IEC

IEC TS 61000-5-10

Edition 1.0 2017-05

TECHNICAL SPECIFICATION

colour inside

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –
Part 5-10: Installation and mitigation guidelines – Guidance on the protection of facilities against HEMP and IEMI

IEC TS 61000-5-10:2017-05(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.20

ISBN 978-2-8322-4352-7

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 5-10: Installation and mitigation guidelines – Guidance on the protection of facilities against HEMP and IEMI

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specification IEC 61000-5-10 has been prepared by subcommittee 77C: High-power transient phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms part 5-10 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

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

Enquiry draft	Report on voting
77C/260/DTS	77C/262/RVDTS

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

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61000 series, published under the general title *Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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 the 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).

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 5-10: Installation and mitigation guidelines – Guidance on the protection of facilities against HEMP and IEMI

1 Scope

This part of IEC 61000 provides guidelines to protect commercial facilities from the high-power electromagnetic disturbances of high-altitude electromagnetic pulse (HEMP) and intentional electromagnetic interference (IEMI). These guidelines are developed from the entire body of IEC SC 77C publications.

This document is applicable to both existing facilities and new buildings when the customer has decided that protection of critical electronics from HEMP and IEMI is important to the function of the facility.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TR 61000-1-3, *Electromagnetic compatibility (EMC) – Part 1-3: General – The effects of high-altitude EMP (HEMP) on civil equipment and systems*

IEC TR 61000-1-5, *Electromagnetic compatibility (EMC) – Part 1-5: General – High power electromagnetic (HPEM) effects on civil systems*

IEC 61000-2-9, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 9: Description of HEMP environment – Radiated disturbance*

IEC 61000-2-10:1998, *Electromagnetic compatibility (EMC) – Part 2-10: Environment – Description of HEMP environment – Conducted disturbance*

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

IEC 61000-2-13, *Electromagnetic compatibility (EMC) – Part 2-13: Environment – High-power electromagnetic (HPEM) environments – Radiated and conducted*

IEC 61000-4-23:2016, *Electromagnetic compatibility (EMC) – Part 4-23: Testing and measurement techniques – Test methods for protective devices for HEMP and other radiated disturbances*

IEC 61000-4-24, *Electromagnetic compatibility (EMC) – Part 4-24: Testing and measurement techniques – Test methods for protective devices for HEMP conducted disturbance*

IEC 61000-4-25, *Electromagnetic compatibility (EMC) – Part 4-25: Testing and measurement techniques – HEMP immunity test methods for equipment and systems*

IEC TR 61000-4-32, *Electromagnetic compatibility (EMC) – Part 4-32: Testing and measurement techniques – High-altitude electromagnetic pulse (HEMP) simulator compendium*

IEC 61000-4-33, *Electromagnetic compatibility (EMC) – Part 4-33: Testing and measurement techniques – Measurement methods for high-power transient parameters*

IEC TR 61000-4-35, *Electromagnetic compatibility (EMC) – Part 4-35: Testing and measurement techniques –HPEM simulator compendium*

IEC 61000-4-36:2014, *Electromagnetic compatibility (EMC) – Part 4-36: Testing and measurement techniques – IEMI immunity test methods for equipment and systems*

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

IEC TR 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*

IEC 61000-5-5:1996, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 5: Specification of protective devices for HEMP conducted disturbance*

IEC TR 61000-5-6, *Electromagnetic compatibility (EMC) – Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences*

IEC 61000-5-7:2001, *Electromagnetic compatibility (EMC) – Part 5-7: Installation and mitigation guidelines – Degrees of protection provided by enclosures against electromagnetic disturbances (EM code)*

IEC TS 61000-5-8, *Electromagnetic compatibility (EMC) – Part 5-8: Installation and mitigation guidelines – HEMP protection methods for the distributed infrastructure*

IEC TS 61000-5-9, *Electromagnetic compatibility (EMC) – Part 5-9: Installation and mitigation guidelines – System-level susceptibility assessments for HEMP and HPEM*

IEC 61000-6-6, *Electromagnetic compatibility (EMC) – Part 6-6: Generic standards – HEMP immunity for indoor equipment*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms, definitions and abbreviated terms apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
attenuation
reduction in magnitude (e.g., as a result of absorption and/or scattering) of an electric or magnetic field or a current or voltage

Note 1 to entry: It is usually expressed in dB.

3.1.2
bandratio
br
ratio of the high and low frequencies between which there is 90 % of the energy

Note 1 to entry: If the spectrum has a large DC content, the lower limit is nominally defined as 1 Hz.

3.1.3
conducted HPEM environment
totality of high-power electromagnetic currents and voltages that are either coupled to or directly injected into cables and wires with voltage levels that typically exceed 1 kV

3.1.4
continuous wave
CW
time waveform that has a fixed frequency and is continuous

3.1.5
coupling
interaction of HEMP/IEMI fields with a system or equipment to produce currents and voltages on system surfaces, cables and wires

3.1.6
E1, E2, E3
terminology for the HEMP electric fields

Note 1 to entry: E1 is early time HEMP electric field, for times less than 1 µs, E2 is intermediate time HEMP electric field, for times between 1 µs and 1 s, and E3 is late time HEMP electric field, for times greater than 1 s.

3.1.7
electromagnetic compatibility
EMC
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[SOURCE: IEC 60050-161:1990, 161-01-07]

3.1.8
electromagnetic disturbance
any electromagnetic phenomenon which may degrade the performance of a device, equipment or system

[SOURCE: IEC 60050-161:1990, 161-01-05, modified – the last part of the definition has been deleted.]

3.1.9
electromagnetic interference
EMI
degradation of the performance of a device, transmission channel or system caused by an electromagnetic disturbance

Note 1 to entry: Disturbance and interference are respectively cause and effect.

[SOURCE: IEC 60050-161:1990, 161-01-06, modified – in the definition "equipment" has been replaced by "device" and a new note has been added.]

3.1.10
shield
electromagnetic shield
electrically continuous housing for a facility, area, or component used to attenuate incident electric and magnetic fields by both absorption and reflection

3.1.11
(electromagnetic) susceptibility
inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

Note 1 to entry: Susceptibility is a lack of immunity.

[SOURCE: IEC 60050-161:1990, 161-01-21]

3.1.12
equipment
modules, devices, apparatuses, subsystems, complete systems and installations

3.1.13
equipment under test
EUT
particular equipment being subjected to the test

3.1.14
high-altitude electromagnetic pulse
HEMP
electromagnetic pulse produced by a nuclear explosion outside the earth's atmosphere

Note 1 to entry: This typically occurs above an altitude of 30 km.

3.1.15
high-power microwaves
HPM
narrowband signals, nominally with peak power in a pulse, in excess of 100 MW at the source

Note 1 to entry: This is a historical definition that depended on the strength of the source. The interest in this document is mainly on the EM field incident on an electronic system.

3.1.16
hyperband signal
signal or waveform with a pbw (see 3.1.21) value between 163,4 % and 200 % or a bandratio > 10

3.1.17
hypoband signal
narrowband signal or waveform with a pbw of < 1 % or a bandratio < 1,01

3.1.18
installation
combination of apparatuses, components and systems assembled and/or erected (individually) in a given area

Note 1 à l'article: For physical reasons (e.g. long distances between individual items) it is in many cases not possible to test an installation as a unit.

3.1.19
intentional electromagnetic interference
IEMI
intentional malicious generation of electromagnetic energy introducing noise or signals into electric and electronic systems, thus disrupting, confusing or damaging these systems for terrorist or criminal purposes

3.1.20
mesoband signal
signal or waveform with a pbw value between 1 % and 100 % or a bandratio between 1,01 and 3

3.1.21
percentage bandwidth
pbw
bandwidth of a waveform expressed as a percentage of the centre frequency of that waveform

Note 1 to entry: The pbw has a maximum value of 200 % when the centre frequency is the mean of the high and low frequencies. The pbw does not apply to signals with a large DC content (e.g., E1 HEMP) for which the bandratio decades term is used.

3.1.22
port of entry
PoE
physical location (point) on an electromagnetic barrier, where EM energy may enter or exit a topological volume, unless an adequate PoE protective device is provided

Note 1 to entry: A PoE is not limited to a geometrical point.

Note 2 to entry: PoEs are classified as aperture PoEs or conductive PoEs according to the type of penetration. They are also classified as architectural, mechanical, structural or electrical PoEs according to the functions they serve.

3.1.23
pulse
transient waveform that usually rises to a peak value and then decays, or a similar waveform that is an envelope of an oscillating waveform

3.1.24
pulse width
time interval between the points on the leading and trailing edges of a pulse at which the instantaneous value is 50 % of the peak pulse amplitude, unless otherwise stated

3.1.25
radiated HPEM environment
totality of high-power electromagnetic fields with peak electric field levels that typically exceed 100 V/m

3.1.26
rise time (of a pulse)
time interval between the instants in which the instantaneous amplitude of a pulse first reaches specified lower and upper limits, namely 10 % and 90 % of the peak pulse amplitude, unless otherwise stated

[SOURCE: IEC 60050-161:1990, 161-02-05, modified – the note has been incorporated into the definition

3.1.27
source impedance
impedance presented by a source of energy to the input terminals of a device or network

3.1.28
sub-hyperband signal
signal or waveform with a pbw value between 100 % and 163,4 % or a bandratio between 3 and 10

3.1.28
system
combination of apparatuses and/or active components constituting a single functional unit and intended to be installed and operated to perform (a) specific task(s)

3.1.29
transient, adj. and noun
pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval which is short compared with the time-scale of interest

Note 1 to entry: A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity.

[SOURCE: IEC 60050-161:1990, 161-02-01, modified – a note has been added.]

3.1.30
waveguide below cutoff
WBC
a waveguide which severely attenuates the electromagnetic fields at frequencies below the cutoff frequency

3.2 Abbreviated terms

CW	Continuous wave
DS	Damped sinusoid
EMI	Electromagnetic interference
ESD	Electrostatic discharge
EUT	Equipment under test
HEMP	High-altitude electromagnetic pulse
HIRF	High-intensity radiated fields
HPEM	High-power electromagnetic
HPM	High-power microwave
LV	Low voltage
MOV	Metal oxide varistor
MV	Medium voltage
PoE	Port of entry
SE	Shielding effectiveness
SPD	Surge protective device
VPD	Vertically polarized dipole
WBC	Waveguide below cutoff

4 General

IEC SC 77C has developed a wide variety of high-altitude electromagnetic pulse (HEMP) and intentional electromagnetic interference (IEMI) protection reports and standards, and the growth of these publications has been organic, responding to the needs of industry. In addition, some of the standards are being revised to be more specific and useful to industry. IEC SC 77C publications are currently found in many parts of the IEC 61000 series including:

IEC 61000-1: General – two publications

IEC 61000-2: Environment – four publications

IEC 61000-4: Testing and measuring techniques – seven publications

IEC 61000-5: Installation and mitigation guidelines – seven publications

IEC 61000-6: Generic standards – one publication

As the aim of the entire work program in IEC SC 77C is to determine the likely disturbance levels from HEMP and IEMI and to develop protection and test methods to protect electronics from these disturbances, it is felt that a comprehensive guide to consolidate this work will be of great help to industry. In addition all of the IEC SC 77C references used in this document can be considered normative in nature as this document indicates how they are applied.

This document includes several specific examples of how to apply the publications in the IEC SC 77C series. The sample problems should include:

a) application of a protection and testing scheme for the design of a new facility,
b) application of a protection and testing scheme for an existing facility.

For both applications, protection and testing schemes need to be identified for three cases:

1) a HEMP protection and testing scheme;
2) an IEMI protection and testing scheme; and
3) a HEMP plus IEMI protection and testing scheme.

This means there are six schemes covered in this document.

As the aim of this work is to provide protection information dealing with the entire group of IEC SC 77C publications, we recommend that this publication be part of the IEC 61000-5-x series.

Annex A of this publication provides a summary of the scope (Clause 1) of each of the documents within the entire body of IEC SC 77C publications at the beginning of this project, followed with additional discussion concerning the applicability of each of the publications to this document. In most cases the text in the main body will refer to particular standards, and the reader is encouraged to look at Annex A to obtain more information.

5 Development of the environment levels

5.1 General

In order to describe the electromagnetic environments of HEMP and those that produce IEMI, one should refer to IEC 61000-2-9 (radiated) and IEC 61000-2-10 (conducted) for the HEMP, and IEC 61000-2-13 and IEC 61000-4-36 (both cover radiated and conducted environments) for the HPEM environments producing IEMI. For HEMP the standard waveforms (for E1, E2, and E3) are to be used to define the hardening and testing approach. For IEMI the situation is more complex, as there is a wide variety of pulsed waveforms with different parameters that can be produced (both narrowband and wideband), and the peak levels of fields potentially exposing electronics depend both on the technology of the IEMI weapon (discussed in IEC 61000-2-13) and the distance of deployment. In particular it is necessary to be sure to clearly establish the radiated and conducted environments for both threats.

