

## Compensating the Fuse in High-Current IS Barrier

by Analog Services, Inc.

### 1. Background

Intrinsically safe control and sensing circuits have long been used in areas where there is a danger of explosive gas or dust mixtures. The basic principal of intrinsic safety (IS) is to limit voltage and current into the hazardous area. This is typically done with a device called an intrinsic safety barrier. The barrier is placed between a power supply located in a "safe" area and the circuit to be protected in the "hazardous" area.

Although there are various types of barriers, a common one is a zener-resistor barrier, as shown in figure 1. It consists of

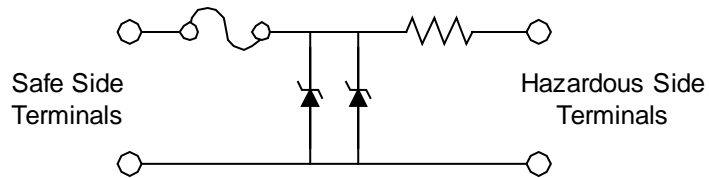


Figure 1 -- Intrinsic Safety Barrier

2 to 3 zener diodes, a

fuse, and a resistor. The zener diodes limit voltage and the resistor limits current. Zener-resistor barriers of this type are entirely passive and are easily understood and applied. And, under the most hazardous conditions, they are sometimes the only acceptable type of barrier.

Various types of Fieldbuses have emerged over the past decade, that attempt to put many devices on the same circuit. In IS applications, however, the number of devices on a given circuit is limited because of the limitations on voltage and current. The number of devices can be increased to some extent by operating them at lower voltage and higher current. High-current IS barriers have been developed to satisfy this requirement. These barriers are designed to operate at lower voltage and higher current than older and more conventional 28 volt barriers. However, there is still a need to maximize the power that can be drawn from these barriers, while still remaining within IS constraints.

An improvement in output power would result if the barrier fuse resistance could be reduced to zero. The fuse itself is a necessary part of the barrier and can't be removed. But it is possible to compensate for the fuse and effectively make it appear to have zero resistance. We present here a circuit that does this. Although the method uses active circuitry, all of the active circuitry is located on the safe side of the barrier. From a safety viewpoint the barrier is still passive and could still be used in situations that demand a passive barrier.

(For a detailed explanation of intrinsic safety and intrinsic safety barriers, see either of references [1] or [2].)

## 2. Passive Barrier Operation and Characteristics

The purpose of the fuse and the effect of fuse resistance on barrier output power are better understood through a more detailed look at the barrier.

The components of the barrier are usually selected, tested, and physically arranged in accordance with IS rules and practices. The barrier circuit of figure 1 shows two zener diodes. Some barriers have three parallel zener diodes. The reason for this is redundancy. There is only one fuse and one current limit resistor because these are either considered infallible or else they fail in such a way as to increase safety. For the purpose of describing how the barrier works, we can assume that just a single zener diode is present.

In normal operation a power supply is connected to the safe side (fuse side) of the barrier and a load is connected at the hazardous side. The power supply voltage is kept at a "working voltage" which is slightly less than the zener diode voltage. The zener diode normally conducts only a small leakage current. It turns ON and conducts a larger current only if there is a power supply fault and the supply voltage tries to rise above the zener clamp voltage. During this fault the zener diode must not fail open, since this would allow excessive voltage into the hazardous area. The fuse is meant to open and protect the zener from failure in the event that it should conduct.

