Power Supply Design Seminar

Demystifying Clearance and Creepage Distance for High-Voltage End Equipment

TEXAS INSTRUMENTS

Reproduced from
2024 Texas Instruments Power Supply Design Seminar
SEM2600
Topic 2
Wei Zhang and Thomas LaBella
Literature Number: SLUP419

Achieving the highest possible power density while still maintaining safety and design guidelines requires more careful high-voltage printed circuit board (PCB) spacing and integrated circuit (IC) package selection. This topic summarizes the considerations and provides a cheat sheet for popular end equipment, including telecommunication, server and wireless infrastructures; motor drives, solar inverters and charging piles; consumer AC/DC applications; and electric vehicles and hybrid electric vehicles.

Introduction

High-voltage PCB spacing and IC package selection are increasingly important to achieve the highest possible power density while still complying with safety and design guidelines. Challenges come from multiple angles, however. As a designer, you must understand:

- Many technical terms, as well as their impact on creepage and clearance.
- The distinction between a normal operating transient voltage and a nonrecurring transient voltage.
- The impact of the equipment's location relative to the primary-side energy source.
- Multiple industry standards addressing creepage, clearance and PCB spacing, where some standards are complimentary, some are redundant and some are conflicting.
- Different industry standards for different end-equipment types.
- Scenarios of safety isolation from the International Electrotechnical Commission (IEC), Underwriters Laboratories (UL) or Deutsche Institut für Normung (DIN) Verband der Elektrotechnik (VDE) to protect human safety vs. functional isolation to maintain proper operation.
- Other considerations such as use-case altitude, pollution degree, IC material group, PCB conformal coating, PCB cutouts and routine transient tests.

In this paper, we will introduce technical terms with their physical meanings, and explain the relationships to and influences on creepage and clearance. We will then provide guidelines and a flowchart with step-by-step instructions to determine proper creepage and clearance with a structured methodology.

Definitions

Creepage and Clearance

Creepage is the shortest distance along the surface of a solid insulation material between two conductive parts, as shown in **Figure 1**. This distance is dimensioned for a pollution degree, material group and working voltage, which is the highest root-mean-square (RMS) voltage to which the insulating material may be subjected. It is defined to ensure that no flashover or breakdown of insulation will occur. Besides working voltage, the factors that most affect creepage are pollution, humidity and condensation.

Clearance is the shortest distance in air between two conductive parts, as shown in **Figure 2**. This distance is dimensioned in order to prevent air ionization or arcing during any required transient overvoltage. The factors that matter the most for clearance are air pressure (altitude) and pollution. There is a multiplication factor for altitudes greater than 2,000 m, which we will cover in **Methodology to Determine Creepage, Clearance and High-Voltage PCB Spacing Requirements**.

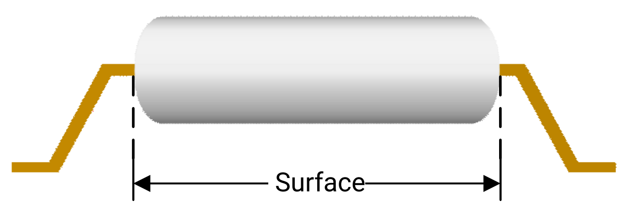


Figure 1. *Creepage.*

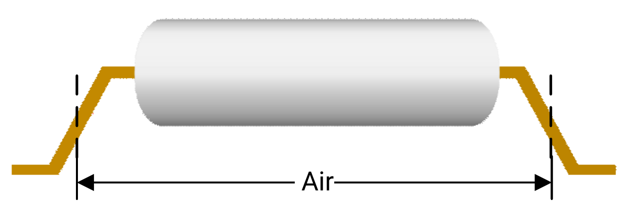


Figure 2. *Clearance.*

Creepage handles long-term steady-state working voltages, while clearance handles short-term transients that are a few milliseconds or less. There is no physical relationship between the two, but the creepage distance cannot be less than the clearance distance. It is important to maximize both creepage and clearance whenever possible while considering the trade-offs of size and cost.

It is also important to note that in some cases where the corner pins are close to the edge of the package, the shortest creepage distance can be across the side instead of the top or bottom, as illustrated in Figure 3.

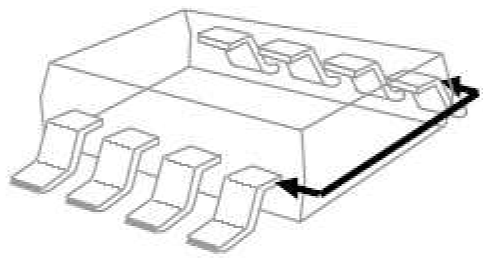


Figure 3. Example where the shortest creepage distance is across the side rather than the top.

