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4-20 ma Current Loop Experiments

Purpose

The purpose of the 4-20 ma demonstrators is to demonstrate how current loops work, demonstrate the response of different transmitters, and demonstrate that it is possible to do data logging on a pneumatic control system if you have the right equipment

Experiment 1 – Trace Out a Current Loop

Current loops are literally a loop of wire that carries a current that varies from 4-20 ma as variable measured by the transmitter varies. For instance, a 4-20 ma transmitter serving a 0-100°F temperature transmitter would have a current that varied linearly from 4 ma at 0°F to 20 ma at 100°F. The loop consists of:

- A power supply of some sort to drive the process. For the loops in the experiment, a 24 vdc power supply is used.
- A transmitter that varies the current as a function of the measured variable. For the experiments, the transmitters vary current as a function of temperature, static pressure, and pneumatic control system pressure.
- A load resistor that converts the current to a voltage for use by the control system. For the experiment, the load resistor is part of a cable that is plugged into the Hobo data logger. The blue and yellow wires are connected to a load resistor, that is hidden under the gray insulation. The voltage it generates is input to the Hobo logger via the jack that when the cable is plugged into the logger input. The wiring diagram provided with the power supply panels illustrates the details of this connection.

As a starting point for the experiment, try to trace out the current loop, from the power supply to the transmitter, to the load resistor, and back to the power supply.

For more details on current loops, see the www.Av8rdas.Wordpress.com blog posts starting in April of 2009.

Experiment 2 – Position Sensitivity

One of the dc power supply panels is connected to a Dwyer static pressure transmitter. With nothing connected to the transmitter, pick it up and rotate it from horizontal to vertical, and then past vertical. Observe the output of the transmitter in the indicator that is part of the package.

What happens to the output?

____

____

Why does this happen?

____

____

Experiment 3 – Noise and Resistance Immunity

1. Use a multi-meter to measure the resistance of the coil of telephone hookup wire that is provided with the lab set-up. (Note that the multi-meter will need to be set to the ohms scale with the ohm/voltage jacks, not the amp/milliamp jacks.) The coil is actually four wires but they are all wired in series to make one long single conductor and create a measurable resistance.

   You should measure at least several ohms of resistance, and maybe 10 to 40 or more ohms depending on which lab set-up you are using. Document the resistance you measured below.

   ____

2. If there is not already a meter in the current loop, insert one so that you can read the current flow in the loop. Note that the meter needs to be wired in series with the current loop with the leads in the milliamp jacks and the range set to milliamps. Note also that current loop transmitters are often polarity sensitive. Meaning if you reverse the polarity they will shut down.
3. Note the current reading in the current loop, and document it below.

   ____

   Bear in mind that this is proportional to the temperature being measured by the RTD and as long as the RTD temperature does not change the current flow should not change
4. Note that there is an alligator clip installed in the white lead coming from the RTD sensor that is the input to the transmitter. Disconnect the lead and then use it and the alligator clip on the coil of wire to insert the wire in series with the RTD sensor. What this does is add resistance to the circuit that is not the resistance associated with the temperature sensor itself, just as a long wiring run between an RTD and a controller or transmitter would. And, since the resistance of copper changes with temperature, the resistance of the coil of wire will also change with temperature. When you do this, what happens to the signal coming from the transmitter (document your observation below)?

   ____

5. Based on you observations, do you think resistance type temperatures are sensitive to the resistance of the leads in the circuits between them and the controller they serve?
6. Remove the coil of wire from the RTD circuit and reconnect the RTD directly to the transmitter. Document the current flow in the current loop below (it should return to about the value you documented in step 3 if the temperature has not changed).

   ____

7. Now insert the coil of wire into the current loop, effectively adding its resistance to the resistance of that circuit. Document the current flow in the current loop after you have added the resistance.

Did it change? Based on your observations, do you think current loops offer advantages in terms of being immune to lead resistance issues?

Experiment 4 - Thermal Response

1. Deploy the data logger for the DC power supply panel serving the static pressure and temperature transmitters so that it logs data as quickly as possible.
2. Take the temperature transmitter, and, with no thermowell in place, heat it up with the hair dryer for 15 seconds.
3. Allow the transmitter to cool back down for 5 minutes.
4. Insert the transmitter in a cup of water to fully cool it for 1 minute.
5. Place the transmitter in the stainless steel or brass thermometer well.
6. Heat the well up with the hair dryer for 15 seconds.
7. Allow the transmitter to cool back down for 5 minutes.
8. Pull data from the data logger and compare the thermal response of the temperature sensor with and without a well. Do you think any differences observed could impact the control system and its ability to achieve tight control?

Experiment 5 – Logging a Pneumatic Signal (Optional; Time Permitting)

1. Deploy the data logger for the DC power supply panel serving the pneumatic pressure transmitters so that it logs data at least once every 5 seconds.
2. Connect the 0-20 psig transmitter inputs to one of the pneumatic demonstrators in the adjacent area so that it is monitoring pressure to one of the lines to an actuator.
3. Allow the data logger to record the variations in pressure as the group working with the pneumatic demonstrator cycles the actuator.
4. Pull data from the logger and observe your results. Do you think that just because you are working with a pneumatic control system it is impossible to log data?

Facility Dynamics Engineering Northwest Satellite Office 8560 North Buchanan Avenue, Portland, OR 97203 Phone (503) 320-2630

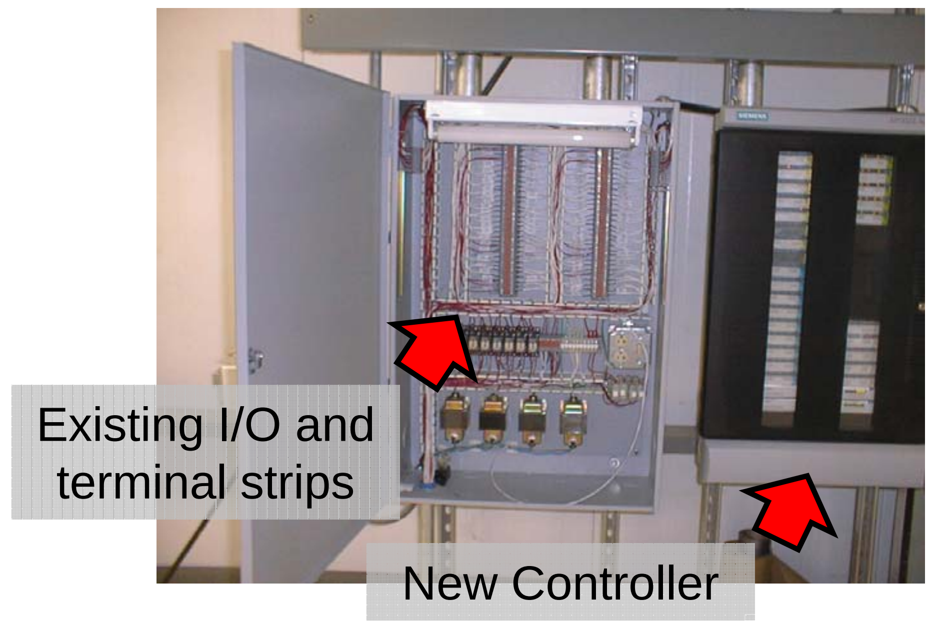
Specialty Terminal Strips

Promoting Commissioning, Maintainability, and Cost Effective Controller Upgrades

Presented By:
David Sellers, Senior Engineer
Facility Dynamics Engineering

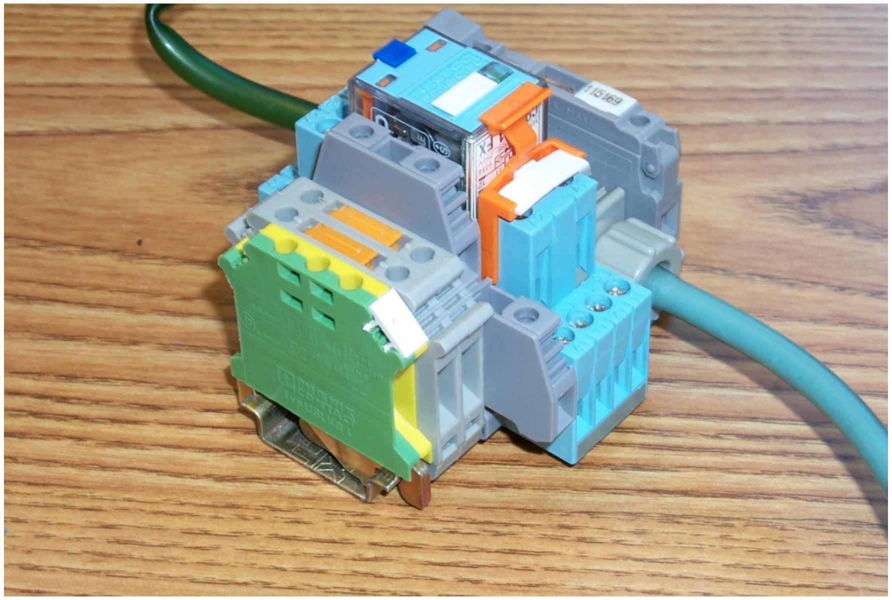
Terminal Strips; An Up-front Investment with Short and Long Term Benefits

The Towers Dorm Complex was one of several facilities where an Allen Bradley PLC based monitoring system was upgraded to a Siemens System using the original sensors and wiring.



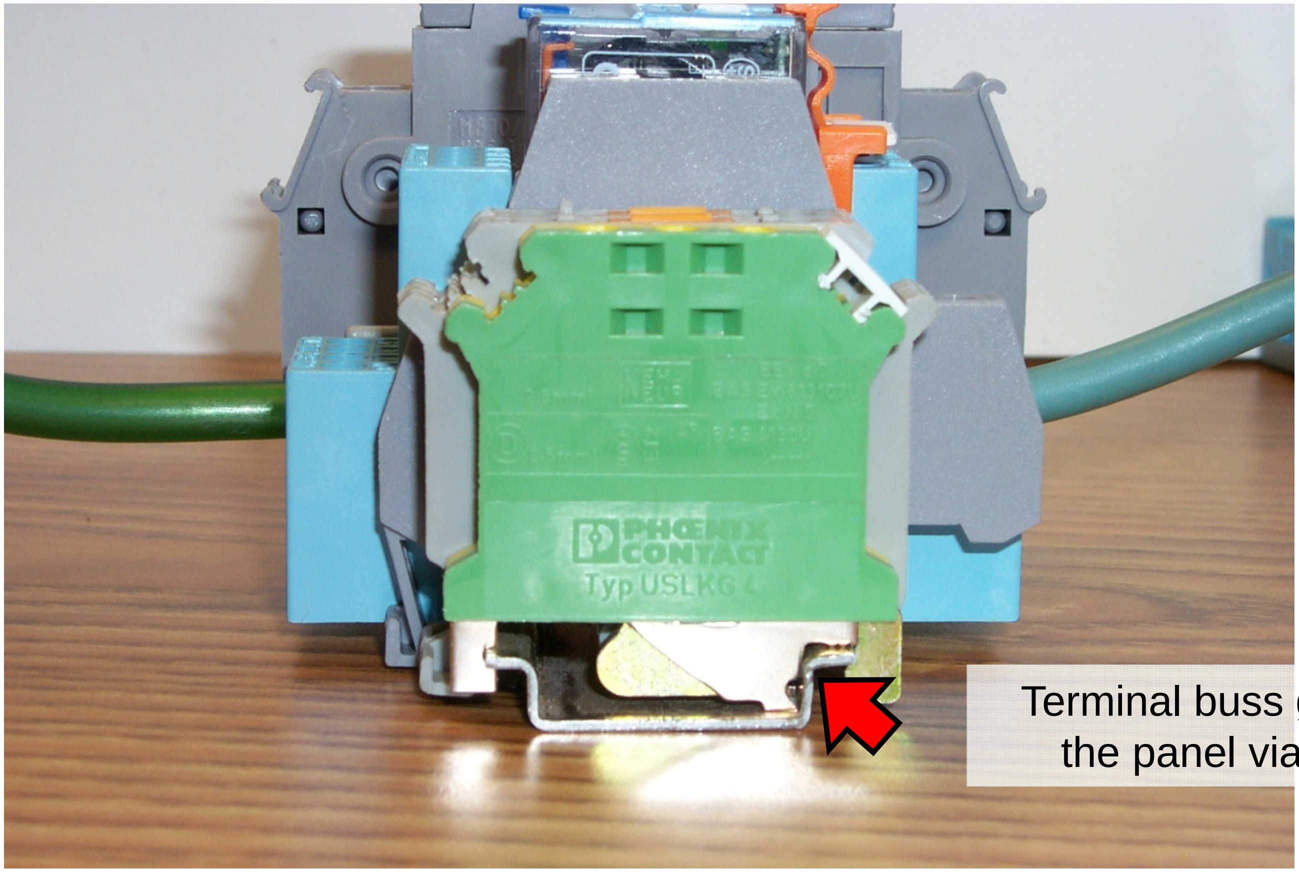
Terminal Strips; An Up-front Investment with Short and Long Term Benefits

