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Temperature References for Highest Accuracy Industrial Thermocouple Measurements

Obtaining high-accuracy thermocouple temperature measurements requires instrumentation designed to minimize errors arising from thermocouple conformity, the cold junction and its reference, the A/D converter and other analog system electronics. The greatest sources of error by far, occur at the termination of the thermocouple to copper (the cold junc-tion) and with thermocouple deviation from the standard.

You can reduce thermocouple deviation from the standard using temperature reference blocks together with standards laboratory traceable measurement devices. Kaye supplies traceable temperature references and standards for this purpose. The largest error remaining stems from the measurement of the cold junction temperature.

The cold junction reference components of your measurement system limit the accuracy of your temperature data. For over 25 years, Kaye has supplied the highest accuracy cold junction temperature references available for industrial measurement and calibration applications. These include Ice Point References and Uniform Temperature References (UTR's) to facilitate cold junction compensation for multiple thermocouples.

Uniform Temperature Reference	Ice Point Reference
• Operates in temperature extremes	• Operates from 0 to 40°C
• Small errors induced with rapid changes in ambient	• Negligible effect from rapid changes in ambient
• Easily reconfigured for different thermocouple types	• Convenient for more permanent installations
• Can be installed near test article in the test environment	• Can only be installed in more stable areas of vibration and ambient, e.g., control room

For over 25 years, the Kaye UTR has proved a reliable reference standard in industrial measurement, data acquisition and calibration applications.

Deciding on a Reference Type

Determine Your Requirements.

The criteria for determining a reference type include environmental considerations, the need for flexibility and the accuracy required for a particular application. The reference equipment best suited to your application depends on the environmental conditions of your test area. In virtually any ambient temperature and vibration envelope, there is a Kaye UTR solution.

UTR's facilitate reconfiguration of T/C types. Ice point references contain matching material thermocouples between ambient and ice point and are not suitable where substantial changes in thermocouple mix will occur. Ice point references operate best in T/C installations where ambient temperature changes can be rapid and vibration is not severe. See the chart to the left for a summary of where to use Kaye's reference equipment.

A discussion of each reference follows, including how to improve measurement accuracy of your total system.

The UTR and how to reduce potential sources of temperature error.

View of a 64-channel UTR. Kaye has also supplied custom UTR's, such as 64-channel units, some with special connectors and water cooling tubes. Custom UTR's have been developed for Rolls-Royce, Arnold Air Force Base, General Electric and Pratt & Whitney.

Important Benefits of Using a Kaye UTR

- Two times the accuracy of conventional UTR's with patented UTR enclosure
- Reduce error from extreme changes in external environment
- Rugged design permits mounting in test cell environment
- Meets your measurement system requirements with a selection of traceable cold junction reference RTD's
- Proven in the aerospace industry since 1974.

The Uniform Temperature Reference (UTR)

UTR construction reduces errors induced from the environment and electrical conditions.

The UTR is a passive device without the need for external power. Its design addresses all thermal errors induced by static and dynamic ambient conditions, providing a superior temperature-stable environment.

The UTR plate is formed by potting a matrix of copper terminal blocks in epoxy inside a cast aluminum frame. Using a matrix construction technique, the UTR employs electrically isolated wafers which are metalized on two faces and soldered between the copper terminals. The wafer's thermal conductivity (approaching that of aluminum) provides excellent electrical isolation and superior thermal coupling between terminals.

Thermocouple terminations are made by screw terminal on one side of the blocks. The outputs, which are thermocouple grade copper conductors, are connected to the opposite side of the copper terminal blocks.

In addition to standard spade lug screws for wiring T/C's, Kaye offers metal oxide insulated thermocouple terminator adapters. Mounted on existing screws, these single T/C adapters eliminate the need for separate splices and strain reliefs.

Foam-filled enclosures thermally isolate the UTR plate(s) from ambient temperature changes.

Each UTR plate accommodates up to 48 channels (32 when shielding is required). A two-plate model with up to 96 channels (64 shielded) is also available.

