Temperature Measurement

1.0 Introduction

Temperature measurement in today's industrial environment encompasses a wide variety of needs and applications. To meet this wide array of needs the process controls industry has developed a large number of sensors and devices to handle this demand. In this experiment you will have an opportunity to understand the concepts and uses of many of the common transducers, and actually run an experiment using a selection of these devices. Temperature is a very critical and widely measured variable for most mechanical engineers. Many processes must have either a monitored or controlled temperature. This can range from the simple monitoring of the water temperature of an engine or load device, or as complex as the temperature of a weld in a laser welding application. More difficult measurements such as the temperature of smoke stack gas from a power generating station or blast furnace or the exhaust gas of a rocket may be need to be monitored. Much more common are the temperatures of fluids in processes or process support applications, or the temperature of solid objects such as metal plates, bearings and shafts in a piece of machinery.

2.0 The history of temperature measurement

There are a wide variety of temperature measurement probes in use today depending on what you are trying to measure, how accurately you need to measure it, if you need to use it for control or just man monitoring, or if you can even touch what you are trying to monitor. Temperature measurement can be classified into a few general categories:

a) Thermometers
b) Probes
c) Non-contact

Thermometers are the oldest of the group. The need to measure and quantify the temperature of something started around 150 A.D. when Galen determined the 'complexion' of someone based on four observable quantities. The actual science of 'thermometry' did not evolve until the growth of the sciences in the 1500's The first actual thermometer was an air-thermoscope described in *Natural Magic (1558, 1589).* This device was the fore runner of the current class of glass thermometers. Up to 1841 there were 18 different temperature scales in use. An instrument maker, Daniel Gabriel Fahrenheit learned to calibrate thermometers from Ole Romer, a Danish astronomer. Between 1708 and 1724 Fahrenheit began producing thermometers using Romer's scale and then modified that to what we know to day as the Fahrenheit scale. Fahrenheit greatly improved the thermometer by changing the reservoir to a cylinder and replaced the spirits used in the early devices with mercury. This was done because it had a nearly linear rate of thermal expansion. His calibration techniques were a trade secret, but it was known that he used a certain mixture of the melting point of a mixture of sea salt, ice and water and the armpit temperature of a healthy man as calibration points. When the scale was adopted by Great Britain the temperature of 212 was defined as the boiling point of water. This point as well as the melting point of plain ice were used as two known calibration points. About 1740 Anders Celsius proposed the centigrade scale. It is not clear who invented the scale, but it divided the range of the melting point of ice (100) to the steam point of water (0) into 100 parts, hence ‘centigrade’. Linnaeus inverted the scale so that 0 was the ice point and 100 was the steam point. In 1948 the name of the centigrade scale was changed to Celsius.

About the time that Fahrenheit was experimenting with his liquid filled devices, Jaspeh L. Gay-Lussac was working with gas filled tubes. He concluded that at a constant pressure, the volume of the gas would expand at a particular rate for each degree of temperature rise, that being 1/267 per degree. In 1874 Victor Regnault obtained better experimental results, showing this number to be 1/273 and concluded that the pressure would approach zero at 1/273.15 degrees C. This lead to the definition of zero pressure at -273.15 degrees C, or what we now know as the absolute scale.

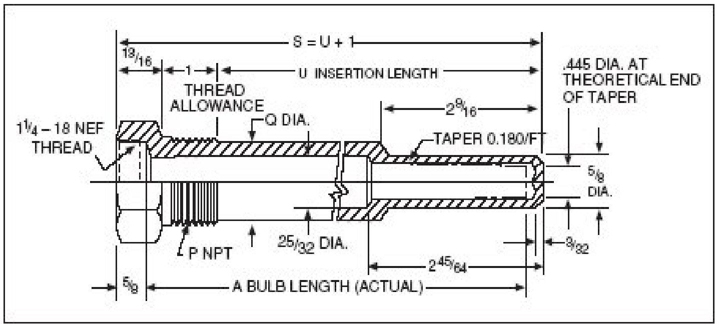
3.0 Thermometers

3.1 Glass Tube Thermometers

3.1.1 Description and construction

There are a wide variety of thermometers available on the market today. Some highly precise measurements are still done with glass thermometers. Since the properties of fluids, and in particular, mercury are well known, the only limitation to accuracy and resolution come in the form of how well you can manufacture a glass tube with a precision bore. Some manufacturers have made thermometers that have variable scales for specific uses. One such use is a process called wet viscosity. In this process it is important to know the precise temperature of the water bath. The glass thermometer is still used because of it extreme repeatability. These specialized thermometers have a bore that narrows at a particular point. In this way it can expand a two degree temperature range in the middle of its scale to approximately two inches long, allowing readings down to a fraction of a tenth of a degree C.

Many of today’s thermometers use fluids other than mercury due to the hazards of spilled mercury. These newer devices use other fluids that have been engineered to have specific rates of expansion. The draw back to these fluids is that they typically do not have the high temperature capabilities that mercury does. One major drawback of the glass thermometer is the limited pressure capacity of the glass. Also inserting the glass bulb into a pressurized fluid or chamber caused the accuracy of the thermometer to suffer. This led to the use of ‘thermowells’.



A thermowell is a closed end metal tube that sticks into the chamber or fluid, and the thermometer sits in this well, making contact with its sides.

3.1.2 Ranges and accuracy

The range of a thermometer and it reading accuracy is dependent on the size of the hole, the length of the tube and the fluid in the thermometer. Typically the smaller the reading increment, the less range it will have. As an example, a 0.1° C accuracy mercury thermometer with a range of 100°C will typically be about 600 mm long. The restrictions rest with how well the maker can fabricate a readable scale. To increase readability some manufacturers have moved to non-round thermometer bodies, The rounded corner on the reading side acts as a magnifying glass, making the liquid column show up wider, and easier to read. The round thermometer is still the standard and there are a variety of holders and seals to fit them. There are also armored sleeves to put them in that allow them to be used, but reduce the chance of breakage.

The chart below lists some thermometers commercially available. These are clearly not all the thermometers available, but a limited selection to give you some idea of what some more standard sizes and ranges are.

Low temp deg C	High temp deg C	reading Deg C	length mm	material	cost
-1	51	0.1	460	Mercury	$28
-1	101	0.1	610	Mercury	$39
-1	210	0.1	610	Mercury	$91
-10	110	1	300	Mercury	$44
100	650	2	405	Mercury	$145
200	1200	5	405	Mercury	$145
-10	500	2	405	Mercury	$81
20	750	5	405	Mercury	$15
20	930	5	405	Mercury	$70
-35	50	1	305	Spirits	$16
-10	260	1	305	Spirits	$27
0	300	2	305	Spirits	$16
20	500	2	405	Spirits	$27
-1	101	0.2	450	Spirits	$87
-1	201	0.5	430	Spirits	$92
-50	50	1	305	Spirits	$33

The accuracy of a thermometer is greatly dependent on the manufacturing process, but also can be affected by usage. As stated earlier, the pressure exerted on the thermometer bulb can affect the reading to a certain degree. Even more so the amount of immersion in the fluid will have a drastic effect on the accuracy. Most commercial thermometers have lines etched in them to show you the calibrated depth of immersion. Failure to immerse the thermometer in deep enough will cause low readings, while putting it in too deeply will cause the readings to be artificially high. Thermometers are not designed to be totally immersed in the fluid they are measuring.

3.1.3 Controls

It is possible to use the glass tube thermometer to create a control element. By placing a conductive element inside the glass tube, such that the mercury touches it at the desired operating point, and a second contact in the mercury at the bottom, you can create an electrical switch. There was a time when these were the predominant control device, but with the advent of electronic sensing elements these have been relegated to back shelves and dusty corners. There are still some applications in chemistry where these are useful, since the wetted portion, or portion that contacts the measured material, is only glass.

3.2 Bimetal Thermometers

3.2.1 Description and construction

The Bimetal thermometer was designed to be a less accurate, but more rugged measuring device than the glass thermometer. In many industrial applications there are still locations where it is desirable to know what the temperature of a fluid or device is, but it is not worth the cost of a more expensive probe and readout. Some examples of this are cooling water loops, gas grills, furnaces and ovens. In general the user would like a quick check to see what the approximate temperature is, but don't need to know to the tenth of a degree. Probably within a few degrees is more than enough for most of the applications. Bimetal thermometers are constructed of a metal sensing rod, which conducts the temperature to the thermal element, the thermal element and a scale.

The bimetal sensing element consists of a metal element shaped like a flat spring. This element is two different metallic materials sandwiched together. When a temperature is sensed by the element, the metallic components want to expand. Since they are different materials and expand at different rates, a stress in generated in the coil of material. This stress causes the element to try to wrap around itself. The indicator needle is attached to the end of this either directly or by mechanism. The motion of the spring shaped material moves the indicator. Prior to the advent of electrical thermostats, the most common use of these thermometers was in home heating systems. The thermostat consisted of a bimetallic spring such as used in the gage type thermometer and a switch, usually a mercury level switch. As the spring wound and unwound with temperature change, the angle of the mercury switch would change, closing or opening the contacts. These are still used in many homes today. Another typical location that you may find this type of thermometer is your home grill, or if you have purchased an in-oven thermometer. Many of these have exposed elements such that you can look and see how they are constructed.

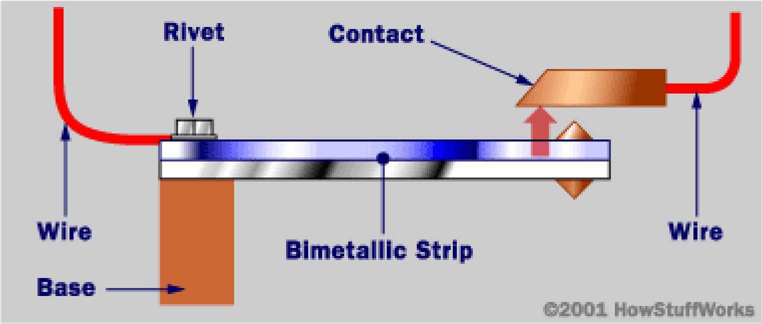
3.2.2 Ranges and accuracy

In general the bimetallic element can be extremely accurate. Home thermostats, for instance, were typically accurate to one degree or so. Today's dial type come in a wide range of sizes, temperature ranges and accuracies. A small pocket thermometer for testing air conditioning systems or cooking has a dial about an inch in diameter and a temperature range of 0 to 220 degrees F. These are generally marked off in two degree increments. Larger units with 2, 3 or even 5" dial faces will typically be accurate to 1% of the span of the unit. Ranges as high as 1000° F are available, however ranges around the 500° F value are more common.

As with glass thermometers, these devices expect a certain depth of immersion into the measured medium. There are a number of standard 'grades' of accuracy that are defined for bimetal thermometers. You will find a copy of the accuracy standards for Ashcroft® Thermometers included in the appendix.

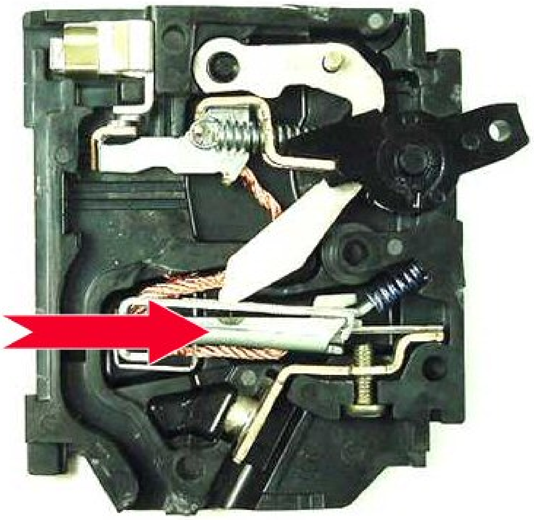
3.2.3 Controls

The earliest control systems using bimetallic elements were simple switches. These are still in use today in many places, some of which may surprise you. By placing a bimetallic element in a location where its motion can make cause a contact to be made or broken, and attaching a wire to the element as well as the contact, you can create a simple temperature switch. The figure below shows this simple configuration.



It is easy to see how such a simple switch could have many applications. This system is basicly what is still in use today in most small air conditioners and home ovens. By changing the gap to the contact, the set temperature at which it will make contact can be changed. This simple and effective switch has been used for years. Other locations where this has been use extensively, and still is, are automotive turn signal relays and electrical circuit breakers. The addition of a small heating element around the bimetal strip and forming it with a slight curve so the action is a 'snap' closure rather than a slow closure, a simple and effective timing relay was created. The amount of current flowing thru the bimetal strip controlled how quickly it heated and how fast it would trip. It is for this reason that most earlier model cars had turn signals that flashed faster with trailers attached than without. This was actually a safety feature that was designed in. If there were inadequate current flow the contact would never break, preventing the 'blinkers' from functioning. The most common reason there was inadequate current flow was that one of the lamps was burned out. The lack of the turn signals blinking was an indicator for the operator to have the turn signals serviced. Many vehicles still use this system, however they are being replaced with electronic units in newer vehicles.

Another location that the bimetal strip is heavily incorporated is the electrical circuit breaker. The circuit breaker consists of two portions. An electromagnet to detect severe overloads and disconnect the load immediately and a bimetal strip to handle small current overloads. As current flows thru the strip it deflects, releasing the holding bar and allowing the breaker to interrupt the current flow. This is also used in many motor control systems in a similar fashion.



4.0 Probes

4.1 Introduction

Following the development of the thermometer, the next step in the evolution of temperature measurement was the development of the temperature probe. In 1826 an inventor named Becquerel used the first platinum-vs-palladium thermocouple. Prior to this time all temperature measurement was done with liquid or gas filled thermometers. The invention of the thermocouple ushered in a whole new wave of development, culminating in what we know today as practical thermometry. This resistance element was the first in a series of devices that are not classified as probes or transducers. These fall into three general categories:

a) Resistance elements
b) Thermopiles
c) Semiconductor

The first category of elements is the class of resistance elements. The device Becquerel used was actually a resistance element. Today the term thermocouple is used to describe the voltage creating devices in the thermopile classification. This whole classification of probes are capable of measuring temperature, but they also require additional instrumentation or circuitry to make that measurement available to a user. This additional circuitry can come in the form of specially designed display units, generic laboratory equipment, data loggers or computer data acquisition systems. Each of he different probes require slightly different techniques and equipment and the specific techniques will be discussed in the actual transducer or probe section. In general these devices are all electronic in nature and the display will be in the form of a resistance, voltage, or current that is then scaled and displayed by the device reading the probe.

Most devices have standard tables or calibration curves that allow a user to look up the measured temperature given the electrical reading that the probe produces. A selection of these can be found in the appendix.

4.2 Resistance elements.

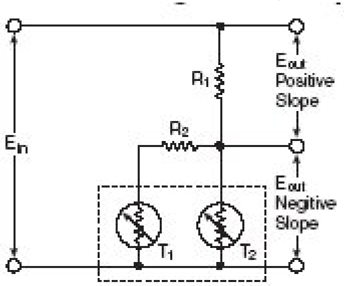
4.2.1 Introduction

Resistance elements were the first probes that came into being. Early inventors understood the relationship between temperature and the resistance of different elements. This gave rise to a series of elements called thermistors. The thermistor is a thermal resistance element that changes resistance with temperature. The amount of resistance change is defined by $\Delta R = k\Delta T$ where ΔR is the resistance change, k is the first order coefficient of resistance of the material and ΔT is the temperature change. The temperature is measured by passing a small DC current thru the device and measuring the voltage drop produced.

The second type of device in this class is the RTD or Resistance Temperature Detector. The RTD was developed after the thermistor to obtain greater accuracy. Today the RTD is one of the most accurate measuring devices available. The device operates on the basis of changes of resistance of pure metals. The Platinum RTD is the standard for high accuracy measurement elements. These devices are much more linear and accurate than thermocouples, but they respond much slower and are much more costly.

4.2.2 Thermistors

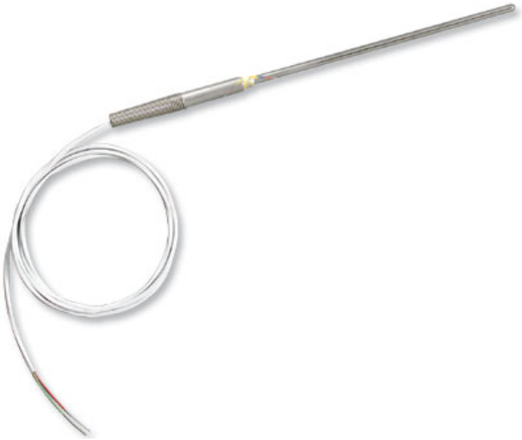
The thermistor is a device that changes its electrical resistance with temperature. In particular materials with predictable values of change are most desirable. The original thermistors were made of loops of resistance wire, but the typical thermistor in use today is a sintered semiconductor material that is capable of large changes in resistance for a small change in temperature. These devices exhibit a negative temperature coefficient, meaning that as the temperature increases the resistance of the element decreases. These have extremely good accuracy, ranging around 0.1° to 0.2°C working over a range of 0 to 100°C. These are still the most accurate transducers manufactured for temperature measurement, however thermistors are non-liner in response. This leads to additional work to create a linear output and significantly adds to the error of the final reading. A new class of thermistors have been developed that are called *Linear Response* elements. These elements actually consist of two elements that are both sensing the same temperature. Connecting these in a resistor circuit such as shown in the figure below, will allow for a linear voltage output from the probe. Kits containing the two resistors are typically available as well.



One of the big advantages of thermistors is the small size and low cost of the devices. A typical thermistor can be less than a tenth of an inch in diameter and cost around fifteen dollars in single quantities, and less than a dollar in production quantities. A linear response device will cost a few dollars more. In addition to the non-linear response, careful attention must be paid to the circuit design, or an undesirable effect called *self heating* will significantly affect the reading. Since the device is a resistor, the only viable method of measuring the sensed temperature is to apply a small known current across the device and measure the resulting voltage. If the current flow is too high, the resistor will dissipate energy in the form of heat. This heat, generated by the resistor can significantly affect the temperature that is being sensed. The total heat dissipated by the thermistor in the circuit should be 1mw/°C or less in air, but can be as high as 8mw/°C in liquid. While the resistance values for thermistors vary greatly across manufacturers and models of devices, a table is provided in the appendix showing the resistance vs temperature values for the non-linear thermistors available from Omega Engineering.

4.2.2.1 Packaging

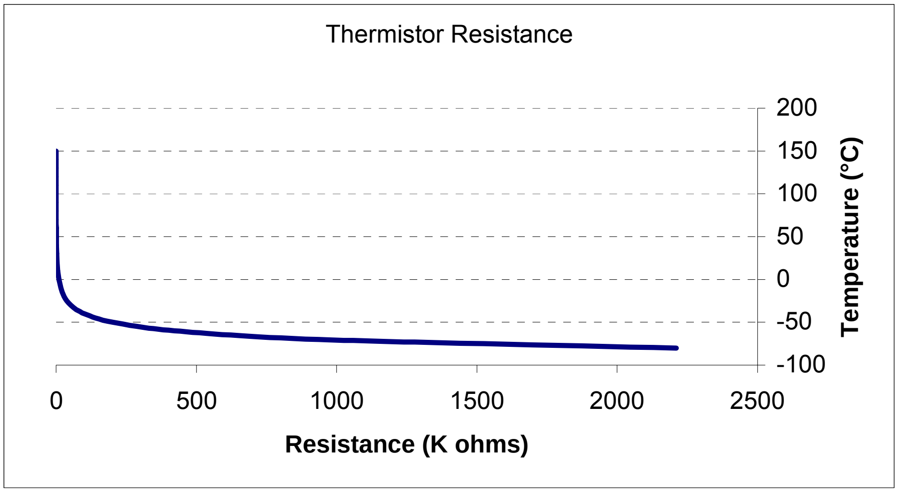
Thermistors are available in a variety of packages, but are most typically found in the bead or probe designs. Some newer units are also available in a straight surface mount configuration, but these are normally used by EE types rather than ME types. The bead type device is not particularly rugged, but is compact and inexpensive. These are mostly used to measure the temperature of air or other gases. Flat beads, encapsulated in rectangular blocks of engineered plastic are also available to glue to hard surfaces. Probes are thermistors that are encapsulated in long tubes of material, typically stainless steel. These types of probes, pictured below and in the bottom of the picture to the right, are very rugged and are designed to be inserted into holes drilled into solid materials or directly inserted into fluids.



