Surging Across the Barrier: Digital Isolators Set the Standard for Reinforced Insulation

INTRODUCTION

Optocouplers have traditionally been used to isolate potentially dangerous voltages in many types of electrical equipment. Today, more modern digital isolators based on transformer or capacitive coupling are widely used. Transformer-based digital isolators offer many benefits such as improved performance, integrated functionality, lower power dissipation, better longer-term reliability, and improved ease of use.

Isolation can be required for several reasons. It allows functional circuit operation when disparate ground references or supply voltages are used. Equipment operators or medical patients must be protected from shocks or dangerous currents during long-term system operation. Damage to sensitive and/or costly systems due to electrical surges—such as lightning strikes—must be prevented.

Over time, national and international standards were developed with the goal of providing uniform specification and testing of isolators and electrical systems employing isolation. Safety certifications can be achieved both at the component level and for the end system, and certification requirements can vary in different regions of the world even when the same base safety standards are referenced. Isolators that meet a superset of safety standard specifications provide maximum flexibility to equipment vendors in meeting these varying requirements.

There are a variety of reasons for requiring galvanic isolation in electrical systems. The most obvious—and most critical—is the protection of human operators from potentially lethal shocks. Shock hazards can come from the mains power that the equipment is plugged into, or from high voltages generated within an enclosure. A reinforced insulation rating is required when humans are being protected from potentially lethal shock.

In large industrial settings there may be potential differences between physically separated ground points that may create unwanted current flow. Ground loops can also lead to noise and hum in a system.

High reliability or high availability systems often require that individual circuit faults be contained such that overall system operation is not impaired beyond an acceptable level. Isolation can be used in these systems to contain faults so neighboring circuitry remains operational.

Different portions of an electrical system may have unreferenced grounds or be referenced to unrelated high-side supply voltages, again leading to a need for isolation. Finally, noise in a particular portion of a circuit may need to be contained to eliminate interference with sensitive electronics.

SAFETY STANDARDS

The International Electrotechnical Commission (IEC) publishes a number of international standards related to electrical safety, while national bodies such as Underwriters Laboratory (UL) in the US and Verband der Elektrotechnik (VDE) in Germany publish regional specifications. Testing and certification to the standards is provided by several entities, including UL, VDE, the Canadian Standards Association (CSA), and Technischer Überwachungs-Verein (TÜV) in Germany. The choice of which certification to obtain depends on the region where the component or

Table 1. System-Level Standards Relevant to Applications Requiring Isolation by Market and Region

	Household	Industrial	Information Technology	Measurement and Control	Medical	Telecom
International	IEC 60065	IEC 60204	IEC 60950	IEC 61010-1	IEC 60601	IEC 60950
Germany	VDE 860		EN 60950	VDE 410/0411	VDE 0750	VDE 0804
USA	UL 60065	UL 508, UL 60947	UL 60950	UL 61010	UL 60601	UL 60950
Canada		CSA. 14-10	CSA 60950	CSA 61010	CSA 601	CSA 60950

system will be sold, as well as the end user. In some cases an equipment vendor may require certification to an IEC standard from a specific company (for example, TÜV) even if certification to that same standard has already been obtained through another agency (such as CSA). This is sometimes based on preference or previous experience, but there can also be differences in the certification levels that drive these requirements.

Standards bodies have been working to harmonize the international and regional documents to simplify the certification process. This is a slow process due to the number and complexity of the standards. Until this is achieved, component suppliers are best served in meeting a superset of the various requirements to provide maximum flexibility in terms of worldwide sale of the end equipment.

Further complicating the situation is the fact that there are system-level and component-level standards for isolation. The system-level standards most relevant to applications requiring isolation are:

This approach provides a system isolation specification that flows down to the component level. System requirements are used to define the isolation characteristics of the individual parts that comprise the system. Following the system standard should result in a known level of safety in the final system design.

Standards that apply to specific isolation components are

- 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

These standards certify that a digital isolator component meets particular safety requirements, but will not guarantee the isolation level of the overall system. Determining suitability of individual digital isolators is left to the system designer based on the overall safety requirements.

Another consideration is how the various parameters are handled by each agency. For example, UL 1577 documents the creepage and clearance achieved and verifies survival to the specified withstand voltage. There is no specific requirement on creepage or clearance so long as the component passes the test. On the other hand, IEC 60950 mandates specific creepage and clearance requirements based on the working voltage. The component must meet the creepage and clearance for a given voltage regardless of the test results.

Some of the component-level standards are written specifically for products utilizing optical communication across an isolation barrier. These products, known as optocouplers, have been in use for some time and are governed by the IEC 60747 and UL 1577 standards. Modern digital isolators that use transformer or capacitive coupling across an isolation barrier are now widely used as an alternative to optocouplers. The standards bodies have begun to catch up to technology changes in isolation products. For example, VDE 0884-10 was released in 2006 to address components utilizing transformer-based and capacitive isolation. The IEC is currently working to harmonize these standards.

