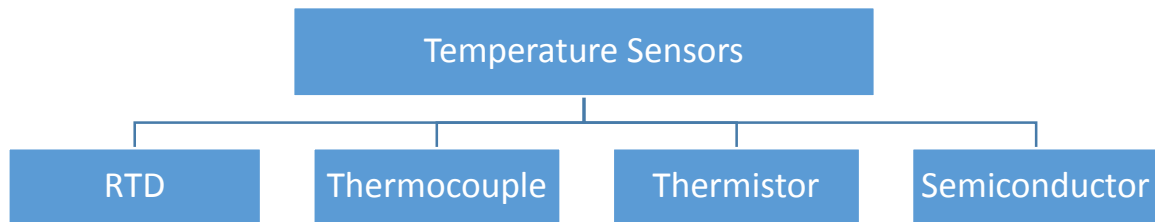
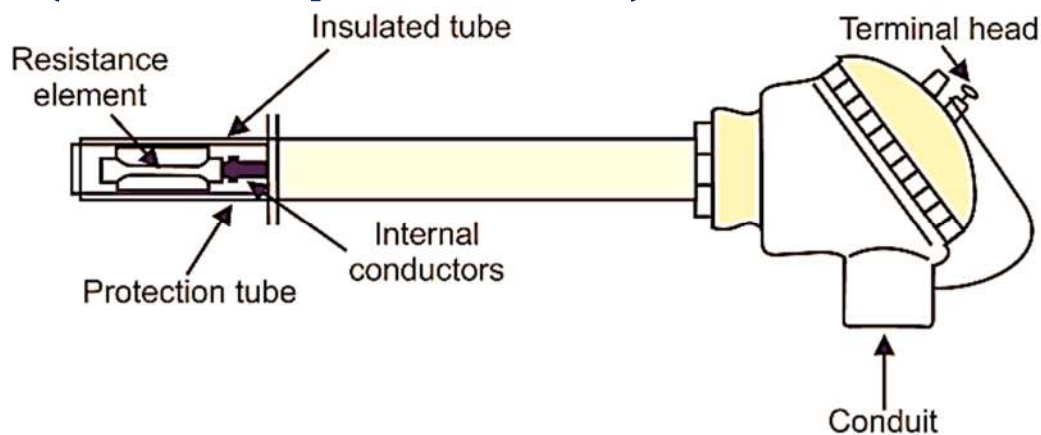


④ Temperature Measurements

Temperature is one of the most common process variables measured in industries.



➤ RTD (Resistive Temperature Detector):



- The RTD wire is a pure material (platinum, nickel, copper) which change their electrical resistance as a function of temperature.
- RTD is a passive device (Need external electrical current).
- Type: [PT100 , PT300 , PT1000 ,].

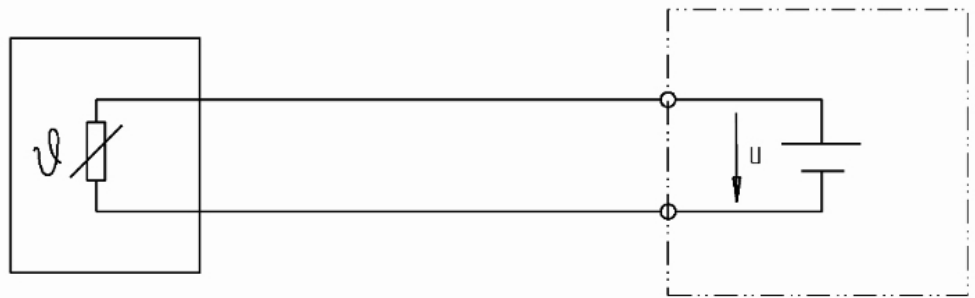
❖ PT100:

- Mean : 100 ohm at 0 °C
- Type: 2 wire , 3 wires , 4 wires
- $R = R_0(1 + \alpha T)$
 $R_0 = 100$, $\alpha = 0.0038$
1 (ohm) = 2.5 °C (above 100 ohm)
#110 ohm >>> $10 * 2.5 = 25$ °C

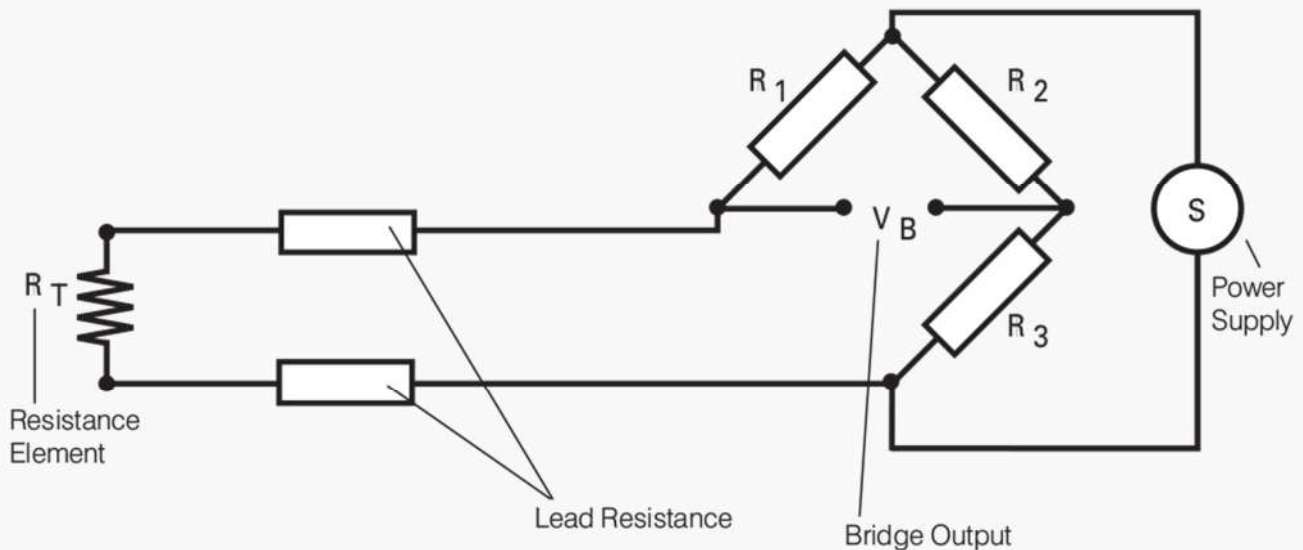


PT100 in 2-wire connection

With a 2-wire connection, the resistance of the cable is added as an error in the measurement.

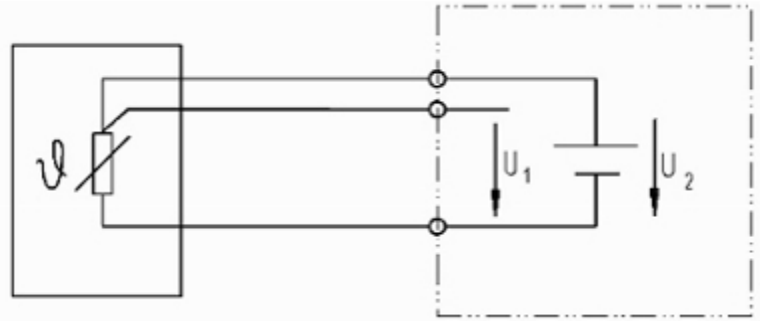


The simple two wire RTD connection shown in Figure is used only where high accuracy is not essential - the resistance of the connecting wires is always included with that of the sensor, leading to errors in the signal (resistance of element + lead resistance, usually copper). In fact, a standard restriction with this installation is a maximum of 1 - 2 ohms resistance per conductor - which is typically about 300 feet of cable. This applies equally to balanced bridge and fixed bridge systems. The values of the lead resistance can only be determined in a separate measurement (without the RTD sensor) and therefore a continuous correction during the temperature measurement is not possible.



