Intrinsic Safety Circuit Design

Making instruments intrinsically safe need not seem like a nightmare. Here, the basics of intrinsic safety circuit design are discussed.

Paul S. Babiarcz

Intrinsic safety prevents instruments and other low-voltage circuits in hazardous areas from releasing sufficient energy to ignite volatile gases. Although it is used widely in Europe to safely install and operate instrumentation circuits in hazardous areas, it has caused much confusion in North American markets. Many users have heard of it and want to know more; however, most feel uncomfortable applying intrinsically safe products. One reason is that intrinsic safety has been a part of Section 504 of the National Electric Code only since 1990. In addition, the number of different products on the market and seemingly endless calculations make applying intrinsic safety seem like an engineer’s nightmare.

This is the first of a series of short articles that explain how to make the most common field devices (thermocouples, RTDs, contacts, solenoid valves, transmitters, and displays) intrinsically safe. We will begin with an introduction to the practical side of intrinsic safety circuit design.

Start With The Field Device

All intrinsically safe circuits have three components: the field device, referred to as the intrinsically safe apparatus; the energy-limiting device, also known as a barrier or intrinsically safe associated apparatus; and the field wiring. When designing an intrinsically safe circuit, begin the analysis with the field device. This will determine the type of barrier that can be used so that the circuit functions properly under normal operating conditions but still is safe under fault conditions.

More than 85% of all intrinsically safe circuits involve commonly known instruments. Figure 1 shows the approximate use of intrinsically safe apparatus in hazardous areas.

An intrinsically safe apparatus (field device) is classified either as a simple or nonsimple device. Simple apparatus is defined in paragraph 3.12 of the ANSI/ISA-RP 12.6-1987 as any device which will neither generate nor store more than 1.2 volts, 0.1 amps, 25 mW or 20 µJ. Examples are simple contacts, thermocouples, RTDs, LEDs, noninductive potentiometers, and resistors. These simple devices do not need to be approved as intrinsically safe. If they are connected to an approved intrinsically safe associated apparatus (barrier), the circuit is considered intrinsically safe.

A nonsimple device can create or store levels of energy that exceed those listed above. Typical examples are transmitters, transducers, solenoid valves, and relays. When these devices are approved as intrinsically safe, under the entity concept, they have the following entity parameters: Vmax (maximum voltage allowed); Imax (maximum current allowed); Ci (internal capacitance); and Li (internal inductance).

The Vmax and Imax values are straightforward. Under a fault condition, excess voltage or current could be transferred to the intrinsically safe apparatus (field device). If the voltage or current exceeds the apparatus’ Vmax or Imax, the device can heat up or spark and ignite the gases in the hazardous area. The Ci and Li values describe the device’s ability to store energy in the form of internal capacitance and internal inductance.

In Figure 1, Current use of intrinsically safe apparatus in hazardous areas, an intrinsically safe device, also known as a barrier or intrinsically safe associated apparatus; and the field wiring make up the intrinsically safe circuit.

Figure 1. Current use of intrinsically safe apparatus in hazardous areas.

Figure 2. Barrier circuit
Limiting Energy To The Field Device

To protect the intrinsically safe apparatus in a hazardous area, an energy-limiting device must be installed. This is commonly referred to as an intrinsically safe associated apparatus or barrier. Under normal conditions, the device is passive and allows the intrinsically safe apparatus to function properly. Under fault conditions, it protects the field circuit by preventing excess voltage and current from reaching the hazardous area. The basic circuit diagram for an intrinsically safe barrier is shown in Figure 2.

There are three components to a barrier that limit current and voltage: a resistor, at least two zener diodes, and a fuse. The resistor limits the current to a specific value known as the short circuit current, \( I_{sc} \). The zener diode limits the voltage to a value referred to as open circuit voltage, \( V_{oc} \). The fuse will blow when the diode conducts. This interrupts the circuit, which prevents the diode from burning and allowing excess voltage to reach the hazardous area. There always are at least two zener diodes in parallel in each intrinsically safe barrier. If one diode should fail, the other will operate providing complete protection.

