BS EN 61000-4-9:2016

BSI Standards Publication

Electromagnetic compatibility (EMC)

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

National foreword

This British Standard is the UK implementation of EN 61000-4-9:2016. It is identical to IEC 61000-4-9:2016. It supersedes BS EN 61000-4-9:1994 which will be withdrawn on 7th April 2017.

The UK participation in its preparation was entrusted by Technical Committee GEL/210, EMC - Policy committee, to Subcommittee GEL/210/11, EMC - Standards Committee.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Impulse magnetic field immunity test (IEC 61000-4-9:2016)

Compatibilité électromagnétique (CEM) - Partie 4-9: Techniques d'essai et de mesure - Essai d'immunité au champ magnétique impulsionnel
(IEC 61000-4-9:2016)

Elektromagnetische Verträglichkeit (EMV) - Teil 4-9: Prüf- und Messverfahren - Prüfung der Störfestigkeit gegen impulsförmige Magnetfelder
(IEC 61000-4-9:2016)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

European foreword

The text of document 77B/728/CDV, future edition 2 of IEC 61000-4-9, prepared by SC 77B "High frequency phenomena” of IEC/TC 77 “Electromagnetic compatibility" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61000-4-9:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-05-17
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-08-17

This document supersedes EN 61000-4-9:1993.

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Endorsement notice

The text of the International Standard IEC 61000-4-9:2016 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

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.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60050	series	International Electrotechnical Vocabulary	-	series

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

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

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61000-4-9 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
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

$T_{\mathrm{d}} = 1{,}18 \times T_{\mathrm{w}}$

SEE: Figure 2.

3.1.4
front time
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.

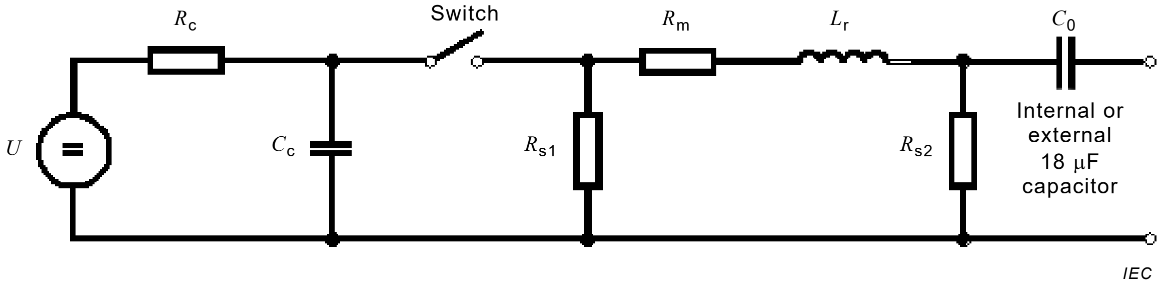
Therefore only the 8/20 µs waveform is relevant. The combination wave generator shall be able to deliver the required impulse current to the induction coils specified in 6.3.

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

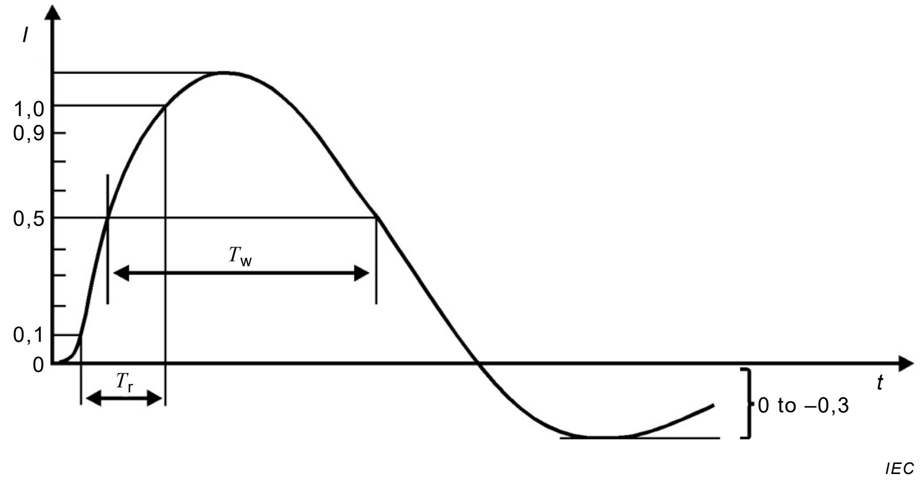
6.2.2 Performance characteristics of the generator

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	$T_f = 1{,}25 \times T_r = 8 \pm 20\ \%$	$T_d = 1{,}18 \times T_w = 20 \pm 20\ \%$

A generator with floating output shall be used.



Front time: $T_f = 1{,}25 \times T_r = 8\ \mu s \pm 20\ \%$

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

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.

