AN583: Safety Considerations and Layout Recommendations for Digital Isolators

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This application note details the creepage and clearance requirements of an isolator type component, such as a digital isolator, used to provide protection from electric shock. It also details layout recommendations to enhance a design's robustness and ensure compliance with end safety standards.

To ensure safety in end-user applications, high voltage circuits (i.e., circuits with >30 VAC) must be physically separated from the safety extra-low voltage circuits (SELV is a circuit with <30 VAC) by a certain distance (creepage/clearance). If a component, such as a digital isolator, straddles this isolation barrier, it must meet those creepage/clearance requirements and provide a sufficient high-voltage breakdown protection rating (commonly referred to as working voltage protection). Refer to the end-system specification (61010-1, 60950-1, 60601-1, etc.) requirements before starting any design that uses a digital isolator. These standards dictate both the working voltage requirement and the creepage/clearance distance spacing necessary to deem an end product safe for end-customer use.

KEY POINTS

- Safety Considerations
- Key Term Definitions
- Guidelines for Proper Creepage and Clearance
- Layout Recommendations

1. Key Term Definitions

The following are key terms that should be understood before reading this application note:

Safety Extra-Low-Voltage—A voltage less than 30 VRMS (60 VDC)

Hazardous—A voltage greater than 30 VRMS (60 VDC)

Basic Insulation—A single-level of protection against electric shock. See Table 2.

Reinforced/Double Insulation—Two-levels of protection against electric shock. See Table 2. Rated (Proof) Isolation Voltage—The maximum voltage an isolation barrier is rated to withstand. This is typically 2500, 3750, or 5000 VRMS for 1 minute.

Production Isolation Test Voltage—The voltage to which an isolation component manufacturer must test the component in order to be compliant with a given standard. This test voltage is typically 1.2x the Rated Isolation Voltage for a test duration of 1 second. Each standard has slightly different test voltage requirements. The most strenuous and inclusive requirement is chosen for this test.

Creepage—The shortest path between two conductive parts measured along the surface of the insulation.

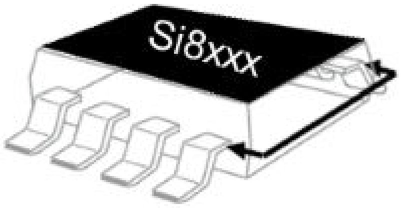

Figure 1.1. Creepage

Clearance—The shortest path that an arc may travel through air.

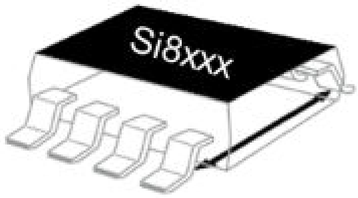

Figure 1.2. Clearance

Time-Dependent Dielectric Breakdown—The amount of time it takes a component's isolation barrier to fail for a given voltage. In general, the lower the voltage, the exponentially longer the time a safety component can survive.

Pollution Degree—The end environment in which an end system is used. Table 1 summarizes the different pollution degrees. Skyworks Solutions digital isolators are rated to Pollution Degree 2.

- Pollution Degree 1: No pollution or only dry, nonconductive pollution occurs. The pollution has no effect.
- Pollution Degree 2: Normally, only nonconductive pollution occurs. Temporary conductivity caused by condensation is to be expected.
- Pollution Degree 3: Conductive pollution or dry nonconductive pollution that becomes conductive due to condensation. This is to be found in industrial environments or construction sites (harsh environments).
- Pollution Degree 4: The pollution generates persistent conductivity caused by conductive dust, rain, or snow. The following table lists pollution degree definitions.

Table 1.1. Pollution Degree Definitions

Pollution Degree 1	Pollution Degree 2	Pollution Degree 3	Pollution Degree 4
Clean room environments	Equipment being evaluated at 60950	Electrical equipment in industrial and farming areas	Electrical equipment for outdoor use
Inside sealed components	Laboratories	Unheated rooms	
	Test stations	Boiler rooms	
	Office environments		

The following table details some typical differences between basic and reinforced isolation requirements. See the specific standard for your design, as creepage requirements will vary from one standard to another. The numbers listed below provide a good rule of thumb for most standards.

Table 1.2. Typical Differences between Basic and Reinforced Isolation Requirements

Insulation Type	Creepage/Clearance	Proof (Rated) Test	Production Test
Basic	3.2 mm	2500 V_{RMS} (1 min)	3000 V_{RMS} (1 sec)
Reinforced/Double	6.4 mm	5000 V_{RMS} (1 min)	6000 V_{RMS} (1 sec)

2. Selecting Adequate Creepage and Clearance for a Given Specification

The amount of creepage distance required for a given system depends on the end system's certification standard. In general, this distance is dictated by the Pollution Degree of the environment in which the system will be used and the highest working voltage present in the system. For example, the IEC60950-1 regulates the requirements for Telecom Equipment, and the IEC61010-1 regulates the requirements for Industrial and Test Equipment. The table below lists the Basic Insulation creepage requirements for IEC60950-1. From this table, one can see that the Basic Insulation creepage distance required for a Pollution Degree 2, Material Group IIIa/b (the most common material group), 250 V_{RMS}, system is 2.5 mm. A component whose package provides less is not adequate for the design.

