

Clearance and Creepage

By David P. Scopelliti
D-Scope-Tech, Inc.

SCOPE:

To discuss and define the terms associated with the safety requirements of Creepage and Clearance along with Pollution Degree and a very brief discussion of Comparative Tracking Index (CTI). The results of several related experiments are also presented to demonstrate the concepts discussed.

DEFINITIONS:

You will need to understand the following general terms as they will be used throughout this paper:

- Dielectric: Insulating material such as plastic or air
- Conductor: Typically the metallic contacts or hardware; anything electrically conductive within close proximity to the connector
- Dielectric Withstanding Voltage (DWV) and Breakdown: The amount of voltage that an insulator can withstand and the amount of voltage that cause an arc through that insulation
- Insulation resistance (IR): Also called Surface Insulation Resistance (SIR) is the amount of resistance to current flow by an insulator primarily along the surface.
- Leakage current: The amount of electrical current flowing through or along an insulator.
- Low Level Contact Resistance (LLCR): The electrical resistance of the interface between two contact elements (plug and receptacle), measured at levels designed not to disrupt the thin film oxides associated with degraded performance.
- Tracking: The electrical breakdown of the surface insulation resistance of an insulator

WHAT IS CLEARANCE AND CREEPAGE AND WHY DO WE CARE ABOUT IT?

These are actually two simple concepts and are product safety terms and requirements for many types of products/assemblies/components. Regulating agencies such as IEC, UL and CSA have very specific product application guidelines and requirements that must be met in order to sell said products in many countries. These standards help to ensure safe operation of the products reducing the risk of electric shock or other injuries to the end users as well as reducing fire hazards. These standards are also designed to protect other components in close proximity to those being rated/tested to help avoid propagation of a failure throughout a system. Most of what we will discuss in this paper will be related to electrical connectors, printed wiring boards/printed circuit boards (PWB or PCB) and cable assemblies.

NOTE: To keep this document simple, manageable and concise we will not be discussing the individual standards and specification requirements directly since there are many variables and individual requirements for each specific application.

WHAT IS CLEARANCE?

Clearance is the distance between two electrical conductors *through the air*. In the simplest terms it is the distance a spark has to travel, like in a Dielectric Withstanding Voltage (DWV) Breakdown test.

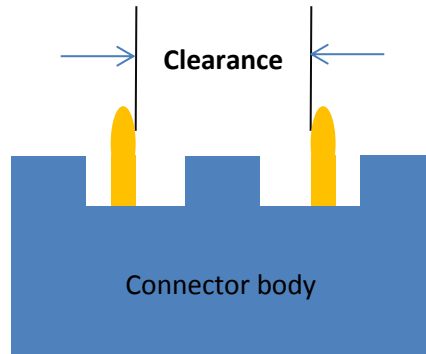


Figure 1

Typical connector body and contacts demonstrating the Clearance distance

WHAT IS CREEPAGE?

Creepage is the linear distance along all of the insulating surfaces between two electrical conductors. As far as electrical measurements are concerned the result of this parameter is basically the equivalent of a Surface insulation resistance measurement (SIR or IR). Notice that since this is the total surface distance between the conductors, it is considerably longer than the Clearance distance of the same contacts.

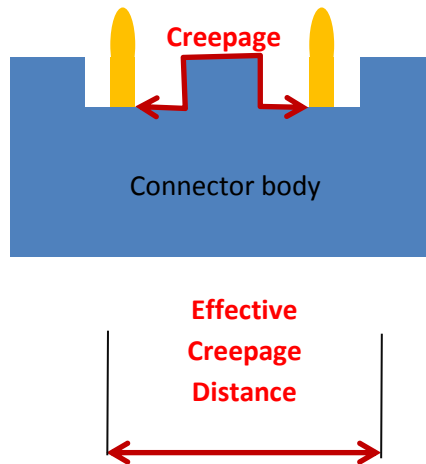


Figure 2

Typical connector body and contacts demonstrating the Creepage distance

WHY DO WE HAVE TWO DIFFERENT REQUIREMENTS AND WHAT IS THE DISTINCTION?