5.2 High-altitude electromagnetic pulse (HEMP)

The radiated HEMP environment is fully defined in IEC 61000-2-9, and it provides worst-case time and frequency waveforms that are to be used for protection design. For facilities, which possess electronics inside building structures, the emphasis on the protection of facilities will be mainly for the early time E1 HEMP disturbances. As such the E1 HEMP Fourier transform is a composite of the expected HEMP waveforms for all scenarios, and therefore it is appropriate for evaluating the shielding effectiveness required to reduce the external E1 HEMP fields to levels such that the electronics inside building structures can survive and continue to maintain function. The E2 HEMP radiated environment is not a significant concern for the electronics inside building structures as the level is low, although the conducted E2 HEMP environment could be important to ensure that E1 HEMP filters can survive. It is also true that the E3 HEMP could create serious stability issues for the operation of the public utility electrical grid due to harmonics in the power supply (harmonics of 50 Hz or 60 Hz), and it is likely that some of these harmonics will propagate from the high voltage grid to the low voltage grid and through the E1 HEMP filters. In general, however, the shielding for radiated fields is aimed only at reducing the E1 HEMP fields.

For the conducted HEMP environment it is important to recognize that the conducted E1 HEMP fields couple differently to external power and telecommunications cables as a function of whether they are elevated or buried cables. As indicated in IEC 61000-2-10 the induced E1 HEMP currents on above ground cables can be more than 10 times higher than for a buried cable. The E2 and E3 coupling is also defined in IEC 61000-2-10, although E3 is relevant for the power network itself, and the impact on a building operating at low voltage will be the harmonics generated in the transmission grid (especially the 2^{nd} harmonic) that can propagate to the low voltage system and into a building. Since these harmonics are close to the fundamental frequency, they cannot be filtered. There is also an important Annex C in IEC 61000-2-10:1998 that discusses E1 HEMP coupling to simple antennas. Antennas need to be evaluated both with respect to the E1 HEMP in-band signal that will reach transmitters and receivers in the building and the common mode currents on the shields of cables leading to the facility (this requires proper high frequency grounding).

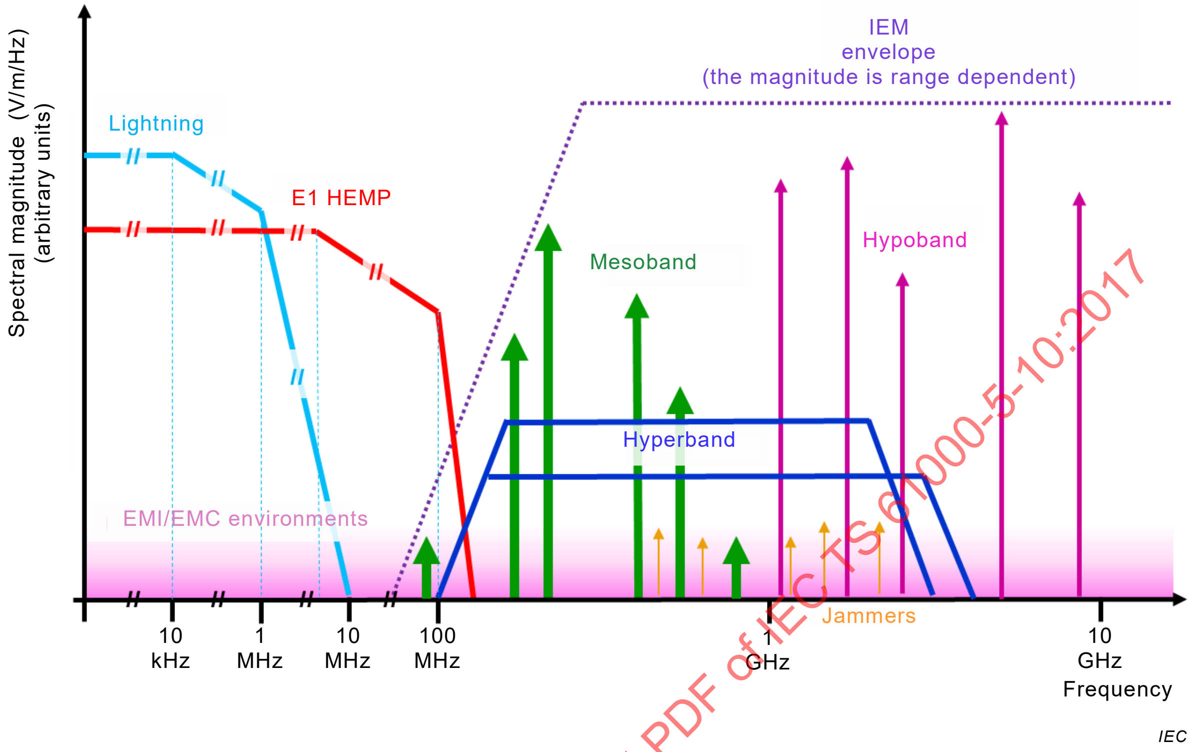
One should also consider the level of protection that may be needed as a function of the “importance” of the facility. IEC 61000-2-11 considers that some facilities may not require as high a level of shielding effectiveness due to their ability to respond to temporary outages with on site personnel or with regard to their mission. Since IEC 61000-2-11 has six levels (and some sublevels), these are probably too much for this document to consider. This document proposes that a shielding effectiveness of ~60 dB is practical and useful as a well-shielded option for new critical national infrastructure buildings. For existing buildings for retrofit purposes a lower level of shielding effectiveness of ~30 dB is considered practical, largely due to cost factors. This is discussed further in 6.2.2.

5.3 Intentional electromagnetic interference (IEMI)

The main information in the IEC SC 77C documents comes from IEC 61000-2-13, which provides the basic radiated and conducted IEMI disturbances for both narrowband and wideband sources. Although this document properly describes the types of waveforms that can be created, a newer publication, IEC 61000-4-36, provides a broader range of wideband and narrowband test waveforms that may be easier to use. It is suggested that one should select a set of waveforms that describe the range of disturbances that need to be dealt with from a protection point of view. As an approximation, this document will focus on the peak field levels of both wideband and narrowband radiated IEMI fields. With the assumption that the shielding effectiveness can be designed for frequency content between 1 MHz and 10 GHz (due mainly to reflection), then the focus for protection is shifted to computing the peak radiated fields inside a facility. In addition, it is possible that conducted IEMI disturbances can be injected into power and communications lines outside a facility and should also be considered.

5.4 Comparison of the HEMP and IEMI radiated fields

Figure 1 compares the frequency spectra of the E1 HEMP and the narrowband and wideband IEMI radiated fields. The E1 HEMP electric field has spectral magnitude up to 1 GHz, while the IEMI radiated environments extend to frequencies of about 10 GHz. While it is possible that weapons can produce even higher frequency content (above 10 GHz), it is also clear that as the frequency content becomes higher, the typical susceptibility levels of the electronics also rise. This is believed to be related to the fact that wiring inside and outside equipment behaves as receiving antennas, and the power levels of coupled signals decrease as the square of the wavelength [1][1].



NOTE Adapted from IEC TR 61000-1-5, IEC 61000-2-9 and IEC 61000-2-13.

Figure 1 – Comparison of IEMI radiated environments with those of E1 HEMP and lightning

6 Protection and testing approach for new facilities

6.1 General

As an example of designing a new facility for HEMP protection, where the importance of the facility is evaluated to be high, consider a minimum 60 dB shielding level target for constructing a new shielded building. It is noted that the use of the term shielding effectiveness (SE) in this document refers to the reduction of external disturbances in the time domain. It is important to recognize that to reduce the EM fields inside a facility requires not only metallic walls, but also careful treatment of all apertures and wire penetrations. Fortunately power filters are currently available on a commercial basis to achieve time domain reductions required for transients injected from the power system into a building. In addition surge arresters can be used on other signal wires, although in many cases the use of a non-metallic fiber optic cable fed through a waveguide below cutoff provides a better alternative.

For facilities of perhaps lower "importance" or where some degradation of performance of electronics inside the facility can be tolerated, a lower level of protection (10 dB to 40 dB) could be considered. In this case careful selection of traditional building materials and architectural shielding techniques can be used to enhance the natural attenuation of the structure.

1 Numbers in square brackets refer to the Bibliography.

It is likely that with the proper protection and test procedures, it should be possible to protect against the IEC E1 HEMP radiated field and most “reasonable” levels of radiated environments that can produce IEMI. IEC standards cover nearly all of the needed aspects of protection as discussed in 6.2, 6.3, 6.4 and Clause 7.

6.2 HEMP protection for new facilities

6.2.1 General

Subclauses 6.2, 6.3 and 6.4 of this document identify the basic hardening approach to be applied for new facilities. A representative illustration (see Figure 2) from IEC TR 61000-1-5 displays the main aspects required for protection, including the treatment for antennas.

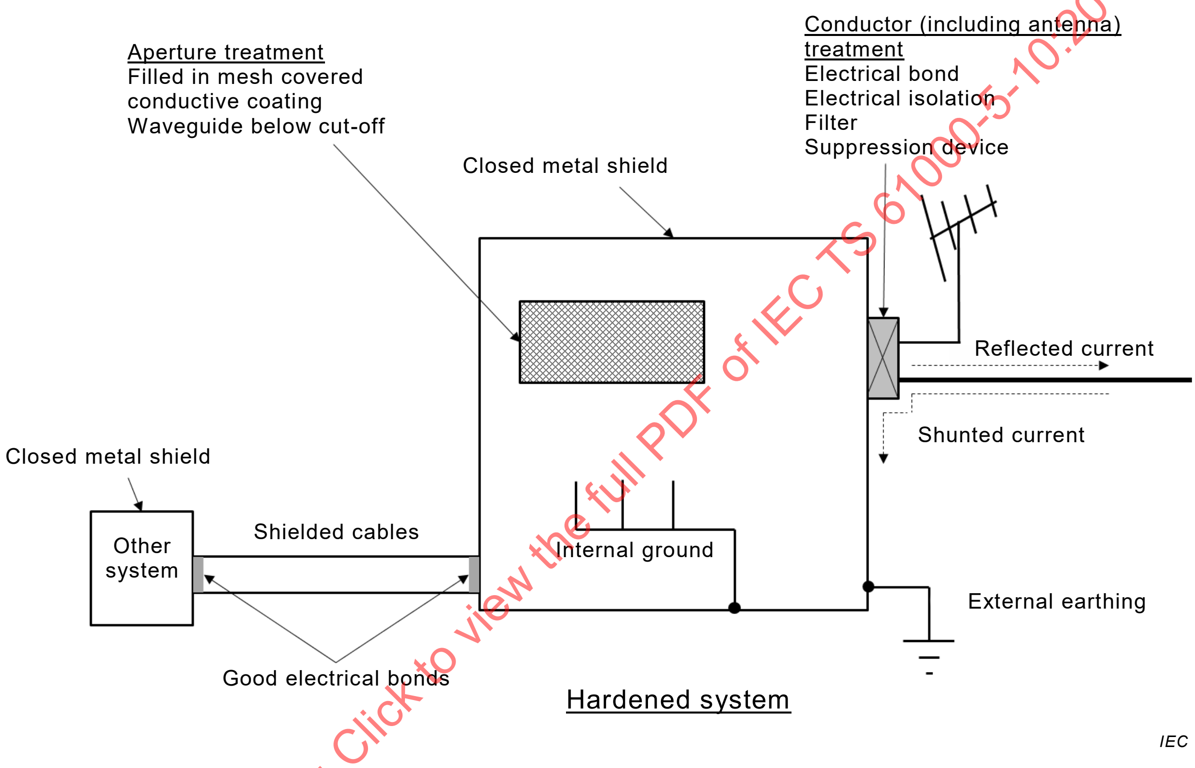


Figure 2 – Basic high frequency shielding approach for a building

Each of the aspects in Figure 2 will be discussed in this document, and the following discussion in the remainder of Clause 6 and in Clause 7 will make reference to both the protection techniques and the test methods required to verify that the performance of the protection elements are satisfactory.

6.2.2 Electromagnetic shield

Several of the publications of IEC SC 77C have dealt with developing HEMP hardening concepts (IEC 61000-2-11), including the definition of test levels for equipment as a function of the hardening concept applied to their building concept (IEC 61000-4-25). In the HEMP generic standard (IEC 61000-6-6) the protection concepts are evaluated, and the basic immunity requirements for equipment inside different buildings are developed. One of the tables from the generic HEMP standard is shown in Table 1.

It is noted that Table 1 provides very general categories of protection, which include electromagnetic shielding to reduce the fields inside a facility, so they do not couple high levels of induced currents and voltages on internal cabling or couple directly to the equipment cases. In addition to the reduction of the EM fields, each concept also requires a reduction of external currents and voltages induced on different types of external conductors that penetrate the shield. These conductors are referred to as PoEs, including those associated with power, telecommunications, data ports, and antenna signals. While the reductions are not precisely balanced between the radiated and conducted disturbances, the intent is to ensure that if a high level of RF shielding is achieved it is necessary to ensure that a high level of PoE protection is also achieved. This will allow in some cases that no further effort is required to harden equipment inside a building if the protection level is high (e.g. concept 6 in Table 1).

