Signal Conditioning Whitepaper

What is Signal Conditioning Anyway?

Introduction

The purpose of this paper is to attempt to explain the most important issues related to Signal Conditioning and sensor interface technologies. It is not meant to be comprehensive, but instead to cover the basics and help the user in creating a successful installation.

Definition of Signal Conditioning

Signal Conditioners are electronic instruments used in factory or machine automation, to convert sensor measurement signal levels to industry standard control signals. Industry standard control signals provide computer and control system manufacturers a common communication method to effectively receive and transmit measurement and control data. Examples of measurement data include temperature or AC/DC voltage/current signals from various sensors. Examples of control data include on/off signals for a heating element or proportional signals for a valve actuator.

Common Input Signals to Signal Conditioners

There are many thousands of types of sensors used for very general or very specific measurement requirements. Since Signal Conditioners are used to enable process automation, most of the signals measured are produced by sensors and are electrical in nature. Sensor elements for automation usually provide an electrical output or a way of measuring changes in the sensor's electrical properties.

Usually an electrical reference or excitation source is required for sensors whose electrical properties are measured. As an example, a very common temperature sensor is a Resistive Temperature Detector (RTD). Since the resistance of an RTD changes with temperature, a constant DC current excitation source is used as a reference to produce a proportionally changing voltage [Ohm's Law: Voltage = Current (I) x Resistance (R)]. Thus, a Signal Conditioner that measures an RTD input provides a current reference as excitation and measures the voltage produced.

Types of Sensors and Inputs

There are nine common sensor signal input types:

Sensor/Input	Types	Signal Measured (excitation)	Application
Thermocouples	B, C, E, J, K, N, R, S, T	Millivolts DC	Temperature measurement
RTD	Pt100, Pt200, Pt500, Pt1000, Cu10, Ni120	Resistance (DC current)	Temperature measurement
DC Current	4-20mA, 1-5A, 0-100microA, 0-1mA, 1-5mA	Amps DC (24V DC)	Standard control signals or sensor outputs
DC Voltage	1-5V, 0-10V, +/-5V, +/-10V, 0-100V, 0-500V	Volts DC	Standard control signals or sensor outputs
Strain Gage / Bridge	0-10mV, 0-20mV, 0-30mV, +/-10mV, +/-50mV	Millivolts DC (5-10V DC)	Weight, pressure, stress, compression
Potentiometer	0-100 Ohm, 0-500 Ohm, 0-1000 Ohm, 0-10 KOhm	Resistance (DC voltage)	Setpoint adjust, position feedback, tank level
Frequency/Pulse	Sine wave, square wave, triangle wave or pulse spike	mV or V DC (5V, 12V, 24V DC)	Proximity sensor for rate, speed, flow and accumulation
AC Current	0-100mA, 0-1A, 0-5A	Amps AC	Power or load measurement
AC Voltage	0-500mV, 0-24V, 0-120 V AC	Volts AC	Power or load measurement

Standard Output Signals

4-20mA is the industry standard signal for process control (0-20mA is common in other parts of the world as well). The primary advantages of a 4-20mA signal is the "live zero" which refers to the 4mA minimum (0% of full scale) and the fact that current signals have a high immunity to induced noise. The live zero is an advantage in the case where signal wires might be damaged. If there were an open circuit no current would flow (e.g. 0mA or -25% of full scale) and an operator would be sure to recognize a problem, versus the case where a 0-10V signal is used and an open circuit would produce 0V (or an indeterminate value) which might be mistaken for 0% of full scale.

Regarding noise, the physical principals of electromagnetics prove that voltage signals and high impedance voltage input instruments are much more susceptible to noise generated by radio transmitters or electric motors and power lines than current signals and their low input impedance instruments. Other popular signal levels are 1-5V and 2-10V, which are the result of 4-20mA current signals and 250 Ohm and 500 Ohm load resistors, respectively.

Relay Outputs

Relay outputs are also common in control systems. They are used to apply power (Typically 120 V AC) to motors, lights, pumps, horns, conveyors and other devices. In some cases, relays are used to produce a count and will switch DC power (12V or 24 V DC) to represent flow rates, or maybe the number of bottles sealed on a bottling line. Solid State Relays are used for fast switching and/or where high reliability is required since they have no mechanical delays or wear. Solid state relays often operate at transistor-to-transistor logic (TTL) levels of 5 V DC and are available for higher levels of AC and DC power.