So our Clearance distance determines how much voltage will cause an arc. Creepage distance comes into play after the arc occurs. When an electric arc happens over an insulating surface, it is possible that a carbon trace will be left behind on the surface over which the arc occurred. Carbon is much more electrically conductive than the insulating materials under discussion. This arc and the resulting carbonization essentially degrade the SIR reducing the isolation between the associated conductors and increasing the leakage current. This also shortens the equivalent electrical length and makes the product more susceptible to subsequent arcing thus lowering the breakdown voltage.

NOTE: The fuzzy grey lines in the following figures represent carbonization of the surface as a result of an electrical arc.



Figure 3

The arc occurs in the left image, but on the right, even after the arc is gone, the damage remains

Here are equivalent PWB examples with the addition of a cutout in the board:

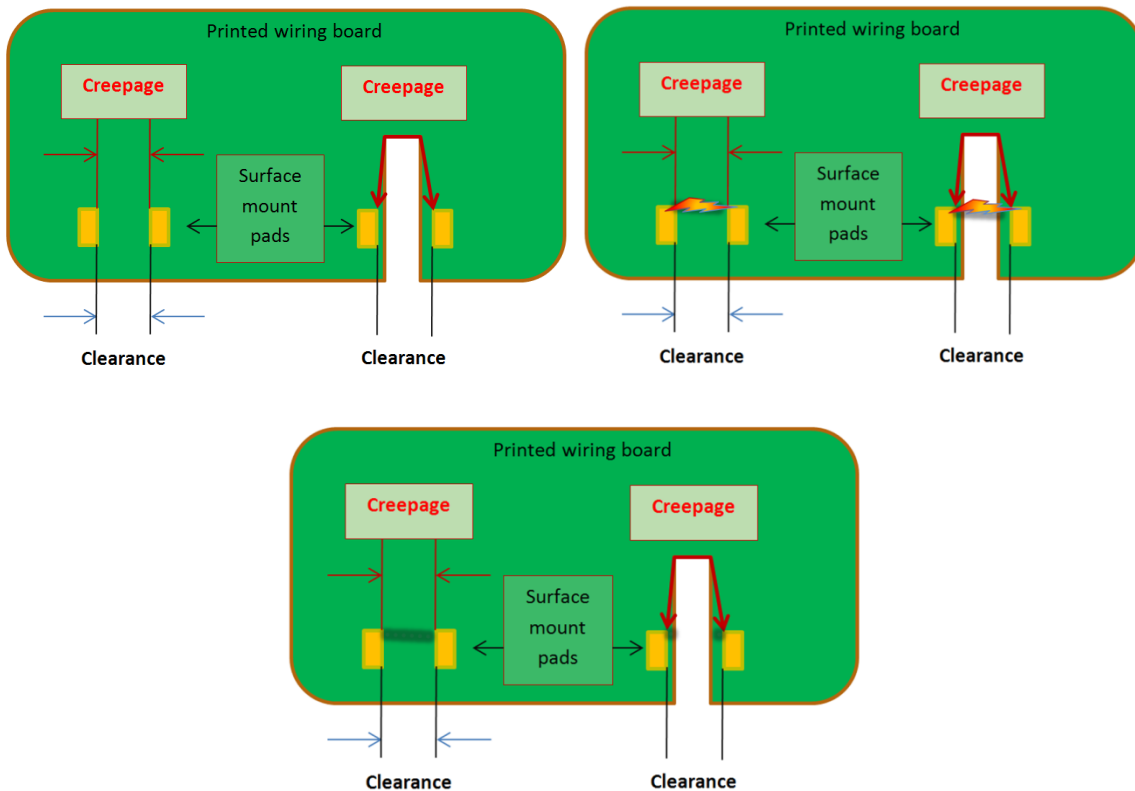


Figure 4

In the Figure 4, PCB examples the difference in physical features (the cutout between the pads) demonstrates the concept of a product exhibiting equal Clearance distance, but vastly different Creepage distance all based on the geometry of the product. You can see that the carbon trace continues between the two adjacent pads on the left, but the carbon trace is incomplete because of the cutout on the right side of the board.