A simple analogy is a restriction in a water pipe with an overpressure shut-off valve. The restriction prevents too much water from flowing through the point, just like the resistor in the barrier limits current. If too much pressure builds up behind the restriction, the overpressure shutoff valve turns off all the flow in the pipe. This is similar to what the zener diode and fuse do with excess voltage. If the input voltage exceeds the allowable limit, the diode shorts the input voltage to ground and the fuse blows, shutting off electrical power to the hazardous area.

A diagram showing the relationship between open circuit voltage and ignition current is shown in Figure 4. This diagram is used to determine if a circuit is safe for use in a hazardous area. The parameters that determine the safety of a circuit are the open circuit voltage \( V_{oc} \) and the short circuit current \( I_{sc} \). The allowed capacitance \( C_{a} \) and inductance \( L_{a} \) must also be considered. These parameters are usually found on the product or in the control wiring diagram from the manufacturer.

Figure 3. Comparison of the entity values of an intrinsically safe apparatus and associated apparatus

<table>
<thead>
<tr>
<th>Associated Apparatus (barrier)</th>
<th>Apparatus (field device)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open circuit voltage ( V_{oc} )</td>
<td>( \leq ) ( V_{max} )</td>
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<td>( \geq ) ( L_{i} )</td>
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Determining Safe Energy Levels

Voltage and current limitations are ascertained by ignition curves, as seen in Figure 4. A circuit with a combination of 30 V and 150 mA would fall on the ignition level of gases in Group A. This combination of voltage and current could create a spark large enough to ignite the mixture of gases and oxygen. Intrinsically safe applications always stay below these curves where the operating level of energy is about 1 watt or less. There are also capacitance and inductance curves which must be examined in intrinsically safe circuits.

Will The Circuit Work?

It also is important to make sure that the intrinsically safe circuit will work under normal conditions. With the current-limiting resistor, a voltage drop will occur between the input and output of the barrier. This has to be accounted for in your circuit design. In the subsequent articles in this series, a step-by-step explanation will be given on how to calculate these voltage drops and make sure that the circuit is safe.

The purpose of this series of articles is to simplify the application of intrinsic safety. Consider the ignition curves to demonstrate a point about thermocouples.
A thermocouple is classified as a simple device. It will not create or store enough energy to ignite any mixture of volatile gases. If the energy level of a typical thermocouple circuit were plotted on the ignition curve in Figure 4, it would not be close to the ignition levels of the most volatile gases in Group A.

Is the thermocouple which is installed in a hazardous area (Figure 5) intrinsically safe? The answer is no, because a fault could occur on the recorder which could cause excess energy to reach the hazardous area, as seen in Figure 6. To make sure that the circuit remains intrinsically safe, a barrier to limit the energy must be inserted (Figure 7).

The next installment in this series will explain how the selection is made for thermocouples and RTDs, which comprise about 13% of all intrinsically safe applications.

BEHIND THE BYLINE
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Intrinsic Safety Circuit Design–Part 2

Fault conditions in hazardous-area temperature sensors can be explosive without the proper protection. You can safeguard all of the devices in your application with one type of intrinsic safety barrier.

Paul S. Babiarz

When thermocouples and RTD’s (resistance temperature devices) are installed in hazardous areas, barriers are required to make their circuits intrinsically safe. These intrinsic safety barriers prevent excess energy from possible faults on the safe side from reaching the hazardous area. Without the barriers, excessive heat or sparks produced by the fault condition could ignite volatile gases or combustible dusts.

Hundreds of different barriers are available from North American suppliers. The multitude of products can give control engineers nightmares as they try to select the proper barrier for common instrumentation loops. The search can be simplified, however. One type of barrier can be selected to make all thermocouples and RTD’s intrinsically safe so that polarity problems are avoided and calculations are not necessary.

Normally, the design of all intrinsically safe circuits centers on one of two approaches: the universal approach, which uses a universal device that often is isolated so that a ground for safety is not required; or the engineered approach, which uses grounded safety barriers.

Isolated temperature converters. These universal devices measure temperature in hazardous areas, but at a higher cost. (Dispensing with the need for a ground is a convenience that may cost two to three times as much as grounded safety barriers.) Isolated temperature converters accept a low-level DC signal from a thermocouple or 3-wire RTD and convert it into a proportional 4-20 mA signal in the safe area. They also are available with set points that trip an on-off signal to the safe side when the temperature reaches a designated level. These units must be approved as intrinsically safe.

