TECHNICAL REPORT

IEC TR 61000-5-6

First edition
2002-06

PUBLICATION FONDAMENTALE EN CEM
BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –

Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences

Compatibilité électromagnétique (CEM) –

Partie 5-6:
Guides d'installation et d'atténuation –
Atténuation des influences électromagnétiques externes

Reference number
IEC/TR 61000-5-6:2002(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

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International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE X

For price, see current catalogue

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences

FOREWORD

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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 61000-5-6, which is a technical report, has been prepared by subcommittee 77C: High power transient phenomena, of IEC technical committee 77: Electromagnetic compatibility. It has the status of a basic EMC publication in accordance with IEC Guide 107.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
77C/110/CDV	77C/122/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document, which is purely informative, is not to be regarded as an International Standard.

The committee has decided that the contents of this publication will remain unchanged until 2007. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

A bilingual version of this technical report may be issued at a later date.

INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts published either as International Standards or as technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-6-1).

This part of IEC 61000 gives guidelines for the mitigation of external electromagnetic influences.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences

1 Scope and general considerations

1.1 Scope

This part of IEC 61000 covers guidelines for the mitigation of external electromagnetic influences impinging upon a facility, aimed at ensuring electromagnetic compatibility (EMC) among electrical and electronic apparatus or systems. These influences include lightning, RF transmitters, power-line and telecom transients, high-altitude electromagnetic pulse (HEMP) and other high-power electromagnetic transients. More particularly, this technical report is concerned with the arrangement of shielding and screening against radiated disturbances, and with mitigation of conducted disturbances. These arrangements include appropriate electromagnetic barriers for industrial, commercial, and residential installations.

The concept of barriers installed for mitigating potentially penetrating and unwanted electromagnetic noise is applicable even when there is no designed-in electromagnetic shield. The enclosure through which power and signal (communications, control, etc.) cables must enter or exit may be considered as a potential electromagnetic barrier that will provide some level of protection. The concept of enclosure can be understood as the perimeter walls of a building, the walls of a single room, or the housing of an apparatus, with protection installed at all points of electromagnetic penetration into the enclosure.

This technical report is intended for use by installers, manufacturers and users of sensitive electrical or electronic installations or systems, and of equipment with emission levels that could degrade the overall electromagnetic (EM) environment. It applies primarily to new installations but, where economically feasible, it may be applied to extensions or modifications to existing facilities. While the technical principles are applicable to individual equipment or apparatus, such application is not included in the scope of this technical report.

1.2 General considerations

1.2.1 Elementary interference control

In its simplest form, the interference problem consists of a source of disturbance, a victim and the medium between the two. Interference control consists of suppressing the disturbance source, strengthening the victim, or impeding the source-victim interaction through the medium. When the source is not controllable (for example, lightning, portable transmitters, HEMP, etc.), and the inherent strength of the victim is dictated by other considerations (for example, circuit density and operating power), interference control is relegated to the intervening medium. Furthermore, for interference control oriented toward victim protection, control measures tend to be applied fairly close to the susceptible circuits (at the system or subsystem levels).

Increasing the separation between them, enclosing one or the other in a shield or orthogonalizing them (for example, rejecting common-mode interference on differential-mode signalling lines) can reduce the interaction between source and victim. All three techniques can be combined to form a closed electromagnetic barrier between the source and the victim. For sources outside the system, the barrier may be applied at the system level. For sources inside the system, electromagnetic compatibility requires two barriers: one at the source to control emissions, and one at the victim to control susceptibility. This concept is illustrated in figure 1. In this technical report, we will concentrate on sources outside the system.

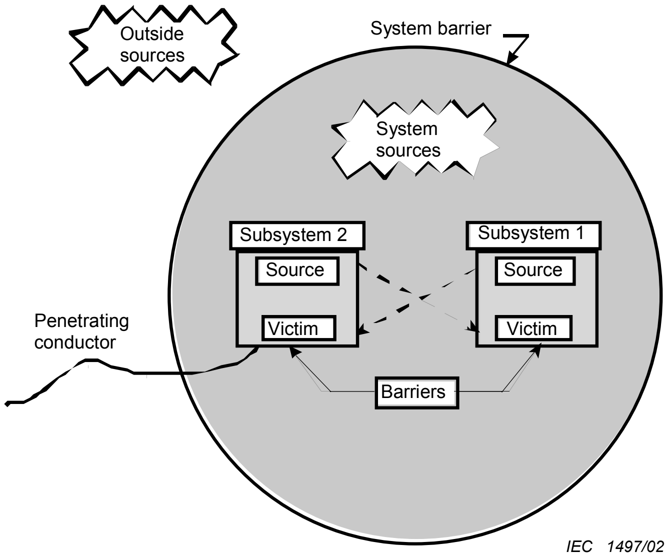


Figure 1 – System barrier topology

1.2.2 Shields and interfaces

Shields are used for attenuating the direct coupling of radiated electromagnetic disturbances from the external environment onto the internal electronics circuits and, conversely, to limit the radiation of disturbances from the internal circuits to the exterior, thus contributing to the electromagnetic compatibility (EMC) of the installation. The shields considered in this document are electromagnetically closed structures. Any form of electromagnetically open structure is not recommended for achieving a fully compliant installation. Some examples of structure shielding applications include

– telecom facilities, such as relay stations, multipurpose radio installations;
– TV and broadcasting studios;
– test rooms and laboratories (telecom, metrology, high-voltage engineering);
– metrology facilities in educational institutions;
– diagnostic and therapy rooms in medical facilities;
– computer rooms for business and industry.

Interface protection devices are used for mitigating the propagation of conducted electromagnetic disturbances from the environment into the internal electronics and may, conversely, limit the emission of disturbances from the internal electronics into the environment. This assumes that bi-directional protection devices are applied. Thus, when installed in conjunction with a shield, these devices contribute to achieving electromagnetic compatibility for the installation. Protection devices that will be discussed in this technical report include filters, decoupling devices and surge-protective devices (SPDs).

The filters considered in this document are limited to low-voltage passive circuits for high-frequency disturbances that are part of an installation. Filters and other interface devices incorporated in individual apparatus are not included within the scope of this document. Low-frequency filters, such as those used to mitigate power-line harmonics, are also not included in the scope of this document.

A complete installation can include the interconnection of several properly shielded cabinets with screened cables. However, the selection of such cables and proper bonding of the cable screens is not within the scope of this publication, but is addressed in IEC 61000-5-2.

The installation of filters and other mitigation means, including shields, is predicated on the existence of a properly designed earthing system, as described in IEC 61000-5-2.

The recommendations presented in this technical report address the EMC concerns of the installation. The safety aspects of any installation are of prime importance but while not ignored, are not within the scope of this technical report. Reference to safety issues may be found in IEC 60364-1, IEC 60364-5-54, and IEC 60364-5-548. The efficient transportation of power within the installation is a prime function of any facility, but is also excluded from the scope of this technical report. Nevertheless, these two issues are taken into consideration in the recommendations concerning EMC. These two issues can be implemented concurrently for enhanced EMC of the installed sensitive apparatus or systems without conflict by applying the recommended practices presented in this technical report and the relevant safety requirements such as those of IEC 60364. As each installation is unique, it is the responsibility of the designer and the installer to select and abide by the relevant recommendations most appropriate to a particular installation. It is important to note that the recommendations presented in this technical report do not seek to preclude existing installation practices, when they have been shown to perform satisfactorily. Special mitigation methods might not be necessary when the installed equipment satisfy applicable emission and immunity standards.

1.2.3 Summary

Clauses 1-3 provide general information concerning the scope, references and definitions applicable to this publication.

Clause 4 provides an overview and introduction of the general approach to applying EMC concepts in the design of installations through the use of appropriate interface protection devices.

Clause 5 provides information on the application of shields to mitigate the coupling of radiated disturbances and to create a boundary between different zones of disturbance levels.

Clause 6 provides information on the application of filters as interface protection devices that can be inserted in power and signal cables entering the shield or enclosure.

Clause 7 provides information on the application of decoupling devices as interface protection devices that can be inserted in power cables or applied to signal cables entering the shield or enclosure.

Clause 8 provides information on the application of SPDs as interface protection devices that can be inserted in power or signal cables entering the shield or enclosure.

It is emphasized that this technical report does not discuss in detail the internal design of these mitigation means. However, some knowledge of their fundamental characteristics, as well as some information on the EM disturbance environment, is necessary to make an appropriate selection of measures and to install them in a way that will not make them ineffective.

2 Reference documents

IEC 60050(161), *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 60050(195), *International Electrotechnical Vocabulary (IEV) – Chapter 195: Earthing and protection against electric shock*

IEC 60050(300), Part 312, *International Electrotechnical Vocabulary (IEV) – Electrical and electronic measurements and measuring instruments – Part 312: General terms relating to electrical measurements*

IEC 60335-1, *Household and similar electrical appliances – Safety – Part 1: General requirements*

IEC 60364-1, *Electrical installations of buildings – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60364-5-54, *Electrical installations of buildings – Part 5: Selection and erection of electrical equipment – Chapter 54: Earthing arrangements and protective conductors*

IEC 60364-5-548, *Electrical installations of buildings – Part 5: Selection and erection of electrical equipment – Section 548: Earthing arrangements and equipotential bonding for information technology installations*

IEC 60939-1, *Complete filter units for radio frequency suppression – Part 1: Generic specification*

IEC 60939-2, *Complete filter units for radio frequency suppression – Part 2: Sectional specification. Selection of methods for test and general requirements*

IEC/TR2 61000-2-5, *Electromagnetic compatibility – Part 2: Environment – Section 5: Classification of electromagnetic environments*. Basic EMC publication

IEC 61000-2-11, *Electromagnetic compatibility – Part 2-11: Environment – Classification of HEMP environments*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test*. Basic EMC publication

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-12, *Electromagnetic compatibility (EMC) – Part 4-12: Testing and measurement techniques – Oscillatory waves immunity test*

IEC/TR 61000-5-1, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 1: General considerations*. Basic EMC publication

IEC/TR 61000-5-2, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*

IEC/TR 61000-5-3, *Electromagnetic compatibility (EMC) – Part 5-3: Installation and mitigation guidelines – HEMP protection concepts*

IEC/TR2 61000-5-4, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 4: Immunity to HEMP – Specifications for protective devices against HEMP radiated disturbance*. Basic EMC publication

IEC 61000-5-5, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 5: Specification of protective devices for HEMP conducted disturbance.* Basic EMC publication

IEC 61000-5-7, *Electromagnetic compatibility (EMC) – Part 5-7: Installation and mitigation guidelines – Degrees of protection provided by enclosures against electromagnetic disturbances (EM code)*

IEC 61024-1, *Protection of structures against lightning – Part 1: General principles*

IEC 61312-1, *Protection against lightning electromagnetic impulse (LEMP) – Part 1 – General principles*

IEC/TS 61312-2, *Protection against lightning electromagnetic impulse (LEMP) – Part 2: Shielding of structures, bonding inside structures and earthing*

IEC/TS 61312-3, *Protection against lightning electromagnetic impulse (LEMP) – Part 3: Requirements of surge protective devices (SPDs)*

IEC 61312-4, *Protection against lightning electromagnetic impulse (LEMP) – Part 4: Protection of equipment in existing structures*

IEC/TR 62066, *General basic information regarding surge overvoltages and surge protection in low-voltage a.c. power systems*[1]

CISPR 17, *Methods of measurement of the suppression characteristics of passive radio interference filters and suppression components*

3 Terms, definitions and acronyms

For the purposes of this technical report, the definitions of IEC 60050(161) together with the following definitions apply.

3.1
apparatus
finished combination of devices (or equipment) with an intrinsic function intended for the final user and intended to be placed on the market as a single commercial unit

3.2
attenuation
ratio of the input to the output values of quantities of the same kind in a device or system

NOTE When this ratio is less than unity it is usually replaced by its reciprocal, the gain.

[IEV 312-06-06]

3.3
device
combination of components having a given function, forming part of a piece of equipment, apparatus, or system

NOTE For example, thermostat, relay, push buttons, switch or contactor.

3.4
(local) earth
(local) ground (US)
part of the earth which is in electric contact with an earth electrode and the electric potential of which is not necessarily equal to zero

3.5
earth (verb)
ground (verb) (US)
make an electric connection between a given point in a system or in an installation or in equipment and a local earth

NOTE The connection to local earth may be

– intentional, or

[1] To be published

– unintentional or accidental

and may be permanent or temporary.

[IEV 195-01-08]

3.6
earth electrode
ground electrode (US)
conductive part, which may be embedded in a specific conductive medium, e.g. concrete or coke, in electric contact with the Earth

[IEV 195-02-01]

3.7
earthing arrangement
grounding arrangement (US)
earthing system (deprecated)
all the electric connections and devices involved in the earthing of a system, an installation and equipment; the electrical circuit, or a part of it, including the earth electrode, which performs the earthing of a system, an installation and equipment

[IEV 195-02-20, modified]

3.8
electromagnetic compatibility
EMC (abbreviation)
ability of an equipment or system to function satisfactorily in its *electromagnetic environment* without introducing *electromagnetic disturbances* to anything in that environment

[IEV 161-01-07]

3.9
electromagnetic disturbance
any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

NOTE An electromagnetic disturbance may be an *electromagnetic noise*, an *unwanted signal*, or a change in the propagation medium itself.

