



# A basic guide to Creepage and Clearance

in Transformers and Power Supply Units

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# **EN 61558** (Safety of transformers, reactors, power supply units and combinations thereof) **AND OTHER SAFETY STANDARDS**

The standard EN 61558 is applied in absence of explicit requirements in each product's specific standard. It defines all the safety requirements of transformers, including Creepage and Clearance (Cr & Cl).

In recent years many technical committees are aligning their standards to EN 60664 "Insulation coordination for equipment within low-voltage supply systems", so far as is reasonable according to the reference products and sectors.

"Horizontal" standards like EN 60664 have, in fact, the function of guidelines for technical committees, in order to standardize the requirements for homogeneous topics as much as possible.

For this reason, it's common for the requirements of different standards to be essentially aligned with each other.

Moreover, EN 60335, EN 62368, EN 60950, EN 61347, EN 60598, EN 62115 and many other standards include explicit references to EN 61558 for the compliance of transformers.

Though, in some cases, the specific product standards (e.g. electromedical, intrinsic safety - Ex i, etc.) have electrical safety requirements significantly different than those of EN 61558.

# What is Clearance?

*Clearance (Cl) is the shortest distance in air between two conductive parts<sup>1</sup>.*

The evaluation of clearance is done measuring the length of the shortest path through air, considering that this path doesn't pass through insulating bodies, like insulating tape, sleeving, coating, plastic parts etc.

Note that two parts of insulating material close together, even if glued, don't count as a one-piece part, meaning that the Cl path passes through the junction.

# What is Creepage?

*Creepage (Cr) is the shortest distance along the surface of an insulating material between two conductive parts.*

The same considerations made for Clearance also apply to Creepage, except that the Creepage path doesn't pass through air, but it's bound to the surface of insulating bodies.

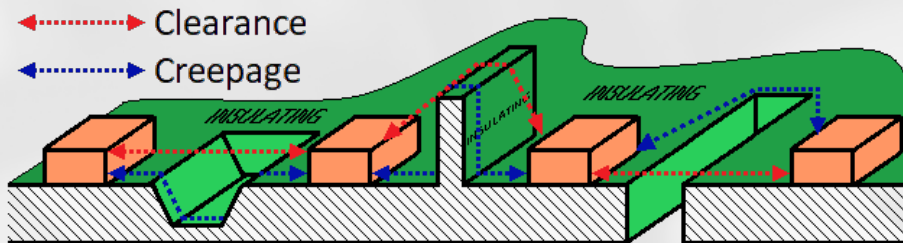
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<sup>1</sup> The conductive parts (or conductive bodies) of the simplest transformer are:

- primary winding;
- secondary winding;
- core.

# Graphical representation of Creepage and Clearance

The figure below can help to better understand Creepage and Clearance through a simple example, where conductive parts are represented by coppery cubes, while insulating parts are those coloured green (to symbolize a PCB).

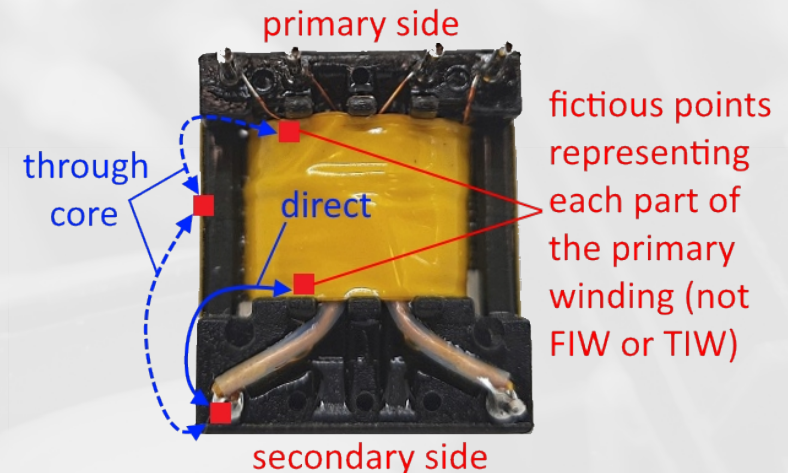


## Indirect paths

When evaluating Cr & Cl, “indirect paths” must be considered as well.

For a transformer, a typical “direct path” is primary winding – secondary winding.