Advantages of isolated temperature converters as compared to grounded safety barriers include:
• Good signal response
• No ground required for safety

Disadvantages include:
• More versatile application
• One product for all applications

Figure 1. Current use of intrinsically safe apparatus in hazardous areas.

Figure 2. Typical values of barrier in thermocouple circuit.
Grounded safety barriers. These are passive devices that prevent all excess energy from a fault occurring on the safe side from reaching the hazardous area. Under normal conditions, the barriers allow the circuit to function properly by allowing the signals to pass between the field device and the control room. In a fault condition, the barriers limit voltage and current to levels that are not sufficient enough to ignite gases. For a more detailed explanation, refer to Part 1 of this series.

Advantages of grounded safety barriers as compared to isolated temperature converters include:
- Less expensive
- Precise signal response
- Very small (less than ½ in. wide)
- Simple application
- One barrier for all types of thermocouple and RTD’s

Disadvantages include:
- Requires ground
- Requires some engineering

Examine The Barrier Parameters

Articles in this series will focus on methods to select the proper grounded safety barriers. Before we analyze thermocouple and RTD circuits, we should examine the functional parameters necessary to select the proper barrier. These parameters are: polarity of circuit; rated voltage of barrier; and resistance of barrier.

Polarity. The circuit’s polarity must be known in order to choose the correct type of barrier. DC barriers are rated either as positive or negative. AC barriers can be connected to circuits with either a positive or negative supply. SIGNAL & RETURN barriers are used for transmitter and switching applications. All of these barriers are available in single- or double-channel versions. However, because double-channel barriers save space and money by being connected to two legs of a loop, they are becoming the standard.

Rated voltage. Like any electrical device, safety barriers have a rated nominal voltage, Vn, referred to as working voltage. The barrier’s Vn should be greater than or equal to the supply to the barrier, much like the rated voltage of a lamp must be equal to or greater than the supply to it. If the voltage supply to the barrier is much greater than its Vn, the barrier will sense a fault. The protective zener diodes will conduct, causing leakage currents and inaccurate signals on the loop. Most barriers have a rated working voltage that guarantees a minimal leakage current from 1 to 10 micro amps if it is not exceeded. If the supply voltage to the barrier becomes too high, the zener diode will conduct. The resulting high current through the fuse will cause the fuse to blow. Excess supply voltage is the main reason why grounded barriers fail.

Internal resistance. Every safety barrier has an internal resistance, Ri, that limits the current under fault conditions. Ri also creates a voltage drop across the barrier. This drop can be calculated by applying Ohm’s law, V=IR. Not accounting for the voltage drop produces the most problems in the proper functioning of intrinsically safe systems.

Thermocouple System Design Pointers

Polarity. A thermocouple has two wires, each with a positive and negative polarity. Two single-channel barriers, each with the proper polarity, could be used. Problems would occur if the positive leg to the thermocouple were connected to the negative terminal of the barrier or vice versa. There are two possible barrier choices for thermocouple circuits:
- Thermocouple circuit with one positive and one negative lead
  - 1 standard DC barrier, positive polarity
  - 1 standard DC barrier, negative polarity
  - 1 double AC barrier

When barriers and thermocouples are being installed, the technician may forget which wire is positive and which is negative. To avoid polarity problems on the terminals, a double AC barrier should be used. The wires can be connected to either terminal and the circuit will function properly as long as thermocouple polarity is maintained throughout.

Rated voltage. A thermocouple produces a very small voltage (less than 0.1 V). It is connected to a voltmeter which has a high impedance and which requires a very small current. Since the thermocouple produces such a small voltage, choose a double AC barrier with a higher rated nominal voltage (Vn). A survey of most double AC barriers on the market shows that they are rated at low nominal voltages from 1 V and higher. Select one between 1 and 10 V.

Internal resistance. Since the mV signal has a very small current and is going to a high-impedance voltmeter, the resistance of the barrier will not influence circuit function. A simple rule of thumb is that when a signal is going to a high-impedance voltmeter, an internal resistance of less than 1000 ohms will not affect the mV signal. It usually is good practice, however, to select a barrier with a low resistance in case the circuit is modified later.