PT100 in 3-wire connection

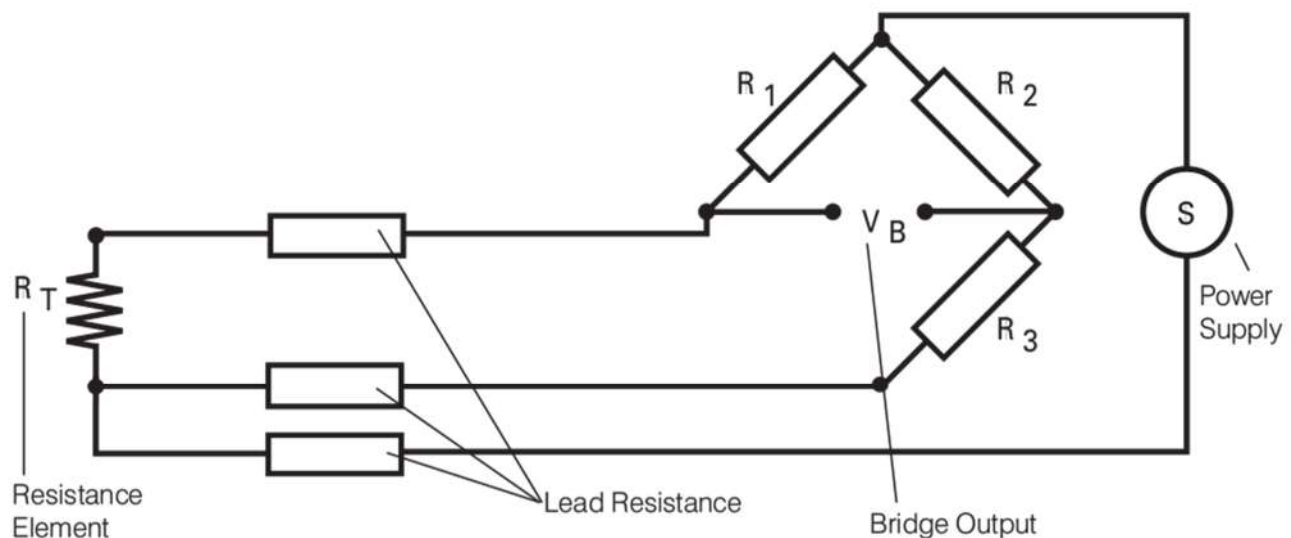
The influence of the lead resistance is compensated to the greatest possible extent with a 3-wire connection.



A better wiring configuration is shown in Figure In this RTD circuit diagram, the two leads of the sensor are on adjoining legs. Although there is lead resistance in each leg of the bridge, the lead resistance is cancelled out from the measurement. It is assumed that the two lead resistances are equal, therefore demanding high quality connection cables. This allows an increase to 10 ohms - usually allowing cable runs of around 1500 feet or more, if necessary.

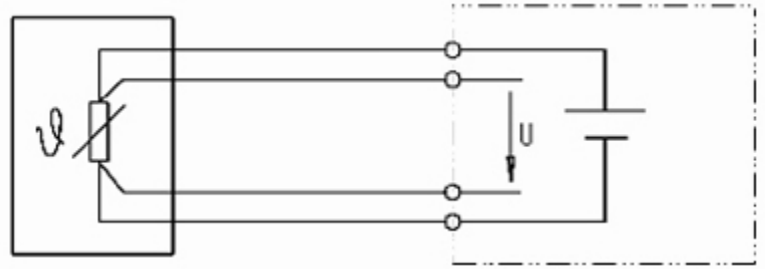
Also, with this wiring configuration, if fixed bridge measurement is being made, compensation is clearly only good at the bridge balance point. Beyond this, errors will grow as the imbalance increases. This, however, can be minimized by using larger values of resistance in the opposite bridge circuits to reduce bridge current changes.

The pt100 3 wire configuration is very popular for general industrial applications and is widely used in terminal heads when used with 4 to 20mA current transmitters and where dual element duplex sensors are used.



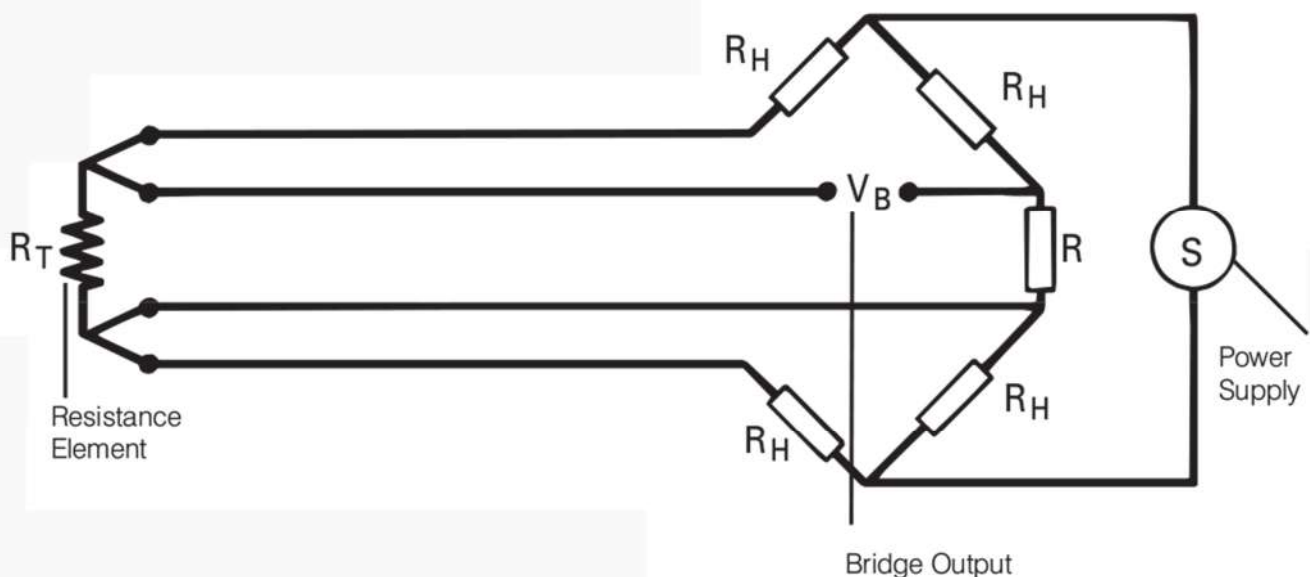
Pt100 in 4-wire connection

The 4-wire connection completely eliminates the influence of the connection lead on the measuring result since any possible asymmetries in the lead resistance of the connection lead are also compensated.



The best wiring arrangement is the four wire configuration as depicted in figure. This provides for full cancellation of spurious effects with the bridge type measuring technique. Cable resistance of up to 15 ohms can be handled with this arrangement, accommodating cable runs of around 3,000 feet. Incidentally, the same limitation as for three wire connections applies if the fixed-bridge, direct-reading approach is being used.