Several physical and electrical isolator characteristics are specified within the various safety standards. The insulating properties of the component, as well as the physical dimensions of the packaging and insulating barrier, are specified in order to withstand specific voltage stresses. Different stresses are defined based on magnitude and duration.

Working Voltage

Working Voltage is a continuous dc or ac voltage that the component is specified to endure over its lifetime. IEC 60950 specifies three levels for working voltage: 250 V_{RMS}, 320 V_{RMS} and 400 V_{RMS}.

Withstand Voltage

Withstand Voltage—also called Isolation Voltage—is an overvoltage condition that the component will survive for up to one minute. UL 1577 withstand voltage ratings of 1 kV_{RMS}, 2.5 kV_{RMS}, 3.5 kV_{RMS} and 5 kV_{RMS} are common.

Surge Voltage

Surge Voltage defines survivability after a repetitive series of short duration high voltage pulses (see Figure 1). An isolator must pass 10 kV surge voltage testing to achieve a reinforced insulation rating to the VDE 0884-10 specification. The ability to pass this test is primarily determined by the insulation thickness (also known as Distance Through Insulation or DTI) and the quality of the insulating material. The applied electric field tends to concentrate at defect points within the insulator, so lower defect densities generally lead to higher breakdown ratings. Thicker materials are more resistant to breakdown since the field

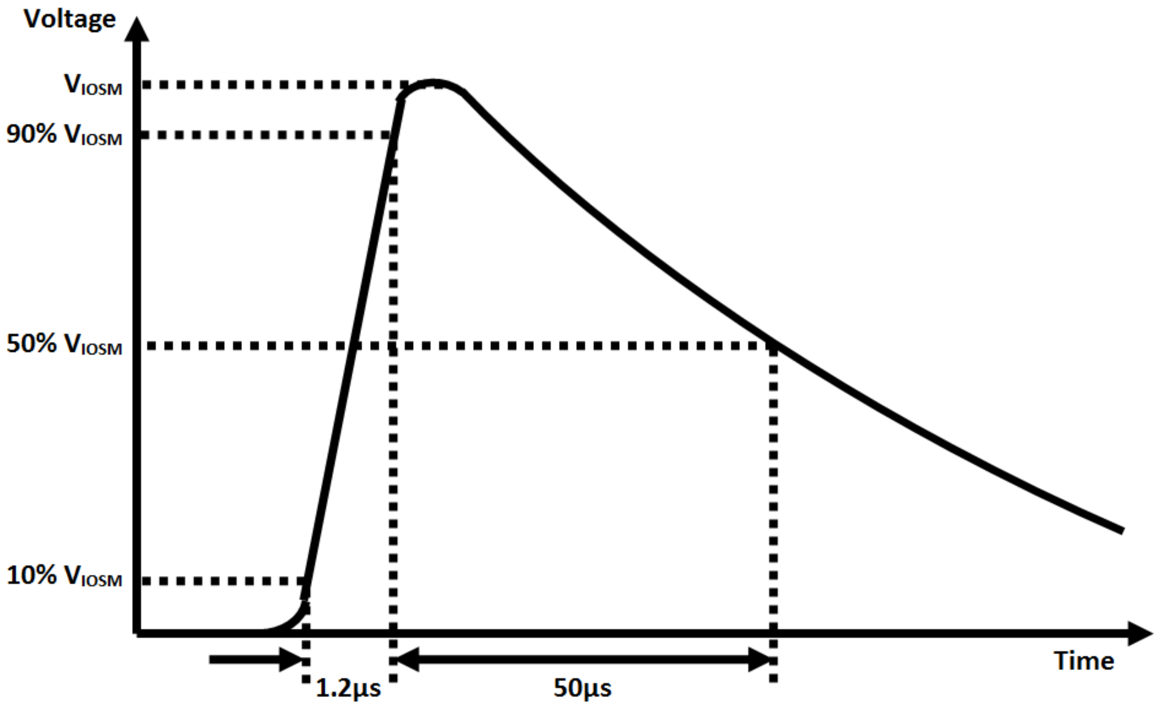

Figure 1. Surge Voltage Waveform

strength is inversely proportional to the distance between the conductors on either side of the insulation.

Optocouplers commonly meet this requirement because DTI is typically 400 µm, which reduces the impact of insulation quality on the breakdown characteristics. Simply put, the insulation is so thick that a high quality material is not required to pass the 10 kV test. Transformer-based digital isolators use a high quality 20 µm polyimide layer deposited in a clean room environment. Since this material has a much lower defect level than the injection molded epoxies used in optocouplers, a much thinner layer can still meet the 10 kV requirement. Capacitive isolators also use a high-quality insulating layer, in this case silicon dioxide (SiO_2), deposited during wafer fabrication. Silicon dioxide has a high dielectric strength, but typically can't be deposited in very thick layers without creating mechanical stress within the film. Thicker SiO_2 also reduces the capacitance, which in turn reduces the coupling efficiency across the barrier. For this reason, capacitive isolators typically will not pass the 10 kV surge test and, therefore, can't be certified by VDE as reinforced insulation.