Here is an example of how an arc and the associated carbon trace can degrade insulation resistance and withstanding voltage:

Test Steps (NOTE: Test setup is shown in Figure 6; IR equipment limit 45,000 MΩ):

1. Initial IR @ 500 VDC was measured in accordance with EIA-364-21. Result: >45,000 MΩ (>45.0 GΩ)
2. Initial Dielectric Breakdown Voltage was performed in accordance with EIA-364-20. Result: 1161 VAC
3. The evidence of the breakdown occurred between the pads shown in Figure 5 in the red oval, leaving the carbon path shown.
4. Final IR @ 500 VDC was measured in accordance with EIA-364-21. Result: 40 MΩ (0.040 GΩ)
5. Final Dielectric Breakdown Voltage was performed in accordance with EIA-364-20. Result: 609 VAC
6. Microscopic photos were taken.

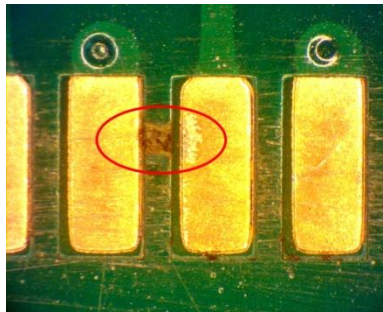


Figure 5

After arcing as a result of the Voltage Breakdown test the carbon trace highlighted above was left.

Following is a summary of the data observed:

CLEARANCE TEST RESULTS		
<u>Test Step</u>	<u>IR (MΩ)</u>	<u>DWV (VAC)</u>
Initial	>45,000	1161
Final	40	609

Table 1

As shown in Table 1 the IR decreased by a factor of 1000 and the DWV breakdown decreased to almost half of what it was originally.

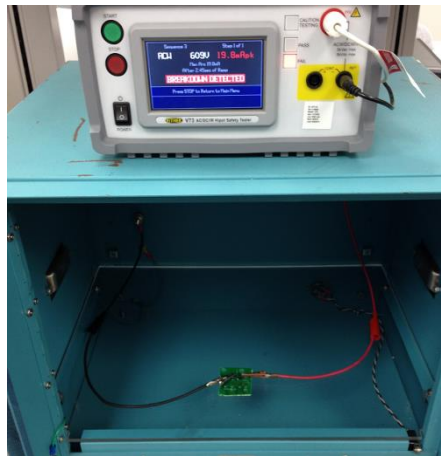


Figure 6

IR/DWV test setup; performed with Vitrek V73 AC/DC/IR Hipot Safety Tester

You can see that the DWV breakdown decreased from 1161 VAC down to 734 VAC after being contaminated with carbon.

POLLUTION DEGREE

So what about *Pollution Degree* ... how does Pollution degree come into play?

Pollution degree is an application specific parameter that takes into account how pollutants will affect products exposed to different environments from a high voltage/safety standpoint.