Grounding, Signal References and Ground Loops

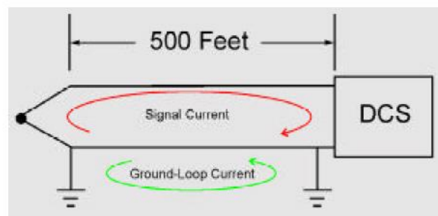
Measuring process variables such as temperature, pressure and flow are very common in today's industrial applications. Sensor manufacturers provide the technical specifications required to interface their devices to a wide variety of control and measurement systems. However, signal grounding and electrical references are often not mentioned in manufacturer's application notes and are often overlooked in system design. This oversight can lead to significant problems and the need for signal ground isolation. A signal reference is the relative ground potential (or ground voltage) at the point of measurement. Theoretically, every point has a different ground potential determined by the charge density of the surrounding environment. For example if you have ever been shocked when touching a door knob after walking across a carpet, you have felt the discharge of your relative ground potential to that of the door's.

In industrial applications two different grounds may be inadvertently connected together, one at the point of measurement (the sensor) and the other at the point of control (computer or control room). Since these two grounds are typically wired together you do not get the same spark seen the instant you touch the door knob. Instead, there is a small "ground current" that may flow from the higher ground potential to the lower. This current will produce signal errors and the cause is commonly referred to as a "Ground Loop". The Ground Loop refers to the circular conducting path that exists between the two points (sensor and control room), the "earth ground" conducts through moisture and the minerals in the soil while the signal wires conduct for the other half of the loop. Connecting the signal wire completes a loop between the earth and the two points.

An example might be a pressure sensor on a tank in a tank farm that measures the half full level of the fluid in the tank. A control room operator monitors the levels of all the tanks spread out over several acres on the tank farm. The pressure sensors are grounded to the tanks and the power system of the control room is grounded for the safety of the operator. One day a thunder storm blows over the tank farm and a large thunderhead (cloud) passes over the tank. The electrical charge of the thunderhead raises the ground potential of the earth and tank below. The result is a very significant differential in ground potentials between the tank and the control room and because the two grounded points are connected together a large error current flows down the wire to the control room and the instrument monitoring the tank level may read a full tank of fluid due to the erroneous ground current.

Isolators and Isolation of Signal Grounds

If the explanation of ground potentials and ground loops is not entirely clear, don't worry. Just keep in mind when developing or checking a control system is where the grounds are located. If there are two devices or sensors that are grounded, then a signal ground isolator will be required to ensure signal integrity.



Ground Loop Problem

A signal ground isolator (or Isolator) provides a "floating" ground reference at the input and output of the device. This means that neither the input nor the output circuits are connected to ground. Typically an isolator has a power transformer where the primary side of the transformer, which accepts the main power, is electrically isolated from the dual secondary side which provides power to the input and output circuitry. The input and output circuitry will be isolated from each other with an optical isolator chip or another isolation transformer. High quality optical isolators and transformers are typically rated to provide several hundred to several thousand volts of isolation. These types of isolators are called three way isolators because they isolate input from output, input from power and output from power.

Another example of grounding sensors and isolation can be considered in the case of a common industrial boiler used for steam heat and power generation. In this example, several thermocouple sensors are embedded or even braised to the boiler vessel, which is typically made of steel. This is done to ensure maximum thermal conductivity between the vessel and the thermocouple sensor. In addition, grounding thermocouples at the point of measurement reduces signal errors due to electromagnetic interference or radio frequency noise, which can be induced on the thermocouple wires from motors or walky-talkies.

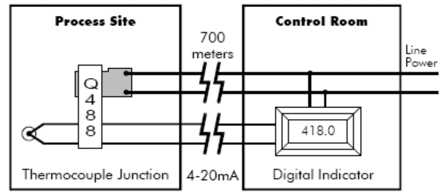
In this example, if the boiler controller shares the same (good steel) ground as the thermocouples in the vessel then a control engineer might get away with not using signal isolators to separate each grounded thermocouple because the good conducting steel vessel acts as one large ground point. However, there will always be a chance of ground currents and errors in the system if each of the thermocouples is not isolated from the others. Additionally, if the system has a remote steam trap for heat transfer and more grounded thermocouples at that point, and they are connected back to the boiler controller, then the probability for having grounding problems will be very high. This is actually a very common occurrence, where one portion of a system works well until another portion is connected. To prevent problems such as this, ioSelect carries only isolating thermocouple signal conditioners.

