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REDLINE VERSION

INTERNATIONAL STANDARD

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –
Part 4-9: Testing and measurement techniques – ~~Pulse~~ Impulse magnetic field immunity test

colour inside

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-9: Testing and measurement techniques – Impulse magnetic field immunity test

FOREWORD

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

International Standard IEC 61000-4-9 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms Part 4-9 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 B on induction coil field distribution;
b) new Annex D on measurement uncertainty;
c) new Annex E on mathematical modeling of surge waveform;
d) new Annex F on characteristics using two standard induction coils;
e) new Annex G on 3D numerical simulations;
f) coil factor calculation and calibration using current measurement have been addressed in this edition.

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

CDV	Report on voting
77B/728/CDV	77B/745A/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- withdrawn,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 "pulse magnetic field".

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-9: Testing and measurement techniques – ~~Pulse~~ Impulse magnetic field immunity test

1 Scope and object

This part of IEC 61000 ~~relates to~~ specifies the immunity requirements, test methods, and range of recommended test levels for equipment~~, only under operational conditions,~~ subjected to ~~pulse~~ impulse magnetic disturbances mainly ~~related to~~ encountered in:

– industrial installations,
– power plants,
– railway installations,
– 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 4.

This standard does not consider disturbances due to capacitive or inductive coupling in cables or other parts of the field installation. Other IEC standards dealing with conducted disturbances cover these aspects.

The object of this standard is to establish a common ~~and reproducible basis~~ reference for evaluating the ~~performance~~ immunity of electrical and electronic equipment ~~for household, commercial and industrial applications~~ when subjected to ~~pulse~~ impulse magnetic fields. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.

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:

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

The task of the described laboratory test is to find the reaction of the equipment under test (EUT) under specified operational conditions to impulse magnetic fields caused by switching and lightning effects.

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)

~~IEC 60060-2:1973, *High-voltage test techniques – Part 2: Test procedures*~~

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

~~IEC 60469-1:1987, *Pulse techniques and apparatus – Part 1: Pulse terms and definitions*~~

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
combination wave generator
CWG
generator with 1,2/50 μs open-circuit voltage waveform and 8/20 μs short-circuit current waveform

Note 1 to entry: This definition is abbreviated from the equivalent definition in IEC 61000-4-5.

Note 2 to entry: This note applies to the French language only.

3.1.3
duration
$\boldsymbol{T_d}$
<surge current for 8/20 μs> virtual parameter defined as the time interval between the instant at which the surge current rises to 0,5 of its peak value, and then falls to 0,5 of its peak value (T_w), multiplied by 1,18

$T_d = 1{,}18 \times T_w$

SEE: Figure 2.

3.1.4
front time
$\boldsymbol{T_f}$
<surge current> virtual parameter defined as 1,25 times the interval T_r between the instants when the impulse is 10 % and 90 % of the peak value

SEE: Figure 2.

3.1.5
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]

3.1.6
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 volume~~ uniformity in a defined volume

3.1.7
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.

3.1.8
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

3.1.9
reference ground plane ~~**(GRP)**~~
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]~~

3.1.10
rise time
T_r
interval of time between the instants at which the instantaneous value of an impulse first reaches 10 % value and then 90 % value

SEE: Figure 2.

3.1.11
surge
transient wave of electrical current, voltage or power propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease

3.1.12
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.

3.1.13
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]

3.1.14
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.

~~**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)~~

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

3.2 Abbreviated terms

AE	Auxiliary equipment
CDN	Coupling/decoupling network
CWG	Combination wave generator
EFT/B	Electrical fast transient/burst
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
EUT	Equipment under test
MU	Measurement uncertainty
RGP	Reference ground plane

4 General

The magnetic fields to which equipment is subjected may influence the reliable operation of equipment and systems.

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

Pulse magnetic fields are generated by lightning ~~strokes~~ strikes on buildings and other metal structures including aerial masts, earth conductors and earth networks and by initial fault~~s~~ transients in low, medium and high voltage electrical systems.

In high voltage sub-stations, ~~a pulse~~ an impulse magnetic field may also be generated by the switching of high voltage bus-bars and lines by circuit breakers.

The test is mainly applicable to electronic equipment to be installed in electrical generation and distribution plants as well as in ~~telecontrol~~ their control centres. It is not relevant for distribution network equipment (e.g. transformers, power lines).

Product committees may consider other ~~possible~~ applications.

~~The test field waveform is that of the standard current pulse, waveform 6,4/16 µs.~~

~~NOTE The waveform 6,4/16 µs according to IEC 60469-1 corresponds to the 8/20 µs of IEC 60060-2.~~

5 Test levels

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

Table 1 – Test levels

Level	Pulse magnetic field strength A/m (peak)
1	not applicable
2	not applicable
3	100
4	300
5	1000
X[a]	special

NOTE The magnetic field strength is expressed in A/m; 1 A/m corresponds to a free space ~~induction~~ 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.
The level ~~can be given in the product~~ 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 test levels shall be selected according to the installation conditions. Classes of installation are given in Annex C.

~~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 m^{-1} (1 m standard coil for testing table-top or~~

~~small equipment) to 0,66 m⁻¹ (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 non-repetitive (single shot) pulse current generator with characteristics as follows:~~

~~*Specifications*~~

~~Rise time:~~	~~6,4 μs ± 30 %~~
~~Duration:~~	~~16 μs ± 30 %~~
~~Output current range:~~	~~100 A to 1 000 A, divided by the coil factor~~
~~Polarity:~~	~~positive and negative~~
~~Phase relationship with the power frequency:~~	~~synchronizable from 0° to 360° with 10° steps~~
~~Synchronization:~~	~~triggerable by external signal~~

~~A standard current pulse generator, e.g. the surge hybrid generator (waveform 1,2/50 – 6,4/16 μs), may be used.~~

~~NOTE The output current range for the standard coil is from 120 A to 1 200 A peak.~~

~~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;~~
- ~~rise time;~~
- ~~duration.~~

~~A 1,8 mm wire diameter (2,5 mm²) should be used for the loop for short-circuit current operation; however, the mechanical rigidity should be taken into account.~~

~~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.~~

~~A same coil is suitable for the generation of the magnetic fields considered in this standard; it may be a *"single turn"* coil and shall have a suitable current capability, as may be necessary for the selected test level.~~

~~Multi-turn coils may be used in order to have a lower testing current.~~

~~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 fields over the whole volume of the EUT's *(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, watthour 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 EUT's.~~
- ~~The double coil (Helmholtz coil) shall comprise 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 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 EUT's, 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 corresponding to the pulse 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 pulse test of the present standard.~~

~~The calibration procedure shall be carried out with the test generator and induction coil.~~

~~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 of 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 combination 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 Combination wave generator

6.2.1 General

For this application, the combination wave generator is used as a current source.

NOTE The combination wave generator specified in this standard has identical wave shape definitions to the ones given in IEC 61000-4-5.

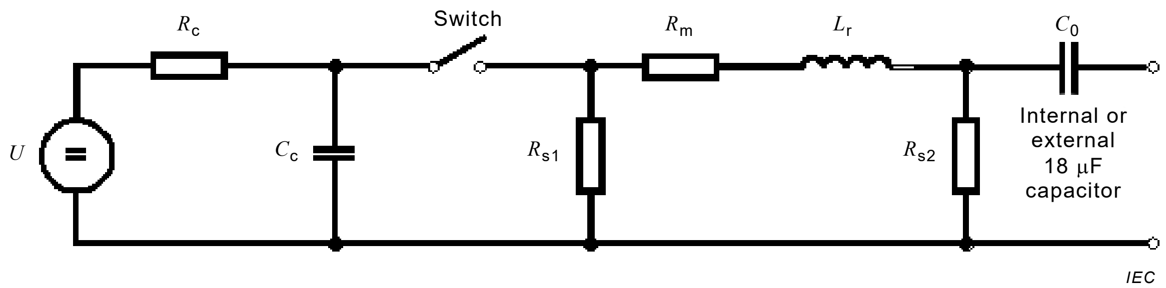
Therefore only the 8/20 µs waveform is relevant. The combination wave generator shall be able to deliver the required impulse current to the induction coils specified in 6.3.

The waveform is specified as a short-circuit current and therefore shall be measured without the induction coil connected.

This generator is intended to generate a surge having:

- a short-circuit current front time of 8 µs;
- a short-circuit current duration of 20 µs.

A simplified circuit diagram of the generator is given in Figure 1. The values for the different components R_{S1}, R_{S2}, R_m, L_r, and C_c are selected so that the generator delivers an 8/20 µs current surge into a short-circuit.



Key

U	High-voltage source
R_c	Charging resistor
C_c	Energy storage capacitor
R_s	Impulse duration shaping resistors
R_m	Impedance matching resistor
L_r	Rise time shaping inductor
C_o	Internal or external 18 µF capacitor

Figure 1 – Simplified circuit diagram of the combination wave generator

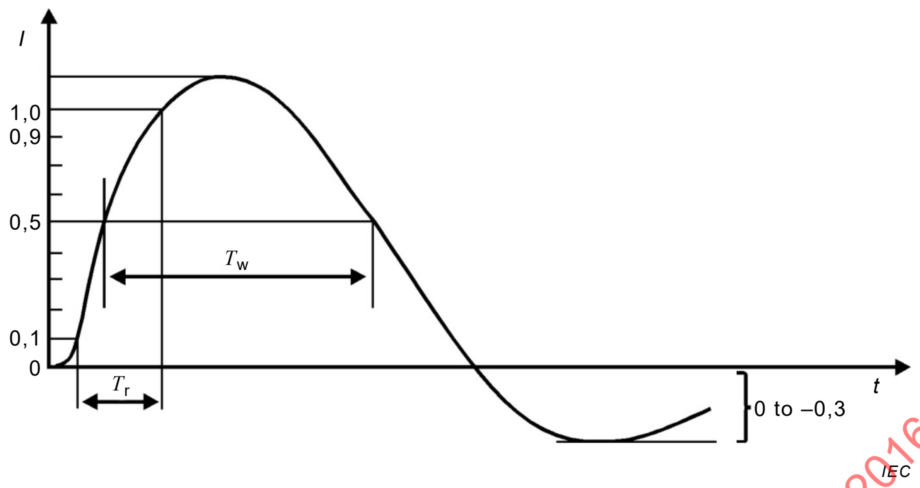
6.2.2 Performance characteristics of the generator

Polarity	positive and negative
Phase shifting	in a range between 0° to 360° relative to the phase angle of the a.c. line voltage to the EUT with a tolerance of ± 10°
Repetition rate	1 per minute or faster
Short-circuit peak output current	100 A to 1 000 A or the required test level divided by the coil factor
Waveform of the surge current	see Table 2 and Figure 2
Short-circuit peak output current tolerance	± 10 %

Table 2 – Definitions of the waveform parameters 8/20 µs

	Front time T_f µs	**Duration T_d** µs
Short-circuit current	$T_f = 1{,}25 \times T_r = 8 \pm 20$ %	$T_d = 1{,}18 \times T_w = 20 \pm 20$ %

A generator with floating output shall be used.



Front time: T_f= 1,25 × T_r = 8 µs ± 20 %

Duration: T_d = 1,18 × T_w = 20 µs ± 20 %

NOTE 1 The value 1,25 is the reciprocal of the difference between the 0,9 and 0,1 thresholds.

NOTE 2 The value 1,18 is derived from empirical data.

Figure 2 – Waveform of short-circuit current (8/20 µs) at the output of the generator with the 18 µF capacitor in series

6.2.3 Calibration of the generator

If a current transformer (probe) is used to measure short-circuit current, it should be selected so that saturation of the magnetic core does not take place. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz. The calibration shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with a bandwidth of not less than 1 MHz. The calibration shall be performed for all test levels, which are applied for testing.

The characteristics of the generator shall be measured through an external capacitor of 18 µF in series with the output, under short-circuit conditions. If the 18 µF capacitor is implemented in the generator, no external 18 µF capacitor is required for calibration.

All performance characteristics stated in 6.2.2, with the exception of phase shifting, shall be met at the output of the generator.

6.3 Induction coil

6.3.1 Field distribution

For the two single-turn standard coils of 1 m × 1 m and 1 m × 2,6 m, the field distribution is known and shown in Annex B. Therefore, no field verification or field calibration is necessary; the current measurement as shown in Figure 3 is sufficient.

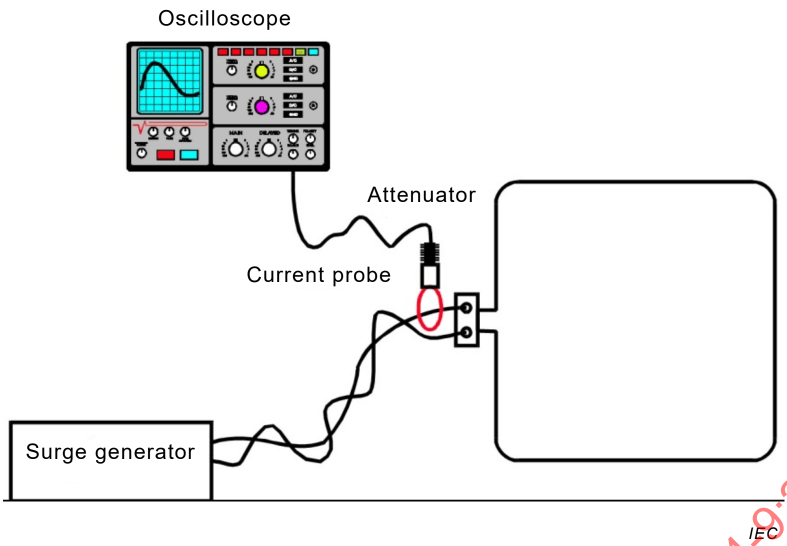


Figure 3 – Example of a current measurement of standard induction coils

Other coils of different dimensions may be used for an EUT which does not fit inside either of the two standard coils. In these cases, the field distribution shall be determined by measurement or calculation (see Annex A).

6.3.2 Characteristics of the standard induction coils of 1 m × 1 m and 1 m × 2,6 m

The standard 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 tolerance of the standard coils is ±1 cm, measured between the centre lines (centre of the cross-section). The characteristics of induction coils with respect to the magnetic field distribution are given in Annex B.

6.4 Calibration of the test system

The essential characteristics of the test system shall be calibrated by a current measurement (see Figure 3).

The output current shall be verified with the generator connected to the standard induction coil specified in 6.2.1 for all applicable test levels. In order to comply with the specifications given in Table 3 and Table 4, an external capacitor (e.g. 18 μF) in series may be required. The capacitor may be incorporated in the generator. The connection shall be realized by twisted conductors or a coaxial cable of up to 3 m length and of suitable cross-section.

The following specifications given in Table 3 and Table 4 shall be verified.

Table 3 – Specifications of the waveform time parameters of the test system

	Front time T_f	Duration T_d
System using 1 m × 1 m standard induction coil	$T_f = 1{,}25 \times T_r = 8\ \mu s\ ^{+2{,}4}_{-0{,}8}\ \mu s$	$T_d = 1{,}18 \times T_w = 20\ \mu s\ ^{+6}_{-2}\ \mu s$
System using 1 m × 2,6 m standard induction coil	$T_f = 1{,}25 \times T_r = 8\ \mu s\ ^{+3{,}2}_{-0{,}8}\ \mu s$	$T_d = 1{,}18 \times T_w = 20\ \mu s\ ^{+8}_{-2}\ \mu s$

Table 4 – Specifications of the waveform peak current of the test system

Test level	Peak current I ± 10 % 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	111	152
4	333	453
5	1 111	1 515
X[a]	special/0,9	special/0,66

NOTE The values 0,9 and 0,66 are the calculated coil factors of standard induction coils as described in A.2.3 (see Annex A).

[a] "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.

If a current transformer (probe) is used to measure short-circuit current it should be selected so that saturation of the magnetic core does not take place. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz. The calibration shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with a bandwidth of not less than 1 MHz.

7 Test setup

7.1 Test equipment

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

– equipment under test (EUT);

– auxiliary equipment (AE) when required;

– cables (of specified type and length);

– combination wave generator (CWG) with an internal/external (e.g. 18 μF) capacitor;

~~– test generator;~~

~~– termination network, back filter.~~

– induction coil;

– reference ground plane ~~(GRP)~~ 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 a 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 combination 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:

– surge impulse present at the induction coil terminals.

It is sufficient to verify that the surge 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 impulse magnetic field applied to a table-top EUT

Table-top EUTs shall be placed on a non-conductive table. The 1 m × 1 m 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 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 × 2,6 m, either the proximity method (see 7.4) can be used or larger induction coils may be constructed to suit the dimensions of the EUT for different field orientation of the magnetic field.

NOTE If it is impractical to construct coils for very large equipment, the proximity method is the only suitable test method.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the loop antenna 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 EUT that can be tested.

An RGP is not required below the EUT (see Figure 4 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.

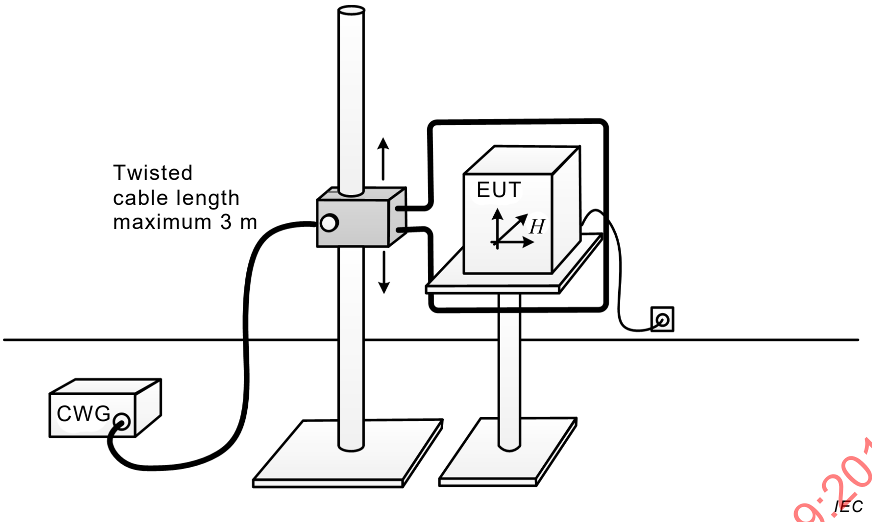


Figure 4 – Example of test setup for table-top equipment showing the vertical orthogonal plane

7.4 Test setup for impulse magnetic field applied to a floor standing EUT

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

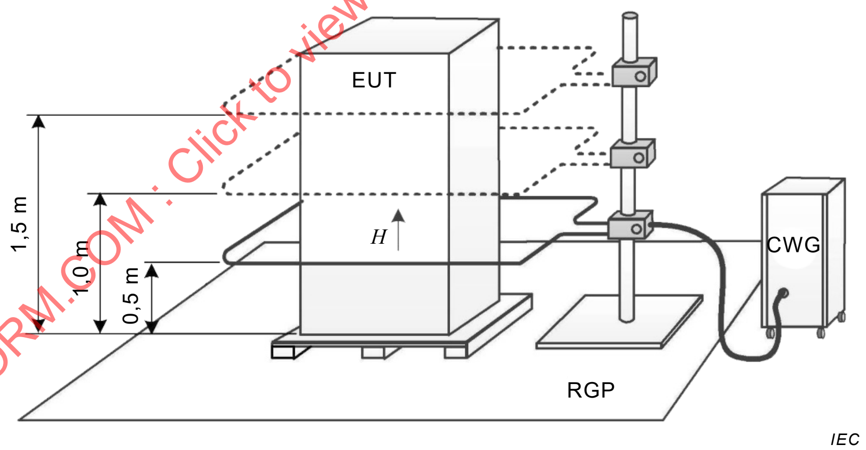


Figure 5 – Example of test setup for floor standing equipment showing the horizontal orthogonal plane

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. The distance between the positions shall be (0,5 ± 0,05) m. Figure 5 indicates that three positions have to be tested. In any case, the induction coil shown in Figure 5 shall not be placed below 0,5 m. Figure 6 shows an example for testing with a vertical orthogonal plane.

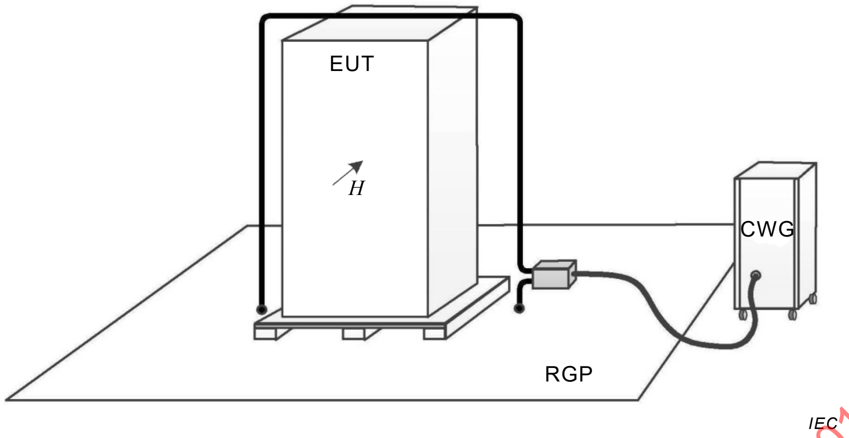


Figure 6 – Example of test setup for floor standing equipment showing the vertical orthogonal plane

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, either the proximity method (see Figure 7 and 7.5 for more detailed information) can be used or larger induction coils may be constructed to suit the dimensions of the EUT for a different field orientation of the magnetic field (see Annex A).

If it is impractical to construct coils for very large equipment, the proximity method is the only suitable test method. Product committees may select either the proximity method or use a suitable coil.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the loop antenna 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 EUT that can be tested.

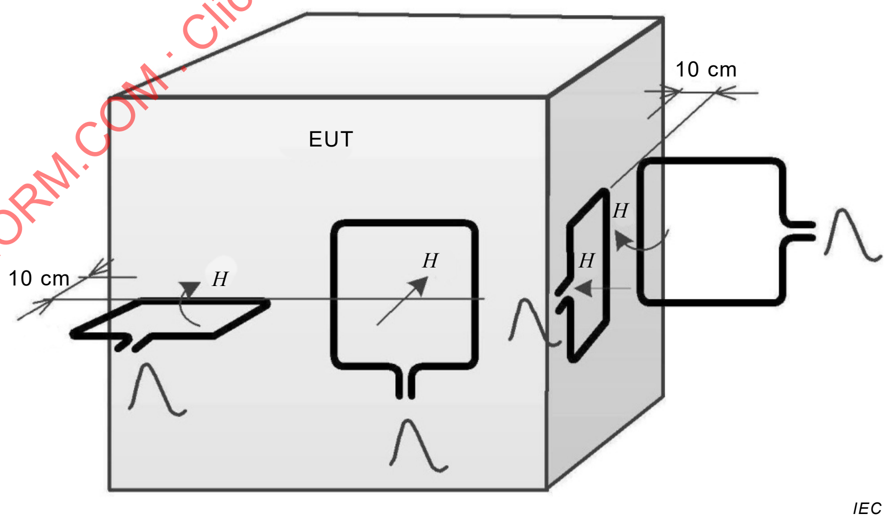


Figure 7 – Example of test setup using the proximity method

7.5 Test setup for impulse magnetic 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 may be the only practical test method without the RGP in place. Figure 7 gives an example for a test setup for in-situ testing. The 1 m × 1 m standard induction coil shall be used when examining EUTs using the proximity method. Furthermore 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 centre of the standard induction coil.

Testing of table top equipment according to 7.3 may also be performed but this is not the preferable test method.

8 Test procedure

8.1 General

The test procedure ~~shall~~ includes:

– the verification of the test instrumentation according to 7.2;
– ~~verification~~ the establishment of the laboratory reference conditions;
– ~~preliminary verification~~ the 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 % 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

~~The test shall be carried out on the basis of a test plan including verification of the performances of the EUT as defined in the technical specification.~~

~~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 at least 5 pulses of positive and 5 pulses of negative polarity.~~

~~The time interval between pulses shall be no less than 10 s.~~

~~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.~~

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;
- number of impulses (for each orthogonal orientation):

  number of impulses unless otherwise specified by the relevant standard:

  – for d.c. powered EUT, five positive and five negative impulses;

  – for single-phase a.c. powered EUT, 20 positive and 20 negative impulses without phase synchronization;
  – for three-phase a.c. powered EUT, 20 positive and 20 negative impulses without phase synchronization;
- impulse repetition rate not less than one impulse per minute (product committees may specify this repetition rate);
- representative operating conditions of the EUT;
- three orthogonal orientations of the magnetic field in case of table-top equipment;
- three orientations of the magnetic field in case of floor standing equipment;
- locations of the induction coil relative to the EUT (test points).

For most products, phase synchronization may not be appropriate; therefore product committees should decide on the need of phase synchronization for their products.

NOTE 1 The application of tests with different phase angles may be more critical for equipment with inverter technology.

NOTE 2 Special safety considerations may be needed when using the generator's CDN output.

9 Evaluation of test results ~~and test report~~

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.

~~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:~~

~~1) normal performance within the specification limits;~~

~~2) temporary degradation or loss of function or performance which is self-recoverable;~~

~~3) temporary degradation or loss bf function or performance which requires operator intervention or system reset;~~

~~4) degradation or loss of function which is not recoverable due to damage of equipment(components) or software, or loss of data.~~

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.~~

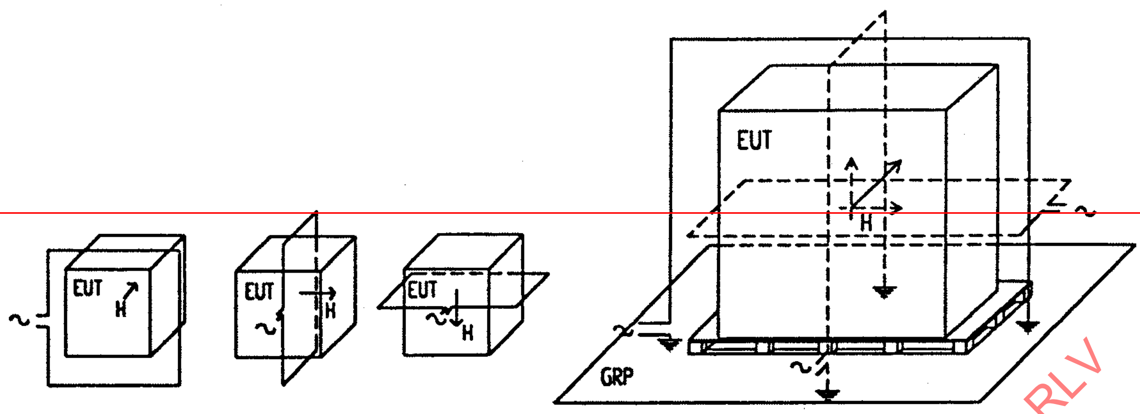
~~For these conditions it shall be verified that the equipment is able to recover its operative capabilities by itself at the end of the test; the time interval during which the equipment has lost its functional capabilities shall be therefore recorded.~~
~~These verifications are binding for the definitive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

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

10 Test report

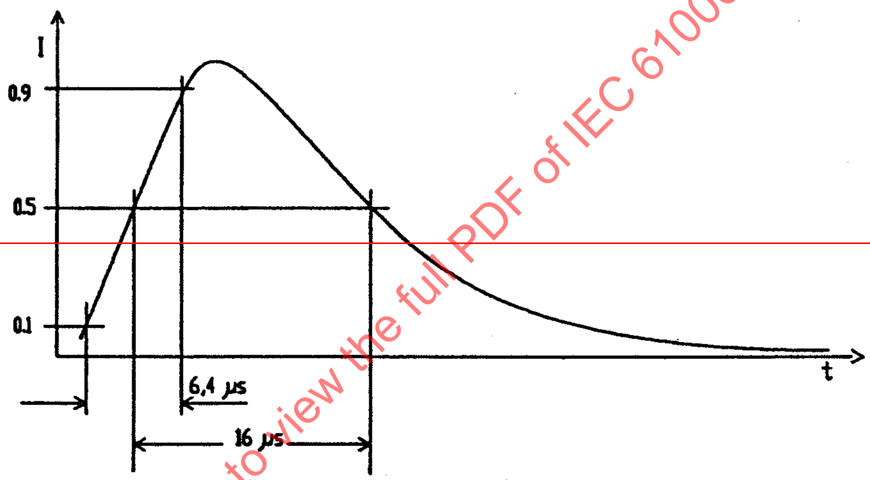
The test report shall contain all the information necessary to reproduce the test. In particular, the following shall be recorded:

- the items specified in the test plan required by Clause 8 of this standard;
- 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;
- performance level defined by the manufacturer, requestor or purchaser;
- 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.

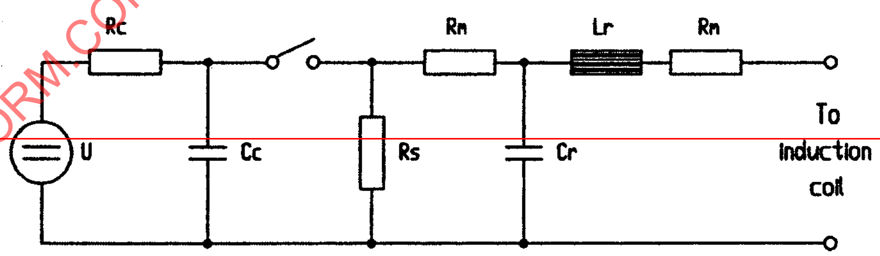


~~Table-top equipment~~ ~~Floor-standing equipment~~

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



~~**Figure 2 – Current waveform of the test generator for pulse magnetic field (6,4/16 µs)**~~

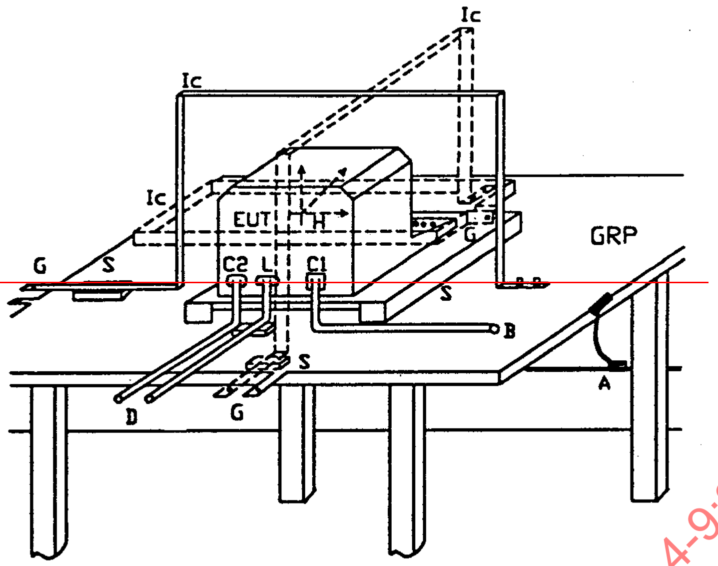


~~U: High voltage source~~ ~~Lr: Rise time shaping resistor~~

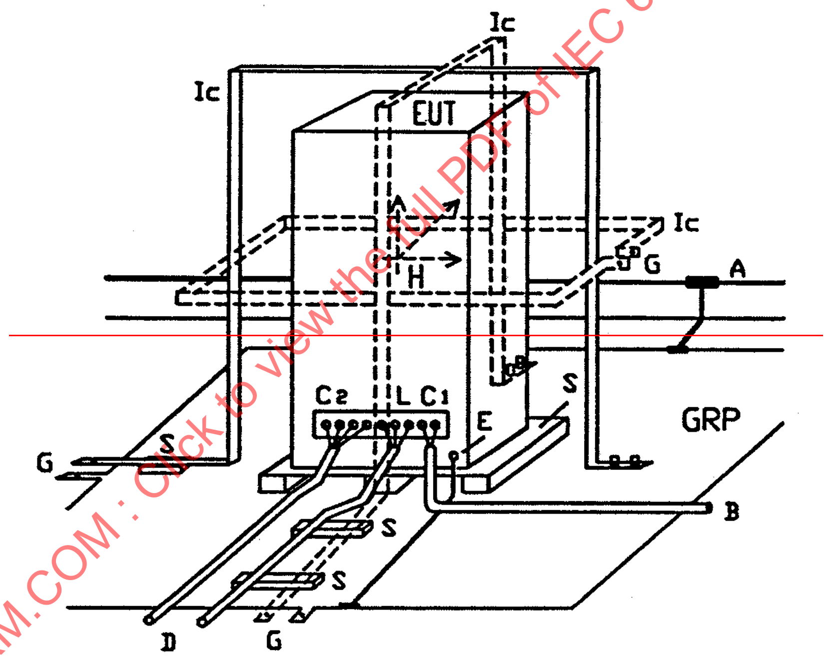
~~Rc: Charging resistor~~ ~~Rm: Impedance matching resistor~~

~~Cc: Energy storage capacitor~~ ~~Rs1, Rs2: Pulse duration shaping resistors~~

~~**Figure 3 – Schematic circuit of the test generator for pulse magnetic field (6,4/16 µs)**~~



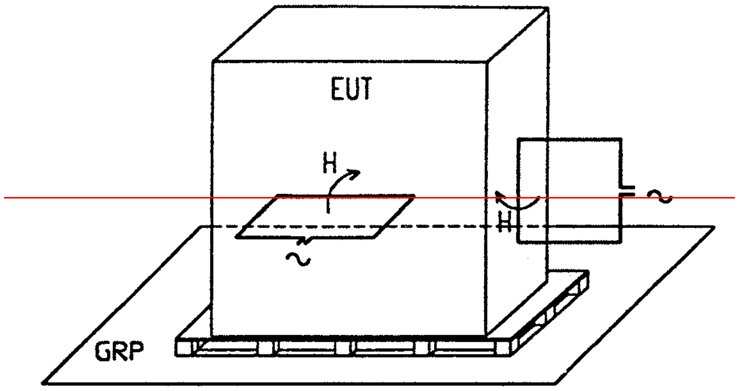
~~**Figure 4 – Example of test set-up for table-top equipment**~~



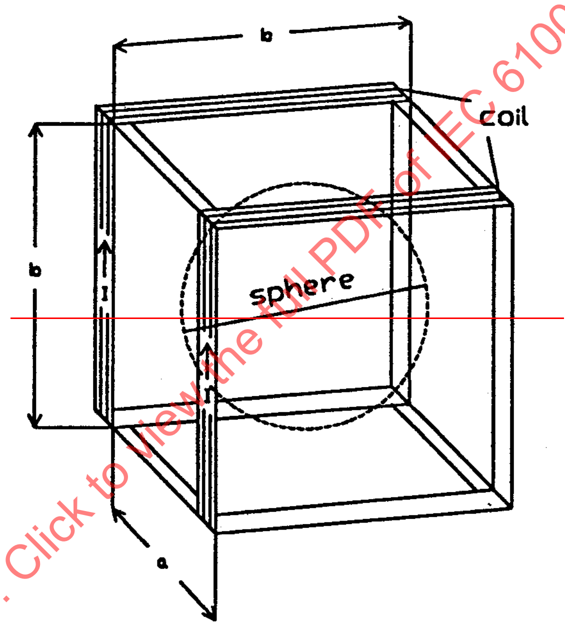
~~**Figure 5 – Example of test set-up for floor-standing equipment**~~

~~*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~~ informative)

Characteristics of non standard induction coils ~~calibration method~~

A.1 General

When an EUT does not fit into standard induction coils, either the proximity method may be used or non standard induction coils may be used. Non standard coils are constructed to accommodate the dimensions of the EUT for the different orientations of the magnetic field.