[IEV 161-01-05]

3.10
electromagnetic interference
EMI (abbreviation)
degradation of the performance of an equipment, transmission channel, or system caused by an electromagnetic disturbance

[IEV 161-01-06]

3.11
equipment
general term for apparatus, appliance, system, etc.

NOTE For the purposes of the present document, to make a distinction between the collective (plural) nature of the term “equipment” and an individual “piece of equipment”, the term “apparatus” will be used when the meaning is a single piece.

3.12
equipotential bonding
provision of electric connections between conductive parts, intended to achieve equipotentiality

[IEV 195-01-10]

3.13
facility
entity (such as a hospital, a factory, machinery, etc.) that is built, constructed, installed or established to perform some particular function or to serve or facilitate some particular end

3.14
filter
two-port network that transmits signals with low attenuation at all frequencies within one or more frequency bands and with high attenuation at all other frequencies

3.15
HEMP
high altitude electromagnetic pulse

3.16
installation
several combined items of apparatus or systems put together at a given place to fulfil a specific objective but not intended to be placed into service as a single functional unit

3.17
maximum continuous operating voltage
maximum voltage which may be continuously applied to the SPDs mode of protection (equal to the rated voltage)

3.18
residual voltage (current)
peak value of voltage (current) that appears at the output terminals of an SPD or filter during application of a standard stress at the input terminals

3.19
screen
shield
device intended to reduce the penetration of an electric, magnetic or electromagnetic field into a given region, or to separate electric circuits. A shield is used when a mechanical barrier is intended

3.20
screening
shielding
act of reducing the magnitude of an electric or magnetic field provided by a good electrical conductor

3.21
shielded enclosure, screened room
mesh or sheet metallic housing designed expressly for the purpose of separating electromagnetically the internal and the external environment

[IEV 161-04-37]

3.22
shielding effectiveness, EMC
for a given external source, the ratio of electric or magnetic field strength at a point before and after the placement of the shield in question

3.23
surge-protective device
SPD
device that is intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component that is intended to limit surge voltages and divert surge currents

3.24
system
several items of apparatus combined to fulfil a specific objective

Acronyms

EM	electromagnetic
EMC	electromagnetic compatibility
EMI	electromagnetic interference
HEMP	high-altitude electromagnetic pulse
RF	radio frequency
SE	shielding effectiveness
SPD	surge-protective device
UPS	uninterruptible power supply

4 Mitigation of radiated and conducted disturbances

4.1 Topological concepts

As a practical matter, the system to be protected is required to communicate with the outside world via conductive and non-conductive (radiating) paths that penetrate the enclosure electromagnetic shield and thus introduce imperfections (openings) in the shield. In addition, other penetrations may be introduced for entry and egress as well as for providing internally a controlled environment for system operators as well as for the internal equipment, such as electronics, water, air, sewers, etc. Therefore, a conceptually simple problem may become quite complex electromagnetically. The concept of topological control has been introduced to account for a system's inherent electromagnetic complexity. Such a concept may be applied to simplify both the system electromagnetic coupling problem and to develop and implement electromagnetic interference control.

In figure 2 we show a generalized, but simple, system topology enclosed in a volume surrounded by the outer surface. The outer surface may be fabricated from common materials (concrete, brick, steel reinforcing bars, metal, etc.) and is penetrated by conductive and non-conductive penetrations such as doors, windows, seams, electrical lines, plumbing, etc. The electronic equipment may be located in different compartments or rooms. This equipment is usually interconnected by wiring harnesses or cables. Environmental control equipment and ducts may also interconnect the equipment rooms. These conductors provide paths for electromagnetic energy to either exit or enter the enclosure.

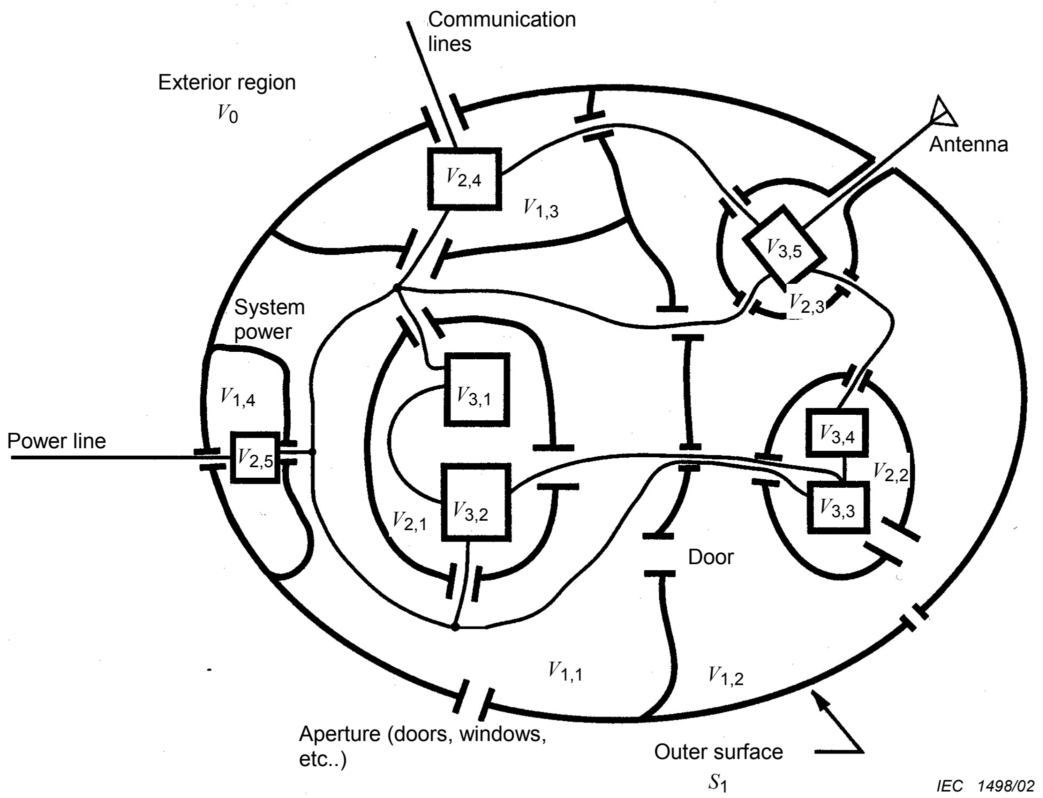


Figure 2 – Generalized system topology

All electrical devices, systems and installations produce or utilize at various frequencies energy which propagates through conductors connected to the apparatus. This energy can interfere with other equipment. Screening may be necessary either to protect a facility from an external electromagnetic environment, or to prevent the radiation of electromagnetic disturbances created by the internal equipment operation.

A formal topological approach may be used 1) to describe the system, and 2) to design a consistent approach to protect the equipment. A formal approach for decomposing a system into its smaller, more tractable, parts is possible. Following the notation provided in figure 2 the generalized system is subdivided into the volumes and surfaces. The exterior region or volume is identified as V_0; interior volumes or layers are identified as $V_{j,k}$, where the first subscript indicates the surface traversed (outside to inside) and the second subscript indicates the volume within that (jth) surface. The topological approach aids in identifying the various surfaces and volumes in a particular system and is very useful in describing and accounting for system electromagnetic shields. The notation may be used for further analysis as may be warranted. For example, in figure 2, the surface of volume 2 could have different characteristics in the boundaries to volume 1 and volume 3. This approach also aids in accounting for the assessment of every penetration in all surfaces.

4.2 Mitigation needs

Mitigation is required if EMC between an apparatus and its environment is not achieved. However, if EMC has been achieved then no further mitigation is required. Mitigation can be achieved by using a barrier between the source and the victim. For conducted disturbances this barrier is typically a combination of SPDs and filters or other decoupling devices, and for radiated disturbances it can be a screen and perhaps a filter as needed, the attenuation of which is compatible with that of the screen in the frequency range considered.

The attenuation provided by a barrier has to be compatible with the need, that is, be at least equal to the difference between the disturbance level and the immunity level of the apparatus to that disturbance. For verification purposes, in most of the cases, disturbances are simulated and the immunity of an apparatus is compared against a standard. Thus, the attenuation provided corresponds to the difference between the disturbance level (expected or measured) and the immunity level determined in a laboratory test or by reference to an established immunity level.

According to uncertainties on disturbance level(s) and immunity level(s), a margin should be considered as well, and added to the basic attenuation needed. This margin generally depends on the criticality of the equipment. For most low-risk domestic or industrial applications of equipment satisfying applicable EMC requirements, there is no need for additional mitigation.

4.3 The general concept of enclosure

As discussed in IEC 61000-5-1, it is useful to extend the concept of enclosure as being the boundary of a facility. An enclosure may be envisaged as a complete building, a room, a rack, a single cabinet and even, by extension of the concept, as an individual apparatus or a circuit board within an apparatus. This facility interfaces with its environment by “ports” as shown in figure 3. IEC 61000-5-1 provides further discussion of the concept of ports.

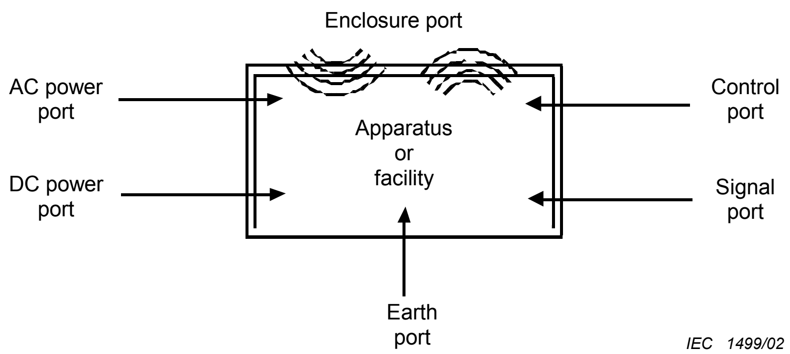


Figure 3 – Ports of an apparatus or facility

The scope of this technical report is restricted to the practices involved in the implementation of the electrical installation in a facility. These activities involve the selection of functional elements of the system and the relevant interconnections. This should also include the interconnection to external sensors, actuators, telecommunication networks and the power supply.

4.4 Interactions at the enclosure boundary

Interactions at the enclosure boundary involve two directions of propagation:

- disturbances originating in the environment that can enter the enclosure;
- disturbances generated within the enclosure that can exit the enclosure;
- a shield provided mainly to protect a circuit against radiated disturbances that will also restrict the emission of radiated disturbances from the circuit;
- likewise, a filter installed to mitigate the entry of a certain type of conducted disturbances will also restrict the emission of the same type of disturbances, although the effect might not be bi-directional.

This technical report presents the fundamental concepts for installation practices that limit radiated disturbances by screening and limiting the propagation of conducted disturbances across the enclosure boundaries through the use of filters, decoupling devices, and overvoltage protective devices.

5 Shielding

5.1 General

Electromagnetic shielding of buildings, rooms, compartments, cabinets, rack chassis and equipment makes it possible to ensure compliance with the EMC for equipment exposed to radiated disturbances. IEC 61000-2-5 may be used as a guide for EMC limits within each zone, and IEC 61000-2-11 and IEC 61000-5-3 together may be used as a guide to develop HEMP limits within each zone. Conversely, radiated disturbances emitted by equipment can be prevented from “polluting” the environment by enclosing it in an appropriate shielded enclosure (figure 4). Low-frequency electric fields are relatively easy to mitigate. Low-frequency magnetic fields are more difficult to screen and will involve a shield with a large wall thickness and/or a high permeability. IEC 61000-5-7 may be used to qualify the protection levels for equipment enclosures once the level of desired protection is identified.