The exact type of electrical connection can vary from exposed leads such as this to various types of connections. Regardless of the type of thermistor, some type of electronics is required to get a reading. This can be part of a circuit on a larger board or it can be a stand alone meter. Such meters are available in both readout only or control type devices. Either of these types expect a certain amount of information to properly linearize the signal and make it useful. These will be covered in greater detail in a later section.

4.2.2.2 Range and accuracy

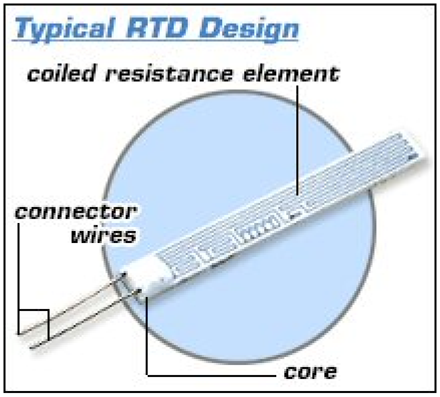
As stated earlier, thermistors can have very high accuracy. This accuracy is limited and influenced by a number of factors. The first is the actual construction of the resistor material. A thermistor can be the most accurate sensing element that is on the market today. The manufacturing tolerances can create thermistors with accuracy and repeatability as low as 0.1°C or as high as 5°C. Typically the lower cost the worse the accuracy. Another major factor is the selection of the circuitry to read the device. If insufficient current is flowed thru the device, external noise will be a problem because the signal levels will be very low. If the current is too high, the probe will start dissipating heat, artificially shifting the temperature reading. The third significant factor is the linearization of the meter. Since the thermistor is not a linear device, most meters will use some type of polynomial curve fit algorithm to create a calibrated formula of temperature vs resistance. This formula is highly dependent on the calibration done in the field. Some meters will allow you to enter several points, from which it will calculate its curve value. While the thermistor is a good choice for small measurements that do not require high precision, being done with a small processor and dedicated electronics, it is no longer considered the standard in electronic temperature measurement it once was. Temperature ranges for thermistors typically run from around -80°C to +150°C. There are some specialty units that have ranges down below and above these. The usable range for a thermistor is dependent on its ability to give reasonable resistance changes over a wide temperature change. As an example the values of resistance for the Omega 30KΩ probe range from 884KΩ at -40°C. to as low as 500Ω at +150°C on the same probe. The 3KΩ probe has a range of 2.211MΩ at -80°C to 55Ω at +150°C. I am sure you can imagine how difficult it would be to create a measurement system to read such a wide range of values, while still holding to the power dissipation limitations. For this reason most thermistors are used within a span of only about 100°C. Both of these units are ± 0.1°C, however this changes to ± 0.2°C for temperatures above 100°C.
The chart below shows the resistance curve for the 3K probe.



The thermistor is particularly useful in small temperature change environments. As an example, if you need to control a process to a very tight tolerance over a very narrow temperature range, say ± 10°C, a thermistor may be your best choice, especially in lower temperature ranges. The actual usable temperature rage of any thermistor is dependent on how its semiconductor substrate was created and what it resistance relationship is. A number of units may need to be evaluated to find one that has the desired characteristics.

4.2.3 RTD

The Resistance Temperature Detector (RTD) technically includes thermistor devices, however the term 'RTD' has come to stand for the specialized pure metal detector rather than the more generic semiconductor resistance element. These pure metal devices are highly accurate and stable over long periods of time. Unlike the thermistor, the Platinum RTD is a linear device. Its resistance changes linearly proportionally to temperature. Most RTDs in use today consist of a length of fine platinum wire wrapped around a ceramic or glass core. The element itself is very fragile and is usually placed inside a sheath material. The wire coil is made of material as pure as they can get. The purity of the metal is a factor in how accurate the transducer is. While platinum is the standard, nickel, copper, balco and tungsten are also used, but the last two are fairly rare and used only in special circumstances.



4.2.3.1 Range and accuracy

The temperature range of a Platinum RTD typically runs from -270°C to +850°C. This is a much wider range than that of the thermistor. Many available platinum RTDs have adopted the IEC (International Electrotechnical Commission) or DIN (Deutsche Institute for Normung) standard specifying a resistance of 100Ω@ 0°C and a temperature coefficient of 0.00385 Ω/°C. This works out to be 138.5 Ω@ 100°C. The accuracy and deviation fall into two classes in the standard, class A and class B. The table below shows the deviation for these two classes. As can be seen from the table the deviation of resistance values grows larger as the deviation from the base temperature grows larger. Not all probes fall into this standard. RTD probes with other base resistances, such as 500 and 1000 Ω@ 0°C, are available. These are typically used in lower temperature applications.

Temperature and resistance deviation of Platinum RTD				
Temp	Class A		Class B	
°C	±Ω	±°C	±Ω	±°C
-200	0.24	0.55	0.56	1.3
-100	0.14	0.35	0.32	0.8
0	0.06	0.15	0.12	0.3
100	0.13	0.35	0.3	0.8
200	0.2	0.55	0.48	1.3
300	0.27	0.75	0.64	1.8
400	0.33	0.95	0.79	2.3
500	0.38	1.15	0.93	2.8
600	0.43	1.35	1.06	3.3
650	0.46	1.45	1.13	3.6
700	Not usable		1.17	3.8
800			1.28	4.3
850			1.34	4.6

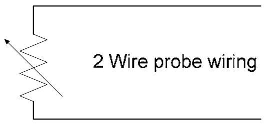
In addition to the stated deviation and accuracy data in the standard, other accuracy issues must also be considered. Like the thermistor, the device is a resistance based device. In order to read the resistance, a known DC current is set up to flow thru the device, and the voltage generated across the resistance yields the proper temperature. Too large of a current flow can cause self heating and affect the measured temperature. The self heating factor 'S' gives the measurement error for the element in °C/mW. With a given value of current (I) the milliwatt value of power dissipation can be calculated with $P=I^2R$, where R is the resistance at the indicated temperature. The temperature measurement error is then calculated from $\Delta T = PxS$. The value of S is obtained from the transducer data sheet. As an example an Omega 1PT100FR1328 has a self heating value of 0.2KΩ/mW @0°C. If you apply the temperature coefficient this equates to an S value of 770°C/W.

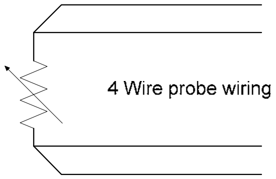
$$S = \frac{HeatingValue(K/mW)}{1000(\Omega/K\Omega)} \times \alpha(\Omega/°C) \times 1000(mW/W)$$

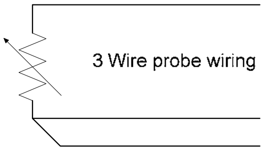
If you select a measurement current of 1µA, the temperature reading at 0°C would be .077°C high.

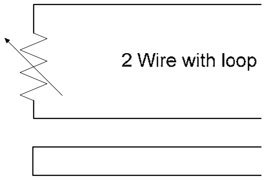
$$\Delta T = I^2 \times R \times S$$

This is an extremely small current and would generate a voltage signal of only 10mV. In order to obtain a higher voltage value a higher current would have to be selected. Selecting a current of 1ma would generate a voltage value of 10V at 0°C, but it would also add 77°C of measurement error. It is easy to see it is desirable to keep the voltage and current as low as possible to reduce self heating effects. In order to do this and keep the noise to a minimum, a variety of wiring combinations have been used to increase reliability of the reading. The combinations below are most used.







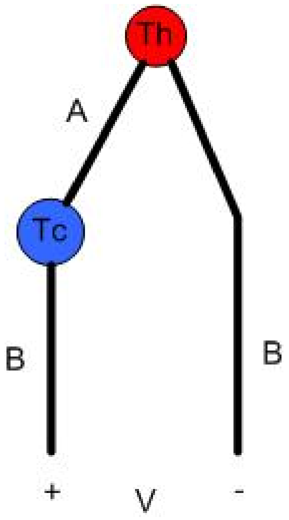


The two wire is the simplest system and used where precision is not a large issue. The three wire system is often used in bridge measurement systems. Power and power feedback feed a single end of the element improving accuracy. The 4 wire system is used where long leads are employed. This takes into account the resistance of the lead wires, allowing it to be canceled out. The two wire with loop is an alternate method of canceling lead resistance. It however, does not give the advantages of balanced power compensation that the four lead system does.

4.3 Thermopiles

4.3.1 Introduction

In 1821 Thomas Johann Seebeck found that a circuit made from to dissimilar metals with junctions at different temperatures would deflect a compass needle. He initially believed this to be due to magnetism produced by a temperature difference. He soon realized that this was caused by an electrical current created by the temperature difference. More specifically the temperature difference produces an electrical potential. This is known as the Seebeck effect. The voltage difference generated by two junctions of dissimilar metals is directly proportional to the temperature difference between the two junctions (Th, Tc). This is the basis for the thermocouple invented by Nobili in 1829. The reverse effect, the Peltier effect, was discovered by Jean-Charles-Athanase Peltier. This effect shows that when a current is passed thru a junction of dissimilar metals in a certain direction, the junction will heat up. If the current is passed in the opposite direction, it will cool down. It is actually possible to generate a low enough temperature in this way to liquefy nitrogen.



The thermopile is a group of thermocouples connected in series. While the thermocouple is used widely as a single junction device in industry, the thermopile device consists of many thermocouple junctions in such a way that thermal radiation can be absorbed by one set of junctions (the active junction). This causes a differential temperature between the set of active junctions and the reference junctions producing a voltage. These are particularly useful in measurement of thermal radiation in a particular wavelength when used with a selective wave plate or filter. The thermocouple itself has become the industry standard for most measurement applications due to its extremely low cost, ruggedness and wide range of measurable temperatures.

4.3.2 Thermocouples

The thermocouple is an extremely versatile device. Since the measurement of the temperature occurs only at the actual interface between the two metals, the measurement area can be as large or as small as one chooses. Most thermocouples today are made from two pieces of dissimilar wire, welded together in a bead. This junction can be as large or small as desired, simply by selecting the appropriate sized wire. Thermocouples can be created by physically connecting the two metals together as well as welding them. The only requirement is that the two metals be in good physical contact. If one is not careful with wire insulation, a spot of missing insulation can quickly become the new thermocouple, rather than the welded thermocouple that is inserted into the process.

Thermocouples come in a wide variety of materials. Each material pair has different characteristics of temperature range and voltage. The voltage produced by the thermocouple is always small, in the millivolt range, and is also non-linear. Deriving the temperature from the voltage produced requires that the output be matched to a lookup table or fed thru a polynomial curve formula to return an actual temperature. The table below shows some common thermocouple sets and their basic parameters.

Type	Materials	Min temp	Max temp	Min°C	Max°C
J	Iron Constantan(Cu-Ni)	0°C	750°C	0 mV	42.281 mV
T	Copper Constantan(Cu-Ni)	-250°C	350°C	-6.18 mV	17.819 mV
K	Cromel (Ni-Cr) Alumel (Ni- Al)	-200°C	1250°C	-5.891 mV	50.644 mV
E	Cromel (Ni-Cr) Constantan(Cu-Ni)	-200°C	900°C	-8.825 mV	68.787 mV
N	Nicrosil (Ni-Cr-Si) NiSil (Ni-Si-Mg)	-260°C	1300°C	-4.336 mV	47.513 mV
S	Platinum-13% Rhodium Platinum	-50°C	1768°C	-0.236 mV	18.693 mV
B	Platinum-30% Rhodium Platinum-6% Rhodium	0°C	1820°C	0 mV	13.82 mV
C	Tungsten-5% Rhenium Tungsten-26% Rhenium	0°C	2320°C	0 mV	37.107 mV

The first three are the most common of the thermocouples in use throughout industry. The most predominate for years was the Type J. This has been replaced in more recent years with the type T and K thermocouples due to the maintenance issues of the Type J iron thermocouple wire and iron connections corroding.

Thermocouples and wires come in a variety of packages and insulations to handle a wide variety of applications. The actual thermocouple is no more than a weld bead on the end of the two material wires. These can be extremely small, with the smallest thermocouple wire being around 0.001” in diameter. This can create a micro thermocouple with a response time under 0.05 seconds. The response time of a thermocouple is defined as the time it takes to reach 62.3% of an instantaneous temperature change. These microscopic thermocouples would be very useful to measure the body temperature of a honey bee, but would certainly not be well suited to measuring the temperature of water flowing at thirty feet per second in a ten inch diameter pipe. For this reason there are a wide variety of probes and sheath materials. Probes are typically thermocouples placed inside a stainless steel, or other material tube. This tube can be open on the end exposing the junction, or closed, encasing the junction. In addition this junction can be either isolated from the sheath material, or welded to it. All of these configurations are available in sheath diameters from .010” to ¼” in diameter. In addition the sheath material may be other than stainless steel. Inconel is a higher temperature material and is used where stainless steel is not satisfactory. In addition to the standard probes described above there is a wide array of cement on, bolt on and surface measurement probes. There are also armored cable units for extremely harsh industrial environments.

Thermocouple Tip Styles

Like the thermocouple probe itself, the thermocouple wire comes in a wide variety of configurations. Insulation, wire size, cable protection are all available in a variety of choices. The wire itself comes in two grades. Extension grade and thermocouple grade. Typically the extension grade is not as precisely controlled for material content, and as a result is less expensive. The thermocouple grade is more precisely controlled, and is suited for welding thermocouples. Wire size varies greatly, but most extension grade wire is between 24 AWG and 14 AWG diameter. Most all thermocouple wire is also prepared as a duplex wire. This means that there are two insulated wires inside an outer sheath. Each wire is one of the materials required for the appropriate thermocouple selected. As an example, a Type T thermocouple wire would contain one copper wire and one constantan wire. Each of these would be insulated, and then an insulating outer cover would be added. The insulation materials will vary from Polyvinyl to glass braid to Teflon. The particular combination of insulating materials is dictated by the temperature of the environment it will be in.

In addition to a variety of materials and sizes, there is a wide selection of colors. Each color corresponds to a particular thermocouple type. In duplex wire the red colored insulation is always on the **NEGATIVE** lead. The positive lead will be color coded as will the outer sheath material. The following colors are the standard indicator colors in the United States. Other color codes exist in Europe.

Type	Materials	Color	Outer cover
J	Iron	White	Black
	Constantan(Cu-Ni)	Red	
T	Copper	Blue	Blue
	Constantan(Cu-Ni)	Red	
K	Cromel (Ni-Cr)	Yellow	Yellow
	Alumel (Ni- Al)	Red	
E	Cromel (Ni-Cr)	Purple	Purple
	Constantan(Cu-Ni)	Red	
N	Nicrosil (Ni-Cr-Si)	Orange	Orange
	NiSil (Ni-Si-Mg)	Red	
S	Platinum-13% Rhodium	Black	Green
	Platinum	Red	
B	Platinum-30% Rhodium	Gray	Gray
	Platinum-6% Rhodium	Red	
C	Tungsten-5% Rhenium	White	White/ Red stripe
	Tungsten-26% Rhenium	Red	

In addition to the wires being coded with this color scheme, the connectors are also color coded the same color as the outer cover code. This allows for easy identification of the materials and wires in a system. One additional color that is common, but not in the list is white. White connectors and wire are plain copper on both, or all three, terminals for use with thermistors and RTDs.

4.3.2.1 Accuracy and range

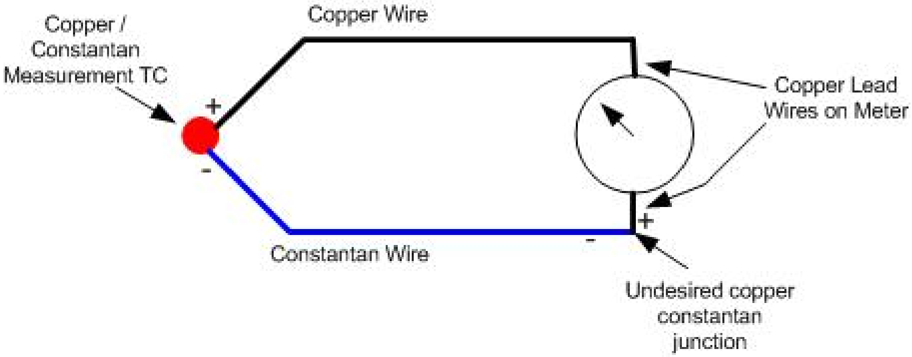
The table in the section above shows the typical temperature limits of some of the more standard thermocouple configurations. These ranges are considered to be the extreme operating range of the thermocouples. Since the thermocouple is actually just a pair of wires welded together, it is possible to use these outside the stated operating range. The physical limit is based on the melting point of the wire. There is no calibration for values outside the operating range, and field calibration will have to be used. Accuracy of thermocouples is base on the purity of the wire and the wire junction. In previous years thermocouples were welded using a mercury bath. This has been replaced with carbon block welders operating under inert gas. Each type of wire has its own limits of error based on materials deviations. There are also special wires available that have been manufactured and tested at much tighter compositions. The table below shows the standard wires available from Omega, and their limits of error.

The limits of error in this table show two values, a temperature and a percent. The temperature is the value of the reading in +/- degrees C. This is the value that should be used unless the percent of scale value is greater. The percent of scale value is calculated by the taking the measured temperature above 0°C x Percent listed in the table. As an example a Type T standard error thermocouple reading 200°C would have a calculated error of +/- 1.5°C. This is greater than the 1°C designated as the base. This means that the actual temperature that the thermocouple is sensing is 200°C ±1.5 (between 198.5°C and 201.5°C). This same thermocouple indicating a reading of 50°C would have a calculated error of 0.375°C. This is less than the 1°C base value, so the actual value of the temperature is 50°C±1 (between 49°C and 51°C).

