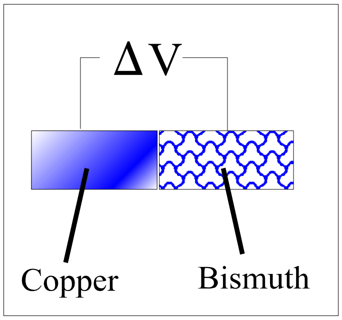
TECHNICAL BRIEF

TB-42, Thermocouple Basics

TB-42

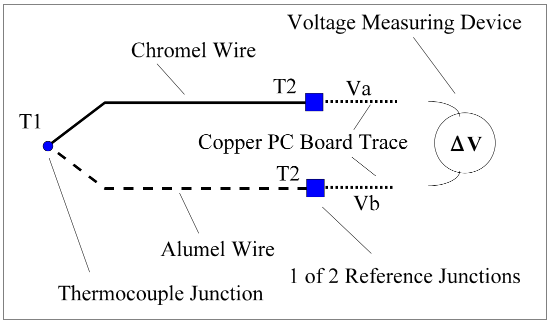
An Introduction to the Thermocouple



Early thermocouple of Thomas Seebeck

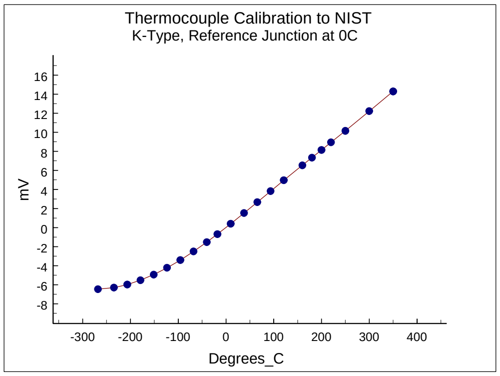
The thermocouple is the most common temperature measurement device used for instrumentation purposes. Thermocouples exhibit wide temperature range, fast response, ruggedness, low cost, and repeatability. Potential problems with thermocouples include: low output voltage, low sensitivity, non-linearity, and electrical connections. Precision instrumentation such as Techkor's ARGUS, 4000T, or 9000T measurement systems overcome these limitations enabling accurate measurements.

Thermocouple effects were originally observed by the Estonian physician Thomas Seebeck. While experimenting with a junction of bismuth and copper, he accidentally observed a magnetic disturbance on a nearby compass. Seebeck experimented with different metal combinations at various temperatures, noting relative magnetic field strengths. His work was published as "thermo-magnetism" in a 1822 paper, "Magnetische Polarisation der Metalle und Erze durch Temperatur-Differenze." Further investigations have shown the *Seebeck Effect* to be purely electrical in nature. The electrical effect is highly repeatable and naturally occurring making it useful in temperature measurement.



K-Type thermocouple connection

A thermocouple is formed by joining two dissimilar metals such as Chromel and Alumel (K-type). The thermocouple generates a voltage proportional to the temperature difference (gradient) between T1 and T2. The *law of intermediate metals* states that a third metal (copper traces) connected to the two thermocouple wires will not have any effect on the output voltage as long as the two connections are at the same temperature (T2s). In practice, the thermocouple is connected to an electronic circuit to measure the voltage potential and display the appropriate temperature. The temperature difference between T1 and T2 is directly proportional to the voltage difference V_a - V_b (e.g., 40.6 :V/°C for K-type), and the absolute temperature of the junction (T1) can be found by measuring the reference junction temperature (T2). This is typically accomplished with an electronic ice point reference circuit.



Nonlinear Thermocouple Response to Temperature

In a thermocouple measurement system, the output voltage will change due to a temperature change at the measuring thermocouple junction (desired) and also due to a change in the temperature of any parasitic thermocouples. Parasitic thermocouples are formed when the measuring thermocouple wire eventually has to be connected to a measurement circuit (copper or tin). The parasitic thermocouples require some form of temperature reference for absolute accuracy. Accurate readings can be accomplished by having only one parasitic thermocouple (cold junction) and maintaining it at a stable known temperature. Historically, the reference junction (cold junction) was placed in an ice bath. Modern thermocouple systems rely on an electronically generated cold junction reference for their accuracy. Instead of maintaining a set reference temperature for the cold junction thermocouple, the electronic compensator monitors the cold junction temperature with a solid-state temperature probe and provides a voltage to cancel out the cold junction voltage. Combining the measurement thermocouple voltage with the cold junction voltage and the cold junction compensator voltage produces an accurate temperature reading. The result is a measurement system which responds only to temperature changes in the measurement thermocouple. Systems are typically designed to produce a 0V output for a 0°C temperature. Each thermocouple style (e.g., K, J ,T, etc.) will form a different cold junction and needs to have different cold junction compensation circuitry.

Potential problems with thermocouples include: low output voltage, low sensitivity, non-linearity, and electrical connections. Typical thermocouple sensitivities are around 50 :V/°C. Extensive amplification is necessary to bring thermocouple voltages up to Volt levels. The non-linearities inherent to thermocouples can be several percent over full scale ranges. Careful attention must be paid to thermocouple calibrations to account for this nonlinearity. Connections in thermocouple systems must be made with great care. Unintended thermocouple effects from a copper and solder junction creates a 3 :V/°C thermocouple. In general, it is difficult to construct end-to-end thermocouple measurement systems with accuracies better than 0.5°C.

Thermocouples are available in a wide variety of junction styles. Each junction combination has its own temperature range and sensitivity. A few of the more common are listed below.

Style	Metal Junction	Minimum Temperature	Maximum Temperature	Sensitivity at 25°C	I	R	O	V
J	Iron-Constantan Ir/Cu-Ni	-346°F (-210°C)	2193°F (1200°C)	51.7 :V/°C	yes	yes	yes	yes
K	Chromel-Alumel Ni-Cr/Ni-Al	-454°F (-270°C)	2501°F (1372°C)	40.6 :V/°C	yes	no	yes	no
T	Copper-Constantan Cu/Cu-Ni	-454°F (-270°C)	752°F (400°C)	40.6 :V/°C	yes	yes	yes	yes
E	Chromel-Constantan Ni-Cr/Cu-Ni	-454°F (-270°C)	1832°F (1000°C)	60.9 :V/°C	yes	no	yes	no
R	Pt (13%)Rh-Rhodium	-58°F (-50°C)	3214°F (1768°C)	6 :V/°C	yes			
S	Pt (10%)Rh-Rhodium	-58°F (-50°C)	3214°F (1768°C)	6 :V/°C	yes			

where I = Inert media, R = Reducing media, O = Oxidizing media, V = Vacuum

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