Note that larger induction coils give repeatable results, but it may not be practical to construct very large coils. The maximum dimensions of non standard induction coils are determined by whether the waveform requirements of the 1 m × 2,6 m coil can be achieved. The proximity method may give useful but not necessarily reproducible results.

NOTE Due to the possible large dimensions of EUTs, the coils can be made of "C" or "T" cross-sectional shape in order to have sufficient mechanical rigidity.

A.2 Determination of the coil factor

A.2.1 General

The induction coil factor shall be determined by measurement or 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 measurement

A.2.2.1 General

In order to compare the test results from different coils, the induction coil factor shall be measured in a free space condition without an EUT.

A magnetic field sensor of adequate sensitivity shall be used to measure the magnetic field strength H generated by the induction coil.

The field sensor should be positioned at the centre of the induction coil and with suitable orientation to detect the maximum value of the field. The current I in the induction coil shall be measured and adjusted to obtain a field strength within the measurement range of the magnetic field sensor. The coil factor, k_{CF}, is obtained as $k_{CF} = H/I$.

A.2.2.2 Coil factor measurement for table-top equipment

The following procedure should be carried out:

The induction coil shall be positioned at a minimum of 1 m from conductive or magnetic structures. Insulating material may be used to support the induction coil. The induction coil is connected to an a.c. source. The measurement can be carried out at any frequency (e.g. 50 Hz or 60 Hz).

A.2.2.3 Coil factor measurement for floor standing equipment

The following procedure should be carried out:

The induction coil should be positioned on the RGP, which may form one side of the coil. Except for the RGP, all other conductive or magnetic structures shall be at least 1 m from the coil. Insulating material may be used to support the induction coil. The induction coil shall be connected to an a.c. source. The measurement shall be carried out at power frequency.

A.2.3 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

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

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 inductor 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 $b = 3 \times a$.

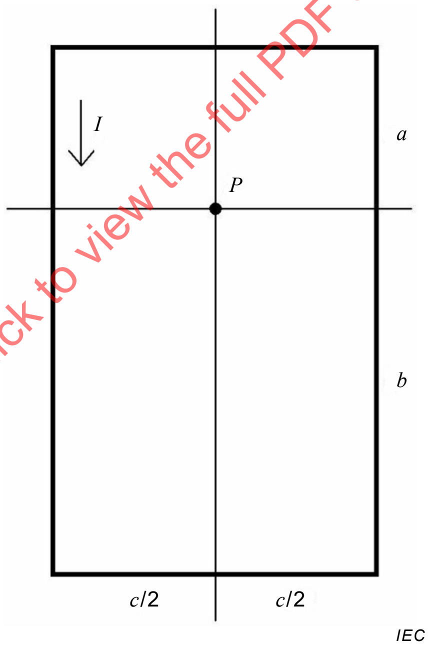


Figure A.1 – Rectangular induction coil with sides $a + b$ and c

A.3 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 field measurement mentioned in A.2.2.1 is also applicable for large non standard induction coils. The measurement of the magnetic field may be done with a measurement system comprising ~~wide band~~ calibrated sensors ~~(10 MHz minimum bandwidth, available in the market) and recording instruments e.g. transient recorders or storage oscilloscopes~~, for example a "Hall effect" or multi-turn loop sensors with a diameter of at least one order of magnitude smaller than the induction coil and a power frequency narrow band instrument. The maximum EUT volume is limited by the +3 dB isoline in the x-y plane and by the ±3 dB isolines in the x-z plane.

~~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, because it is a characteristic parameter of the induction coil; it is therefore applicable for the evaluation of magnetic field at power frequency and other frequencies 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.~~

A.4 Verification of non standard induction coils

The measurement may be carried out by injecting the power frequency current into the induction coil and measuring the magnetic field using sensors placed at the geometrical centre of the coil as shown in Figure A.2.

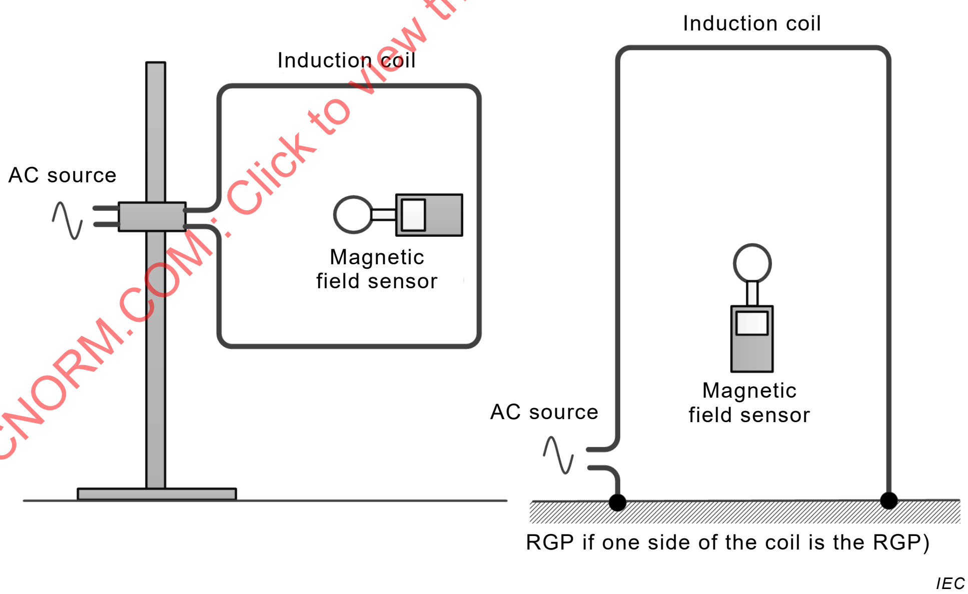


Figure A.2 – Example of verification setup for non standard induction coils

The induction coil factor can be calculated from equation (A.1) if the largest cross-section dimension of the coil inductor is not more than 0,02 of the shortest side of the coil.

If one side of the coil is the RGP, an additional source of uncertainty is the finite size of the RGP. This can be evaluated through the relative deviation between the coil factors calculated assuming the presence and absence of an infinite size RGP.

~~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).~~

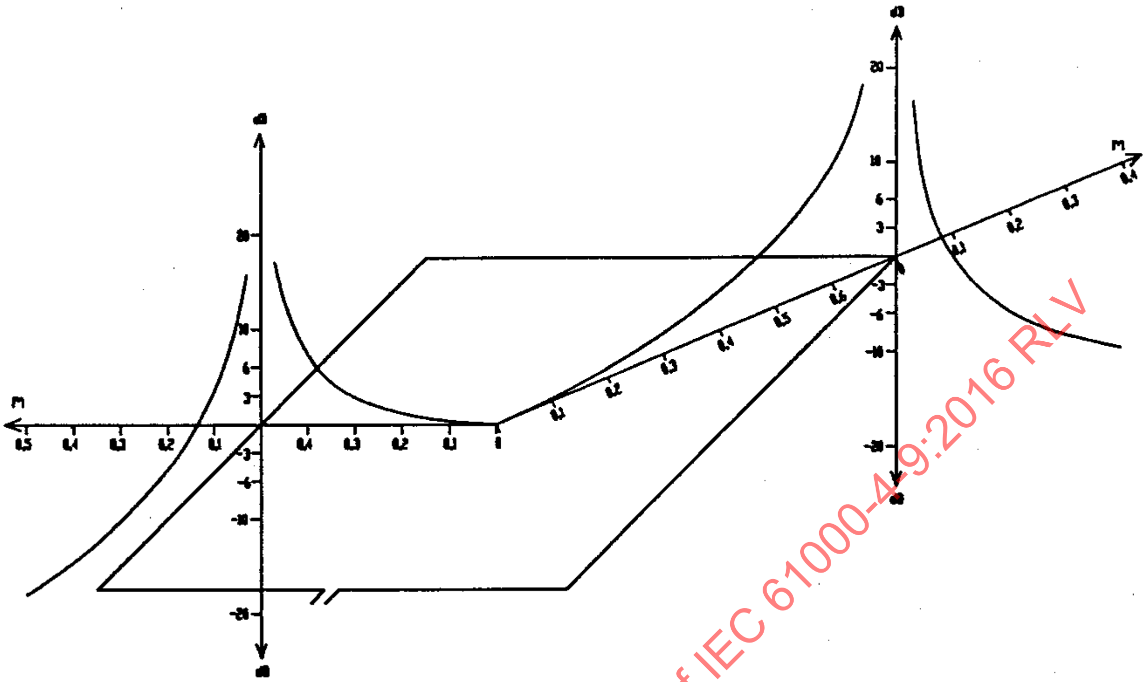
~~*In the selection of the form, arrangement and dimensions of the test coil, the following points have been considered:*~~

- ~~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.~~

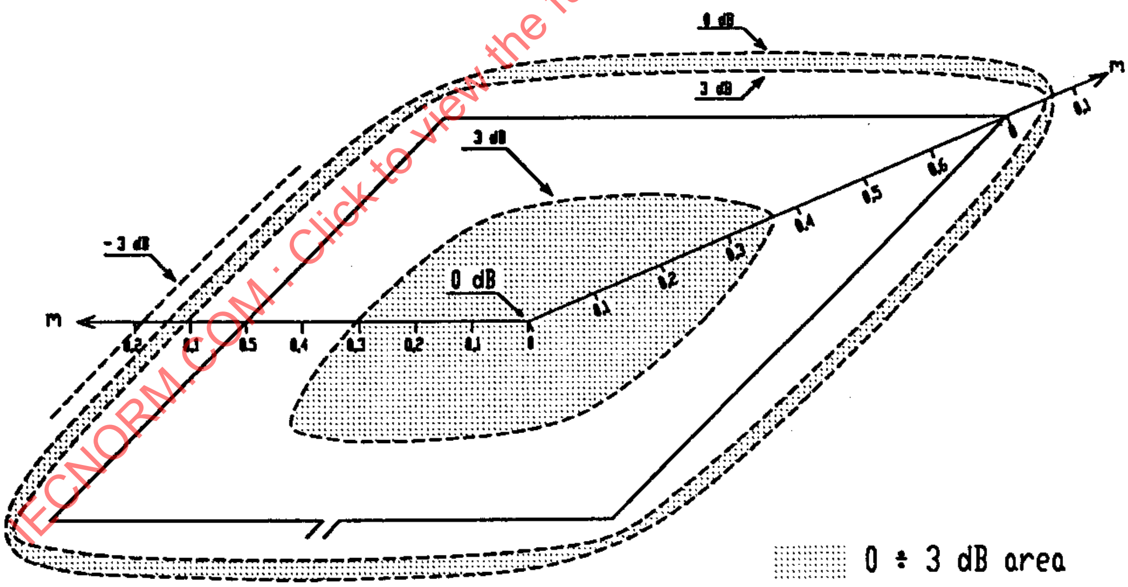
~~B.4 Summary of characteristics of induction coils~~

~~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:~~

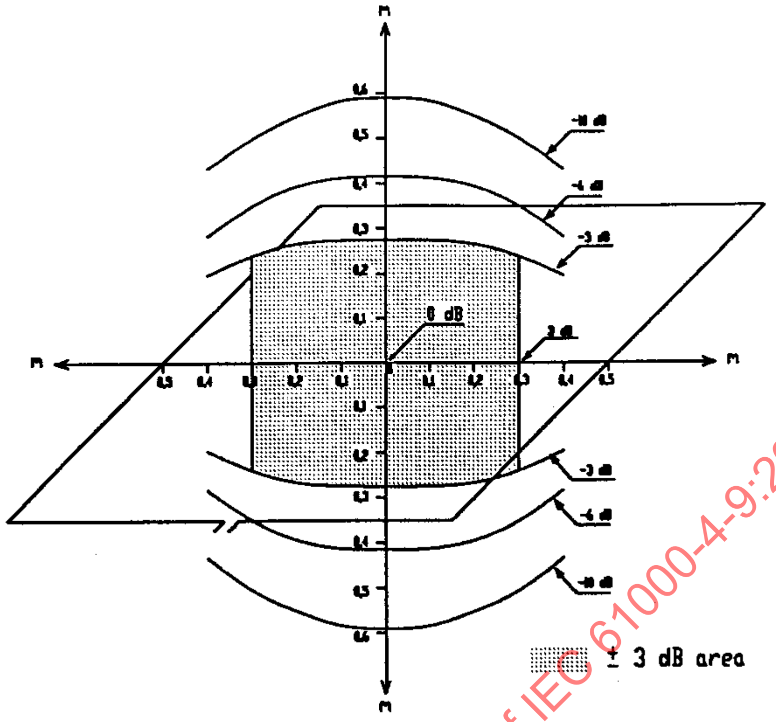
- ~~*single square coil, 1 m side:* testing volume 0,6 m × 0,6 m × 0,5 m high (0,2 m minimum distance from EUT to the coil);~~
- ~~*double square coils, 1 m side, 0,6 spaced:* testing volume 0,6 × 0,6 × 1 m high (0,2 m minimum distance from EUT to the coil); increasing of the separation of the coils 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.~~



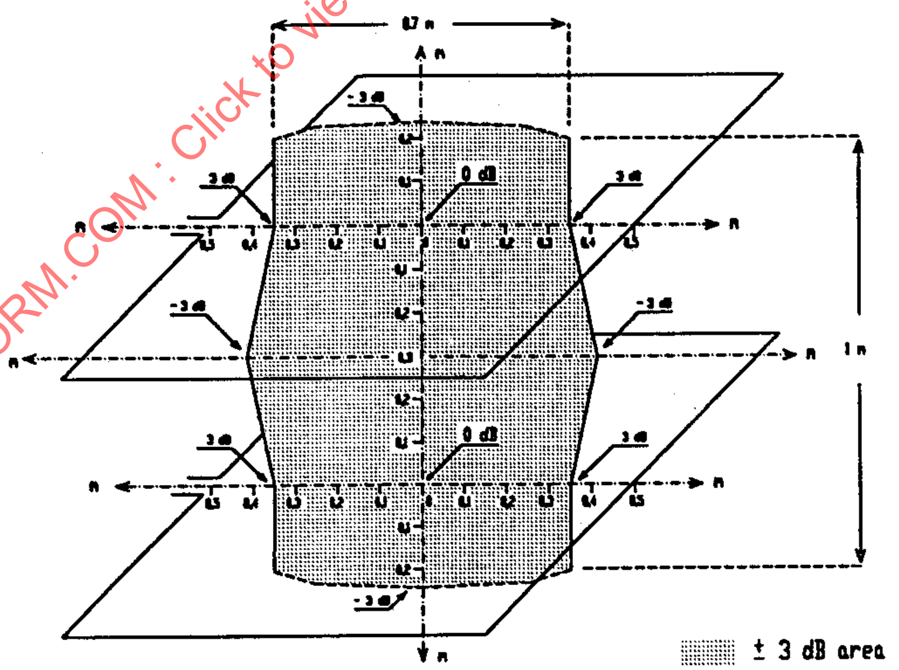
~~Figure B.1 – Characteristics of the field generated by a square induction coil (1 m side) in its plane~~



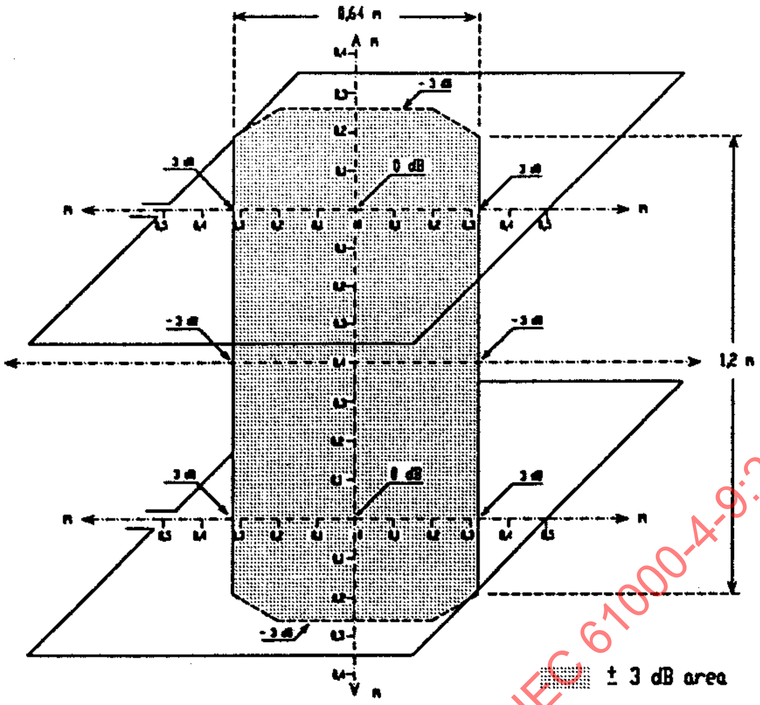
~~Figure B.2 – 3 dB area of the field generated by a square induction coil (1 m side) in its plane~~



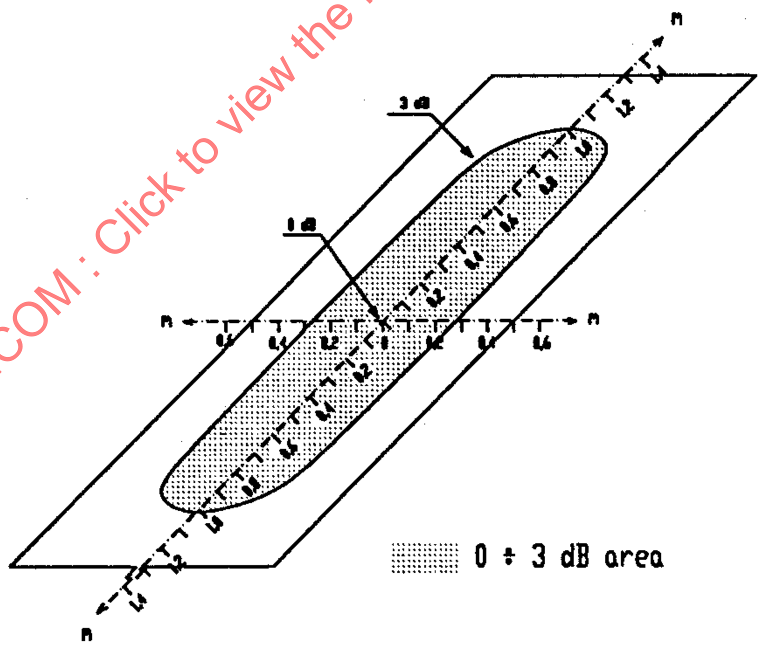
~~Figure B.3 – 3 dB area of the field generated by a square induction coil (1 m side) in the mean orthogonal plane (component orthogonal to the plane of the coil)~~



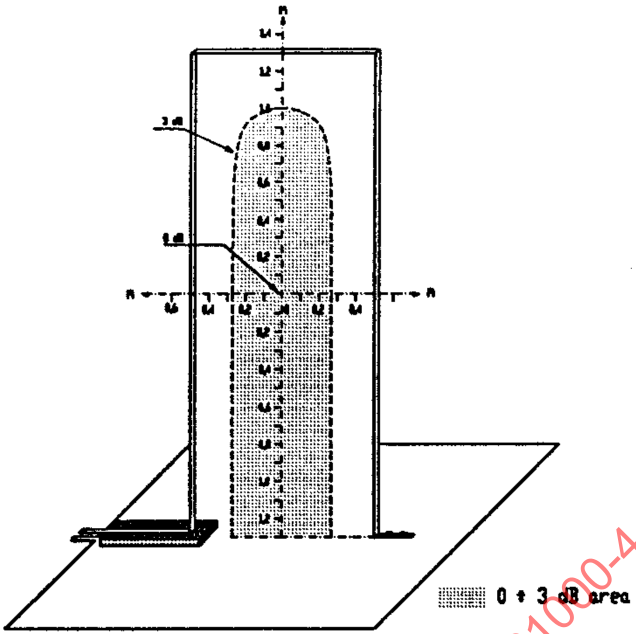
~~Figure B.4 – 3 dB area of the field generated by two square induction coils (1 m side) 0,6 m spaced, in the mean orthogonal plane (component orthogonal to the plane of the coils)~~



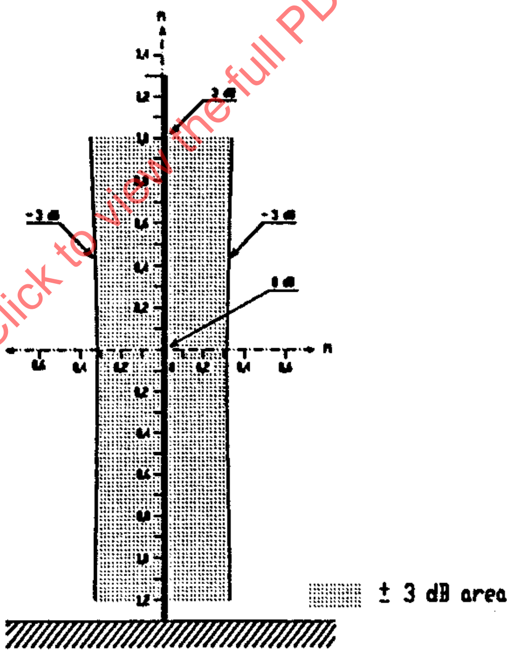
~~Figure B.5 – 3 dB area of the field generated by two square induction coils (1 m side) 0,8 m spaced, in the mean orthogonal plane (component orthogonal to the plane of the coils)~~



~~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)

Information on the field distribution of standard induction coils

B.1 General

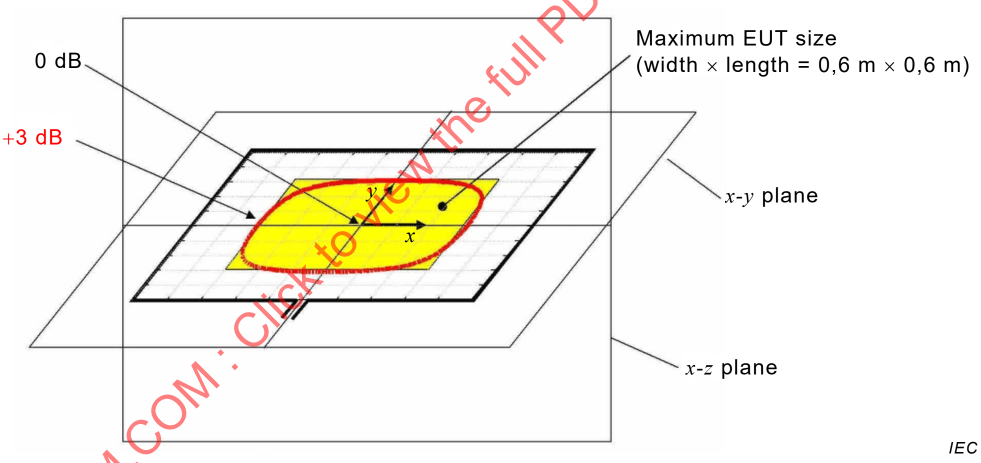
Annex B gives information on the maximum size of an EUT and its location in the standard induction coils. The maximum EUT volume is limited by the +3 dB isoline in the x-y plane and by the ±3 dB isolines in the x-z plane.

The inductance for the single turn standard 1 m × 1 m coil is approximately 2,5 µH and for the 1 m × 2,6 m standard coil is approximately 6 µH.

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

B.2 1 m × 1 m induction coil

The +3 dB and -3 dB isolines for the magnetic field strength (magnitude) are shown in Figure B.1 for the x-y plane and in Figure B.2 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 B.1 – +3 dB isoline for the magnetic field strength (magnitude) in the x-y plane for the 1 m × 1 m induction coil

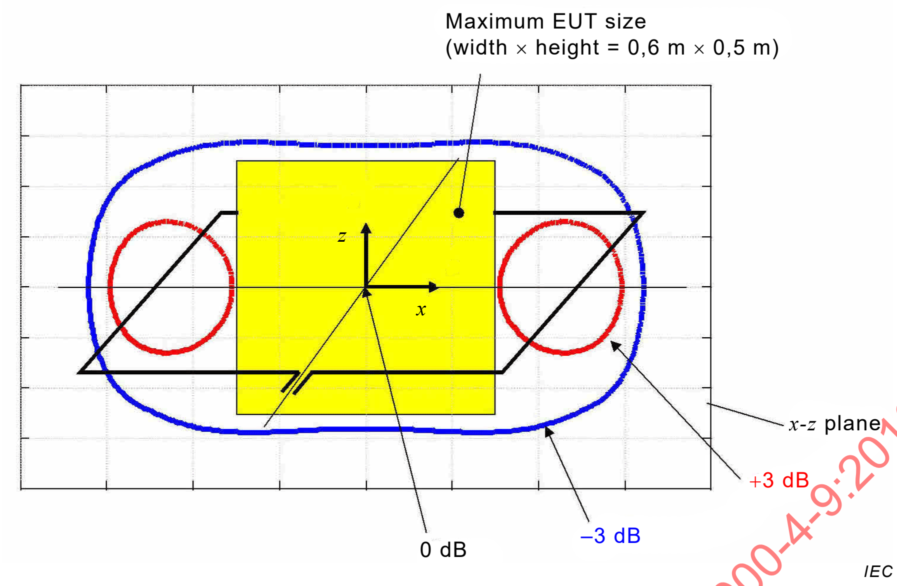
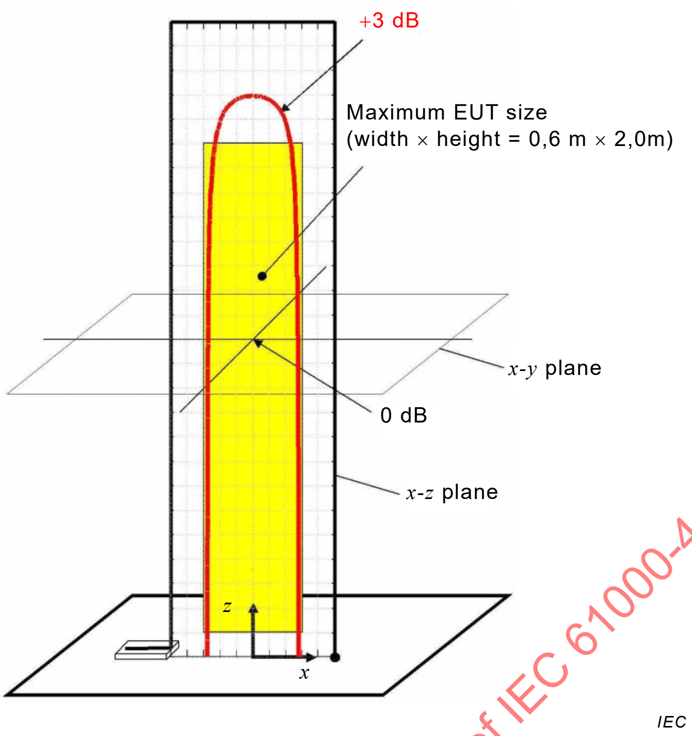


Figure B.2 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x-z* plane for the 1 m × 1 m induction coil

B.3 1 m × 2,6 m induction coil with reference ground plane

The +3 dB and -3 dB isolines for the magnetic field strength (magnitude) are shown in Figure B.3 for the *x-z* plane and in Figure B.4 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 B.3 – +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

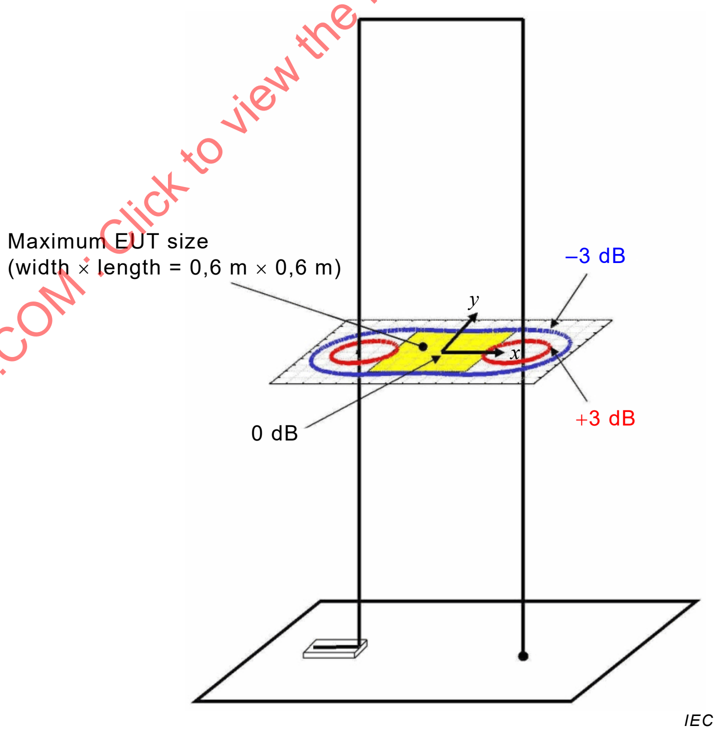
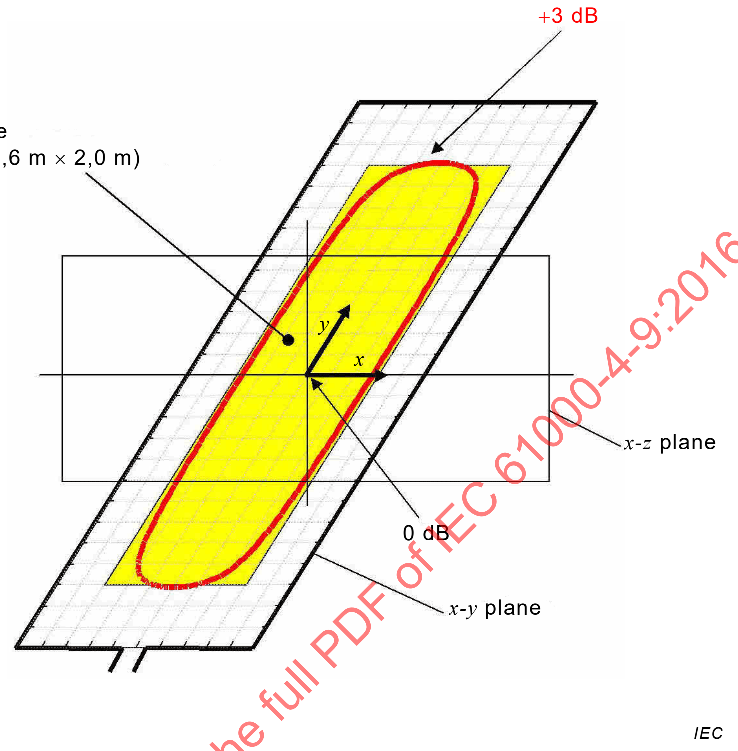


Figure B.4 – +3 dB and -3 dB isolines for the magnetic field strength (magnitude) in the *x-y* plane for the 1 m × 2,6 m induction coil with reference ground plane

B.4 1 m × 2,6 m induction coil without reference ground plane

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure B.5 for the *x*-*y* plane and in Figure B.6 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 B.5 – +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

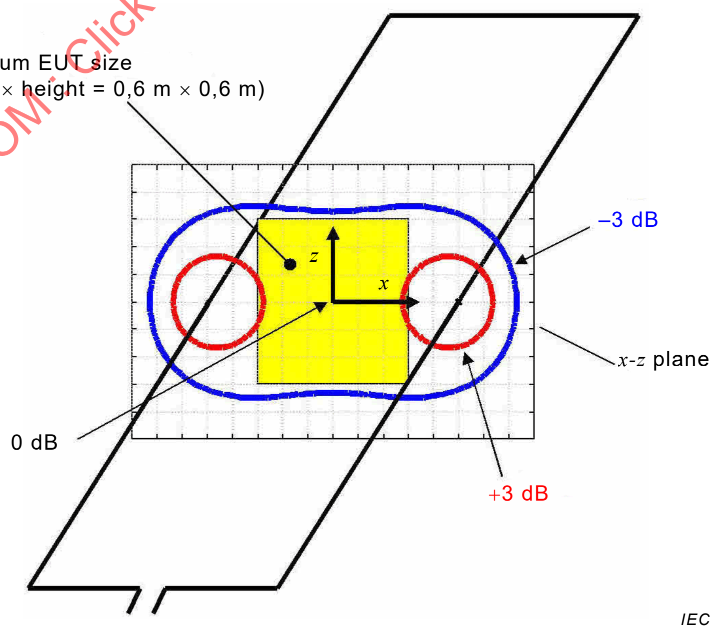


Figure B.6 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x*-*z* plane for the 1 m × 2,6 m induction coil without reference ground plane

Annex C
(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.