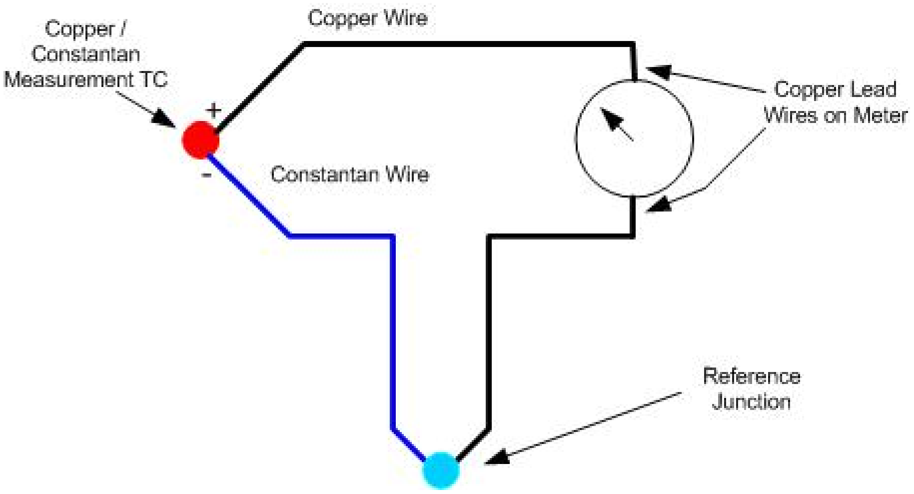
Type	Standard	SLE
J	2.2°C	1.1°C
	0.75%	0.4%
T	1°C	0.5°C
	0.75%	0.4%
K	2.2°C	1.1°C
	0.75%	0.4%
E	1.7°C	1°C
	0.5%	0.4%

4.3.2.2 Measurement.

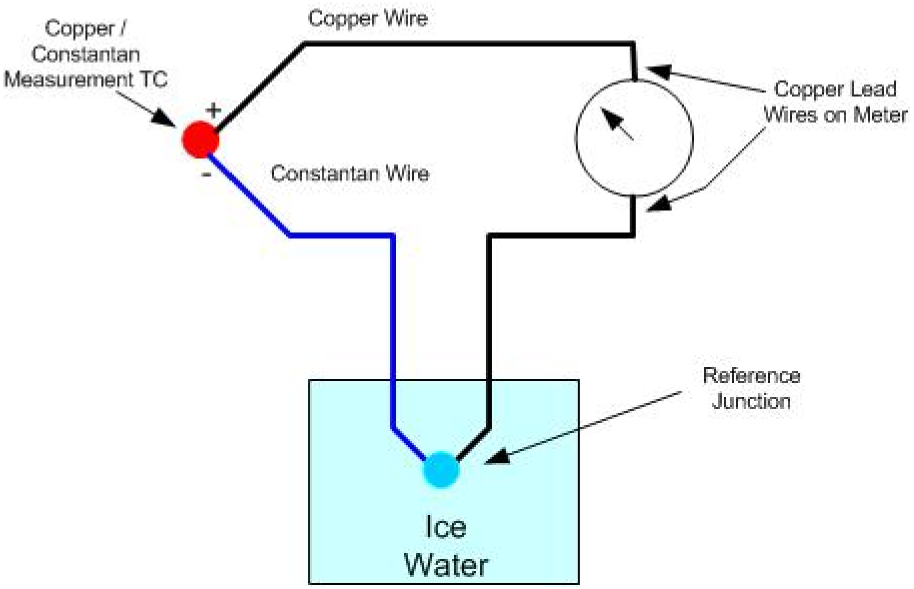
Any measurement with a thermocouple requires an understanding of how dissimilar metal junctions actually effect the measurement. Lets take the simple case of a single TC attached to a simple analog mV meter.



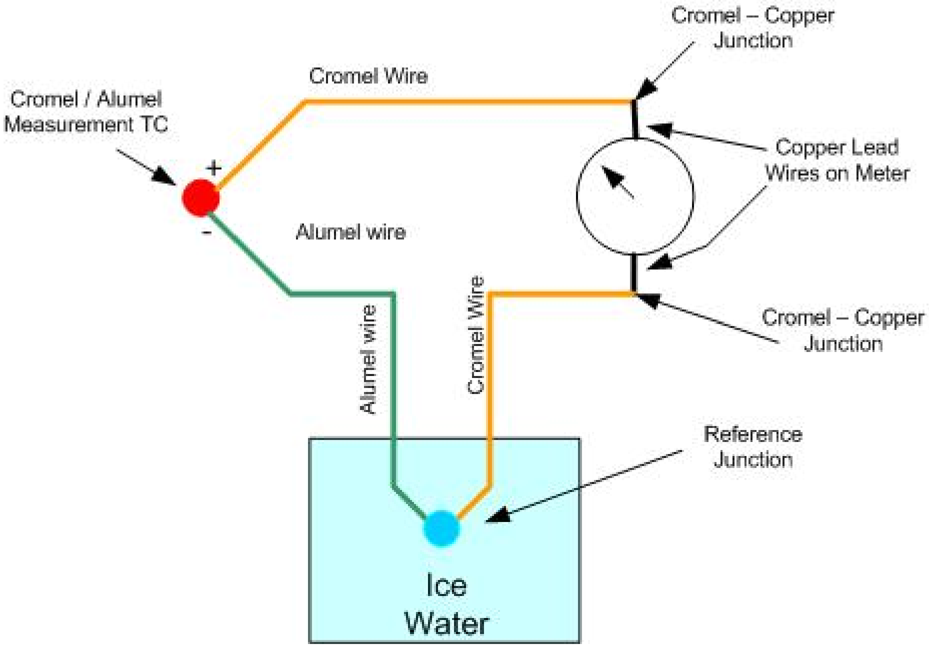
You can see in this graphic that there is a second copper – constantan junction where the meter leads connect to the thermocouple wires. This junction will be measuring whatever the temperature of the meter is. Note also that the voltage of this junction is opposing that of the measurement TC. This will case an error of approximately negative room temperature. This is solved by adding an additional thermocouple to the circuit. This added thermocouple will convert the constantan wire back to copper. Like the undesired junction the temperature of this reference junction will also buck the temperature of the measurement junction. The trick is to put this reference TC at a known value, and then add the voltage from that value back into the reading.



Looking at a simple measurement we can follow the voltage. An unknown temperature on the measurement TC is generating a voltage of 12.013mV. At room temperature of 18°C, the reference junction will generate a voltage of 0.709mV (from the table). Adding the reference voltage back to the measured voltage, we get a true reading of 12.722mV. Looking this up on the table we find that the actual measured temperature is between 262 and 263°C. It would be nice if we didn't have to worry about the temperature of the room varying while we are taking measurements, or having to add the reference voltage back in. It just so happens that if we place the reference thermocouple into an ice bath or 0°C water, that we solve both of these problems. The voltage generated by a Type T thermocouple at 0°C is 0mV. The final configuration is shown in the following graphic.



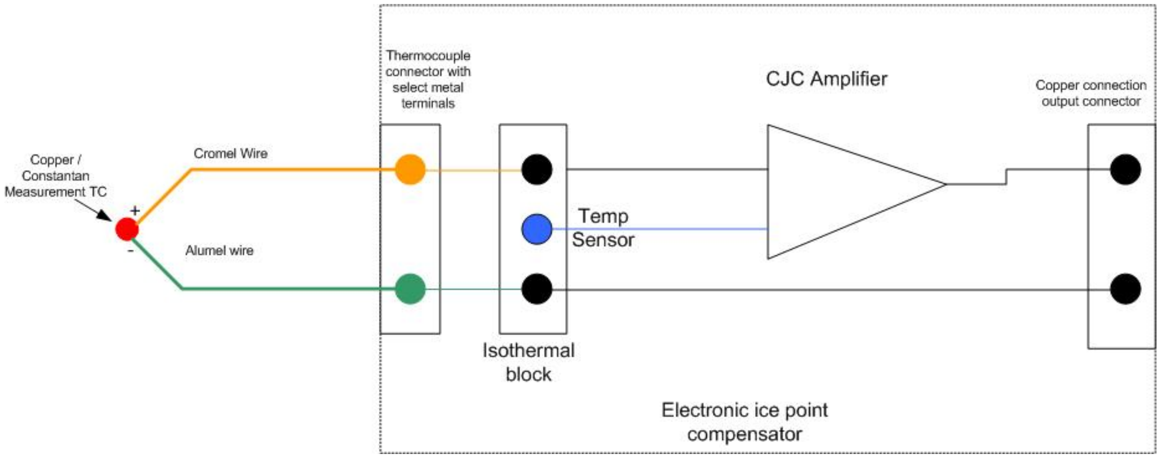
This technique works for Type T, J and K thermocouples. Other materials do not necessarily generate 0mV at 0°C and the math is still required. Thermocouples of types other than T do leave one other problem. The figure below shows the same ice bath configuration for a type K thermocouple.



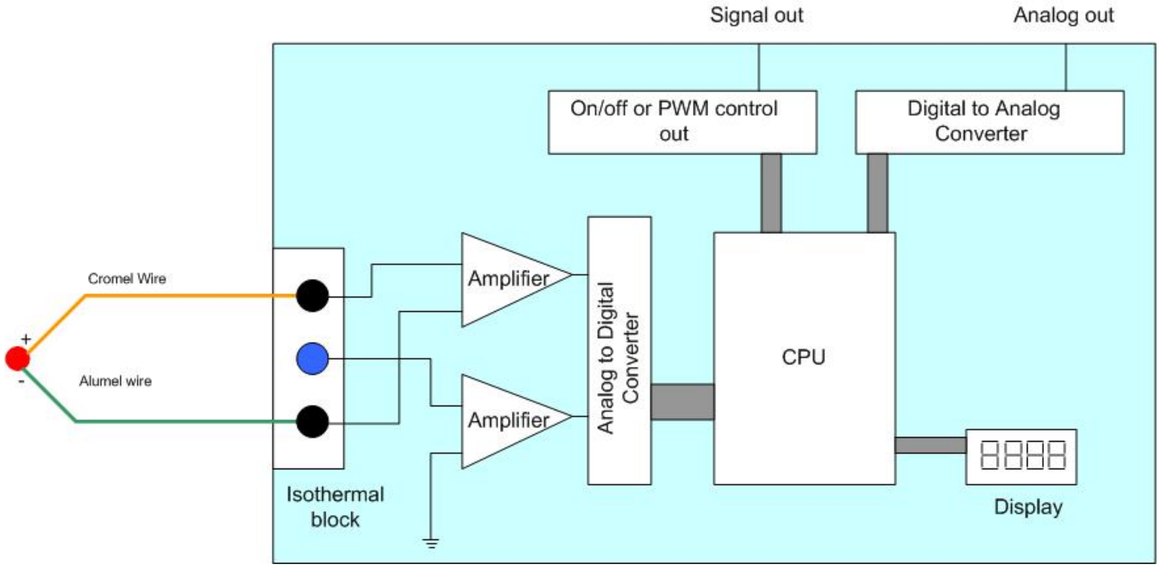
Note that there is a difference between the Type K and the Type T wiring. In this Type K wiring there are two cromel – copper junctions. If these two were at different temperatures, there would be an error induced. The normal technique for this, is to make sure both of these connections occur at or close to the same temperature. Isothermal terminal connections with both junctions placed close together minimizes error from these two junctions.

This system with the ice bath works well for short term operations with one or two thermocouples, it would be impossible to deal with several thousand ice baths in a process plant. To get around this issue, manufacturers have developed three different devices. The electronic ice bath, the electronic ice point compensator and cold junction compensation. The electronic ice point bath is little more than a precisely calibrated thermopile, holding a plate at the constant temperature of 0°C. The reference thermocouple is then attached to this plate, making it a “dry” ice bath. The electronic ice point compensator is an electronic box with a thermocouple connector on one end and a copper-copper connector on the output. The internal wiring is similar to what you see below.

This device uses cold junction compensation to convert the wire types from the special metal type to standard copper. The output connections can then be wired to any device using straight copper wire. The heart of this device is the technique of cold junction compensation or CJC. This technique involves measuring the temperature of an isothermal block where the connections to the thermocouple wire are made, and then adding the appropriate voltage to the positive lead to compensate for the voltage removed by the junction created at the isothermal block. The sensor typically used for this is a semiconductor temperature sensor, which will be discussed in detail in a later section.



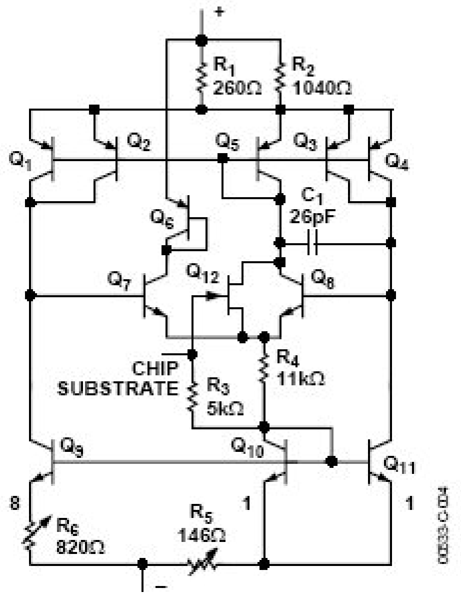
The use of CJC devices and the CJC technique has been aided by microprocessor based meters and readouts. In the early days of the technique, each TC type had to be dealt with separately. For instance, the voltage at the isothermal block generated by room temperature is different from one TC type to another. The electronics had to know which TC type it was, and how to linearize the effects. In today's meters and controllers, the isothermal block is now at the back of the meter, eliminating the dual metal thermocouple connector. In this way multiple TC types can be dealt with by simply changing the programming running in the processor. The following block diagram shows a typical controller.

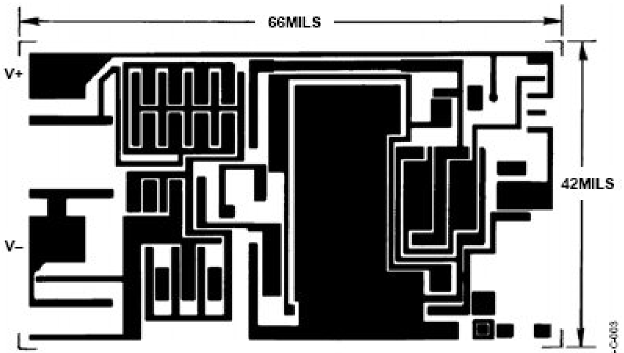


This diagram shows the basic components inside a modern temperature controller or meter. The temperature is converted to a voltage by the thermocouple. The voltage is amplified and then passed to the CPU. The CPU also acquires the temperature of the thermal block. With these two pieces of information the CPU can calculate the true temperature being read by the thermocouple. Based on this value it can display it, output an analog signal depicting that temperature in some scaled value and handle the control of some component to manipulate the process that the temperature is monitoring.

4.4 Semiconductor Probes

Semiconductor probes are the third main category of probe. Like a resistance probe, they require a current (or voltage) supply to create a reading. This is where the similarity ends. Semiconductor probes are created from a semiconductor wafer that contains a number of active circuits. Probably the most common of these are the Analog Devices AD590 Device. The actual circuit that the device consists of is shown below.





THE AD590 IS AVAILABLE IN LASER-TRIMMED CHIP FORM; CONSULT THE CHIP CATALOG FOR DETAILS

This device is essentially a temperature variable resistance device, which then converts the change in resistance to a change in current. In this particular device, the controlled current output is equal to 1µA/°K. These devices do not typically have the accuracy that an RTD would due to the manufacturing tolerances, however they are extremely cost effective for large volume applications. The devices have a relatively large initial tolerance or absolute offset, but this is countered by a very high level of repeatability. As an example, an AD590K will vary as much as ±2.5°C at 25°C, but once you know what this offset is, you can adjust for it and the device will be able to make measurements that are repeatable to within 0.1°C. It will do this for a cost of $8.95 (Single part and $6.50 / 1000), and require virtually no other circuitry before the temperature signal can be used in a larger circuit. The Dallas semiconductor MAX7500 is a fully digital implementation with a ±2°C error, and a 2 wire digital output ready to interface to small microprocessors. This devise is even less expensive at $0.65 (per 1000).

In addition to the AD590, there are literally hundreds of semiconductor devices that output their data as either a current, a voltage or even a digital bit stream. National semiconductor shows 12 current products, and Dallas Semiconductor shows 99 devices. Most of these are based on the same theory as the AD590, but in a variety of temperature ranges and output types. The simplicity of this device makes it extremely useful for electronic ice point compensation devices. While these devices are generally useful, one should take care in designing the circuitry to prevent accidental destruction of the device or some section of your system. In general it is best to get your favorite Electrical Engineer involved when using a device like this. However, a backyard experimenter can easily use one for non critical systems at home, as there are a wide variety of application notes available on the web, showing how to use these for home thermometers and such.

5.0 Non-Contact devices

The non-contact temperature sensor category includes a wide variety of primarily optical devices. These all operate on some form of radiative heat transfer measurement. In general, all things radiate heat. This heat can be detected as a radiation from the device. By measuring this radiation, you can determine the temperature of the device, not only from a distance of a few millimeters, but also from millions of light years distant. While most mechanical engineers won't really care what the temperature of a particular star in another galaxy may be, they very well may want to know what the temperature of a piece of steel emerging from a heat treat furnace may be. Running up and touching the piece of nearly molten metal was once the primary method of measuring its temperature. Today we look at its radiation signature and determine the temperature.

5.1 Single reading devices

If you are looking to cost effectively measure the temperature of a piece of steel emerging from a furnace, you probably don't care what the exact temperature of the entire surface is. A general temperature of the chunk will probably be adequate. For this we use a single point reading device. This type of device works by allowing the radiation to strike an infrared sensitive element. The radiation is directed to this element by a simple system of lenses. These lenses can focus the radiation from a small spot hundreds of feet away or a large area from very close. These systems require that you have a certain knowledge of the material you are sensing. The emissivity of the material is a number between 0 and 1 that takes into account *wavelength, waveband, reflectivity, transmissivity, absorptivity, absorption coefficient etc*. This is not the same thing as *Total Emissivity* that you learned about in your thermal radiation course. This emissivity is referred to as **spectral emissivity**. In order to get an accurate reading with a thermal radiation thermometer you will need to have this value. They are most easily obtained from tables. An Infrared Radiation Thermometer measurement with an emissivity correction is **almost always required** when one meets two simple conditions:

a) the object of interest is expected to be significantly hotter than its surroundings (and there's no other source of IR radiation which can reflect off the object into the Thermometer, like sunlight, arc lamp or quartz lamp radiation etc.) and,
b) when you are reasonably confident that you know the value of the spectral emissivity of the object (of course within the response waveband of the Thermometer).

The thermal radiation from the surroundings will be reflected from the object of measurement, except under the most unusual conditions, into the IR Thermometer. That results in the sensor reading a falsely high temperature (the magnitude of the error depends on several factors, not the least of which is the reflectivity of the object and the difference in temperature between the object and its surroundings)

If you are in a position to use this type of measurement, spend a long time reading the current literature on spectral emissivity to be sure you understand how to set your instrument or you will most certainly get temperatures that are of little or no value.

5.2 Camera Field Devices

Today's market has a wide variety of devices that fall into the camera field area. These devices "look" at objects and display the varying temperatures that it sees as an image. These devices are an adaptation of heat seeker heads originally created for military missile use. Think of the device as a digital camera, similar to what you might buy at your local discount store. The CCD element "sees" light in a variety of visible wavelengths and returns the results of these findings to a display or memory card. Those wavelengths that are close to 700nm are returned as red's and oranges, and those closer to 450nm are returned as blues and violets. Our mind sees these results and recognizes these colors. The thermal camera style device does the same thing, but in the infrared wavelength range (between 1mm and 750nm). Different systems work in different ranges. Two ranges of IR device exist, far IR (typically those wavelengths longer than 1000nm) and near IR (those wavelengths closer to the visible range than 1000nm). Both of these devices work the same way, but use slightly different detector designs in order to obtain information in the desired wavelength. The basic principle is the same as the digital camera, with the single difference that the computer chip looks at the signal from the detector grid, and converts it to a signal that the human eye can understand. In this way we can "look" at a picture of the infrared radiation being emitted by the bodies in the image field, with different wavelengths (temperatures) being displayed as different intensities or colors.