Barrier selection. For proper operation of thermocouples in hazardous areas, select safety barriers based on the following parameters:
- Barrier type: double-channel AC barrier to avoid polarity problems
- Rated voltage: Barrier Vn > 1 V
- Internal resistance: barrier with lowest resistance (less than 110 ohms)

Safety and installation check. Since the thermocouple is a simple device, it does not need third-party approval. Make sure that the barrier has the proper approvals for hazardous area locations. The thermocouple wires will be different.
from terminal connections on the barrier. Always use consistent wiring from the thermocouple to the barrier and then to the control room. This will cancel any thermocouple effect caused by the dissimilar metals on the barrier connection.

**RTD System Design Pointers**

RTD’s come in 2-, 3-, and 4-wire versions. The 3-wire RTD is used in more than 80% of all applications. The 2-wire version is not as accurate and is used mostly in the heating, ventilation, and air conditioning industry for set-point temperature measurements. The 4-wire RTD provides the most accurate signal, but is more expensive and requires one more extension wire to the process area.

Understanding RTD accuracy is essential in selecting the correct barrier. Many RTD measurements are in the form of a Wheatstone bridge, whose output voltage is a function of the RTD resistance. The bridge requires four connection wires, an external source, and three resistors that have a balanced temperature coefficient. The RTD normally is separated from the bridge by a pair of extension wires.

With a 2-wire RTD, the impedance of the barrier in series with the RTD will cause an imbalance on the bridge and will affect the accuracy of the temperature reading. This effect can be minimized by using a third wire to measure the voltage (refer to Figure 3 for this discussion). If wires A and B are perfectly matched and if the resistance in both channels of the barrier is the same, the impedance effects will cancel because each is in an opposite leg of the bridge. The third wire, C, acts as a sense lead to the voltmeter.

**Current loop A & B:** Polarity. The current loop to the RTD has a positive and a negative polarity. Possible solutions are similar to the thermocouple:

1. standard DC barrier, positive polarity
2. standard DC barrier, negative polarity
3. double AC barrier

Select the double AC barrier to avoid polarity problems. Because it is smaller, it is also less expensive.

**Current loop A & B:** Rated voltage. The constant current amperage sent to the RTD typically is in the micro amp (10^-6) level. The maximum resistance of the most commonly used RTD, Pt100 is 390 ohms at 1560°C. The voltage drop across the RTD will be in mV, so the Vn of the RTD loop is similar to the thermocouple. To be safe, select a barrier with a Vn greater than 1 V, similar to the Vn of the thermocouple barrier.

**Current loop A & B:** Internal resistance. The constant current source will have a rated maximum load or burden (resistance load it can drive). Assume that this maximum load is 500 ohms and the maximum resistance of the RTD at the highest temperature is 390 ohms. Knowing this information, the Ri of the barrier can be calculated:

\[
\text{control room} \leq \text{barrier} + \text{RTD resistance} + \text{resistance} + \text{resistance}
\]

\[
500 \text{ ohms} < \text{Ri ohms} + 390 \text{ ohms}
\]

\[
\text{Ri} < 110 \text{ ohms}
\]

**Current loop A & B:** Barrier selection. Use the same barrier that was used for the thermocouple circuit.

**Leg C to the voltmeter:** Barrier selection. The RTD leg going to the voltmeter (C) is a millivolt signal similar to the thermocouple circuit. The rated voltage, Vn, and internal resistance, Ri, of the barrier will have the same parameters as the barriers used in the thermocouple and current loop of the RTD. Selecting the correct barrier to make all thermocouples and RTD’s intrinsically safe is not difficult. Use a double-channel AC barrier with a rated voltage greater than 1 volt with the lowest internal resistance. The double-channel barrier is the lowest cost solution. The AC version will avoid any polarity problems. A barrier with a rated voltage between 1 and 10 volts will provide a wide selection which have a low resistance and are approved for the hazardous areas where the temperature sensors are located. This single barrier can then be used to make all thermocouples and RTDs intrinsically safe. And don’t forget, all thermocouples and RTD’s are simple devices, so they do not need third party approval to be intrinsically safe. When they are connected to an approved intrinsically safe barrier, the circuits are intrinsically safe.

Many temperature sensors are attached to 4-20 mA temperature transmitters, which comprise 22% of all intrinsically safe applications. The next article in this series will show how to make these transmitters intrinsically safe.