Table 1 – Radiated and conducted environments for early time HEMP and concepts 1 to 6 (IEC 61000-6-6)

Concept	Equipment location	Radiated disturbance[a], kV/m	Conducted disturbance AC power and telecom, kV	Conducted disturbance I/O data ports[b], A	Conducted disturbance Exterior antennas[c], kV
6	Within a room or building with excellent RF shielding (80 dB) and PoE protection (80 dB)	0,005	0,015	0,0075	0,007
5	Within a room or building with good RF shielding (60 dB) and PoE protection (60 dB)	0,05	0,150	0,075	0,07
4	Within a room or building with good RF shielding (40 dB) and nominal PoE protection (40 dB)	0,5	1,5	0,75	0,72
3	Within a structure with some shielding (20 dB) and nominal PoE protection (40 dB)	5	1,5	7,5	0,72
2B	Within a structure with metal or rebar shielding (20 dB) and nominal lightning protection at the exterior antennas and the AC mains (20 dB)	5	60	7,5	4
2A	Within a structure with metal or rebar shielding (20 dB) without lightning protection at the exterior antennas and the AC mains (0 dB)	5	600 25[d]	7,5	1 800/f 450 ≥ f ≥ 25 (f is expressed in MHz)
1B	Within a poorly shielded building or residence (0 dB) with nominal lightning protection at the exterior antennas and the AC mains (20 dB)	50	60	75	4
1A	Within a poorly shielded building or residence (0 dB) without lightning protection at the exterior antennas and the AC mains (0 dB)	50	600 25[d]	75	1 800/f 450 ≥ f ≥ 25 (f is expressed in MHz)

a The radiated environment does not include ESD performance but the ESD test is required by this document for protection against internally generated transients. The ESD environment is defined in IEC 61000-4-2.

b Bulk cable current for a 10 m signal cable. For longer cables, increase the current proportionally to a length of up to a maximum of 100 m.

c The exterior antenna response depends on the size of the antenna and is approximately equal to 1 800/f kV where f is the centre frequency of the antenna for 450 MHz ≥ f ≥ 25 MHz. If nominal lightning protection is used at the antenna, the response will be about 4 kV. Lightning protection is assumed for protection concepts 1B and 2B. For protection concepts 3 to 6, the response for a 25 MHz antenna is used to maximise the severity level. Consult an HEMP specialist to determine the appropriate test values for antennas that operate out of the frequency range indicated above.

d For underground lines without insulation breakdown, the time waveform is 25/500 ns wave with a 50 Ω source impedance. Insulation breakdown may modify the actual disturbance.

It is noted in Table 1 that for new buildings both concepts 5 and 6 look acceptable for the electronics equipment inside the facility from an EMC point of view. The residual conducted environments are much lower than those normally tested for residential EMC immunity (IEC 61000-4-4, IEC 61000-4-5 and IEC 61000-6-1). The E1 HEMP radiated environments are pulsed waveforms with peak values of 5 V/m and 50 V/m (concepts 6 and 5) which are higher than the CW test levels in IEC 61000-4-3, but equipment failures due to HEMP waveform testing do not normally occur below 1 kV/m (IEC TR 61000-1-3).

For retrofit hardening, the expense of the shielding installation and the options available for shielding can be much higher than for new construction, so it appears that a protection concept between 3 and 4 would be appropriate (for preventing damage). This means that for the radiated fields the goal should be to achieve 30 dB attenuation, while achieving 40 dB for the conducted environments. It is important to recognize that the protection of the commercial power entry is one of the most important conductive penetrations because above ground power lines are often exposed to a very high level by HEMP. Therefore special power filters shall be used and tested according to IEC 61000-4-24.

A level of 60 dB attenuation should be sufficient for critical or 'important' commercial facilities, and in some cases a level of 30 dB allowing equipment to upset on a temporary basis should be allowed (damage would not be allowed). The testing of the shield should not be performed until all of the other elements of protection have been added (waveguides, filters, doors, grounding system, etc.). Then the test methods of IEC 61000-4-23 can be used to validate the shielding effectiveness of the shield.

Another aspect is the external grounding of the facility at high frequencies (above 1 MHz). There are techniques such as circumferential bonding of cable connectors, and even clamping techniques with low inductance ground cables that allow the extension of lightning grounding practices to higher frequencies (IEC TR 61000-5-3 and IEC TR 61000-5-6). In addition the contact of the metallic floor of the new facility on concrete provides a large surface that has low impedance to ground. In this case the metallic shield should be welded instead of being bolted due to the possibility of water leakage and corrosion. Additional external grounds should connect the building to the grounding system especially where external conductors (such as power lines and their filters) attach to the shield, as these locations are likely to have a high level of surface current flow when surge arresters and filters operate. Internal grounding of equipment should be far from the external conductor grounding location to prevent currents continuing to flow inside the enclosure in case of a leak [2].

Other particular considerations for the electromagnetic shield include the following aspects (IEC TR 61000-1-5, IEC TR 61000-5-3 and IEC TR 61000-5-6):

- Waveguides below cutoff for air flow and also for feeding fiber optic cables through the shield need to be designed according to the frequency range of the E1 HEMP.
- Architectural pipes shall be bonded to the shield at their point of entry.
- Personnel doors need to be designed to a consistent level as the overall shield with a double door interlock if there is a risk that a single door could be left open for long periods of time.
- Antenna shields and other shielded cables entering the shielded facility shall be bonded to the shield at the point of entry with a low inductance bond. Protection for receivers and transmitters connected to external antennas (through the signal wire) shall be designed based on coupling analysis to the external antennas.
- Internal grounding of electronic equipment should be to the inside of the shield, so holes are never drilled through the shield.
- Placing critical external equipment outside the shield is not recommended, but if this is necessary (as shown in Figure 2) the electric power for this equipment shall flow from inside the shielded volume to the external equipment through conduits or shielded cables or if a shield is not used, then surge protective devices SPDs shall be used at both ends of the cables. For the case of a shielded conduit a CW test can be performed to ensure there is no leakage after installation. For shielded cables and surge arresters, the IEC accepts tests of prototype protection and quality control for surge arresters/filters.

With regard to external power and other metallic conducted penetrations and waveguides below cutoff, it is recommended that these penetrations be located in one general area of the building, and that this area not be near a door. In addition, the area where these penetrations are located should have additional grounding straps/plates connecting the building to the external grounding grid.

Once all external metallic cables, filters, doors, waveguides, etc., have been properly mounted to the shield, then SE evaluation of the shield, including all connected penetration plates can be performed (IEC 61000-4-23). This testing involves low level testing, but can reveal problems in bonding conductors and waveguide arrays to the shield. Nonlinear surge arresters and filters should be tested at the appropriate high levels, but this testing can be performed in the laboratory on prototypes. It is noted that non-linear surge arresters on cables may provide a path for penetration of low level currents induced on those cables during CW testing, and they may radiate fields inside giving the appearance of a failure of the shielding effectiveness test. This possibility should be considered during the final testing of a facility.

6.3 IEMI protection for new facilities

For the IEMI protection of a new facility (IEMI as shown in Figure 1), a 60 dB protection level is sufficient, although some effort is needed to ensure that the IEMI source cannot get too close to the building to create a very high external and internal environment (IEC 61000-4-36). In addition an IEMI radiated field detector should be mounted inside the facility near the critical equipment to determine if an IEMI event is occurring or has occurred that could cause electronic equipment to not operate properly. This type of detector is intended to cover both narrowband and wideband EM fields as summarized in Figure 1. These detectors are designed to possess the ability to detect and alarm at levels that are high enough to interfere with the electronics inside the facility. This type of detector can also be used to qualify the protection scheme during testing and provide a cue for restoration of the operation of the facility.

Modern shield designs appear to be able to extend their shielding effectiveness at levels of 80 dB to 100 dB upwards from 1 GHz (to 10 GHz or more). CW SE tests performed to evaluate the shield when completed will need to be extended at least up to 10 GHz (IEC 61000-4-23).

Waveguides below cutoff (needed mainly for airflow and exhaust) will need to be made of a smaller diameter for IEMI (10 cm for E1 HEMP and 1 cm for IEMI), and the main issue will be to ensure that the overall size of the waveguide arrays is sufficiently large to provide the correct air flow. Also, bringing architectural pipes into the building below ground level will reduce the need to use the smaller pipe diameters, as the high-frequency IEMI fields cannot penetrate the soil and "reflect" through the floor. This is convenient as the 10 cm diameter pipes are a convenient size for sewage pipes, while 1 cm pipes would not be satisfactory.

The power line entry to the building is less of a problem for radiated IEMI than for E1 HEMP, as the IEMI field coupling of very narrow and high frequency pulses is not as efficient as for E1 HEMP. The induced currents will be much lower for IEMI (roughly a factor of 10 lower for above ground power entries and even more for buried power line entries), and therefore it is clear that the full E1 HEMP power filter will not be needed (although if the facility is protected to both E1 HEMP and IEMI then the HEMP power filters will be needed, and they shall also attenuate the IEMI currents and voltages for frequencies up to 10 GHz).

While the radiated fields are very important with regard to facility protection, it is possible that conducted disturbances could be injected into external wiring that is accessible to an attacker. Studies have shown that injections of transients in a differential mode can propagate well even for frequencies above 1 GHz. It is therefore very important to restrict public access to wiring that may enter the facility of interest. This includes telecommunications and power wiring. If access cannot be restricted then filters that can attenuate frequencies above 10 MHz should be considered for lines connected to sensitive equipment inside.

For all metallic cables and metallic pipes carrying water and sewage, and considering the IEMI radiated disturbances, it is recommended to bury these cables and pipes and to have them enter through the floor of the facility. Typical soil and concrete materials will attenuate the IEMI high frequency fields significantly, and any propagation of conducted transients along the cables and pipes will not be significant due to the dispersive effect of the soil/concrete around them.

Numerical evaluations are needed to evaluate the coupling to external antennas (to determine the in-band conducted disturbance), especially for those antennas providing a GPS signal. These are found at nearly all facilities today, and they are likely critical to the operation of the electronics inside. The penetration of an antenna cable through the facility wall and shield also requires consideration as metallic cable shields act as broadband antennas for high-level IEMI fields and should be grounded before entering a facility. It should also be noted that many GPS antennas have active semiconductor components located very close to the antenna elements. The active part of the antenna is likely to be exposed to a high-level radiated disturbance and could be vulnerable to typical IEMI fields. Also the coaxial cable connected between the receiver and antenna may be used to provide DC power to the active elements and may use the screen of the cable as ground return. If the ground return is broken, for example, to terminate the cable screen at the shield wall, then the antenna/receiver may cease to function. Given the complications involved with GPS antennas with active elements and IEMI radiated fields, it is recommended that only passive GPS antennas be used.

6.4 HEMP and IEMI protection for new facilities

To combine the protection for E1 HEMP and IEMI (assuming that the E1 HEMP hardening was the main objective) the main issues are to reduce the size of the "apertures" for all exposed (not below ground) waveguides below cutoff, and to evaluate the IEMI coupling for external antennas. The IEMI protection approach should include security considerations to keep an attacker at some distance from the facility and should also include some IEMI radiated field detection devices to determine whether the facility is under a continuous attack.

The CW SE testing of the shielding for the radiated fields (IEC 61000-4-23) will require an extended frequency range (above 1 GHz to a level of at least 10 GHz), and any PoE protection testing may require the injection of additional conducted disturbance waveforms (found in IEC 61000-4-36).

7 Protection and testing approach for existing facilities

7.1 General

This approach is considerably different from that for building a new facility. One of the first requirements will be for the facility to identify its "criticality" with regard to whether it can stop operating for some time and how long that time should be. This will provide some guidance with regard to the "objective" for protecting the electronic equipment inside the facility and whether upset of electronics is acceptable or even minor damage if replacement equipment is available.

For an existing facility it is clear that an assessment of the facility should be performed first. IEC TS 61000-5-9 provides examples of different assessment methodologies, and of course the evaluation of the SE of the existing facility is an important first step. For facilities with less than 30 dB of natural shielding (this covers almost all cases for non-shielded facilities) there are rapid techniques for evaluating the shielding effectiveness (use of the commercial radio spectrum, for example, as described in IEC 61000-4-23). Once this "as-is" SE level is known and the objective level is determined, then there are different hardening techniques available to increase the level of protection. Some of these will be slightly different for HEMP and IEMI (IEC TR 61000-5-6).