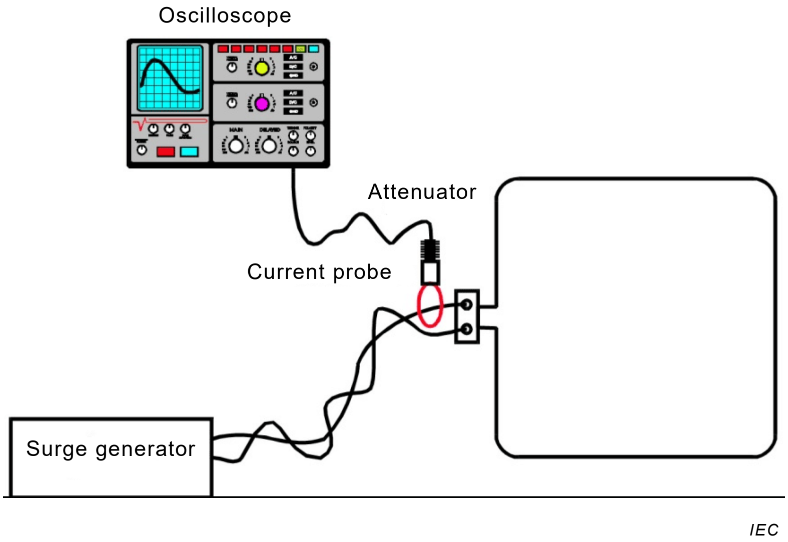


Figure 3 – Example of a current measurement of standard induction coils

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	$T_\mathrm{f} = 1{,}25 \times T_\mathrm{r} = 8\ \mu\mathrm{s}\ {}^{+2{,}4}_{-0{,}8}\ \mu\mathrm{s}$	$T_\mathrm{d} = 1{,}18 \times T_\mathrm{w} = 20\ \mu\mathrm{s}\ {}^{+6}_{-2}\ \mu\mathrm{s}$
System using 1 m × 2,6 m standard induction coil	$T_\mathrm{f} = 1{,}25 \times T_\mathrm{r} = 8\ \mu\mathrm{s}\ {}^{+3{,}2}_{-0{,}8}\ \mu\mathrm{s}$	$T_\mathrm{d} = 1{,}18 \times T_\mathrm{w} = 20\ \mu\mathrm{s}\ {}^{+8}_{-2}\ \mu\mathrm{s}$

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.

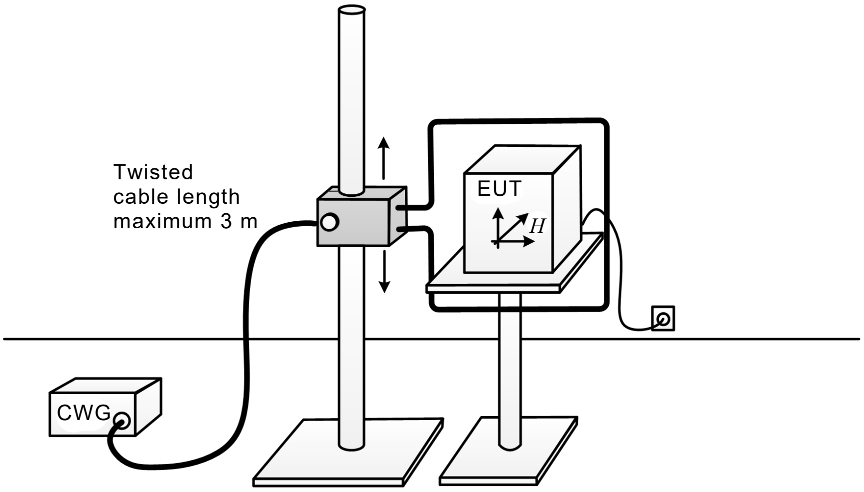


Figure 4 – Example of test setup for table-top equipment showing the vertical orthogonal plane

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.

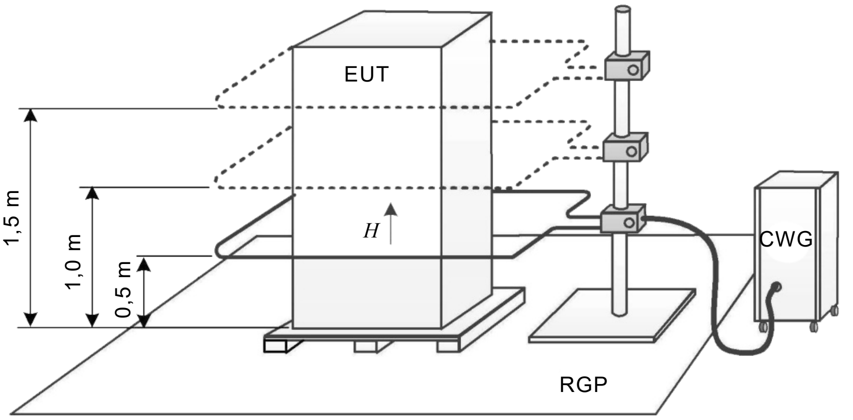


Figure 5 – Example of test setup for floor standing equipment showing the horizontal orthogonal plane

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.