It is also possible for creepage and clearance to be the same. In Figure 4, for example, depopulating the middle pins of the UCC21551-Q1 dual-channel isolated gate driver increases the creepage and clearance.

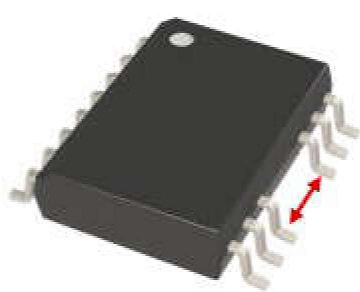


Figure 4. Functional isolation example where creepage and clearance are the same.

Material Group and Comparative Tracking Index

The comparative tracking index (CTI) categorizes insulating materials based on the voltage at which electrical breakdown occurs. The CTI rating is determined by a test that applies a voltage to a material on which there are 50 drops of water, contaminated with 0.1% ammonium chloride. The CTI rating is the maximum voltage that the material can withstand during this test where there is less than 0.5 A of tracking current flowing [1]. Table 1 shows the categories of insulating materials based on the CTI. These material groups can help you determine the required creepage distance for a given insulation requirement, as discussed in **Methodology to Determine Creepage, Clearance and High-Voltage PCB Spacing Requirements**.

Material group	CTI range (V_{RMS})
I	600 ≤ CTI
II	400 ≤ CTI < 600
IIIa	175 ≤ CTI < 400
IIIb	100 ≤ CTI < 175 Or if not specified

Table 1. Material groups based on the CTI.

Most FR4 materials used in PCB fabrication are rated for material group IIIa. All Texas Instruments isolation products are material group I in order to help reduce the package size and PCB footprint required.

Pollution Degree

The next important parameter for determining required creepage and clearance distances is the pollution degree. Pollution degree environments are classified into four categories [2]:

- Pollution degree 1: There is no pollution, or only dry, nonconductive pollution. These systems are sealed to exclude dust and moisture, or the PCB uses conformal coating so that components will not be subject to humidity- or temperature-related condensation.
- Pollution degree 2: The environment can temporarily become conductive from occasional condensation. Common examples of environments classified by pollution degree 2 are labs, offices and enclosures for servers, telecommunications equipment and wireless infrastructures.

- Pollution degree 3: The environment is subject to conductive pollution, or nonconductive pollution that can become conductive from expected condensation. Common examples are industrial applications, farming equipment and unheated factory rooms.
- Pollution degree 4: Continuous conductivity occurs from conductive dust, rain or other wet conditions. This is common for outdoor applications.

Transient Overvoltage Category

Another factor used in determining the required clearance is the transient overvoltage category, which categorizes equipment based on where it is connected relative to the mains voltage. This voltage level is not categorized by math, but rather by a probabilistic implication based on the equipment's location.

Figure 5 is a diagram of a residential building with examples of locations labeled for different transient overvoltage categories. The four categories are [3]:

- Category I: This lowest category is for circuits connected in a way that takes measures to limit overvoltage transients. Examples include equipment such as 24-V_{AC} thermostats and sprinkler systems connected to the mains through a step-down transformer.
- Category II: This category is for equipment supplied from a fixed installation. Examples include equipment plugged into an outlet that is 10 m away from category III.
- Category III: This is for equipment with a fixed installation subject to special requirements. Examples include equipment permanently connected such as switches within a fuse panel, air conditioners or industrial machinery hardwired to the AC mains.
- Category IV: This is for equipment used at the origin of installation, which means connected directly to the mains voltage. Examples include electricity meters, distribution panels and utility transformers.

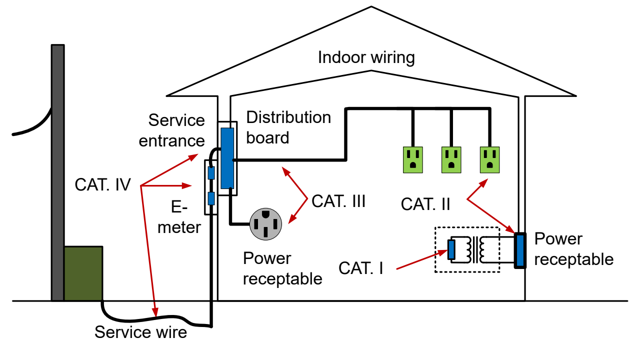


Figure 5. *Example transient overvoltage categories.*

Standards Pertaining to Creepage, Clearance and PCB Spacing

There are numerous standards relating to creepage and clearance. Some of these are complementary, some are contradictory, and many are redundant. There is no one standard where you can just use an equation or lookup table to figure out the required creepage and clearance.