Types Of Signal Conditioners Or Isolating Transmitters

Signal Conditioners can amplify, convert, boost, transform, buffer, filter, alarm and isolate process control signals. There seems to be no limit to the variety of things control engineers want to do to or with control signals. Signal conditioners go by many names, converters, transducers, isolators, transmitters, and black boxes. Conventionally most signal conditioners and signal isolators fall into three categories, based on the number of wires required for power and signal. The three types are referred to as four-wire, three-wire and two-wire transmitters.

Four-Wire Transmitter

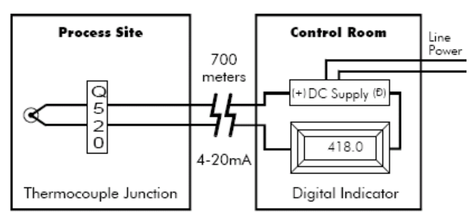
A four-wire transmitter has two-wires for power and two-wires for the signal output. A four-wire transmitter can be AC or DC powered, typically 120 V AC, 240 V AC or 12 V DC, 24 V DC. In most cases, the power supplies are transformer isolated to ensure that ground faults are not introduced through the power circuit. Sometimes manufacturers provide a wide-ranging power supply which is typically jumper selectable for AC power or the DC power supplies will operate through a range greater than 12V to 24 V DC (e.g. 9 to 30 V DC). In the case of ioSelect's SelectPak product, a unique universal power supply is available (19 to 264 V AC or DC). Four-wire transmitters provide a powered output, either a voltage signal (e.g. 0-10V, 1-5V), or a current signal (e.g. 4-20mA, 10-50mA) and in some cases a relay (e.g. solid state or contact closure).



Four-wire transmitters are popular because they are complete. Since they have their own power supply they do not use power from the input or output signal lines. The power supply also allows four-wire transmitters to power their output signal. Therefore, four-wire transmitters are often used to boost signals for retransmission. This makes the four-wire transmitter a popular solution to improve signal drive to other instruments on the output. Four-wire transmitters are typically isolated from power and many models are optically isolated between the input and output circuit.

Two-Wire Transmitter

A two-wire transmitter has two-wires for both power and the output signal. A two-wire transmitter is always DC powered and the output can only be a current signal, typically 4-20mA, or 0-20mA. The two-wire transmitter is considered a field device and requires very little power (i.e. milliwatts). Therefore, it is appropriate for hazardous environments (explosive) such as chemical refineries and pharmaceutical plants. In this example the advantage of the low DC power requirement, which ranges from 10 to 48 V DC at currents as low as 4mA, reduces the chances of an electrical spark causing ignition of flammable vapors. In addition, two-wire transmitters save on wire costs since both the signal and power are on the same wires. Locating a two-wire transmitter as far as 2000 feet from the control room is possible and at half the wiring cost of a four-wire transmitter.

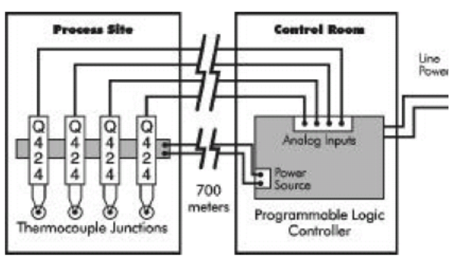


Since a two-wire transmitter's signal is a regulated current from a DC power supply, its ability to provide a signal to other devices depends on the size of the power supply. For example if the two-wire transmitter has a 12V minimum power requirement and a 24 V DC power supply is used to power the transmitters output current loop, which results in 12 volts of remaining loop drive available (e.g. 24V power supply - 12V transmitter = 12V remain for other devices). The maximum load or resistance that can be added to this loop is 12V divided by 20mA (maximum signal) or 600 Ohms.

So if two other instruments, maybe an indicator and chart recorder, were to be installed in the loop and their input impedance was 250 Ohms then this would use all but 2V (100 Ohms) of the loop drive. To increase the loop drive, a 36 V DC power supply could be used, permitting more instruments to be added to the loop. Two-wire transmitters may be isolated from input to output, incorporating either an isolation transformer or an optical isolator. Many low cost two-wire transmitters are not isolated, which makes it important to ensure that the input sensor is not grounded.

