Technical White Paper

Distance Through Insulation: How Digital Isolators Meet Certification Requirements

Saleem Marwat

ABSTRACT

Distance Through Insulation (DTI) is a critical parameter in evaluation of high voltage characteristics of digital isolators. Since digital isolators use capacitive and inductive isolation technologies with thin-film insulation layers, there are a lot of misconceptions in the market about the thinner dielectric and the resulting DTI when compared to optocouplers and other legacy isolators. In this paper, we explore insulation-related clauses of several international safety standards and discuss how digital isolators are certified to basic and reinforced insulation ratings despite their thin DTI.

Table of Contents

1 Introduction....2
2 Solid Insulation....2
3 Why International Standards for High Voltage Components Have Minimum DTI Requirements....2
4 Quality of Insulation Materials....3
5 Various IEC Standards and their DTI Requirements....3
5.1 IEC 60747-17....3
5.2 UL 1577....3
5.3 IEC 62368-1....3
5.4 IEC 60601-1 4
5.5 IEC 61010-1 5
6 Conclusion....6
7 References....6

List of Figures

Figure 1-1. Clearance, Creepage, and DTI....2

List of Tables

Table 4-1. Common Insulators Used for High-Voltage Isolation....3
Table 5-1. Mains Transient Voltages....4
Table 5-2. Minimum Creepage Distances and Air Clearances providing Means of Patient Protection....5
Table 5-3. Test Voltages for Solid Insulation Forming a Means of Protection....5
Table 5-4. Clearances and Creepage Distances for Mains Circuits of Overvoltage Category II above 300 V....5
Table 5-5. Test voltages for Solid Insulation in Mains Circuits of Overvoltage Category II above 300 V....6

Trademarks

All trademarks are the property of their respective owners.

Copyright © 2021 Texas Instruments Incorporated

1 Introduction

When it comes to high voltage safety certifications, the following three distances are of utmost importance to determine insulation ratings of semiconductor components: clearance, creepage, and DTI. Clearance is the shortest distance in air between two conductive parts and creepage is the shortest distance along the surface of a solid insulation material between two conductive parts across the isolation barrier. DTI, on the other hand, is the shortest distance within an insulating material interposed between two conductive parts. In other words, DTI is the distance inside a solid insulation whereas clearance and creepage are distances outside the solid insulation. See Figure 1-1 for typical depiction of clearance, creepage, and DTI.

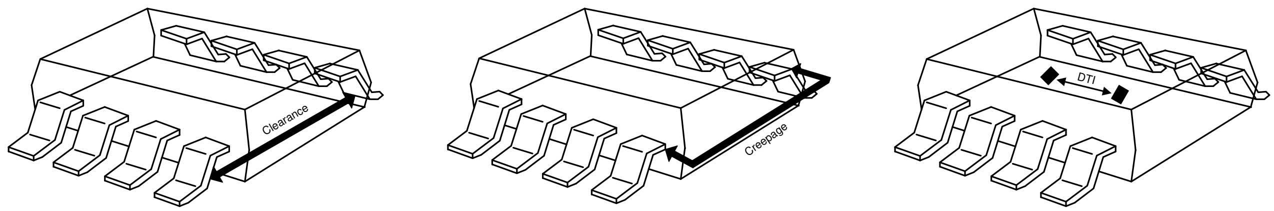

Figure 1-1. Clearance, Creepage, and DTI

There are a lot of misconceptions in the market about DTI requirements of digital isolators. These misconceptions arise due to confusion caused by the complexity of the international end-equipment standards and multiple clauses of these standards that deal with DTI requirements and exceptions. Some equipment manufacturers believe that the large DTI requirements outlined in certain clauses of their equipment standards strictly apply to digital isolators; this is simply not true. Digital isolators use a much thinner, yet more robust, insulation material when compared to optocouplers and other legacy isolators, and therefore many international standards have different test criteria for isolators with thin DTI compared to legacy isolators.