An indirect path can be primary winding – core – secondary winding, since any uncoated core is conductive.



Example of direct and indirect paths.  
Red dots represent the conductive bodies of the transformer, while blue arrows symbolize possible paths to consider when evaluating Cr & Cl.

# Common examples in transformers

Creepage and Clearance are, by definition, the shortest distances identified between all the possible paths between the conductive parts of interest.

The drawings in the next slides show some examples of paths that are often considered when evaluating Creepage and Clearance between primary winding and secondary winding of transformers.

But first, a clarification about the type of wire used for the windings:

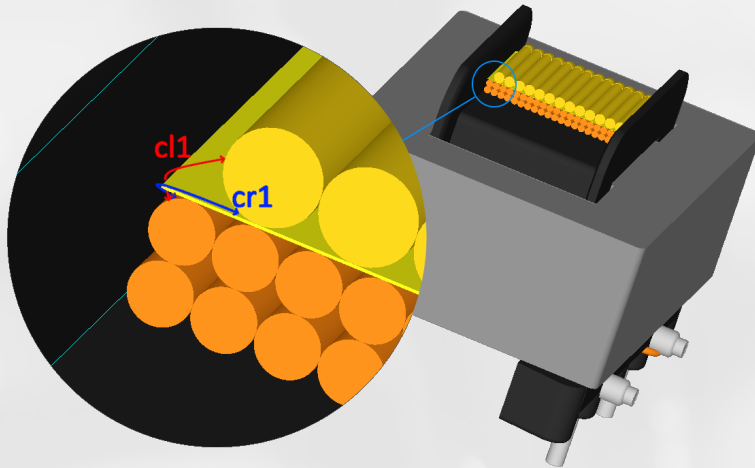
the enamel of a simple *enamelled wire* is not relevant towards the safety distances, so this type of wire must be considered as uninsulated, hence conductive;

on the contrary, *wires with solid and continuous insulation*, like those with solid multi-layer insulation (*TIW*) those with high thickness secure enameling (*FIW*) or electrical cables with appropriate thermal index, have to be considered insulated with regard to the evaluation of Creepage and Clearance.

As a result, the only parts of a winding made with an insulated wire that are relevant for the evaluation of Creepage and Clearance, are those from which the insulation is removed: usually the ends soldered on pins and the pins themselves.

For simplicity's sake, the following examples will only mention the TIW wire to exemplify any kind of wire with solid insulation.

## Example 1



The drawing shows a transformer with primary winding (orange wire) and secondary winding (yellow wire) separated by yellow insulating tape, represented in cross-section.

In this case a simple enamelled wire has been used for both windings, meaning that insulating tape is the only insulation separating the turns of the two windings with regard to Creepage and Clearance.

Therefore, the shortest paths between the turns of the two windings passing around the insulating tape, like Cr1 and Cl1, are to be considered.

This drawing shows an end of the primary winding insulated by a tube and soldered to a pin. As in example 1, the wire used for the secondary winding is not TIW. As for the primary winding, we have two cases:

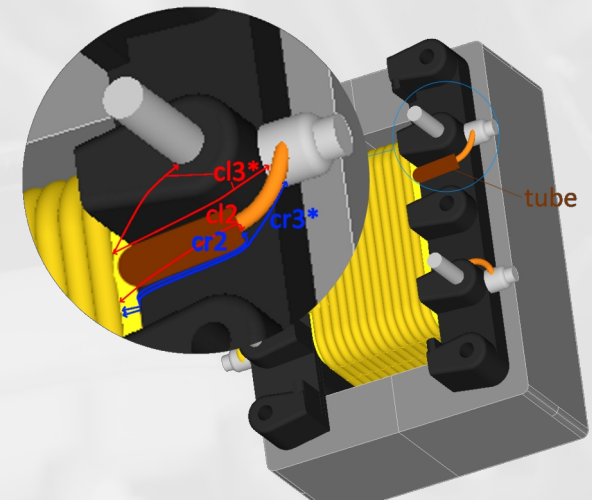
- 1) besides the tube, the wire is simply enamelled;
- 2) besides the tube, a TIW wire has been used.

In the first case, the shortest distances (Cr2 and Cl2) could be those between the end of the tube on the primary winding and the closest point on the turns of the secondary winding.

