

High Voltage Spacing

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Introduction

How much spacing is needed in high voltage circuits and setups? The general guideline in common use is to allow 7,500 to 10,000 volts, dc per inch in air. When dealing with ac, the general guideline is to multiply the rms voltage by three to determine the spacing that's required. However, there are techniques to reduce the spacing for both dc and ac. In addition, there are requirements from UL, IEC, and IPC to consider when designing products.

Spacing Concerns

When evaluating spacing, both clearance and creepage distances need to be addressed. Clearance is the shortest distance between two conductive parts, or between a conductive part and ground, measured through air or other insulating medium. Creepage distance is the shortest distance separating two conductors as measured along the surface touching both conductors.

The general guideline of 7,500 to 10,000 volts per inch is affected by the shapes of the conductors. Sharp points will require greater spacing, and large radii surfaces will require less spacing.

Arcs or flashover can occur along the surface of some materials at distances much shorter than the flashover distance in air. Therefore, it is extremely important in high voltage designs to look for places where creepage can occur.

Factors that affect breakdown voltage besides conductor shape include surface characteristics of insulators and the altitude. If agency approval is needed, there are more rigorous requirements to be addressed. When designing for compliance, additional parameters that must be taken into account include "pollution degree," "overvoltage category" and "comparative tracking index" (a measure of resistance to surface tracking). For further information on compliance issues, see the articles and industry standards referenced below.

Improvements

To increase breakdown voltage, the first item to check is the conductor shapes. Although most engineers know that sharp points need to be eliminated, it's worth a careful look to be sure that the conductor geometry is good. End caps of some components and edges of PCB traces can be particularly troublesome. Large radii can be achieved with the addition of metallic balls and toroid rings.

Whether operating in air or in an insulating material, spacing can be reduced by addressing the geometry of the conductors, and the electric field gradients. Software is available to analyze the electric field. These analyses can lead to ways to further improve the voltage capability of an assembly.

Creepage distances can be increased when conductors cannot be moved by using judiciously placed holes and by using material convolutions. Both creepage and clearance can be improved by encapsulation. Encapsulation can reduce spacing requirements to hundreds of kV/inch, which is more than an order of magnitude better than unencapsulated parts. Of critical importance is obtaining good adhesion. In fact without good adhesion and if conditions are right, breakdown can occur at voltages lower than in air. Other approaches include the use of oil and other insulating liquids and gasses. Examples include transformer oil, silicone oil and sulphur hexafluoride gas.

Whether building up a surface to add convolutions, or when using any type of encapsulation, it is generally a good idea to have a continuous, homogeneous insulation system. Under certain conditions, multiple insulation types in series can work, however, it is more difficult to achieve a reliable design. It is also important to keep insulator surfaces clean and dry, since moisture, flux and finger prints can degrade the voltage capability of surfaces.

Conclusion

Substantial spacing is required for high voltage assemblies and test setups. However, the spacing can be reduced by addressing the geometry and insulation method. For further information, please contact me (see below).

This article is for general information only. It is not intended to be used as definitive or official material. For design and practice of high voltage, see industry reference documents, including those from UL and IEC.

Industry Standards

IPC-2221A, Generic Standard on Printed Board Design, addresses spacing in sections 6.3 and 10.1.4, along with table 6-1.

UL 61010A-1, Electrical Equipment For Laboratory Use; Part 1: General Requirements

UL 61010B-1, Electrical Equipment For Measurement, Control, and Laboratory Use; Part 1: General Requirements. See Annex C - Measurement of CLEARANCES and CREEPAGE DISTANCES, Annex D - Parts between which insulation requirements are specified (see 6.4 and 6.5.2)

UL 60950, Safety of Information Technology Equipment

NFPA 70 - National Electrical Code®. An old, obsolete version for reference is available online at <http://www.nfpa.org/PDF/A445-490.pdf?src=necdigest>. See pages 774-775, table 490-24

For Further Reading

General article on spacing and IEC requirements:

The Evaluation of Spacings in Electronic Product Design, M. A. Lamothe. Compliance Engineering, 2001 Reference Guide.

<http://www.ce-mag.com/archive/01/Spring/Lamothe.html>

(Click [link#1](#) for this article.)

Another good general article:

Product Safety Requirements for Laboratory Equipment, Steve Conlon, Conformity 2004: The Annual Guide. <http://www.conformity.com/A04F12.pdf>

How to measure creepage distances:

Clearance and Creepage Distance Measurement, Moe Lamothe.

<http://www.lamothe-approvals.com/Articles/clearancecreepage measurement.htm>

(Click [link#2](#) for this article.)

How to compare voltage and safety ratings of electronic instruments:

Isolation and Safety Standards for Electronic Instruments,

[http://zone.ni.com/devzone/conceptd.nsf/webmain/6D1C1BE6590C0D4A86256C1A0078763C/\\$File/WP1457.pdf](http://zone.ni.com/devzone/conceptd.nsf/webmain/6D1C1BE6590C0D4A86256C1A0078763C/$File/WP1457.pdf)

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