2 Solid Insulation

Solid Insulation is defined as insulation consisting entirely of solid material. The intrinsic material characteristics of solid insulation directly impact its insulation behavior. As the electric strength of solid insulation is considerably greater than that of air, the distances through solid insulation are much smaller than the clearance so that high electric stresses result. In insulation systems, gaps or voids may occur between electrodes and insulation and between different layers of insulation. Partial discharges can occur in these voids at voltages far below the level of puncture and this influences the service life of the solid insulation. As opposed to air, solid insulation is not a renewable insulating medium and therefore high voltage peaks which may occur infrequently can have a very damaging and irreversible effect on solid insulation. This situation can occur while in service and during routine high-voltage testing. The physical and geographical location of the equipment can affect the insulation system significantly. Environmental factors such as altitude, temperature, vibrations and humidity require consideration to ensure that the insulation remains reliable over the life time of the equipment.

3 Why International Standards for High Voltage Components Have Minimum DTI Requirements

Many International Electro-technical Commission (IEC) system-level safety standards have minimum DTI requirements for components that provide high voltage insulation. This is because dielectric *thickness* and *quality* determine the electric field withstand capability of isolators. Historically, optocouplers have been used as isolators in high voltage applications and therefore many safety standards ended up with much thicker DTI requirement, such as a minimum of 0.4 mm, 0.6 mm, or 1 mm for increasing working voltage ratings. These DTI thickness requirements correspond to the voltage withstand capability of the lower quality insulation material used by optocouplers and other legacy isolators. Since digital isolators use newer isolation technologies and high-quality dielectric material, such as silicon dioxide (SiO_2), they do not need to be thick to provide high-quality insulation.

Copyright © 2021 Texas Instruments Incorporated

4 Quality of Insulation Materials

All insulators are not created equal. Quality of insulation depends on its dielectric strength. As Table 4-1 shows, air has a low dielectric strength and solid insulators such as epoxy, silica filled mold compound, polyimide and SiO_2 have progressively higher dielectric strengths. SiO_2 is an excellent insulator because, unlike polyimide and other polymer-based insulators, SiO_2-based insulators do not degrade with exposure to ambient moisture. SiO_2-based insulators tend to have very high working voltages for the lifetime of the components.

Table 4-1. Common Insulators Used for High-Voltage Isolation

Insulator	Dielectric Strength
Air	~ 1 V_{RMS}/µm
Epoxy	~ 20 V_{RMS}/µm
Silica filled Mold Compound	~ 100 V_{RMS}/µm
Polyimide	~ 300 V_{RMS}/µm
SiO_2	~ 500 V_{RMS}/µm

5 Various IEC Standards and their DTI Requirements

The following discusses some common international standards and their relevant clauses which allow digital isolators with much thinner DTI to be certified with basic and reinforced insulation ratings. Both component and equipment standards are included in the following.

5.1 IEC 60747-17

This is a semiconductor component standard for magnetic and capacitive coupler for basic and reinforced insulation. This standard subjects semiconductor components to a battery of environmental and high voltage tests and provides basic or reinforced insulation designations. The standard does not use DTI as criteria for basic or reinforced rating. There are other criteria such as 10 kV_{PEAK} surge and insulation lifetime tests which determine whether a component can claim basic or reinforced insulation rating.

5.2 UL 1577

UL 1577 is Underwriters Laboratories safety standard for optical isolators but it is also used to certify other semiconductor components such as digital isolators. This standard recognizes components as either single protection or double protection based on several environmental and dielectric withstand voltage tests. This standard does not have any minimum DTI criteria for certification and ratings are accorded to the components based on the dielectric strength of the insulation material.