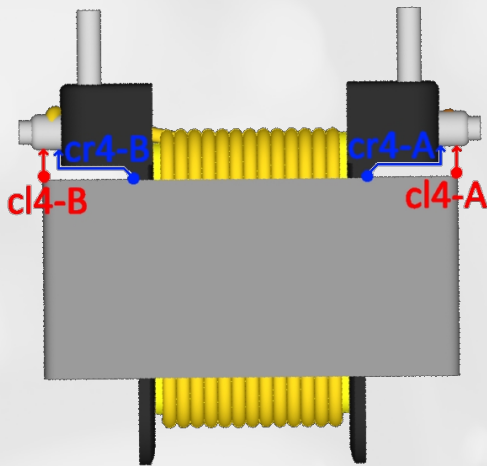
In the second case, the end of the primary winding is fully insulated up to the soldering on the pin, so the shortest distances (Cr3\* e Cl3\*) could be those between the pin on the primary side and the closest point on the turns of the secondary winding.

Cl3\* is represented by two different arrows, indicating that Creepage and Clearance paths that have to be verified can be many.

## Examples 2 and 3



## Example 4



This is an example of indirect paths.

In some cases the shortest distances can be those between the terminals of the primary winding and the terminals of the secondary winding, passing through the core.

In this example

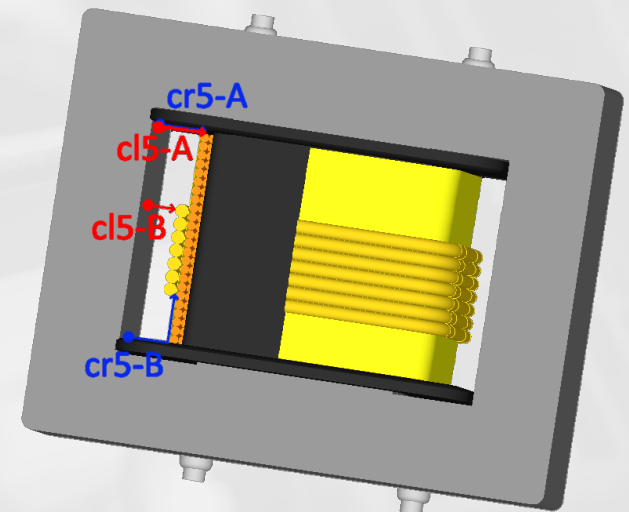
- distances Cr4-A and Cl4-A are those between a terminal of the primary winding and the closest point on the core, respectively through air and along the bobbin surface;
- distances Cr4-B and Cl4-B are those between a terminal of the secondary winding and the closest point on the core, respectively through air and along the bobbin surface;
- the path lengths are calculated as follows:  $Cr4 = Cr4-A + Cr4-B$  and  $Cl4 = Cl4-A + Cl4-B$ .

This other example of indirect paths applies in case of windings made with simple enamelled wire.

In this case the shortest paths could be between the primary winding turns and the secondary winding ones, passing through the core.

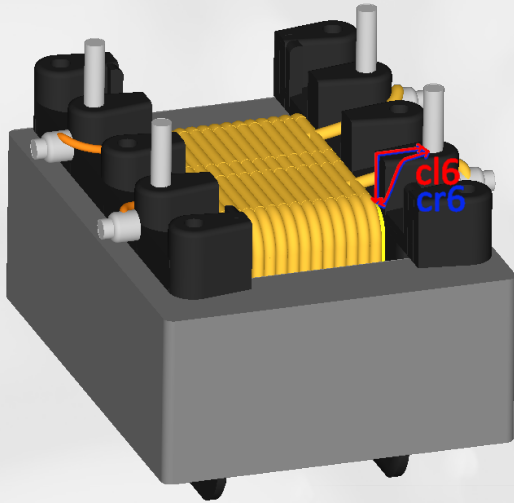
The path lengths are calculated as follows:  
 $Cr5 = Cr5-A + Cr5-B$  and  $Cl5 = Cl5-A + Cl5-B$ .

## Example 5





## Example 6



Other possible paths to consider are those between the primary winding turns and the secondary winding pins.

The drawing shows two paths of this kind, between a secondary winding pin and the closest point on the primary winding (which happens to be under the insulating tape) made with simple enamelled wire.