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Use The 80/20 Rule In Intrinsic Safety Circuit Design

Part 3 of this series on intrinsic safety circuit design describes how to select barriers for intrinsically safe 4-20 mA transmitters. Use the 80/20 Rule to simplify this process.

Paul S. Babiarz

The 80/20 Rule actually is five rules that are based on the fact that certain practices prevail 80% of the time, and 20% of applications are more difficult. This article focuses on how to choose intrinsically safe barriers when the transmitters are installed in hazardous areas for both the 80% standard category and the remaining 20% more difficult applications.

The most common way to process and send analog signals in the instrumentation industry is via 4-20 mA transmitters. Transmitters can be one of the simplest devices involving barriers. However, improper selection of intrinsically safe barriers in loops with 4-20 mA transmitters can introduce too much impedance on the circuit and cause the transmitters to function improperly at the high end near the 20 mA reading.

Before selecting barriers, examine how 4-20 mA analog circuits function. Transmitters convert a physical measurement such as temperature or pressure into an electrical signal that can be sent without signal modification to a control system over a long distance. The brains of the system, the DCS, interprets the electrical signal into the physical measurement. Because these analog signals are sent to a DCS, 4-20 mA circuits are called analog inputs or A/I. Using temperature as an example, examine the function of the transmitter (Fig. 1).

A power source in the DCS usually supplies 24 VDC to the transmitter. The transmitter converts the physical measurement into an electrical current signal. Transmitter current ranging from 4-20 mA is sent back to the DCS. Current signals are used to avoid potential voltage drops or electrical interference associated with voltage signals. However, because the controller reads a voltage signal, a conversion resistor (most commonly 250 ohms) converts the 4-20 mA current range into a voltage signal on the DCS input channel. Applying Ohm’s Law of V = IR, the controller has a 1-to-5 V signal (Table 1).

Assume the temperature span to be measured is from 0°C to 100°C. The transmitter is calibrated so that a 4 mA signal equals the low reading of 0° and a 20 mA signal equals the high reading of 100°. The DCS then runs the signal through a conversion resistor which can be placed either on the supply (+) or return (-) lead of the circuit, converting the signal back to a voltage reading.

There are three types of barriers for intrinsically safe transmitter applications: ungrounded repeaters, grounded repeaters, or grounded safety barriers. Each has its advantages and disadvantages (Table 2).

Table 1. Conversion of physical measurement to electrical signals.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>converted to mA signal</th>
<th>multiplied by ohm resistor</th>
<th>= converted to a voltage reading in the DCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C (min)</td>
<td>4 mA (0.004 A)</td>
<td>x 250</td>
<td>= 1 V</td>
</tr>
<tr>
<td>100°C (max)</td>
<td>20 mA (0.020 A)</td>
<td>x 250</td>
<td>= 5 V</td>
</tr>
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Table 1. Conversion of physical measurement to electrical signals.

Z-137
Repeater suit most transmitter applications, but at a higher cost. Grounded or ungrounded repeaters supply a constant regulated voltage of 15 to 17 V to the transmitter from a 24 V source. The return channel is then run through the barrier, which repeats it without any appreciable loss in signal. For example, if a transmitter sends 19.6 mA through the barrier, it is repeated in the barrier without any loss so that 19.6 mA reaches the control room. Repeaters act like mirrors by retransmitting, or repeating, the analog signals.

When budget constraints or control panel space are important considerations, grounded safety barriers may be a better choice.

80/20 Rule #1: In North America, most analog circuits are protected by grounded safety barriers because of lower costs.

Table 2. Advantages and disadvantages of grounded safety barriers, grounded and ungrounded repeaters.

<table>
<thead>
<tr>
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<td>Precise signal response</td>
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<td></td>
<td>No ground required</td>
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<tr>
<td></td>
<td>Can use transmitters with higher operating voltage</td>
<td>Possible radio frequency interference</td>
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<tr>
<td></td>
<td>Isolation, if good ground not available</td>
<td>May not be compatible</td>
</tr>
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</table>

80/20 Rule #2: Most transmitter circuits have the conversion resistor on the return channel. Use the double channel supply and return barrier.