In this section, we will introduce the various standards, and explain when and how to use them in **Methodology to Determine Creepage, Clearance and High-Voltage PCB Spacing Requirements**. But first, let's separate the standards into two categories: those relating to user safety in an insulation system, and those relating to PCBs.

The foundational standard for user safety in an insulation system is IEC 60664-1, which applies to systems up to 1.5 kV_{DC} or 1 kV_{AC}. IEC 60664-1 covers creepage, clearance and electric strength testing. There are several other standards specific to certain end equipment that build on IEC 60664-1 but add more specific guidelines. These include IEC 62368-1 and IEC 60950-1 for telecommunications, servers, audio and video, and cloud computing [4], [5]; IEC 61800-5 for motor drivers [6]; and IEC 62109-1 for solar [7].

The standards for PCB spacing address proper or functional operation only and do not address user safety. The primary standard is Institute for Printed Circuits (IPC)-2221B, which is a general standard that covers generic requirements [8]. Another common standard addressing PCB spacing is IPC-9592B, which builds on

IPC-2221B but adds specific guidelines for the computer and telecommunications industries [9]. IPC-9592B is a little stricter than IPC-2221B. Furthermore, IEC 62368-1 also provides guidelines for both coated and uncoated PCBs for telecommunications, servers, audio and video, and cloud computing.

Insulation Standards

There are various insulation standards for isolators that verify an insulation barrier's ability to withstand electrical, mechanical and thermal stresses as well as environmental influences. These include DIN VDE V 0884-11 for the European Union, UL 1577 for the United States and China Quality Certification (CQC) GB4943.1 for China [10-12]. The parameters addressed in these certification standards describe the insulation barrier, and do not directly relate to creepage and clearance. What does matter for creepage and clearance are the isolation grades, such as basic, reinforced and functional.

Isolation Grades and Guidelines

There are five types of isolation grades [13]:

- Functional isolation is just for proper circuit operation in the presence of things such as ground bounce, high operating voltages and transients between secondary circuits (not the primary mains). Functional isolation is not related to user safety.
- Basic isolation is a single level of isolation that protects users against electric shock under both normal and abnormal operating conditions.
- Supplementary isolation is an additional layer of isolation protection to address single-fault conditions. If the first layer of isolation fails, a supplementary one will protect users against electric shock.
- Double isolation is a combination of basic and supplementary isolation.
- Reinforced isolation provides the same ratings and protection as double isolation, but is implemented in a single layer of insulation material.

The two types of isolation that are most common in practice and addressed by the isolation standards introduced in Insulation Standards are basic and reinforced. Any required creepage and clearance distances depend on whether the design requires basic or reinforced isolation.

IEC 60664-1, IEC 62368-1 and IEC 60950-1 all provide guidelines to help determine whether an application requires basic or reinforced isolation. In these guidelines, the terms "ordinary person" and "user" are used interchangeably. The standards also use different terminology to classify different voltage levels, but it is possible to simplify the terminology into three energy-source classes depending on their voltage:

- Energy source class 1 (ES1) consists of circuits with a voltage up to 60 V. These circuits are safe to touch and no isolation is needed from users. IEC 60950-1 defines this voltage class as safety extra low voltage (SELV). This class includes circuits in telecommunications network voltage class one (TNV-1), as defined by IEC 60950-1.
- ES2 includes circuits with voltages between 60 V and 120 V. These require basic isolation between the circuit and user. These include circuits in the TNV-2 and TNV-3 classes, as defined by IEC 60950-1.
- ES3 includes circuits with voltages above 120 V. These voltages are considered hazardous and require reinforced isolation between the circuit and user.

Figure 2H in IEC 60950-1 offers a very comprehensive guide to determine the required isolation levels between different circuits. The figure shows when functional, basic or reinforced isolation is required between primary circuits; earthed/unearthed SELV; earthed/unearthed TNV-1, 2 or 3; and earthed/unearthed hazardous voltages. Connecting a circuit to earth ground will often reduce the isolation level required. Table 2 is a simplified summary of Figure 2H in IEC 60950-1, along with common examples.

