Electrical Conductor Spacing Standards for Printed Circuit Boards

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Exponent consultants routinely investigate printed circuit board (PCB) failures, and one particular failure mode routinely encountered is the formation of conductive paths between electrical components or traces. Such paths are often enabled by placing elements on a printed circuit board too close to one another. The two most important spacing distances are the shortest distance through air between any two conductors (clearance distance), and the linear distance traveled over the surface of the PCB between any two conductors (creepage distance). Both of these distances are determined by the voltage used on the PCB. Proper selection of electrical conductor spacing on printed circuit boards is important not only for proper circuit operation, but also for preventing electrical breakdown of insulating materials between conductors, which can result in the failure of a PCB.

A breakdown along a clearance path occurs through the air (similar in concept to a “carpet shock”) and is a fast phenomenon, in which damage is often caused by a very short-duration impulse. Therefore, the required clearance spacing is determined using the expected maximum peak voltage, including transients, in circuits. In contrast, a breakdown along a creepage distance is occurs as a result of tracking (the electrical breakdown on the surface of an insulating material), which is a slow phenomenon and depends on DC or root-mean-square (rms) voltage levels rather than peak voltage. A circuit with inadequate creepage distances may last for days, weeks, or months before it fails.1 Creepage distances are therefore important to the conductor spacings on a PCB, because the conductors on its outer layer are separated by the surface of the PCB, as opposed to being separated by air, and because creepage breakdowns typically occur over smaller distances than those associated with clearance breakdowns.

Established minimum creepage distances are based on extensive studies of materials in specified conditions. For example, Day and Stonard studied the influence of insulation material and contamination on tracking and flashover in 1977.11 The results of the study showed that tracking resistance (i.e. the ability to mitigate tracking) increases with creepage distance, decreases with voltage, and depends on the material characteristics of the insulating medium.
In the early 1980s, several research projects related to insulation coordination were conducted by a study group that included 27 German and 9 U.S. manufacturers. The main objective of the set of projects was to study the effects of environmental pollution on insulating materials and to improve the dimensioning rules for creepage and clearance distances. The study produced the new dimensioning rules shown in Figure 1, categorized by pollution degree and material group.

![Figure 1](image_url)

**Figure 1.** Proposal for creepage and clearance distances based on rated impulse voltage

The influences of humidity, corrosive atmosphere, and dust deposition on insulation resistance were documented in another study of more than 30,000 insulators. The author proposed dimensioning rules for clearance and creepage distances categorized by four micro-environment categories:

- Category 1 includes insulators that are always kept clean and dry in an environment with less than 75% relative humidity and no salt-containing dust
- Category 2 also includes insulators in an environment with less than 75% relative humidity but where deposition of salt-containing dust is expected
- Category 3 includes insulators in an environment that is weather protected but is subjected to circulating outdoor air, and consequently, can be exposed to relative humidity as high as 95% for up to 100 hrs/year
- Category 4 includes insulators that are not weather protected.

<table>
<thead>
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<th>No.</th>
<th>Pollution Degree</th>
<th>Material Group</th>
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<td>I-IIIb</td>
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<td>4</td>
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<td>5</td>
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<td>IIIa</td>
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<td>6</td>
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Other researchers have conducted similar research to investigate factors affecting insulation coordination and have proposed creepage and clearance distances. In 1995, Maeda et al. examined the creepage breakdown characteristics of printed wiring boards in silicone gel and presented an experimental equation to calculate breakdown voltage based on creepage distance, intrinsic capacity, relative permittivity, insulation layer thickness, and electrode location.\textsuperscript{vi} In 1997, Yamada et al. investigated AC creepage breakdown and impulse creepage flashover voltages on printed wiring boards in four different experimental environments.\textsuperscript{vii} In 2004, Du et al. investigated the effects of temperature, pressure, signal frequency, and electric stress (voltage per unit length) on dielectric breakdown and discharge energy on printed circuit board.\textsuperscript{viii}

The results of research on creepage and clearance were eventually incorporated into standards, including Underwriters Laboratories (UL) 840, which is one to consider when designing PCBs to meet clearance and creepage distance requirements.

UL 840 is a standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment. In addition to defining clearance and creepage distances, UL 840 also accounts for the amount of contamination to which the electronics might be exposed (Degree of Pollution), as well as the material properties of the insulating medium between conductors (Material Group). UL 840 defines the various degrees of pollution as follows.\textsuperscript{ix}

- Pollution Degree 1 — No pollution, or only dry, nonconductive pollution. The pollution has no influence.
- Pollution Degree 2 — Normally, only nonconductive pollution. However, a temporary conductivity caused by condensation can be expected.
- Pollution Degree 3 — Conductive pollution, or dry, nonconductive pollution that becomes conductive due to condensation that is expected.
- Pollution Degree 4 — Pollution that generates persistent conductivity through conductive dust or rain and snow.

UL 840 defines the materials groups based on the Comparative Tracking Index (CTI), which is determined in accordance with International Electrotechnical Commission (IEC) 60112 (or UL 746, ASTM D 3638). CTI is a voltage that enables tracking after 50 drops of ammonium chloride solution have fallen on the material. Tracking is an electrical breakdown on the surface of an insulating material that occurs when a voltage difference gradually creates a conductive leakage path across the surface of the material by forming a carbonized track.\textsuperscript{ix}
The standards on creepage and clearance distances vary among industries and equipment applications. Although UL-840 provides general guidance, other standards may be applicable based on a particular application. For example, UL 61010-1 is an electrical equipment standard for measurement, and UL 2735 is a standard for smart meters. Both have requirements for clearance and creepage distances.

The reliability of printed circuit boards used in electronics depends strongly on the design decisions regarding clearance and creepage distances. Several research studies and industry standards provide guidance regarding the selection of appropriate clearance and creepage distances, depending on the device voltage rating, materials used, and degree of pollution. Exponent has broad experience with creepage standards and has helped clients understand how inappropriate creepage distances produce device failures after extended periods of operation in various pollution environments.

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References


