

## Balancing the Major Elements of an Isolator for Safety's Sake

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For years, designers of industrial, medical, and other isolated systems had limited options when implementing safety isolation: the only reasonable choice was the optocoupler. Today, digital isolators offer advantages in performance, size, cost, power efficiency, and integration. Understanding the nature and interdependence of three key elements of a digital isolator is important in choosing the right digital isolator. These elements are insulation material, their structure, and data transfer method.

Designers incorporate isolation because of safety regulations or to reduce noise from ground loops, etc. Galvanic isolation ensures data transfer without an electrical connection or leakage path that might create a safety hazard. Yet isolation imposes constraints such as delays, power consumption, cost, and size. A digital isolator's goal is to meet safety requirements while minimizing incurred penalties.

Optocouplers, a traditional isolator, incur the greatest penalties. They consume high levels of power and limit data rates to below 1 Mbps. More power efficient and higher speed optocouplers are available but impose a higher cost penalty.

Digital isolators were introduced over 10 years ago to reduce penalties associated with optocouplers. They use CMOS-based circuitry and offer significant cost and power savings while significantly improving data rates. They are defined by the previously noted elements. Insulating material determines inherent isolation capability and is selected to ensure compliance to safety standards. Structure and data transfer methods are chosen to overcome the cited penalties. All three elements must work together to balance design targets, but the one target that cannot be compromised and "balanced" is the ability to meet safety regulations.

### INSULATION MATERIAL

Digital isolators use foundry CMOS processes and are limited to materials commonly used in foundries. Nonstandard materials complicate production, resulting in poor manufacturability and higher costs. Common insulating materials include polymers such as polyimide

(PI), which can be spun on as a thin film, and silicon dioxide (SiO<sub>2</sub>). Both have well known insulating properties and have been used in standard semiconductor processing for years. Polymers have been the basis for many optocouplers, giving them an established history as a high voltage insulator.

Safety standards typically specify a one minute voltage withstand rating (typically 2.5 kV rms to 5 kV rms) and working voltage (typically 125 V rms to 400 V rms). Some standards also specify shorter duration, higher voltage (e.g., 10 kV peak for 50  $\mu$ s) as part of certification for reinforced insulation. Polymer-/polyimide-based isolators yield the best isolation properties, as seen in Table 1.

**Table 1. Isolation Properties**

	Polymer-based Optocoupler	Polyimide-based Digital Isolator	SiO <sub>2</sub> -based Digital Isolator
Withstand Voltage (1 minute)	7.5 kV rms	5 kV rms	5 kV rms
Lifetime at 400 V rms Working Voltage	25 years	50 years	25 years
Surge Level for Reinforced Insulation	20 kV	12 kV	7 kV
Distance Through the Insulation (Insulation Thickness)	400 $\mu$ m	14-26 $\mu$ m	7-15 $\mu$ m

Polyimide-based digital isolators are similar to optocouplers and exceed lifetime at typical working voltages. SiO<sub>2</sub>-based isolators provide weaker protection against surges, preventing use in medical and other applications.

The inherent stress of each film is also different. Polyimide has lower stress than SiO<sub>2</sub> and can increase in thickness as needed. SiO<sub>2</sub> thickness, and therefore isolation capability, is limited; stress associated with thick SiO<sub>2</sub> layers, for example on the order of 15  $\mu$ m, may lead to cracked wafers during processing or delamination over the life of the isolator. Polyimide-based digital isolators use isolation layers as thick as 26  $\mu$ m.

### ISOLATOR STRUCTURE

Digital isolators use transformers or capacitors to magnetically or capacitively couple data across an isolation barrier, compared to optocouplers that use light from LEDs.

Transformers pulse current through a coil, as shown in Figure 1, to create a small, localized magnetic field that induces current in another coil. The current pulses are short—1 ns—so the average current is low.