In this example the secondary winding is made with TIW wire, whereas if it had been only enamelled, the shortest path would have been between the primary turns and the secondary turns, passing around the insulating tape as in example 1.

Clearance and Creepage paths overlap because there aren't distances through air shorter than those along the bobbin surface.

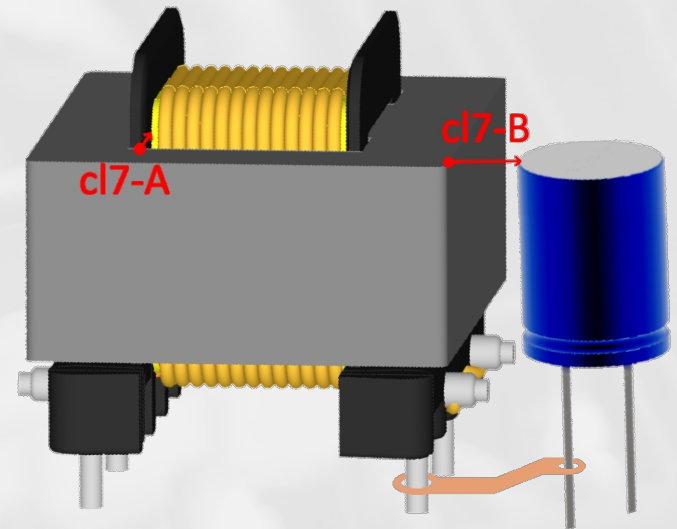
Positioning other components next to the transformer may affect the compliance of Creepage and Clearance. When evaluating Creepage and Clearance, it is necessary to also consider the conductive parts of possible components electrically connected to the windings of the transformer.

In this example

- the primary winding is made with simple enamelled wire;
- the secondary winding is made with TIW wire;
- a capacitor is electrically connected to the secondary winding.

A possible path to consider for evaluating Clearance is between the primary winding turns (under the tape) towards the uninsulated top of the capacitor, passing through the core.

## Example 7



# Which factors affect the required Creepage and Clearance?

- **Voltage** across windings, between adjacent windings and between pri/sec winding groups
- Required **insulation type** (functional, basic, supplementary, double/reinforced<sup>2</sup>)
- **Overvoltage category** (I, II, III, IV)
- **Pollution degree** (P1, P2, P3)
- **CTI** of the insulating materials
- Max **altitude**, where over 2000m
- Operating frequency<sup>3</sup>
- Homogeneous/inhomogeneous electric field<sup>3</sup>

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2 Double and reinforced insulation guarantee equivalent safety, although obtained in a different manner.

3 Factors not covered herein, since their effect is negligible with the most common switching frequencies.

# Voltage across and between windings

First of all, the required Cr & CI depend on the voltages across the windings and across the insulations between windings.

Voltages having an impact on Cr & CI are the following:

- Maximum **RMS voltage** and **repetitive peak voltage**<sup>4</sup> measured **across the windings or series of windings**;
- Maximum **RMS voltage** and **repetitive peak voltage**<sup>4</sup> measured **across the input/output insulation**, that is between any primary side pin and any secondary side pin, whether at the main rated maximum voltage (e.g. for 90-264V wide range it usually is 230V or 240V, not 264V), at no-load and at maximum load. During tests, the output pole on which the highest voltage is measured shall be EARTHED.
- Maximum **RMS voltage** and **repetitive peak voltage**<sup>4</sup> measured **between each couple of physically adjacent**<sup>5</sup> **and not interconnected windings**, at the main rated maximum voltage, at no-load or at maximum load.

The higher these voltages, the higher the required Cr & CI.

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4 Repetitive peak voltage has an impact only if both the following conditions are true:

- it exceeds 750Vpk;
- the double insulation is obtained through insulated wires.

In this case, partial discharge type tests are required.

Random transient voltages must be disregarded.

5 Windings physically separated only by insulating material.

# Insulation types

Safety transformers, which are by far the most commonly applied in power electronic equipment, require double or reinforced insulation.

Cr & Cl have to comply with this insulation level.