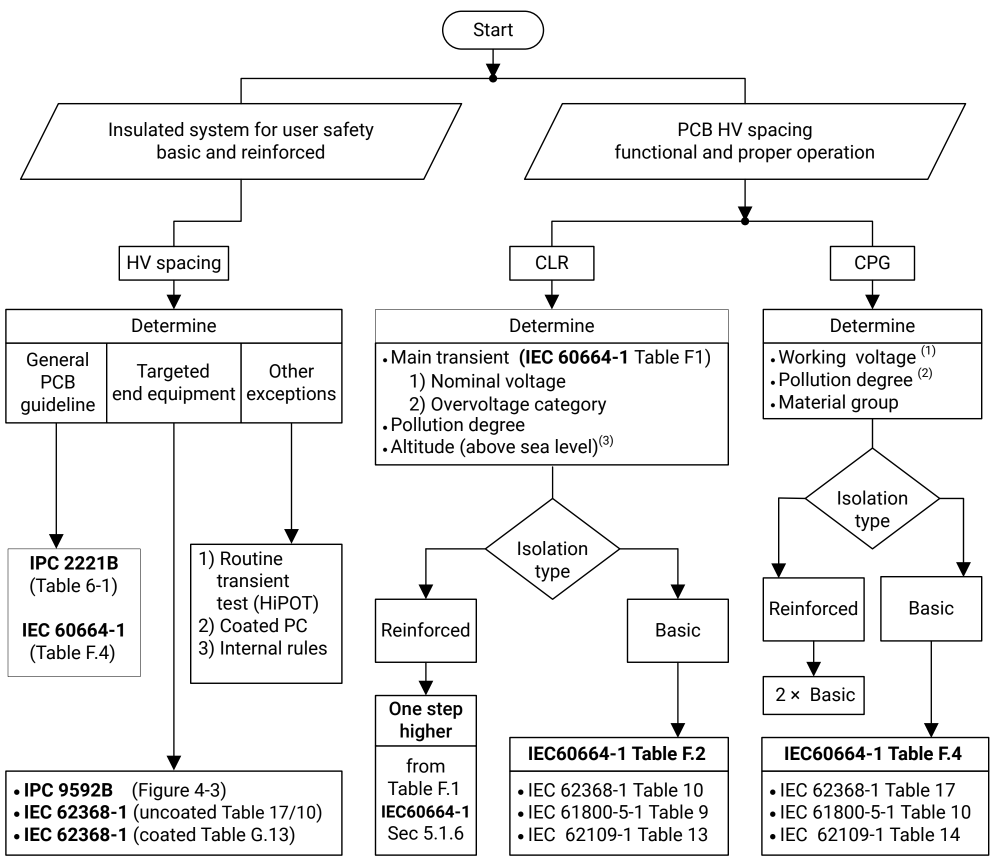
Isolation grade	Parts being separated		Example
Functional	SELV	SELV	<60-V brick module
	Reinforced circuit		
Basic	Primary, ES2, TNV-2, TNV-3, hazardous	Earthed SELV	• >60-V DC/DC. • AC/DC rectifiers with 12-V or 48-V output. • 400-V onboard charger.
	Primary	Unearthed hazardous	
Reinforced	Primary, hazardous	Unearthed SELV	AC/DC rectifiers with 12-V or 48-V output
	ES2, TNV-2, TNV-3		>60-V DC/DC

Table 2. *Examples of isolation grades required for common applications.*

Methodology to Determine Creepage, Clearance and High-Voltage PCB Spacing Requirements

Flowchart

We have introduced several definitions, classifications, ratings, standards and complex guidelines. Now, in order to simplify and expedite the development process, we put it all together into a single flowchart (see **Figure 6**) with step-by-step instructions to determine the proper creepage and clearance for an application.



(1) Working voltage: highest r.m.s. value of the a.c. or d.c. voltage across insulation, **IEC 60664-1** section 3.5
(2) Coat PCB can help reduce to pollution degree (A) per **IEC 62109-1** follow **IEC 60664-3**, or
(B) **IEC62368** reduce the CPG distance using Table G.13
(3) For **Altitude > 2000m**, use correction factor from **IEC60664-1** Table A.2

Figure 6. *Flowchart for determining the required creepage and clearance for an application.*

The flowchart has two main paths: one for insulated systems for user safety and one for PCB spacing. The path for user safety has two subpaths: one for determining creepage and one for clearance.

Let's explain how to use this flowchart to determine creepage for user safety, clearance for user safety, and high-voltage spacing for PCBs.

Determining Creepage in Insulated Systems for User Safety

For creepage, you need to know the working voltage of the application, the material group of the insulating material, and the pollution degree of the environment. The next step is to determine whether you need basic or reinforced isolation using Figure 2H in IEC 60950-1. If you need basic isolation, use the creepage distance value determined by the next step. If you need reinforced isolation, double the distance determined in the next step.