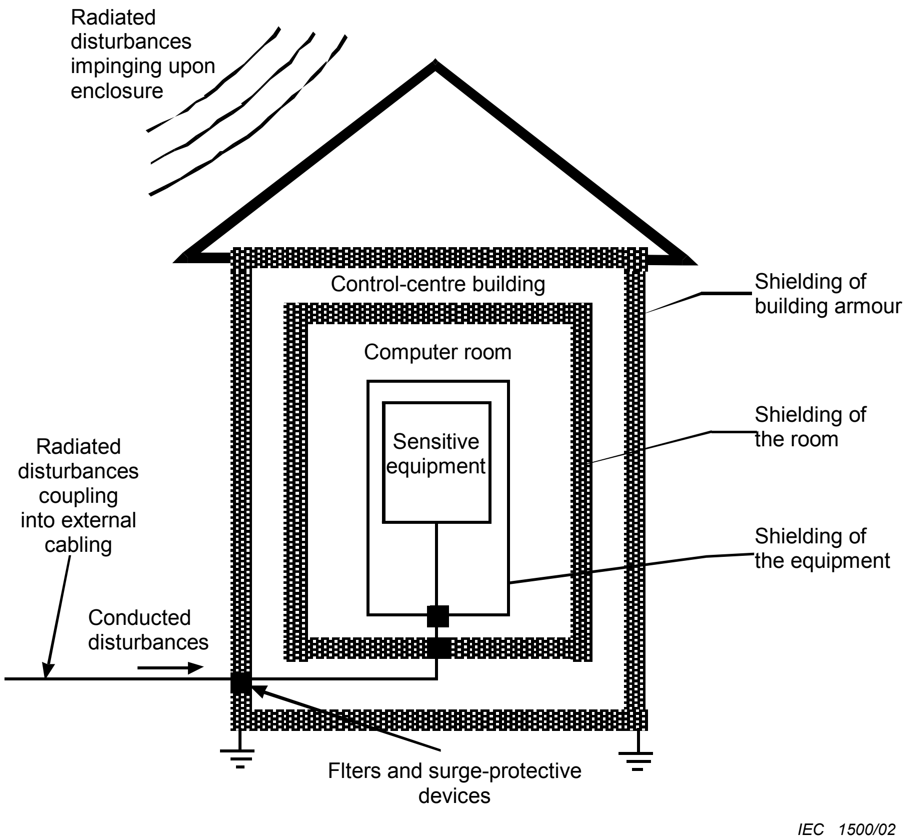


Figure 4 – Topological concept of shields with interfaces at penetration points

Screening of rooms and cabinets with appropriate penetration protection is only one of several actions that may be used to limit the effect of radiated electromagnetic disturbances. For instance, maintaining appropriate distances between emitters and victims is a relatively effective means of mitigation for radiated disturbances. Obtaining a satisfactory result may involve other actions such as

a) selecting correct cabling and wiring (adding a screen jacket over cables or wires);

b) applying good cable layout and management;

c) implementing good earthing and bonding practices;

d) using devices limiting the emissions or increasing the immunity.

Refer to IEC 61000-5-1 and IEC 61000-5-2) and to other clauses of this technical reportfor guidelines concerning these actions:

– clause 6 ;
– clause 7 ;
– clause 8 .

The objective of this clause is to present the main arrangements used in mitigation methods involving screening of installations, that is:

– introduction of the concept of mitigation zones and review of the corresponding types of shielded enclosures;
– guidance on preservation of shielding effectiveness for housings with apertures based on a set of generic EMC rules;

– generic information on the implementation of screening, progressing from the sensitive apparatus to the complete building, as well as on the means of dealing with the unavoidable apertures/penetrations.

5.2 Classification of protection zones

For the purpose of designing and applying appropriate mitigation measures, it is useful to consider a hierarchy of zones of protection, from the unprotected environment to the strong protection of especially sensitive equipment. For the purposes of this technical report, the particular zones are defined as follows:

zone 0 – no protection

zone 1 – buildings protected by reinforced concrete outdoor walls

zone 2 – rooms shielded by special materials

zone 3 – internal equipment shielded by metallic materials or metallized enclosures

zone 4 – sensitive apparatus enclosed within a special shielded rack

Figure 5 shows a schematic representation of the hierarchy of the classification for protection of zones 0 through 4. Note that not all barriers may be present in a given installation. Zones may be selected in a more arbitrary manner.

5.2.1 Zone 1 – Building shield

Zone 1 applies to buildings containing welded iron reinforcing bars for concrete outdoor walls. The reinforcement bars should be interconnected preferentially by as many welds as feasible. Thus the reinforcement forms a good earthing structure. Note that steel reinforcing bars may not always be interconnected so that a good electrical bond is made. In such situations the steel reinforcing bars may not represent an adequate shield. An important first measure is a well-designed and implemented lightning conductor with conductive connections to the earth. Conductive penetrations should be protected with appropriate limiting (surge-protective device) and filtering.

5.2.2 Zone 2 – Room shield

Zone 2 applies to indoor facilities with protection measures. In this case the shield is effective when it consists of continuously connected (welded) sheet-metal walls or walls with a metal surface. Bolted or otherwise interconnected walls will result in some degradation of the shielding effectiveness. All the screens of leads entering this zone must have a short connection to the metal walls. The penetrating leads should also be protected against overvoltages with appropriate limiting (surge-protective device) and filtering.

5.2.3 Zone 3 – Equipment shield

Zone 3 applies where individual apparatus is protected by metal cabinets or metallized enclosures. The earth connection should be a short lead to the earthing arrangement. Conductive penetrations should be protected with appropriate limiting (surge-protective device) and filtering.

5.2.4 Zone 4 – Apparatus shield

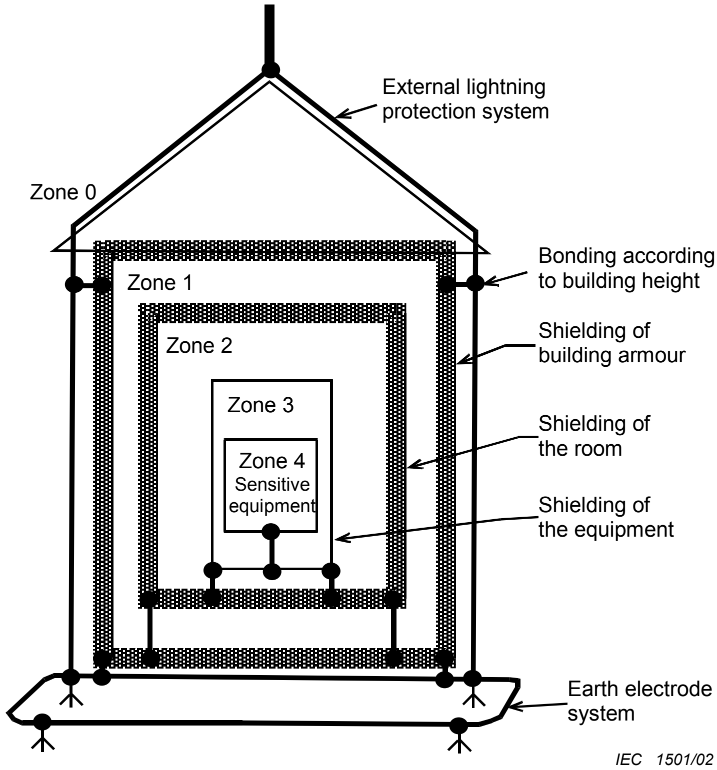


Figure 5 – Zones of protection of shielding and earthing systems

Zone 4 applies at the individual apparatus level; it is not within the scope of this technical report, but is the responsibility of the apparatus manufacturer. This zone may also include highly sensitive equipment that may require additional protection.

5.3 Design principles for screening

5.3.1 General

The design principles presented in this clause are not intended to serve as a comprehensive guide for the detailed design of a specific installation; rather, they are offered as an overview of design considerations that can serve as useful checks for a proposed installation. Providing effective screening techniques require a design by specialists, taking into consideration the specifics of the installation. By application of different materials it is possible to obtain a good shielding effectiveness over the whole disturbance spectrum of electromagnetic fields. Screening can be provided by the following materials and constructions:

– metallic enclosure or cabinets;
– rooms with continuous metallic walls;
– clamped or welded iron mats, grids and sheets inside of walls;
– metallic meshed wire or meshed screen;
– metallic or metalled fabric;
– metallic foil;
– metal sheets (copper or aluminium or other good conductive metals);
– metallized plastics with undamaged surfaces and a good contact across all seams;
– window glass with wire mesh fused in the glass or metallized glass, both continuously bonded to the wall shield.

Note that for screening against low-frequency electric fields, metallized plastic might be adequate. However, screening against low-frequency magnetic fields requires metal walls of sufficient thickness, conductivity and permeability. The electrical continuity of the walls must be ensured, especially in the case of the lower frequency magnetic fields.

5.3.2 Shielding effectiveness

The effectiveness of a shielded enclosure depends on many parameters. In theory, a shielded enclosure may be designed to produce attenuation ranging from a few dB to over 100 dB in a frequency range up to 10 GHz and beyond. However, in practice, the effectiveness of an enclosure with penetrations of all types will be reduced and limited by these penetrations. For practical purposes, the shielding effectiveness of a solid metallic cabinet or enclosure is mainly determined by the following factors:

– the disturbance currents, which should be run over the outer surface of the cabinets or in closed loops over the surfaces via connections to the earth/ground;

– the installation of penetrating cables: for good performance all signal cables penetrating the cabinet should either be filtered/limited and/or their screens should be earthed directly to the cabinet (see IEC 61000-5-2);

– the electrical length of seams of all parts of the enclosure should be as small as possible, preferably smaller than one-tenth of the wavelength of the impinging disturbance (this conditional limit is not applicable to low-frequency magnetic fields);

– the size of holes should be as small as possible relative to the incident wavelength or should be fitted with pipes (waveguide beyond cutoff); this topic is discussed further in 5.4.6.

5.3.3 Maintaining shielding effectiveness

The following is a set of simple rules that can help when checking whether a shielded enclosure is correctly installed.

a) Ensure a correct path for all common-mode currents that could flow in cables entering the enclosure.

This rule implies that screens of all cables should be connected over 360° to the wall of the shielded enclosure. It applies to all types of cables such as coaxial cables, screened multi-lead signal cables, power cables, etc. Screens may continue through the wall into the inside of the enclosure, as is for instance necessary for the correct signal transport by coaxial cables.

If the 360° circumferential contact cannot be maintained for some reason, the shortest possible connection between the cable screen and the wall, on the outside – not inside – of the enclosure, is advised. This type of connection, however, will impair the quality of the shielded enclosure, particularly at higher frequencies.

b) Ensure a correct path for all disturbance currents that could flow through any metallic object towards the shielded enclosure.

This rule applies for instance to metallic tubing for water or cooling liquid for air conditioners. Again, a 360° circumferential contact between the tubing and the wall is necessary.

c) If possible, all conductors mentioned under rules a) and b) above should enter through a single metal panel, far from large openings in the enclosure.

The metal wall of a shielded enclosure provides a short path for all common-mode currents and diverts those currents around the shielded enclosure; it thereby acts as a barrier for disturbances. Openings should normally be closed, such as doors equipped with contact strips. In some cases a double shield door may be warranted. Rule c) will still provide some protection if the doors are occasionally open. The EMC cabinet discussed in IEC 61000-5-2 is an example of this topology

d) Limit the bandwidth of the signals or power entering the shielded enclosure to the bare minimum needed for the particular signal. Employ filters and mount them correctly against the wall.

In particular, the way filters are mounted has the largest influence on their correct operation. A simple filter which is correctly mounted is preferable to an expensive filter which is incorrectly installed (refer to clause 6).

In addition, in large shielded rooms the power-input cable needs attention. A three-phase power cable, equipped with a neutral conductor and a protective earth inside an earthed screen is correctly installed if the earthed screen is circumferentially connected to the metal wall, as stipulated by rule a). The protective earth and the neutral conductors may also be connected there to the metal wall.[2]

e) If any overvoltage protection is applied at a cable to limit the differential-mode voltage, the filters mentioned in rule d) above should be mounted between the SPDs and the shielded enclosure.

Note that SPDs of the voltage-switching type (see 8.5.2) might generate new fast disturbances when they operate. The filters, mounted downstream from the SPDs, should reduce these SPD-related disturbances before they enter the shielded enclosure. Furthermore, the SPDs will serve to limit the external overvoltages impinging on the filters, allowing a more cost-effective selection of filters.

f) Ensure that all walls of the shielded enclosure form a single metallic, well-conducting surface.

Different parts of the shielded enclosure should be interconnected over their full perimeter, preferentially by welding the seams. Other good ways of ensuring conducting seams, such as many bolts or screws are allowed as well, but at a reduced shielding effectiveness. Painted surfaces divert the currents that provide the screening effect where these currents would cross the seams. Conductivity must be maintained by removing the paint and applying corrosion protection. Alternate fastener methods may also be used, such as self-tapping screws, “pop-nails”, etc.

g) All openings in the wall of a shielded enclosure should be carefully considered.

The following types of openings (apertures) might be encountered:

– a long slit, such as an open seam;
– a large circular hole;
– many small holes with the same open area as the large hole;
– holes protected by a mesh;
– holes protected by tubes or honeycomb arrays of tubes.

See 5.4.6 for further details on how to deal with these various types of apertures.

The specific implementation of a protection scheme will require a risk assessment of the overall protection so that the installation benefit/cost may be determined.

5.4 Implementation of screening

In preceding clauses, the need for screening has been described from the point of view of external influences impinging upon the facility, with a sequence of zones starting from the outside and progressing toward the equipment – the most significant part of the installation. When a facility is being designed for general EMC purposes, it is reasonable to begin the protection design from the outside and progress inward, taking advantage of an overall protection scheme, as described in IEC 61000-5-1. For HEMP environments the situation is

[2] Note that in some countries, national codes prohibit multiple connections of the neutral to the earthing system. In that case, a filter is also required for the neutral conductor.

the same, and IEC 61000-5-4 provides information on how to specify the screening levels once they are determined. When sensitive equipment is being installed in an existing building, it is more likely that any screening that would turn out to be necessary would start at the apparatus level and progress outward. Adding screening to an existing building is expensive, and its implementation will depend on the value of the equipment to be protected.