- Expedite controller hardware replacement and upgrades
- Provide a contractual boundary
- Enhance labeling and identification
- Simplify and standardize troubleshooting
- $3-$15 first cost investment = life cycle savings that pays for itself many times over



Grounding Terminals

Minimize EMF and RFI problems

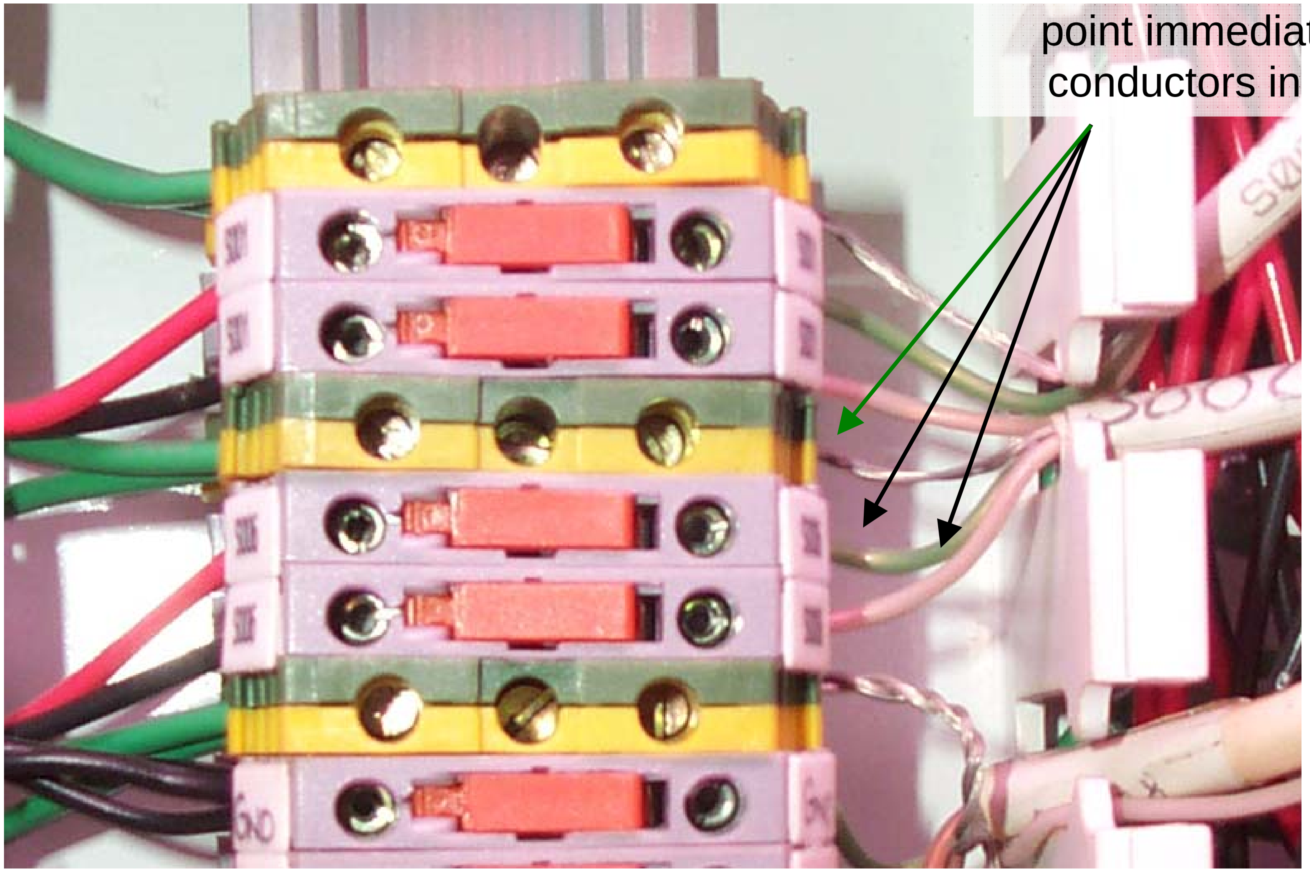


Terminal buss grounded directly to the panel via the mounting rail

Grounding Terminals

Minimize EMF and RFI problems

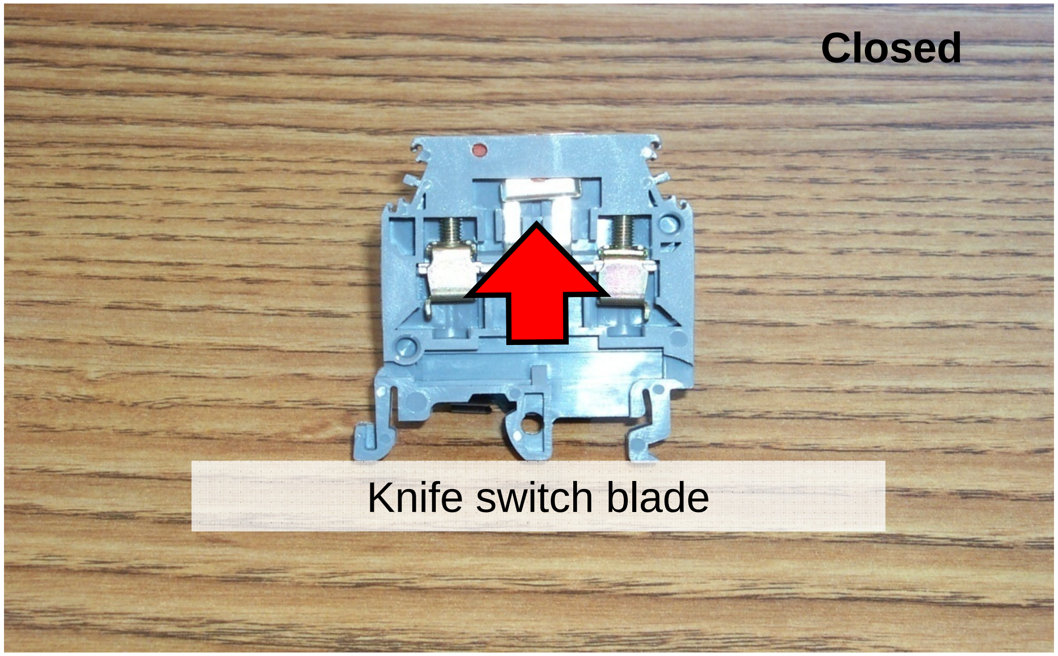
Shield drain has a secure connection point immediately adjacent to the conductors in the cable it serves



Switch Blocks;

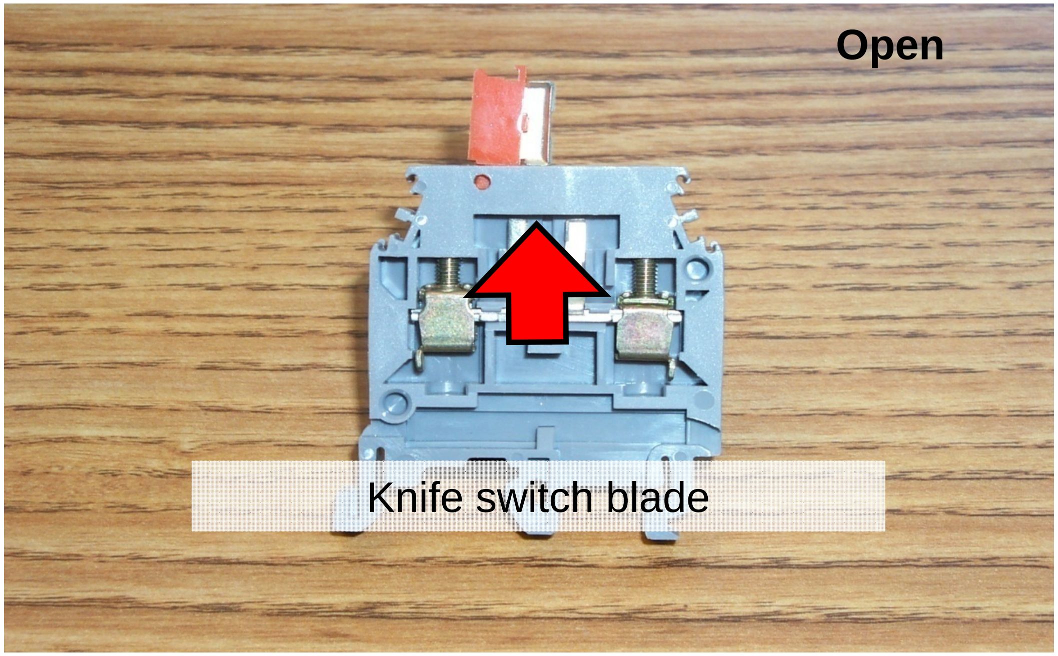
Aid Troubleshooting and Maintenance

- Disconnect wiring with out lifting wires
- Measure current with out interrupting operation



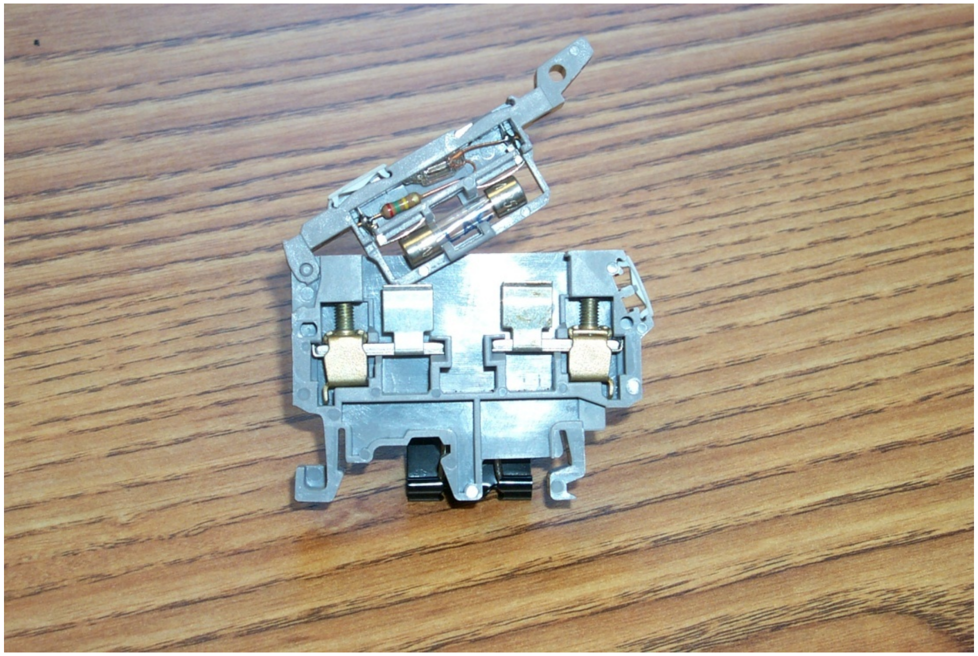
Switch Blocks;
Aid Troubleshooting and Maintenance

- Disconnect wiring with out lifting wires
- Measure current with out interrupting operation