The supply channel is constructed like the positive DC barrier; it prevents a fault on the safe side from transferring excess energy to the transmitter. The return channel has two diodes in series which allow the signal to pass only in one direction back to the DCS, and prevent any excess fault energy from being transferred to the transmitter. These diodes and the supply channel have voltage drops which must be accounted for in the analog circuit (Fig. 3).

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Figure 2. Positive DC barrier.

Figure 3. Supply and return barrier.
80/20 Rule #3: The supply voltage normally is 24 VDC.

■ Select the voltage input, Vn.
One of the reasons that barriers fail is because the voltage supply is too high. Use a regulated supply source with a high end of tolerance that does not exceed the barrier rating and a low end that is enough to drive the circuit. A 24 Vdc source ±1% usually is a good choice.

■ Determine the internal resistance, $R_i$ (also referred to as end-to-end resistance) of the barrier best suited for your circuit. The most critical component of the barrier selection is the barrier’s internal resistance. If the resistance is too high, the transmitter will not work near 20 mA. As seen in Table 1 and the following discussion, at 20 mA the voltage drops across the barrier and the conversion resistor will be the highest. If the internal resistance is too low, the barrier’s short circuit current, $I_{sc}$, may exceed the transmitter’s entity parameter, $I_{max}$.

The easiest way to determine the barrier’s permitted resistance is to calculate the total voltage drop on the circuit. To select the proper transmitter barrier, determine the following:
- Hazardous area Groups A-G or C-G
- Placement of the conversion resistor on either the supply or return leg of the circuit
- Size of the conversion resistor (250 ohms is most common)
- Minimum operating voltage of the transmitter (This figure, also referred to as lift-off voltage, is in the transmitter data sheet. Most operate at a minimum of 12 V or lower.)
- Entity parameters of approved transmitter

■ Case 1. Assume that conditions are as follows:
- Groups A-G
- Supply
- 250 ohms
- 12 V
- $V_{max} = 30 V$, $I_{max} = 150 mA$, $C_i = 0 \mu F$, $L_i = 0 \text{ mH}$
Calculate the maximum allowable resistance of the barrier under worst-case conditions when the transmitter is sending a 20 mA signal. The supply is 24 Vdc; the transmitter requires a minimum of 12 V; and the 250 ohm conversion resistor requires 5 V at 20 mA. Simple subtraction leaves a maximum allowable voltage drop of 7 V. Using Ohm’s Law, this converts to an internal resistance of 350 ohms. Allow for a cable resistance of about 10 ohms. Thus, the circuit functions properly with a barrier having an internal resistance of 340 ohms.

Next, to make sure the circuit is safe, verify that the barrier’s entity parameters match the transmitter’s entity parameters. This design offers the lowest cost solution where two transmitters can be connected to one double channel barrier. This circuit arrangement allows one common barrier to be used for most circuits (Fig. 4).

■ Case 2. Use the same conditions as in Case 1, except change the placement of the conversion resistor to the return side, and use the supply and return barrier. Voltage drop on the barrier occurs on both the supply and return side. Voltage drop on the return side diodes is about 0.7 V. This leaves a maximum drop of 6.3 V on the supply side or a maximum resistance of 305 ohms (allowing 10 ohms for cable resistance). Again, verify the entity parameters of the barrier and transmitter.

80/20 Rule #4: The two solutions above cover 80% of all transmitter applications.

But what happens if the circuit falls into the 20% category? Grounded safety barriers may not work in conditions where a loop-powered indicator is connected, or where the transmitter requires a minimum voltage greater than 12 V. In these cases, the easiest solution is to use a repeater barrier. Repeaters provide a regulated power supply of 15-17 V to the transmitters and can drive a conversion resistor load of 750 to 1000 ohms (Fig. 5).
If repeaters still are not the best solution, there may be other ways to use grounded safety barriers. Either the impedance in the circuit must be reduced or the voltage must be increased. If these alternatives are used, recheck the barrier and transmitter entity parameters to make sure the circuit is safe.

Reducing Impedance

- **Case 1.** Reduce the conversion resistor. As seen in Fig. 2, only two fixed sources of impedance can be reduced: the conversion resistor or the barrier. One solution is to reduce the conversion resistor to 100 or 50 ohms to obtain maximum voltage readings of 2.0 to 1.0 V respectively. (Example: 20 mA (0.02 A) x 100 ohms = 2 V.) This may be practical for new installations, but it may not be possible for cases where additions are being made to an existing control system.