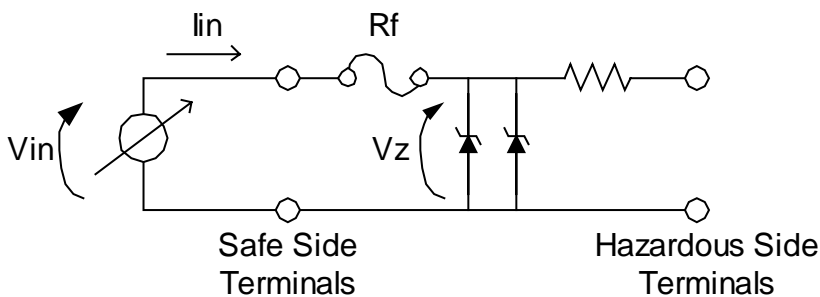
Barriers have two important ratings: (1) Maximum open-circuit voltage at the hazardous area terminals and (2) maximum end-to-end (safe side to hazardous side) resistance. The end-to-end resistance is the sum of the fuse resistance and current limit resistance. The amount of power that can be gotten into the hazardous area is maximized by increasing the power supply voltage and decreasing the barrier end-to-end resistance. The power supply voltage cannot be any higher than the maximum open circuit voltage rating of the barrier. And, once this voltage is specified, then IS constraints dictate the value of the current limit resistor. This leaves the reduction of the fuse resistance as the only avenue to increased output power. In high-current barriers the fuse can be a significant fraction of the end-to-end resistance (Typical values are 5 ohm for the fuse and 20 ohm for the current limit resistance.), which is all the more reason to try to eliminate its effect.

One way to reduce fuse resistance, of course, is to use a fuse that blows at a high current. However, this simply results in enormously large zener diodes which are capable of absorbing a large amount of power until the fuse blows. This is unreasonable from an economic and size viewpoint. In the next section we present a way of effectively reducing the fuse resistance to zero to increase power output, while still maintaining the actual fuse presence to protect the zener diodes.

Not only does the fuse resistance affect output power, but in a low voltage/high current barrier, there may not be a satisfactory current rating for the fuse. If the rating is low enough to protect the zener diodes, then it may be so low that the fuse will open simply as a result of shorting the hazardous side terminals together. This is undesirable, since such short circuits can often occur by accident or during installation. The active circuit to be presented in the next section includes current limiting so that the fuse is normally never subjected to a current sufficient to cause it to blow.

### 3. Compensating Fuse Resistance

The compensation works by regulating the voltage across the barrier zener diodes. The power supply at the safe side of the barrier is adjusted up or down as needed to maintain



$$V_z = V_{in} - I_{in} \cdot R_f$$

$R_f = \text{fuse resistance}$

Figure 2 -- Determination of  $V_z$

this voltage. The fuse resistance and fuse voltage drop are no longer important because regulating the voltage across the zeners is the same as placing a regulated supply directly across the zeners. It is normally straightforward to regulate a circuit voltage by sensing the voltage and using feedback. However, in

this case, no connection can be made to the junction of the fuse and the zener diodes. This would violate the safety requirements of the barrier. However, if we know the fuse resistance, we can calculate the voltage across the zeners from the voltage and current measured at the safe side terminals. This is illustrated in figure 2. Except for a refinement to be described, this is how the method works.

We don't necessarily know  $R_f$ , the fuse resistance. And  $R_f$  is likely to change with temperature and current. Therefore, a better way of finding  $V_z$  is to use a second fuse in series with the first. The second fuse is nominally identical to the first fuse and is located in close proximity to the first fuse. The two fuses conduct essentially the same current and are at the same temperature, so that their resistances track each other. The complete circuit with compensated fuse resistance is shown in figure 3. Resistors  $R_1 - R_4$  and operational amplifier  $A_1$  comprise a differential amplifier which measures the voltage drop across  $R_f$ . The voltage at the output of  $A_2$  is given by

$$V_2 = -\left(\frac{R_6}{R_5}\right)\left[\left(\frac{R_3 + R_1}{R_1}\right)\left(\frac{R}{R_2 + R_4}\right)(V_z + V_f) - \left(\frac{R_3}{R_1}\right)(V_z + 2V_f)\right] - \left(\frac{R_6}{R_2 + R_4}\right)(V_z + V_f)$$

where  $V_f$  is the voltage drop across either fuse.