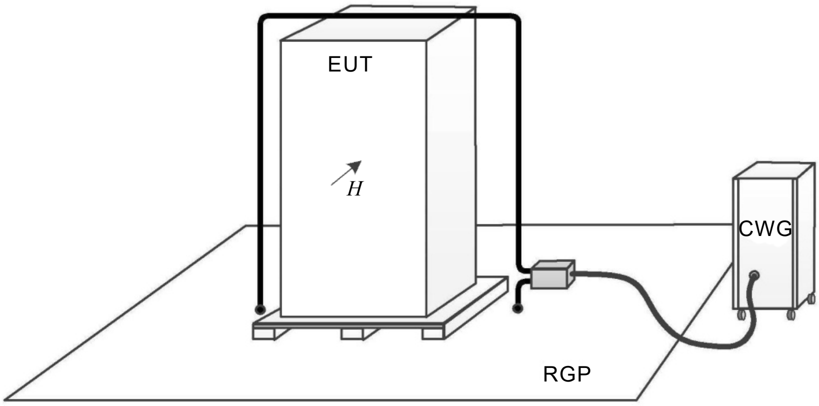


Figure 6 – Example of test setup for floor standing equipment showing the vertical orthogonal plane

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.

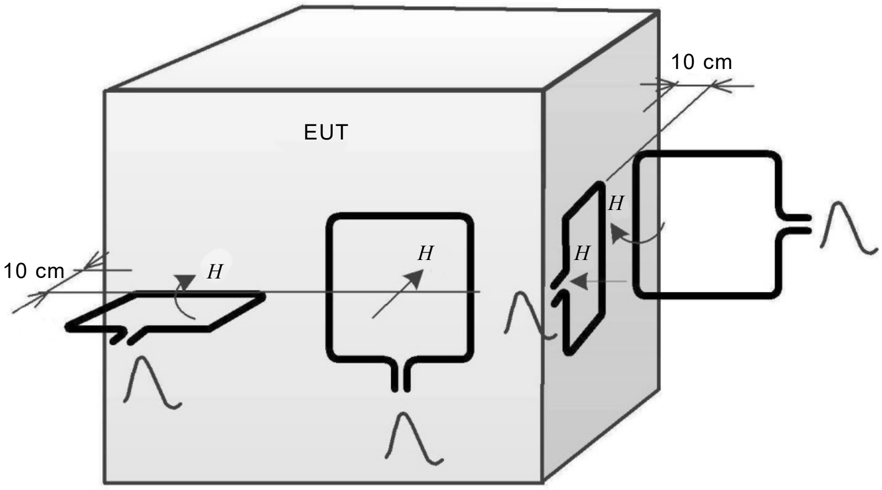


Figure 7 – Example of test setup using the proximity method

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

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

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 $b = 3 \times a$.

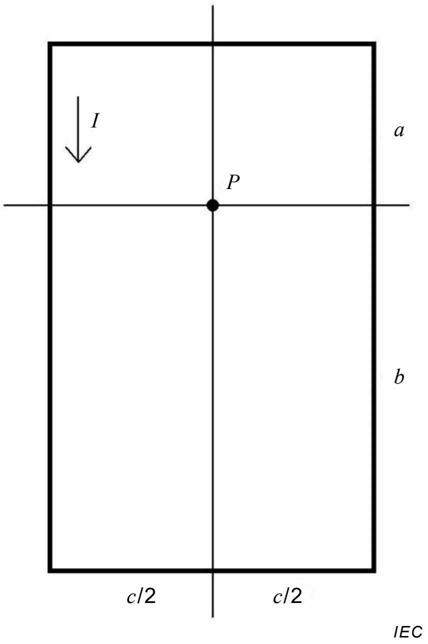


Figure A.1 – Rectangular induction coil with sides $a + b$ and c

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.

