

INTERNATIONAL STANDARD



BASIC EMC PUBLICATION

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



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2020 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.



IEC 61000-4-36

Edition 2.0 2020-03
REDLINE VERSION

INTERNATIONAL STANDARD



BASIC EMC PUBLICATION

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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.20

ISBN 978-2-8322-8045-4

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD	7
INTRODUCTION	2
1 Scope	10
2 Normative references	10
3 Terms, definitions and abbreviated terms	10
3.1 Terms and definitions	10
3.2 Abbreviated terms	14
4 General	16
5 IEMI environments and interaction	16
5.1 General	16
5.2 IEMI environments	17
5.2.1 Technical capability groups	17
5.2.2 IEMI deployment scenarios	17
5.2.3 Radiated IEMI environment summary	18
5.2.4 Published conducted IEMI environments	18
5.3 Interaction with victim equipment, systems and fixed installations	19
5.3.1 General	19
5.3.2 Protection level	20
6 Test methods	20
6.1 Derivation of applicable test methods	20
6.2 Derivation of transfer functions	21
6.3 Radiated tests using IEMI simulator	22
6.4 Radiated tests using a reverberation chamber	22
6.5 Complex waveform injection (CWI)	22
6.6 Damped sinusoidal injection (DSI)	22
6.7 Electrostatic discharge (ESD)	22
6.8 Electrically fast transient (EFT)	23
6.9 Antenna port injection	23
7 Test parameters	23
7.1 Derivation of immunity test parameters	23
7.2 Radiated test parameters	24
7.2.1 Generic hyperband test parameters (skilled capability group)	24
7.2.2 Generic mesoband test parameters (skilled capability group)	25
7.2.3 Generic hypoband/ narrowband test parameters (skilled capability group)	27
7.3 Generic conducted IEMI test parameters	29
7.3.1 General	29
7.3.2 Characteristics and performance of the fast damped oscillatory wave generator	29
7.4 Tailored test level derivation	30
7.5 Relevance of EMC immunity data	31
Annex A (informative) Failure mechanisms and performance criteria	32
A.1 General	32
A.2 Failure mechanisms	32
A.2.1 General	32
A.2.2 Noise	33

A.2.3	Parameter offset and drifts	33
A.2.4	System upset or breakdown.....	34
A.2.5	Component destruction	34
A.3	Effect of pulse width.....	35
A.4	Performance criteria	35
A.5	References	36
Annex B (informative)	Developments in IEMI source environments	38
B.1	General.....	38
B.2	IEMI environment.....	39
B.3	IEMI sources.....	40
B.4	Published radiated IEMI environments	44
B.4.1	IEC 61000-2-13 [B.14]	44
B.4.2	Mil-Std-464C	44
B.4.3	Selection of parameters for mesoband immunity test	46
B.4.4	International Telecommunication Union (ITU)	46
B.5	Summary	49
B.6	References	50
Annex C (informative)	Interaction with buildings.....	52
C.1	Building attenuation	52
C.2	Coupling to cables	53
C.3	Low voltage cable attenuation.....	54
C.4	References	55
Annex D (informative)	Relation between plane wave immunity testing and immunity testing in a reverberation chamber	57
D.1	General.....	57
D.2	Relation between measurements of shielding effectiveness in the two environments	58
D.3	Relation between immunity testing in the two environments	61
D.4	Additional aspects.....	63
D.5	References	63
Annex E (informative)	Complex waveform injection – Test method.....	66
E.1	General.....	66
E.2	Prediction	66
E.2.1	General	66
E.2.2	Example	70
E.3	Construction	72
E.4	Injection.....	76
E.5	Summary	78
E.6	References	78
Annex F (informative)	Significance of test methodology margins	80
F.1	General.....	80
F.2	Examples.....	80
F.2.1	General	80
F.2.2	Negative contributions	81
F.2.3	Positive contributions.....	83
F.2.4	Summary	85
F.3	References	85
Annex G (informative)	Intentional EMI – The issue of jammers	86

G.1	General.....	86
G.2	Effects	86
G.3	Published accounts of jamming.....	87
G.4	Risk assessment.....	87
G.5	Mitigation	87
G.6	References	88
Annex H (normative) Hyperband and mesoband radiated transients immunity test method		90
H.1	Overview.....	90
H.2	Test equipment	90
H.2.1	General	90
H.2.2	Test facility	90
H.2.3	Hyperband transient pulse radiating test system	91
H.2.4	Mesoband transient pulse radiating test system	91
H.2.5	Measurement chain	91
H.3	Field uniformity assessment.....	92
H.3.1	Field uniformity assessment in an anechoic chamber.....	92
H.3.2	Field uniformity in GTEM waveguide	95
H.4	Test set-up	95
H.4.1	General	95
H.4.2	Arrangement of table-top equipment	97
H.4.3	Arrangement of floor-standing equipment	97
H.4.4	Arrangement of wiring.....	97
H.5	Test procedure.....	98
H.5.1	General	98
H.5.2	Laboratory reference conditions.....	98
H.5.3	Execution of the test	98
H.5.4	Evaluation of test results	100
H.6	Test report	100
H.7	References	101
Annex I (informative) Calibration method and measurement uncertainty of sensors for the measurement of radiated hyperband and mesoband transient fields.....		102
I.1	General.....	102
I.2	Calibration method in TEM waveguides in IEC 61000-4-20:2010, Annex E [I.1]...	102
I.2.1	General	102
I.2.2	Probe calibration requirements	103
I.2.3	Field probe calibration procedure in case of a one-port TEM waveguide	104
I.3	Calibration procedures for D-dot sensors in the time domain.....	105
I.3.1	General	105
I.4	Measurement uncertainty	107
I.5	References	108
Bibliography.....		109
Figure 1 – Example of radiated and conducted IEMI interaction with a building.....		19
Figure 2 – Assessment options		21
Figure 3 – Examples of ports		23
Figure 4 — Typical Example of hyperband waveform		25
Figure 5 — Typical Example of mesoband waveform.....		27

Figure 6 – Typical hypoband/narrowband waveform.....	28
Figure 7 – Waveform of the damped oscillatory wave (open circuit voltage)	29
Figure A.1 – IEMI induced offset of sensor output – Corruption of information	33
Figure A.2 – Collision of an induced disturbance with data bits [A.1].....	34
Figure A.3 – Examples of destruction on a chip [A.2]	34
Figure A.4 – Generic failure trend as a function of pulse width	35
Figure B.1 – A comparison of HPEM and IEMI spectra [B.6]	38
Figure B.2 – Representation of typical IEMI radiation and coupling onto systems [B.3]	40
Figure B.3 – Parameter space in power/frequency occupied by sophisticated IEMI (i.e. DEW) sources in comparison to common RF systems [B.1].....	41
Figure B.4 – Peak power and energy from continuous and pulsed (durations shown) microwave sources, narrowband and wideband	41
Figure B.5 – Peak powers of various types of pulsed HPM hypoband/narrowband sources [B.1].....	42
Figure B.6 – Peak versus average power for microwave sources with duty factors indicated	42
Figure B.7 – Phase coherence leading to a compact HPM source with N^2 scaling of output power.....	43
Figure B.8 – Briefcase mesoband UWB DS source sold by Diehl-Rheinmetall [B.3]	43
Figure B.9 – A do-it-yourself electromagnetic weapon made from an oven magnetron [B.13].....	44
Figure B.10 – Wideband (mesoband and hyperband) EME derived from [B.17]	46
Figure B.11 – Plot of entire narrowband system weight as a function of output microwave power for land-mobile and land-transportable systems	50
Figure C.1 – Typical unprotected low-rise building plane wave E-field attenuation collected from references.....	52
Figure C.2 – Cable coupling and resonance region	54
Figure C.3 – Mains cable attenuation profile	55
Figure E.1 – LLSC reference field measurement set-up	67
Figure E.2 – LLSC induced current measurement set-up	68
Figure E.3 – Typical LLSC magnitude-only transfer function	68
Figure E.4 – Prediction of induced current using minimum phase constraints.....	69
Figure E.5 – IEC 61000-2-9 early-time (E1) HEMP environment	70
Figure E.6 – Overlay of transfer function and threat (frequency domain)	71
Figure E.7 – Predicted current	71
Figure E.8 – Example of de-convolution result	73
Figure E.9 – Damped sinusoidal waveforms – Ten-component fit.....	73
Figure E.10 – Approximated and predicted transient	74
Figure E.11 – Approximated and predicted transient (0 ns to 100 ns).....	74
Figure E.12 – Approximation and prediction transient – Frequency domain comparison	75
Figure E.13 – Variation in error for an increasing number of damped sinusoids	76
Figure E.14 – Complex injection set-up.....	77
Figure E.15 – Amplifier requirements for various current levels	77
Figure E.16 – Comparison of predicted (green) and injected (red) current.....	78
Figure F.1 – Variation in induced currents as a result of configuration	81

Figure F.2 – Comparison of HPD and VPD induced currents	82
Figure F.3 – System variability	82
Figure F.4 – Comparison of single- and multi-port injection	83
Figure F.5 – Example of transfer functions and worst-case envelope	84
Figure F.6 – Comparison of individual and worst-case transfer function predictions	84
Figure F.7 – Comparison between predicted and measured induced currents	85
Figure H.1 – Measurement chain for field uniformity assessment and transient responses	91
Figure H.2 – Test set-up for field uniformity assessment in anechoic chamber	93
Figure H.3 – Example of test set-up for table-top equipment/system	96
Figure H.4 – Example of test set-up for floor-standing equipment/system	96
Figure H.5 – Example of test set-up in GTEM waveguide	97
Figure I.1 – Example of the measurement points for the validation	104
Figure I.2 – Set-up for calibration of E-field probe in one-port TEM waveguide	105
Figure I.3 – Cone and ground plane sensor calibration set-up	106
Table 1 – Possible IEMI deployment scenarios	18
Table 2 – Summary of high power radiated IEMI source output (rE_{far}) by capability group	18
Table 3 – Examples of protection levels	20
Table 4 – Generic hyperband test parameters (skilled capability group)	24
Table 5 – Radiated hyperband test waveform and other pulse parameters	24
Table 6 – Generic mesoband test parameters (skilled capability group)	25
Table 7 – Comparison of quality factor (Q) with bandratio	26
Table 8 – Radiated mesoband waveform and other pulse parameters	26
Table 9 – Generic hypoband/narrowband test parameters (skilled capability group)	28
Table 10 – Conducted IEMI test levels	29
Table 11 – Open circuit specifications	30
Table 12 – Short circuit specifications	30
Table A.1 – Recommended performance criteria	36
Table B.1 – IEMI environments from IEC 61000-2-13	44
Table B.2 – Hypoband/narrowband HPM environment from [B.17]	44
Table B.3 – Hyperband/ Wideband (mesoband/hyperband) HPM environment from [B.17]	45
Table C.1 – Shielding effectiveness measurements for various power system buildings and rooms	53
Table E.1 – Time waveform norms	72
Table I.1 – Calibration frequencies	104
Table I.2 – Type B expanded uncertainties for sensor calibrations in GTEM cell field generation system	107
Table I.3 – Type B expanded uncertainties for sensor calibrations in the cone and ground plane cell field generation system	108

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-36: Testing and measurement techniques – IEMI immunity test methods for equipment and systems

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 61000-4-36 has been prepared by subcommittee 77C: High power transient phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms part 4-36 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

This second edition cancels and replaces the first edition published in 2014. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) addition of a hyperband and mesoband radiated transients immunity test method in Annex H;
- b) addition of a calibration method of sensors for radiated hyperband and mesoband transient fields and measurement uncertainty in Annex I.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
77C/295/FDIS	77C/299/RVD

Full information on the voting for the approval of this standard 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.

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 publication will remain unchanged until the stability date indicated on the IEC website 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.

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 4-36: Testing and measurement techniques – IEMI immunity test methods for equipment and systems

1 Scope

This part of IEC 61000 provides methods to determine test levels for the assessment of the immunity of equipment and systems to intentional electromagnetic interference (IEMI) sources. It introduces the general IEMI problem, IEMI source parameters, derivation of test limits and summarises practical test methods.

2 Normative references

~~The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.~~

~~IEC 61000-4-4, Electromagnetic compatibility (EMC) — Part 4-4: Testing and measurement techniques — Electrical fast transient/burst immunity test~~

~~IEC 61000-4-12, Electromagnetic compatibility (EMC) — Part 4-12: Testing and measurement techniques — Ring wave immunity test~~

~~IEC 61000-4-18, Electromagnetic compatibility (EMC) — Part 4-18: Testing and measurement techniques — Damped oscillatory wave immunity test~~

There are no normative references in this document.

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 (as a result of absorption and/or scattering) of an electric or magnetic field or a current or voltage, usually expressed in decibels

[SOURCE: IEC 61000-2-13:2005 [3]¹, 3.1]

¹ Numbers in square brackets refer to the Bibliography.

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 (see IEC 61000-2-13 [3] for further details).

[SOURCE: IEC 61000-2-13:2005 [3], 3.2, modified – The second part of the definition has been made into a note.]

3.1.3 bandratio decades

~~brd~~

bandratio expressed in decades as: bandratio decades = $\log_{10}(\text{bandratio})$

[SOURCE: IEC 61000-2-13:2005 [3], 3.3]

3.1.4 burst

~~time frame in which a series of pulses occurs with a given repetition rate~~
sequence of a limited number of distinct pulses or oscillations of limited duration

Note 1 to entry: When multiple bursts occur, the time between bursts is usually defined.

SOURCE: [IEC 60050-161:1990 [19], 161-02-07, modified – The note has been added.]

