Safety Reliability of Digital Isolators

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Designers do not add galvanic isolation to their systems because they want to—they do it because they are required to meet domestic or international safety regulations. The downside is that isolation is placed directly in a data path, introducing delays and slowing down system performance. Adding isolation also increases power consumption, size, and cost. These are unfortunate trade-offs. For years, designers used optocouplers and grudgingly managed the trade-offs, but a new breed of galvanic isolators, digital isolators, have come to market and reduced those penalties. They enable smaller, more energy efficient and cost effective designs capable of higher levels of performance. However, safety standards have not kept pace, creating confusion and uncertainty about whether digital isolators can achieve the one reason designers use galvanic isolation: do they meet safety regulations?

The answer is yes: digital isolators can provide the same safety required by domestic and international standards. However, unlike optocouplers from most suppliers which have similar structures, digital isolators are designed and manufactured in different ways that affect isolation capability, particularly when compared to the stalwart isolation capability of optocouplers. Therefore, not all digital isolator technologies and implementations provide the same level of safety.

Consider four key isolator elements:

- Insulating material
- Isolation element
- Data transmission architecture
- Package

There are different options for each element, and the resulting combination defines an isolator's capabilities. We will focus on the insulating material which is a key differentiator for safety. Optocouplers use a variety of polymer materials, including the epoxy molding compound of the package. Digital isolators use a similar polymer, or polyimide, material or they may use silicon dioxide. The materials and manufacturing process lead to differences in both the life time of the insulation and the ability to withstand high voltage surges. Let us first consider safety standards and how they relate to different types of isolators.

UNDERSTANDING ISOLATION REQUIREMENTS: THE COMPLEXITY OF STANDARDS

System-level standards address differences between environmental conditions and system usage. Requirements for household appliances, for example, differ from patient monitors used in hospitals or motor drives in factories. They often address isolation safety by calling out component-level standards specific to galvanic isolators. There are three such standards of note:

- IEC 60747: Semiconductor Devices—Part 1: General
- UL 1577: Standard for Optical Isolators
- VDE 0884-10: Semiconductor Devices—Magnetic and Capacitive Coupler for Safe Isolation

While each has a similar objective—ensure user, operator, and equipment safety—they take different approaches. IEC 60747 includes distinctions between classes of isolation (for example, basic vs. reinforced insulation) while UL 1577 emphasizes the capability of isolators to withstand certain voltage levels over a defined period of time, typically one minute. It is common for system designers to rely on certification from more than one of these component-level standards in order to cover all possible uses and conditions.

The rise of digital isolators has complicated matters because many of these standards were written at a time when designers were stuck with optocouplers. The standards address weaknesses associated with optocouplers and provide means for guaranteeing safety.

These methods work well for optocouplers; however, they may not apply to digital isolators. Consider the case of certified working voltage, which is the continuously applied voltage across an isolation barrier. The expectation is that an isolator with a certified working voltage should withstand that voltage over its life.

IEC 60747 requires a production partial discharge test to validate optocoupler working voltages. Standards bodies have determined that partial discharge inception and deception voltages correlate with optocoupler working voltages. The manufacturing process uses an injection molding which is prone to creating voids within the plastic material. These voids can experience higher electric fields under stress and result in partial discharge induced degradation. Using a partial discharge test at high voltages detects the presence of voids and can be used to reject parts that would otherwise fail in the field.

This partial discharge approach is not fully applicable to digital isolators. Digital isolators do use similar package materials which must be tested for defects using partial discharge, but there are other aging mechanisms related to the insulating materials. The main isolation materials used for isolation elements are deposited through well-controlled wafer-level processes and are less prone to voids and, thus, partial discharge; however, other aging mechanisms start to dominate. When a digital isolator claims a certain working voltage, usually denoted as VIORM, based on IEC 60747, that may be misleading, as it reflects only the ability to pass a partial discharge test at a given voltage

Because partial discharge is an incomplete test for digital isolator working voltage, additional testing and characterization are required. Future standards from IEC will address this and incorporate these new methods. In the interim, it is incumbent on digital isolator suppliers to show how they guarantee lifetime operation at rated working voltages.

