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TECHNICAL REPORT

Electromagnetic compatibility (EMC) – Part 4-35: Testing and measurement techniques – HPEM simulator compendium

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

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FOREWORD

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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 61000-4-35, which is a technical report, has been prepared by subcommittee 77C: High power transient phenomena, of IEC technical committee 77: Electromagnetic compatibility.

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

Enquiry draft	Report on voting
77C/189/DTR	77C/193/RVC

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

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

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

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- withdrawn,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

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

INTRODUCTION

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

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

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

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts published either as international standards, 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 4-35: Testing and measurement techniques – HPEM simulator compendium

1 Scope

This part of IEC 61000 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 will be included in a further stage of the project. In the sense of this report the group of HPEM simulators consists of narrow band 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.

HEMP simulators are the subject of a separate compendium (IEC 61000-4-32) and thus are outside the scope of this Technical Report.

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

2 Normative references

The following referenced documents are indispensable for the application 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 60050-161, *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*

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

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

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

IEC 61000-4-21, *Electromagnetic compatibility (EMC) – Part 4-21: Testing and measurement techniques – Reverberation chamber test methods*

3 Terms and definitions

For the purposes of this document, the following general definitions apply, as well as the terms and definitions given in IEC 60050-161 (IEV) and IEC 61000-2-13.

3.1
bandratio
***b*r**
ratio of the high and low frequencies, which are given by the 90 % energy bandwidth (B_{90EB}); if the signal spectrum has a large d.c. content, the lower limit is nominally defined as 1 Hz.

$$b_{\mathrm{r}} = \frac{f_h}{f_l}$$

3.2
energy bandwidth
***B*90EB**
if $A_{0,9}$ is the collection of non-negative pairs $\{f_l, f_h\}$ of real numbers that satisfy the equation

$$\frac{\int_{f_l}^{f_h} \left|\hat{S}(f)\right|^2 df}{\int_{0}^{\infty} \left|\hat{S}(f)\right|^2 df} = 0,9. \tag{1}$$

where $\hat{S}(f)$ denotes the signal spectrum. The 90 % fractional energy bandwidth (B_{90EB}) is then defined as the infimum of all intervals f_l to f_h that satisfy Equation 1

$$B_{90EB} = \inf\left\{\left(f_h - f_l\right):\ \left\{f_l, f_h\right\}\ \text{in}\ A_{0.9}\right\}. \tag{2}$$

where inf{M} denotes the infimum (or smallest element) of a given set M

NOTE Although more than one pair of $\{f_l, f_h\}$ might satisfy Equation 1, that is $A_{0,9}$ contains more than a single pair of frequencies, B_{90EB} is unique. For example, if the spectral magnitude is a rectangular function, the 90 % fractional bandwidth is a single value, even though $A_{0,9}$ contains an infinite number of distinct pairs $\{f_l, f_h\}$. The 90 % fractional energy bandwidth provides good information on how the signal energy is distributed in the frequency domain. This quality makes B_{90EB} a useful measure for characterizing signals in terms of their spectral occupancy and electromagnetic interference on other sources.

3.3
far field
region, where the angular field distribution and the waveform is essentially independent of the distance from the source [1][1]. In the far field region the power flux density approximately obeys an inverse square law of the distance

NOTE The far field region of an antenna, radiating into free space, is characterized by a transverse electromagnetic field and that the ratio between the electric and magnetic field strength equals the characteristic wave impedance of free space:

$$\frac{E}{H} = \eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120 \cdot \pi \quad \approx 377 \quad \Omega$$

---

1 The number in square brackets refers to the bibliography.

3.4
fractional bandwidth
***b*_f_**
ratio of the 90 % energy bandwidth (B_{90EB}) and the centre frequency (f_c) of a waveform

$$bf = \frac{B_{90EB}}{f_c} = 2\frac{(f_h - f_\ell)}{(f_h + f_\ell)}$$

3.5
full width at half maximum
T_{FWHM}
duration of a signal; time difference at which the signal (e.g. electrical field strength) is equal to half of its maximum value

3.6
high altitude electromagnetic pulse
HEMP
electromagnetic pulse produced by a nuclear explosion outside the Earth's atmosphere

NOTE Typically above an altitude of 30 km. See IEC 61000-2-9 and IEC 61000-2-10 for details.

3.7
high power electromagnetic
HPEM
general area or technology involved in producing intense electromagnetic radiated fields or conducted voltages and currents with a peak power which has the capability to damage or upset electronic systems

3.8
high power electromagnetic radiated environment
a radiated environment with a peak power density that exceeds 26 W/m^2 (100 V/m or 0,27 A/m)

NOTE In this Technical Report the HPEM radiated environment is used for an environment that is characterized by a peak power density of more than 663 W/m^2 (500 V/m or 1,33 A/m).

3.9
high power microwaves
HPM
narrowband signals, normally with peak power in a pulse, in excess of 100 MW at the source.

NOTE This is a historical definition that depended on the strength of the source. The interest in this Technical Report is mainly on the EM field incident on an electronic system. Therefore in this Technical Report HPM is used for a narrowband microwave field that is characterized by a peak power density of more than 663 W/m^2 (500 V/m or 1,33 A/m).