3.1.5 conducted HPEM environment

high-power electromagnetic currents and voltages that are either coupled or directly injected to cables and wires with voltage levels that typically exceed 1 kV

[SOURCE: IEC 61000-2-13:2005 [3], 3.5]

3.1.6 continuous wave CW

time waveform that has a fixed frequency and is continuous

[SOURCE: IEC 61000-2-13:2005 [3], 3.6]

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 60050-161:2018, 161-01-07.]

3.1.8 electromagnetic disturbance

any electromagnetic phenomenon which ~~may~~ can degrade the performance of a device, equipment or system

[SOURCE: IEC 60050-161:2018, [19] 161-01-05, modified – The last part of the definition, "or adversely affect living or inert matter", has been removed.]

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 60050-161:2018 [19], 161-01-06, modified – Notes 1 and 2 have been removed and a new Note 1 has been added.]

3.1.10 shield

<electromagnetic> 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~~ possibility of degradation to the performance of a device, equipment or system ~~to perform without degradation~~ in the presence of an electromagnetic ~~disturbance~~ field

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

~~**3.1.12 equipment under test EUT equipment being subjected to the test**~~

3.1.12 high-altitude electromagnetic pulse HEMP

electromagnetic pulse produced by a nuclear explosion outside the earth's atmosphere

Note 1 to entry: Typically above an altitude of 30 km.

[SOURCE: IEC 61000-2-13:2005 [3], 3.12]

3.1.13 high-power microwave 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.

[SOURCE: IEC 61000-2-13:2005 [3], 3.13]

3.1.14 hyperband signal

signal or waveform with a pbw (see 3.1.19) value between 163,4 % and 200 % or a bandratio > 10

[SOURCE: IEC 61000-2-13:2005 [3], 3.14]

3.1.15 hypoband signal

narrowband signal or waveform with a pbw (see 3.1.19) of < 1 % or a bandratio < 1,01

[SOURCE: IEC 61000-2-13:2005 [3], 3.15, modified – The second term "narrowband signal" has been removed.]

3.1.16

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

[SOURCE: IEC 61000-2-13:2005 [3], 3.16]

3.1.17

L band

radar frequency band between 1 GHz and 2 GHz

[SOURCE: IEC 61000-2-13:2005 [3], 3.17]

3.1.18

mesoband signal

signal or waveform with a pbw (see 3.1.19) value between 1 % and 100 % or a bandratio between 1,01 and 3

[SOURCE: IEC 61000-2-13:2005 [3], 3.18]

3.1.19

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., HEMP) for which the bandratio decades is used.

[SOURCE: IEC 61000-2-13:2005 [3], 3.19]

3.1.20

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.

[SOURCE: IEC 61000-2-13:2005 [3], 3.20, modified – The second term "point-of-entry" has been removed.]

3.1.21

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

[SOURCE: IEC 61000-2-13:2005 [3], 3.21]

3.1.22

pulse repetition frequency

prf

number of pulses per unit time, measured in Hz ~~(per second)~~

3.1.23

radiated HPEM environment

high-power electromagnetic fields with peak electric field levels that typically exceed 100 V/m

[SOURCE: IEC 61000-2-13:2005 [3], 3.22]

3.1.24

rE_{far}

~~electric field normalised at a distance of 1 m from the antenna as derived from an E-field measurement at a given distance in the far-field~~

measured or known electric field multiplied by the distance at which it was measured to give an equivalent voltage at a distance of 1 m from the antenna

3.1.25

sub-hyperband signal

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

[SOURCE: IEC 61000-2-13:2005 [3], 3.23]

3.1.26

transient

pertaining to or designating a phenomenon or 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 60050-702:2019 [20], 702-07-781, modified – The words "pertaining to or designating a" and the note have been added.]

3.1.27

ultrawideband

UWB

signal that has a percent bandwidth greater than 25 %

[SOURCE: IEC 61000-2-13:2005 [3], 3.25]

3.2 Abbreviated terms

AC	Anechoic chamber
BCI	Bulk current injection
CWI	Complex waveform injection
DEW	Directed energy weapon
DS	Damped sinusoid
DSI	Damped sinusoid injection
EFT	Electrically fast transient
EM	Electromagnetic
EME	Electromagnetic environment
EMI	Electromagnetic interference



EMP	Electromagnetic pulse
ERTMS	European rail traffic management system
ESD	Electrostatic discharge
EUT	Equipment under test
FO	Fibre optic
FOL	Fibre optic link
FT	Fourier transform
GNSS	Global navigation satellite system
GPS	Global positioning system
GSM-R	Global system for mobile – railways
GTEM	Gigahertz transverse electromagnetic
HEMP	High-altitude electromagnetic pulse
HIRA	Half impulse radiating antenna
HIRF	High-intensity radiated field
HPD	Horizontally polarized dipole
HPEM	High-power electromagnetic
HPM	High-power microwave
IC	Integrated circuit
IEMI	Intentional electromagnetic interference
IFT	Inverse Fourier transform
IRA	Impulse radiating antenna
LEMP	Lightning electromagnetic pulse
LISN	Line impedance stabilization network
LLSC	Low level swept current
LLSF	Low level swept field
LNA	Low noise amplifier
MPA	Minimum phase algorithm
NEMP	Nuclear electromagnetic pulse
NLTL	Non linear transmission line
OATS	Open area test site
prf	Pulse repetition frequency
SAC	Semi-anechoic chamber
SE	Shielding effectiveness
TEM	Transverse electromagnetic mode
TMR	Triple modular redundancy
UAV	Unmanned aerial vehicle
UFA	Uniform field area
URSI	International radio scientific union
UWB	Ultra wideband
VPD	Vertically polarized dipole

4 General

The use of electromagnetic sources to generate intentional electromagnetic interference (IEMI) is of increasing concern as the reliance of society on technology increases significantly. Many technical papers have been published that show the effects of IEMI are cause for concern; they are summarised in [1]. A summary of failure mechanisms at equipment level is provided in Annex A.

~~The effects of IEMI on equipment can be similar to the effects caused by high-power electromagnetic (HPEM) environments. HPEM environments include high-intensity radiated fields (HIRF) generated by radio and radar systems, lightning electromagnetic pulse (LEMP) and electrostatic discharge (ESD). Some of these HPEM environments have similar characteristics to those sources used to cause IEMI but are unintentional EMI sources, i.e. non-malicious. However, it is possible to use information regarding qualification of equipment and systems to these environments to inform the likely response to IEMI.~~

IEMI can be included within the set of HPEM environments, which also include high-intensity radiated fields (HIRFs) generated by radio and radar systems, lightning electromagnetic pulse (LEMP) and electrostatic discharge (ESD).

The IEC defines IEMI (see 3.1.16) as "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".

Within this definition it is possible to also include jammers, which are designed to overload antenna receiver circuits (front doors) by operating at or close to the victim receiver frequency of operation. Jammers typically require low power to operate due to the fact that receivers are designed to operate at very low power levels (nW or less). More information on the issue of jammers can be found in Annex G.

This document complements IEC 61000-4-25 [2], which deals with high-altitude electromagnetic pulse (HEMP) immunity test methods for equipment and systems.

5 IEMI environments and interaction

5.1 General

There are many types of sources ~~that can generate~~ which are capable of generating electromagnetic environments ~~that can potentially be used to cause~~ causing intentional electromagnetic interference (IEMI). IEC 61000-2-13 [3] discusses the various environments that can be generated and categorises them in terms of time characteristics, frequency range and bandratio. Further details and actual examples are included within Annex B.

A key requirement of developing IEMI test methods and test levels is to achieve a good understanding of the environment in which the victim equipment or system will be required to operate. Within this document specific focus is provided for victim equipment that is integrated within a site or other fixed installation and it is generally assumed that such equipment is housed within a building.

IEMI phenomena are unlike other EMC standardised phenomena where assumptions can be made about the general or average disturbance level arriving at victim equipment ports. Important parameters related to the IEMI interaction with victim systems which will affect the test level include:

- a) IEMI source parameters
 - 1) frequency range of the source,

- 2) ~~amplitude of the source vs. distance to the victim system~~ peak and average power of the source,
 - 3) pulse width, pulse repetition frequency, burst length of the source,
 - 4) source mobility,
 - 5) technical ~~capability~~ complexity of the source ~~user/designer~~,
 - 6) antenna characteristics and/or conducted injection method characteristics
- b) the protection level of the equipment, system or ~~fixed~~ installation
- 1) the range or distance between the IEMI source and the victim electronics,
 - 2) the propagation channel loss including the properties of the intervening barriers (attenuation and absorption).

Once these characteristics of the IEMI source and environment are well understood, then appropriate test methods and test levels for ports on the victim equipment can be determined.

One approach would be to take all of the IEMI source parameters of interest and combine them such that one set of test levels is derived. The disadvantage of this approach is that, should effects be observed, it would be difficult to assign them to any single IEMI parameter set. In addition the combination of widely varying waveform characteristics would likely result in an extreme set of test levels.

Some IEMI sources generate waveforms/environments that are similar to other electromagnetic (EM) environments, for example electrostatic discharge (ESD) or lightning electromagnetic pulse (LEMP). Analytical methods can be used to determine the amount of similarity between IEMI environments and other EM environments, in particular through the use of waveform norms (see IEC 61000-4-33 [4]). Any deficiencies in the test evidence could be made up through increasing the distance between the IEMI source and the electronic systems of interest or by undertaking testing focussed on specific frequencies.

5.2 IEMI environments

5.2.1 Technical capability groups

IEMI sources vary in complexity. It is therefore important to understand the relationship between this complexity and the technical capability of the perpetrator. This document defines three levels:

- a) Novice – Individuals or small groups with minimal technical or financial support.
- b) Skilled – Moderately well-funded adversaries with training and expertise in relevant technology.
- c) Specialist – Well-funded adversaries with post-graduate level training and access to substantial research capabilities, resources and funding.

When considering the IEMI sources of interest it is important to consider the deployment scenario.

5.2.2 IEMI deployment scenarios

IEMI sources can be packaged and deployed in different ways, although this generally depends on the technical capability of the designer and the available resources. A set of potential scenarios for deployment of IEMI generators is given in Table 1.

Table 1 – Possible IEMI deployment scenarios

Deployment scenarios	Example use	Victim interaction	Technical capability group
Man portable	Carried to the victim and used while in possession of the adversary. Could be assembled in place.	Direct Radiated Conducted	Novice Skilled
Hand delivered	Carried to the victim and concealed, perhaps remotely activated. Could be assembled in place.	Direct Radiated Conducted	Novice Skilled
Fixed installation	Set-up in a space adjacent to the victim, i.e. an adjoining room or building.	Radiated Conducted	Novice Skilled Specialist
Automotive / marine delivered	Mounted inside a pick-up truck or on the after deck of a marine vessel.	Radiated Conducted	Skilled Specialist
Air delivered	Installed inside an aircraft bay, carried as a pod, or dropped (i.e., E-bomb).	Radiated	Specialist

5.2.3 Radiated IEMI environment summary

Table 2 provides a summary of threat source environments defined by capability group. ~~The term ' rE_{far} ' describes the electric field normalised at a distance of 1 m from the antenna as derived from an E field measurement at a given distance in the far field. It is equivalent to equivalent isotropic radiated power (EIRP) which is derived from the power density at a given distance in the far field.~~

Table 2 – Summary of high power radiated IEMI source output (rE_{far}) by capability group

Category	IEMI source type	IEMI source name or technology type	rE_{far} (V)	Near/far distance Far field boundary (approx.)
Novice	Hyperband	ESD gun	5 000	1 m
	Hypoband	Microwave oven magnetron	2 000	1 m
Skilled	Hyperband	Commercially available solid state pulser (e.g. pockels cell driver)	60 000	1 m
	Mesoband	Commercially available pulser	120 000	2 m
	Hypoband	Typical Radar	450 000	5 m
Specialist	Hyperband	Military demonstrator (e.g. jolt)	5 300 000	50 m
	Mesoband	Military mesoband demonstrator	500 000	5 m
	Hypoband	Military hypoband demonstrator	30 000 000	50 m

NOTE Table 2 does not include jammers. These are discussed in Annex G.

5.2.4 Published conducted IEMI environments

Unlike the situation with radiated IEMI sources, examples of conducted IEMI sources are less common. However, it has been shown that many conducted EMC tests exist within published civilian EMC documents such as IEC 61000-4-18 [5], IEC 61000-4-4 [6] and IEC 61000-4-25 [2] and that the sources that generate these test waveforms can be uprated or applied to equipment ports in a different way or otherwise used for malicious effect. There are also various military

standards that contain relevant conducted tests ~~such as Mil Std 461 [8] and Defence Standard 59 411 [9].~~

5.3 Interaction with **victim equipment, systems and** ~~fixed~~ installations

5.3.1 General

The magnitude of the IEMI environment impinging on a victim system is primarily dependent upon two factors:

- 1) the range or distance between the IEMI source and the victim electronics;
- 2) the propagation ~~channel~~ loss, including the **attenuation** properties of intervening barriers (~~attenuation and absorption~~).

It is important to note that radiated IEMI interacts not only with apertures and structures, but also cables. The total EM disturbance presented to the victim electronics inside is therefore a function of the direct radiated IEMI and the coupling of this IEMI to EM conductors such as cables, pipe-work and ducting. When determining an appropriate test level for a particular radiated IEMI environment of concern, an assessment of the transfer of the IEMI to the victim electronics inside the building is required and this should include any attenuation afforded by the building material, propagation loss and any other aspects that can affect the resulting currents or voltages presented to the equipment.