Table 2.1. IEC60950-1 MAINS Creepage Requirements

Working Voltage (VRMS or VDC)	Functional, Basic, and Supplementary Insulation		
	Pollution Degree 2		
	Material Group		
	I	II	IIIa or IIIb
<50	0.6	0.9	1.2
100	0.7	1.0	1.4
150	0.8	1.1	1.6
250	1.3	1.8	2.5
400	2.0	2.8	4.0

Note:

1. The data in this table is for basic isolation. Double all the distances for reinforced insulation. Dimensions are in millimeters.

2.1 Creepage Distance Provided by Skyworks Packages

Skyworks offers numerous packages with various creepage distances. The following table details these differences.

Table 2.2. Typical Creepage Distances Offered by Skyworks Packages

Package	Nominal Creepage (mm)	Creepage in Air Per IEC60112 (mm)
QSOP-16	3.6	3.6
SOIC-8	4.01	3.9
NB SOIC-16	4.01	3.9
WB SOIC-16	8	7.6
DIP8	7	7
SDIP6	8.3	8.3
LGA8	10	10

For most of the packages listed above, the Nominal creepage and the creepage in air as determined by IEC60112 (the standard that defines how to measure creepage) is the same. However, it should be noted that the JEDEC standard, 16 lead WB SOIC package has 7.6 mm of creepage. This is less than the nominal 8 mm of creepage listed due to the metal tabs left on the sides of the package during manufacturing. This 7.6 mm is adequate for most applications; however, some 220–250 VAC medical and industrial systems require 8 mm to ensure safety. All isolation suppliers using typical, non-custom, JEDEC standard SOIC packages have this same restriction on creepage (note that this condition is similar for the other SOIC packages listed above). To achieve the 4.01 and 8 mm of creepage for these JEDEC SOIC packages, conformal coating is required to cover the metal tabs.

2.1.1 Using PTI and CTI to Reduce Creepage Distance Requirements

The required creepage distance can be reduced if an isolation component has been qualified to a higher proof tracking index (PTI) rating or comparative tracking index (CTI) rating. In many cases, the distance can be cut in half if the component is rated to Material Group I instead of Material Group IIIa or IIIb (the most common ratings for components). For example, from Table 2.1 IEC60950-1 MAINS Creepage Requirements on page 4, the end user can reduce the required creepage from 4 to 2 mm (for a 400 V_{RMS} based system) if the component is rated to material group I. Skyworks Solutions isolator packages are all rated to Material Group I and Pollution Degree 2. Additional certification paperwork might be necessary to accommodate this creepage distance reduction. IEC60112 details the CTI/PTI testing standard.

2.1.2 Using Grooves to Extend Effective Creepage Distance for a Given Package

PCB grooves can be used to increase the creepage distance for a given package in a given system. See the figure below; clearance is not affected since it is line-of-sight. When using grooves, ensure that the groove does not weaken the PCB to the point that the board fails standard mechanical tests.

Figure 2.1. PCB Grooves Used to Increase Creepage Distance

2.2 Ensuring an Adequate Withstand Rating

The second requirement of a safety component is its voltage withstand rating. Every safety component has a Time Dependent Dielectric breakdown profile. Time-dependent breakdown is unique to each component. Manufacturers of safety components usually provide these profiles in their data sheets. The following figures illustrate the profiles for the Si86xxxx family.