Sources of Error in a UTR

Two major areas where temperature measurement errors can arise in a UTR are the reference RTD and the UTR plate. Each area contributes errors under static ambient temperature conditions. Additional errors are induced by dynamic ambient temperature changes. With proper design, the reference equipment minimizes these sources of error.

Reference Sensor Errors

Static errors from the Resistance Temperature Detector (RTD) are associated with how it was calibrated, how well it tracks over the ambient range and drift that may occur with aging. Dynamic errors stem from a lead/lag effect where the reference is responding earlier or later than the various cold junctions.

Tracking Errors: To a large extent cold junction temperature accuracy is determined by how closely the reference matches or tracks its theoretical curve over the measurement range. It is not unusual to see specifications which list a reference tracking error of 0.02˚ to 0.05˚C **per degree** of shift from calibration temperature. Consequently, a reading taken 10˚C from the calibration point can produce up to a 0.5˚C error.

Proper calibration techniques will minimize this error. Instrumentation that uses a quadratic fit to three temperature/resistance calibration points for the reference RTD can reduce this error to 0.10˚C over the **entire** 0 to 60˚C range.

Aging Errors: Reference RTD's that are annealed and protected from deterioration due to moisture and vibration drift no more than 0.05˚C per year.

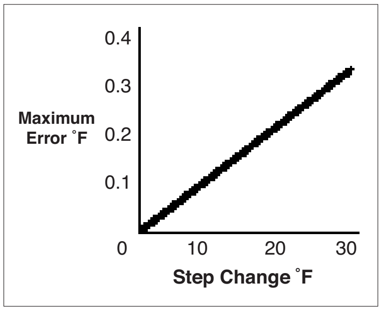


Figure 1. The maximum error (max. temperature difference between any two points) as a function of the magnitude of a step change in ambient temperature where the UTR temperature was equal to the ambient temperature before the change.

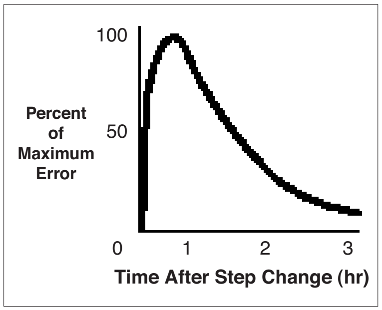


Figure 2. The relative magnitude of the maximum error as a function of elapsed time after the step change in ambient temperature.

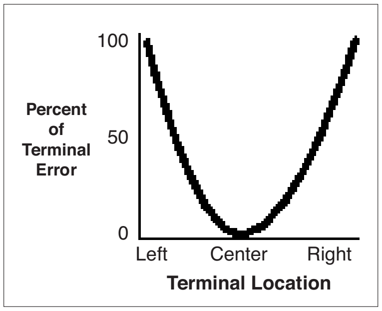


Figure 3. The distribution of error as a function of terminal location.

Non-uniformity Errors in the UTR Plate

Errors induced in the UTR plate are controlled by two parameters: thermal isolation from the environment, and thermal coupling within the plate.

Since no significant power is dissipated within the enclosure, static non-uniformity can only be produced by temperature gradients in the external environment. Dynamic errors occur due to changes in the ambient temperature.

Static Non-uniformity:
A thermal scatter error results when the cold junction terminals and their associated cold junction reference device differ in temperature because static temperature gradients are imposed on the measurement assembly.

Imbalance of the junction terminals can result if the UTR is exposed to non-uniform ambient conditions. To minimize, mount the UTR to a surface with consistent composition and in an area where ambient conditions will have the same effect on the entire UTR. Air flow past one end of the UTR, for example, will cause an imbalance.

Dynamic Non-uniformity:
In spite of the high thermal conductance between terminals on the UTR, it is possible to develop small differences in temperature between terminals due to unbalanced rates of heating or cooling.