Based on your end equipment, look up the required creepage distance; for general-purpose end equipment, use Table F.4 in IEC 60664-1. For audio, video, and information and telecommunications equipment, use Table 17 in IEC 62368-1. For motor drives, use Table 10 in IEC 61800-5-1. For solar applications, use Table 14 in IEC 62109-1.

Based on your end equipment, look up the required creepage distance:

- For general-purpose end equipment, use Table F.4 in IEC 60664-1.
- For audio, video, and information and telecommunications equipment, use Table 17 in IEC 62368-1.
- For motor drives, use Table 10 in IEC 61800-5-1.
- For solar applications, use Table 14 in IEC 62109-1.

Table 3 is a small subset of Table F.4 in IEC 60664-1, simplified to show common working voltages and pollution degrees. You can see that for pollution degree 1, there is no pollution, so the material group does not matter. For pollution degree 2 and material group I, an application with a 400-V working voltage would require 2 mm of creepage for basic isolation, or (doubled) 4 mm of creepage for reinforced isolation. For pollution degree 2 and material group III, an application with a 400-V working voltage would require 4 mm of creepage for basic isolation, or (doubled) 8 mm of creepage for reinforced isolation.

	Creepage distances to avoid failure caused by tracking (mm)			
	Pollution degree 1	Pollution degree 2		
	All material groups	Material group		
V_{RMS}		I	II	III
63	0.2	0.63	0.9	1.25
400	1.0	2.0	2.8	4.0
800	2.4	4.0	5.6	8.0
1,000	3.2	5.0	7.1	10.0

Table 3. *Subset of IEC 60664-1 Table F.4, showing common working voltages, pollution degrees and material groups.*

Determining Clearance in Insulated Systems for User Safety

For clearance, you need to know the required transient voltage for the application, which is a function of the mains nominal voltage and the transient overvoltage category. You also need to know the pollution degree of the environment and the intended operating altitude (meters above sea level).

Using the mains nominal voltage and transient overvoltage category, see Table F.1 in IEC 60664-1 to determine the required impulse voltage rating. If you require basic isolation, then this is the voltage you need to use to determine clearance. If your application is for audio, video, or information and telecommunications equipment, you need to use IEC 62368-1, which gives the clearances for both basic and reinforced isolation in those types of end equipment. For any other end-equipment type, you will be using a table that only gives values for basic isolation. Therefore, for reinforced isolation, you need to use the impulse voltage that is one step up from your application in Table F.1 in IEC 60664-1.

Section 5.1.6 in IEC 60664-1 describes this process in more detail.

Table 4 is a small subset of Table F.1 in IEC 60664-1, simplified to show common working voltages. Use this table to determine the required impulse voltage rating. For example, a 230-V line-to-neutral application installed in transient overvoltage category II would require 2,500 V of impulse voltage for basic isolation, or 4,000 V for reinforced isolation if using any standard other than IEC 62368-1.

Voltage line to neutral (V_{RMS})	Mains transient/rated impulse voltage (V_{PEAK})			
	Overvoltage category			
	I	II	III	IV
≤50	330	500	800	1,500
≤150 (for example, 120 V in the U.S.)	800	1,500	2,500	4,000
≤300 (for example, 230 V in the European Union, China)	1,500	2,500	4,000	6,000
≤600 (for example, industrial motors, ship power)	2,500	4,000	6,000	8,000

Table 4. *Subset of IEC 60664-1 Table F.1, showing common working voltages.*

For some systems, you may not be subjected to AC mains transients. For these cases, you can calculate the required impulse voltage rating by adding 1,200 V to the nominal line-to-neutral voltage, as described in Section 5.3.3.2.3 in IEC 60664-1.

Now that you know the required impulse voltage, you will look up the required clearance for applications up to 2,000 m above sea level from the appropriate table based on your end-equipment type. For general-purpose end equipment, use Table F.2 in IEC 60664-1. For audio, video, and information and telecommunications equipment, use Table 10 in IEC 62368-1. For motor drives, use Table 9 in IEC 61800-5. For solar applications, use Table 13 in IEC 62109-1.

Table 5 is a small subset of Table F.2 in IEC 60664-1, simplified to show common impulse voltage ratings. For comparison, we've included the values from IEC 62368-1 Table 10 in parentheses. You can see how for audio, video, information and telecommunications applications, the requirements are a little stricter.