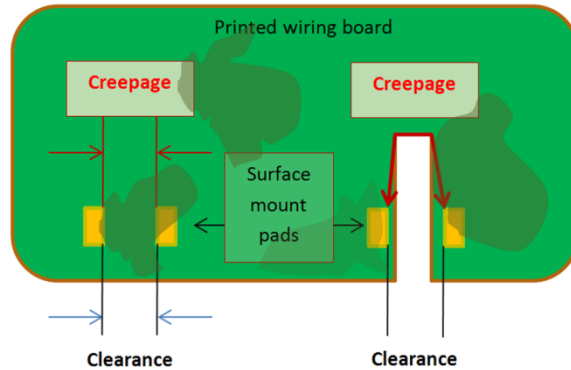


Figure 7

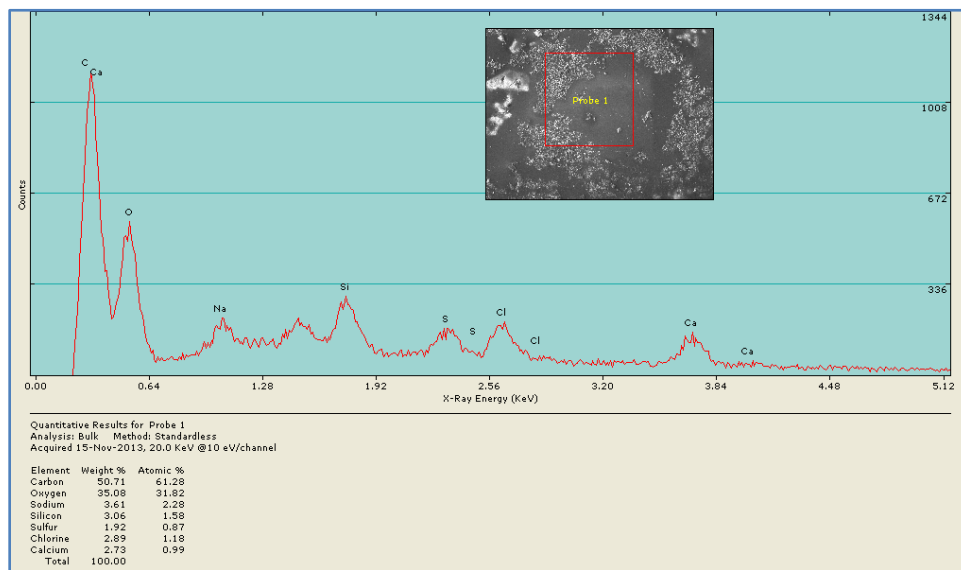
PCB with pollution contamination indicated

A pollution degree rating of 1 means that there will be maximum protection (such as conformal coating) against contamination while pollution degree 3 means that there will be no protection against such contamination.

Here is an example of how pollution can degrade insulation resistance and withstanding voltage (Pollution Degree 3):

Test Steps (NOTE: No Initial Breakdown was performed since this would have nullified the IR measurements):

1. Initial IR @ 500 VDC was measured in accordance with EIA-364-21. Result: >45,000 M Ω (>45.0 G Ω)
2. The test board was contaminated with an "artificial pollution" mixture (suspension in tap water) as shown in the Scanning Electron Microscope/Energy Dispersive X-ray Spectrum (SEM/EDX) below:



3. The test board was subjected to a one hour air dry period at ambient temperature.
4. IR @ 500 VDC was measured in accordance with EIA-364-21. Result: 158 MΩ (0.158 GΩ)
5. The test board was subjected to an oven dry at +105°C
6. IR @ 500 VDC was measured in accordance with EIA-364-21. Result: 45,000 MΩ (45.0 GΩ)
7. The test board was swabbed with a damp cotton swab moistened with tap water
8. IR @ 500 VDC was measured in accordance with EIA-364-21. Result: 1.55 MΩ (0.00155 GΩ)
9. The test board was subjected to a one hour air dry period at ambient temperature.
10. IR @ 500 VDC was measured in accordance with EIA-364-21. Result: 45,000 MΩ (45.0 GΩ)
11. Final Dielectric Breakdown Voltage was performed in accordance with EIA-364-20. Result: 863 VAC
12. Microscopic photos were taken.

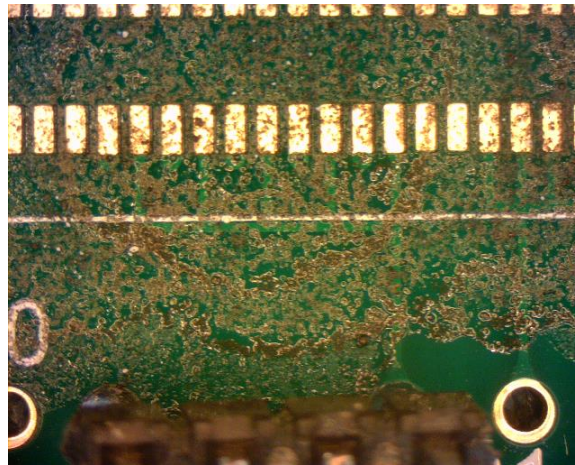


Figure 8
Pollutant contaminated board

Following is a summary of the data observed:

