# Understanding 4-20 mA Current Loops

***Application Note***

Rev. 10/05/06

## 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. Three to fifteen 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 1950's electric and electronic controls made their debut. The new 4-20 mA current signaling emulated the 3-15 psi pneumatic signal. Current signaling quickly became the preferred method because wires are easier to install and maintain than pneumatic pressure lines and energy requirements are a lot lower – you no longer needed a 20 to 50 horsepower compressor for instance. Also, electronics allowed for more complicated control algorithms.

## 4-20 mA Current Loop Basics

The 4-20 mA current loop is a very robust sensor signaling standard. Current loops are ideal 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. A DC power supply;
2. A 2-wire transmitter;
3. A receiver resistor that converts the current signal to a voltage;
4. The wire that interconnects it all.

The two "Rwire" symbols represent the resistance of the wires running out to the sensors and back to the power supply and HVAC/R controller.

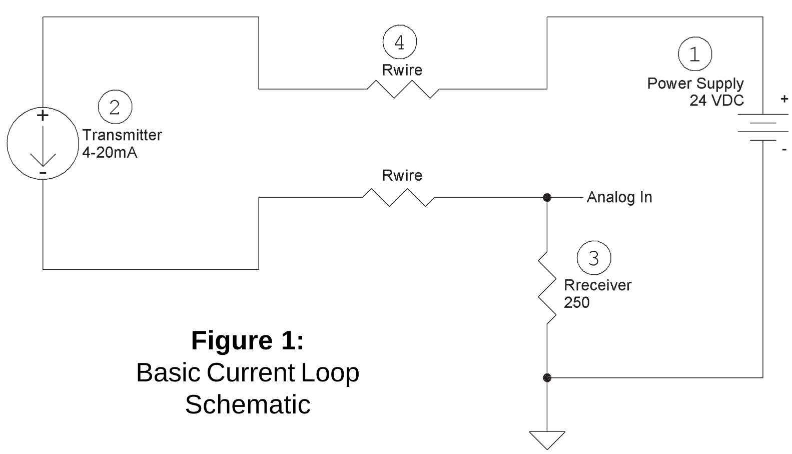


**Figure 1:**
Basic Current Loop
Schematic

In Figure 1, 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 it is proportional to the parameter that is being measured. The loop current flows back to the controller through the wire, and then flows through the Rreceiver resistor to ground and returns to the power supply. The current flowing through Rreceiver produces a voltage that is easily measured by an analog input of a controller. For a 250Ω resistor, the voltage will be 1 VDC at 4 mA and 5 VDC at 20 mA.

## 4-20 mA Current Loop Components

### 1. The Power Supply

Power supplies for 2-wire transmitters must always be DC because the change in current flow represents the parameter that is 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 VDC, 24 VDC, 15 VDC and 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.

### 2. The 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 electrical signal is a current proportional to the temperature, humidity or pressure 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.

BAPI specifies the power to our current transmitters as a range, 15 to 24 VDC for a humidity transmitter or 7 to 40 VDC for a T1K temperature transmitter. The lower voltage is the minimum voltage necessary to guarantee proper transmitter operation. The higher voltage is the maximum voltage the transmitter can withstand and operate to its stated specifications.

### 3. The Receiver Resistor

It is much easier to measure a voltage than it is to measure a current. Therefore, many current loop circuits (such as the circuit in Figure 1) use a Receiver Resistor (Rreceiver) to convert the current into a voltage. In Figure 1, Rreceiver is a 250Ω precision resistor. The current flowing through it produces a voltage that is easily measured by an analog input of a controller. For the 250Ω 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 250Ω; however, depending upon application, resistances of 100Ω to 750Ω may be used.

### 4. The Wire

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

$$E = I \times R$$

E = the voltage across the resistor in volts;
I = the current flowing through the conductor in amperes;
R = the conductor's resistance in Ohms.

Table 1 Copper Wire Resistance @ 20°C (68°F)

| American Wire Gauge | Ohms per 1000 feet |
|---|---|
| 14 | 2.525 |
| 16 | 4.016 |
| 18 | 6.385 |
| 20 | 10.15 |
| 22 | 16.14 |
| 24 | 25.67 |

Wire resistances for common wire gauges are shown in Table 1 above.

## Insensitivity to Electrical Noise

The greatest advantage of using a current loop for data transmission is a current loop's inherent insensitivity to electrical noise. Every current transmitter has some output resistance associated

## Insensitivity to Electrical Noise continued...

with it. Ideally, the current transmitter's output resistance would be infinite. However, real world transmitters have very large but not infinite output resistances. For example, the BAPI T1K Temperature Transmitter has an output resistance of 3,640,000 Ohms or 3.64 MegΩ. This output resistance can be represented as a resistor in a circuit schematic.

The circuit schematic at right (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 MegΩ), the vast majority of the noise voltage is dropped across the transmitter, and only a tiny fraction is dropped across the Rreceiver. Since the controller sees only the voltage across the Rreceiver, the noise voltage has almost no effect upon the controller.

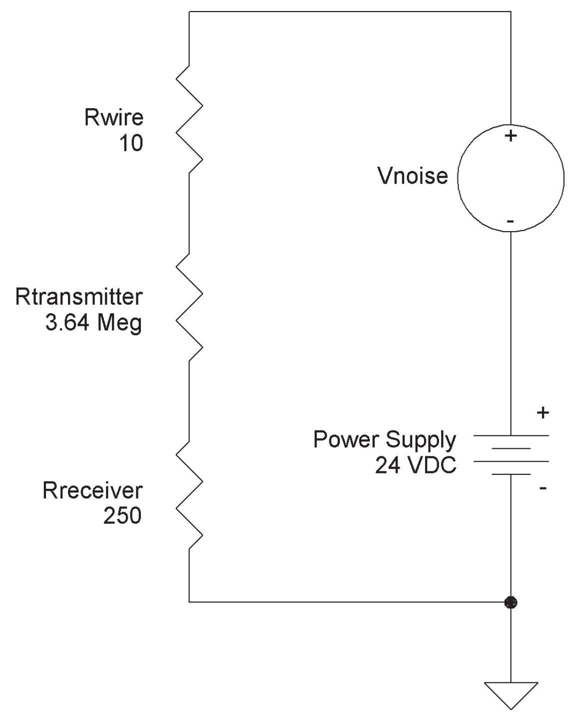


Figure 2;
Current loop noise model

**Noise Reduction Example:**
If the noise source in Figure 2 has an amplitude of 20 Volts, then the noise voltage seen across the Rreceiver is only 0.0014 volts.

This is because the noise voltage measured across any resistor is equal to the Ohms of that resistor divided by the total Ohms in the circuit multiplied by the noise voltage.

Voltage Noise at Rreceiver =
Vnoise x Rreceiver/(Rwire+Rtransmitter+Rreceiver)

Vnoise = 20 x 250/3,640,260 = 0.0014 volts

The voltage across Rreceiver at 20 mA of loop current is five volts. Adding 0.0014 volts of noise is only 0.028% of five volts, which is an insignificant error.

This same principle applies to voltage fluctations in the power supply. The high output impedance of the T1K Temperature Transmitter rejects errors due to power supply fluctuations. If the power supply of 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, or 5 micro-amps. This equals only 0.00125 volts across the 250Ω Rreceiver resistor, which is an insignificant fluctation.

If you would like more information about 4 to 20 mA current loops, call your BAPI representative or download the BAPI Application Notes: <u>Current Loop Configurations</u> or <u>Designing Current Loops</u> from our website at www.bapihvac.com