Figure 1 shows a typical radiated and conducted IEMI scenario with a vehicle-mounted IEMI source illuminating a building and separately injecting into a power cable. The fields generated by the radiating source penetrate through apertures and separately couple to conductors (both outside and inside the building), generating induced currents and voltages that can affect the victim electronic equipment. The current/voltage generated by the conducted source is coupled to the conductor, allowing it to propagate inside the building and potentially affect electronic equipment.

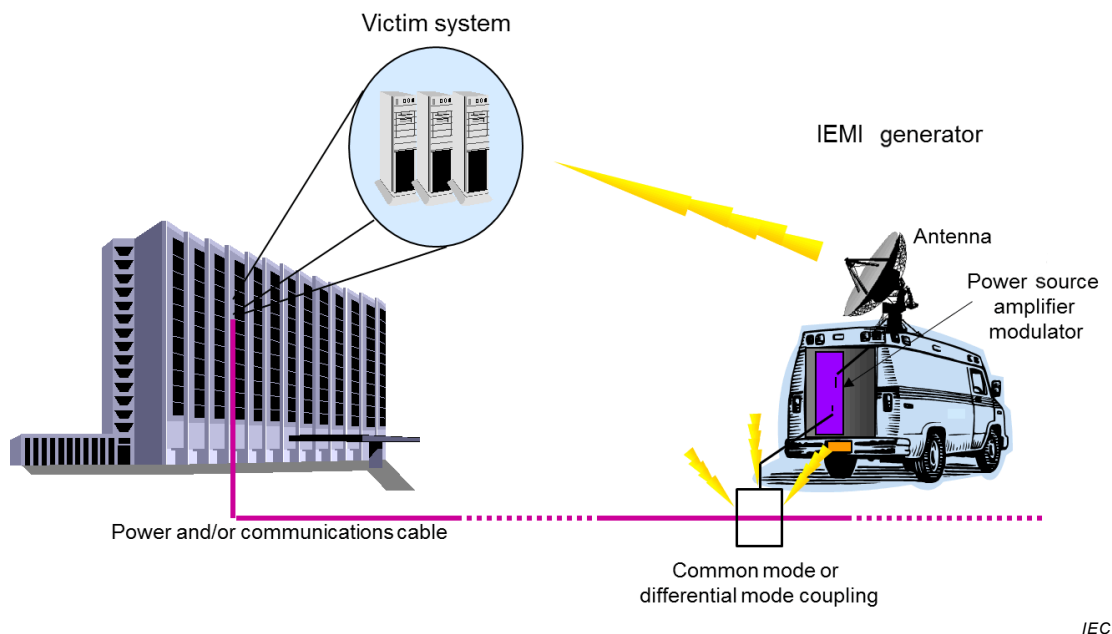


Figure 1 – Example of radiated and conducted IEMI interaction with a building

It should be noted that cable attenuation and attenuation afforded by lumped components (such as transformers) should be considered when determining the currents and voltages presented at the electronic equipment. It should also be noted that different coupling modes (i.e. common mode or differential mode) ~~may~~ **can** result in very different path losses during the propagation.

5.3.2 Protection level

Given the discussion above it can be implied that victim ~~electronic equipment~~ electronics located inside ~~a fixed installation~~ equipment, systems or installations will have an "inherent protection level" which is a function of the physical distance between the IEMI source and the victim electronics and the loss in the propagation channel. A discussion on the radiated and conducted interaction of IEMI sources within buildings is provided in Annex C.

Examples of protection levels are indicated in Table 3. These levels have been identified using the information in Annex C. However, it is highly important that the actual protection level is quantified through measurements, possibly as part of a site survey. Test methods which can be used to assess the barrier attenuation/propagation loss are discussed in Clause 6.

Table 3 – Examples of protection levels

Example of protection level (EPL) rating	Assumed range to victim (m)	Path loss (dB)	Assumed barrier attenuation (dB)	Total EPL (dB)
EPL0	2	6	0	6
EPL1	10	20	0	20
EPL2	12	22	4	26
EPL3	18	25	7	32
EPL4	30	28 29,5	11	39 40,5
EPL5	30	28 29,5	18	46 47,5
EPL6	35	31	29	60
NOTE Path loss equals the assumed range to victim in dB reference to 1 m. The path loss equates to the assumed threat to the victim range expressed in dB relative to 1 m.				

The EPL should be considered when deriving the applicable IEMI immunity test parameters discussed in Clause 7. In the absence of actual data the generic EPLs in Table 3 can be used.

6 Test methods

6.1 Derivation of applicable test methods

A detailed discussion on test methods is included in IEC TS 61000-5-9 [7]. The test methods summarised below encompass the evaluation of the "example protection level" and the immunity test level for potential victim equipment.

As IEMI falls into two main categories, namely radiated and conducted, the methods for testing against IEMI fall broadly into the same categories.

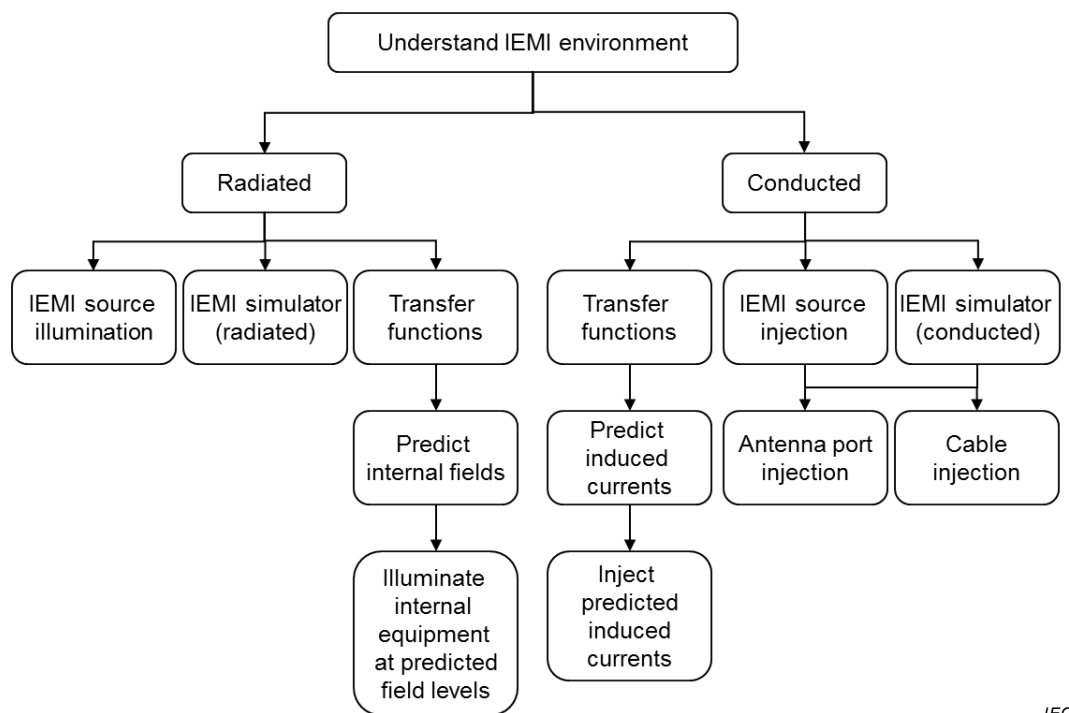
Testing against radiated IEMI can be undertaken with the IEMI source of interest, a simulated environment such as that shown in IEC TR 61000-4-35 [8], or by injecting the signal expected to be induced into conductors by exposure to the IEMI radiated environment. The latter relies on knowledge of the transfer function² of each conductor of concern (typically these conductors are cable bundles that carry power and/or data that is vital to the continuing function of the equipment or system).

² A measure of internally induced current or electromagnetic field as a result of an externally illuminating electromagnetic environment.

Testing against conducted IEMI is typically undertaken with either the IEMI source directly or with a conducted simulator. Although it is possible to use a radiated method to assess against the effects of conducted IEMI, it is not commonplace.

Once the preferred test methodology has been agreed, it is possible to determine the required test levels.

Figure 2 shows the options available when undertaking an assessment of the effects of IEMI on equipment or systems.



IEC

Figure 2 – Assessment options

It is essential that testing is conducted in a representative configuration and that careful consideration is given to those aspects of the test set-up that can have a significant impact on test results, for example cable layout. If the requirement is for equipment to be immune to IEMI when in a power-off configuration, then testing with the equipment powered off is applicable. For all other cases, testing with the equipment powered and functioning is essential. Research has shown that transient effects can be significantly enhanced when the equipment is being operated functionally, for example with computer equipment that is constantly conducting hard drive operations or memory intensive functions.

A summary of test methods that can be used for the assessment of equipment or systems to the effects of IEMI is provided below.

6.2 Derivation of transfer functions

Transfer functions are essential for any equipment or system that is to be tested against the effects of a radiated IEMI source using conducted methods and can also be used to evaluate the protection level of a victim installation.

Transfer functions can either be measured (using techniques such as those discussed in IEC TS 61000-5-9 [7]) or generated analytically using some understanding of relevant geometry.

Transfer functions provide the means of estimating induced currents or voltages on conductors as a result of an EM field illuminating the conductor or from an EM source injected onto external

cabling. Transfer functions are generally measured over a broad frequency range (e.g. ~1 MHz to ~1 GHz) and enable predictions to be computed for any IEMI environment with similar frequency content. Transfer functions can be extended to tens of GHz by measuring internally induced EM fields and reflecting the change in dominance of the interaction mechanism from cable coupling to aperture coupling.

For applicable test methods and test set-up see IEC TS 61000-5-9 [7].

6.3 Radiated tests using IEMI simulator

IEMI simulators are becoming increasingly available as the threat of IEMI is understood and accepted to pose real risk to the continuing operation of electronic equipment. IEC TR 61000-4-35 [8] contains details on IEMI simulators and their respective parameters. The equipment under test (EUT) shall be set-up in a representative condition of its intended use for the results to be indicative of the EUT response when fielded. The use of IEMI simulators to assess the protection level of ~~a fixed~~ **an operational** installation is not recommended since it ~~may~~ **can** present a significant interference risk.

For applicable test methods and test set-up of IEMI sources see IEC TR 61000-4-35 [8].

6.4 Radiated tests using a reverberation chamber

IEC TR 61000-4-35 [8] also provides some examples of reverberation chambers. Reverberation chambers can be used to produce the high field levels for equipment level testing and are useful for testing of a material's shielding effectiveness in accordance with IEC 61000-4-21 [9].

Care should be taken to understand how the results of measurements made within a reverberation chamber compare with the realistic case of IEMI interaction which is closer to a plane wave phenomenon. This difference is discussed in Annex D.

For applicable test methods and test set-up see IEC 61000-4-21 [9].

6.5 Complex waveform injection (CWI)

This method takes the predicted currents from transfer functions and injects them onto conductors one-by-one whilst monitoring for effects. The injected waveforms are a function of the resonances measured by the transfer function and the environment itself and are complex in nature, i.e. they contain many frequencies. Further details on this method can be found in Annex E.

6.6 Damped sinusoidal injection (DSI)

This method uses single frequency damped sinusoidal waveforms and is generally required to be repeated across many frequencies to give an indication of how an EUT ~~may~~ **can** respond to an IEMI environment. For applicable test methods and test set-up see IEC 61000-4-12 [10] and IEC 61000-4-18 [5].

6.7 Electrostatic discharge (ESD)

Testing to IEC 61000-4-2 [11] provides confidence of the continuing operation of the EUT as a result of ESD. ESD is **a complex event** generally **characterised by** a fast transient with a rise-time of the order of hundreds of picoseconds and **a pulse-width** of tens of nanoseconds. This information may be used to ~~inform~~ **infer** likely susceptibility to certain IEMI environments via the generation of radiated fields.

For applicable test methods and test set-up see IEC 61000-4-2 [11].

6.8 Electrically fast transient (EFT)

The EFT test has parameters that compare favourably with certain IEMI conducted environments, and data from the test defined in IEC 61000-4-4 [6] may be used to indicate the response of an EUT to IEMI.

For applicable test methods and test set-up see IEC 61000-4-4 [6].

6.9 Antenna port injection

This type of test provides valuable information on the response of transceiver systems to the effects of IEMI including jammers which are discussed in Annex G. The IEMI environment of interest shall either be used directly to inject signals into the antenna port or to determine (through the use of transfer functions) those signals that would exist at the associated electronics. Figure 3 shows a typical EUT with various ports including an antenna port.

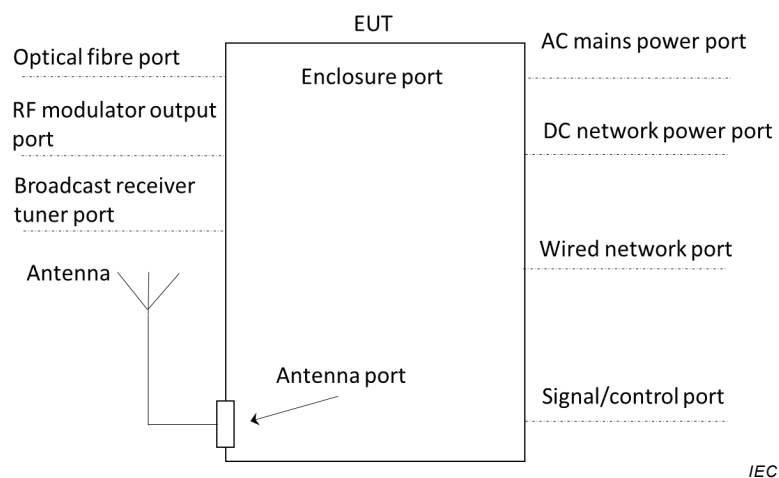


Figure 3 – Examples of ports

In general, antenna ports are commonly subjected to an ESD test. Also covered under 6.7, this is likely to provide useful information concerning the response of antenna ports to IEMI environments.