Three-Wire Transmitters

Three-wire transmitters are a blend of the four and two-wire versions. The three-wire transmitter uses two-wires for power and the third wire is used for the signal (+) positive terminal. The power (-) negative terminal is used as a common reference for power and the signal (-) negative reference. This allows the best of both transmitters features to be utilized. There is one less wire required than a four-wire transmitter and powered outputs are provided for both 4-20mA signals and 0-10V signals. These transmitters can be lower in cost than four-wire transmitters because they are DC powered and do not incorporate an isolating power supply. However, due to this cost saving technique, designers must be aware of grounding especially since several transmitters are usually connected to one power supply, and the negative (-) terminal is common to all signals.



Three-wire transmitters may be isolated from input to output incorporating either an isolated transformer or an optical isolator.

Limit Alarm Trips

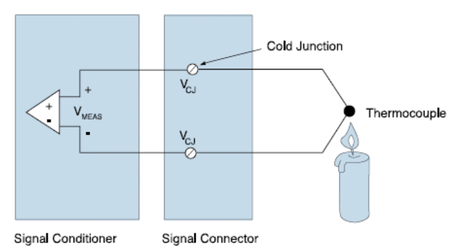
Limit Alarms are considered a type of four-wire transmitter since they have two-wires for power and at least two-wires for the relay signal output. Limit Alarms, or Limit Trips as they are sometimes called, are very similar to a thermostat or the temperature controller of your heater or air conditioner in your office building or home. A limit alarm has a setpoint that is used as a reference against a process variable. On your thermostat at home you may have the temperature set for a cozy 72°F or 23 °C. If the room temperature gets below that "setpoint" level then the heater will turn on. This is an example of on/off control. A limit alarm does the same thing, however it is used in many more applications than just on/off control. One of the most popular uses for limit alarms is safety back up systems. If a temperature gets too high the limit alarm might light a control panel annunciator to alert a control room operator. Alternatively, if a pressure level gets too high or coolant level too low the limit alarm could use its relay output to turn on a horn, indicating a dangerous condition. Other applications include secondary control back-up, where if a computer controlling a system locked up and could do nothing, the secondary signal monitors (i.e. limit alarms) would trip and begin a controlled shut down process to prevent damage and other hazards.

Details of Sensor Conditioning

Sensors are devices that convert physical phenomena, such as temperature, strain, pressure, or light, into electrical properties, such as voltage or resistance. Sensor characteristics define many of the signal conditioning requirements of a control system.

Thermocouples

The most popular sensor for measuring temperature is the thermocouple. Although the thermocouple is inexpensive, rugged, and can operate over a very wide range of temperatures, the thermocouple has some unique signal conditioning requirements. A thermocouple operates on the principle that the junction of two dissimilar metals generates a voltage that varies with temperature. However, connecting the thermocouple wire to the wire that connects it to the measurement device creates an additional thermoelectric junction, referred to as the cold junction. The actual measured voltage therefore includes both the thermocouple voltage and the cold-junction voltage.

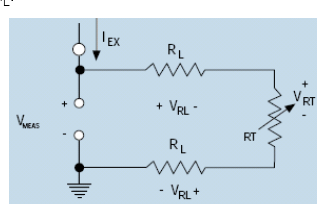


The method of compensating for these unwanted cold-junction voltages is called cold-junction compensation. Most signal conditioning products compensate for cold junctions by using an additional sensor, such as thermistor or IC sensor, placed on the signal connector or terminal block to measure the ambient temperature at the cold junction directly. Software, or circuitry, can then compute the appropriate compensation for the unwanted thermoelectric voltage.

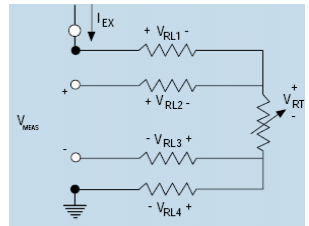
Sensitivity and noise are also important measurement issues with thermocouples. Thermocouple outputs are very low in level and change only 7 to 50 µV for every 1 °C change in temperature, making the signals very susceptible to the effects of electrical noise. Therefore, thermocouple conditioners include low pass noise filters for suppressing 50 and 60 Hz noise and high-gain instrumentation amplifiers to boost the level of the signal. Amplifying the thermocouple signal also increases the resolution, or sensitivity, of the measurement. For example, a typical control device with an ADC input range of ±10 V and an onboard gain of 50 has a resolution of 98 µV. This corresponds to about 2 °C for a type J or K thermocouple. However, by adding a signal conditioner with an additional gain of 100 to the system, the measurement resolution increases to 1 µV, which corresponds to a fraction of a degree Celsius.