5.4.1 Sensitive apparatus

Apparatus containing sensitive components can be shielded if necessary by metallic cage(s) or by metallized plastic box(es), depending on the needs. According to the definition of apparatus, that is, “placed on the market as a single commercial unit”, the apparatus screening should be the responsibility of the apparatus manufacturer rather than the responsibility of the installer. However, if a mass-produced consumer-type apparatus designed for moderate environments is going to be installed in a harsh environment, the necessary adaptation becomes a concern for the installer.

5.4.2 Shielding of racks and chassis (zones 4/3 barrier)

Metallic racks and chassis are furnished by various suppliers who control the shielding design. Typical shielding practices involve the assembly of many individual electrical and electronic building blocks to result in a single housing. In this case a metallic enclosure increases the shielding effectiveness.

5.4.3 Shielding of cabinets (zones 3/2 barrier)

The use of shielded cabinets is necessary in the case of high electromagnetic fields, such as those greater than 30 V/m. These cabinets also provide protection against outgoing radiated disturbances.

Protection of cable penetrations can be obtained by use of special filters that are installed on the incoming cables (power and control/signal ports). These filters must have a good bonding connection to the cabinet wall. All metal parts should be bonded together with high quality, permanent connections via the shortest path to the earth/ground system. Most important is the treatment of the frame and the racks.

5.4.4 Shielding of rooms (zones 2/1 barrier)

Good-quality shielded rooms, or shielded enclosures have been in use for many years for performing electronic measurements where a low electromagnetic ambient level is necessary, or where potentially damaging emission must be contained. Refer to IEC 61000-2-5 for acceptable ambient levels. The use of shielded rooms has been extended to non-measurement applications, such as protection of personnel working near high-power radar sites or industrial RF emission sources, and protection of sensitive equipment such as medical devices, biomedical instruments and computers.

The room shield may consist of meshed conductors inside of the walls such as steel reinforcing bars, grids or metal sheets installed on the surface of walls. Figure 6 represents the shielding effectiveness of a continuous solid metallic shield with penetration protection. Shielding provided by discontinuous conductors, such as steel reinforcing bars, will be much less than shown in figure 6 (see table 1). All doors and other openings (ventilation openings, windows, etc.) must be constructed with screening material, and they must have a short bonding strap to the other screening materials.

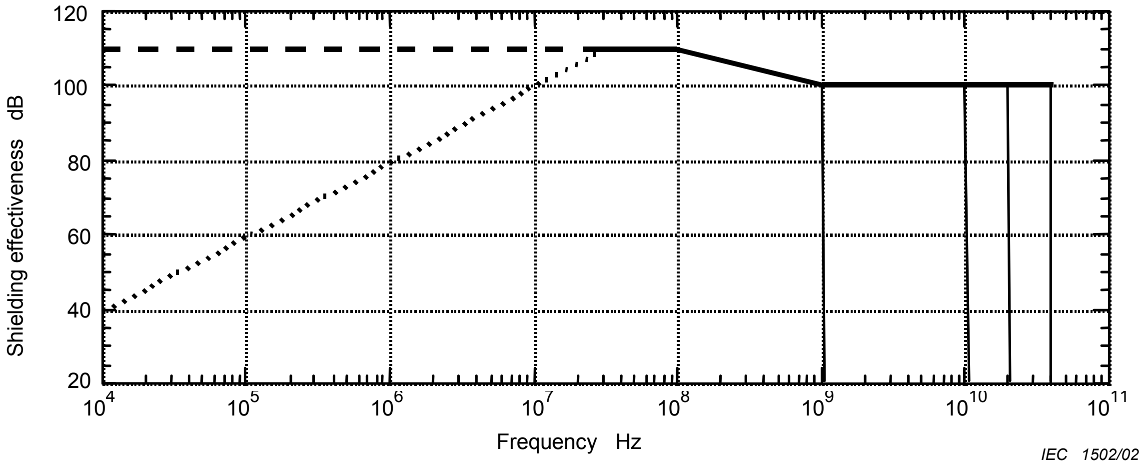


Figure 6 – Example of performance of high-efficiency shielded enclosure

5.4.5 Shielding of buildings (zones 1/0 barrier)

The reinforcement bars of a concrete building can provide a limited screening effect up to 20 dB when implemented with a view toward EMC benefits, as illustrated by the experimental measurement results of table 1. When a building consists of steel panels on a steel frame, appropriate EMC measures (bonding) applied at the time of construction can produce cost-effective benefits.

Table 1 – Measured shielding effectiveness of a 2 × 2 m cage made of concrete building armour, against a 20-ns rise-time pulse (equivalent frequency less than 20 MHz)

Type of armour			**Attenuation** dB	
Diameter mm	**Spacing** mm	**Bonding of bars**	**Electric field**	**Magnetic field**
14	200	Binding	6	4
14	100	Binding	No data	10
8	100	Binding	9	9
8	100	Welding	19	11

The shielding effectiveness of the armour can be improved by welding the connections of the reinforcement bars and adding armour grids of small diameter and small mesh. The metal frames of all openings should be bonded to the armour at multiple points.

All incoming and outgoing leads (power network or data network) should be protected against direct as well as indirect lightning discharges (see IEC 61024-1 and IEC 61312-1,-2,-3,-4,-5). These lines should have an outer metallic sheathing that is bonded to the earthing system. If an outer sheathing is not present, protection by means of a filter and/or an SPD may be necessary. Both the filter and the SPD must be connected to the nearest earthing arrangement at the point where the cables enter the building. If this is not practical, another suitable point of entry should be selected. For instance, with an antenna on the roof, the screen of the antenna cable should be connected to the local earthing arrangement of the roof. Often the screen of the cable connector can be used for this connection, providing a circumferential connection to a metallic wall. This measure is a very economical protection and far superior to a pigtail connection (a wire connecting the connector to the metallic wall).

5.4.6 Dealing with apertures

Apertures in a shield are generally unavoidable (cable entries, ventilation, windows). These openings may be designed as waveguides beyond cutoff. If they are constructed correctly, they can maintain the shielding effectiveness for a broad range of frequencies. Deliberate or unintended apertures and the uncontrolled entrance of cable jackets into enclosures create most of the weak points. Doors should have metal surfaces and contact fingers over the full circumference. Ventilation openings should be protected as indicated below. The effect of a window can be reduced by installing wire meshes, with dimensions depending on the frequency of the disturbing radiation. Window protection is available for indoor installation, and thermally insulated outer wall windows with metallic meshes sandwiched between glass plates may also be used. The achievable screening value depends on the number of mesh layers. The window mesh should be peripherally bonded to the facility shield.

Honeycombs

In a honeycomb array, the tube diameter and length should be selected for the maximum frequency at which the shielded enclosure must operate (figures 7 and 8) and should be selected so that the array tubes operate as waveguides beyond cutoff at the high frequency of interest. All tubes should form well-conducting contacts over the lines where they touch each other. Mesh or honeycomb arrays should contact the wall in which they are mounted over their full perimeter.

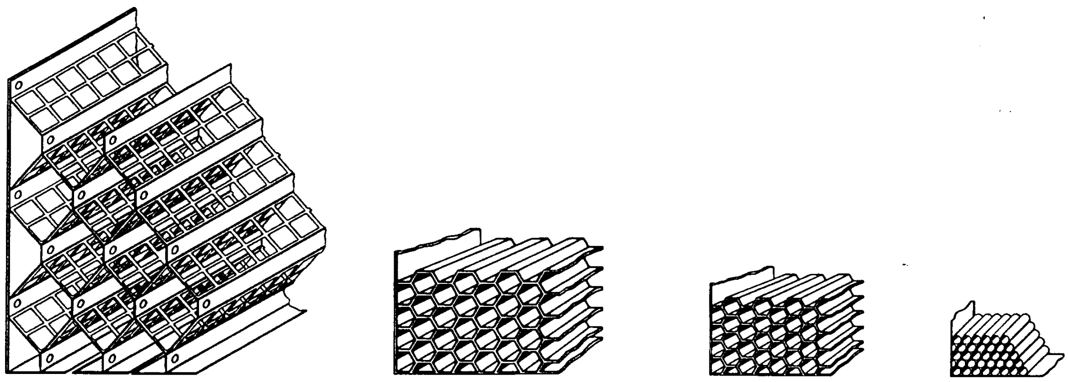


Figure 7 – Honeycomb inserts for different cut-off frequencies

Non-conductive tubing, such as water drains, should be fitted inside a metal pipe. The dimensions of the pipes should be chosen similar to the honeycomb. The pipe should contact the wall over its full perimeter. Fibre optic cables should penetrate a wall through a metallic pipe. No metal cladding or metal leads should pass through the wall with the fibre cable without proper care for the disturbance currents.

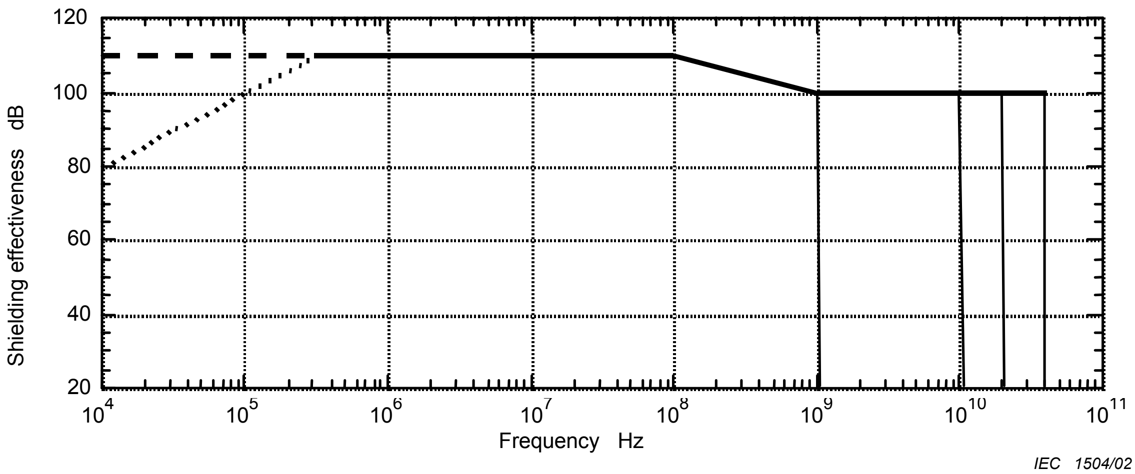


Figure 8 – Typical screening attenuation of honeycomb inserts

Conductive gaskets

Conductive gaskets are applied to reduce the effect of apertures and to maintain bonding of components of an enclosure. Such gaskets are employed for either temporary or semi-permanent sealing applications between joints or structures. The gasket is compressed between the mating surfaces to be bonded, thus providing the conductive path across the joint between them; screen currents can then flow without abrupt changes in current density across the joint, thus maintaining the ideal screen performance. Gaskets should be used to make firm, continuous and uniform contact with seam surfaces, to avoid joining only at irregular spots between the surfaces. There are three types of gaskets classified by usage:

a) permanently mounted cover plates or assemblies: gaskets for these applications include knitted wire mesh gaskets pressed into the desired gasket shape, or soft metals such as indium;

b) access cover plates with high joint unevenness, frequently opened but always closed on the same portions of the gaskets: elastomeric gaskets are used for this application;

c) removable cover plates with symmetrical mounting patterns which are replaceable but not necessarily in the original orientation: the preferred gaskets are sponge elastomers with oriented wires which exhibit low closure force and low compression set, and are removable and reusable.

Gasket types and other materials

There are many types, shapes, binders, and materials for gaskets that are designed for EMC applications, as illustrated by the following paragraphs. Their effectiveness is dependent upon the conductivity of the surfaces that require maintenance.

a) Knitted wire mesh gaskets. These are made from resilient, conductive knitted wire and they somewhat resemble the outer jacket of a coaxial cable.

b) Oriented-immersed wire gaskets. These are made with many fine parallel, transverse conductive wires providing very low parallel impedance across the gasket interface.

c) Conductive plastics and elastomer gaskets. These are made with many tiny silver balls immersed in a silicone rubber or vinyl elastomer binder and a carrier.

d) Spring-finger stock. Spring-finger contact strips now use conducting self-adhesive backing to eliminate older mechanical fastening methods. Manufacturers usually apply those strips because they facilitate a large area connection of doors to the shielded enclosure.

Gasket mounting

Several methods are available to mount the gasket onto a metal mating surface

– hold-in slot;
– pressure-sensitive adhesive;
– bond non-functional portion of gasket;
– conductive adhesive;
– bolt-through boltholes.

EMC sealants

Many types of sealants are available, such as epoxies, caulking as rubber and elastics, and grease.

a) Conductive epoxies. Conductive epoxies are used to join, bond, and seal two or more metallic mating surfaces.

b) Conductive caulking. Conductive caulking is used to screen and seal two or more metallic mating members mechanically held by other means.

c) Conductive grease. Conductive grease is a low-resistance, silver-silicone grease which contains no carbon or graphite fillers. Its principal use is for power substation switches and on suspension insulators to reduce EM disturbances.