~~For applicable test methods and test set-up see Mil-Std-461 test method CS116 [5].~~

7 Test parameters

7.1 Derivation of immunity test parameters

The key to deriving immunity test levels lies in understanding the IEMI source of interest, the immunity requirement of the equipment or system that is to be assessed and the protection level for a given scenario.

For example, if the equipment or system is to be located within a secure facility (assuming 20 dB of attenuation for physical barriers) and such that an IEMI source cannot be any closer than 50 m (distance) away, this provides a useful bound on the test level. It ~~may~~ can be prudent to consider some margin to deal with issues such as measurement uncertainty or measurement limitation to ensure that the test results carry a high level of confidence. This gives a solid foundation for developing the required test level. Once this is understood, the test levels can be derived using a radiated IEMI source or simulator or with the use of transfer functions as discussed in 6.2.

Subclause 7.2 indicates generic test parameters based on the skilled category using the environment levels derived in Table 2 and the examples of protection levels indicated in Table 3.

7.2 Radiated test parameters

7.2.1 Generic hyperband test parameters (skilled capability group)

Table 4 defines the immunity test levels for hyperband IEMI environments (i.e. those with a bandratio ≥ 10).

Table 4 – Generic hyperband test parameters (skilled capability group)

EPL	Amplitude	Rise time	Pulse width	prf	Pulse length Burst duration
	(V/m)	(ps)	(ns)	(Hz)	(s)
EPL0	30 000	100 to 500	0,2 to 5	1 to 1 000	1 to 10
EPL1	6 000				
EPL2	3 000				
EPL3	1 500				
EPL4	675 565				
EPL5	300 252				
EPL6	60				
NOTE Any combination of waveform parameters in Table 4 will result in a different frequency spectrum of the waveform applied during the test. In some cases, this will result in a test that is less severe when considering the overall content or the associated maximum derivative of the applied waveform.					

All combinations of the parameter ranges given in Table 4 are **not** simultaneously achievable with existing IEMI test sources. Once a test level is selected, some parameter variation is recommended within the stated parameter ranges, if possible.

Table 5 shows a description of the radiated hyperband test waveform and other important test parameters.

Table 5 – Radiated hyperband test waveform and other pulse parameters

Bandratio	$\geq 10^a$
Pulse to pulse amplitude reproducibility	amplitude (E-field) $\pm 10\%$ ^b
Rise time	100 ps to 500 ps $\pm 20\%$
Pulse width	0,2 ns to 5 ns $\pm 20\%$
Pulse repetition frequency	1 Hz to 1 000 Hz $\pm 10\%$ ^b
Burst duration	1 s to 10 s $\pm 10\%$ ^b
Minimum number of bursts	1
Minimum burst interval (period)	2 s $\pm 20\%$
Radiated E-field exposure test level	selectable according to Table 4 $\pm 20\%$
Field polarization	selectable, horizontal or vertical, or both
^a The 3 dB bandratio of the hyperband waveform is measured and confirmed that it is greater than or equal to 10.	
^b The mean amplitude of the pulses in a burst is used. The reproducibility of the pulse amplitude (the flatness of the burst envelope) is important to control in order to accurately describe the test level used during exposure.	

An example of a hyperband waveform is given in Figure 4.

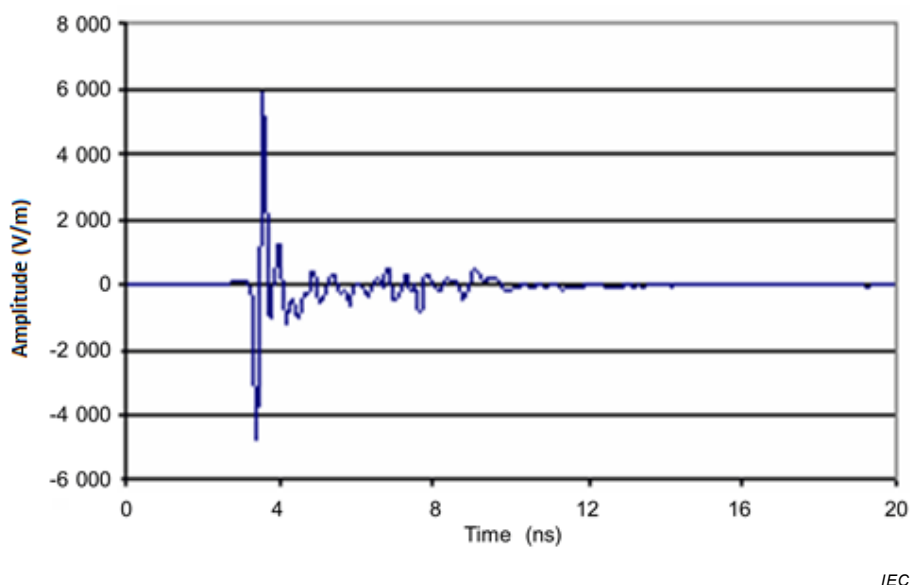


Figure 4 – Typical Example of hyperband waveform

7.2.2 Generic mesoband test parameters (skilled capability group)

These types of IEMI environment are characterised by a damped sinusoidal waveform. Table 6 contains the test levels and associated parameters. It should be noted that any combination of waveform parameters in Table 6 will result in a different frequency spectrum of the waveform applied during the test. In some cases, this will result in a test that is less strenuous when considering the overall content or the associated maximum time derivative of the applied waveform.

Table 6 – Generic mesoband test parameters (skilled capability group)

EPL	Amplitude, E_e E_{pk} (V/m)	Dominant frequency, f_e f_d (MHz)	Damping factor, Q	Pulse repetition frequency (prf) (Hz)	Pulse length/surst Burst duration (s)
EPL0	60 000	80 to 500	5 to 20	1 to 1 000	1 to 10
EPL1	12 000				
EPL2	6000				
EPL3	3 000				
EPL4	1 350 1 130				
EPL5	600 504				
EPL6	120				

The waveforms are well described by damped sine waves as shown in Equation (1) with the characteristics E_e , f_e and Q found in Table 5. The normalizing constant k is defined so that the maximum value of E_e will be equal to $E_{pp}/2$. Further information can be found in IEC 61000-2-10.

$$E_c(t) = k(E_{pp}/2)e^{\frac{-\pi f_c t}{Q}} \sin(2\pi f_c t)$$

~~Immunity data from relevant test standards (for example IEC 61000-4-18, DO160 [15], Mil Std 461 [5]) may cover some of the requirements in Table 5 or assist in the identification of frequencies that require further investigation.~~

It should be noted that not all combinations of the parameter ranges given in Table 6 are simultaneously achievable with existing IEMI sources. Once a test level is selected, some parameter variation is recommended within the stated parameter ranges if possible.

The waveform shape is well described by damped sine waves as shown in Formula (1).

$$E(t) = kE_{pk} e^{-\pi f_d t / Q} \sin(2\pi f_d t) \quad (1)$$

where, k is a normalising factor, f_d is the dominant frequency of the oscillation and t is time. The mesoband bandratio values of 1,01 to 3 can be shown by Formula (1) to correspond to Q -factor values of ~5 to 100, as shown in Table 7, however Q -factor values of between ~5 to 20 are more typically observed from IEMI generators and through IEMI and HEMP coupling to cables. Further information can be found in IEC 61000 2-13 [3].

Table 7 – Comparison of quality factor (Q) with bandratio

Quality factor Q	Normalising factor k	Bandratio
4,8	1,171	3,00
5,0	1,164	2,87
10,0	1,080	1,81
15,0	1,053	1,51
20,0	1,040	1,36
100,0	1,008	1,01

Table 8 shows a description of the radiated mesoband test waveform and other important test parameters. For more detail information, see Annex B.

Table 8 – Radiated mesoband waveform and other pulse parameters

Dominant oscillation frequencies ^a	80 MHz to 500 MHz ± 10 % ^b
Bandratio	shall be within the range 1,01 to 3 ^c
Pulse to pulse amplitude reproducibility	amplitude (E-field) ± 10 % ^d
Pulse repetition frequency	1 Hz to 1 000 Hz ^b
Burst duration	1s to 10s ± 20 % ^b
Minimum number of bursts	1
Minimum burst interval (period)	2 s ± 20 %
Radiated E-field exposure test level	selectable according to Table 6 ± 20 %
Field polarization	selectable, horizontal and vertical or circular
^a Dominant oscillation frequency is defined as the dominant frequency (the frequency with the highest spectral magnitude contribution) identified from a Fourier transformation of the measured time domain waveform. ^b These are ranges of recommended values. The user selects values appropriate to the situation. A minimum number of three frequencies is recommended to cover the frequency range of mesoband sources.	

- ^c The 3 dB bandratio of the mesoband waveform is measured and it is confirmed that it lies within the range 1,01 to 3.
- ^d The mean amplitude of the pulses in a burst is used. The reproducibility of the pulse amplitude (the flatness of the burst envelope) is important to control in order to accurately describe the test level used during exposure.

An example of a mesoband waveform is given in Figure 5.

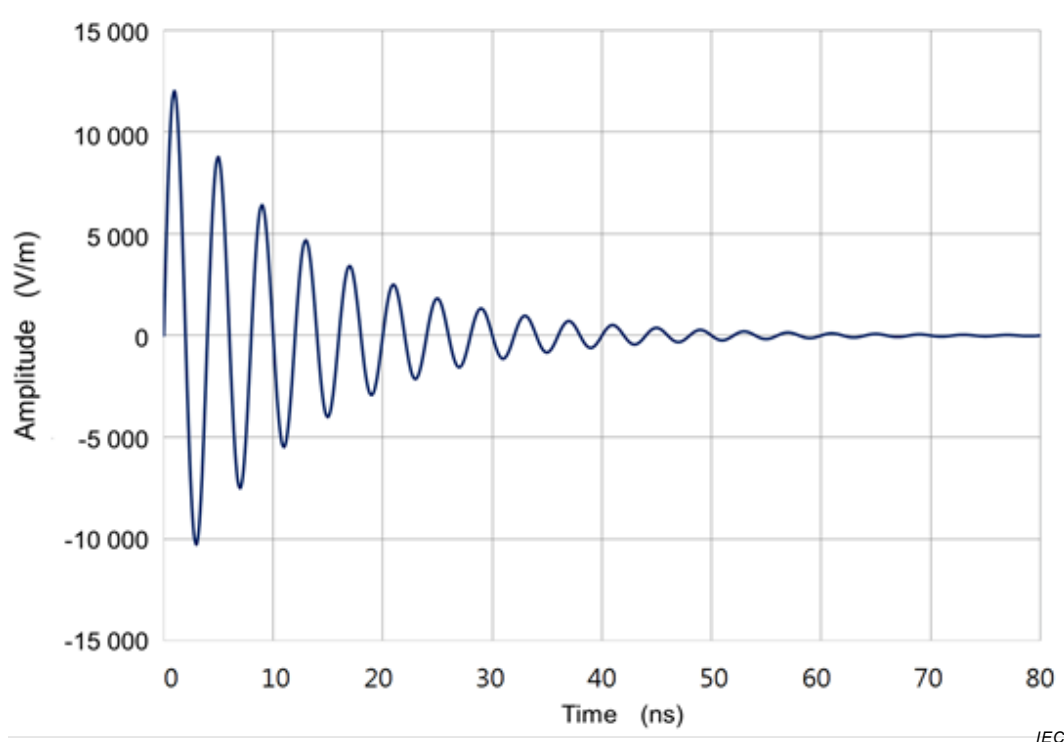


Figure 5 – ~~Typical~~ Example of mesoband waveform

7.2.3 Generic hypoband/~~narrowband~~ test parameters (skilled capability group)

Table 9 gives the test levels for hypoband/~~narrowband~~ IEMI which are characterised by low relative bandwidth, centre frequencies of ≥ 1 GHz and an associated pulse repetition frequency of $\leq$ ~~100~~ 1000 Hz.

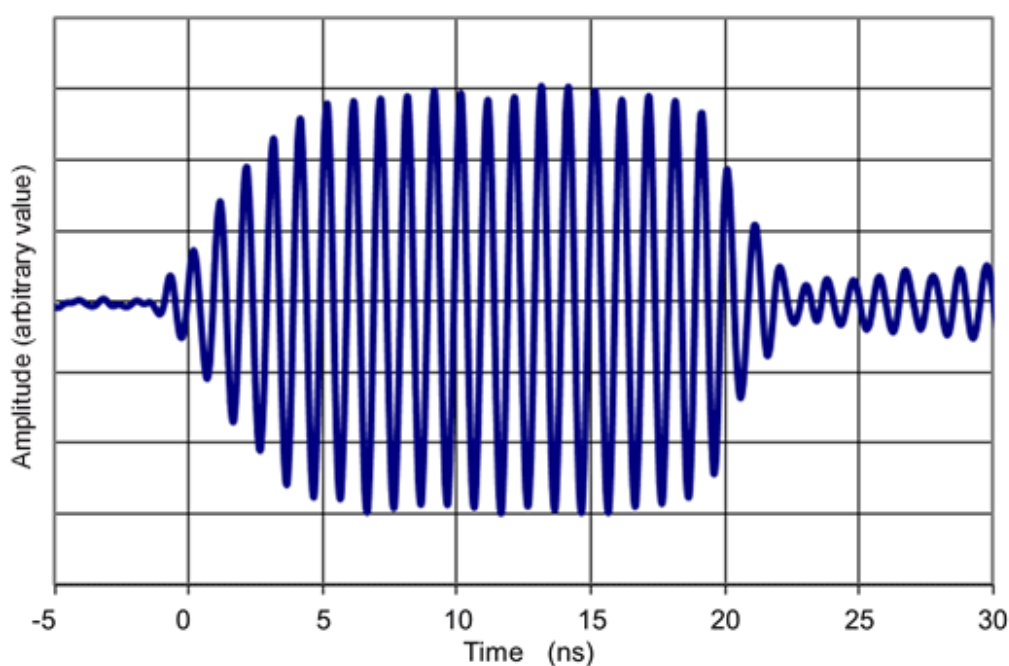
Table 9 – Generic hypoband/narrowband test parameters (skilled capability group)

EPL	Amplitude (V/m)	Pulse width (μ s)	Pulse repetition frequency (Hz)	Pulse length/ Burst duration (s)
EPL0	225 500	0,01 to 10	Single-shot 1 to 1 000	1 to 10
EPL1	45 000			
EPL2	22 550			
EPL3	11 300			
EPL4	5 050 4 240			
EPL5	2 250 1 890			
EPL6	450			

NOTE Any combination of waveform parameters in Table 9 will result in a different frequency spectrum of the waveform applied during the test. In some cases, this will result in a test that is less severe when considering the overall content or the associated maximum derivative of the applied waveform.