Required impulse withstand voltage (kV)	Minimum clearances (mm)		
	Pollution degree		
	1	2	3
0.5	0.04	0.2	0.8
1.5	0.5 (0.76)		0.8
2.5	1.5 (1.8)		
4.0	3.0 (3.8)		
6.0	5.5 (7.9)		

Table 5. *Subset of IEC 60664-1 Table F.2 showing common impulse voltages and pollution degrees. The numbers in parentheses are clearance values from Table 10 in IEC 62368-1.*

Finally, if the operating altitude is greater than 2,000 m, use Table A.2 in IEC 60664-1 to determine the appropriate multiplication factor for clearances.

Determining High-Voltage PCB Spacing

For PCB high-voltage spacing, you will need to look up the required spacing based on end equipment. Additionally, there are other exceptions that you may need to consider. These exceptions can include PCB conformal coating in scenarios where it is not possible to meet required clearance distances, routine transient high-potential tests during production to ensure dielectric withstand strength against high voltages, or any other internal rules that may apply.

Table F.4 in IEC 60664-1 (the same table used to determine creepage) and Table 6-1 in IPC-2221B give general PCB guidelines. The first two columns in Table F.4 in IEC 60664-1 cover "printed wiring material," or PCB traces. These values are very close to the values in Table 6-1 of IPC-2221B for conductors on external PCB layers that do not use conformal coating. IPC-2221B includes the clearance requirements for internal PCB layers, external PCB layers with and without conformal coating, and clearances for external component assemblies. IPC-9592B gives specific guidelines for computer and telecommunications end equipment. Those clearance guidelines are a little more conservative than the more general IPC-2221B. They state that if any conductors cannot meet the required clearances, then you must use conformal coating.

Figure 7 shows the required clearance versus peak voltage for different standards: IEC 60664-1, IPC-2221B for uncoated external layers, IPC-2221B for coated external layers, IPC-2221B for inner layers and IPC-9592B. You can see how inner PCB layers require much less spacing than external layers, and external layers with conformal coating require less spacing than external layers without conformal coating. For example, if an application has 400-V peak voltages, an inner PCB layer only requires 0.25 mm of clearance according to IPC-2221B. For external layers that are not conformal coated, the clearances range from 2 mm to 2.6 mm depending on the standard. For the generic standards, IEC 60664-1 requires 2 mm and IPC-2221B requires 2.5 mm. In this case, we advise you to go with the more conservative 2.5 mm. For a computer or telecommunications application, the clearance would need to be 2.6 mm per IPC-9592B. If it is not possible to meet these clearances, you would need to use conformal coating. With conformal coating, external layers would only require 0.8 mm of clearance.

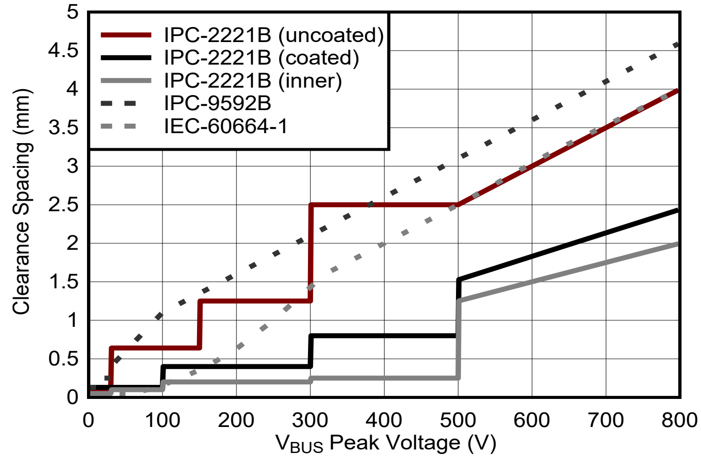


Figure 7. *PCB high-voltage clearance requirements as given by different standards.*

Example Using the Flowchart: Telecommunications AC/DC Front End

We went through the flowchart and described how to use the relevant tables from several standards. Now, let's go through an example of a telecommunications AC/DC front end, as shown in Figure 8. This application has a universal 85- to 265-V_{AC} input and a 40- to 60-V_{DC} output, which is floating relative to earth ground.