- **Case 2.** Select a barrier with lower resistance.

### 80/20 Rule #5: Many hazardous locations are classified as Groups C-G.

Ignition curves in Groups C-G allow higher rated voltages and current before gases ignite (see Part 1 of this series, October 1992). Barriers designed for hydrogen and other gases classified as Group A or B require higher series resistance than barriers designed for only the more common gases in Groups C and D. Thus, most intrinsically safe instruments should have entity parameters (Imax, maximum short circuit current) that are higher for Groups C-G. (As a practical matter, most instrument manufacturers have not taken advantage of this fact.) With the Group C-G rating high-current barriers can be used, which have a lower internal resistance. These barriers have corresponding lower voltage drops but higher Isc (Table 3).

### Increasing Voltage Supply

If the voltage supply is increased too much, the barrier may sense a fault and the fuse could blow, interrupting the circuit. Some allowance can be tolerated for increasing the voltage supply on barriers with a nominal rated voltage of 24 VDC.

- **Case 1: Resistor on the supply side.** When transmitters are first energized, they transmit 4 mA for calibrating zero readings. There always is at least a 1 V drop across the resistor before the supply reaches the barrier. The voltage supply could be increased to 25 to 26 V without the barrier sensing a fault condition. This would allow 1 to 2 additional volts on the circuit.

- **Case 2: Resistor on the return side.** Since the resistor is on the return side, the barriers receive the total voltage supply. Since this circuit is more sensitive to voltage increases, be careful about increasing the supply above the barrier's nominal rated voltage, Vn.

Before the zener diodes in the barriers reach their rated voltage, there may be some leakage current that could affect the transmitter signals. Diode leakage current values ranging from 1 to 10 µA are listed by the barrier manufacturers. In Case 1, this could mean that the current signal could be deformed by a maximum of 0.025% at 4 mA (1 µA/4 mA).

When the resistor is placed on the return side, leakage current is on the supply side and does not affect the transmitter's 4-20 mA signal.

Transmitters comprise 22% of all intrinsically safe circuits. The next article will feature discrete inputs, also referred to as switching. These represent 32% or almost one-third of all intrinsically safe circuits.

### Table 3. Typical values of barriers rated for different groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Internal Resistance (Ri)</th>
<th>Voltage Drop at 20 mA</th>
<th>Short Circuit Current, Isc</th>
<th>Open Circuit Voltage, Voc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier #1 A-G</td>
<td>340 ohms</td>
<td>6.8 V</td>
<td>93 mA</td>
<td>28 V</td>
</tr>
<tr>
<td>Barrier #2 C-G</td>
<td>140 ohms</td>
<td>2.8 V</td>
<td>213 mA</td>
<td>28 V</td>
</tr>
</tbody>
</table>

See SIB Series of Intrinsically Safe Transmitters

Part 4 of this series describes how to make a switch intrinsically safe by using a switch amplifier or a grounded safety barrier.

Paul S. Babiarz

Digital inputs constitute almost one-third of all process signals. They also are known as binary, on-off, 0/1, or simple switching signals where a switch is either opened or closed. The most common examples of these are mechanical or reed contacts, transistors, limit, float, on-off, and pushbutton switches. As defined in paragraph 3.12 of the ANSI/ISA-RP12.6-1987, switches are simple devices that neither generate nor store more than 1.2 V, 0.1 A, 25 mW, or 20µJ. Since switches are simple devices, they do not have to be approved as intrinsically safe. If they are connected to an approved intrinsically safe associated apparatus (barrier), the circuit is deemed to be intrinsically safe.

To make a switch intrinsically safe, the user may select a switch amplifier or a safety barrier. A switch amplifier is an intrinsically safe relay that solves virtually all switching applications. However, if power is not available in the control panel or if panel space is an important consideration, a grounded safety barrier may be a better choice. There is not a significant cost savings of one alternative over the other. Each has its own advantages and disadvantages, as shown in Table 1.

