Properly designed and installed, a 4-20mA current loop interface is usually the least expensive, most reliable, and simplest means of electrically sending a single measurement value (such as temperature, pressure or flow rate) from a transmitting device to one or more receiving devices at another location, especially over long distances. However, certain application guidelines and installation practices must be followed for successful system implementation. This technical bulletin addresses the knowledge needed to properly interface various systems components, particularly from different manufacturers, and suggests methods for troubleshooting non-working installations. Part I is a primer on current loops. If you are already experienced with current loop concepts and are primarily interested in troubleshooting a problem, you may want to skim or skip Part I and proceed to part II. If you are planning an installation, reviewing the last part of Part I starting at the section entitled THE TRANSMITTER will help avoid common mistakes (so you won't be so likely to have to read the troubleshooting section in Part II after installation!)

PART I – ALL ABOUT 4-20mA CURRENT LOOPS

DATA COMMUNICATION METHODS – ANALOG VS. DIGITAL

Measurement data can be electrically transmitted from point A to point B using analog or digital methods such as pulse, frequency or RS-232 serial data signaling[1] over both wired and wireless data links. (Wireless data links are useful where installing cable would be prohibitively expensive or impossible.)

A Current Loop is one method for sending a measured value such as flow rate from a sensing device to one or more a receiving devices using analog[2] electrical signaling.

The use of analog signals is limited to less stringent accuracy and range[3] requirements, but has the advantage of low cost, reliability and universality for many applications. Universality means that components from different manufacturers can communicate with each other just by connecting wires, with no hardware or software customization. Due to the simplicity and ubiquity of 4-20mA current loops, interoperability may be achieved by just a few device switch settings or by entering setup parameters for one or more of the interconnected devices.

ANALOG SIGNALS – WHY USE CURRENT RATHER THAN VOLTAGE?

An analog electrical signal uses a voltage or current level to represent a range of measurement values. For example, a flow sensor may have an analog voltage output ranging from 0 to 5Vdc, where 0V represents zero GPM and 5V represents the full-scale flow rate for the sensor, say 100GPM. (Then at 50GPM the sensor analog output would be 2.5V, representing midscale flow.) The 0-5V sensor output can then be wired directly to an indicator device which can be scaled or configured to display 100GPM when it "sees" 5V at its input. Another example would be connecting the same sensor analog output to a PLC (Programmable Logic controller.) The PLC could then be programmed to interpret any voltage below 1V (representing 20GPM) as a plugged pump inlet and sound an alarm after turning off the pump. The 0-5V and other voltage analog output (and input) ranges are commonly offered by many manufacturers. As it turns out, however, using a current instead of a voltage to represent measurement values has the following advantages:

(1) LONGER DISTANCES[4] ARE POSSIBLE OVER SMALLER (AND EVEN UNSHIELDED) WIRES - Using current rather than voltage to represent the measurement value, there is no accuracy degradation due to the resistance of small gauge and/or very long interconnecting wires as there is with voltage signals unless you assure that the receiving device input resistance is at least 1000 times higher than the total interconnecting wiring resistance. But as you increase the input resistance the measurement voltage becomes susceptible to noise degradation from nearby noisy electrical cables and equipment. The interconnecting wires also act as an antenna and pick up strong radio signals which may corrupt the voltage signal, resulting in erroneous measurements.

(2) BETTER NOISE IMMUNITY - Because current signals can be connected to a very low input resistance at the receiving end, they are much less susceptible to electrical noise problems. In fact it is usually not necessary to use shielded cables as long as twisted pair wiring is used, which is much more effective than shielding for current signals.

(Shielding can actually be detrimental for both voltage and current measurement circuits if equipment manufacturer's grounding recommendations are not carefully observed.)

(3) A SINGLE TWISTED PAIR CAN CARRY BOTH POWER AND SIGNAL - In many cases current from the analog current signal can also provide power for the sensor so that a single twisted pair cable can both power the sensor and transmit the measurement. This type of sensor is known both as a two-wire sensor or a loop-powered sensor. For a voltage measurement signal, however, four conductors are needed, and must be sized larger to minimize wiring voltage drops, adding significantly to cable diameter and cost as cable lengths become longer.

WHAT IS A CURENT LOOP?

The simplicity gained in using current instead of voltage to represent a measurement parameter is found in the current loop concept, that is, current flowing in a simple series electrical circuit referred to as a "loop". The loop is just the familiar electrical circuit in which two or more devices are connected in a series path. According to Kirchoff's Law, this implies that the current in every interconnecting wire in the circuit is the same at any given instant in time.

So as long as the measurement remains steady, you can break the circuit at any point and insert an ammeter and the current will be that same particular value wherever you choose to measure it. *Figure 1* shows ammeters (represented by circles) inserted along the loop wiring indicating identical currents everywhere in the loop (at any given instant in time.)

Now if you change the measurement current to a new value (say by changing the flow rate measured by the flow sensor), any place you measure in this series circuit loop will indicate the same new current – if it is working properly. (As we will see later this provides a troubleshooting strategy – if the current is different in one part of the loop that becomes a clue as to why and where things aren't working.)

So why 4-20mA and not 0-50mA? There have been other current range choices, but most are no longer used. As the upper limit of the current range (usually representing the sensor's full-scale reading) increases beyond 20mA, voltage drops due to resistance in the wiring become increasingly problematic – we'll see why further on. At the other end of the range, it is challenging for the component designers to get a current signal (or voltage signal for that matter) to behave near zero. More importantly, a loop-powered (or two-wire) sensor gets its power by "siphoning off" most of that bottom end 4 mA and using it to power the device. (If the sensor power requirement is more than 4mA it cannot be loop-powered, or an older standard like 10-50mA could be used.) So 4mA has come to be the low scale measurement value standard for whatever the sensor is measuring. In the case of flow sensors it typically represents zero flow (or with bi-directional sensors full scale reverse flow.)

Now we are ready to describe the types of devices connected in a current loop and how they function: first the transmitting device that sets the loop current to a value representing a sensor measurement, then one or more receiving devices which "read" the loop current to perform some function (such as displaying a measurement or controlling a pump), and finally a power supply to supply the loop power.

THE TRANSMITTER

A transmitter is any device that has produces a 4-20mA (milliamp) analog output signal representing a measurement value such as flow rate. For flow rate, 4 mA flowing around the loop typically is chosen to represent zero fluid flow rate and 20 mA to represent the full scale flow rate of the flow sensor or flow meter[5]. Intermediate current values represent any flow rate between zero and full-scale flow. For example, the 12mA current shown in *Figure 1* represents a flow rate of 50% of the full scale flow of 1000GPM because 12mA is half way between 4mA and 20mA. If your flow sensor or meter has a 4-20mA output (sometimes called 4-20mA analog output since the output current is an "analog" of the measurement), then the transmitter is built into the sensor or meter. If it doesn't, you will need to add an external transmitter (such as Seametrics AO55) to convert the flow sensor pulse output to a 4-20mA current.