7.2 HEMP protection for existing facilities

For E1 HEMP protection, special attention will need to be given for all external conductors entering the building. One important goal is to bury these cables (for a distance of at least

10 m as they approach the building) so that they enter the building from underground with a burial depth of at least 30 cm; this reduces the conducted disturbance by more than a factor of 10. In addition, all external antenna cable shields and other shielded cables shall be grounded (with a low inductance grounding method) before they enter the facility. Any existing backup power system should be hardened or a new external hardened power system could be designed using a containerized approach with shielded power cables connecting the backup power supply to the shielded building. Again, the backup power supply cables should enter the building from underground.

It is likely that a shielding effectiveness objective in the range of 30 dB could be reasonable for cases in which short interruptions of operation are acceptable without damage. This level can be viewed as reasonable when examining Table 1 and concepts 3 and 4. Note that damage to electronics seldom occurs from an E1 HEMP pulse below 1,6 kV/m, which is approximately midway between concepts 3 and 4 for the radiated disturbance. Concepts 3 and 4 are similar with regard to the protection from conducted disturbances. These residual levels are generally compatible with EMC generic standards for industrial applications. It should be noted that higher protection levels could be used for this case, but for the purposes of this document, the 30 dB attenuation level is assumed. It is also true that this 30 dB level might be sufficient for a new facility depending on whether upset can be tolerated (see Clause 6).

To achieve an increase in shielding effectiveness, either external or internal shielding could be added to the building or to a critical room inside the building. Another possibility is to build a shielded room inside the building or in the case where there are a small number of critical electronics to build a shielded rack.

If the additional shielding required is modest (10 dB to 20 dB), then it is possible to deal with cable protection techniques inside the building, including better bonding and grounding, adding gaskets, using better connectors, adding ferrites on cables, or even replacing critical cabling with fiber optics (IEC TR 61000-5-6). There is a large range of possibilities.

7.3 IEMI protection for existing facilities

An assessment is required for all existing facilities regarding the IEMI threat. This assessment consists of three parts: one is the estimation of the strength of the IEMI source (IEC 61000-2-13), the second is the determination of the nearest point of attack, and the third is to evaluate the shielding effectiveness of the facility for frequencies between 1 GHz and 10 GHz (IEC 61000-4-23). This range of frequencies is not usually examined for the E1 HEMP, as it is defined to reach only up to 1 GHz.

With this information, it is possible to determine the likely field levels that could reach the electronics inside the building. For example a suitcase IEMI wideband source could provide a range (m) times peak field level (kV/m) of 500 kV, so at a range of 10 m it could produce 50 kV/m at the outside of the building under ideal conditions. If the building provides 30 dB of attenuation across the frequency range of the IEMI radiated waveform, then the IEMI field would peak at 1,6 kV/m. This is a level where electronics have not been damaged (IEC TR 61000-1-5) so this would be a successful situation if temporary upset of electronics is permitted.

One important difference between IEMI and E1 HEMP is the fact that preventing an IEMI attacker from getting close to the electronics allows one to reduce the level of shielding required for the equipment. It is important to control personnel and vehicle access to ensure that it is not possible for IEMI weapons to be placed close to a building wall, especially a wall that is close to the location of the internal critical electronics. This factor is not considered at all for HEMP, as E1 HEMP is a plane wave coming from space and does not decrease for propagation distances on the order of the size of a building. The IEMI electric fields will decrease on the order of $1/r$ from the weapon where r is the distance (range) from the weapon.

As in the case of HEMP, reinstalling critical equipment in one or two rooms can minimize the amount of radiated field shielding required for IEMI. Also, by ensuring that all external cables entering the building are buried below ground reduces the level of the conducted disturbances due to the higher frequency content involved in IEMI (relative to E1 HEMP) which reduces the penetration of the radiated fields. There is a separate concern that cables that are accessible outside a building (external power plugs or telecom cabinets) can be targets for injecting IEMI conducted disturbances, which will propagate well in differential mode into the building. If these access points cannot be eliminated, then it is important to protect the equipment inside the building directly connected to these lines.

One special factor to be considered for IEMI is to protect the in-band response of antennas, including GPS antennas. If the GPS signals are required for the facility to work properly, it will be necessary to analyse the levels of voltage and current that could arrive at the GPS receiver and to build in surge protection (limiters) against this disturbance. It should also be considered that this disturbance will likely be repetitive, and the protection techniques should consider this aspect. Without any protection, it is likely that receiver(s) could be damaged. It should be noted that surge protectors, while preventing damage, can still pass enough energy to create interference in a received signal.

Also as mentioned before for the new facility protection approach, it is wise to include an IEMI field detector near critical electronics to allow the facility operator to know if the facility is under continuous attack (IEMI attacks can last for hours or days, while HEMP waveforms occur only one or two times from a single nuclear detonation at high altitudes). Even if an attack is relatively short in time, an IEMI field detector would be useful in determining the possible cause of electronic malfunctions.

A second special factor is to ensure that any waveguide below cutoff arrays or panels (for air flow or to allow fiber optic cables to enter the building from the outside) are sized properly for the higher frequencies. To achieve more than an 80 dB level of attenuation, a 1 cm diameter waveguide is needed for IEMI, while a 10 cm diameter waveguide is needed for E1 HEMP (in both cases the waveguide length should be 6 times the diameter to achieve more than 80 dB). For lower levels of shielding effectiveness, the lengths of the waveguides can be reduced.

7.4 HEMP and IEMI protection for existing facilities

As noted in 7.3, the main factor in protecting from IEMI in addition to HEMP is to determine the level of external field that an attacker may produce. If this level is equal to or lower than 50 kV/m, this means that the same level of shielding can be used for both radiated disturbances. Of course the shielding level should not decrease above 1 GHz as compared to the level measured between 1 MHz and 1 GHz.

Another factor of importance is to evaluate the in-band response of all antennas against the IEMI conducted disturbance to determine whether non-linear transient protection will be required for the connected transmitter and/or receiver. It is likely that the transient protection requirements could be quite different from E1 HEMP and the EM fields that would produce IEMI. In particular transient protection devices that can respond to the rise time of HEMP induced transients may not respond quickly enough for faster rising IEMI transients.

For waveguides below cutoff, protecting against both types of radiated E1 HEMP or IEMI fields requires that smaller waveguide diameters be used (for IEMI). This actually can be an advantage provided that the proper airflow can be guaranteed, as 6 cm long waveguides are not as heavy as 60 cm long waveguides (assuming that a high level of shielding effectiveness is required).

As for testing when combining protection against both HEMP and IEMI, after add-on protection is provided, it will be necessary to re-evaluate the shielding effectiveness of the building, rooms and racks (depending on the approach) to ensure that the protection level achieved is adequate across the entire frequency range using the techniques suggested in IEC 61000-4-23.

For conducted penetrations, if conductive penetrations were designed for E1 HEMP and are located above ground, then it will be necessary to compute the conducted waveforms for IEMI to determine the requirements for surge protection devices and filters and to test these devices in the laboratory to ensure that they work properly. Information on many of these conducted transients can be found in IEC 61000-4-36.

8 Method to develop other shield-level examples

This document has provided two particular examples of shielding effectiveness in a comprehensive fashion. Using the protection concepts developed in IEC 61000-2-11 and the related documents IEC 61000-4-25 and IEC 61000-6-6, it is possible to develop a consistent protection and test program by considering the basic factors described here and by examining the summaries of the publications of IEC SC 77C as presented in Annex A. Clearly if more details are required, the particular publications should be consulted.

9 Hardness maintenance

9.1 General

The protection measures that are used in a facility shall remain in place to be effective in protecting the facility from HEMP or IEMI. This means that maintenance of protection measures is necessary over the lifetime of the facility.

9.2 General annual maintenance

The first step is that during the construction of the protection for the facility (new or existing) it is necessary to identify and mark each piece of equipment that has a role in protecting the facility. This includes any shielding used, special doors, waveguides below cutoff, filters, surge arresters, conduits, etc. In addition the organization responsible for the protection of the facilities shall document this information and assign a department or person to be responsible for the maintenance of the protection measures.

On an annual basis shield doors (if used) should be cleaned, lubricated and adjusted according to the requirements of the supplier. The hinges should be inspected for wear and if contact fingers are used, these should be replaced when needed.

For the shield walls, penetration wires, architectural pipes, filters, waveguide air vent panels, waveguide feedthroughs and panels added for cable penetrations, visual inspections should be performed on at least an annual basis to ensure that panels have not become loose or to ensure that new wire penetrations have not been drilled through the shield walls. If problems are found these deficiencies should be corrected quickly as seemingly minor problems can reduce the protection level of the facility to a large extent.

With regard to the shield walls, it is not always easy to see whether a shield violation has occurred. For this reason a retest of the shield should be performed periodically using the same test method used originally to qualify the facility and by comparing to the original data from those tests. It is not necessary to perform the complete original test, but rather to select a single frequency, such as 1 GHz, to check for shield leakage.

9.3 PoE filter and MOV maintenance

Commercial power filters are very important to the performance of the facility, and since they consist of both electrical filters and MOVs, it is important to check that the components have not degraded over time. Other PoEs may be protected only by an MOV, and therefore these components should also be maintained. Maintenance support and advice should be provided by the supplier of the filter or other PoE protection. The following general maintenance activities are recommended:

1) Annual visual inspection to check the condition of the filter or PoE case, i.e. no charring, warping or discolouration of the case or corrosion.
2) Annual visual inspection of the MOVs (no charring, discolouration or clear signs of fatigue).
3) MOV testing is achieved by de-energizing the filter, disconnecting the MOV, and by performing the MOV test to determine that the minimum reference voltage (varistor voltage) at 1 mA is achieved (see IEC 61000-5-5). This test is to be performed either annually or on a schedule determined by the facility owner.

The following maintenance activities (those that are applicable) should be performed at least once every 5 years or on a shorter schedule depending on the criticality of the facility. The acceptable levels of performance should be provided by the manufacturers:

a) Thermal imaging of filters and varistors in hard-to-access areas to look for hot spots.
b) Insertion loss measurements of the filter, which require the filter to be isolated from the circuit.
c) Capacitance and power factor measurements. Require the filter to be isolated from the circuit.

Annex A
(informative)

IEC SC 77C publications

A.1 General

Preparation of SC 77C standards is consistent with the development of EMC standards within the IEC and is therefore structured according to "IEC publication 61000" which is divided into seven major parts as indicated:

Part 1: General

Part 2: Environment

Part 3: Limits

Part 4: Testing and measurement techniques

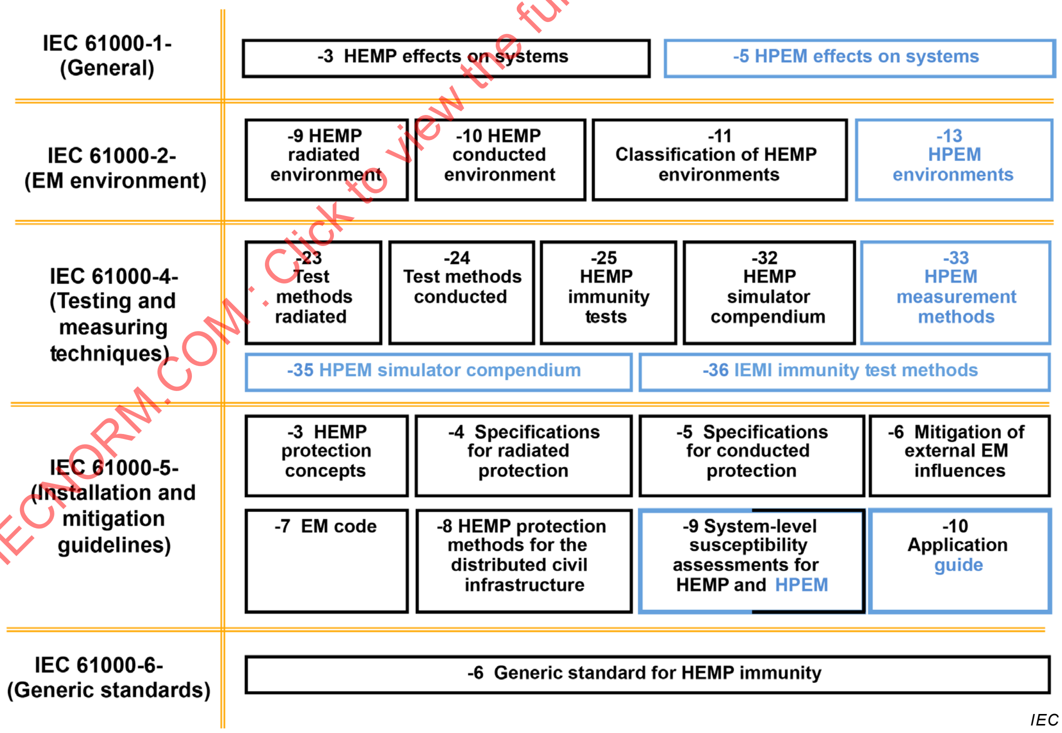
Part 5: Installation and mitigation guidelines

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several subparts. These are published either as International Standards, Technical Specifications or Technical Reports.

Figure A.1 indicates the publications produced by IEC SC 77C.



