Understanding 4-20 mA current loops

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Current loop history

Many people in the HVAC/R industry remember the days of pneumatic control; some buildings, in fact, still use pneumatic control systems. In these systems, ratio controllers, PID controllers, temperature sensors and actuators are powered by compressed air. 3 to 15 pounds per square inch is the modulation standard: 3 psi for a live zero and 15 psi for 100%. Any pressure below 3 psi is a dead zero and an alarm condition.

In the 1950s, electric and electronic controls made their debut. This new 4-20 mA current signaling emulated the 3-15 psi pneumatic signal. As electronic circuitry became less expensive, current signaling quickly became the preferred method. In this method, wires are easier to install and maintain than pneumatic pressure lines, and energy requirements are much lower, eliminating the need for a 20-50 horsepower compressor.

4-20 mA current loop basics

The 4-20 mA current loop is a very robust signaling standard. Current loops are idea for data transmission because of their inherent insensitivity to electrical noise. In a 4-20 mA current loop, all the signaling current flows through all components; the same current flows even if the wire terminations are less than perfect. All the components in the loop drop voltage due to the signaling current flowing through them. The signaling current is not affected by these voltage drops as long as the power supply voltage is greater than the sum of the voltage drops around the loop at the maximum signaling current of 20 mA.

Figure 1 shows a schematic of the simplest 4-20 mA current loop. There are four components:

1. DC power supply
2. 2-wire transmitter
3. Receiver resistor that converts current signal to a voltage
4. The wire that interconnects it all

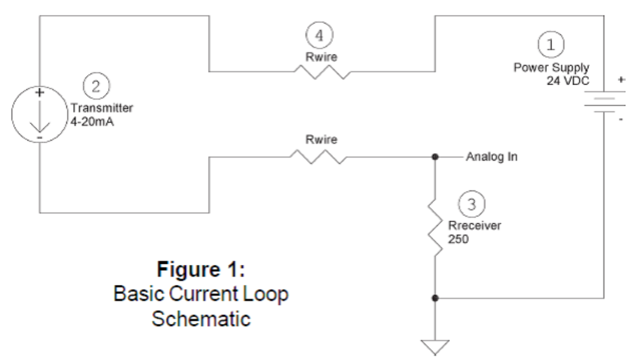

Figure 1:
Basic Current Loop Schematic

In this schematic, current supplied from the power supply flows through the wire to the transmitter and the transmitter regulates the current flow within the loop. The current allowed by the transmitter is called the *loop current*, and is proportional to the parameter being measured. The loop current flows back to the controller through the wire, and then flows through the $R_{receiver}$ resistor to ground and returns to the power supply. The current flowing through $R_{receiver}$ produces a voltage that is easily measured by an analog input of a controller. For 250Ω resistor, the voltage will be 1 VDC at 4 mA and 5 VDC at 20 mA.

4-20 mA current loop components

Power supply

Power supplies for 2-wire transmitters must always be DC, because the change in current flow represents the parameter being measured. If AC power were used, the current in the loop would be changing all the time. Therefore, the change in current flow from the transmitter would be impossible to distinguish from change in current flow caused by the AC power supply.

For 4-20 mA loops with 2-wire transmitters, common power supply voltages are 36, 24, 15 or 12 VDC.

Current loops using 3-wire transmitters can have either AC or DC power supplies. The most common AC power supply is the 24 VAC control transformer. Be sure to check any transmitter's installation literature for the proper voltage requirements.

Transmitter

The transmitter is the heart of the 4-20 mA signaling system. It converts a physical property, such as temperature, humidity or pressure, into an electrical signal. This signal is a current proportional to the property being measured. In a 4-20 mA loop, 4 mA represents the low end of the measurement range and 20 mA represents the high end.

Wilcoxon specifies the power to our current transmitters as a range of 12 to 30 VDC. The lower voltage is the minimum voltage necessary to ensure proper operation of the transmitter. The higher voltage is the maximum voltage the transmitter can withstand while operating to its stated specifications.
is easily measured by an analog input of a controller. For the 250W resistor, the voltage will be 1 VDC at 4 mA of loop current and 5 VDC at 20 mA of loop current. The most common receiver resistor in a 4-20 mA loop is 250W; however, depending on the application, resistances of 100W to 750W may be used.