The resistance thermometer can also be energized from a constant current source, and the potential difference developed across it measured directly by some kind of potentiometer. An immediate advantage is that here, incidentals like conductor resistance and selector switch contact resistance are irrelevant. The essentials for this voltage-based method are simply a stabilized and accurately known current supply for the RTD sensor (giving a direct relationship of voltage to resistance and thus to temperature) and a high impedance voltmeter (DVM, or whatever) to measure the voltage developed with negligible current flow.

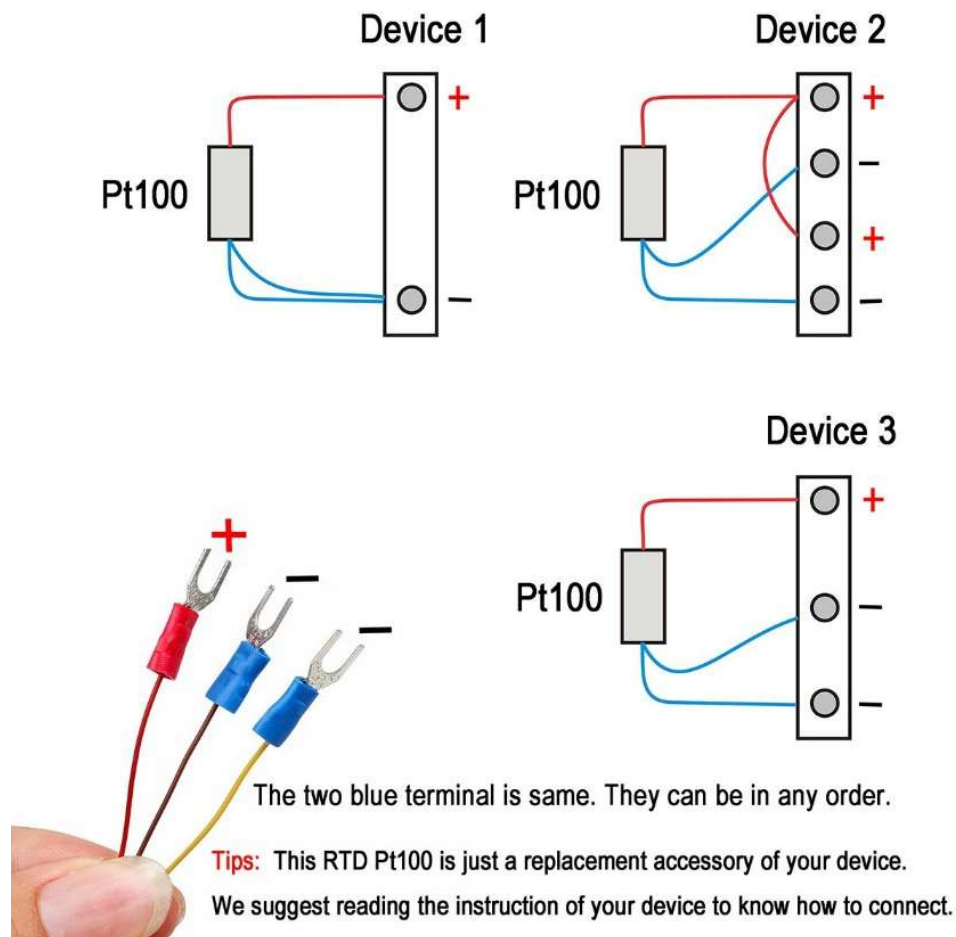


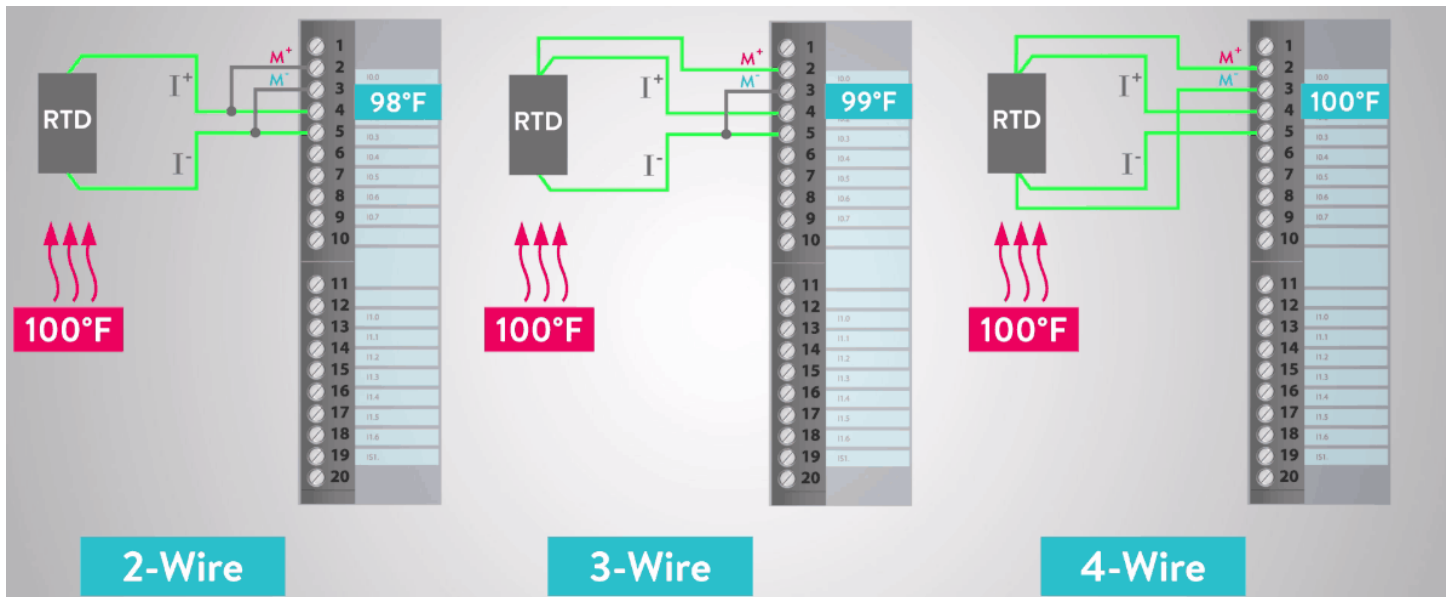
❖ Example: Measuring error at 150 °C, cable length 10 m, conductor cross-section 0.22 mm²:

Measuring element	Connection method	Tolerance class	Measuring error in °C
Pt100	2-wire	B	5,25
	2-wire	A	4,65
	4-wire	B	1,05
	4-wire	A	0,45
Pt1000	2-wire	B	1,47
	2-wire	A	0,87
	4-wire	B	1,05
	4-wire	A	0,45

Conclusion

- The highest measurement accuracies are only achievable with a Pt100 in a 4-wire connection.
- A Pt1000 measuring element in class A also offers good measurement accuracies in a 2-wire connection and represents an economical alternative to 3- or 4-wire connections for machine building.