~~These~~ Recommendations for test levels are ~~outlined~~ given in Clause 5.

~~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.~~ The actual selection of test levels ~~shall be chosen according to~~ should take into account:

– the electromagnetic environment;
– the potential proximity of impulse 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 ~~pulse~~ impulse 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 devices 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

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 ~~lightning and initial transient fault current~~ switching phenomena in medium-voltage and high-voltage substations.

~~*Residential, office, hospital protected areas* far away from earth conductors of lightning protection systems may be representative of this environment.~~

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

Locations of this class of environment are characterized by a potential proximity ~~of earth conductors of lightning protection systems and metallic structures~~ 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.

~~*Commercial areas, control building, field of not heavy industrial plants* provided with lightning protection system or metallic structures in the proximity, *computer room of H.V. sub-stations* may by representative of this environment.~~

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

Locations of this class of environment are characterized by ~~the ground conductors of the lightning protection system or structures~~ the presence of medium-voltage 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.

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

Class 5: ~~Severe industrial environment~~

Harsh electromagnetic environment ~~is~~ which can be characterized by the following attributes: conductors, bus-bars or M.V.or H.V. lines carrying tens of kA~~; ground conductors of the lightning protection system or high structures like the line towers carrying the whole lightning current~~.

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 ~~a~~ higher test levels can penetrate ~~a lower severity environment~~ 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~~

~~The magnetic field strength ranges from a few hundreds A/m (peak) up to the order of 1 kA/m (peak) in the proximity of earth conductors, intended for protection from lightning and metal structures involved in the conduction of such transient currents; lower field strength values are representative of environments for equipment and systems installed inside buildings.~~

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 rise time of a 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,

a) identify the functional relationship (measurement model) between the influence (input) quantities and the measured (output) quantity,

b) obtain an estimate and standard uncertainty of the input quantities,

c) obtain an estimate of the interval containing, with a high level of confidence, the true value of the measurand.

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 standards, 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 behavior, 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 current impulse injected into the coil

H_P Peak of the magnetic field impulse

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

T_f Front time of the current and magnetic field impulses: $T_f = 1{,}25\ T_r$

T_r Rise time of the current and magnetic field impulses, defined as the time from 10 % to 90 % of the peak value

T_w Width of the current and magnetic field impulses

T_d Duration of the current and magnetic field impulses: $T_d = 1{,}18\ T_w$

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 surge current and to the surge 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
- reading of 10% level
- reading of 90% level
- reading of 50% level
- 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 surge current and surge magnetic field calibration

D.4.1 General

In the case of the magnetic field test, the disturbance quantities are the surge current generated by the test generator and injected into the coil terminals and the surge 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, T_f and T_d for the surge current, and H_P for the surge 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 surge magnetic field has the same front time and width as the surge current, and the peak of the magnetic field is obtained as $H_P = k_{CF} \times I_P$.

The approach adopted here to evaluate impulse MU is described in D.4.6 and D.4.7. Tables D.1, D.2, and D.3 give examples of uncertainty budgets for the surge parameters. The tables include the input quantities that are considered most significant for these examples, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining each uncertainty budget.

D.4.2 Front time of the surge current

The measurand is the surge current front time calculated by using the functional relationship

$$T_f = 1{,}25\sqrt{(T_{90\%} - T_{10\%} + \delta R)^2 - T_{MS}^2} \tag{D.1}$$

where

$$T_{MS} = \frac{\alpha}{B} \tag{D.2}$$

and:

$T_{10\%}$ is the time at 10 % of peak amplitude

$T_{90\%}$ is the time at 90 % of peak amplitude

δR is the correction for non-repeatability

T_{MS} is the rise time of the step response of the measuring system (10 % to 90 %) in µs

B is the –3 dB bandwidth of the measuring system in kHz

α is the coefficient whose value is (360 ± 40) µs × kHz (B in kHz and T_{MS} in µs)

Table D.1 – Example of uncertainty budget for surge current front time (T_f)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{10\%}$	0,74	µs	0,005 0	µs	triangular	2,45	0,002 0	-1,256 3	1	0,002 6	µs
$T_{90\%}$	7,94	µs	0,005 0	µs	triangular	2,45	0,002 0	1,256 3	1	0,002 6	µs
δR	0	µs	0,025	µs	normal (k=1)	1,00	0,025 0	1,256 3	1	0,031 4	µs
A	360	µs kHz	40	µs · kHz	rectangular	1,73	23,094 0	-0,000 3	1/kHz	0,005 8	µs
B	500	kHz	50	kHz	rectangular	1,73	28,867 5	0,000 2	µs/kHz	0,005 3	µs
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,0325 6	µs
							$U(y)$ = 2 $u_c(y)$			0,06	µs
							y			8,95	µs

[a] Probability density function

***$T_{10\ \%}$*, *$T_{90\ \%}$*:** is the time reading at 10 % or 90 % of the peak amplitude. The error bound is obtained assuming a sampling frequency of 100 MS/s and a trace interpolation capability of the scope (triangular probability density function). Were this not the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here, for additional contributors see D.4.5. The readings are assumed to be $T_{10\ \%}$ = 0,74 µs and $T_{90\ \%}$ = 7,94 µs.

***T_{MS}*:** is the calculated rise time of the step response of the measuring system. The coefficient α (see Clause D.2), depends on the shape of the impulse response of the measuring system. The range 360 ± 40 is representative of a wide class of systems, each having a different shape of the impulse response (see D.4.6 and Table D.4). 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, 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 500 kHz and a 50 kHz error bound of a rectangular probability density function are assumed for B.

***δR*:** is the 10 % to 90 % rise time non-repeatability. It quantifies the lack of repeatability in the measurement of $T_{90\%}$ – $T_{10\%}$ due to the measuring instrumentation, the layout of the measurement setup and the surge generator itself. It is determined experimentally. 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

$$s\left(q_k\right)=\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(q_j-\overline{q}\right)^2} \tag{D.4}$$

where $\bar{q}$ is the arithmetic mean of the q_j values. An error bound $s(q_k)$ = 25 ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

D.4.3 Peak of the surge current and magnetic field

The measurand is the peak of the surge current injected into the coil and calculated by using the functional relationship

$$I_{\mathrm{p}} = \frac{V_{\mathrm{PR}}}{R_{\mathrm{T}}} \frac{1+\delta R+\delta V}{1-\left(\frac{\beta}{B}\right)^2} \tag{D.5}$$

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 (14,8 ± 1,6) kHz

Table D.2 – Example of uncertainty budget for the peak of surge current (I_{P})

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{PR}	1,15	V	0,002 2	V	triangular	2,45	0,000 92	1 001	1/Ω	0,918	A
R_{T}	0,001	Ω	0,000 05	Ω	rectangular	1,73	0,000 03	-151·10^3	A/Ω	33,23	A
δR	0	1	0,03	1	Normal (k =1)	1,00	0,030 00	1 151	A	34,53	A
δV	0	1	0,02	1	rectangular	1,73	0,011 55	1 151	A	13,29	A
B	14,8	kHz	1,6	kHz	rectangular	1,73	0,923 76	0,136	A/kHz	0,126	A
B	500	kHz	50	kHz	rectangular	1,73	28,867 51	-0,0040	A/kHz	0,117	A
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,050	kA
							$U(y) = 2\ u_c(y)$			0,10	kA
							y			1,15	kA
							Expressed in % of 1,15 kA			8,6	%

[a] Probability density function

***V_{PR}*:** is the voltage peak reading at the output of the current probe. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with an interpolation capability (triangular probability density function).

***R_{T}*:** is the transfer resistance 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. It is a type A evaluation quantified by the experimental standard deviation of a sample of repeated measurements of the peak current. It 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 DC. 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.4.7). The interval (14,8 ± 1,6) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: see D.4.2., same meaning and same values both for the estimate and error bound.

The uncertainty of the peak of the surge magnetic field is obtained from the functional relationship $H_P = k_{CF} \times I_P$, where k_{CF} is the coil factor as measured or calculated as described in the standard. Therefore, if the calculated k_{CF} is 0,90 (e.g. in the case of a square induction coil whose side is 1 m) and its expanded uncertainty is 5 %, then the best estimate of H_P is 1,04 kA/m and its expanded uncertainty is 9,9 % (see Table D.2)

D.4.4 Duration of the current impulse

The measurand is the duration of the surge current injected into the coil calculated by using the functional relationship

$$T_d = 1{,}18 \cdot \left(T_{50\%,F} - T_{50\%,R} + \delta R\right) \cdot \left[1 - \left(\frac{\beta}{B}\right)^2\right] \quad \text{(D.6)}$$

where

$T_{50\%,R}$ is the time at 50 % of peak amplitude at the rising edge of the impulse

$T_{50\%,F}$ is the time at 50 % of peak amplitude at the falling edge of the impulse

δR is the correction for non-repeatability

B is the –3 dB bandwidth of the measuring system

β is the coefficient which value is (14,8 ± 1,6) kHz

Table D.3 – Example of uncertainty budget for current impulse width (T_d)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{50\%,R}$	3,44	μs	0,005 0	μs	triangular	2,45	0,002 0	-1,181 1	μs	0,002 4	μs
$T_{50\%,F}$	22,34	μs	0,005 0	μs	triangular	2,45	0,002 0	1,181 1	μs	0,002 4	μs
δR	0	μs	0,15	μs	Normal (k =1)	1,00	0,150 0	1,181 1	μs	0,177 1	μs
β	14,8	kHz	1,6	kHz	rectangular	1,73	0,923 8	-0,002 6	μs/kHz	0,002 5	μs
B	500	kHz	50	kHz	rectangular	1,73	28,867 5	0,000 1	μs/kHz	0,002 2	μs
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,177 2	μs
							$U(y) = 2\, u_c(y)$			0,4	μs
							y			22,3	μs

[a] Probability density function

$T_{50\%,R}$*, *$T_{50\%,F}$: is the time reading at 50 % of the peak amplitude on the rising or falling edge of the surge current. The error bound is obtained assuming a sampling frequency of 100 MS/s (the same as in D.4.2) and a trace interpolation capability of the scope (triangular probability density function). Were this not the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here. For additional contributors see D.4.5. The readings are assumed to be $T_{50\%,R}$ = 3,44 μs and $T_{50\%,F}$ = 22,34 μs.

δR: quantifies the non-repeatability of the $T_{50\%,F} - T_{50\%,R}$ time difference measurement due to the measuring instrumentation, the layout of the measurement setup and the test generator itself. It is determined experimentally. This is a type A evaluation quantified by the experimental standard deviation of a sample of repeated measurements. An error bound $s(q_k)$ = 150 ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

β: see D.4.3, same meaning and same values both for the estimate and error bound.

B: see D.4.2, same meaning and same values both for the estimate and error bound.

D.4.5 Further MU contributions to time measurements

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.

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.

D.4.6 Rise time distortion due to the limited bandwidth of the measuring system

The distortion of the rise-time is evaluated through the usual rule of combination of the rise-times, which is valid when two non-interacting systems are cascaded and their step responses monotonically increase, i.e.

$$T_{\mathrm{rd}} = \sqrt{T_{\mathrm{r}}^2 + T_{\mathrm{MS}}^2} \qquad \text{(D.7)}$$

where T_{rd} is the rise-time of the signal at the output of the measuring system (distorted rise-time), T_{r} is the rise-time of the signal at the input of the measuring system, and T_{MS} is the rise time of the step response of the measuring system. It is important to observe that the derivation of equation (D.7) is based on the following definition of the rise time

$$T_{\mathrm{MS}} = \sqrt{2\pi \int_0^{\infty} (t - T_{\mathrm{s}})^2 h_0(t) dt} \qquad \text{(D.8)}$$

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

$$T_{\mathrm{s}} = \int_0^{\infty} t h_0(t) dt \qquad \text{(D.9)}$$

Equation (D.8) 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 times are usually combined through equation (D.7). With the –3 dB bandwidth of the system, the two definitions lead to comparable rise times. If we define

$$\alpha = T_{MS} \cdot B \tag{D.10}$$

then 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.4. It is evident from Table D.4, that it is not possible to identify a unique value of α because α depends both on the adopted definition of the rise time (e.g. based on thresholds or on equation (D.7)) 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.4, 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 of 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.4 – α factor (see equation (D.10)) of different unidirectional impulse responses corresponding to the same bandwidth of system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (crit. damp.)	Rectangular	Triangular
α, using equation (D.8)	332	399	363	321	326
α, 10 % to 90 %	339	350	344	354	353

D.4.7 Impulse peak and width 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

$$V_{out}(t) = \int_0^t V_{in}(\tau) \cdot h(t-\tau) d\tau \tag{D.11}$$

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 around the time instant t_p when the input reaches its peak value V_p

$$V_{in}(t) = V_p + \frac{V''_{in}(t_p)}{2} \cdot (t-t_p)^2 + \frac{V'''_{in}(t_p)}{6} \cdot (t-t_p)^3 + \ldots \tag{D.12}$$

Note that the first order term is missing from equation (D.12) 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.12) into equation (D.11) 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

$$V_{pd} = \frac{V_p}{A}\left[1-\left(\frac{\beta}{B}\right)^2\right] \tag{D.13}$$

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

$$\beta = \alpha \cdot \sqrt{\frac{\left|V''_{in}(t_p)\right|}{4\pi V_p}} \tag{D.14}$$

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.4.6. Since the mathematical expression for the standard surge waveforms are given in Annex E of this standard, the value of β can be numerically calculated and is reported in Table D.5.

The estimate of the distortion of the input impulse width T_W is simply obtained considering that the area of the output impulse is that of the input impulse divided by the d.c. attenuation A. Therefore

$$V_p T_W = A V_{pd} T_{wd} \tag{D.15}$$

where T_{wd} is the output impulse width. Hence

$$T_{wd} = \frac{V_p}{A V_{pd}} \cdot T_W = \frac{1}{1-\left(\frac{\beta}{B}\right)^2} \cdot T_W \tag{D.16}$$

Table D.5 – β factor (equation (D.14)) of the standard current surge waveform

kHz	8/20 μs
β	14,8 ± 1,6

D.5 Application of uncertainties in the surge generator compliance criterion

Generally, in order to be confident that the current and the magnetic field surges 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)

Mathematical modelling of surge current waveforms

E.1 General

Annex E provides reference mathematical waveforms for:

- designing surge generators,
- simulations of surge performance on digital apparatus.

The formulae have been defined considering the following requirements:

1) To reproduce the nominal front time and duration as defined in the standard for the surge generators with output in short-circuit condition.
2) To help the designers of digital apparatus to build up a circuit model of the source generators by using the simplified circuits reported in the standard with the nominal values of the circuit elements, if any.
3) To have derivative equal to zero at starting time in order to avoid instability when numerical simulations are performed.
4) To have the same basic formula used in IEC for transient phenomena such as ESD, EFT/B and surge.

NOTE For current surge (8/20 μs), the defined mathematical waveforms match well with those defined in IEEE Std C62.45-2002.

The following parameter definitions are used:

a) T_w is the width time defined as the time between the 50 % of the rising and falling front of the waveform.
b) T_r is the rise time for current surge defined as the time between the 10 % and 90 % of the early time response of the waveform.
c) T_d is the duration time between the minimum value of the early time response and the 50 % of the falling time.
d) T_f is the front time defined as the time between the intersection of a line, having a slope that approximates the early time response, with the horizontal line that passes through the minimum and maximum value of the waveform respectively. The following values are defined that match well with the waveforms provided by the simplified circuits using model simulations:

   current surge (8/20 μs): $T_f = 1{,}25 \times T_r$; $T_d = 1{,}18 \times T_w$
e) BW is the bandwidth of the surge waveforms defined at the frequency where the spectral response begins to roll off with a slope of –60 dB/decade.

E.2 Normalized time domain current surge (8/20 μs)

The normalized time domain expression of the 8/20 μs current surge is given by

$$I_{\mathrm{SURGE}}(t) = k_i \cdot \left[\frac{i_1}{k_{\mathrm{SURGE}}} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{\eta_{\mathrm{SURGE}}}}{1+\left(\frac{t}{\tau_1}\right)^{\eta_{\mathrm{SURGE}}}} \cdot e^{\frac{-t}{\tau_2}} \right] \tag{E.1}$$

The coefficients that appear in equation (E.1) have the following values

$k_i = 1$ $\tau_1 = 47{,}52\ \mu s$ $\tau_2 = 4{,}296\ \mu s$ $i_1 = 0{,}939$ $\eta_{SURGE} = 2{,}741$

$$k_{SURGE} = e^{\frac{-\tau_1}{\tau_2} \cdot \left(\frac{\eta_{SURGE} \cdot \tau_2}{\tau_1}\right)^{\frac{1}{\eta_{SURGE}}}} \tag{E.2}$$

The plot of the 8/20 µs current surge as a function of time is shown in Figure E.1.

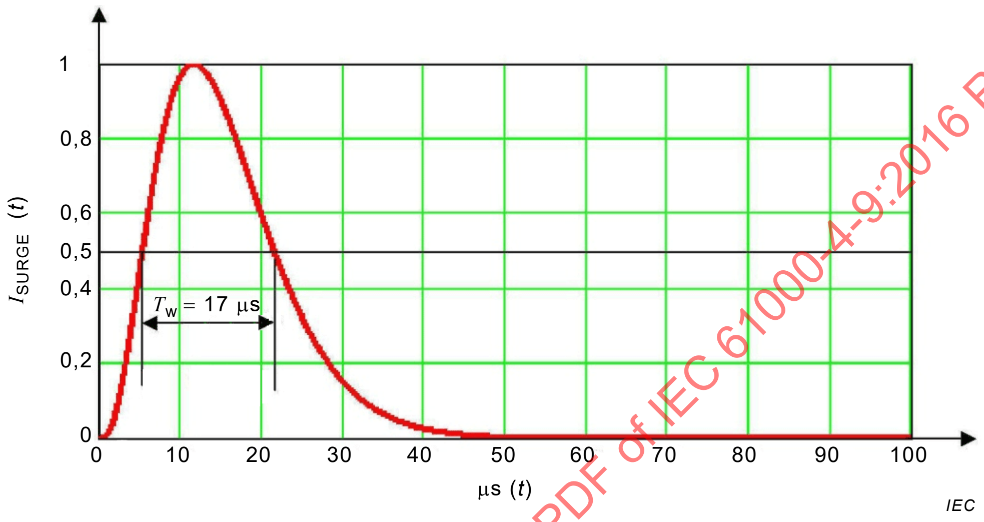


Figure E.1 – Normalized current surge (8/20 µs): Width time response T_w

An expansion to highlight the early time response is plotted in Figure E.2.

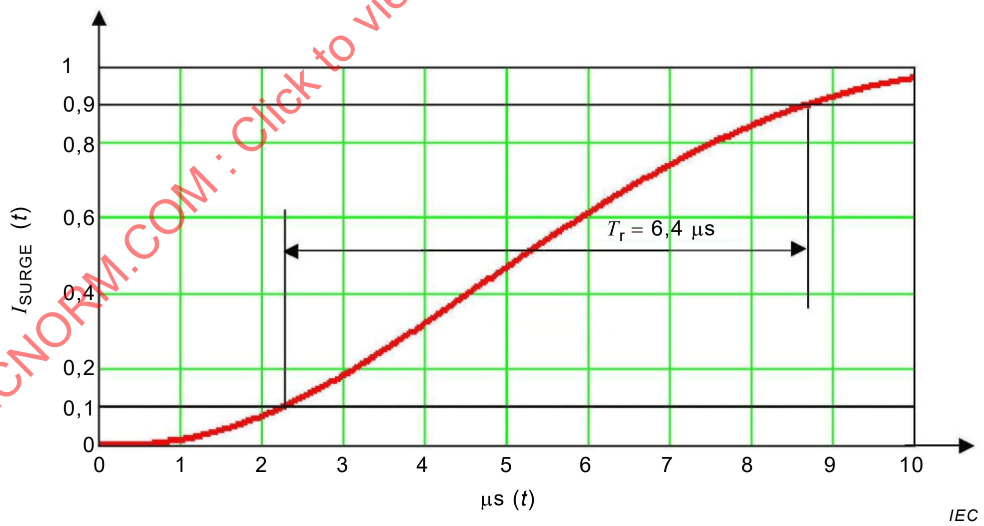


Figure E.2 – Normalized current surge (8/20 µs): Rise time response T_r

The magnitude of the spectral response corresponding to equation (E.1) is shown in Figure E.3.

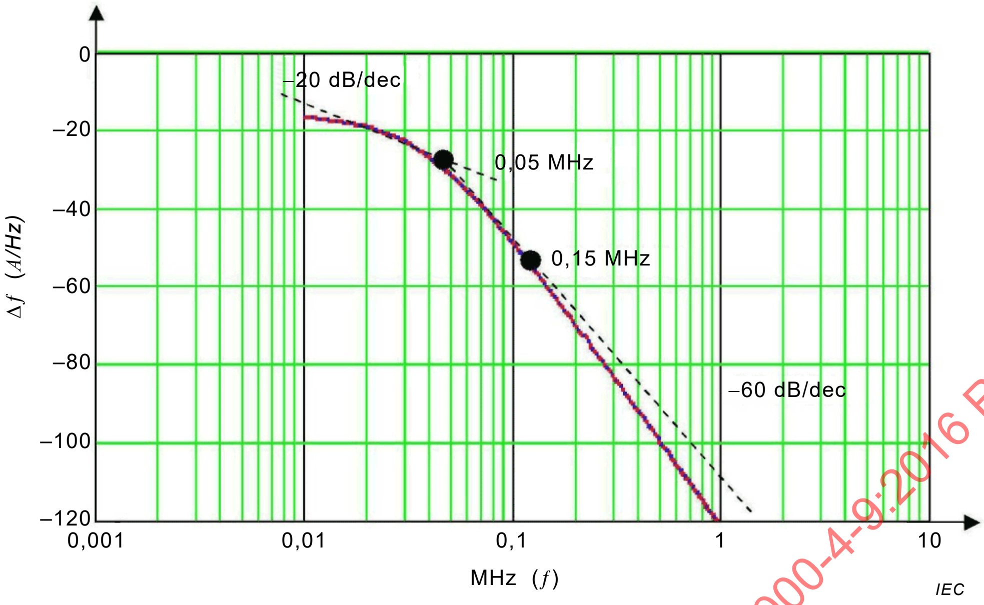


Figure E.3 – Current surge (8/20 μs): Spectral response with Δf = 10 kHz

The current impulse in the time domain is simulated well for frequencies up to 0,15 MHz, therefore the associated bandwidth BW = 0,15 MHz.

Annex F
(informative)

Characteristics using two standard induction coils

F.1 General

Annex F gives an example of Helmholtz coils using two 1 m × 1 m standard induction coils connected in parallel to the combination wave generator. This double induction coil may be used to obtain a better field homogeneity and for testing larger EUTs.

The test volume of the double 1 m × 1 m standard induction coils, which are 0,8 m spaced, is defined in Clause F.3.

F.2 Particular requirements for calibration

The characteristics of this test system can be calibrated by using a current measurement as described in Figure F.1. The current in both coils should be measured and should be identical.

The output current can be verified with the generator connected to the two standard induction coils. In order to comply with the specification given in Table 3 for the 1 m × 1 m standard induction coil, an external capacitor (e.g. 18 μF) in series may be required. The capacitor may be incorporated in the generator. The connection is realized by twisted conductors with a suitable cross-section of up to 3 m length. Identical cable length should be used to supply both coils and to ensure proper distribution of the current. The current in both coils should be checked for the same H-field orientation.

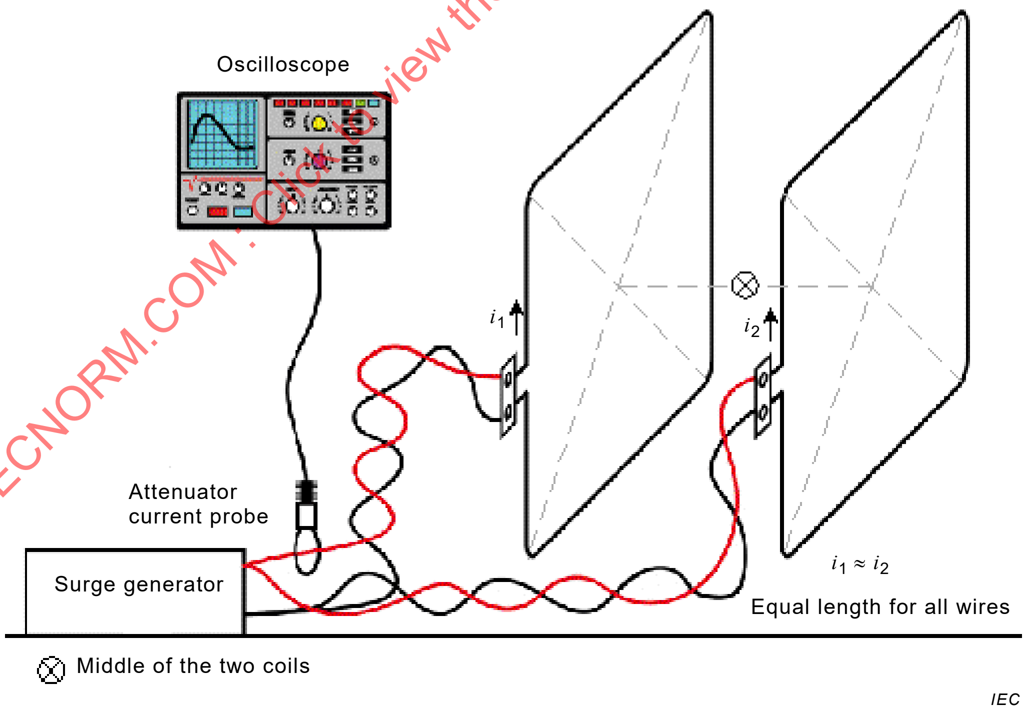


Figure F.1 – Example of a test system using double standard induction coils

The specifications given in Table F.1 can be verified for all applicable test levels.

Table F.1 – Specifications of the waveform peak current of this test system

Test level	**Peak current I ± 10 % in each coil** A
1	not applicable
2	not applicable
3	106
4	319
5	1 064
X[a]	Special/0,94

NOTE 1 The value 0,94 is the measured and simulated coil factor in the middle of the two coils.

NOTE 2 A combination wave generator with higher current supply capabilities than required for tests level 4 in IEC 61000-4-5 may be needed for testing at test levels 5 or X.

[a] "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.

If a current transformer (probe) is used to measure the short-circuit current, it should be selected, so that saturation of the magnetic core does not occur. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz. The calibration should be carried out with a current probe and an oscilloscope or other equivalent measurement instrumentation with a bandwidth of not less than 1 MHz.

F.3 Field distribution of the double induction coil arrangement

Clause F.3 gives information on the maximum size of an EUT and its location in the double coil arrangement. According to the main part of the standard, the EUT shall be located within a volume, where the magnitude of the magnetic field strength is within ±3 dB of the field strength, in the centre of the double coil arrangement.

For the field computations the finite cross-section of the coil conductors are neglected (thin wire approximation). The computations were performed for two 1 m × 1 m standard induction coils, 0,8 m spaced.

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure F.2 for the x-y plane and in Figure F.3 for the x-z plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 1,4 m.