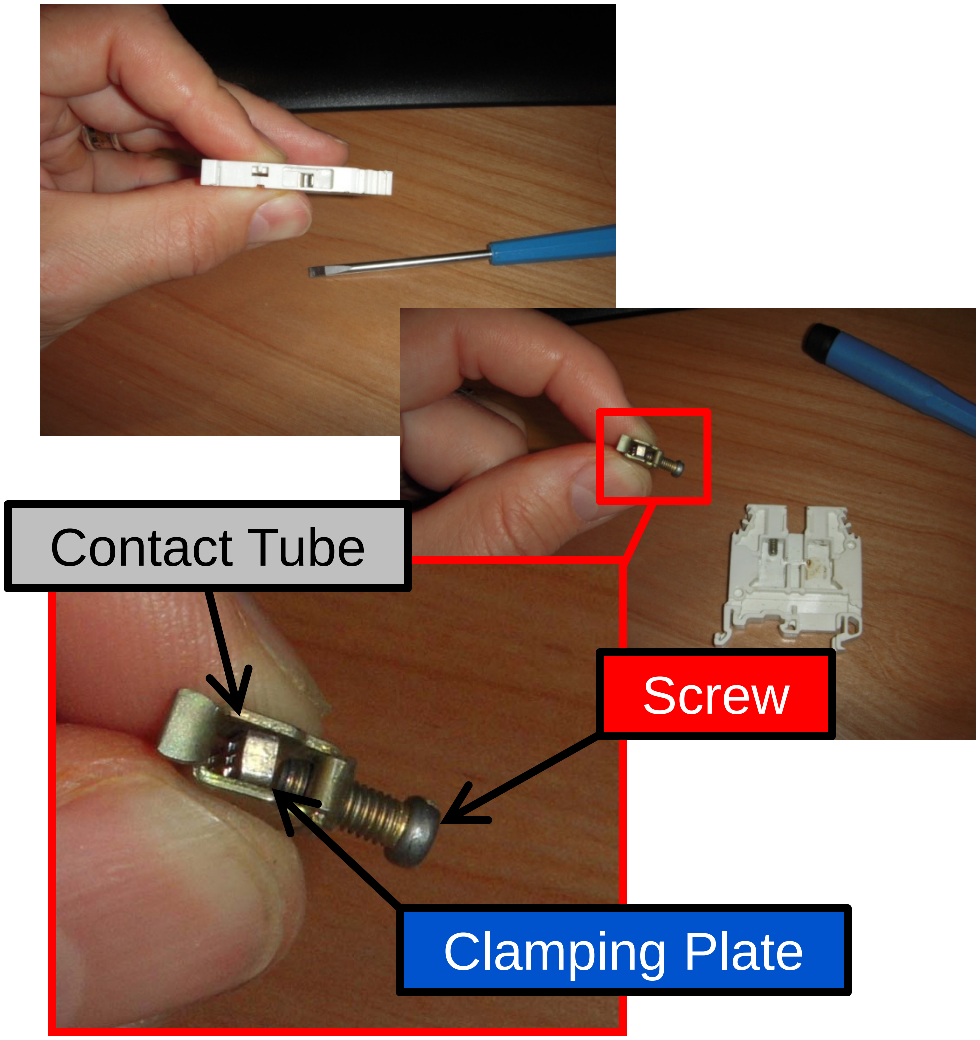


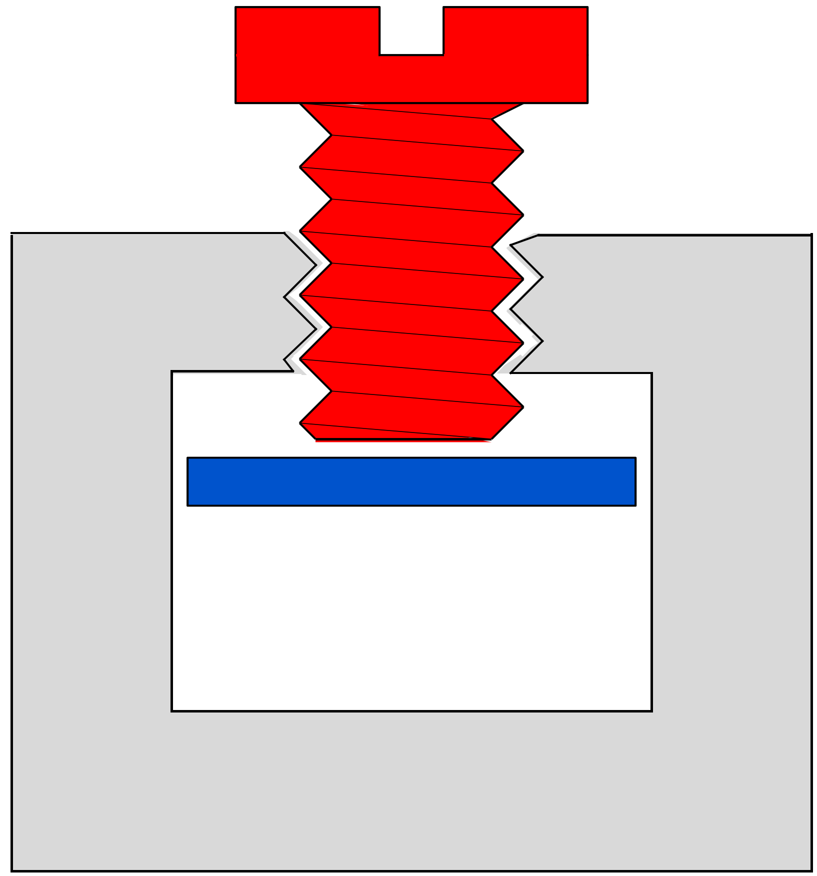
Fuse Blocks;
Enhanced System Integrity

- Code compliance
- Fuse blown indication



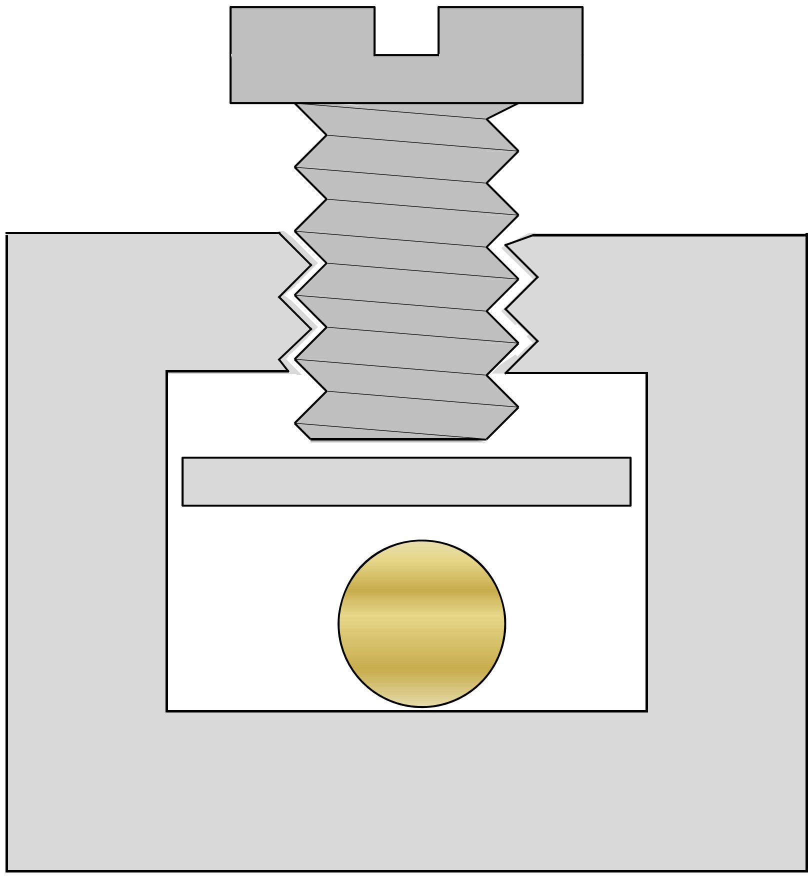
Tubular Screw Clamp Terminals





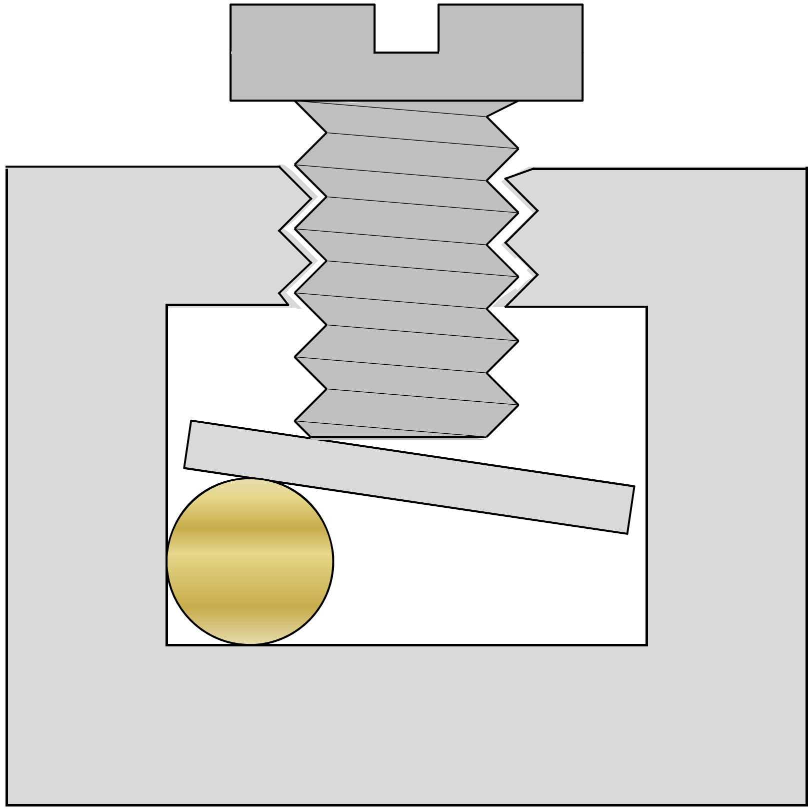
Tubular Screw Clamp Terminals

- Plate free to float between screw and tube
- Clamping a solid conductor
  - Conductor inserted between plate and tube



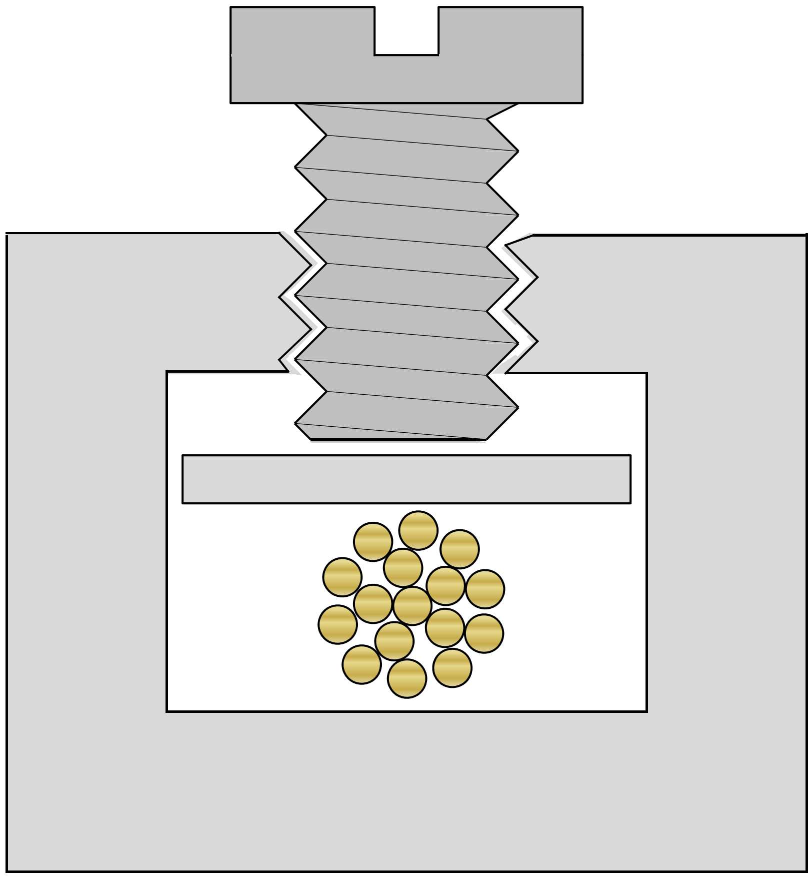
Tubular Screw Clamp Terminals

- Plate free to float between screw and tube
- Clamping a solid conductor
  - Conductor inserted between plate and tube
  - Tightening the screw tends to clamp the conductor between a corner of the contact tube and the plate until the screw can no longer compress the conductor