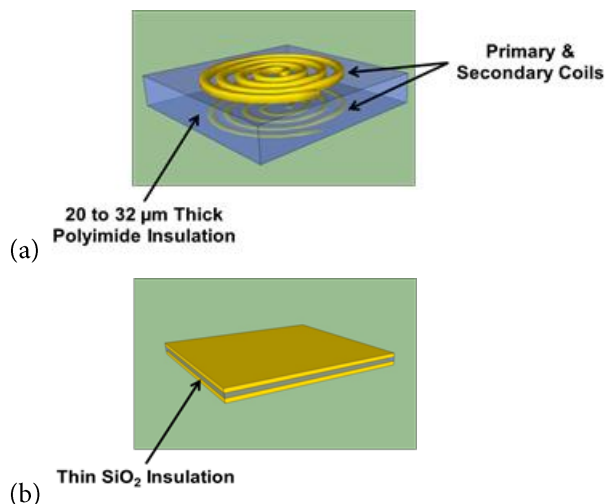


Figure 1. (a) Transformer with thick polyimide insulation where current pulses create magnetic fields to induce current on the secondary coil; (b) capacitor with thin  $\text{SiO}_2$  insulation using low current electric fields to couple across isolation barrier.

Transformers are also differential and provide excellent common-mode transient immunity, as high as  $100 \text{ kV}/\mu\text{s}$  (optocouplers are typically about  $15 \text{ kV}/\mu\text{s}$ ). Magnetic coupling also is less sensitive to the distance between the transformer coils compared with the dependence for capacitive coupling on the distance between plates. This allows for thicker insulation between transformer coils resulting in higher isolation capability. Combined with low stress polyimide films, high levels of isolation may be achieved for transformers using polyimide vs. capacitors using  $\text{SiO}_2$ .

Capacitors are also single-ended and have higher susceptibility to common-mode transients. Differential pairs of capacitors can compensate, but this increases size and cost.

Beyond overall performance, there is another benefit to using transformers: they allow for integration of isolated power. ADI's *isoPower*® technology incorporates an isolated dc-to-dc converter with data isolation to create a complete isolation solution. After all, the transformer is the key element of an isolated dc-to-dc converter. Such solutions are not possible with capacitor- or LED-based isolators.

#### DATA TRANSMISSION METHODS

Optocouplers use light from LEDs to transmit data across an isolation barrier: the LED turns on for logic HIGH and off for logic LOW. While the LED is on, the optocoupler burns power, making optocouplers a poor choice wherever power consumption is a concern. Most optocouplers leave the signal conditioning at the input and/or output to the designer, which is not always the easiest to implement.

Digital isolators use more advanced circuitry to encode and decode data, allowing for more rapid data transmission and the ability to handle complex, bidirectional interfaces such as USB and I<sup>2</sup>C.

One method encodes rising and falling edges as double or single pulses that drive a transformer (Figure 2). These pulses are decoded back into rising/falling edges on the secondary side. This reduces power consumption by  $10\times$  to  $100\times$  compared to optocouplers because power is not continuously applied as with optocouplers. Refresh circuits can be included to regularly update the dc level.

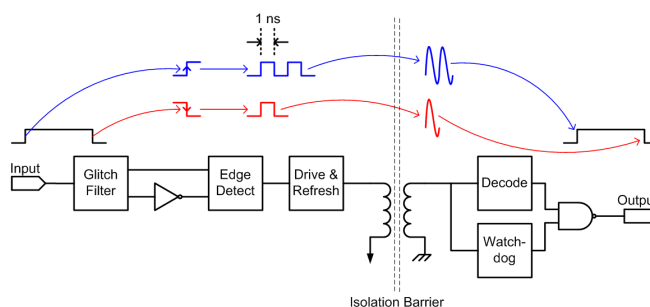


Figure 2. One method for transferring data encodes edges as single or double pulses.

Another method uses RF modulated signals in much the same way that optocouplers use light; logic HIGH signal results in continuous RF transmission. This is often referred to as an “on-off” scheme. The benefit of this scheme is that it can result in faster transmission of data across the isolation barrier; however, jitter can sometimes be a problem. Also, on-off approaches consume more power than pulse-based methods because logic HIGH signals continuously burn power. With a pulse-based method, power can be reduced to levels as low as  $1 \mu\text{W}$ , something that cannot be achieved with other approaches.

Differential techniques may also be employed for common-mode rejection. However, these are best used with differential elements such as transformers.