All combinations of the parameter ranges given in Table 9 are simultaneously achievable with existing IEMI test sources. Once a test level is selected, some parameter variation is recommended within the stated parameter ranges, if possible.

An example of a hypoband/narrowband waveform is shown in Figure 6.



IEC

NOTE The y-axis is amplitude (scale intentionally removed).

Figure 6 – Typical hypoband/narrowband waveform

7.3 Generic conducted IEMI test parameters

7.3.1 General

This document defines conducted IEMI test levels in Table 10. The user shall define specific test levels relevant to a specific IEMI environment by following the process in Clause 6.

Table 10 – Conducted IEMI test levels

V_{oc} V	I_{sc} A	Waveform	Basic document
100	2	Damped sinusoids ^a	IEC 61000-4-18 [5]
250	5	Damped sinusoids ^a	IEC 61000-4-18 [5]
500	10	Damped sinusoids ^a	IEC 61000-4-18 [5]
1 000	20	Damped sinusoids ^a	IEC 61000-4-18 [5]
2 000	40	Damped sinusoids ^a	IEC 61000-4-18 [5]
4 000	80	Damped sinusoids ^a	IEC 61000-4-18 [5]
4 000	80	5/50 ns	IEC 61000-4-4 [6]
8 000	160	5/50 ns	IEC 61000-4-4 [6]
16 000	320	5/50 ns	IEC 61000-4-4 [6]

NOTE 1 Voltage and current levels shown in the table are for common mode values.

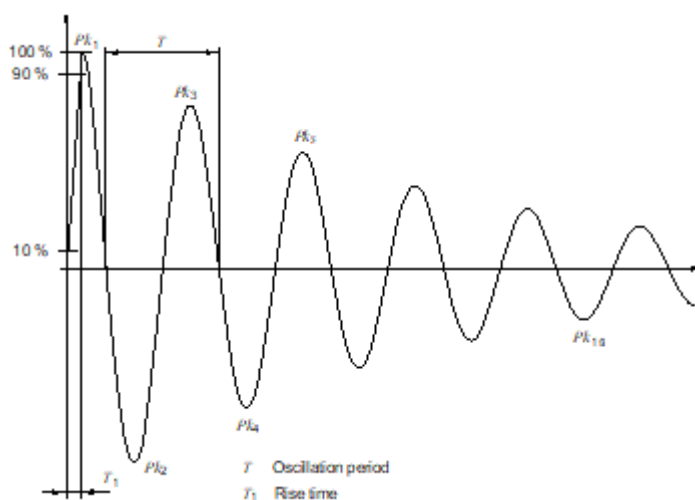
NOTE 2 For the two highest immunity test levels, it is sufficient to test with a single pulse.

^a IEC 61000-4-18 [5] defines the following test frequencies: 3 MHz, 10 MHz and 30 MHz. Depending on the characteristics of the incident IEMI electric field, tests ~~may~~ can be recommended for damped sinusoids with frequencies of 100 MHz or 300 MHz using the waveshape defined in IEC 61000-4-18 [5].

7.3.2 Characteristics and performance of the fast damped oscillatory wave generator

Subclause 7.3.2 details the characteristics and performance requirements of the fast damped oscillatory wave generator required to undertake the testing referred to in Table 10, footnote a.

The waveform of the fast damped oscillatory wave is given in Figure 7.



IEC

Figure 7 – Waveform of the damped oscillatory wave (open circuit voltage)

Open circuit specifications associated with Figure 7 are given in Table 11:

Table 11 – Open circuit specifications

Voltage rise time (T_1 in Figure 7)	5 ns $\pm$ 30 %
Voltage oscillation frequencies ^a	3 MHz, 10 MHz and 30 MHz $\pm$ 10 %
Repetition rate Pulse repetition frequency	5 000/s Hz $\pm$ 10 %
Decaying (see Figure 7)	Pk_5 shall be > 50 % of the Pk_1 value and Pk_{10} shall be < 50 % of the Pk_1 value
Burst duration	3 MHz: 50 ms $\pm$ 20 %
Burst period	300 ms $\pm$ 20 %
Output impedance	50 Ω $\pm$ 20 %
Open circuit voltage	Pk_1 value, 100 V to 4 kV $\pm$ 10 % (see Figure 7)
Phase relationship with the power frequency	No requirement
Polarity of the first half-period	Positive and negative
^a Oscillation frequency is defined as the reciprocal of the period between the first and third zero crossings after the initial peak. This period is shown as T in Figure 7.	

Short circuit specifications associated with Figure 7 are given in Table 12:

Table 12 – Short circuit specifications

Current rise time (T_1 in Figure 7):	3 MHz: < 330 ns 10 MHz: < 100 ns 30 MHz: < 33 ns
Current oscillation frequencies ^a	3 MHz, 10 MHz and 30 MHz $\pm$ 30 %
Decaying (see Figure 7)	Pk_5 shall be > 25 % of the Pk_1 value and Pk_{10} shall be < 25 % of the Pk_1 value
Short circuit current (Pk_1 value)	5 A to 80 A $\pm$ 20 %
^a Oscillation frequency is defined as the reciprocal of the period between the first and third zero crossings after the initial peak. This period is shown as T in Figure 7.	

7.4 Tailored test level derivation

The test levels defined within 7.2 and 7.3 are provided to allow the reader to apply generic IEMI test levels to equipment and systems where prior knowledge of a particular IEMI environment is not available.

For situations where one or more specific IEMI environments are the subjects of the assessment, tailored test levels shall be derived by considering the source-to-victim path using the following steps:

- a) understand the IEMI threat environment of particular interest
- b) measure the protection level by obtaining transfer function (coupling) data
 - 1) develop analytically
 - 2) measure
- c) predict induced currents/voltages/fields/power at the location of the equipment/systems
- d) create an envelope predictions

- e) assess immunity of equipment/systems
 - 1) inject predicted induced waveforms into equipment/systems
 - 2) compare injected results with existing immunity data (if available)

7.5 Relevance of EMC immunity data

Immunity data from general EMC testing ~~may~~ can be useful in determining whether testing to the levels presented within this document is necessary to declare immunity to IEMI environments. A rigorous mathematical approach utilising waveform norms should be used as the basis for such assessments. Further information on the application of waveform norms can be found in IEC 61000-4-33 [4].

Measurement uncertainties, whose quantitative calculations are possible, for example, intensity of projected electric field, discharge voltage of static electric test facilities, current induced in cables, etc., shall be included in any test report. It ~~may~~ can be necessary to consider the use of additional test margins to take account of limitations in test methods; further details on this subject can be found in Annex F. Additionally, any test reports shall include the statement that test results are dependent on the test conditions and configuration of the tested equipment, and the note that the test results are, therefore, only valid for the cases specifically under identical test conditions, test methods and equipment configuration.

Information and determination of measurement uncertainty for EMC testing can be found in CISPR TR 16-4-1 [12], CISPR 16-4-2 [13], CISPR 16-4-3 [14], CISPR 16-4-4 [15] and IEC TR 61000-1-6 [16] and are equally applicable to the determination of measurement uncertainty for IEMI test results.

Annex A (informative)

Failure mechanisms and performance criteria

A.1 General

Electronic components and subsystems are essential parts of modern systems like airplanes, communication, IT infrastructure, traffic management, **industrial controls** or safety systems. Since these electronic components have begun to control safety critical functions, concern is growing over the vulnerability of electronic systems. Therefore the susceptibility of critical systems is of vital interest since an upset or failure in these systems could cause major accidents or economic disasters. As a consequence, the investigation of the susceptibility of electronic systems as well as their protection and hardening against IEMI threats is of great interest [A.1]³, [A.2], [A.3], [A.4] and [A.5].

There have been several documented cases, where high-power electromagnetic (HPEM) environments caused unwanted action or failure. In addition the last decade has witnessed worldwide numerous IEMI susceptibility investigations. Published reports of such investigations document a variety of observed effects such as:

- disturbed screens (flickering of screens, distorted displays, black screens),
- display of wrong data,
- corruption of signals and data (signal drifts, corruption of signals, lost data),
- false response of sensors and systems,
- unintentional response or action of systems (movement of actuator, change of course),
- decreased performance (reduction of computational performance, data transfer),
- hang up of software,
- reboot of digital devices (computer, controller, processor),
- destruction of components.

Due to the large range of observed effects, the systematic assessment (fail/pass) as well as the development of sufficient protection measures require a classification of the effects and the failure mechanisms, which summarise the essential information.

A.2 Failure mechanisms

A.2.1 General

If the observed effects are analysed with regard to the underlying failure mechanism, five main categories can be extracted:

- 1) noise
- 2) parameter offset and drifts
- 3) corruption of information
- 4) system upset or breakdown
- 5) component destruction

³ Numbers in square brackets refer to the references in Clause A.5.

Any of these mechanisms can occur on a system as a result of an incident EM environment, sometimes with disastrous consequences. Further details are given for each of the categories below.

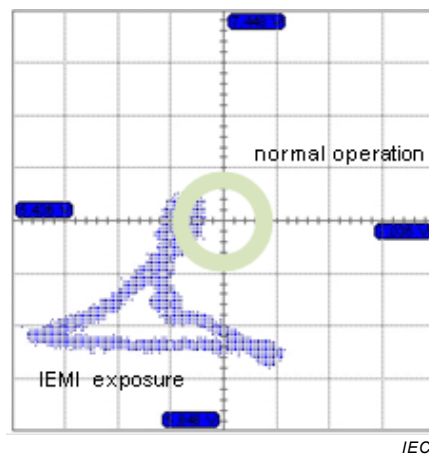
A.2.2 Noise

Electromagnetic disturbances can raise the noise level on signal and power lines, which results in flashing of displays or reduced data rates.

In a particular case of jamming the IEMI source (jammer) operates at or close to the frequency of operation and the induced noise level overloads the receiver circuits. Due to the fact that receivers are designed to operate at very low signal levels, jamming typically requires less radiated power.

A.2.3 Parameter offset and drifts

Parameters of analogue circuits are subject to changes (e.g. offset, drift) caused by induced signals. According to the application, these parameter changes can result in distortions of signals and/or false control signals and affect control circuits as well as the system status. This is shown in Figure A.1:



[Source: Bundeswehr Research Institute for Protective Technologies and NBC-Protection, WIS.]

**Figure A.1 – IEMI induced offset of sensor output –
Corruption of information**

Injected signals are capable of changing bits of a data stream and of corrupting transferred information. In the worst case the receiving subsystem interprets the injected signal or the corrupted data stream as valid information or instructions. Typical effects of this class are the activation of a pop up menu, the opening and closing of programs, device failure messages, wrong sensor readings, and movements of actuators. This is shown in Figure A.2:

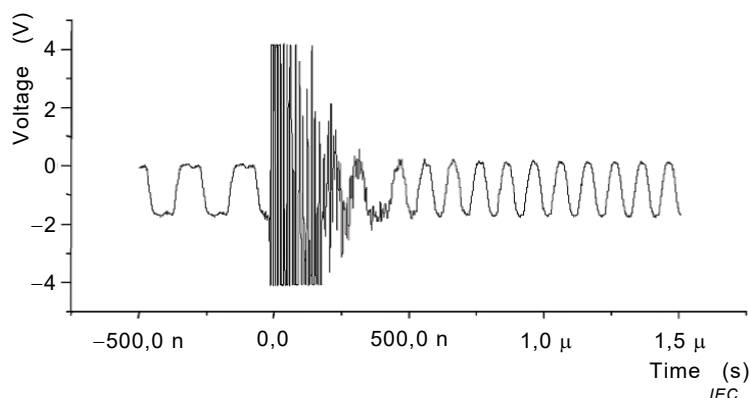


Figure A.2 – Collision of an induced disturbance with data bits [A.1]

A.2.4 System upset or breakdown

A system upset or breakdown is the inability of a physically undamaged system to perform its desired function. Upsets and breakdowns are caused by electromagnetic disturbances that are capable of affecting the logic state of an electronic system (e.g. by triggering digital devices, by changing counters or altering the state of logic circuits). After a reset (self, external, or power reset), the system will return to its usual capabilities.

A.2.5 Component destruction

Insulating layers of printed circuit boards or components (e.g. integrated circuits) can be sensitive to interfering disturbances. If the dielectric insulation is too thin, induced voltage signals can cause an electrical breakdown. The resulting component destructions range from flashover effects over melted lines to bond wire destruction (see Figure A.3).