NOTE Black text indicates publications dealing with HEMP, while blue/grey text indicates HPEM/IEMI publications.

Figure A.1 – Organization of the current publications of IEC SC 77C

A summary of key aspects of each document relevant to this document is subsequently given.

A.2 IEC TR 61000-1-3: General – The effects of high-altitude EMP (HEMP) on civil equipment and systems

The purpose of this document is to describe the effects that have occurred during actual and simulated electromagnetic pulse testing throughout the world. These effects include those observed during the high-altitude nuclear tests conducted by the United States and the Soviet Union in 1962, and the HEMP simulator tests conducted by many countries during the years after atmospheric testing ended. In addition to direct effects, this publication also contains information on HEMP coupling to "long lines" as it is important to verify that particular levels of currents and voltages can be induced by HEMP on these lines; this provides a basis for direct injection testing of electronic equipment. It should be noted that in most cases, the electrical equipment tested or exposed did not contain the sensitive electronics in use today. Also it should be emphasised that all tests and exposures did not produce failure of the equipment; factors such as the geometry of the HEMP interaction and the electromagnetic shielding of the equipment are variables that can produce differing results. The description of these effects is intended to illustrate the seriousness of the possible effects of HEMP on modern electronic systems.

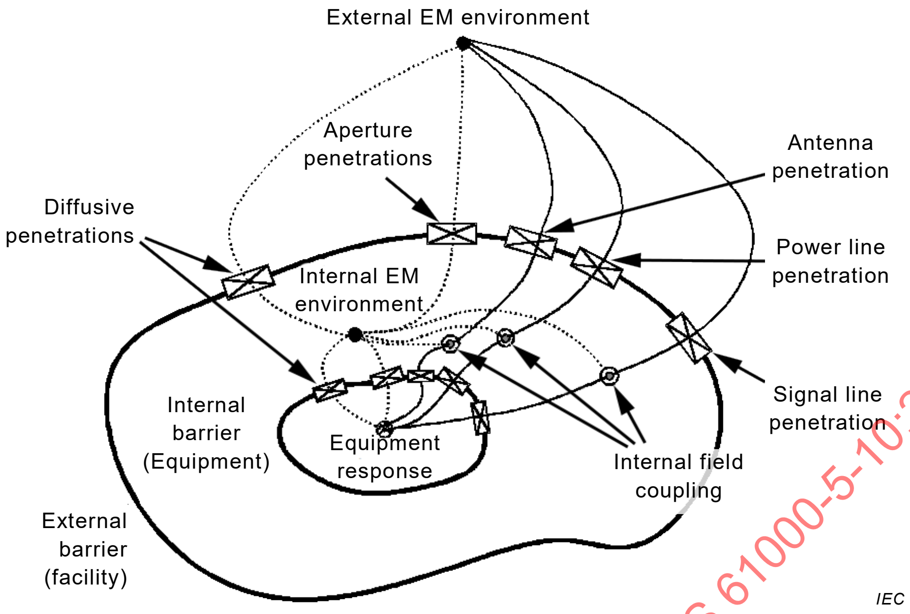
This technical report provides information of failures of commercial electronic equipment both during nuclear high-altitude tests and in simulators where the HEMP E1 field was reproduced. Impacts on HF and VHF radios occurred at levels as low as 5 kV/m, including transistor damage to radios tested in the early 1970s. Radios operating at higher frequencies were not affected at levels below 50 kV/m. In terms of commercial electronics tested in the mid-1980s, critical upsets of TVs, VCRs, stereo receivers, personal computers, cordless telephones and medical equipment occurred at levels as low as 6,7 kV/m with damage beginning at 16,6 kV/m. The report also indicates that long line systems are susceptible to HEMP with public street light fuses failing in Honolulu at a level of about 5,6 kV/m and MV/LV pole transformers being damaged during injection testing at 264 kV to 304 kV when no lightning protection was present. This level of voltage is equivalent to an induced long line current for above ground medium voltage power lines of about 750 A, well below the IEC 61000-2-10 E1 HEMP worst case specification of 4 kA.

A.3 IEC TR 61000-1-5: General – High power electromagnetic (HPEM) effects on civil systems

This technical report provides background material describing effects of high-power electromagnetic (HPEM) fields, currents and voltages on civil systems. In the light of newly emerging transient antenna technology and the increasing use of digital electronics, the possibility of equipment being upset or damaged by these environments is of concern. This document begins with a general introduction to this subject and a listing of the pertinent definitions used. Following these clauses, the HPEM environments that are of concern are described and a discussion of the various effects that these environments can induce in civil systems is presented. Finally, techniques used to protect systems against these environments are summarised.

This publication identifies the different types of HPEM threats that might affect commercial systems, including radar systems (which could impact aircraft), and electromagnetic weapons that are designed to harm commercial systems. This latter category is of greatest interest for protection. Both narrowband and wideband disturbances are described in general terms including the levels where effects might occur for typical electronics. IEC 61000-2-13 provides additional detail on how to categorize these effects for different types of waveforms.

The document also introduces various protection schemes for buildings. Figure A.2 and Figure A.3 show important aspects of the protection. It should be noted that while these figures are contained in a document dealing with HPEM (or IEMI), they are also appropriate for the protection of E1 HEMP.



Key

- EM barrier (shield)
- Conductor transmission
- Field transmission
- Barrier penetration
- EM Field point
- Field excitation
- Response location

Figure A.2 – Topological diagram for the simple system

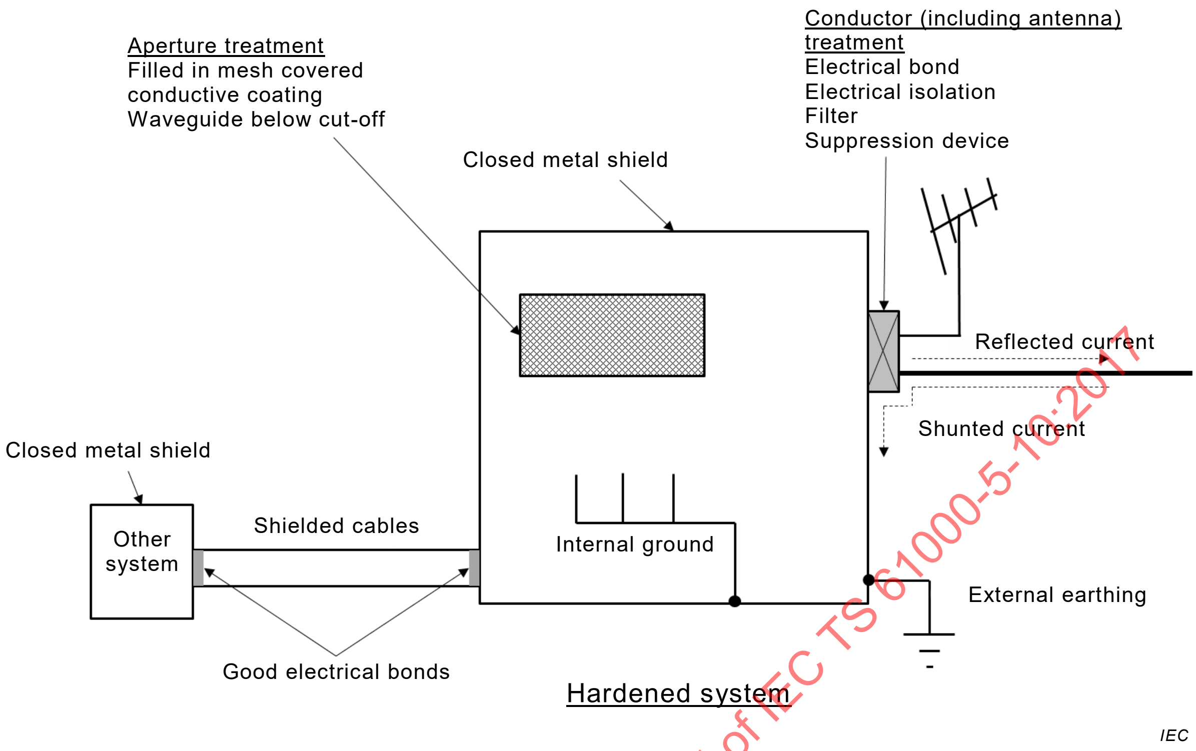


Figure A.3 – Illustration of typical HPEM inadvertent penetration protection methods

A.4 IEC 61000-2: Environment – Section 9: Description of HEMP environment – Radiated disturbance

This standard defines the HEMP environment that is one of the consequences of a high-altitude nuclear explosion.

For the general case of the electromagnetic pulse (EMP), those dealing with this subject consider two cases:

- high-altitude nuclear explosions,
- low-altitude nuclear explosions.

For civil systems the most important case is the high-altitude nuclear explosion. In this case, the other effects of the nuclear explosion such as blast, ground shock, thermal and nuclear ionizing radiation are not present at the ground level. However the electromagnetic pulse associated with the explosion may cause disruption of, and damage to, communication, electronic and electric power systems thereby upsetting the stability of modern society.

The object of this standard is to establish a common reference for the HEMP environment in order to select realistic stresses to apply to victim equipment for evaluating their performance.

This standard presents the three components of the HEMP including the early time (E1), intermediate time (E2) and late time (E3) “radiated” fields. These are all described analytically and are plotted in Figure A.4 and Figure A.5. The standard also describes the attenuation of the E1 field as it penetrates the soil, which is of interest when coupling to buried cables. It is noted that the E1 HEMP field is of greatest interest to the protection of commercial electronics inside buildings. The E2 and E3 HEMPs are of greatest interest only for the coupling to very long lines (greater than 100 m for E2 and 1 km for E3).

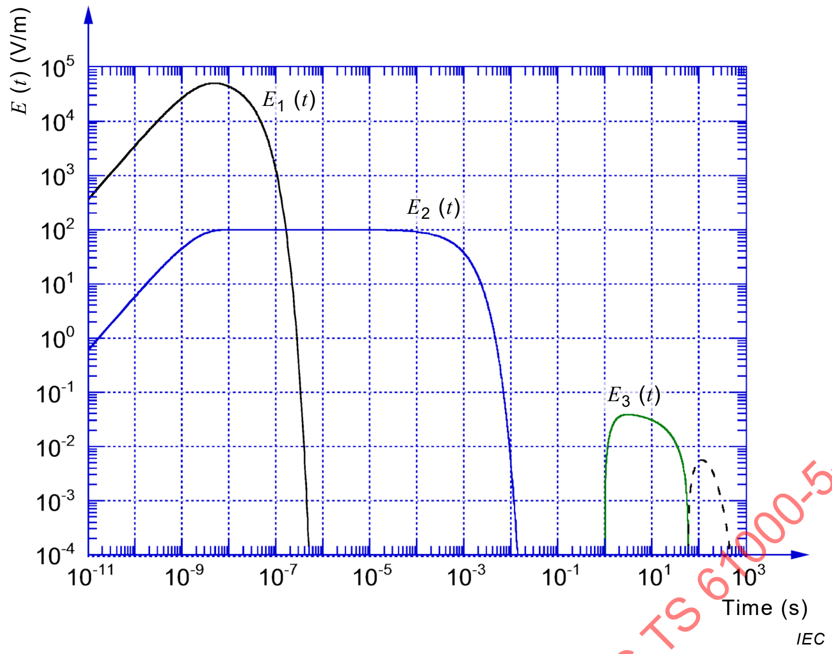


Figure A.4 – Complete standard HEMP time waveform with the dashed line indicating a negative value of the E3 HEMP waveform

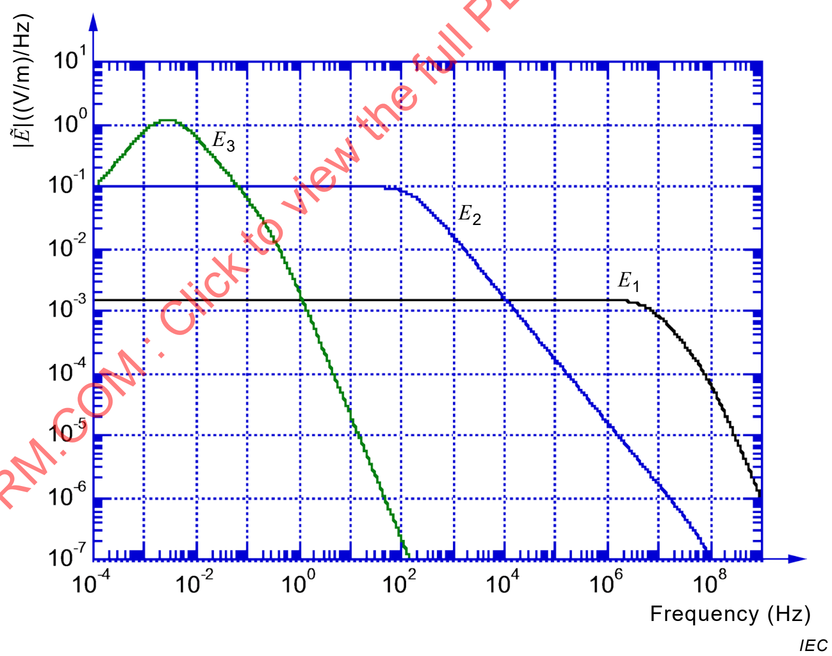


Figure A.5 – Amplitude spectrum of each HEMP component

A.5 IEC 61000-2-10: Environment – Description of HEMP environment – Conducted disturbance

This standard defines the HEMP conducted environment (i.e. the environment that couples to and propagates through conductors such as power lines).