3.10
hyperband signal
signal with a pbw value between 163,4 % and 200 % or a b_r of >10

3.11
hyperband simulator
simulator that radiates an electromagnetic field with a hyperband waveform

3.12
hypo- or narrowband signal
signal with a pbw of <1 % or a b_r of <1,01

3.13
hypo- or narrowband simulator
simulator that radiates an electromagnetic field with a hypoband waveform

3.14
mesoband signal
signal with a pbw value between 1 % and 100 % or a b_r between 1,01 and 3

3.15
mesoband simulator
simulator that radiates an electromagnetic field with a mesoband waveform

3.16
percentage bandwidth
pbw
bandwidth of a waveform expressed as a percentage of the centre frequency of that waveform

$$pbw = \frac{2\,(f_h - f_\ell)}{(f_h + f_\ell)} \times 100$$

with pbw at a maximum value of 200 %

3.17
short pulse signal
pulse with a rise time in the picoseconds to nanosecond region and a duration (T_{FWHM}) of nanoseconds to tens of nanoseconds

3.18
simulator with spot frequencies
hypoband simulator that operates on dedicated frequencies (spot frequencies) within the specified range

3.19
sub-hyperband signal
signal with a pbw value between 100 % and 163,4 % or a b_r between 3 and 10

3.20
sub-hyperband simulator
simulator that radiates an electromagnetic field with a sub-hyperband waveform

3.21
transient
pertaining to or designating a phenomena or a quantity which varies between two consecutive steady states during a time interval short compared with the time-scale of interest

[IEV 161-02-01]

NOTE A transient can be a unidirectional impulse of either polarity or a damped oscillatory wave with the first peak occurring in either polarity.

3.22
tunable simulator
hypoband simulator that is able to operate at each frequency within the specified frequency range

3.23
ultra wideband signal
UWB
signal with a pbw value of more than 25 %

3.24
ultra wideband simulator
UWB
simulator that radiates a electromagnetic field with a ultra wideband waveform

3.25
wideband signal
WB
signal with a pbw value between 1 % and 25 %

3.26
wideband simulator
WB
simulator that radiates a electromagnetic field with a wideband waveform

4 General

Interest in High-Power Electromagnetics (HPEM), particularly the generation of high-power electromagnetic fields and their effects on electronics appears to have increased in recent times. As components for High-Power Microwave (HPM), wideband (WB) and ultra-wideband (UWB) technologies have achieved notable progress, high-power generator systems difficult or impossible to build ten years ago are now being used for an increasingly wide variety of applications. With the advent of HPEM sources capable of producing output powers in the GW range, there has been interest in using HPEM devices in military defence applications to disrupt or destroy offensive electronic systems.

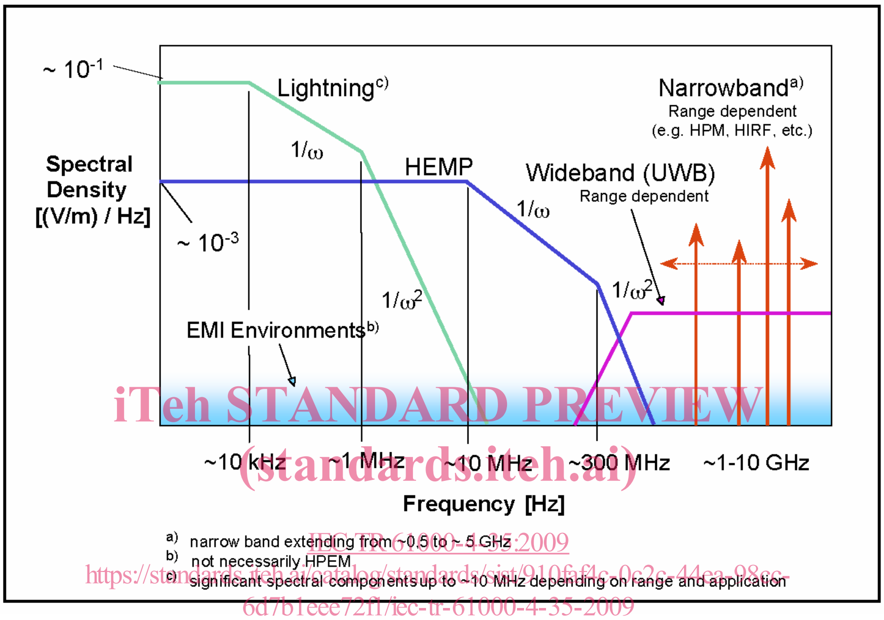
In numerous publications it has been reported that the technical capability to interrupt and/or damage sensitive electronics by generating Intentional Electromagnetic Interference (IEMI) exists and could be used for malicious purposes [2], [3], [4], [5].