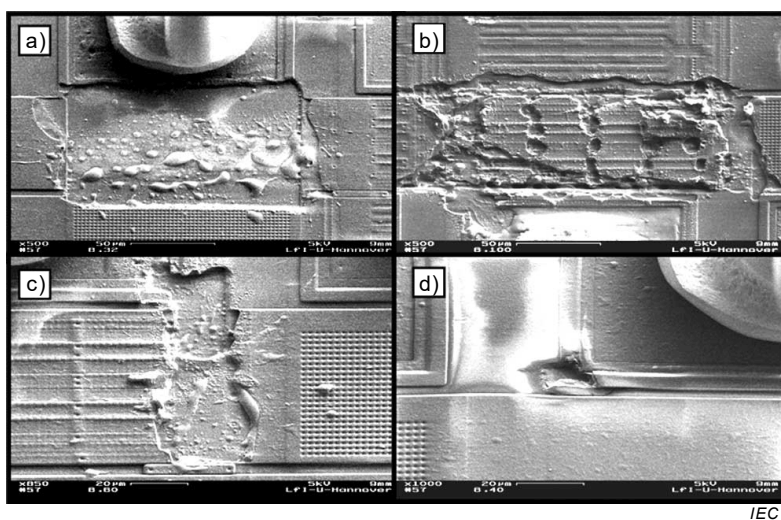


Figure A.3 – Examples of destruction on a chip [A.2]

The identification of which destruction mechanism occurs requires additional detailed examinations of the system (e.g. opening of **integrated circuits** (ICs) and detailed on-chip investigation). As the destructive effects are of a permanent nature, usually the time consumption of such additional examination is not a problem. In contrast, the temporary nature of interferences requires a real-time measurement of signals and additional measurements, which enable observation, storage and analysis of the internal stages of the system under investigation.

A.3 Effect of pulse width

Electronic equipment generally responds to either the peak power or the average power of the incident IEMI environment. Much data has been collected to determine the relationship between peak and average effects [A.6], [A.7], [A.8], [A.9], [A.10], [A.11], and the trend from this data is summarised in Figure A.4.

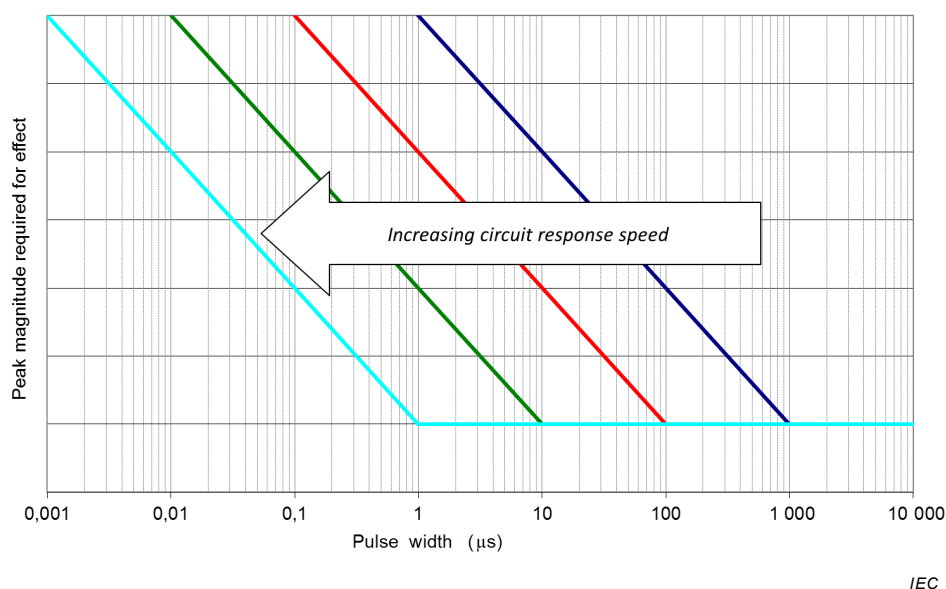


Figure A.4 – Generic failure trend as a function of pulse width

Figure A.4 shows how the peak power for failure for a typical circuit will decrease as the pulse width increases, corresponding to the average power failure mode. At the transition point the circuit no longer reacts to the increasing average power and appears to depend only on the peak power corresponding to the peak power mode.

A comparison between the failure modes of typical older analogue equipment and newer digital equipment is given in several of the references. Most modern equipment cannot be defined as wholly analogue or wholly digital in nature, and the assumption that a single mechanism is responsible for the equipment susceptibility is a simplification. However, it is clear from the references that for many systems there is a dependency on pulse width and the peak power required. Additionally, as indicated by the arrow in Figure A.4, faster circuits are generally more susceptible to shorter pulse widths.

A.4 Performance criteria

Determination of a system under test either passing or failing a test requires classification of the test results in terms of the loss of function or the degradation of performance of the system under test, relative to a performance level defined by its manufacturer or specified in the test plan.

Recommended performance criteria are shown in Table A.1.

Table A.1 – Recommended performance criteria

Performance	Description
Normal	Normal performance within specified limits.
Tolerable interference	Appearing disturbances can be tolerated or do not influence the main function.
Performance degradation	The appearing disturbance reduces the efficiency and capability of the system.
Temporary loss of function	Temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention.
Persistent loss of function	Temporary loss of function or degradation of performance, the correction of which requires operator intervention.
Permanent loss of main function	Loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer shall define the performance criteria of the system under test in accordance with Table A.1.

A.5 References

- [A.1] Nitsch, D.; Camp, M.; Sabath, F.; ter Haseborg, J.L.; Garbe, H.; "Susceptibility of some electronic equipment to HPEM threats", IEEE Transactions on Electromagnetic Compatibility, vol.46, no.3, pp. 380- 389, Aug. 2004
- [A.2] Camp, M.; Garbe, H.; "Susceptibility of Personal Computer Systems to Fast Transient Electromagnetic Pulses", IEEE Transactions on Electromagnetic Compatibility, vol.48, no.4, pp.829-833, Nov. 2006
- [A.3] Sabath, F.; "Classification of Electromagnetic Effects at System Level", Ultra-Wideband, Short Pulse electromagnetics 9, Springer Science+Business Media, pp. 325- 334, 2010, ISBN 978-0-387-77844-0
- [A.4] IEC TR 61000-1-5, *Electromagnetic compatibility (EMC) – Part 1-5: General – High power electromagnetic (HPEM) effects on civil systems*
- [A.5] Hoad, R.; Carter, N.J.; Herke, D.; Watkins, S.P.; Trends in EM susceptibility of IT equipment, IEEE Transactions on Electromagnetic Compatibility, vol.46, no.3, pp. 390-395, Aug. 2004
- [A.6] Unified Electromagnetic Environmental Protection: A Design Guide, Part A: Introduction and the Philosophy of Hardening', by Dr NJ Carter, QinetiQ
- [A.7] 'A time-domain view of the choice of transient excitation waveforms for enhanced response of electronic systems', Interaction Note 560, by C. E. Baum September 2000
- [A.8] 'Measuring the upset of CMOS and TTL due to HPM-Signals', by Norbert Esser and Bernd Smailus, ABB AG Corporate Research Center
- [A.9] 'Pulse Length and Power Dependency of the failure threshold of a Low Noise Amplifier', by Rolf Jonsson, Magnus Hoijer, Swedish Defence Research Agency
- [A.10] 'HPM Effects on Electronic Components and the Importance of this knowledge in Evaluation of System Susceptibility', by Gunnar Goransson, FOA Defence Research Establishment

- [A.11] 'Comparative Susceptibility Study of Pulse and Constant Illumination of Wires over Ground Planes', by KP Slattery, CKC Laboratories, Inc.

Annex B (informative)

Developments in IEMI source environments

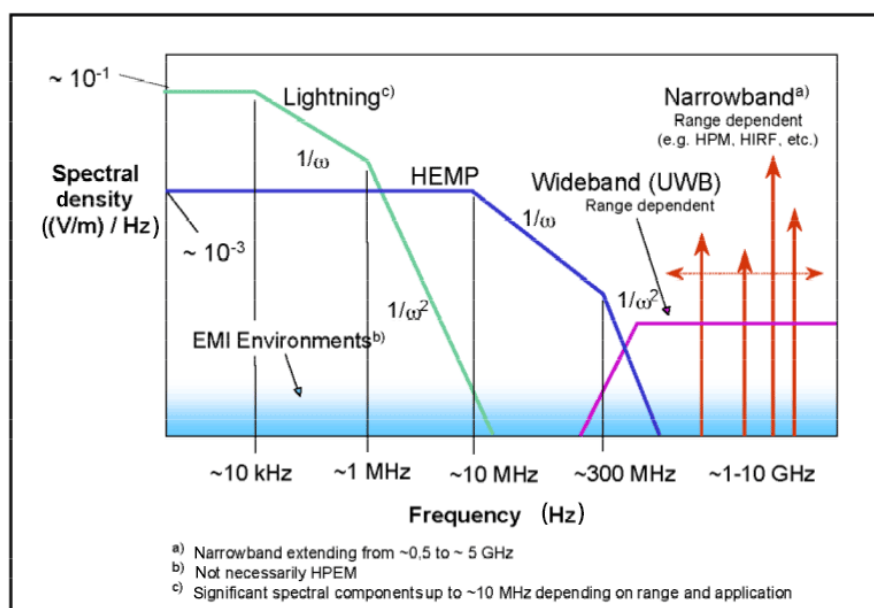
B.1 General

The use of electromagnetic sources [B.1]⁴ to generate intentional electromagnetic interference (IEMI) is becoming an increasing concern as the reliance of society on technology increases significantly. Many technical papers have been published that show the effects of IEMI are cause for concern [B.2], [B.3].

The effects of IEMI on equipment can be similar to the effects caused by high-power electromagnetic (HPEM) environments. HPEM environments include high-intensity radiated fields (HIRFs) generated by radio and radar systems, lightning electromagnetic pulse (LEMP) fields and electrostatic discharge (ESD). Some of these HPEM environments have similar characteristics to those sources used to cause IEMI but are unintentional EMI sources, i.e. they are not used for malicious use. However, it is possible to use information regarding qualification of equipment and systems to these environments to inform the likely response to IEMI.

~~Recently two new terms have arisen in the EMC field — EM terrorism [4] and intentional electromagnetic interference (IEMI) [5]. Over the past 12 years~~ The scientific community has decided to accept the more generic term IEMI [B.4], which includes EM terrorism [B.5]. In February 1999 at a workshop held at the Zurich EMC Symposium, a widely accepted definition for IEMI was suggested: “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”.

Figure B.1 qualitatively presents several of these electromagnetic environments, along with the narrowband and wideband IEMI threats that are the subject of this document [B.6].



IEC

Figure B.1 – A comparison of HPEM and IEMI spectra [B.6]

⁴ Numbers in square brackets refer to the references in Clause B.6.

In August 1999 the problem of IEMI was recognized by the International Radio Scientific Union (URSI) during a special session that resulted in an URSI resolution. The URSI “Resolution of Criminal Activities using Electromagnetic Tools” [B.7] was intended to make people aware of the following:

- The existence of criminal activities using electromagnetic tools and associated phenomena.
- The fact that criminal activities using electromagnetic tools can be undertaken covertly and anonymously and that physical boundaries such as fences and walls can be penetrated by electromagnetic fields.
- The potentially serious nature of the effects of criminal activities using electromagnetic tools on the infrastructure and important functions in society such as transportation, communication, security, and medicine.
- That the possible disruptions of the health and economic activities of nations could have major consequences.

The URSI Council recommended to the scientific community in general, and the EMC community in particular, to take account of this threat and to undertake the following actions:

- Perform additional research pertaining to criminal activities using electromagnetic tools in order to establish appropriate levels of vulnerability.
- Investigate techniques for appropriate protection against criminal activities using electromagnetic tools and to provide methods that can be used to protect the public from the damage that can be done to the infrastructure by terrorists.
- Develop high-quality testing and assessment methods to evaluate system performance in these special electromagnetic environments.
- Provide data regarding the formulation of standards of protection and support standardization work.

It should be noted that the International Electrotechnical Commission (IEC) added the IEMI threat to its previous standardization work dealing with HEMP in 1999.

B.2 IEMI environment

In order to understand the nature of IEMI threats it is necessary to understand the different types of electromagnetic environments that can be produced and that can affect exposed equipment. This document focuses mainly on radiated threats, although injected threats will be summarised.

In terms of system vulnerabilities, the narrowband threat is usually one of very high power and high energy, since the electrical energy is delivered in a narrow frequency band. It is fairly easy to deliver fields in the order of many kV/m at a single frequency. Of course each system under test ~~may~~ can have a vulnerable frequency that is different from others. Often the malfunctions observed in testing equipment with narrowband waveforms are those of permanent damage. Available test facilities using the narrowband or hypoband waveforms can be found in an article by Sabath *et al.* in [B.8].

The wideband threat is somewhat different. Since a time domain pulse produces energy over many frequencies at the same time, the energy density at any single frequency is considerably less. Therefore damage is not as likely as in the narrowband case; however, it is easier to find a system's vulnerability since many frequencies are applied to the system simultaneously. Sources that have been built in the past typically produce repetitive pulses that can continue for many seconds, thereby increasing the probability of producing a system upset. Test facilities producing these types of waveforms are described in an article by Prather, *et al.* [B.9].

While the waveform characteristics are defined above, there are two primary ways that they ~~may~~ can be delivered to a system. One is through the application of radiated fields, and the other is through injection along cables and wires. These two methods of delivery are consistent with the general treatment of electromagnetic disturbances in the field of electromagnetic compatibility (EMC) where nearly all environments and tests are defined in terms of radiated or injected environments [B.10].