In electrical terminology, the transmitter is a variable current source. Its sole purpose is to set or regulate the loop current according to the measurement value it receives from the sensor. As a current source, one of its most important specified characteristics is its compliance range. This is the voltage range of its terminal voltage over which it will correctly source or regulate the current to track the sensor measurement value changes. The importance of the compliance range is discussed further in the Troubleshooting section and in Appendix B.

RECEIVERS

Receiving devices must have analog current or voltage inputs. Examples include remote displays, indicators, process monitors and controllers such as PLCs, as well as actuators such as valves and motors controllers Usually you can connect more than one receiver in the loop.

If you do, all will receive exactly the same measurement value from the transmitter since the current at any point in a series circuit is the same. (If a receiving device has only voltage inputs, Appendix A tells how to convert the 4-20mA loop current to a voltage by simply adding a resistor across the receiving device's voltage input terminals.)

THE POWER SUPPLY

As illustrated in *Figures 1 and 2*, the power supply for the current loop supplies a dc voltage that powers the loop just as a battery might power a simple series electrical circuit. It may also provide power to operate loop-powered transmitting or receiving devices in the loop, by "stealing" power as in a two-wire transmitter mentioned earlier, or by direct connection to one (but only one[6]) of the other devices in the loop. Sometimes the loop power supply is built into one (but only one) of the transmitting or receiving devices themselves so a separate external loop power supply is not required. These are referred to as active (as opposed to most, which are passive[7]) current loop devices.

The power supply voltage required depends on the sum of the voltage drops in the loop at maximum loop current (20mA). The term "voltage drop" (or "voltage burden") refers to the voltage between any two consecutive terminals connected in loop. There are the voltage drops between the plus and minus terminal of each transmitting or receiving device in the loop as well as the voltage drops from one end to the other of any one of the wires connecting the power supply and devices in the loop. In *Figure 2* note that the voltage drops going clockwise around the loop starting at the power supply positive (+) terminal add up exactly to the power supply voltage. This is true no matter how the current in the loop or power supply voltage vary as the measured value varies (satisfying Kirchoff's Voltage Law). Note also that the polarities of the voltage drops around the loop are all opposite to that of the polarity of the power supply. This last detail is the key to wiring the plus and minus terminals of each component in the loop correctly.

An important troubleshooting rule is that the power

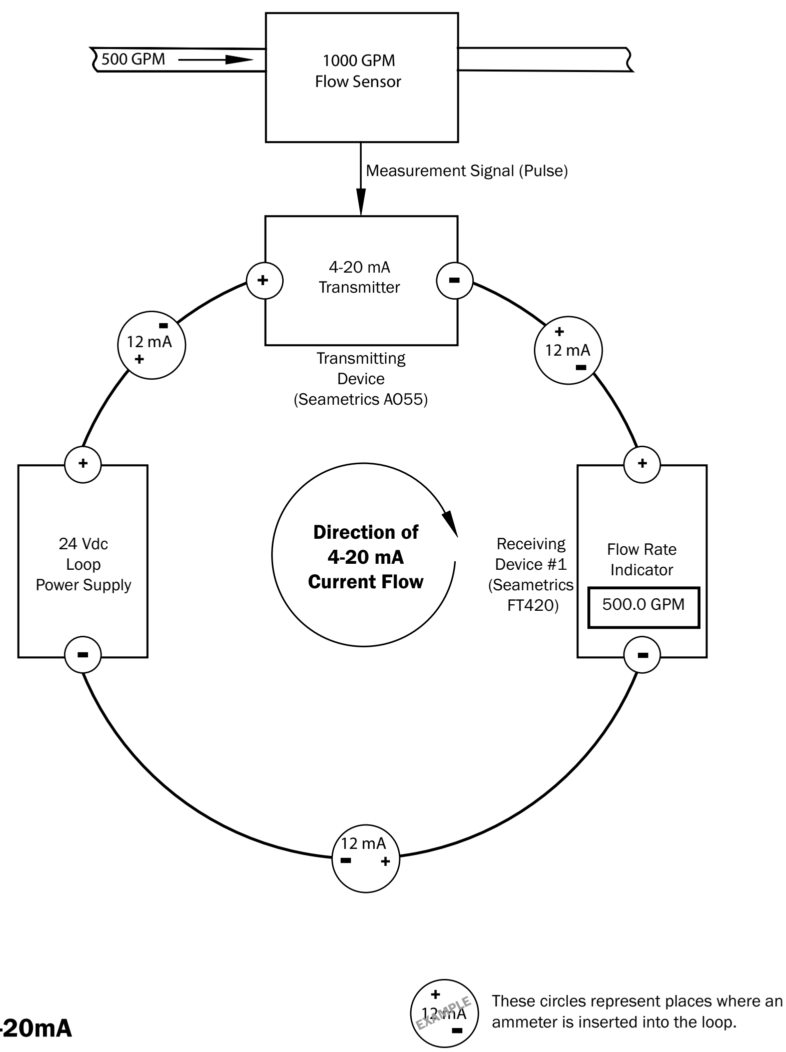

Figure 1
Measuring Currents in a 4-20mA Loop

supply voltage must always be at least as high as the worst-case sum of all of the voltage drops in the loop. If not, the loop current will not be able to reach its full scale 20mA value. Appendix B explains how to calculate these voltage drops (using manufacturers device specifications, wire resistance tables and the Ohm's Law expression V=IR) to assure that the full-scale current can always be reached.

In most cases the loop power is provided by a 24Vdc regulated power supply, Regulation is not strictly necessary in many cases but protects against extreme AC power fluctuations and potentially exceeding the voltage limits of the transmitting device's analog output voltage range (which can be as low as 30Vdc.) It is occasionally possible to use a regulated 12V power supply but careful attention to the calculations in Appendix B must be followed to verify the possibility. Higher voltage power supplies are occasionally necessary due to the additional voltage drops, especially if there are many receiving devices in the same loop. If there is a choice, linear power supplies are preferred over switching power supplies, which are more likely to introduce noise into sensitive instrumentation such as flow meters. However the extra noise will generally not cause problems with the current loop itself due to its excellent noise immunity.

Electrically, current loop receiving devices are passive and resistive. Passive means that they use power from the loop and do not supply power to the loop. Resistive means that at their terminals they electrically act like a resistor (usually of 50 to 500 Ohms. If you know the terminal input resistance from the manufacturer's specifications, you can use Ohm's Law (V=IR) to determine the voltage between its terminals (called the voltage drop) for any particular loop current. You may or may not be able to directly or accurately measure the input resistance with an ohmmeter, however, due to internal protection circuits which mask it.