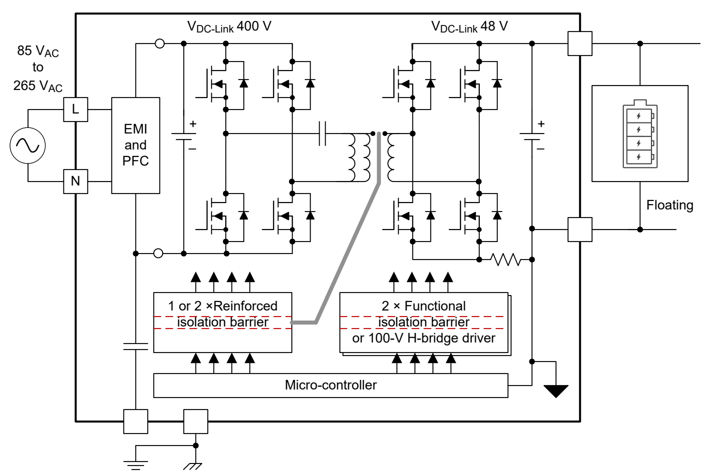


Figure 8. *Example of an AC/DC front end for telecommunications equipment.*

The first step is to determine the required creepage, which requires knowledge of the working voltage, pollution degree and material group. The highest working voltage inside this converter is 400 V, as that is the DC link voltage. The pollution degree will be 2 because this power supply will be inside an enclosure for telecommunications equipment.

It is important to look up the creepage required for all three material groups, as this creepage will be specific to the individual components used in the system. For example, an isolated gate driver from Texas Instruments may have material group I insulation, but an optocoupler from another vendor may have material group II insulation, and PCB FR4 material may have material group IIIa. The goal is to design the power supply for operation up to 5,000 m above sea level.

The next step is to determine whether you need reinforced or basic isolation. The input is primary mains, and the output is unearthed SELV according to IEC 60950-1. From primary mains to unearthed SELV, Figure 2H in IEC 60950-1 states that reinforced isolation is required. Note that connections from output ground to earth ground only require basic isolation, which would have resulted in smaller creepage and clearance requirements. This power supply's output is not grounded to earth ground, though, so the reinforced isolation rules apply. Table 17 in IEC 62368-1 lists the required creepage, and you will double it, since this application requires reinforced isolation. Table 17 specifies that for material group I, you need 4 mm; for material group II, you need 5.6 mm; and for material group III, you need 8 mm of creepage. This includes the doubling factor for reinforced isolation.

It's now time to determine the required clearance. You know that the pollution degree is 2 and the altitude you need to design for is 5,000 m, so the next step is to determine the required mains transient impulse voltage. The mains nominal line-to-neutral voltage is up to 265 V, and the transient overvoltage category is II, since this power converter will be plugged into an outlet. From Table F.1 in IEC 60664-1, you can see that the rated impulse voltage is 2.5 kV for overvoltage category II. If you used the generic IEC 60664-1 Table F.2 clearance rules, you would need to use the next highest value, 4 kV, since this application is for reinforced isolation. However, since this is for a telecommunications application, you will use Table 10 in IEC 62368-1, which gives the values for both basic and reinforced isolation. From the table, you will find that for a 2.5-kV rated impulse voltage, you need 3.6 mm of clearance for reinforced isolation. This is more conservative than the 3 mm of clearance that you would have gotten from using 4 kV in IEC 60664-1 Table F.2.

Now, you need to apply the altitude correction factor from Table A.2 in IEC 60664-1. For 5,000 m, the correction factor is 1.48. The required clearance for the application is 5.33 mm (3.6 mm × 1.48).

Table 6 summarizes the creepage and clearance distances, the parameters required to determine them, and references to the relevant tables from the standards.

Parameter	Value			Source
Mains nominal voltage	235 V_{AC}			Application specifics
Maximum working voltage	400 V_{DC}			
Altitude	5,000 m			
Transient overvoltage category	II			
Pollution degree	2			
Insulation grade	Reinforced			IEC 60950-1 Figure 2H
Material group	I	II	III	Component data sheet
Creepage	4 mm (2 mm × 2)	5.6 mm (2.8 mm × 2)	8 mm (4 mm × 2)	IEC 62368-1 Table 17
Rated impulse voltage	2.5 kV			IEC 60664-1 Table F.1
Altitude correction factor	1.48			IEC 60664-1 Table A.2
Clearance	5.33 mm (3.6 mm × 1.48)			IEC 62368-1 Table 10

Table 6. *Summary of creepage and clearance requirements for an example AC/DC front end for telecommunications.*

Exceptions When You Cannot Meet the Required Creepage and Clearance

We've discussed how PCBs can be conformal coated when it is not possible to meet a clearance requirement. Additionally, you can use PCB cutouts when it is not possible to meet creepage, and perform routine transient tests when it is not possible to meet creepage, clearance, or both, and only functional isolation is required.