For radiated fields, it seems clear that frequencies above 100 MHz are of primary concern in that they are able to penetrate unshielded or poorly protected buildings very well and yet couple efficiently to the equipment inside of the building. In addition, they have the advantage that antennas designed to radiate efficiently at these frequencies are small. Figure B.2 illustrates a qualitative view of how radiated fields ~~may~~ can illuminate and couple to system electronics through apertures (e.g., windows) and through building wiring [B.3].

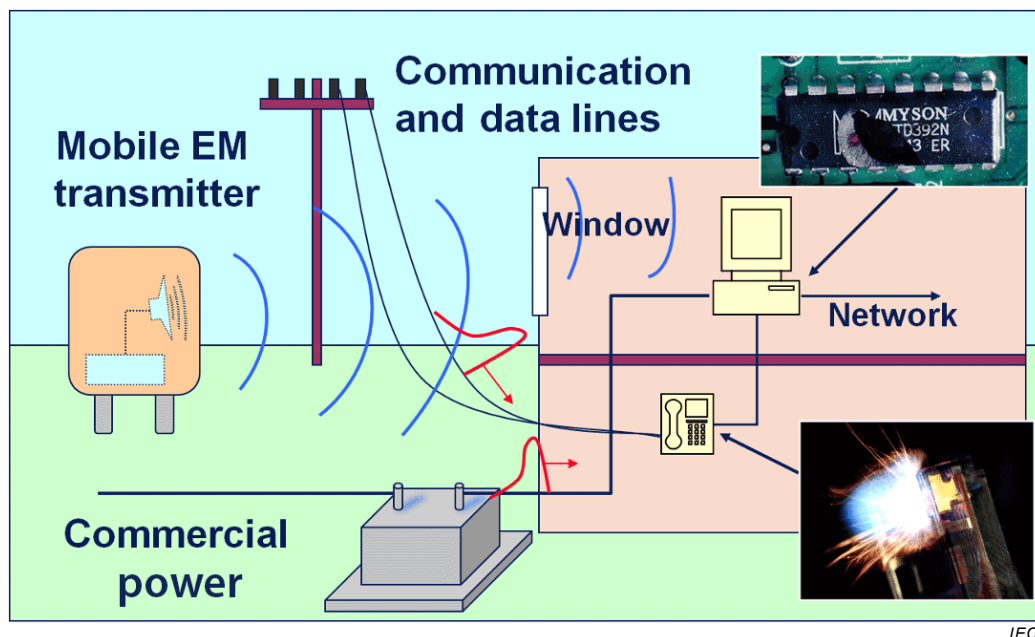
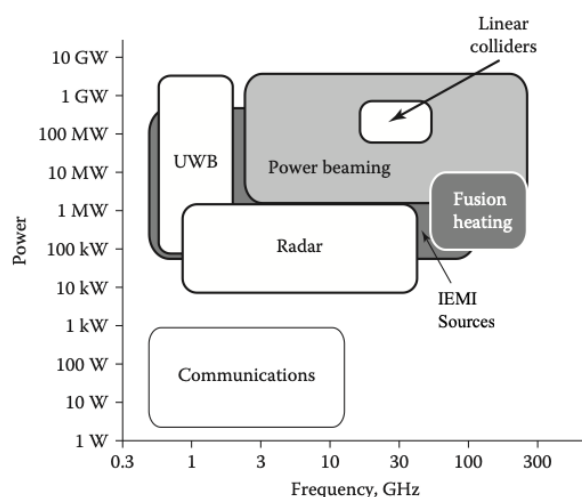


Figure B.2 – Representation of typical IEMI radiation and coupling onto systems [B.3]

For injected voltages and currents, there are some differences in terms of the frequency range of interest. It is well established that if common-mode conducted signals are injected into the power supply or telecom cables outside of a building, frequencies below 10 MHz (and pulse widths wider than 50 ns) propagate more efficiently than higher frequencies. Experiments by Parfenov *et al.* have shown that these “lower” frequencies can disrupt the operation of equipment inside a building [B.11].

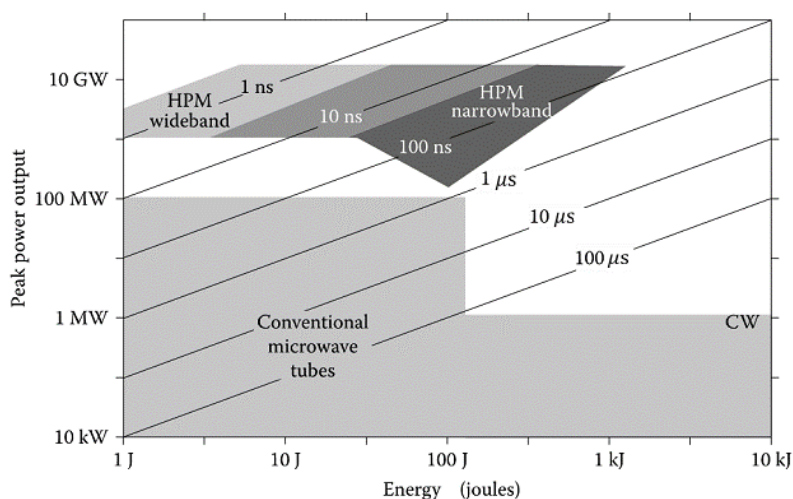
B.3 IEMI sources

The nature of IEMI sources [B.1] varies from very sophisticated sources being developed in research laboratories and industry to threats hastily assembled by novices. The sophisticated sources, termed directed energy weapons (DEWs), occupy a parameter space that is illustrated in Figure B.3 [B.1]. Note that the ~~UWB~~ wideband (hyperband) sources tend to be at lower frequencies and contain much less energy per pulse than the HPM (hypoband or narrowband) sources (see Figure ~~B.3~~ B.4). The sophisticated IEMI sources are increasingly higher power, increasingly more compact, and can be operated repetitively. Recent advances at the Institute of High Current Electronics, Siberian Branch of the Russian Academy of Sciences have taken advantage of phase coherence to demonstrate a roughly N^2 scaling in output power when N -separate HPM sources are operated with phase coherence within 25 %. An example is shown in Figure B.7 [B.12].



IEC

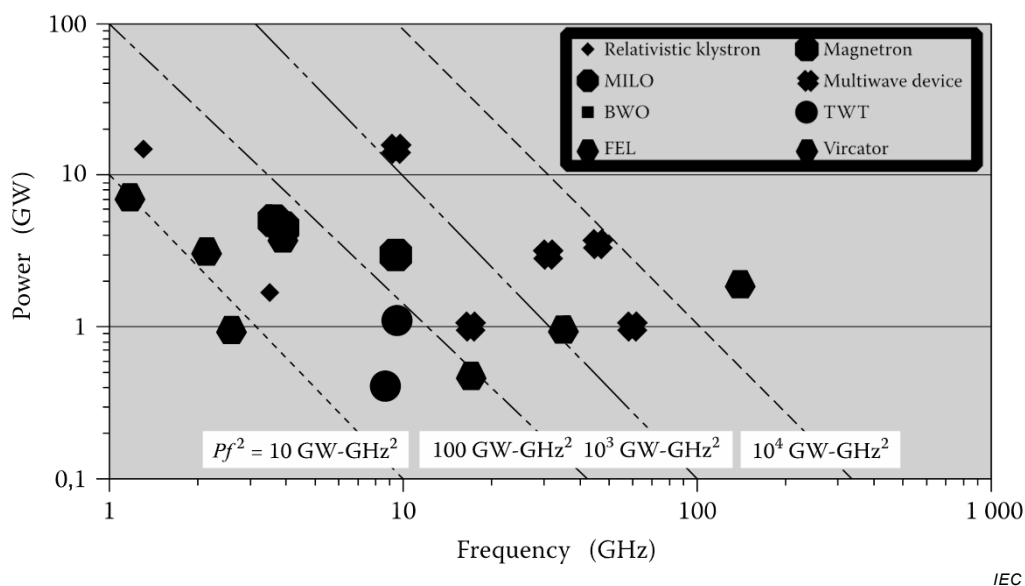
Figure B.3 – Parameter space in power/frequency occupied by sophisticated IEMI (i.e. DEW) sources in comparison to common RF systems [B.1]



IEC

Figure B.4 – Peak power and energy from continuous and pulsed (durations shown) microwave sources, narrowband and wideband

Further, for hypoband or narrowband sources worldwide surveys of typical source power levels have been conducted, see Figure B.4 [B.17]. Figure B.5 and Figure B.6 demonstrate the achieved power levels.



NOTE The values of the quality factor Pf^2 scaling (where P is the output power and f is the frequency) vary over several orders of magnitude.

Figure B.5 – Peak powers of various types of pulsed ~~HPM~~ hypoband/narrowband sources [B.1]

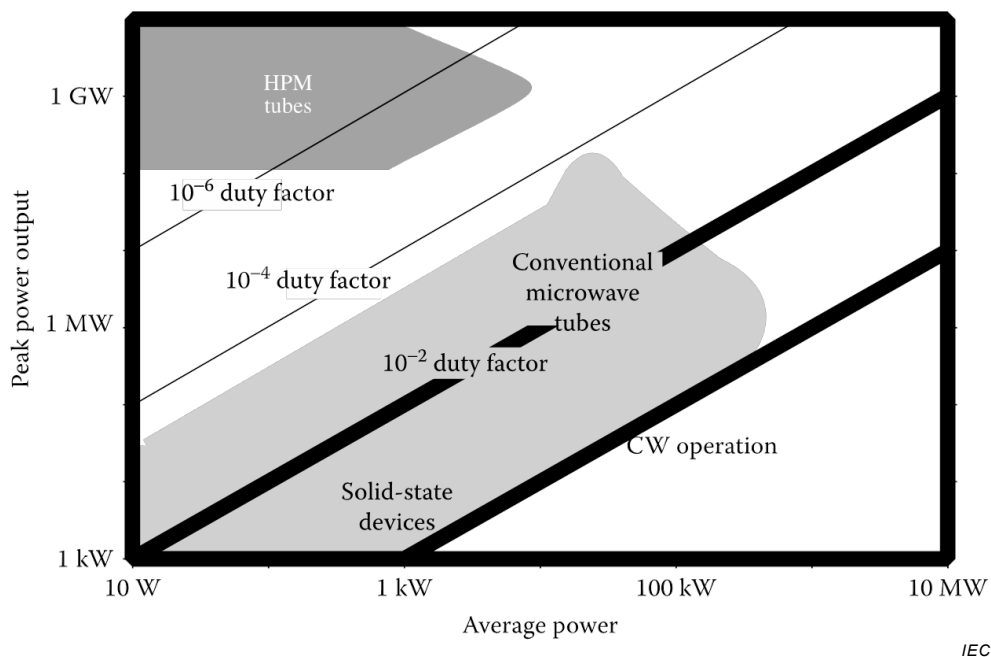
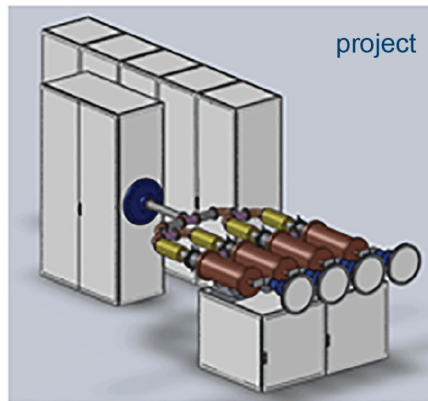


Figure B.6 – Peak versus average power for microwave sources with duty factors indicated

The duty factor for IEMI sources is the product of the pulse length and the pulse repetition rate, and is of the order of 10^{-6} (10^{-5} at most).

A prominent example of a mesoband ~~type of UWB~~ source is the Diehl-Rheinmetall⁵ briefcase sources, shown in Figure B.8 [B.3].



Generation frequency	10 GHz
Microwave pulse duration	0,8 ns
Peak pulse power	4 × 1,5 GW
HVG type - Tesla transformer	
FL impedance	25 Ω
Max FL charging voltage	700 kV
HV pulse length	10 ns
Pulse repetition rate	up to 200 p.p.s.
Time of continuous operation	up to 1 s
Solenoids power supply stored energy	3,5 MJ

- controllable tuning of the RF phase in each channel by NLTLs with biased ferrites;
- enhancement of power density and number of channels N^2
- what about longer pulse phase synchronization?

IEC

NOTE The system depicted is capable of radiating 6,0 GW at X-band [B.12].

Figure B.7 – Phase coherence leading to a compact HPM source with N^2 scaling of output power

- Diehl Munitions Systeme is marketing a small interference source (including antenna)
 - 350 MHz damped sine field
 - 120 kV/m at 1 m (omni-directional antenna)
 - 30-min continuous operation (5 pulses/s or 3 hours in bursts)
 - 20 in x 16 in x 8 in and 62 lb



IEC

Figure B.8 – Briefcase mesoband ~~UWB~~ DS source sold by Diehl-Rheinmetall [B.3]

The narrowband and UWB HPM sources just described are examples of sophisticated sources that took considerable resources to design and develop. At the other extreme are sources that can be constructed by novices using microwave ovens and other readily available components (such as from radar systems). An example is shown in Figure B.9. Although such devices radiated considerably lower powers than the sophisticated devices, at close range they can have effects on exposed electronic systems.

⁵ The mesoband interference source briefcase is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

An example of a Russian industrial scale electromagnetic weapon is the RANETS-E⁶, which was advertised at an Asian air show during the last decade. RANETS-E has goals of achieving operating parameters of 0,5 GW, 10 ns to 20 ns, 500 Hz in X-band, with 45 dB to 50 dB gain antenna [B.1].