6 Filters

6.1 General

Filters are used in power systems and in telecommunication and control system signal cables when disturbance levels do not correspond with the immunity level of the installed equipment. The general function of a filter is to limit the bandwidth; this function can be aimed at several goals, in order of decreasing importance:

– protect electronic equipment against unwanted disturbances, outside the frequency band of the intended signals;
– separate common-mode disturbances from differential-mode signals;
– limit differential-mode bandwidth to the minimum necessary operational width.

Filters can have a two-fold effect by protecting the environment from conducted disturbances generated within equipment and also by protecting the equipment against disturbances generated external to the equipment concerned. This dual role assumes that the filter and other associated mitigating devices such as SPDs are bi-directional. A common application in installations is the limiting of high-frequency disturbances through the application of low-pass filters for power lines or voice-band telephone lines.

Two kinds of filters exist: passive filters and active filters. Active filters are generally incorporated into an apparatus for the purpose of signal processing rather than protection. This type of filter is not usually bi-directional. Active filters are excluded from the scope of this technical report. Passive filters, shunt or series, are designed with a combination of passive circuit components (resistors, inductors and capacitors). These filters pass signals within the pass-band and attenuate signals at other frequencies. Filters aimed at the mitigation of low-frequency disturbances are not included in the scope of this technical report.

When the designer of an installation considers the application of filters for the purpose of preventing interference from external sources, three questions should be resolved, depending on the function of the filter:

a) Reflections: Is the filter designed to properly match the source and load impedances?

b) Insertion loss: Does the filter introduce excessive losses or distortion to the normal operating signal?

c) Non-linear performance: Are the expected disturbance levels within the operating limits of the filter? Will new disturbances be generated if limits are exceeded?

6.2 Fundamental filter characteristics

Fundamental filter characteristics include the following:

– attenuation and insertion loss;

– frequency response;

– filter characteristic impedance.

These characteristics are discussed in the following paragraphs.

6.2.1 Attenuation and insertion loss

Filters considered here are linear, passive and time-invariant two-port devices. Attenuation and insertion losses are determined by the values of the components of the filter circuit. Figure 9a and 9b shows the circuit voltages (U^*, U) and currents (I^*, I) before and after inserting the filter, respectively.

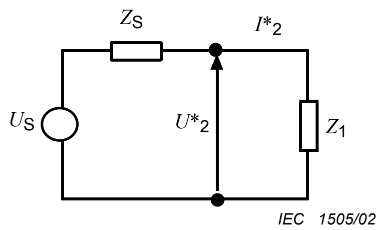


Figure 9a

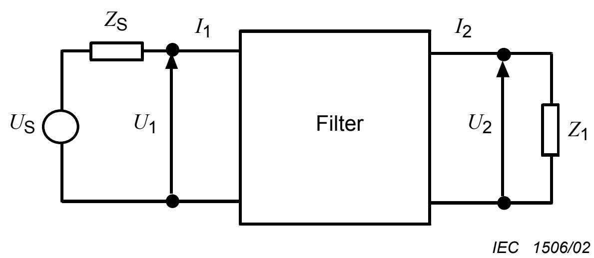


Figure 9b

Figure 9 – Parameters for attenuation and insertion loss

Attenuation and insertion loss are dependent on both the source impedance Z_s and the load impedance Z_l. The insertion loss (I) is referred to a specified test condition as shown in figure 9 and is defined as the ratio of the load voltage before and after the insertion of the filter:

$$I = U^*_2 / U_2 \quad \text{or} \quad I = 20 \log (U^*_2 / U_2) \quad \text{in dB;}$$

CISPR 17 recommends the choice of Z_S and Z_l = 50 Ω.

The attenuation can refer to different quantities, such as voltage attenuation U_S/U_2, absorption attenuation or total attenuation, depending on the characteristics of the source and load impedances.

It is common to characterize a filter with either its insertion loss or its total attenuation. Quite often, filters are chosen according to their insertion loss in a 50 Ω system where $Z_l = Z_s =$ 50 Ω. In this special case, the insertion loss is equal to the total attenuation. However, insertion loss and total attenuation are dependant on both the source impedance Z_s and the load impedance Z_l.

Note that it is not valid to compare or select filters for their 50 Ω system insertion loss if they are not to be used with those load and source impedances. This is especially true when either the source or the load is reactive.

Important: The (assumed linear) impedance of the signal source, of the filter and of the receiver protected by the filter must be known over a large frequency range, adapted to all possible disturbances, rather than to the frequency band for the signals only.

The impedance of a low-voltage power-line network assumes a large range of values, especially in the frequency range of 9 kHz to several tens of MHz. These impedances also change with time. Insertion loss or attenuation as defined above is therefore of little help in characterizing a power-line filter. In fact, a conservative design should only retain the worst possible behaviour of a power-line filter, when the network impedance assumes any random value. Such a value is called a worst-case value. Refer to 6.4“for more discussion on the worst-case parameters.

Interference suppression filters reach their highest in-band attenuation when they are mismatched with the impedance of the disturbance source, victim apparatus or the line. The simplest “low-pass filter” is a shunt-connected capacitor. In the case of a low-impedance source, the simplest low-pass filter is a series-connected suppression inductance.

6.2.2 Basic types of filters

Depending on the application, filters may be designed with RL, RC and RLC circuits in various combinations. Basic types of filters are briefly described below. In the most elementary form, filtering may be obtained by a series-connected inductance (as a ferrite bead or core threaded on a cable – saturation effects must be taken into account) or a shunt-connected capacitor. Selection of a specific filter type will depend on the application, cost and required performance.

Passive filters utilize the resonance characteristics of series and parallel combinations of inductance and capacitance. The resulting reactance reduces disturbances by introducing a high impedance in series with the disturbance currents and/or by shunting these currents to earth through a low impedance. Several types of filters can be identified.

– Low-pass filter: allows the passage of low frequencies; attenuates high frequencies.
– High-pass filter: allows the passage of high frequencies; attenuates low frequencies.
– Bandpass filter: passes a specific range of pass-band frequencies; attenuates signals with frequencies outside the pass-band.
– Stop-band filter: attenuates a specific range of frequencies within the stop-band; passes frequencies outside the stop-band.

All information concerning two-port filters can be adapted for multiport filters. In addition to the elementary filter types above, double-tuned filters are often used. These filters have one frequency at which parallel resonance occurs and another at which series resonance occurs. The former resonant frequency determines the rejected frequency, the latter the accepted frequency. The low-pass filter is the type most frequently used in EMC applications.

6.3 Functional tasks

Functional tasks of filters include

- preventing interference on an installed apparatus by limiting incoming disturbances in power, control and communication circuits (figure 10);
- reducing the outgoing electromagnetic noise in power networks and in the environment by limiting conducted disturbance emission of cables or radiation from the apparatus (figure 11);
- preventing electromagnetic interference between pieces of equipment or within the equipment itself;
- providing a preferred path for the common-mode current (not only at frequencies inside the band-pass of the filter).

With reference to a specific functional requirement, a detailed analysis is necessary, concerning

- characteristics of disturbance sources (continuous or transient type, frequency range, etc.);
- type of disturbances (common mode, differential mode, mixed type);
- necessary attenuation (value related to the frequency range);
- application conditions (characteristics and topology of the circuit to be filtered, environmental conditions, etc.);
- last but not least, the safety aspects of the installation.

Figures 10 and 11 show the functional tasks of filters with reference to disturbances appearing in common mode and in differential mode. Generally, these two types of disturbances are present at the same time, and the same filtering device could limit both of them.

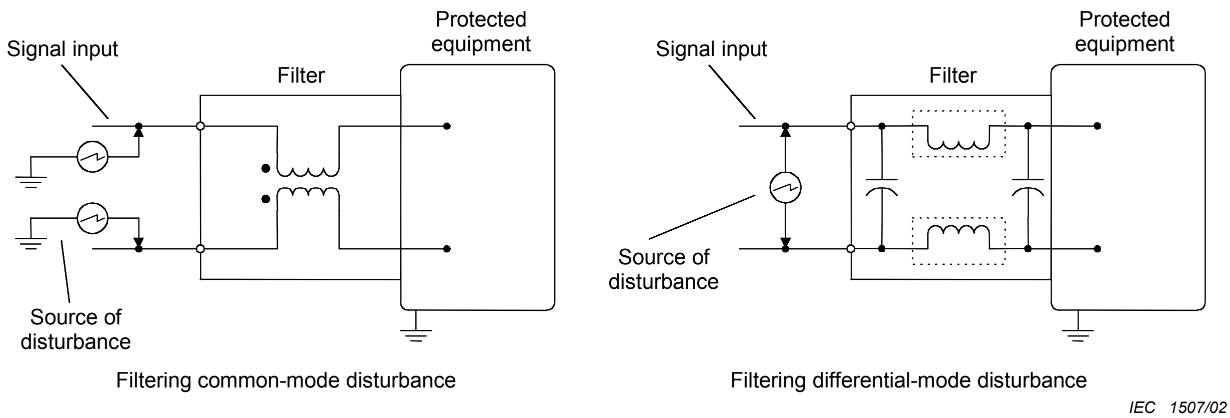


Figure 10 – Prevention of interference on installed equipment

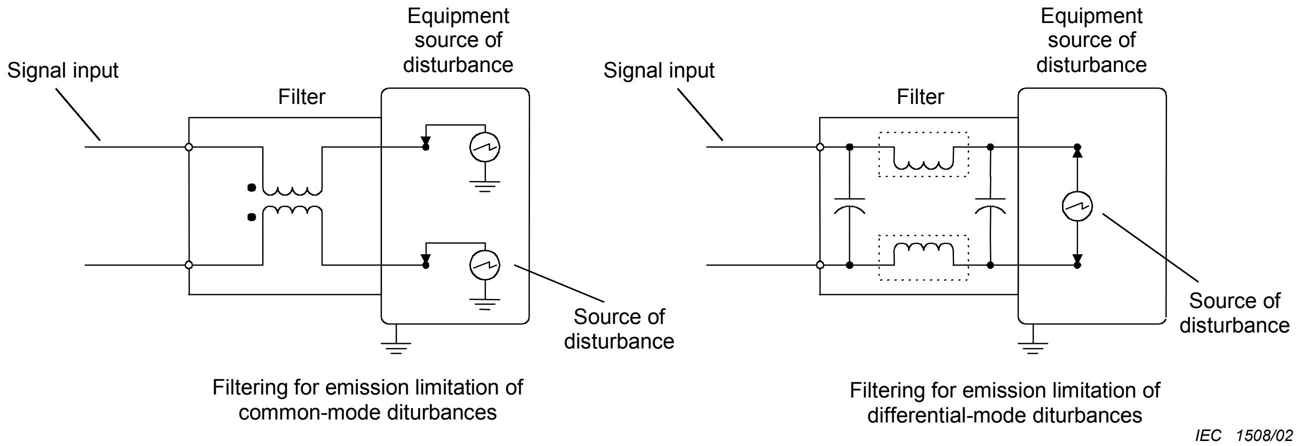


Figure 11 – Reduction of electromagnetic disturbances in the power network and the environment

6.4 Additional filtering concerns

6.4.1 Technical aspects

EMC filters are often subjected to much higher power than conventional filters. Since, for instance, power-line filters have to accommodate the normal power levels, they often will be larger in size and the high power levels could cause a non-linear response as a result of saturation.

Often the energy spectrum of the disturbance is much broader than the energy spectrum of the power, control or signal. In some cases, filtering can be performed in several stages, each one adapted to a different band.

The design of communications filters is premised on impedance matching. In power lines in particular, this is not possible, since power lines are designed to be efficient solely at the power frequency. Thus mismatch often plays a very detrimental role, namely, a drastic reduction of the claimed or expected filtering and, quite often, the occurrence of pronounced ringing.

High-peaked impulse noise combines the high energy of the noise with a very broad frequency spectrum. The presence of saturable materials in the filter inductive components should be taken into consideration.

Cascaded filters must be designed carefully so as to avoid any detrimental interactions.

6.4.2 Economic aspects

There are many alternatives to elimination or mitigation of disturbances. The decision of the most reasonable means must be based on the maximum benefit-to-cost ratio, with the benefit possibly being not much more than what is necessary. No specific single rule can be given for the decision involved, since it depends on the circumstances of the particular system under consideration and its noise environment. Rather, familiarity with all aspects of disturbance elimination and suppression is important. Filtering is quite often the most economical remedy. Filters are usually the preferred means to eliminate differential mode disturbances. The introduction of a filter close to the source can save on costly separation of wiring or on screening if the only concern is conducted disturbances.

6.5 Selection criteria

Filters should be selected and used judiciously. As in all cases of an installation including potentially sensitive equipment, it is desirable that the equipment be intrinsically immune to disturbances and thus perform satisfactorily without the use of external filters or other extensive and perhaps expensive mitigation means. However, when an external filtering action becomes necessary, filters should be applied according to the principles and guidance provided in this technical report, in order to assure proper disturbance mitigation. The first step in the process is to determine the nature of the disturbances against which the protection is necessary:

– frequency range;
– amplitude over the frequency range;
– intentional signal characteristics.

It is then possible to refer to the manufacturer's documentation. This effective application can then be achieved by referring to the filter manufacturer's documentation and tests, in order to determine whether or not the product meets the particular needs of the application. Preferably, the completed filter installation should be checked by performing final tests with the filter installed and operating as intended. If this is not possible, verification may be performed on a partial system where these operating conditions could be emulated.