A "REAL WORLD" EXAMPLE WITH TWO RECEIVING DEVICES

Figure 3 illustrates the current loop concepts discussed so far in a system for setting and regulating flow rate in a piping system. A flow Sensor measures the flow rate in a pipe section and sends pulses proportional to the flow rate to a transmitting device

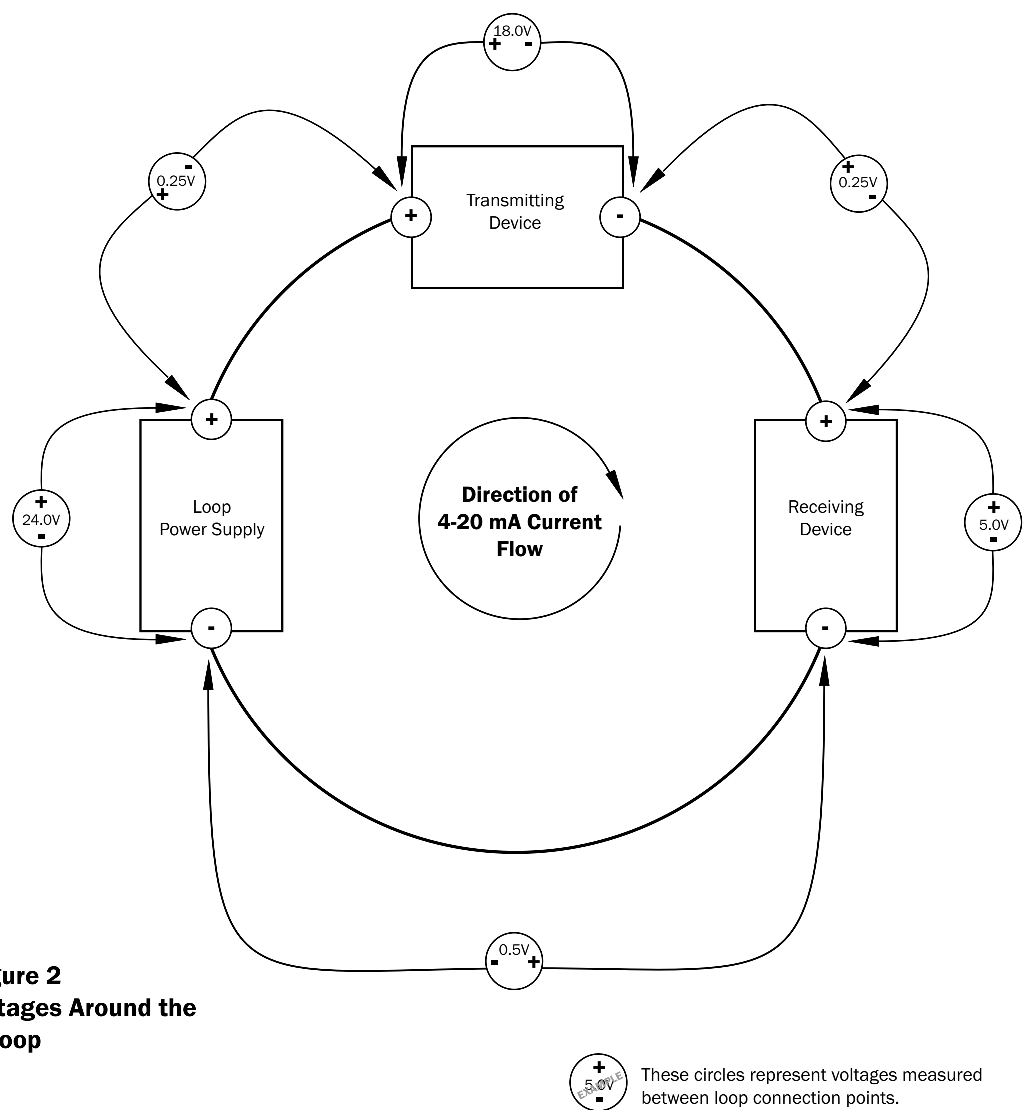

Figure 2
Measuring Voltages Around the Loop

that converts the pulse rate to a loop current value. The loop current value representing the flow rate causes one of the receiving devices, an indicator, to display the flow rate. At the same time, the other receiving device, a pump controller, uses the loop current to compare the actual flow rate with a desired flow rate set by the Pump Speed Adjust setting and continuously adjust the pump speed to maintain the desired flow rate. In the figure the flow rate is 50% of its maximum, so the loop current is 12mA (20mA-0.5 x {20mA-4mA}.) It can be set from 0 to 1000GPM via the Pump Speed Adjust control and over this range the loop current will range from 4 to 20mA in proportion to the actual flow rate.

WIRING THE LOOP

If the distances between the devices in the loop are more than a few feet, twisted pair wiring should be used. Twelve to twenty-four twists per foot gives the best noise immunity. *Figure 4* takes the idealized current loop shown in *Figure 3* and illustrates how the twisted pairs might be routed in practice. If you trace the wiring in *Figure 4* carefully you will see that the wiring forms the same series circuit loop as in *Figure 3*.

GETTING POLARITIES RIGHT

As shown in all the example figures, once the cables are installed and connected to the power supply and the other devices, the wires coming from the transmitting and receiving device terminals are connected so that each wire from one device goes to the opposite polarity terminal of the next, that is positive to negative or negative to positive, just as batteries are wired when in series. After the transmitting and receiving devices are so wired, there will remain one unconnected positive wire from one device and one unconnected negative wire from another device. The unconnected positive wire goes to the positive power supply lead and unconnected negative wire goes to the negative power supply lead as illustrated. The current loop will not work if it is not wired exactly this way. In fact, devices may be damaged.

In summary, wires always connect terminals of opposite polarity when interconnecting transmitting or receiving devices, but when one end of a wire goes to a power supply terminal the polarities must be the same. In the end each device terminal will have only one wire connected to it. If you see more than