The amount of unbalance in the relative heating or cooling rates at various points of the UTR is a function of the total rate of heat-transfer between the UTR and ambient.

Placing the UTR within an insulated enclosure, reduces the unbalance to very low levels. The principal thermal paths from ambient to the UTR include:

1. Conduction through the enclosure cover and insulation.
2. Conduction through the mounting panel.
3. Conduction through the input and output wiring.

Terminals at the edges of a UTR are thermally coupled to ambient somewhat more closely than the central terminals. The edges of the UTR have a ratio of surface area to thermal capacity which is greater than the central portion.

As a result when a UTR operates in a varying ambient temperature, the ends of the UTR will tend to be slightly warmer than the center if the ambient is increasing and slightly cooler if the ambient is decreasing. The principle heat path is from the enclosure through the insulation.

While the design of Kaye's standard UTR's have considered these error sources, UTR enclosures have been provided for particular installation requirements to optimize uniformity for specific applications. When starting the jet-engine test cell on a cold day, for example, one enclosure performs with a maximum error of less than 0.3˚C when exposed to a 25˚C rise in ambient temperature over 40 minutes.

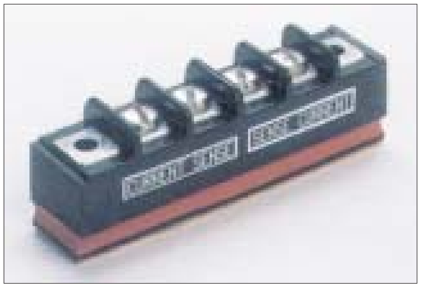
For applications where the UTR assembly is exposed to extreme ambient conditions, Kaye's water cooled UTR version provides temperature stability and uniformity.

Select the RTD You Need

Kaye offers two NIST*-traceable RTD configurations for monitoring the UTR plate temperature: RTD-20 and RTD-100. Each unit is provided with individual quadratic equations which gives temperature as a quadratic function of the unit's output.

*(National Institute of Standards and Technology.)

The Pt 100Ω RTD 4-wire film resistance configuration (RTD-100) is designed for continuous vibration environments. It is housed with 4 screw terminals for excitation and measurement. Excitation is a current of 1mA rms or less.

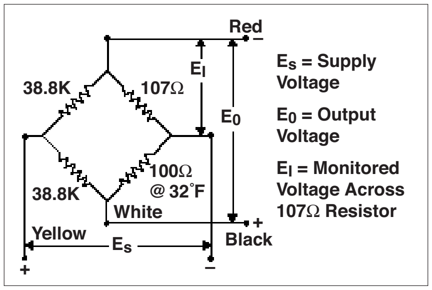


Easy to access and remove, the RTD-100 provides time-savings and convenience when you need to recalibrate the reference.

The RTD-20 is a 4-wire bridge configuration without terminals. Excitation is a voltage of 5 to 24 Volts. Two voltages of less than 100mV are monitored. The diagram to the right shows the monitored points.

Whichever RTD you choose, the exceptional thermal characteristics of the UTR's require that only one RTD be attached to each UTR plate to monitor its temperature. However, provisions have been made to mount two RTD elements on a plate when required by the customer. (See configurations listed on the back page.)

UTR Specifications	
Temperature Error	±0.1˚C at steady state conditions for any terminal to cold junction sensor
Electrical Isolation	1 GΩ channel-to-channel and channel-to-ground
Capacitance	10 pF channel-to-channel and channel-to-shield, 5 pF shield-to-ground
Mounting Dimensions	One plate configuration; 483 mm W standard rack mount panel x 222 mm H x 108 mm D (54 mm on each side of mounting surface) (19" W x 8.75" H x 4.25" D) Two plate configuration; 483 mm H standard rack mount panel; 413 mm W x 114 mm D (19" H x 16.25" W x 4.5" D)
RTD-100 (V0370) Reference Specifications	
Components	Platinum RTD, 4-wire film element (Model V0370)
Accuracy	±0.1˚C; ±0.05˚C per year
Excitation	Less than 1 mA rms
Calibration	Furnished with calibration certificate with quadratic fit over temperature range 0 to 60˚C; other ranges are available
Max. ambient temperature range without damage	–40 to 80˚C
RTD-20 (V0360) Reference Specifications	
Components	Platinum RTD wire wound element with internal bridge. Effective bridge resistance approximately 19KΩ (Model V0360)
Accuracy	±0.1˚C; ±0.05˚C per year
Sensitivity	0.0091 mV/V per ˚C
Power Requirements	5 to 24V DC
Calibration	Furnished with calibration certificate with quadratic fit over temperature range 0 to 60˚C; other ranges are available
Max. ambient temperature range without damage	–40 to 80˚C