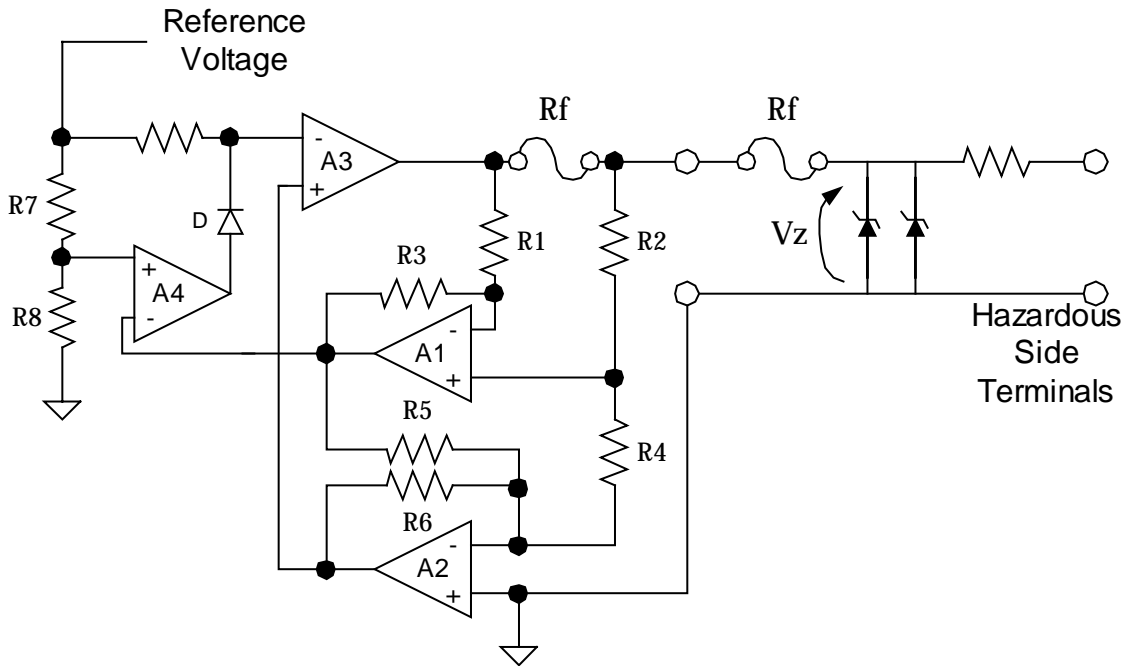


Figure 3 -- Complete Fuse Compensation Circuit

It is assumed that  $R_f$  is much smaller than resistors  $R_1$  and  $R_2$ . If  $R_1 = R_2 = R_3 = R_4 = R$  and  $R_6 = R_5 = 2R$  then  $V_2 = -V_z$  where  $V_2$  is the output of operational amplifier A2. Operational amplifier A3 compares the output of A2 with reference voltage  $V_r$ . The A3 output assumes a value such that  $V_z = -V_r$ . If the required value of  $V_z$  is 10 volt,  $V_r$  would then be set to -10 volt.

The output of current sensing amplifier A1 is  $-V_f$ . It is also applied to operational amplifier A4, which is used as a comparator. Should the measured current become excessive, the A1 output will become more negative than the comparison level set by resistors  $R_7 - R_8$ . This causes the A4 output voltage to rise, turning on diode D and forcing the reference voltage seen by A3 toward zero. This, in turn, prevents the current through the fuses from reaching a value sufficient to open them.

#### 4. Conclusion

An active circuit has been devised that is placed ahead of a passive, zener-resistor IS barrier. This circuit effectively removes the fuse resistance, thereby increasing available load power without compromising the intrinsic safety. The circuit includes automatic current limiting to permit fuses of very low current ratings without concern over nuisance blowing.

#### 5. References

1. Garside, R., "Intrinsically Safe Instrumentation, A Guide," Instrum. Society of America.
2. Magison, E., "Electrical Instruments in Hazardous Locations," 3rd. ed., Instrum. Society of America.

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