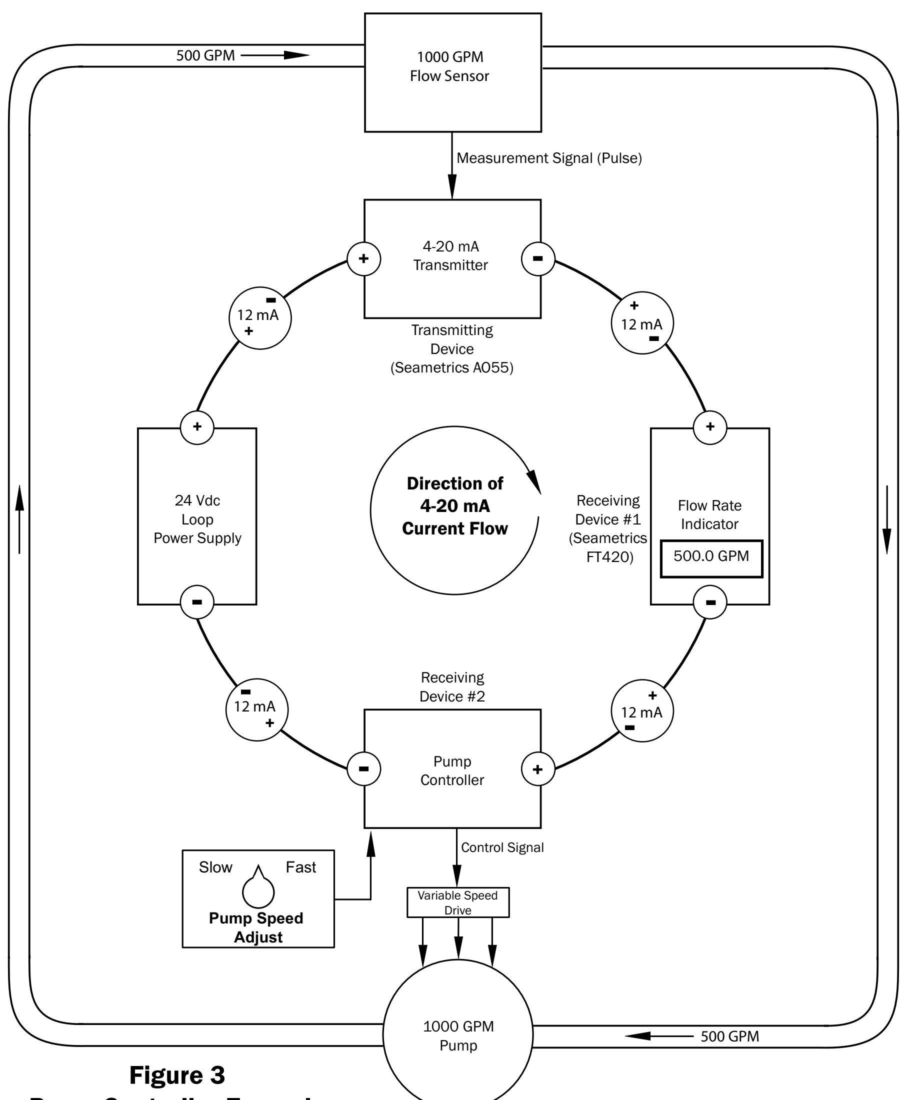

Figure 3
Pump Controller Example

one, you no longer have a simple series circuit and chances are that unwanted stray current will enter or exit the loop on that extraneous wire and result in the signal current being wrong. The exception to this one-wire-per-terminal rule is that the power supply terminals can have as many wires as necessary to power devices in the loop but only if the powered device has galvanically isolated current loop connections. Galvanically isolated means there is no electrical current path inside the device between its power terminals and its current loop terminals. In this case you may run more than one wire to each power supply terminal, for example, to provide current to power the devices themselves (not the loop) or other equipment that can operate from the same power supply. However, if you are not certain about the galvanic isolation barriers and where they are, “sneak” currents and so-called “ground loops” will degrade the accuracy of the loop current, will or even cause it to be out-of-range.

The loop wiring should never be bundled with or run close to other cables carrying high voltage, high current or high frequencies. Current loop wires running in parallel to such cables for any distance should be separated by one to three feet, shielded or not. Shielded cable generally has little benefit for current signals and can be detrimental if the shields are not terminated properly. If shielded cable is used, connect the shields together where the cables meet and connect to earth ground at that point. Leave the shields at the other ends of the cable disconnected and insulated from contact with the surrounding metal. If a receiving device is earth grounded, the shields should be grounded to the same point as the receiving device. If possible, do not connect the power supply negative terminal to this or any other earth ground, metal frame, chassis or enclosure. Grounding the enclosure, negative or common terminal of more than one device in the loop will frequently cause the loop to not work correctly unless the input or output of each grounded device has an electrical isolation barrier. This will be explored further in the troubleshooting section.

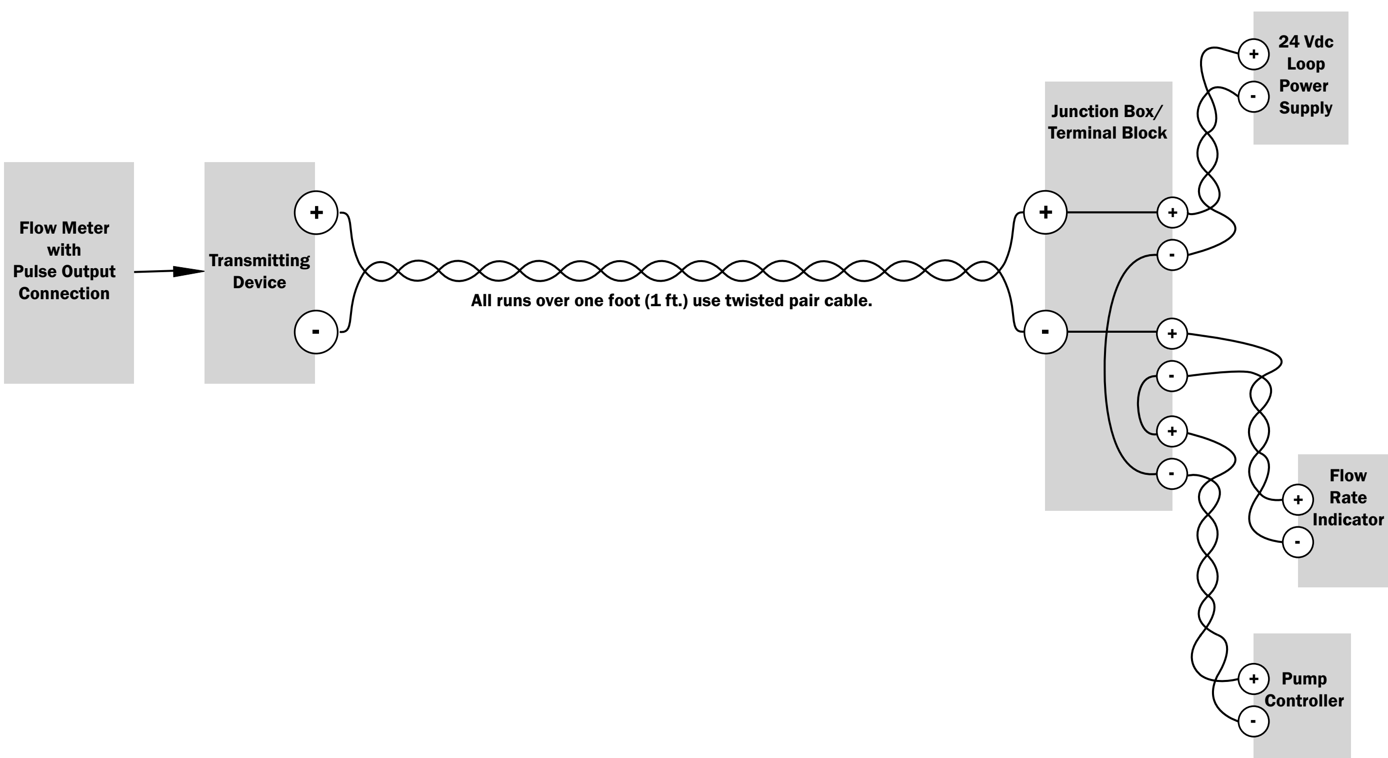

Figure 4
Practical Wiring Arrangement for the Example in Figure 3

PART II– TROUBLESHOOTING 4-20mA CURRENT LOOPS

When a 4-20mA current loop is not working properly the usual suspects are:

1. Wiring is wrong: polarities are reversed or the two-wire rule (see previous section) has been violated. Also check for opens, shorts and high resistances in the loop wiring with an ohmmeter or continuity tester.
2. The device manufacturer's specified voltage drops and long-cable wiring losses exceed the supply voltage of the power supply. (Symptom: Loop current doesn't increase above some value below 20mA)
3. Unsuspected and hidden (unlike the visually observable two-wire rule) "sneak currents" due to "ground loops" or missing or inadvertently bypassed galvanic isolation barriers.
4. The transmitting or receiving devices are improperly setup or configured.