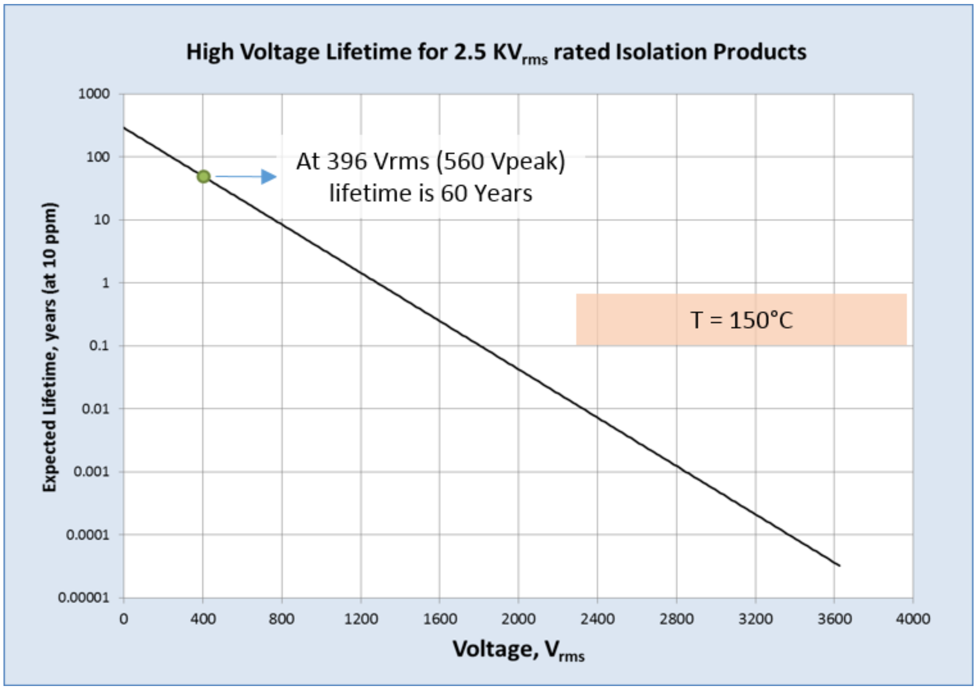

Figure 2.2. Si86xxxB Time-Dependent Dielectric Breakdown

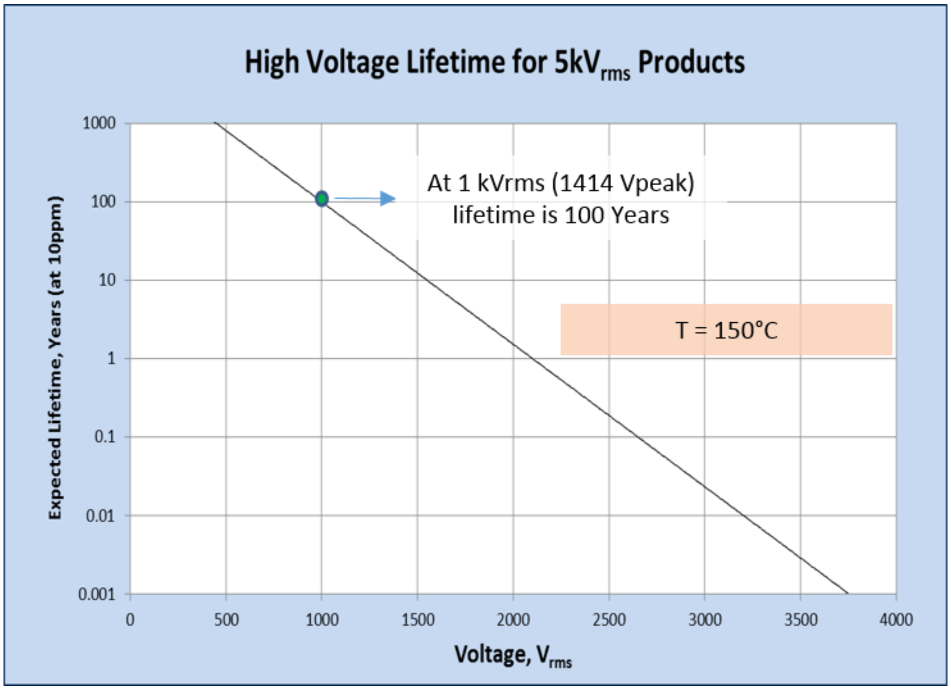

Figure 2.3. Si86xxxD Time-Dependent Dielectric Breakdown

Table 2.3. Test Voltages for Electric Strength Tests for Each Working Voltage Range

Grade of Insulation	Working Voltage		
	<184 Vpk or dc	184 < U < 354 Vpk or dc	354 < U < 1414 Vpk or dc
	Test Voltage		
Basic (V_{RMS})	1000	1500	3000
Reinforced (V_{RMS})[1]	2000 (3200)	3000 (4800)	3000 (4800)

Note:

1. For isolation components with non-homogeneous construction, such as the Si8xxx devices, reinforced insulation requires a 1.6x multiplier.

2.3 Choosing a Component with Adequate Creepage

Assume a designer is designing telecom equipment (e.g., a blade server) whose electronic board is used in a Pollution Degree 2 environment. Also assume the server's control board powers from the main line and is universally powered (up to 250 VAC).

Q: What type of isolation components are required by IEC60950-1 for this system?