The object of this standard is to establish a common reference for the conducted HEMP environment in order to select realistic stresses to apply to victim equipment for evaluating their performance.

This standard uses the standard HEMP radiated environments supplied in IEC 61000-2-9 to determine the coupling to long lines leading to buildings and to some simple antennas both from a worst case and from a probabilistic point of view.

Table A.1 provides probabilistic peak current coupling for E1 HEMP to power and communications lines entering a building for both above ground and buried lines. It can be seen that if the line is buried for more than 10 m, the induced currents are reduced substantially from the worst-case above ground line case. In addition the current waveform rises more slowly and the characteristic impedance (V_{oc}/I_{sc}) is reduced to 50 Ω from 400 Ω.

Table A.1 – Early time HEMP conducted common-mode short-circuit current including the time history and peak value I_{pk} as a function of severity level, length L in m and ground conductivity in S/m

Table A.1a) – Elevated conductor (line height greater than 5 m)

	I_{pk} (A)		
Severity (%)[1]	**L > 200 m**	**100 m < L < 200 m**	**L < 100 m**
50	500	500	5,0 × L
90	1 500	7,5 × L	7,5 × L
99	4 000	20 × L	20 × L

[1] Percentage of currents smaller than the indicated value.

Waveform 1: 10/100 ns.

Source impedance, Z_S = 400 Ω.

Table A.1b) – Buried conductor (depth of 0,3 m)

	I_{pk} (A)
Ground conductivity (S/m)	**All lengths > 10 m**
10^{-2}	200
10^{-3}	300
10^{-4}	400

Waveform 2: 25/500 ns.

Source impedance, Z_S = 50 Ω

For the intermediate time E2 HEMP case, the induced currents are considered only for lines longer than 100 m. As indicated in Table A.2, the currents do not reach a maximum value until the lines are 10 km in length.

Table A.2 – Intermediate time HEMP conducted common-mode short-circuit currents including the time history and peak value I_{pk} as a function of length L in m and ground conductivity in S/m

Table A.2a) – Elevated conductor

Ground conductivity (S/m)	I_{pk} (A)			
	L > 10 000 m	1 000 m < L < 10 000 m	100 m < L < 1 000 m	L < 100 m
10^{-2}	150	75	0,05 × L	0
10^{-3}	350	200	0,15 × L	0
10^{-4}	800	600	0,45 × L	0
Waveform 3: 25/1 500 µs. Source impedance, Z_S = 400 Ω.				

Table A.2b) – Buried conductor

Ground conductivity (S/m)	I_{pk} (A)		
	L > 1 000 m	100 m < L < 1 000 m	L < 100 m
10^{-2}	50	0,05 × L0,15 × L	0
10^{-3}	150	0,45 × L	0
10^{-4}	450		0
Waveform 3: 25/1 500 µs. Source impedance, Z_S = 50 Ω.			

For the late time (E3) HEMP, the main concern with this environment is for high voltage power lines (V > 100 kV) and the possibility that quasi-DC currents will be injected into the AC power system creating half-cycle saturation of transformers and voltage collapse of the network. It is also possible that transformer hot-spot heating could occur, leading to damage of the transformer. For equipment inside a building the main issues of concern are the possible damage of building transformers and the increased flow of power harmonics in the low voltage power network that could affect the operation of commercial electronics. It is not possible to simply estimate the currents that will flow, as they are a function of the resistance in the power network. Figure A.6 illustrates the circuit to be considered.

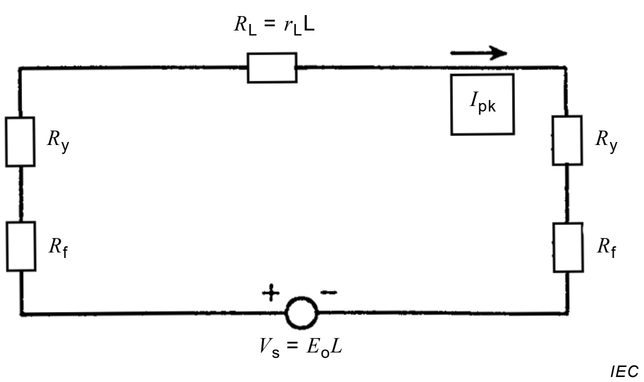


Figure A.6 – Simple equivalent circuit where E_0 is the induced late time HEMP electric field

Using the figure provided, the peak current can be calculated as:

$$I_{pk} = \frac{E_0 L}{2(R_f + R_y) + r_L} \qquad (A.1)$$

where r_L is the parallel wire resistance per unit length (Ω/m), R_f is the ground resistance (Ω),R_y is the parallel winding resistance in one transformer (Ω), and L is the line length (m).

For antenna coupling, there are many types of antennas, so this standard computes the antenna load current (I_L) into 50 Ω for a range of geomagnetic field dip angles (for variations in geomagnetic latitude which controls the polarization of the E1 HEMP fields) and probability (which considers many random angles of incidence) for both loaded vertical monopole antennas and horizontal dipole antennas. The results are given in Table A.3 and Table A.4.

Table A.3 – E1 HEMP response levels for I_L for the loaded vertical monopole antenna[a] (current values are in kA)

Length (L)	1 m			3 m			10 m			100 m		
Severity	50 %	90 %	99 %	50 %	90 %	99 %	50 %	90 %	99 %	50 %	90 %	99 %
Dip angle												
0°	0,06	0,15	0,17	0,23	0,49	0,55	0,76	1,31	1,33	2,37	2,71	3,53
15°	0,06	0,14	0,16	0,23	0,48	0,53	0,76	1,26	1,29	2,28	2,59	3,34
30°	0,05	0,13	0,15	0,2	0,43	0,47	0,65	1,13	1,15	2,03	2,32	3
45°	0,04	0,10	0,12	0,16	0,35	0,39	0,54	0,92	0,94	1,69	1,91	2,51
60°	0,03	0,07	0,08	0,12	0,25	0,27	0,39	0,65	0,67	1,17	1,35	1,79
75°	0,02	0,04	0,04	0,06	0,13	0,14	0,2	0,34	0,34	0,61	0,7	0,91
90°	0	0	0	0	0	0	0	0	0	0	0	0

[a] For the corresponding load voltage values, multiply these values by 50 Ω.

Table A.4 – E1 HEMP response levels for I_L for the loaded horizontal dipole antenna [a] (current values are in kA)

Length (L)	1 m			3 m			10 m			100 m		
Severity	50 %	90 %	99 %	50 %	90 %	99 %	50 %	90 %	99 %	50 %	90 %	99 %
Dip angle												
0°	0,002	0,012	0,032	0,008	0,04	0,13	0,028	0,14	0,39	0,078	0,42	1,26
15°	0,014	0,02	0,036	0,050	0,078	0,14	0,16	0,23	0,4	0,45	0,65	1,33
30°	0,024	0,036	0,044	0,092	0,15	0,17	0,29	0,44	0,54	0,84	1,1	1,58
45°	0,034	0,05	0,054	0,13	0,2	0,22	0,41	0,61	0,64	1,17	1,51	1,83
60°	0,042	0,062	0,062	0,16	0,25	0,26	0,5	0,74	0,76	1,44	1,83	2,05
75°	0,046	0,068	0,070	0,17	0,28	0,29	0,55	0,83	0,85	1,60	2,04	2,18
90°	0,048	0,07	0,072	0,17	0,28	0,3	0,57	0,86	0,88	1,66	2,1	2,22

[a] For the corresponding load voltage values, multiply these values by 50 Ω.

A.6 IEC 61000-2-11: Environment – Classification of HEMP environments

The purpose of this document is to classify the high-altitude EMP (HEMP) electromagnetic environments and to help specify the immunity requirements of an item (e.g. equipment or subsystem) containing electrical or electronic parts to ensure that it will operate during and/or after exposure to a HEMP waveform. This standard is primarily intended for those who are responsible for writing product immunity standards and/or other immunity standards. It provides basic guidance for the selection of immunity test levels for any component, device, equipment, subsystem or system which contains electrical circuits that may be disturbed by electromagnetic signals.

This document considers the reduction of the HEMP environments due to the location of the equipment and the possibility of the reduction of those environments due to the "natural" protection of the building where the equipment is located. Existing buildings may possess the following "protection" concepts:

Concept 1: Above-ground wooden, brick or concrete block building or structure with large windows and doors without rebar or other explicit shielding. Lack or presence of conducted lightning protection (overvoltage protection without filtering) defines subconcepts 1A and 1B, respectively.

Concept 2: Above-ground concrete building or structure with rebar or buried brick or concrete building or structure. Lack or presence of conducted lightning protection (overvoltage protection without filtering) defines subconcepts 2A and 2B, respectively.

Concept 3: Shielded enclosure with minimal RF shielding effectiveness. Typical equipment box with small apertures. Nominal lightning overvoltage and EMI conducted penetration protection (filtering).

Concept 4: Shielded enclosure with modest RF shielding effectiveness and good bonding at all PoEs. Nominal lightning overvoltage and EMI conducted penetration protection (filtering).

Concept 5: Shielded enclosure with good RF shielding effectiveness and PoE protection (overvoltage and filtering).

Concept 6: Shielded enclosure with high-quality RF shielding and PoE protection (overvoltage and filtering).

Table A.5 – Minimum required attenuation of peak time domain external environments for the six principal protection concepts for E1 HEMP

Concept	Minimum attenuation, dB		
	Electric field	Magnetic field	Conducted current
1A	0	0	0
1B	0	0	20
2A	20	20	0
2B	20	20	20
3	20	20	40
4	40	40	40
5	60	60	60
6	80	80	80
NOTE Frequency evaluation ranges for E and H fields are 100 kHz to 30 MHz for concepts 1 and 2, and 1 MHz to 200 MHz for concepts 3 to 6.			

The protection levels indicated in Table A.5 are applicable to E1 HEMP protection and can also be used for protection against IEMI, although the measurement of the shielding effectiveness will need to be extended into the GHz range due the fact that the IEMI environment can reach frequencies as high as 10 GHz at this time. This means that shield leakage at higher frequencies than those considered by E1 HEMP could be important.

A.7 IEC 61000-2-13: Environment – High-power electromagnetic (HPEM) environments – Radiated and conducted

This document defines a set of typical radiated and conducted HPEM environment waveforms that may be encountered in civil facilities. Such disturbances can produce damaging effects on electrical and electronic equipment in the civilian sector, as described in IEC TR 61000-1-5. It is necessary to define the radiated and conducted environments, in order to develop protection methods.

For the purposes of this standard, high-power conditions are achieved when the peak electric field exceeds 100 V/m, corresponding to a plane-wave free-space power density of 26,5 W/m^2. This criterion is intended to define the application of this standard to EM radiated and conducted environments that are substantially higher than those considered for "normal" EMC applications, which are covered by the standards produced by IEC SC 77B.

This document discusses the nature of high-power EM environments, especially those relating to electromagnetic weapons. It begins by relating the frequency content of these environments as shown in Figure A.7. This is important for understanding the requirements for building shielding that may be required to reduce these environments before electronic equipment is exposed.