Sometimes, it may not be possible to meet the required creepage distance on a PCB. This is especially true for cases where an IC insulation is material group I, but the PCB is material group IIIa. For instance, the AC/DC front end for the telecommunications example required 4 mm of creepage for material group I and 8 mm for material group IIIa. There may be a case where a 4-mm creepage package keeps you from using 8 mm of spacing on the PCB. In this case, it is possible to cut a groove in the PCB to increase the creepage. Doing so will have no effect on clearance, but you can increase the creepage, as it is a measure of the shortest distance along the surface of the insulating material. Section 6.2 of IEC 60664-1 gives guidelines for increasing the creepage. If the slot has a width = X, then there are minimum values = X based on the pollution degree. **Figure 9** is a cross-section of a PCB with a cutout, while **Table 7** shows the minimum width the slot needs to be, based on pollution degree.

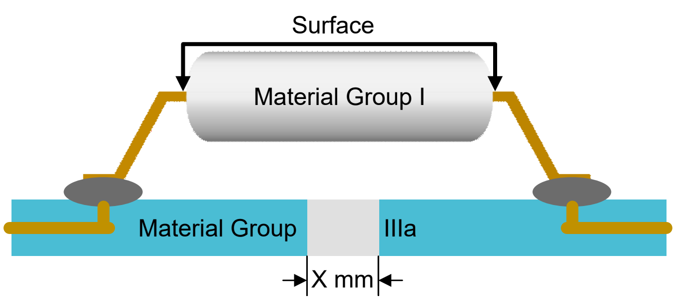


Figure 9. *Cross-sectional area of a PCB with a slot cutout to increase the creepage of the PCB.*

Pollution degree	Minimum dimension
1	0.25 mm
2	1.0 mm
3	1.5 mm

Table 7. *The minimum value of the width of a slot cut into a PCB to increase creepage.*

If you only require functional isolation, you can use a routine transient (high-potential) test in production when it is not possible to meet the required creepage and clearance distances. This test applies a high voltage between two conductors that are intentionally isolated, and measures the resulting leakage current. If the leakage current exceeds a certain threshold, the device fails. The voltage applied during a high-potential test is generally twice the working voltage plus 1,000 V.

For example, an application with a maximum working voltage of 265 V_{AC} would be tested at 2 × 265 + 1,000 = 1,530 V. For this reason, 1.5 kV is a common test voltage. Several standards give guidelines for high-potential testing when it is not possible to meet creepage and clearance: Sections 5.2.2.1 and 5.1.3.3 in IEC 60664-1; Section 5.3.4 in IEC 60950-1; and Section B.4.4 in IEC 62368-1.

Conclusions

There are many standards addressing creepage and clearance distances, and many technical terms that designers need to understand in order to use them. The flowchart and methodology presented in this paper should help you better understand creepage, clearance and high-voltage spacing, and help expedite the development process. With this knowledge, you can increase power density while still maintaining safety design guidelines.

References

1. **Method for the Determination of the Proof and the Comparative Tracking Indices of Solid Insulating Materials.** IEC 60112. IEC: Geneva, Switzerland, Oct. 27, 2020.
2. **Insulation Coordination for Equipment Within Low-Voltage Supply Systems – Part 1: Principles, Requirements and Tests.** IEC 60664-1. IEC: Geneva, Switzerland, May 26, 2020.
3. Electrical Installations for Buildings. IEC 60364. IEC: Geneva, Switzerland.
4. **Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements.** IEC 62368-1. IEC: Geneva, Switzerland, May 26, 2023.
5. **Information Technology Equipment – Safety – Part 1: General Requirements.** IEC 60950-1. IEC: Geneva, Switzerland, May 28, 2013.
6. **Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy.** IEC 61800-5. IEC: Geneva, Switzerland, Aug. 31, 2022.
7. **Safety of Power Converters for Use in Photovoltaic Power Systems – Part 1: General Requirements.** IEC 62109-1. IEC: Geneva, Switzerland, April 28, 2010.
8. **Generic Standard on Printed Board Design.** IPC-2221B. IPC: Bannockburn, Illinois, November 2012.
9. **Requirements for Power Conversion Devices for the Computer and Telecommunications Industries.** IPC-9592, Revision B. IPC: Bannockburn, Illinois, Jan. 14, 2013.
10. Semiconductor Devices – Part 11: Magnetic and Capacitive Coupler for Basic and Reinforced Isolation. DIN VDE V 0884-11. VDE: Frankfurt, Germany, January 2017.
11. **Optical Isolators,** UL 1577. UL: Northbrook, Illinois, April 25, 2014.
12. Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements. CQC GB4943.1. People's Republic of China Certification and Accreditation Administration: Beijing, China, Aug. 1, 2022.
13. "**Isolation Glossary.**" Texas Instruments literature No. SLLA353A, September 2017.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265