The insulation between the windings connected on the mains side and the output ones, or between any winding and another one, can be of the following types:

- **Functional:** doesn't require any minimum Cr, Cl or insulation thickness<sup>6</sup>.
- **Basic:** basic standard requirement, with no required minimum thickness.
- **Supplementary:** further insulation with minimum required thickness, for maintaining a certain degree of safety in case of failure of the basic insulation.
- **Double:** basic + supplementary.
- **Reinforced:** a single insulation system with higher minimum required thickness, guaranteeing the same safety level of double insulation.

Safety transformers shall comply with EN 61558-1 and EN 61558-2-6, and also EN 61558-2-16 in case of switching transformers. They require double or reinforced insulation.

As an example, double or reinforced insulation is required in the typical case of a mains-powered transformer with an Extra Low Voltage (ELV)<sup>7</sup> output that can come into contact with people.

It is also required when there no direct contact is possible but certain insulations, Cr, Cl etc. are not guaranteed against the output conductors.

The higher the insulation level, the higher the required Cr & Cl.

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6 The common winding wire enamel is an example of functional insulation. This insulation level can be applied between windings intended to be mutually connected or in components having no safety function.

7 Extra Low Voltage (ELV), which is considered non-hazardous by European standards, is up to 50Vac or 120Vdc.

Other relevant definitions are:

SELV = ELV with double/reinforced insulation against the mains

PELV = ELV with double/reinforced insulation against the mains, earthed

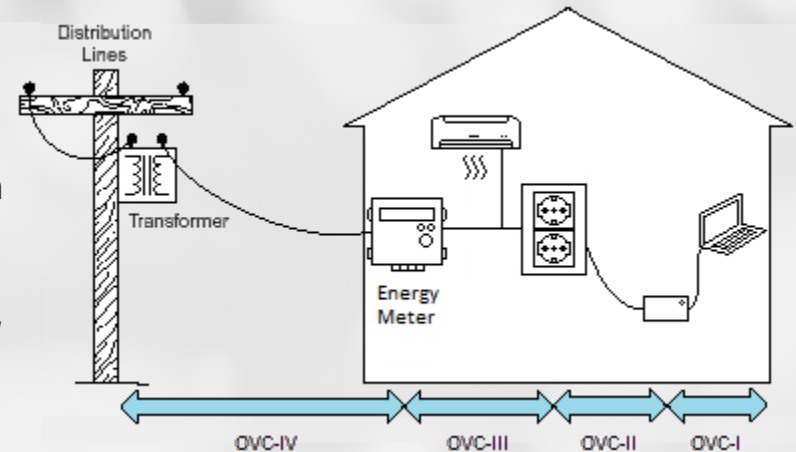
FELV = ELV without double/reinforced insulation.

# Overvoltage category

Is the transformer connected to the fixed installation downstream of the energy meter?

Is it for a mobile equipment?

The overvoltage category, hence the required Cr & Cl, depend on this.



Depending on how the transformer is installed, it must comply with the adequate overvoltage category.

- **OVC-I:** equipment for connection to circuits in which measures are taken to limit transient overvoltages to an appropriately low level (powered by isolating transformer). Examples of such equipment are those containing electronic circuits protected to this level. However, unless the circuits are designed to take the temporary over-voltages into account, equipment of overvoltage category I cannot be directly connected to the mains supply.
- **OVC-II:** equipment to be supplied from the fixed installation, but not permanently connected to it. Typically, mobile equipment connected to the mains via plug. Examples of that equipment are transformers for household appliances, telecommunications, toys, and similar loads.
- **OVC-III:** equipment used in fixed installations and for cases where the reliability and the availability of the equipment is subject to special requirements. Examples of such equipment are transformers in fixed installations and transformers for industrial use with permanent connection to the fixed installation. Typically, fixed equipment connected downstream of a low voltage mains (<1000Vac) utility energy meter.
- **OVC-IV:** equipment used at the origin of installation. Examples are transformers in fixed installations of power plants or immediate to such installations.

The higher the overvoltage category, the higher the required Cr & Cl.

EN 61558 requires OVC-III for general use transformers.

All ITACOIL standard **mains transformers** and most **switching transformers** are OVC-III compliant.

# Pollution degree

Is the transformer<sup>8</sup> installed in a dry and clean place, or there may be conductive dust and moisture? These elements affect the required Creepage.