The IEC recognises certain major trends in civilian electronic systems as follows:

a) increasing use of automated electronic systems in every aspect of civilized societies – communication, navigation, medical equipment, etc.;
b) increasing susceptibility of electronic systems due to higher package densities, use of monolithic integrated circuits (MIC) (system on a chip), multi-chip modules (MCM) (mixing analogue, digital, microwave, etc.), and
c) increasing use of EM spectrum which include radio, TV, microwave ovens, aircraft electronics, automobile electronics, cell phones, direct broadcast satellites, etc.

Since these electronic components began to control safety critical functions, concern grew over the vulnerability of electronic systems. It is easy to envision a component failure leading to a subsystem and consequently a system-level failure, due to an intense HPEM signal. Therefore the susceptibility of critical systems is of vital interest since a setup or failure in these systems could cause major accidents or economic disasters [6]. The increase of non-metallic materials like carbon-fiber composite as well as the decrease of signal levels result in a decreased susceptibility level of electronic systems. As a consequence, the investigation of the susceptibility of electronic systems as well as their protection and hardening against HPEM threats is of great interest.

Figure 1 compares qualitatively the emerging HPEM environments with classical EMC (EMI, lightning) and HEMP environment. It can clearly be seen that the HPEM environment differs significantly in amplitude and/or frequency from the traditional EMC and HEMP environment.



NOTE The magnitude of the electric field spectrum is plotted on the y-axis.

Figure 1 – Several types of HPEM environments (from IEC 61000-2-13)

Annex A of the IEC 61000-2-13 contains four types of intentional electromagnetic environment, coupling and interference cases that can create system malfunctions. Annex B of IEC 61000-2-13 provides some examples of HPEM generators and their categorization on the basis of the technical sophistication level involved in assembling and deploying them.

The recently developed IEC HPEM environment standard (IEC 61000-2-13) provides both radiated and conducted HPEM environments that are possible and perhaps probable. This report provides a logical support to IEC 61000-2-13 by listing data on facilities that can simulate some of the radiated HPEM environment. These HPEM simulators may be useful for system-level in addition to equipment-level immunity tests.

5 Datasheet definitions and instructions

The request for information that was sent to owners of worldwide High-Power Electromagnetic (HPEM) simulators included the following definitions and general instructions. Owners were asked to make sure that the provided information was cleared for public release and free to be published in an IEC document.

Data sheets are structured as follows:

1. General Information

2. Administrative Information

3. Availability

4. Electromagnetic field characteristics

   4.A. Wideband and Ultra Wideband Simulator (mesoband, sub-hyperband and hyperband simulator)

   4.B. Narrowband Simulator (hypoband simulator)

      4.B.1 Tunable simulator

      4.B.2 Simulator with spot frequencies

      4.B.3 Reverberation Chamber

5.Other technical information

Clauses 1, 2, 3 and 5 are filled with data for all kinds of simulators. Under Clause 4 only the specific subclause, which is applicable to the reported simulator, is filled with information. For reasons of clarity, unused subclauses are represented by their headlines only.

The antanna and the impulse voltage source are essential (characterizing) components of a wideband (mesoband, sub-hyperband and hyperband) simulator. Generally, changing one of these components will result in a different waveform. In this report such change is treated like the assembly of a different simulator, which is reported by a separate datasheet.

In case a specific parameter, for example carrier frequency, is not applicable to a specific simulator one might check the not applicable (n/a) box. Further information or explanations to the given data can be provided in the comment field at the end of each clause.

For simulators that are radiating narrowband (hypoband) pulses, peak power density and electric field strength are characterized by its peak r.m.s. value (e.g. Maximum r.m.s. peak E-Field).

The following tables provide definitions and background information on the data provided. In data sheets, blue coloured headlines are used. Therefore, clauses are numbered as on the data sheet.

1. General information

Name of the simulator	Specify the name of the simulator.
Country	Specify the country where the simulator is located.
Simulator type	Select the simulator type with regard to the bandwidth classification as provided in IEC 61000-2-13, (hypoband = narrowband, mesoband, sub-hyperband and hyperband) from the drop down menu. For a detailed description, see bandwidth classification in subclause 4.A.
Major simulator dimension(s)	Specify the longest dimension of the simulator in meters (e.g., 80 m long).
Maximum test volume dimensions	Specify the dimensions in meters of the usable test volume (e.g., 15 m (high) by 20 m (wide) by 50 m (long)). The maximum test volume, specified by height × width × length, is the volume that can be occupied by the object under test without undesirable interactions.
Comments	Space to provide extra information or explanations to the data you have provided in the “General Information” clause.

2. Administrative information

Location	Specify the location of the simulator (nearest city and country).
Mobile	Specify if the simulator is mobile (e.g. has the capability to be transported to another location).
Indoor	Specify if the simulator operates indoor, that is the test area is located indoor.
Outdoor	Specify if the simulator operates outdoor, that is the test area is located outdoor.
Owner	Specify the name of the company or agency that owns the simulator.
Type of Organisation	Select the owners type of organization (government, industry, research institute or university) from the drop down menu.
Point of Contact	Specify the name and full address of the person to contact for more information about the simulator.
Status	Select the current status of the simulator (e.g., under development, operational, stand-by, inoperative).
Initial operation date (year)	Specify the year in which the simulator first became operational.