Filters available on the market should be expected to meet the particular needs of the application with a reasonable EMC margin. A reasonable but misguided quest for economy could result in low-cost but less effective filters; nevertheless, one which will provide a sufficient margin should be selected. The following circuit and filter characteristics, common to all applications, should be carefully considered in the filter selection.

6.5.1 Voltage rating

Filters for the different rated voltage of the power supply are available on the market, such as 125 V, 250 V, 380 V or 440 V (see IEC 60939-2). Some manufacturers specify permissible overvoltage conditions related to a limited period of time.

Telecommunication/control line filters with proper rated voltage are available on the market for telephone circuits, digital and analogue circuits, control lines, coaxial lines, etc.

6.5.2 Current rating

Power-line filters with a wide range of rated current values are available for different applications: filtering of equipment, filtering for shielded rooms and cabinets, protection of the power network in the installation, etc. Values of rated current frequently used are 1 A, 2 A, 4 A, 6 A, 10 A, 30 A, 100 A; many other values are also available.

Filters for applications on telecommunication/control lines are generally designed for current in the range of hundreds of mA.

6.5.3 Duty-cycle and overload operating conditions

These characteristics are mainly applicable to power filters and concern intermittent operation, overloading and possible fault conditions in the power system. Overload conditions may be defined by some manufacturers as over-current related to a specified duration, such as 10 times the rated current for 1 s, 5 times the rated current for 5 s, and so on.

6.5.4 Operating frequency and range of frequencies to be filtered

Filters for d.c. or a.c. power lines are available as well as filters for the typical communications and signal lines frequencies. Low-pass filters are generally used, so any frequency higher than the operating frequency is filtered. Specific band-pass filters may also be used for telecommunication lines.

6.5.5 Voltage drop and signal loss

Power-line filters are characterized by a voltage drop depending on the load condition; at rated current this voltage drop is generally in the order of 1% of the rated voltage or less. The voltage drop of the filter is referred to the rated current and power frequency, and includes the drop across both lines of the power supply circuit.

Filters for telecommunication and control lines can produce signal loss. Values less than 1 dB, required for a proper line impedance termination condition, are generally specified by the manufacturers in the bandwidth of the signal.

6.5.6 Ambient temperature range

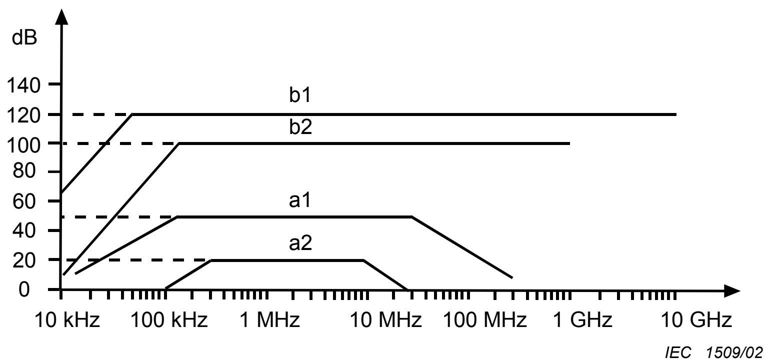
Several climatic categories are defined in IEC 60939-2. A temperature range frequently specified by manufacturers is –25 °C to +85 °C. Due to their power dissipation, power-line filters can exhibit some casing temperature rise, for instance up to 10 °C. In an assembly design, this parameter should be considered for a possible influence on adjacent components.

6.5.7 Insertion loss and attenuation

The insertion loss and the attenuation of common-mode disturbances (line-to-earth) and differential-mode disturbances (line-to-line) are dependent on the frequency and on the operating conditions.

Filters in a wide range of performances are available on the market for the different applications. Limited performances are provided by general application filters, such as in the order of 20 dB to 50 dB for common-mode and differential-mode disturbances in the frequency range 0,1 MHz to 100 MHz. With stringent mounting rules (see 6.6), higher levels of insertion loss are provided by filters for shielded rooms and cabinets; a performance of 80 dB to 120 dB is typical in the frequency range from some tens or hundreds of kHz to 1 GHz or more (figure 12).

The insertion loss of filters is typically designed and measured with the input and output terminated in an impedance of 50 ohms. In this case, the filter insertion loss may be anywhere from 80 dB to 120 dB. However, in the actual installation the line impedance may deviate from 50 ohms with an accompanying degradation in the specified insertion loss.



a1, a2: Low-cost filters for general application

b1, b2: Filters for shielded rooms and cabinets

Figure 12 – Examples of insertion loss characteristics of a.c./d.c. power port filters

6.5.8 Withstand voltage

Filters should be selected with proper withstand voltage corresponding to the line characteristics. Power-line filters are generally characterized by different values of line-to-line and line-to-earth, d.c. or a.c. withstand voltage; values starting from 1 000 V d.c. are generally specified by the manufacturer. Test voltages of power-line filters for HF disturbances are specified in IEC 60939-2. For instance, insulation to earth of 2 000 V or greater is recommended for power-line filters with a rated voltage of 125 V or more. Telecommunication or control-line filters generally present lower withstand voltages.

When filtering power or signal lines affected by transient overvoltages, attention must be paid to the surge withstand capabilities, in common mode and differential mode; the adoption of SPDs may be necessary to protect the filter and the line.

6.5.9 Attenuation of HF transient disturbances

The attenuation of transient disturbances (surges, damped oscillatory, fast transients, etc.) depends on their frequency content, the equivalent impedance of the line at the frequency of interest and the impedance of the load.

The attenuation of high-energy surges, including unidirectional surges, is generally low or insignificant; the attenuation of fast transients or oscillations in the range of MHz is better, generally of the order of a few tens of dB. These attenuation levels are generally not specified by the manufacturers of filters. For filtering power or signal lines subjected to high-energy surges, specific filters with built-in transient suppression devices are available on the market; standard filters complemented by suitable overvoltage protection can also be used.

6.5.10 Leakage current to protective earthing conductor

The shunt capacitors of the power-line filters cause a steady-state leakage current into the protective-earthing conductor. This current, combined with the contribution of the protected apparatus itself, cannot exceed the safety limits set for the different applications. For instance IEC 60335-1 specifies current limits for domestic household appliances in the range 0,5 mA to 5 mA. In order to allow the application of safety rules for equipment and installations, the leakage current of the different filters should be taken into consideration in accordance with applicable electrical installation requirements.

Filters for permanently wired shielded enclosures possess values of leakage current of the order of a small percentage of the rated current; these values imply a dedicated low-impedance connection to earth, to avoid unsafe voltages.

6.5.11 Permissible reactive current

The reactive current of power-line filters for shielded enclosures, cabinets, networks, etc., can be a significant portion of the rated current. This consideration applies especially to filters incorporating high values of capacitance, as in the case of filters for shielded rooms and cabinets, for which the reactive current and possible imbalance should be taken into consideration.

The reactive current is related to the line voltage and is not dependent on the load condition; it must be considered in the design of the power supply network, with particular care for special cases, such as the use of uninterruptible power supply systems.

6.6 Filter installation

When using filters, proper installation is essential to achieve good results; mounting techniques become critical at high frequencies. A wide range of practical solutions is available for power-line filters, for instance:

- built-in connector, also with fuse holders and main switch;
- sealed in a plastic or metal case, for printed-circuit-board mounting;
- metal case with earth terminal, connections by fast-on or screws, etc.

Typical filters for installation on shielded rooms (both power supply and telecommunication or control lines) present a feed-through construction for mounting on a metal plate; care is advised in the preparation the surfaces before the installation of filters for good electrical bonding and to avoid corrosion.

As a general rule, particularly for high-frequency disturbances, filters should be located as near as possible to the apparatus which is the source or victim, to minimize the impedance of the connection. Filters may be enclosed in the apparatus cubicle or mounted in a dedicated unit installed in its proximity. Filter installation must be consistent with the overall shield topology.

6.6.1 Installation and mounting techniques

If filter circuits consist of individual components, such as capacitors, chokes and resistors, the following should be considered:

– components should be arranged along the line to avoid capacitive and inductive coupling between components and between filter inputs and outputs;

– filters should be well screened to prevent coupling between filter inputs and outputs;

– an important safety consideration is related to the selection of the capacitors providing decoupling to earth. These capacitors should not become short circuits when damaged;

– since attenuation of a filter circuit in the MHz range is primarily determined by the capacitors connected to earth, the connecting leads of the capacitors should be as short as possible;

– filter circuits that are to be installed in devices with limited available space should be screened consistent with the shield topology;

– the metallic filter cases should have a non-corroding surface in order to ensure a low contact resistance of the case to the interface with the victim apparatus throughout an extensive period of time;

– some filter circuits that have been combined to form a filter could be subjected to different disturbance levels, or may be intended for apparatus with different immunity levels. They are therefore also designed for different degrees of attenuation. These filter circuits should be decoupled from each other by screening.

6.6.2 Wiring

Physical separation of input and output lines is facilitated by the feed-through mounting technique of the filters. Inputs and outputs of filters should be arranged as far apart as possible; leads from the input and output side should never be in the same bundle.

If screened conductors are to be connected to the filter case, coaxial screw-type connections should be used. The mounting of a filter is often more important than type of filter. Poor mounting of an otherwise good filter will produce poor filtering. The filter earth connection impedance should be as low as possible to avoid the generation of disturbances that would otherwise be applied in common mode to the apparatus to be protected. See figures 13 and 14 for examples.

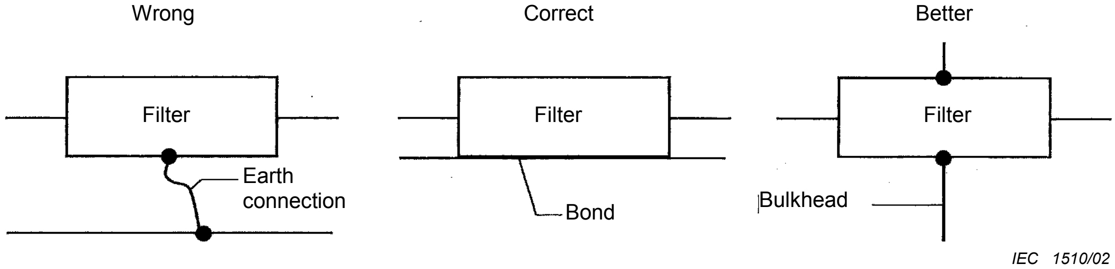


Figure 13 – Mounting of filters

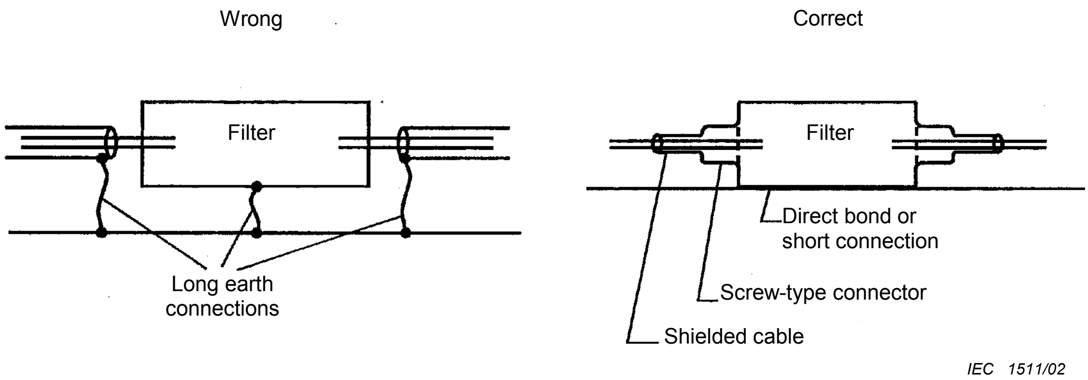


Figure 14 – Connection of screened cables

6.6.3 Installation of cabinet filters

When an installation includes the provision of cabinets or cubicles, in which several individual apparatuses will be operating, these cabinets become the responsibility of the installer, in contrast with the situation where a complete cabinet is supplied by a manufacturer.

There can be situations where the installer will be expected to provide filters where the installation wiring interfaces with this cabinet or cubicle. Figure 15 illustrates the integration of filters within a cubicle, and figure 16 illustrates an arrangement with a separate, dedicated filter unit installed adjacent to an equipment cabinet.