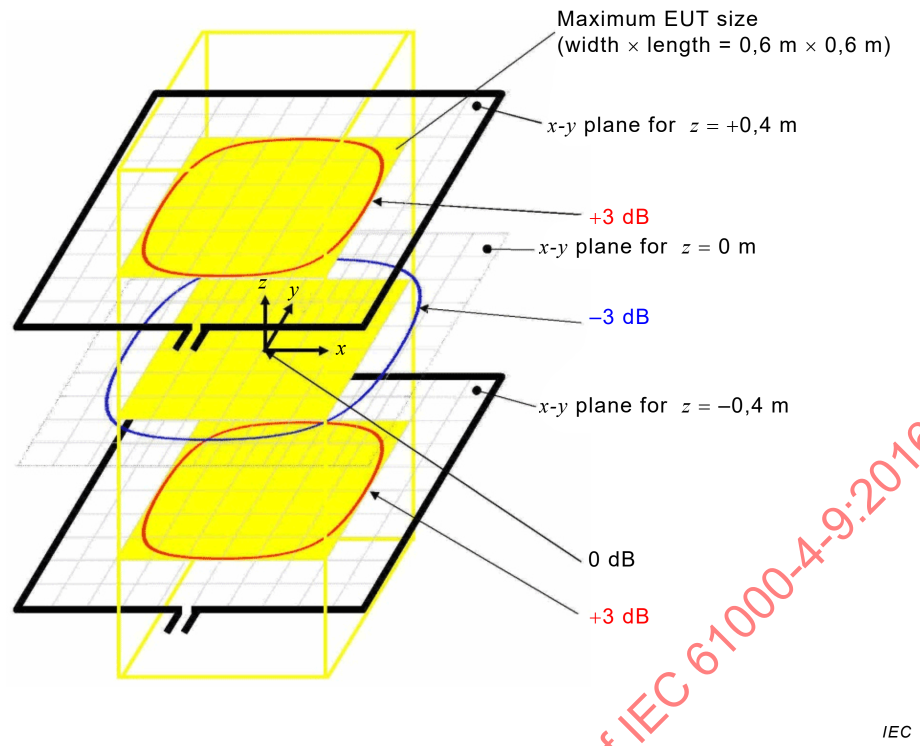


Figure F.2 – +3dB isoline for the magnetic field strength (magnitude) in the x-y plane for the double induction coil arrangement (0,8 m spaced)

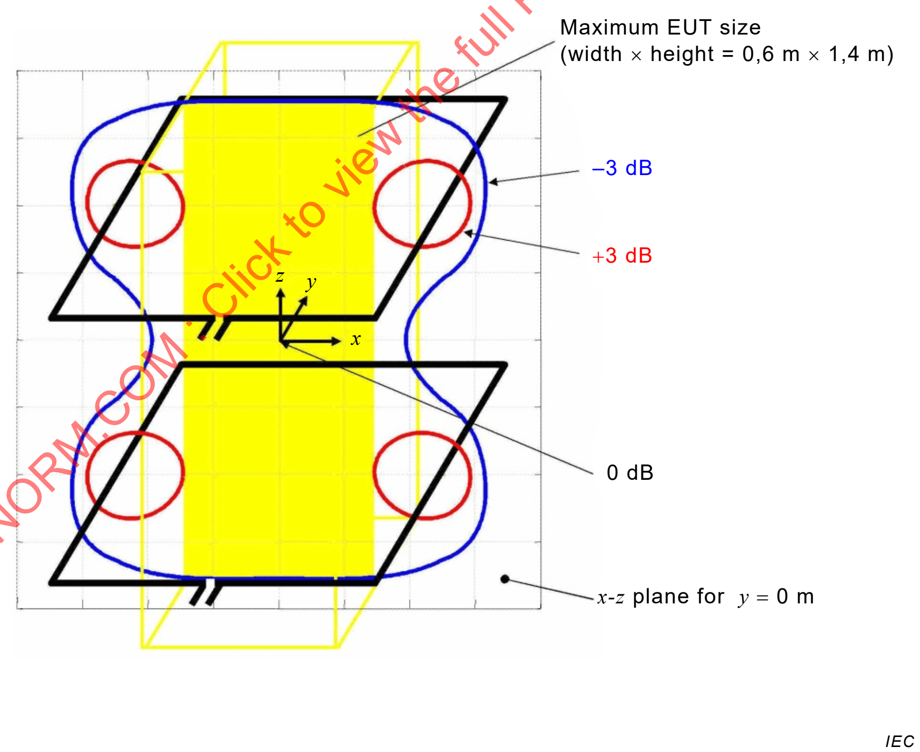


Figure F.3 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the x-z plane for the double induction coil arrangement (0,8 m spaced)

Annex G
(informative)

3D numerical simulations

G.1 General

In Annex G 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 B (static results).

G.2 Simulations

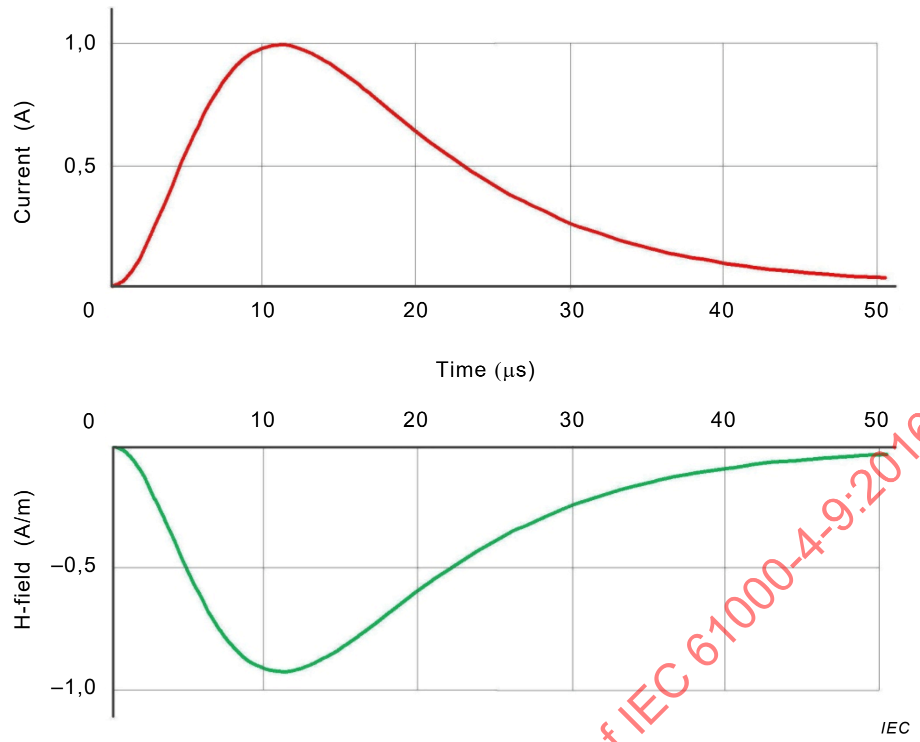
The simulations of Figures G.1 to G.12 are performed as follows:

- The coils are excited by an ideal current source (see the symbol "port") having the mathematical waveform as defined in Annex E of this standard and normalized at 1 A.
- Two extreme shape conductors of the coil are considered: one of a rectangular size 10 cm × 1 cm (reported in Annex G) and a 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 Figure G.2 and Figure G.3; for 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.

G.3 Comments

The following comments have been taken into account as they relate to the figures.

- The computed H-field waveform has the same shape of 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 B.
- 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 centre of the loop. This should be taken into account when carrying out the proximity test method.
- For the double induction coil arrangement, which is 0,6 m spaced (Helmholtz setup), the coil factor in the centre of one coil and between the two coils is respectively: 1,18 m^{-1} and 1,20 m^{-1}; for the one that is 0,8 m spaced it is respectively: 1,07 m^{-1} and 0,94 m^{-1}.



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

Figure G.1 – Current and H-field in the centre of the 1 m × 1 m induction coil

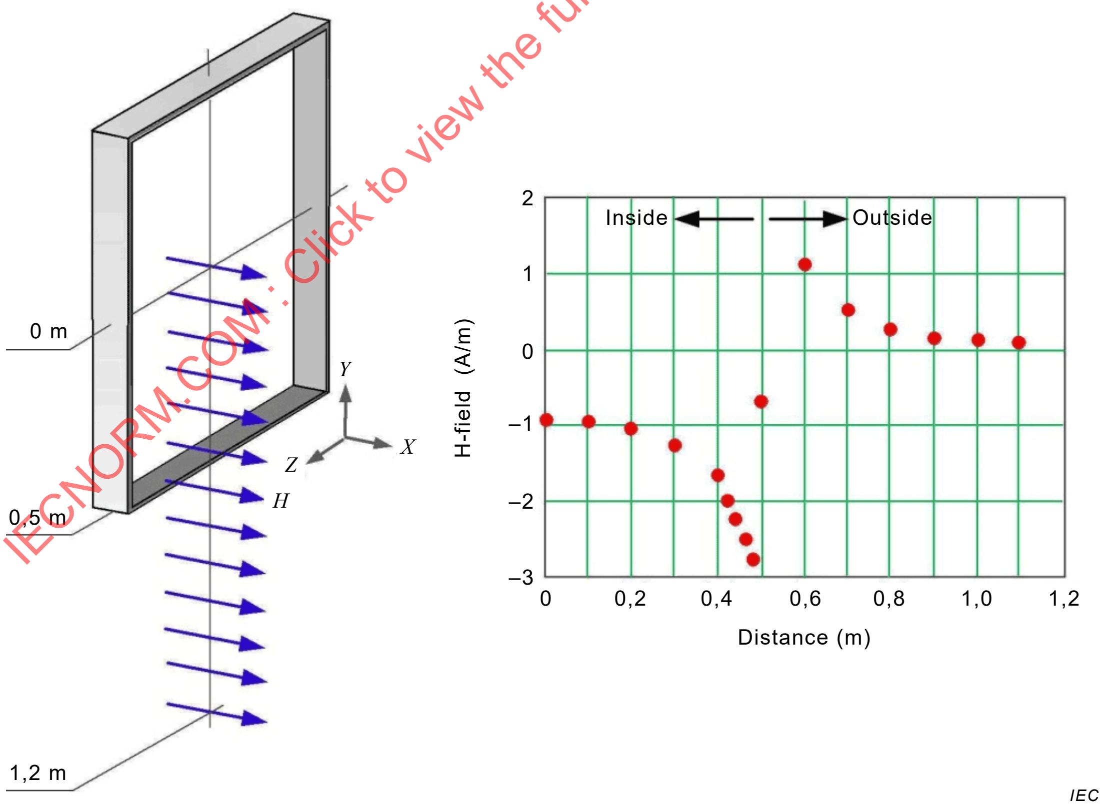


Figure G.2 – Hx-field along the side of 1 m × 1 m induction coil in A/m

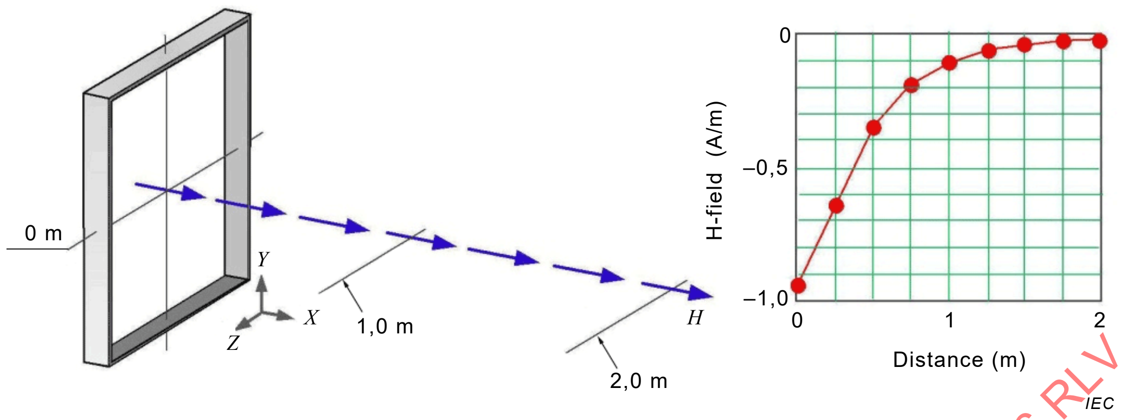


Figure G.3 – Hx-field in direction x perpendicular to the plane of the 1 m × 1 m induction coil

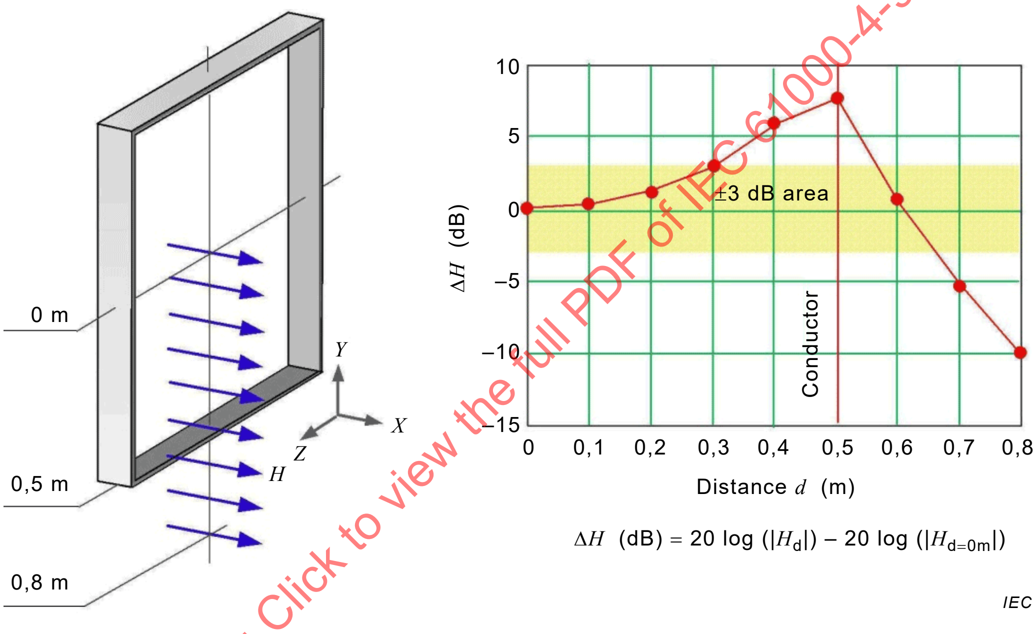


Figure G.4 – Hx-field along the side in dB for the 1 m × 1 m induction coil

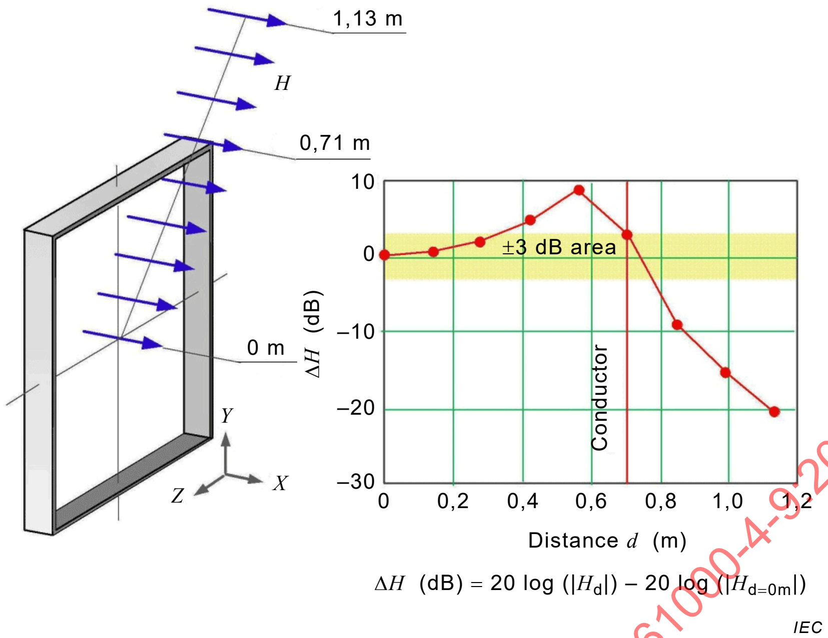


Figure G.5 – Hx-field along the diagonal in dB for the 1 m × 1 m induction coil

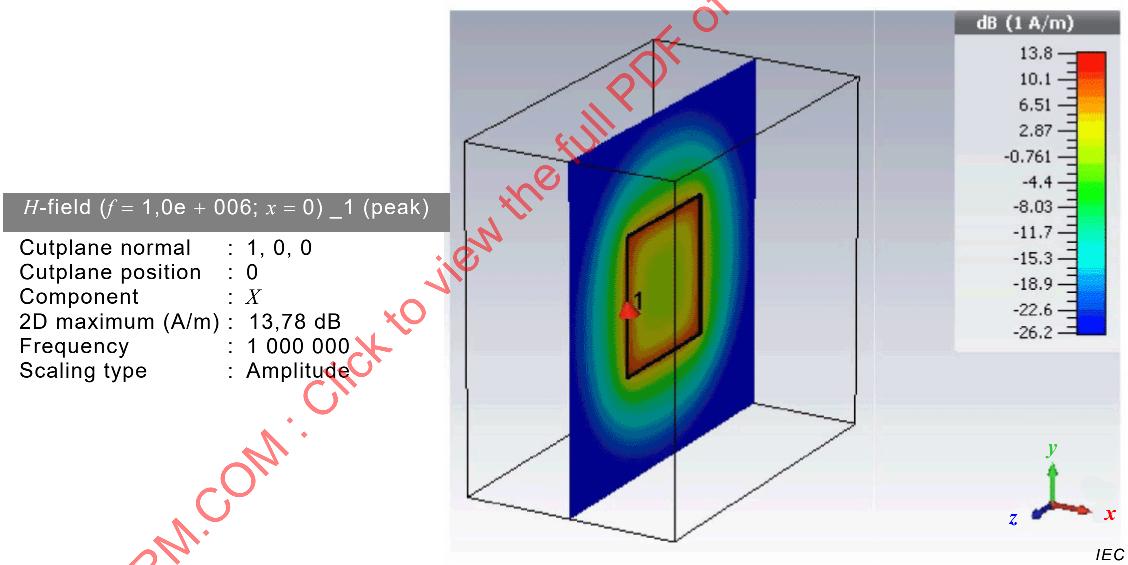


Figure G.6 – Hx-field plot on y-z plane for the 1 m × 1 m induction coil

Maximum plot (peak)		
Cutplane normal	:	0, 0, 1
Cutplane position	:	0,5
Component	:	*X*
2D maximum (A/m)	:	10,05 dB
Frequency	:	1 000 000
Scaling type	:	Amplitude

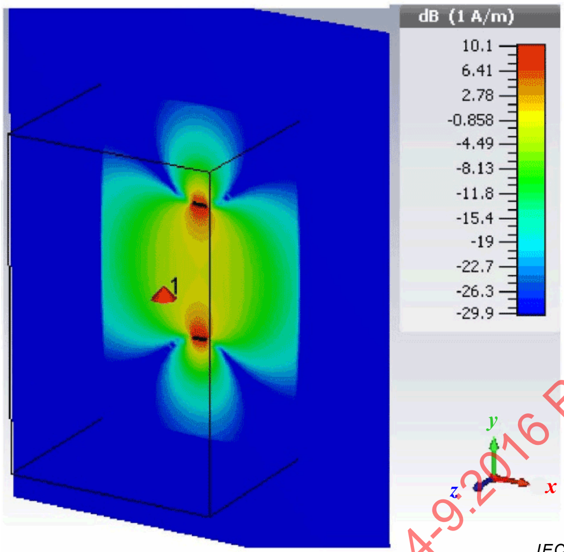


Figure G.7 – *Hx*-field plot on *x-y* plane for the 1 m × 1 m induction coil

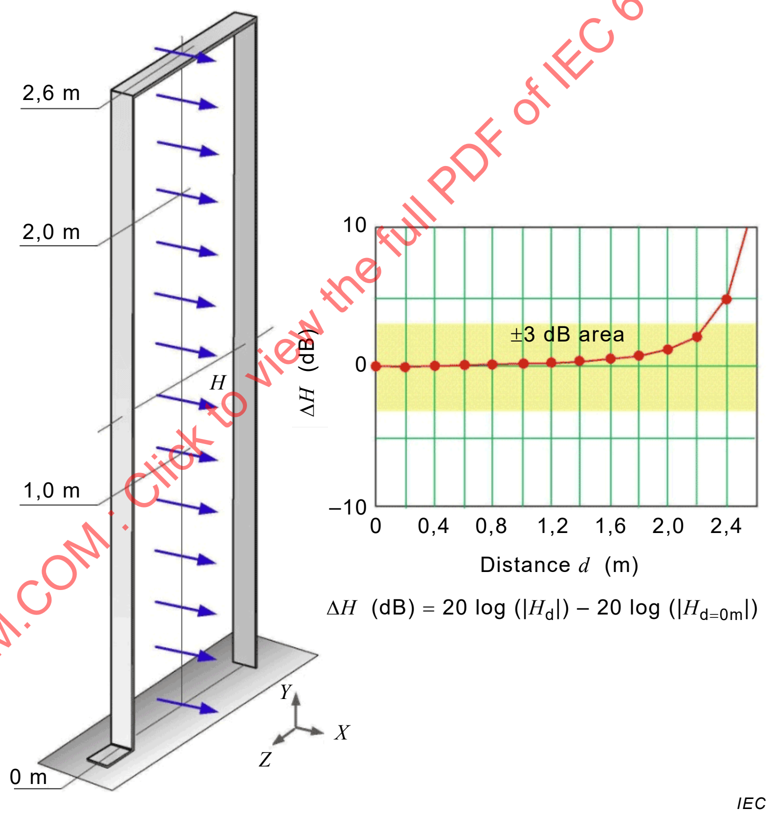


Figure G.8 – *Hx*-field along the vertical middle line in dB for the 1 m × 2,6 m induction coil

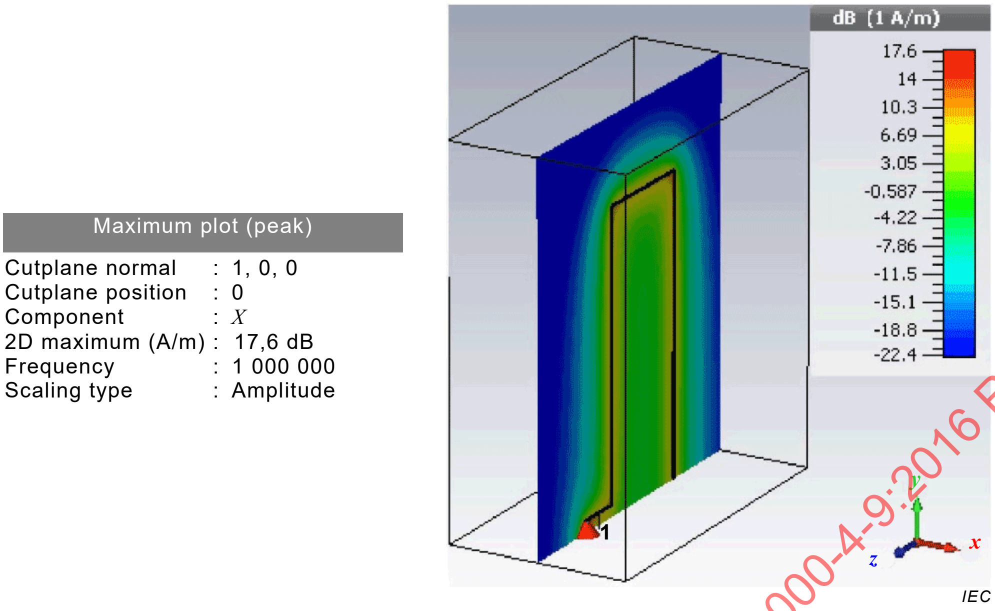


Figure G.9 – Hx-field 2D plot on y-z plane for the 1 m × 2,6 m induction coil

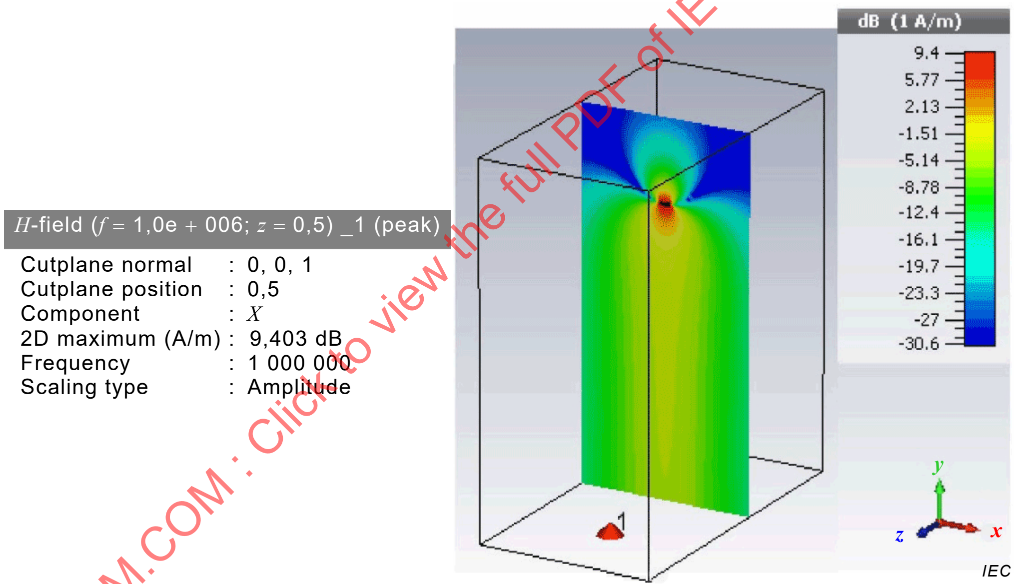


Figure G.10 – Hx-field 2D plot on x-y plane at z = 0,5 m for the 1 m × 2,6 m induction coil

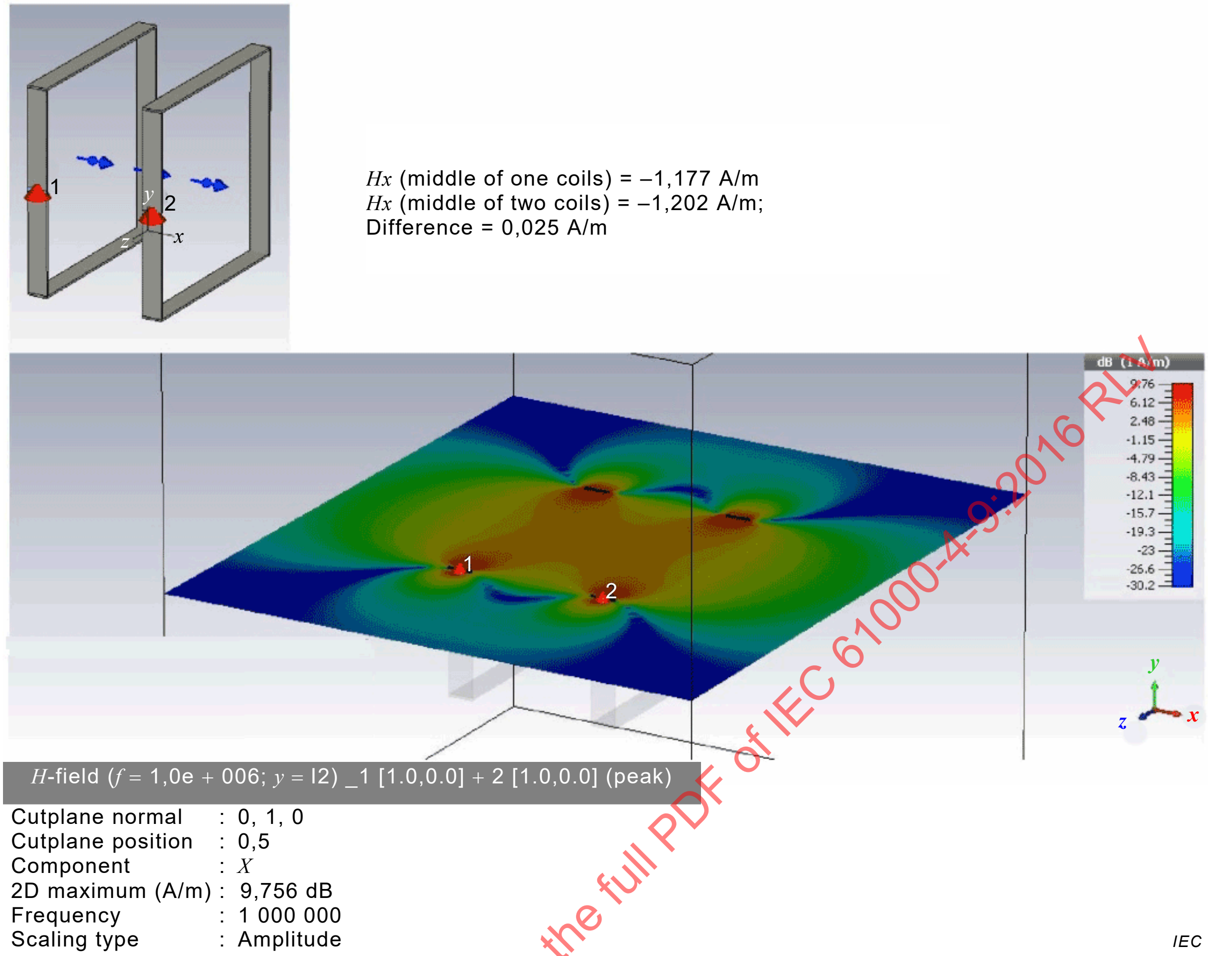
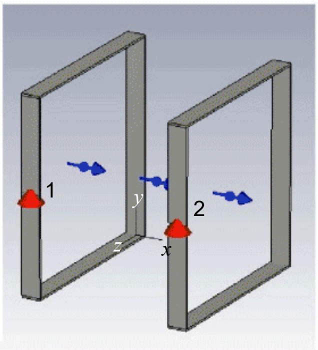
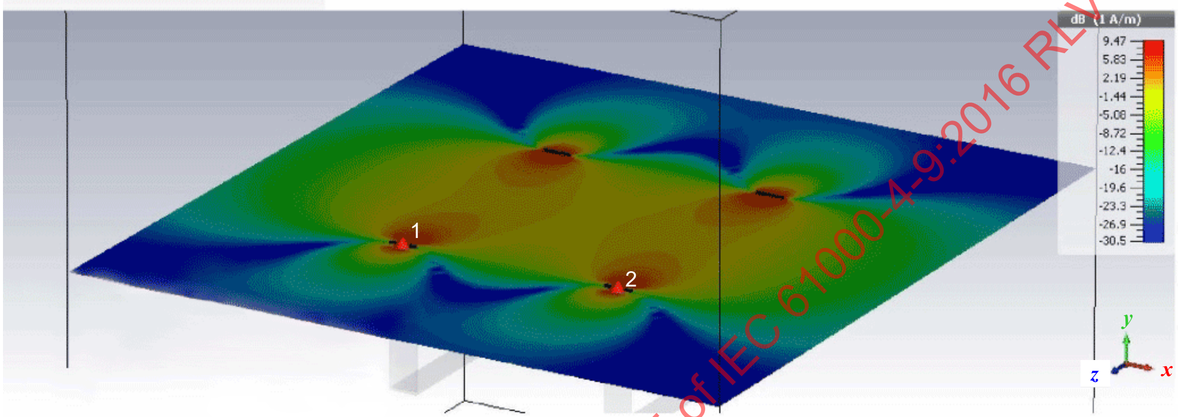


Figure G.11 – Helmholtz setup: *Hx*-field and 2D plot for two 1 m × 1 m induction coils, 0,6 m spaced



Hx (middle of one coils) = –1,066 A/m
Hx (middle of two coils) = –0,941 A/m;
Difference = 0,125 A/m



H-field (f = 1,0e + 006; y = l2) _1 [1.0,0.0] + 2 [1.0,0.0] (peak)

Cutplane normal	:	0, 1, 0
Cutplane position	:	0,5
Component	:	*X*
2D maximum (A/m)	:	9,465 dB
Frequency	:	1 000 000
Scaling type	:	Amplitude

IEC

Figure G.12 – Helmholtz setup: Hx-field and 2D plot for two 1 m × 1 m induction coils, 0,8 m spaced

Bibliography

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IEC 61000-4-9

Edition 2.0 2016-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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BASIC EMC PUBLICATION

PUBLICATION FONDAMENTALE EN CEM

Electromagnetic compatibility (EMC) –
Part 4-9: Testing and measurement techniques – Impulse magnetic field immunity test

Compatibilité électromagnétique (CEM) –
Partie 4-9: Techniques d'essai et de mesure – Essai d'immunité au champ magnétique impulsionnel

IEC 61000-4-9:2016-07(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-9: Testing and measurement techniques – Impulse magnetic field immunity test

FOREWORD

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International Standard IEC 61000-4-9 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility.

It forms Part 4-9 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 B on induction coil field distribution;
b) new Annex D on measurement uncertainty;
c) new Annex E on mathematical modeling of surge waveform;

d) new Annex F on characteristics using two standard induction coils;

e) new Annex G on 3D numerical simulations;

f) coil factor calculation and calibration using current measurement have been addressed in this edition.

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

CDV	Report on voting
77B/728/CDV	77B/745A/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 "pulse magnetic field".

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-9: Testing and measurement techniques – Impulse 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 impulse magnetic disturbances mainly encountered in:

– industrial installations,
– power plants,
– railway installations,
– 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 4.

This standard does not consider disturbances due to capacitive or inductive coupling in cables or other parts of the field installation. Other IEC standards dealing with conducted disturbances cover these aspects.

The object of this standard is to establish a common reference for evaluating the immunity of electrical and electronic equipment when subjected to impulse magnetic fields. The test method documented in this part of IEC 61000 describes a consistent method to assess the immunity of an equipment or system against a defined phenomenon.

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.

The task of the described laboratory test is to find the reaction of the equipment under test (EUT) under specified operational conditions to impulse magnetic fields caused by switching and lightning effects.

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
combination wave generator
CWG
generator with 1,2/50 μs open-circuit voltage waveform and 8/20 μs short-circuit current waveform

Note 1 to entry: This definition is abbreviated from the equivalent definition in IEC 61000-4-5.

Note 2 to entry: This note applies to the French language only.

3.1.3
duration
$\boldsymbol{T_d}$
<surge current for 8/20 μs> virtual parameter defined as the time interval between the instant at which the surge current rises to 0,5 of its peak value, and then falls to 0,5 of its peak value (T_w), multiplied by 1,18

$T_d = 1,18 \times T_w$

SEE: Figure 2.