The standards define three pollution degrees:

- **P1:** no pollution or only dry, non-conductive pollution occurs. Pollution has no influence. This pollution degree is applied to encapsulated transformers and similar. Applying P1 distances requires time-consuming tests.
- **P2:** only non-conductive pollution occurs, except that occasionally a temporary conductivity caused by condensation is to be expected. P2 is assigned to transformers having a reasonably tight enclosure. Hermetic sealing is not required. It's the most common condition.
- **P3:** conductive pollution occurs, or dry non-conductive pollution occurs which becomes conductive due to the condensation which is to be expected.

A higher pollution degree requires a higher Cr, while it has no impact on Cl.

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<sup>8</sup> More precisely, only the points of the transformer to which Cr & Cl requirements apply are actually relevant. In fact, for an encapsulated (and properly tested) transformer, Cr & Cl required for P1 can be applied even in a P3 environment.

# CTI of insulating materials

Different insulating materials require different Creepages.  
CTI is the parameter that matters.

Some insulating materials are prone to surface flashover at higher voltages than others.  
The Comparative Tracking Index (CTI) defines the property of withstanding voltage without triggering surface discharges.  
CTI is correlated to this voltage.

The materials are classified by groups:

Group I	Group II	Group IIIa	Group IIIb
$CTI \geq 600$	$400 \leq CTI < 600$	$175 \leq CTI < 400$	$100 \leq CTI < 175$

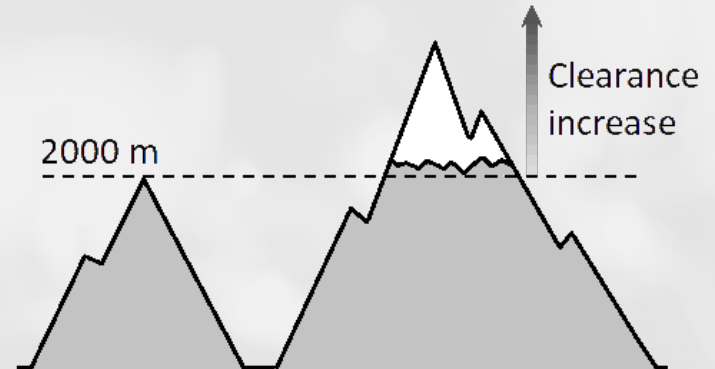
A higher CTI allows shorter Cr, while CI is not affected.

Note:

Thermosetting materials of the bobbins do not normally exceed group IIIa. However, they're the most used for PCB transformers due to their reasonable costs and resistance to conditions of the soldering process.

# Altitude

Does the transformer need to function at an altitude exceeding 2000m?  
If the answer is yes, Clearance needs to be increased.



The Clearances defined by EN 61558 refer to altitudes up to 2000m.

Adapting these distances to higher altitudes requires the appliance of correction coefficients that increase CI with increasing altitude. As an example, for an altitude of 4000m, the required CI increases by 29%.

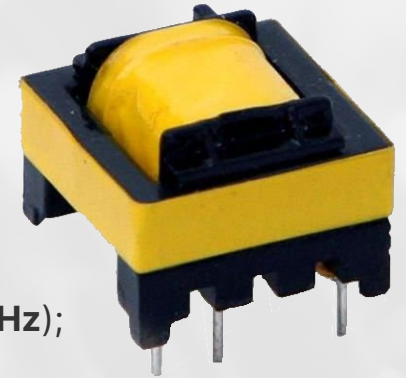
Altitude has no effect on Creepage.



# A typical transformer

As a basic reference, for the most typical example of a switching transformer:

- Connected to **230V** rated mains and with **SELV output**, so with double or reinforced insulation;
- overvoltage category **OVC-III**;
- pollution degree **P2**;
- bobbin material with **CTI=175**, as the majority of bobbins for PCB switching transformers;
- suited for a max altitude of **2000m**;
- with operating frequency in the most common range (roughly around **50-200KHz**);



**Creepage and Clearance of little less than 6mm** are usually sufficient, according to most standards. Our experience teaches us that this situation covers the vast majority of cases in power electronics.

Nonetheless, it is necessary to make specific assessments since each application has its own peculiarities to consider.

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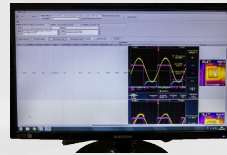
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