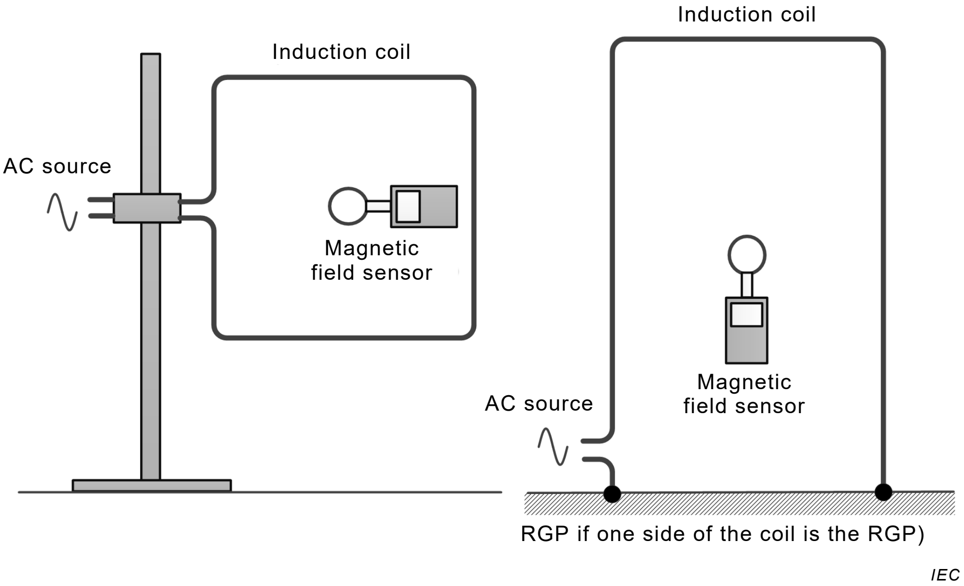


Figure A.2 – Example of verification setup for non standard induction coils

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

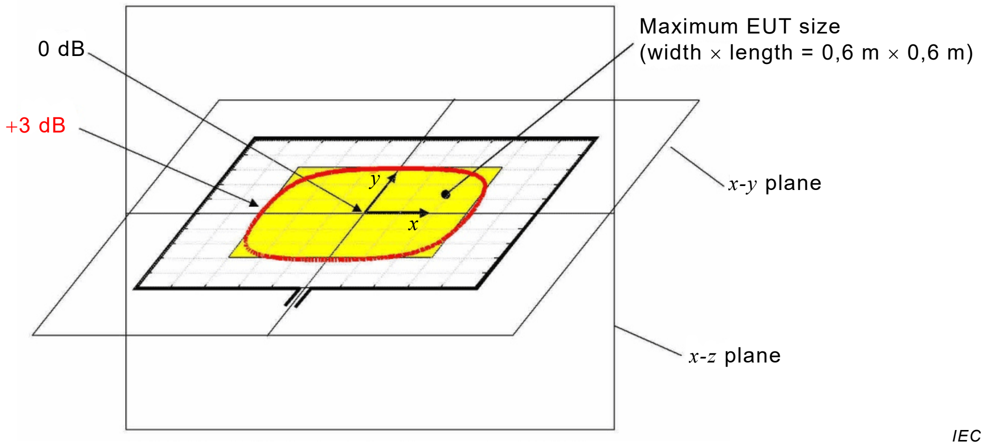
Annex B gives information on the maximum size of an EUT and its location in the standard induction coils. The maximum EUT volume is limited by the +3 dB isoline in the x-y plane and by the ±3 dB isolines in the x-z plane.

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

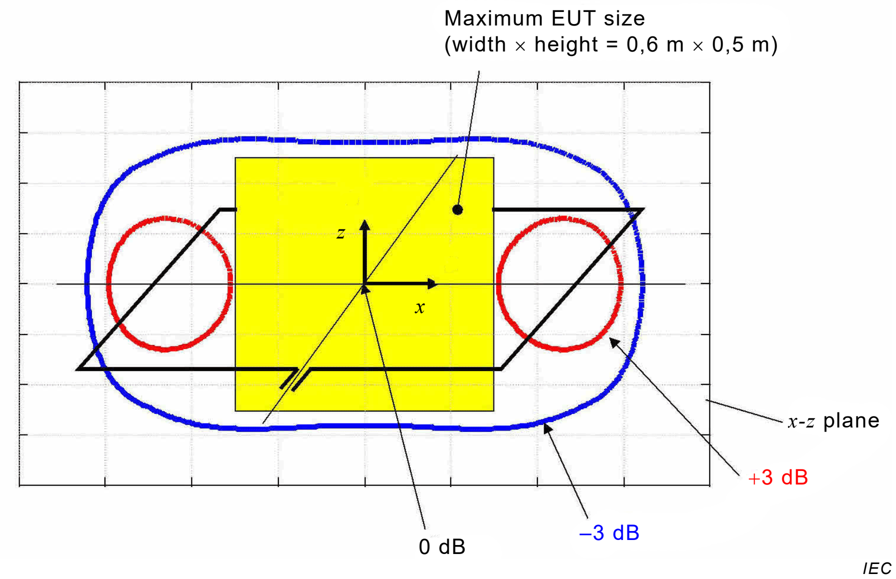
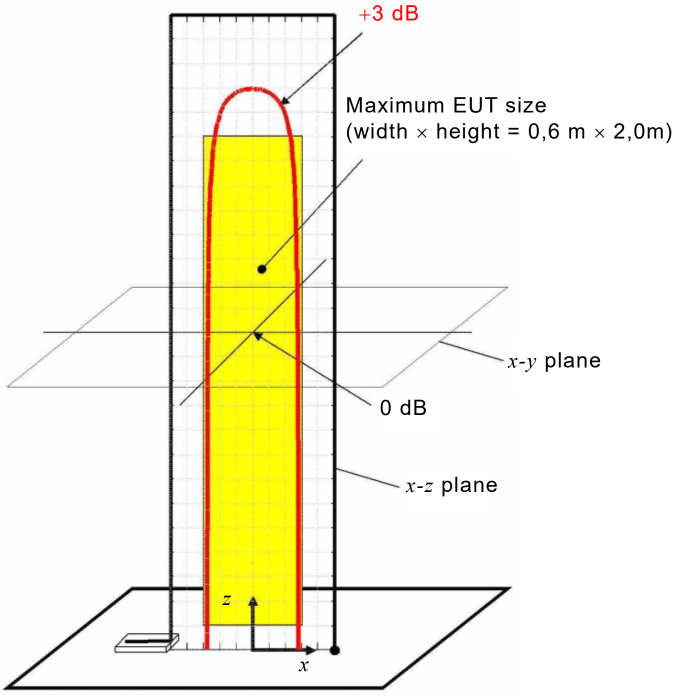


Figure B.2 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the *x*-*z* plane for the 1 m × 1 m induction coil