3.1.4
front time
$\boldsymbol{T_f}$
<surge current> virtual parameter defined as 1,25 times the interval T_r between the instants when the impulse is 10 % and 90 % of the peak value

SEE: Figure 2.

3.1.5
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]

3.1.6
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

3.1.7
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.

3.1.8
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

3.1.9
reference ground plane
flat conductive surface whose potential is used as a common reference

3.1.10
rise time
T_r
interval of time between the instants at which the instantaneous value of an impulse first reaches 10 % value and then 90 % value

SEE: Figure 2.

3.1.11
surge
transient wave of electrical current, voltage or power propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease

3.1.12
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.

3.1.13
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]

3.1.14
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 Abbreviated terms

AE	Auxiliary equipment
CDN	Coupling/decoupling network

CWG	Combination wave generator
EFT/B	Electrical fast transient/burst
EMC	Electromagnetic compatibility
ESD	Electrostatic discharge
EUT	Equipment under test
MU	Measurement uncertainty
RGP	Reference ground plane

4 General

The magnetic fields to which equipment is subjected may influence the reliable operation of equipment and systems.

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

Pulse magnetic fields are generated by lightning strikes on buildings and other metal structures including aerial masts, earth conductors and earth networks and by initial fault transients in low, medium and high voltage electrical systems.

In high voltage sub-stations, an impulse magnetic field may also be generated by the switching of high voltage bus-bars and lines by circuit breakers.

The test is mainly applicable to electronic equipment to be installed in electrical generation and distribution plants as well as in their control centres. It is not relevant for distribution network equipment (e.g. transformers, power lines).

Product committees may consider other applications.

5 Test levels

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

Table 1 – Test levels

Level	**Pulse magnetic field strength** A/m (peak)
1	not applicable
2	not applicable
3	100
4	300
5	1 000
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. The level 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 C.

6 Test instrumentation

6.1 General

The test system comprises the combination 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 Combination wave generator

6.2.1 General

For this application, the combination wave generator is used as a current source.

NOTE The combination wave generator specified in this standard has identical wave shape definitions to the ones given in IEC 61000-4-5.

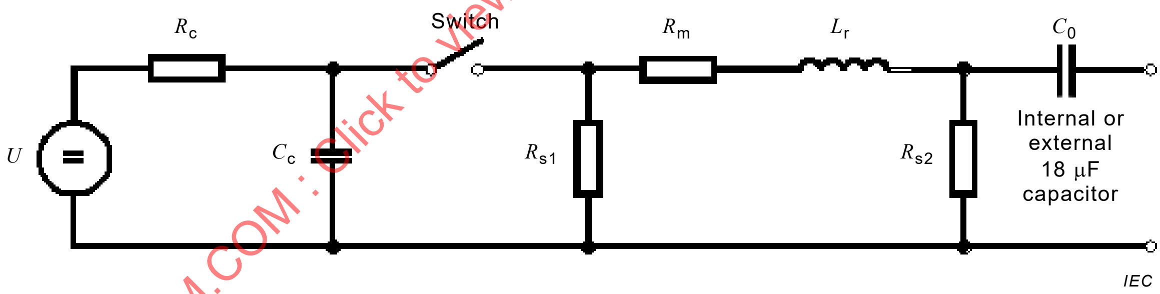
Therefore only the 8/20 µs waveform is relevant. The combination wave generator shall be able to deliver the required impulse current to the induction coils specified in 6.3.

The waveform is specified as a short-circuit current and therefore shall be measured without the induction coil connected.

This generator is intended to generate a surge having:

- a short-circuit current front time of 8 µs;
- a short-circuit current duration of 20 µs.

A simplified circuit diagram of the generator is given in Figure 1. The values for the different components R_{S1}, R_{S2}, R_m, L_r, and C_c are selected so that the generator delivers an 8/20 µs current surge into a short-circuit.



Key

U	High-voltage source
R_c	Charging resistor
C_c	Energy storage capacitor
R_s	Impulse duration shaping resistors
R_m	Impedance matching resistor
L_r	Rise time shaping inductor
C_o	Internal or external 18 µF capacitor

Figure 1 – Simplified circuit diagram of the combination wave generator

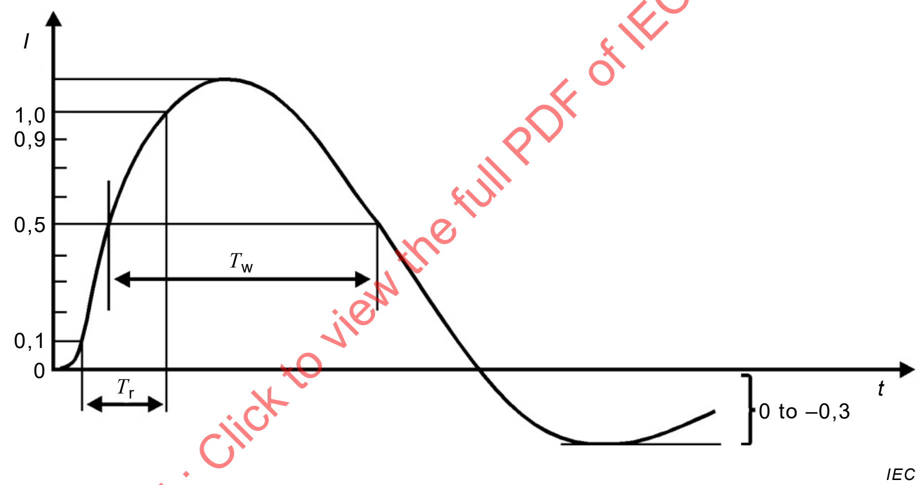
6.2.2 Performance characteristics of the generator

Polarity	positive and negative
Phase shifting	in a range between 0° to 360° relative to the phase angle of the a.c. line voltage to the EUT with a tolerance of ± 10°
Repetition rate	1 per minute or faster
Short-circuit peak output current	100 A to 1 000 A or the required test level divided by the coil factor
Waveform of the surge current	see Table 2 and Figure 2
Short-circuit peak output current tolerance	± 10 %

Table 2 – Definitions of the waveform parameters 8/20 µs

	Front time T_f µs	**Duration T_d** µs
Short-circuit current	T_f = 1,25 × T_r = 8 ± 20 %	T_d = 1,18 × T_w = 20 ± 20 %

A generator with floating output shall be used.



Front time: T_f= 1,25 × T_r = 8 µs ± 20 %

Duration: T_d = 1,18 × T_w = 20 µs ± 20 %

NOTE 1 The value 1,25 is the reciprocal of the difference between the 0,9 and 0,1 thresholds.

NOTE 2 The value 1,18 is derived from empirical data.

Figure 2 – Waveform of short-circuit current (8/20 µs) at the output of the generator with the 18 µF capacitor in series

6.2.3 Calibration of the generator

If a current transformer (probe) is used to measure short-circuit current, it should be selected so that saturation of the magnetic core does not take place. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz. The calibration shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with a bandwidth of not less than 1 MHz. The calibration shall be performed for all test levels, which are applied for testing.

The characteristics of the generator shall be measured through an external capacitor of 18 μF in series with the output, under short-circuit conditions. If the 18 μF capacitor is implemented in the generator, no external 18 μF capacitor is required for calibration.

All performance characteristics stated in 6.2.2, with the exception of phase shifting, shall be met at the output of the generator.

6.3 Induction coil

6.3.1 Field distribution

For the two single-turn standard coils of 1 m × 1 m and 1 m × 2,6 m, the field distribution is known and shown in Annex B. Therefore, no field verification or field calibration is necessary; the current measurement as shown in Figure 3 is sufficient.

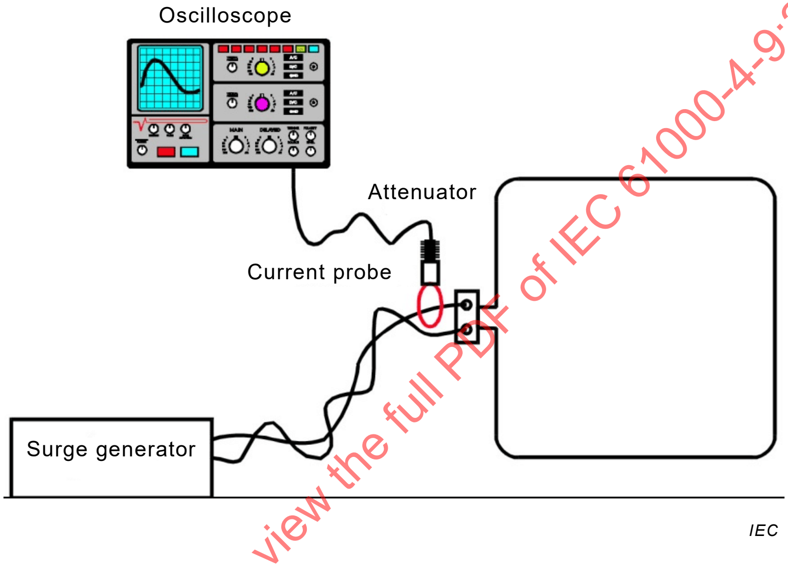


Figure 3 – Example of a current measurement of standard induction coils

Other coils of different dimensions may be used for an EUT which does not fit inside either of the two standard coils. In these cases, the field distribution shall be determined by measurement or calculation (see Annex A).

6.3.2 Characteristics of the standard induction coils of 1 m × 1 m and 1 m × 2,6 m

The standard 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 tolerance of the standard coils is ±1 cm, measured between the centre lines (centre of the cross-section). The characteristics of induction coils with respect to the magnetic field distribution are given in Annex B.

6.4 Calibration of the test system

The essential characteristics of the test system shall be calibrated by a current measurement (see Figure 3).

The output current shall be verified with the generator connected to the standard induction coil specified in 6.2.1 for all applicable test levels. In order to comply with the specifications given in Table 3 and Table 4, an external capacitor (e.g. 18 μF) in series may be required.

The capacitor may be incorporated in the generator. The connection shall be realized by twisted conductors or a coaxial cable of up to 3 m length and of suitable cross-section.

The following specifications given in Table 3 and Table 4 shall be verified.

Table 3 – Specifications of the waveform time parameters of the test system

	Front time T_f	Duration T_d
System using 1 m × 1 m standard induction coil	$T_f = 1{,}25 \times T_r = 8\ \mu s\ ^{+2{,}4}_{-0{,}8}\ \mu s$	$T_d = 1{,}18 \times T_w = 20\ \mu s\ ^{+6}_{-2}\ \mu s$
System using 1 m × 2,6 m standard induction coil	$T_f = 1{,}25 \times T_r = 8\ \mu s\ ^{+3{,}2}_{-0{,}8}\ \mu s$	$T_d = 1{,}18 \times T_w = 20\ \mu s\ ^{+8}_{-2}\ \mu s$

Table 4 – Specifications of the waveform peak current of the test system

Test level	Peak current I ± 10 % 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	111	152
4	333	453
5	1 111	1 515
X[a]	special/0,9	special/0,66

NOTE The values 0,9 and 0,66 are the calculated coil factors of standard induction coils as described in A.2.3 (see Annex A).

[a] "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.

If a current transformer (probe) is used to measure short-circuit current it should be selected so that saturation of the magnetic core does not take place. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz. The calibration shall be carried out with a current probe and oscilloscope or other equivalent measurement instrumentation with a bandwidth of not less than 1 MHz.

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);
– combination wave generator (CWG) with an internal/external (e.g. 18 μF) capacitor;
– induction coil;
– reference ground plane 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 combination 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:

– surge impulse present at the induction coil terminals.

It is sufficient to verify that the surge 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 impulse magnetic field applied to a table-top EUT

Table-top EUTs shall be placed on a non-conductive table. The 1 m × 1 m 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 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 × 2,6 m, either the proximity method (see 7.4) can be used or larger induction coils may be constructed to suit the dimensions of the EUT for different field orientation of the magnetic field.

NOTE If it is impractical to construct coils for very large equipment, the proximity method is the only suitable test method.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the loop antenna 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 EUT that can be tested.

An RGP is not required below the EUT (see Figure 4 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.

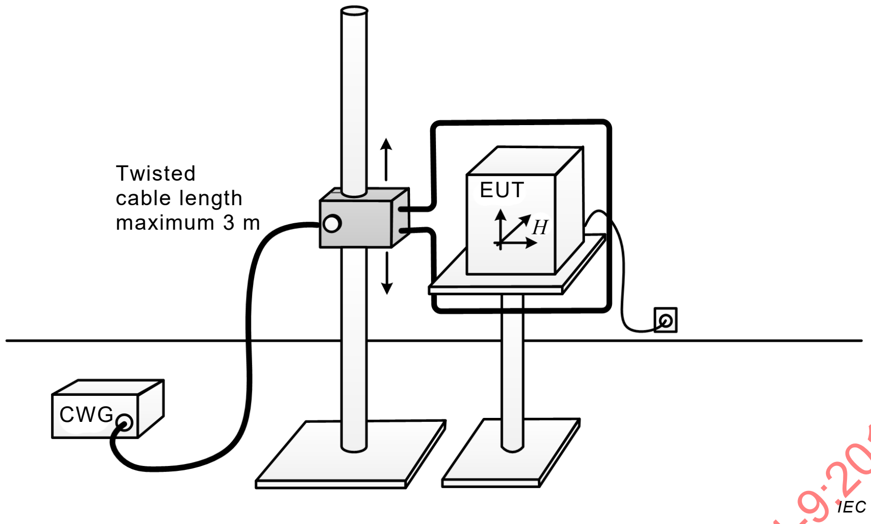


Figure 4 – Example of test setup for table-top equipment showing the vertical orthogonal plane

7.4 Test setup for impulse magnetic field applied to a floor standing EUT

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

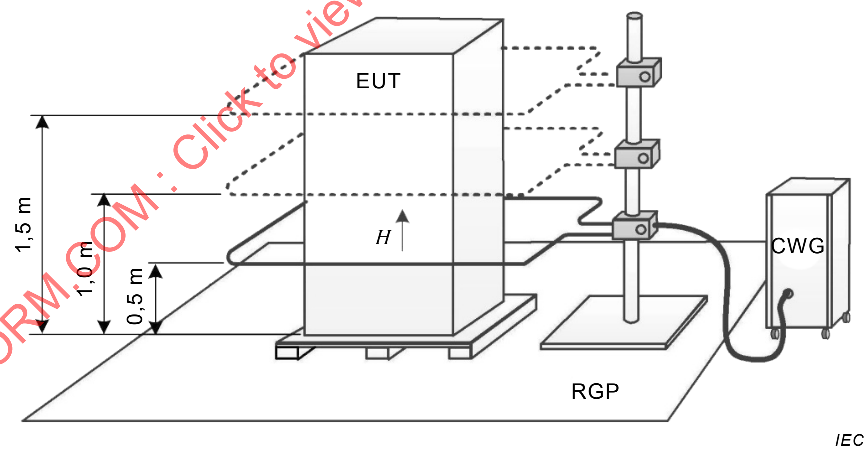


Figure 5 – Example of test setup for floor standing equipment showing the horizontal orthogonal plane

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. The distance between the positions shall be (0,5 ± 0,05) m. Figure 5 indicates that three positions have to be tested. In any case, the induction coil shown in Figure 5 shall not be placed below 0,5 m. Figure 6 shows an example for testing with a vertical orthogonal plane.

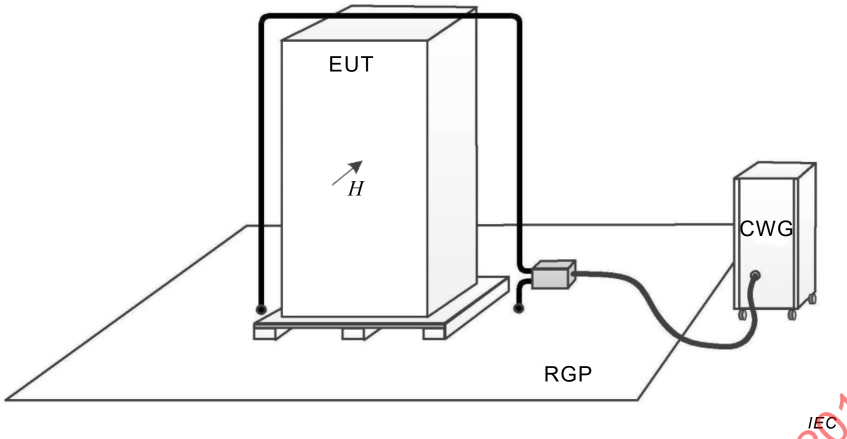


Figure 6 – Example of test setup for floor standing equipment showing the vertical orthogonal plane

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, either the proximity method (see Figure 7 and 7.5 for more detailed information) can be used or larger induction coils may be constructed to suit the dimensions of the EUT for a different field orientation of the magnetic field (see Annex A).

If it is impractical to construct coils for very large equipment, the proximity method is the only suitable test method. Product committees may select either the proximity method or use a suitable coil.

It is not necessary to maximize the impact of cables during this test. The proximity of the cables to the loop antenna 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 EUT that can be tested.

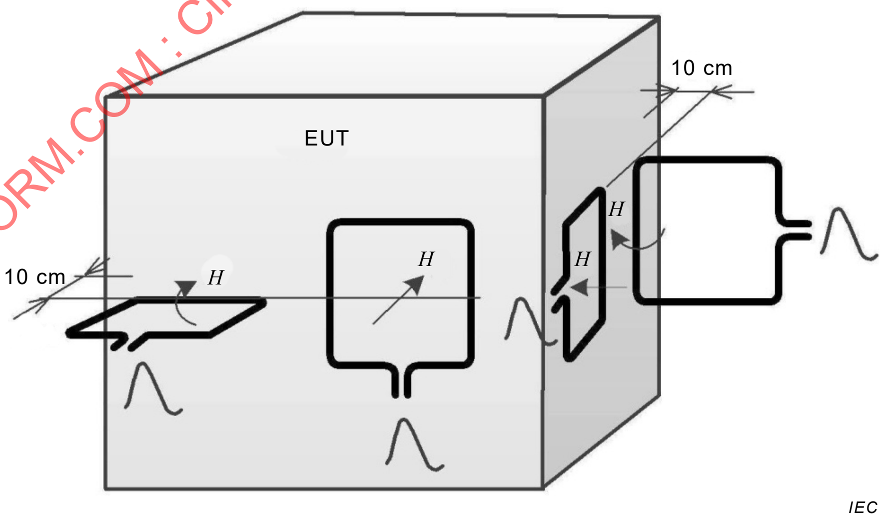


Figure 7 – Example of test setup using the proximity method

7.5 Test setup for impulse magnetic 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 may be the only practical test method without the RGP in place. Figure 7 gives an example for a test setup for in-situ testing. The 1 m × 1 m standard induction coil shall be used when examining EUTs using the proximity method. Furthermore 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 centre of the standard induction coil.

Testing of table top equipment according to 7.3 may also be performed but this is not the preferable test method.

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;
• number of impulses (for each orthogonal orientation):

  number of impulses unless otherwise specified by the relevant standard:

  – for d.c. powered EUT, five positive and five negative impulses;
  – for single-phase a.c. powered EUT, 20 positive and 20 negative impulses without phase synchronization;
  – for three-phase a.c. powered EUT, 20 positive and 20 negative impulses without phase synchronization;

- impulse repetition rate not less than one impulse per minute (product committees may specify this repetition rate);
- representative operating conditions of the EUT;
- three orthogonal orientations of the magnetic field in case of table-top equipment;
- three orientations of the magnetic field in case of floor standing equipment;
- locations of the induction coil relative to the EUT (test points).

For most products, phase synchronization may not be appropriate; therefore product committees should decide on the need of phase synchronization for their products.

NOTE 1 The application of tests with different phase angles may be more critical for equipment with inverter technology.

NOTE 2 Special safety considerations may be needed when using the generator's CDN output.

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 Clause 8 of this standard;
– 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;
– performance level defined by the manufacturer, requestor or purchaser;

- 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)

Characteristics of non standard induction coils

A.1 General

When an EUT does not fit into standard induction coils, either the proximity method may be used or non standard induction coils may be used. Non standard coils are constructed to accommodate the dimensions of the EUT for the different orientations of the magnetic field.

Note that larger induction coils give repeatable results, but it may not be practical to construct very large coils. The maximum dimensions of non standard induction coils are determined by whether the waveform requirements of the 1 m × 2,6 m coil can be achieved. The proximity method may give useful but not necessarily reproducible results.

NOTE Due to the possible large dimensions of EUTs, the coils can be made of "C" or "T" cross-sectional shape in order to have sufficient mechanical rigidity.

A.2 Determination of the coil factor

A.2.1 General

The induction coil factor shall be determined by measurement or 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 measurement

A.2.2.1 General

In order to compare the test results from different coils, the induction coil factor shall be measured in a free space condition without an EUT.

A magnetic field sensor of adequate sensitivity shall be used to measure the magnetic field strength H generated by the induction coil.

The field sensor should be positioned at the centre of the induction coil and with suitable orientation to detect the maximum value of the field. The current I in the induction coil shall be measured and adjusted to obtain a field strength within the measurement range of the magnetic field sensor. The coil factor, k_{CF}, is obtained as $k_{\mathrm{CF}} = H/I$.

A.2.2.2 Coil factor measurement for table-top equipment

The following procedure should be carried out:

The induction coil shall be positioned at a minimum of 1 m from conductive or magnetic structures. Insulating material may be used to support the induction coil. The induction coil is connected to an a.c. source. The measurement can be carried out at any frequency (e.g. 50 Hz or 60 Hz).

A.2.2.3 Coil factor measurement for floor standing equipment

The following procedure should be carried out:

The induction coil should be positioned on the RGP, which may form one side of the coil. Except for the RGP, all other conductive or magnetic structures shall be at least 1 m from the coil. Insulating material may be used to support the induction coil. The induction coil shall be connected to an a.c. source. The measurement shall be carried out at power frequency.

A.2.3 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

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

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 inductor 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 $b = 3 \times a$.

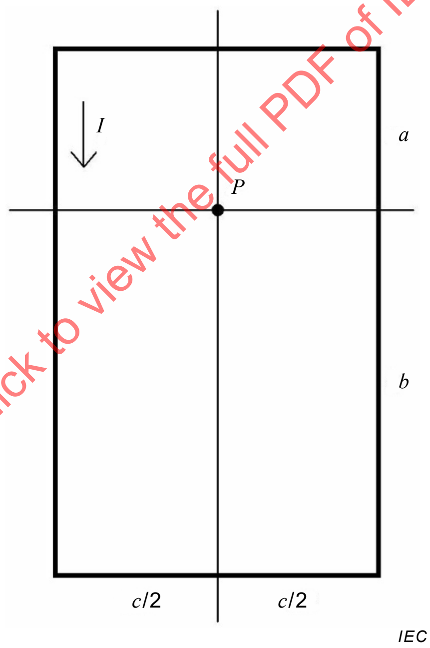


Figure A.1 – Rectangular induction coil with sides $a + b$ and c

A.3 Magnetic field measurement

The field measurement mentioned in A.2.2.1 is also applicable for large non standard induction coils. The measurement of the magnetic field may be done with a measurement system comprising calibrated sensors, for example a "Hall effect" or multi-turn loop sensors with a diameter of at least one order of magnitude smaller than the induction coil and a power frequency narrow band instrument. The maximum EUT volume is limited by the +3 dB isoline in the x-y plane and by the ±3 dB isolines in the x-z plane.

A.4 Verification of non standard induction coils

The measurement may be carried out by injecting the power frequency current into the induction coil and measuring the magnetic field using sensors placed at the geometrical centre of the coil as shown in Figure A.2.

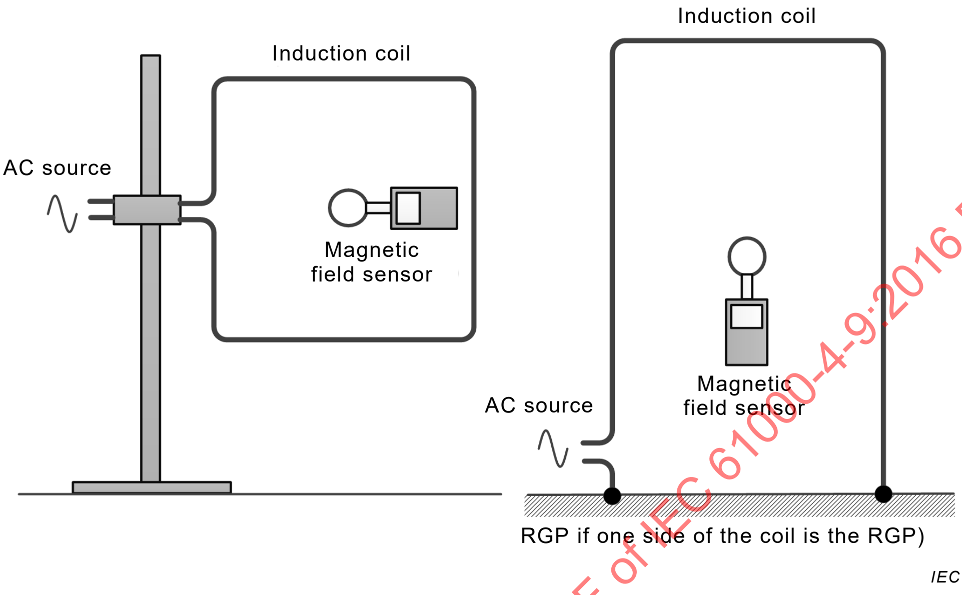


Figure A.2 – Example of verification setup for non standard induction coils

The induction coil factor can be calculated from equation (A.1) if the largest cross-section dimension of the coil inductor is not more than 0,02 of the shortest side of the coil.

If one side of the coil is the RGP, an additional source of uncertainty is the finite size of the RGP. This can be evaluated through the relative deviation between the coil factors calculated assuming the presence and absence of an infinite size RGP.

Annex B
(informative)

Information on the field distribution of standard induction coils

B.1 General

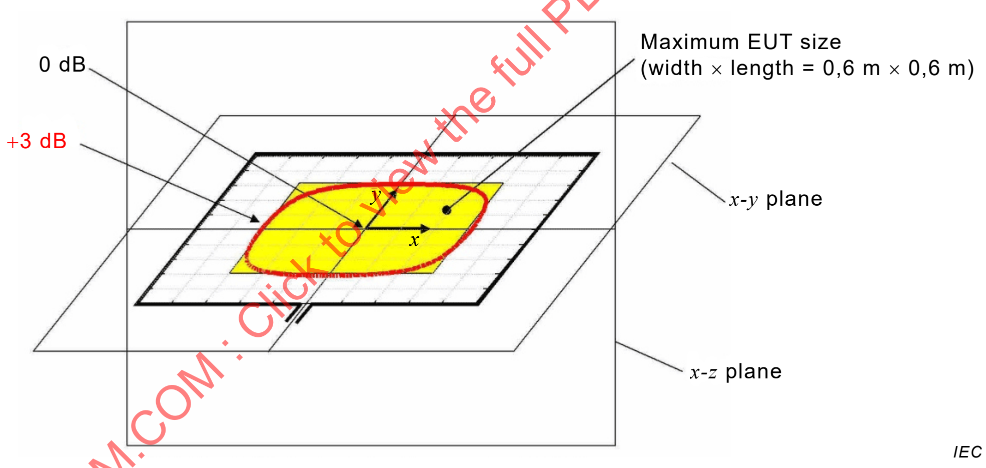
Annex B gives information on the maximum size of an EUT and its location in the standard induction coils. The maximum EUT volume is limited by the +3 dB isoline in the x-y plane and by the ±3 dB isolines in the x-z plane.

The inductance for the single turn standard 1 m × 1 m coil is approximately 2,5 µH and for the 1 m × 2,6 m standard coil is approximately 6 µH.