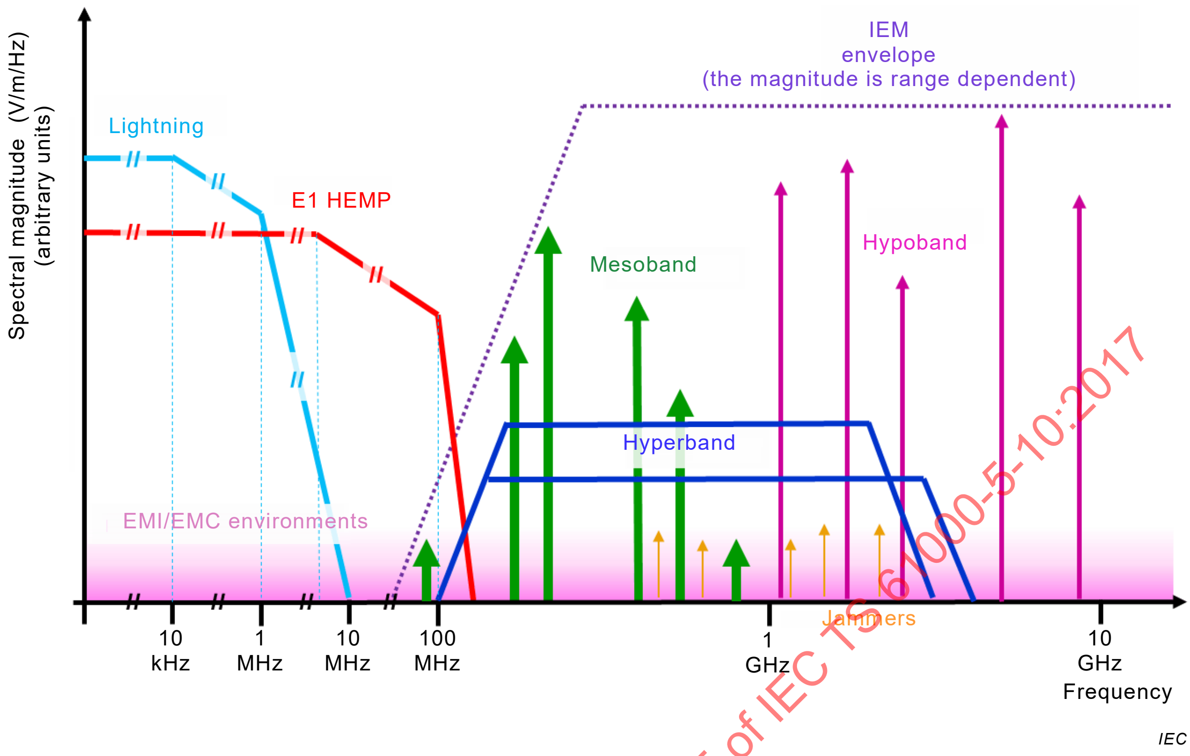


Figure A.7 – Several types of HPEM environments compared with the IEC E1 HEMP waveform

This document also defines a new way to determine the bandwidths of wideband signals that have not been well defined in the past. The method is to determine the bandratio (ratio of frequencies containing 90 % of the energy of the waveform). Table A.6 provides these definitions.

Table A.6 – Definitions for IEMI bandwidth classification

Bandwidth type	Percent bandwidth (pbw)	Bandratio (br)
Hypoband or narrowband	≤ 1 %	≤ 1,01
Mesoband	1 % < pbw ≤ 100 %	1,01 < br ≤ 3
Sub-hyperband	100 % < pbw ≤ 163,4 %	3 < br ≤ 10
Hyperband	163,4 % < pbw ≤ 200 %	br > 10

The document also provides examples of the different types of waveforms. It also defines the range multiplied by the peak time domain field level (r x E_{pk}) as the “strength” of a source, so that to determine the field level at a given range, one divides that product by the range.

This document also provides information regarding the fact that conducted signals are created in two different ways. One is from the coupling of electromagnetic fields to wires and cables, creating induced voltages and currents, which then enter electronic equipment through their power or data cables. The second coupling method includes the direct injection of transient voltages into the power or data lines from outside a building, allowing the propagation of these signals inside the building. This latter case is more efficient as most of the energy is sent to a particular cable, however, often the cable has limits with regard to breakdown that may prevent an extremely high current reaching the equipment. On the other hand, damage to the wiring in a building will also prevent the electronics in a building from operating properly. Also fast wideband signals with narrow pulse widths may not damage the insulation of the wiring and could still damage or upset the connected electronics.

In one of the annexes of the document, different levels of technology contained in electromagnetic weapons are identified, from low-tech, to medium-tech, to high-tech generator systems. Examples are provided of each "class".

A.8 IEC 61000-4-23: Testing and measurement techniques – Test methods for protective devices for HEMP and other radiated disturbances

This part of IEC 61000 provides a protective devices test method for HEMP and other radiated disturbances. It is primarily intended for HEMP testing but can be applied to other externally generated radiated disturbances where appropriate. It provides a brief description of the most important concepts for testing of shielding elements. For each test, the following basic information is provided:

- theoretical foundation of the test (the test concept);
- test set-up including outside-to-in and inside-to-out measurements;
- required equipment;
- test procedures; and
- data processing.

This standard does not provide information on requirements for specific levels for testing.

IEC 61000-4-23:2016 (Edition 2) has been updated to include a new test method, which is described below.

Based on the available space, a transmitting antenna position outside the barrier has mainly been suggested. However, nowadays, many EMP protection facilities in practical use do not actually have enough space available outside the electromagnetic barrier due to physical constraints such as concrete walls or soil to allow the method described in IEC 61000-4-23:2000 (Edition 1) to be applied correctly. From experience many facilities have available space for a 1 m separation or less only.

Therefore, in many practical cases it is not possible to measure shielding effectiveness according to the test method of previous documents. The constructors for EMP protection facilities are also unwilling to build facilities with extra space for measurements with the transmitting antenna outside the barrier due to the great expense and inefficiency of the operational working area for new or existing buildings.

This revised edition provides additionally a method that allows the transmitting antenna to be placed inside the enclosure and the receiving antenna outside the barrier ('inside-to-out' method). Annex F of IEC 61000-4-23:2016 is informative and includes test set-up and procedure examples.

This document provides several methods for evaluating the shielding effectiveness of buildings, cables and connectors, gaskets, and waveguides.

With regard to evaluating the shielding effectiveness of buildings, the CW technique offers many advantages in terms of finding whether there is leakage at particular frequencies, and these frequencies can be extended upward to 10 GHz (to consider IEMI disturbances) beyond the normal range of E1 HEMP. There are three basic techniques available, including "global illumination with active radiators" as shown in Figure A.8. It has the advantage of measuring the illumination of an entire building from a distance, although to test as low as 1 MHz, one should be at least 300 m away to achieve a plane wave condition. This is difficult to do in cases where the shielding effectiveness is high, as the output of the CW pulser should be high to measure signals inside a well-shielded facility. This may create interference issues with commercial broadcasting and normally requires the approval of the national communications agency.

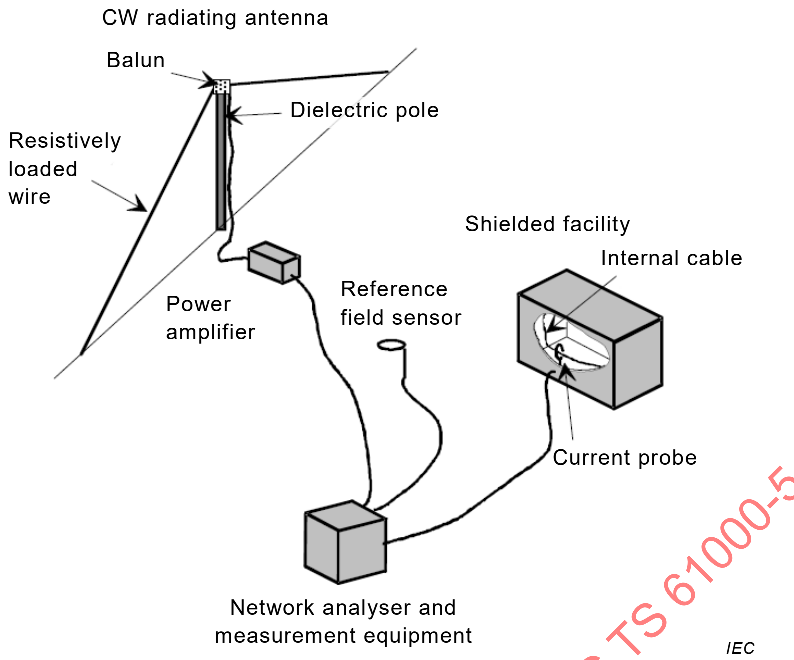


Figure A.8 – Typical configuration of a CW test facility

The second method to evaluate a building shielding effectiveness is to use the ambient EM CW field from communications signals as discussed in IEC 61000-4-23 and shown in Figure A.9. This method is very good when evaluating the shielding effectiveness of existing buildings below 40 dB (and for buildings in which electronics equipment are present and are operating). This technique uses incident plane wave signals (due to the usual distance involved with commercial transmitters). It is of minimal use when trying to evaluate a 60 dB to 80 dB shielding level, as the external signals are rarely high enough to allow internal measurements when there are high levels of attenuation.

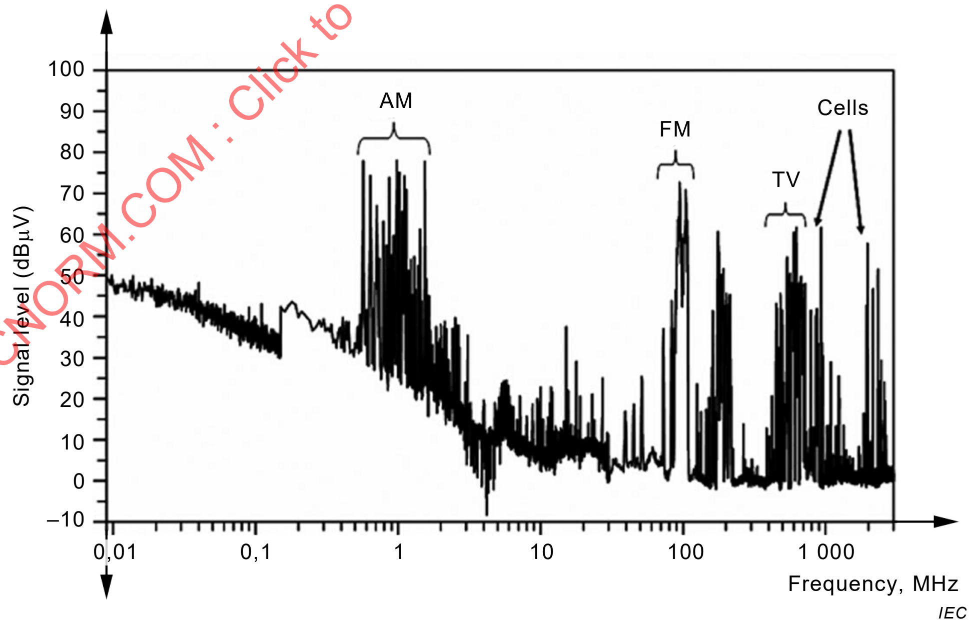


Figure A.9 – Example scan from 9 kHz to 3 GHz for the ambient electromagnetic field from communication signals

To evaluate high-level shields, the localized barrier shielding effectiveness test method is the best. This involves placing a transmitting and receiving antenna on both sides of a shielded surface and measuring the local barrier SE. This does require many measurements, as the entire surface of the closed shield should be evaluated. An example test set-up is shown in Figure A.10.

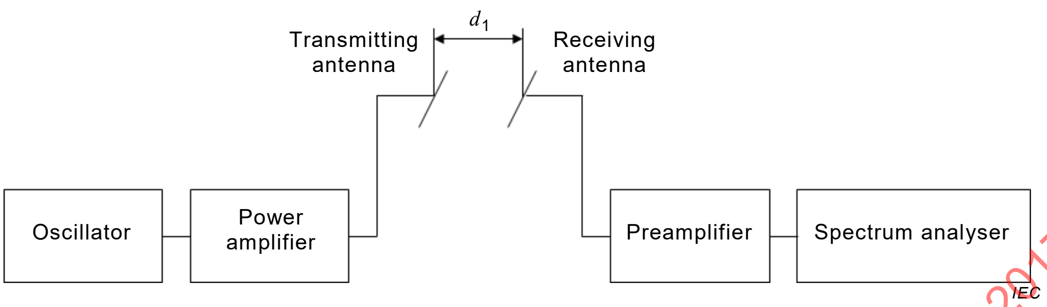


Figure A.10a) – Calibration

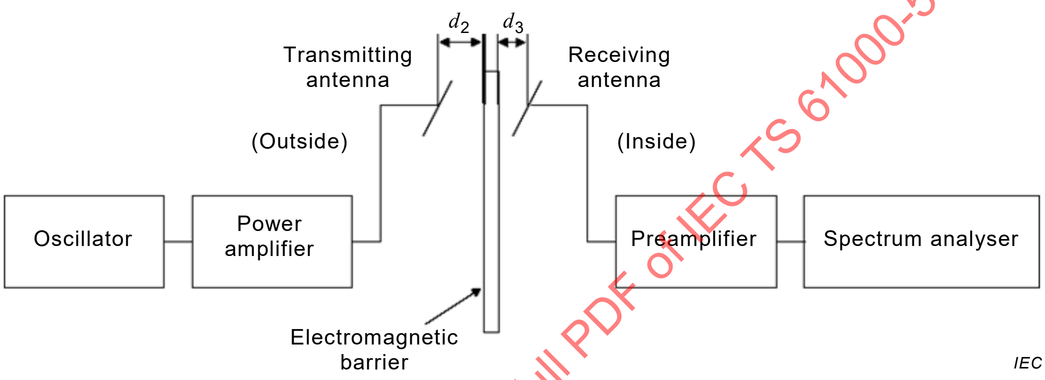


Figure A.10b) – Measurement (outside-to-in)