Multi-channel Ice Point Reference System

Ice Point Temperature Reference Equipment

The K170 Ice Point Reference performs ice point referencing for up to 75 thermocouples. The user wires external thermocouples to the unit's input terminals which are in turn connected to matching internal TC's that terminate to copper at the temperature of a thermoelectrically produced ice-water mixture. Thermocouple grade copper wire is taken from ice to MIL style connectors for output. Individual pass thru shield connections can also be provided.

Discussion of Temperature Measurement Errors

The degree of temperature measurement accuracy you can achieve using an ice point reference depends on the grade of T/C wire selected and the level of calibration you use. With each calibration step described below, you can successively improve temperature measurement accuracy.

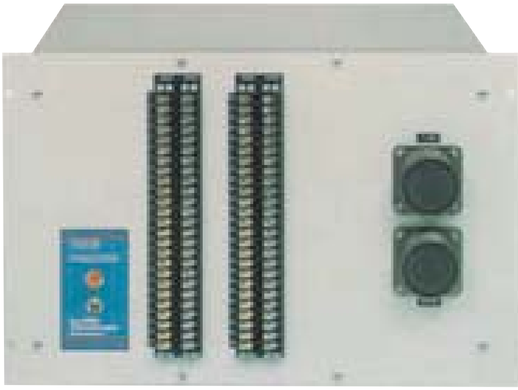
Use premium-grade thermocouple wire for consistent results.

While the difference in cost between standard and premium-grade wire may be significant, the accuracy you can attain with high quality wire is superior. Standard-grade Type N wire with a 0.75% limit of error, for example, will produce a 3˚C error at 400˚C. On the other hand, the premium grade contains a 0.4% or 1.6˚C error at the same measured temperature. The K170 uses only premium-grade wire.

Even after calibration, the premium grade wire will yield better accuracy due to its more homogeneous composition.

How to Meet Your Accuracy Needs.

Assuming the use of premium-grade wire, you can employ the following guidelines to meet your measurement accuracy goals. The example below uses Type N wire.



Method 1: At a gross level using the standard curve fit for a premium Type N T/C—no calibration performed—you can expect about a 1.6˚C error at 400˚C.

Method 2: You obtain an order of magnitude improvement or about a 0.2˚C error with a 3-point calibration of your external T/C's, independent of the K170. The 0.1˚C error from the calibration plus the 0.1˚C from the K170 equal the total error of 0.2˚C. (Assuming the K170 terminals to be at 25˚C, the difference from ice point times the 0.4% wire error equals 0.1˚C.)

Method 3: Improve measurement error further by calibrating with the external thermocouples wired to the K170. This method reduces the error to about 0.1˚C plus 0.4% of difference between the terminal temperature at calibration and at the time of taking actual data.

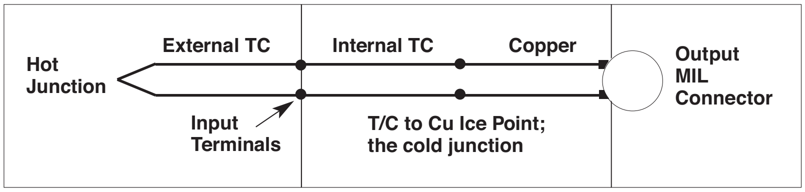
Method 4: Calibrate the internal and external T/C's separately when you need to reduce temperature errors to the lowest possible value. This method reduces the error inherent in the T/C characteristic differences between the internal and external wire, providing a total measurement error of 0.1˚C.