MEASURING HIGH VOLTAGE LIFETIME OF *i*Coupler DIGITAL ISOLATORS

Analog Devices guarantees the working voltage of our *i*Coupler® digital isolators with testing other than partial discharge. *i*Coupler digital isolators use 20 μm thick polyimide insulating layers between planer transformer coils that are part of the wafer fabrication process (see figure below). This manufacturing process allows for the isolation elements to be integrated with any foundry semiconductor process at low cost and with excellent quality and reliability. The cross section below shows the turns of the top and bottom coils separated by the thick polyimide layer. Polyimide materials have been used for insulation for many years; nearly one billion *i*Coupler transformers have been manufactured and used reliably for over ten years.
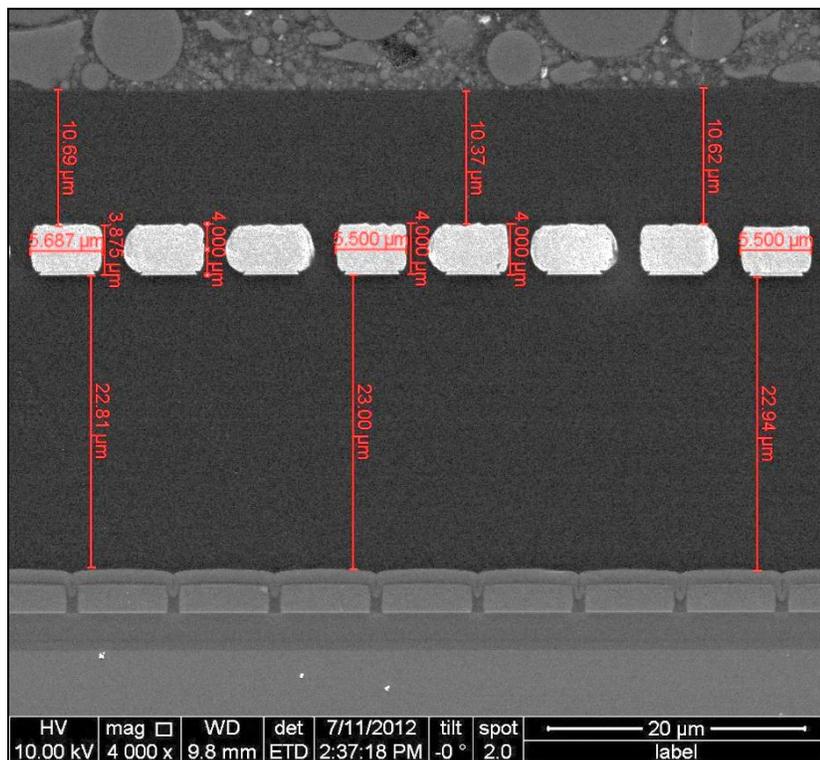
To measure the working voltage lifetime of these chip-scale isolation transformers, we employ a high voltage endurance (HVE) setup. HVE is done through time-to-failure experiments at accelerated voltage levels, usually much higher than the specified working voltages.

Charge injection is the primary HVE failure mechanism that causes isolation breakdown in devices. After charges are injected into the polyimide insulation, they may be trapped in local trap sites where they release energy. If the released energy is high enough, bonds within the polyimide will break, thereby creating more trap sites that will lead to more space charge trapping. This positive feedback eventually leads to insulation breakdown.

Through thermodynamic analysis[1], the lifetime, L, can be expressed as

$$L \sim \frac{e^{-(E-E_t)^n}}{(E-E_t)^m}$$

where E_t is the threshold field where no charge injection will happen, and m, n are scaling constants.
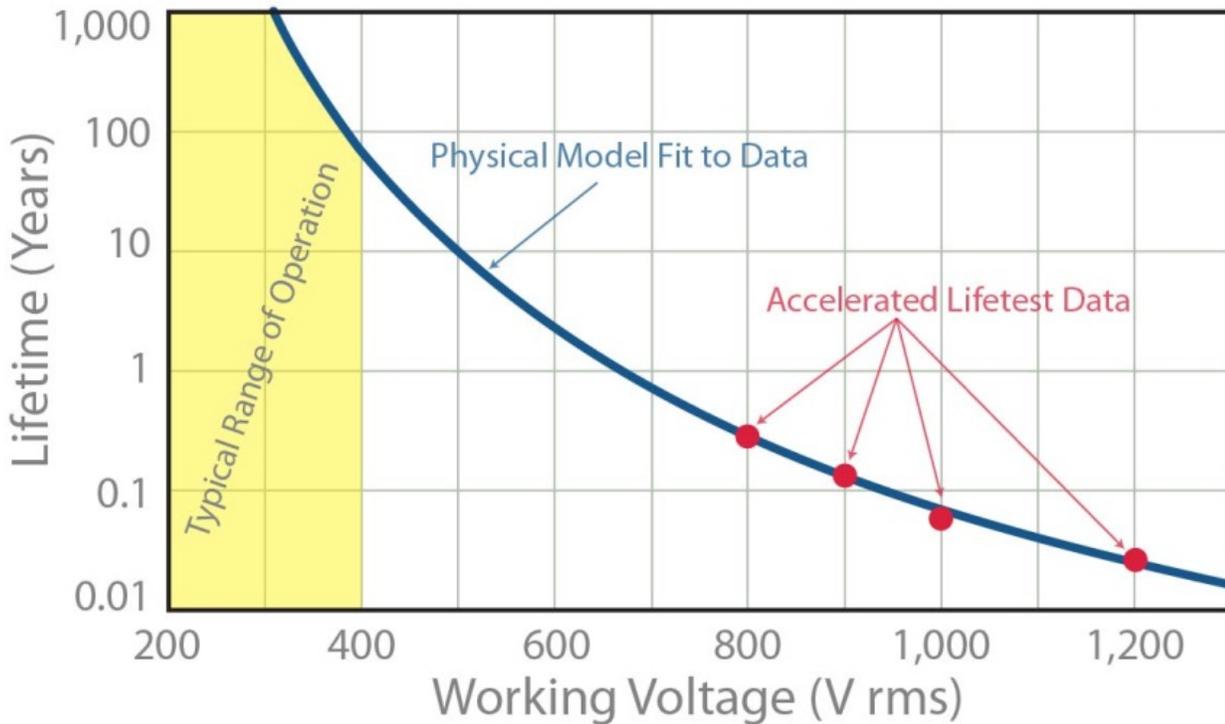
HVE data from *i*Coupler devices has been observed to follow