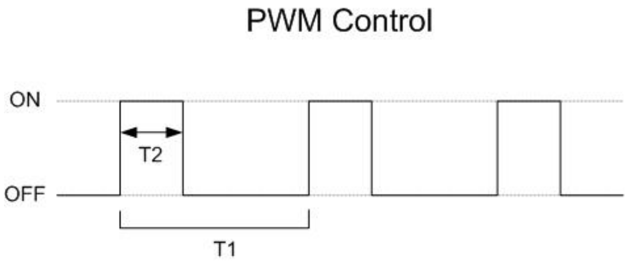
6.1 Control System Outputs

Today's market has hundreds of combinations of temperature readouts and controllers, ranging from simple single input on/off controllers to high end multiple channel PWM controllers. Selecting the appropriate controller or readout can be a daunting task, made worse by the wide variety of terminology and control functions available. The list below includes the most common selections.

ON/OFF control: This method of control is the most basic control method. The output of the control is simply switched on or off as needed to control the process. Typically the switching duration will be longer than one second. The decision on when to turn on or off is based on the control algorithm in the controller. This can be a simple proportional controller, P/D (Proportional / Derivative) or PID (Proportional / Integral / Derivative) type. The actual output element would normally be either a simple relay contact, DC pulse output or SSR (Solid state relay). Other choices can be gotten such as a Triac or SCR, but normally these are only used by EE types.

PWM Control: The PWM or Pulse Width Modulation control is used to control higher end devices. The PWM signal is a square wave output of a fixed frequency that varies the on duration of the signal or the *duty cycle*. This signal is typically a low level DC voltage signal in the rage of 0 to 5 volts or 0 to 24 volts. It can also be done in a current output such as 4 to 20 milliamps. In each of these cases the minimum value represents the off state and the high value represents the on state of the signal. This type of a signal is normally used to control valves or positioners.

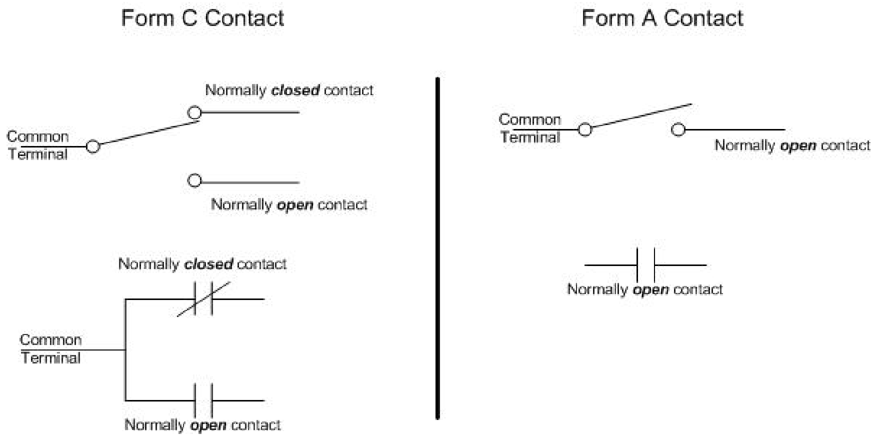
Typically the base frequency of this type of control is in the range of a few hundred hertz, but can be as high as ten or twenty thousand hertz. This frequency is dependent on the particular controller and the needs of the device under control. The ***on*** percentage of the PWM signal generates the desired valve opening, closing or position.



Duty cycle = (T2/T1) x 100
Base Frequency = 1/T1

Analog Output: The analog output control method uses a variable analog signal, such as a 0-10 volt DC, -10 to +10 volt signal or current signal (0 to 20 ma or 4 to 20 ma) as the control output. This signal is generated by the controller, and similar to the PWM control the level is proportional to the controllers command signal. As an example, if the control was generating a 0 to 10 volt control signal, a 25% output would be 2.5volts, and a 50% control output would be 5 volts. This signal is very commonly used in a 4-20 milliamp output configuration since a signal below 4 milliamps indicates a line failure and a definite control action can be taken to put the system in a failed safe mode. This signal output is always a very low power signal and additional power amplification is required at the control device end to make an actual control move.

Relay Output: The relay output control generally consists of a *form C* or *form A* relay contact. The relay contact generally has a current rating of ten amps or less, and many times less than one amp. This type of control is the least expensive of the control outputs and is only useful in and ON/OFF controller. The cycle time from ON to OFF usually needs to be something longer than five seconds to prevent premature failure of the relay. There are two ways in which the relay contact can be shown. The graphic below shows both methods for both a form A and form C contact.



DC Pulse output: This method of control output generates a DC signal that is of low power. The low power signal is fed to a control device that has the ability to turn the low power switching signal into either a high power signal or into an actual control value. For instance, using a pulse output signal for an on off control, wired to a solid state relay can allow a single controller to drive hundreds of thousands of watts of heating capacity. If this same signal is used in a PWM system, it can be used to control the position of valves the size of small cars. The signal itself tells the control device what to do, and the control device uses additional power to amplify this signal to a physical change.

SSR Output: The solid state relay output is an AC semiconductor version of a form A contact. That being it is either on or off. The solid state relay output will switch ONLY alternating current loads and will typically be limited to a maximum current of 5 amps. If larger currents are required, an external SSR is recommended. One caution to note. Solid state relays will switch only an alternating current load, and will only turn off as the voltage on the line side of the relay crosses zero. This only happens twice in each cycle. For this reason, setting an on/off time of less than 1/60th of a second will produce unexpected results. It also means that if you select a longer time and are using a PWM method of control the pulse width time (T2) will always be in 16 millisecond increments. This holds even if you are using a DC pulse width system to control an external SSR. In general it is a good idea to set your T1 time of any PWM or ON/OFF system driving an SSR to not less than one second.

Proportional control: The most basic control algorithm for control of any device, is to measure a command signal and subtract a feedback signal from it, creating an error signal. This error signal is amplified by a certain amount. This amount is known as GAIN. As the feedback signal varies farther from the command signal, the error x GAIN signal grows proportionally larger. This is the signal that generates the control output. In the case of ON/OFF control, when the proportional signal grows higher than a specified limit, the output is turned off. When the signal grows smaller than a certain amount, it turns the output on. This is a typical control method for a heater system. Using a Proportional control with a PWM or analog signal makes a more efficient system. In this control mode the amount of deviation from the set point changes the pulse width or analog output. The higher the error signal, the more the output signal is changed. This is the essence of proportional control. The output is changed proportionally to the error signal.

PD (Proportional – Derivative control): If you want to change the output signal quickly with a smaller change in the error signal you will get the system to hold the temperature some what better. The problem is that in this method the control has a tendency to overshoot, or raise the temperature higher than desired because it is heating faster to get to the set point faster. The rate of change of the feedback signal is known as the derivative of the signal. If the feedback signal deviates too quickly, there is a chance we will overshoot the desired value. By taking the rate of change of the signal into account we know we need to slow down the control output some to reduce this. The derivative of the feedback is subtracted from the error to minimize this. The new control algorithm would look something like:

(Command – feedback) * PropGain – Derivative (feedback) *DGain

PID (Proportional – Integral – Derivative): The PID control takes the PD control one step farther. Since the PD controller can actually settle at a set point different than the desired set point, due to the derivative action if the proportional gain is too low, we need to add an additional element to make sure that it gets there. The derivative action only works while the feedback is changing. If the proportional gain is not high enough the system will happily settle some place near, but not at, the desired control point. An integral is a sum over time. In this case it is the sum of the errors over a period of time. If the system has settled at a point below the set point, for instance, there will be some remaining error signal (command – feedback). Even if this error is small, since the integral is a sum over time, the integral value will begin building, and over time grow larger. If one were to add this new term to the existing control algorithm we would see something like the following:

$$(command - Feedback) \times PGain - d(feedback) \times Dgain + \sum_{T}(Error)$$

As time passes the sum of the error grows until the output is forced to move, calling into play the derivative term once again. The integral value is generally entered as a time value for it to sum over. This number is usually small, some number of seconds or shorter depending on the process.

A. Transmitters and readouts

In addition to controllers, there are a wide variety of devices that fall in the category of transmitters and readouts. These devices are placed in close proximity to the transducer and an signal is output that is capable of being used at varying distances from the transducer. The three most common transmitter outputs are:

- Digital
- Current loop
- Voltage output

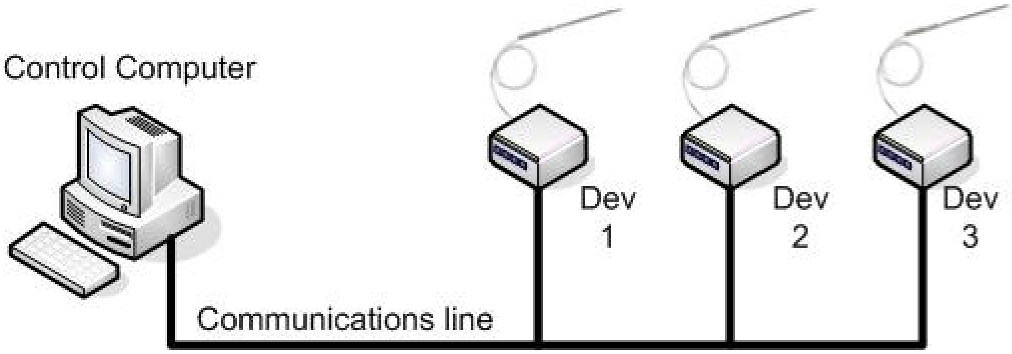
Each of these outputs have their advantages and disadvantages. When selecting an appropriate transmitter the two main criteria that need to be considered are the distance and environment being traversed, and the type of device receiving the data on the other end of the line.

6.2.1 Digital output transmitters.

Digital output transmitters are a class of devices that read the analog signal from a transducer and convert it to a digital data signal that can be sent over a data transmission wire to a remote system. These vary greatly in complexity and also cost. While these are the most expensive of the transmitter series, they are also the most flexible. The two primary transmission protocols are multi-drop and Ethernet. In either case the analog data must be converted to a digital format. This is typically done with a small embedded processor system and an analog-to-digital conversion chip. In some systems this A/D chip is embedded in the processor chip as well. Both of these systems require a significant overhead in additional circuitry for the communications, causing the price to be significantly higher than other methods.

6.2.1.1 Multi-drop

Multi-drop transmission systems use a set of wires that are capable of connecting more than one transmitter at a time. The diagram below shows a simple multi-drop system with three temperature devices and transmitters and a single control computer.

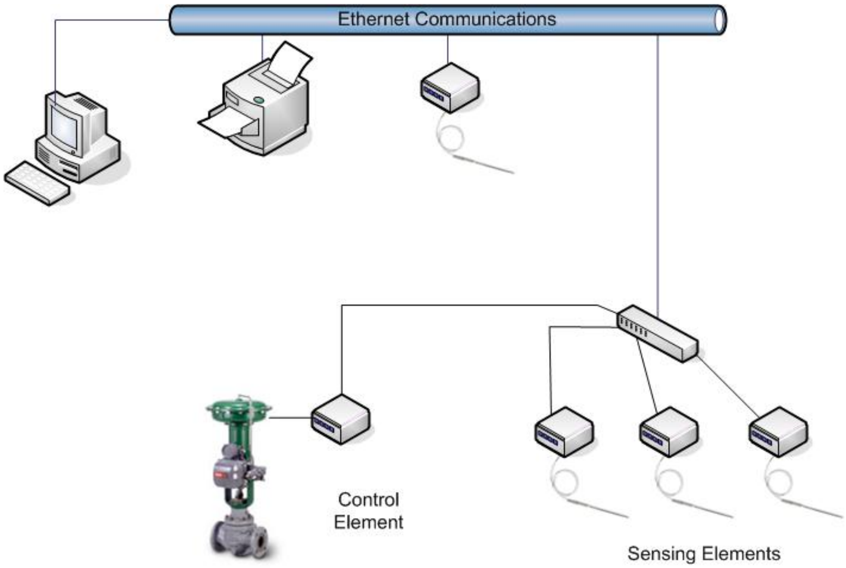


In this diagram you can easily see that the control computer can talk to and take data from a number of devices. While in theory you can have any number of devices on the line, the practical limit is 128 devices. The devices communicate with the computer in a differential voltage mode format to reduce the effects of noise on the communications lines. The two most common formats for this are RS-422 (4 wire cable) and RS-485 (2 wire cable). Neither of these should be confused with RS-232, which is the single point to point communications port found on most computers. Both RS-422 and RS-485 communications require a special card or converter for the computer to work with it.

There are practical length limits to both of these forms as well. It is possible to use up to 4000 feet of cable with a maximum data rate of 56 kilobytes per second data transfer rate. For higher data rates lengths of less than 1500 feet are recommended. Both formats are considered a polled format. This means that the computer must ask each device "what is your reading" and the device will return "my current reading is xxx". Some smarter devices can be programmed to save readings at a particular interval, say once each second. The computer can then ask for all of its data, which it then can erase to make room to save more. A typical RS-422 single reading device will cost around $300.

6.2.1.2 Ethernet devices

The newest entry into the market is the class of Ethernet devices. The incorporation of distributed computing has opened the door to distributed control systems in process plants and factories. The ability of Ethernet to support thousands of devices, and to have a significant amount of intelligence at the control locations, make this a very useful technology for large scale plants. The diagram below shows a simple Ethernet network system.



In the Ethernet system the computer can remotely take data from a wide array of sensing elements, and control an equally wide variety of elements. Some transmitters will be relatively unintelligent, just responding to a few simple commands and returning its data, while other can be programmed with control loops and complex analysis routines before ever passing their data back to the main control computer system. This vast flexibility allows for a wide variety of options, but at a cost. A National Instruments Compact Rio system with 4 thermocouple inputs, 4 RTD inputs and 4 current output control signals will cost nearly $3500.

6.2.2 Current output transmitters

The most common analog style transmitter is the current output device. This device will convert the signal from the probe into a scaled output that is transmitted on a 4 to 20 milliamp output. In a typical transmitter system, the transmitter reads the device input and calculates what the appropriate scaled output should be. As an example, a 0 to 500°F Temperature input would be scaled from 4 to 20 ma. This means that a temperature input of 100°F would be transmitted down the wires as a current of 7.2ma.

Current loop systems work over long wire runs, up to 10,000 feet, and are fairly immune to noise induced on the wires. They are also fairly economical. A simple linear current transmitter from Omega will cost around $100 each.

On the receiving end the computer must convert this signal back into something it can use. The most common method is to flow the current thru a precision resistor and measure the voltage generated across the resistor with a data acquisition card.

6.2.3 Voltage output transmitters

Most voltage output transmitters are intended for fairly short distance use. The lines are very susceptible to noise and are useful only over short distances. The most common use for these types of transmitters are from a readout in a control room environment to a data logging computer. This provides the operator with a visual reading of the temperature, as well as providing a scaled output to the computer for processing. In some installations, the computer is the only device seeing the data, and based on that data, will display messages or values to the operator. These transmitters and readouts are useful and range from a little over a hundred dollars to several hundred dollars. Voltage mode transmitters and outputs are extremely susceptible to induced noise, and should only be used in electrically quiet and short distance (less than 50 feet) applications.

Temperature Experiment

Purpose:

This experiment will give you a basic understanding of how the most common temperature devices work, and provide you with an opportunity to compare the output of a variety of temperature probes and devices.

Equipment:

The following equipment is required:

1. Hot plate with stand
2. Beaker of cool water
3. Ice point unit
4. Thermocouple connector box
5. RTD readout box
6. MicroVolt meter
7. Ohm Meter
8. Glass thermometer
9. BiMetal thermometer
10. thermocouple (x2)
11. RTD Probe
12. Thermistor Probe

Setup:

1. Set up the hotplate with the probe stand on the table.
2. Place the beaker of water on the hot plate under the probe holder
3. Insert the glass thermometer until it is immersed to the proper depth. **Be careful not to force the thermometer in its fitting. Loosen the fitting by hand and slide the thermometer up and down as needed and then tighten the fitting finger tight!**
4. Insert the bi-metal thermometer at least two inches into the water.
5. Insert the RTD into the water and connect its cable to its readout.
6. Insert the Thermistor into the water and connect it to the ohm meter.
7. Insert one thermocouple into the water. Connect it to one of the two TC connectors on the junction box.
8. Insert the second thermocouple into the electronic ice bath and connect it to the second TC connector on the junction box.
9. Connect the output of the junction box to the microvolt meter.

Procedure:

1. Take an initial reading from each device. Compare the readings from the thermistor, RTD and Thermocouple to the theoretical values for the temperature indicated by the glass thermometer. Use the charts provided in the appendix to determine these values. If the value you have is not close to what your expected value is, check your wiring and seek assistance.
2. Start the water heating by turning the hot plate on to its maximum setting.
3. Record data from each device at regular intervals from the current temperature to 200 degrees F. on the glass thermometer.
   You can choose your own interval, however, the more data you get the better your graphs will be. Once each five degrees on the glass thermometer should be an adequate amount of data.
4. Once you have reached 200°F, turn off the hot plate and allow the water to cool before touching any of the probes or the beaker.
5. Once things have cooled, dump the hot water out. You are now done with the experimental portion.

Analysis and results:

1. Taking the data you have compiled, convert the resistance readings from the RTD into temperature readings based on the provided chart. Make sure to interpolate the readings that fall between values on the chart.
2. Create plots of the following using the temperature values from the RTD as your known X axis.
   a. Plot the glass thermometer and the BiMetal thermometer temperature vs. the RTD Temperature.
   b. Plot the Thermocouple mV and Thermistor Ohms vs the RTD Temperature.

3. Answer the following questions:

   1. Compare the plots of the glass thermometer and BiMetal thermometer. What conclusions can you draw from these plots?
   2. Looking at the plot of the thermocouple, what things of significance do you notice that might be important to using it for temperature measurements?
   3. Looking at the plot of the thermistor, what general shape is the plot? What conclusions can you draw for its usefulness in taking temperature measurements.
   4. Of the probes discussed in the reading, select which probe and control method you feel would be the best solution, and why. Be sure to include any pertinent details to support your opinion.

4.1 Hot oil is flowing in a 4” diameter pipe at 30 gallons per minute (maximum temperature 450°F). This signal will need to be read by a computer in a control room 1500 feet away from the measurement point. It is one of only 20 readings to be taken in the plant and none of them are over 1500 feet from the control computer.

4.2 Water is being mixed in a 5000 gallon vessel with a number of chemicals. The average temperature of the water in the mixing vessel must be maintained at 150°F (±1°F). There are an adequate number of heaters in the vessel to raise the temperature at 10°F per minute when turned on full power, and are connected thru a set of DC driven SSR’s.

4.3 A Pre-heat furnace is being installed to treat logs of aluminum 6” in diameter and 10’ long prior to being moved into the extruder. The furnace is segmented 5’ long sections, and is made up of 10 sections. Each section has a variable control valve (4-20ma) to control the flow of natural gas to the burners. The temperature in each segment must be maintained at a value of 400°F to 850°F (±10°F)depending on the segment.

4.4 A freeze drying process uses liquid nitrogen to maintain the temperature in a chamber. The desired temperature is -100°F ±2°F. The control valve is a single on/off solenoid valve.