5.3 IEC 62368-1

IEC 62368-1 Edition 3.0 is an international standard that deals with safety requirements of audio/video, information and communication technology equipment. Clause 5.4.4 of the standard is about solid insulation. Even though sub-clause 5.4.4.2 says that there is no minimum DTI requirement for basic insulation and 0.4 mm minimum DTI for reinforced insulation but in the following sub-clause 5.4.4.4 which deals specifically with solid insulation requirements of semiconductor devices, the standard makes it absolutely clear that there is no minimum DTI requirement for reinforced components as long as they pass type tests and inspection criteria of clause 5.4.7 which basically subjects three samples to thermal cycling sequence. After thermal cycling, one sample is subjected to the electric strength test of clause 5.4.9.1 but the test voltage is multiplied by 1.6. In other words, a 60% margin is added on top of the already high transient voltage which could be 4kV_{PEAK}, 6 kV_{PEAK} or 8 kV_{PEAK}, for example. The other two samples are subjected to the same high voltage test with 60% margin after additional humidity conditioning test.

As an example, if we take a semiconductor component with material group I mold compound that has minimum 8 mm creepage and clearance distances and we try to determine its maximum basic and reinforced insulation working voltages at an altitude up to 2000 m, then we need to turn to Table 12 of IEC 62368-1 partially represented by Table 5-1. In this paper, we'll assume that the intended end equipment operates in overvoltage category II and pollution degree 2 environment. Overvoltage category II equipment refers to pluggable or permanently connected equipment that is supplied from the building wiring. Pollution degree 2 refers to an

Copyright © 2021 Texas Instruments Incorporated

environment where only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation is to be expected.

Table 5-1. Mains Transient Voltages

AC Mains Voltage up to and Including (V_{RMS})	Mains Transient Voltage (V_{PEAK})			
	Overvoltage Category			
	I	II	III	IV
50	330	500	800	1500
100	500	800	1500	2500
150	800	1500	2500	4000
300	1500	2500	4000	6000
600	2500	4000	6000	8000

AC mains voltage and thus semiconductor component's working voltage goes up to 600 V_{RMS} according to Table 5-1 of IEC 62368-1 but we can refer to IEC 60664-1 for higher working voltages as this is allowed by the standard. Table 5-1 shows relationship between basic working voltage with respect to transient voltage. For overvoltage category II, 600 V_{RMS} working voltage corresponds to 4000 V_{PEAK} transient voltage for basic insulation. For reinforced insulation, the transient voltage has to be increased by one level to 6000 V_{PEAK}. Thus applying 60% margin to the transient voltage, we get 9600 V_{PEAK} or 6789 V_{RMS} voltage level that the 3 samples have to pass after thermal cycling and humidity conditioning tests in order to claim 600 V_{RMS} reinforced working voltage per IEC 62368-1. Similarly, for a higher working voltage, we refer to Table F.1 of IEC 60664-1 which has the next higher working voltage of 1000 V_{RMS} or V_{DC} and the corresponding overvoltage category II impulse withstand voltage is 6000 V_{PEAK} for basic insulation.

Therefore, this semiconductor device can claim 600 V_{RMS} reinforced and 1000 V_{RMS} basic insulation as long as it can pass 6789 V_{RMS} voltage withstand test after thermal cycling and humidity conditioning tests. To check that clearance and creepage requirements are also satisfied, we turn to Table 14 and Table 17 of the standard. According to Table 14, 6000 V_{PEAK} and 8000 V_{PEAK} withstand voltages are required for a component with minimum clearance of 8 mm for reinforced and basic insulation respectively. Similarly, Table 17 allows components with 8 mm creepage to have a maximum working voltage of 800 V_{RMS} for reinforced insulation and 1600 V_{RMS} for basic insulation. As we saw earlier, Table 5-1 further limits the working voltage based on overvoltage category and dielectric strength of the component with 60% margin applied.

In summary, as long as the semiconductor component can meet this stringent criteria of thermal cycling followed by 60% higher voltage withstand compared to rated voltage, it does not need to have a minimum DTI for basic or reinforced ratings.