$$L \sim e^{-V^n}$$

where L is the time to failure at 10 ppm, V is the applied, continuous high voltage.

The figure below shows a simplified example where four data points from high voltage stressing samples are used to fit the model and extrapolate back to typical working voltages.

iCoupler High Voltage Lifetime (10 ppm)

This data was measured by subjecting samples to 60 Hz common-mode potential differences from 800 V to 2000 V rms. Time-to-failure for each unit was recorded summarized in the Weibull plot below. Time-to-failure was extrapolated for lower voltages within the intended working voltage range.
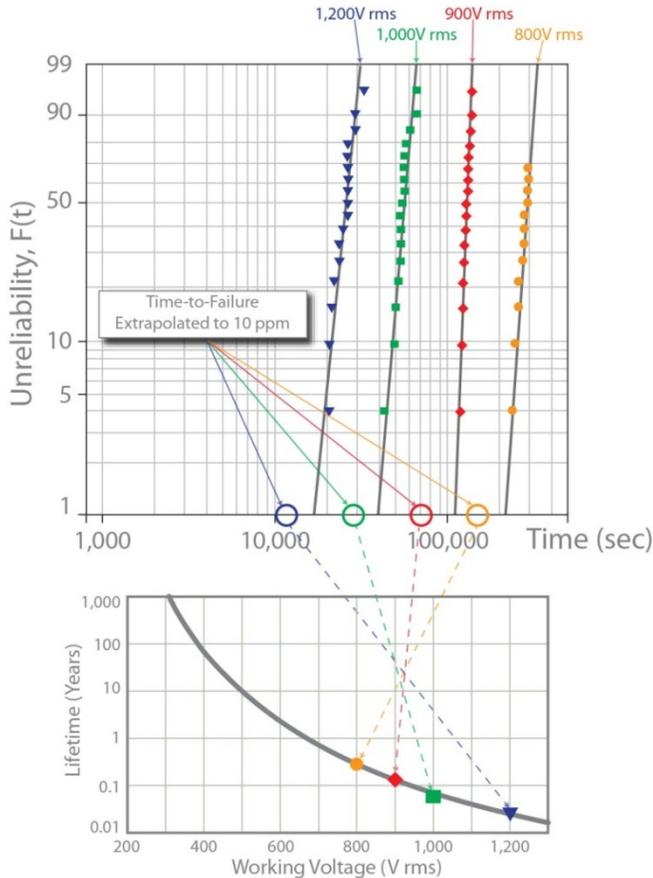
*i*Coupler HVE lifetime depends on whether the applied voltage is ac or dc. Under dc stress, the static field inhibits the trap/recombination release of energy. As a result, dc lifetimes are considerably longer than ac lifetimes. *i*Coupler products always specify the worst-case ac lifetime.

The rms specification of working voltages is also somewhat misleading. A 400 V rms waveform is actually a sinusoid switching between positive 560 V and negative 560 V, so the full peak-to-peak stress across the barrier is actually 1120 V. We have confirmed that the lifetime for a bipolar waveform specified at 400 V rms is the same as a 1120 V peak-to-peak waveform, independent of where it is centered. Where safety is critical, data sheets should be conservative to ensure no potential hazards, which is why data sheets for *i*Coupler digital isolators specify the absolute worst-case working voltage.

CONCLUSION

The introduction of digital isolators has made an already complicated puzzle of safety standards even more confusing because not all standards address requirements for digital isolators, which use different materials and elements for galvanic isolation. For a lifetime under certain working voltage conditions, certification based on partial discharge is not sufficient to guarantee reliably safe operation over decades of use, as is the case with optocouplers. New standards are being written to address this shortcoming, but until then, digital isolator suppliers must complement these standards with reliable data to support claims of decades-long reliability. *i*Coupler digital isolators based on polyimide insulation have done this and can guarantee more than 50 years of safe operation at rated working voltages using an accelerated life test.

REFERENCES

[1] Dissado, L.A., et al. "The Incorporation of Space Charge Degradation in the Life Model for Electrical Insulating Materials." *IEEE Transactions on Dielectrics and Electrical Insulation*. Vol. 2, No. 6, pp. 1147-1158, December, 1995.

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