4.5 A hot plate press has heaters embedded in it to heat the plates. The temperature needs to be adjustable from 100°C to 300°C. The plate is 4’x4’ and exposed to the air. There is on heater installed in each 1’x1’ chunk of the plate.

Appendix
A

AD590 Data sheet (Page 1)

ANALOG DEVICES

Two-Terminal IC Temperature Transducer

AD590

FEATURES

Linear current output: 1 μA/K
Wide temperature range: −55°C to +150°C
Probe compatible ceramic sensor package
2-terminal device: voltage in/current out
Laser trimmed to ±0.5°C calibration accuracy (AD590M)
Excellent linearity: ±0.3°C over full range (AD590M)
Wide power supply range: 4 V to 30 V
Sensor isolation from case
Low cost

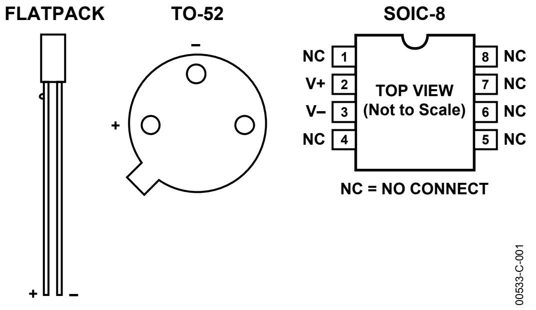


Figure 1. Pin Designations

GENERAL DESCRIPTION

The AD590 is a 2-terminal integrated circuit temperature transducer that produces an output current proportional to absolute temperature. For supply voltages between 4 V and 30 V the device acts as a high-impedance, constant current regulator passing 1 μA/K. Laser trimming of the chip's thin-film resistors is used to calibrate the device to 298.2 μA output at 298.2 K (25°C).

The AD590 should be used in any temperature-sensing application below 150°C in which conventional electrical temperature sensors are currently employed. The inherent low cost of a monolithic integrated circuit combined with the elimination of support circuitry makes the AD590 an attractive alternative for many temperature measurement situations. Linearization circuitry, precision voltage amplifiers, resistance measuring circuitry, and cold junction compensation are not needed in applying the AD590.

In addition to temperature measurement, applications include temperature compensation or correction of discrete components, biasing proportional to absolute temperature, flow rate measurement, level detection of fluids and anemometry. The AD590 is available in chip form, making it suitable for hybrid circuits and fast temperature measurements in protected environments.

The AD590 is particularly useful in remote sensing applications. The device is insensitive to voltage drops over long lines due to its high impedance current output. Any well-insulated twisted pair is sufficient for operation at hundreds of feet from the receiving circuitry. The output characteristics also make the AD590 easy to multiplex: the current can be switched by a CMOS multiplexer or the supply voltage can be switched by a logic gate output.

PRODUCT HIGHLIGHTS

1. The AD590 is a calibrated, 2-terminal temperature sensor requiring only a dc voltage supply (4 V to 30 V). Costly transmitters, filters, lead wire compensation, and linearization circuits are all unnecessary in applying the device.
2. State-of-the-art laser trimming at the wafer level in conjunction with extensive final testing ensures that AD590 units are easily interchangeable.
3. Superior interface rejection occurs, because the output is a current rather than a voltage. In addition, power requirements are low (1.5 mWs @ 5 V @ 25°C). These features make the AD590 easy to apply as a remote sensor.
4. The high output impedance (>10 MΩ) provides excellent rejection of supply voltage drift and ripple. For instance, changing the power supply from 5 V to 10 V results in only a 1 μA maximum current change, or 1°C equivalent error.
5. The AD590 is electrically durable: it withstands a forward voltage of up to 44 V and a reverse voltage of 20 V. Therefore, supply irregularities or pin reversal does not damage the device.

Rev. C

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Fax: 781.326.8703

Appendix
B

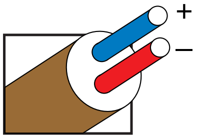
Thermocouple Millivolt Tables

Revised Thermocouple Reference Tables

TYPE T

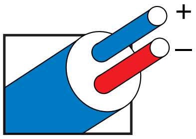
Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

Thermocouple Grade



Copper vs. Copper-Nickel

Extension Grade



MAXIMUM TEMPERATURE RANGE

Thermocouple Grade
– 328 to 662°F
– 200 to 350°C

Extension Grade
– 76 to 212°F
– 60 to 100°C

LIMITS OF ERROR
(whichever is greater)
Standard: 1.0°C or 0.75% Above 0°C
1.0°C or 1.5% Below 0°C
Special: 0.5°C or 0.4%

COMMENTS, BARE WIRE ENVIRONMENT:
Mild Oxidizing, Reducing Vacuum or Inert; Good Where Moisture Is Present; Low Temperature and Cryogenic Applications

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.258	-6.256	-6.255	-6.253	-6.251	-6.248	-6.245	-6.242	-6.239	-6.236	-6.232	-260
-250	-6.232	-6.228	-6.223	-6.219	-6.214	-6.209	-6.204	-6.198	-6.193	-6.187	-6.180	-250
-240	-6.180	-6.174	-6.167	-6.160	-6.153	-6.146	-6.138	-6.130	-6.122	-6.114	-6.105	-240
-230	-6.105	-6.096	-6.087	-6.078	-6.068	-6.059	-6.049	-6.038	-6.028	-6.017	-6.007	-230
-220	-6.007	-5.996	-5.985	-5.973	-5.962	-5.950	-5.938	-5.926	-5.914	-5.901	-5.888	-220
-210	-5.888	-5.876	-5.863	-5.850	-5.836	-5.823	-5.809	-5.795	-5.782	-5.767	-5.753	-210
-200	-5.753	-5.739	-5.724	-5.710	-5.695	-5.680	-5.665	-5.650	-5.634	-5.619	-5.603	-200
-190	-5.603	-5.587	-5.571	-5.555	-5.539	-5.523	-5.506	-5.489	-5.473	-5.456	-5.439	-190
-180	-5.439	-5.421	-5.404	-5.387	-5.369	-5.351	-5.334	-5.316	-5.297	-5.279	-5.261	-180
-170	-5.261	-5.242	-5.224	-5.205	-5.186	-5.167	-5.148	-5.128	-5.109	-5.089	-5.070	-170
-160	-5.070	-5.050	-5.030	-5.010	-4.989	-4.969	-4.949	-4.928	-4.907	-4.886	-4.865	-160
-150	-4.865	-4.844	-4.823	-4.802	-4.780	-4.759	-4.737	-4.715	-4.693	-4.671	-4.648	-150
-140	-4.648	-4.626	-4.604	-4.581	-4.558	-4.535	-4.512	-4.489	-4.466	-4.443	-4.419	-140
-130	-4.419	-4.395	-4.372	-4.348	-4.324	-4.300	-4.275	-4.251	-4.226	-4.202	-4.177	-130
-120	-4.177	-4.152	-4.127	-4.102	-4.077	-4.052	-4.026	-4.000	-3.975	-3.949	-3.923	-120
-110	-3.923	-3.897	-3.871	-3.844	-3.818	-3.791	-3.765	-3.738	-3.711	-3.684	-3.657	-110
-100	-3.657	-3.629	-3.602	-3.574	-3.547	-3.519	-3.491	-3.463	-3.435	-3.407	-3.379	-100
-90	-3.379	-3.350	-3.322	-3.293	-3.264	-3.235	-3.206	-3.177	-3.148	-3.118	-3.089	-90
-80	-3.089	-3.059	-3.030	-3.000	-2.970	-2.940	-2.910	-2.879	-2.849	-2.818	-2.788	-80
-70	-2.788	-2.757	-2.726	-2.695	-2.664	-2.633	-2.602	-2.571	-2.539	-2.507	-2.476	-70
-60	-2.476	-2.444	-2.412	-2.380	-2.348	-2.316	-2.283	-2.251	-2.218	-2.186	-2.153	-60
-50	-2.153	-2.120	-2.087	-2.054	-2.021	-1.987	-1.954	-1.920	-1.887	-1.853	-1.819	-50
-40	-1.819	-1.785	-1.751	-1.717	-1.683	-1.648	-1.614	-1.579	-1.545	-1.510	-1.475	-40
-30	-1.475	-1.440	-1.405	-1.370	-1.335	-1.299	-1.264	-1.228	-1.192	-1.157	-1.121	-30
-20	-1.121	-1.085	-1.049	-1.013	-0.976	-0.940	-0.904	-0.867	-0.830	-0.794	-0.757	-20
-10	-0.757	-0.720	-0.683	-0.646	-0.608	-0.571	-0.534	-0.496	-0.459	-0.421	-0.383	-10
0	-0.383	-0.345	-0.307	-0.269	-0.231	-0.193	-0.154	-0.116	-0.077	-0.039	0.000	0

°C	0	1	2	3	4	5	6	7	8	9	10	°C
0	0.000	0.039	0.078	0.117	0.156	0.195	0.234	0.273	0.312	0.352	0.391	0
10	0.391	0.431	0.470	0.510	0.549	0.589	0.629	0.669	0.709	0.749	0.790	10
20	0.790	0.830	0.870	0.911	0.951	0.992	1.033	1.074	1.114	1.155	1.196	20
30	1.196	1.238	1.279	1.320	1.362	1.403	1.445	1.486	1.528	1.570	1.612	30
40	1.612	1.654	1.696	1.738	1.780	1.823	1.865	1.908	1.950	1.993	2.036	40

°C	0	1	2	3	4	5	6	7	8	9	10	°C
50	2.036	2.079	2.122	2.165	2.208	2.251	2.294	2.338	2.381	2.425	2.468	50
60	2.468	2.512	2.556	2.600	2.643	2.687	2.732	2.776	2.820	2.864	2.909	60
70	2.909	2.953	2.998	3.043	3.087	3.132	3.177	3.222	3.267	3.312	3.358	70
80	3.358	3.403	3.448	3.494	3.539	3.585	3.631	3.677	3.722	3.768	3.814	80
90	3.814	3.860	3.907	3.953	3.999	4.046	4.092	4.138	4.185	4.232	4.279	90
100	4.279	4.325	4.372	4.419	4.466	4.513	4.561	4.608	4.655	4.702	4.750	100
110	4.750	4.798	4.845	4.893	4.941	4.988	5.036	5.084	5.132	5.180	5.228	110
120	5.228	5.277	5.325	5.373	5.422	5.470	5.519	5.567	5.616	5.665	5.714	120
130	5.714	5.763	5.812	5.861	5.910	5.959	6.008	6.057	6.107	6.156	6.206	130
140	6.206	6.255	6.305	6.355	6.404	6.454	6.504	6.554	6.604	6.654	6.704	140
150	6.704	6.754	6.805	6.855	6.905	6.956	7.006	7.057	7.107	7.158	7.209	150
160	7.209	7.260	7.310	7.361	7.412	7.463	7.515	7.566	7.617	7.668	7.720	160
170	7.720	7.771	7.823	7.874	7.926	7.977	8.029	8.081	8.133	8.185	8.237	170
180	8.237	8.289	8.341	8.393	8.445	8.497	8.550	8.602	8.654	8.707	8.759	180
190	8.759	8.812	8.865	8.917	8.970	9.023	9.076	9.129	9.182	9.235	9.288	190
200	9.288	9.341	9.395	9.448	9.501	9.555	9.608	9.662	9.715	9.769	9.822	200
210	9.822	9.876	9.930	9.984	10.038	10.092	10.146	10.200	10.254	10.308	10.362	210
220	10.362	10.417	10.471	10.525	10.580	10.634	10.689	10.743	10.798	10.853	10.907	220
230	10.907	10.962	11.017	11.072	11.127	11.182	11.237	11.292	11.347	11.403	11.458	230
240	11.458	11.513	11.569	11.624	11.680	11.735	11.791	11.846	11.902	11.958	12.013	240
250	12.013	12.069	12.125	12.181	12.237	12.293	12.349	12.405	12.461	12.518	12.574	250
260	12.574	12.630	12.687	12.743	12.799	12.856	12.912	12.969	13.026	13.082	13.139	260
270	13.139	13.196	13.253	13.310	13.366	13.423	13.480	13.537	13.595	13.652	13.709	270
280	13.709	13.766	13.823	13.881	13.938	13.995	14.053	14.110	14.168	14.226	14.283	280
290	14.283	14.341	14.399	14.456	14.514	14.572	14.630	14.688	14.746	14.804	14.862	290
300	14.862	14.920	14.978	15.036	15.095	15.153	15.211	15.270	15.328	15.386	15.445	300
310	15.445	15.503	15.562	15.621	15.679	15.738	15.797	15.856	15.914	15.973	16.032	310
320	16.032	16.091	16.150	16.209	16.268	16.327	16.387	16.446	16.505	16.564	16.624	320
330	16.624	16.683	16.742	16.802	16.861	16.921	16.980	17.040	17.100	17.159	17.219	330
340	17.219	17.279	17.339	17.399	17.458	17.518	17.578	17.638	17.698	17.759	17.819	340
350	17.819	17.879	17.939	17.999	18.060	18.120	18.180	18.241	18.301	18.362	18.422	350
360	18.422	18.483	18.543	18.604	18.665	18.725	18.786	18.847	18.908	18.969	19.030	360
370	19.030	19.091	19.152	19.213	19.274	19.335	19.396	19.457	19.518	19.579	19.641	370
380	19.641	19.702	19.763	19.825	19.886	19.947	20.009	20.070	20.132	20.193	20.255	380
390	20.255	20.317	20.378	20.440	20.502	20.563	20.625	20.687	20.748	20.810	20.872	390
°C	0	1	2	3	4	5	6	7	8	9	10	°C

MAXIMUM TEMPERATURE RANGE

Thermocouple Grade
– 328 to 2282°F
– 200 to 1250°C

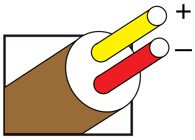
Extension Grade
32 to 392°F
0 to 200°C

LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75% Above 0°C
2.2°C or 2.0% Below 0°C
Special: 1.1°C or 0.4%

COMMENTS, BARE WIRE ENVIRONMENT:

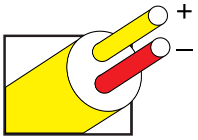
Clean Oxidizing and Inert; Limited Use in Vacuum or Reducing; Wide Temperature Range; Most Popular Calibration

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C



Thermocouple Grade

Nickel-Chromium vs. Nickel-Aluminum



Extension Grade

Revised Thermocouple Reference Tables

TYPE K

Reference Tables
N.I.S.T. Monograph 175
Revised to ITS-90

Thermoelectric Voltage in Millivolts

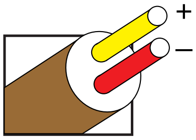
°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-260	-6.458	-6.457	-6.456	-6.455	-6.453	-6.452	-6.450	-6.448	-6.446	-6.444	-6.441	-260
-250	-6.441	-6.438	-6.435	-6.432	-6.429	-6.425	-6.421	-6.417	-6.413	-6.408	-6.404	-250
-240	-6.404	-6.399	-6.393	-6.388	-6.382	-6.377	-6.370	-6.364	-6.358	-6.351	-6.344	-240
-230	-6.344	-6.337	-6.329	-6.322	-6.314	-6.306	-6.297	-6.289	-6.280	-6.271	-6.262	-230
-220	-6.262	-6.252	-6.243	-6.233	-6.223	-6.213	-6.202	-6.192	-6.181	-6.170	-6.158	-220
-210	-6.158	-6.147	-6.135	-6.123	-6.111	-6.099	-6.087	-6.074	-6.061	-6.048	-6.035	-210
-200	-6.035	-6.021	-6.007	-5.994	-5.980	-5.965	-5.951	-5.936	-5.922	-5.907	-5.891	-200
-190	-5.891	-5.876	-5.861	-5.845	-5.829	-5.813	-5.797	-5.780	-5.763	-5.747	-5.730	-190
-180	-5.730	-5.713	-5.695	-5.678	-5.660	-5.642	-5.624	-5.606	-5.588	-5.569	-5.550	-180
-170	-5.550	-5.531	-5.512	-5.493	-5.474	-5.454	-5.435	-5.415	-5.395	-5.374	-5.354	-170
-160	-5.354	-5.333	-5.313	-5.292	-5.271	-5.250	-5.228	-5.207	-5.185	-5.163	-5.141	-160
-150	-5.141	-5.119	-5.097	-5.074	-5.052	-5.029	-5.006	-4.983	-4.960	-4.936	-4.913	-150
-140	-4.913	-4.889	-4.865	-4.841	-4.817	-4.793	-4.768	-4.744	-4.719	-4.694	-4.669	-140
-130	-4.669	-4.644	-4.618	-4.593	-4.567	-4.542	-4.516	-4.490	-4.463	-4.437	-4.411	-130
-120	-4.411	-4.384	-4.357	-4.330	-4.303	-4.276	-4.249	-4.221	-4.194	-4.166	-4.138	-120
-110	-4.138	-4.110	-4.082	-4.054	-4.025	-3.997	-3.968	-3.939	-3.911	-3.882	-3.852	-110
-100	-3.852	-3.823	-3.794	-3.764	-3.734	-3.705	-3.675	-3.645	-3.614	-3.584	-3.554	-100
-90	-3.554	-3.523	-3.492	-3.462	-3.431	-3.400	-3.368	-3.337	-3.306	-3.274	-3.243	-90
-80	-3.243	-3.211	-3.179	-3.147	-3.115	-3.083	-3.050	-3.018	-2.986	-2.953	-2.920	-80
-70	-2.920	-2.887	-2.854	-2.821	-2.788	-2.755	-2.721	-2.688	-2.654	-2.620	-2.587	-70
-60	-2.587	-2.553	-2.519	-2.485	-2.450	-2.416	-2.382	-2.347	-2.312	-2.278	-2.243	-60
-50	-2.243	-2.208	-2.173	-2.138	-2.103	-2.067	-2.032	-1.996	-1.961	-1.925	-1.889	-50
-40	-1.889	-1.854	-1.818	-1.782	-1.745	-1.709	-1.673	-1.637	-1.600	-1.564	-1.527	-40
-30	-1.527	-1.490	-1.453	-1.417	-1.380	-1.343	-1.305	-1.268	-1.231	-1.194	-1.156	-30
-20	-1.156	-1.119	-1.081	-1.043	-1.006	-0.968	-0.930	-0.892	-0.854	-0.816	-0.778	-20
-10	-0.778	-0.739	-0.701	-0.663	-0.624	-0.586	-0.547	-0.508	-0.470	-0.431	-0.392	-10
0	-0.392	-0.353	-0.314	-0.275	-0.236	-0.197	-0.157	-0.118	-0.079	-0.039	0.000	0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023	40
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096	90
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138	140
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540	150
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941	160
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340	170
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739	180
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138	190
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	8.539	200
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	8.940	210
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	9.343	220
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	9.747	230
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	10.153	240
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**°C**