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

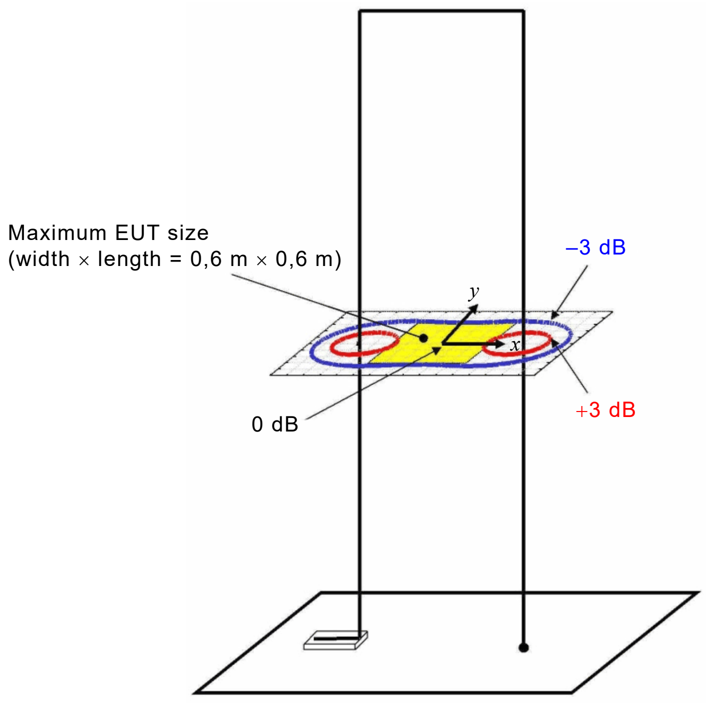
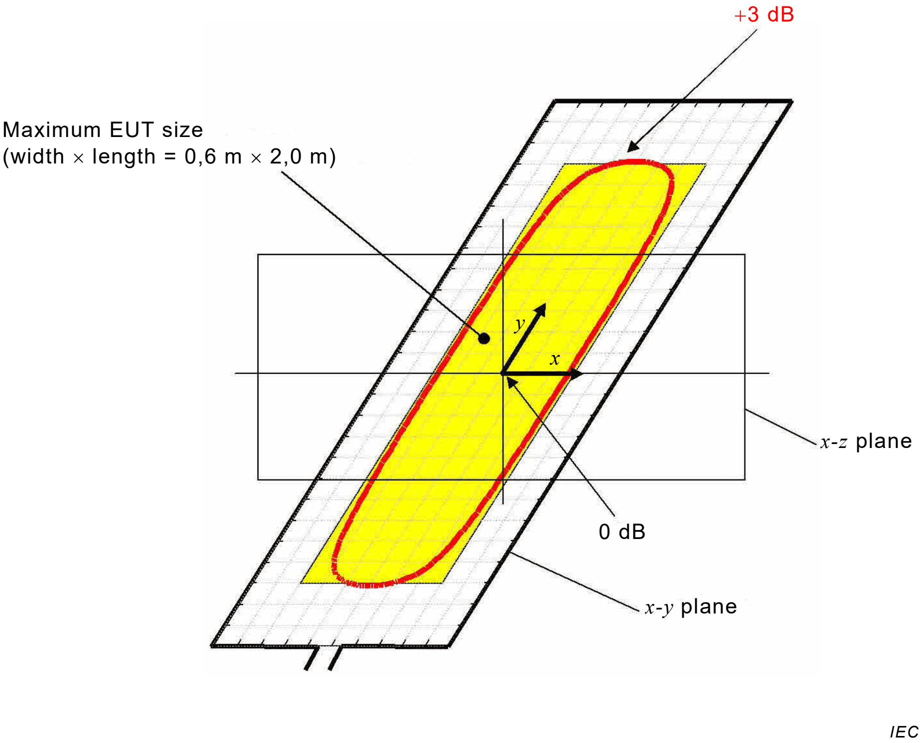


Figure B.4 – +3 dB and -3 dB isolines for the magnetic field strength (magnitude) in the *x-y* plane for the 1 m × 2,6 m induction coil with reference ground plane

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

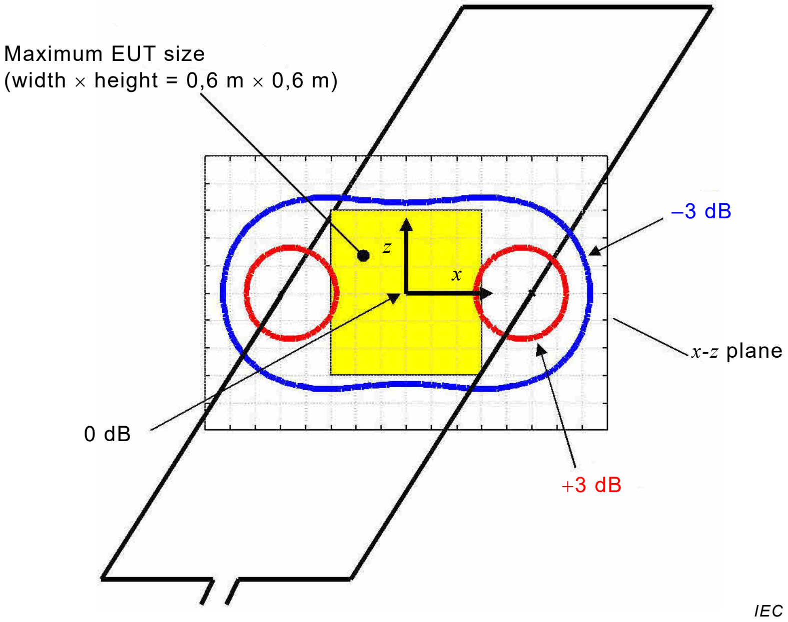


Figure B.6 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the x-z plane for the 1 m × 2,6 m induction coil without reference ground plane