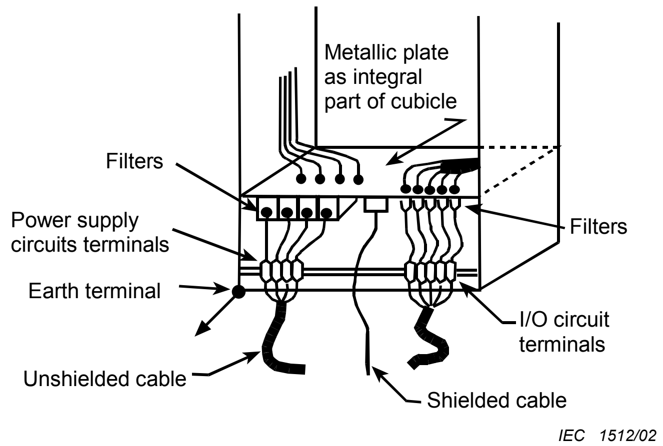


Figure 15 – Example of integration of filters inside an equipment cubicle

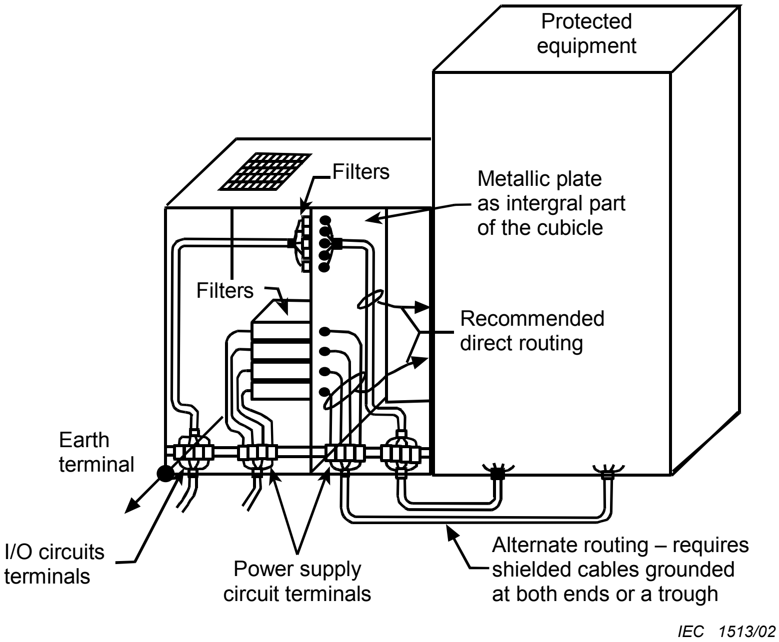


Figure 16 – Example of filter mounting in a dedicated unit

6.7 Filter testing

6.7.1 General considerations

This clause addresses testing procedures for installations that include filters, not test procedures associated with incoming reception or performance verification of filters as loose components. Consequently, the test procedures for the following parameters – essential as prerequisites for a successful system design – will not be discussed here as they are considered to be routine tests on components, not installations:

– voltage and current rating;

– duty cycle and overload conditions;

– voltage drop (power-line filters) and signal loss (telecommunications and control filters);

– climatic conditions.

Performance of filters should be verified after they are installed in the equipment or environment for which they are intended. The effectiveness of the earth connection should be assessed by measuring it by a HF conducted test. Correct installation and connections should be checked with the filters in operation, for the absence of any oscillation. The attenuation tests for transient disturbances should be made on installed filters, as described under 6.7.4.

6.7.2 Insulation to earth and withstand voltage of installed filters

Should an insulation test be advisable (in the case of tight clearances, for instance), the test procedure specified in IEC 60939-1 for testing insulation resistance and dielectric strength applies to both power port filters and telecommunication and control port filters.

Concerning the 1,2/50 µs surge test: the test generator and test procedure specified in IEC 61000-4-5 are applicable as follows. The combination wave test generator (1,2/50 to 8/20) defined in the standard should be used, with the appropriate internal impedances.

The insulation test should be carried out on the filter under no-load condition, and not connected to power supply or signal sources. The test generator may therefore be directly connected to the filter under test without using any coupling/decoupling network. The output terminals of the filter under test should be maintained opened and isolated from earth.

No sign of breakdown or flashover is allowed; any abrupt alteration in the surge waveform observed at the input terminal of the filter should therefore be investigated.

If surge testing is to be carried on *in situ*, the following safety procedures should be implemented:

– all equipment loads should be disconnected;
– everyone in the building should be warned and instructed in safety procedures;
– precautions should be taken so that transients are not inadvertently injected into circuits not under test.

6.7.3 Insertion loss

Refer to CISPR 17 for a detailed procedure of this type of tests.

6.7.4 Attenuation of HF transient disturbances

The test procedures listed in the following apply to power-port filters and to telecommunication and control-port filters. The filter working conditions should be simulated during the test; proper voltage and current should be supplied to the filter, by using an auxiliary circuit including power supply source and load. The following test generators should be used for a comprehensive test of the filter installation:

– electrical fast transient/burst generator;
– combination wave generator 1,2/50 to 8/20, with effective internal impedance of 2 Ω, 12 Ω and 40 Ω;
– ring wave generator, with effective internal impedance of 12 Ω;
– damped oscillatory wave generator.

The characteristics and performances of the test generators are specified in the relevant basic standards IEC 61000-4-4, IEC 61000-4-5 and IEC 61000-4-12. The maximum test level should be selected among the preferred values specified in the standards but should never exceed the rated withstand voltage of the filter. The test voltage should first be set with the test generator under no-load condition; then the test voltage will be applied to the input terminals of the filter under test and recorded. During the test, no malfunction of the system should be observed. Alternately, the residual voltage at the output terminals will be recorded, for both common-mode and differential-mode test conditions, to verify the attenuation of the filter as installed.

7 Decoupling devices

7.1 Isolation transformers

Isolation transformers are useful devices to break the conductive continuity of a circuit while maintaining passage of differential-mode signals (here, “signals” are understood as normal operating communication signals or a.c./d.c. power). Depending upon their application, that is, the signals to be passed through, their frequency bandpass ranges over a few kHz. Even at higher frequencies (tens of kHz), some isolation transformers are still capable of passing a substantial part of the primary differential voltage into the secondary winding.

A common misconception is that “isolation” transformers attenuate all transient overvoltages, without recognizing that, in most cases, this performance is limited to common-mode conducted disturbances. Figure 17 illustrates how a general-purpose transformer allows an impinging surge in the differential mode to pass essentially unattenuated onto a loaded secondary circuit. The only attenuation that should be expected is that corresponding to the voltage drop associated with the equivalent series impedance of the transformer. Even worse, some configurations giving rise to resonances can enhance the voltage across the secondary. Figure 18 illustrates how a transformer built with an inter-winding screen and advertised as a “super-isolation” transformer can in fact produce a higher voltage across the secondary if improperly applied with an expectation of differential-mode decoupling. The measurement, as shown in figure 18, illustrates the misconception that isolation transformers decouple all surges: it is only true for common mode, and only up to some frequency, above which inter-winding capacitance becomes significant and the decoupling effect degrades. See figure 19 for an indication of a screen connection.

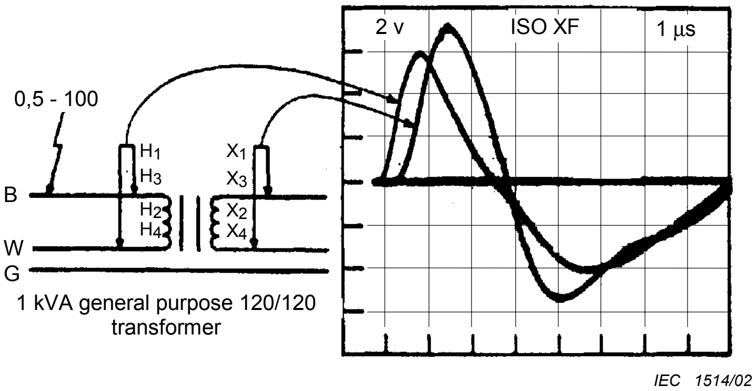


Figure 17 – Laboratory measurement showing the propagation of a 0,5 µs to 100 kHz ring wave, applied in differential mode, through an ordinary isolation transformer

Note that, in figure 18, the secondary has not been bonded to the earthing system. Such an arrangement is generally permitted only when the transformer is part of an apparatus. When the transformer is part of the fixed wiring, bonding of the secondary is generally mandated by national codes, as shown in figure 17. The proper application of an isolation transformer, therefore, is limited to breaking a common-mode circuit at low frequencies. In that role, it finds many applications for power circuits as well as communications circuits, especially when linking systems that do not have a common earthing arrangement. Of course, the insulation level between primary and secondary must take into consideration the magnitude of the overvoltages that can occur in the specific application. The stray capacitance between primary and secondary of the isolation transformer can be reduced by interposing a screen. The current through the inter-winding capacitance is most often a common-mode current from 1 and 2 to 3 and 4 in figure 19a.

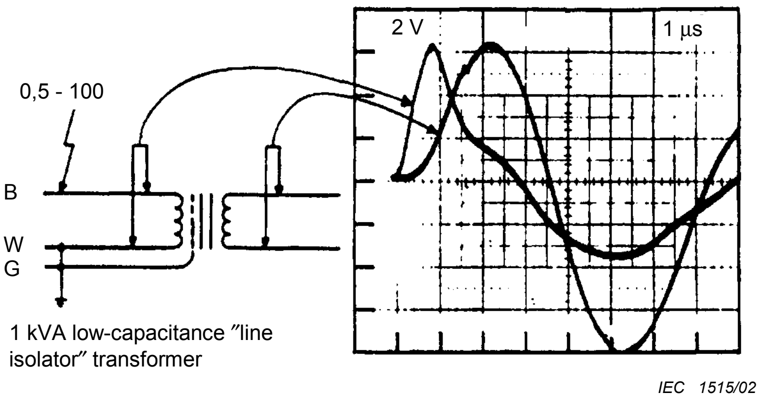


Figure 18 – Propagation of a 0,5 µs to 100 kHz ring wave operating in the differential mode through a "line isolator" transformer

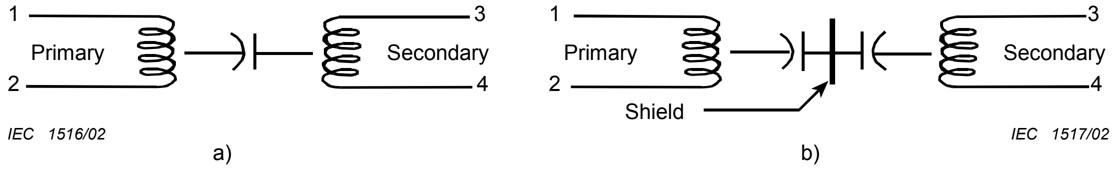


Figure 19 – Inter-winding coupling in an isolation transformer

The main benefit of the screen in figure 19b is to provide a path for that common-mode current around the secondary winding. Furthermore, this path should have a low transfer impedance i.e., the ratio of output voltage to input current, with respect to the electronics supplied by the secondary. Therefore, the screen and also the transformer core should be connected to the common earthing system via the shortest bond, if such a system is present, as shown in figure 18. If such a common earthing system is not present, the screen and core should be earthed to the earthing system at the secondary or to the low-voltage side (4) of the secondary.

If the transformer contains more than one screen, at least one screen should be connected as described above. The additional screens are often designed to reduce high-frequency capacitive differential-mode-to-differential mode (DM-DM) cross-talk. Their earthing strongly depends on the actual layout and design. Inductive DM-DM cross-talk (figures 17 and 18) cannot be reduced by additional screens. To this end, filters or SPDs should be applied.

There are a variety of devices available for power-line conditioning which can provide varying levels of decoupling. These devices fall into three general classifications: line isolation, voltage regulation, or power factor correction. Many of the products available have or claim to have some combination of more than one of these three capabilities.

Line-voltage regulators can take a variety of forms. For example, some of the oldest technology used some form of saturable reactor or inductor. These devices either change the phase relationship of the lines to adjust the output voltage or they adjust the saturation of the magnetic cores to regulate the output. Devices using these technologies do not usually provide any significant level of decoupling and may generate non-linear components.

Another form of line voltage regulators uses various forms of transformer configurations, for example, ferro-resonant transformers and tap-changing transformers. Of these devices the ferro-resonant transformer provides a certain amount of isolation by virtue of its inherent operating principle. The tap-changing transformer may or may not provide line decoupling. The decoupling capabilities of both these transformer types can be improved by the implementation of one or more of inter-winding screens, filters and SPDs.

There is also a family of line regulators that convert the incoming utility a.c. waveform to d.c. and then reconvert the d.c. back to an a.c. waveform. The technologies used to accomplish this vary, and it is beyond the scope of this document to describe them in detail. The decoupling provided by this class of product is typically quite high if the device is properly installed.

7.2 Motor-generator sets

Motor generators are another form of decoupling power-conditioning device. They completely isolate their loads from the utility service. Motor generators are configured so that the utility service drives the motor section of the device. The motor, through some arrangement of mechanical linkage, drives the generator, which in turn powers the load(s). Therefore, there is no electrical connection between the utility and the load. In special cases, it might be necessary to further enhance the decoupling by providing a non-conductive shaft for coupling the two machines. A conductive linkage may, in fact, enhance the coupled energy into the facility.

Usually motor-generators can only support the loads for a relatively short time on loss of utility power. This is because, upon loss of utility power to the motor, the only source of energy to the device is the inertial energy of its rotating components. This time can be extended somewhat through the use of an inertial mass, such as a flywheel.

Under normal conditions, there are no problems with output waveform distortions; however, there are some areas for the installation designer to be aware of. Some other areas of concern would be output voltage and frequency regulation and the overall quality of the delivered power.

7.3 Engine generators

Engine generators are not dependent at all on the local utility service. As the prime mover, the engine drives a generator which supplies the electrical energy to the loads. Energy to the prime mover is usually some form of fossil fuel, for example, diesel.

Often engine generators are used as an emergency backup to the utility service. An important economic consideration in these cases is whether or not it is necessary to provide an uninterrupted transition from utility service to engine generator service. If such a transition is desirable, then provisions must be made to sense when the utility service is failing so that the engine generator can be started and the loads switched from the utility. It should be noted that engine generators require ventilation and thereby create possible penetrations and may require special assessment procedures.

7.4 Uninterruptible power supplies (UPS)

The UPS is a class of power conditioning device which has the following general attributes.

– It is capable of sustaining power to a load after the loss of utility service.

– It can provide isolation from the service utility feed.

UPS-type devices typically use batteries as an emergency source of energy should the utility service fall below certain preset magnitudes. The length of time UPS devices can sustain the load is dependent upon the load demand and the size of the battery bank associated with the UPS.

The degree of isolation provided is determined by several factors in the intrinsic design of the particular model of UPS. There are two generic design approaches to UPS configurations, usually referred to as either off-line UPS or on-line UPS.

Off-line UPS allows utility power to service the load under normal conditions. During periods when the UPS detects certain abnormalities in the utility service, the device switches to inverter output.

On-line UPS normally services the load from its inverter output and will only switch to utility service if the device detects an error in its internal circuitry or is manually forced to switch.

In the case of off-line UPS the degree of isolation will depend on what provisions are made to condition the utility service in the normal mode of operation of the UPS. In the case of the on-line UPS there is a reasonably high degree of load isolation from the utility service intrinsic in the UPS design. This is a result of the UPS device converting the incoming utility a.c. service to a d.c. voltage and then reconverting the d.c. voltage to a conditioned a.c. voltage which is supplied to the load. For an off-line inverter type, the isolation is frequently provided by a by-pass isolation transformer inside the UPS.

There are several attributes concerning UPS that a designer needs to consider. Several have already been implied, such as the autonomy time duration desired and whether to choose an on-line or an off-line device. Some others are:

– output impedance of the UPS device. When operating in the UPS mode, these devices will have higher output impedance than the utility service. Consequently, the power quality can be affected by the load conditions such as harmonic emissions, switching, etc.;

– quality of the UPS output waveform. Various methods are employed to reconstruct the a.c. sine wave from a d.c. source. For example, pulse-width modulation, static inverters, ferro-resonant transformers, etc. Some or all of these methods can introduce certain amounts of waveform distortion. In the process of selecting the proper UPS size, both the rated power in the power system and the current peak, including the harmonic effect of the loads, are to be considered.

7.5 Optical links

The ultimate decoupling method is to eliminate electrically conducting connections across an interface. For low-energy signals, this decoupling can be obtained by optical links, either in the form of an opto-coupler or a system with optical fibre transmission. In opto-couplers, a modulated light beam is transmitted across a short air gap in a package of the type used for discrete semiconductor components. Opto-couplers are generally incorporated in apparatus and, therefore, are not addressed here in detail. Incidentally, the capacitance of opto-couplers should not be ignored when relying on a built-in device to perform the interface. When fibre links are used in an installation, similar mounting procedures as described in figures 15 and 16 should be applied.

Commercial fibre optic data transmission hardware has now reached maturity and has become a cost-effective means of decoupling for EMC purposes. In contrast with telecom applications that provide data transmission over considerable distances, decoupling fibre optic need be only long enough to provide dielectric strength commensurate with the application. However, if the transducers at the two ends of the fibre link are susceptible to EM disturbances, the expected result might not be achieved, thereby negating the potential effectiveness of the fibre. Fibre bundles may be sensitive to mechanical vibrations or to ionizing radiation. Some designs include a metal wire to facilitate pulling the bundle or provide an easy communication means for installers at the two ends of the bundle or metal cladding to provide mechanical strength. The presence of such metallic elements will likely defeat the intended decoupling.

8 Surge-protective devices

8.1 General

SPDs are used in power circuits as well as communication circuits to protect equipment from transient, high-frequency disturbances in the form of surge voltages or surge currents. In contrast to filters that are mostly used for mitigating continuous disturbances, SPDs are designed for mitigating surges that occur as single events (possibly as bursts) in a random, generally unpredictable manner. Often, SPDs are used in combination with filters.

The general approach to mitigation of surges is to establish a parallel path that can divert the surge current from the equipment, in a low-impedance path that will produce a relatively low voltage drop across the terminals of the protected apparatus. Thus, most SPDs are connected in shunt with the line, one component for differential mode and two components for common mode. Occasionally, some series elements can contribute to the mitigation by selectively limiting the propagation of the surge towards the protected apparatus. Mitigation may be performed in several stages:

– relatively slow-response, high-energy device;

– relatively faster response, with limited energy capability;

– final filtering or limiting of the residual overvoltage from upstream SPDs.

A comprehensive application guide on SPDs is beyond the scope of this technical report and involves a detailed knowledge of the surge environment ("the threat"), accurate knowledge of the apparatus immunity (sometimes difficult to determine), and of the capabilities and side-effects of various types of SPDs. Thus, the following paragraphs are aimed at providing a broad discussion of the issues rather than specific recommendations for a particular installation. Several documents are under development in the IEC, for example IEC 62066, which addresses in detail the application and installation of SPDs. In addition, for the specification of SPDs to protect against the HEMP conducted environment, IEC 61000-5-5 will be useful.

The following discussion of SPD application is presented from the point of view of enhancing EMC in low-voltage systems, both power and communications. This point of view involves two functions of an SPD:

– direct equipment protection by mitigation of stresses imposed on equipment by the voltages associated with the impinging surges;
– indirect equipment protection by prevention of large surge currents within the building wiring that would induce disturbing or destructive voltages in adjacent circuits.

8.2 Direct equipment protection

Direct equipment protection is the prime motivation for installing SPDs in power and communication circuits. This protective function can be accomplished at many points of the installation, including the apparatus itself. In that case, the SPD is under the control of the apparatus manufacturer and might appear to be outside of the scope of the present technical report. However, as discussed in 8.4, the presence of such an SPD in an apparatus can impact the overall EMC effectiveness of the installation.

Based on the postulate that surges originate mostly from the outside, an obvious location for installing an SPD is at the entrance point of the building. This provision of an SPD is applicable to the entrance of the power service as well as the entrance of a communications service (telephone, TV, telemetry). However, two other sources of surges should not be overlooked:

– switching surges created by turning power on or off within the installation (a normal occurrence), or by fault clearing with fuses or circuit breakers (a rare but potentially troublesome occurrence);
– surges associated with direct lightning strikes to the building, with the lightning current seeking a direct path toward earth through the earthing arrangement of the building. A second possibility is an indirect path through the power and communications services that carry the surge current from the building toward the remote earthed point of these services via the service entrance SPDs.

In spite of the protection offered by an SPD installed at the service entrance, many installations do not apply this benefit, claiming that their experience of no significant damage does not justify the expense. In some countries or localities, certain classes of installations are required to include this type of protection and must be monitored. Thus, in this case as in other examples, the degree of protection installed will depend on the value of the equipment to be protected and the risk that the facility owner is willing to accept.

Consequently, awareness of the risks of surge damage will frequently result in the provision of an SPD at some point of the installation. Commercial devices are available for installation at the service entrance, at service sub-panels, and as plug-in devices that can be inserted in receptacles where "sensitive" equipment is connected. A concern for this type of device is assurance that the function is maintained. Some designs include a disconnect in case of SPD failure which removes the failed SPD from the line, ensuring continuing operation of the load, but without surge protection. An indication of that condition may be provided by the SPD manufacturer (a requirement in some countries) and must be monitored.

This unregulated situation produces some confusion as no overall guidance is provided to the end-user on the performance-effective and cost-effective selection of multiple SPDs. Within the limited scope of this discussion, the following factors should be considered, with further details to be found in documents currently under development by the IEC.

– Select an SPD with voltage-limiting characteristics consistent with the level of protection desired within the system (the compatibility level in EMC terms) to achieve the prime function of the SPD.
– Select an SPD with steady-state voltage rating consistent with the maximum continuous operating voltage occurring in the system, to avoid overstressing or premature ageing of the SPD under long-term overvoltages. Select an SPD with current (energy) handling capability consistent with the current (energy) that the surge source can deliver to the SPD, to ensure long life of the SPD under repeated surge occurrences. Install SPDs consistent with the overall protection topology. That is, bonding and interconnection should be applied so that the topology is not compromised.

8.3 Installation of multiple SPDs

With the general use of SPDs, the situation is often created where several SPDs are connected across the power line, effectively in parallel (all in a line-to-neutral configuration, or in a configuration involving a line-to-earth SPD, followed by line-to-neutral SPDs), with only the wiring impedance providing a separation of the SPDs. This situation is generally described as “cascaded SPDs”, and can be the result of a deliberate, well-designed plan, or of the uncontrolled presence of SPDs.

In a well-designed plan, also designated as a “co-ordinated cascade”, the SPD located upstream, presumably at the service entrance, is selected with ratings consistent with the expected impinging surges. This is intended to divert most of that surge to earth at that point, leaving only a residual surge current to propagate inside the building. Downstream, additional SPDs may be installed to deal with the residual surge, or any surge that might be generated within the building and propagate toward specific, sensitive load equipment without the benefit of the SPD located at the service entrance. (Ultimately, the service entrance could have some action on these internally generated surges, but that action would be delayed by the round-trip time and degraded by the wiring impedance from the origin of the surge to the SPD.) These additional SPDs (which may have different characteristics) are therefore sized to handle the residual surge at a lower cost than the full-sized upstream SPD. However, this intended, deliberate unequal sharing of the surge might not be achieved if the limiting voltage of the downstream SPD is significantly lower than that of the upstream SPD. If this were the case, the downstream SPD would “draw” most of the residual surge, leaving the higher-limiting upstream SPD essentially unused, contrary to the expectation that this upstream SPD would absorb most of the surge energy. Of course, the upstream SPD will provide some degree of protection to the remainder of the equipment within the facility by virtue of its having lowered the initial surge at the building interface.

Actually, there are virtually millions of residential installations where no SPD is provided at the service entrance, which means that the built-in SPDs of the apparatus or the plug-in SPDs installed by the occupant are in fact drawing the surge current into themselves. Field experience shows that even where these internal SPDs have only a moderate surge-carrying capacity, their failure rate is not conspicuously objectionable. Thus the scenario of an uncoordinated cascade, where the service entrance SPDs does very little, is not a major threat to the survival of the equipment inside the building – as long as the apparatus involves only one port (generally the a.c. power port). Subclause 8.4 describes a scenario where multiport apparatus might be in jeopardy. In addition to this side-effect, the uncoordinated cascade is a waste of resources, as an SPD with higher limiting voltage at the service entrance is not providing any significant relief to the low-limiting SPDs built in the apparatus or plugged in by the occupant.

8.4 Side-effects of uncoordinated cascades

In an uncoordinated cascade, there is a greater likelihood that the SPD with the lowest limiting voltage will be the one installed at the end of a branch circuit. This is a result of the apparent trend of manufacturers and installation designers to expect surge voltages which are higher at the entrance of a building than inside the building. For many years, this perception was encouraged by the “staircase” of “installation categories” in IEC 60664 (1980) (later changed to “overvoltage categories”). Research on the coordination of cascades has shown that in such cases, a substantial part of the surge current is left to flow within the building, creating EM fields that couple disturbances in adjacent circuits, instead of having the surge current diverted at the service entrance. If the SPDs inside the building includes, as some do, diversion of the surge current toward the protective earth conductor, the user-end of that conductor will be raised to a potential higher than that of adjacent earthed metal, an undesirable and potentially damaging situation. This is merely an example of an application of SPDs that is inconsistent with the overall protection topology.

8.5 Typical protective devices

SPDs that may be useful to an installer include a variety of technologies, as listed below. Detailed information on the application of these devices is addressed in other documents under development and is not included in the scope of the present technical report.

8.5.1 Voltage-limiting type SPDs

This type of SPD comprises at least one non-linear component that has a high impedance when no surge is present but will reduce its impedance progressively with increased surge current and voltage. Common examples of components used as non-linear devices for this function are metal-oxide varistors and silicon avalanche diodes. A voltage-limiting type SPD has a continuous voltage versus current characteristic. Because this type of device maintains its limiting voltage while conducting the surge current, significant power is dissipated in the non-linear component, which must be sized properly for the specific application.

8.5.2 Voltage-switching type SPDs

This type of SPD comprises at least one non-linear component that has a high impedance when no surge is present, but can have a sudden change in impedance to a low value in response to a voltage surge. Common examples that use non-linear devices for this function are spark gaps, gas tubes and thyristors. These SPDs are sometimes called “crowbar type”. A voltage-switching device has a discontinuous voltage versus current characteristic. In some cases, the abrupt change in impedance can produce high rates of current changes in the protected circuit, that can induce significant disturbances in adjacent circuits.

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Typeset and printed by the IEC Central Office
GENEVA, SWITZERLAND