POLLUTION TEST RESULTS		
<u>Test Step</u>	<u>IR (MΩ)</u>	<u>DWV (VAC)</u>
Initial	>45,000	1161 (Previous sample)
Air dry	158	
+105°C dry	45,000	
Humidified	1.55	
Air dry	45,000	863

COMPARATIVE TRACKING INDEX (CTI)

- Yet another assembly/application specific requirement to assess the surface characteristics of insulating materials.
- Each dielectric material is rated with a certain CTI via an interesting rating system.
- The CTI is established by applying a high voltage and then dropping 50 drops of a mild ammonium chloride solution and assessing when tracking has occurred.
- The CTI test method is specified in IEC standard 60112

INDUSTRY STANDARDS AND SPECIFICATIONS

Following is a brief look into the industry standards governing these parameters.

The following is an excerpt from the Clearance section of many of the related industry standards (from *IEC 62368-1, Audio-video, Information and Communication Technology Equipment*) that illustrates clearance requirements in the range most likely encountered in telecommunications and most consumer applications:

Peak working voltage	Basic insulation or supplementary insulation			Reinforced insulation		
	mm			mm		
V peak or d.c. up to and including	Pollution degree			Pollution degree		
	1 ^a	2	3	1 ^a	2	3
330	0,01	0,2	0,8	0,04	0,6	1,5
400	0,02			0,074		
500	0,04			0,13		
600	0,06			0,234		
800	0,13			0,76	0,76	
1 000	0,26	0,26				
1 200	0,42			1,19		
1 500	0,76			1,8		1,8
2 000	1,27			2,8		

The following is an excerpt from the Creepage section of *IEC 62368-1, Audio-video, Information and Communication Technology Equipment*, that illustrates those requirements in the range most likely encountered in telecommunications and most consumer applications:

RMS working voltage up to and including V	Pollution degree						
	1 ^a	2			3		
	Material group						
	I, II, IIIa, IIIb	I	II	IIIa, IIIb	I	II	IIIa, IIIb see Note
10	0,08	0,4	0,4	0,4	1,0	1,0	1,0
12,5	0,09	0,42	0,42	0,42	1,05	1,05	1,05
16	0,1	0,45	0,45	0,45	1,1	1,1	1,1
20	0,11	0,48	0,48	0,48	1,2	1,2	1,2
25	0,125	0,5	0,5	0,5	1,25	1,25	1,25
32	0,14	0,53	0,53	0,53	1,3	1,3	1,3
40	0,16	0,56	0,8	1,1	1,4	1,6	1,8
50	0,18	0,6	0,85	1,2	1,5	1,7	1,9
63	0,2	0,63	0,9	1,25	1,6	1,8	2,0
80	0,22	0,67	0,95	1,3	1,7	1,9	2,1
100	0,25	0,71	1,0	1,4	1,8	2,0	2,2
125	0,28	0,75	1,05	1,5	1,9	2,1	2,4
160	0,32	0,8	1,1	1,6	2,0	2,2	2,5
200	0,42	1,0	1,4	2,0	2,5	2,8	3,2

REFERENCES

1. *IEC 62368-1, Audio-video, information and communication technology equipment*, International Electro technical Commission, Geneva, Switzerland.
2. *UL 60950-1, Information Technology Equipment – Safety – Part1: General Requirements*, Underwriters Laboratories, USA
3. *UL 840, Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment*, Underwriters Laboratory, USA

MORE INFORMATION

Here is a link to a very nice online calculator that is published by Dave Lorusso, Lorusso Compliance Services, LLC:

<http://www.creepage.com/>

The following document is an excellent comparison of the old vs. new standard and requirements:

<http://www.ecma-international.org/publications/files/ECMA-TR/TR-106.pdf>

Here are a few more links that give some different perspectives on the subject:

<http://electronics.stackexchange.com/questions/22796/creepage-distance-for-pcbs-handling-line-voltage-ac>

<http://www.pcbtechguide.com/2009/02/creepage-vs-clearance.html>

<http://www.intertek.com/blog/2011/07-04-iec-60601-1/>