Voltage levels may be specified as a peak voltage or in rms terms, so careful attention must be paid to the details within each standard.

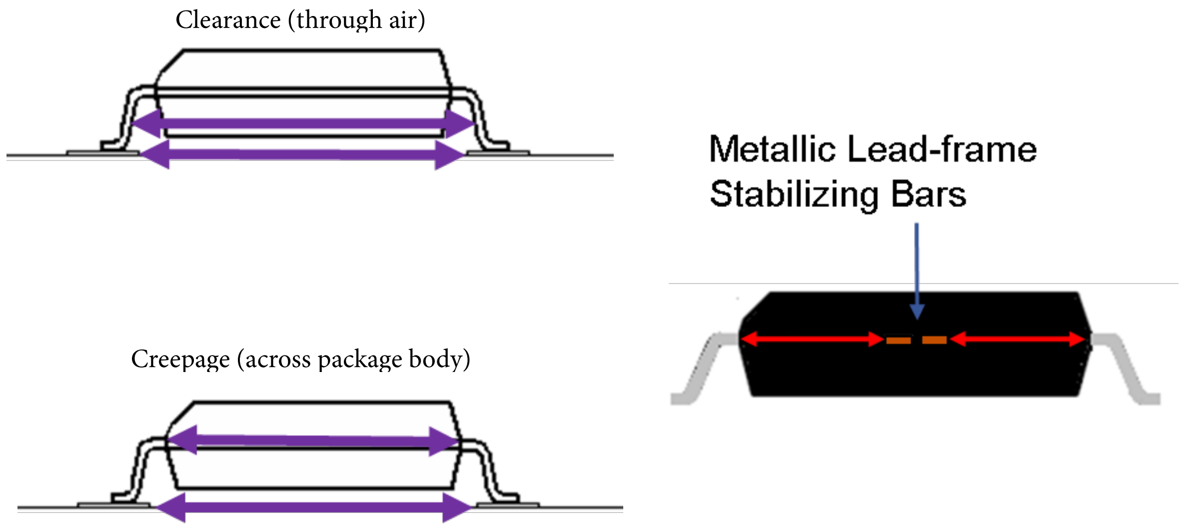

Figure 2. Creepage and Clearance

PHYSICAL AND ENVIRONMENTAL EFFECTS

There are two basic levels of insulation specified within the safety standards. Functional insulation is that which is required to allow a circuit to operate properly. An example would be isolating different ground potentials between two circuits to avoid an overvoltage situation. Functional insulation does not provide protection from shock. Insulation that does provide protection from shock is referred to as basic insulation or reinforced insulation in the IEC standards. Basic insulation provides protection from shock for users of the end equipment. Reinforced insulation is a single insulation system that provides protection equal to two redundant single insulation systems. Safety regulations frequently require either redundant single insulation or reinforced insulation to protect users from lethal shocks. Using reinforced insulation is more practical since redundant single insulation systems require power between the two isolation boundaries.

The required physical distance across the isolation barrier is determined primarily by the desired voltage ratings, but the characteristics of the environment play a part as well. Two dimensions—creepage and clearance—are used to describe the isolation distance. Creepage is the shortest distance along a solid surface across the isolation barrier, while clearance is the shortest line-of-sight path through air across the barrier.

Figure 2 shows how creepage and clearance are defined for a gull-wing style package such as a SOIC (small outline integrated circuit). An important consideration is that metallic stabilizing bars visible on the package ends must be subtracted from the creepage measurement.

Conductive paths will develop along a surface in the presence of an electric field and electrolytic contaminants. This process is referred to as tracking and is characterized by the Comparative Tracking Index (CTI). The CTI for a given material is the voltage that causes tracking with a specific quantity of an electrolyte on the surface. Higher CTI values indicate that a material has more resistance to tracking, and will allow a lower creepage value.

The final characteristic that determines creepage requirements is the level of contamination in the environment, referred to as Pollution Degree. Environments are classified into four groups based on the amount of dry pollutants and condensation present. Higher levels of contamination and condensation result in higher creepage requirements. Tables within the standards are used to determine the creepage requirements once the voltage ratings, CTI, and pollution degree are known.

CONCLUSION

Galvanic isolation is essential in many electrical system designs. International and regional standards have been developed to ensure uniform specification and testing of isolator components and systems. There are several technologies available to achieve the necessary isolation for a particular system requirement, and each has its own strengths. Isolators that meet the superset of international and regional standards—including 10 kV surge testing—provide maximum flexibility to equipment vendors in meeting these varying requirements.

For more information on digital isolators, please visit www.analog.com/icoupler.

RESOURCES

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