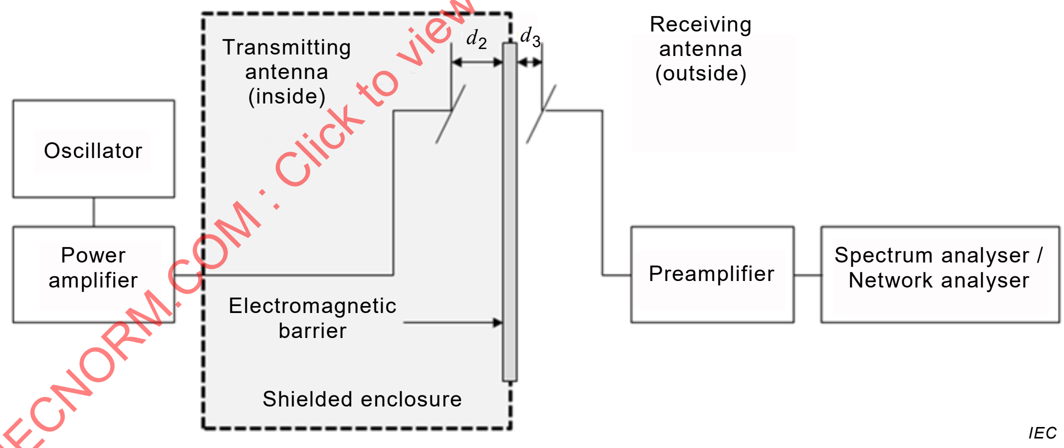


Figure A.10c) – Measurement (inside-to-out)

Dimensions

d_1 (at least 2 m)	=	$d_2 + d_3$ + barrier thickness
d_2	=	d_1 – 30 cm (within dynamic range and physical constraints)
d_3	=	30 cm (within dynamic range and physical constraints)

Figure A.10 – Measurement methods for evaluating shielding effectiveness of high-level shields

As for cables, waveguides and other connections to allow penetration through a shield, there are two aspects to be considered with regard to testing. The first is to ensure that the external shield currents flow to the EM shield instead of penetrating inside. For this the local barrier CW test is the best suited, where the test is performed near each penetration point. In addition there will be a need to ensure that the signal and power lines do not carry transients inside the building, so these will likely require filters and/or SPDs that shall be tested with time domain pulsers to measure the effectiveness of the protection. These tests are defined in IEC 61000-4-24. The performances of cable shields and waveguides are already well defined by CW test techniques applied by industry, and those standards can be used as required.

A.9 IEC 61000-4-24: Testing and measurement techniques – Test methods for protective devices for HEMP conducted disturbance

This document deals with methods for testing protective devices for HEMP conducted disturbance. It includes two-terminal elements, such as gas discharge tubes, varistors, and two-port SPDs, such as HEMP combination filters. It covers testing of voltage breakdown and voltage-limiting characteristics but also methods to measure the residual voltage and/or the residual current, peak rate of rise and root action for the case of very fast changes of voltage and current as a function of time. This standard does not cover insertion loss measurement methods.

This standard describes the test method, the test levels and the test residuals required for all types of wire penetrations through a shielded test volume. These include AC/DC power lines, symmetric data lines, non-symmetric data lines and coaxial lines. The standard identifies reduced levels for the conducted environments depending on whether the cable entry is above ground or is buried. It also provides residual levels (pass levels during the time domain tests) for signal and power ports. There is a strong motivation to not have any non–fiber-optic signal cables penetrating the shield as all metallic PoEs shall have filters that have passed high-level time domain injection tests. In addition, the standard provides motivation to ensure that power and signal lines enter the shielded area from below ground as the injection levels required are lower as shown in Table A.7. The E1 residuals for different classes of facilities are also provided in Table A.8 for the power line filter.

Table A.7 – Overview of conducted early time HEMP test requirements defined in other specifications

Type	Rise time	FWHM [a]	Source impedance [b]	Peak short-circuit current	Specifications
CEP_1	< 10 ns	100 ns ±30 %	400 Ω ±15 Ω	4 000 A ±10 %	IEC 61000-2-10, 99 % severity for elevated conductor, for cable length longer than 200 m
CEP_2	< 10 ns	100 ns ±30 %	400 Ω ±15 Ω	1 500 A ±10 %	IEC 61000-2-10, 90 % severity for elevated conductor, for cable length longer than 200 m
CEP_3	< 10 ns	100 ns ±30 %	400 Ω ±15 Ω	500 A ±10 %	IEC 61000-2-10, 50 % severity for elevated conductor, for cable length longer than 200 m
CEP_4	< 25 ns	500 ns ±30 %	50 Ω ±5 Ω	400 A ±10 %	IEC 61000-2-10, for buried conductor in the ground conductivity of 10^{-4}, for cable length longer than 10 m
CEP_5	≤ 20 ns	500 ns +10 %	≥ 60 Ω	2 500 A ±10 %	According to [4], wire-to- ground
CEP_6	≤ 20 ns	500 ns +10 %	≥ 60 Ω	5 000 A ±10 %	According to [4], common-mode, under installed conditions only

[a] FWHM is an acronym for full-width at half-maximum (amplitude).

[b] In all cases, for practical reasons lower source impedance may be used. However the source impedance should not be less than typically 10 Ω to ensure that the applied pulse voltage is greater than the breakdown voltage of the non-linear components in the DUT.

Table A.8 – Performance criteria of a filter against early time HEMP at the AC power port with a nominal load of 2 Ω

Severity Level	Protection Concepts	Peak residual current or voltage		Peak rate of rise	Root action
		I_{Load}, A	U_{Load}, V	A/s	$A\sqrt{s}$
Level 1	IEC 61000-6-2 (industrial)	U_{Load} / R_{Load}	$2 \cdot \hat{U}_{Nom}$ [a]	2×10^{8}	3,2
Level 2	Critical infrastructures	50	100	5×10^{7}	$8{,}0 \times 10^{-1}$
Level 3	Special case (Mil-Std-188-125-1)	10	20	10^{7}	$1{,}6 \times 10^{-1}$
Level X	User defined	UD [b]	UD	UD	UD

[a] $\hat{U}_{Nom}$ is the peak value of the nominal operating voltage.

[b] UD means "user defined".

A.10 IEC 61000-4-25: Testing and measurement techniques – HEMP immunity test methods for equipment and systems

This document describes the immunity test levels and related test methods for electrical and electronic equipment and systems exposed to high-altitude electromagnetic pulse (HEMP) environments. It defines ranges of immunity test levels and establishes test procedures. Specifications for test equipment and instrumentation test set-up, test procedures, pass/fail criteria, and test documentation requirements are also defined by this standard. These tests are intended to demonstrate the immunity of electrical and electronic equipment when subjected to HEMP radiated and conducted electromagnetic disturbances. For radiated disturbance immunity tests, specifications are defined in this standard both for small test facilities and large HEMP simulators.

It defines specifications for laboratory immunity tests. On-site tests performed on equipment in the final installation to verify immunity are also specified. These verification tests use the same specifications as laboratory tests, except for the climatic environmental specifications.

The objective of this document is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment, when subjected to HEMP radiated environments and the associated conducted transients on power, antenna, and input/output (I/O) signal and control lines.

This standard defines the radiated and conducted immunity test methods that will need to be applied if one were to test electronic equipment, but based on its location (within a shielded level). In many cases the test methods are adapted from other test methods used in the IEC for EMC immunity testing, as those test methods already exist. In some cases, for example the radiated E1 HEMP field testing that would be necessary for equipment fully exposed outside, a high-level E1 HEMP simulator is required. These have been built at various locations around the world and the large simulators can be found in the HEMP simulator compendium, IEC TR 61000-4-32. The conducted test methods are adapted from many of the standard IEC EMC immunity test methods, however, again at the high levels, there are new test methods that have been defined. For testing buildings and other shielded areas, it is not expected that equipment inside will require high-level tests, but protective devices such as filters and SPDs will need to be tested to ensure that they can provide the proper protection at the building level.

A.11 IEC TR 61000-4-32: Testing and measurement techniques – High-altitude electromagnetic pulse (HEMP) simulator compendium

This technical report provides information about extant system-level high-altitude EMP (HEMP) simulators and their applicability as test facilities and validation tools for IEC SC 77C immunity test requirements. This report provides the first detailed listing of HEMP simulators throughout the world. This report is the preliminary summary of this effort. It should be updated on a regular basis as the status of test facilities changes.

The main body of the report is a collection of datasheets describing 42 EMP simulators in 14 countries that are still operational or could be made available for use by the international community. They have been constructed in the past in 14 countries to test large transportable vehicles to determine if they can survive the E1 HEMP field. These simulators vary in size with some having the capability to test large aircraft or vehicles. A few can only test equipment with a maximum height of 1,5 m. It is not likely that any of these simulators could test a full building, unless the simulator was transportable.

A.12 IEC 61000-4-33: Testing and measurement techniques – Measurement methods for high-power transient parameters

This document provides a basic description of the methods and means (e.g., instrumentation) for measuring responses arising from high-power transient electromagnetic parameters. These responses can include:

– the electric (E) and/or magnetic (H) fields (e.g., incident fields or incident plus scattered fields within a system under test),
– the current I (e.g., induced by a transient field or within a system under test),
– the voltage V (e.g., induced by a transient field or within a system under test), and
– the charge Q induced on a cable or other conductor).

These measured quantities are generally complicated time-dependent waveforms, which can be described approximately by several scalar parameters, or “observables”. These parameters include:

– the peak amplitude of the response,
– the waveform rise-time,
– the waveform fall-time (or duration),
– the pulse width, and
– mathematically defined norms obtained from the waveform.

This standard provides information on the measurement of these waveforms and on the mathematical determination of the characterizing parameters. It does not provide information on specific level requirements for testing.

This standard is focused on the methods to measure fast transient waveforms that also simultaneously possess high amplitudes. This means that special attention is required for designing sensors that will not break down under high voltage levels and that will also perform well at frequencies in the GHz range. Also, special attention is required to provide sufficient shielding of instrumentation cables and to account for signal loss in measurement cables.

While this standard is very important for measuring high-level signals, its most important application for protecting equipment inside shielded buildings is to ensure that the conducted transient testing of filters and SPDs at high levels applies the required time waveforms. For the case of IEMI, measurements in the 1 GHz to 10 GHz range should be designed to ensure that the measured fields and currents are properly identified.

A.13 IEC TR 61000-4-35: Testing and measurement techniques – HPEM simulator compendium

This technical report provides information about extant system-level high-power electromagnetic (HPEM) simulators and their applicability as test facilities and validation tools for immunity test requirements in accordance with the IEC 61000 series of standards. HPEM simulators with the capability of conducted susceptibility or immunity testing are included in IEC 61000-4-36. In the sense of this report the group of HPEM simulators consists of narrowband microwave test facilities and wideband simulators for radiated high-power electromagnetic fields. IEC 61000-2-13 defines high-power electromagnetic (HPEM) radiated environments as those with a peak power density that exceeds 26 W/m^2 (100 V/m or 0,27 A/m). This part of IEC 61000 focuses on a sub-set of HPEM simulators capable of achieving much higher fields. Therefore the HPEM radiated environments used in this document are characterized by a peak power density exceeding 663 W/m^2 (500 V/m or 1,33 A/m). The intention of this report is to provide the first detailed listing of both narrowband (hypoband) and wideband (mesoband, sub-hyperband and hyperband) simulators throughout the world.

A general description of HPEM simulators, as listed in this report, is presented. A database was created by collecting information from simulator owners and operators, and these data are presented for the technical characterization of the test facilities. In addition, some important commercial aspects, such as availability and operational status, are also addressed.

This report reviews the availability of large sized narrowband and wideband simulators available throughout the world for evaluating the immunity of electronic equipment and systems, although the systems are typically no larger than an automobile or a small fighter aircraft. In most cases the simulators are used to test equipment. The point is that these simulators, with few exceptions, are not really applicable for the testing of fixed buildings at high levels. This is due to the limitations with regard to the narrowness of the beams and the distances necessary to expose a large building.

It is true that many of the portable simulators could expose part of a building and could therefore prove that the electronics inside could operate without interruption. It is felt that this approach for protecting a new or existing building and then testing at high levels is a difficult approach to apply, as compared to evaluating the penetration of CW fields to determine the shielding effectiveness of a building and then using linear transfer functions to determine the likely time waveforms of various transient fields from E1 HEMP or IEMI.

A.14 IEC 61000-4-36: Testing and measurement techniques – IEMI immunity test methods for equipment and systems

This document provides methods to determine test levels for the assessment of the immunity of equipment and systems to IEMI sources. It introduces the general IEMI problem, IEMI source parameters, derivation of test limits and summarises practical test methods.

This document considers a range of IEMI source parameters including:

1) the frequency range of the source,
2) the amplitude of the source vs. distance to the victim system,
3) the pulse width, pulse repetition frequency, burst length of the source,
4) the source mobility, and
5) the technical capability of the source user/designer.

In addition the document includes the protection level of the fixed installation considering

a) the range or distance between the IEMI source and the victim electronics,