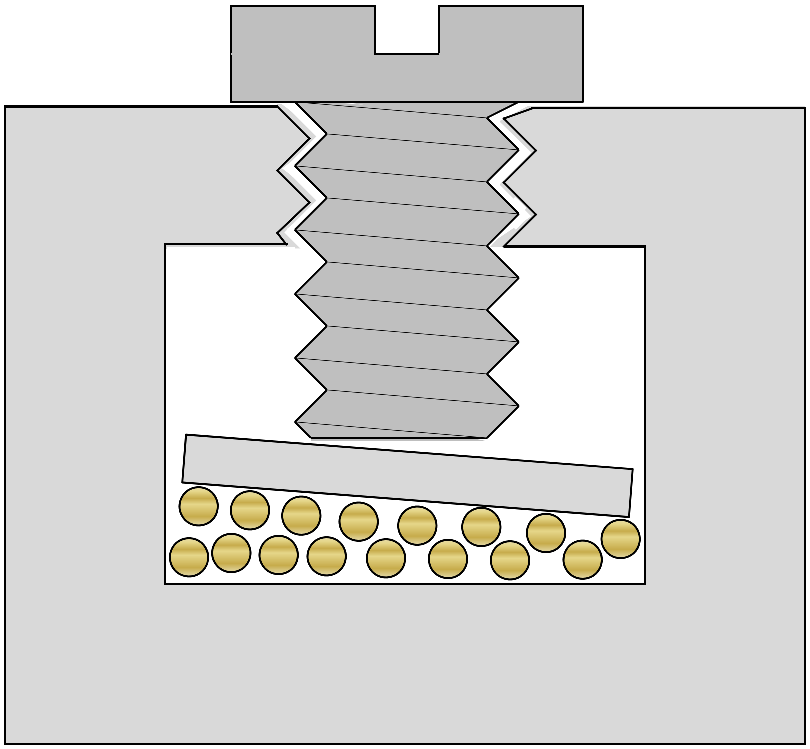
Tubular Screw Clamp Terminals

- Plate free to float between screw and tube
- Clamping a stranded conductor
  - Conductor inserted between plate and tube



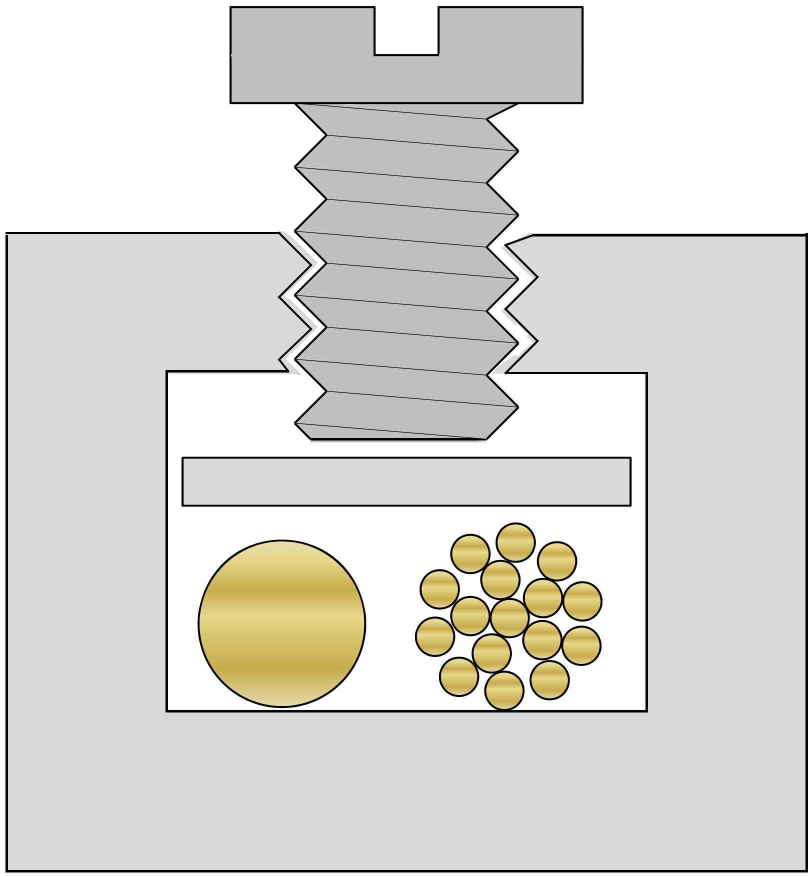
Tubular Screw Clamp Terminals

- Plate free to float between screw and tube
- Clamping a stranded conductor
  - Conductor inserted between plate and tube
  - Tightening the screw tends to distort the bundle, spreading the strands out until they fill the space between the plate and contact tube and the plate can no longer compress them



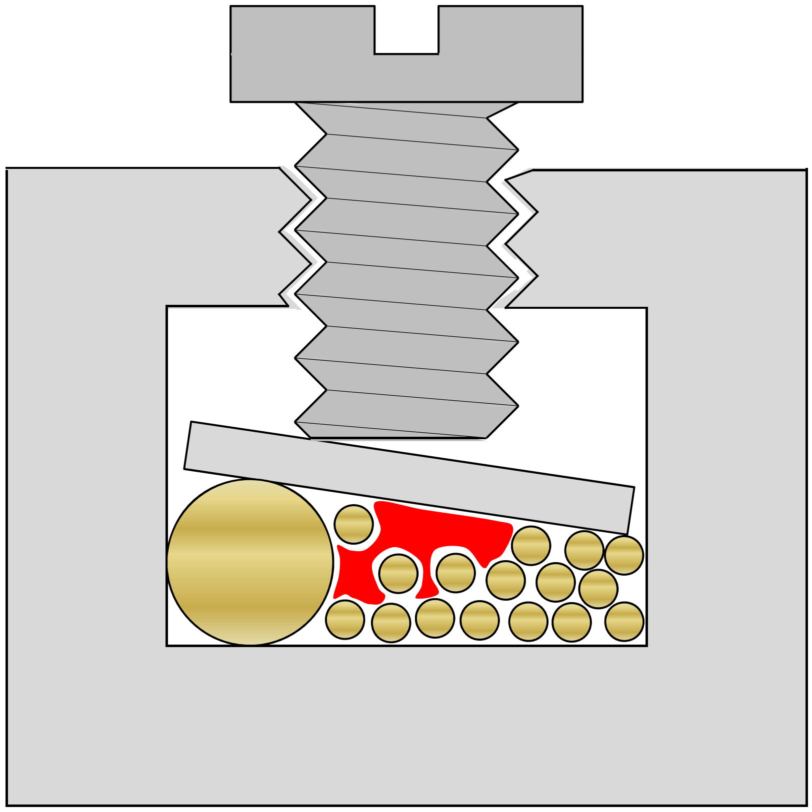
Tubular Screw Clamp Terminals

- Plate free to float between screw and tube
- Clamping a solid with a stranded conductor
  - Conductors inserted between plate and tube

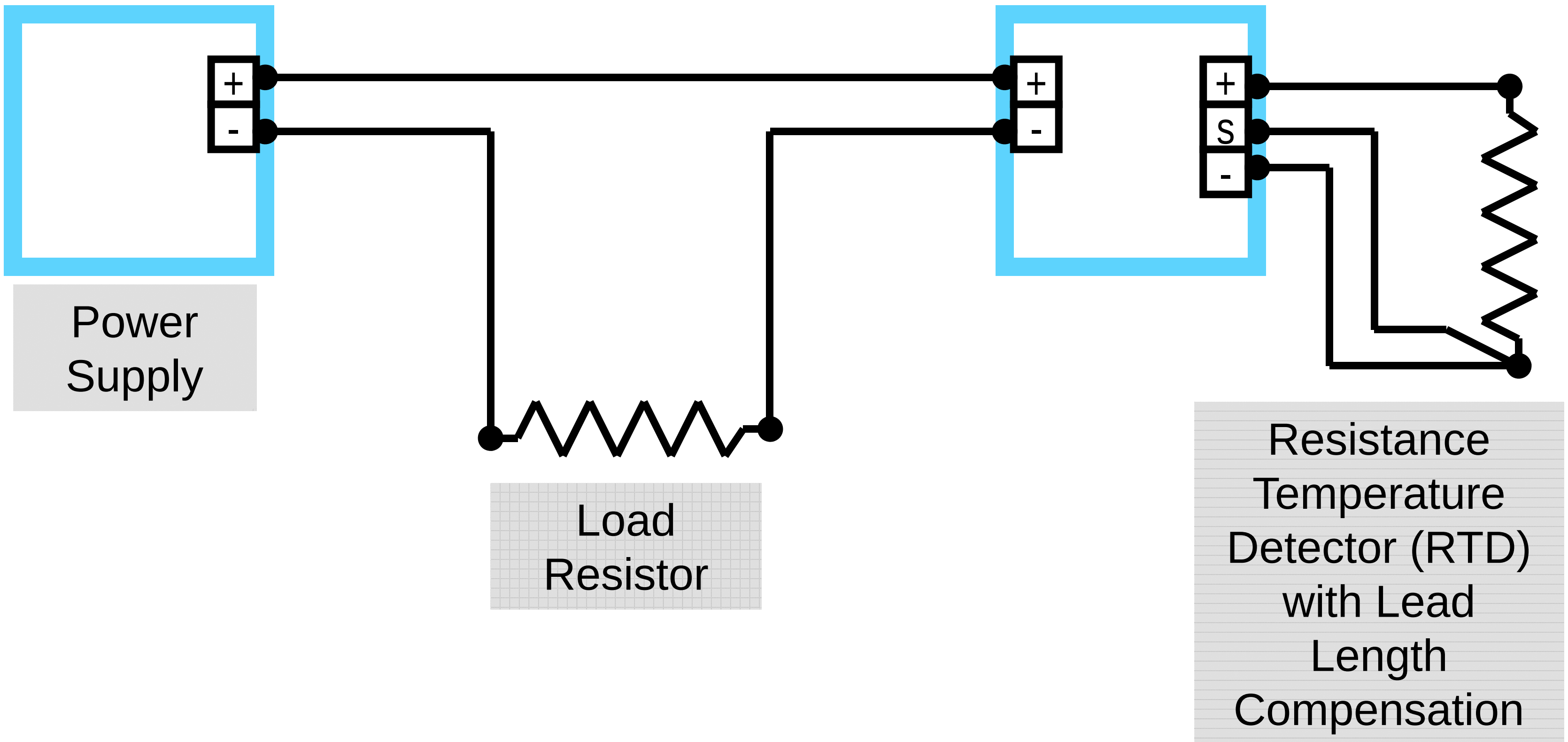


Tubular Screw Clamp Terminals

- Plate free to float between screw and tube
- Clamping a solid conductor
  - Conductor inserted between plate and tube
  - When tightened, the screw tends to bottom out on the solid conductor and some of the strands, leaving other strands loosely gripped between the plate and the contact tube

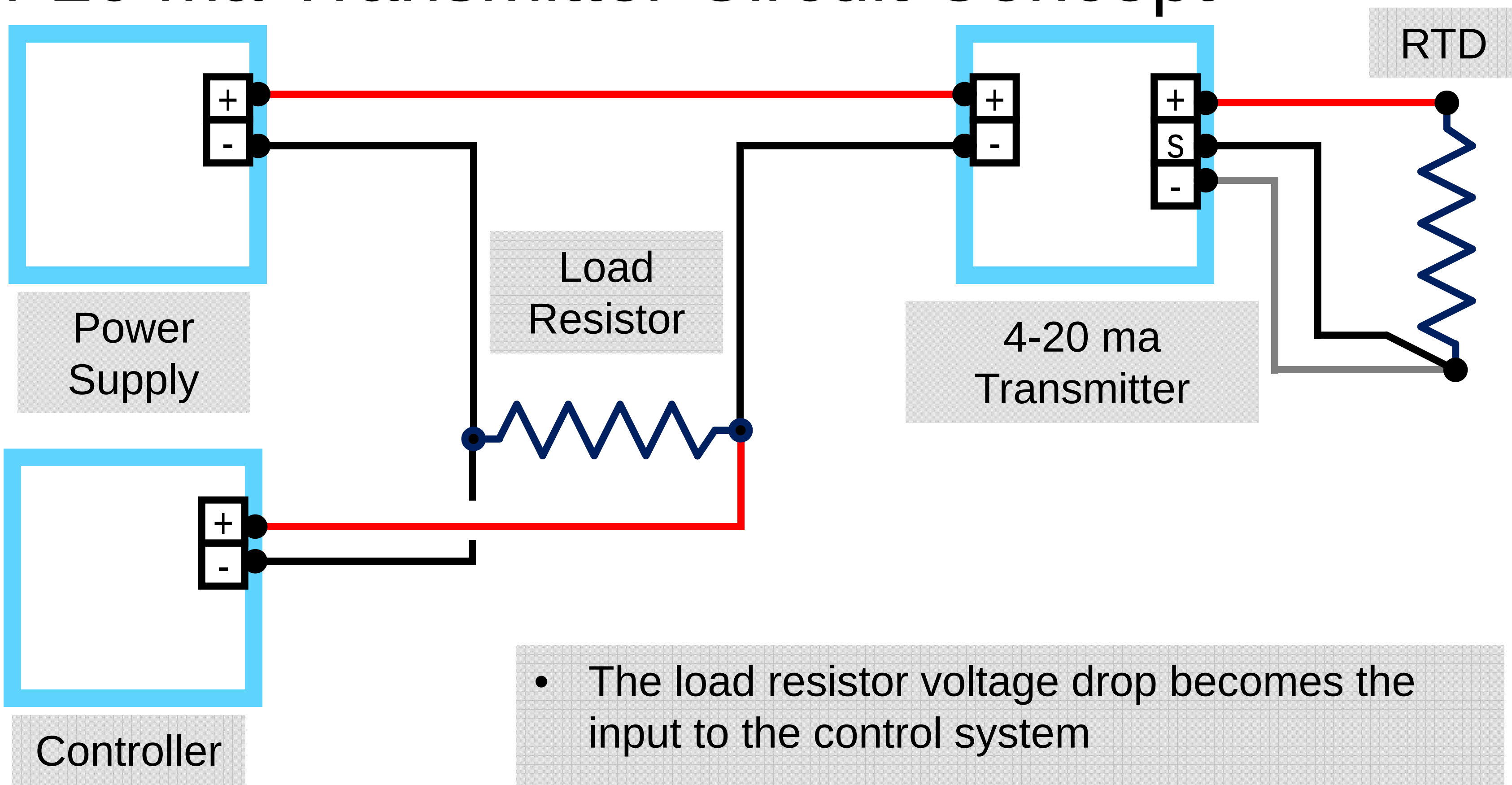


4-20 ma Transmitter Circuit Concept



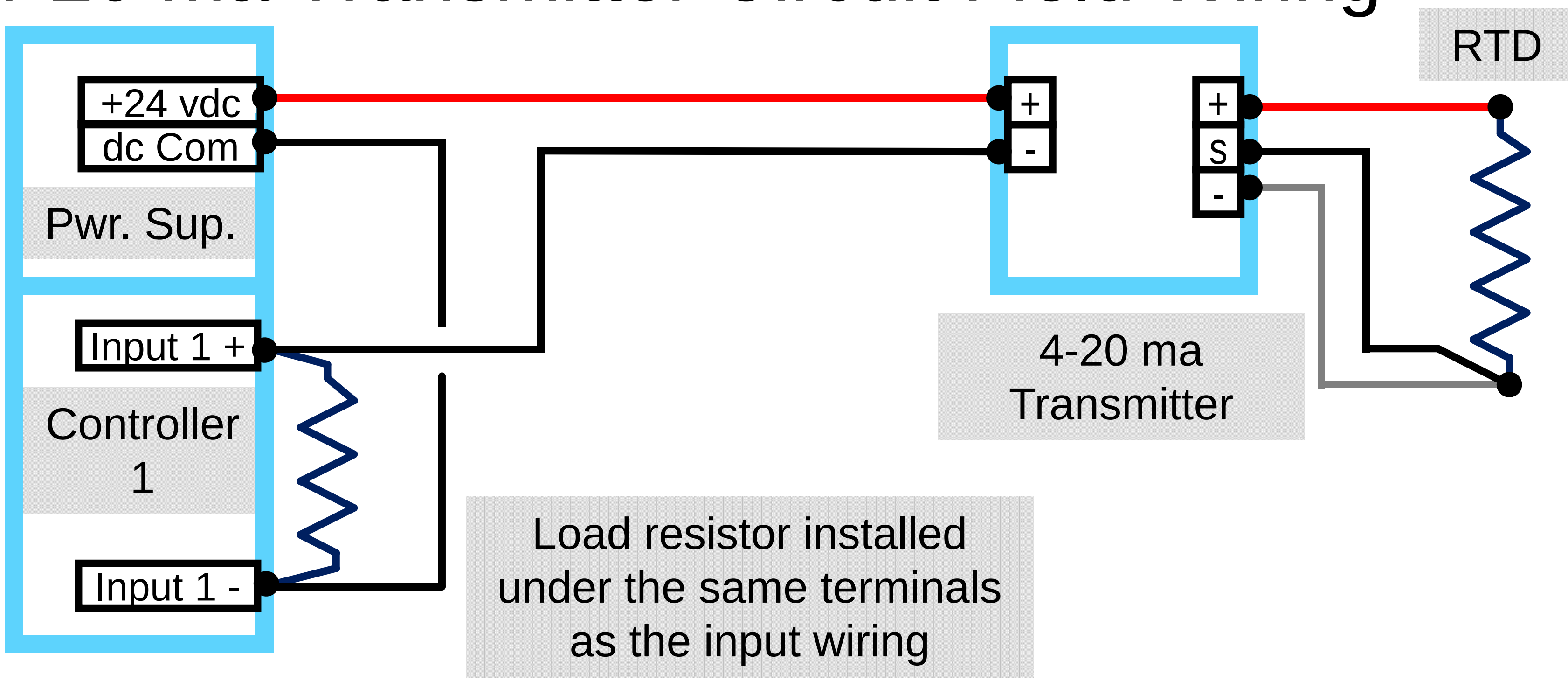
Solving E = I x R for Different Currents and Resistances				
Load resistance, ohms	250		500	
Current loop current, amps	0.004	0.020	0.004	0.020
Load resistance voltage drop, volts	1.000	5.000	2.000	10.000

4-20 ma Transmitter Circuit Concept

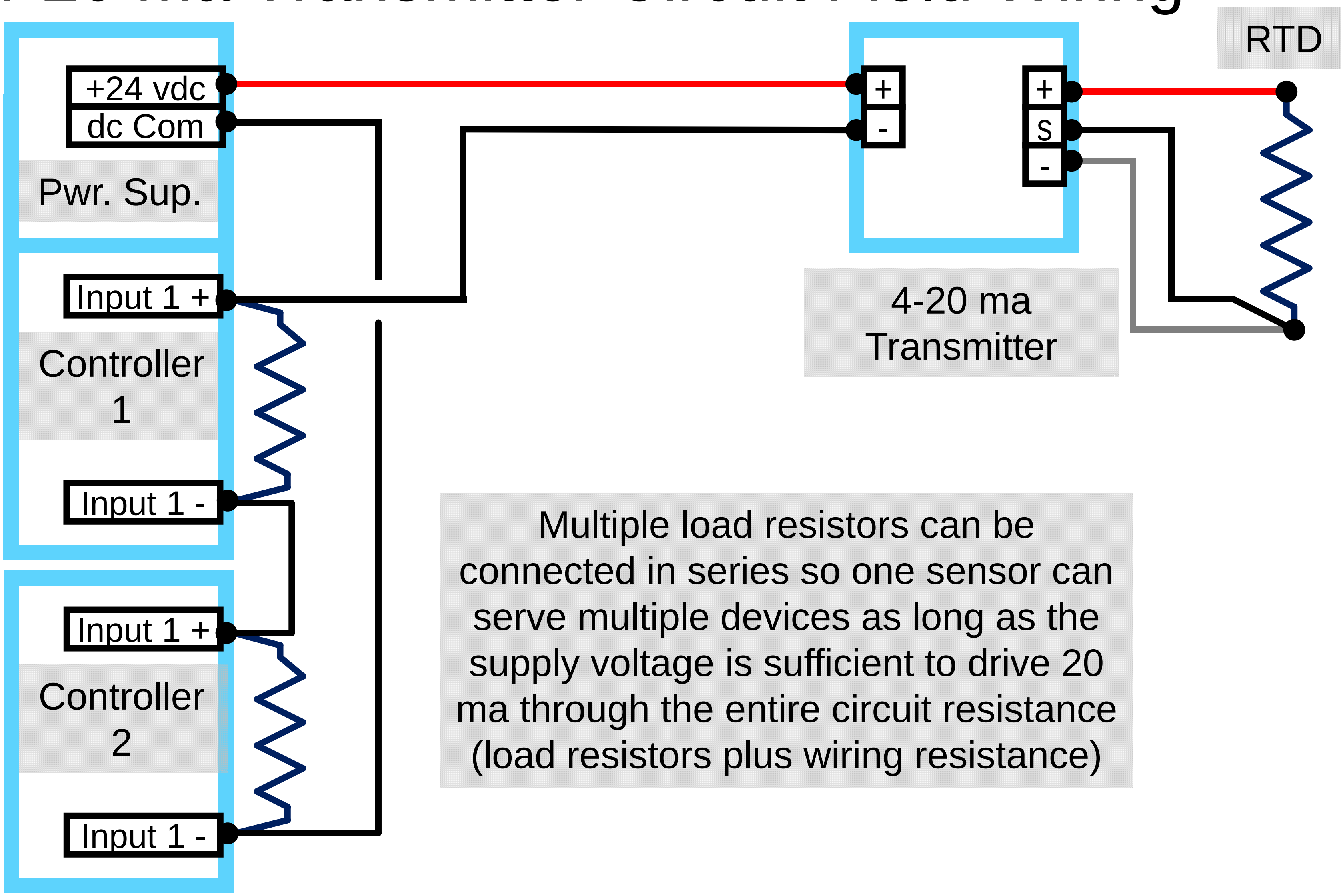


- The load resistor voltage drop becomes the input to the control system
- The loop can have multiple load resistors as long as there is sufficient voltage to drive 20ma through the total circuit resistance