WIRING PROBLEMS

Wiring problems are diagnosed by inspection and measurement. If inspection doesn't reveal the problem, disconnect the wire to the transmitter positive terminal and connect the leads of an ammeter (such as a DVM on appropriate mA range) with the negative ammeter lead to the transmitter positive terminal and the disconnected wire to the ammeter's positive lead. Force the measured sensor parameter (such as flow rate) to low zero and check to see whether the ammeter reads close to 4mA. If the ammeter reads much more than 4mA the transmitter is probably defective (shorted output) or there are other problems.[8] If the ammeter reads 0 the loop may have a broken wire, transmitter or power supply polarity is reversed or the power supply voltage is too low. Check the power supply voltage to see if it is correct. If it is, open the loop (disconnect the wire to the transmitter) and close (reconnect it) to see if the voltage at the power supply terminals changes. If it changes more than 25mV there is a wiring short which should be isolated with an ohmmeter.

EXCESSIVE VOLTAGE DROPS

If the sensor zero scale ammeter reading is correct (4mA), force the transmitter to increase its output in steps until it is as close to full scale (20mA) as it will go. Meanwhile watch the ammeter (inserted where the loop was previously opened at the transmitter). For a flow rate analog output, for example, set the flow rate through the flow sensor to an upper range (known if possible) flow rate. If the loop current indicated by the ammeter stays at 4mA as the measurement parameter is increased, the transmitting device or sensor are wrongly configured, unpowered, or defective. If the ammeter reading stops increasing at some point while the measured parameter (flow in this case) is still being increased, then there is a voltage drop problem, which can be diagnosed by ohmmeter measurements between all adjacent terminals going around the loop with power supply positive terminal disconnected. Wires will typically be 10 Ohms or less, receiving device inputs should be 50 to 500 Ohms, typically 250 Ohms, and the transmitter terminals should show a resistance above 1 Megohm, when the positive ohmmeter lead is connected to the positive transmitter analog output terminal and negative to negative. If ohmmeter readings fall outside these ranges try disconnecting wires to where resistance measurements are being taken. If the resistances seem OK in a newly installed system, the calculations described in Appendix B should be performed to verify correct design.

SNEAK CURRENTS

Sneak (also known as stray or leakage) currents are currents that "sneak" in or out of the loop via unintended or unsuspected paths causing the current to be different in different sections of the loop. Devices not getting power from the loop itself or having connections to other equipment can have unsuspected internal sneak paths. If the loop current as indicated by the ammeter does not correspond to expected value everywhere in the loop and the loop conditions described in Appendix B appear to be met, the next step is to search out "sneak" currents and ground isolation problems. Sneak currents problems should suspected if currents measured at different places in the loop are not the same while the measurement value is remaining constant. If this is suspected, disconnect one end of each wire, one at a time, starting with the wire leaving the positive power supply terminal, and insert an ammeter in series to reconnect the loop as shown in Figure 1. Each ammeter reading should be the same. Going around the loop moving away from the positive power supply terminal in the direction of current flow (clockwise in Figure 1) note whether the current changes from the previous measurement. If it decreases, there is a sneak path is probably due to leakage (faulty device), a wiring short, or lack of adequate galvanic isolation in next device back toward the power supply. Check the manufacturer's instruction manual to see if the current loop connections are galvanically isolated. If current increases, a device may be configured wrongly as an active loop device, particularly if it is not a loop-powered device[7]. Check the manufacturer's instruction manual to reconfigure.

As one example of an application where the above problem may occur, *Figure 5* shows a PLC wrongly measuring the loop current at its analog input due to various sneak current paths. Note that the dashed lines labeled (1) effectively short out the PLC's analog input sense resistor, causing it to see zero current in the loop. Other sneak paths occur via the ground wiring as shown by the dashed lines labeled (2). Yet another sneak path not shown could be through the piping system attached to the flowmeter and the fluid flowing through it.

A simple way to determine if sneak paths are causing current loop malfunction is to systematically disconnect, any wires to devices or power supply that are not actually part of the loop wiring itself and note whether the problem cures itself. Examples would be ground wires, external power supply wires and any other wires going to other places. A disconnected wire that cures the problem then helps pinpoint the likely cause.

DEVICE CONFIGURATION AND INTEROPERABILITY PROBLEMS

Interoperability refers to the ability of components from different manufacturers or even the same manufacturer to work together properly. It is important to understand the electrical characteristics of each of the components you wish to interconnect via a 4-20mA current loop. Interoperability must be carefully reviewed prior to purchase and installation if all are to work together properly. Even simple current loop devices do not necessarily achieve interoperability out-of-the-box. Sensors with passive current loop outputs may simply produce 4mA at zero or low scale and 20 mA at nominal full scale so there may be no configuration or setup to do. Receiving devices, however, will usually have to translate the loop current to a useful range of values representing the desired units of measure. This may be done via switches, keypad or programming via a serial communications port connected to a computer to enter zero offset, scaling, filtering and other parameters. Additionally jumpers may be used to select options such as active or passive loop operation. Careful early attention to device manufacturer's instructions and doing a dry run test setup before actual site deployment is a good way to avoid searching for the right configuration settings while standing in ankle-deep mud holding soggy manuals in both hands!

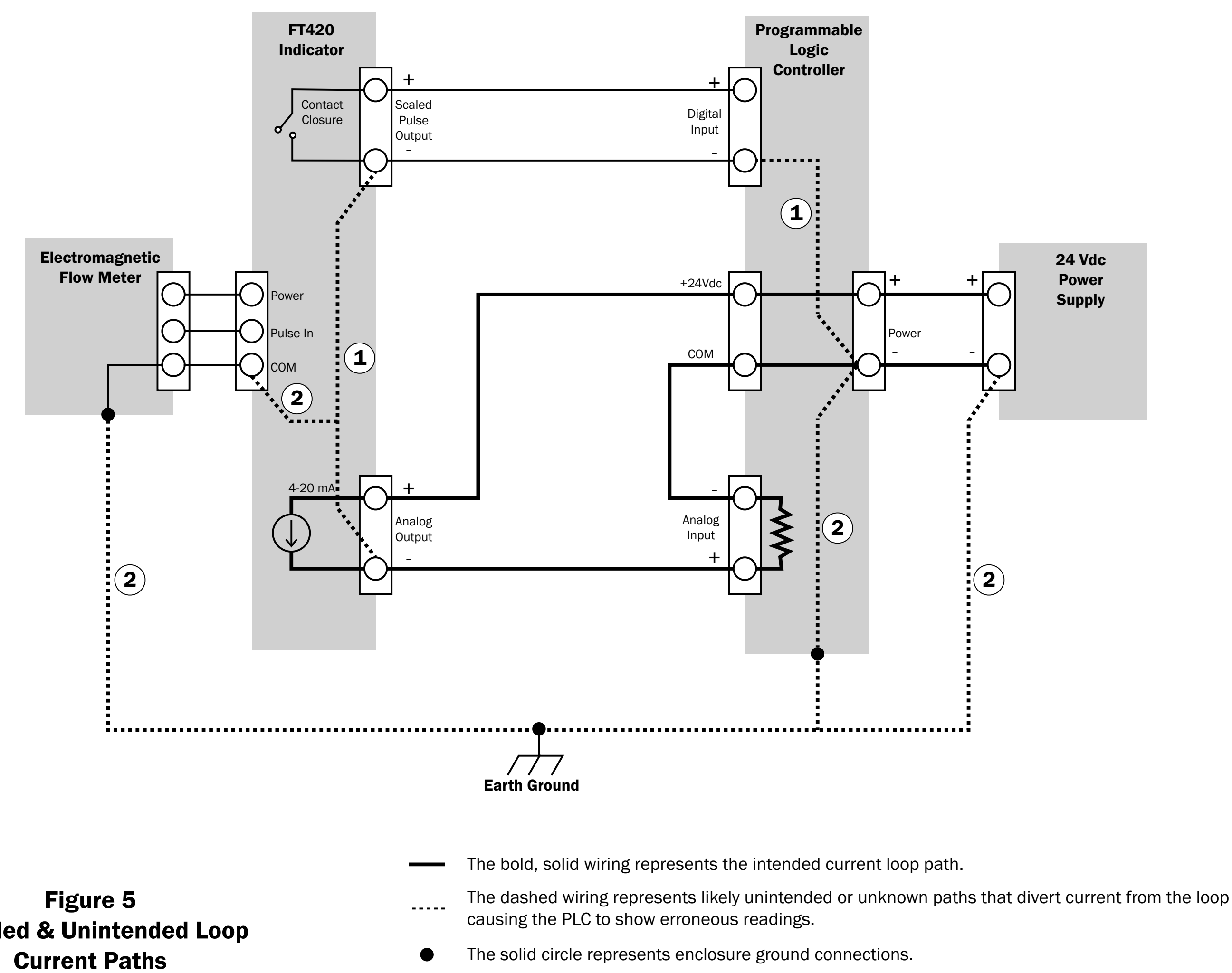

Figure 5
Intended & Unintended Loop Current Paths

OAQ
(OCCASIONALLY ASKED QUESTIONS)

1. Is it possible to damage a 4-20mA device by reversing the polarity of connections?

ANS: Usually not. Well-designed products have reverse polarity protection built-in.

2. How many receiving devices can be used in a single current loop with each transmitting device?

ANS: In theory as many as you want, as long as you increase the power supply voltage to compensate for the additional full scale (20mA) voltage drops of each added device and don't exceed the transmitter maximum voltage drop specification at low scale (4mA.) Power supplies at least as high as 125Vdc have been used in special system designs. (Don't try this however, without professional help!

3. What is the maximum cable length for 4-20mA signalling?

ANS: With careful attention to design, 10,000 ft or greater distances are achievable on 26AWG and larger unshielded twisted pairs. The transmitting device specification should be checked for maximum capacitive loading for more than 1000 ft. The loop power supply voltage may need to be increased above the standard 24V. The transmitting device may require a wider compliance range.

4. What is the difference between a 2-wire and 4-wire device?

ANS: A two-wire device is powered by the loop itself so it does not require the two extra wires that are needed to power a four-wire device.

5. What is meant by active and passive currents loop connections?

ANS: A device configured for active current loop connection supplies power to the loop along with the 4-20mA signal, usually via an internal 12 or 24Vdc power supply. When one of the devices (and only one) is configured as active, there is no need for a separate loop power supply. In general passive-configured devices must have galvanically isolated loop terminals, but active-configured devices need not be.

6. What is the HART protocol?

ANS: HART is a data communication interface that carries both an (analog) 4-20 mA current loop signal and a (digital) serial data message on the same twisted pair.

APPENDIX A
Converting voltage inputs to current loop inputs

If the receiving device has only a voltage input, it is easily converted to a current input by adding a resistor between the plus and minus input terminals. Use the Ohm's Law expression R=V/I to determine the resistor value. Divide the voltage input's full-scale voltage by 0.020A (20mA.)

For example if a PLC voltage full-scale input voltage is 5V, then 5/0.020 = 250 Ohms. Then when the transmitting device causes 20mA to flow in the loop the PLC voltage input will read 5.0V (because V = I x R = 0.020A x 250 Ohms = 5V.). At low scale when 4mA is flowing around the loop the PLC input will read 1V (because V = I x R = 0.004A x 250 Ohms = 1V.) Thus the 4-20mA current signal is converted by the resistor to a 1-5V voltage signal.

To avoid errors due to resistor heating make the resistor power rating 5-10 times larger than the maximum actual power used by the resistor. The actual power (at 20mA) is 0.0004 x R, so for the previous example the actual power is 0.0004A x 250 Ohms = 0.1Watt. Multiplying this by 5 gives a minimum resistor power rating of 1/2Watt.

Finally, remember to account for the added measurement error due to the difference between the nominal resistor value selected and its true value as specified by its tolerance and temperature coefficient of resistance. If you use a metal film or wire-wound resistor types the temperature coefficient can usually be ignored and both can be purchased with tolerances of 1% and better. A 0.1% or 0.25% tolerance resistor will assure that the accuracy degradation due to the resistance error will be minimal. The resistor should be located at or near the receiving device analog input to minimize noise and loading errors.

APPENDIX B
VERIFYING TRANSMITTER COMPLIANCE MARGIN

Each device as well as the wiring in the loop produces a voltage drop that varies with loop current. (For simplicity of later calculations, we will not treat the power supply as a voltage drop in the loop[9].) The wiring and receiving devices are essentially resistive elements so each voltage drop will be (according to Ohm's Law) just the resistance of the device across its terminals or the resistance of the wire multiplied by the loop current. These voltage drops then will be at their maximum when the loop current is at its maximum (20mA.) The total of all the wiring and device voltage drops must add up to exactly the loop power supply voltage according to Kirchoff's Voltage Law. To make this happen the transmitting device continuously adjusts its internal resistance, and therefore its voltage drop to make this happen. As loop current increases, the wiring and receiving device voltage drops will increase so the transmitting device must decrease its voltage drop to compensate. It does this automatically by virtue of its electrical function of sourcing current, but only over a range of voltage drops sometimes referred to as its compliance range. The transmitting device specification will include a minimum and maximum voltage drop across its terminals. The voltages between these limits are its compliance range for proper operation.