5.4 IEC 60601-1

IEC 60601-1 Edition 3 is an international standard with general requirements for basic safety and essential performance for medical electrical equipment. This standard has its own medical terminology where insulation is called means of protection, basic insulation is called one means of protection and reinforced insulation refers to two means of protection. There is further division of who is receiving the protection from medical electrical equipment: operator or patient. Two Means of Patient Protection (2 MOPP) provides the highest level of protection that is equivalent to reinforced insulation for the patient.

The minimum DTI requirements in this standard are also somewhat similar to IEC 62368-1. Although Clause 8.8.2 requires 0.4 mm minimum DTI for supplementary or reinforced insulation for peak working voltage greater than 71 V, but it also provides an option to bypass this DTI requirement to components with solid insulation in clause 8.9.3 if they pass thermal cycling, humidity conditioning test, followed by high AC withstand voltage of clause 8.8.3 except that the test voltage is multiplied by 1.6.

Using the example of a semiconductor device described earlier, we first determine the maximum working voltage that's possible with a minimum creepage and clearance distance of 8 mm. For this, we refer to Table 12 of IEC 60601-1. Table 5-2 is a partial representation of Table 12.

Copyright © 2021 Texas Instruments Incorporated

Table 5-2. Minimum Creepage Distances and Air Clearances providing Means of Patient Protection

Working Voltage V_{DC}	Working Voltage V_{RMS}	Spacing Providing One MOPP		Spacing Providing Two MOPP	
		Creepage (mm)	Clearance (mm)	Creepage (mm)	Clearance (mm)
17	12	1.7	0.8	3.4	1.6
43	30	2	1	4	2
85	60	2.3	1.2	4.6	2.4
177	125	3	1.6	6	3.2
354	250	4	2.5	8	5
566	400	6	3.5	12	7

So, with a minimum creepage distance of 8 mm, this component will be limited to a maximum 354 V_{DC} or 250 V_{RMS} of working voltage to provide two means of patient protection. Next, we determine the dielectric strength of solid insulation that the component must pass after thermal cycling and humidity preconditioning treatment. Clause 8.8.3 refers to Table 6 of IEC60601 – 1 (partially represented by Table 5-3) to answer this question.

Table 5-3. Test Voltages for Solid Insulation Forming a Means of Protection

Peak Working Voltage (U) V_{PEAK}	Peak Working Voltage (U) V_{DC}	AC Test Voltage (V_{RMS})			
		Means of Patient Protection			
		Protection from Mains Part		Protection from Secondary Circuits	
		One MOPP	Two MOPP	One MOPP	Two MOPP
U < 42.4	U < 60	1500	3000	500	1000
42.4 < U ≤ 71	60 < U ≤ 71	1500	3000	750	1500
71 < U ≤ 184	71 < U ≤ 184	1500	3000	1000	2000
184 < U ≤ 212	184 < U ≤ 212	1500	3000	1000	2000
212 < U ≤ 354	212 < U ≤ 354	1500	4000	1500	3000

The component must pass a dielectric withstand voltage of 6400 V_{RMS} (= 1.6 x 4000 V_{RMS}) to claim 250 V_{RMS} or 354 V_{PEAK} working voltage with 2 MOPP from mains circuits.

5.5 IEC 61010-1

IEC 61010-1 Edition 3 is an international standard that has general safety requirements for electrical equipment for measurement, control, and laboratory use. Creepage and clearance distance requirements for mains circuits of overvoltage category II up to 300 V (RMS or DC) are provided in clause 6.7.2.1 (Table 4 of IEC 61010-1). For voltages above 300 V of overvoltage category II, we'll refer to Table K.2 of the standard. Table 5-4 is the partial representation of Table K.2 of IEC 61010-1.