°C	0	1	2	3	4	5	6	7	8	9	10	°C
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561	250
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971	260
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382	270
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795	280
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209	290
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624	300
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040	310
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457	320
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874	330
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293	340
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713	350
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133	360
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554	370
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975	380
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397	390
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820	400
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243	410
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667	420
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091	430
440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516	440
450	18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898	18.941	450
460	18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324	19.366	460
470	19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750	19.792	470
480	19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175	20.218	480
490	20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602	20.644	490
500	20.644	20.687	20.730	20.772	20.815	20.857	20.900	20.943	20.985	21.028	21.071	500
510	21.071	21.113	21.156	21.199	21.241	21.284	21.326	21.369	21.412	21.454	21.497	510
520	21.497	21.540	21.582	21.625	21.668	21.710	21.753	21.796	21.838	21.881	21.924	520
530	21.924	21.966	22.009	22.052	22.094	22.137	22.179	22.222	22.265	22.307	22.350	530
540	22.350	22.393	22.435	22.478	22.521	22.563	22.606	22.649	22.691	22.734	22.776	540
550	22.776	22.819	22.862	22.904	22.947	22.990	23.032	23.075	23.117	23.160	23.203	550
560	23.203	23.245	23.288	23.331	23.373	23.416	23.458	23.501	23.544	23.586	23.629	560
570	23.629	23.671	23.714	23.757	23.799	23.842	23.884	23.927	23.970	24.012	24.055	570
580	24.055	24.097	24.140	24.182	24.225	24.267	24.310	24.353	24.395	24.438	24.480	580
590	24.480	24.523	24.565	24.608	24.650	24.693	24.735	24.778	24.820	24.863	24.905	590
600	24.905	24.948	24.990	25.033	25.075	25.118	25.160	25.203	25.245	25.288	25.330	600
610	25.330	25.373	25.415	25.458	25.500	25.543	25.585	25.627	25.670	25.712	25.755	610
620	25.755	25.797	25.840	25.882	25.924	25.967	26.009	26.052	26.094	26.136	26.179	620
630	26.179	26.221	26.263	26.306	26.348	26.390	26.433	26.475	26.517	26.560	26.602	630
640	26.602	26.644	26.687	26.729	26.771	26.814	26.856	26.898	26.940	26.983	27.025	640
650	27.025	27.067	27.109	27.152	27.194	27.236	27.278	27.320	27.363	27.405	27.447	650
660	27.447	27.489	27.531	27.574	27.616	27.658	27.700	27.742	27.784	27.826	27.869	660
670	27.869	27.911	27.953	27.995	28.037	28.079	28.121	28.163	28.205	28.247	28.289	670
680	28.289	28.332	28.374	28.416	28.458	28.500	28.542	28.584	28.626	28.668	28.710	680
690	28.710	28.752	28.794	28.835	28.877	28.919	28.961	29.003	29.045	29.087	29.129	690
700	29.129	29.171	29.213	29.255	29.297	29.338	29.380	29.422	29.464	29.506	29.548	700
710	29.548	29.589	29.631	29.673	29.715	29.757	29.798	29.840	29.882	29.924	29.965	710
720	29.965	30.007	30.049	30.090	30.132	30.174	30.216	30.257	30.299	30.341	30.382	720
730	30.382	30.424	30.466	30.507	30.549	30.590	30.632	30.674	30.715	30.757	30.798	730
740	30.798	30.840	30.881	30.923	30.964	31.006	31.047	31.089	31.130	31.172	31.213	740
750	31.213	31.255	31.296	31.338	31.379	31.421	31.462	31.504	31.545	31.586	31.628	750
760	31.628	31.669	31.710	31.752	31.793	31.834	31.876	31.917	31.958	32.000	32.041	760
770	32.041	32.082	32.124	32.165	32.206	32.247	32.289	32.330	32.371	32.412	32.453	770
780	32.453	32.495	32.536	32.577	32.618	32.659	32.700	32.742	32.783	32.824	32.865	780
790	32.865	32.906	32.947	32.988	33.029	33.070	33.111	33.152	33.193	33.234	33.275	790
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**°C**

Revised Thermocouple Reference Tables

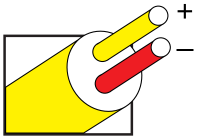
TYPE K

Reference Tables
N.I.S.T.
Monograph 175
Revised to
ITS-90



Thermocouple Grade

Nickel-Chromium vs. Nickel-Aluminum



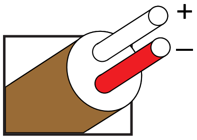
Extension Grade

MAXIMUM TEMPERATURE RANGE
Thermocouple Grade
– 328 to 2282°F
– 200 to 1250°C
Extension Grade
32 to 392°F
0 to 200°C
LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75% Above 0°C
2.2°C or 2.0% Below 0°C
Special: 1.1°C or 0.4%
COMMENTS, BARE WIRE ENVIRONMENT:
Clean Oxidizing and Inert; Limited Use in Vacuum or Reducing; Wide Temperature Range; Most Popular Calibration
TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Thermoelectric Voltage in Millivolts

°C	0	1	2	3	4	5	6	7	8	9	10	°C
800	33.275	33.316	33.357	33.398	33.439	33.480	33.521	33.562	33.603	33.644	33.685	800
810	33.685	33.726	33.767	33.808	33.848	33.889	33.930	33.971	34.012	34.053	34.093	810
820	34.093	34.134	34.175	34.216	34.257	34.297	34.338	34.379	34.420	34.460	34.501	820
830	34.501	34.542	34.582	34.623	34.664	34.704	34.745	34.786	34.826	34.867	34.908	830
840	34.908	34.948	34.989	35.029	35.070	35.110	35.151	35.192	35.232	35.273	35.313	840
850	35.313	35.354	35.394	35.435	35.475	35.516	35.556	35.596	35.637	35.677	35.718	850
860	35.718	35.758	35.798	35.839	35.879	35.920	35.960	36.000	36.041	36.081	36.121	860
870	36.121	36.162	36.202	36.242	36.282	36.323	36.363	36.403	36.443	36.484	36.524	870
880	36.524	36.564	36.604	36.644	36.685	36.725	36.765	36.805	36.845	36.885	36.925	880
890	36.925	36.965	37.006	37.046	37.086	37.126	37.166	37.206	37.246	37.286	37.326	890
900	37.326	37.366	37.406	37.446	37.486	37.526	37.566	37.606	37.646	37.686	37.725	900
910	37.725	37.765	37.805	37.845	37.885	37.925	37.965	38.005	38.044	38.084	38.124	910
920	38.124	38.164	38.204	38.243	38.283	38.323	38.363	38.402	38.442	38.482	38.522	920
930	38.522	38.561	38.601	38.641	38.680	38.720	38.760	38.799	38.839	38.878	38.918	930
940	38.918	38.958	38.997	39.037	39.076	39.116	39.155	39.195	39.235	39.274	39.314	940
950	39.314	39.353	39.393	39.432	39.471	39.511	39.550	39.590	39.629	39.669	39.708	950
960	39.708	39.747	39.787	39.826	39.866	39.905	39.944	39.984	40.023	40.062	40.101	960
970	40.101	40.141	40.180	40.219	40.259	40.298	40.337	40.376	40.415	40.455	40.494	970
980	40.494	40.533	40.572	40.611	40.651	40.690	40.729	40.768	40.807	40.846	40.885	980
990	40.885	40.924	40.963	41.002	41.042	41.081	41.120	41.159	41.198	41.237	41.276	990
1000	41.276	41.315	41.354	41.393	41.431	41.470	41.509	41.548	41.587	41.626	41.665	1000
1010	41.665	41.704	41.743	41.781	41.820	41.859	41.898	41.937	41.976	42.014	42.053	1010
1020	42.053	42.092	42.131	42.169	42.208	42.247	42.286	42.324	42.363	42.402	42.440	1020
1030	42.440	42.479	42.518	42.556	42.595	42.633	42.672	42.711	42.749	42.788	42.826	1030
1040	42.826	42.865	42.903	42.942	42.980	43.019	43.057	43.096	43.134	43.173	43.211	1040
1050	43.211	43.250	43.288	43.327	43.365	43.403	43.442	43.480	43.518	43.557	43.595	1050
1060	43.595	43.633	43.672	43.710	43.748	43.787	43.825	43.863	43.901	43.940	43.978	1060
1070	43.978	44.016	44.054	44.092	44.130	44.169	44.207	44.245	44.283	44.321	44.359	1070
1080	44.359	44.397	44.435	44.473	44.512	44.550	44.588	44.626	44.664	44.702	44.740	1080
1090	44.740	44.778	44.816	44.853	44.891	44.929	44.967	45.005	45.043	45.081	45.119	1090
1100	45.119	45.157	45.194	45.232	45.270	45.308	45.346	45.383	45.421	45.459	45.497	1100
1110	45.497	45.534	45.572	45.610	45.647	45.685	45.723	45.760	45.798	45.836	45.873	1110
1120	45.873	45.911	45.948	45.986	46.024	46.061	46.099	46.136	46.174	46.211	46.249	1120
1130	46.249	46.286	46.324	46.361	46.398	46.436	46.473	46.511	46.548	46.585	46.623	1130
1140	46.623	46.660	46.697	46.735	46.772	46.809	46.847	46.884	46.921	46.958	46.995	1140
1150	46.995	47.033	47.070	47.107	47.144	47.181	47.218	47.256	47.293	47.330	47.367	1150
1160	47.367	47.404	47.441	47.478	47.515	47.552	47.589	47.626	47.663	47.700	47.737	1160
1170	47.737	47.774	47.811	47.848	47.884	47.921	47.958	47.995	48.032	48.069	48.105	1170
1180	48.105	48.142	48.179	48.216	48.252	48.289	48.326	48.363	48.399	48.436	48.473	1180
1190	48.473	48.509	48.546	48.582	48.619	48.656	48.692	48.729	48.765	48.802	48.838	1190
1200	48.838	48.875	48.911	48.948	48.984	49.021	49.057	49.093	49.130	49.166	49.202	1200
1210	49.202	49.239	49.275	49.311	49.348	49.384	49.420	49.456	49.493	49.529	49.565	1210
1220	49.565	49.601	49.637	49.674	49.710	49.746	49.782	49.818	49.854	49.890	49.926	1220
1230	49.926	49.962	49.998	50.034	50.070	50.106	50.142	50.178	50.214	50.250	50.286	1230
1240	50.286	50.322	50.358	50.393	50.429	50.465	50.501	50.537	50.572	50.608	50.644	1240
1250	50.644	50.680	50.715	50.751	50.787	50.822	50.858	50.894	50.929	50.965	51.000	1250
1260	51.000	51.036	51.071	51.107	51.142	51.178	51.213	51.249	51.284	51.320	51.355	1260
1270	51.355	51.391	51.426	51.461	51.497	51.532	51.567	51.603	51.638	51.673	51.708	1270
1280	51.708	51.744	51.779	51.814	51.849	51.885	51.920	51.955	51.990	52.025	52.060	1280
1290	52.060	52.095	52.130	52.165	52.200	52.235	52.270	52.305	52.340	52.375	52.410	1290
1300	52.410	52.445	52.480	52.515	52.550	52.585	52.620	52.654	52.689	52.724	52.759	1300
1310	52.759	52.794	52.828	52.863	52.898	52.932	52.967	53.002	53.037	53.071	53.106	1310
1320	53.106	53.140	53.175	53.210	53.244	53.279	53.313	53.348	53.382	53.417	53.451	1320
1330	53.451	53.486	53.520	53.555	53.589	53.623	53.658	53.692	53.727	53.761	53.795	1330
1340	53.795	53.830	53.864	53.898	53.932	53.967	54.001	54.035	54.069	54.104	54.138	1340
1350	54.138	54.172	54.206	54.240	54.274	54.308	54.343	54.377	54.411	54.445	54.479	1350
1360	54.479	54.513	54.547	54.581	54.615	54.649	54.683	54.717	54.751	54.785	54.819	1360
1370	54.819	54.852	54.886									1370
°C	0	1	2	3	4	5	6	7	8	9	10	°C

Revised Thermocouple Reference Tables

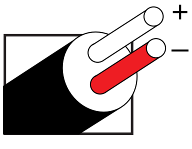


Thermocouple Grade

TYPE J

Reference Tables
N.I.S.T.
Monograph 175
Revised to
ITS-90

Iron vs. Copper-Nickel



Extension Grade

MAXIMUM TEMPERATURE RANGE

Thermocouple Grade
32 to 1382°F
0 to 750°C

Extension Grade
32 to 392°F
0 to 200°C

LIMITS OF ERROR
(whichever is greater)
Standard: 2.2°C or 0.75%
Special: 1.1°C or 0.4%

COMMENTS, BARE WIRE ENVIRONMENT:
Reducing, Vacuum, Inert; Limited Use in
Oxidizing at High Temperatures;
Not Recommended for Low Temperatures

TEMPERATURE IN DEGREES °C
REFERENCE JUNCTION AT 0°C

Thermoelectric Voltage in Millivolts

°C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	°C
-200	-8.095	-8.076	-8.057	-8.037	-8.017	-7.996	-7.976	-7.955	-7.934	-7.912	-7.890	-200
-190	-7.890	-7.868	-7.846	-7.824	-7.801	-7.778	-7.755	-7.731	-7.707	-7.683	-7.659	-190
-180	-7.659	-7.634	-7.610	-7.585	-7.559	-7.534	-7.508	-7.482	-7.456	-7.429	-7.403	-180
-170	-7.403	-7.376	-7.348	-7.321	-7.293	-7.265	-7.237	-7.209	-7.181	-7.152	-7.123	-170
-160	-7.123	-7.094	-7.064	-7.035	-7.005	-6.975	-6.944	-6.914	-6.883	-6.853	-6.821	-160
-150	-6.821	-6.790	-6.759	-6.727	-6.695	-6.663	-6.631	-6.598	-6.566	-6.533	-6.500	-150
-140	-6.500	-6.467	-6.433	-6.400	-6.366	-6.332	-6.298	-6.263	-6.229	-6.194	-6.159	-140
-130	-6.159	-6.124	-6.089	-6.054	-6.018	-5.982	-5.946	-5.910	-5.874	-5.838	-5.801	-130
-120	-5.801	-5.764	-5.727	-5.690	-5.653	-5.616	-5.578	-5.541	-5.503	-5.465	-5.426	-120
-110	-5.426	-5.388	-5.350	-5.311	-5.272	-5.233	-5.194	-5.155	-5.116	-5.076	-5.037	-110
-100	-5.037	-4.997	-4.957	-4.917	-4.877	-4.836	-4.796	-4.755	-4.714	-4.674	-4.633	-100
-90	-4.633	-4.591	-4.550	-4.509	-4.467	-4.425	-4.384	-4.342	-4.300	-4.257	-4.215	-90
-80	-4.215	-4.173	-4.130	-4.088	-4.045	-4.002	-3.959	-3.916	-3.872	-3.829	-3.786	-80
-70	-3.786	-3.742	-3.698	-3.654	-3.610	-3.566	-3.522	-3.478	-3.434	-3.389	-3.344	-70
-60	-3.344	-3.300	-3.255	-3.210	-3.165	-3.120	-3.075	-3.029	-2.984	-2.938	-2.893	-60
-50	-2.893	-2.847	-2.801	-2.755	-2.709	-2.663	-2.617	-2.571	-2.524	-2.478	-2.431	-50
-40	-2.431	-2.385	-2.338	-2.291	-2.244	-2.197	-2.150	-2.103	-2.055	-2.008	-1.961	-40
-30	-1.961	-1.913	-1.865	-1.818	-1.770	-1.722	-1.674	-1.626	-1.578	-1.530	-1.482	-30
-20	-1.482	-1.433	-1.385	-1.336	-1.288	-1.239	-1.190	-1.142	-1.093	-1.044	-0.995	-20
-10	-0.995	-0.946	-0.896	-0.847	-0.798	-0.749	-0.699	-0.650	-0.600	-0.550	-0.501	-10
0	-0.501	-0.451	-0.401	-0.351	-0.301	-0.251	-0.201	-0.151	-0.101	-0.050	0.000	0
0	0.000	0.050	0.101	0.151	0.202	0.253	0.303	0.354	0.405	0.456	0.507	0
10	0.507	0.558	0.609	0.660	0.711	0.762	0.814	0.865	0.916	0.968	1.019	10
20	1.019	1.071	1.122	1.174	1.226	1.277	1.329	1.381	1.433	1.485	1.537	20
30	1.537	1.589	1.641	1.693	1.745	1.797	1.849	1.902	1.954	2.006	2.059	30
40	2.059	2.111	2.164	2.216	2.269	2.322	2.374	2.427	2.480	2.532	2.585	40
50	2.585	2.638	2.691	2.744	2.797	2.850	2.903	2.956	3.009	3.062	3.116	50
60	3.116	3.169	3.222	3.275	3.329	3.382	3.436	3.489	3.543	3.596	3.650	60
70	3.650	3.703	3.757	3.810	3.864	3.918	3.971	4.025	4.079	4.133	4.187	70
80	4.187	4.240	4.294	4.348	4.402	4.456	4.510	4.564	4.618	4.672	4.726	80
90	4.726	4.781	4.835	4.889	4.943	4.997	5.052	5.106	5.160	5.215	5.269	90
100	5.269	5.323	5.378	5.432	5.487	5.541	5.595	5.650	5.705	5.759	5.814	100
110	5.814	5.868	5.923	5.977	6.032	6.087	6.141	6.196	6.251	6.306	6.360	110
120	6.360	6.415	6.470	6.525	6.579	6.634	6.689	6.744	6.799	6.854	6.909	120
130	6.909	6.964	7.019	7.074	7.129	7.184	7.239	7.294	7.349	7.404	7.459	130
140	7.459	7.514	7.569	7.624	7.679	7.734	7.789	7.844	7.900	7.955	8.010	140
150	8.010	8.065	8.120	8.175	8.231	8.286	8.341	8.396	8.452	8.507	8.562	150
160	8.562	8.618	8.673	8.728	8.783	8.839	8.894	8.949	9.005	9.060	9.115	160
170	9.115	9.171	9.226	9.282	9.337	9.392	9.448	9.503	9.559	9.614	9.669	170
180	9.669	9.725	9.780	9.836	9.891	9.947	10.002	10.057	10.113	10.168	10.224	180
190	10.224	10.279	10.335	10.390	10.446	10.501	10.557	10.612	10.668	10.723	10.779	190
200	10.779	10.834	10.890	10.945	11.001	11.056	11.112	11.167	11.223	11.278	11.334	200
210	11.334	11.389	11.445	11.501	11.556	11.612	11.667	11.723	11.778	11.834	11.889	210
220	11.889	11.945	12.000	12.056	12.111	12.167	12.222	12.278	12.334	12.389	12.445	220
230	12.445	12.500	12.556	12.611	12.667	12.722	12.778	12.833	12.889	12.944	13.000	230
240	13.000	13.056	13.111	13.167	13.222	13.278	13.333	13.389	13.444	13.500	13.555	240
250	13.555	13.611	13.666	13.722	13.777	13.833	13.888	13.944	13.999	14.055	14.110	250
260	14.110	14.166	14.221	14.277	14.332	14.388	14.443	14.499	14.554	14.609	14.665	260
270	14.665	14.720	14.776	14.831	14.887	14.942	14.998	15.053	15.109	15.164	15.219	270
280	15.219	15.275	15.330	15.386	15.441	15.496	15.552	15.607	15.663	15.718	15.773	280
290	15.773	15.829	15.884	15.940	15.995	16.050	16.106	16.161	16.216	16.272	16.327	290
300	16.327	16.383	16.438	16.493	16.549	16.604	16.659	16.715	16.770	16.825	16.881	300
310	16.881	16.936	16.991	17.046	17.102	17.157	17.212	17.268	17.323	17.378	17.434	310
320	17.434	17.489	17.544	17.599	17.655	17.710	17.765	17.820	17.876	17.931	17.986	320
330	17.986	18.041	18.097	18.152	18.207	18.262	18.318	18.373	18.428	18.483	18.538	330
340	18.538	18.594	18.649	18.704	18.759	18.814	18.870	18.925	18.980	19.035	19.090	340
350	19.090	19.146	19.201	19.256	19.311	19.366	19.422	19.477	19.532	19.587	19.642	350
360	19.642	19.697	19.753	19.808	19.863	19.918	19.973	20.028	20.083	20.139	20.194	360
370	20.194	20.249	20.304	20.359	20.414	20.469	20.525	20.580	20.635	20.690	20.745	370
380	20.745	20.800	20.855	20.911	20.966	21.021	21.076	21.131	21.186	21.241	21.297	380
390	21.297	21.352	21.407	21.462	21.517	21.572	21.627	21.683	21.738	21.793	21.848	390
400	21.848	21.903	21.958	22.014	22.069	22.124	22.179	22.234	22.289	22.345	22.400	400
410	22.400	22.455	22.510	22.565	22.620	22.676	22.731	22.786	22.841	22.896	22.952	410
420	22.952	23.007	23.062	23.117	23.172	23.228	23.283	23.338	23.393	23.449	23.504	420
430	23.504	23.559	23.614	23.670	23.725	23.780	23.835	23.891	23.946	24.001	24.057	430
440	24.057	24.112	24.167	24.223	24.278	24.333	24.389	24.444	24.499	24.555	24.610	440
450	24.610	24.665	24.721	24.776	24.832	24.887	24.943	24.998	25.053	25.109	25.164	450
460	25.164	25.220	25.275	25.331	25.386	25.442	25.497	25.553	25.608	25.664	25.720	460
470	25.720	25.775	25.831	25.886	25.942	25.998	26.053	26.109	26.165	26.220	26.276	470
480	26.276	26.332	26.387	26.443	26.499	26.555	26.610	26.666	26.722	26.778	26.834	480
490	26.834	26.889	26.945	27.001	27.057	27.113	27.169	27.225	27.281	27.337	27.393	490
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**°C**