The example in *Figure B1* illustrates what happens if the lower limit of the compliance range is violated. In this example, the transmitting device requires a minimum of 10.0 volts to supply the full scale 20mA to the loop (per the manufacturer's specifications.) The figure shows 16mA flowing around the loop resulting in 12.0V across the transmitting device so it is well within its compliance range at this loop current value. However, the loop current will not be able to increase to the full-scale 20mA because at 20mA the voltages across the two receiving devices must increase by 3V which means the transmitting device voltage would have to drop by 3V to 9.0V[10] so that the sum of the drops does not exceed the 24V power supply voltage. Since 9.0V is less than the minimum 10.0V that the transmitting device needs to operate, it will not able to supply the full 20mA, To resolve the problem either the input sense

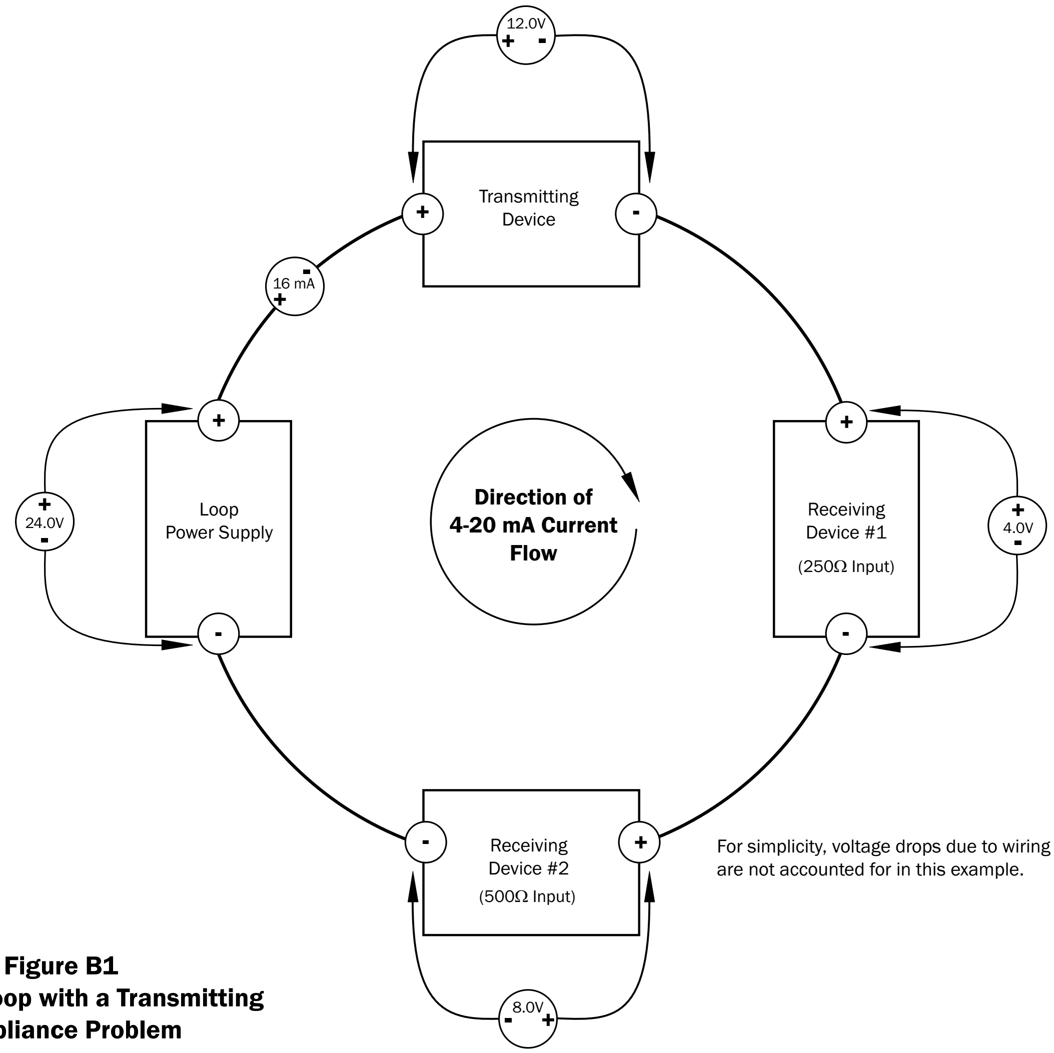

Figure B1
A Current Loop with a Transmitting Compliance Problem

resistor on one or both of the receiving devices must be reduced or the power supply voltage needs to be increased (or a transmitting device changed to one that will operate at a lower voltage.) Also since some receivers need more than 20mA to activate an overrange alarm, the components in the loop must be chosen so that the voltage across the transmitting device will not drop below its minimum allowed value before the required alarm current is reached with some compliance voltage margin for component variations with temperature and time, line voltage fluctuations, etc..

Outside the transmitting device's compliance range, it is unable to reliably source sufficient current at the lower compliance voltage limit and it may be damaged at the upper limit. To ensure proper operation, first calculate and add up all the voltage drops in the loop when the loop current is at 20mA. For calculating purposes, use the transmitting device's lower compliance voltage value for its voltage drop (typically between 6 and 12V.) For the wiring, add up the wire lengths and use *Table B1* below find the total wire resistance. (For multiconductor cables, remember to double the length of the cable to account for the two conductors carrying loop current in both directions.) For receiving devices, the manufacturers specifications should give the input internal resistance (typically between 50 and 500 Ohms.) Now multiply each resistance (in Ohms) by 0.020A (20mA) to get all the voltage drops for receiving devices and wiring. Finally add the voltage drops of the wiring, the transmitting device and the receiving device(s.) If the sum exceeds the power supply voltage, the transmitter will be unable to source the full 4-20mA range, working properly only up to some current value below 20mA. If the sum of voltage drops is less than the power supply voltage, then subtracting the loop voltage drops from the power supply voltage gives the minimum transmitter compliance range voltage.

When the loop power supply is a regulated 24Vdc, wire size is sufficiently large (especially for long distances) and there is only one receiving device, there will normally be sufficient margin. (Wire resistance is rarely an issue unless it is grossly undersized for long distances.) If the power supply is less than 24Vdc (or worse, unregulated), or there are many or high-resistance receiving devices, there may be insufficient margin (that is, the subtraction result is, say, 1 volt or less. It is always good to have a volt or more of margin to account for later wiring changes such as rerouted longer cables and circuit drift over time and temperature and for overrange detection, if used, by the receiving devices.)