4-20 ma Transmitter Circuit Field Wiring

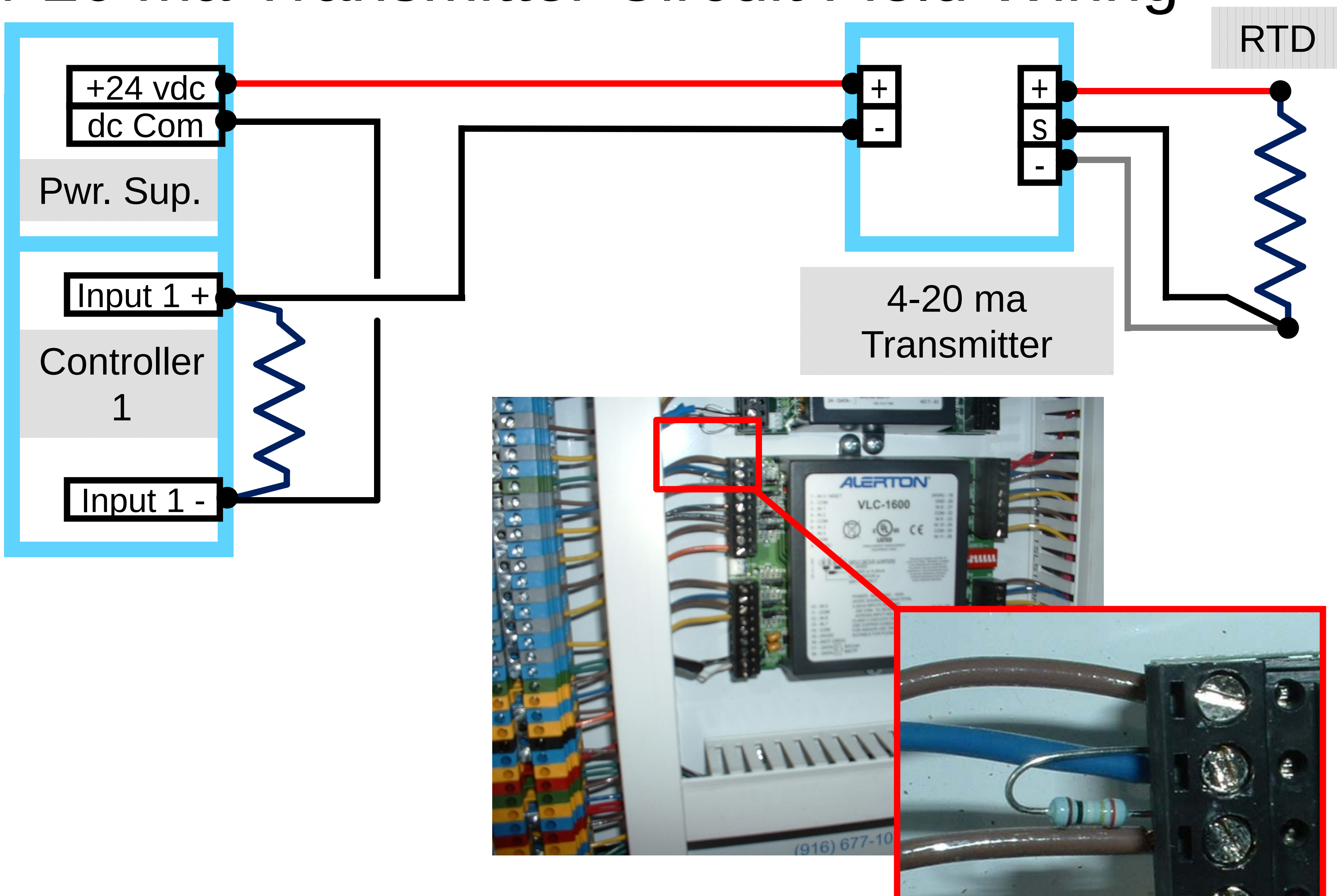


4-20 ma Transmitter Circuit Field Wiring

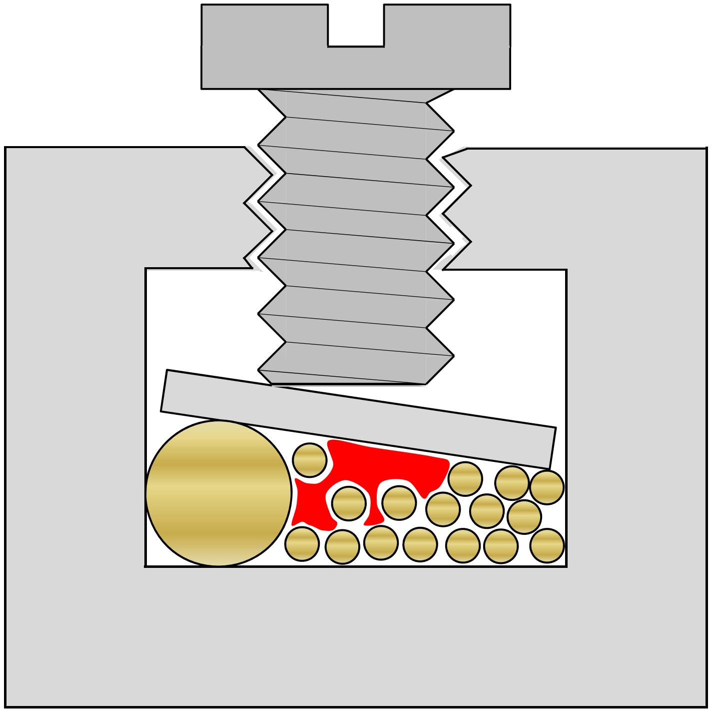


Multiple load resistors can be connected in series so one sensor can serve multiple devices as long as the supply voltage is sufficient to drive 20 ma through the entire circuit resistance (load resistors plus wiring resistance)

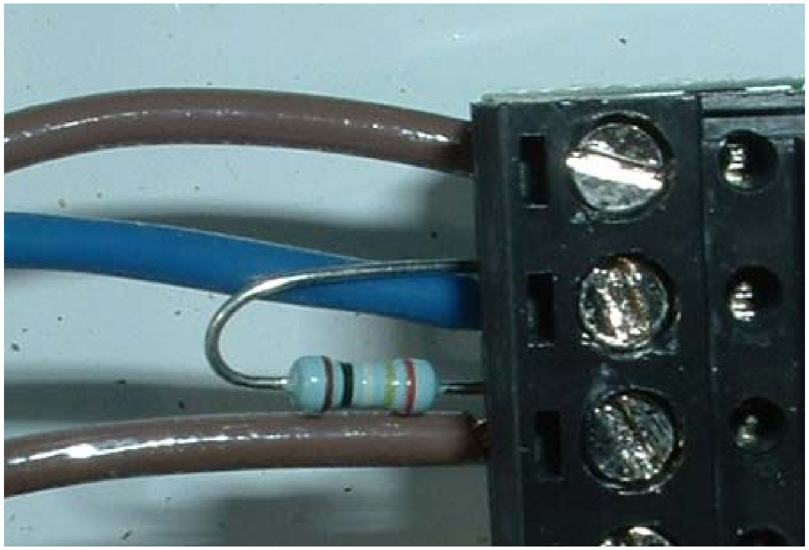
4-20 ma Transmitter Circuit Field Wiring



4-20 ma Field Wiring Issue



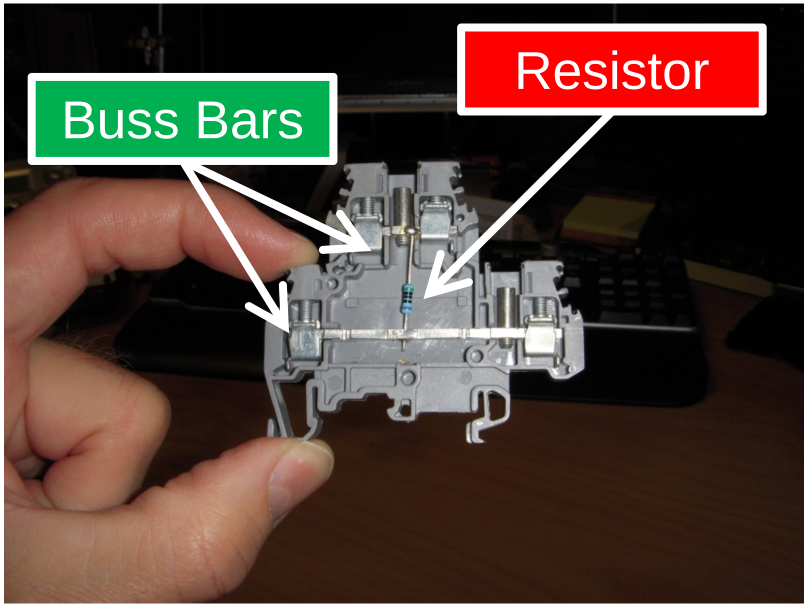
Space between conductors = Loose grip



Loose grip = Loose connection

Loose connection = Poor data integrity

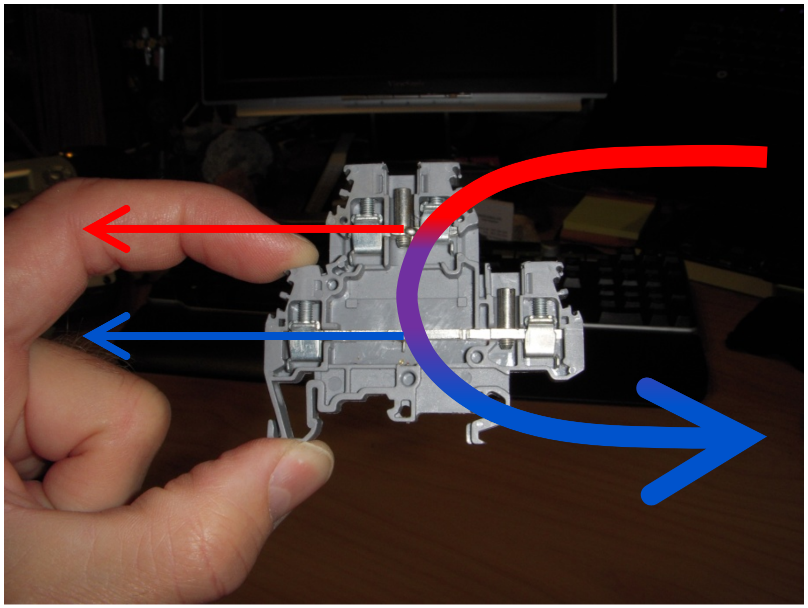
4-20 ma Field Wiring Solution



Resistor terminal block

- Two continuous buss bars
- Precision resistor brazed between the buss bars

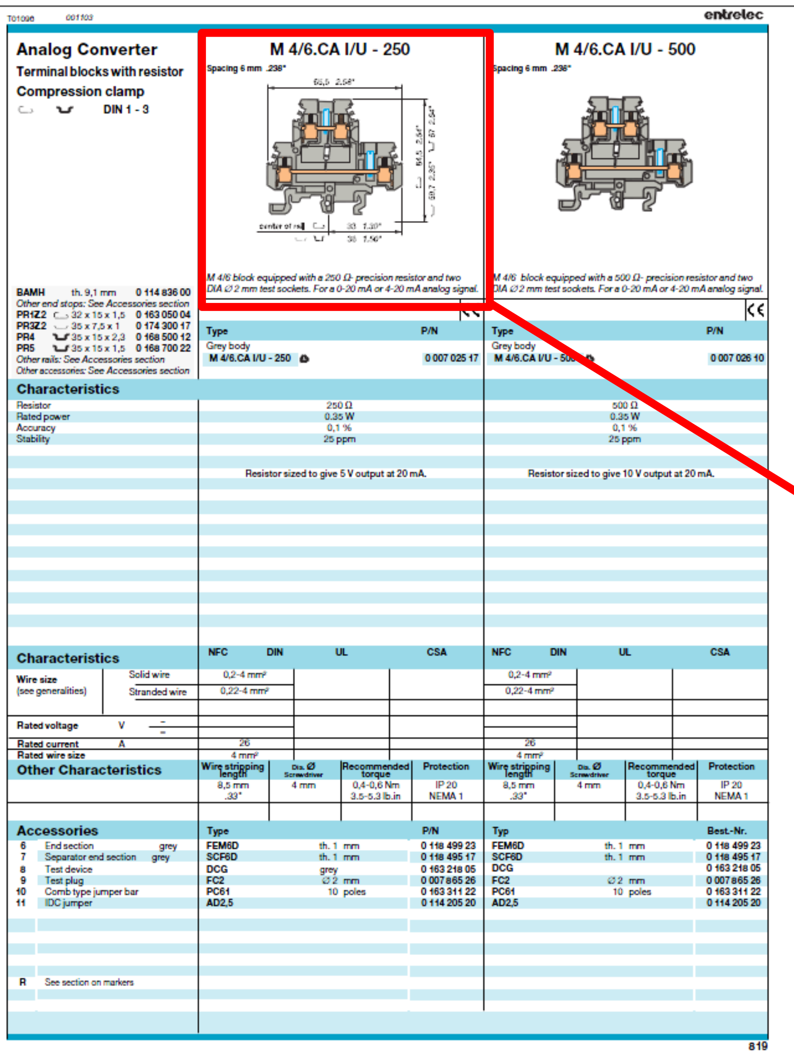
4-20 ma Field Wiring Solution



Resistor terminal block

- Two continuous buss bars
- Precision resistor brazed between the buss bars
- Current loop flows through the resistor on one side
- Voltage picked up to the controller on the other size

Entrelec's Solution



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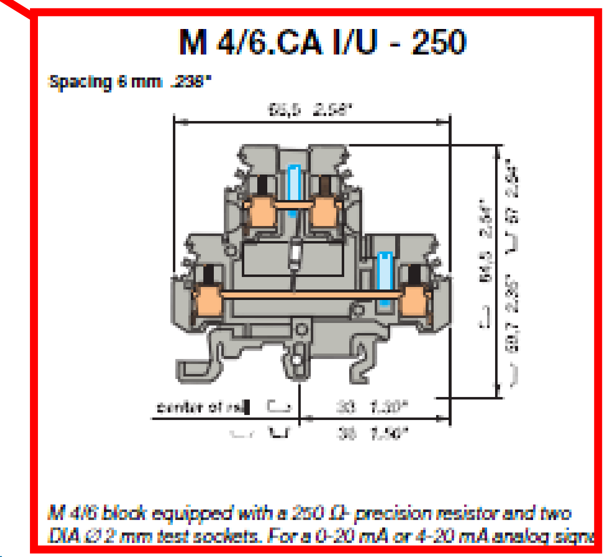

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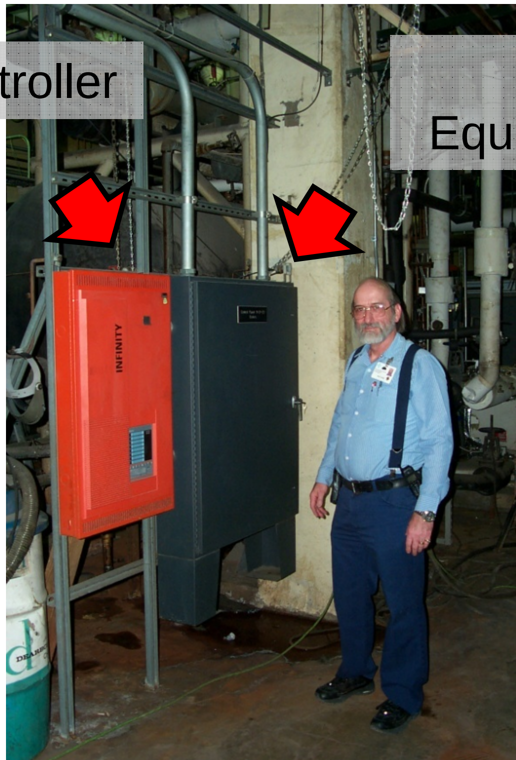

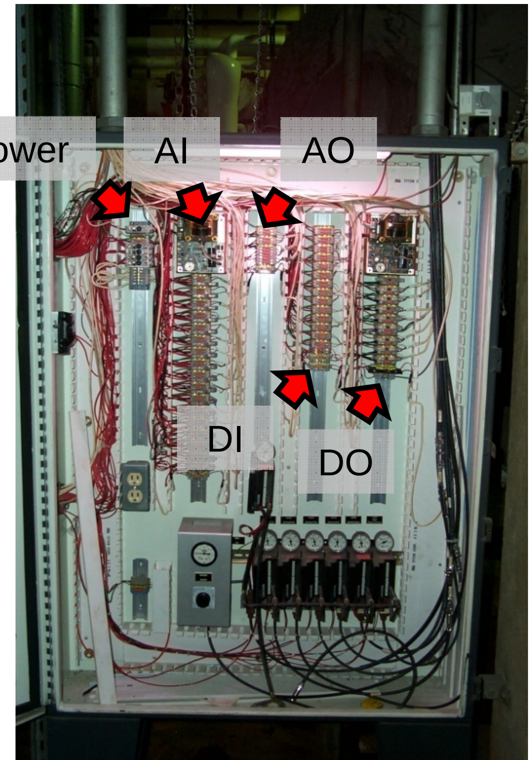

MEMORIAL HOSPTIAL OF CARBONDALE

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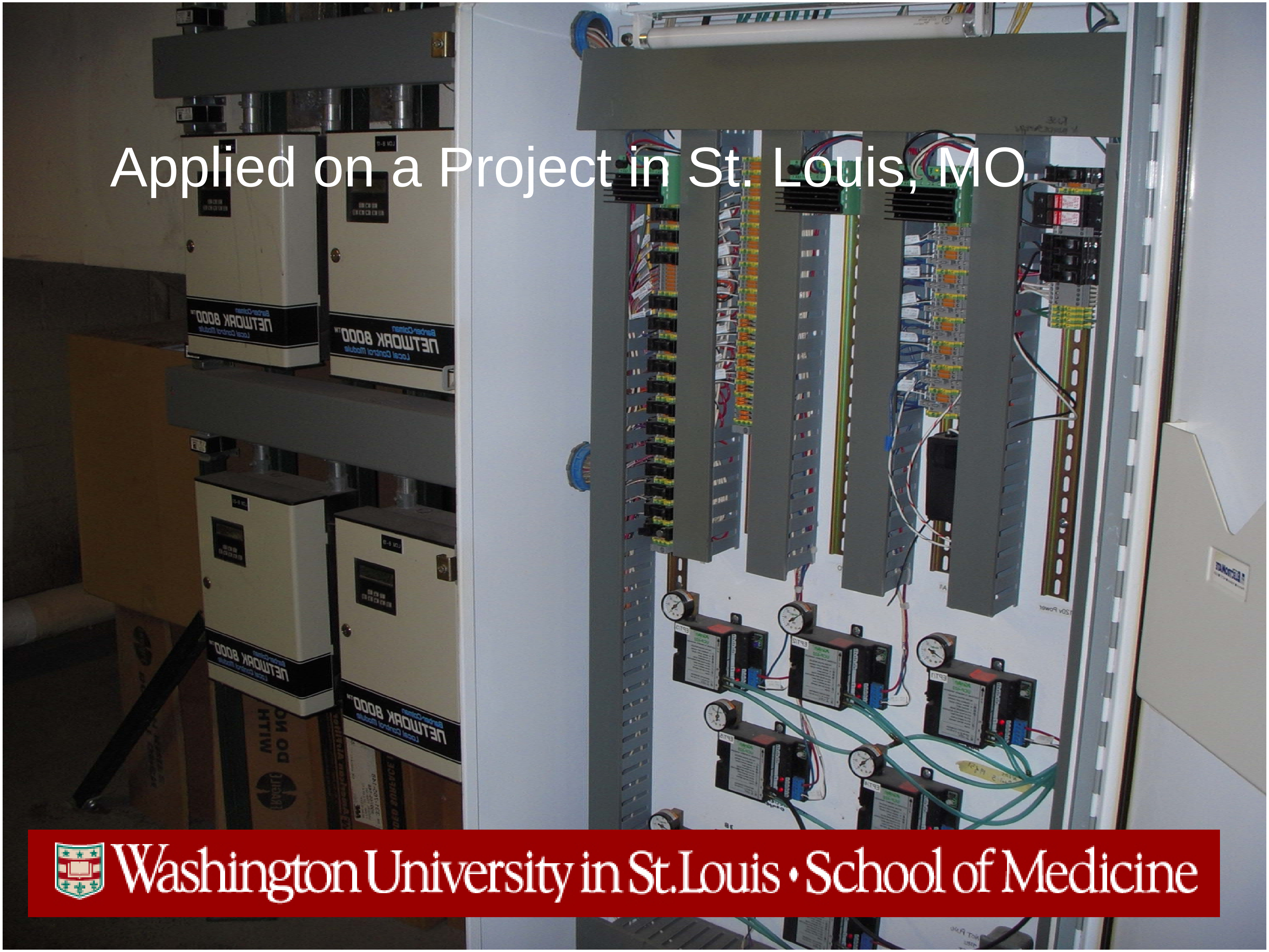

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Applied on a Project in St. Louis, MO

Washington University in St.Louis • School of Medicine

How to engineer 4-20 mA loops

BY DAVID SELLERS, PE, *Facility Dynamics Engineering, Portland, Ore.*

This article discusses the what, why, and how of engineering with 4-20 mA loops. It is a summary of first two posts in a series on the topic that I started in April 2009 in my blog, "A Field Guide for Engineers."

Current loops are a very common way to transmit data from a sensor to a remote location. Using a 4-20 mA signal opens the door to measuring just about anything, from flow to pressure to carbon dioxide, in measurement applications ranging from BAS in operational buildings to data loggers supporting commissioning or troubleshooting efforts.

What 4-20 mA current loops are and how they work

In general, current loops use a transmitter between the sensor measuring the process variable and the input device associated with the control system. Process variables could include temperatures, flows, humidity, and carbon dioxide. Today, if you want to measure it, there is probably a sensor with a 4-20 mA output that is available to do so. Typical input devices include the field panels and controllers associated with current technology, direct digital control systems, independent stand-alone controllers, and local indicators intended to display the process variable but not necessarily control it.

The transmitter generates a dc current that is directly proportional to the measured-process variable. For instance, a 4-20 mA transmitter rated for 0-100 F would generate 4 mA at 0 F, and 20 mA at 100 F.

The common standard is to provide a linear signal that varies from 4-20 mA, as the measured variable shifts over the field sensor's range. Other standards exist, like 10-50 mA, but they are not common in the commercial HVAC market and usually limited to process control applications.

At the circuit board level, most control systems work with voltages rather than currents. Most current loop signals ultimately are converted to a voltage at the controller or indicator they serve, which is the function of the load resistor (Figure 1). The varying current through the load resistor causes a varying voltage, which is picked up by the controller electronics. Table 1 illustrates the voltages produced by the two most common scaling resistors in use. If you've had some experience and exposure to controls, you will likely notice the voltages are also common input standards.

Current loops can serve multiple devices by simply wiring the loop in series through the load resistors, and as long as the power supply has enough voltage to drive 20 mA through the sum of the resistances (including the wire), the process will work.

Data logger applications

"How do you hook up a 4-20 mA current loop to a data logger?" Questions like this often arise while an engineer is in the field on a project. In addition to building up power supply panels, teams must also realize that these panels are major components of the solution (see Figure 2).

The dc power supply panel is the gray box and the data logger is the tan square inside of the lower left-hand corner. The green rectangle toward the top center of the panel is the actual dc power supply, which is wired to the terminal blocks immediately below it on the low voltage side and to a standard 120 vac cord and plug on the high-voltage side. The square black boxes to the right are transmitters that I was about to install to monitor the 3-psi to 15-psi signal serving a couple of pneumatic control valves and dampers. The picture in Figure 2 was taken while I was checking to make sure everything was working properly before I installed the panel in the field. Figure 3 shows the panel installed in the field.

In the left-hand portion of Figure 3, the actual damper actuator that is being monitored is not included in the picture, but the pneumatic signal transmitter is the black box tie-wrapped to the catwalk railing in the upper left corner. In Figure 4, you can see the black tubing leading from the transmitter to the pneumatic line serving the actuator we are monitoring.

Transmitting information over distances

When you are sitting at a modern control system front end, it's easy to forget that there are a lot of things between you and the process parameter that you are trying to measure, as illustrated in Figure 5.

For instance, on the input side of the system in Figure 5, the transmitter, wiring, controller, network device, and workstation all can introduce errors into the reading observed by the operator relative to what is going on at the sensor.

Current loops offer advantages in noise immunity and allowing information from a sensitive but low-gain-measuring element to be accurately transmitted over long distances. For instance, a 100-ohm platinum resistance temperature device (RTD) is an accurate way to measure temperature, but the resistance change associated with a temperature change is modest—fractions of an ohm per degree F.

RTD measurements typically are made by applying the RTD in a resistance-bridge and using the change in voltage as in indication of the change in temperature. Since the changes in resistance are small, the associated changes in voltage are small, typically on the order of millivolts (mV) per degree F.

Often in the field, the induced voltages from the conductors serving the machinery can exceed these voltage levels by several orders of magnitude. For example, when troubleshooting a chiller-interlock circuit, I kept picking up 10-15 vac in a circuit that was isolated from any power supply. Then I realized that my control conductors were running in a long cable tray in parallel with the large conductors carrying hundreds of amps to a different chiller in the plant. Consequently, the long run of parallel wires was acting like a transformer, inducing a voltage in the interlock circuit from the power feeders. Turning off the chiller made the induced voltage go away.

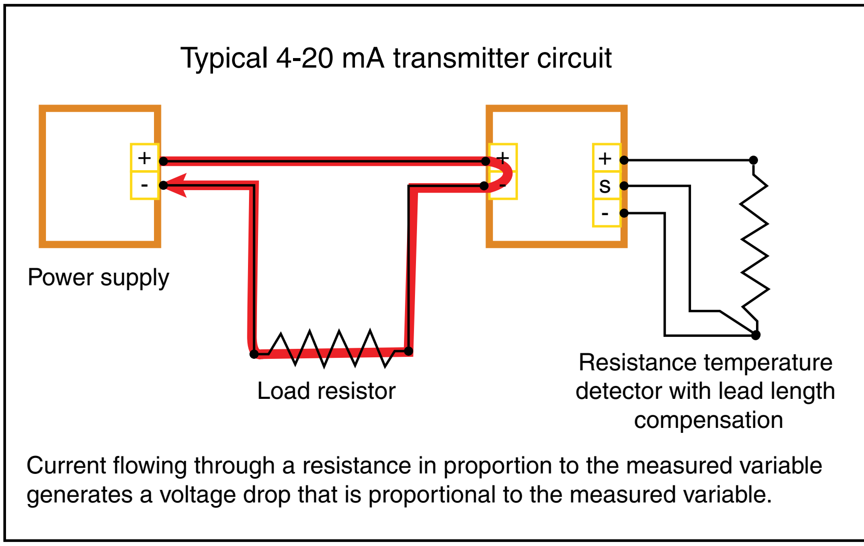

Figure 1: *This diagram shows a typical 4-20 mA current loop arrangement and operation. All photos and figures: David Sellers.*

Solving E = I x R for different currents and resistances				
Load resistance, ohms	250		500	
Current loop current, amps	0.004	0.020	0.004	0.020
Load resistance voltage drop, volts	1.000	5.000	2.000	10.000

Table 1: *Scaling resistor voltage drops for common resistors with a 4-20 mA current flowing through them.*

Figure 2: *This dc power supply panel will power up four or more 4-20 mA devices and use them as inputs to a data logger.*