Perform this calibration by monitoring the temperature of a shorted terminal when the K170 has stabilized at each ambient calibration point. Kaye offers this calibration as a service.

Ice Point Reference Specifications	
Reference Temperature	0˚C
Long Term Drift	None
Stability	±0.02˚C typ. ±0.05˚C guar.
Total Instrument Error	±0.05˚C max.
Number of Channels	Up to 75
Power	115V AC, 60Hz or 230V AC, 50Hz
Dimensions	483mm W x 273mm D (19" W x 10.75" D)

Height—See table below.

Ch	*Non-Shielded*	*T/C Shielded*
6	178mm (7")	NA
12	178mm (7")	NA
24	178mm (7")	178mm (7")
36	178mm (7")	311mm (12.25")
50	311mm (12.25")	311mm (12.25")
75	311mm (12.25")	400mm (15.75")



Thermocouple circuit of the K170 with external T/C wire connected to input terminals.

Ordering Information

Uniform Temperature Reference	
Model	**Description**
	UTRs and RTD Reference specified separately.
X0280	Shielded UTR plate, 32 channels, with enclosure. Specify RTD Reference below.
X0290	Non-shielded UTR plate, 48 channels, with enclosure. Specify RTD Reference below.
X0630	Shielded UTR two plates, 64 channels, water cooled enclosure, Quick disconnect thermo couple terminals, 4 output connectors: MS 3122, MS 3126. Specify RTD Reference below.
X0670	Shielded UTR two plates, 64 channels, with enclosure, 4 output connectors: MS3122E-22-SSP. Specify RTD Reference below.
	UTRs included with one RTD Reference per plate.
X0632	Same as X0630 plus one V0360 full bridge 4-wire RTD per plate.
X0636	Same as X0630 plus one V0370 4-wire RTD per plate.
X0672	Same as X0670 plus one V0360 full bridge 4-wire RTD per plate.
X0676	Same as X0670 plus one V0370 4-wire RTD per plate.
	UTRs included with two RTD References per plate.
X0634	Same as X0630 plus two V0360 full bridge 4-wire RTD's per plate.
X0638	Same as X0630 plus two V0370 4-wire RTD's per plate.
X0674	Same as X0670 plus two V0360 full bridge 4-wire RTD's per plate.
X0678	Same as X0670 plus two V0370 4-wire RTD's per plate.
	RTD References
V0360	Calibrated Resistance Temperature Detector (RTD-20), full bridge circuit
V0370	Calibrated 100Ω 4-wire platinum element (RTD-100) in housing screw terminals.

Ice Point Reference

Model Number	*Number of Channels*	*TC Type (A)*	*Terminal Location (B)*	*Shielding (C)*	*Line Voltage (D)*	*Calibration (E)*
X0260 (K170-6C)	6	X	X	X	X	O
X0261 (K170-12C)	12	X	X	X	X	O
X0262 (K170-24C)	24	X	X	X	X	O
X0263 (K170-36C)	36	X	X	X	X	O
X0264 (K170-50C)	50	X	X	X	X	O
X0265 (K170-75C)	75	X	X	X	X	O

Column A: Specify Thermocouple Type.

# of Chs		
______	Chromel/Constantan	(E)
______	Iron/Constantan	(J)
______	Chromel/Alumel	(K)
______	Plat-13% Rh/Pt	(R)
______	Plat-10% Rh/Pt	(S)
______	Copper/Alloy #11	(SX,RX)
______	Copper/Constantan	(T)

Column B: Specify Terminal Location. Inputs and Outputs to be located on Front Panel or Rear Panel.

Column C: Specify Shielded or Non-shielded.

Column D: Specify line voltage.

Column E: Optional Factory Calibration.