°C	0	1	2	3	4	5	6	7	8	9	10	°C
500	27.393	27.449	27.505	27.561	27.617	27.673	27.729	27.785	27.841	27.897	27.953	500
510	27.953	28.010	28.066	28.122	28.178	28.234	28.291	28.347	28.403	28.460	28.516	510
520	28.516	28.572	28.629	28.685	28.741	28.798	28.854	28.911	28.967	29.024	29.080	520
530	29.080	29.137	29.194	29.250	29.307	29.363	29.420	29.477	29.534	29.590	29.647	530
540	29.647	29.704	29.761	29.818	29.874	29.931	29.988	30.045	30.102	30.159	30.216	540
550	30.216	30.273	30.330	30.387	30.444	30.502	30.559	30.616	30.673	30.730	30.788	550
560	30.788	30.845	30.902	30.960	31.017	31.074	31.132	31.189	31.247	31.304	31.362	560
570	31.362	31.419	31.477	31.535	31.592	31.650	31.708	31.766	31.823	31.881	31.939	570
580	31.939	31.997	32.055	32.113	32.171	32.229	32.287	32.345	32.403	32.461	32.519	580
590	32.519	32.577	32.636	32.694	32.752	32.810	32.869	32.927	32.985	33.044	33.102	590
600	33.102	33.161	33.219	33.278	33.337	33.395	33.454	33.513	33.571	33.630	33.689	600
610	33.689	33.748	33.807	33.866	33.925	33.984	34.043	34.102	34.161	34.220	34.279	610
620	34.279	34.338	34.397	34.457	34.516	34.575	34.635	34.694	34.754	34.813	34.873	620
630	34.873	34.932	34.992	35.051	35.111	35.171	35.230	35.290	35.350	35.410	35.470	630
640	35.470	35.530	35.590	35.650	35.710	35.770	35.830	35.890	35.950	36.010	36.071	640
650	36.071	36.131	36.191	36.252	36.312	36.373	36.433	36.494	36.554	36.615	36.675	650
660	36.675	36.736	36.797	36.858	36.918	36.979	37.040	37.101	37.162	37.223	37.284	660
670	37.284	37.345	37.406	37.467	37.528	37.590	37.651	37.712	37.773	37.835	37.896	670
680	37.896	37.958	38.019	38.081	38.142	38.204	38.265	38.327	38.389	38.450	38.512	680
690	38.512	38.574	38.636	38.698	38.760	38.822	38.884	38.946	39.008	39.070	39.132	690
700	39.132	39.194	39.256	39.318	39.381	39.443	39.505	39.568	39.630	39.693	39.755	700
710	39.755	39.818	39.880	39.943	40.005	40.068	40.131	40.193	40.256	40.319	40.382	710
720	40.382	40.445	40.508	40.570	40.633	40.696	40.759	40.822	40.886	40.949	41.012	720
730	41.012	41.075	41.138	41.201	41.265	41.328	41.391	41.455	41.518	41.581	41.645	730
740	41.645	41.708	41.772	41.835	41.899	41.962	42.026	42.090	42.153	42.217	42.281	740
750	42.281	42.344	42.408	42.472	42.536	42.599	42.663	42.727	42.791	42.855	42.919	750
760	42.919	42.983	43.047	43.111	43.175	43.239	43.303	43.367	43.431	43.495	43.559	760
770	43.559	43.624	43.688	43.752	43.817	43.881	43.945	44.010	44.074	44.139	44.203	770
780	44.203	44.267	44.332	44.396	44.461	44.525	44.590	44.655	44.719	44.784	44.848	780
790	44.848	44.913	44.977	45.042	45.107	45.171	45.236	45.301	45.365	45.430	45.494	790
800	45.494	45.559	45.624	45.688	45.753	45.818	45.882	45.947	46.011	46.076	46.141	800
810	46.141	46.205	46.270	46.334	46.399	46.464	46.528	46.593	46.657	46.722	46.786	810
820	46.786	46.851	46.915	46.980	47.044	47.109	47.173	47.238	47.302	47.367	47.431	820
830	47.431	47.495	47.560	47.624	47.688	47.753	47.817	47.881	47.946	48.010	48.074	830
840	48.074	48.138	48.202	48.267	48.331	48.395	48.459	48.523	48.587	48.651	48.715	840
850	48.715	48.779	48.843	48.907	48.971	49.034	49.098	49.162	49.226	49.290	49.353	850
860	49.353	49.417	49.481	49.544	49.608	49.672	49.735	49.799	49.862	49.926	49.989	860
870	49.989	50.052	50.116	50.179	50.243	50.306	50.369	50.432	50.495	50.559	50.622	870
880	50.622	50.685	50.748	50.811	50.874	50.937	51.000	51.063	51.126	51.188	51.251	880
890	51.251	51.314	51.377	51.439	51.502	51.565	51.627	51.690	51.752	51.815	51.877	890
900	51.877	51.940	52.002	52.064	52.127	52.189	52.251	52.314	52.376	52.438	52.500	900
910	52.500	52.562	52.624	52.686	52.748	52.810	52.872	52.934	52.996	53.057	53.119	910
920	53.119	53.181	53.243	53.304	53.366	53.427	53.489	53.550	53.612	53.673	53.735	920
930	53.735	53.796	53.857	53.919	53.980	54.041	54.102	54.164	54.225	54.286	54.347	930
940	54.347	54.408	54.469	54.530	54.591	54.652	54.713	54.773	54.834	54.895	54.956	940
950	54.956	55.016	55.077	55.138	55.198	55.259	55.319	55.380	55.440	55.501	55.561	950
960	55.561	55.622	55.682	55.742	55.803	55.863	55.923	55.983	56.043	56.104	56.164	960
970	56.164	56.224	56.284	56.344	56.404	56.464	56.524	56.584	56.643	56.703	56.763	970
980	56.763	56.823	56.883	56.942	57.002	57.062	57.121	57.181	57.240	57.300	57.360	980
990	57.360	57.419	57.479	57.538	57.597	57.657	57.716	57.776	57.835	57.894	57.953	990
1000	57.953	58.013	58.072	58.131	58.190	58.249	58.309	58.368	58.427	58.486	58.545	1000
1010	58.545	58.604	58.663	58.722	58.781	58.840	58.899	58.957	59.016	59.075	59.134	1010
1020	59.134	59.193	59.252	59.310	59.369	59.428	59.487	59.545	59.604	59.663	59.721	1020
1030	59.721	59.780	59.838	59.897	59.956	60.014	60.073	60.131	60.190	60.248	60.307	1030
1040	60.307	60.365	60.423	60.482	60.540	60.599	60.657	60.715	60.774	60.832	60.890	1040
1050	60.890	60.949	61.007	61.065	61.123	61.182	61.240	61.298	61.356	61.415	61.473	1050
1060	61.473	61.531	61.589	61.647	61.705	61.763	61.822	61.880	61.938	61.996	62.054	1060
1070	62.054	62.112	62.170	62.228	62.286	62.344	62.402	62.460	62.518	62.576	62.634	1070
1080	62.634	62.692	62.750	62.808	62.866	62.924	62.982	63.040	63.098	63.156	63.214	1080
1090	63.214	63.271	63.329	63.387	63.445	63.503	63.561	63.619	63.677	63.734	63.792	1090
1100	63.792	63.850	63.908	63.966	64.024	64.081	64.139	64.197	64.255	64.313	64.370	1100
1110	64.370	64.428	64.486	64.544	64.602	64.659	64.717	64.775	64.833	64.890	64.948	1110
1120	64.948	65.006	65.064	65.121	65.179	65.237	65.295	65.352	65.410	65.468	65.525	1120
1130	65.525	65.583	65.641	65.699	65.756	65.814	65.872	65.929	65.987	66.045	66.102	1130
1140	66.102	66.160	66.218	66.275	66.333	66.391	66.448	66.506	66.564	66.621	66.679	1140
1150	66.679	66.737	66.794	66.852	66.910	66.967	67.025	67.082	67.140	67.198	67.255	1150
1160	67.255	67.313	67.370	67.428	67.486	67.543	67.601	67.658	67.716	67.773	67.831	1160
1170	67.831	67.888	67.946	68.003	68.061	68.119	68.176	68.234	68.291	68.348	68.406	1170
1180	68.406	68.463	68.521	68.578	68.636	68.693	68.751	68.808	68.865	68.923	68.980	1180
1190	68.980	69.037	69.095	69.152	69.209	69.267	69.324	69.381	69.439	69.496	69.553	1190
°C	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**°C**

Appendix C

Thermistor Resistance Tables

Thermistor Resistance vs. Temperature

Model No.	44004 44033	44005 44030	44007 44034	44006 44031	44008 44032
Ω 25°C	2252	3000	5000	10,000	30,000
BODY	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE
END	YELLOW ORANGE	GREEN BLACK	VIOLET YELLOW	BLUE BROWN	GREY RED
TEMP. °C	RESISTANCE Ω				
- 80	1660K	2211K	3685K	3558K	
79	1518K	2022K	3371K	3296K	
78	1390K	1851K	3086K	3055K	
77	1273K	1696K	2827K	2833K	
76	1167K	1555K	2592K	2629K	
75	1071K	1426K	2378K	2440K	
74	982.8K	1309K	2182K	2266K	
73	902.7K	1202K	2005K	2106K	
72	829.7K	1105K	1843K	1957K	
71	763.1K	1016K	1695K	1821K	
-70	702.3K	935.4K	1560K	1694K	
69	646.7K	861.4K	1436K	1577K	
68	595.9K	793.7K	1323K	1469K	
67	549.4K	731.8K	1220K	1369K	
66	506.9K	675.2K	1126K	1276K	
65	467.9K	623.3K	1039K	1190K	
64	432.2K	575.7K	959.9K	1111K	
63	399.5K	532.1K	887.2K	1037K	
62	369.4K	492.1K	820.5K	968.4K	
61	341.8K	455.3K	759.2K	904.9K	
-60	316.5K	421.5K	702.9K	845.9K	
59	293.2K	390.5K	651.1K	791.1K	
58	271.7K	361.9K	603.5K	740.2K	
57	252.0K	335.7K	559.7K	692.8K	
56	233.8K	311.5K	519.4K	648.8K	
55	217.1K	289.2K	482.2K	607.8K	
54	201.7K	268.6K	447.9K	569.6K	
53	187.4K	249.7K	416.3K	534.1K	
52	174.3K	232.2K	387.1K	501.0K	
51	162.2K	216.0K	360.2K	470.1K	
-50	151.0K	201.1K	335.3K	441.3K	
49	140.6K	187.3K	312.3K	414.5K	
48	131.0K	174.5K	291.0K	389.4K	
47	122.1K	162.7K	271.3K	366.0K	
46	113.9K	151.7K	253.0K	344.1K	
45	106.3K	141.6K	236.2K	323.7K	
44	99.26K	132.2K	220.5K	304.6K	
43	92.72K	123.5K	205.9K	286.7K	
42	86.65K	115.4K	192.5K	270.0K	
41	81.02K	107.9K	180.0K	254.4K	
-40	75.79K	101.0K	168.3K	239.8K	884.6K
39	70.93K	94.48K	157.5K	226.0K	830.9K
38	66.41K	88.46K	147.5K	213.2K	780.8K
37	62.21K	82.87K	138.2K	201.1K	733.9K
36	58.30K	77.66K	129.5K	189.8K	690.2K
35	54.66K	72.81K	121.4K	179.2K	649.3K
34	51.27K	68.30K	113.9K	169.3K	611.0K
33	48.11K	64.09K	106.9K	160.0K	575.2K
32	45.17K	60.17K	100.3K	151.2K	541.7K
31	42.42K	56.51K	94.22K	143.0K	510.4K
-30	39.86K	53.10K	88.53K	135.2K	481.0K
29	37.47K	49.91K	83.22K	127.9K	453.5K
28	35.24K	46.94K	78.26K	121.1K	427.7K
27	33.15K	44.16K	73.62K	114.6K	403.5K
26	31.20K	41.56K	69.29K	108.6K	380.9K
25	29.38K	39.13K	65.24K	102.9K	359.6K
24	27.67K	36.86K	61.45K	97.49K	339.6K
23	26.07K	34.73K	57.90K	92.43K	320.9K
22	24.58K	32.74K	54.58K	87.66K	303.3K
21	23.18K	30.87K	51.47K	83.16K	286.7K
-20	21.87K	29.13K	48.56K	78.91K	271.2K
19	20.64K	27.49K	45.83K	74.91K	256.5K
18	19.48K	25.95K	43.27K	71.13K	242.8K
17	18.40K	24.51K	40.86K	67.57K	229.8K
16	17.39K	23.16K	38.61K	64.20K	217.6K
15	16.43K	21.89K	36.49K	61.02K	206.2K
14	15.54K	20.70K	34.50K	58.01K	195.4K
13	14.70K	19.58K	32.63K	55.17K	185.2K
12	13.91K	18.52K	30.88K	52.48K	175.6K
11	13.16K	17.53K	29.23K	49.94K	166.6K
-10	12.46K	16.60K	27.67K	47.54K	158.0K
9	11.81K	15.72K	26.21K	45.27K	150.0K
8	11.19K	14.90K	24.83K	43.11K	142.4K
7	10.60K	14.12K	23.54K	41.07K	135.2K
6	10.05K	13.39K	22.32K	39.14K	128.5K
5	9534	12.70K	21.17K	37.31K	122.1K
4	9046	12.05K	20.08K	35.57K	116.0K
3	8586	11.44K	19.06K	33.93K	110.3K
2	8151	10.86K	18.10K	32.37K	104.9K
- 1	7741	10.31K	17.19K	30.89K	99.80K
0	7355	9796	16.33K	29.49K	94.98K
+ 1	6989	9310	15.52K	28.15K	90.41K
2	6644	8851	14.75K	26.89K	86.09K
3	6319	8417	14.03K	25.69K	81.99K
4	6011	8006	13.34K	24.55K	78.11K
5	5719	7618	12.70K	23.46K	74.44K
6	5444	7252	12.09K	22.43K	70.96K
7	5183	6905	11.51K	21.45K	67.66K
8	4937	6576	10.96K	20.52K	64.53K
9	4703	6265	10.44K	19.63K	61.56K
+10	4482	5971	9951	18.79K	58.75K
11	4273	5692	9486	17.98K	56.07K
12	4074	5427	9046	17.22K	53.54K
13	3886	5177	8628	16.49K	51.13K
14	3708	4939	8232	15.79K	48.84K
15	3539	4714	7857	15.13K	46.67K
16	3378	4500	7500	14.50K	44.60K
17	3226	4297	7162	13.90K	42.64K
18	3081	4105	6841	13.33K	40.77K
19	2944	3922	6536	12.79K	38.99K
+ 20	2814	3748	6247	12.26K	37.30K
21	2690	3583	5972	11.77K	35.70K
22	2572	3426	5710	11.29K	34.17K
23	2460	3277	5462	10.84K	32.71K
24	2354	3135	5225	10.41K	31.32K
25	2252	3000	5000	10.00K	30.00K
26	2156	2872	4787	9605	28.74K
27	2064	2750	4583	9227	27.54K
28	1977	2633	4389	8867	26.40K
29	1894	2523	4204	8523	25.31K
+ 30	1815	2417	4029	8194	24.27K
31	1739	2317	3861	7880	23.28K
32	1667	2221	3702	7579	22.33K
33	1599	2130	3549	7291	21.43K
34	1533	2042	3404	7016	20.57K
35	1471	1959	3266	6752	19.74K
36	1412	1880	3134	6500	18.96K
37	1355	1805	3008	6258	18.21K
38	1301	1733	2888	6026	17.49K
+ 39	1249	1664	2773	5805	16.80K

Notes: Data in white refers to thermistors with ±0.2°C interchangeability. Data in purple refer to thermistors with ±0.1°C interchangeability. Temperature/resistance figures are the same for both types. Only thermistors with ±0.2°C interchangeability are available encased in Teflon® as standard parts. For part no. of Teflon® encased thermistors add 100 to part no. of ±0.2°C interchangeable thermistors. Example: 44005 is a standard thermistor. 44105 is a Teflon® encased thermistor with the same resistance values..