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: $H_\mathrm{P} = k_\mathrm{CF} \times I_\mathrm{P}$
T_f	Front time of the current and magnetic field impulses: $T_\mathrm{f} = 1{,}25\ T_\mathrm{r}$
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: $T_\mathrm{d} = 1{,}18\ T_\mathrm{w}$

NOTE The meaning and the relations among the symbols $u(x_i)$, c_i, $u_i(y)$, $u_\mathrm{c}(y)$, $U(y)$ 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

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

where

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

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:

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

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

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

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	$-151 \cdot 10^3$	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

$\boldsymbol{V_\mathrm{PR}}$: 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).

$\boldsymbol{R_\mathrm{T}}$: 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.

$\boldsymbol{\delta R}$: 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.

$\boldsymbol{\delta V}$: 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 $H_\text{P} = k_\text{CF} \times I_\text{P}$, 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

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

where

$T_{50\%,\text{R}}$	is the time at 50 % of peak amplitude at the rising edge of the impulse
$T_{50\%,\text{F}}$	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
$T_{50\%,\text{R}}$	3,44	µs	0,005 0	µs	triangular	2,45	0,002 0	-1,181 1	µs	0,002 4	µs
$T_{50\%,\text{F}}$	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
							$u_\text{c}(y) = \sqrt{\Sigma u_i(y)^2}$			0,177 2	µs
							$U(y) = 2\,u_\text{c}(y)$			0,4	µs
							y			22,3	µs

[a] Probability density function

$T_{50\%,\text{R}}$, $T_{50\%,\text{F}}$: 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 $T_{50\%,\text{R}}$ = 3,44 µs and $T_{50\%,\text{F}}$ = 22,34 µs.

δR: quantifies the non-repeatability of the $T_{50\%,\text{F}} - T_{50\%,\text{R}}$ 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.

$\boldsymbol{\beta}$: see D.4.3, same meaning and same values both for the estimate and error bound.

$\boldsymbol{B}$: 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

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

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

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

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

$$V_{\mathrm{p}} T_{\mathrm{W}} = A V_{\mathrm{pd}} T_{\mathrm{wd}} \tag{D.15}$$

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

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

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

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

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.