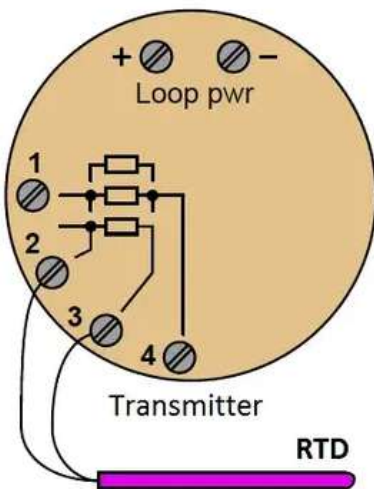




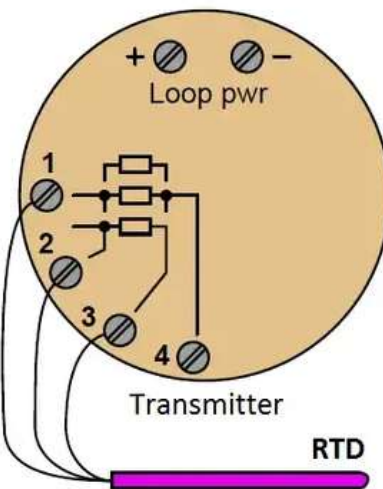
- What happen if we connect PT100(2-wires) far from controller?
Error occurs because of cable resistance.
 - ✓ Use 3 – 4 wires .
 - ✓ Use temperature transmitter.
- What happen if we connect PT100(3-wires) to 4-wire controller?
 - ✓ make bridge near to sensor **NOT** near the controller.
- What happen if we connect PT100(2-wires) to 4-wire temperature transmitter?
 - ✓ make junction as close to the sensor as possible.

➤ RTD Sensor Connections :

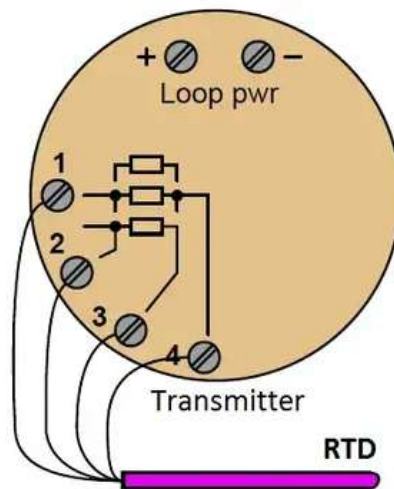
Transmitter Connection to
2 Wire RTD



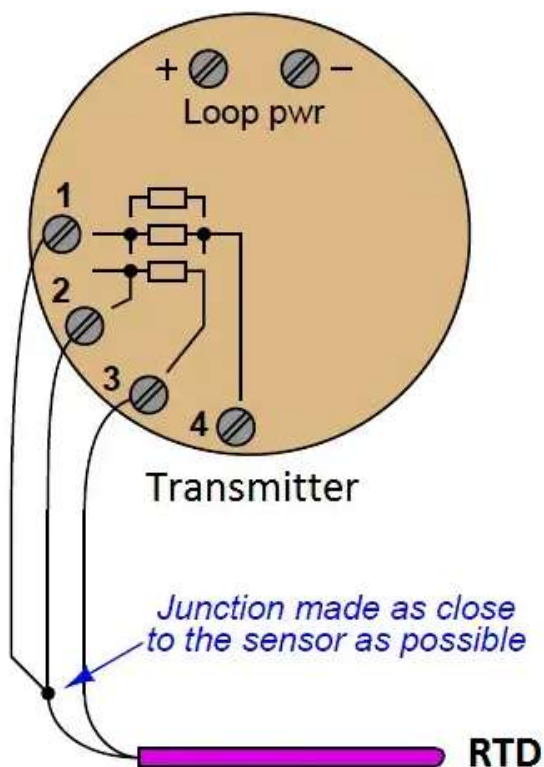
Transmitter Connection to
3 Wire RTD



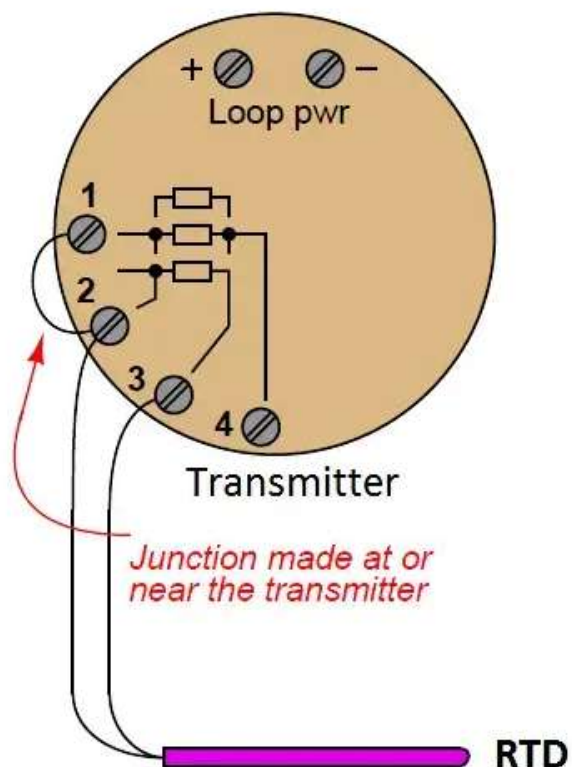
Transmitter Connection to
4 Wire RTD



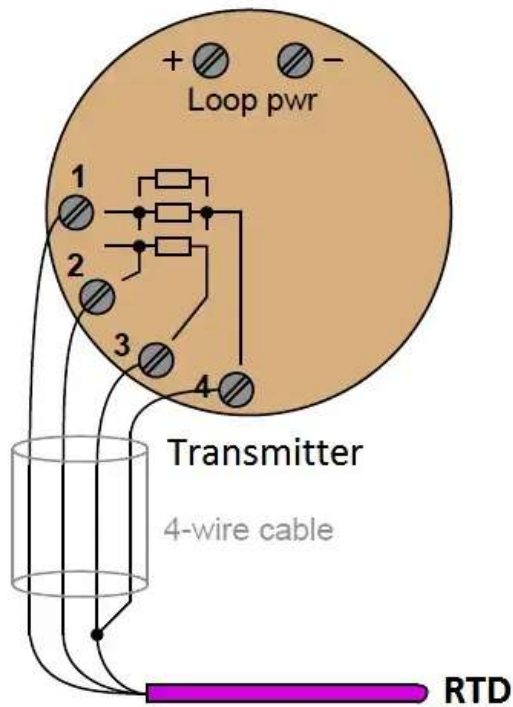
Correct way to use a 3-wire
transmitter on a 2-wire RTD



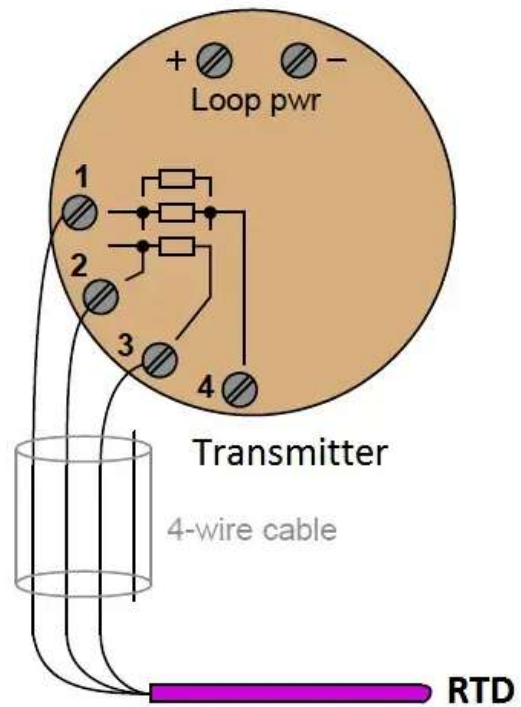
Incorrect way to use a 3-wire
transmitter on a 2-wire RTD