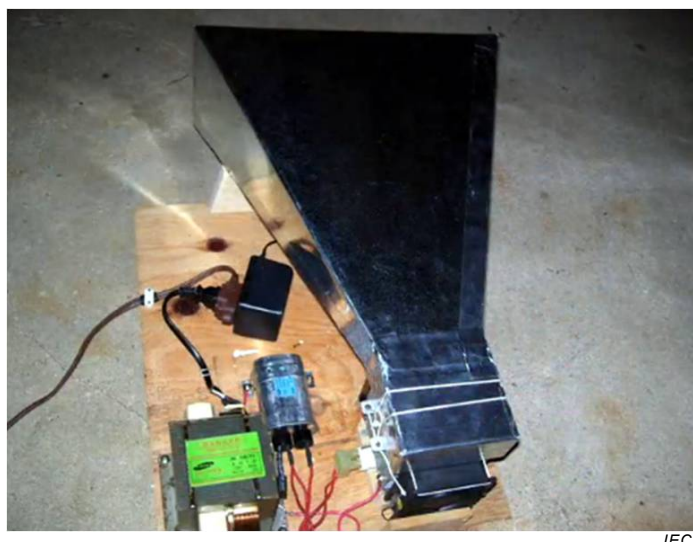


Figure B.9 – A do-it-yourself electromagnetic weapon made from an oven magnetron [B.13]

B.4 Published radiated IEMI environments

B.4.1 IEC 61000-2-13 [B.14]

IEC 61000-2-13 [B.14] presents several sources which could be considered as applicable to the IEMI threat. These are summarised in Table B.1.

Table B.1 – IEMI environments from IEC 61000-2-13

Name	Band	Typical operating frequency	Electric field	Source type
Phaser	Hypoband or narrowband	1,1 GHz	2,3 kV/m at 3 m	Magnetron
Dispatcher	Mesoband	500 MHz	100 kV/m at 1 m	Marx generator
Disrupter	Hyperband	200 MHz to 2 GHz (instantaneous bandwidth)	500 kV/m at 1 m	Impulse radiating antenna-based system

B.4.2 Mil-Std-464C

~~Mil-Std 464C [16] contains a list of multiple HPM⁷ threats with an overall compilation of these threats.~~

⁶ RANETS-E is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

~~⁷ The Mil-Std uses HPM to define a threat, which radiates high peak power electromagnetic pulses intended to disrupt or damage electronic systems. This part of IEC 61000 uses the more accurate term, IEMI, as not all IEMI sources operate in the microwave part of the radio frequency spectrum.~~

~~Table B.2 and Table B.3 are taken from Mil-Std-464C. Table B.2 provides field strengths that exist at one kilometre for the hypoband/narrowband threat high-power microwave (HPM) environment. HPM is a military term used to describe a class of IEMI systems which can be used in military scenarios. Table B.3 provides a spectral magnitude description for wideband HPM at a distance of 100 meters.~~

Mil-Std-464C [B.17] produced by the Department of Defense (DoD) discusses a wide range of electromagnetic environments (EMEs) and provides detailed descriptions and characteristics of the EME that military platforms/equipment could experience. It provides minimum performance and test requirements for equipment. In addition to standard electromagnetic compatibility (EMC) environments, version C includes a high power microwave (HPM) narrowband and wideband electromagnetic environment.

Table B.2 and Table B.3 are taken from Mil-Std-464C [B.17]. Table B.2 provides field strengths that exist at 1 km for the hypoband/narrowband threat HPM environment. HPM is a military term used to describe a class of IEMI systems which can be used in military scenarios. Table B.3 and Figure B.10 provide a spectral magnitude description for wideband HPMs at a distance of 100 m. Of specific relevance here, it provides a table displaying the electric field spectral distribution for wideband threats. It should be pointed out that the levels given in Table B.2 and Table B.3 do not represent the verification requirements for a given system. For a given system a unique HPM worst-case environment has to be defined based on the operational scenarios, tactics and/or mission profiles of that system in combination with the types of HPM-weapons it can encounter.

Table B.2 – Hypoband/narrowband HPM environment from [B.17]

Frequency range (MHz)	Electric field (kV/m at 1 km)
2 000 to 2 700	18,0
3 600 to 4 000	22,0
4 000 to 5 400	35,0
8 500 to 11 000	69,0
14 000 to 18 000	12,0
28 000 to 40 000	7,5

Table B.3 – ~~Hyperband/~~ Wideband (mesoband/hyperband) HPM environment from [B.17]

Frequency range (MHz)	Broad-band electric field distribution (mV/m/MHz at 100 m)
30 to 150	33 000
150 to 225	7 000
225 to 400	7 000
400 to 700	1 330
700 to 790	1 140
790 to 1 000	1 050
1 000 to 2 000	840
2 000 to 2 700	240
2 700 to 3 000	80

Frequency range (MHz)	Electric field at 100 m engagement range (V/m/MHz)
--------------------------	--



70 to 100 (mesoband)	33
100 to 150 (mesoband)	33
150 to 200 (mesoband)	7
200 to 225 (mesoband)	7
225 to 400 (mesoband)	7
400 to 700 (hyperband)	1,33
700 to 790 (hyperband)	1,14
790 to 1 000 (hyperband)	1,05
1 000 to 2 000 (hyperband)	0,84
2 000 to 2 700 (hyperband)	0,24
2 700 to 3 000 (hyperband)	0,08

The table as published in the standard is very easy to misinterpret, however detailed scrutiny and information from other sources [B.18] identify that the data presented in Table A-5 of Mil-Std-464C:2010 [B.17] is a composite of the maxima of four wideband threat waveforms.

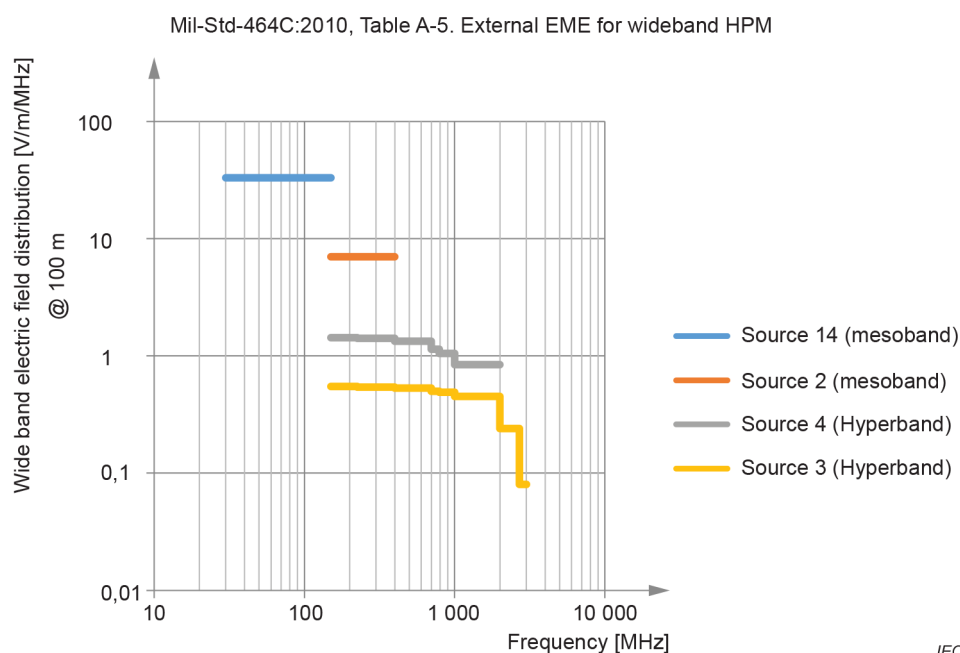


Figure B.10 – Wideband (mesoband and hyperband) EME derived from [B.17]

Within Mil-Std-464C [B.17] the mesoband and hyperband EME is defined in terms of the frequency domain's "electric field distribution" or "spectral magnitude". This information on its own is not sufficient to provide an adequate reconstruction of the equivalent time domain waveforms which are summarised by the distribution.

B.4.3 Selection of parameters for mesoband immunity test

B.4.3.1 General

Mesoband sources are typically used to produce radiated (rather than conducted) waveforms and typically employ a dipole (or a derivative thereof) as the radiating element. The dipole design strongly influences the dominant radiating frequency of the source. The dominant radiating frequency is herein defined as the frequency with the highest spectral magnitude contribution identified from a Fourier transformation of the measured time domain waveform.

Mesoband sources are tuneable, such that the dominant frequency f_d of the source waveform can be altered. However, alteration of the dominant frequency is done by changing either

- the pulsed power supply;
- the gas pressure, gas type, or gap spacing of the primary switch, if a Marx or Tesla or derivative is employed;
- the dipole antenna length/geometry; or
- any combination of the above.

Therefore tuning of mesoband sources cannot typically be achieved dynamically (during use) and requires the user to adjust key parameters in order to tune the source to a different dominant frequency. This is important in terms of the practicalities of testing with mesoband waveforms. In order to make the test practical a limited number of dominant frequencies should be selected.

The Q -factor for the mesoband pulse can be derived from Formula (1). As long as the percent bandwidth of the pulse corresponds to the 1 % to 100 % requirement to classify the waveform as mesoband, then a wide range of Q -factor values is acceptable. Values between 4,8 to 100 are considered acceptable.

Mesoband sources are pulse repetition frequency (prf) and burst duration limited. The maximum prf of the sources indicated above is 1 kHz but 100 Hz may be more typical of spark gap type switching type systems.

Mesoband sources are often burst duration limited as they are typically battery powered, whereas a mesoband immunity test simulation can be mains powered and capable of delivering mesoband pulses continuously. It is therefore important to set a burst duration limit and burst interval to be representative of the threat which is being simulated.

B.4.3.2 Dominant frequency (f_d) selection

The selection of the number of dominant frequencies to use during testing shall be selectable by the user within the range 80 MHz to 500 MHz as identified above. A minimum of three frequencies shall be selected to cover the required range. The dominant frequency selection could correspond to a known threat source or to a known susceptibility of the equipment under test. However, in terms of practicality the following can be used for guidance.

Immunity testing for mesoband sources is most likely to take place in semi-anechoic chambers where the test distance is limited to 3 m to 5 m. These chambers are generally compliant with field uniformity down to 80 MHz. Using 80 MHz as a reasonable lower bound for f_d is a compromise in terms of field uniformity, dipole dimensions and near/far field boundary conditions.

It seems reasonable and practical to use the Mil-Std-464C [B.17] frequency ranges to guide the selection of f_d .

To qualify the source as mesoband, the bandratio shall be between 1,01 and 3 (percent bandwidth between 1 % and 100 %). Assuming a bandratio of 2 for the two mesoband sources indicated in Figure B.10 and selecting the smallest number of frequencies that both cover the required frequency range, whilst also using known dominant frequencies of sources in the published literature, it is recommended that a minimum of three dominant frequencies be selected for mesoband immunity testing.

B.4.3.3 Q -factor

The Q -factor is not a parameter that is simple to select and is generally a consequence of the pulse radiating equipment configuration. The Q -factor by itself is not known to be a relevant

with susceptibility, though a larger Q will result in a marginally longer pulse width. It is therefore considered that the Q -factor may lie anywhere within the range 4,8 to 100 as long as the bandratio remains within the range 1,01 to 3.

B.4.3.4 Pulse repetition frequency selection

The selection of the pulse repetition frequency to use during testing shall be selectable by the user within the range 1 Hz to 1 kHz as identified above. The pulse repetition frequency selection could correspond to a known threat source or to a known susceptibility of the equipment under test.

Generally speaking it is known that there is a relationship between the number of pulses in an exposure and an effect in the equipment [B.19] [B.20]. It has been observed that after some minimum number of pulses the susceptibility level, in terms of E-field, can decrease. However, the number of pulses is highly dependent on the function (clock period, data rate, cycle time, etc.) of the EUT and parameters of the test waveform.

Therefore it is recommended that the user selects the pulse repetition frequency appropriate to the test up to a maximum pulse repetition frequency of 1 kHz.

B.4.3.5 Burst duration and interval selection

The selection of the burst duration to use during testing shall be selectable by the user within the range 1 s to 10 s as identified above. The burst duration selection could correspond with a known threat source or to a known susceptibility of the equipment under test. Whilst a maximum burst duration of 10 s is possible, for practical purposes and considering the equipment under test's response time a burst duration limit of 2 s is considered adequate.

A single burst at each test level is considered adequate if the pulse repetition frequency is at the maximum. However, for guidance a minimum burst to burst interval (burst duty cycle) of one burst every 2 s with a 2-s rest period is considered practicable if it is identified that a particular threat source is capable of burst repetition.

B.4.3.6 E-field polarization

Mesoband threat sources are typically deployed with a horizontally polarised antenna. Horizontal polarization is therefore the preferred polarization for mesoband immunity testing and it is considered acceptable to use this polarization only. However, vertical or circular polarizations could be used to correspond with a known threat source if necessary.

B.4.3.7 Test environment

Free field radiated tests with the mesoband waveforms described previously can be difficult to conduct in an outdoor open air environment due to spectrum management and other interference and safety related concerns. It is considered practical to conduct mesoband immunity testing within a semi-anechoic, fully anechoic room or within a transverse electromagnetic mode (TEM) waveguide. The primary constraint for testing within a room or cell is achieving an appropriate field uniformity over the equipment under test volume at the available test distance.

The minimum suggested dominant frequency is 80 MHz, at a typical test distance of 3 m within a semi-anechoic chamber (SAC) test chamber. At this distance it can be difficult to maintain far field conditions if the largest antenna aperture dimension is not kept to a minimum, hence field uniformity should be satisfied in accordance with Annex H.

B.4.4 International Telecommunication Union (ITU)

The International Telecommunication Union (ITU) has published a "High-power electromagnetic immunity guide for telecommunication systems" [B.21] that also contains published levels of IEMI environments.