Receiver resistor

It is much easier to measure a voltage than it is to measure a current. This is the reason many current loop circuits (such as the circuit shown in Figure 1) use a receiver resistor ($R_{receiver}$) to convert the current into a voltage. In Figure 1, $R_{receiver}$ is a 250W precision resistor. The current flowing through it produces a voltage that is easily measured by an analog input of a controller. For the 250W resistor, the voltage will be 1 VDC at 4 mA of loop current and 5 VDC at 20 mA of loop current. The most common receiver resistor in a 4-20 mA loop is 250W; however, depending on the application, resistances of 100W to 750W may be used.

Wire

Sending current through wire produces a voltage drop proportional to the length and thickness (gauge) of the wire. All wire has resistance, usually expressed in Ω per 1,000 feet. The voltage drop can be calculated using Ohm's law:

$$E = I \times R$$

where E is the voltage across the resistor (in volts); I is the current flowing through the conductor (in amperes); and R is the conductor's resistance (in Ω).

Resistances for common wire gauges are given in Table 1.

Table 1: Wire resistances

Copper wire resistance at 20°C (68°F)	
American wire gauge	**Ω per 1,000 ft.**
14	2.525
16	4.016
18	6.385
20	10.15
22	16.14
24	25.67

Insensitivity to electrical noise

The greatest advantage of using a current loop for data transmission is its inherent insensitivity to electrical noise. Every current transmitter has some output resistance associated with it. Ideally, the current transmitter's output resistance would be infinite; however, actual transmitters have very large but finite output resistances. For example, a temperature transmitter can have an output resistance of 3,640,000 Ω (3.64 MΩ). This output resistance can be represented as a resistor in a circuit schematic.

The circuit schematic in Figure 2 shows the component resistances of a 4-20 mA current loop with a noise source added to the loop. Because of the high output resistance of the transmitter (3.64 MΩ), the vast majority of the noise voltage is dropped across the transmitter ($R_{transmitter}$), and only a tiny fraction is dropped across the receiver ($R_{receiver}$). Since the controller sees only the voltage across $R_{receiver}$, the noise voltage has almost no effect on the controller.

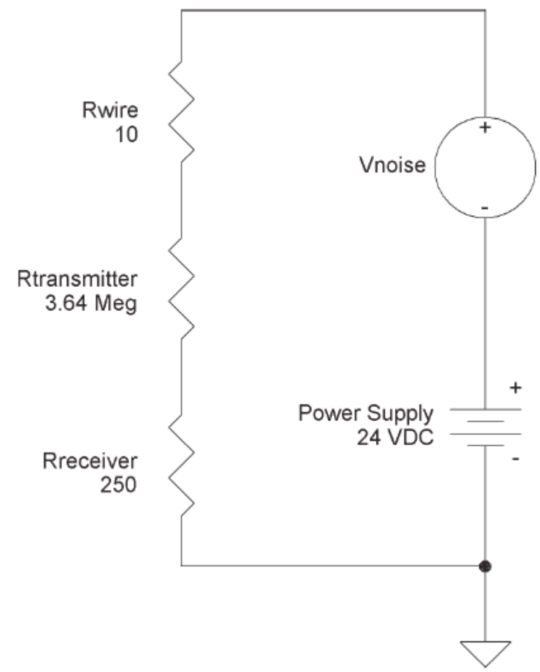

Figure 2;
Current loop noise model

Noise reduction example

If the noise source in Figure 2 has an amplitude of 20 V, then the noise voltage seen across $R_{receiver}$ is only 0.0014 V. This is because the noise voltage measured across any resistor is equal to Ohms of that resistor divided by the total Ohms in the circuit multiplied by the overall noise voltage, as given by the equation below:

$$\text{Voltage noise at } R_{receiver} = \frac{V_{noise} \times R_{receiver}}{R_{wire} + R_{transmitter} + R_{receiver}}$$

$$\text{In this example, the noise voltage at } R_{receiver} = \frac{20\text{ V} \times 250\ \Omega}{3{,}640{,}000\ \Omega} = 0.0014\text{ V.}$$

The voltage across $R_{receiver}$ at 20 mA of loop current is 5 V. Adding 0.0014 V of noise is a 0.028% error, which is insignificant.

This same principle applies to voltage fluctuations in the power supply. The high output impedance of the temperature transmitter rejects errors due to power supply fluctuations. If the power supply in Figure 1 is varied such that the voltage dropped across the transmitter varies from 7 to 24 VDC, the output current only changes by 0.000005 amps (5 µamps). This equals only 0.00125 V across the 250 Ω $R_{receiver}$ resistor, which is a negligible fluctuation.