Transmitters | Whitepaper

How Transmitters Make RTDs Even Better

Accurate temperature sensing is vital to industrial power/process control and automated energy management. Many sensors lose accuracy over long distances, due to the inherent resistance of lead wires. If you need accurate readings from sensing points that are hundreds – even thousands of feet away, a temperature transmitter may be indispensable.

This white paper explains the advantages of employing temperature transmitters, how to set them up, and how to troubleshoot a sensor-transmitter circuit.

Note: There are many types of transmitters. Those described in this paper are devices transmitting a signal over 2 wires. Transmitters in this paper do not refer to devices that employ wireless signals.

Consult your device's spec sheet for exact procedures for installation and configuration.

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Benefits and Limitations of RTDs

Resistance temperature detectors are temperature sensors whose resistance increases with temperature in a known and repeatable manner. Because RTDs are accurate and stable, many process control and energy management systems use them for sensing. RTDs supply a larger signal than thermocouples and don't require special extension lead wires. They typically have better interchangeability and stability than thermistors and are more rugged and reliable than solid-state sensors.

RTDs do have one inherent limitation: Their passive resistance signal deteriorates over long distances. Extension leads between the RTD and readout or control instrument not only add resistance to cause apparently higher readings, but this added resistance changes with the ambient temperature of the leads. Copper, the most common lead material, is used as the sensing element of some RTDs because of its temperature-dependent resistance. However, most RTDs are manufactured from platinum because of the metal's superior stability and temperature range.

For most industrial applications, 3 or 4-wire instrument circuitry can significantly reduce the effects of lead resistance[1]. This involves running one or two extra wires that removes the average lead wire resistance from the measurement. These methods, however, may be impractical or unduly expensive over a few hundred feet due to the cost of the additional wires. Even worse, electrical noise from motors or fluorescent lights can degrade the RTD signal.

It turns out that a temperature transmitter overcomes all these limitations while preserving the advantages of an RTD.

The 2-Wire Current Transmitter

Current transmitters accept a low-level signal from a process transducer (like an RTD) and translates it into a 4 to 20 mA current output. Depending on the transducer, this signal can represent temperature, pressure, humidity, liquid level, or other inputs. The 4 to 20 mA scale directly corresponds to a specified span sensed by the transducer. For example, a temperature transmitter with a span of 32 to 212°F (0 to l00°C) produces 4 mA at 32°F (O°C) and 20 mA at 212°F (100°C). The midpoint, 12 mA, represents the midpoint of the span, 122°F (50°C). Other values are directly proportional.

[1] For more, reference Minco whitepaper "Temperature Accuracy Considerations for RTD Measurement Techniques"

Why a current signal? As indicated, long leads add to a resistance reading. Similarly, leads' resistance will degrade a voltage signal, and electrical noise will obscure it. A current signal, on the other hand, is equal at both ends of an electrical loop. Lead and contact resistance, thermal EMFs and noise can't affect it. Two wires can carry the signal thousands of feet[2] with no loss in signal integrity.

A two-wire transmitter is the most economical type available. The transmitter draws power from a DC supply in the control room and taps part of this power for its own electronics. It then acts like a variable resistor to precisely regulate current over the 4 to 20 mA signal span. This signal is independent of other resistances in the loop, up to a certain maximum. The same two wires, therefore, carry both the transmitter power and the current signal. This means you don't need power at the sensing site; one DC power supply in the control room can operate several transmitters. Although 3- and 4-wire transmitters are available, they require extra power leads.

When are Transmitters Necessary?

There are no firm rules on when to specify transmitters. Each temperature monitoring system has unique cost and accuracy requirements, and unique design problems to overcome. In general, transmitters offer three advantages which may help your system: they eliminate lead effects from temperature readings, their output is immune to electrical noise, and they condition the RTD signal.

The Effects of RTD Lead Resistance

One of the best reasons to use transmitters is to counteract the effects of lead resistance in RTDs. Transmitters can improve the accuracy of 2-wire RTDs if their lead length is more than a few feet. Use of 3-wire RTDs and appropriate compensating circuits can reduce lead error to 1/20th or less than that of an uncompensated system, yet inherent errors remain in 3-wire resistance measurements[3] and are exasperated over extended distances. Accuracy requirements can occasionally be satisfied with 3-lead RTDs over distances of several hundred feet, especially with a high resistance element like 2000Ω nickel-iron[4]. Four-wire RTD systems involve bridge circuits that correct even more lead wire errors, but the two extra leads may cost more than a transmitter. At distances over 500 feet, a transmitter may be the only way to carry the accuracy of the RTD to the control electronics.

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[2] Twisted cable and shielding are addressed in section "Protection Against Electrical Noise".

[3] Reference: Minco whitepaper "Temperature Accuracy Considerations for RTD Measurement Techniques".

[4] This is addressed in more detail in the section, "Protection Against Electrical Noise".

Protection Against Electrical Noise

Noise from motors, fluorescent lamps, or other sources will degrade resistance or voltage signals, but has less effect on the transmitter's controlled current. A transmitter's minimum signal current is 4 mA, whereas a typical RTD measurement circuit uses 1 mA (or even 0.1 mA for RTD resistance over 2000 ohms). Therefore, the signal-to-noise ratio with a transmitter is dramatically improved over direct RTD input. It may be practical to use transmitters even over relatively short distances in especially noisy areas. Noise can be further reduced by simply twisting the 2 power/signal wires together, equally distributing EMI across both wires. Any induced current occurs in both wires in opposite direction, effectively "cancelling out". Shielded twisted cable offers yet another degree of noise protection, but the additional cost is often unnecessary.

Signal Conditioning

You may want transmitters for their signal conditioning circuitry alone. A resistance reading, to be useful, must be converted to voltage, usually by a non-linear resistive network. The transmitter makes this conversion and linearizes the temperature reading as well. RTD resistance/temperature curves are non-linear; without instrument compensation, errors of several degrees can result. Transmitters give you a signal which is a direct function of temperature, not RTD resistance, within stated limits of accuracy. With the transmitter's linear response, you don't need complex equations to interpret readings.

The current output at any temperature can be found with this formula:

$$I_T = 4\ \mathrm{mA} + 16\ \mathrm{mA} \times \left[\frac{(T - T_{min})}{(T_{max} - T_{min})}\right]$$

where IT is the actual current output at sensor temperature T, Tmin is the bottom of the specified temperature range, and Tmax is the top of the specified temperature range.

For example, let's assume our transmitter has a 32°F to 212°F temperature range. What is the output at 85°F? Using the above formula:

$$I_T = 4\ \mathrm{mA} + 16\ \mathrm{mA} \times \left[\frac{(85 - 32)}{(212 - 32)}\right] = 8.71\ \mathrm{mA}$$

This linear 4 to 20 mA signal is an industry standard for many sensor types. If you need to read temperature, pressure, humidity, and other values within one system, you could specify 4 to 20 mA output for all your sensors. You would then need only one field interface device or instrument for data acquisition, instead of several tailored to different sensors.

The second assembly was composed of a standard 3mm-thick vapor chamber (VC) with a 3mm-thick heat sink mounted on top with a thermal interface material in between. The heat sink consisted of a 2mm-thick base plate and 1mm tall fins. It had an identical copper block standing in as the CPU.

Network Integration[5]

In complicated systems, it's just not practical to have a 4-wire bridge circuit for every single sensor. Transmitters can use the same network protocol as is used throughout the process, HVAC, and manufacturing world. The HART (Highway Addressable Remote Transducer) protocol provides bidirectional communication which allows the controller to receive temperature and diagnostic data from the transmitter, and remotely send programming commands to the transmitter. Capitalizing on the digital signal alone, up to 63 HART transmitters in multidrop mode can be connected using a single controller input and power source.

Locate the transmitter near the RTD in an area where the ambient temperature stays within the operating temperature range of the transmitter (32 to 122°F, if unknown). Mount the transmitter.

Connect the transmitter as shown below, observing the +/– polarity of the current loop. Do not exceed the specified maximum DC supply voltage (see specifications for your model). The RTD connections have no polarity, but 3-lead and 4-lead RTDs must follow the schematic diagram printed on the transmitter. For the RTD, good connections are a must; a few ohms of resistance in the connection can cause an error of several degrees.

Figure 1 shows a typical installation. The transmitter is mounted with the thermometer at the sensing site, and a twisted pair of wires carry the signal to the instrument or data acquisition device. At the control location a fixed resistor R1 (typically built-in to the controller/indicator) converts the current signal to a useful voltage.

[5] This content is only applicable to HART transmitters (TT511, TT521, TT531)

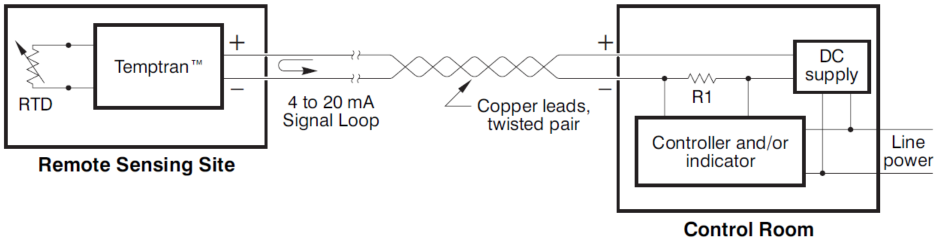

Figure 1.

Power Supply[6]

Shielded The power supply is in series with the transmitter and R1. Current capacity allows 23 mA per transmitter (23 mA is often a fault condition for an open-circuit RTD). Tight regulation of the power supply is not always necessary; transmitters can typically handle AC ripple effects down totheir minimum operating voltage. Consult the transmitter specifications for supply voltage effects.

Load Resistor[7]

R1 is the fixed resistor which converts the current signal to a voltage proportional to temperature. It is often built into instruments designed to accept a current input. In this case, you must get the value of R1 from the instrument's specs (or measure it, if possible) before calculating Rloop max. A common value, 250 Ω, will produce a 1 to 5 VDC drop from the 4 to 20 mA signal. An alternative is a 240 Ω resistor with a 20 Ω calibration potentiometer. If you supply R1, choose a stable resistor with a Temperature Coefficient of Resistance less than 100 ppm/°C, and a calibration tolerance within ±0.1 %. Allow for 60 mA current when determining the resistor's power rating.

Signal Wires and Current Loop Resistance[8]

Shielded wire is seldom necessary between the transmitter and control point. A simple pair of twisted copper wires with low voltage insulation is typically adequate. The wires should be color coded to identify polarity. This formula gives the maximum allowable resistance of the current carrying loop, including extension wires and fixed resistor R1:

$$R_{loop\ \mathrm{max}} = \frac{V_{supply} - V_{transmitter\ \mathrm{min}}}{0.023\ \mathrm{A}}$$

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[6] This content is only applicable to HART transmitters (TT511, TT521, TT531)

[7] This content is only applicable to HART transmitters (TT511, TT521, TT531)

[8] This content is only applicable to HART transmitters (TT511, TT521, TT531)

where Vtransmitter min is the minimum operating voltage required by the transmitter (see transmitter specifications for your particular model).

As an example, if your supply voltage is 24 VDC and the transmitter operating voltage is 8.0 to 30VDC, Rloop max is 695 Ω. At this maximum, however, a drop in the DC voltage or unexpected contact resistances could cause problems. A safer value would be about 80% of maximum, or 556 Ω in this case. Assuming R1 is 250 Ω, this leaves 306 Ω for the signal wires, or 153 Ω in each wire. If you're using AWG 22 cable, the resistance per foot is .0165 Ω. The maximum distance between the transmitter and control point in this example is then:

$$\frac{153\Omega}{.0165\Omega/ft} = 9272\ ft = \text{over 1.75 miles!}$$

Remote Programming[9]

Transmitters that are installed in an industrial application sometimes present physical and logistical challenges to reprogram if the temperature range needs to change. Acquiring the device – perhaps in an inaccessible area (e.g. cramped quarters, a hazardous area, the top of a 4-story storage tank, somewhere requiring disassembly to access, or a place that cannot be accessed during normal operation).

In addition, uninstalling the transmitter, reprogramming it, and then re-installing it, can be a lot of work.
A HART compatible transmitter can be re-configured across the 4-20mA network without the need to physically access the device.

Transmitter Calibration

As with any measurement device, transmitters must be calibrated to ensure measurement accuracy and provide useful data. Nominal calibration can be done by using resistance from the theoretically perfect (nominal) RTD resistance/temperature characteristic curve. Transmitter manufacturers typically supply their product(s) with nominal calibration. Replacing a faulty transmitter with an equivalent model will not affect the calculated system accuracy, because both original and replacement transmitters had equivalent accuracy, tolerance, and calibration reference values.

[9] This content is only applicable to HART transmitters (TT511, TT521, TT531)

If greater system accuracy is required, a transmitter can be calibrated to the measured resistance of an RTD at the temperatures corresponding to the transmitter's 4 mA and 20 mA output (temperature range). In this manner, the transmitter calibration compensates for the RTD's deviation from theoretically perfect (nominal). The improved accuracy is only as good as the accuracy of the RTD resistance/temperature measurements, which typically require expensive laboratory grade equipment for both temperature control and resistance measurement. Some RTD manufacturers can perform high accuracy measurements and provide a match calibrated sensor/transmitter set for a modest fee. Replacing a faulty transmitter or sensor (RTD) typically requires replacement of both with another match calibrated pair.

Due to the wide variety of transmitter designs (in both analog and digital domains), programming protocols, and software interfaces, specific calibration procedures are beyond the scope of this whitepaper. Minco recommends consulting the transmitter manufacturer or manufacturer's authorized representative for detailed calibration procedures.

Installing a Transmitter

Installation of a transmitter varies widely from model to model, but certain caveats apply universally. That said, consult the documentation or instructions that came with the device. This is especially critical for agency certified transmitters that will be used in classified hazardous areas.

Common Destructive Wiring Errors

- Don't connect the power supply to the transmitters' RTD input; this could destroy the electronics.
- Don't connect power to the RTD.

Common Non-Destructive Errors

- A common error is reversing the polarity of the power supply/signal loop. Most transmitters have diode protection to prevent damage. RTDs have no polarity to observe.
- Don't connect multiple transmitters in series. The one reading the lowest temperature will control the current of the entire loop.
- Don't put the load resistor R1 (see Figure 1) in parallel with the transmitter or power supply. All load resistors, whether built into instruments or separate, must be in series with the signal loop.

Electrical Connections and Grounding

All RTD and signal loop connections can be made with solder, crimp connectors, screw terminals, or wire nuts. If you use wire nuts, be sure they are the right size and tightened completely. Some transmitters have built-in screw terminals.

Many transmitter applications use PLC systems with built-in power supplies and input modules that may already have the necessary ground(s). In such systems, if a user grounded the current loop, it would short circuit the signal to ground, and no current would go through R1. This would render the sensor useless.

Metal cases of RTDs are isolated from the sensing element, so they can be in contact with earth ground without affecting the signal loop.

Special Installations

The above example may be the most common configuration, but there are many specialized installations to be found as well. The following are some frequently encountered alternatives:

Using Instruments in Series

More than one load resistor, and accompanying instrument, may be put in series in one transmitter signal loop. Figure 2 shows such an installation. There is no limit to the number of instruments in the loop as long as the total of R1, R2, and other load resistors, plus the lead resistance, does not exceed Rloop max. If the instruments do not interact and have sufficient input impedance, you could connect them all in parallel with one load resistor R1.

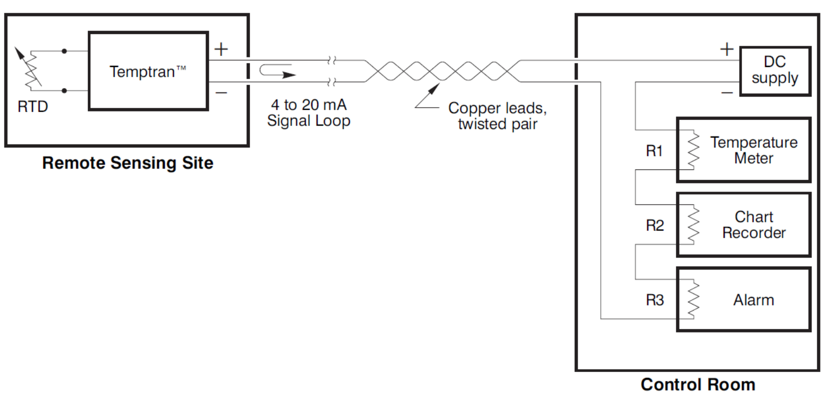

Figure 2: Special Installations

Hazardous Environments

Transmitters that are not certified as intrinsically safe may be used in hazardous environments if mounted within a suitable explosion-proof (or flame-proof) connection head. The connection head and all signal loop wiring must meet thelocal electrical code requirements for the hazardous area classification and protection method.

Multiple Loops

Figure 3 shows an installation with several sensing points. The only limitation on the number of transmitters used here is the current capacity of the power supply and common power leads. The signal voltage across R1, R2, etc., can be hooked to different instruments, manually switched, or multiplexed for computer data acquisition. The load resistors may be built into instruments or multiplexers.

As an alternative to the circuit in Figure 3, you could use one load resistor and switch the power supply. Excluding transmission line effects, analog-based transmitters may stabilize in under 0.5 milliseconds after power comes on, so rapid computer-controlled switching is possible. Microprocessor based transmitters might take longer to stabilize. As an added benefit, switching power between transmitters limits the heat dissipation of each one.

The optional earth ground shown can help limit signal loop noise. Be sure that the loop is grounded at only one point, preferably at the negative terminal of the power supply. Accidental grounding at another point might cause erratic signals.

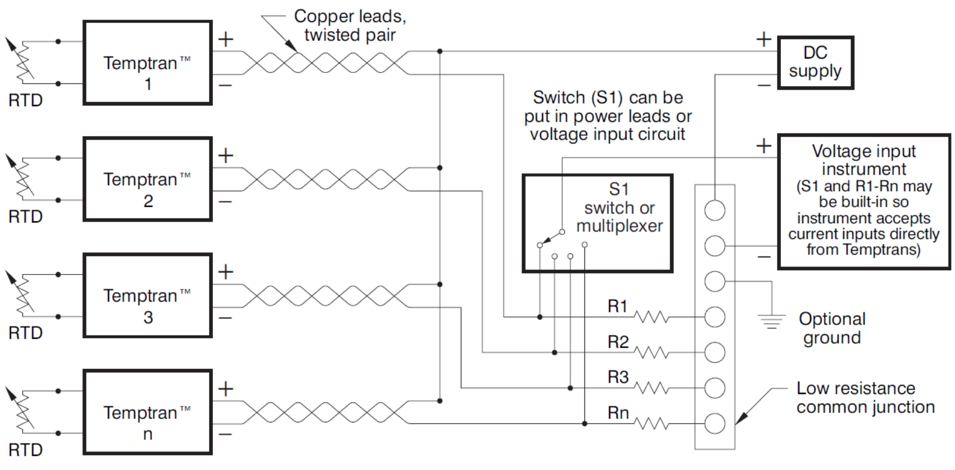

Figure 3: Multiple Loops

Troubleshooting Guide

The following represent commonly encountered errors and suggestions for fixing them. Although they are primarily for analog-based transmitters, many also apply to microprocessor-based transmitters.

Symptoms	Procedure References
TEMPERATURE DOES NOT CHANGE	1 to 10, 11 to 13
TEMPERATURE STAYS BELOW BOTTOM OF RANGE (below 4 mA)	2 to 11, 14, 16 to 20, 23
TEMPERATURE STAYS ABOVE TOP OF RANGE (above 20 mA)	1, 2, 7 to 10, 12 to 14, 22, 24 to 26
TEMPERATURE CHANGES UNPREDICTABLY/ERRADICALLY	6, 7, 14, 17, 19 to 22, 27 to 29
TEMPERATURE CHANGES WHEN OTHER ELECTRICAL LOADS ARE SWITCHED ON OR OFF	7, 14, 15, 27 to 29
TEMPERATURE IS SEVERAL DEGREES TOO HIGH OR TOO LOW	6 to 10, 14, 21 to 23, 25, 30
TEMPERATURE IS JUST A DEGREE HIGH OR LOW	8 to 10, 13, 23, 25, 30 to 32
TEMPERATURE KEEPS INCREASING OR DECREASING DAY-BY-DAY	7, 13, 24, 30

Procedures

1 RTD open-circuited or transmitter short-circuited.

2 RTD resistance too high or low.

3 RTD short-circuited. CHECK THAT THE RTD IS OPERATING CORRECTLY

A. Turn power to transmitter off because the current may rise above 20 mA while the RTD is disconnected.

B. Disconnect the RTD and ohm it. Its resistance should approximately agree with the room temperature values listed on thecorresponding RTD resistance/ temperature table.