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

B.2 1 m × 1 m induction coil

The +3 dB and -3 dB isolines for the magnetic field strength (magnitude) are shown in Figure B.1 for the x-y plane and in Figure B.2 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 B.1 – +3 dB isoline for the magnetic field strength (magnitude) in the x-y plane for the 1 m × 1 m induction coil

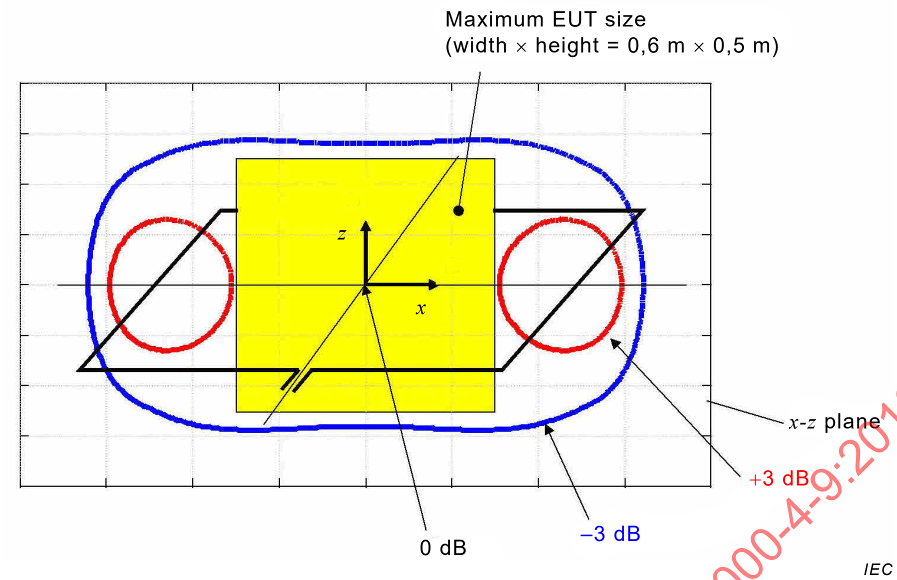
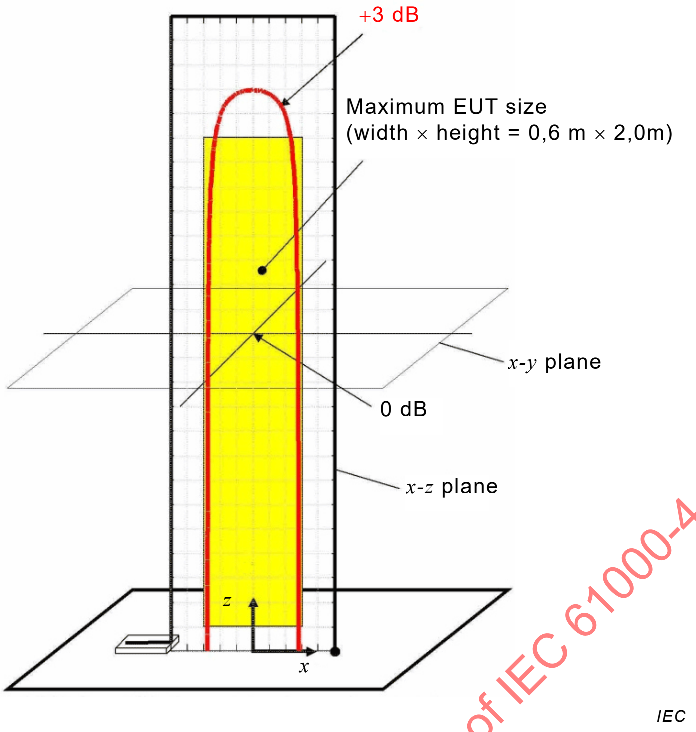


Figure B.2 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x*-*z* plane for the 1 m × 1 m induction coil

B.3 1 m × 2,6 m induction coil with reference ground plane

The +3 dB and -3 dB isolines for the magnetic field strength (magnitude) are shown in Figure B.3 for the *x*-*z* plane and in Figure B.4 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 B.3 – +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

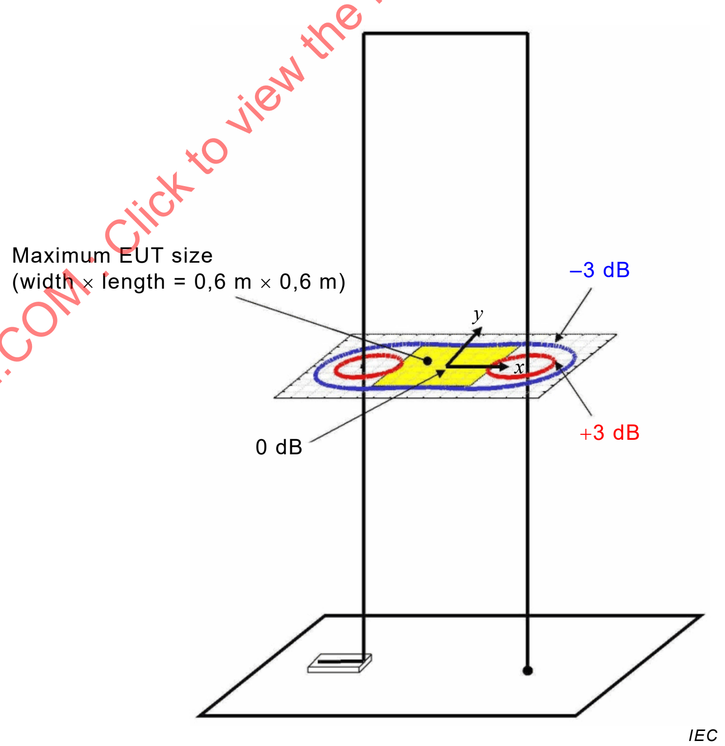
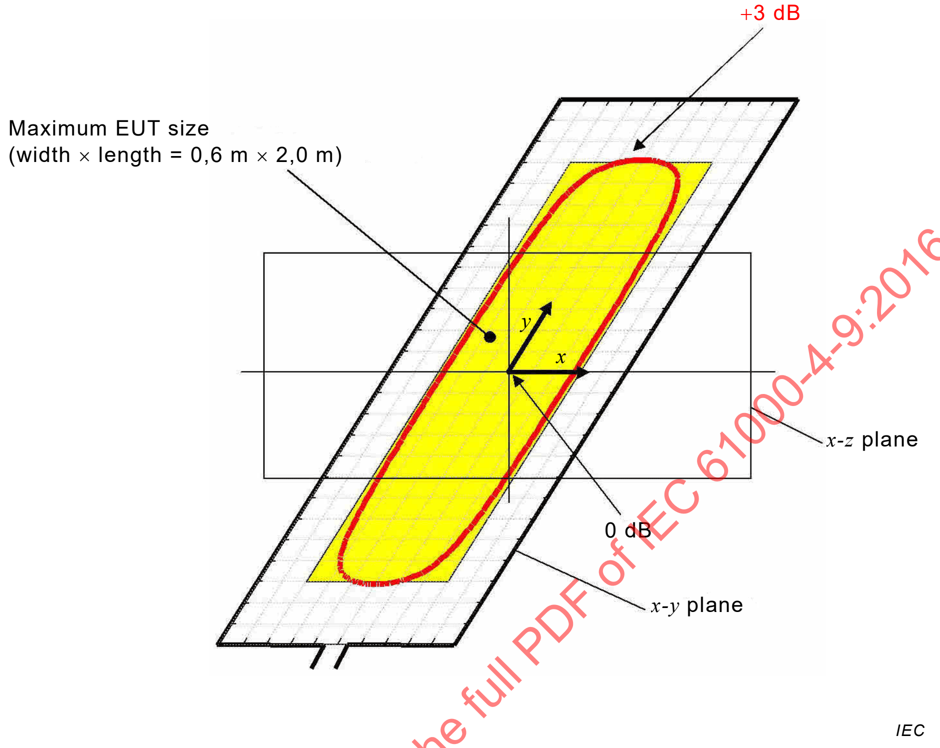


Figure B.4 – +3 dB and -3 dB isolines for the magnetic field strength (magnitude) in the x-y plane for the 1 m × 2,6 m induction coil with reference ground plane

B.4 1 m × 2,6 m induction coil without reference ground plane

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure B.5 for the *x*-*y* plane and in Figure B.6 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 B.5 – +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

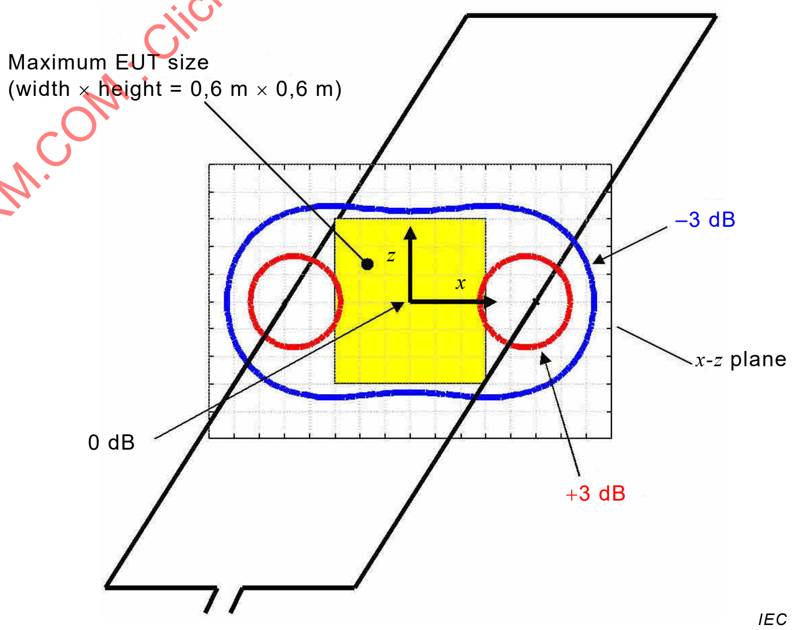


Figure B.6 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x*-*z* plane for the 1 m × 2,6 m induction coil without reference ground plane

Annex C
(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 impulse 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 impulse 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-voltage 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-voltage 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 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 rise time of a 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.

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 standards, 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 behavior, 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 current impulse injected into the coil
H_P	Peak of the magnetic field impulse
k_{CF}	Coil factor of the induction coil: $H_P = k_{CF} \times I_P$
T_f	Front time of the current and magnetic field impulses: $T_f = 1{,}25\ T_r$
T_r	Rise time of the current and magnetic field impulses, defined as the time from 10 % to 90 % of the peak value
T_w	Width of the current and magnetic field impulses
T_d	Duration of the current and magnetic field impulses: $T_d = 1{,}18\ T_w$

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 surge current and to the surge 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
- reading of 10% level
- reading of 90% level
- reading of 50% level
- 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 surge current and surge magnetic field calibration

D.4.1 General

In the case of the magnetic field test, the disturbance quantities are the surge current generated by the test generator and injected into the coil terminals and the surge 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, T_f and T_d, for the surge current, and H_P for the surge 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 surge magnetic field has the same front time and width as the surge current, and the peak of the magnetic field is obtained as $H_P = k_{CF} \times I_P$.

The approach adopted here to evaluate impulse MU is described in D.4.6 and D.4.7. Tables D.1, D.2, and D.3 give examples of uncertainty budgets for the surge parameters. The tables include the input quantities that are considered most significant for these examples, the details (numerical values, type of probability density function, etc.) of each contributor to MU and the results of the calculations required for determining each uncertainty budget.

D.4.2 Front time of the surge current

The measurand is the surge current front time calculated by using the functional relationship

$$T_f = 1{,}25\sqrt{(T_{90\%} - T_{10\%} + \delta R)^2 - T_{MS}^2} \qquad \text{(D.1)}$$

where

$$T_{MS} = \frac{\alpha}{B} \qquad \text{(D.2)}$$

and:

$T_{10\%}$ is the time at 10 % of peak amplitude

$T_{90\%}$	is the time at 90 % of peak amplitude
δR	is the correction for non-repeatability
T_{MS}	is the rise time of the step response of the measuring system (10 % to 90 %) in µs
B	is the –3 dB bandwidth of the measuring system in kHz
α	is the coefficient whose value is (360 ± 40) µs × kHz (B in kHz and T_{MS} in µs)

Table D.1 – Example of uncertainty budget for surge current front time (T_f)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{10\%}$	0,74	µs	0,005 0	µs	triangular	2,45	0,002 0	-1,256 3	1	0,002 6	µs
$T_{90\%}$	7,94	µs	0,005 0	µs	triangular	2,45	0,002 0	1,256 3	1	0,002 6	µs
δR	0	µs	0,025	µs	normal (k=1)	1,00	0,025 0	1,256 3	1	0,031 4	µs
A	360	µs kHz	40	µs · kHz	rectangular	1,73	23,094 0	-0,000 3	1/kHz	0,005 8	µs
B	500	kHz	50	kHz	rectangular	1,73	28,867 5	0,000 2	µs/kHz	0,005 3	µs
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,0325 6	µs
							$U(y)$ = 2 $u_c(y)$			0,06	µs
							y			8,95	µs

[a] Probability density function

***T*$_{10\ \%}$, *T*$_{90\ \%}$:** is the time reading at 10 % or 90 % of the peak amplitude. The error bound is obtained assuming a sampling frequency of 100 MS/s and a trace interpolation capability of the scope (triangular probability density function). Were this not the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here, for additional contributors see D.4.5. The readings are assumed to be $T_{10\ \%}$ = 0,74 µs and $T_{90\ \%}$ = 7,94 µs.

T_{MS}: is the calculated rise time of the step response of the measuring system. The coefficient α (see Clause D.2), depends on the shape of the impulse response of the measuring system. The range 360 ± 40 is representative of a wide class of systems, each having a different shape of the impulse response (see D.4.6 and Table D.4). 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, a cable and a scope) by using the following equation:

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

An estimate of 500 kHz and a 50 kHz error bound of a rectangular probability density function are assumed for B.

δR: is the 10 % to 90 % rise time non-repeatability. It quantifies the lack of repeatability in the measurement of $T_{90\%} - T_{10\%}$ due to the measuring instrumentation, the layout of the measurement setup and the surge generator itself. It is determined experimentally. 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

$$s(q_k) = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(q_j - \bar{q}\right)^2} \qquad \text{(D.4)}$$

where $\bar{q}$ is the arithmetic mean of the q_j values. An error bound $s(q_k)$ = 25 ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

D.4.3 Peak of the surge current and magnetic field

The measurand is the peak of the surge current injected into the coil and calculated by using the functional relationship

$$I_\mathrm{p} = \frac{V_\mathrm{PR}}{R_\mathrm{T}} \frac{1 + \delta R + \delta V}{1 - \left(\frac{\beta}{B}\right)^2} \tag{D.5}$$

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 (14,8 ± 1,6) kHz

Table D.2 – Example of uncertainty budget for the peak of surge current (I_P)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_PR	1,15	V	0,002 2	V	triangular	2,45	0,000 92	1 001	1/Ω	0,918	A
R_T	0,001	Ω	0,000 05	Ω	rectangular	1,73	0,000 03	-151·10[3]	A/Ω	33,23	A
δR	0	1	0,03	1	Normal (k =1)	1,00	0,030 00	1 151	A	34,53	A
δV	0	1	0,02	1	rectangular	1,73	0,011 55	1 151	A	13,29	A
β	14,8	kHz	1,6	kHz	rectangular	1,73	0,923 76	0,136	A/kHz	0,126	A
B	500	kHz	50	kHz	rectangular	1,73	28,867 51	-0,0040	A/kHz	0,117	A
							$u_\mathrm{c}(y) = \sqrt{\Sigma u_i(y)^2}$			0,050	kA
							$U(y) = 2\ u_\mathrm{c}(y)$			0,10	kA
							y			1,15	kA
							Expressed in % of 1,15 kA			8,6	%

[a] Probability density function

V_PR: is the voltage peak reading at the output of the current probe. The error bound is obtained assuming that the scope has an 8-bit vertical resolution with an interpolation capability (triangular probability density function).

R_T: is the transfer resistance 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. It is a type A evaluation quantified by the experimental standard deviation of a sample of repeated measurements of the peak current. It 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 DC. 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.4.7). The interval (14,8 ± 1,6) kHz is representative of a wide class of systems, each having a different shape of the impulse response.

B: see D.4.2., same meaning and same values both for the estimate and error bound.

The uncertainty of the peak of the surge magnetic field is obtained from the functional relationship $H_P = k_{CF} \times I_P$, where k_{CF} is the coil factor as measured or calculated as described in the standard. Therefore, if the calculated k_{CF} is 0,90 (e.g. in the case of a square induction coil whose side is 1 m) and its expanded uncertainty is 5 %, then the best estimate of H_P is 1,04 kA/m and its expanded uncertainty is 9,9 % (see Table D.2)

D.4.4 Duration of the current impulse

The measurand is the duration of the surge current injected into the coil calculated by using the functional relationship

$$T_d = 1{,}18 \cdot \left(T_{50\%,F} - T_{50\%,R} + \delta R\right) \cdot \left[1 - \left(\frac{\beta}{B}\right)^2\right] \qquad \text{(D.6)}$$

where

$T_{50\%,R}$ is the time at 50 % of peak amplitude at the rising edge of the impulse

$T_{50\%,F}$ is the time at 50 % of peak amplitude at the falling edge of the impulse

δR is the correction for non-repeatability

B is the –3 dB bandwidth of the measuring system

β is the coefficient which value is (14,8 ± 1,6) kHz

Table D.3 – Example of uncertainty budget for current impulse width (T_d)

Symbol	Estimate	Unit	Error bound	Unit	PDF[a]	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{50\%,R}$	3,44	µs	0,005 0	µs	triangular	2,45	0,002 0	-1,181 1	µs	0,002 4	µs
$T_{50\%,F}$	22,34	µs	0,005 0	µs	triangular	2,45	0,002 0	1,181 1	µs	0,002 4	µs
δR	0	µs	0,15	µs	Normal (k =1)	1,00	0,150 0	1,181 1	µs	0,177 1	µs
β	14,8	kHz	1,6	kHz	rectangular	1,73	0,923 8	-0,002 6	µs/kHz	0,002 5	µs
B	500	kHz	50	kHz	rectangular	1,73	28,867 5	0,000 1	µs/kHz	0,002 2	µs
							$u_c(y) = \sqrt{\Sigma u_i(y)^2}$			0,177 2	µs
							$U(y) = 2\ u_c(y)$			0,4	µs
							y			22,3	µs

[a] Probability density function

$T_{50\%,R}$, $T_{50\%,F}$: is the time reading at 50 % of the peak amplitude on the rising or falling edge of the surge current. The error bound is obtained assuming a sampling frequency of 100 MS/s (the same as in D.4.2) and a trace interpolation capability of the scope (triangular probability density function). Were this not the case, a rectangular probability density function should be assumed. Only the contributor to MU due to the sampling rate is considered here. For additional contributors see D.4.5. The readings are assumed to be $T_{50\%,R}$ = 3,44 µs and $T_{50\%,F}$ = 22,34 µs.

δR: quantifies the non-repeatability of the $T_{50\%,F} - T_{50\%,R}$ time difference measurement due to the measuring instrumentation, the layout of the measurement setup and the test generator itself. It is determined experimentally. This is a type A evaluation quantified by the experimental standard deviation of a sample of repeated measurements. An error bound $s(q_k)$ = 150 ns (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

β: see D.4.3, same meaning and same values both for the estimate and error bound.

B: see D.4.2, same meaning and same values both for the estimate and error bound.

D.4.5 Further MU contributions to time measurements

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.

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.

D.4.6 Rise time distortion due to the limited bandwidth of the measuring system

The distortion of the rise-time is evaluated through the usual rule of combination of the rise-times, which is valid when two non-interacting systems are cascaded and their step responses monotonically increase, i.e.

$$T_{\mathrm{rd}} = \sqrt{T_{\mathrm{r}}^2 + T_{\mathrm{MS}}^2} \tag{D.7}$$

where T_{rd} is the rise-time of the signal at the output of the measuring system (distorted rise-time), T_{r} is the rise-time of the signal at the input of the measuring system, and T_{MS} is the rise time of the step response of the measuring system. It is important to observe that the derivation of equation (D.7) is based on the following definition of the rise time

$$T_{\mathrm{MS}} = \sqrt{2\pi \int_0^{\infty} (t - T_{\mathrm{s}})^2 h_0(t) dt} \tag{D.8}$$

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

$$T_{\mathrm{s}} = \int_0^{\infty} t h_0(t) dt \tag{D.9}$$

Equation (D.8) 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 times are usually combined through equation (D.7). With the –3 dB bandwidth of the system, the two definitions lead to comparable rise times. If we define

$$\alpha = T_{\mathrm{MS}} \cdot B \tag{D.10}$$

then 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.4. It is evident from Table D.4, that it is not possible to identify a unique value of α because α depends both on the adopted definition of the rise time (e.g. based on thresholds or on equation (D.7)) 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.4, 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 of 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.4 – α factor (see equation (D.10)) of different unidirectional impulse responses corresponding to the same bandwidth of system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (crit. damp.)	Rectangular	Triangular
α, using equation (D.8)	332	399	363	321	326
α, 10 % to 90 %	339	350	344	354	353

D.4.7 Impulse peak and width distortion due to the limited bandwidth of the measuring system

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

$$V_{\mathrm{out}}(t) = \int_0^t V_{\mathrm{in}}(\tau) \cdot h(t-\tau) d\tau \tag{D.11}$$

where $V_{\mathrm{in}}(t)$ 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 around the time instant t_{p} when the input reaches its peak value V_{p}

$$V_{\mathrm{in}}(t) = V_{\mathrm{p}} + \frac{V''_{\mathrm{in}}(t_{\mathrm{p}})}{2} \cdot (t-t_{\mathrm{p}})^2 + \frac{V'''_{\mathrm{in}}(t_{\mathrm{p}})}{6} \cdot (t-t_{\mathrm{p}})^3 + \ldots \tag{D.12}$$

Note that the first order term is missing from equation (D.12) since $V'(t_{\mathrm{p}}) = 0$. Further $V''_{\mathrm{in}}(t_{\mathrm{p}}) < 0$, because the concavity points downwards (maximum), and $V'''_{\mathrm{in}}(t_{\mathrm{p}}) > 0$, because, for the standard waveforms of interest here, the rise time is lower than the fall time. Substituting equation (D.12) into equation (D.11) 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

$$V_{pd} = \frac{V_p}{A}\left[1-\left(\frac{\beta}{B}\right)^2\right] \tag{D.13}$$

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

$$\beta = \alpha \cdot \sqrt{\frac{\left|V''_{in}(t_p)\right|}{4\pi V_p}} \tag{D.14}$$

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.4.6. Since the mathematical expression for the standard surge waveforms are given in Annex E of this standard, the value of β can be numerically calculated and is reported in Table D.5.

The estimate of the distortion of the input impulse width T_W is simply obtained considering that the area of the output impulse is that of the input impulse divided by the d.c. attenuation A. Therefore

$$V_p T_W = A V_{pd} T_{wd} \tag{D.15}$$

where T_{wd} is the output impulse width. Hence

$$T_{wd} = \frac{V_p}{A V_{pd}} \cdot T_W = \frac{1}{1-\left(\frac{\beta}{B}\right)^2} \cdot T_W \tag{D.16}$$

Table D.5 – β factor (equation (D.14)) of the standard current surge waveform

kHz	8/20 μs
β	14,8 ± 1,6

D.5 Application of uncertainties in the surge generator compliance criterion

Generally, in order to be confident that the current and the magnetic field surges 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)

Mathematical modelling of surge current waveforms

E.1 General

Annex E provides reference mathematical waveforms for:

- designing surge generators,
- simulations of surge performance on digital apparatus.

The formulae have been defined considering the following requirements:

1) To reproduce the nominal front time and duration as defined in the standard for the surge generators with output in short-circuit condition.
2) To help the designers of digital apparatus to build up a circuit model of the source generators by using the simplified circuits reported in the standard with the nominal values of the circuit elements, if any.
3) To have derivative equal to zero at starting time in order to avoid instability when numerical simulations are performed.
4) To have the same basic formula used in IEC for transient phenomena such as ESD, EFT/B and surge.

NOTE For current surge (8/20 μs), the defined mathematical waveforms match well with those defined in IEEE Std C62.45-2002.

The following parameter definitions are used:

a) T_w is the width time defined as the time between the 50 % of the rising and falling front of the waveform.
b) T_r is the rise time for current surge defined as the time between the 10 % and 90 % of the early time response of the waveform.
c) T_d is the duration time between the minimum value of the early time response and the 50 % of the falling time.
d) T_f is the front time defined as the time between the intersection of a line, having a slope that approximates the early time response, with the horizontal line that passes through the minimum and maximum value of the waveform respectively. The following values are defined that match well with the waveforms provided by the simplified circuits using model simulations:

   current surge (8/20 μs): T_f =1,25 × T_r; T_d = 1,18 × T_w
e) BW is the bandwidth of the surge waveforms defined at the frequency where the spectral response begins to roll off with a slope of –60 dB/decade.

E.2 Normalized time domain current surge (8/20 μs)

The normalized time domain expression of the 8/20 μs current surge is given by

$$I_{\text{SURGE}}(t) = k_i \cdot \left[\frac{i_1}{k_{\text{SURGE}}} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{\eta_{\text{SURGE}}}}{1+\left(\frac{t}{\tau_1}\right)^{\eta_{\text{SURGE}}}} \cdot e^{\frac{-t}{\tau_2}} \right] \quad \text{(E.1)}$$

The coefficients that appear in equation (E.1) have the following values

$k_i = 1$ $\tau_1 = 47{,}52\ \mu\text{s}$ $\tau_2 = 4{,}296\ \mu\text{s}$ $i_1 = 0{,}939$ $\eta_{\text{SURGE}} = 2{,}741$

$$k_{\text{SURGE}} = e^{\frac{-\tau_1}{\tau_2} \cdot \left(\frac{\eta_{\text{SURGE}} \cdot \tau_2}{\tau_1}\right)^{\frac{1}{\eta_{\text{SURGE}}}}} \tag{E.2}$$

The plot of the 8/20 μs current surge as a function of time is shown in Figure E.1.

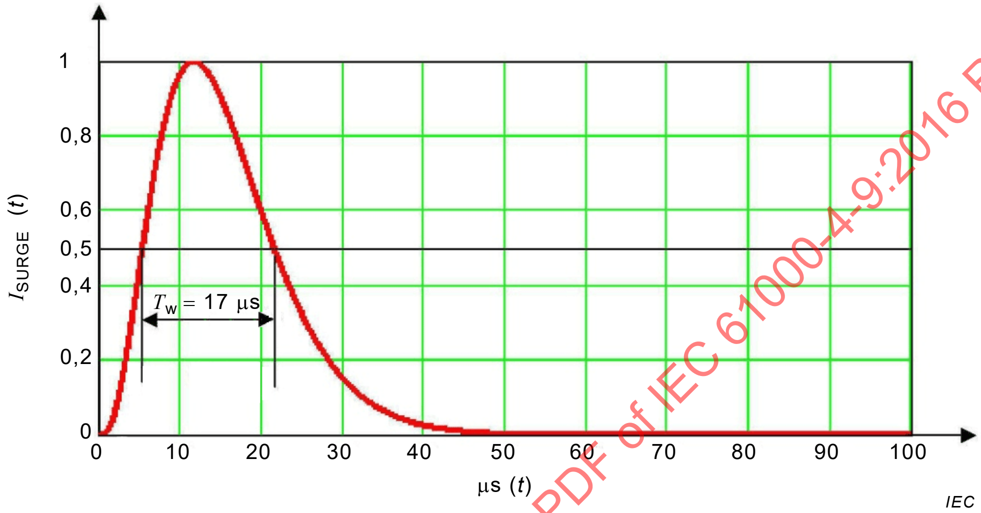


Figure E.1 – Normalized current surge (8/20 μs): Width time response T_w

An expansion to highlight the early time response is plotted in Figure E.2.

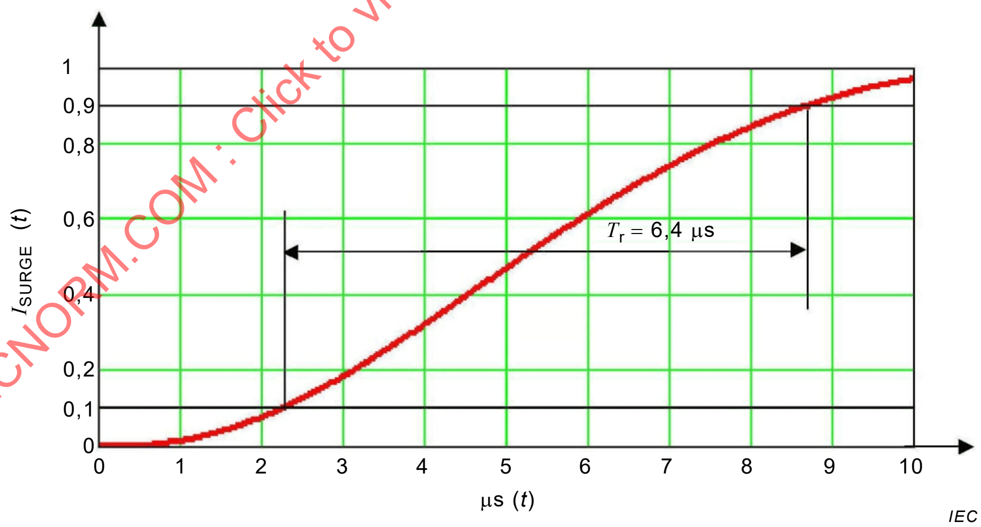


Figure E.2 – Normalized current surge (8/20 μs): Rise time response T_r

The magnitude of the spectral response corresponding to equation (E.1) is shown in Figure E.3.

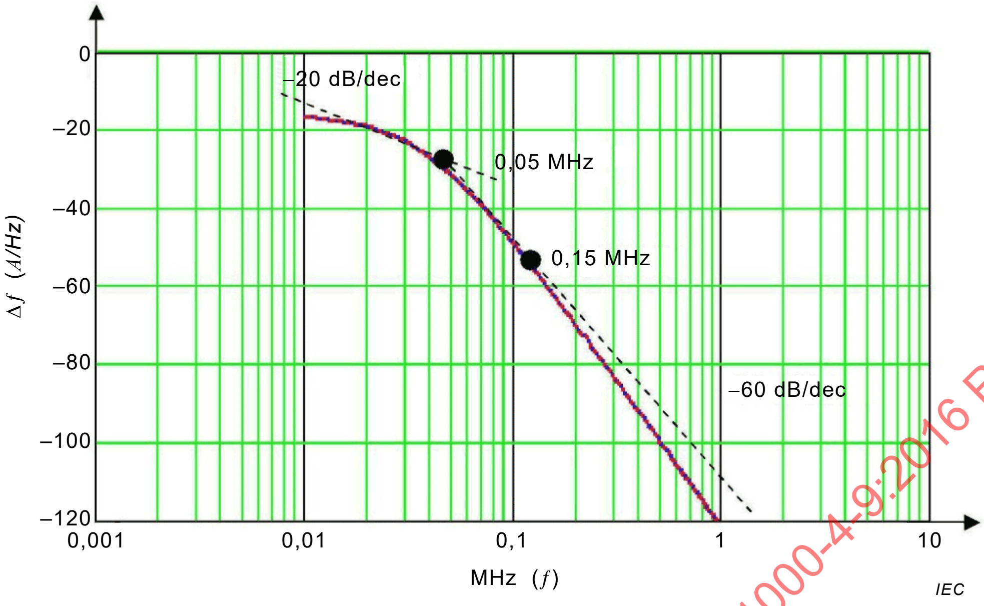


Figure E.3 – Current surge (8/20 μs): Spectral response with Δf = 10 kHz

The current impulse in the time domain is simulated well for frequencies up to 0,15 MHz, therefore the associated bandwidth BW = 0,15 MHz.

Annex F
(informative)

Characteristics using two standard induction coils

F.1 General

Annex F gives an example of Helmholtz coils using two 1 m × 1 m standard induction coils connected in parallel to the combination wave generator. This double induction coil may be used to obtain a better field homogeneity and for testing larger EUTs.

The test volume of the double 1 m × 1 m standard induction coils, which are 0,8 m spaced, is defined in Clause F.3.

F.2 Particular requirements for calibration

The characteristics of this test system can be calibrated by using a current measurement as described in Figure F.1. The current in both coils should be measured and should be identical.

The output current can be verified with the generator connected to the two standard induction coils. In order to comply with the specification given in Table 3 for the 1 m × 1 m standard induction coil, an external capacitor (e.g. 18 μF) in series may be required. The capacitor may be incorporated in the generator. The connection is realized by twisted conductors with a suitable cross-section of up to 3 m length. Identical cable length should be used to supply both coils and to ensure proper distribution of the current. The current in both coils should be checked for the same H-field orientation.

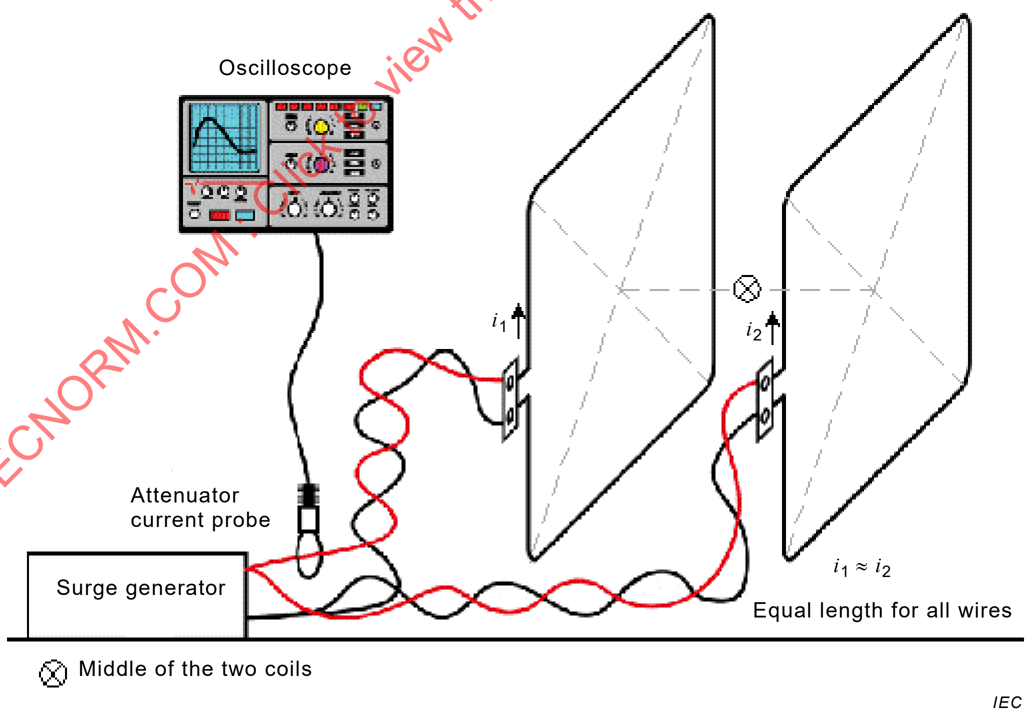


Figure F.1 – Example of a test system using double standard induction coils

The specifications given in Table F.1 can be verified for all applicable test levels.

Table F.1 – Specifications of the waveform peak current of this test system

Test level	Peak current I ± 10 % in each coil A
1	not applicable
2	not applicable
3	106
4	319
5	1 064
X[a]	Special/0,94

NOTE 1 The value 0,94 is the measured and simulated coil factor in the middle of the two coils.

NOTE 2 A combination wave generator with higher current supply capabilities than required for tests level 4 in IEC 61000-4-5 may be needed for testing at test levels 5 or X.

[a] "X" can be any level, above, below or in between the others. The level shall be specified in the dedicated equipment specification.

If a current transformer (probe) is used to measure the short-circuit current, it should be selected, so that saturation of the magnetic core does not occur. The lower (-3 dB) corner frequency of the probe should be less than 100 Hz. The calibration should be carried out with a current probe and an oscilloscope or other equivalent measurement instrumentation with a bandwidth of not less than 1 MHz.

F.3 Field distribution of the double induction coil arrangement

Clause F.3 gives information on the maximum size of an EUT and its location in the double coil arrangement. According to the main part of the standard, the EUT shall be located within a volume, where the magnitude of the magnetic field strength is within ±3 dB of the field strength, in the centre of the double coil arrangement.

For the field computations the finite cross-section of the coil conductors are neglected (thin wire approximation). The computations were performed for two 1 m × 1 m standard induction coils, 0,8 m spaced.

The +3 dB and –3 dB isolines for the magnetic field strength (magnitude) are shown in Figure F.2 for the x-y plane and in Figure F.3 for the x-z plane. The maximum EUT size is width × length × height = 0,6 m × 0,6 m × 1,4 m.

