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BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

colour inside

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

FOREWORD

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International Standard IEC 61000-4-10 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms Part 4-10 of the IEC 61000 series. 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 1993 and Amendment 1:2000. This edition constitutes a technical revision.

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

a) new Annex A on induction coil field distribution;
b) new Annex D on measurement uncertainty;
c) new Annex E for numerical simulations;
d) calibration using current measurement has been addressed in this edition.

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

CDV	Report on voting
77B/730/CDV	77B/746A/RVC

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- withdrawn,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 (insofar 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).

~~These standards and reports will be published in chronological order and numbered accordingly.~~

This part is an international standard which gives immunity requirements and test procedures related to "damped oscillatory magnetic field".

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

1 Scope and object

This part of IEC 61000 ~~relates to~~ specifies the immunity requirements ~~of equipment, only under operational conditions~~, test methods, and range of recommended test levels for equipment subjected to damped oscillatory magnetic disturbances related to medium voltage and high voltage sub-stations.

~~The applicability of this standard to equipment installed in different locations is determined by the presence of the phenomenon, as specified in clause 3.~~

The test defined in this standard is applied to equipment which is intended to be installed in locations where the phenomenon as specified in Clause 4 will be encountered.

This standard does not ~~consider~~ specify disturbances due to capacitive or inductive coupling in cables or other parts of the field installation. IEC 61000-4-18, which deals with conducted disturbances, covers these aspects.

The object of this standard is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment for medium voltage and high voltage sub-stations when subjected to damped oscillatory magnetic fields.

The test is mainly applicable to electronic equipment to be installed in H.V. sub-stations. Power plants, switchgear installations, smart grid systems may also be applicable to this standard and may be considered by product committees.

NOTE As described in IEC Guide 107, this is a basic EMC publication for use by product committees of the IEC. As also stated in Guide 107, the IEC product committees are responsible for determining whether this immunity test standard is applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria. TC 77 and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular immunity test levels for their products.

This standard ~~has the object to~~ defines:

– ~~recommended~~ a range of test levels;
– test equipment;
– test setups;
– test procedures.

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 60068-1:1988, *Environmental testing – Part 1: General and guidance*~~

IEC 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at www.electropedia.org)

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

~~The following definitions and terms are used in this standard and apply to the restricted field of magnetic disturbances; not all of them are included in IEC 60050(161) [IEV].~~

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

3.1.1
calibration
set of operations which establishes, by reference to standards, the relationship which exists, under specified conditions, between an indication and a result of a measurement

Note 1 to entry: This term is based on the "uncertainty" approach.

Note 2 to entry: The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.2
damped oscillatory wave generator
generator delivering a damped oscillation whose frequency can be set to 100 kHz or 1 MHz and whose damping time constant is five periods

3.1.3
immunity
ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.1.4
induction coil
conductor loop of defined shape and dimensions, in which a current flows, generating a magnetic field of defined ~~constancy in its plane and in the enclosed~~ uniformity in a defined volume

3.1.5
induction coil factor
ratio between the magnetic field strength generated by an induction coil of given dimensions and the corresponding current value

Note 1 to entry: The field is that measured at the centre of the coil plane, without the EUT.

~~**4.4**~~
~~**immersion method**~~
~~method of application of the magnetic field to the EUT, which is placed in the centre of an induction coil (figure 1)~~

3.1.6
proximity method
method of application of the magnetic field to the EUT, where a small induction coil is moved along the side of the EUT in order to detect particularly sensitive areas

~~**4.6**~~
~~**ground (reference) plane (GRP)**~~
~~a flat conductive surface whose potential is used as a common reference for the magnetic field generator and the auxiliary equipment (the ground plane can be used to close the loop of the induction coil, as in figure 5)~~
~~[IEV 161-04-36, modified]~~

~~**4.7**~~
~~**decoupling network, back filter**~~
~~electrical circuit intended to avoid reciprocal influence with other equipment not submitted to the magnetic field test~~

~~**4.8**~~
~~**burst**~~
~~a sequence of a limited number of distinct pulses or an oscillation of limited duration~~
~~[IEV 161-02-07]~~

3.1.7
reference ground
part of the Earth considered as conductive, the electrical potential of which is conventionally taken as zero, being outside the zone of influence of any earthing (grounding) arrangement

[SOURCE: IEC 60050-195:1998, 195-01-01]

3.1.8
system
set of interdependent elements constituted to achieve a given objective by performing a specified function

Note 1 to entry: The system is considered to be separated from the environment and other external systems by an imaginary surface which cuts the links between them and the considered system. Through these links, the system is affected by the environment, is acted upon by the external systems, or acts itself on the environment or the external systems.

3.1.9
transient, adjective and noun
pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval short compared to the time scale of interest

[SOURCE: IEC 60050-161:1990, 161-02-01]

3.1.10
verification
set of operations which is used to check the test equipment system (e.g. the test generator and its interconnecting cables) to demonstrate that the test system is functioning

Note 1 to entry: The methods used for verification may be different from those used for calibration.

Note 2 to entry: For the purposes of this basic EMC standard this definition is different from the definition given in IEC 60050-311:2001, 311-01-13.

3.2 Abbreviations

AE	Auxiliary equipment
EMC	Electromagnetic compatibility
EUT	Equipment under test
MU	Measurement uncertainty
PE	Protective earth
RGP	Reference ground plane

4 General

Damped oscillatory magnetic fields are generated by the switching of H.V. bus-bars by isolators or disconnectors. The magnetic fields to which equipment is subjected may can influence the reliable operation of equipment and systems.

The following tests are intended to demonstrate the immunity of equipment when subjected to damped oscillatory magnetic field related to the specific location and installation condition of the equipment (e.g. proximity of equipment to the disturbance source).

~~The test is mainly applicable to electronic equipment to be installed in H.V. sub-stations. Possible other applications may be considered by the product committees.~~

The wave shape of the test field ~~consists of~~ corresponds to a damped oscillatory wave (see Figure 2). The characteristics are given in 6.2.2.

Information on the oscillation frequency is given in Annex C.

5 Test levels

The preferred range of test levels is given in Table 1.

Table 1 – Test levels

Level	Damped oscillatory magnetic field strength A/m (peak)
1	not applicable
2	not applicable
3	10
4	30
5	100
X[a]	special

NOTE The magnetic field strength is expressed in A/m; 1 A/m corresponds to a free space magnetic flux density of 1,26 μT.

a ~~"n.a." = not applicable.~~
"x" ~~is an open~~ can be any level, above, below or in between the others. This level, as well the duration of the test, ~~can be given in the product specification~~ shall be specified in the dedicated equipment specification.

~~Information on the selection of the test levels is given in Annex C.~~

~~Information on actual levels is given in annex D.~~

~~The duration of the test is 2 s.~~

The test levels shall be selected according to the installation conditions. Classes of installation are given in Annex B.

~~6 Test equipment~~

~~The test magnetic field is obtained by a current flowing in an induction coil; the application of the test field to the EUT is by the *immersion method*.~~

~~An example of application of the immersion method is given in figure 1.~~

The test equipment includes the current source (test generator), the induction coil and auxiliary test instrumentation.

6.1 Test generator

The generator, with the output waveform corresponding to the test magnetic field, shall be able to deliver the required current in the induction coils specified in 6.2.

The generator power capability shall therefore be dimensioned by taking into account the coil impedance; the inductance may range from 2,5 µH for the 1 m standard coil, to several µH (e.g. 6 µH) for a rectangular induction coil (1 m × 2,6 m, see 6.2).

The specifications of the generator are:

– current capability, determined by the maximum selected test level and induction coil factor (see 6.2.2 and annex A), ranging from 0,87 (1 m standard coil for testing table-top or small equipment to 0,66 (rectangular induction coil, 1 m × 2,6 m, for testing floor-standing or large equipment).
– operability in short-circuit condition;
– low output terminal connected to the earth terminal (for connection to the safety earth of the laboratory);
– precautions to prevent the emission of large disturbances that may be injected in the power supply network or may influence the test results.

The characteristics and performances of the current source or test generator for the field considered in this standard are given in 6.1.1.

6.1.1 Characteristics and performances of the test generator

The test generator is a repetitive damped sinusoid current generator with characteristics as follows:

Specifications

Oscillation frequency: 0,1 MHz and 1 MHz ± 10 %

Decay rate: 50 % of the peak value after 3 to 6 cycles

Repetition rate: at least 40 transients/s at 0,1 MHz, 400 transients/s at 1 MHz

Test duration: 2 s (+10 %, –0 %) or continuous

Output current range: from 10 A to 100 A, divided by the coil factor

NOTE The output current range for the standard coil is from 12 A to 120 A.

The waveform of the output current is given in figure 2.

The schematic circuit of the generator is given in figure 3.

6.1.2 Verification of the characteristics of the test generator

In order to compare the results for different test generators, the essential characteristics of the output current parameters shall be verified.

The output current shall be verified with the generator connected to the standard induction coil specified in 6.2.1 a); the connection shall be realized by twisted conductors or coaxial cable of up to 3 m length and suitable cross-section.

The emission of disturbances by the generator shall be verified (see 6.1).

The characteristics to be verified are:

– output current peak value;
– damping;
– frequency of oscillation;
– repetition rate.

The verifications shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with 10 MHz minimum bandwidth.

The accuracy of the measurements shall be ±10 %.

6.2 Induction coil

6.2.1 Characteristics of the induction coil

The induction coil, connected to the test generator previously defined (see 6.1.1), shall generate a field strength corresponding to the selected test level and the defined homogeneity.

The induction coil shall be made of copper, aluminium or any conductive non-magnetic material, of such cross-section and mechanical arrangement as to facilitate its stable positioning during the tests.

The coil shall be *"single turn"* and have a suitable current capability, as necessary for the selected test level.

The induction coil shall be adequately dimensioned to surround the EUT (three orthogonal positions).

Depending on the size of the EUT, induction coils of different dimensions may be used.

The dimensions recommended below are suitable for the generation of magnetic field over the whole volume of the EUTs *(table-top equipment or floor-standing equipment)*, with an acceptable variation of ±3 dB.

The characteristics of induction coils in respect of the magnetic field distribution are given in annex B.

a) *Induction coil for table-top equipment*

– The induction coil of standard dimensions for testing small equipment (e.g. computer monitors, watt-hour meters, transmitters for process control, etc.) has a square (or circular) form with 1 m side (or diameter), made of a conductor of relatively small cross-section.

– The test volume of the standard square coil is 0,6 m × 0,6 m × 0,5 m (height).

– A double coil of standard size (Helmholtz coil) could be used in order to obtain a field homogeneity better than 3 dB or for testing larger EUTs.

– The double coil (Helmholtz coil) shall be comprised of two or more series of turns, properly spaced (see figure 7, figure B.4, figure B.5).

– The test volume of a double standard size coil, 0,8 m spaced, for a 3 dB homogeneity is 0,6 m × 0,6 m × 1 m (height).

– For example, the Helmholtz coils, for a 0,2 dB inhomogeneity, have dimensions and separation distances as given in figure 7.

b) *Induction coil for floor-standing equipment*

– Induction coils shall be made according to the dimensions of the EUT and the different field polarizations.

– The coil shall be able to envelop the EUT; the coil dimensions shall be such as to give a minimum distance of coil conductors to EUT walls equal to 1/3 of the dimension of the EUT considered.

– The coils shall be made of conductors of relatively small cross-section.

NOTE Due to the possible large dimensions of EUTs, the coils may be made of "C" or "T" sections in order to have sufficient mechanical rigidity.

– The test volume is determined by the testing area of the coil (60 % × 60 % of each side) multiplied by a depth corresponding to 50 % of the shorter side of the coil.

6.2.2 Calibration of the induction coil, coil factor

In order to make it possible to compare the test results from different test equipment, the induction coils shall be calibrated in their operating condition, before conducting the test (without the EUT, in free space condition).

An induction coil of the correct dimensions for the EUT dimensions shall be positioned at 1 m minimum distance from the wall of the laboratory and any magnetic material, by using insulating supports, and shall be connected to the test generator as prescribed in 6.1.2.

Appropriate magnetic field sensors (B.W. > 10 MHz), with dynamics and frequency response in accordance with the oscillatory field, shall be used to verify the magnetic field strength generated by the induction coil.

The field sensor shall be positioned at the centre of the induction coil (without the EUT) and with suitable orientation to detect the maximum value of the field.

The current in the induction coil shall be adjusted to obtain the field strength specified by the test level.

The calibration shall be carried out at power frequency: the current value that generates a given field strength shall be used for the damped oscillatory test of the present standard.

The calibration procedure shall be carried out on the test generator and induction coils.

The coil factor is determined (and verified) by the above procedure.

The coil factor gives the current value to be injected in the coil to obtain the required test magnetic field (H/I).

Information on the measurement of the test magnetic field is given in annex A.

6.3 Test and auxiliary instrumentation

6.3.1 Test instrumentation

The test instrumentation includes:

– current measuring system (sensors and instrument) for setting and measuring the current injected in the induction coil;

– termination networks, back filters, etc., on power supply, control and signal lines.

The termination network gives a defined impedance of 50 Ω to earth for all the external circuits connected to the EUT terminals. It may be represented by the line impedance stabilization network for power supply circuits, coupling/decoupling network, or resistor-capacitor series for input/output control and signal circuits. These networks shall be described

~~in the test plan. The termination networks, back filters, etc. shall be compatible with the operating signals.~~

~~Back filters shall be used in the connections to the simulator (see 6.3.2).~~

~~The current measuring system is a calibrated current probe or shunt; the transient current measurement instrumentation shall have a bandwidth up to 10 MHz.~~

~~The accuracy of the measurement instrumentation shall be ±10 %.~~

~~**6.3.2 Auxiliary instrumentation**~~

~~The auxiliary instrumentation comprises a simulator and any other instrument necessary for the operation and verification of the EUT functional specifications.~~

6 Test instrumentation

6.1 General

The test system comprises the damped oscillatory wave generator and the induction coil for a table-top test setup and, in addition, an RGP for a floor-standing test setup.

6.2 Damped oscillatory wave generator

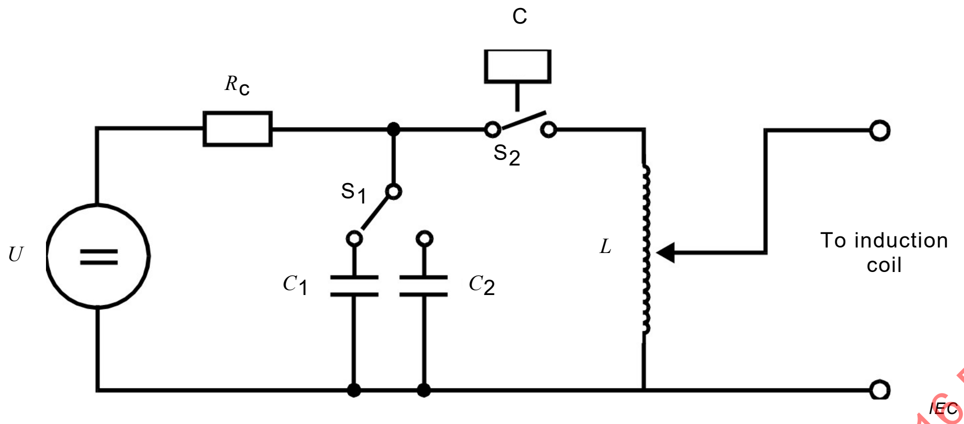
6.2.1 General

The damped oscillatory wave generator shall be able to deliver the required impulse current to the induction coils specified in 6.3.

NOTE For this application, a modified version of a damped oscillatory wave generator similar to the generator mentioned in IEC 61000-4-18 is used as a current source.

The waveform is specified as a short-circuit current and therefore shall be measured with the induction coil connected.

A simplified circuit diagram of the generator is given in Figure 1.



U:	High voltage source	R_c:	Charging resistor
C:	Control duration	L:	Coil oscillation circuit
S_1	Frequency selector	S_2	Duration selector

C_1, C_2: Capacitors oscillation circuit (switchable from 0,1 MHz to 1 MHz)

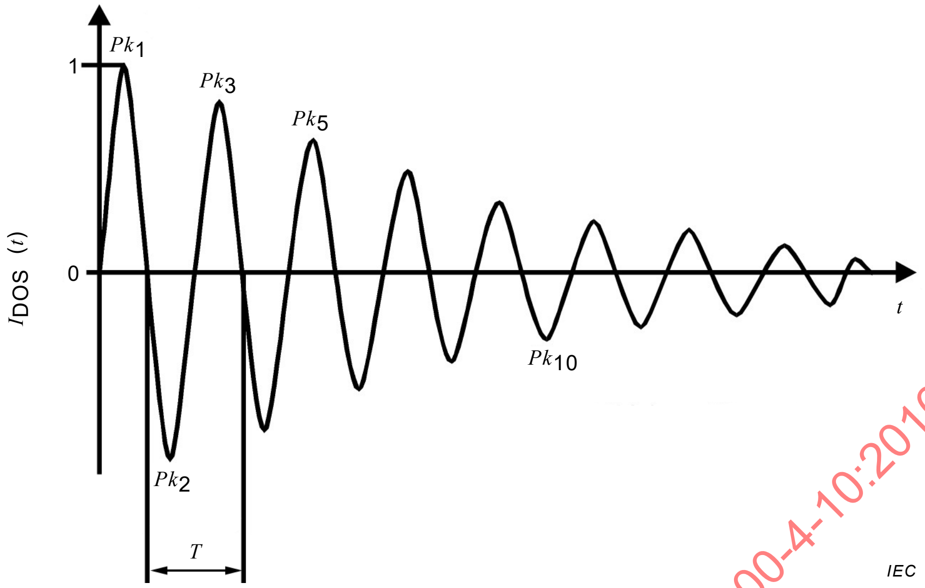
Figure 1 – Simplified schematic circuit of the test generator for damped oscillatory magnetic field

6.2.2 Performance characteristics of the generator connected to the standard induction coil

The performance characteristics below are applicable for the generator connected to the standard induction coils outlined in 6.3.

Oscillation period	see Table 3
Current in the coils (Pk_1 value)	see Table 2
Waveform of the damped oscillatory magnetic field	see Figure 2
Decay rate D_{r1}, D_{r2}	Pk_5 shall be > 50 % of the Pk_1 value and Pk_{10} shall be < 50 % of the Pk_1 value
Repetition rate $1/T_{rep}$ (see Figure 3)	40/s ± 10 % for 100 kHz and 400/s ± 10 % for 1 MHz
Test duration	not less than 2 s
Phase shifting	no requirement

Oscillation frequency is defined as the reciprocal of the period of the first and third zero crossings after the initial peak. This period is shown as T in Figure 2.



Key

T = 1 µs (1 MHz) or 10 µs (0,1 MHz)

Figure 2 – Waveform of short-circuit current in the standard coils

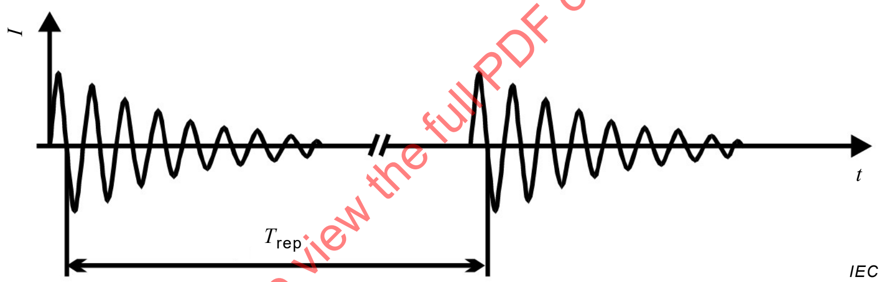


Figure 3 – Waveform of short-circuit current showing the repetition time T_{rep}

The formula of the ideal waveform of Figure 2, $I_{DOS}(t)$, is as follows:

$$I_{DOS}(t) = K_i \frac{i_1}{KH} \left(\frac{\left(\frac{t}{t_{1h}}\right)^{nh}}{1+\left(\frac{t}{t_{1h}}\right)^{nh} e^{\frac{t}{t_{2h}}}} \right) \sin(\beta t)$$

with

$$KH = e^{-\frac{t_{1h}}{t_{2h}}\left(nh\frac{t_{2h}}{t_{1h}}\right)^{\frac{1}{nh}}}$$

where the parameters for oscillation period T = 1 µs are:

K_i = 1; i_1 = 0,963; t_{1h} = 0,08 µs; t_{2h} = 4,8 µs; nh = 2,1; β = 6,27 × 10^6 rad/s:

and the parameters for the oscillation period T = 10 µs are:

K_i = 1; i_1 = 0,963; t_{1h} = 0,8 µs; t_{2h} = 48 µs; nh = 2,1; β = 0,627 × 10^6 rad/s;

6.3 Standard induction coil

For the two single-turn standard coils of 1 m x 1 m and 1 m x 2,6 m, the field distribution is known and shown in Annex A. Therefore, no field verification or field calibration is necessary; the current measurement as shown in Figure 4 is sufficient.

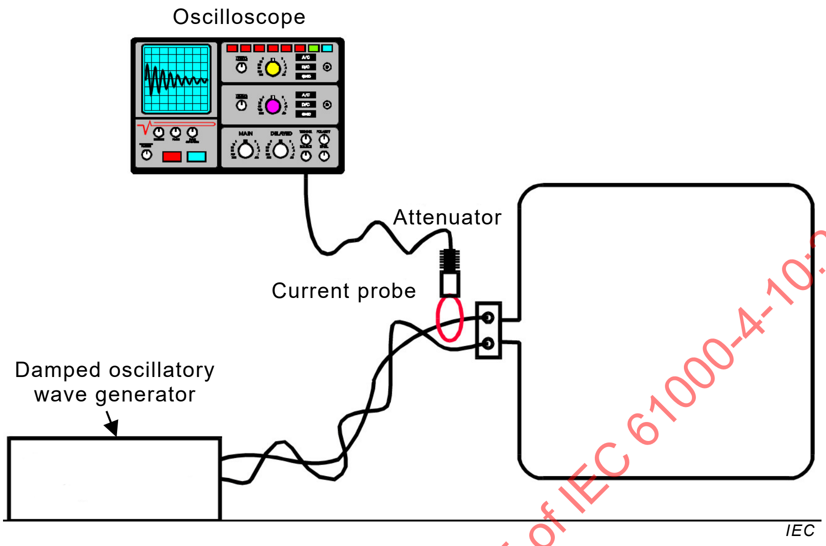


Figure 4 – Example of a current measurement of standard induction coils

The induction coil shall be made of copper, aluminium or any conductive non-magnetic material, of such cross-section and mechanical arrangement as to facilitate its stable positioning during the tests.

The characteristics of induction coils with respect to the magnetic field distribution are given in Annex A.

6.4 Calibration of the test system

The essential characteristics of the test system shall be calibrated by a current measurement (see Figure 4).

The output current shall be verified with the generator connected to the standard induction coil specified in 6.3. The connection shall be realized by twisted conductors or a coaxial cable of up to 3 m length and a suitable cross-section.

The specifications given in Table 3 are not applicable for calibrations performed at test level 5 with the 1 m × 2,6 m standard induction coil connected. In this case, the calibration shall be performed by only using the 1 m × 1 m standard induction coil.

The following specifications given in Table 2 and Table 3 shall be verified.

Table 2 – Peak current specifications of the test system

Test level	Peak current I ± 20 % A	
	System using 1 m × 1 m standard induction coil	**System using 1 m × 2,6 m standard induction coil**
1	not applicable	not applicable
2	not applicable	not applicable
3	11,1	15,2
4	33,3	45,5
5	111	see note 2
X	special/0,9	special/0,66

NOTE 1 The values 0,9 and 0,66 are the calculated coil factors of standard induction coils.

NOTE 2 The calculated value is 152; however, there is currently no commercial generator available.

Table 3 – Waveform specifications of the test system

Calibration items	Oscillation frequency	
	100 kHz	**1 MHz**
Oscillation period	T = 10 µs ± 1 µs	T = 1 µs ± 0,1 µs
Repetition time of the pulses	T_{rep} = 25 ms ± 2,5 ms	T_{rep} = 2,5 ms ± 0,25 ms
Decay rate of one pulse	$D_{r1} = \lvert I(PK_5) \div I(PK_1) \rvert > 50\ \%$ $D_{r2} = \lvert I(PK_{10}) \div I(PK_1) \rvert < 50\ \%$	$D_{r1} = \lvert I(PK_5) \div I(PK_1) \rvert > 50\ \%$ $D_{r2} = \lvert I(PK_{10}) \div I(PK_1) \rvert < 50\ \%$

The calibrations shall be performed at all levels which are used by laboratories.

The calibrations shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with a 10 MHz minimum bandwidth.

7 Test setup

7.1 Test equipment

~~The test set-up comprises~~ The following ~~components~~ equipment is part of the test setup:

– equipment under test (EUT);
– auxiliary equipment (AE) when required;
– cables (of specified type and length);
– damped oscillatory wave generator;
~~– ground (reference) plane (GRP);~~
~~– test generator;~~
– standard induction coil;
~~– termination network, back filter.~~
– RGP in case of testing floor standing equipment.

~~Precautions shall be taken if the test magnetic field may interfere with the test instrumentation and other sensitive equipment in the vicinity of the test set-up.~~

~~Examples of test set-ups are given in the following figures:~~

~~Figure 4: Example of test set-up for table-top equipment~~

~~Figure 5: Example of test set-up for floor-standing equipment~~

~~7.1 Ground (reference) plane~~

~~The ground plane (GRP) shall be placed in the laboratory; the EUT and auxiliary test equipment shall be placed on it and connected to it.~~

~~The ground plane shall be a non-magnetic metal sheet (copper or aluminium) of 0,25 mm thickness; other metals may be used but in this case they shall have 0,65 mm minimum thickness.~~

~~The minimum size of the ground plane is 1 m × 1 m.~~

~~The final size depends on the dimensions of the EUT.~~

~~The ground plane shall be connected to the safety earth system of the laboratory.~~

~~7.2 Equipment under test~~

~~The equipment is configured and connected to satisfy its functional requirements. It shall be placed on the GRP with the interposition of a 0,1 m thickness insulating support (e.g. dry wood).~~

~~The equipment cabinets shall be connected to the safety earth directly on the GRP with connection of minimum length via the earth terminal of the EUT.~~

~~The power supply, input and output circuits shall be connected to the sources of power supply, control and signals via the back filters.~~

~~The cables supplied or recommended by the equipment manufacturer shall be used. In absence of any recommendation, unshielded cables shall be adopted, of a type appropriate for the signals involved. All cables shall be exposed to the magnetic field for 1 m of their length.~~

~~The back filters shall be inserted in the circuits at 1 m cable lengths from the EUT and connected to the ground plane.~~

~~The input and output circuits, to the simulator, shall be provided with back filters in order to prevent interference to that equipment.~~

~~The communication lines (data lines) shall be connected to the EUT by the cables given in the technical specification or standard for this application. Each line in the proximity of the EUT shall be maintained at a distance of about 0,1 m from the GRP.~~

~~7.3 Test generator~~

~~The test generator shall be placed at less than 3 m distance from the induction coil.~~

~~One terminal of the generator shall be connected to the ground plane.~~

~~7.4 Induction coil~~

~~The induction coil, of the type specified in 6.2.1, shall enclose the EUT placed at its centre.~~

~~Different induction coils may be selected for testing in the different orthogonal directions, according to the general criteria specified in 6.2.1 a) and b).~~

~~Induction coils used in the vertical position (horizontal polarization of the field) can be bonded (at the foot of one vertical conductor) directly to the ground plane, which represents the low side of the coil, as a part of it. In this case, 0,1 m minimum distance from EUT to the ground plane is sufficient.~~

~~The induction coil shall be connected to the test generator in the same way as for the calibration procedure specified in 6.2.2.~~

~~The induction coil selected for the tests shall be specified in the test plan.~~

7.2 Verification of the test instrumentation

The purpose of verification is to ensure that the test setup is operating correctly. The test setup includes:

– the damped oscillatory wave generator;
– the induction coil;
– the interconnection cables of the test equipment.

To verify that the system is functioning correctly, the following signal should be checked:

– impulse present at the standard induction coil terminals.

It is sufficient to verify that the impulse is present at any level by using suitable measuring equipment (e.g. current probe, oscilloscope).

NOTE Test laboratories can define an internal control reference value assigned to this verification procedure.

7.3 Test setup for table-top EUT

Table-top EUTs shall be placed on a non-conductive table. The 1 m × 1 m standard induction coil may be used for testing EUTs with dimensions up to 0,6 m × 0,6 m × 0,5 m (L × W × H). The 1 m × 2,6 m standard induction coil may be used for testing EUTs with dimensions up to 0,6 m × 0,6 m × 2 m (L × W × H).

The induction coil shall be positioned in three orthogonal orientations.

When an EUT does not fit into the induction coil of 1 m x 2,6 m, the proximity method (see 7.4) shall be applied.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the induction coil can impact the results so the cables shall be routed to minimize this impact. The minimized cabling dimension shall be incorporated into the determination of the maximum size of an EUT that can be tested.

An RGP is not required below the EUT (see Figure 5 below). The induction coil shall be kept at least 0,5 m from any conducting surfaces, for example the walls and floor of a shielded enclosure.

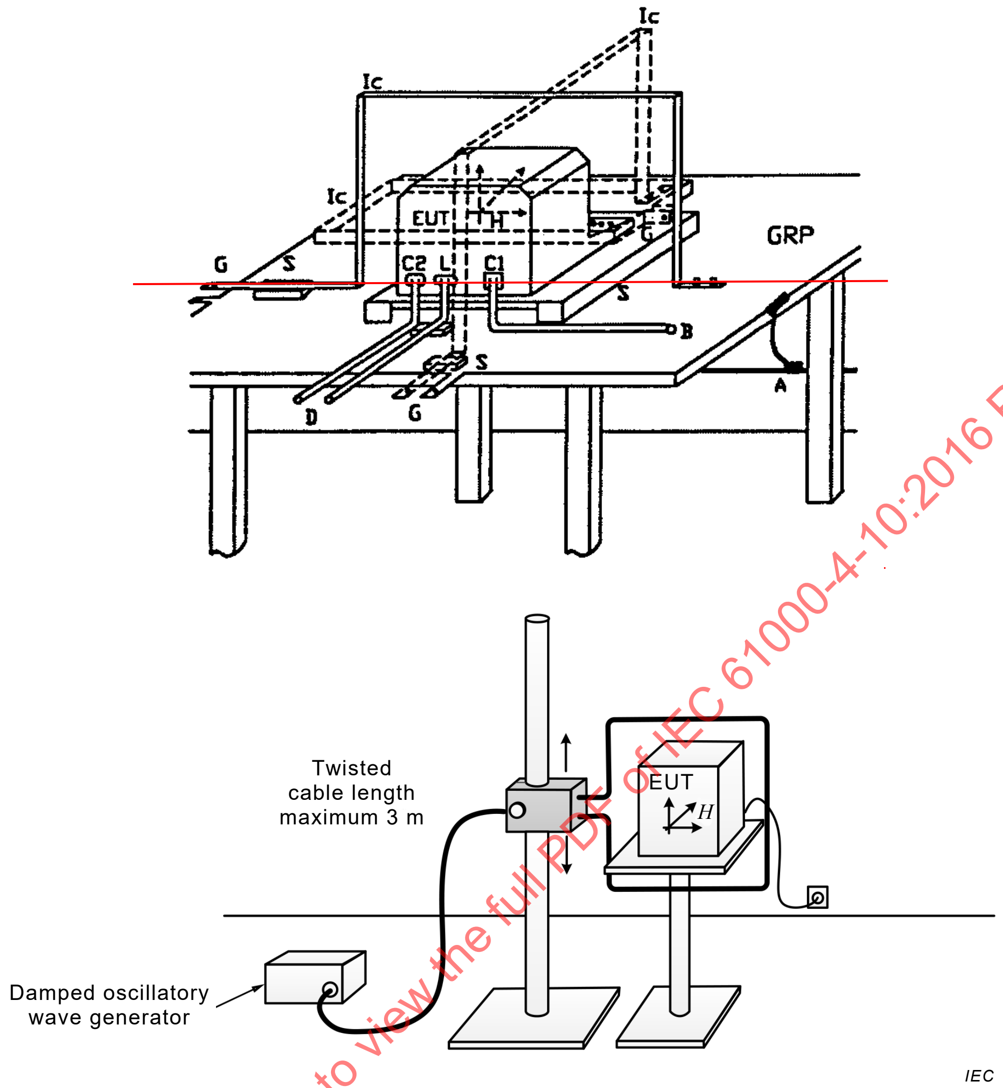


Figure 5 – Example of test setup for table-top equipment

7.4 Test setup for floor standing EUT

The standard induction coil for testing floor standing equipment (e.g. racks) has a rectangular shape of 1 m × 2,6 m where one short side may be the RGP for large sized equipment (see Figure 7). The 1 m × 1 m induction coil can be used for floor standing equipment with the maximum dimensions of 0,6 m × 0,6 m.

The RGP shall have a minimum thickness of 0,65 mm and a minimum size of 1 m × 1 m. The EUT shall be insulated from the RGP.

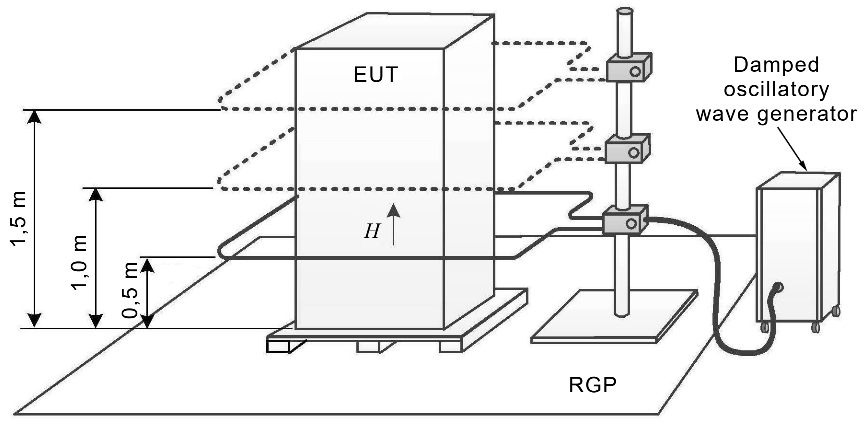


Figure 6 – Example of test setup for floor standing equipment showing the horizontal orthogonal plane

For floor standing equipment (e.g. cabinets) where the top of the EUT is greater than 0,75 m from the RGP, more than one position shall be tested. In any case, the induction coil shown in Figure 6 shall not be placed below 0,5 m. Figure 7 shows an example for testing with a vertical orthogonal plane.

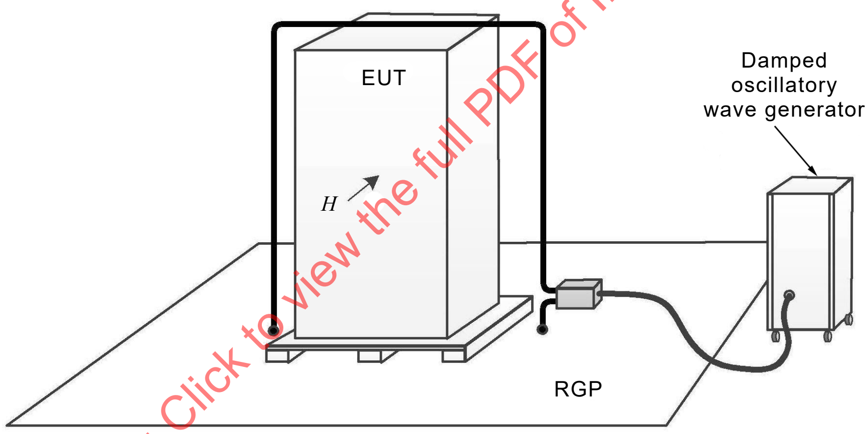


Figure 7 – Example of test setup for floor standing equipment showing the vertical orthogonal plane

The test volume of the rectangular coil is 0,6 m × 0,6 m × 2 m (L × W × H).

When an EUT does not fit into the rectangular coil of 1 m × 2,6 m, the proximity method (see Figure 8 and 7.5 for more detailed information) shall be applied.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the induction coil can impact the results so the cables shall be routed to minimize this impact. The minimized cabling dimension shall be incorporated into the determination of the maximum size of the EUT that can be tested.

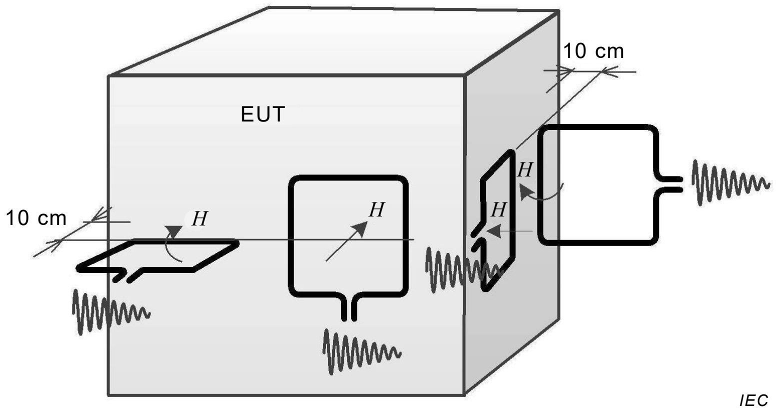


Figure 8 – Example of test setup using the proximity method

7.5 Test setup for damped oscillatory field applied in-situ

In-situ testing is generally the only practical test method available for large machinery or similar equipment. During in-situ testing, an RGP is normally not available. Therefore the proximity method is the only practical test method without the RGP in place. Figure 8 gives an example for a test setup for in-situ testing. The 1 m × 1 m standard induction coil should be used when examining EUTs using the proximity method. Further, it is necessary that the standard induction coil is isolated from the EUT. The distance between the standard induction coil and the EUT shall be (10 ± 1) cm.

NOTE The distance has been defined to ensure the same field strength as in the center of the standard induction coil.

8 Test procedure

8.1 General

The test procedure ~~shall~~ includes:

– the verification of the test instrumentation according to 7.2;

– the ~~verification~~ establishment of the laboratory reference conditions;

– the ~~preliminary verification~~ confirmation of the correct operation of the ~~equipment~~ EUT;

– ~~carrying out~~ the execution of the test;

– the evaluation of the test results (see Clause 9).

8.2 Laboratory reference conditions

~~In order to minimize the effect of environmental parameters on the test results, the test shall be carried out in climatic and electromagnetic reference conditions as specified in 8.1.1 and 8.1.2.~~

8.2.1 Climatic conditions

~~The tests shall be carried out in standard climatic conditions in accordance with IEC 68-1:~~

~~– temperature: 15 °C to 35 °C~~

~~– relative humidity: 25°A to 75 %~~

~~– atmospheric pressure: 86 kPa to 106 kPa~~

~~NOTE Any other value may be given in the product specifications.~~

Unless otherwise specified in generic, product-family or product standards, the climatic conditions in the laboratory shall be within any limits specified for the operation of the EUT and the test equipment by their respective manufacturers.

Tests shall not be performed if the relative humidity is so high as to cause condensation on the EUT or the test equipment.

8.2.2 Electromagnetic conditions

The electromagnetic conditions of the laboratory shall be such as to guarantee the correct operation of the EUT so as not to influence the test results~~; otherwise, the tests shall be carried out in a Faraday cage~~.

~~In particular, the electromagnetic field value of the laboratory shall be at least 20 dB lower than the selected test level.~~

8.3 ~~Carrying out~~ Execution of the test

Verification shall be performed. It is preferable to perform the verification prior to the test (see 7.2).

The test shall be ~~carried out on the basis of~~ performed according to a test plan ~~including verification of the performances of the EUT as defined in the technical specification~~ which shall specify the test setup, including:

~~The power supply, signal and other functional electrical quantities shall be applied within their rated range.~~

~~If the actual operating signals are not available, they may be simulated.~~

~~Preliminary verification of equipment performances shall be carried out prior to applying the test magnetic field.~~

~~The test magnetic field shall be applied by the immersion method to the EUT, previously set up as specified in 7.2.~~

~~The test level shall not exceed the product specification.~~

~~NOTE In order to detect the most susceptible side/positions of the EUT, mainly of a stationary type, the proximity method may be used for investigation purposes. This method is not to be used for certification. An example of application of the test field by proximity method is given in figure 6.~~

~~The test is performed by applying the damped oscillatory magnetic field for 2 s.~~

~~The test shall be implemented at two frequencies, at least, in the range between 30 kHz and 10 MHz. Preferably, it shall be made at 0,1 MHz and 1 MHz. Any other test frequency in the range 30 kHz and 10 MHz may be chosen by product committee or product specification; they shall be recorded in the test plan.~~

~~The test shall be made at repetition rate of at least 40 Hz for 0,1 MHz and at 400 Hz for the 1 MHz wave. The repetition rate will be increased or decreased proportionally to the test frequency.~~

~~a) *Table-top equipment*~~

~~– The equipment shall be subjected to the test magnetic field by using the induction coil of standard dimensions (1 m × 1 m) specified in 6.2.1 a) and shown in figure 4.~~

~~– The induction coil shall then be rotated by 90° in order to expose the EUT to the test field with different orientations.~~

b) *Floor-standing equipment*

The equipment shall be subjected to the test magnetic field by using induction coils of suitable dimensions as specified in 6.2.1 b); the test shall be repeated by moving and shifting the induction coils, in order to test the whole volume of the EUT for each orthogonal direction.

The test shall be repeated with the coil shifted to different positions along the side of the EUT, in steps corresponding to 50 % of the shortest side of the coil.

NOTE The moving of the induction coil in steps corresponding to 50 % of the shortest side of the coil gives overlapping test fields.

The induction coil shall then be rotated by 90° in order to expose the EUT to the test field with different orientations and the same procedure.

- test level;
- test duration (not less than 2 s);
- oscillation frequencies;
- representative operating conditions of the EUT;
- orientations of the field;
- number of test points;
- locations of the standard induction coil relative to the EUT (test points);
- selection and justification of test points (recommended are areas of EUT susceptible to damped oscillatory magnetic fields).

Testing and calibration shall be performed based on the waveform specified in Figure 2 and Figure 3.

NOTE Product committees can apply longer test durations, if appropriate for their products.

The test duration shall be applied only one time for each orientation.

9 Evaluation of test results

This clause gives a guide for the evaluation of the test results and for the test report , related to this standard.

The variety and diversity of equipment and systems to be tested make the task of establishing the effects of this test on equipment and systems difficult.

The test results shall be classified on the basis of the operating conditions and the functional specifications of the equipment under test, as in the following, unless different specifications are given by product committees or product specifications in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or the requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

a) normal performance within the specification limits specified by the manufacturer, requestor or purchaser;

b) temporary loss of function or degradation of performance which is self-recoverable ceases after the disturbance ceases, and from which the equipment under test recovers its normal performance, without operator intervention;

c) temporary loss of function or degradation of performance, the correction of which requires operator intervention or system reset;

d) loss of function or degradation of performance which is not recoverable owing to damage of equipment (components) to hardware or software, or loss of data.

The manufacturer's specification may define effects on the EUT which may be considered insignificant, and therefore acceptable.

This classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards, or as a framework for the agreement on performance criteria between the manufacturer and the purchaser, for example where no suitable generic, product or product-family standard exists.

Equipment shall not become dangerous or unsafe as a result of the application of the tests ~~defined in this standard~~.

~~In the case of acceptance tests, the test program and the interpretation of the test results have to be described in the specific product standard.~~

~~As general rule, the test result is positive if the equipment shows its immunity, for all the period of application of the test, and at the end of the tests the EUT fulfils the functional requirements established in the technical specification.~~

~~The technical specification may define effects on the EUT, that may be considered insignificant and therefore acceptable.~~

~~For these conditions it shall be verified that the equipment is able to recover its operative capabilities by itself at the end of the test; the time interval during which the equipment has lost its functional capabilities shall be therefore recorded.~~

~~These verifications are binding for the definitive evaluation of the test result.~~

~~The test report shall include the test conditions and the test results.~~

10 Test report

The test report shall contain all the information necessary to reproduce the test. In particular, the following shall be recorded:

- the items specified in the test plan required by 8.3;
- identification of the EUT and any associated equipment, for example, brand name, product type, serial number;
- identification of the test equipment, for example, brand name, product type, serial number;
- any special environmental conditions in which the test was performed, for example, shielded enclosure;
- any specific conditions necessary to enable the test to be performed;
- the performance level defined by the manufacturer, requestor or purchaser;
- the performance criterion specified in the generic, product or product-family standard;
- any effects on the EUT observed during or after the application of the test disturbance, and the duration for which these effects persist;
- the rationale for the pass/fail decision (based on the performance criterion specified in the generic, product or product-family standard, or agreed between the manufacturer and the purchaser);
- any specific conditions of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance;
- the induction coils selected for the tests;
- the position and orientation of the induction coil relative to EUT.

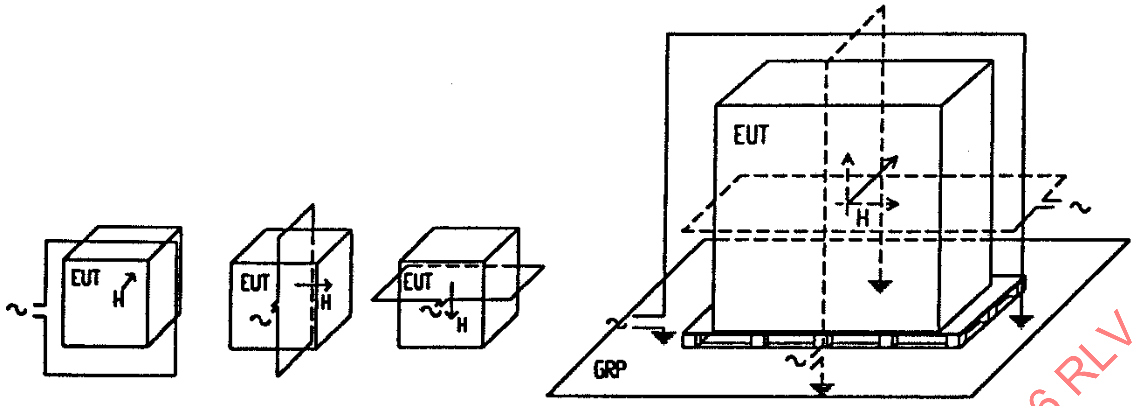


Table-top equipment Floor-standing equipment

Figure 1 – Example of application of the test field by the immersion method

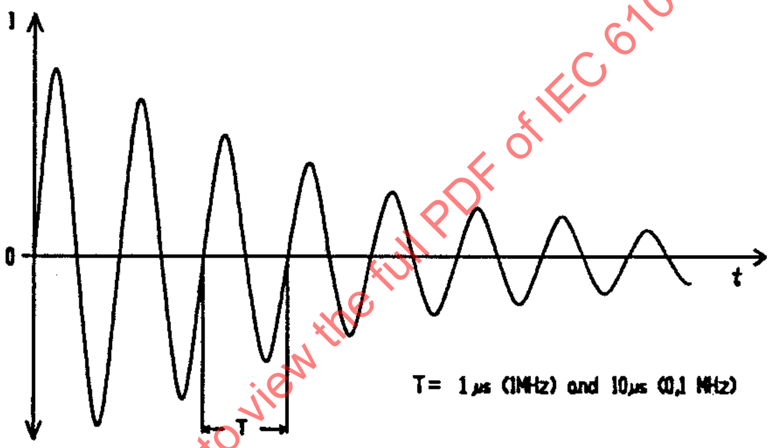
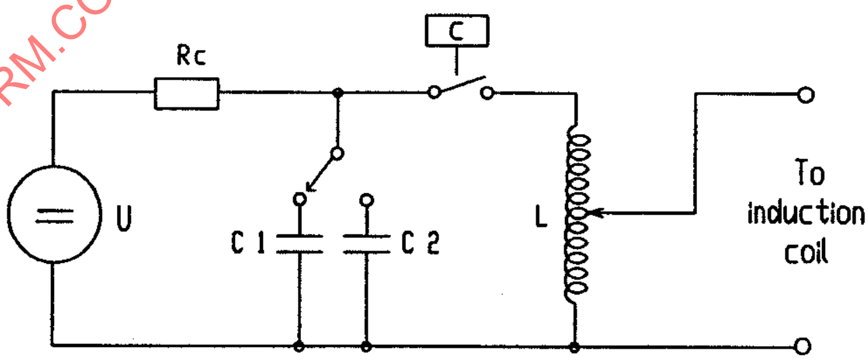


Figure 2 – Current waveform of the test generator for damped oscillatory magnetic field (sinusoid wave)

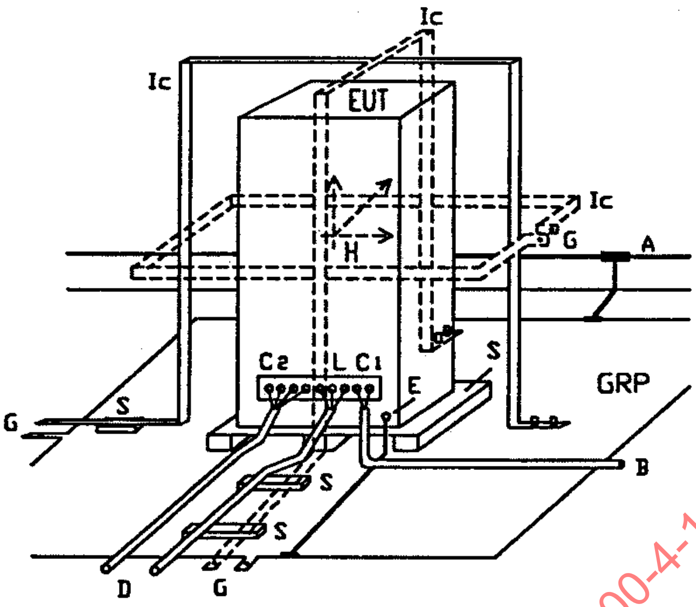


U: High voltage source Rc: Charging resistor

C: Control duration L: Coil oscillation circuit

C1-2: Capacitors oscill. circuit (switchable for 0,1-1 MHz)

Figure 3 – Schematic circuit of the test generator for damped oscillatory magnetic field



~~**Figure 5 – Example of test set-up for floor-standing equipment**~~

~~*References common to figure 4 and figure 5*~~

~~GRP: Ground plane~~	~~C1: Power supply circuit~~
~~A: Safety earth~~	~~C2: Signal circuit~~
~~S: Insulating support~~	~~L: Communication line~~
~~EUT: Equipment under test~~	~~B: To power supply source~~
~~Ic: Induction coil~~	~~D: To signal source, simulator~~
~~E: Earth terminal~~	~~G: To the test generator~~

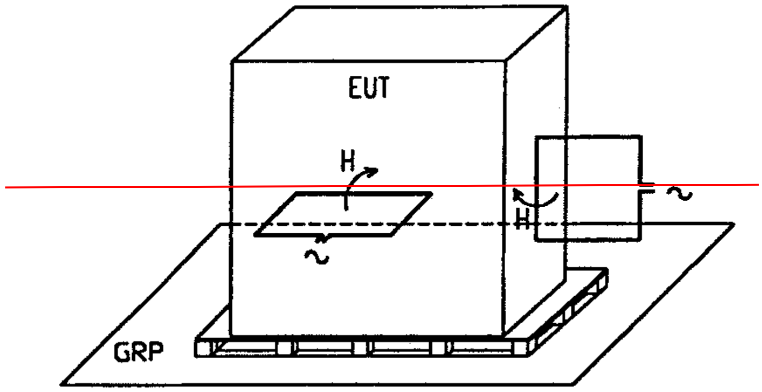
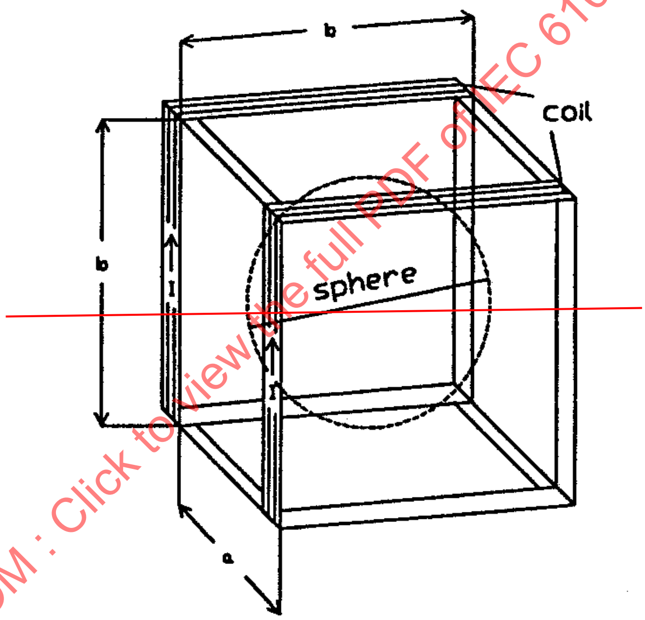


Figure 6 – Example of investigation of susceptibility to magnetic field by the proximity method



n: Number of turns in each coil a: Separation of the coils

b: Side of the coils (m) I: Current value (A)

H: Magnetic field strength (A/m) H: 1,22 × n/b × I

(with a = b/2,5 the non-homogeneity of the magnetic field strength is ± 0,2 dB)

Figure 7 – Illustration of Helmholtz coils

~~Annex A~~
~~(normative)~~

~~Induction coil calibration method~~

~~A.1 Magnetic field measurement~~

~~The magnetic field test is related to free space condition, without the EUT and at 1 m minimum distance from the laboratory walls and any magnetic material.~~

~~The measurement of the magnetic field may be done with a measurement system comprising wide band sensors (10 MHz minimum bandwidth, available in the market) and recording instruments e.g. transient recorders or storage oscilloscopes.~~

~~A.2 Calibration of the induction coil~~

~~The calibration shall be carried out by injecting the calibration current at power frequency in the induction coil and measuring the magnetic field by sensors placed at its geometrical centre.~~

~~Proper orientation of the sensor shall be selected in order to obtain the maximum value.~~

~~The *"induction coil factor"* shall be determined for each induction coil as the ratio "field strength/current" of injection (H/A).~~

~~The "coil factor", determined at a.c. current, is not related to the current waveform, but is a characteristic parameter of the induction coil; it is therefore applicable for the evaluation of magnetic field of different waveform, like the transient ones defined in this standard.~~

~~For standard dimension coil, the coil factor is determined by the manufacturer of the coil, and can be verified by laboratory measurements before carrying out the tests.~~

Annex A
(informative)

Information on the field distribution of standard induction coils

A.1 General

Annex A gives information on the maximum size of an EUT and its location in the standard induction coils. The field is considered sufficiently uniform if the magnitude of the magnetic field strength is within ±3 dB of the field strength in the centre of the induction coil.

For the field computations the finite cross-section of the loop conductors are neglected (thin wire approximation).

A.2 Determination of the coil factor

A.2.1 General

The induction coil factor should be determined by calculation. The coil factor is used to calculate the current in the induction coil to obtain the required magnetic field strength in the centre of the induction coil.

A.2.2 Coil factor calculation

The coil factor can be calculated from the geometrical dimensions of the induction coil. For a single-turn, rectangular induction coil having sides $a + b$ and c (see Figure A.1), the coil factor k_{CF} is given by

$$k_{CF}(P) = \frac{H(P)}{I} = \frac{1}{4\pi}\left[\frac{4a/c + c/a}{\sqrt{a^2 + (c/2)^2}} + \frac{4b/c + c/b}{\sqrt{b^2 + (c/2)^2}}\right] \quad \text{(A.1)}$$

where $H(P)$ is the magnetic field at point P and I is the induction coil current. Equation (A.1) is valid, when the largest dimension of the cross-section of the coil conductor is small compared to the shortest side of the induction coil. For a square induction coil with side c and if P is at the centre of the coil, then $a = b = c/2$. If P is at the centre of a rectangular coil, then $a = b$. If the RGP is the bottom side of the coil, then equation (A.1) is still valid, taking into account the image of the actual (physical) coil. In this case, if P is at the centre of the physical coil, then the k_{CF} of the coil formed by the physical coil plus its image is given by equation (A.1) with $b = 3 \times a$.

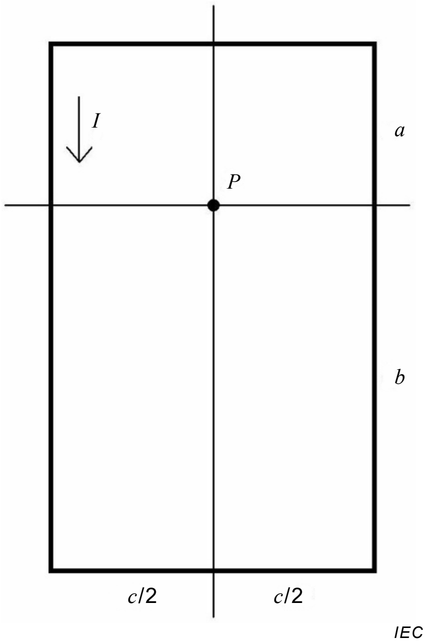
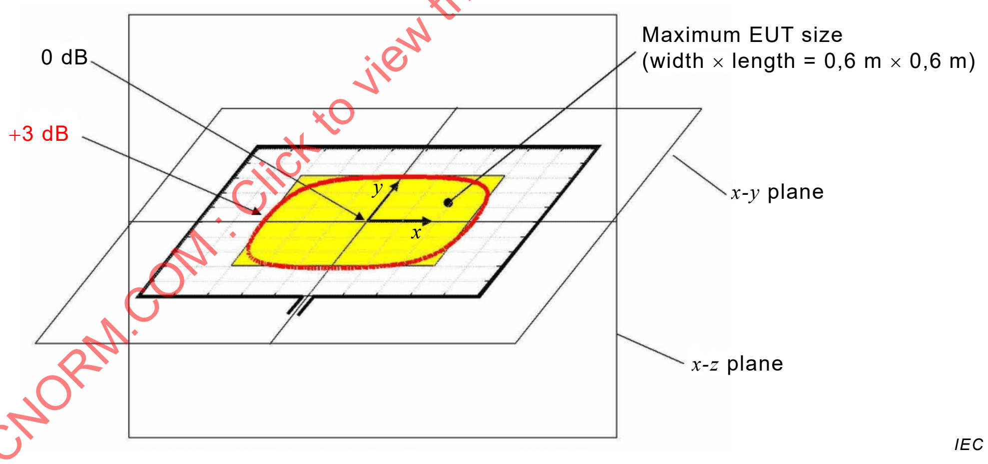


Figure A.1 – Rectangular induction coil with sides *a* + *b* and *c*

A.3 1 m × 1 m standard induction coil

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure A.2 for the *x-y* plane and in Figure A.3 for the *x-z* plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 0,5 m.



NOTE The –3 dB isoline is not shown because it is outside the loop.

Figure A.2 – +3 dB isoline for the magnetic field strength (magnitude) in the *x-y* plane for the 1 m × 1 m induction coil

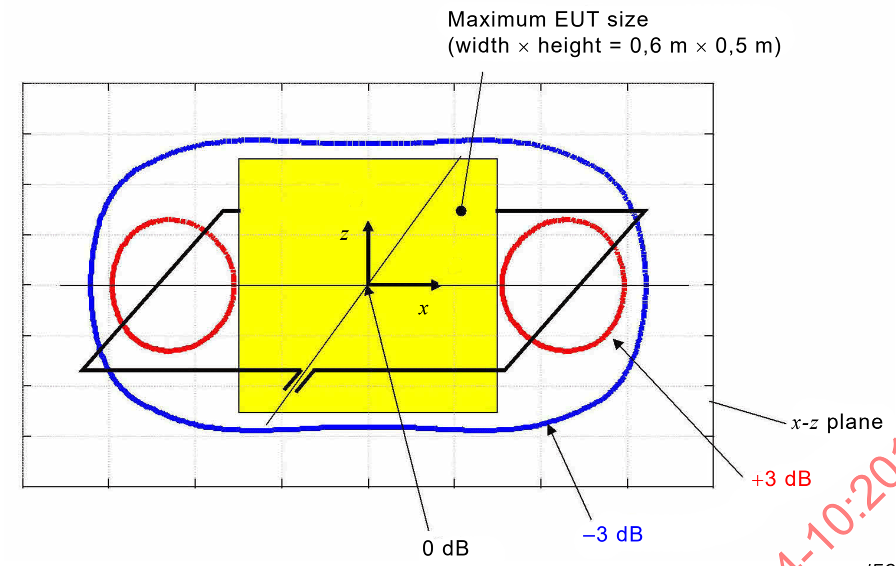
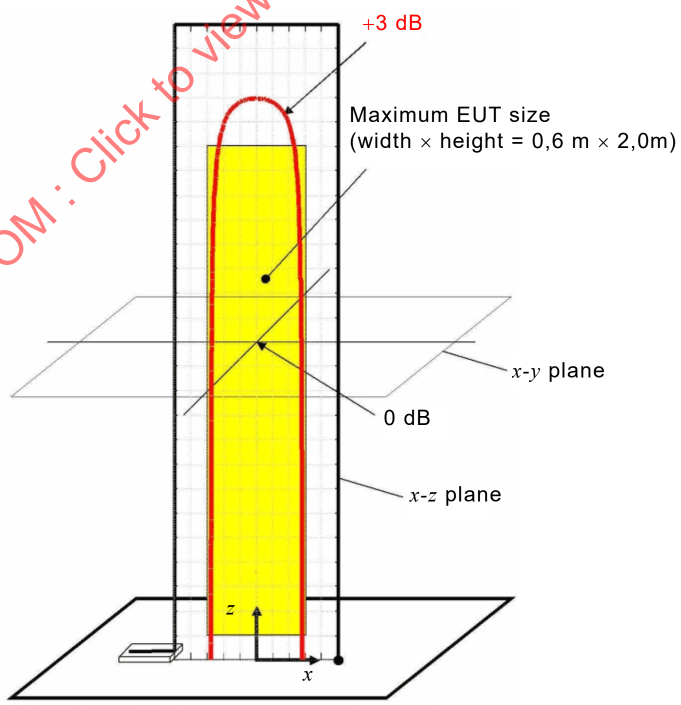


Figure A.3 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x-z* plane for the 1 m × 1 m induction coil

A.4 1 m × 2,6 m standard induction coil with reference ground plane

The +3 dB and -3 dB isolines for the magnetic field strength (magnitude) are shown in Figure A.4 for the *x-z* plane and in Figure A.5 for the *x-y* plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 2 m.

For the calculation of the ± 3 dB isolines the size of the reference ground plane is considered as infinite.



NOTE The –3 dB isoline is not shown because it is outside the loop.

Figure A.4 – +3 dB isoline for the magnetic field strength (magnitude) in the *x-z* plane for the 1 m × 2,6 m induction coil with reference ground plane

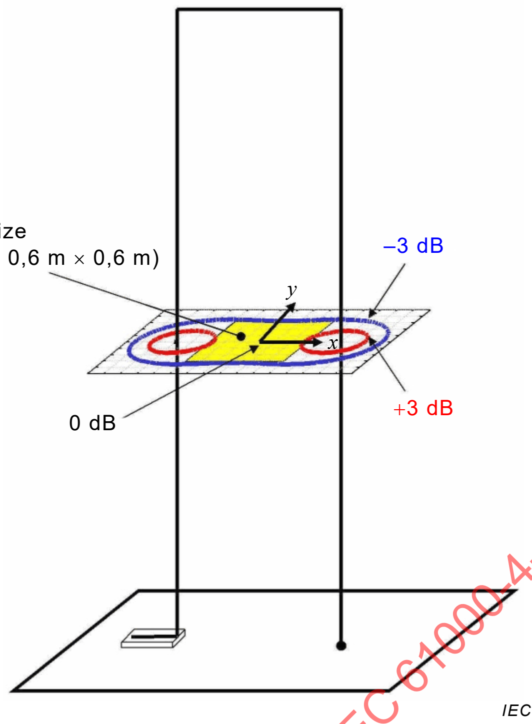
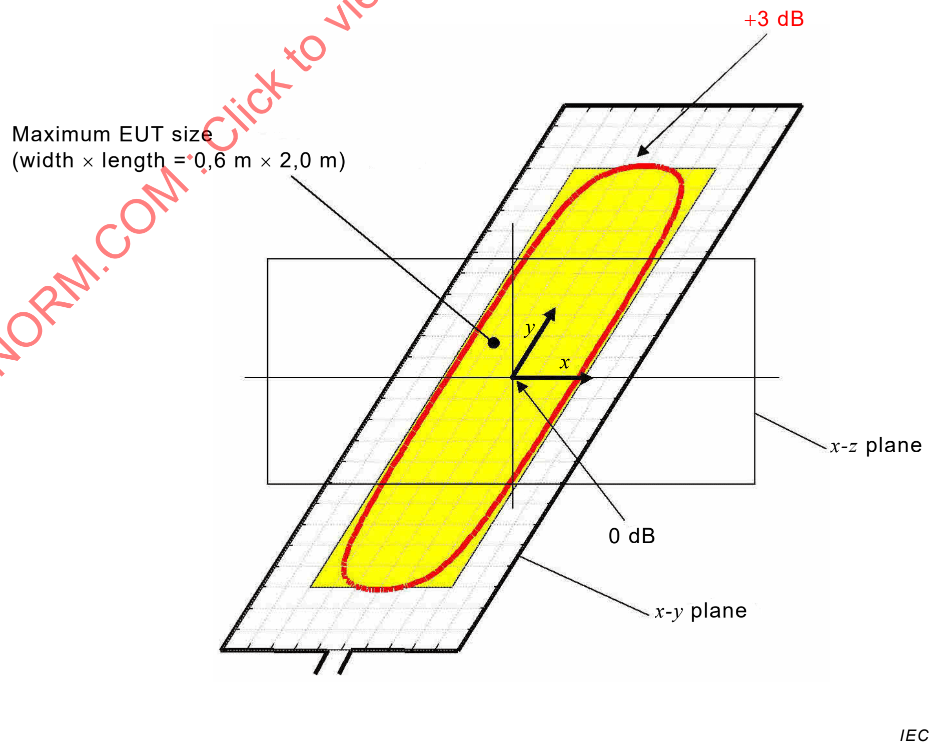


Figure A.5 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x*-*y* plane for the 1 m × 2,6 m induction coil with reference ground plane

A.5 1 m × 2,6 m standard induction coil without reference ground plane

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure A.6 for the *x*-*y* plane and in Figure A.7 for the *x*-*z* plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 2 m.



NOTE The –3 dB isoline is not shown because it is outside the loop.

Figure A.6 – +3 dB isoline for the magnetic field strength (magnitude) in the *x*-*y* plane for the 1 m × 2,6 m induction coil without reference ground plane

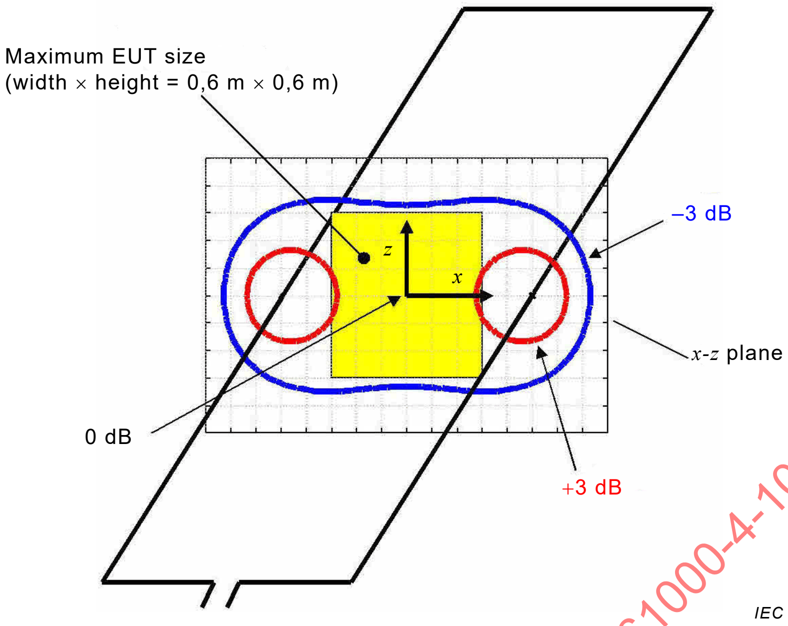


Figure A.7 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x*-*z* plane for the 1 m × 2,6 m induction coil without reference ground plane

Annex B
(normative)

Characteristics of the induction coils

B.1 General

This annex considers the problems of generation of the test magnetic fields.

In the first stage, both the immersion and proximity methods were considered.

In order to know the limits of application of such methods, some questions have been emphasized.

In the following the reasons for the values are explained.

B.2 Induction coil requirements

The requirement of the induction coil is *"3 dB tolerance of the test field in the volume of the EUT";* this tolerance has been considered a reasonable technical compromise in respect of a test characterized by severity levels in 10 dB steps, due to practical limits in the generation of constant field over a wide range of volumes.

The constancy of the field is a requirement limited to a single direction, orthogonal to the coil plane. The field in different directions is obtainable in successive test steps by rotating the induction coil.

B.3 Induction coil characteristics

The characteristics of induction coils of different dimensions suitable for testing *table-top equipment* or *floor-standing equipment* are given in diagrams showing:

– profile of the field generated by a square induction coil (1 m side) in its plane (see figure B.1);
– 3 dB area of the field generated by a square induction coil (1 m side) in its plane (see figure B.2);
– 3 dB area of the field generated by a square induction coil (1 m side) in the mean orthogonal plane (component orthogonal to the plane of the coil) (see figure B.3);
– 3 dB area of the field generated by two square induction coils (1 m side) 0,6 m spaced, in the mean orthogonal plane (component orthogonal to the plane of the coils) (see figure B.4);
– 3 dB area of the field generated by two square induction coils (1 m side) 0,8 m spaced, in the mean orthogonal plane (component orthogonal to the plane of the coils) (see figure B.5);
– 3 dB area of the field generated by a rectangular induction coil (1 m × 2,6 m) in its plane (see figure B.6);
– 3 dB area of the field generated by a rectangular induction coil (1 m × 2,6 m) in its plane (ground plane as a side of the induction coil) (see figure B.7);
– 3 dB area of the field generated by a rectangular induction coil (1 m × 2,6 m), with ground plane, in the mean orthogonal plane (component orthogonal to the plane of the coil) (see figure B.8).

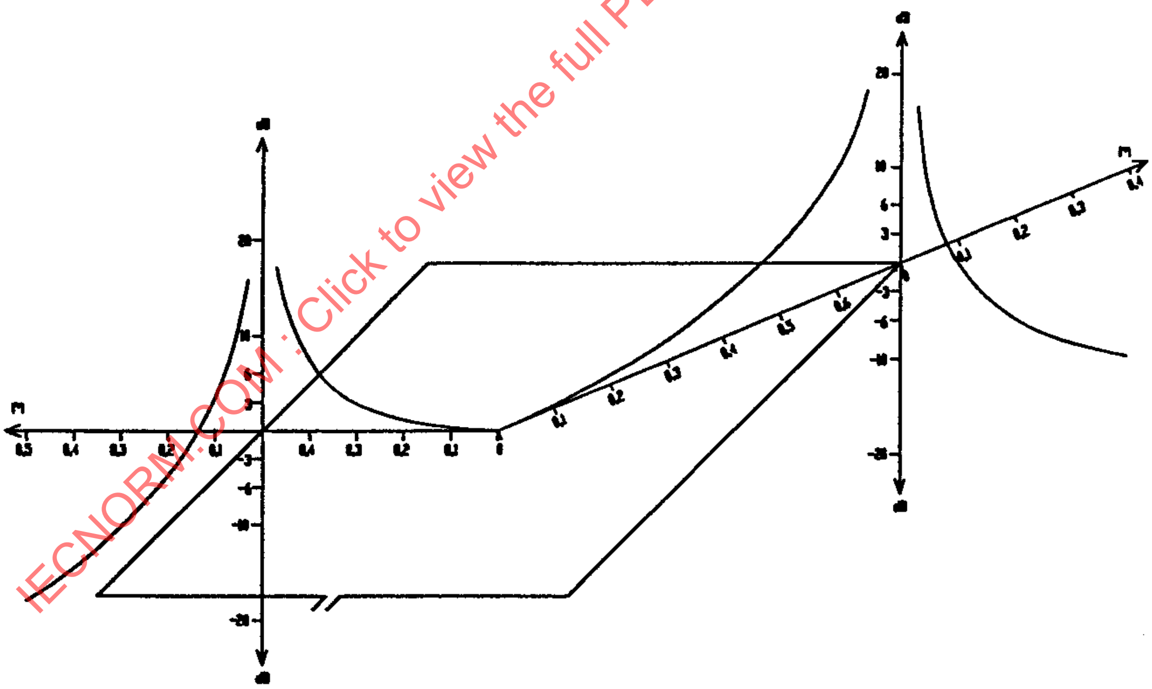
~~In the selection of the form, arrangement and dimensions of the test coil, the following points have been considered:~~

- ~~the 3 dB area, inside and outside the induction coil, is related to the shape and dimensions of the induction coil;~~
- ~~for a given field strength, driving current value, power and energy of the test generator are proportional to the dimensions of the induction coil.~~

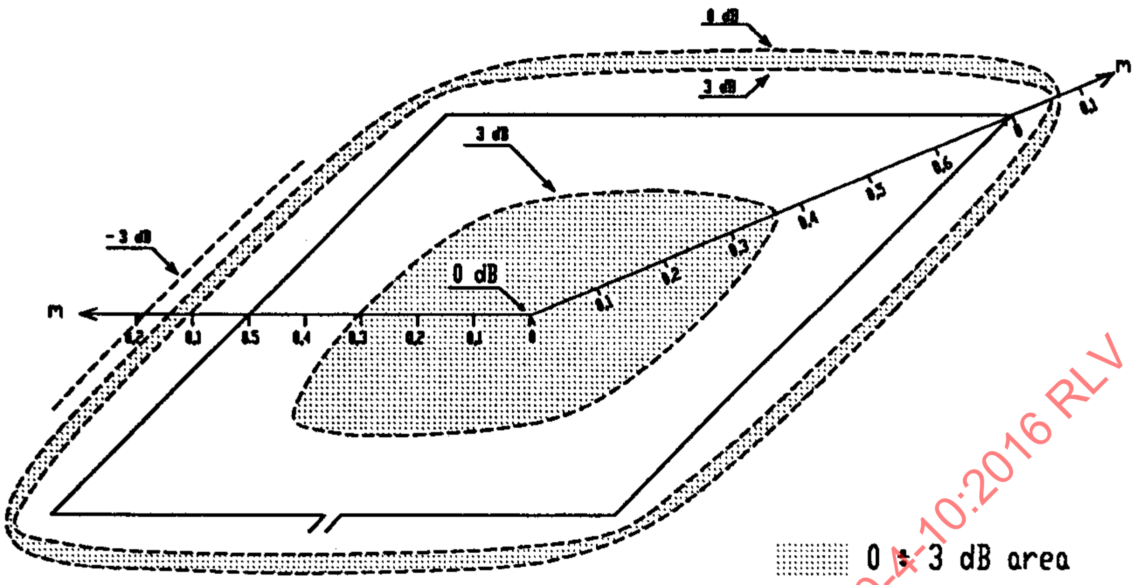
~~B.4 Summary of characteristics of induction coils~~

~~On the basis of the data on the field distribution of coils with different sizes, and in view of adopting the test method given in this standard to different classes of equipment, the conclusions that can be drawn are as follows:~~

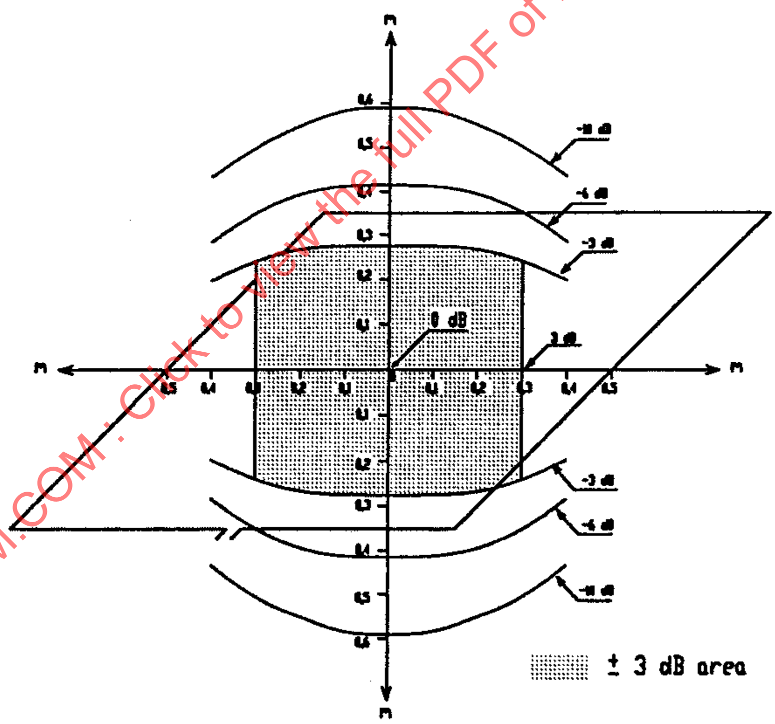
- ~~*single square coil, 1 m side*: testing volume 0,6 m × 0,6 m × 0,5 m high (0,2 m minimum distance from EUT to the coil);~~
- ~~*double square coils, 1 m side, 0,6 spaced*: testing volume 0,6 × 0,6 × 1 m high (0,2 m minimum distance from EUT to the coil); increasing of the separation of the coils up to 0,8 m, extends the maximum high of testable EUT (see the 3 dB area, in the mean orthogonal plane) up to 1,2 m.~~
- ~~*single rectangular coil, 1 m × 2,6 m*: testing volume 0,6 m × 0,6 m × 2 m high (0,2 and 0,3 m minimum distance from EUT to the coil, respectively for the horizontal and vertical dimensions of EUT); if the induction coil is bonded to the GRP, a 0,1 m distance from it is sufficient.~~



~~Figure B.1 – Characteristics of the field generated by a square induction coil (1 m side) in its plane~~



~~Figure B.2 – 3 dB area of the field generated by a square induction coil (1 m side) in its plane~~



~~Figure B.3 – 3 dB area of the field generated by a square induction coil (1 m side) in the mean orthogonal plane (component orthogonal to the plane of the coil)~~

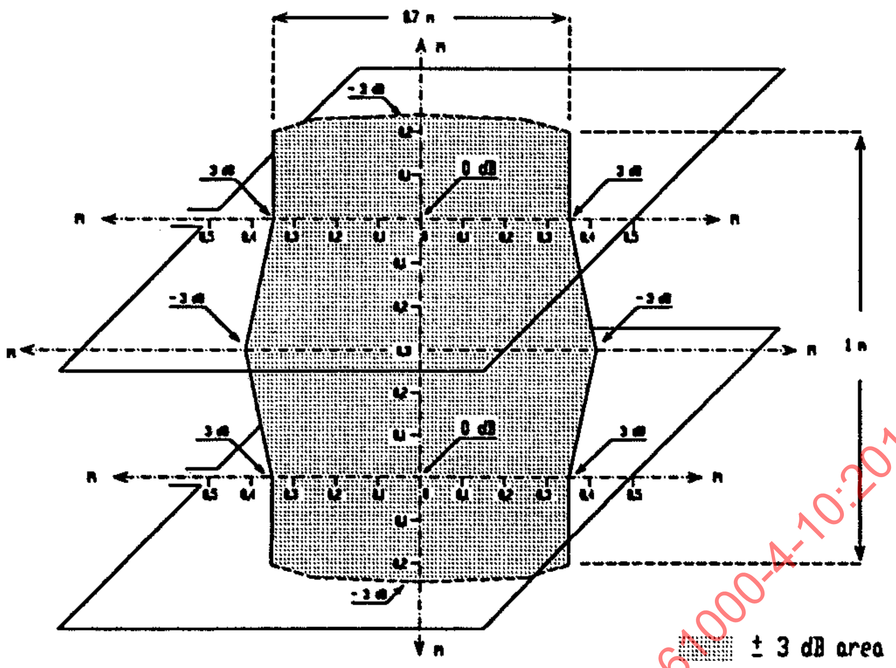


Figure B.4 – 3 dB area of the field generated by two square induction coils (1 m side) 0,6 m spaced, in the mean orthogonal plane (component orthogonal to the plane of the coils)

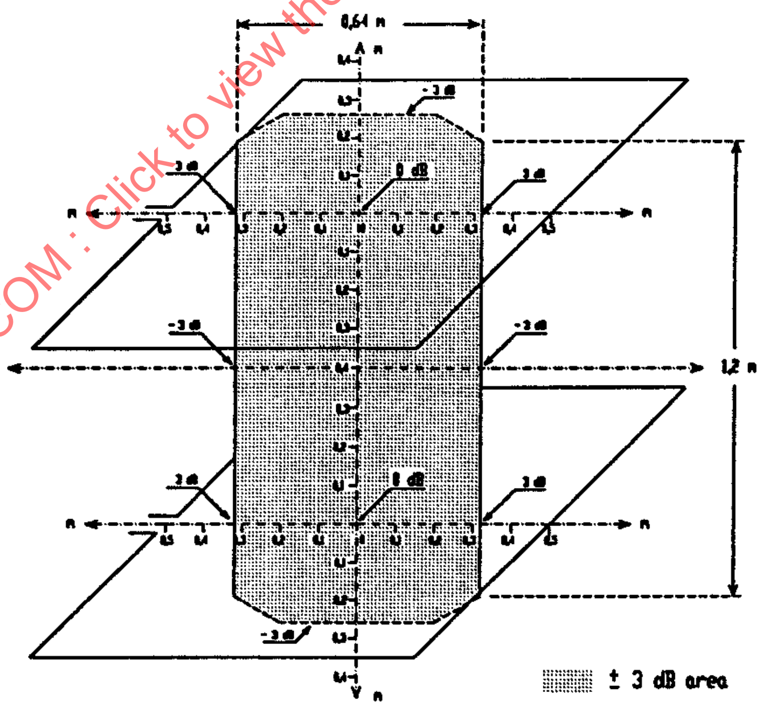
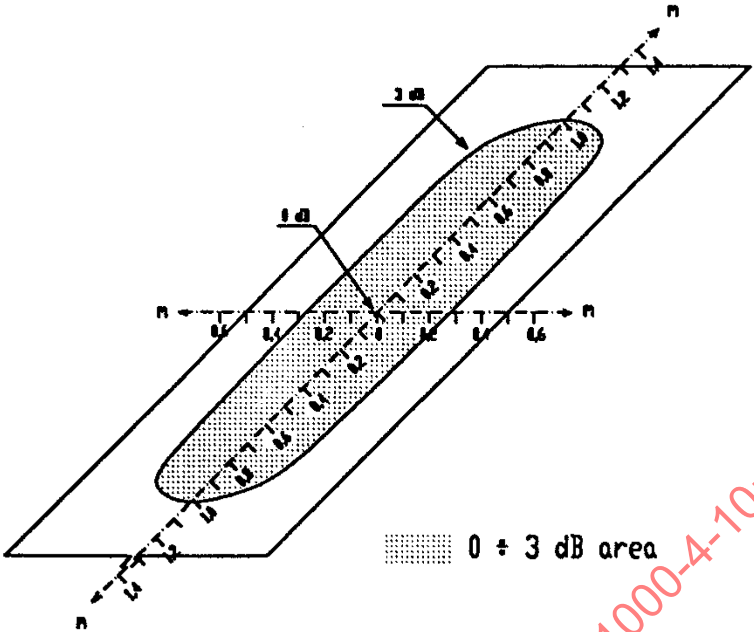
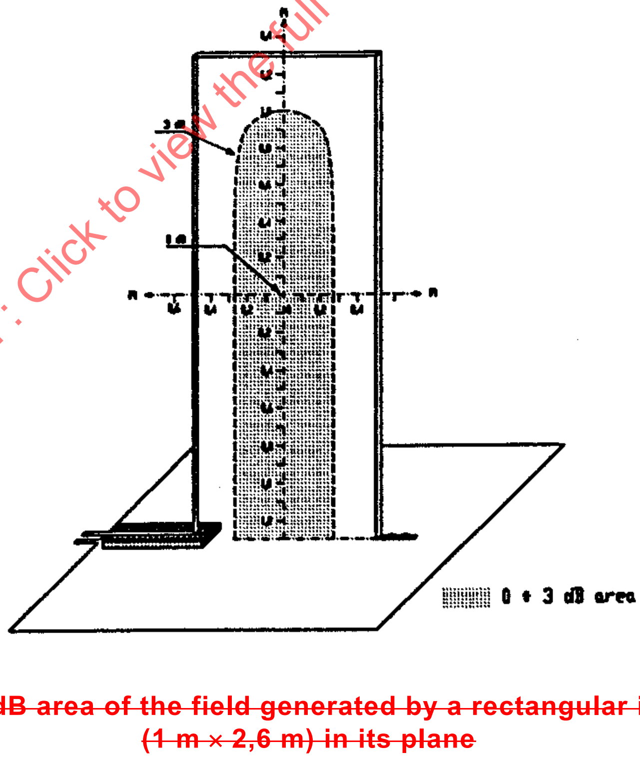


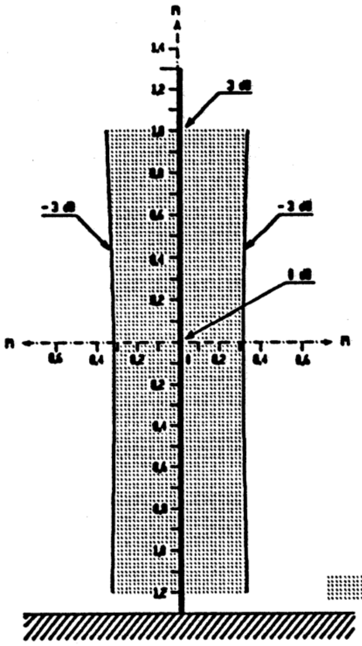
Figure B.5 – 3 dB area of the field generated by two square induction coils (1 m side) 0,8 m spaced, in the mean orthogonal plane (component orthogonal to the plane of the coils)



~~**Figure B.6 – 3 dB area of the field generated by a rectangular induction coil (1 m × 2,6 m) in its plane**~~



~~**Figure B.7 – 3 dB area of the field generated by a rectangular induction coil (1 m × 2,6 m) in its plane (ground plane as a side of the induction coil)**~~



~~Figure B.8 – 3 dB area of the field generated by a rectangular induction coil (1 m × 2,6 m) with ground plane, in the mean orthogonal plane (component orthogonal to the plane of the coil)~~

Annex B
(informative)

Selection of the test levels

Test levels shall be selected in accordance with the electromagnetic environment in which the equipment concerned is intended to be used taking into account most realistic installation ~~and environmental~~ conditions.

~~The immunity tests are correlated with these levels in order to establish a performance level for the environment in which the equipment is expected to operate.~~

Recommendations for test levels are given in Clause 5. The actual selection of test levels ~~shall be chosen according to~~ should take into account:

– the electromagnetic environment;
– the potential proximity of damped oscillatory magnetic field disturbances sources to the equipment concerned;
– the installation conditions typically to be expected for an installation in the electromagnetic environment under consideration;
– the need and amount of compatibility margins, i.e. the margin between the maximum disturbance level and considered immunity level.

An appropriate test level for equipment depends on the electromagnetic environment in which equipment is intended to be used. Based on common installation practices which are representative for the electromagnetic environment concerned, a guide for the selection of test levels for damped oscillatory magnetic fields testing may be the following:

Class 1*:* Electromagnetic environment with particular mitigation measures employed in order to allow electromagnetic phenomena to occur to a certain extent only (e.g. phenomenon does not occur, phenomenon occurs with a relatively low amplitude only, etc.)

Controlled electromagnetic environment: where sensitive devices are planned to be used (e.g. electron microscopes, cathode ray tubes, etc.)

The test is not applicable to equipment intended to be used in this class of environment ~~where sensitive device using electron beam can be used (*monitors, electron microscope, etc.,* are representative of these devices)~~.

Class 2*:* ~~Well protected~~ Electromagnetic environment representative for residential areas

~~*Shielded areas of industrial installations and H.V. sub-stations* may be representative of this environment.~~

The test is not applicable to equipment intended to be used in this class of environment because the ~~areas~~ locations concerned are not subjected to the influence of switching ~~of H.V. bus-bars by isolators~~ phenomena in medium- and high-voltage substations.

Class 3*:* ~~Protected~~ Electromagnetic environment representative for office/commercial areas

Locations of this class of environment are characterized by ~~M.V. circuits and H.V. bus-bars switched by isolators far away (a few hundred metres) from equipment concerned~~ a potential proximity to medium-voltage and high-voltage switchgear or to conductors carrying corresponding transients. A computer room in the vicinity of ~~*H.V.*~~ a sub-station ~~may~~ might be a representative ~~of this environment~~ for such location.

Class 4*:* Typical industrial Electromagnetic environment representative for industrial areas

Fields of heavy industrial and power plants and the control room of H. V. sub-stations may be representative of this environment.

Locations of this class of environment are characterized by M.V. circuits and H.V. bus-bars switched by isolators at relative distance (a few tens of metres) from equipment concerned the presence of medium- or high-voltage substations and of conductors carrying transient fault currents. Control rooms of sub-stations and fields with high-current equipment/installations might be representatives for such locations.

Class 5*:* Severe industrial environment

Harsh electromagnetic environment is which can be characterized by the following attributes: proximity of M.V. and H.V. bus-bars switched by isolators; proximity of high power electrical equipment conductors, bus-bars or M.V. or H.V. lines carrying tens of kA.

Switchyard areas of heavy industrial plants, M.V/H.V. sub-stations and power stations may might be representatives of this for locations with such an electromagnetic environment.

Class X*:* Special electromagnetic environment

The minor or major electromagnetic separation of interference sources from equipment circuits, cables, lines etc., and the quality of the installations may require the use of a higher or lower environmental test levels than those described above. This may need a case-by-case assessment.