#### CHOOSING THE RIGHT COMBINATION

Digital isolators offer significant, compelling [advantages over optocouplers](#) in terms of size, speed, power consumption, ease of use, and reliability. Within the class of digital isolators, different combinations of insulating material, structure, and data transfer method distinguish different products, making some more or less suitable to particular applications. As noted above, polymer-based materials offer the most robust isolation capability; this material can be used in almost all applications, but the most stringent, such as health care and heavy industrial

equipment, will gain the most advantage. To achieve the most robust isolation, polyimide thickness may be increased beyond what is reasonable for capacitors. Therefore, capacitor-based isolation may be best suited for functional isolation where safety isolation is not required. In those cases, transformer-based isolation may make the most sense, especially when combined with a differential data transfer method that takes full advantage of the differential nature of transformers.

While each designer will choose an isolator with the appropriate balance of properties best suited to her or his application, three parameters tend to stand out: timing, power consumption, and, of course, isolation. To assess different technologies, consider the following chart, which utilizes a figure of merit based on timing divided by isolation capability plotted against power consumption. In this case, we have chosen to use surge withstand threshold (a high voltage pulse with a 2  $\mu$ s rise time and 50  $\mu$ s fall time used to establish suitability for reinforced insulation) to measure isolation capability. Power consumption is the maximum power, in mW, per channel at 1 Mbps data rates; we chose 1 Mbps as a representative rate because most power sensitive applications run at modest data rates. For timing, we looked at the total timing delay for a signal to pass across the isolation barrier. Therefore, this includes not only the propagation delay, but also the jitter and output rise and fall times.

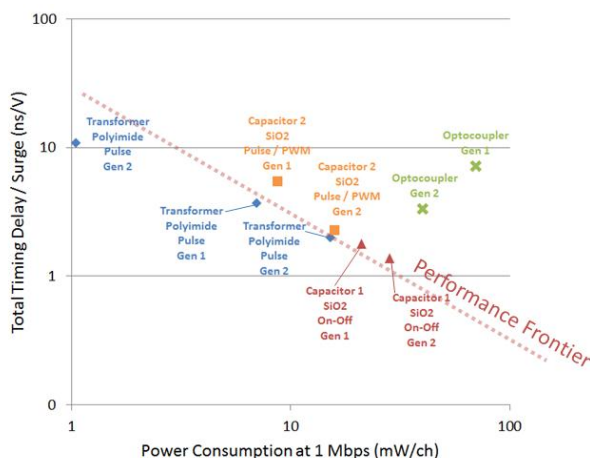


Figure 3. Combinations of the different isolator characteristics lead to different figure of merit positions. One aspect remains clear: optocouplers lag behind digital isolators.

When plotted in this way, one can see the presence of a performance frontier occupied by digital isolators. The optocouplers are positioned far behind the frontier, and while recent improvements to optocouplers have moved

them closer to the performance frontier, they are still far behind digital isolators. One can also see that different technologies also occupy different positions along the frontier, with transformer/polyimide-based digital isolators with pulse encoding methods showing much lower power efficiency and on-off keying approaches showing much better timing performance.

Hidden within this chart are the subtle details of how different digital isolator vendors have moved along this frontier from one generation to the next. ADI's second generation approach moved to either side of the frontier by, in one case, reducing power consumption and, in the other case, reducing total timing delay. These changes were made without changing isolation capability. The Cap1 vendor only moved along the frontier in one direction and did so by increasing isolation capability; however, doing so increased the total timing delay. This is seemingly due to the fact that increasing SiO<sub>2</sub> thickness to achieve better isolation reduced the coupling needed to transfer data; that, in turn, reduces performance.

## SUMMARY

When they developed their digital isolation technology, Analog Devices considered the various differences in the four elements of digital isolation, with a focus on insulating material, isolating element, and the method for transferring data across the isolation barrier. They established that the core iCoupler technology would be based on polyimide insulation and chip scale transformers because this combination affords the greatest flexibility not only to integrate other functions, such as isolated power, but also to allow the use of different methods for transferring data. The pulse-based method we have employed for nearly 14 years continues to provide excellent power efficiency and timing performance, yet still leaves open the possibility to employ other methods with their own benefits. This can all be done without compromising the isolation capability that, above all else, is the primary reason designers use isolators.

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