A: The answer is found by going to the IEC60950-1 specification. For convenience, refer to Table 2.1 IEC60950-1 MAINS Creepage Requirements on page 4 and Table 2.3 Test Voltages for Electric Strength Tests for Each Working Voltage Range on page 7 in this document. From Table 2.1 IEC60950-1 MAINS Creepage Requirements on page 4, the component must have a creepage of 5 mm (assumes Material group IIIa; only 2.6 mm is required for a component in Material group I). Also, from Table 2.3 Test Voltages for Electric Strength Tests for Each Working Voltage Range on page 7, the component must pass a 4800 V_{RMS} 1–minute qualification test and be rated for 250 V_{RMS} reinforced insulation. A glance at these tables may suggest that the requirements are larger than necessary. However, since the system is powered from a 250 V_{RMS} mains power source, reinforced insulation is in fact required. This reinforced insulation requirement increases the overall required creepage distance and 1–minute sustained voltage requirements of the system as dictated by IEC60950-1. From Table 2.2 Typical Creepage Distances Offered by Skyworks Packages on page 4, one can see that the WB SOIC-16, DIP8, SDIP6 or LGA8 package could be used for this application. CTI/PTI documentation would need to be submitted if a smaller package was necessary.

3. Layout Recommendations

The following guidelines can be used to enhance the layout design of systems using digital isolators. Refer to the family data sheets for more details concerning specific devices.

3.1 PCB Material

For safety reasons, it is recommended that standard epoxy-glass PCB material Flame Retardant 4 (FR-4) be used in all designs since it meets the requirements of Underwriters Laboratories UL94-V0. Cheaper alternatives have higher dielectric losses at high frequencies, absorb more moisture, and provide less strength and stiffness. Moreover, FR-4 exhibits flammability characteristics that are self-extinguishing. Assuming a rise/fall time >1 ns, trace lengths up to 10 inches can be supported for data rate of 150 Mbps.

3.1.1 Use Four-Layer Designs

Four layers of metal are required to achieve a low EMI PCB design.

- To avoid issues caused by stray impedances from vias, route the high-speed traces on the top layer.
- To establish controlled impedances and provide low-inductance current return paths for high-speed signals, place a solid ground plane next to the high-speed signal layer.
- To increase high-frequency bypass capacitance, place the power plane next to the ground.
- Since slower speed signals radiate less energy, route these signals on the bottom layer. These signals usually have fewer critical layout requirements when EMI is an issue.

The above order can be reversed if it facilitates the design.

3.1.2 Use Conformal Coating to Reduce Creepage Requirements

As discussed earlier, a higher CTI/PTI rated device reduces the creepage/clearance requirements for most end systems. Conformal coating is also an alternative to higher CTI/PTI and grooves can be used to reduce creepage/clearance requirements. Since the typical voltage breakdown in air is approximately 1100 V/mm, a 4 mm creepage rate component (not including the internal barrier's isolation) will break (arc) down at approximately 4400 V. The breakdown of a component with conformal coating is significantly higher than that of air (usually 5x). Refer to standards requirements when supplementary isolation, such as conformal coating, is used.

3.1.3 Use these Routing Guidelines

Use the following guidelines to avoid noise pickup and lower EMI. See the reference section for additional layout recommendations.

1. Use appropriate bypass capacitors (usually 0.1 µF, 1 µF) between VDD and GND. The capacitors should be placed as close as possible to the package. See the data sheet for exact details.
2. Place bulk capacitors (10 µF) close to power components.
3. Use 45° bends instead of right-angle (90°) bends for signals. This enhances impedance matching.
4. To reduce inductances, avoid changing layers with signals.
5. Use power and ground planes to control impedances and minimize noise from power components.
6. Use short trace lengths between the isolator and connecting circuits.
7. To enhance the robustness of a design, it is further recommended that the user also add 1 µF bypass capacitors and include 100 W resistors in series with the inputs and outputs if the system is excessively noisy.

4. References

- High-speed Digital Design, Johnson/Graham, 1993.
- Eliminating the Myths About Printed Circuit Board Power/ground Plane Decoupling, Archambeault, 2001.
- Noise Reduction Techniques in Electronic Systems, Ott, 1988.

5. Document Change List

Revision 0.1 to Revision 0.2

- Rewrote "4. Selecting Adequate Creepage and Clearance for a Given Specification" on page 3.
- Removed “5.1. Supply Pins”, “5.2. Input Pin”, and “5.3. Output Pin Termination” subsections from "5. Layout Recommendations" on page 6.

Revision 0.2 to Revision 0.3

- Updated 2.2 Ensuring an Adequate Withstand Rating.
- Updated Figure 2.2 Si86xxxB Time-Dependent Dielectric Breakdown on page 6.
- Added Figure 2.3 Si86xxxD Time-Dependent Dielectric Breakdown on page 6.
- Updated Table 2.3 Test Voltages for Electric Strength Tests for Each Working Voltage Range on page 7.

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