RTDs

Another popular temperature-sensing device is the resistance temperature detector (RTD), a device whose resistance increases with temperature. The most popular type of RTD is made of platinum and has a nominal resistance of 100 Ohms at 0 °C. Because an RTD is a resistive device, you must pass a current through the RTD to produce a voltage that a DAQ device can measure. With relatively low resistance (100 Ohms) that changes only slightly with temperature (less than 0.4 Ohms/ °C), RTDs require signal conditioners with high-precision excitation current sources, high-gain amplifiers, and provisions for four wire and three wire measurements that minimize lead error effects. For example, a two-wire RTD measurement includes voltage drop errors caused by the excitation current passing through lead resistance, R_L.



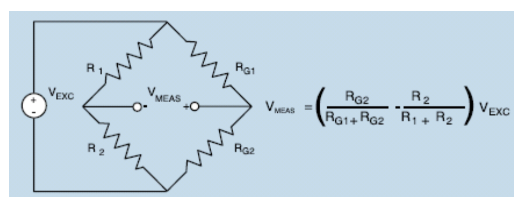
These errors, which can be significant, are removed by using a four-wire RTD measurement. The four-wire configuration uses a second pair of wires to carry the excitation current to the RTD. Therefore, only negligible current flows through the sensing wires, so the lead resistance error is very small.



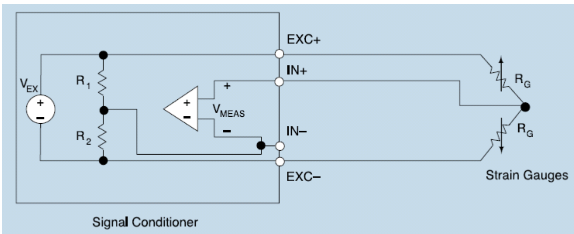
Strain Gauges

The strain gauge is a device commonly used in mechanical testing and measurement. The most common gage, the bonded-resistance strain gage, consists of a grid of very fine foil or wire whose electrical resistance varies linearly with the strain applied to the device. When using a strain gage, you bond the strain gage to the device under test, apply force, and measure the strain by detecting changes in resistance. Strain gauges are also used in sensors that detect force or other derived parameters, such as acceleration, pressure, and vibration.

Strain measurement requires detecting very small changes in resistance, and the Wheatstone bridge circuit is used predominantly. The Wheatstone bridge circuit consists of four resistive elements with a voltage excitation supply applied to the ends of the bridge. Strain gages can occupy one, two, or four arms of the bridge, with any remaining positions filled with fixed resistors. The figure below shows a configuration with a half-bridge strain gauge consisting of two strain elements, RG1 and RG2, combined with two fixed resistors, R1 and R2.



With a voltage powering the bridge, the measurement system measures the voltage across the bridge. In the unstrained state, when the ratio of RG1 to RG2 equals the ratio of R1 to R2, the measured voltage is 0V. This condition is referred to as a balanced bridge. As strain is applied to the sensor, their resistance values change creating a change in the measured voltage. Strain-gauge conditioning products have voltage excitation sources, gain amplifiers, and provisions for bridge-completion resistors, which should be very precise and stable.



Because strain-gauge bridges are rarely balanced perfectly, some signal conditioners also use offset null process in which you adjust the resistance ratio of the unstrained bridge to balance the bridge and remove any initial DC offset voltage. Alternatively, you can measure this initial offset voltage and use this measurement in your conversion routines to compensate for the unbalanced initial condition.

Conclusion

There are many specific types of signal conditioners available and we hope this guide has helped narrow things down a bit. For additional assistance do not hesitate to give us a call at (877) 3 GET IOS, or send an email to info@ioselect.com.

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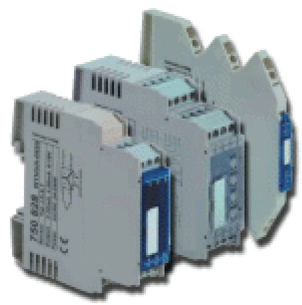

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