**Switch Amplifiers**

The most common application is switching through an intrinsically safe relay (Fig. 1). Relays, which normally are powered by 110 VAC or 24 VDC, have a low voltage and current which are safe at the contact in the hazardous area. When this contact is closed, the relay transfers the signal from the hazardous location to the non-hazardous side. A closed switch on the hazardous side operates a relay or optocoupler output on the non-hazardous side. The signals are electrically isolated so that grounding is not required.

When proximity switches became a popular means of sensing the presence of objects and materials, the NAMUR-style sensor was developed. Contrary to popular opinion, NAMUR is not an approval standard. It was organized by the German chemical industry to develop operating standards for proximity switches. A NAMUR-style proximity switch is a 2-wire DC sensor that operates at 8.2 V with switch points operating between 1.2 to 2.1 mA. This NAMUR standard later was superseded by the German Standard DIN 199234, Measurement And Control:

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**Figure 1. Switch amplifier — 2 channels.**
Electrical Sensors Used For Intrinsically Safe 2-Wire DC Systems. Because these switches required a remote amplifier for operation, most switch amplifiers standardized on an intrinsically safe voltage of 8.2 V and current of 8 mA at the contacts in hazardous areas. This provided enough power to operate NAMUR-style proximity switches safely. The amplifiers are sensitive enough to detect closed contacts in corrosive or abusive areas. Despite the fact that the intrinsically safe voltage and current at the contacts are very low, most modern switch amplifiers will detect a closed contact when the resistance of the circuit is less than 3000 ohms. Intrinsically safe switches can be located a long distance from the switch amplifiers and still function properly.

Switch amplifiers are available with two different output contacts to the safe side, relays and optocouplers. The more commonly used relay versions are applied in slow speed switching to operate smaller pumps, motors, or other electrical devices. Optocouplers are transistors operated by photo diodes to close the output contacts. These outputs have lower contact ratings but an almost infinite switching capability. Optocouplers are used for switching back to a DCS or for high-speed counting operations up to thousands of times per second (KHz).

Switching Through Safety Barriers
When a 110 V supply is not available in the control panel, safety barriers frequently are used for digital inputs back to a DCS. There are two methods of switching: current sourcing or current sinking. Both of these methods can use the same types of barriers that were used for transmitters (see Part 3 of this series).

The current sourcing method of switching in Fig. 2 could use the same signal and return barrier that was used for 4-20 mA transmitters. The voltage to the switch is supplied through the supply channel. The second channel is used for signal return. A closed switch will close the contact in the DCS. Most digital input signals operate with 24 V and 10 mA. If the same barrier is used for switching as 4-20 mA transmitters, there will be about a 3 to 4 V drop across the barrier.

The barrier used for current sinking switching can be a single-channel DC barrier as seen in Fig. 3. When the switch is open, the DCS input will sense 24 V. When the switch is closed, the DCS will recognize a lower voltage. This lower voltage is calculated as a voltage divider circuit.

Make sure the rated voltage of the barrier, Vn, is equal to or greater than the voltage supply. Since most switching uses 24 VDC, select a barrier rated at 24 V. The internal resistance of the barrier is not as critical since the current in digital inputs usually is very small. However, it always is good practice to select a barrier with low resistance. Check the approvals of the barriers to make sure that they are rated for the proper hazardous area group location.

Intrinsically safe relays, also referred to as switch amplifiers, can be applied universally for all digital inputs. However, if safety barriers are used, the same barriers used to make analog inputs intrinsically safe can be used for either current sourcing or current sinking switching.

The next article in this series will explain how to make digital outputs intrinsically safe.

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<table>
<thead>
<tr>
<th>Switch Amplifiers</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td></td>
</tr>
<tr>
<td>Simple application</td>
<td>Needs power supply</td>
</tr>
<tr>
<td>No ground required</td>
<td>Larger in size</td>
</tr>
<tr>
<td>No internal resistance</td>
<td></td>
</tr>
<tr>
<td>LEDs to indicate power and monitor operations</td>
<td></td>
</tr>
<tr>
<td>Sensitive to detect closed contacts in corrosive areas</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safety Barriers</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td></td>
</tr>
<tr>
<td>Smaller size</td>
<td>Requires grounding</td>
</tr>
<tr>
<td>Does not require power supply</td>
<td>Has internal resistance</td>
</tr>
</tbody>
</table>

Table 1. Advantages and disadvantages of switch amplifiers and safety barriers.