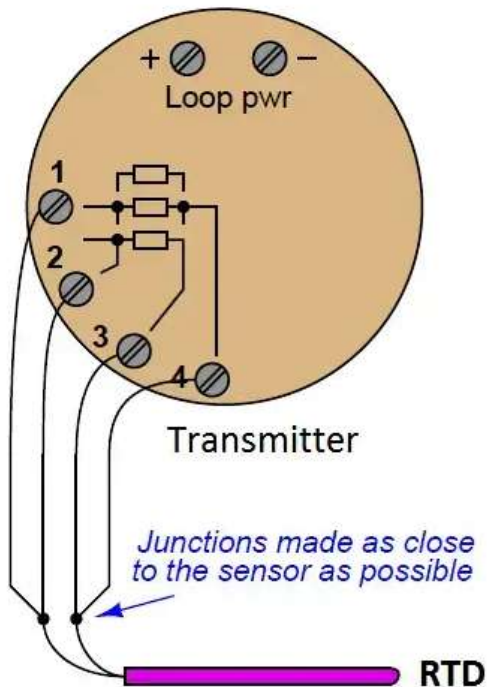
Correct way to use a 4-wire transmitter on a 3-wire RTD



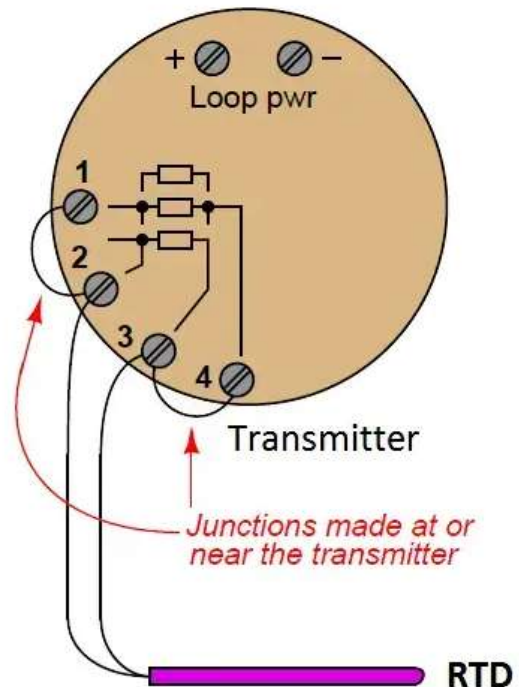
Correct way to use a 3-wire transmitter on a 3-wire RTD



Correct way to use a 4-wire transmitter on a 2-wire RTD

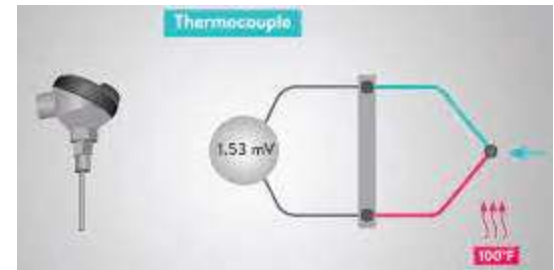


Incorrect way to use a 4-wire transmitter on a 2-wire RTD



➤ TC (thermocouples):

It's a simple device consisting of two dissimilar wires joined at their ends, it generate (mv) when heat is applied to hot junction.



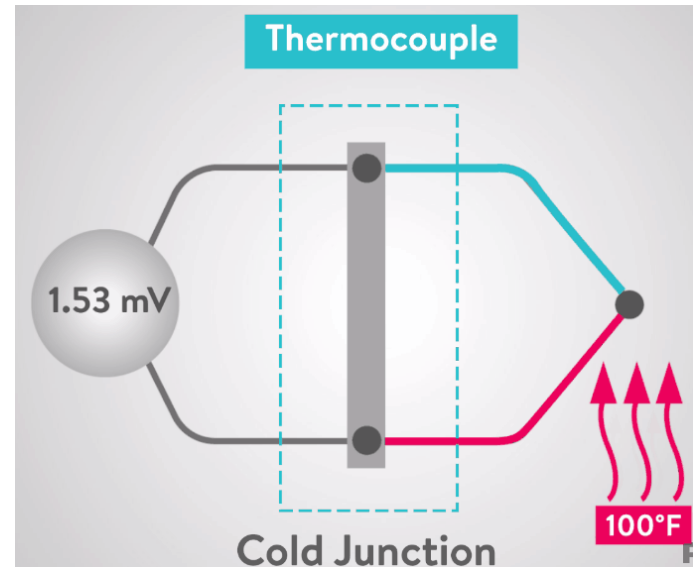
➤ Common Thermocouple Types

ANSI Code	ANSI MC 96.1 Color Coding		Alloy Combination		Maximum T/C Grande temp. range	EMF(mv)Over Max.temp.range	IEC 584-3 Color Coding	IEC Code
	Thermocouple	Extension	+ Lead	- Lead				
K			NICKEL-CHROMIUM Ni-Cr	NICKEL-ALUMINUM Ni-Al	-270 to 1372°C -454 to 2501°F	-8.458 to 54.886		K
J			IRON Fe (magnetic)	CONTANTAN COOPER-NICKEL Cu-Ni	-210 to 1200°C -346 to 2193°F	-8.095 to 69.553		J
T			COPPER Cu	CONTANTAN COOPER-NICKEL Cu-Ni	-270 to 400°C -454 to 752°F	-6.258 to 20.872		T
E			NICKEL-CHROMIUM Ni-Cr	CONTANTAN COOPER-NICKEL Cu-Ni	-270 to 1000°C -454 to 1832°F	-9.835 to 76.373		E
N			NICROSIL Ni-Cr-Si	NISIL Ni-Si-Mg	-270 to 1300°C -450 to 2372°F	-4.345 to 47.513		N
S	NONE ESTABLISHED		PLATINUM-10% RHODIUM Pt-10%Rh	PLATINUM Pt	-50 to 1768°C -58 to 3214°F	-0.236 to 18.693		S
R	NONE ESTABLISHED		PLATINUM-13% RHODIUM Pt-13%Rh	PLATINUM Pt	-50 to 1768°C -58 to 3214°F	-0.226 to 21.101		R
B	NONE ESTABLISHED		PLATINUM-30% RHODIUM Pt-30%Rh	PLATINUM-6% RHODIUM Pt-6%Rh	0 to 1820°C 32 to 3308°F	0 to 13.820		B

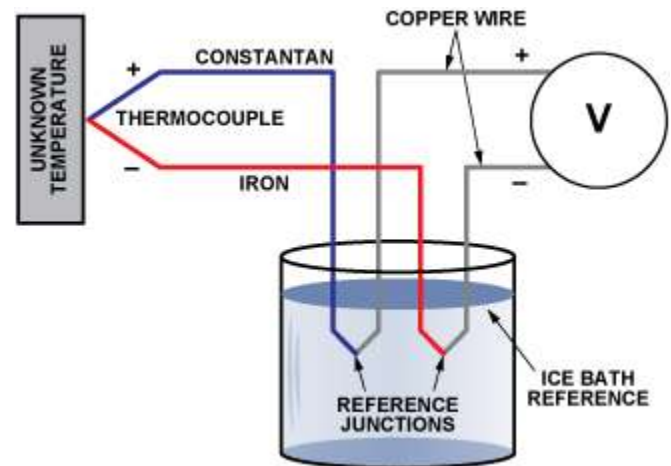
International Type Designation	Conductor Material		Temperature range (°C)
K	Ni-Cr	(+)	0 to +1100
	Ni-Al	(-)	
T	Cu	(+)	-185 to +300
	Cu-Ni	(-)	
J	Fe	(+)	+20 to +700
	Cu-Ni	(-)	
E	Ni-Cr	(+)	0 to +800
	Cu-Ni	(-)	
N	Ni-Cr-Si	(+)	0 to +1250
	Ni-Si	(-)	