Thermistor Resistance vs. Temperature

Model No.	44004 44033	44005 44030	44007 44034	44006 44031	44008 44032
Ω 25°C	2252	3000	5000	10,000	30,000
BODY	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE
END	YELLOW ORANGE	GREEN BLACK	VIOLET YELLOW	BLUE BROWN	GREY RED
TEMP. °C	RESISTANCE Ω				
+40	1200	1598	2663	5592	16.15K
41	1152	1535	2559	5389	15.52K
42	1107	1475	2459	5193	14.92K
43	1064	1418	2363	5006	14.35K
44	1023	1363	2272	4827	13.80K
45	983.8	1310	2184	4655	13.28K
46	946.2	1260	2101	4489	12.77K
47	910.2	1212	2021	4331	12.29K
48	875.8	1167	1944	4179	11.83K
49	842.8	1123	1871	4033	11.39K
+50	811.3	1081	1801	3893	10.97K
51	781.1	1040	1734	3758	10.57K
52	752.2	1002	1670	3629	10.18K
53	724.5	965.0	1608	3504	9807
54	697.9	929.6	1549	3385	9450
55	672.5	895.8	1493	3270	9109
56	648.1	863.3	1439	3160	8781
57	624.8	832.2	1387	3054	8467
58	602.4	802.3	1337	2952	8166
59	580.9	773.7	1290	2854	7876
+60	560.3	746.3	1244	2760	7599
61	540.5	719.9	1200	2669	7332
62	521.5	694.7	1158	2582	7076
63	503.3	670.4	1117	2497	6830
64	485.8	647.1	1079	2417	6594
65	469.0	624.7	1041	2339	6367
66	452.9	603.3	1006	2264	6149
67	437.4	582.6	971.1	2191	5940
68	422.5	562.9	938.0	2122	5738
69	408.2	543.7	906.3	2055	5545
+70	394.5	525.4	875.7	1990	5359
71	381.2	507.8	846.4	1928	5180
72	368.5	490.9	818.3	1868	5007
73	356.2	474.7	791.2	1810	4842
74	344.5	459.0	765.1	1754	4682
75	333.1	444.0	740.0	1700	4529
76	322.3	429.5	715.9	1648	4381
77	311.8	415.6	692.7	1598	4239
78	301.7	402.2	670.3	1549	4102
79	292.0	389.3	648.8	1503	3970
+80	282.7	376.9	628.1	1458	3843
81	273.7	364.9	608.2	1414	3720
82	265.0	353.4	588.9	1372	3602
83	256.7	342.2	570.4	1332	3489
84	248.6	331.5	552.6	1293	3379
85	240.9	321.2	535.4	1255	3273
86	233.4	311.3	518.8	1218	3172
87	226.2	301.7	502.8	1183	3073
88	219.3	292.4	487.4	1149	2979
89	212.6	283.5	472.6	1116	2887
+90	206.1	274.9	458.2	1084	2799
91	199.9	266.6	444.4	1053	2714
92	193.9	258.6	431.0	1023	2632
93	188.1	250.9	418.2	994.2	2552
94	182.5	243.4	405.7	966.3	2476
95	177.1	236.2	393.7	939.3	2402
96	171.9	229.3	382.1	913.2	2331
97	166.9	222.6	370.9	887.9	2262
98	162.0	216.1	360.1	863.4	2195
99	157.3	209.8	349.7	839.7	2131

Model No.	44004 44033	44005 44030	44007 44034	44006 44031	44008 44032
Ω 25°C	2252	3000	5000	10,000	30,000
BODY	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE	BLACK ORANGE
END	YELLOW ORANGE	GREEN BLACK	VIOLET YELLOW	BLUE BROWN	GREY RED
TEMP. °C	RESISTANCE Ω				
+100	152.8	203.8	339.6	816.8	2069
101	148.4	197.9	329.8	794.6	2009
102	144.2	192.2	320.4	773.1	1950
103	140.1	186.8	311.3	752.3	1894
104	136.1	181.5	302.5	732.1	1840
105	132.3	176.4	294.0	712.6	1788
106	128.6	171.4	285.7	693.6	1737
107	125.0	166.7	277.8	675.3	1688
108	121.6	162.0	270.1	657.5	1640
109	118.2	157.6	262.6	640.3	1594
+110	115.0	153.2	255.4	623.5	1550
111	111.8	149.0	248.4	607.3	1507
112	108.8	145.0	241.6	591.6	1465
113	105.8	141.1	235.1	576.4	1425
114	103.0	137.2	228.7	561.6	1386
115	100.2	133.6	222.6	547.3	1348
116	97.6	130.0	216.7	533.4	1311
117	95.0	126.5	210.9	519.9	1276
118	92.5	123.2	205.3	506.8	1241
119	90.0	119.9	199.9	494.1	1208
+120	87.7	116.8	194.7	481.8	1176
121	85.4	113.8	189.6	469.8	1145
122	83.2	110.8	184.7	458.2	1114
123	81.1	107.9	179.9	446.9	1085
124	79.0	105.2	175.3	435.9	1057
125	77.0	102.5	170.8	425.3	1029
126	75.0	99.9	166.4	414.9	1002
127	73.1	97.3	162.2	404.9	976.3
128	71.3	94.9	158.1	395.1	951.1
129	69.5	92.5	154.1	385.6	926.7
+130	67.8	90.2	150.3	376.4	903.0
131	66.1	87.9	146.5	367.4	880.0
132	64.4	85.7	142.9	358.7	857.7
133	62.9	83.6	139.4	350.3	836.1
134	61.3	81.6	136.0	342.0	815.0
135	59.8	79.6	132.6	334.0	794.6
136	58.4	77.6	129.4	326.3	774.8
137	57.0	75.8	126.3	318.7	755.6
138	55.6	73.9	123.2	311.3	736.9
139	54.3	72.2	120.3	304.2	718.8
+140	53.0	70.4	117.4	297.2	701.2
141	51.7	68.8	114.6	290.4	684.1
142	50.5	67.1	111.9	283.8	667.5
143	49.3	65.5	109.2	277.4	651.3
144	48.2	64.0	106.7	271.2	635.6
145	47.0	62.5	104.2	265.1	620.3
146	45.9	61.1	101.8	259.2	605.5
147	44.9	59.6	99.40	253.4	591.1
148	43.8	58.3	97.10	247.8	577.1
149	42.8	56.9	94.87	242.3	563.5
+150	41.9	55.6	92.70	237.0	550.2

Notes: Data in white refer to thermistors with ±0.2°C interchangeability.
Data in purple refer to thermistors with ±0.1°C interchangeability.
Temperature/resistance figures are the same for both types.
Only thermistors with ±0.2°C interchangeability are available encased in Teflon® as standard parts. For part no. of Teflon® encased thermistors add 100 to part no. of ±0.2°C interchangeable thermistors. Example: 44005 is a standard thermistor. 44105 is a Teflon® encased thermistor with the same resistance values.

Appendix
D

Bi-Metal thermometer data sheet

Bimetal Thermometer Accuracy Definitions

ASME B40.3* STANDARD ACCURACIES:

Example #1: Range 0/250°F Grade A
Span = 250-0 = 250°F
Accuracy at 20% of span (50°F) = ±1% = ±2.5°F
Accuracy at 50% of span (125°F) = ±1% = ±2.5°F
Accuracy at 100% of span (250°F) = ±1% = ±2.5°F

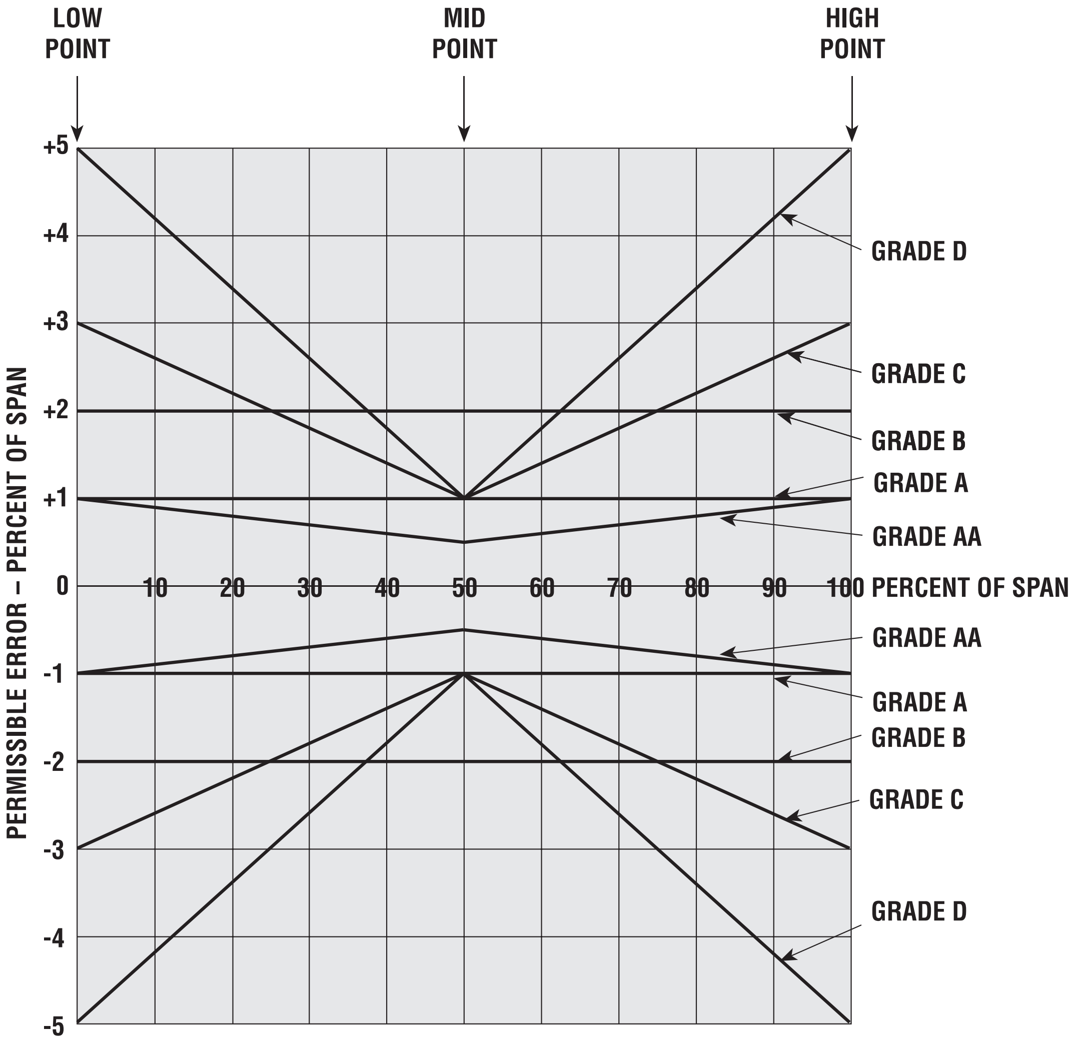
Example #2: –40/160°F Grade E
Span = 160-(–40) = 200°F
Accuracy at 20% of span (0°F) = ±3.4% = ±6.8°F
Accuracy at 50% of span (60°F) = ±1% = ±2.0°F
Accuracy at 100% of span (160°F) = ±5% - ±10.0°F

Example #3: Range 50/300°F Grade AA
Span = 300-(–50) = 250°F
Accuracy at 0% of span (50°F) = ±1% = ±2.5°F
Accuracy at 50% of span (175°F) = ±0.5% = ±1.25°F
Accuracy at 70% of span (225°F) = ±0.7% = ±1.75°F

ACCURACY:

Thermometer accuracy is graded as shown in the table below. Adjustment of the case of a thermometer, with an adjustable angle connection, may affect its accuracy. This effect should not exceed 0.5% of span .

*ASME B40.3 may be ordered from:
American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016



Appendix E

Thermocouple coefficients listing

NIST Thermocouple coefficients.

http://www.temperatures.com/tctables.html

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************************************
* This section contains coefficients for type K thermocouples for
* the two subranges of temperature listed below.  The coefficients
* are in units of °C and mV and are listed in the order of constant
* term up to the highest order.  The equation below 0 °C is of the form
* E = sum(i=0 to n) c_i t^i.
*
* The equation above 0 °C is of the form
* E = sum(i=0 to n) c_i t^i + a0 exp(a1 (t - a2)^2).
*
*     Temperature Range (°C)
*        -270.000 to 0.000
*         0.000 to 1372.000
************************************
name: reference function on ITS-90
type: K
temperature units: °C
emf units: mV
range: -270.000, 0.000, 10
  0.000000000000E+00
  0.394501280250E-01
  0.236223735980E-04
 -0.328589067840E-06
 -0.499048287770E-08
 -0.675090591730E-10
 -0.574103274280E-12
 -0.310888728940E-14
 -0.104516093650E-16
 -0.198892668780E-19
 -0.163226974860E-22
range: 0.000, 1372.000, 9
 -0.176004136860E-01
  0.389212049750E-01
  0.185587700320E-04
 -0.994575928740E-07
  0.318409457190E-09
 -0.560728448890E-12
  0.560750590590E-15
 -0.320207200030E-18
  0.971511471520E-22
 -0.121047212750E-25
exponential:
 a0 =  0.118597600000E+00
 a1 = -0.118343200000E-03
 a2 =  0.126968600000E+03
```

```
************************************
* This section contains coefficients of approximate inverse
* functions for type K thermocouples for the subranges of
* temperature and voltage listed below. The range of errors of
* the approximate inverse function for each subrange is also given.
* The coefficients are in units of °C and mV and are listed in
* the order of constant term up to the highest order.
* The equation is of the form t_90 = d_0 + d_1*E + d_2*E^2 + ...
*     + d_n*E^n,
* where E is in mV and t_90 is in °C.
*
*    Temperature        Voltage            Error
*      range              range            range
*      (°C)               (mV)             (° C)
*    -200. to 0.      -5.891 to 0.000    -0.02 to 0.04
*     0. to 500.      0.000 to 20.644    -0.05 to 0.04
*     500. to 1372.   20.644 to 54.886   -0.05 to 0.06
********************************************************
Inverse coefficients for type K:

Temperature  -200.             0.           500.
  Range:        0.           500.          1372.

  Voltage   -5.891          0.000         20.644
  Range:     0.000         20.644         54.886

         0.0000000E+00  0.000000E+00 -1.318058E+02
         2.5173462E+01  2.508355E+01  4.830222E+01
        -1.1662878E+00  7.860106E-02 -1.646031E+00
        -1.0833638E+00 -2.503131E-01  5.464731E-02
        -8.9773540E-01  8.315270E-02 -9.650715E-04
        -3.7342377E-01 -1.228034E-02  8.802193E-06
        -8.6632643E-02  9.804036E-04 -3.110810E-08
        -1.0450598E-02 -4.413030E-05  0.000000E+00
        -5.1920577E-04  1.057734E-06  0.000000E+00
         0.0000000E+00 -1.052755E-08  0.000000E+00

  Error      -0.02          -0.05          -0.05
  Range:      0.04           0.04           0.06




 ************************************
* This section contains coefficients for type K thermocouples for
* the two subranges of temperature listed below.  The coefficients
* are in units of °C and mV and are listed in the order of constant
* term up to the highest order.  The equation below 0 °C is of the form
* E = sum(i=0 to n) c_i t^i.
*
* The equation above 0 °C is of the form
* E = sum(i=0 to n) c_i t^i + a0 exp(a1 (t - a2)^2).
*
*     Temperature Range (°C)
*        -270.000 to 0.000
```

```
*         0.000 to 1372.000
************************************
name: reference function on ITS-90
type: K
temperature units: °C
emf units: mV
range: -270.000, 0.000, 10
  0.000000000000E+00
  0.394501280250E-01
  0.236223735980E-04
 -0.328589067840E-06
 -0.499048287770E-08
 -0.675090591730E-10
 -0.574103274280E-12
 -0.310888728940E-14
 -0.104516093650E-16
 -0.198892668780E-19
 -0.163226974860E-22
range: 0.000, 1372.000, 9
 -0.176004136860E-01
  0.389212049750E-01
  0.185587700320E-04
 -0.994575928740E-07
  0.318409457190E-09
 -0.560728448890E-12
  0.560750590590E-15
 -0.320207200030E-18
  0.971511471520E-22
 -0.121047212750E-25
exponential:
 a0 =  0.118597600000E+00
 a1 = -0.118343200000E-03
 a2 =  0.126968600000E+03



************************************
* This section contains coefficients of approximate inverse
* functions for type K thermocouples for the subranges of
* temperature and voltage listed below. The range of errors of
* the approximate inverse function for each subrange is also given.
* The coefficients are in units of °C and mV and are listed in
* the order of constant term up to the highest order.
* The equation is of the form t_90 = d_0 + d_1*E + d_2*E^2 + ...
*     + d_n*E^n,
* where E is in mV and t_90 is in °C.
*
*    Temperature        Voltage            Error
*      range              range            range
*      (°C)               (mV)             (° C)
*    -200. to 0.      -5.891 to 0.000    -0.02 to 0.04
*     0. to 500.      0.000 to 20.644    -0.05 to 0.04
*     500. to 1372.   20.644 to 54.886   -0.05 to 0.06
********************************************************
Inverse coefficients for type K:
```

```
Temperature  -200.            0.           500.
  Range:        0.          500.          1372.

  Voltage   -5.891          0.000         20.644
  Range:     0.000         20.644         54.886

         0.0000000E+00  0.000000E+00 -1.318058E+02
         2.5173462E+01  2.508355E+01  4.830222E+01
        -1.1662878E+00  7.860106E-02 -1.646031E+00
        -1.0833638E+00 -2.503131E-01  5.464731E-02
        -8.9773540E-01  8.315270E-02 -9.650715E-04
        -3.7342377E-01 -1.228034E-02  8.802193E-06
        -8.6632643E-02  9.804036E-04 -3.110810E-08
        -1.0450598E-02 -4.413030E-05  0.000000E+00
        -5.1920577E-04  1.057734E-06  0.000000E+00
         0.0000000E+00 -1.052755E-08  0.000000E+00

  Error      -0.02          -0.05          -0.05
  Range:      0.04           0.04           0.06


 ************************************
* This section contains coefficients for type J thermocouples for
* the two subranges of temperature listed below.  The coefficients
* are in units of °C and mV and are listed in the order of constant
* term up to the highest order.  The equation is of the form
* E = sum(i=0 to n) c_i t^i.
*
*     Temperature Range (°C)
*        -210.000 to 760.000
*         760.000 to 1200.000
************************************
name: reference function on ITS-90
type: J
temperature units: °C
emf units: mV
range:  -210.000,    760.000,  8
 0.000000000000E+00
 0.503811878150E-01
 0.304758369300E-04
-0.856810657200E-07
 0.132281952950E-09
-0.170529583370E-12
 0.209480906970E-15
-0.125383953360E-18
 0.156317256970E-22
range:   760.000,   1200.000,  5
 0.296456256810E+03
-0.149761277860E+01
 0.317871039240E-02
-0.318476867010E-05
 0.157208190040E-08
-0.306913690560E-12
```

```
************************************
* This section contains coefficients of approximate inverse
* functions for type J thermocouples for the subranges of
* temperature and voltage listed below. The range of errors of
* the approximate inverse function for each subrange is also given.
* The coefficients are in units of °C and mV and are listed in
* the order of constant term up to the highest order.
* The equation is of the form t_90 = d_0 + d_1*E + d_2*E^2 + ...
*     + d_n*E^n,
* where E is in mV and t_90 is in °C.
*
*    Temperature        Voltage            Error
*      range              range            range
*      (°C)               (mV)             (° C)
*    -210. to 0.      -8.095 to 0.000    -0.05 to 0.03
*     0. to 760.       0.000 to 42.919   -0.04 to 0.04
*     760. to 1200     42.919 to 69.553  -0.04 to 0.03
********************************************************
Inverse coefficients for type J:

Temperature  -210.             0.           760.
  Range:        0.           760.          1200.

  Voltage   -8.095          0.000         42.919
  Range:     0.000         42.919         69.553

         0.0000000E+00  0.000000E+00 -3.11358187E+03
         1.9528268E+01  1.978425E+01  3.00543684E+02
        -1.2286185E+00 -2.001204E-01 -9.94773230E+00
        -1.0752178E+00  1.036969E-02  1.70276630E-01
        -5.9086933E-01 -2.549687E-04 -1.43033468E-03
        -1.7256713E-01  3.585153E-06  4.73886084E-06
        -2.8131513E-02 -5.344285E-08  0.00000000E+00
        -2.3963370E-03  5.099890E-10  0.00000000E+00
        -8.3823321E-05  0.000000E+00  0.00000000E+00

  Error      -0.05          -0.04          -0.04
  Range:      0.03           0.04           0.03
```