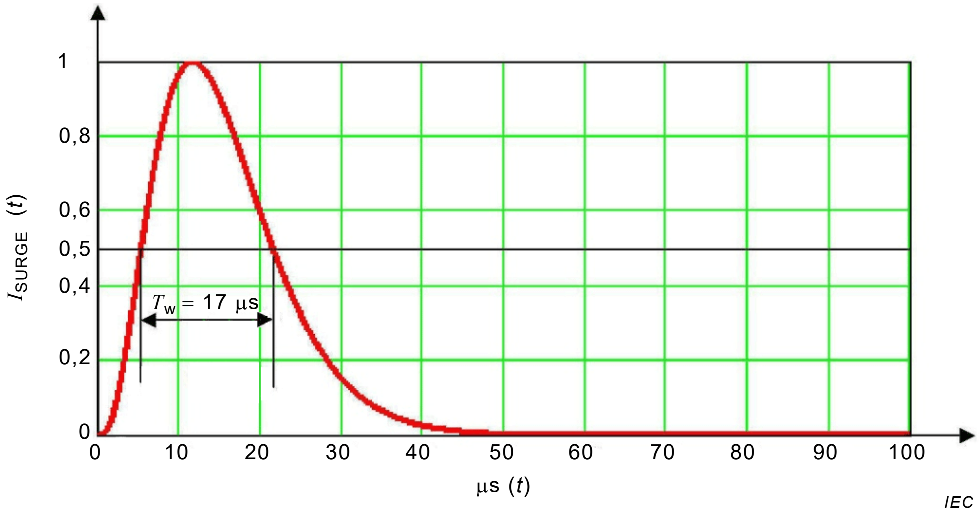


Figure E.1 – Normalized current surge (8/20 μs): Width time response T_w

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

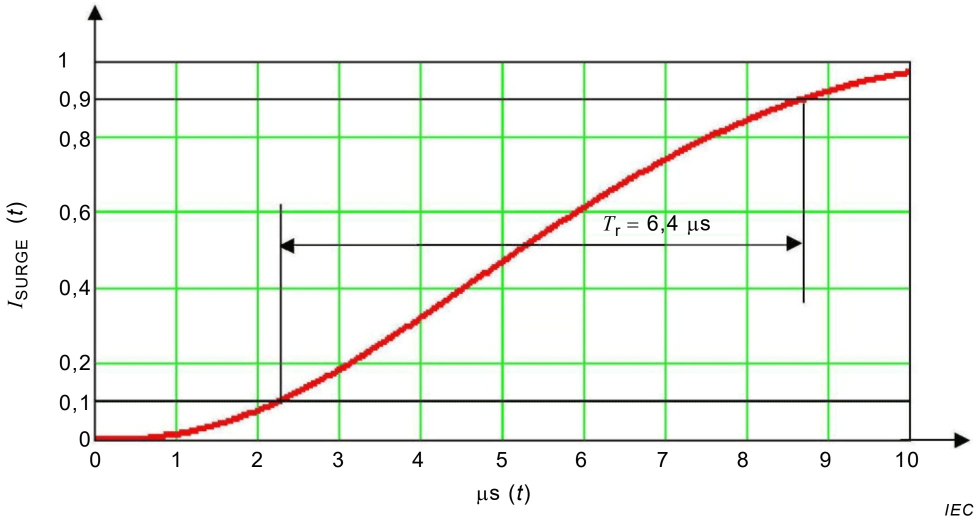


Figure E.2 – Normalized current surge (8/20 μs): Rise time response T_r

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

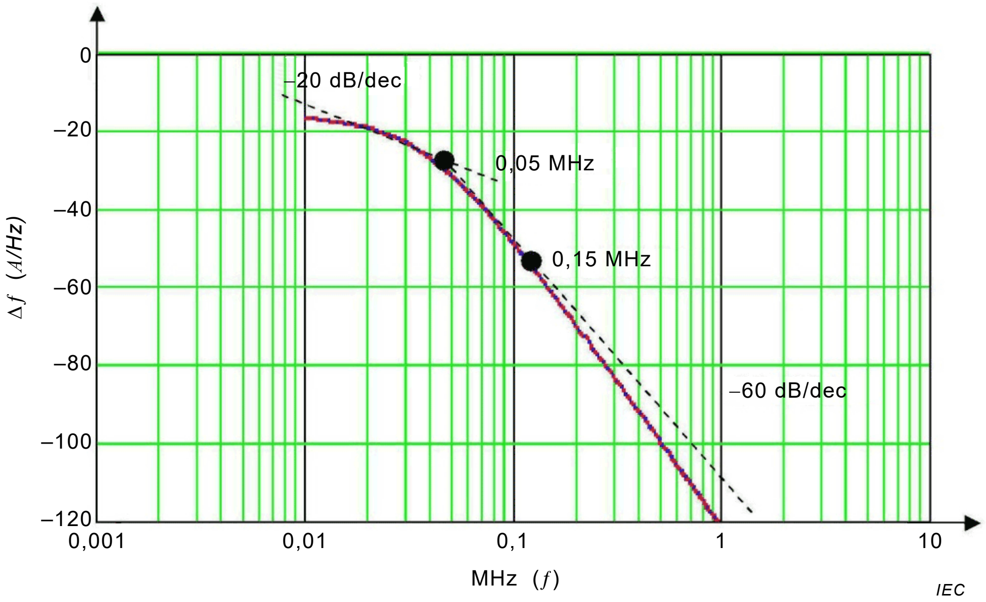


Figure E.3 – Current surge (8/20 μs): Spectral response with Δ*f* = 10 kHz

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.

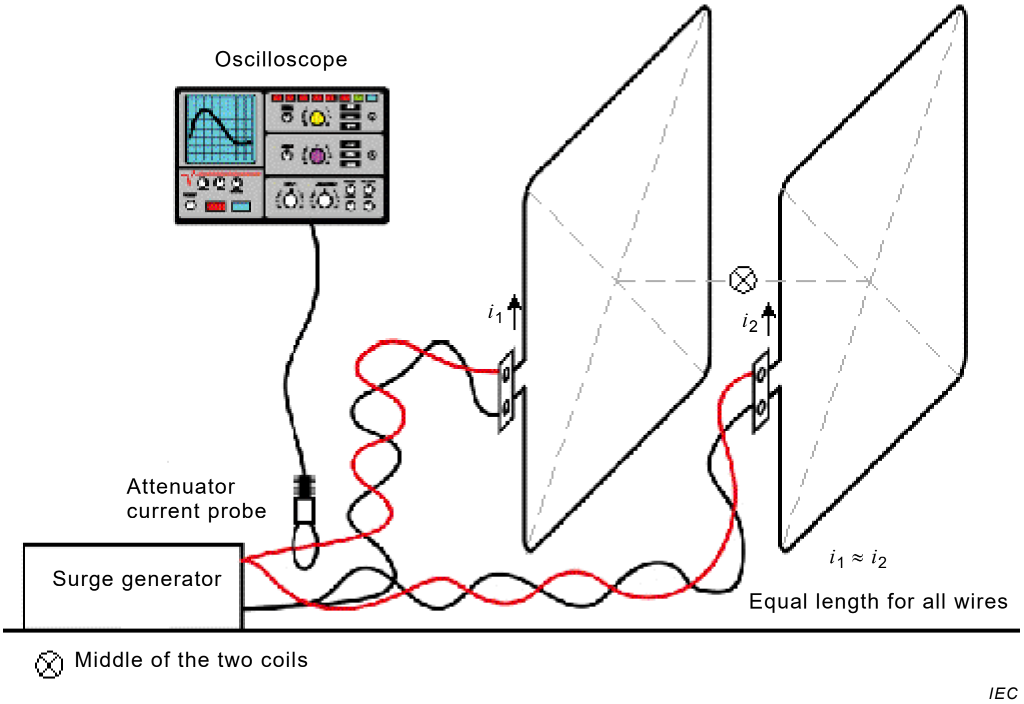


Figure F.1 – Example of a test system using double standard induction coils

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.