If there is insufficient margin, the easiest solution may be to increase the loop power supply voltage. However, if the power supply voltage is higher than the maximum transmitter compliance voltage, then another voltage margin calculation should be done, this time at 0.004A (4mA), to verify that transmitter voltage does not rise above its upper compliance voltage drop at 4mA, possibly overheating, degrading its accuracy or damaging it. If the compliance range is exceeded, it is easy to add extra resistance in the loop to fix the problem. The power rating of the resistor of R Ohms should be at least (0.0008)R Watts.

AWG WIRE SIZE	OHMS/1000 FT
26	44.4
24	27.7
22	17.5
20	10.9
18	6.92
16	4.35
14	2.73
12	1.71

TABLE B1
RESISTANCE OF COPPER WIRE (AT 68°F)

GLOSSARY

(Note: The definitions below are intended only for the context of current loop signaling.)

ACTIVE DEVICE An active current loop device connects an internal power source in series with its output, eliminating the need for an external loop power supply[7]. See also PASSIVE DEVICE.

ANALOG SIGNALING Analog signaling uses a continuous range of voltages or currents to represent a range of measurement values[2]. A mathematical relationship called a transfer function defines the translation between them.

CURRENT LOOP A means of transferring data reliably and simply over long distances using an electrical signal in a series circuit to encode data, using either analog or digital current levels to represent the data[11].

COMPLIANCE RANGE The range of allowable voltages between the output terminals of a transmitting device for proper current loop operation. Usually specified by the device's minimum and maximum terminal voltages in the manufacturer's specifications.

DIGITAL SIGNALING Unlike analog data signaling, digital signaling transmits measurement or other data using two or more discrete voltage levels, encoding the data in the timing of changes between the voltage levels.

FOUR-WIRE DEVICE A device which cannot operate solely from power derived from the loop and therefore require two extra wires to provide power. See also TWO-WIRE DEVICE and LOOP- POWERED DEVICE.

GALVANIC ISOLATION An electrically insulating barrier using inductive, capacitive or electro-optical components to prevent unwanted stray or "sneak" currents from disturbing the signaling circuit and degrading measurement accuracy. It may also help prevent electrical noise in the environment from corrupting signal integrity, particularly noise in the grounding system.

LOOP-POWERED DEVICE A device which is powered by the current loop so it does not need its own power supply. Also known as a TWO-WIRE device.

PASSIVE DEVICE A passive current loop device uses power from the current loop to process the 4-20mA signal and if LOOP-POWERED, also to power its electrical circuitry. It cannot supply power to the loop, so a loop power must be supplied by an ACTIVE DEVICE or a separate loop power-supply[7].

RECEIVING DEVICE A device that uses the 4-20mA current loop signal to indicate or use the measurement represented by the loop current for control or other purposes.

SNEAK CURRENTS "Sneak" currents are unwanted stray currents that corrupt the current loop signal integrity. They are "sneaky" because they divert current into or out of the loop via unsuspected paths, often invisible to the troubleshooter because they are hidden within various components of the system. They often take advantage of hidden internal ground connections. If they are very small they may be called leakage currents.

TRANSMITTING DEVICE A device that produces the 4-20mA current loop signal that represents and is derived from a measurement.

TWO-WIRE DEVICE See LOOP POWERED DEVICE.

TWISTED PAIR CABLE A type of multiconductor cable in which the conductors are twisted together in pairs, one pair for each signal. This greatly increases the immunity of the signal to electrical noise and is generally more effective than shielding, though both are frequently used together. Current loop signals should always be carried on twisted pair wiring.

FOOTNOTES:

1. Other data transmission methods include:

(a) Pulse signaling provides low-cost, high accuracy transmission of potentially large-valued measurements such as total flow volume over long periods of time. It is commonly used because signals cannot provide the necessary accuracy, resolution and range needed for this type of measurement.

(b) Frequency signaling uses frequency variation of a signal instead of a (voltage or current) variation to represent a measurement value such as flow rate.

(c) Serial data signaling is appropriate where high precision, wide-ranging, rapidly-changing or multiple simultaneous measurements need to be sent over the same cable, often at high speed and in both directions. Using an RS-485 serial digital data link, distances of up to 4000 ft can be achieved. Serial digital data links also typically require three wires rather than two. To go longer distances special cable or modems may be required. Serial digital data links also typically require three wires rather than two.

2. An analog signal uses a range of voltages or currents to represent a measured value such as 0 Volts is interpreted by a receiving device (such as a display) to be 0 GPM, 10V is interpreted to be 1000 GPM and all values between 0 and 10V are interpreted as intermediate values of flow rate. Typically, a digital signal accepts only two current or voltage values as valid (0 and 5 Volts for example.) The measurement value is then encoded in the signal by the timing of changes between these two voltages. For example, for a pulse encoded signal every time the voltage goes from 5Volts to 0 volts and then back to 5V represents that 10 gallons have passed through a flow meter. In frequency encoding, 100 Hz might represent a flow rate of 5000 GPM. In serial data encoding patterns of voltage changes represent alphabetic or numeric characters. Morse code or RS-232 ASCII encoding are examples.

3. Analog signaling does not have enough resolution for wide-ranging or high value counting measurements such as Gallons total flow or total operating hours. Precisely and accurately transmitting measurements needing a resolution of more than a few thousand parts becomes very expensive but is easily done using digital signaling.

4. With Pulse, Frequency and Serial Digital data transmission, longer distances are more difficult to achieve and troubleshooting is hit-and-miss without an oscilloscope or data analyzer.

5. If bidirectional flow was being measured by the sensor then mid-scale, 12mA, could represent 0 GPM, 4mA might represent 100GPM reverse flow and 20mA would represent 100 GPM forward flow.

6. Powering more than one from the loop power supply will generally short out one of the other devices, making it non-functional.

7. Some devices can be configured as either active or passive, often by setting configuration switches, jumpers, or terminal connections. In the active mode, the device's passive input or output is connected in series with an internal power source to eliminate the requirement for a separate loop power supply. If the current measured into the plus terminal of the device is found to differ from the current leaving the minus terminal, a "sneak path" exists which is probably a result of the way the internal loop power source is grounded.

8. A current above 20mA can also be caused by sneak currents, ground loops, or out-of-range measured parameter values.

9. The power supply could be considered to be a negative voltage drop, that is a voltage rise, more in line with the conventional expression of Kirchoff's Voltage Law. For simplicity, we prefer here to restate it as "the sum of the voltage rises in a loop equal the sum of the voltage drops." In common electrical terminology the power supply is a voltage source (rise) and the voltage drops are loads.

10. From Ohm's Law the voltage across Receiving Device #1 is 250Ω x 0.016A = 4.0V at 16 mA, but changes to 250Ω x 0.020A = 5.0V at 20 mA. Likewise the voltage across Receiving Device #2 is 500Ω x 0.016A = 8.0V at 16 mA, but changes to 500Ω x 0.020A = 10.0V at 20 mA.

11. Once commonly used for serial data transmission, using current loops for digital data only is obsolete. However, the industrial HART protocol overlays an independent digital serial data message on a 4-20mA current loop signal.

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