Table 5-4. Clearances and Creepage Distances for Mains Circuits of Overvoltage Category II above 300 V

Voltage Line-to-Neutral AC RMS or DC	Values for Clearance	Values for Creepage Distance		
		Other Insulating Material		
		Pollution Degree 2		
		Material Group I	Material Group II	Material Group III
V	mm	mm	mm	mm
> 300 ≤ 600	3.0	3.0	4.3	6.0
> 600 ≤ 1000	5.5	5.5	7.2	10.0

Note that the creepage distance values shown in the table above are for basic insulation. For reinforced insulation, the creepage distance values must be doubled. So, based on this table, our semiconductor component example with minimum 8 mm creepage and clearance distances and material group I can claim up to 600 V (RMS or DC) for reinforced insulation and 1000 V (RMS or DC) for basic insulation.

Next, we turn to DTI requirements for solid insulation. Clause 6.7.2.2.2 and Table K.9 of IEC 61010-1 require a minimum DTI of 0.4 mm, 0.6 mm, or 1 mm for RMS or DC working voltages of up to 300 V, 600 V, and 1000 V respectively. So, based on these DTI requirements, it would seem that semiconductor components with

Copyright © 2021 Texas Instruments Incorporated

thin dielectric might not be certified to this standard but what most observers do not realize that clause 14.1a of the standard allows applicable safety requirements of a relevant IEC standard, such as IEC 62368-1, to bypass the minimum DTI requirements of this standard. Since IEC 62368-1 allows thermal cycling and humidity preconditioning tests followed by dielectric test with 60% margin to bypass the minimum DTI requirements, the same is allowed for IEC 61010-1 according to clause 14.1a.

To determine test voltage after thermal cycling and humidity preconditioning tests, we turn to clause 6.7.2.2.1 of the standard for working voltages up to 300 V and Table K.5 for voltages between 300 V and 1000 V for overvoltage category II. Table K.5 of IEC 61010-1 is represented by Table 5-5.

Table 5-5. Test voltages for Solid Insulation in Mains Circuits of Overvoltage Category II above 300 V

Voltage Line-to-Neutral AC RMS or DC (V)	Test voltage			
	5s AC Test (V_{RMS})		Impulse Test (V_{PEAK})	
	Basic and Supplementary Insulation	Reinforced Insulation	Basic and Supplementary Insulation	Reinforced Insulation
> 300 ≤ 600	2210	3510	4000	6400
> 600 ≤ 1000	3310	5400	6000	9600

As already determined, the example device can claim 600-V reinforced insulation and 1000-V basic insulation working voltage based on creepage and clearance distances, thereafter we need to multiply the respective AC test voltage or impulse test voltage of Table 5-5 by 1.6 and then claim the corresponding working voltages if the component passes the test.

6 Conclusion

Even though many international standards specify DTI requirements based on optocoupler and other legacy isolators, these standards have alternate clauses that allow the use of digital isolators with much thinner DTI to pass stringent test criteria based on thermal cycling and humidity tests followed by very high dielectric withstand voltages. Texas Instruments' digital isolators are fully certified by multiple safety agencies, such as VDE, CSA, TUV, CQC, etc., with basic and reinforced ratings. For a complete list of certified isolators from Texas Instruments, see Digital Isolators – Certificates. In summary, thicker DTI is not a prerequisite for digital isolators in safety-critical applications. When it comes to high voltage insulation in safety-critical applications, quality of insulation is as important, if not more, than quantity.

7 References

- IEC 60747-17 Edition 1.0, Semiconductor devices – Part 17: Magnetic and capacitive coupler for basic and reinforced insulation, September 2020
- UL 1577 Edition 5, Standard for Safety - Optical Isolators, April 2014
- IEC 62368-1 Edition 3.0, Audio/video, information and communication technology equipment – Part 1: Safety requirements, October 2018
- IEC 60601-1 Edition 3.0+A1, Medical electrical equipment – Part 1: General requirements for basic safety and essential performance, December 2005 & July 2012
- IEC 61010-1 Edition 3.0+A1, Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements, June 2010 & December 2016
- Texas Instruments, *Enabling high voltage signal isolation quality and reliability* white paper, Tom Bonifield, 017

Copyright © 2021 Texas Instruments Incorporated

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated