instruments.

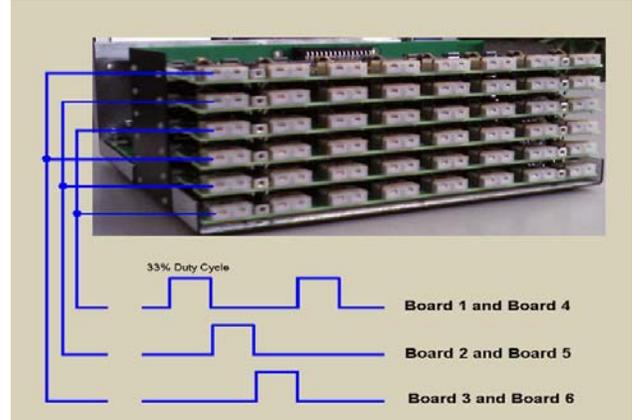
- A high stability thermistor is used for the CJC. Each CJC is painstakingly calibrated at Data Translation with NIST traceable, high accuracy instrumentation.
- Each high stability reference current is characterized and the values stored in ROM. These values are used to calculate resistance based on measured voltage at the A/D.

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#### VII. Custom DC-DC Converter

DC-DC converters are widely available off the shelf – TEMPpoint has a custom DC-DC converter network on each channel to optimize energy efficiency, maximize accuracy, and minimize heat generation.

The TEMPpoint DC-DC converters deploy a special



operating mode which powers alternating boards. This reduces peak energy requirements and minimizes heat internal generation – 48 channel TEMPpoint instruments require only 4W of power!

Figure 4. Custom DC-DC converters deploy a special operating mode powering alternating boards. This approach minimizes voltage spikes, heat dissipation, and noise. It also optimizes energy efficiency.

Minimizing internal heating and reducing power consumption to 4W improves accuracy. One of the most significant sources of error in temperature instrumentation is internal heating. This is particularly true with thermocouple instruments where the CJC or reference junction is located some distance from the A/D. Temperature differences within the instrument between these two points are a significant source of error. This is an even more significant error with the presence of an internal power supply.

#### VIII. High Stability Reference Voltage per Channel

Reference voltage sources are perhaps the least glamorous part of instrument design – they are rarely, if ever, mentioned in marketing material and largely taken for granted. They are, however, terribly important to accurate measurement results. Analog voltage measurements must be compared with some reference voltage, and the accuracy and stability of the reference voltage is critical to the overall accuracy and stability of the measurement results. For this reason, each TEMPpoint channel has a dedicated precision reference voltage design for high accuracy and high stability.

## IX. Channel to Channel Isolation

With the latest technology applied to each measurement channel front end, the integrity of the data from each channel needs to be protected from cross talk and noise from adjacent channels and from the environment. With the TEMPpoint approach, each channel is galvanically isolated to +/-500V from adjacent channels. Further galvanic isolation to the interface of +/-250V is designed in. Further, common mode rejection is 150dB.

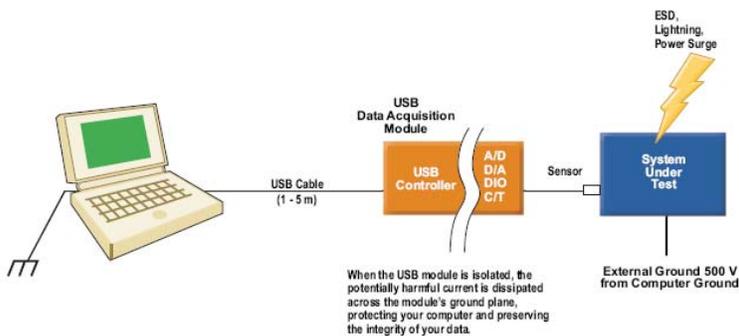


Figure 5. Galvanic isolation plays an important role in accurate measurement by eliminating the effects of cross talk and reducing noise. When using USB interface modules and instruments, galvanic isolation protects the PC from external high voltage events – such as a lightning strike or accidental grounding of a signal on high voltage.

Galvanic isolation and common mode rejection are very important for thermocouples – easily the most common temperature sensor in use. There are two reasons:

- First, consider that a thermocouple is a pair of wires which can easily act as an antenna picking up all sorts of noise. Common-mode rejection and anti-aliasing filters enable TEMPpoint to measure only the signal not the noise
- Second, a very common cause of thermocouple instrument failure is accidental grounding of a thermocouple to a high potential surface, which sends a high voltage to the instrument. With +/-500V channel-to-channel isolation, the instrument is protected from most voltage spikes. In fact, this level of galvanic isolation enables some test environments to use thermocouples instead of more expensive sensors (which are sometimes required due to this potential failure mode).

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## X. Engineering Units over Common Interfaces

Moving from the analog front end towards the instrument user, applying the latest technology enables the instrument user to get engineering units or electrical units over today's common interfaces. As applied within the TEMPpoint product line, this means that the choice of temperature, voltage, or resistance values can be reported from the instrument over the USB or LXI Ethernet interface.

USB is the obvious interface of choice for laboratory instrument deployment – an environment where a small number of instruments are deployed close to a PC. For deployment of larger numbers of instruments and applications where instruments are deployed remotely, Ethernet is the choice. LXI is rapidly emerging as the Ethernet protocol of choice for large scale instrument deployments. LXI enables engineers to quickly and easily deploy instruments remotely – and more importantly, it enables engineers to quickly and easily access remotely deployed instruments (for measurements or configuration).

Each TEMPpoint instrument converts electrical measurements to temperature.

- Thermocouple instruments support all common thermocouple types with NIST temperature look-up tables. (Supported thermocouples are types B, E, J, K, N, R, S, T).
- RTD instruments support Pt100, Pt500, and Pt1000 RTDs with European and American Alpha curves.
- Electrical units can also be reported directly – thermocouple instruments can report voltage. RTD instruments can report voltage or resistance.

## XI. Graphical, Easy-to-Use Software

The latest instrument technology today starts with the analog hardware front-end where high accuracy and data integrity is the focus. Then it passes through firmware (and interface) where easy to implement protocols must be deployed and engineering units reported. The final step is the software interface which defines instrument use/experience for the customer. No instrument is complete today without a highly intuitive, easy-to-use software interface.

Software for the TEMPpoint instrument family provides access to the full functionality of the instrument. The user can easily configure channels, scan rates, and reported units. Values can be logged to disk and viewed on a chart recorder or viewed in a digital display. Developed in Measure Foundry – a graphical application builder software package from Data Translation - this approach enables customers to easily modify the “ready-to-measure” application to fit their specific needs.

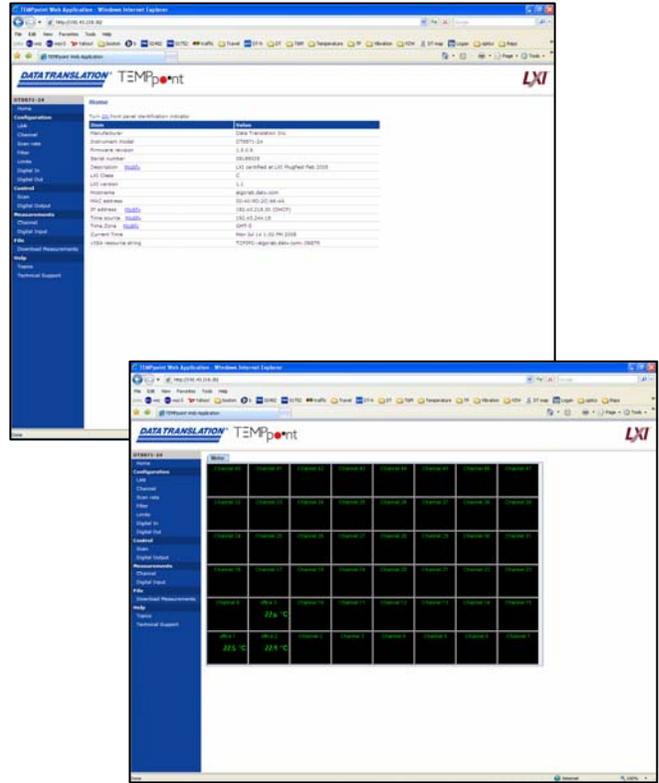
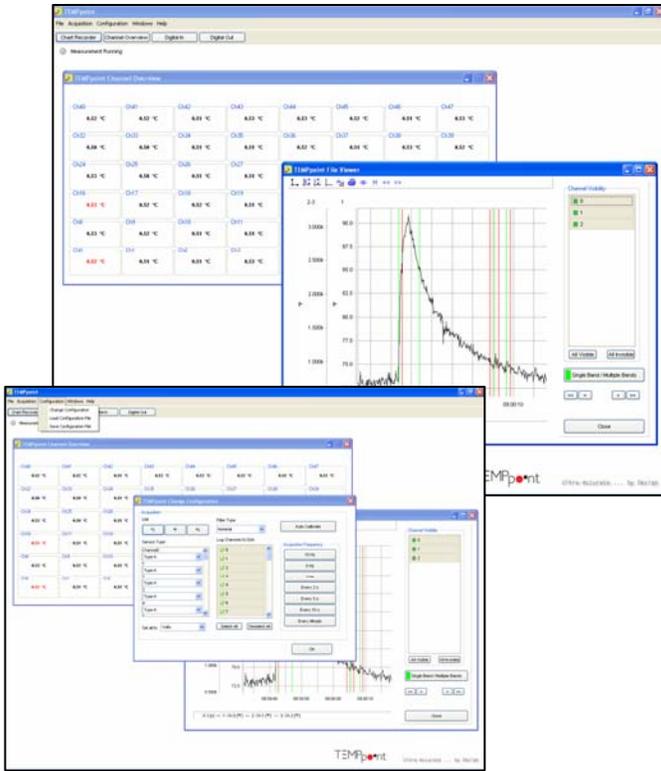


Figure 6. TEMppoint software features an intuitive graphical interface. Temperature measurements are displayed in a digital readout and in chart recorder format. The configuration menu enables the user to easily select thermocouple type, temperature units, scan rate, etc.

Figure 7. TEMppoint internal web browser enables instrument configuration over a network via a web-browser. Measurements can be observed in the channel display window, and they can be downloaded with a single click. The Ethernet TEMppoint web browser interface complies with the increasingly popular LXI standard.

Further, the LXI Ethernet TEMppoint instrument has an internal web browser which enables users to easily set up the instrument and monitor temperature readings. It has the same functionality as the desktop software – i.e. easily configure channels, scan rates, reported units, etc. The browser displays channel readings, and measurement values can be downloaded directly from the browser.

For those who will write their own software, the TEMppoint architecture is fully compliant with a wide range of software tools – IVI-COM, .NET, SCPI, etc.

## **Conclusion**

Silicon based technology marches on at a remarkable rate. Applying the latest aspects of this technology to temperature measurement enables high accuracy, high robustness measurements that give customer confident results. Applying the latest technology all the way through to the user experience at the interface and software also makes it easy to make these measurements.

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