Figure 3: *This shows a dc power supply panel deployed in the field.*

Figure 4: *The black tubing leads from the transmitter to the pneumatic line serving the actuator.*

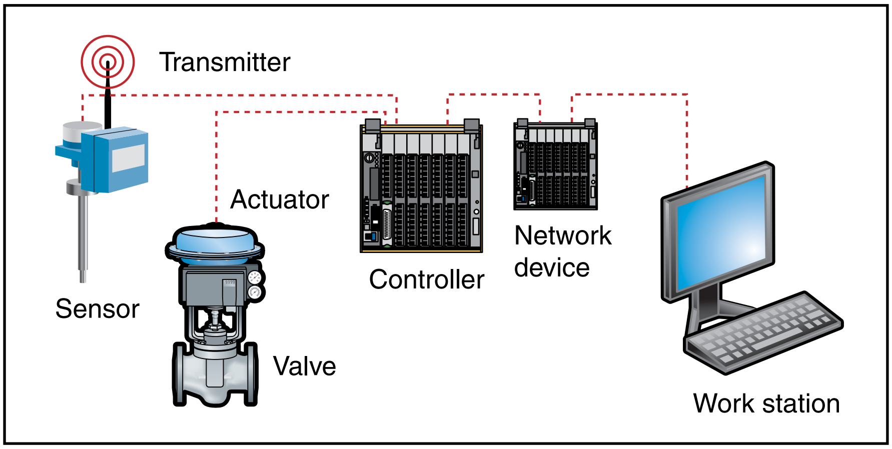

Figure 5: *The path from sensor to operator to actuated service contains a number of elements that can impact the accuracy of what you see and what you get as a result.*

Shielding

10-15 V of induced signal would completely obscure an mV-signal on cable carrying information from an RTD to a controller. Shielding helps address the issue by blocking and channeling away the undesired signal. For control systems, shielding typically is a metallic foil or metallic braided sheath that is wrapped around individual wires or pairs of wires with the entire assembly enclosed in an insulating jacket of some sort (see Figures 6 and 7).

Typically, control wiring for commercial office buildings is in the form of #18TSP, which stands for one pair (P) of 18-gauge wire (#18), which is twisted (T) and shielded with a foil jacket (S).

In Figure 6, from left to right, are Ethernet Category 5 cable (CAT5) #16 unshielded twisted pair, #18 three conductor twisted shielded, and #18 TSP. In Figure 7, from left to right, are the stripped jacket (blue), the three conductors, (black, red, and white), the fiberglass strand used to strip the jacket off the conductors, the foil shield, and the shield drain wire.

It's important to realize that just because a cable is shielded does not always mean the shield will be effective, because installation practices can play a big part in the success or failure of a shielding system. For instance, if the shield wire is grounded (accidentally or intentionally) at both ends of the cable, then the shield becomes a current-carrying conductor between the two

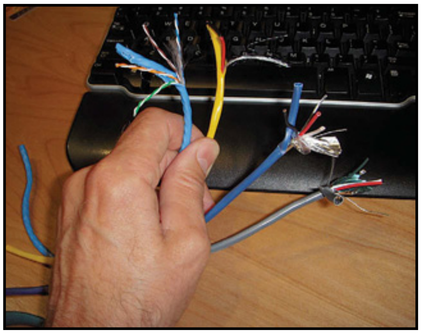

Figure 6: *These are typical control wiring cables found in a commercial building control system.*

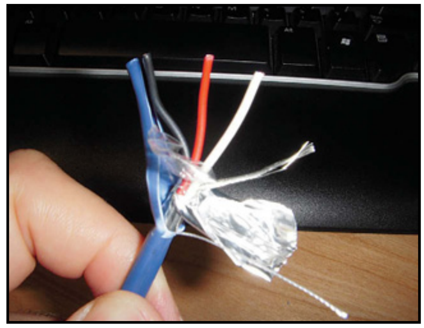

Figure 7: *A detailed look at the construction of a typical shielded cable is pictured.*

grounding points. A common misconception is to think of ground as being 0 V, but if you measure the ground voltage at different places relative to a common point in a building, there are actually minor voltage differences.

Once the conductor is connected to ground at two different points at a different voltage, by virtue of the physics, a current will flow due to the voltage difference across the conductor. Additionally, a flowing current generates electromagnetic fields, which can couple to adjacent conductors and induce voltages and currents.

Even if shielding were perfectly implemented and eliminated the potential for noise in the measured signal, the wires that are carrying the mV signal from the RTD to the controller still can cause a problem. More specifically, wire has a resistance; even in good conductors such as copper. Consequently, a long run of wire adds to the resistance of the RTD, and without special compensation circuits, can be interpreted as part of the signal. The Control Design Guide on the Portland Energy Conservation Web site contains an example of how much this can impact the information from an RTD in a typical HVAC application.

The relationship between shielding and 4-20 mA current loops is that by their nature, 4-20 mA current loops are resistant to noise and it's possible to use unshielded cable when installing them. While possible, the cost of shielding for a #18TSP is relatively modest compared to the cost of a typical wiring installation. So, you are better off using a shielded cable that can serve multiple types of inputs. This makes it less confusing to install the wiring in the first place and provides some flexibility in terms of changes that might be made down the line to the input devices and/or the control equipment.

Lessons learned

Early in my career, I learned a valuable lesson about the significance of lead resistance and the impact it can have on the parameter one is trying to measure. After measuring and re-measuring, I discovered that the lead resistance in a 1,000-ohm-copper-RTD circuit, which amounted to 1.5 F, was greater than the temperature change the control system needed to detect to make the decision to start or stop a chiller (about 0.5 F).

Compounding the problem was the fact that resistance of the lead conductors

Summary of blog posts on the topic of 4-20 mA current loops

4-20 mA current loops: interpreting current loop information—April 4, 2009

This post explains how to interpret data from current loops and some of the calibration issues associated with them. The calibration issues discussed also apply to other signal technologies, not just current loops. This post includes information on how to make a spreadsheet that will help interpret current loop data.

4-20 mA current loops: power supply panel parts—May 1, 2009

The topic of this blog entry is how to build a power supply panel that will allow you to use a 4-20 mA current loop with a typical data logger. A similar technique is used to interface these devices to a BAS when the controllers do not have the ability to drive the current loops directly.

4-20 mA current loops: answering a few questions—May 10, 2009

This post answers a few questions about the first posts in the series and includes some information on wireless signal transmission technologies.

4-20 mA current loops: assembling the dc power supply panel—May 30, 2009

Wiring information and assembly tips for constructing a dc power supply panel are provided based on the materials list in the previous post. This post also discusses the details of terminal block construction and how they can impact the accuracy of the data you are collecting.

Using the dc power supply panel in the field: picking cable—June 30, 2009

This post looks at some of the details associated with instrumentation cables and considerations as you pick cable to use with a field deployment of your power supply panel.

Demonstrating HVAC filtration savings with data loggers—Sept. 13, 2009

This post covers a couple of the power supply panels in action supporting data loggers in a field trial that contrasts two different filter technologies.

between the control panel and the RTD varied with temperature. As a result, when the mechanical rooms were cool, the lead resistance error was different from when the mechanical rooms where hot. Again, the change was more than the change I was trying to measure because in the winter the mechanical rooms could be in the low 60s F, while temperatures in the summer could exceed 120 F.

Adding a 4-20 mA transmitter to the RTD circuit was one way to address some of these issues in my particular situation as well as in general. For one thing, since the signal is a current rather than a voltage, it is fairly immune to the impact of induced voltages. In addition, as long as the power supply is adequate, the wires can be run for literally miles serving multiple controllers and indicators without degrading the signal.

It's important to remember that the transmitter itself, being another device between the process and the controller, will introduce its own errors on a number of fronts including hysteresis, linearity, temperature effects, and mounting effects. However, in most instances, the cost is worth the benefit.

In addition to the technical reasons, current loops are attractive because they are a common standard supported by many manufacturers. This is beneficial because a user or device that can pick up a signal from a 4-20 mA current loop can measure just about anything, from temperature and flow to pressure and toxic gas levels.

Conclusion

If this article has tweaked your interest in current loops, you may find my other posts on the topic to be of interest. The blogs start in April of 2009 and are summarized in the sidebar, which includes instructions for building a dc power supply panel so you can use 4-20 mA transmitters with field deployed data loggers.

Given how flexible the technology is, future blog posts will expand on this topic, including how to apply current loops to measure and troubleshoot the systems we all work with to control the built environment. |cse|

Sellers is a member of Consulting-Specifying Engineer's editorial advisory board. His background includes more than 30 years of experience with commissioning, design engineering, facilities engineering, mechanical and control system contracting, and project engineering in a wide array of facilities. This article was developed in collaboration with the Building Commissioning Assn

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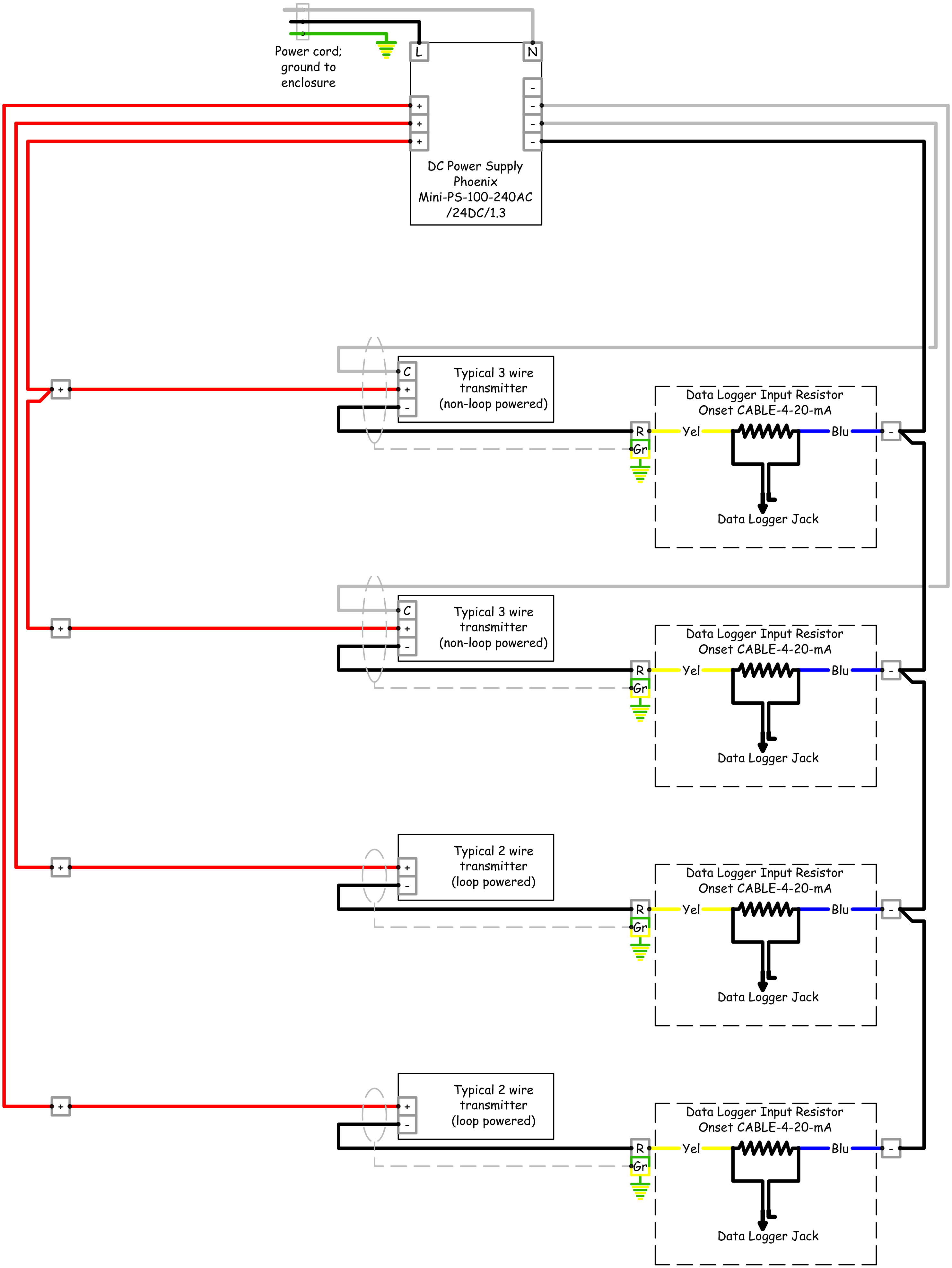

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