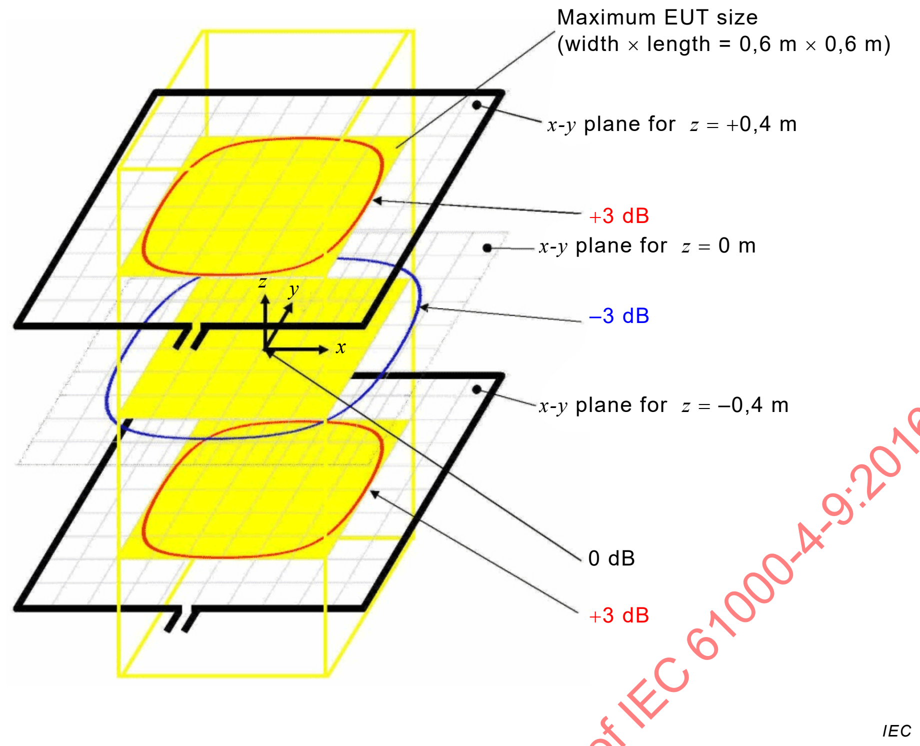


Figure F.2 – +3dB isoline for the magnetic field strength (magnitude) in the *x-y* plane for the double induction coil arrangement (0,8 m spaced)

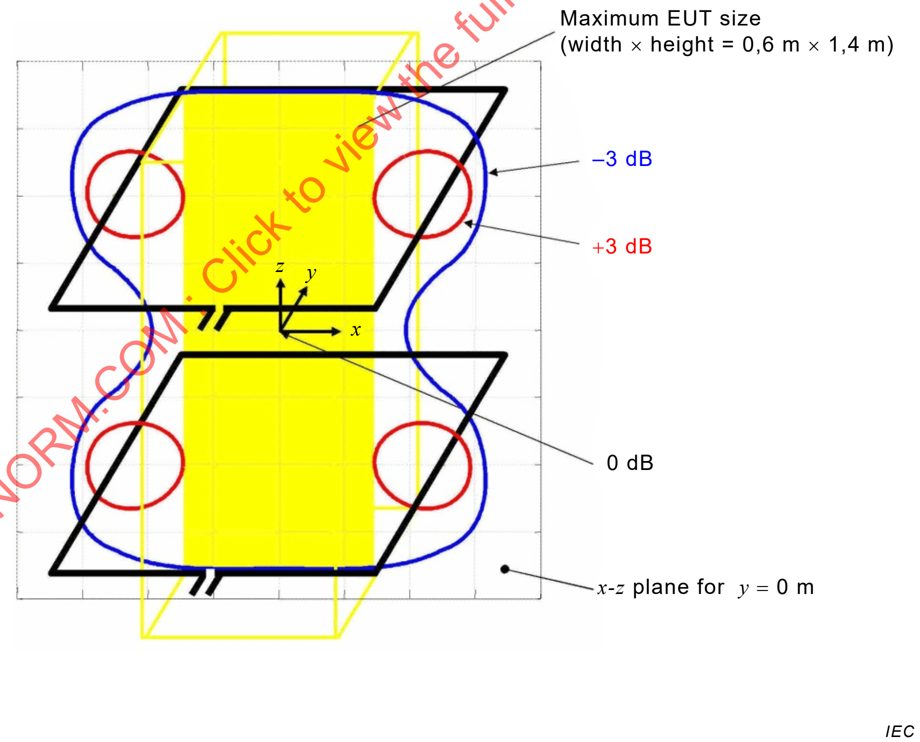


Figure F.3 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x-z* plane for the double induction coil arrangement (0,8 m spaced)

Annex G
(informative)

3D numerical simulations

G.1 General

In Annex G 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 B (static results).

G.2 Simulations

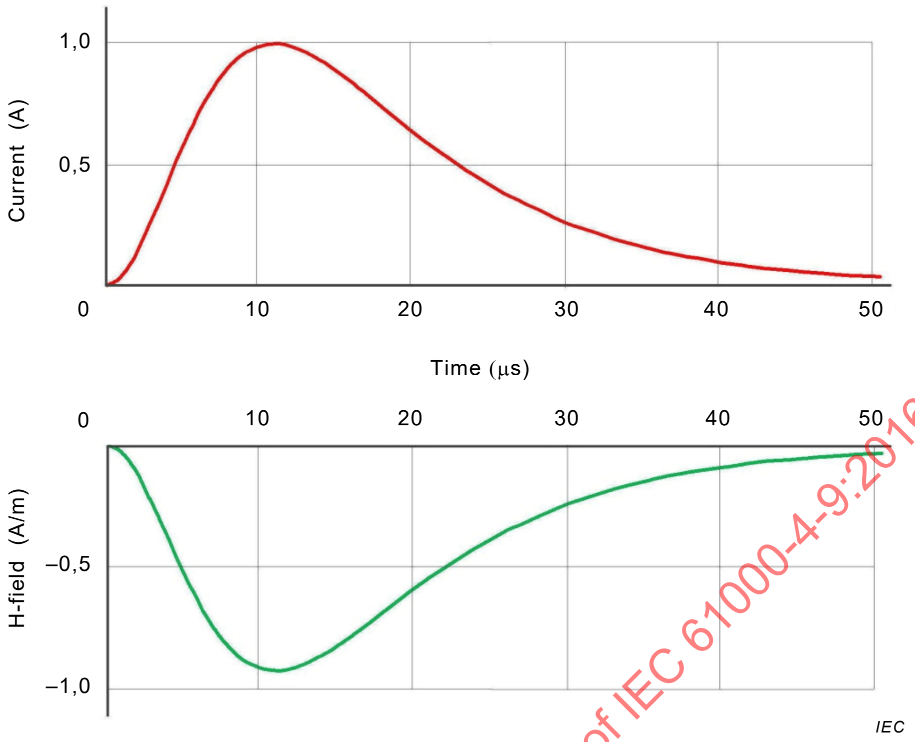
The simulations of Figures G.1 to G.12 are performed as follows:

- The coils are excited by an ideal current source (see the symbol "port") having the mathematical waveform as defined in Annex E of this standard and normalized at 1 A.
- Two extreme shape conductors of the coil are considered: one of a rectangular size 10 cm × 1 cm (reported in Annex G) and a 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 Figure G.2 and Figure G.3; for 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.

G.3 Comments

The following comments have been taken into account as they relate to the figures.

- The computed H-field waveform has the same shape of 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 B.
- 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 centre of the loop. This should be taken into account when carrying out the proximity test method.
- For the double induction coil arrangement, which is 0,6 m spaced (Helmholtz setup), the coil factor in the centre of one coil and between the two coils is respectively: 1,18 m^{-1} and 1,20 m^{-1}; for the one that is 0,8 m spaced it is respectively: 1,07 m^{-1} and 0,94 m^{-1}.



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

Figure G.1 – Current and H-field in the centre of the 1 m × 1 m induction coil

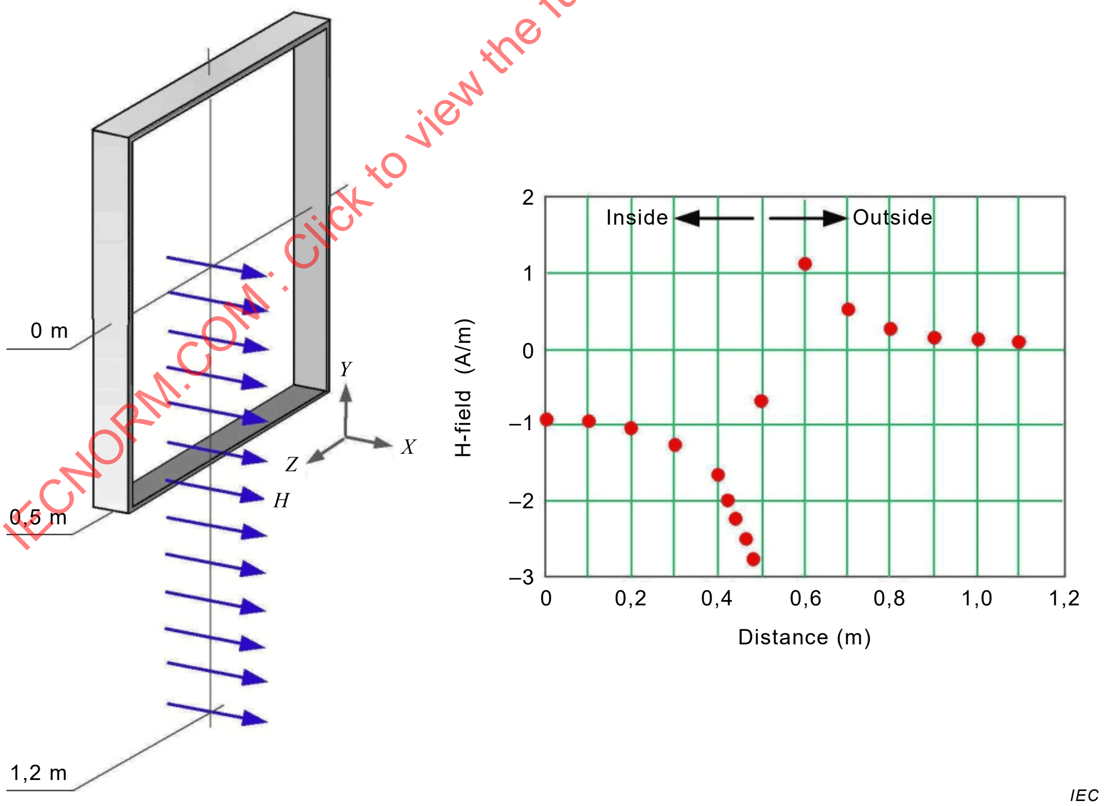


Figure G.2 – Hx-field along the side of 1 m × 1 m induction coil in A/m

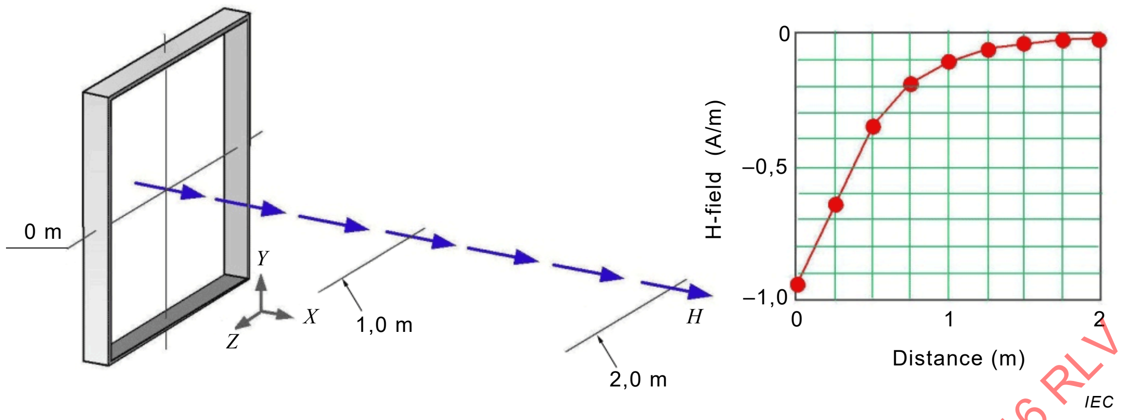


Figure G.3 – *Hx*-field in direction *x* perpendicular to the plane of the 1 m × 1 m induction coil

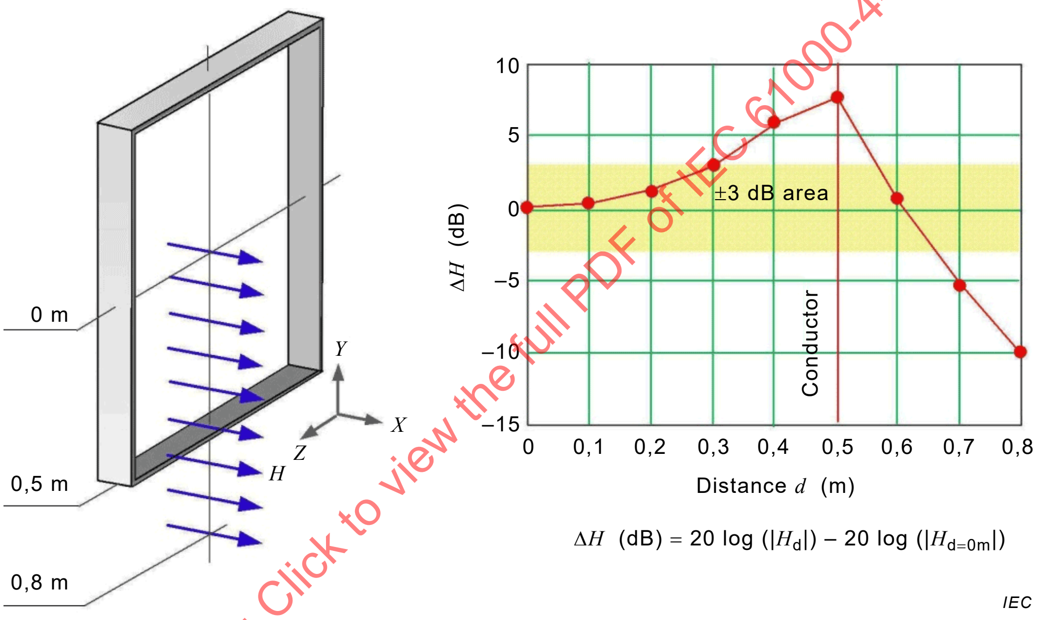


Figure G.4 – *Hx*-field along the side in dB for the 1 m × 1 m induction coil

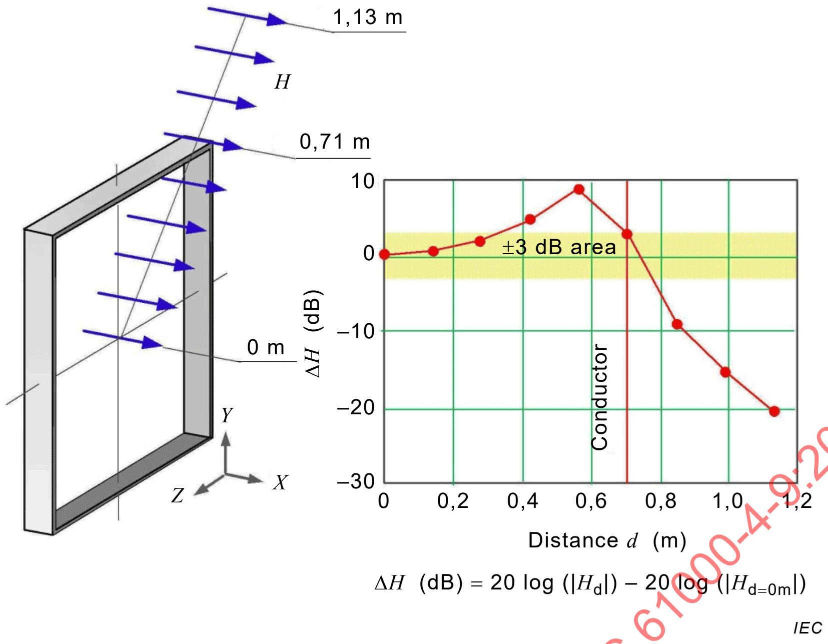


Figure G.5 – *Hx*-field along the diagonal in dB for the 1 m × 1 m induction coil

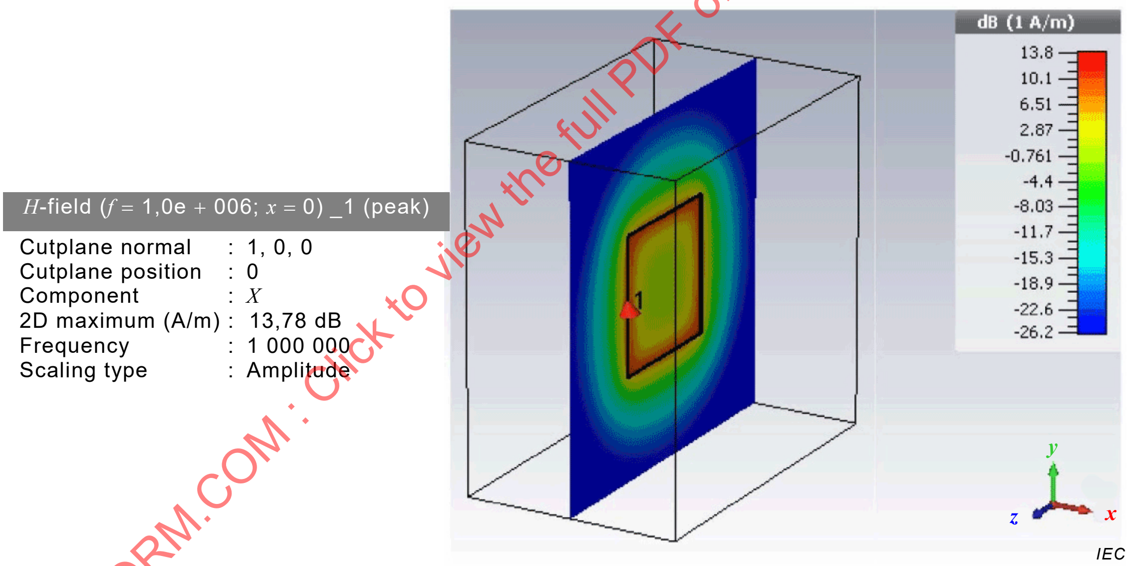


Figure G.6 – *Hx*-field plot on *y*-*z* plane for the 1 m × 1 m induction coil

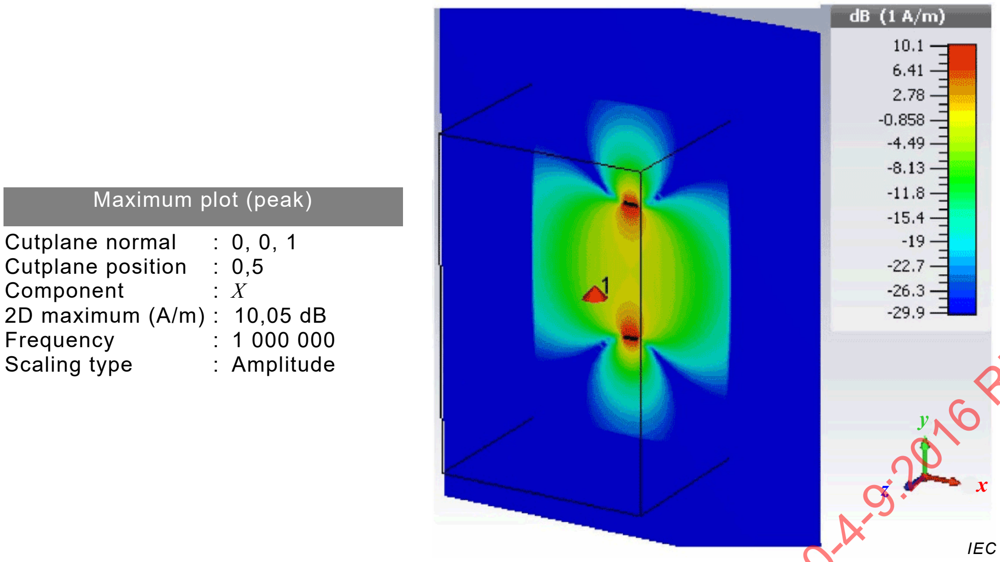


Figure G.7 – *Hx*-field plot on *x*-*y* plane for the 1 m × 1 m induction coil

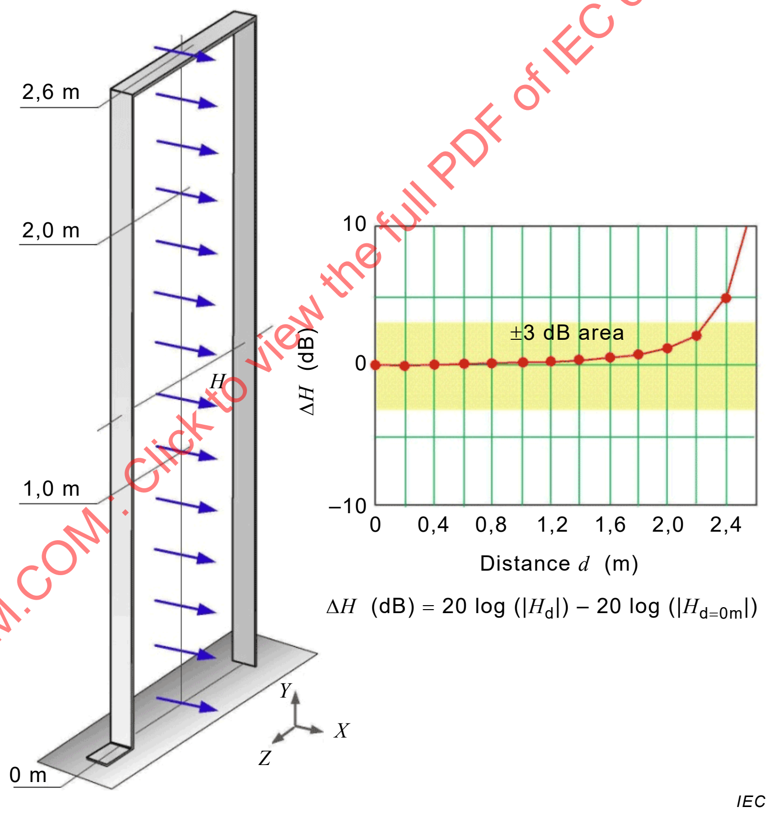


Figure G.8 – *Hx*-field along the vertical middle line in dB for the 1 m × 2,6 m induction coil

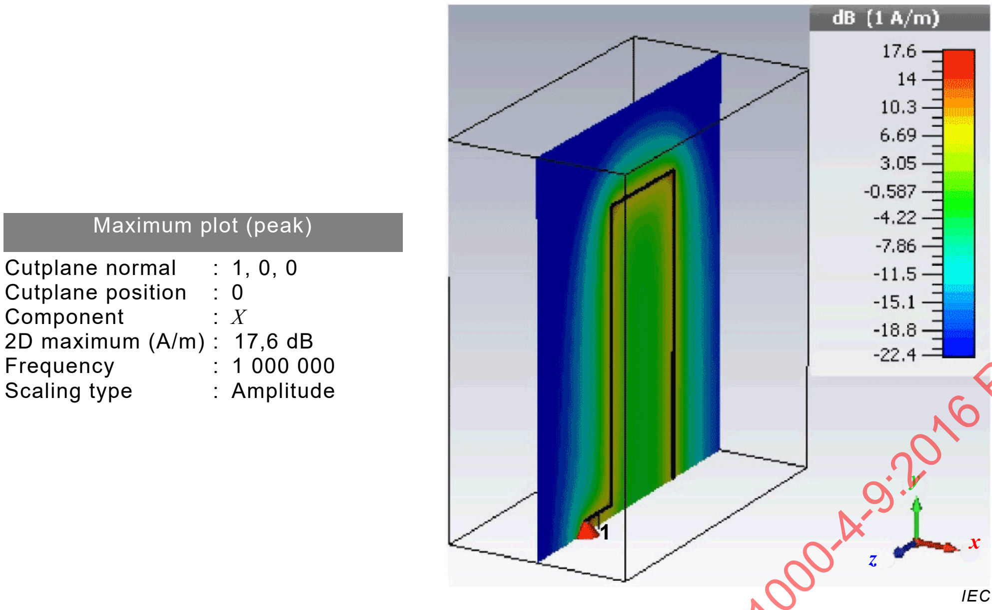


Figure G.9 – Hx-field 2D plot on y-z plane for the 1 m × 2,6 m induction coil

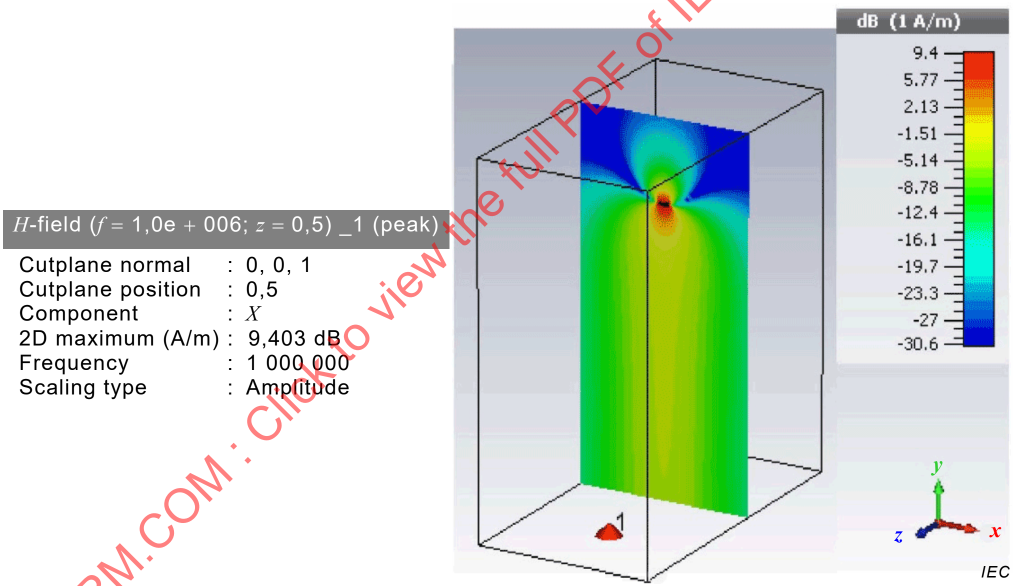


Figure G.10 – Hx-field 2D plot on x-y plane at z = 0,5 m for the 1 m × 2,6 m induction coil

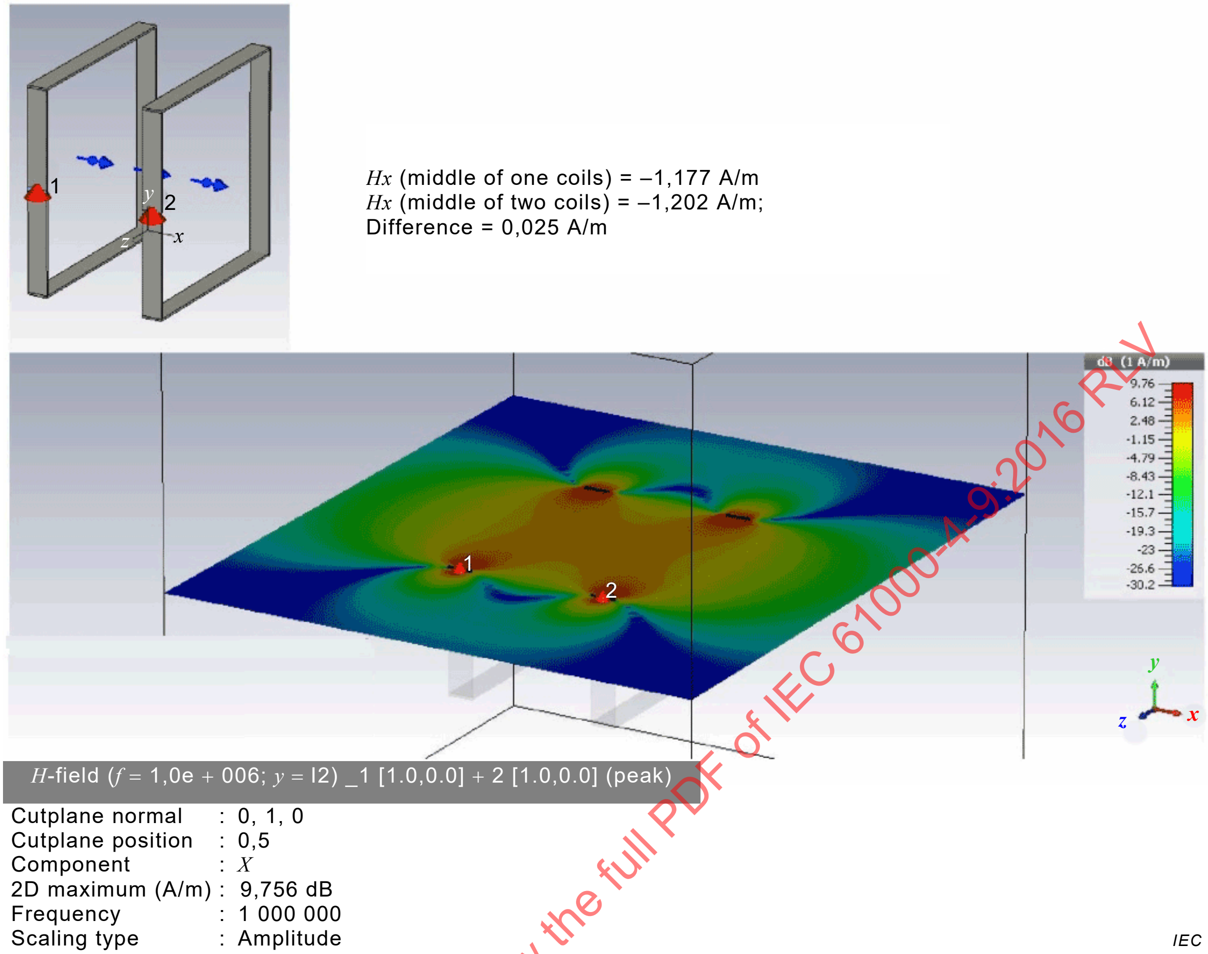


Figure G.11 – Helmholtz setup: *Hx*-field and 2D plot for two 1 m × 1 m induction coils, 0,6 m spaced

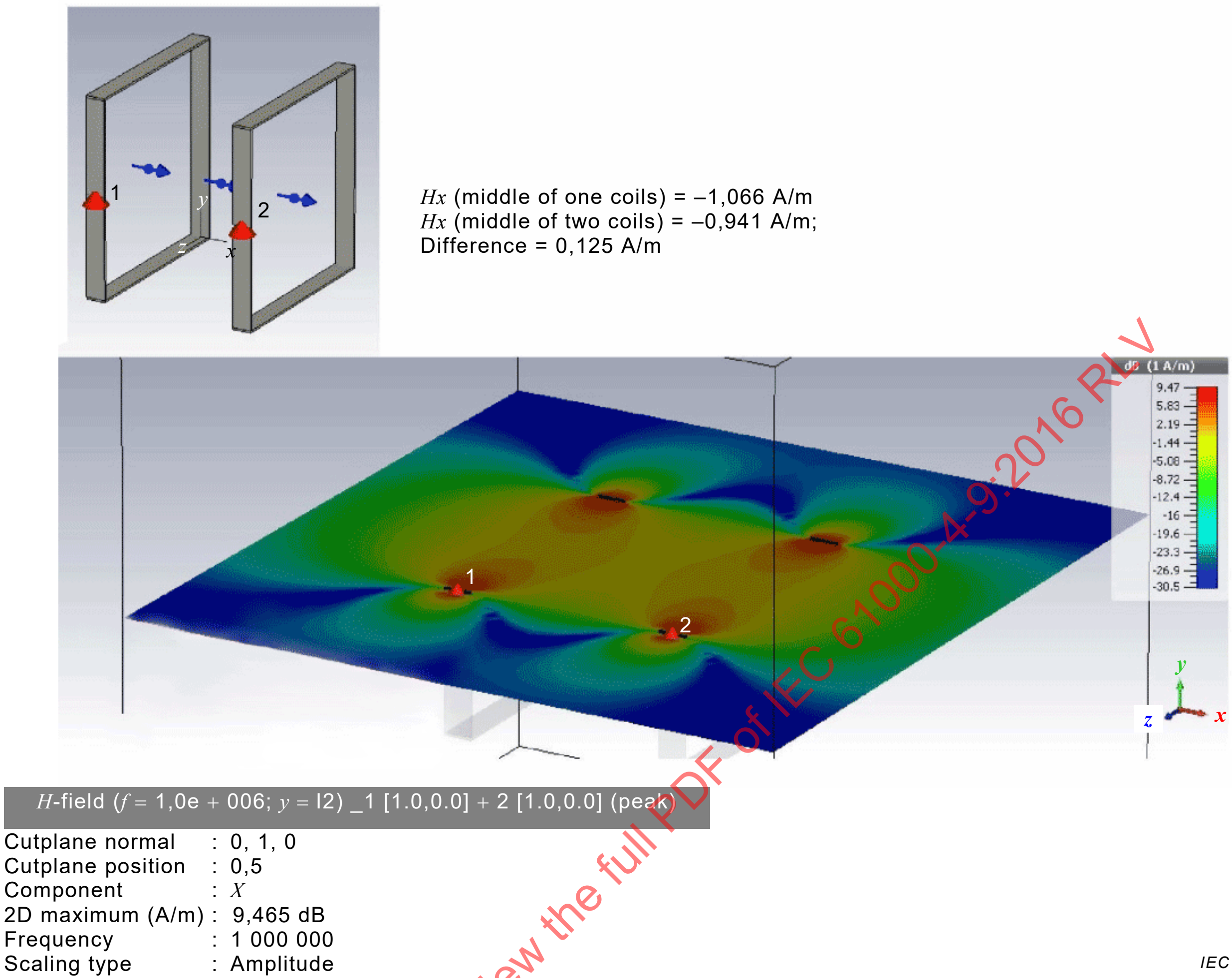


Figure G.12 – Helmholtz setup: Hx-field and 2D plot for two 1 m × 1 m induction coils, 0,8 m spaced

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

Partie 4-9: Techniques d'essai et de mesure – Essai d'immunité au champ magnétique impulsionnel

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Elle constitue la Partie 4-9 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 B relative à la distribution du champ de bobine d'induction;

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

c) nouvelle Annexe E relative à la modélisation mathématique de la forme d'onde de choc;

d) nouvelle Annexe F relative aux caractéristiques utilisant deux bobines d'induction normalisées;

e) nouvelle Annexe G relative aux simulations numériques 3D;

f) le calcul du facteur de bobine et l'étalonnage à l'aide par la mesure du courant ont été abordés dans la présente édition.