➤ Reference(cold) junction:

- ❖ Tc has two junctions; the difference in temperature of these junctions is what is used to measure temperature.
- ❖ Cold junction is located in a transmitter or signal conditioner.
- ❖ The voltage measured at cold junction directly affects the temperature difference between the hot & cold junction.
- ❖ Therefore, the temperature at cold junction should be known; and the process to determine exact cold junction temperature is known as (cold junction compensation).
- ❖ cold junction compensation can be performed by either the temperature transmitter, TC input card for DSC or PLC, alarm trip or other signal conditioner.



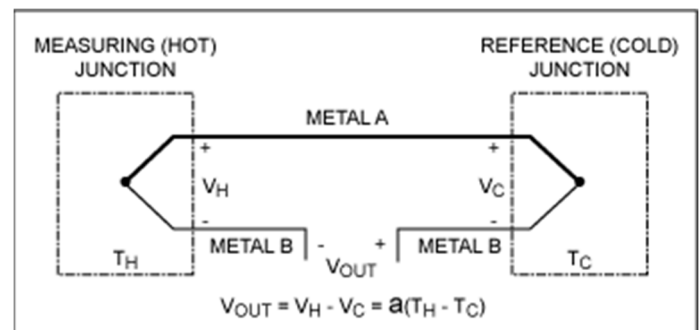
The simplest case occurs when the cold junction is at 0°C, also known as an ice-bath reference. If $T_c = 0^\circ\text{C}$, then $V_{\text{OUT}} = V_H$. In this case, the voltage measured at the hot junction is a direct translation of the actual temperature at that junction.



$$V_{\text{out}} = V_H - V_C$$

$$= \alpha (T_H - T_C)$$

The scale factor (α) which relates the voltage difference to the temperature difference, is known as the Seebeck coefficient.



➤ Do I need an RTD Sensor or a Thermocouple?

Whether you choose a thermocouple or an RTD Pt100 sensor depends on the application and measurement requirements (accuracy, speed of response, temperature range etc.) of the user. It is not a case of one being better than the other as both thermocouples and RTD Sensors have their own merits and uses.

Temperature Range: Thermocouples have a wider temperature range than RTD Sensors, with some able to measure temperatures up to 2900°F and beyond. For most industrial applications RTD Sensors are limited to 1100°F and more often to 480°F.

Accuracy: If high accuracy is of most importance, then a Pt100, which is the most common RTD sensor in general use, is the better choice.. Even the least accurate Pt100 (Class B) will usually be more accurate than a thermocouple. Pt100s are available with very high accuracies, 1/10 DIN elements for example, have an accuracy of $\pm 0.03^{\circ}\text{C}$ at 0°C .

Stability: Thermocouples tend to drift over time due to chemical changes such as oxidation, whereas measurements from RTD Pt100 sensors are stable and repeatable if the sensor is kept within the temperature range of the RTD sensor.

Response Times: Whilst ever smaller diameters have improved RTD response times considerably, thermocouples, especially with a grounded or exposed junction, are still very much faster in response to changes in temperature.

Durability: Because of the more fragile nature of Pt100 elements, thermocouples are considered more rugged and durable especially for high vibration applications where Pt100 sensors are not suitable. In summary, a thermocouple is a simple rugged sensor that can withstand significantly more mechanical abuse than a Pt100.

Cost: Thermocouples are generally less expensive to manufacture and have lower material costs, except for the cabling where thermocouple wires are slightly more expensive than the copper wires used for RTD sensors.

Advantages and Disadvantages of RTD Sensors and Thermocouples

Sensor Type	Advantages	Disadvantages
RTD Pt100	High Accuracy High stability Highly repeatable	Passive Low vibration resistance Slower response Low range (Motor winding)
Thermocouple	Wide Temperature Range(Boiler) Fast response Very small size Low cost	Less accurate Less stable Long term drift

➤ Temperature Gauge:

A temperature gauge is a device used for the accurate measurement and reading of temperature gradient. The term temperature gauge usually, though not always, refers to a device showing readings on a numbered dial.

Dial thermometer gauges are often found in industrial and commercial settings. They are also common in certain everyday domestic settings and appliances.

Temperature measurement gauges fall into two broad categories - contact thermometers, and non-contact thermometers. People often buy a temperature gauge to help monitor ambient temperatures at the mounting location. These are non-contact sensors.

Certain types of contact temperature gauge are also designed to be coupled with a probe or thermistor. These can then be used to check the surface or inner temperature of an object or medium they are in direct contact with, such as a water temperature gauge.



Analog

Digital



Temperature gauges measure the thermal state of a homogeneous substance. The measuring system must be brought as closely together as possible with the body to be measured. The most widely used measuring methods for temperature measurement rely on temperature-dependent characteristics of the body and substance.

➤ Temperature Switch:

A mechanical device that is used to monitor and control the temperature in manufacturing and industrial processes by turning ON & OFF switch contacts once a fixed temperature range is reached is known as a temperature switch. This switch is a small and cost-effective solution to measure temperature within moveable & space-constrained applications. The temperature switch symbol is shown.

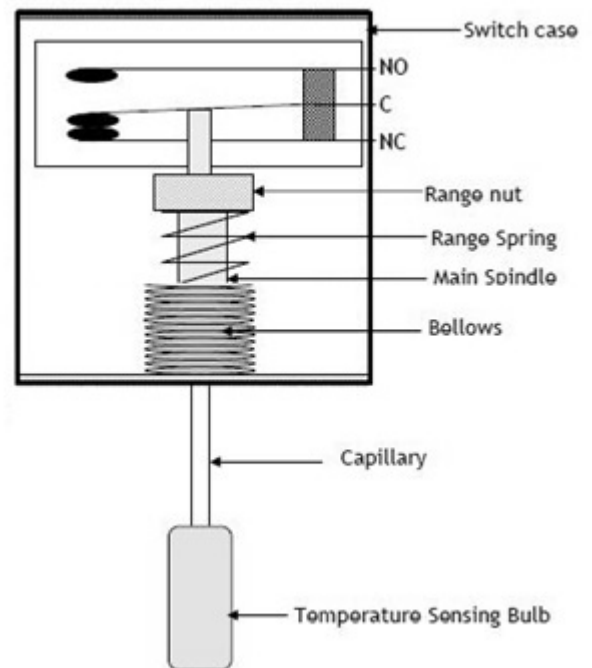


The switching condition of these switches mainly changes based on the input temperature. So this function is used as protection from overheating. So, these switches are mainly responsible for monitoring the temperature of equipment & machinery.

Temperature Switch Construction

The different components used in this switch mainly include switch case, range nut, range spring, main spindle, bellows, capillary, and temperature sensing bulb. The construction diagram of the temperature switch is shown below.

As shown in the above diagram, the fluid within the temperature sensing bulb responds to variations in temperature. Once temperature increases, the pressure within the bellows increases. So the increase in the temperature sensing bulb will compress the bellows & moves the spindle up until the force of spring as well as the pressure of bellows are in equilibrium. The spindle movement is moved toward the switch & causes ON & OFF action based on the set point of the switch.



Working Principle

The working of a temperature switch mainly depends on the variations of temperature taking place within an enclosed space. The function of a temperature switch is to trigger when changes in temperature occur.

Once the sensing probe in this switch detects an increase in temperature, then it opens the electric contacts. Similarly, if the switch detects a decrease in temperature then electrical

contacts will be closed. So these variations in temperature can be used to activate a switching mechanism.

Specifications

The temperature switch specifications include the following:

- Voltage supply ranges from 12 to 30VDC.
- Its accuracy is $\pm 0.1\%FS$ $\pm 0.3\%FS$ $\pm 0.5\%FS$.
- Pressure resistance typically min 40bar to max 300bar.
- Long-term stability (1 year): $\pm 0.1\%FS$
- Response time $T=90^{\circ}C$ at 5.4s and $T=50^{\circ}C$ at 2.3s.

Temperature Switch Types

These switches are categorized into two types mechanical temperature switches and electronics temperature switches.

Mechanical Temperature Switches

Mechanical temperature switches are available in two types bimetallic and liquid expansion temperature switches which are used for measuring or detecting the change in temperature.

The advantages of a liquid expansion thermometer include less cost, compact size, and more accurate whereas the disadvantages are; that response time is high, leakage occurs, resistant to temperature & shock, etc.

Electronic Temperature Switch

This temperature switch mainly includes a power supply source, measuring element, and electronic circuit. This switch is used to measure temperature by changing it into a switching signal through the change in temperature of the measuring element. This switching signal changes in proportion to the temperature & can be calculated accordingly. Electronic temperature switches are applicable where high accuracy is necessary.

Temperature Switch Vs Thermostat

The difference between a temperature switch and a thermostat includes the following:

Temperature Switch	Thermostat
The temperature switch is also known as a thermal switch.	The thermostat is also known as an indicator or thermometer.
The main function of this switch is to measure temperature.	A thermostat device's function is to regulate temperature,
This switch is a bi-stable electromechanical device.	This is a closed-loop control device.
Generally, these switches are classified into two types electronic and mechanical.	Thermostats are classified into three types programmable, non-programmable and smart.
This switch includes two main parts like sensing part and snap-action contacts.	The thermostat includes different parts like flange, frame, housing, and wax element.

What is the Purpose of Temperature Switch?

The main purpose of the temperature switch is to monitor the temperature of machinery & equipment. These are used to limit temperature in industries and protect machinery from overheating.

What is the Deadband of Temperature Switch?

The deadband of the temperature switch is the difference within temperature between the increased set point & decreased set point.

Are Temperature Switches Normally Open or Closed?

When the temperature switch is Normally Open (NO), then the switch contacts are NO normally open at minimum temperature. Similarly, Normally Closed (NC) means that the switch contacts are NC at minimal temperature.

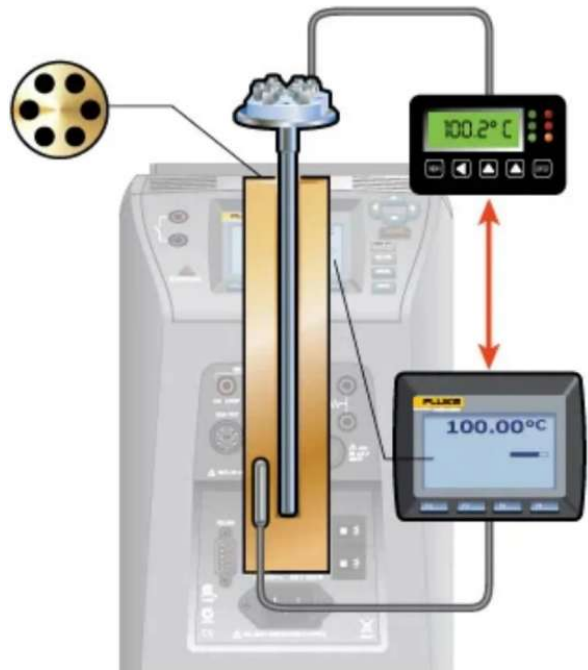
This switch gets activated by a change in temperature & changes its condition from NO to close or from NC to open. The NO thermal switch contacts usually stay open which will close with the increase in temperature.

Simulating thermocouples and RTDs for calibration and testing :

Thermocouples and RTDs are the most common sensors used in process temperature measurements.

Simulating a process sensor signal into a process instrument or control system input enables a technician to verify whether the device responds correctly to the temperature measured by the instrument. There are many ways to perform RTD and thermocouple simulation for testing purposes.

You can use a mV dc source and a mV vs temperature look up table for simulating thermocouples or a resistance decade box and resistance vs temperature look up table for simulating RTDs. This method, however, has become outdated with modern temperature calibrators that do the conversion for the user. With modern calibrators, simply select the sensor type to simulate, input the temperature to source and connect to the devices under test.



How to perform the test via RTD and thermocouple simulation?

To use a thermocouple simulator to test a device with a thermocouple input:

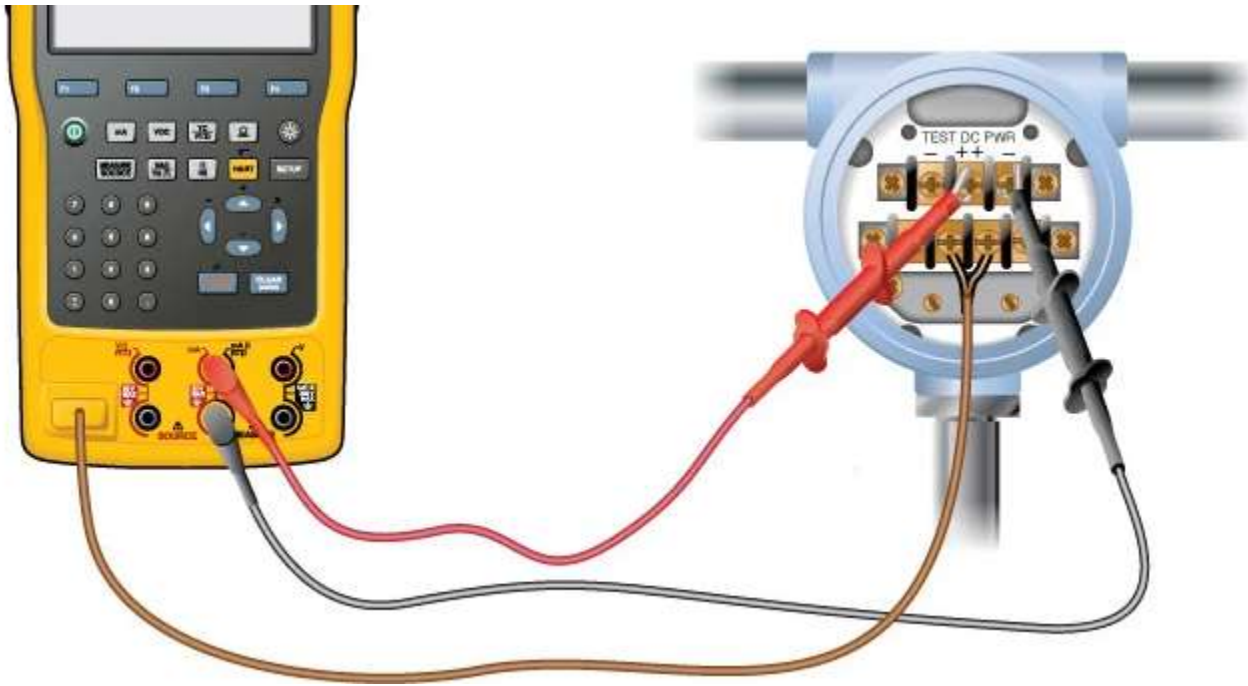
1. Disconnect the process measurement sensor and connect the test connection wires in its place (Figure A).
2. Connect the mini connector from the test wires to the TC source connection of the calibrator.
3. Connect a DMM or other measurement tool to the tested device's mA output.
4. Verify the devices range or span. Apply the 0% value with the simulator and verify with the DMM that the output mA value or voltage is as expected.
5. Repeat the test, applying the 50% and 100% temperature signals.
6. If the measured output of the device is within limits, the test is complete. If not, adjust the device at zero (offset, 0%) and span (gain, 100%).
7. Repeat steps 4 and 5 and verify for a correct response.

To use an RTD simulator to test a device with an RTD input:

1. Connect the calibrator to the device input as shown in figure B.
2. Connect the calibrator output with the right combination to match the device configuration (2, 3 or 4-wire).
3. Use the test procedure at left for thermocouple testing, starting at step 3.

Temperature transmitter calibration

The performance of temperature transmitters and related instruments can decline, especially in the harsh environments found in industrial settings. Temperature transmitter calibration maintains reliability and uptime.



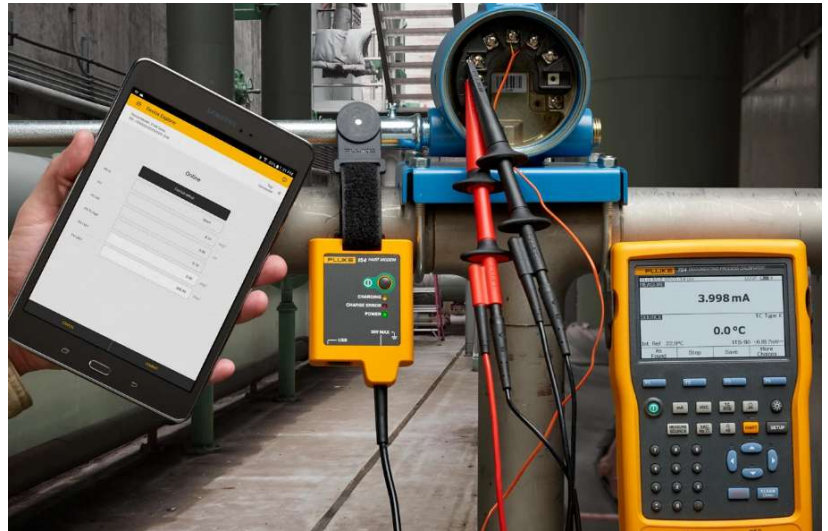
Fluke calibrators, such as the Fluke 724 Temperature Calibrator or the Fluke 754 Documenting Process Calibrator, can provide the three things necessary to accurately calibrate a temperature transmitter – sourcing temperature, providing loop power and measuring the resulting output current.

Most advanced documenting process calibrators, such as the Fluke 754, can also test and calibrate both temperature and pressure instruments, which keeps the number of instruments a technician needs to carry to a minimum. The 754 can even calibrate the most-used tasks of HART electronic instrumentation, including pulsed instruments such as RTD transmitters. A calibrator combined with a dry well such as the Fluke Calibration 9142 Field Metrology Well provides a complete closed-loop solution.

When comparing calibrators, the traceability of test equipment is also an important factor. Traceability means the calibration's test and measurement functions have been verified to perform within required specification and those specifications are traceable to national and international standards. All Fluke test equipment can be ordered with a NIST-traceable calibration.

Calibrating a HART temperature transmitter

Calibrating a HART temperature transmitter requires an accurate temperature simulator or temperature source, mA measurement, and a HART communication tool for calibration. You can use separate tools or a calibrator that integrates all three to perform this task. HART is an industry standard defining the communications protocol between smart field devices and a control system that uses 4-20 mA wiring.



Before going to the field, gather the needed calibration and communication test tools. If testing an RTD transmitter, be sure to bring extra test leads for connections. Testing a 3-wire RTD requires five test leads—three for simulating the RTD sensor and two for measuring the mA signal. If using a separate communicator, you will need its test lead set as well. For thermocouple (TC) calibrations, be sure to have the correct TC test wire type with a mini-connector terminated with the correct TC connector type (i.e. Type K wires and connector to simulate a Type K thermocouple).

Ensuring accuracy

Your mA measurement tool and temperature source calibrator should be at least four times more accurate than the device being tested. To make that determination, refer to the data sheets of both the transmitter and the calibrator being tested, and account for temperature and stability (time). The Fluke 754 Documenting Process Calibrator has the HART functionality built in to enable smart trims on transmitters. It can also document transmitter performance before and after adjustment and calculate pass/fail errors.

The Fluke 154 HART Communicator is a tablet-based HART communication tool that pairs with a documenting process calibrator or a multifunction process calibrator to give you a complete HART calibration and configuration solution.

How to perform the test:

This example assumes that the transmitter is isolated from the process and is not electrically connected to a loop power supply. A separate 250-ohm resistor is not necessary because the Fluke 754 incorporates a resistor in series with the loop supply through its mA jacks. The 3144 in this example is configured for a type K thermocouple sensor with a span of 0 °C to 300 °C.

1. Select MEAS mA, SOURCE T/C type K to configure the calibrator to measure the analog mA output of the transmitter and source the correct temperature stimulus at the 3144 input. Press ENTER to select.
2. Press the As Found softkey, then press ENTER to select Instrument for a linear transmitter calibration. Fill in the appropriate test tolerance and press the Done softkey.
3. Press the Auto Test softkey to begin calibration. Once the test is complete, an error summary table is displayed. When done viewing the table, press the Done softkey. Press Done again to accept, or ENTER to change the tag, serial number or ID fields.
4. If the As Found test failed, then adjustment is necessary. Press the Adjust softkey. Select Sensor Trim and press ENTER. Select Perform user trim – both and press ENTER.
5. For best results, press LRV to apply the LRV for the Lower Trim value. Press Trim and then Continue to move to the Upper Trim. Press URV, then Trim, then Done. If the 3144 is used with the digital PV output, skip to step 7 and perform the As Left test. If the analog 4-20 mA output is used in the process, continue to step 6.
6. Select Output Trim and press ENTER. The value of the primary variable (PVA0) is in the upper right corner of the display. This is normally a 4-mA signal. The mA value is in the center of the display. Press Fetch to load the measured mA value. Press Send to send the value to the 3144 to trim the output section for the 4-mA value. Press Continue for the 20-mA trim and repeat this step.
7. After completing Output Trim, press Done and proceed with the As Left verification test. Press As Left. Press Done and then press Auto Test. On completion, an error summary table is displayed. If errors are highlighted, the test has failed, and further adjustment is required. Return to step 5 for adjustment of the 3144.