Caution: The RTD may read high if your hands accidentally warm it up.

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4 Transmitter or current loop open-circuited.

A. Ohm the current loop wiring.

B. Verify the transmitter connections to the loop.

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5 Current loop and RTD connections swapped. Check wiring at transmitter.

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6 Below minimum operating voltage at transmitter’s current loop terminals due to excess resistance in the current loop. Measure the voltage across the current loop terminals. Make sure the measured voltage is within the specified supply voltage range (see specifications for your model). Different transmitter models have different supply voltage ranges. Note: The voltage may range as high as the power supply's voltage and the voltage across the transmitter will change when the current signal changes.

Check total resistance of the loop:

A. Turn off power supply, temporarily place a short across its terminals.

B. Disconnect the two current loop wires from the transmitter and ohm the loop. Resistance should be less than the resistance calculated from the loop resistance formula for your transmitter (see specifications for your model).

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7 RTD or current loop misconnected to other control wiring, current loops, or voltages.
With meter, check for unwanted currents, voltages, and connections.

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8 Transmitter type does not match RTD type. Most RTDs are identified (etched or labeled) with a base part number and element code or description. Make sure the element code or description on the transmitter label matches the element code or description on the RTD. Some RTDs do not have a third lead and some transmitters require only 2 leads. If you have a 3-lead sensor and the transmitter only has terminals for two, connect the common-color wires together. For example, connect the two white wires of a red/white/white sensor together in the same RTD terminal of the transmitter and connect the red lead to the other RTD transmitter terminal.

9 Wrong transmitter range installed. Check against your records/plans that the temperature range matches the one listed on transmitter's label and that it matches temperature range programmedinto the controller.

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10 Building Automation System scaled for another temperature range or is not reading correctly. If everything matches and the RTD’s resistance ohms okay (see 3B), you can test that the controller is reading correctly:

1. Connect as shown in Figure 4.
2. The variable resistor should have a resistance which covers the sensor's range of resistance (printed on the transmitter label), e.g., for a 100 ohm platinum RTD, use a decade box or a 250 ohm potentiometer.
3. Set the decade box or RTD simulator or variable resistor/potentiometer to whatever it takes so that the transmitter outputs 4 mA, as measured by your current meter. Confirm thecontroller’s reading is the 4 mA temperature as specified on the transmitter label.
4. Set the variable resistor so transmitter puts out 20 mA. Confirm thecontroller’s reading is the 20 mA temperature as specified on the transmitter label.

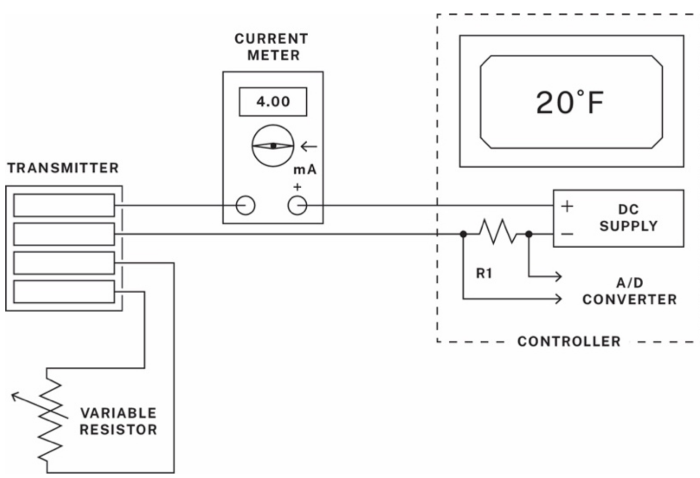

Figure 4.

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11 Current loop polarity reversed. Using voltmeter, check the polarity of the voltage at the transmitter's current loop terminals. Consult your transmitter’s label, model specification drawing, installation instructions, or user manual for the polarity of the current loop terminals.

12	Current loop wires shorted together at some point. Check for short.
13	You're asking for Duct #1's temperature but the controller is answering with Duct #4's temperature, for example. Open the current loop at the transmitter for Duct #1 or else short the sensor's terminals (see #34 below). The controller should correctly sense that the temperature is below the bottom of the range.
14	Ground loop currents are adding or subtracting from current loop because circuit is earth-grounded at some point. Ohm from each current loop to earth ground or other suspect wiring to check for accidental shorting along the wire run. None of the transmitter's connection points should be grounded. However, some control systems may intentionally connect the negative side of the power supply to earth ground.
15	RTD element or its leads are not insulated from mounting hardware. Disconnect the RTD from the transmitter, and while installed, ohm from the RTD leads to its mounting hardware — the resistance should be greater than 2 megohms.
16	Power supply voltage too low or high. Measure the voltage at the power supply's terminals to see that it is within your system's tolerances.
17	Power supply not connected to current loop. Check for loose, broken, or disconnected wires.
18	DC power supply not plugged in/turned on. Check for correct voltage at the power supply output terminals.
19	Power supply overloaded – too many current loops on one supply. Measure the voltage at the power supply's terminals to see that it is within your system's tolerances. Low output voltage is a sign of overloading the supply. Alternatively, compare measured output voltage and current with the supply's specs.
20	Wrong AC source for power supply, e.g., trying to run off 115 VAC with input switch set to 230 VAC. Check for proper 115 or 230 VAC wiring and switch settings.
21	Poor RTD connections or broken/intermittent wires at terminations. To discover broken lead wires, monitor the temperature or current as you flex the lead wires.

22	Corrosion has increased resistance at the RTD terminations. Clean connections and wire.
23	Shunting by a high resistance path across RTD connections is causing lowered reading. Remove dirt and debris; clean. 2 megohms is the threshold where shunting may become a problem. Don't try to ohm the transmitter's terminals – they are a low impedance.
24	Operating temperatures beyond ratings of RTD. Maximum temperature of many HVAC RTDs is 275°F (135°C). However, some have a maximum temperature of 122°F (50°C).
25	Calibration pot settings disturbed. RECALIBRATE transmitter per manufacturer’s instructions.
26	Power supply connected in parallel with loop readout resistor. Check for this miswiring and correct.
27	Lead wires are in area of high AC noise. Because of the good AC noise rejection of modern instruments, electrical noise is not normally a problem. Switch your current meter to the AC scale to check for noise above the background AC level; read the background with meter leads shorted together. Next, measure the AC voltage across the R1 sense resistor shown in Figure 1. Test if AC pickup is through the RTD leads by shorting the RTD terminals together right at the transmitter to see if the AC decreases. You will have to judge how much AC is too much for yourcontroller. The 4-20 mA current loop is highly immune to noise pickup, however, any noise picked up in long RTD input leads will show up in the current signal. If you want to use shielding around the RTD leads, connect the shield to the negative current loop terminal of the transmitter at the transmitter end; do not connect the shield at the end by the RTD. (This assumes the shield is not grounded.)
28	Noise picked up on current loop. Use twisted pair instead of straight wires.
29	AC power applied to the current loop terminals of transmitter or power supply is providing AC riding atop the DC. Set meter to AC volts scale and connect to transmitter current loop terminals. If you find excess AC, check power supply and check for accidental connection to other wiring.

30 Ambient temperatures are too high or low for transmitter. Move the transmitter to a more moderate environment and extend the lead wires to the RTD. Some transmitters have a maximum ambient operating temperature of 122°F (50°C). The transmitter will function outside these limits, but factory specifications are not guaranteed. Prolonged operation at temperatures outside the specificationsmay affect accuracy and/or performance.

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31 Transmitter calibrated for a specific sensor has been connected to the wrong sensor. Match calibrated transmitters are calibrated to one individual RTD. Match calibrated sensor/transmitter sets may be identified with identification tags or labels. If transmitters or RTDs were swapped around, significant temperature errors are likely.

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32 Transmitter or sensor has drifted just a degree or two. Recalibrate per #25 above.

Notes:

- As the temperature increases, causing an increase in the current signal to 20 mA, the voltage across the transmitter's current loop terminals always drops.
- By temporarily shorting the RTDs terminals with a wire or paper clip, the current loop will be forced to minimum output (2-3 mA) or error condition to test the controller's readout. This will not harm the transmitter, nor will it change the calibration.
- You can check the current in a loop without causing a discontinuity or a change in current to be seen by thecontroller: To insert a current meter into a loop, connect its leads to the wire or terminals on each side of the point where you're going to break the loop – then go ahead and open the loop there. The transmitter will handle the meter's added resistance with no change in current.

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