Le texte de cette norme est issu des documents suivants:

CDV	Rapport de vote
77B/728/CDV	77B/745A/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.

Le comité a décidé que le contenu de cette publication ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives à la publication recherchée. A cette date, la publication sera

- reconduite,
- supprimée,
- remplacée par une édition révisée, ou
- amendée.

IMPORTANT – Le logo "*colour inside*" qui se trouve sur la page de couverture de cette publication indique qu'elle contient des couleurs qui sont considérées comme utiles à une bonne compréhension de son contenu. Les utilisateurs devraient, par conséquent, imprimer cette publication en utilisant une imprimante couleur.

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 impulsionnel".

COMPATIBILITÉ ÉLECTROMAGNÉTIQUE (CEM) –

**Partie 4-9: Techniques d'essai et de mesure –
Essai d'immunité au champ magnétique impulsionnel**

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 impulsionnelles, principalement dans les:

– installations industrielles,
– centrales électriques,
– installations ferroviaires,
– postes moyenne et haute tension.

L'applicabilité de la présente norme aux équipements installés dans différentes zones est déterminée par la présence du phénomène dans les conditions spécifiées à l'Article 4.

La présente norme n'examine pas les perturbations provoquées par le couplage capacitif ou inductif sur les câbles ou autres parties de l'installation. D'autres normes IEC traitant des perturbations conduites couvrent ces aspects.

La présente norme a pour objet d'établir une référence commune pour évaluer l'immunité des équipements électriques et électroniques lorsqu'ils sont soumis à des champs magnétiques impulsionnels. La méthode d'essai documentée dans la présente partie de l'IEC 61000 décrit une méthode cohérente d'évaluation de l'immunité d'un équipement ou d'un système par rapport à un phénomène défini.

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.

La tâche du laboratoire d'essai décrit consiste à déterminer la réaction de l'équipement en essai (EUT) dans les conditions de fonctionnement spécifiées aux champs magnétiques impulsionnels générés par la commutation et les effets de la foudre.

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 combinées
CWG
générateur avec une forme d'onde de tension en circuit ouvert de type 1,2/50 µs et une forme d'onde de courant de court-circuit de type 8/20 µs

Note 1 à l'article: Cette définition est un raccourci de la définition donnée dans l'IEC 61000-4-5.

Note 2 à l'article: L'abréviation "CWG" est dérivée du terme anglais développé correspondant "combination wave generator".

3.1.3
durée
$\boldsymbol{T_d}$
<courant de choc pour 8/20 µs> paramètre virtuel défini comme l'intervalle de temps entre le moment où le courant de choc atteint 0,5 de sa valeur de crête et le moment où il chute à 0,5 de sa valeur de crête (T_w), multiplié par 1,18

$T_d = 1{,}18 \times T_w$

VOIR: Figure 2.

3.1.4
durée du front
$\boldsymbol{T_f}$
<courant de choc> paramètre virtuel défini comme 1,25 fois l'intervalle T_r entre les moments où l'impulsion est égale à 10 % et 90 % de la valeur de crête

VOIR: Figure 2.

3.1.5
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]

3.1.6
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

3.1.7
facteur de bobine d'induction
rapport entre l'intensité du champ 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.

3.1.8
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

3.1.9
plan de masse de référence
surface conductrice plane dont le potentiel est pris comme référence

3.1.10
temps de montée
T_r
durée de l'intervalle de temps entre les instants auxquels la valeur instantanée d'une impulsion atteint pour la première fois 10 %, puis 90 %

VOIR: Figure 2.

3.1.11
onde de choc
onde transitoire de courant, tension ou puissance électrique se propageant le long d'une ligne ou dans un circuit et comportant une montée rapide suivie d'une décroissance plus lente

3.1.12
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.

3.1.13
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]

3.1.14
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 Termes abrégés

AE	Auxiliary equipment (équipement auxiliaire)
CWG	Combination wave generator (générateur d'ondes combinées)
EFT/B	Electrical fast transient/burst (transitoires électriques rapides en salves)
CEM	Compatibilité électromagnétique
DES	Décharges électrostatiques
EUT	Equipment under test (équipement en essai)
MU	Measurement uncertainty (incertitude de mesure)
RCD	Réseau couplage/découplage
RGP	Reference ground plane (plan de masse de référence)

4 Généralités

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 aux champs magnétiques impulsionnels qui s'appliquent à l'emplacement spécifique et aux conditions d'installation de l'équipement (l'équipement situé à proximité de la source de perturbation, par exemple).

Les champs magnétiques impulsionnels sont provoqués par la chute de la foudre sur des bâtiments ou les autres structures métalliques (les mâts d'antenne, les conducteurs de terre ou les réseaux de terre, par exemple) et par les transitoires de défaut initial se produisant dans les réseaux de puissance basse, moyenne ou haute tension.

Dans les postes haute tension, le champ magnétique impulsionnel peut également être généré par la commutation de barres et lignes haute tension par des disjoncteurs.

L'essai s'applique principalement aux équipements électroniques destinés aux centrales de production et de distribution d'électricité, ainsi qu'à leur centre de commande. Il ne concerne pas les équipements de réseau de distribution (les transformateurs et les lignes d'énergie, par exemple).

Les comités de produits peuvent étudier d'autres applications.

5 Niveaux d'essais

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

Tableau 1 – Niveaux d'essai

Niveau	Intensité des champs magnétiques impulsionnels A/m (crête)
1	non applicable
2	non applicable
3	100
4	300
5	1 000
X[a]	spécial
NOTE L'intensité du champ 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. Le niveau 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 C.

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 combinées

6.2.1 Généralités

Pour cette application, le générateur d'ondes combinées est utilisé comme source de courant.

NOTE Le générateur d'ondes combinées spécifié dans la présente norme présente des définitions de forme d'onde identiques à celles données dans l'IEC 61000-4-5.

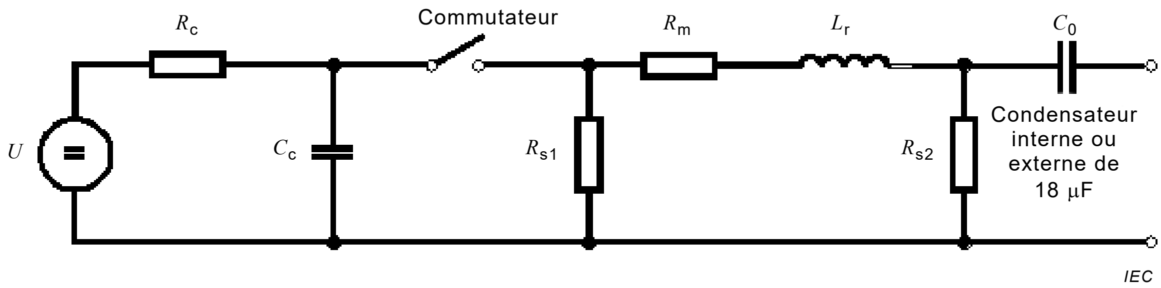
Par conséquent, seule la forme d'onde 8/20 µs est pertinente. Le générateur d'ondes combinées doit être en mesure de délivrer le courant de choc exigé aux bobines d'induction spécifiées en 6.3.

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

Ce générateur est destiné à générer une onde de choc présentant:

- une durée du front de courant de court-circuit de 8 µs;
- une durée de courant de court-circuit de 20 µs.

Un schéma de circuit simplifié du générateur est donné à la Figure 1. Les valeurs des différents composants R_{S1}, R_{S2}, R_m, L_r et C_c sont choisies de manière à ce que le générateur délivre un courant de choc de 8/20 µs dans un court-circuit.



Légende

U Source haute tension

R_c Résistance de charge

C_c Condensateur de stockage d'énergie

R_s Résistance de mise en forme de la durée d'impulsion

R_m Résistance d'adaptation d'impédance

L_r Inductance de mise en forme du temps de montée

C_o Condensateur interne ou externe de 18 µF

Figure 1 – Schéma de circuit simplifié du générateur d'ondes combinées

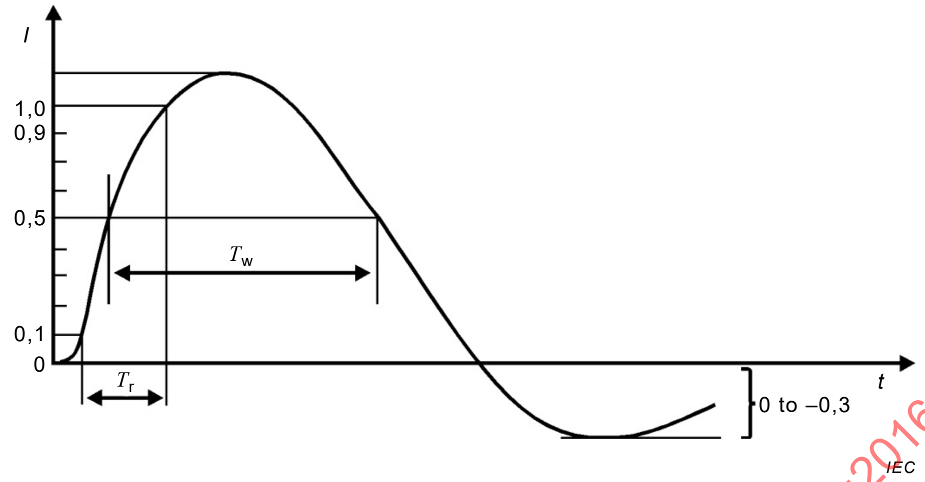
6.2.2 Caractéristiques de performances du générateur

Polarité	positive ou négative
Décalage de phase	dans une gamme de 0° à 360° par rapport à l'angle de phase de la tension d'alimentation en courant alternatif au niveau de l'EUT avec une tolérance de ± 10°
Fréquence de répétition	1 par minute ou plus rapide
Courant de sortie de crête de court-circuit	100 A à 1 000 A ou le niveau d'essai exigé divisé par le facteur de bobine
Forme d'onde du courant de choc	voir le Tableau 2 et la Figure 2
Tolérance du courant de sortie de crête de court-circuit	± 10 %

Tableau 2 – Définitions des paramètres de forme d'onde 8/20 µs

	Durée du front T_f µs	**Durée T_d** µs
Courant de court-circuit	T_f = 1,25 × T_r = 8 ± 20 %	T_d = 1,18 × T_w = 20 ± 20 %

Un générateur à sortie flottante doit être utilisé.



Durée du front: $T_f = 1{,}25 \times T_r = 8\ \mu s \pm 20\ \%$

Durée: $T_d = 1{,}18 \times T_w = 20\ \mu s \pm 20\ \%$

NOTE 1 La valeur 1,25 est la réciproque de la différence entre les seuils de 0,9 et 0,1.

NOTE 2 La valeur 1,18 est déduite de données empiriques.

Figure 2 – Forme d'onde du courant de court-circuit (8/20 µs) à la sortie du générateur avec le condensateur de 18 µF en série

6.2.3 Etalonnage du générateur

Si un transformateur de courant (sonde) est utilisé pour mesurer le courant de court-circuit, il convient de le choisir de manière à éviter la saturation du noyau magnétique. Il convient que la fréquence de coupure basse (-3 dB) de la sonde soit inférieure à 100 Hz. L'étalonnage doit être effectué avec une sonde de courant et un oscilloscope ou autre instrument de mesure équivalent d'une largeur de bande minimale de 1 MHz. L'étalonnage doit être réalisé pour tous les niveaux d'essai qui sont appliqués pour les essais.

Les caractéristiques du générateur doivent être mesurées à travers d'un condensateur externe de 18 µF en série avec la sortie, dans les conditions de court-circuit. Si le condensateur de 18 µF est monté dans le générateur, aucun condensateur externe de 18 µF n'est exigé pour l'étalonnage.

Toutes les caractéristiques de performance établies en 6.2.2, à l'exception du décalage de phase, doivent être satisfaites à la sortie du générateur.

6.3 Bobine d'induction

6.3.1 Distribution du champ

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 B. Par conséquent, aucune vérification ni aucun étalonnage du champ ne sont nécessaires, la mesure du courant présentée à la Figure 3 étant suffisante.

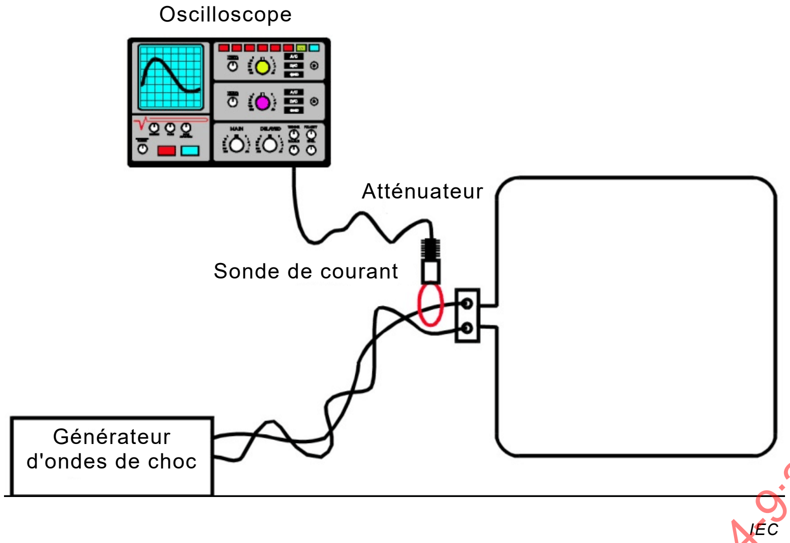


Figure 3 – Exemple de mesure du courant des bobines d'induction normalisées

D'autres bobines de dimensions différentes peuvent être utilisées pour un EUT qui ne s'insère pas dans l'une ou l'autre des deux bobines normalisées. Dans ce cas, la distribution du champ doit être déterminée par mesure ou calcul (voir l'Annexe A).

6.3.2 Caractéristique des bobines d'induction normalisées de 1 m × 1 m et de 1 m × 2,6 m

La bobine d'induction normalisée doit être en cuivre, en aluminium ou tout autre matériau conducteur non magnétique. Sa section et sa conception doivent permettre de lui donner une position stable pendant les essais.

La tolérance des bobines normalisées est de ±1 cm, mesurée entre les lignes centrales (centre de la section). Les caractéristiques des bobines d'induction en fonction de la distribution du champ magnétique sont données à l'Annexe B.

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 3).

Le courant de sortie doit être vérifié avec le générateur connecté à la bobine d'induction normalisée spécifiée en 6.2.1 pour tous les niveaux d'essai applicables. Afin de satisfaire aux spécifications données au Tableau 3 et au Tableau 4, un condensateur externe (18 µF, par exemple) en série peut être exigé. Le condensateur peut être incorporé dans le générateur. La connexion doit être réalisée par des conducteurs torsadés ou un câble coaxial de 3 m de long au maximum et présentant une section adaptée.

Les spécifications suivantes données au Tableau 3 et au Tableau 4 doivent être vérifiées.

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

	Durée du front T_f	Durée T_d
Système utilisant une bobine d'induction normalisée de 1 m × 1 m	$T_f = 1{,}25 \times T_r = 8\ \mu s\ ^{+2{,}4}_{-0{,}8}\ \mu s$	$T_d = 1{,}18 \times T_w = 20\ \mu s\ ^{+6}_{-2}\ \mu s$
Système utilisant une bobine d'induction normalisée de 1 m × 2,6 m	$T_f = 1{,}25 \times T_r = 8\ \mu s\ ^{+3{,}2}_{-0{,}8}\ \mu s$	$T_d = 1{,}18 \times T_w = 20\ \mu s\ ^{+8}_{-2}\ \mu s$

Tableau 4 – Spécifications du courant de crête de forme d'onde du système d'essai

Niveau d'essai	Courant de crête I ± 10 % 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	111	152
4	333	453
5	1 111	1 515
X[a]	spécial/0,9	spécial/0,66

NOTE Les valeurs 0,9 et 0,66 sont les facteurs de bobine calculés des bobines d'induction normalisées, tels qu'indiqués en A.2.3 (voir l'Annexe A).

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

Si un transformateur de courant (sonde) est utilisé pour mesurer le courant de court-circuit, il convient de le choisir de manière à éviter la saturation du noyau magnétique. Il convient que la fréquence de coupure basse (-3 dB) de la sonde soit inférieure à 100 Hz. L'étalonnage doit être effectué avec une sonde de courant et un oscilloscope ou autre instrument de mesure équivalent d'une largeur de bande minimale de 1 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 combinées (CWG) avec condensateur interne/externe (18 µF, par exemple);
– bobine d'induction;
– 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 combinées;
– 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 de choc présente aux bornes de la bobine d'induction.

Il est suffisant de vérifier que l'onde de choc 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 le champ magnétique impulsionnel appliqué à un EUT de table

Les EUT de table doivent être placés sur une table non conductrice. La bobine d'induction 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 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) peut être utilisée ou des bobines d'induction plus importantes peuvent être construites de manière à correspondre aux dimensions de l'EUT pour une orientation de champ différente du champ magnétique.

NOTE S'il s'avère peu pratique de construire des bobines pour des équipements très volumineux, la méthode de proximité est la seule méthode d'essai adaptée.

L'impact des câbles ne doit pas être optimisé pendant cet essai. La proximité des câbles avec l'antenne-cadre 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 4 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).

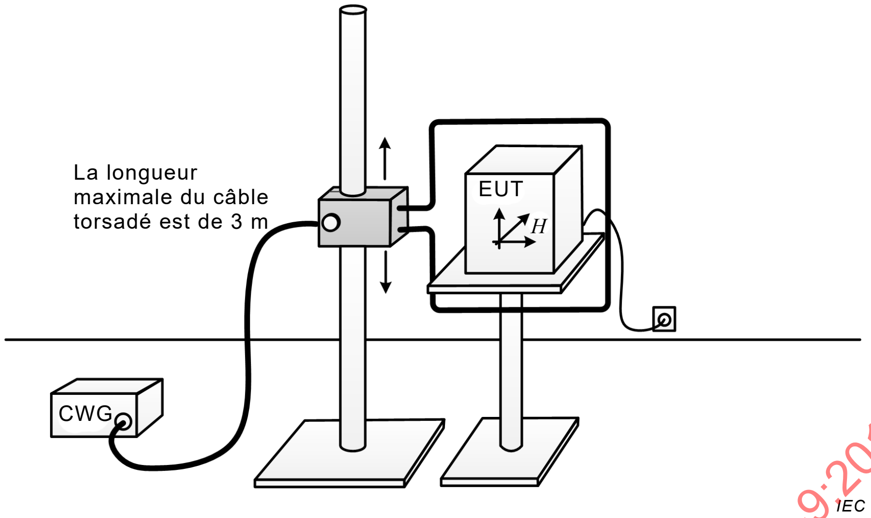


Figure 4 – Exemple de montage d'essai pour équipement de table montrant le plan orthogonal vertical

7.4 Montage d'essai pour le champ magnétique impulsionnel appliqué à un EUT posé au sol

La bobine d'induction de dimensions normalisées pour soumettre à essai l'équipement posé au sol (des baies, par exemple) est de forme rectangulaire de 1 m × 2,6 m, un côté court pouvant être le plan de masse de référence pour les équipements de grande taille. La bobine d'induction de 1 m × 1 m peut être utilisée pour les équipements posés au sol avec des dimensions maximales de 0,6 m × 0,6 m.

Le plan de masse de référence doit présenter une épaisseur minimale de 0,65 mm et une taille minimale de 1 m × 1 m. L'EUT doit être isolé du plan de masse de référence.

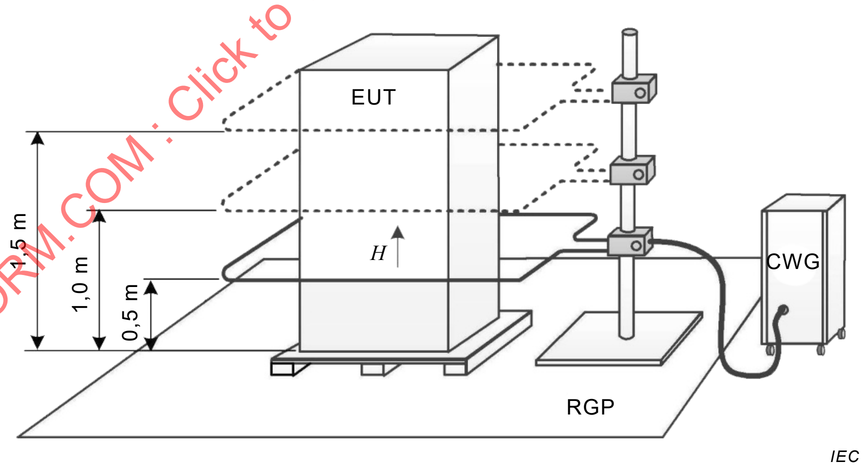


Figure 5 – Exemple de montage d'essai pour équipement posé au sol montrant le plan orthogonal horizontal

Pour les équipements posés au sol (des armoires, par exemple) dans lesquels le haut de l'EUT est à plus de 0,75 m au-dessus du plan de masse de référence, plusieurs positions doivent être soumises à essai. La distance entre les positions doit être de (0,5 ± 0,05) m. La Figure 5 indique que trois positions doivent être soumises à essai. Dans tous les cas, la bobine d'induction présentée à la Figure 5 ne doit pas être placée à moins de 0,5 m. La Figure 6 présente un exemple d'essai avec un plan orthogonal vertical.

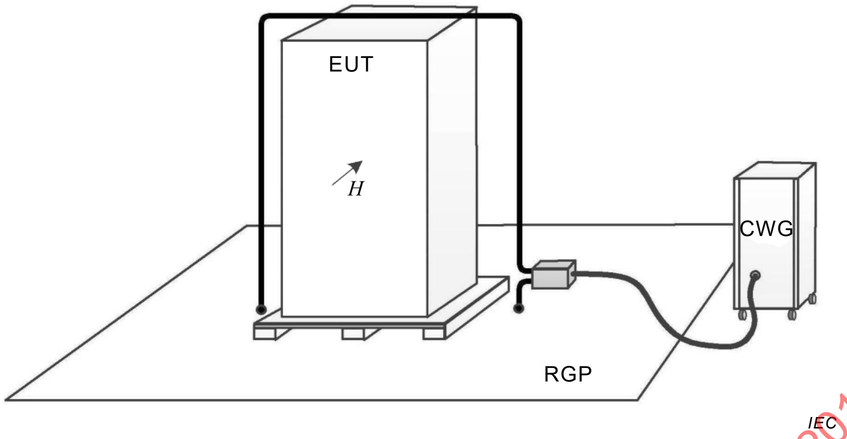


Figure 6 – Exemple de montage d'essai pour équipement posé au sol montrant le plan orthogonal vertical

Le volume d'essai de la bobine rectangulaire est de 0,6 m × 0,6 m × 2 m (L × l × H).

Lorsqu'un EUT ne s'intègre pas dans la bobine rectangulaire de 1 m × 2,6 m, la méthode de proximité (voir la Figure 7 et 7.5 pour des informations détaillées) peut être utilisée ou des bobines d'induction plus importantes peuvent être construites de manière à correspondre aux dimensions de l'EUT pour une orientation de champ différente du champ magnétique (voir l'Annexe A).

S'il s'avère peu pratique de construire des bobines pour des équipements très volumineux, la méthode de proximité est la seule méthode d'essai adaptée. Les comités de produits peuvent choisir la méthode de proximité ou utiliser une bobine adaptée.

L'impact des câbles ne doit pas être optimisé pendant cet essai. La proximité des câbles avec l'antenne-cadre 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.

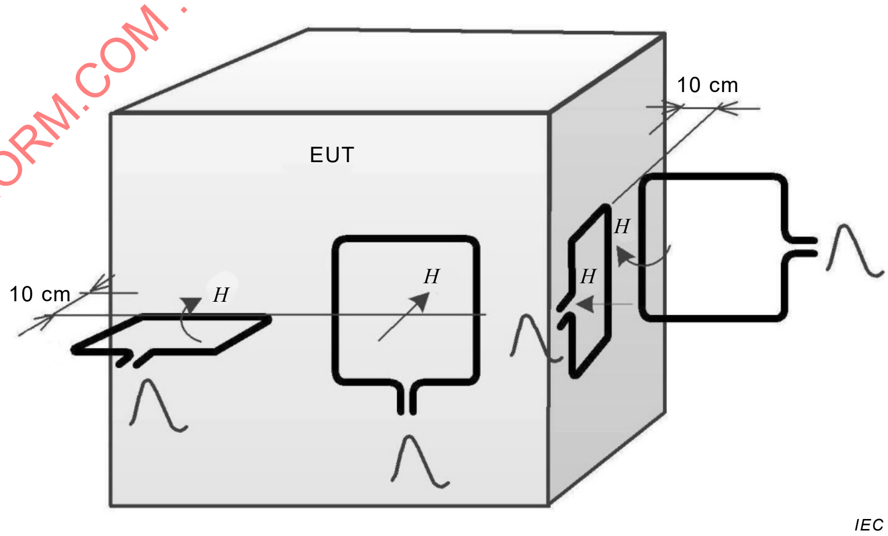


Figure 7 – Exemple de montage d'essai utilisant la méthode de proximité

7.5 Montage d'essai pour le champ magnétique impulsionnel appliqué in situ

Les essais in situ sont en général la seule méthode d'essai pratique pour les machines de grande taille ou équipements similaires. En principe, pendant les essais in situ, un plan de masse de référence n'est pas disponible. Par conséquent, la méthode de proximité peut être la seule méthode d'essai pratique sans plan de masse de référence en place. La Figure 7 donne un exemple de montage d'essai pour les essais in situ. La bobine d'induction normalisée de 1 m × 1 m doit être utilisée lors de l'examen des EUT à l'aide de la méthode de proximité. De plus, la bobine d'induction normalisée doit être isolée de l'EUT. La distance entre la bobine d'induction normalisée et l'EUT doit être de (10 ± 1) cm.

NOTE La distance a été définie afin d'assurer la même intensité du champ que celle présente au centre de la bobine d'induction normalisée.

L'essai de l'équipement de table selon 7.3 peut également être réalisé, mais il ne s'agit pas de la méthode d'essai préférentielle.

8 Procédure d'essai

8.1 Généralités

La procédure d'essai comprend:

– la vérification de l'instrumentation d'essai selon 7.2;
– l'établissement des conditions de référence du laboratoire;
– la confirmation du bon fonctionnement de l'EUT;
– l'exécution de l'essai;
– l'évaluation des résultats d'essai (voir Article 9).

8.2 Conditions de référence du laboratoire

8.2.1 Conditions climatiques

Sauf spécification contraire dans les normes génériques, de famille de produits ou de produit, les conditions climatiques dans le laboratoire doivent être dans les limites spécifiées pour le fonctionnement de l'EUT et de l'équipement d'essai par leurs fabricants respectifs.

Les essais ne doivent pas être réalisés si l'humidité relative est telle qu'elle cause une condensation sur l'EUT ou sur l'équipement d'essai.

8.2.2 Conditions électromagnétiques

Les conditions électromagnétiques du laboratoire doivent être de nature à garantir le bon fonctionnement de l'EUT afin de ne pas influencer les résultats de l'essai.

8.3 Exécution de l'essai

La vérification doit être réalisée. Il est préférable de procéder à la vérification avant l'essai (voir 7.2).

L'essai doit être réalisé selon un programme d'essais qui doit spécifier le montage d'essai, y compris:

- le niveau d'essai;
- le nombre d'impulsions (pour chaque orientation orthogonale):

  le nombre d'impulsions, sauf spécification contraire dans la norme appropriée:

  – pour l'EUT alimenté en courant continu, cinq impulsions positives et cinq impulsions négatives;
  – pour l'EUT alimenté en courant alternatif monophasé, 20 impulsions positives et 20 impulsions négatives sans synchronisation de phase;
  – pour l'EUT alimenté en courant alternatif triphasé, 20 impulsions positives et 20 impulsions négatives sans synchronisation de phase;
- la fréquence de répétition des impulsions d'au moins une impulsion par minute (les comités de produits peuvent spécifier cette fréquence de répétition);
- les conditions de fonctionnement représentatives de l'EUT;
- trois orientations orthogonales du champ magnétique dans le cas de l'équipement de table;
- trois orientations du champ magnétique dans le cas de l'équipement posé au sol;
- les emplacements de la bobine d'induction par rapport à l'EUT (points d'essai).

Pour la plupart des produits, la synchronisation de phase peut ne pas être appropriée. Par conséquent, il convient que les comités de produits déterminent sa nécessité pour leurs produits.

NOTE 1 L'application des essais avec différents angles de phase peut être plus critique pour les équipements possédant un onduleur.

NOTE 2 Des considérations particulières relatives à la sécurité peuvent s'avérer nécessaires lors de l'utilisation de la sortie du RCD du générateur.

9 Évaluation des résultats d'essais

Les résultats d'essai doivent être classés en termes de perte de fonction ou de dégradation des performances de l'équipement en essai, par rapport à un niveau de performances défini par son fabricant ou par le demandeur de l'essai, ou en accord entre le fabricant et l'acheteur du produit. La classification recommandée est la suivante:

a) performances normales dans les limites spécifiées par le fabricant, le demandeur de l'essai ou l'acheteur;
b) perte temporaire de fonction ou dégradation temporaire des performances cessant après la disparition de la perturbation. L'équipement en essai retrouve alors son fonctionnement normal sans l'intervention d'un opérateur;
c) perte temporaire de fonction ou dégradation temporaire des performances exigeant l'intervention d'un opérateur;
d) perte de fonction ou dégradation des performances non récupérable, due à un endommagement de l'équipement ou du logiciel, ou à une perte de données.

La spécification du fabricant peut définir des effets sur l'EUT pouvant être considérés comme étant non significatifs, et donc acceptables.

Cette classification peut être utilisée comme un guide pour l'élaboration des critères de performances, par les comités responsables des normes génériques, de produit ou de famille de produits, ou comme un cadre pour l'accord sur les critères de performances entre le fabricant et l'acheteur, par exemple lorsqu'aucune norme générique, de produit ou de famille de produits appropriée n'existe.

L'équipement ne doit pas devenir dangereux ou non sûr suite à l'application des essais.

10 Rapport d'essai

Le rapport d'essai doit contenir toutes les informations nécessaires pour reproduire l'essai. En particulier, les éléments suivants doivent être consignés: