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PUBLICATION FONDAMENTALE EN CEM

**Electromagnetic compatibility (EMC) –
Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides**

**Compatibilité électromagnétique (CEM) –
Partie 4-20: Techniques d'essai et de mesure – Essais d'émission et d'immunité dans les guides d'onde TEM**

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CONTENTS

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Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides

FOREWORD

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International Standard IEC 61000-4-20 has been prepared by 77B: High-frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility, in cooperation with CISPR (International Special Committee on Radio Interference) subcommittee A: Radio interference measurements and statistical methods.

This second edition cancels and replaces the first edition published in 2003 and its amendment 1 (2006), and constitutes a technical revision.

It forms Part 4-20 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

The main changes with respect to the first edition of this standard and its amendment are the following:

- consistency of terms (e.g. test, measurement, etc.) has been improved;

- clauses covering test considerations, evaluations and the test report have been added;
- references to large TEM waveguides have been eliminated;
- a new informative annex has been added to deal with calibration of E-field probes.

The text of this standard is based on the following documents:

FDIS	Report on voting
77B/637/FDIS	77B/641/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 of 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 the base publication and its amendments will remain unchanged until the stability result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

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, Technical Specifications or Technical Reports, some of which have already been published as sections. Others are and will be published with the part number followed by a dash and a second number identifying the subdivision (example: IEC 61000-6-1).

This part of IEC 61000 is an International Standard which gives emission, immunity and HEMP transient testing requirements.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-20: Testing and measurement techniques – Emission and immunity testing in transverse electromagnetic (TEM) waveguides

1 Scope and object

This part of IEC 61000 relates to emission and immunity test methods for electrical and electronic equipment using various types of transverse electromagnetic (TEM) waveguides. These types include open structures (for example, striplines and electromagnetic pulse simulators) and closed structures (for example, TEM cells). These structures can be further classified as one-, two-, or multi-port TEM waveguides. The frequency range depends on the specific testing requirements and the specific TEM waveguide type.

The object of this standard is to describe

- TEM waveguide characteristics, including typical frequency ranges and EUT-size limitations;
- TEM waveguide validation methods for EMC tests;
- the EUT (i.e. EUT cabinet and cabling) definition;
- test set-ups, procedures, and requirements for radiated emission testing in TEM waveguides and
- test set-ups, procedures, and requirements for radiated immunity testing in TEM waveguides.

NOTE Test methods are defined in this standard for measuring the effects of electromagnetic radiation on equipment and the electromagnetic emissions from equipment concerned. The simulation and measurement of electromagnetic radiation is not adequately exact for quantitative determination of effects for all end-use installations. The test methods defined are structured for a primary objective of establishing adequate repeatability of results at various test facilities for qualitative analysis of effects.

This standard does not intend to specify the tests to be applied to any particular apparatus or system(s). The main intention of this standard is to provide a general basic reference for all interested product committees of the IEC. For radiated emissions testing, product committees should select emission limits and test methods in consultation with CISPR standards. For radiated immunity testing, product committees remain responsible for the appropriate choice of immunity tests and immunity test limits to be applied to equipment within their scope. This standard describes test methods that are separate from those of IEC 61000-4-3.[1]

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 61000-2-11:1999, *Electromagnetic compatibility (EMC) – Part 2-11: Environment – Classification of HEMP environments*

[1] These other distinct test methods may be used when so specified by product committees, in consultation with CISPR and TC 77.

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

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

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

CISPR 16-1-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-1-4, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus – Antennas and test sites for radiated disturbance measurements*

CISPR 16-2-3:2006, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements*

CISPR 22, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050(161), as well as the following, apply.

3.1.1
transverse electromagnetic mode
TEM mode
waveguide mode in which the components of the electric and magnetic fields in the propagation direction are much less than the primary field components across any transverse cross-section

3.1.2
TEM waveguide
open or closed transmission line system, in which a wave is propagated in the transverse electromagnetic mode to produce a specific field for testing purposes

3.1.3
TEM cell
closed TEM waveguide, often a rectangular coaxial transmission line, in which a wave is propagated in the transverse electromagnetic mode to produce a specific field for testing purposes and with an outer conductor completely enclosing an inner conductor

3.1.4
two-port TEM waveguide
TEM waveguide with input/output ports at both ends

3.1.5
one-port TEM waveguide
TEM waveguide with a single input/output port

NOTE Such TEM waveguides typically feature a broadband transmission-line termination at the non-port end.

3.1.6
stripline
terminated transmission line consisting of two or more parallel plates between which a wave is propagated in the transverse electromagnetic mode to produce a specific field for testing purposes

NOTE Striplines usually have open sides for EUT access and monitoring.

3.1.7
inner conductor or septum
inner conductor of a coaxial transmission-line system, often flat in the case of a rectangular cross-section, and which may be positioned symmetrically or asymmetrically with respect to the outer conductor

3.1.8
outer conductor or chassis
outer conductor of a coaxial transmission line system, often having a rectangular cross-section

3.1.9
characteristic impedance
for any constant phase wave-front, the magnitude of the ratio of the voltage between the inner conductor and the outer conductor to the current on either conductor and which is independent of the voltage/current magnitudes and depends only on the cross-sectional geometry of the transmission line

NOTE TEM waveguides are typically designed to have a characteristic impedance of 50 Ω. TEM waveguides with a characteristic impedance of 100 Ω are often used for transient testing.

3.1.10
anechoic material
material that exhibits the property of absorbing, or otherwise reducing, the level of electromagnetic energy reflected from that material

3.1.11
broadband transmission-line termination
broadband line termination
termination which combines a low-frequency discrete-component load, to match the characteristic impedance of the TEM waveguides (typically 50 Ω), and a volume of high-frequency anechoic material

3.1.12
correlation algorithm
mathematical routine for converting TEM waveguide voltage measurements to open-area test sites (OATS), semi-anechoic chamber (SAC), or free space field strength levels

3.1.13
EUT type
grouping of products with sufficient similarity in electromagnetic characteristics to allow testing with the same test installation and the same test protocol

3.1.14
exit cable
cable that connects the EUT to equipment external to the TEM waveguide or cable exiting the usable test volume

NOTE Test volume is specified in 5.2.2.

3.1.15
interconnecting cable
cable that connects subcomponents of the EUT within the test volume but does not exit the test volume

3.1.16
test set-up support
non-reflecting, non-conducting, low-permittivity support and positioning reference that allows for precise rotations of the EUT as required by a correlation algorithm or test protocol

NOTE A typical material is foamed polystyrene. Wooden supports are not recommended (see [4][2]).

3.1.17
ortho-angle
angle that the diagonal of a cube makes to each side face at the trihedral corners of the cube; assuming that the cube is aligned with the TEM waveguide Cartesian coordinate system, the azimuth and elevation angles of the projection of the cube diagonal are 45°, and the angles to the face edges are 54,7°

NOTE 1 Figure A.2a shows a diagram of the ortho-angle.

NOTE 2 When associated with the EUT, this angle is usually referred to as the ortho-axis.

3.1.18
primary (field) component
electric field component aligned with the intended test polarization

NOTE In conventional two-port TEM cells, the septum is parallel to the horizontal floor, and the primary mode electric field vector is vertical at the transverse centre of the TEM cell.

3.1.19
secondary (field) component
in a cartesian coordinate system, either of the two electric field components orthogonal to the primary field component and orthogonal to each other

3.1.20
resultant field (amplitude)
root-sum-squared values in V/m of the primary and the two secondary field components

3.1.21
manipulator
any type of manual or automatic non-metallic test set-up support similar to a turntable, and capable of supporting an affixed EUT throughout numerous positions as required by a correlation algorithm or test protocol

NOTE An example of a manipulator design is shown in Figure A.2.

3.1.22
hyper-rotated TEM waveguide
TEM waveguide that has been reoriented such that its ortho-axis is normal to the surface of the Earth

NOTE Additional details are given in [6].

3.1.23
gravity-dependent / -independent
the gravitation force of the earth has a fixed direction. The EUT can be rotated around all three axes. Due to different rotation positions, the EUT is affected by the gravitation force in different directions. The EUT is gravity-independent if it is working properly in all positions,

2 Figures in square brackets refer to the bibliography.

which means working properly regardless of the direction of the gravity vector relative to the EUT. The EUT is gravity-dependent if it does not work properly in one or more test positions

3.2 Abbreviations

BALUN	balanced-to-unbalanced transformer
DFT	discrete Fourier transform
EUT	equipment under test
FFT	fast Fourier transform
GTEM	gigahertz transverse electromagnetic
HEMP	high-altitude electromagnetic pulse
OATS	open-area test site
PoE	points of entry
RF	radio frequency
SAC	semi-anechoic chamber
SPD	surge protective device
TDR	time-domain reflectometer
TE	transverse electric (mode), (H-mode)
TEM	transverse electromagnetic
TM	transverse magnetic (mode), (E-mode)
VSWR	voltage-standing-wave-ratio

4 General

This standard describes basic characteristics and limitations of TEM waveguides, namely test volume, field uniformity, purity of the TEM mode, and frequency ranges. Various general properties of TEM waveguides are described in Annex D.

Radiated emission measurements in a TEM waveguide are usually correlated with the open-area test site (OATS) and semi-anechoic chamber (SAC) methods, which provide valid and repeatable measurement results of disturbance field strength from equipment. In this case so-called correlation algorithms are used to convert TEM waveguide measurement results to OATS-equivalent data, as described in Annex A.

TEM waveguides can also be used as field generators for testing the immunity of equipment to electromagnetic fields. Details are given in Annex B. Immunity testing in TEM waveguides is cited in several other standards listed in the Bibliography. Field generation properties can also be used for measuring field strength, see Annex E and other publications listed in the Bibliography.

TEM waveguide tests are not restricted to radiated measurements on fully assembled equipment. They may also be applied to the testing of components, integrated circuits, and the shielding effectiveness of gasket materials and cables. For further information see Bibliography.

5 TEM waveguide requirements

5.1 General

TEM waveguides can be used for emission and immunity tests when certain requirements are met. For the validation of a TEM waveguide the following methods shall be applied.

This clause focuses on general validation aspects such as the dominant TEM mode and field homogeneity. Specific validation requirements for emission, immunity, and transient testing are given in the Annex A, Annex B, and Annex C, respectively.

5.2 General requirements for the use of TEM waveguides

5.2.1 TEM mode verification

TEM waveguides may exhibit resonances above a certain cut-off frequency determined by the cross-sectional dimensions and/or the waveguide length. For practical use, the field in a TEM waveguide is considered to propagate in a TEM mode when the following requirements are met. This verification of the TEM mode applies to waveguides used either for immunity or emissions testing. The TEM mode behaviour shall be confirmed at regular intervals (see 5.2.3).

NOTE 1 Generally, a TEM waveguide manufacturer should verify and document the TEM mode behaviour over the desired frequency range and include verification data with the system documentation.

Using an immunity-type uniform-area verification procedure (according to 5.2.3) the magnitudes of the secondary (unintended) electric field components shall be at least 6 dB less than the primary component of the electric field, over at least 75 % of the tested points in a defined cross-section of the TEM waveguide (perpendicular to the propagation direction). For this 75 % of test points, a primary electric field component tolerance greater than $^{-0}_{+6}$ dB up to $^{-0}_{+10}$ dB, or a secondary electric field component level up to –2 dB of the primary field component, is allowed for a maximum of 5 % of the test frequencies (at least one frequency), provided that the actual tolerance and frequencies are stated in the test reports. The frequency range is 30 MHz up to the highest frequency of intended use of the TEM waveguide. The first frequency step shall not exceed 1 % of the fundamental frequency and thereafter 1 % of the preceding frequency in 80 MHz to 1 000 MHz, 5 % below 80 MHz and above 1 000 MHz. One constraint on the sweep speed is the response time of the field probe.

NOTE 2 The TEM field is the dominant mode and the cavities are low Q values, therefore resonances are not expected to be narrow. For this reason the use of logarithmic frequencies is acceptable for TEM mode verification testing.

NOTE 3 For transient tests the start frequency should be 100 kHz.

NOTE 4 The 6 dB criterion from 5.2.1 specifies the dominant TEM mode and not the field uniformity, and is separate from and not to be confused with the field uniformity requirements of 5.2.3. Further information about field uniformity is given in [17].

5.2.2 Test volume and maximum EUT size

The maximum size of an EUT is related to the size of the “usable test volume” in the TEM waveguide. The usable test volume of the TEM waveguide depends on the size, geometry, and the spatial distribution of the electromagnetic fields.

The usable test volume of a TEM waveguide (see Figures A.6 to A.9) depends on the “uniform area” as defined in 5.2.3. The propagation direction of the waveguide TEM mode (typically z-axis) is perpendicular to a uniform area (transverse plane, typically xy-plane). In the xy-plane the entire cross-section of the usable test volume has to fulfil the requirements of the uniform area defined in 5.2.3. The minimum value for the distance h_{EUT} between EUT and each conductor or absorber of the waveguide (see Figures A.6 to A.9) is given by the distance between the boundary of the uniform area (see 5.2.3) and the conductor. However, h_{EUT}

should not be zero, in order to avoid the possible change of the EUT operational condition by the close coupling between EUT and conductors of the waveguide (recommended: h_{EUT} should be larger than 0,05 h). Along the z-axis (propagation direction) the usable test volume is limited by $z_{min} \leq z \leq z_{max}$. The length of the test volume is $L = z_{max} - z_{min}$. The requirements of a uniform area shall be validated for cross-sections at each z with $z_{min} \leq z \leq z_{max}$. It can be assumed that the TEM mode requirements are fulfilled for $z_{min} \leq z \leq z_{max}$ under the following conditions:

- if TEM mode requirements are fulfilled at the position z_{max}, and the geometry of the waveguide is similar to one of the types shown in Figures A.6 to A.9 with a constant aspect ratio of h to w (inherent shape) for $0 < z < z_{max}$, or,
- if TEM mode requirements are fulfilled at the positions z_{min} and z_{max}, and the waveguide cross-section is constant or uniformly tapered for $z_{min} < z < z_{max}$ and the derivatives dh/dz and dw/dz are a smooth function for $z_{min} < z < z_{max}$ (no kinks or steps in the conductor geometries).

The maximum size of an EUT is related to the size of the usable test volume. The EUT shall be verified not to be larger than 0,6 w times 0,6 L (see Figures A.6 to A.9).

NOTE 1 The ISO 11452 series recommends an EUT size of 0,33 $w \times$ 0,6 L, and MIL-STD 462F recommends 0,5 $w \times$ 0,5 L.

The maximum usable EUT height is recommended to be 0,33 h, with h equal to the distance between the inner and outer conductors (conductor spacing) at the centre of the EUT in the test volume (for example, between septum and floor in a TEM cell). For all TEM waveguides, the EUT shall fit within the usable test volume for all rotation positions.

NOTE 2 Most standards restrict EUT size to 0,33 h. Most data sheets from TEM cell suppliers limit the EUT height to a maximum of 0,5 h. Except for highly accurate calibration, such as for field probes and sensors, the EUT height can exceed 0,33 h, but it should not exceed the manufacturer's recommendations. The maximum usable EUT height can be higher than 0,33 h if the manufacturer provides information about the measurement uncertainty for larger EUTs. More information about loaded waveguide effects is given in [25].

5.2.3 Validation of usable test volume

5.2.3.1 General considerations

This subclause uses the concept of a "uniform area" which is a hypothetical area in which variations of the field magnitude are acceptably small (see [15]). The TEM waveguide dimensions determine the size of this uniform area (plane), unless the EUT can be fully illuminated in a smaller surface. The maximum size of an EUT is related to the size of the usable test volume (see 5.2.2).

NOTE 1 In general the exact form and the location of the uniform area are not specified, but are determined using the procedures of this standard.

NOTE 2 If no other definition is given, the uniform area should be a vertical plane orthogonal to the propagation direction of the field. It should be one plane face area in front of the EUT.

NOTE 3 The vertical plane assumes that the direction of TEM mode propagation is near horizontal (aligned to the z-axis) and plane wave propagation is given. If the TEM mode propagation direction is in some other direction, the uniform area plane may be re-orientated accordingly.

The use of a transmission line set-up avoids perturbation due to ground-reflected fields as in a semi-anechoic chamber set-up; thus, uniform fields may be established in the vicinity of the inner and outer conductors (in the normal direction only).

In principle, the uniform area may be located at any distance from the input port; the location will depend on the specific waveguide geometry. The uniform area is valid only for that distance from the input port at which it is calibrated. To allow EUT rotation, the uniform area