It should be noted that the lines of equipment (e.g. cabling, bus bars, overhead lines) associated to electromagnetic environments with higher test levels can penetrate into locations being assigned to an environment with lower test levels. In such cases a re-assessment of the latter location with respect to the suitable test levels should be carried out.

The above selection of test levels in terms of electromagnetic environments should be used as a guide only. There might be cases where a location might be assigned to one of the above types of electromagnetic environments but due to the features of the equipment concerned or other circumstances a different test level than that associated to that type of electromagnetic environment might be more appropriate. Corresponding assessment should be done by the parties involved (e.g. product committees).

Annex D
(informative)

Information on magnetic field strength

Data are restricted to prediction of the environment and field measurements on the operation of H.V. bus-bar isolators.

The prediction of the magnetic field under the H.V. bus-bars, in the aperture of isolators, gives values up to 100 A/m (peak).

Measurements carried out by using wide band sensors, at different H.V. sub-station locations show values ranging from 10 A/m (peak) in the sub-station area up to 100 A/m (peak) in the proximity of the capacitive voltage transformers.

Annex C
(informative)

Damped oscillatory magnetic field frequency

The phenomenon is typical of the switching of isolators in H.V. sub-stations, and particularly in H.V. bus-bars.

The opening and closing operation of H.V. isolators gives rise to sharp front-wave transients, with time of the order of tens of ns; in propagation in H.V. circuits (bus-bars). These phenomena are smoothed by the overall capacitance of the structures of H.V. equipment as they propagate.

The voltage front-wave has an evolution that includes reflections due to the mismatching of the characteristic impedance of the H.V. circuits involved. In this respect, the resulting transient voltage and current in H.V. bus-bars are characterized by a fundamental oscillation frequency that depends on the length of the circuit and on the propagation time.

The transient current peak value that generates the magnetic fields object of defined in this standard is directly related to the peak voltage on the bus-bars and their characteristic impedance; the voltage is about twice the phase peak value of the H.V. system, and the current (determined also by the characteristic impedance of such circuits) is about 2 kA peak.

The frequency of oscillation is determined by the length of the H.V. and by the self-inductance of H.V. circuits (1 μH/m), the series capacity of the circuit-breaker in the off-state (500 pF), the concentrated capacity of capacitive voltage transformers (some nF), of current transformers (300 pF) and of H.V. supports (20 pF each).

The oscillation frequency ranges from about 100 kHz to a few MHz depending on the influence of the parameter yet mentioned and the length of the bus-bars, which may vary from tens of meters to hundreds of meters (400 m may occur).

In this respect the oscillation frequency of 1 MHz may be considered representative of most situations, but 100 kHz has been considered appropriate for big H.V. sub-stations.

The repetition frequency is variable and, provided the other conditions are the same, is a function of the distance between the switching contacts: that is, with closed contacts, there is the maximum repetition frequency, while for distances between the contacts at the limit of extinction of the arc, the minimum repetition frequency in respect of each phase is twice the power frequency (100/s for 50 Hz and 120/s for 60 Hz H.V. systems), but at these frequencies the maximum magnetic field strength occurs.

The repetition rates selected for the 0,1 MHz and 1 MHz test fields represent therefore a compromise, taking into account the different durations of the phenomena, the representativity of the different frequencies and the problems related to the power of the test generator.

Annex D
(informative)

Measurement uncertainty (MU) considerations

D.1 General

The compliance of the realized disturbance quantity with the disturbance quantity specified by this standard is usually confirmed through a set of measurements (e.g. measurement of the peak of a damped oscillatory current impulse with an oscilloscope by using a current probe). The result of each measurement includes a certain amount of measurement uncertainty (MU) due to the imperfection of the measuring instrumentation as well as to the lack of repeatability of the measurand itself. The evaluation of MU is done here according to the principles and methods described in IEC TR 61000-1-6.

In order to evaluate MU it is necessary to:

a) identify the sources of uncertainty, related both to the measuring instrumentation and to the measurand,
b) identify the functional relationship (measurement model) between the influence (input) quantities and the measured (output) quantity,
c) obtain an estimate and standard uncertainty of the input quantities,
d) obtain an estimate of the interval containing, with a high level of confidence, the true value of the measurand.

Further details are given in IEC TR 61000-1-6.

These estimates and uncertainties, derived for a particular disturbance quantity, do not describe the degree of agreement between the simulated electromagnetic phenomenon, as defined in the basic standard, and the real electromagnetic phenomenon in the world outside the laboratory.

Since the effect of the parameters of the disturbance quantity on the EUT is a priori unknown and in most cases the EUT shows a nonlinear behaviour, a single estimate and uncertainty numbers cannot be defined for the disturbance quantity. Therefore each of the parameters of the disturbance quantity will be accompanied by the corresponding estimate and uncertainty. This yields to more than one uncertainty budget.

D.2 Legend

I_P Peak of the damped oscillatory current impulse injected into the coil

H_P Peak of the magnetic field impulse

k_{CF} Coil factor of the induction coil: $H_P = k_{CF} \times I_P$

NOTE The meaning and the relations among the symbols $u(x_i)$, c_i, $u_i(y)$, $u_c(y)$, $U(y)$ and y are explained in IEC TR 61000-1-6.

D.3 Uncertainty contributors to the peak current and to the damped oscillatory magnetic field measurement uncertainty

The following list shows the contributors used to assess both the measuring instrumentation and test setup influences:

- reading of peak value
- bandwidth of the measuring system

- shape of the impulse response of the measuring system
- oscilloscope horizontal axis measurement error
- oscilloscope vertical axis measurement error
- measurement system, measurand and setup repeatability (type A)
- calibration of oscilloscope and measuring system
- coil factor of the induction coil

D.4 Uncertainty of peak current and damped oscillatory magnetic field calibration

D.4.1 General

In the case of the magnetic field test, the disturbance quantities are the damped oscillatory current generated by the test generator and injected into the coil terminals and the damped oscillatory magnetic field applied to the EUT. As discussed in Clause D.1, an uncertainty budget for each measured parameter of the disturbance quantity is required. The parameters of these disturbance quantities are I_P for the impulse current and H_P for the impulse magnetic field. It is assumed that the magnetic field generated by the induction coil is proportional to the current flowing into its terminals, the constant of proportionality being the coil factor k_{CF}. Therefore the impulse magnetic field has the same waveshape as the impulse current and the peak of the magnetic field is obtained as $H_P = k_{CF} \times I_P$.

Additional parameters characterize the disturbance, i.e. the frequency of oscillation and damping. However the evaluation of the measurement uncertainty of these parameters, although required, is less demanding than that of impulse peak. Therefore attention is focused here on measurement uncertainty of the peak of the impulse.

The approach adopted here to evaluate the impulse MU is described in D.4.4 and D.4.5. Table D.1 gives an example of the uncertainty budget for the peak current impulse. The table includes the input quantities that are considered most significant for this example, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining the uncertainty budget.

D.4.2 Peak current

The measurand is the peak of the damped oscillatory current impulse calculated by using the functional relationship

$$I_p = \frac{V_{PR}}{R_T} \frac{1 + \delta R + \delta V}{1 - \left(\frac{\beta}{B}\right)^2} \quad \text{(D.1)}$$

where

V_{PR} is the impulse voltage peak reading

R_T is the transfer resistance of the current probe

δR is the correction for non-repeatability

δV is the d.c. vertical accuracy of the scope

B is the –3 dB bandwidth of the measuring system

β is the coefficient whose value is (63,8 ± 7,1) kHz at the oscillation frequency f_0 = 0,1 MHz and (638 ± 71) kHz at the oscillation frequency f_0 = 1 MHz

The damped oscillatory current impulse oscillation frequency f_0 = 1 MHz is assumed for the following example of uncertainty budget.

Table D.1 – Example of uncertainty budget for the peak of the damped oscillatory current impulse (I_p)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{PR}	0,115	V	0,000 2	V	triangular	2,45	0,000 09	1 004	1/Ω	0,092	A
R_T	0,001	Ω	0,000 05	Ω	rectangular	1,73	0,000 03	-11 5470	A/Ω	3,33	A
δR	0	1	0,03	1	normal (k=1)	1,00	0,030	115,5	A	3,46	A
δV	0	1	0,02	1	rectangular	1,73	0,011 6	115,5	A	1,33	A
β	638	kHz	71	kHz	rectangular	1,73	40,99	0,001 48	A/kHz	0,061	A
B	10 000	kHz	1 000	kHz	rectangular	1,73	577,4	-0,000 09	A/kHz	0,054	A
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			4,99	A
							$U(y) = 2\ u_c(y)$			9,98	A
							Y			115	A
							Expressed in % of 115 A			8,6	%

[a] Probability density function

V_{PR}: is the voltage peak reading at the output of a current probe or across a current shunt. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with interpolation capability (triangular probability density function). If the interpolation capability is not available or not active, then the rectangular probability density function is used.

R_T: is the transfer impedance (or sensitivity) of the current shunt or probe. An estimated value of 0,001 Ω and an error bound of 5 % (rectangular probability density function) are assumed.

δR: quantifies the non-repeatability of the measurement setup, layout and instrumentation. This is a type A evaluation based on the formula of the experimental standard deviation $s(q_k)$ of a sample of n repeated measurements q_j and given by

$$s(q_k) = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(q_j - \bar{q}\right)^2} \qquad \text{(D.2)}$$

where $\bar{q}$ is the arithmetic mean of the q_j values. δR is expressed in relative terms, and an estimate of 0 % and an error bound of 3 % (1 standard deviation) are assumed.

δV: quantifies the amplitude measurement inaccuracy of the scope at d.c. δV is expressed in relative terms. A 2 % error bound of a rectangular probability density function and an estimate of 0 % are assumed.

β: is a coefficient which depends on the shape of both the impulse response of the measuring system and the standard impulse waveform in the neighborhood of the peak (see D.4.5). The interval (638 ± 71) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: the bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a current probe or shunt, a cable and a scope) by using the following equation:

$$\frac{1}{B} = \sqrt{\left(\frac{1}{B_1}\right)^2 + \left(\frac{1}{B_2}\right)^2 + \ldots} \quad \text{(D.3)}$$

An estimate of 10 MHz and a 1 MHz error bound of a rectangular probability density function are assumed for B.

NOTE The uncertainty of the peak of the magnetic field impulse is obtained from the functional relationship $H_P = k_{CF} \times I_P$ where k_{CF} is the coil factor as measured through the calibration procedure described in this standard (i.e. at power frequency). Therefore, if the measured k_{CF} is 0,90 (e.g. in the case of a square induction loop whose side is 1 m) and its expanded uncertainty is 5 % then the best estimate of H_P is 104 A/m and its expanded uncertainty is 9,9 % (see Table D.1)

D.4.3 Further MU contributions to amplitude and time measurements

The following contributions may also have an impact on the MU budget:

DC offset: The d.c. offset of the scope contributes to the voltage peak measurement uncertainty, if the peak is measured from the nominal d.c. zero line of the scope. This contribution can be ignored, if the readout software of the scope measures the peak from the pulse base line.

Time base error and jitter: The oscilloscope specifications may be taken as error bounds of rectangular probability density functions. Usually these contributions are negligible.

Vertical resolution: The contribution depends on the vertical amplitude resolution ΔA and on the slope of the trace dA/dt. The uncertainty is related to the half width of the resolution and is $(\Delta A/2)/(dA/dt)$. If trace interpolation is performed (see the oscilloscope manual) a triangular probability density function is used, otherwise a rectangular probability density function is used. This contribution may not be negligible when $|dA/dt| < (\Delta A/T_i)$, where T_i is the sampling interval of the scope.

D.4.4 Rise time of the step response and bandwidth of the frequency response of the measuring system

Let T_{MS} be the rise time of the step response of the measuring system as defined by equation (D.4)

$$T_{MS} = \sqrt{2\pi \int_0^{\infty} (t - T_s)^2 h_0(t) dt} \quad \text{(D.4)}$$

where $h_0(t)$ is the impulse response of the measuring system having a normalized area, i.e. $\int_0^{\infty} h_0(t) dt = 1$, and T_s is the delay time given by

$$T_s = \int_0^{\infty} t h_0(t) dt \quad \text{(D.5)}$$

Equation (D.4) is easier to handle, from the mathematical point of view, than the usual one based on the 10 % and 90 % threshold levels. Nonetheless, in the technical applications, the

10 % to 90 % rise time definition is usually adopted. Given the –3 dB bandwidth of the system the two definitions lead to comparable rise times. Indeed, if we define

$$\alpha = T_{MS} \cdot B \qquad \text{(D.6)}$$

we find that the α values derived from the two definitions of rise-time do not differ very much. The values of α, corresponding to different shapes of the impulse response $h(t)$, are given in Table D.2. It is evident from Table D.2 that it is not possible to identify a unique value of α since α depends both on the adopted definition of the rise time (e.g. based on thresholds or on equation (D.4)) and on the shape of the impulse response of the measuring system. A reasonable estimate of α can be obtained as the arithmetic mean between the minimum (321×10^{-3}) and maximum (399×10^{-3}) values that appear in Table D.2, that is 360×10^{-3}. Further, it can be assumed that, if no information is available about the measuring system apart from its bandwidth, any value of α between 321×10^{-3} and 399×10^{-3} is equally probable. Differently stated, α is assumed to be a random variable having a rectangular probability density function with lower and upper bounds 321×10^{-3} and 399×10^{-3}, respectively. The standard uncertainty of α quantifies both: a) the indifference to the mathematical model adopted for the definition of the rise-time, and b) the indifference to the shape of the impulse response of the system.

Table D.2 – α factor (see equation (D.6)) of different unidirectional impulse responses corresponding to the same bandwidth of the system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (crit. damp.)	Rectangular	Triangular
α, using equation (D.4)	332	399	363	321	326
α, 10 % to 90 %	339	350	344	354	353

D.4.5 Impulse peak distortion due to the limited bandwidth of the measuring system

The distorted impulse waveform $V_{out}(t)$ at the output of the measuring system is given by the convolution integral

$$V_{out}(t) = \int_0^t V_{in}(\tau) \cdot h(t-\tau) d\tau \qquad \text{(D.7)}$$

where $V_{in}(t)$ is the input impulse waveform and $h(t)$ is the impulse response of the measuring system. Note that $A \cdot h(t) = h_0(t)$, where A is the d.c. attenuation of the measuring system. The input waveform can be approximated by its Taylor series expansion about the time instant t_p when the input reaches its peak value V_p

$$V_{in}(t) = V_p + \frac{V''_{in}(t_p)}{2} \cdot (t-t_p)^2 + \frac{V'''_{in}(t_p)}{6} \cdot (t-t_p)^3 + \ldots \qquad \text{(D.8)}$$

Note that the first order term is missing from equation D.8 since $V'(t_p) = 0$. Further $V''_{in}(t_p) < 0$, because the concavity points downwards (maximum), and $V'''_{in}(t_p) > 0$, because, for the standard waveforms of interest here, the rise time is lower than the fall time. Substituting equation D.8 into equation D.7 and after simplifications, valid when the bandwidth of the measuring system is large with respect to the bandwidth of the input signal (so that the power series terms whose order is greater than two are negligible), we obtain

$$V_{pd} = \frac{V_p}{A}\left[1-\left(\frac{\beta}{B}\right)^2\right] \quad (D.9)$$

where V_{pd} is the output impulse peak, A is the d.c. attenuation of the measuring system and

$$\beta = \alpha \cdot \sqrt{\frac{\left|V''_{in}\left(t_p\right)\right|}{4\pi V_p}} \quad (D.10)$$

Note that the parameter β depends on the second derivative of the standard input waveform and on the parameter α defined and derived in D.4.4. A simple mathematical expression for the standard damped oscillatory waveform, useful for uncertainty calculation, is given by

$$V_{in}(t) = V_p e^{-\omega_0 \zeta \left[t - \frac{\pi}{2\omega_0}\right]} \sin(\omega_0 t) \quad (D.11)$$

where $f_0 = \omega_0/(2\pi)$ is the oscillation frequency and ζ is the damping. The value of β can be analytically derived from equations (D.10) and (D.11) as

$$b >> \alpha\sqrt{\pi} f_0 \quad (D.12)$$

The value of β, as obtained from equation (D.12), is reported in Table D.3.

Table D.3 – β factor (equation (D.12)) of the damped oscillatory waveform

kHz	f_0 = 0,1 MHz	f_0 = 1 MHz
β	63,8 ± 7,1	638 ± 71

NOTE 1 Equation (D.12) is an approximation because the exponential decay about the instant $t = t_p$ is neglected.

NOTE 2 The values of β obtained by using equation (D.12) and reported in Table D.3 do not appreciably differ from the ones obtained through computation from the mathematical waveform defined in this standard.

NOTE 3 Damping ζ can be obtained by measuring the ratio $\rho > 1$ between the amplitude of one maximum (or minimum) of the oscillation and the next one. It is given by equation (D.11).

$$\zeta = \frac{1}{2\pi}\ln\rho \quad (D.13)$$

For a compliant waveform, ζ is in the range 0,02 to 0,04.

D.5 Application of uncertainties in the damped oscillatory wave generator compliance criterion

Generally, in order to be confident that the current and the magnetic field oscillatory transients are within their specifications, the calibration results should be within the specified limits of this standard (tolerances are not reduced by MU).

Further guidance is given in IEC TR 61000-1-6:2012, Clause 6.

Annex E
(informative)

3D numerical simulations

E.1 General

In Annex E some other information is reported concerning the H-field distributions inside and outside the coils for testing by using 3D numerical simulations in the time domain (dynamic results) and frequency domain (2D-numerical plot of the H-field) as extension of the 2D plots of Annex A (static results).

E.2 Simulations

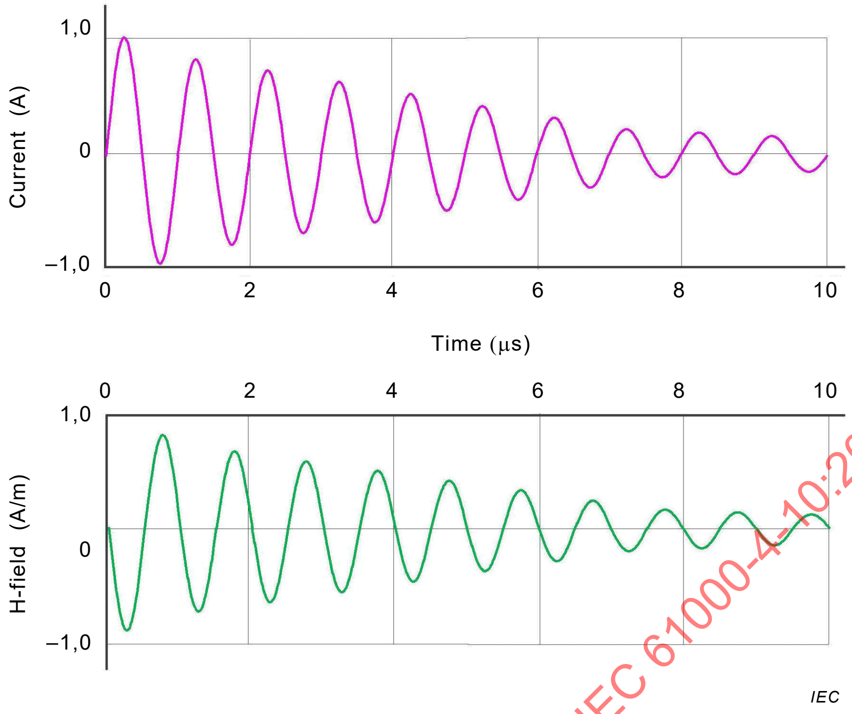
The simulations of Figures E.1 to E.10 are performed as follows:

- The coils are excited by an ideal current source (see the symbol "port") having the mathematical waveform as defined in the text of this standard and normalized at 1 A.
- Two extreme shape conductors of the coil are considered: rectangular of size 10 cm × 1 cm (reported in Annex E) and round wire of 1 mm radius (results not reported for brevity).
- Default mesh cells are used to speed up the computation for the plots of Figures E.2 and E.3; for the other figures optimized mesh cells are used for better accuracy.
- H-field amplitude is indicated as Hx_i where x indicates that the considered H-field component is parallel to the x-axis while the subscript i corresponds to the H-field probe position from the loop centre to the last far away position.
- The 2D H-field plots are calculated at 1 MHz frequency and 0 dB refers to 1 A/m.

E.3 Comments

From the simulations, the following considerations arise:

- The computed H-field waveform has the same shape as that of the coil current source.
- Very little difference can be noted when comparing computed H-field waveforms with two extreme conductor shapes for the same coil size.
- In the centre of the coils, the induction coil factors are 0,90 m^{-1} and 0,65 m^{-1} respectively for square and rectangular coils, which practically do not depend on the shape of the coil conductor.
- It is confirmed also by transient simulations that the variation of the H-field is less than +3 dB for the areas shown in Annex A.
- It is shown and quantified that the H-field increases rapidly when the probe used for H-field computation approaches the conductors of the coil.
- The H-field value outside the loop is about 20 dB to 40 dB (1/10 to 1/100) lower than the field at the center of the loop. This should be taken into account when carrying out the proximity test method.



NOTE The amplitude of the Hx-field inside the loop is negative due to the chosen probe directions.

Figure E.1 – Current with period of 1 µs and H-field in the center of the 1 m × 1 m standard induction coil

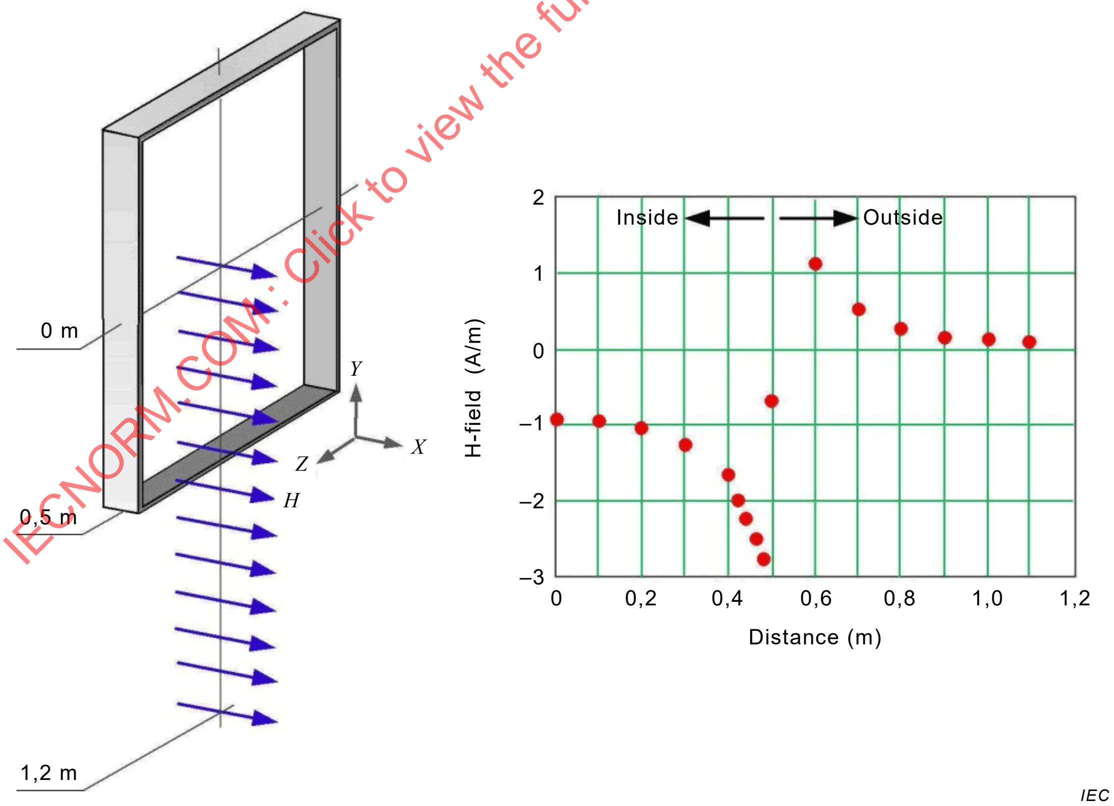


Figure E.2 – Hx–field along the side of 1 m × 1 m standard induction coil in A/m

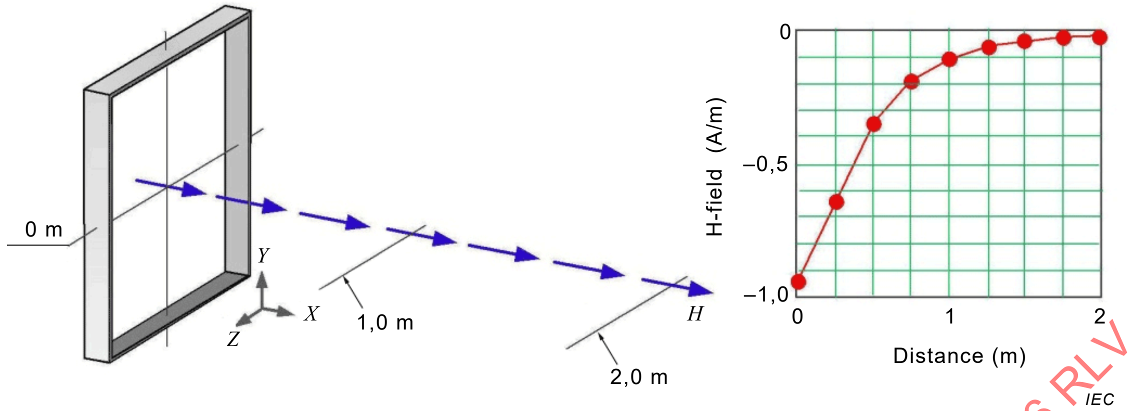


Figure E.3 – Hx–field in direction x perpendicular to the plane of the 1 m × 1 m standard induction coil

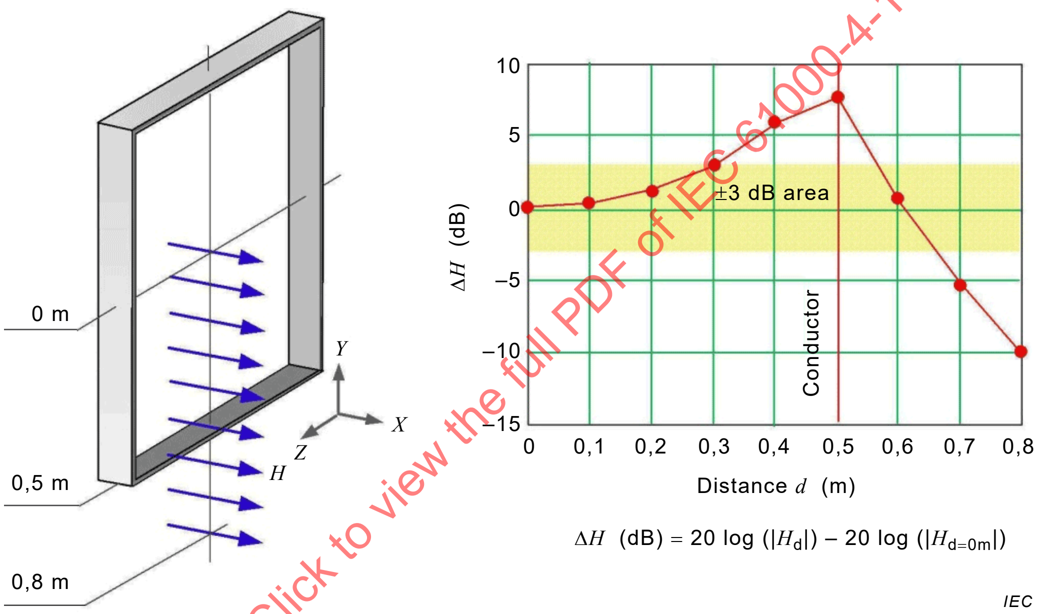


Figure E.4 – Hx–field along the side in dB for 1 m × 1 m standard induction coil

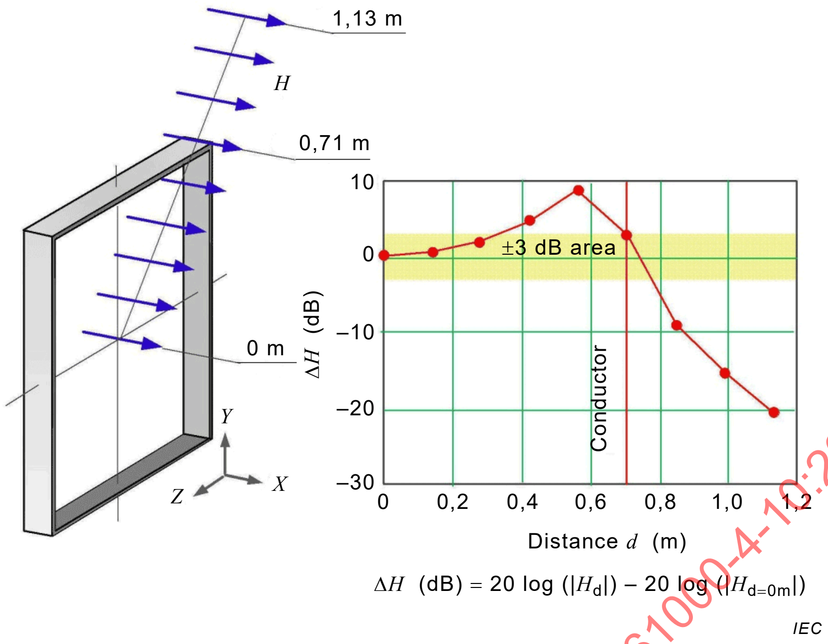


Figure E.5 – Hx–field along the diagonal in dB for the 1 m × 1 m standard induction coil

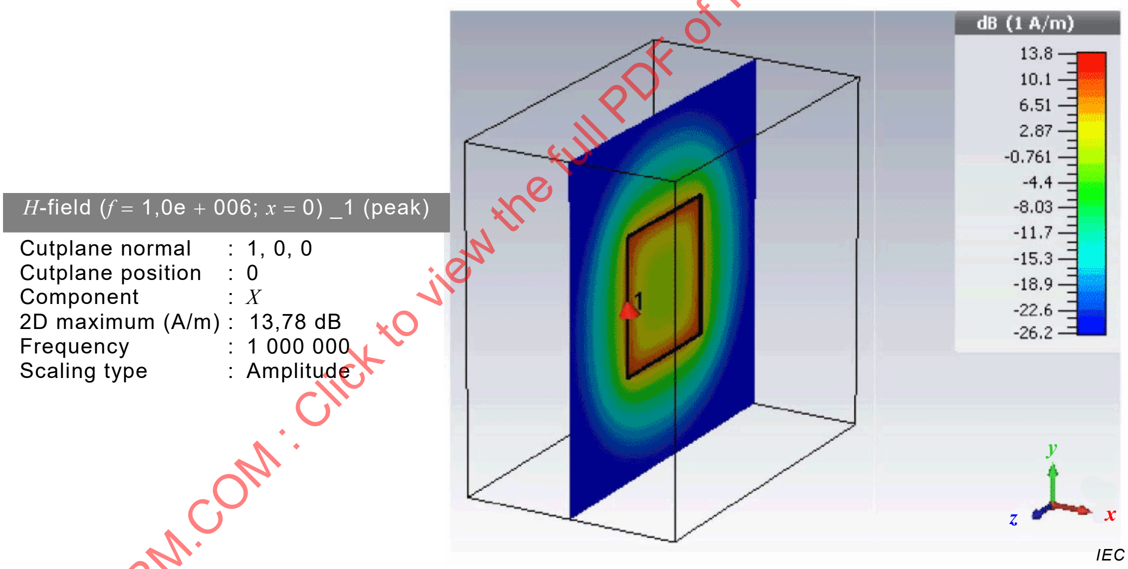


Figure E.6 – Hx–field plot on y-z plane for the 1 m × 1 m standard induction coil

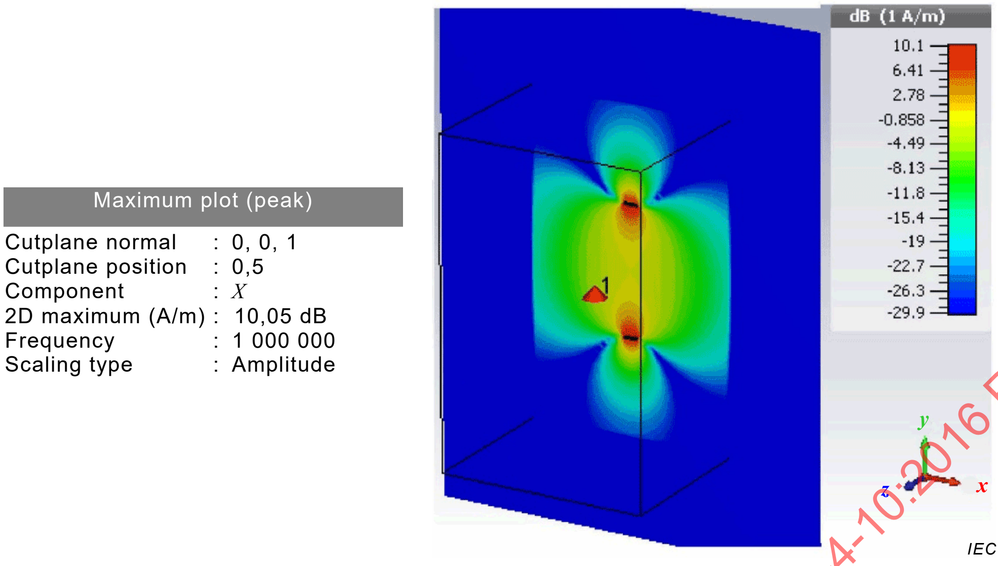


Figure E.7 – Hx-field plot on x-y plane for the 1 m × 1 m standard induction coil

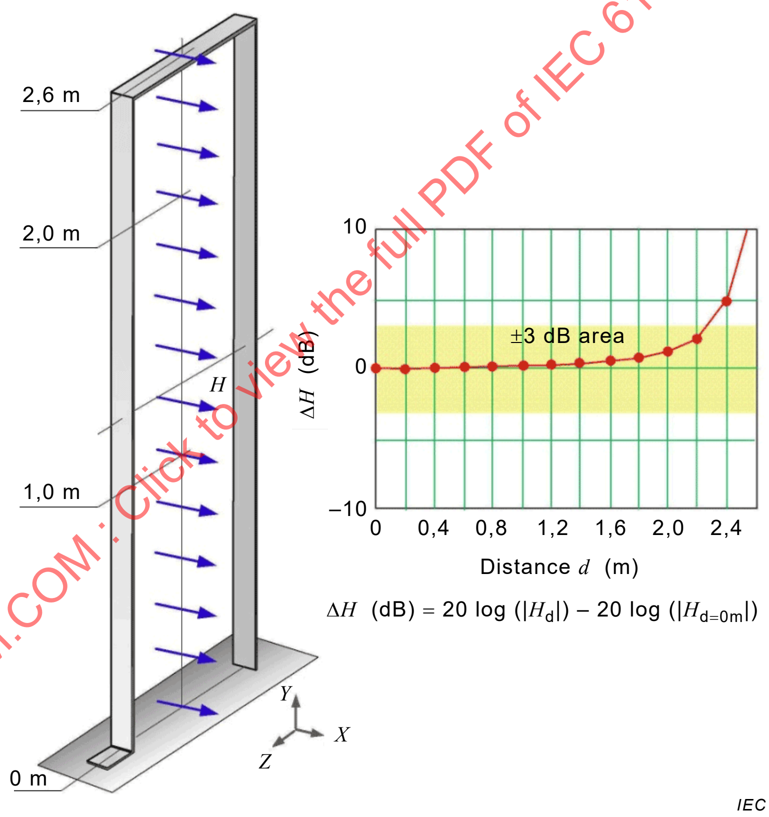


Figure E.8 – Hx–field along the vertical middle line in dB for the 1 m × 2,6 m standard induction coil

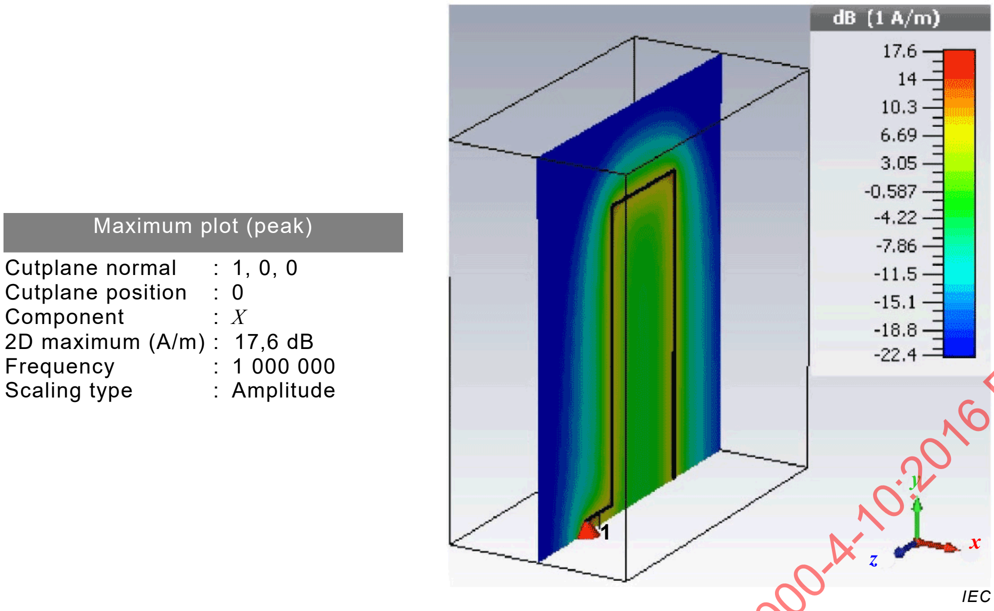


Figure E.9 – H_x–field 2D–plot on y-z plane for the 1 m × 2,6 m standard induction coil

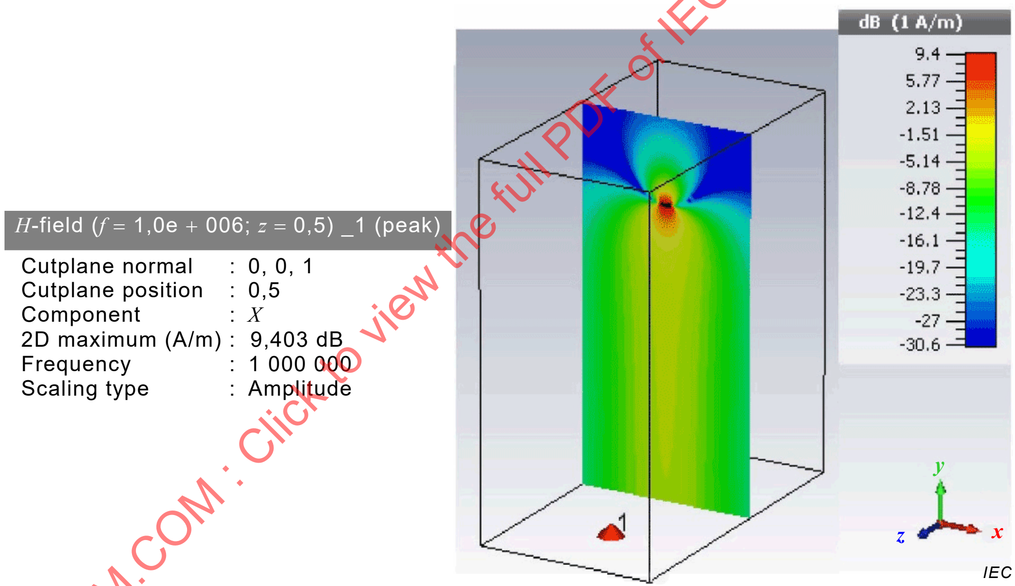


Figure E.10 – H_x–field 2D–plot on x-y plane at z = 0,5 m for the 1 m × 2,6 m standard induction coil

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IEC TR 61000-1-6:2012, *Electromagnetic compatibility (EMC) – Part 1-6: General – Guide to the assessment of measurement uncertainty*

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

IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*

IEC 61000-4-10

Edition 2.0 2016-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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BASIC EMC PUBLICATION

PUBLICATION FONDAMENTALE EN CEM

Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

Compatibilité électromagnétique (CEM) – Partie 4-10: Techniques d'essai et de mesure – Essai d'immunité du champ magnétique oscillatoire amorti

IEC 61000-4-10:2016-07(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

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.
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International Standard IEC 61000-4-10 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms Part 4-10 of the IEC 61000 series. 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 1993 and Amendment 1:2000. This edition constitutes a technical revision.

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

a) new Annex A on induction coil field distribution;
b) new Annex D on measurement uncertainty;

c) new Annex E for numerical simulations;

d) calibration using current measurement has been addressed in this edition.

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

CDV	Report on voting
77B/730/CDV	77B/746A/RVC

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 (insofar 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).

This part is an international standard which gives immunity requirements and test procedures related to "damped oscillatory magnetic field".

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test

1 Scope and object

This part of IEC 61000 specifies the immunity requirements, test methods, and range of recommended test levels for equipment subjected to damped oscillatory magnetic disturbances related to medium voltage and high voltage sub-stations.

The test defined in this standard is applied to equipment which is intended to be installed in locations where the phenomenon as specified in Clause 4 will be encountered.

This standard does not specify disturbances due to capacitive or inductive coupling in cables or other parts of the field installation. IEC 61000-4-18, which deals with conducted disturbances, covers these aspects.

The object of this standard is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment for medium voltage and high voltage sub-stations when subjected to damped oscillatory magnetic fields.

The test is mainly applicable to electronic equipment to be installed in H.V. sub-stations. Power plants, switchgear installations, smart grid systems may also be applicable to this standard and may be considered by product committees.

NOTE As described in IEC Guide 107, this is a basic EMC publication for use by product committees of the IEC. As also stated in Guide 107, the IEC product committees are responsible for determining whether this immunity test standard is applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria. TC 77 and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular immunity test levels for their products.

This standard defines:

- a range of test levels;
- test equipment;
- test setups;
- test procedures.

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 60050 (all parts), *International Electrotechnical Vocabulary (IEV)* (available at www.electropedia.org)

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

3.1.1
calibration
set of operations which establishes, by reference to standards, the relationship which exists, under specified conditions, between an indication and a result of a measurement

Note 1 to entry: This term is based on the "uncertainty" approach.

Note 2 to entry: The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.2
damped oscillatory wave generator
generator delivering a damped oscillation whose frequency can be set to 100 kHz or 1 MHz and whose damping time constant is five periods

3.1.3
immunity
ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.1.4
induction coil
conductor loop of defined shape and dimensions, in which a current flows, generating a magnetic field of defined uniformity in a defined volume

3.1.5
induction coil factor
ratio between the magnetic field strength generated by an induction coil of given dimensions and the corresponding current value

Note 1 to entry: The field is that measured at the centre of the coil plane, without the EUT.

3.1.6
proximity method
method of application of the magnetic field to the EUT, where a small induction coil is moved along the side of the EUT in order to detect particularly sensitive areas

3.1.7
reference ground
part of the Earth considered as conductive, the electrical potential of which is conventionally taken as zero, being outside the zone of influence of any earthing (grounding) arrangement

[SOURCE: IEC 60050-195:1998, 195-01-01]

3.1.8
system
set of interdependent elements constituted to achieve a given objective by performing a specified function

Note 1 to entry: The system is considered to be separated from the environment and other external systems by an imaginary surface which cuts the links between them and the considered system. Through these links, the system is affected by the environment, is acted upon by the external systems, or acts itself on the environment or the external systems.

3.1.9
transient, adjective and noun
pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval short compared to the time scale of interest

[SOURCE: IEC 60050-161:1990, 161-02-01]

3.1.10
verification
set of operations which is used to check the test equipment system (e.g. the test generator and its interconnecting cables) to demonstrate that the test system is functioning

Note 1 to entry: The methods used for verification may be different from those used for calibration.

Note 2 to entry: For the purposes of this basic EMC standard this definition is different from the definition given in IEC 60050-311:2001, 311-01-13.

3.2 Abbreviations

AE	Auxiliary equipment
EMC	Electromagnetic compatibility
EUT	Equipment under test
MU	Measurement uncertainty
PE	Protective earth
RGP	Reference ground plane

4 General

Damped oscillatory magnetic fields are generated by the switching of H.V. bus-bars by isolators or disconnectors. The magnetic fields to which equipment is subjected can influence the reliable operation of equipment and systems.

The following tests are intended to demonstrate the immunity of equipment when subjected to damped oscillatory magnetic field related to the specific location and installation condition of the equipment (e.g. proximity of equipment to the disturbance source).

The wave shape of the test field corresponds to a damped oscillatory wave (see Figure 2). The characteristics are given in 6.2.2.

Information on the oscillation frequency is given in Annex C.

5 Test levels

The preferred range of test levels is given in Table 1.

Table 1 – Test levels

Level	Damped oscillatory magnetic field strength A/m (peak)
1	not applicable
2	not applicable
3	10
4	30
5	100
X[a]	special

NOTE The magnetic field strength is expressed in A/m; 1 A/m corresponds to a free space magnetic flux density of 1,26 μT.

[a] "X" can be any level, above, below or in between the others. This level, as well the duration of the test, shall be specified in the dedicated equipment specification.

The test levels shall be selected according to the installation conditions. Classes of installation are given in Annex B.

6 Test instrumentation

6.1 General

The test system comprises the damped oscillatory wave generator and the induction coil for a table-top test setup and, in addition, an RGP for a floor-standing test setup.

6.2 Damped oscillatory wave generator

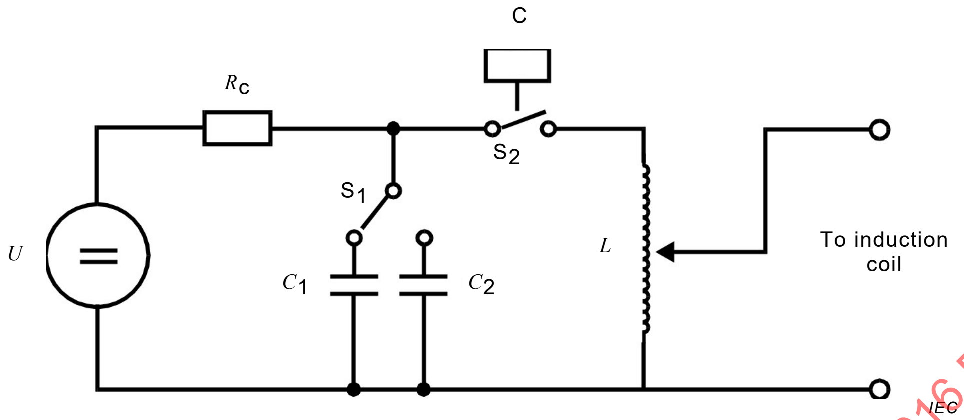
6.2.1 General

The damped oscillatory wave generator shall be able to deliver the required impulse current to the induction coils specified in 6.3.

NOTE For this application, a modified version of a damped oscillatory wave generator similar to the generator mentioned in IEC 61000-4-18 is used as a current source.

The waveform is specified as a short-circuit current and therefore shall be measured with the induction coil connected.

A simplified circuit diagram of the generator is given in Figure 1.



U:	High voltage source	R_C:	Charging resistor
C:	Control duration	L:	Coil oscillation circuit
S_1	Frequency selector	S_2	Duration selector
C_1, C_2:	Capacitors oscillation circuit (switchable from 0,1 MHz to 1 MHz)		

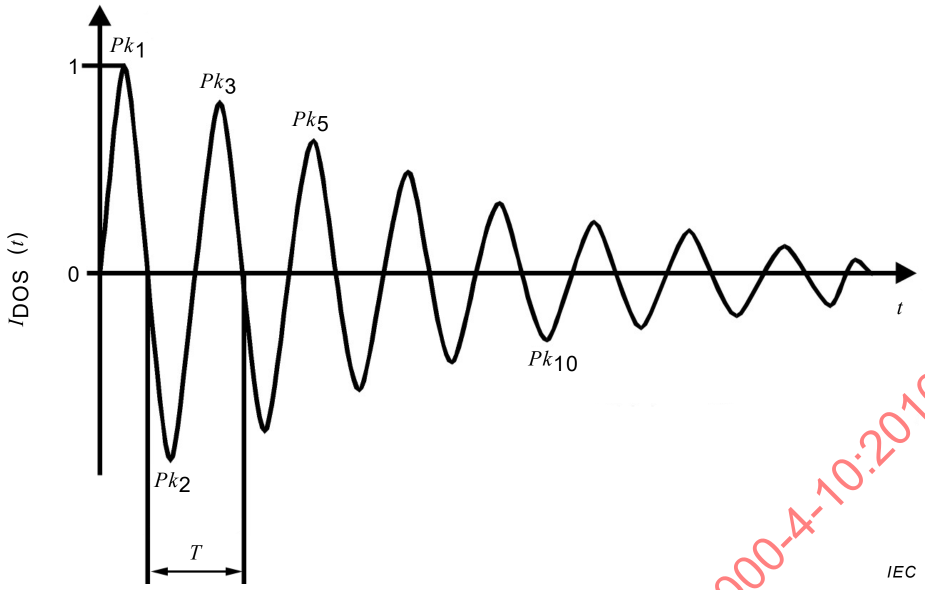
Figure 1 – Simplified schematic circuit of the test generator for damped oscillatory magnetic field

6.2.2 Performance characteristics of the generator connected to the standard induction coil

The performance characteristics below are applicable for the generator connected to the standard induction coils outlined in 6.3.

Oscillation period	see Table 3
Current in the coils (Pk_1 value)	see Table 2
Waveform of the damped oscillatory magnetic field	see Figure 2
Decay rate D_{r1}, D_{r2}	Pk_5 shall be > 50 % of the Pk_1 value and Pk_{10} shall be < 50 % of the Pk_1 value
Repetition rate $1/T_{rep}$ (see Figure 3)	40/s ± 10 % for 100 kHz and 400/s ± 10 % for 1 MHz
Test duration	not less than 2 s
Phase shifting	no requirement

Oscillation frequency is defined as the reciprocal of the period of the first and third zero crossings after the initial peak. This period is shown as T in Figure 2.



Key

T = 1 µs (1 MHz) or 10 µs (0,1 MHz)

Figure 2 – Waveform of short-circuit current in the standard coils

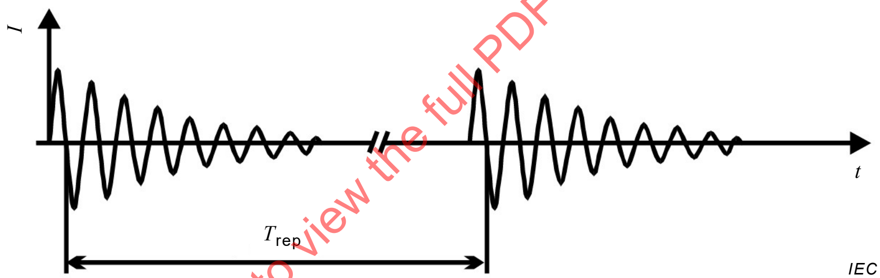


Figure 3 – Waveform of short-circuit current showing the repetition time T_{rep}

The formula of the ideal waveform of Figure 2, $I_{DOS}(t)$, is as follows:

$$I_{DOS}(t) = K_i \frac{i_1}{KH} \left(\frac{\left(\frac{t}{t_{1h}}\right)^{nh}}{1+\left(\frac{t}{t_{1h}}\right)^{nh}} e^{-\frac{t}{t_{2h}}} \right) \sin(\beta t)$$

with

$$KH = e^{-\frac{t_{1h}}{t_{2h}}\left(nh\frac{t_{2h}}{t_{1h}}\right)^{\frac{1}{nh}}}$$

where the parameters for oscillation period T = 1 µs are:

K_i = 1; i_1 = 0,963; t_{1h} = 0,08 µs; t_{2h} = 4,8 µs; nh = 2,1; β = 6,27 × 10^6 rad/s:

and the parameters for the oscillation period T = 10 μs are:

K_i = 1; i_1 = 0,963; t_{1h} = 0,8 μs; t_{2h} = 48 μs; nh = 2,1; β = 0,627 × 10^6 rad/s;

6.3 Standard induction coil

For the two single-turn standard coils of 1 m x 1 m and 1 m x 2,6 m, the field distribution is known and shown in Annex A. Therefore, no field verification or field calibration is necessary; the current measurement as shown in Figure 4 is sufficient.

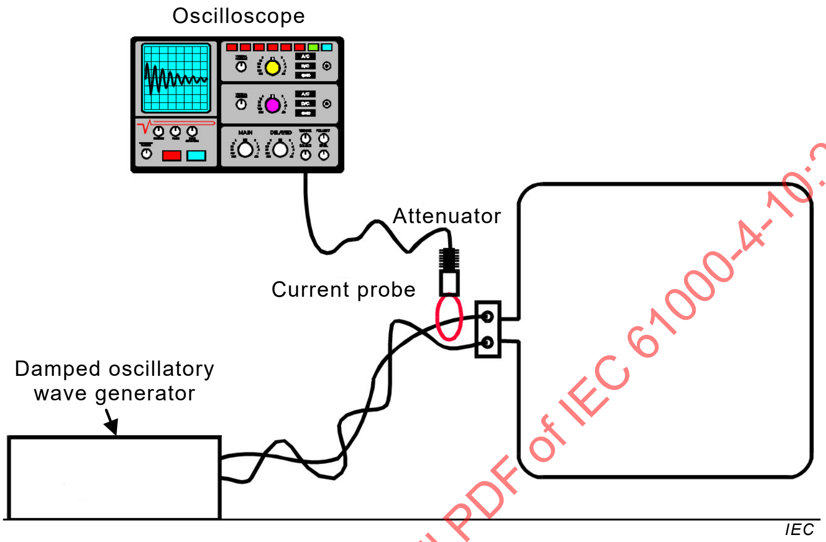


Figure 4 – Example of a current measurement of standard induction coils

The induction coil shall be made of copper, aluminium or any conductive non-magnetic material, of such cross-section and mechanical arrangement as to facilitate its stable positioning during the tests.

The characteristics of induction coils with respect to the magnetic field distribution are given in Annex A.

6.4 Calibration of the test system

The essential characteristics of the test system shall be calibrated by a current measurement (see Figure 4).

The output current shall be verified with the generator connected to the standard induction coil specified in 6.3. The connection shall be realized by twisted conductors or a coaxial cable of up to 3 m length and a suitable cross-section.

The specifications given in Table 3 are not applicable for calibrations performed at test level 5 with the 1 m × 2,6 m standard induction coil connected. In this case, the calibration shall be performed by only using the 1 m × 1 m standard induction coil.

The following specifications given in Table 2 and Table 3 shall be verified.

Table 2 – Peak current specifications of the test system

Test level	Peak current I ± 20 % A	
	System using 1 m × 1 m standard induction coil	System using 1 m × 2,6 m standard induction coil
1	not applicable	not applicable
2	not applicable	not applicable
3	11,1	15,2
4	33,3	45,5
5	111	see note 2
X	special/0,9	special/0,66

NOTE 1 The values 0,9 and 0,66 are the calculated coil factors of standard induction coils.

NOTE 2 The calculated value is 152; however, there is currently no commercial generator available.

Table 3 – Waveform specifications of the test system

Calibration items	Oscillation frequency	
	100 kHz	1 MHz
Oscillation period	T = 10 µs ± 1 µs	T = 1 µs ± 0,1 µs
Repetition time of the pulses	T_{rep} = 25 ms ± 2,5 ms	T_{rep} = 2,5 ms ± 0,25 ms
Decay rate of one pulse	$D_{r1} = \lvert I(PK_5) \div I(PK_1) \rvert > 50\ \%$ $D_{r2} = \lvert I(PK_{10}) \div I(PK_1) \rvert < 50\ \%$	$D_{r1} = \lvert I(PK_5) \div I(PK_1) \rvert > 50\ \%$ $D_{r2} = \lvert I(PK_{10}) \div I(PK_1) \rvert < 50\ \%$

The calibrations shall be performed at all levels which are used by laboratories.

The calibrations shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with a 10 MHz minimum bandwidth.

7 Test setup

7.1 Test equipment

The following equipment is part of the test setup:

– equipment under test (EUT);
– auxiliary equipment (AE) when required;
– cables (of specified type and length);
– damped oscillatory wave generator;
– standard induction coil;
– RGP in case of testing floor standing equipment.

7.2 Verification of the test instrumentation

The purpose of verification is to ensure that the test setup is operating correctly. The test setup includes:

– the damped oscillatory wave generator;

– the induction coil;
– the interconnection cables of the test equipment.

To verify that the system is functioning correctly, the following signal should be checked:

– impulse present at the standard induction coil terminals.

It is sufficient to verify that the impulse is present at any level by using suitable measuring equipment (e.g. current probe, oscilloscope).

NOTE Test laboratories can define an internal control reference value assigned to this verification procedure.

7.3 Test setup for table-top EUT

Table-top EUTs shall be placed on a non-conductive table. The 1 m × 1 m standard induction coil may be used for testing EUTs with dimensions up to 0,6 m × 0,6 m × 0,5 m (L × W × H). The 1 m × 2,6 m standard induction coil may be used for testing EUTs with dimensions up to 0,6 m × 0,6 m × 2 m (L × W × H).

The induction coil shall be positioned in three orthogonal orientations.

When an EUT does not fit into the induction coil of 1 m x 2,6 m, the proximity method (see 7.4) shall be applied.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the induction coil can impact the results so the cables shall be routed to minimize this impact. The minimized cabling dimension shall be incorporated into the determination of the maximum size of an EUT that can be tested.

An RGP is not required below the EUT (see Figure 5 below). The induction coil shall be kept at least 0,5 m from any conducting surfaces, for example the walls and floor of a shielded enclosure.

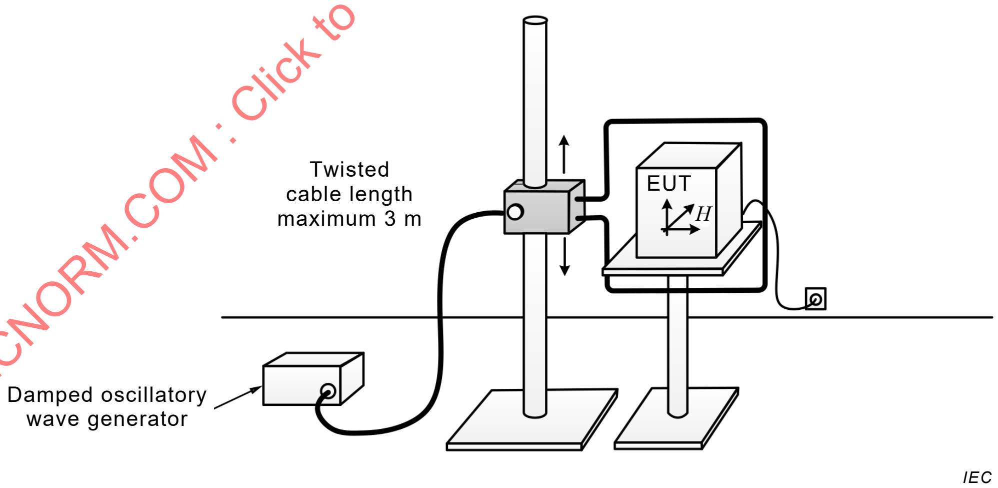


Figure 5 – Example of test setup for table-top equipment

7.4 Test setup for floor standing EUT

The standard induction coil for testing floor standing equipment (e.g. racks) has a rectangular shape of 1 m × 2,6 m where one short side may be the RGP for large sized equipment (see Figure 7). The 1 m × 1 m induction coil can be used for floor standing equipment with the maximum dimensions of 0,6 m × 0,6 m.

The RGP shall have a minimum thickness of 0,65 mm and a minimum size of 1 m × 1 m. The EUT shall be insulated from the RGP.

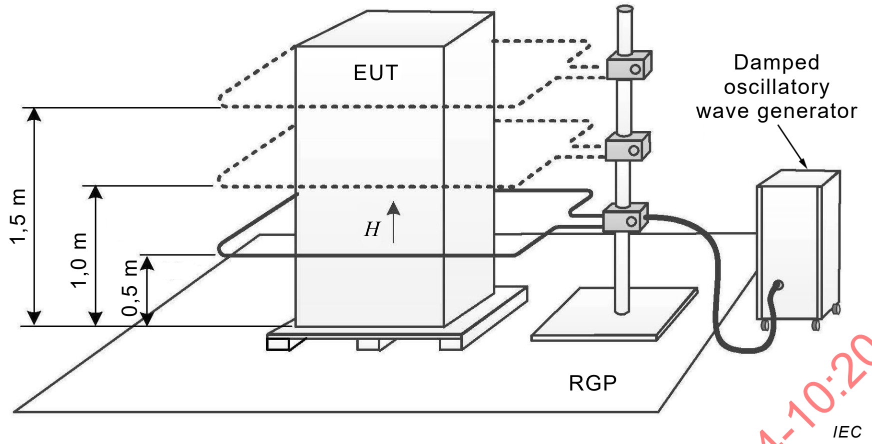


Figure 6 – Example of test setup for floor standing equipment showing the horizontal orthogonal plane

For floor standing equipment (e.g. cabinets) where the top of the EUT is greater than 0,75 m from the RGP, more than one position shall be tested. In any case, the induction coil shown in Figure 6 shall not be placed below 0,5 m. Figure 7 shows an example for testing with a vertical orthogonal plane.

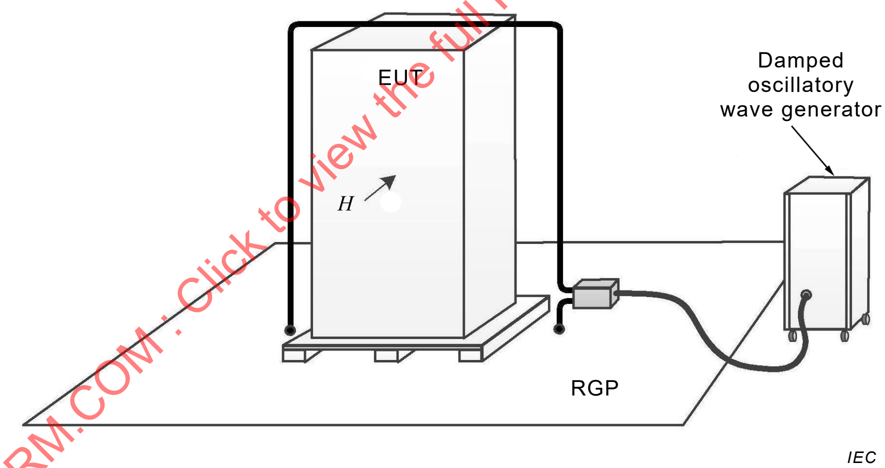


Figure 7 – Example of test setup for floor standing equipment showing the vertical orthogonal plane

The test volume of the rectangular coil is 0,6 m × 0,6 m × 2 m (L × W × H).

When an EUT does not fit into the rectangular coil of 1 m × 2,6 m, the proximity method (see Figure 8 and 7.5 for more detailed information) shall be applied.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the induction coil can impact the results so the cables shall be routed to minimize this impact. The minimized cabling dimension shall be incorporated into the determination of the maximum size of the EUT that can be tested.

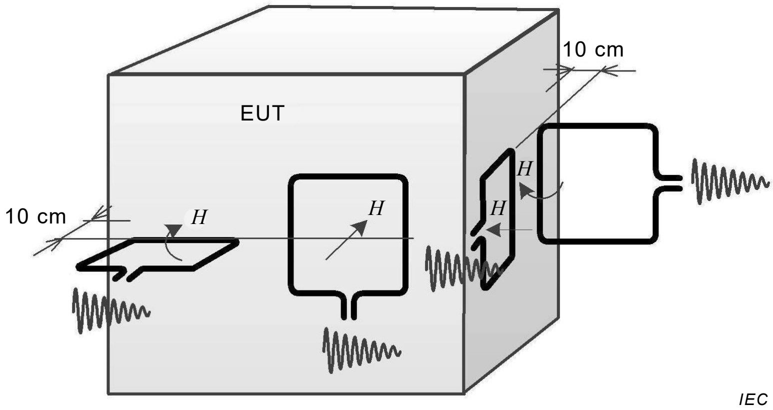


Figure 8 – Example of test setup using the proximity method

7.5 Test setup for damped oscillatory field applied in-situ

In-situ testing is generally the only practical test method available for large machinery or similar equipment. During in-situ testing, an RGP is normally not available. Therefore the proximity method is the only practical test method without the RGP in place. Figure 8 gives an example for a test setup for in-situ testing. The 1 m × 1 m standard induction coil should be used when examining EUTs using the proximity method. Further, it is necessary that the standard induction coil is isolated from the EUT. The distance between the standard induction coil and the EUT shall be (10 ± 1) cm.

NOTE The distance has been defined to ensure the same field strength as in the center of the standard induction coil.

8 Test procedure

8.1 General

The test procedure includes:

– the verification of the test instrumentation according to 7.2;
– the establishment of the laboratory reference conditions;
– the confirmation of the correct operation of the EUT;
– the execution of the test;
– the evaluation of the test results (see Clause 9).

8.2 Laboratory reference conditions

8.2.1 Climatic conditions

Unless otherwise specified in generic, product-family or product standards, the climatic conditions in the laboratory shall be within any limits specified for the operation of the EUT and the test equipment by their respective manufacturers.

Tests shall not be performed if the relative humidity is so high as to cause condensation on the EUT or the test equipment.

8.2.2 Electromagnetic conditions

The electromagnetic conditions of the laboratory shall be such as to guarantee the correct operation of the EUT so as not to influence the test results.

8.3 Execution of the test

Verification shall be performed. It is preferable to perform the verification prior to the test (see 7.2).

The test shall be performed according to a test plan which shall specify the test setup, including:

- test level;
- test duration (not less than 2 s);
- oscillation frequencies;
- representative operating conditions of the EUT;
- orientations of the field;
- number of test points;
- locations of the standard induction coil relative to the EUT (test points);
- selection and justification of test points (recommended are areas of EUT susceptible to damped oscillatory magnetic fields).

Testing and calibration shall be performed based on the waveform specified in Figure 2 and Figure 3.

NOTE Product committees can apply longer test durations, if appropriate for their products.

The test duration shall be applied only one time for each orientation.

9 Evaluation of test results

The test results shall be classified in terms of the loss of function or degradation of performance of the equipment under test, relative to a performance level defined by its manufacturer or the requestor of the test, or agreed between the manufacturer and the purchaser of the product. The recommended classification is as follows:

a) normal performance within limits specified by the manufacturer, requestor or purchaser;

b) 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;

c) temporary loss of function or degradation of performance, the correction of which requires operator intervention;

d) loss of function or degradation of performance which is not recoverable, owing to damage to hardware or software, or loss of data.

The manufacturer's specification may define effects on the EUT which may be considered insignificant, and therefore acceptable.

This classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards, or as a framework for the agreement on performance criteria between the manufacturer and the purchaser, for example where no suitable generic, product or product-family standard exists.

Equipment shall not become dangerous or unsafe as a result of the application of the tests.

10 Test report

The test report shall contain all the information necessary to reproduce the test. In particular, the following shall be recorded:

- the items specified in the test plan required by 8.3;
- identification of the EUT and any associated equipment, for example, brand name, product type, serial number;
- identification of the test equipment, for example, brand name, product type, serial number;
- any special environmental conditions in which the test was performed, for example, shielded enclosure;
- any specific conditions necessary to enable the test to be performed;
- the performance level defined by the manufacturer, requestor or purchaser;
- the performance criterion specified in the generic, product or product-family standard;
- any effects on the EUT observed during or after the application of the test disturbance, and the duration for which these effects persist;
- the rationale for the pass/fail decision (based on the performance criterion specified in the generic, product or product-family standard, or agreed between the manufacturer and the purchaser);
- any specific conditions of use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance;
- the induction coils selected for the tests;
- the position and orientation of the induction coil relative to EUT.

Annex A
(informative)

Information on the field distribution of standard induction coils

A.1 General

Annex A gives information on the maximum size of an EUT and its location in the standard induction coils. The field is considered sufficiently uniform if the magnitude of the magnetic field strength is within ±3 dB of the field strength in the centre of the induction coil.

For the field computations the finite cross-section of the loop conductors are neglected (thin wire approximation).

A.2 Determination of the coil factor

A.2.1 General

The induction coil factor should be determined by calculation. The coil factor is used to calculate the current in the induction coil to obtain the required magnetic field strength in the centre of the induction coil.

A.2.2 Coil factor calculation

The coil factor can be calculated from the geometrical dimensions of the induction coil. For a single-turn, rectangular induction coil having sides $a + b$ and c (see Figure A.1), the coil factor k_{CF} is given by

$$k_{CF}(P) = \frac{H(P)}{I} = \frac{1}{4\pi}\left[\frac{4a/c + c/a}{\sqrt{a^2 + (c/2)^2}} + \frac{4b/c + c/b}{\sqrt{b^2 + (c/2)^2}}\right] \qquad (A.1)$$

where $H(P)$ is the magnetic field at point P and I is the induction coil current. Equation (A.1) is valid, when the largest dimension of the cross-section of the coil conductor is small compared to the shortest side of the induction coil. For a square induction coil with side c and if P is at the centre of the coil, then $a = b = c/2$. If P is at the centre of a rectangular coil, then $a = b$. If the RGP is the bottom side of the coil, then equation (A.1) is still valid, taking into account the image of the actual (physical) coil. In this case, if P is at the centre of the physical coil, then the k_{CF} of the coil formed by the physical coil plus its image is given by equation (A.1) with $b = 3 \times a$.

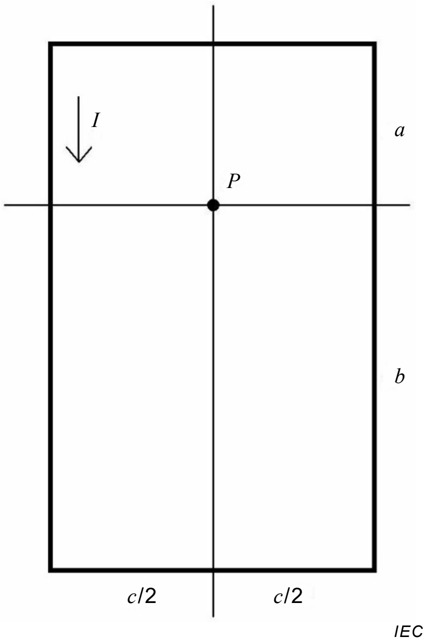
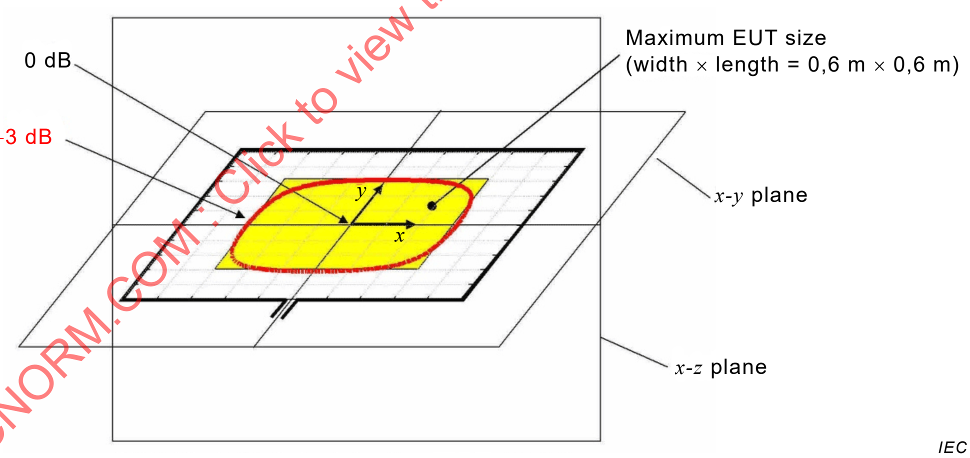


Figure A.1 – Rectangular induction coil with sides $a + b$ and c

A.3 1 m × 1 m standard induction coil

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure A.2 for the x-y plane and in Figure A.3 for the x-z plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 0,5 m.



NOTE The –3 dB isoline is not shown because it is outside the loop.

Figure A.2 – +3 dB isoline for the magnetic field strength (magnitude) in the x-y plane for the 1 m × 1 m induction coil

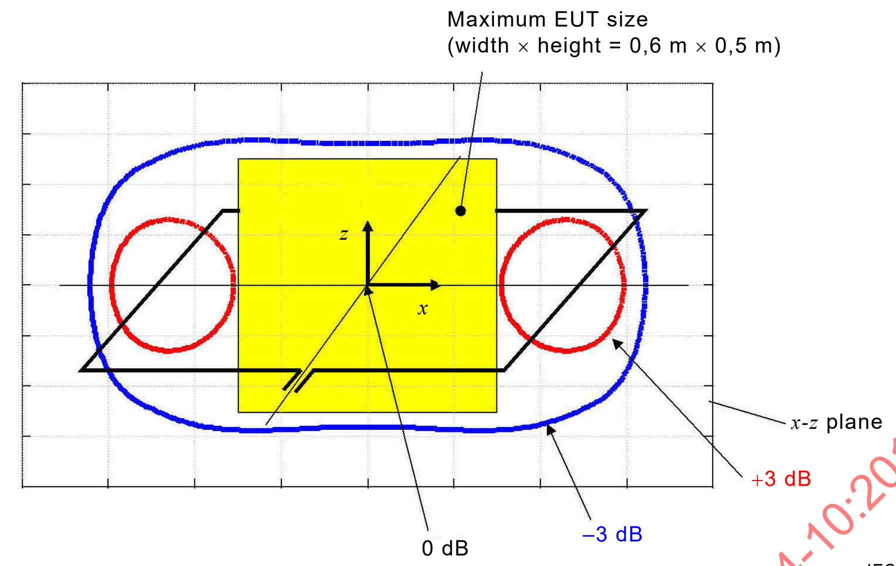
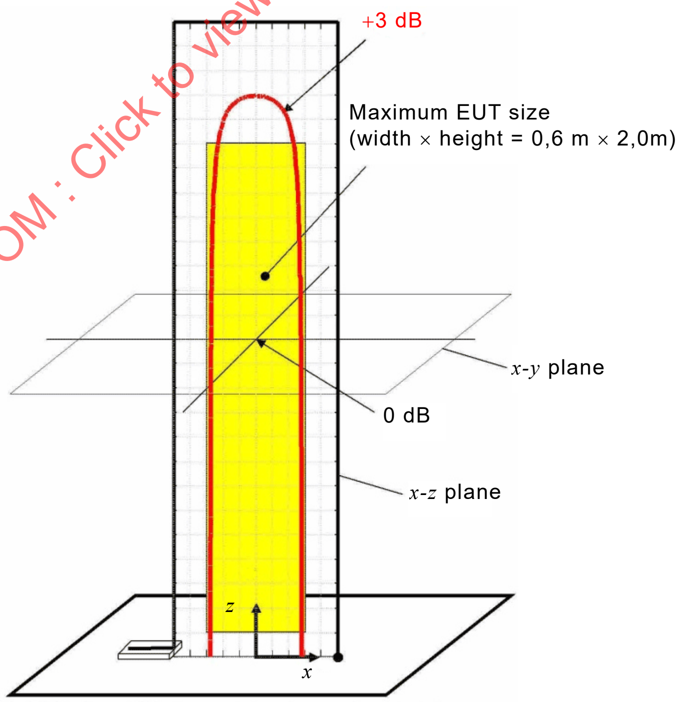


Figure A.3 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x-z* plane for the 1 m × 1 m induction coil

A.4 1 m × 2,6 m standard induction coil with reference ground plane

The +3 dB and -3 dB isolines for the magnetic field strength (magnitude) are shown in Figure A.4 for the *x-z* plane and in Figure A.5 for the *x-y* plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 2 m.

For the calculation of the ± 3 dB isolines the size of the reference ground plane is considered as infinite.



NOTE The –3 dB isoline is not shown because it is outside the loop.

Figure A.4 – +3 dB isoline for the magnetic field strength (magnitude) in the *x-z* plane for the 1 m × 2,6 m induction coil with reference ground plane

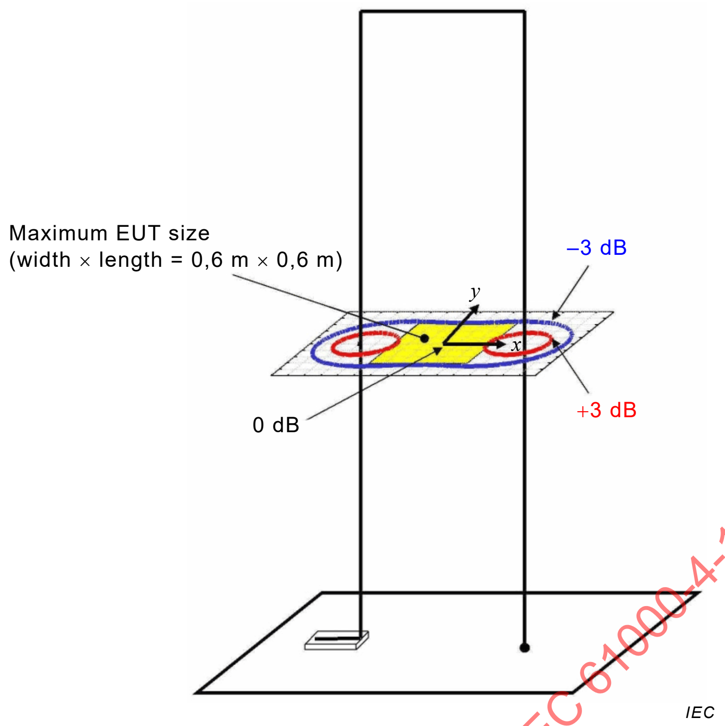
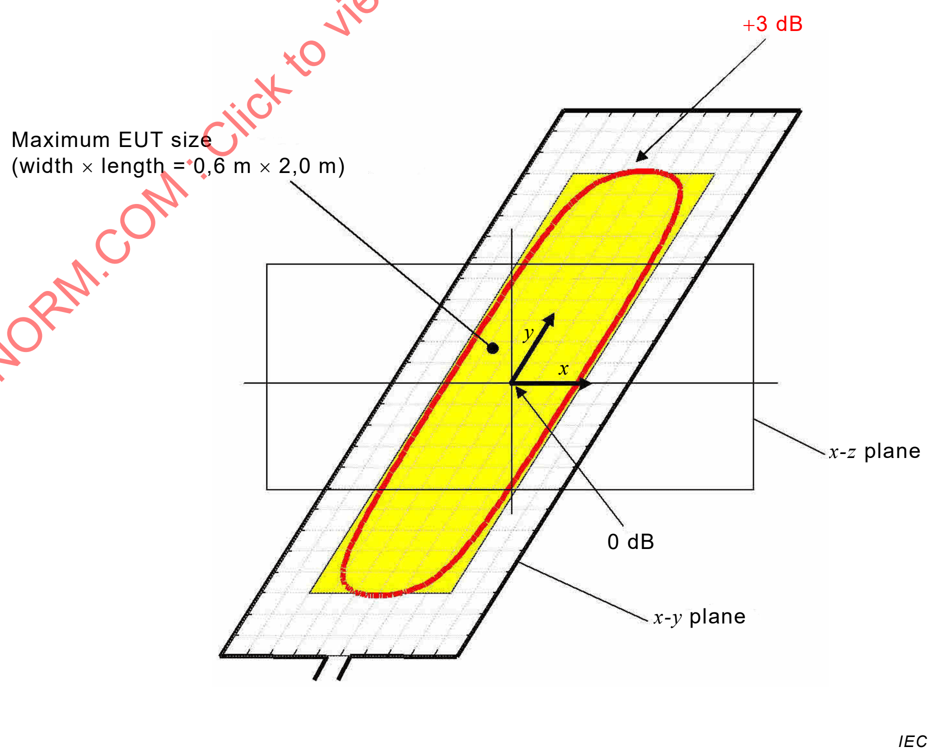


Figure A.5 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x-y* plane for the 1 m × 2,6 m induction coil with reference ground plane

A.5 1 m × 2,6 m standard induction coil without reference ground plane

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure A.6 for the *x-y* plane and in Figure A.7 for the *x-z* plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 2 m.



NOTE The –3 dB isoline is not shown because it is outside the loop.

Figure A.6 – +3 dB isoline for the magnetic field strength (magnitude) in the *x-y* plane for the 1 m × 2,6 m induction coil without reference ground plane

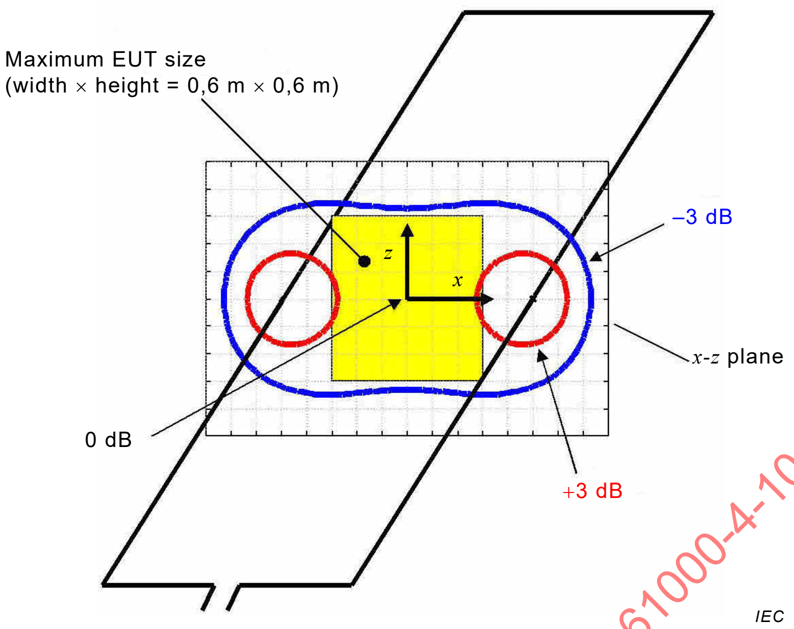


Figure A.7 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the x-z plane for the 1 m × 2,6 m induction coil without reference ground plane

Annex B
(informative)

Selection of the test levels

Test levels shall be selected in accordance with the electromagnetic environment in which the equipment concerned is intended to be used taking into account most realistic installation conditions.

Recommendations for test levels are given in Clause 5. The actual selection of test levels should take into account

– the electromagnetic environment;
– the potential proximity of damped oscillatory magnetic field disturbances sources to the equipment concerned;
– the installation conditions typically to be expected for an installation in the electromagnetic environment under consideration;
– the need and amount of compatibility margins, i.e. the margin between the maximum disturbance level and considered immunity level.

An appropriate test level for equipment depends on the electromagnetic environment in which equipment is intended to be used. Based on common installation practices which are representative for the electromagnetic environment concerned, a guide for the selection of test levels for damped oscillatory magnetic fields testing may be the following:

Class 1*:* Electromagnetic environment with particular mitigation measures employed in order to allow electromagnetic phenomena to occur to a certain extent only (e.g. phenomenon does not occur, phenomenon occurs with a relatively low amplitude only, etc.)

Controlled electromagnetic environment: where sensitive devices are planned to be used (e.g. electron microscopes, cathode ray tubes, etc.)

The test is not applicable to equipment intended to be used in this class of environment.

Class 2: Electromagnetic environment representative for residential areas

The test is not applicable to equipment intended to be used in this class of environment because the locations concerned are not subjected to the influence of switching phenomena in medium- and high-voltage substations.

Class 3: Electromagnetic environment representative for office/commercial areas

Locations of this class of environment are characterized by a potential proximity to medium-voltage and high-voltage switchgear or to conductors carrying corresponding transients. A computer room in the vicinity of a sub-station might be a representative for such location.

Class 4*:* Electromagnetic environment representative for industrial areas

Locations of this class of environment are characterized by the presence of medium- or high-voltage substations and of conductors carrying transient fault currents. Control rooms of sub-stations and fields with high-current equipment/installations might be representatives for such locations.

Class 5: Harsh electromagnetic environment which can be characterized by the following attributes: conductors, bus-bars or M.V.or H.V. lines carrying tens of kA

Switchyard areas of heavy industrial plants, M.V/H.V. sub-stations and power stations might be representatives for locations with such an electromagnetic environment.

Class X: Special electromagnetic environment

The minor or major electromagnetic separation of interference sources from equipment circuits, cables, lines, etc., and the quality of the installations may require the use of higher or lower test levels than those described above. This may need a case-by-case assessment.

It should be noted that the lines of equipment (e.g. cabling, bus bars, overhead lines) associated to electromagnetic environments with higher test levels can penetrate into locations being assigned to an environment with lower test levels. In such cases a re-assessment of the latter location with respect to the suitable test levels should be carried out.

The above selection of test levels in terms of electromagnetic environments should be used as a guide only. There might be cases where a location might be assigned to one of the above types of electromagnetic environments but due to the features of the equipment concerned or other circumstances a different test level than that associated to that type of electromagnetic environment might be more appropriate. Corresponding assessment should be done by the parties involved (e.g. product committees).

Annex C
(informative)

Damped oscillatory magnetic field frequency

The phenomenon is typical of the switching of isolators in H.V. sub-stations, and particularly in H.V. bus-bars.

The opening and closing operation of H.V. isolators gives rise to sharp front-wave transients, with time of the order of tens of ns. These phenomena are smoothed by the overall capacitance of the structures of H.V. equipment as they propagate.

The voltage front-wave has an evolution that includes reflections due to the mismatching of the characteristic impedance of the H.V. circuits involved. In this respect, the resulting transient voltage and current in H.V. bus-bars are characterized by a fundamental oscillation frequency that depends on the length of the circuit and on the propagation time.

The transient current peak value that generates the magnetic fields defined in this standard is directly related to the peak voltage on the bus-bars and their characteristic impedance; the voltage is about twice the phase peak value of the H.V. system, and the current (determined also by the characteristic impedance of such circuits) is about 2 kA peak.

The frequency of oscillation is determined by the length of the H.V. and by the self-inductance of H.V. circuits (1 μH/m), the series capacity of the circuit-breaker in the off-state (500 pF), the concentrated capacity of capacitive voltage transformers (some nF), of current transformers (300 pF) and of H.V. supports (20 pF each).

The oscillation frequency ranges from about 100 kHz to a few MHz depending on the influence of the parameter mentioned and the length of the bus-bars, which may vary from tens of meters to hundreds of meters (400 m may occur).

In this respect the oscillation frequency of 1 MHz may be considered representative of most situations, but 100 kHz has been considered appropriate for big H.V. sub-stations.

The repetition frequency is variable and, provided the other conditions are the same, is a function of the distance between the switching contacts: that is, with closed contacts, there is the maximum repetition frequency, while for distances between the contacts at the limit of extinction of the arc, the minimum repetition frequency in respect of each phase is twice the power frequency (100/s for 50 Hz and 120/s for 60 Hz H.V. systems), but at these frequencies the maximum magnetic field strength occurs.

The repetition rates selected for the 0,1 MHz and 1 MHz test fields represent therefore a compromise, taking into account the different durations of the phenomena, the representativity of the different frequencies and the problems related to the power of the test generator.

Annex D
(informative)

Measurement uncertainty (MU) considerations

D.1 General

The compliance of the realized disturbance quantity with the disturbance quantity specified by this standard is usually confirmed through a set of measurements (e.g. measurement of the peak of a damped oscillatory current impulse with an oscilloscope by using a current probe). The result of each measurement includes a certain amount of measurement uncertainty (MU) due to the imperfection of the measuring instrumentation as well as to the lack of repeatability of the measurand itself. The evaluation of MU is done here according to the principles and methods described in IEC TR 61000-1-6.

In order to evaluate MU it is necessary to:

a) identify the sources of uncertainty, related both to the measuring instrumentation and to the measurand,
b) identify the functional relationship (measurement model) between the influence (input) quantities and the measured (output) quantity,
c) obtain an estimate and standard uncertainty of the input quantities,
d) obtain an estimate of the interval containing, with a high level of confidence, the true value of the measurand.

Further details are given in IEC TR 61000-1-6.

These estimates and uncertainties, derived for a particular disturbance quantity, do not describe the degree of agreement between the simulated electromagnetic phenomenon, as defined in the basic standard, and the real electromagnetic phenomenon in the world outside the laboratory.

Since the effect of the parameters of the disturbance quantity on the EUT is a priori unknown and in most cases the EUT shows a nonlinear behaviour, a single estimate and uncertainty numbers cannot be defined for the disturbance quantity. Therefore each of the parameters of the disturbance quantity will be accompanied by the corresponding estimate and uncertainty. This yields to more than one uncertainty budget.

D.2 Legend

I_P Peak of the damped oscillatory current impulse injected into the coil

H_P Peak of the magnetic field impulse

k_{CF} Coil factor of the induction coil: $H_P = k_{CF} \times I_P$

NOTE The meaning and the relations among the symbols $u(x_i)$, c_i, $u_i(y)$, $u_c(y)$, $U(y)$ and y are explained in IEC TR 61000-1-6.

D.3 Uncertainty contributors to the peak current and to the damped oscillatory magnetic field measurement uncertainty

The following list shows the contributors used to assess both the measuring instrumentation and test setup influences:

- reading of peak value
- bandwidth of the measuring system

- shape of the impulse response of the measuring system
- oscilloscope horizontal axis measurement error
- oscilloscope vertical axis measurement error
- measurement system, measurand and setup repeatability (type A)
- calibration of oscilloscope and measuring system
- coil factor of the induction coil

D.4 Uncertainty of peak current and damped oscillatory magnetic field calibration

D.4.1 General

In the case of the magnetic field test, the disturbance quantities are the damped oscillatory current generated by the test generator and injected into the coil terminals and the damped oscillatory magnetic field applied to the EUT. As discussed in Clause D.1, an uncertainty budget for each measured parameter of the disturbance quantity is required. The parameters of these disturbance quantities are I_P for the impulse current and H_P for the impulse magnetic field. It is assumed that the magnetic field generated by the induction coil is proportional to the current flowing into its terminals, the constant of proportionality being the coil factor k_{CF}. Therefore the impulse magnetic field has the same waveshape as the impulse current and the peak of the magnetic field is obtained as $H_P = k_{CF} \times I_P$.

Additional parameters characterize the disturbance, i.e. the frequency of oscillation and damping. However the evaluation of the measurement uncertainty of these parameters, although required, is less demanding than that of impulse peak. Therefore attention is focused here on measurement uncertainty of the peak of the impulse.

The approach adopted here to evaluate the impulse MU is described in D.4.4 and D.4.5. Table D.1 gives an example of the uncertainty budget for the peak current impulse. The table includes the input quantities that are considered most significant for this example, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining the uncertainty budget.

D.4.2 Peak current

The measurand is the peak of the damped oscillatory current impulse calculated by using the functional relationship

$$I_p = \frac{V_{PR}}{R_T} \frac{1 + \delta R + \delta V}{1 - \left(\frac{\beta}{B}\right)^2} \qquad \text{(D.1)}$$

where

V_{PR}	is the impulse voltage peak reading
R_T	is the transfer resistance of the current probe
δR	is the correction for non-repeatability
δV	is the d.c. vertical accuracy of the scope
B	is the –3 dB bandwidth of the measuring system
β	is the coefficient whose value is (63,8 ± 7,1) kHz at the oscillation frequency f_0 = 0,1 MHz and (638 ± 71) kHz at the oscillation frequency f_0 = 1 MHz

The damped oscillatory current impulse oscillation frequency f_0 = 1 MHz is assumed for the following example of uncertainty budget.

Table D.1 – Example of uncertainty budget for the peak of the damped oscillatory current impulse (I_p)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{PR}	0,115	V	0,000 2	V	triangular	2,45	0,000 09	1 004	1/Ω	0,092	A
R_T	0,001	Ω	0,000 05	Ω	rectangular	1,73	0,000 03	-11 5470	A/Ω	3,33	A
δR	0	1	0,03	1	normal (k=1)	1,00	0,030	115,5	A	3,46	A
δV	0	1	0,02	1	rectangular	1,73	0,011 6	115,5	A	1,33	A
β	638	kHz	71	kHz	rectangular	1,73	40,99	0,001 48	A/kHz	0,061	A
B	10 000	kHz	1 000	kHz	rectangular	1,73	577,4	-0,000 09	A/kHz	0,054	A
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			4,99	A
							$U(y) = 2\ u_c(y)$			9,98	A
							Y			115	A
							Expressed in % of 115 A			8,6	%

[a] Probability density function

V**PR**: is the voltage peak reading at the output of a current probe or across a current shunt. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with interpolation capability (triangular probability density function). If the interpolation capability is not available or not active, then the rectangular probability density function is used.

R**T**: is the transfer impedance (or sensitivity) of the current shunt or probe. An estimated value of 0,001 Ω and an error bound of 5 % (rectangular probability density function) are assumed.

δR: quantifies the non-repeatability of the measurement setup, layout and instrumentation. This is a type A evaluation based on the formula of the experimental standard deviation $s(q_k)$ of a sample of n repeated measurements q_j and given by

$$s(q_k) = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(q_j - \overline{q}\right)^2} \quad \text{(D.2)}$$

where $\overline{q}$ is the arithmetic mean of the q_j values. δR is expressed in relative terms, and an estimate of 0 % and an error bound of 3 % (1 standard deviation) are assumed.

δV: quantifies the amplitude measurement inaccuracy of the scope at d.c. δV is expressed in relative terms. A 2 % error bound of a rectangular probability density function and an estimate of 0 % are assumed.

β: is a coefficient which depends on the shape of both the impulse response of the measuring system and the standard impulse waveform in the neighborhood of the peak (see D.4.5). The interval (638 ± 71) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: the bandwidth B of the measuring system can be experimentally obtained (direct measurement of the bandwidth) or calculated from the bandwidth B_i of each element of the measurement system (essentially a current probe or shunt, a cable and a scope) by using the following equation:

$$\frac{1}{B}=\sqrt{\left(\frac{1}{B_1}\right)^2+\left(\frac{1}{B_2}\right)^2+\ldots} \tag{D.3}$$

An estimate of 10 MHz and a 1 MHz error bound of a rectangular probability density function are assumed for B.

NOTE The uncertainty of the peak of the magnetic field impulse is obtained from the functional relationship $H_P = k_{CF} \times I_P$ where k_{CF} is the coil factor as measured through the calibration procedure described in this standard (i.e. at power frequency). Therefore, if the measured k_{CF} is 0,90 (e.g. in the case of a square induction loop whose side is 1 m) and its expanded uncertainty is 5 % then the best estimate of H_P is 104 A/m and its expanded uncertainty is 9,9 % (see Table D.1)

D.4.3 Further MU contributions to amplitude and time measurements

The following contributions may also have an impact on the MU budget:

DC offset: The d.c. offset of the scope contributes to the voltage peak measurement uncertainty, if the peak is measured from the nominal d.c. zero line of the scope. This contribution can be ignored, if the readout software of the scope measures the peak from the pulse base line.

Time base error and jitter: The oscilloscope specifications may be taken as error bounds of rectangular probability density functions. Usually these contributions are negligible.

Vertical resolution: The contribution depends on the vertical amplitude resolution ΔA and on the slope of the trace dA/dt. The uncertainty is related to the half width of the resolution and is $(\Delta A/2)/(dA/dt)$. If trace interpolation is performed (see the oscilloscope manual) a triangular probability density function is used, otherwise a rectangular probability density function is used. This contribution may not be negligible when $|dA/dt| < (\Delta A/T_i)$, where T_i is the sampling interval of the scope.

D.4.4 Rise time of the step response and bandwidth of the frequency response of the measuring system

Let T_{MS} be the rise time of the step response of the measuring system as defined by equation (D.4)

$$T_{MS}=\sqrt{2\pi\int_0^{\infty}(t-T_s)^2\,h_0(t)\,dt} \tag{D.4}$$

where $h_0(t)$ is the impulse response of the measuring system having a normalized area, i.e. $\int_0^{\infty} h_0(t)\,dt=1$, and T_s is the delay time given by

$$T_s=\int_0^{\infty} t\,h_0(t)\,dt \tag{D.5}$$

Equation (D.4) is easier to handle, from the mathematical point of view, than the usual one based on the 10 % and 90 % threshold levels. Nonetheless, in the technical applications, the

10 % to 90 % rise time definition is usually adopted. Given the –3 dB bandwidth of the system the two definitions lead to comparable rise times. Indeed, if we define

$$\alpha = T_{MS} \cdot B \quad \text{(D.6)}$$

we find that the α values derived from the two definitions of rise-time do not differ very much. The values of α, corresponding to different shapes of the impulse response $h(t)$, are given in Table D.2. It is evident from Table D.2 that it is not possible to identify a unique value of α since α depends both on the adopted definition of the rise time (e.g. based on thresholds or on equation (D.4)) and on the shape of the impulse response of the measuring system. A reasonable estimate of α can be obtained as the arithmetic mean between the minimum (321×10^{-3}) and maximum (399×10^{-3}) values that appear in Table D.2, that is 360×10^{-3}. Further, it can be assumed that, if no information is available about the measuring system apart from its bandwidth, any value of α between 321×10^{-3} and 399×10^{-3} is equally probable. Differently stated, α is assumed to be a random variable having a rectangular probability density function with lower and upper bounds 321×10^{-3} and 399×10^{-3}, respectively. The standard uncertainty of α quantifies both: a) the indifference to the mathematical model adopted for the definition of the rise-time, and b) the indifference to the shape of the impulse response of the system.

Table D.2 – α factor (see equation (D.6)) of different unidirectional impulse responses corresponding to the same bandwidth of the system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (crit. damp.)	Rectangular	Triangular
α, using equation (D.4)	332	399	363	321	326
α, 10 % to 90 %	339	350	344	354	353

D.4.5 Impulse peak distortion due to the limited bandwidth of the measuring system

The distorted impulse waveform $V_{out}(t)$ at the output of the measuring system is given by the convolution integral

$$V_{out}(t) = \int_0^t V_{in}(\tau) \cdot h(t-\tau) d\tau \quad \text{(D.7)}$$

where $V_{in}(t)$ is the input impulse waveform and $h(t)$ is the impulse response of the measuring system. Note that $A \cdot h(t) = h_0(t)$, where A is the d.c. attenuation of the measuring system. The input waveform can be approximated by its Taylor series expansion about the time instant t_p when the input reaches its peak value V_p

$$V_{in}(t) = V_p + \frac{V''_{in}(t_p)}{2} \cdot (t - t_p)^2 + \frac{V'''_{in}(t_p)}{6} \cdot (t - t_p)^3 + \ldots \quad \text{(D.8)}$$

Note that the first order term is missing from equation D.8 since $V'(t_p) = 0$. Further $V''_{in}(t_p) < 0$, because the concavity points downwards (maximum), and $V'''_{in}(t_p) > 0$, because, for the standard waveforms of interest here, the rise time is lower than the fall time. Substituting equation D.8 into equation D.7 and after simplifications, valid when the bandwidth of the measuring system is large with respect to the bandwidth of the input signal (so that the power series terms whose order is greater than two are negligible), we obtain

$$V_{pd} = \frac{V_p}{A}\left[1-\left(\frac{\beta}{B}\right)^2\right] \quad (D.9)$$

where V_{pd} is the output impulse peak, A is the d.c. attenuation of the measuring system and

$$\beta = \alpha \cdot \sqrt{\frac{\left|V''_{in}(t_p)\right|}{4\pi V_p}} \quad (D.10)$$

Note that the parameter β depends on the second derivative of the standard input waveform and on the parameter α defined and derived in D.4.4. A simple mathematical expression for the standard damped oscillatory waveform, useful for uncertainty calculation, is given by

$$V_{in}(t) = V_p e^{-\omega_0 \zeta \left[t - \frac{\pi}{2\omega_0}\right]} \sin(\omega_0 t) \quad (D.11)$$

where $f_0 = \omega_0/(2\pi)$ is the oscillation frequency and ζ is the damping. The value of β can be analytically derived from equations (D.10) and (D.11) as

$$b >> \alpha\sqrt{\pi}\, f_0 \quad (D.12)$$

The value of β, as obtained from equation (D.12), is reported in Table D.3.

Table D.3 – β factor (equation (D.12)) of the damped oscillatory waveform

kHz	f_0 = 0,1 MHz	f_0 = 1 MHz
β	63,8 ± 7,1	638 ± 71

NOTE 1 Equation (D.12) is an approximation because the exponential decay about the instant $t = t_p$ is neglected.

NOTE 2 The values of β obtained by using equation (D.12) and reported in Table D.3 do not appreciably differ from the ones obtained through computation from the mathematical waveform defined in this standard.

NOTE 3 Damping ζ can be obtained by measuring the ratio $\rho > 1$ between the amplitude of one maximum (or minimum) of the oscillation and the next one. It is given by equation (D.11).

$$\zeta = \frac{1}{2\pi}\ln\rho \quad (D.13)$$

For a compliant waveform, ζ is in the range 0,02 to 0,04.

D.5 Application of uncertainties in the damped oscillatory wave generator compliance criterion

Generally, in order to be confident that the current and the magnetic field oscillatory transients are within their specifications, the calibration results should be within the specified limits of this standard (tolerances are not reduced by MU).

Further guidance is given in IEC TR 61000-1-6:2012, Clause 6.

Annex E
(informative)

3D numerical simulations

E.1 General

In Annex E some other information is reported concerning the H-field distributions inside and outside the coils for testing by using 3D numerical simulations in the time domain (dynamic results) and frequency domain (2D-numerical plot of the H-field) as extension of the 2D plots of Annex A (static results).

E.2 Simulations

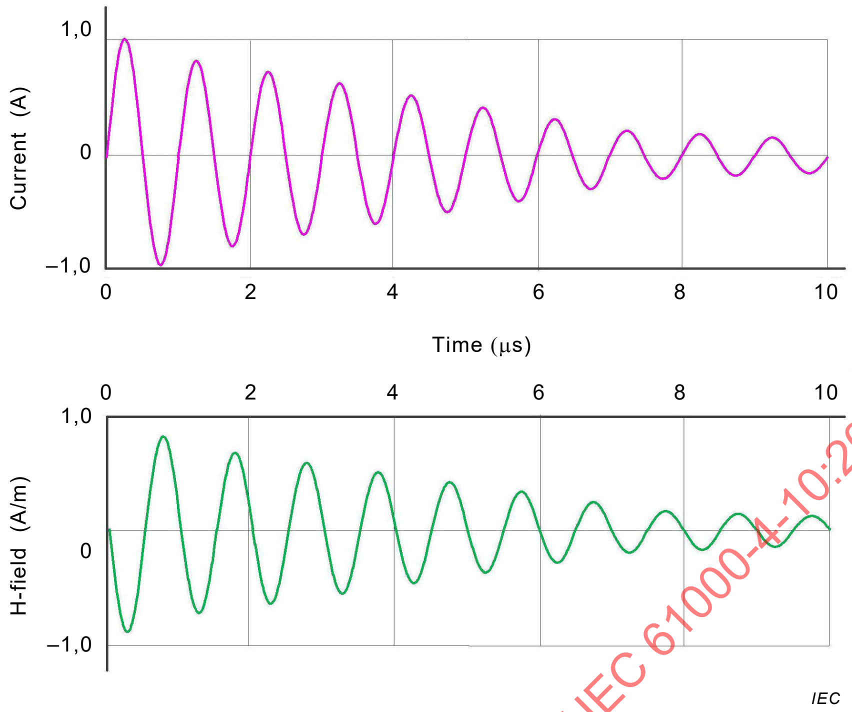
The simulations of Figures E.1 to E.10 are performed as follows:

- The coils are excited by an ideal current source (see the symbol "port") having the mathematical waveform as defined in the text of this standard and normalized at 1 A.
- Two extreme shape conductors of the coil are considered: rectangular of size 10 cm × 1 cm (reported in Annex E) and round wire of 1 mm radius (results not reported for brevity).
- Default mesh cells are used to speed up the computation for the plots of Figures E.2 and E.3; for the other figures optimized mesh cells are used for better accuracy.
- H-field amplitude is indicated as Hx_i where x indicates that the considered H-field component is parallel to the x-axis while the subscript i corresponds to the H-field probe position from the loop centre to the last far away position.
- The 2D H-field plots are calculated at 1 MHz frequency and 0 dB refers to 1 A/m.

E.3 Comments

From the simulations, the following considerations arise:

- The computed H-field waveform has the same shape as that of the coil current source.
- Very little difference can be noted when comparing computed H-field waveforms with two extreme conductor shapes for the same coil size.
- In the centre of the coils, the induction coil factors are 0,90 m^{-1} and 0,65 m^{-1} respectively for square and rectangular coils, which practically do not depend on the shape of the coil conductor.
- It is confirmed also by transient simulations that the variation of the H-field is less than +3 dB for the areas shown in Annex A.
- It is shown and quantified that the H-field increases rapidly when the probe used for H-field computation approaches the conductors of the coil.
- The H-field value outside the loop is about 20 dB to 40 dB (1/10 to 1/100) lower than the field at the center of the loop. This should be taken into account when carrying out the proximity test method.



NOTE The amplitude of the Hx-field inside the loop is negative due to the chosen probe directions.

Figure E.1 – Current with period of 1 µs and H-field in the center of the 1 m × 1 m standard induction coil

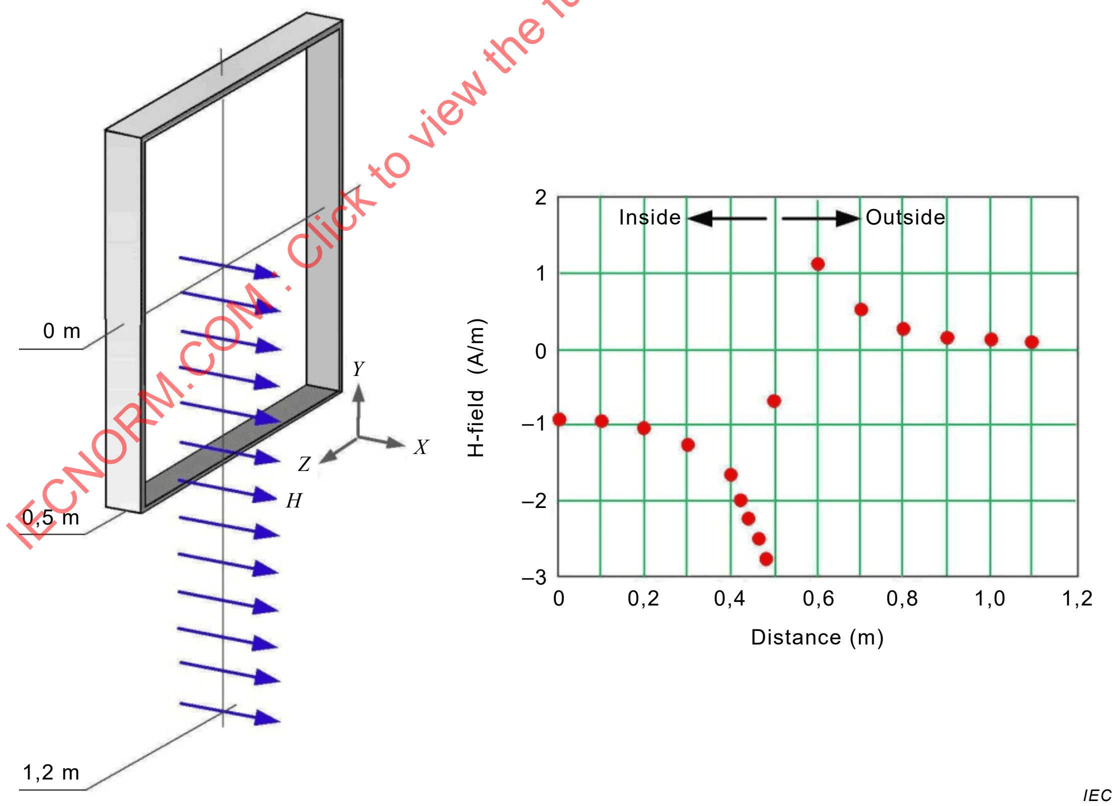


Figure E.2 – Hx–field along the side of 1 m × 1 m standard induction coil in A/m

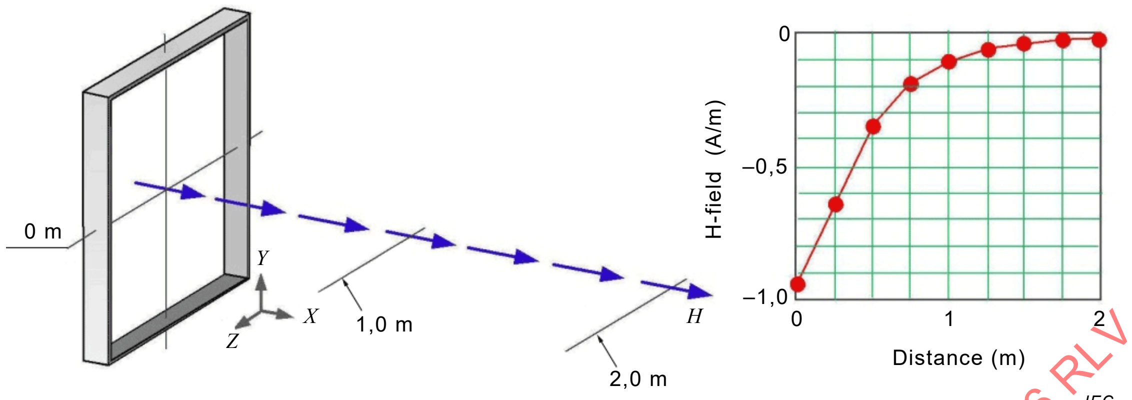


Figure E.3 – *Hx*–field in direction *x* perpendicular to the plane of the 1 m × 1 m standard induction coil

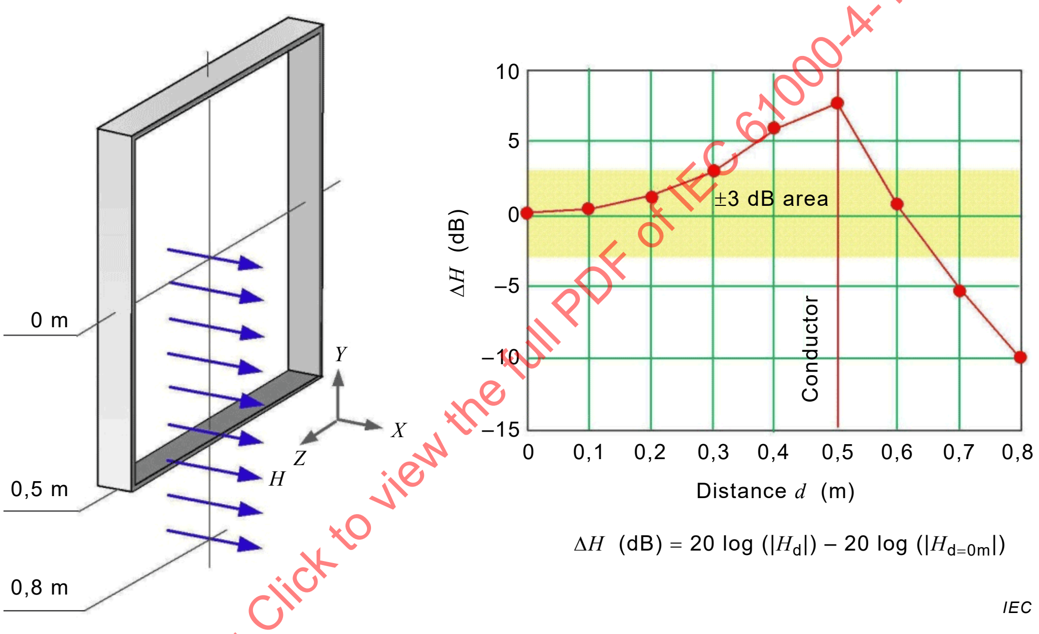


Figure E.4 – *Hx*–field along the side in dB for 1 m × 1 m standard induction coil

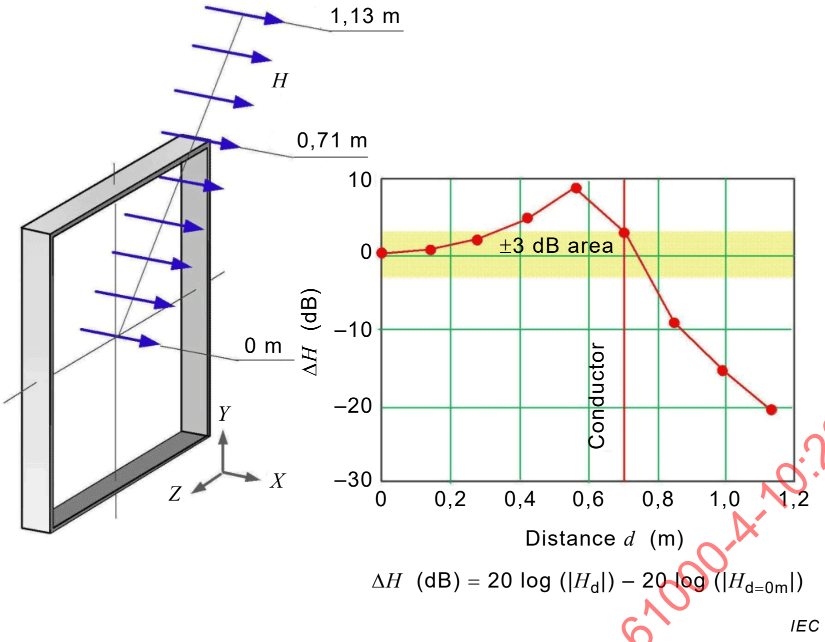


Figure E.5 – Hx–field along the diagonal in dB for the 1 m × 1 m standard induction coil

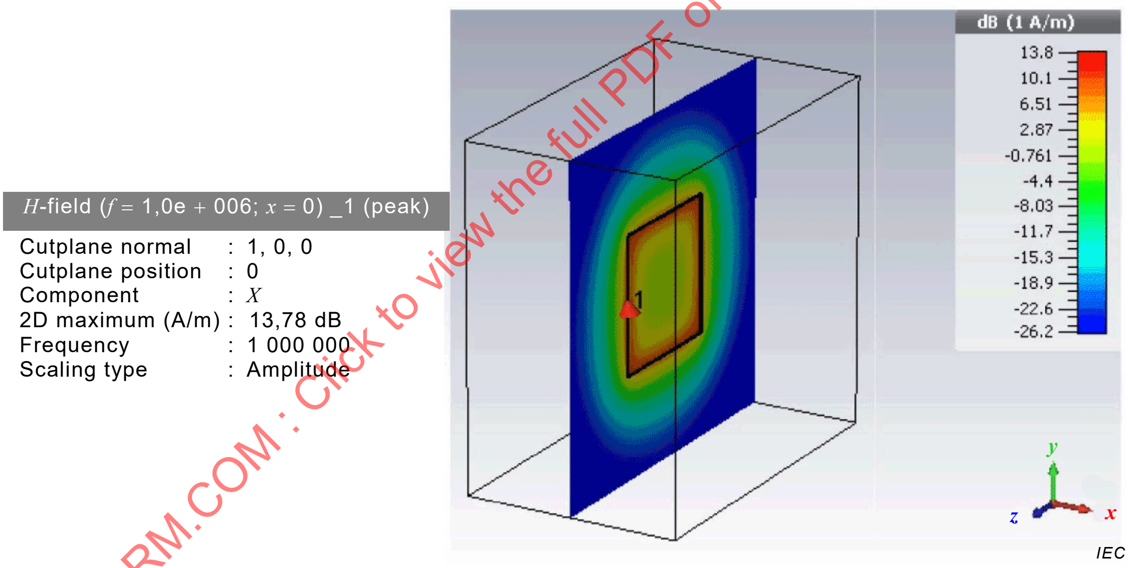


Figure E.6 – Hx–field plot on y-z plane for the 1 m × 1 m standard induction coil

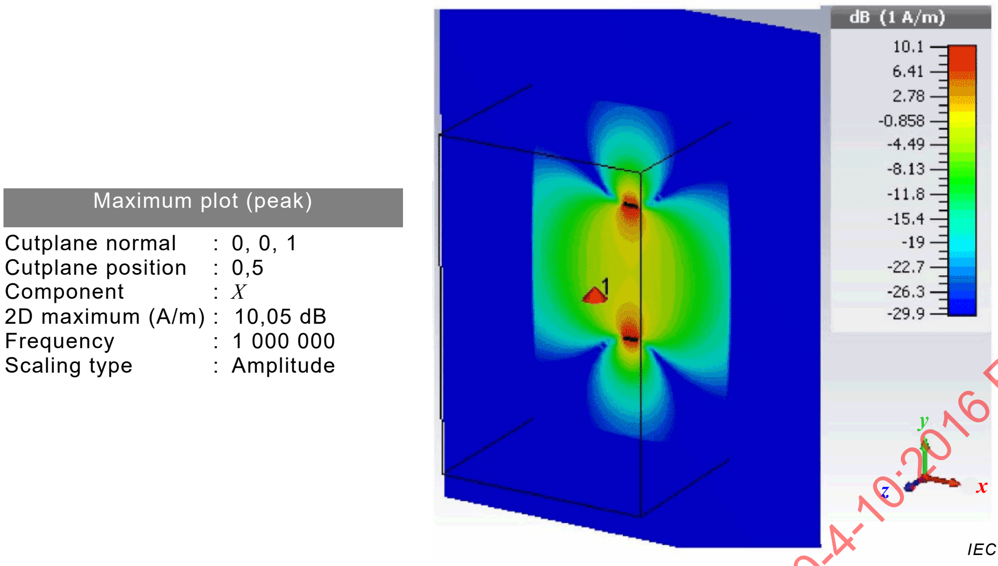


Figure E.7 – Hx-field plot on x-y plane for the 1 m × 1 m standard induction coil

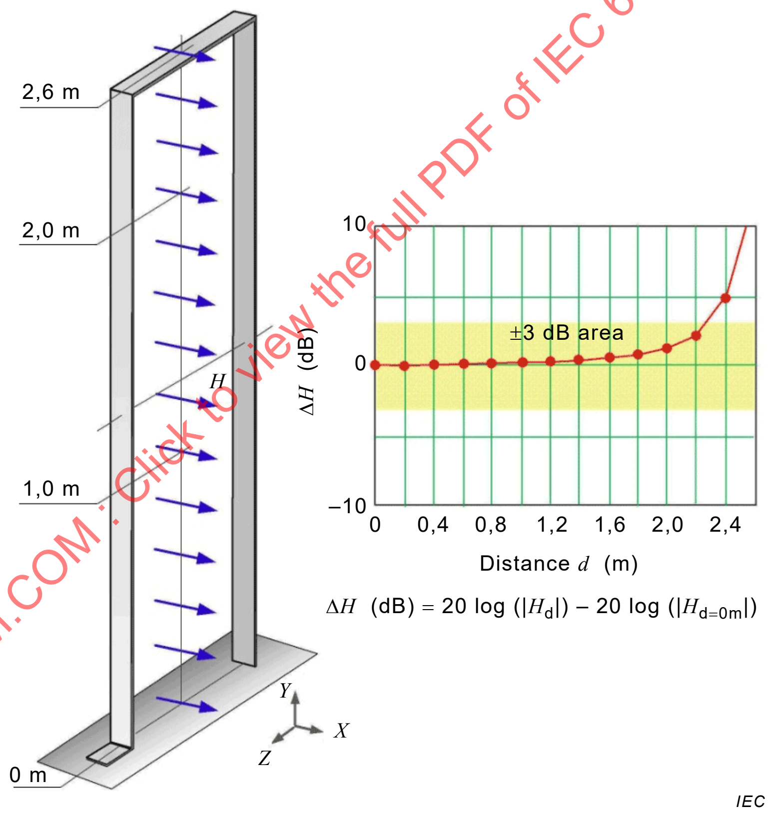


Figure E.8 – Hx–field along the vertical middle line in dB for the 1 m × 2,6 m standard induction coil

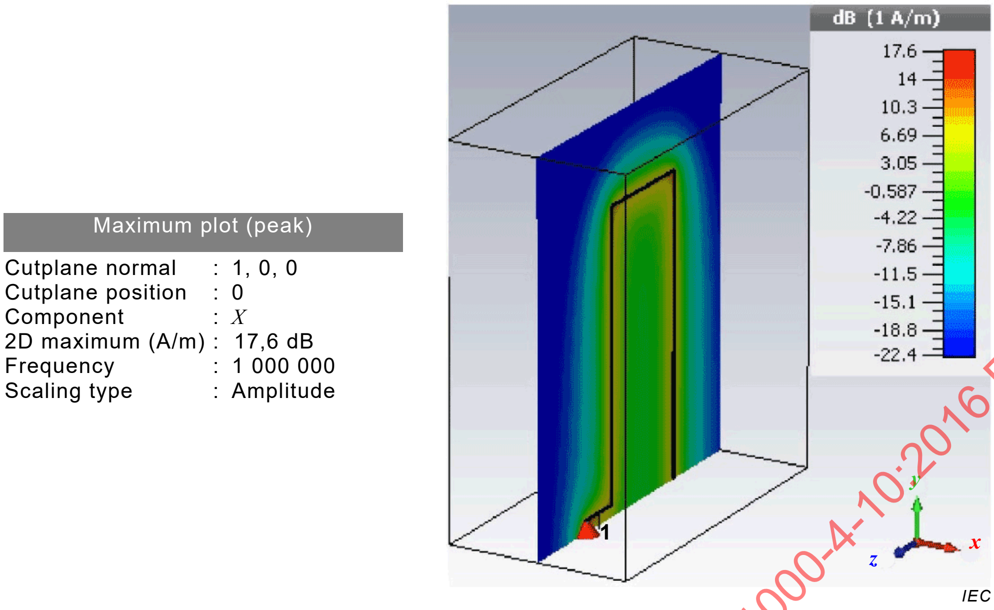


Figure E.9 – Hx–field 2D–plot on y-z plane for the 1 m × 2,6 m standard induction coil

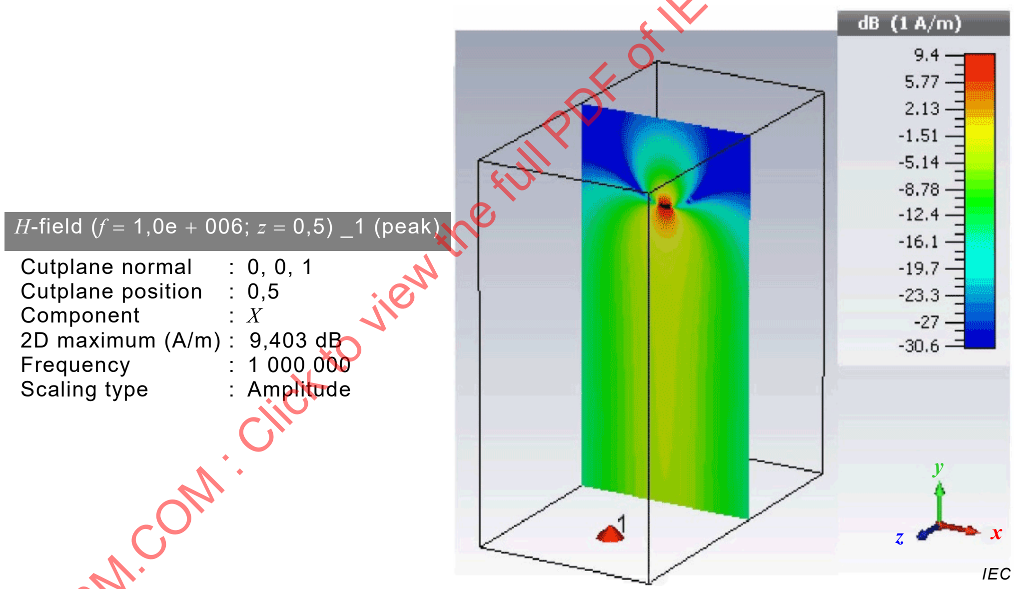


Figure E.10 – Hx–field 2D–plot on x-y plane at z = 0,5 m for the 1 m × 2,6 m standard induction coil

Bibliography

IEC TR 61000-1-6:2012, *Electromagnetic compatibility (EMC) – Part 1-6: General – Guide to the assessment of measurement uncertainty*

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

IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

Partie 4-10: Techniques d'essai et de mesure – Essai d'immunité du champ magnétique oscillatoire amorti

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La Norme internationale IEC 61000-4-10 a été établie par le sous-comité 77B: Phénomènes haute fréquence, du comité d'études 77 de l'IEC: Compatibilité électromagnétique.

Elle constitue la Partie 4-10 de la série IEC 61000. Elle a le statut d'une publication fondamentale en CEM conformément au Guide 107 de l'IEC.

Cette deuxième édition annule et remplace la première édition parue en 1993 et l'Amendement 1:2000. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) nouvelle Annexe A relative à la distribution du champ de bobine d'induction;

b) nouvelle Annexe D relative à l'incertitude de mesure;

c) nouvelle Annexe E pour les simulations numériques;

d) l'étalonnage par la mesure du courant a été abordé dans la présente édition.

Le texte de cette norme est issu des documents suivants:

CDV	Rapport de vote
77B/730/CDV	77B/746A/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Cette publication a été rédigée selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 61000, publiées sous le titre général *Compatibilité électromagnétique (CEM),* peut être consultée sur le site web de l'IEC.

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- reconduite,
- supprimée,
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INTRODUCTION

L'IEC 61000 est publiée en plusieurs parties, conformément à la structure suivante:

Partie 1: Généralités

Considérations générales (introduction, principes fondamentaux)

Définitions, terminologie

Partie 2: Environnement

Description de l'environnement

Classification de l'environnement

Niveaux de compatibilité

Partie 3: Limites

Limites d'émission

Limites d'immunité (dans la mesure où elles ne relèvent pas de la responsabilité des comités de produits)

Partie 4: Techniques d'essai et de mesure

Techniques de mesure

Techniques d'essai

Partie 5: Guide d'installation et d'atténuation

Guide d'installation

Méthodes et dispositifs d'atténuation

Partie 6: Normes génériques

Partie 9: Divers

Chaque partie est à son tour subdivisée en plusieurs parties, publiées soit comme normes internationales, soit comme spécifications techniques ou rapports techniques, dont certaines ont déjà été publiées en tant que sections. D'autres sont publiées avec le numéro de la partie suivi d'un tiret et d'un second chiffre identifiant la subdivision (exemple: IEC 61000-6-1).

La présente partie constitue une norme internationale qui traite des exigences en matière d'immunité et des procédures d'essai qui s'appliquent au "champ magnétique oscillatoire amorti".

COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

**Partie 4-10: Techniques d'essai et de mesure –
Essai d'immunité du champ magnétique oscillatoire amorti**

1 Domaine d'application et objet

La présente partie de l'IEC 61000 spécifie les exigences en matière d'immunité, les méthodes d'essai et la plage des niveaux d'essai recommandés des équipements soumis aux perturbations magnétiques oscillatoires amorties dans les postes moyenne et haute tension.

L'essai défini dans la présente norme s'applique aux équipements destinés à être installés à des emplacements où les phénomènes spécifiés à l'Article 4 sont rencontrés.

La présente norme ne spécifie pas les perturbations provoquées par le couplage capacitif ou inductif sur les câbles ou autres parties de l'installation. L'IEC 61000-4-18, qui porte sur les perturbations conduites, couvre ces aspects.

La présente norme a pour objet d'établir une base commune et reproductible pour évaluer la performance des équipements électriques et électroniques des postes moyenne et haute tension lorsqu'ils sont soumis à des champs magnétiques oscillatoires amortis.

L'essai s'applique principalement aux équipements électroniques destinés à être installés dans des postes haute tension. Les centrales électriques, les installations d'appareillage et les réseaux intelligents peuvent également être concernés par la présente norme et peuvent être pris en compte par les comités de produits.

NOTE Comme indiqué dans le Guide 107 de l'IEC, il s'agit d'une publication fondamentale en CEM destinée à être utilisée par les comités de produits de l'IEC. Comme l'indique également le Guide 107, les comités de produits de l'IEC ont la responsabilité de déterminer si cette norme d'essai d'immunité est appliquée ou non, et si elle l'est, ils ont la responsabilité de déterminer les niveaux d'essai et critères de performances appropriés. Le comité d'études 77 et ses sous-comités sont prêts à coopérer avec les comités de produits dans le cadre de l'évaluation de la valeur des essais d'immunité particuliers pour leurs produits.

La présente norme définit:

– une plage de niveaux d'essai;
– l'équipement d'essai;
– les montages d'essai;
– les procédures d'essai.

2 Références normatives

Les documents suivants sont cités en référence de manière normative, en intégralité ou en partie, dans le présent document et sont indispensables pour son application. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60050 (toutes les parties), *Vocabulaire Électrotechnique International (VEI)* (disponible à l'adresse www.electropedia.org)

3 Termes, définitions et termes abrégés

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions donnés dans l'IEC 60050 ainsi que les suivants s'appliquent.

3.1.1
étalonnage
ensemble des opérations établissant, en référence à des étalons, la relation qui existe, dans les conditions spécifiées, entre une indication et un résultat de mesure

Note 1 à l'article: Cette définition s'appuie sur l'approche "incertitude".

Note 2 à l'article: La relation entre les indications et les résultats de mesure peut être donnée, en principe, dans un diagramme d'étalonnage.

[SOURCE: IEC 60050-311:2001, 311-01-09]

3.1.2
générateur d'ondes oscillatoires amorties
générateur délivrant une oscillation amortie dont la fréquence peut être définie à 100 kHz ou de 1 MHz et dont la constante de temps d'amortissement est de cinq périodes

3.1.3
immunité
aptitude d'un dispositif, d'un appareil ou d'un système à fonctionner sans dégradation en présence d'une perturbation électromagnétique

[SOURCE: IEC 60050-161:1990, 161-01-20]

3.1.4
bobine d'induction
boucle d'induction de forme et de dimensions définies dans laquelle un courant circule, en engendrant un champ magnétique d'uniformité constante dans un volume défini

3.1.5
facteur de bobine d'induction
rapport entre l'excitation magnétique provoquée par une bobine d'induction de dimensions données et la valeur du courant correspondant

Note 1 à l'article: Le champ est mesuré au centre du plan de la bobine, sans tenir compte de l'EUT.

3.1.6
méthode de proximité
méthode d'application du champ magnétique à l'EUT, dans laquelle une bobine de faible induction est déplacée le long du côté de l'EUT de manière à détecter des zones particulièrement sensibles

3.1.7
terre de référence
partie de la Terre considérée comme conductrice, dont le potentiel électrique est pris, par convention, égal à zéro, étant hors de la zone d'influence de toute installation de mise à la terre

[SOURCE: IEC 60050-195:1998, 195-01-01]

3.1.8
système
ensemble d'éléments reliés entre eux associés pour atteindre un objectif déterminé en réalisant une fonction spécifiée

Note 1 à l'article: Le système est considéré comme étant séparé de l'environnement et des autres systèmes extérieurs par une surface imaginaire qui coupe les liaisons entre eux et le système étudié. Par ces liaisons, le système subit les actions de l'environnement ou de systèmes extérieurs, ou bien agit lui-même sur l'environnement ou les systèmes extérieurs.

3.1.9
transitoire, adjectif et nom
se dit d'un phénomène ou d'une grandeur qui varie entre deux régimes établis consécutifs dans un intervalle de temps relativement court à l'échelle des temps considérée

[SOURCE: IEC 60050-161:1990, 161-02-01]

3.1.10
vérification
ensemble des opérations utilisées pour vérifier le système d'essai (par exemple, le générateur d'essai et ses câbles d'interconnexion) et pour démontrer que le système d'essai fonctionne

Note 1 à l'article: Les méthodes utilisées pour la vérification peuvent être différentes de celles utilisées pour l'étalonnage.

Note 2 à l'article: Pour les besoins de la présente norme fondamentale en CEM, cette définition est différente de celle donnée dans l'IEC 60050-311:2001, 311-01-13.

3.2 Abréviations

AE	Auxiliary equipment (équipement auxiliaire)
CEM	Compatibilité électromagnétique
EUT	Equipment under test (équipement en essai)
MU	Measurement uncertainty (incertitude de mesure)
PE	Protective earth (terre de protection)
RGP	Reference ground plane (plan de masse de référence)

4 Généralités

Les champs magnétiques oscillatoires amortis sont générés par la commutation de barres haute tension à l'aide d'isolateurs ou de sectionneurs. Les champs magnétiques auxquels est soumis l'équipement peuvent influencer le bon fonctionnement de celui-ci et des systèmes.

Les essais suivants ont pour objet de démontrer l'immunité de l'équipement lorsqu'il est soumis au champ magnétique oscillatoire amorti qui s'applique à l'emplacement spécifique et aux conditions d'installation de l'équipement (l'équipement situé à proximité de la source de perturbation, par exemple).

La forme d'onde du champ d'essai correspond à une onde oscillatoire amortie (voir la Figure 2). Les caractéristiques sont données en 6.2.2.

Des informations relatives à la fréquence d'oscillation sont données à l'Annexe C.

5 Niveaux d'essais

La plage préférentielle des niveaux d'essais est donnée au Tableau 1.

Tableau 1 – Niveaux d'essai

Niveau	Intensité du champ magnétique oscillatoire amorti A/m (crête)
1	non applicable
2	non applicable
3	10
4	30
5	100
X[a]	spécial

NOTE L'excitation magnétique est exprimée en A/m. 1 A/m correspond à une induction magnétique en espace libre de 1,26 µT.

[a] "X" peut être un niveau supérieur, inférieur ou intermédiaire aux autres niveaux. Ce niveau, ainsi que la durée de l'essai, doit être spécifié dans la spécification correspondante de l'équipement.

Les niveaux d'essai doivent être sélectionnés en fonction des conditions d'installation. Les classes d'installation sont données à l'Annexe B.

6 Instrumentation d'essai

6.1 Généralités

Le système d'essai est composé du générateur d'ondes combinées et de la bobine d'induction pour le montage d'essai du matériel de table et, de plus, d'un plan de masse de référence pour le montage d'essai du matériel posé au sol.

6.2 Générateur d'ondes oscillatoires amorties

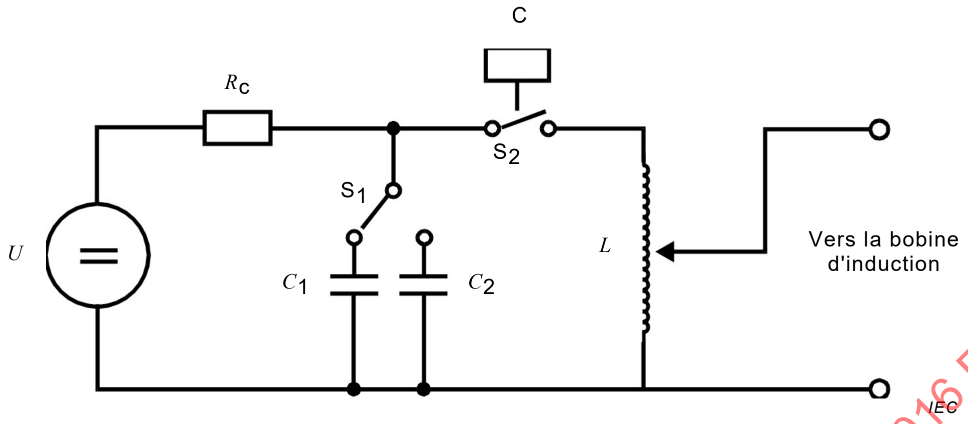
6.2.1 Généralités

Le générateur d'ondes oscillatoires amorties doit être en mesure de délivrer le courant de choc exigé aux bobines d'induction spécifiées en 6.3.

NOTE Pour cette application, une version modifiée d'un générateur d'ondes oscillatoires amorties similaire au générateur mentionné dans l'IEC 61000-4-18 est utilisée comme source de courant.

La forme d'onde est spécifiée comme étant un courant de court-circuit. Par conséquent, elle doit être mesurée avec une bobine d'induction connectée.

Un schéma de circuit simplifié du générateur est donné à la Figure 1.



U:	Source haute tension	R_c:	Résistance de charge
C:	Durée de commande	L:	Bobine du circuit oscillant
S_1	Sélecteur de fréquence	S_2	Sélecteur de durée
C_1, C_2:	Condensateurs du circuit oscillant (commutable de 0,1 MHz à 1 MHz)		

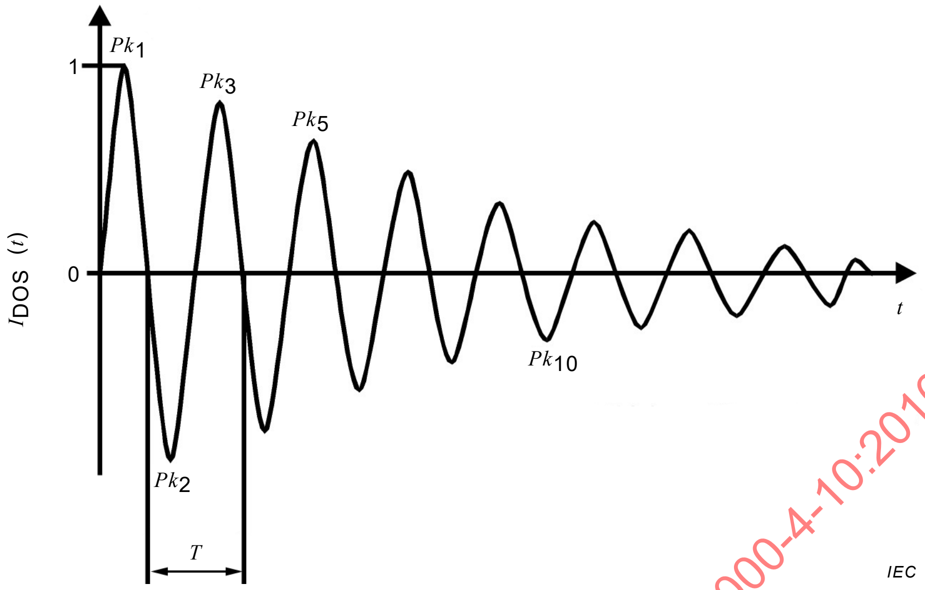
Figure 1 – Schéma simplifié du générateur d'essai produisant le champ magnétique oscillatoire amorti

6.2.2 Caractéristiques de performances du générateur connecté à la bobine d'induction normalisée

Les caractéristiques de performances ci-dessous s'appliquent au générateur connecté à des bobines d'induction normalisées présenté en 6.3.

Période d'oscillation	voir le Tableau 3
Courant dans les bobines (valeur Pk_1)	voir le Tableau 2
Forme d'onde du champ magnétique oscillatoire amorti	voir la Figure 2
Le taux de décroissance D_{r1}, D_{r2}	Pk_5 doit être > 50 % de la valeur Pk_1 et Pk_{10} doit être < 50 % de la valeur Pk_1
Fréquence de répétition $1/T_{rep}$ (voir la Figure 3)	40/s ± 10 % pour 100 kHz et 400/s ± 10 % pour 1 MHz
Durée de l'essai	au moins 2 s
Décalage de phase	pas d'exigence

La fréquence d'oscillation est définie comme étant la réciproque de la période des premier et troisième passages du zéro après la crête initiale. Cette période est appelée T à la Figure 2.



Légende

T = 1 µs (1 MHz) ou 10 µs (0,1 MHz)

Figure 2 – Forme d'onde du courant de court-circuit dans les bobines normalisées

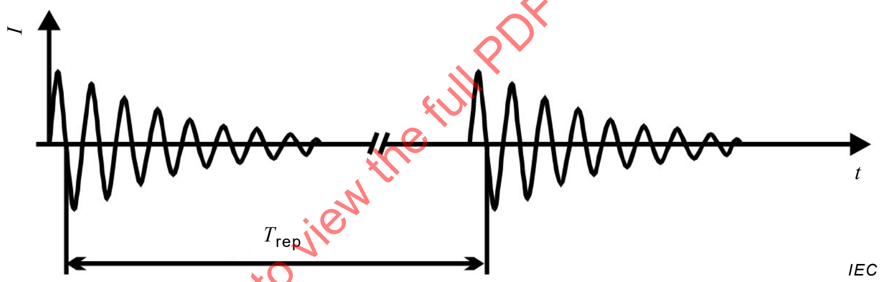


Figure 3 – Forme d'onde du courant de court-circuit présentant le temps de répétition T_{rep}

La formule de la forme d'onde idéale de la Figure 2, $I_{DOS}(t)$, est la suivante:

$$I_{DOS}(t) = K_i \frac{i_1}{KH} \left(\frac{\left(\frac{t}{t_{1h}}\right)^{nh}}{1+\left(\frac{t}{t_{1h}}\right)^{nh} e^{\frac{t}{t_{2h}}}} \right) \sin(\beta t)$$

avec

$$KH = e^{-\frac{t_{1h}}{t_{2h}}\left(nh\frac{t_{2h}}{t_{1h}}\right)^{\frac{1}{nh}}}$$

où les paramètres de la période d'oscillation T = 1 µs sont:

K_i = 1; i_1 = 0,963; t_{1h} = 0,08 µs; t_{2h} = 4,8 µs; nh = 2,1; β = 6,27 × 10^6 rad/s:

et les paramètres de la période d'oscillation T = 10 µs sont:

K_i = 1; i_1 = 0,963; t_{1h} = 0,8 µs; t_{2h} = 48 µs; nh = 2,1; β = 0,627 × 10^6 rad/s;

6.3 Bobine d'induction normalisée

Pour les deux bobines normalisées à une seule spire de 1 m × 1 m et de 1 m × 2,6 m, la distribution du champ est connue et présentée à l'Annexe A. Par conséquent, aucune vérification du champ ni aucun étalonnage ne sont nécessaires, la mesure du courant présentée à la Figure 4 étant suffisante.

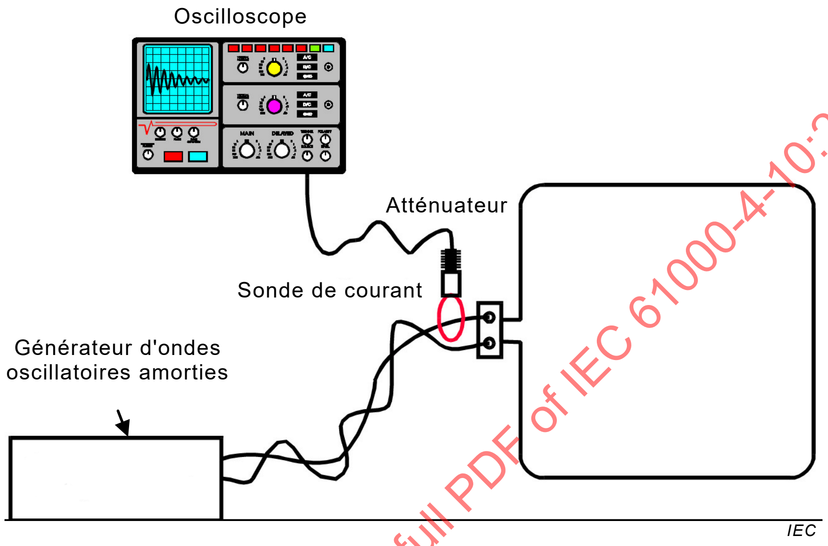


Figure 4 – Exemple de mesure du courant des bobines d'induction normalisées

Cette bobine doit être en cuivre, en aluminium ou en matériau conducteur non magnétique. Sa section et sa conception doivent permettre de lui donner une position stable pendant les essais.

Les caractéristiques des bobines d'induction en fonction de la distribution du champ magnétique sont données à l'Annexe A.

6.4 Etalonnage du système d'essai

Les caractéristiques essentielles du système d'essai doivent être étalonnées par une mesure du courant (voir la Figure 4).

Le courant de sortie doit être vérifié avec le générateur connecté à la bobine d'induction normalisée spécifiée en 6.3. La connexion doit être réalisée par des conducteurs torsadés ou par un câble coaxial de 3 m de long au maximum et présentant une section adaptée.

Les spécifications données au Tableau 3 ne sont pas applicables pour les étalonnages réalisés au niveau d'essai 5 avec la bobine d'induction normalisée de 1 m × 2,6 m connectée. Dans ce cas, l'étalonnage doit être réalisé en utilisant uniquement la bobine d'induction normalisée de 1 m × 1 m.

Les spécifications suivantes données au Tableau 2 et au Tableau 3 doivent être vérifiées.

Tableau 2 – Spécifications de courant de crête du système d'essai

Niveau d'essai	Courant de crête I ± 20 % A	
	Système utilisant une bobine d'induction normalisée de 1 m × 1 m	**Système utilisant une bobine d'induction normalisée de 1 m × 2,6 m**
1	non applicable	non applicable
2	non applicable	non applicable
3	11,1	15,2
4	33,3	45,5
5	111	voir note 2
X	spécial/0,9	spécial/0,66

NOTE 1 Les valeurs 0,9 et 0,66 sont les facteurs de bobine calculés des bobines d'induction normalisées.

NOTE 2 La valeur calculée est de 152. Toutefois, aucun générateur n'est actuellement disponible dans le commerce.

Tableau 3 – Spécifications de forme d'onde du système d'essai

Eléments d'étalonnage	Fréquence d'oscillation	
	100 kHz	**1 MHz**
Période d'oscillation	T = 10 µs ± 1 µs	T = 1 µs ± 0,1 µs
Temps de répétition des impulsions	T_{rep} = 25 ms ± 2,5 ms	T_{rep} = 2,5 ms ± 0,25 ms
Taux de décroissance d'une impulsion	$D_{r1} = \lvert I(PK_5) \div I(PK_1) \rvert$ > 50 % $D_{r2} = \lvert I(PK_{10}) \div I(PK_1) \rvert$ < 50 %	$D_{r1} = \lvert I(PK_5) \div I(PK_1) \rvert$ > 50 % $D_{r2} = \lvert I(PK_{10}) \div I(PK_1) \rvert$ < 50 %

Les étalonnages doivent être réalisés à tous les niveaux qui sont utilisés par les laboratoires.

Les étalonnages doivent être effectués avec une sonde de courant et un oscilloscope ou autre instrumentation de mesure équivalente d'une largeur de bande minimale de 10 MHz.

7 Montage d'essai

7.1 Équipement d'essai

L'équipement suivant fait partie intégrante du montage d'essai:

– équipement en essai (EUT);
– équipement auxiliaire (AE), si exigé;
– câbles (de type et de longueur spécifiés);
– générateur d'ondes oscillatoires amorties;
– bobine d'induction normalisée;
– plan de masse de référence dans le cas des équipements d'essai posés au sol.

7.2 Vérification de l'instrumentation d'essai

La vérification a pour objet de s'assurer que le montage d'essai fonctionne correctement. Le montage d'essai comprend:

– le générateur d'ondes oscillatoires amorties;
– la bobine d'induction;
– les câbles d'interconnexion de l'équipement d'essai.

Pour vérifier que le système fonctionne correctement, il convient de vérifier le signal suivant:

– impulsion présente aux bornes de la bobine d'induction normalisées.

Il est suffisant de vérifier que l'impulsion est présente à tous les niveaux en utilisant un équipement de mesure adapté (une sonde de courant, un oscilloscope, par exemple).

NOTE Les laboratoires d'essai peuvent définir une valeur de référence de contrôle interne attribuée à cette procédure de vérification.

7.3 Montage d'essai pour EUT de table

Les EUT de table doivent être placés sur une table non conductrice. La bobine d'induction normalisée de 1 m × 1 m peut être utilisée pour soumettre à essai les EUT dont les dimensions atteignent 0,6 m × 0,6 m × 0,5 m (L × l × H). La bobine d'induction normalisée de 1 m × 2,6 m peut être utilisée pour soumettre à essai les EUT dont les dimensions atteignent 0,6 m × 0,6 m × 2 m (L × l × H).

La bobine d'induction doit être positionnée dans trois orientations orthogonales.

Lorsqu’un EUT ne s'intègre pas dans la bobine d'induction de 1 m × 2,6 m, la méthode de proximité (voir 7.4) doit être appliquée.

L'impact des câbles ne doit pas être optimisé pendant cet essai. La proximité des câbles avec la bobine d'induction peut avoir un impact sur les résultats, par conséquent, les câbles doivent cheminer de manière à réduire le plus possible cet impact. La dimension de câblage limitée doit être incorporée dans la détermination de la taille maximale de l'EUT qui peut être soumis à essai.

Un plan de masse de référence n'est pas exigé sous l'EUT (voir la Figure 5 ci-dessous). La bobine d'induction doit être placée à au moins 0,5 m des surfaces conductrices (les parois et le plancher d'une enceinte blindée, par exemple).

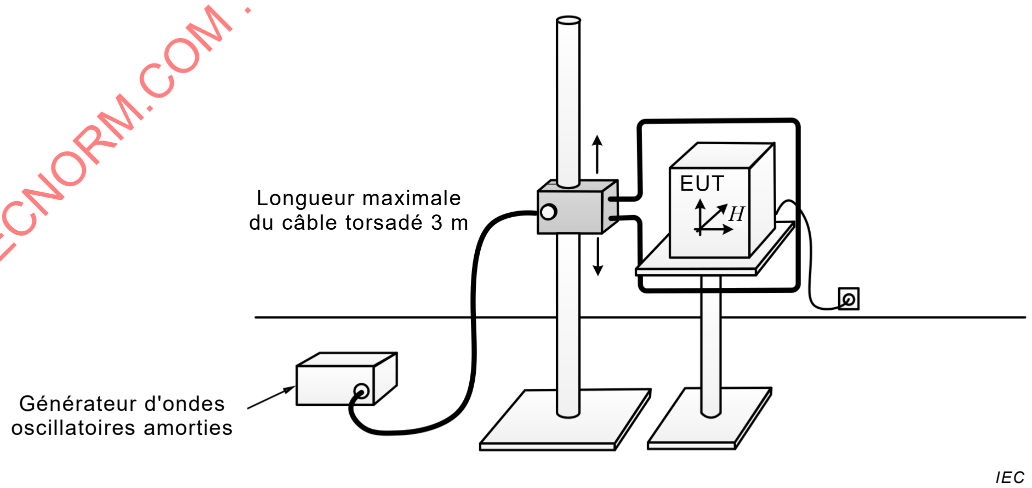


Figure 5 – Exemple de montage d'essai pour équipement de table