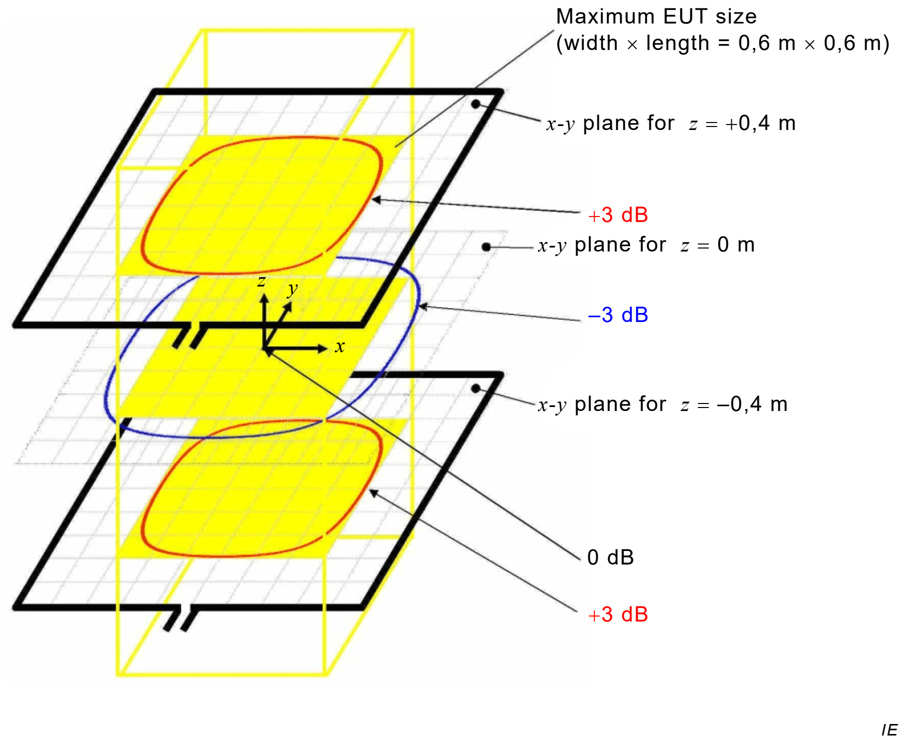


Figure F.2 – +3dB isoline for the magnetic field strength (magnitude) in the x-y plane for the double induction coil arrangement (0,8 m spaced)

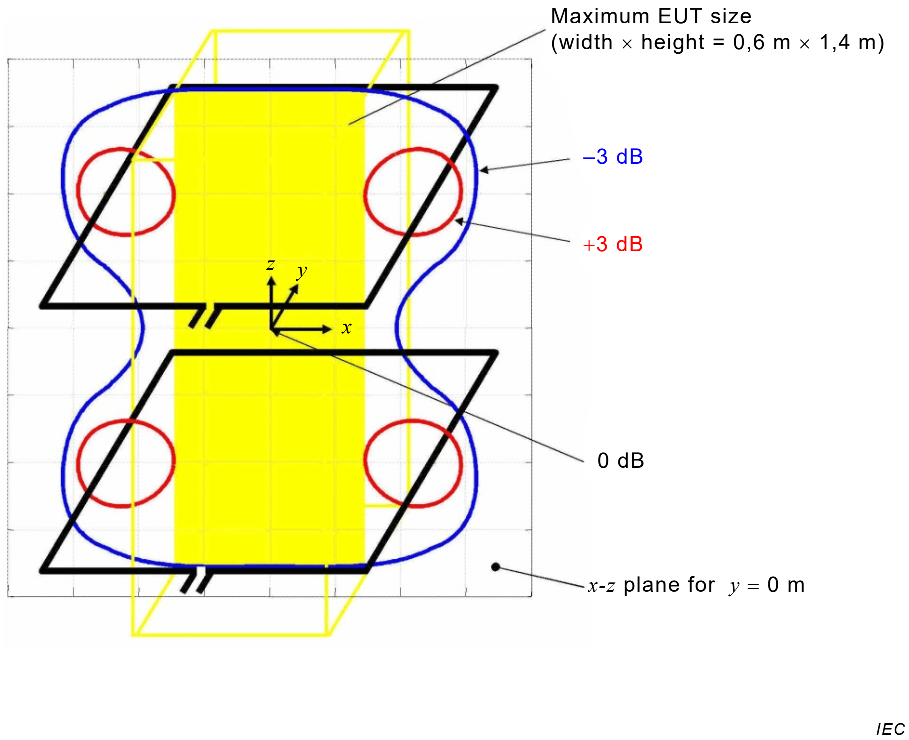


Figure F.3 – +3 dB and –3 dB isolines for the magnetic field strength (magnitude) in the x-z plane for the double induction coil arrangement (0,8 m spaced)

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

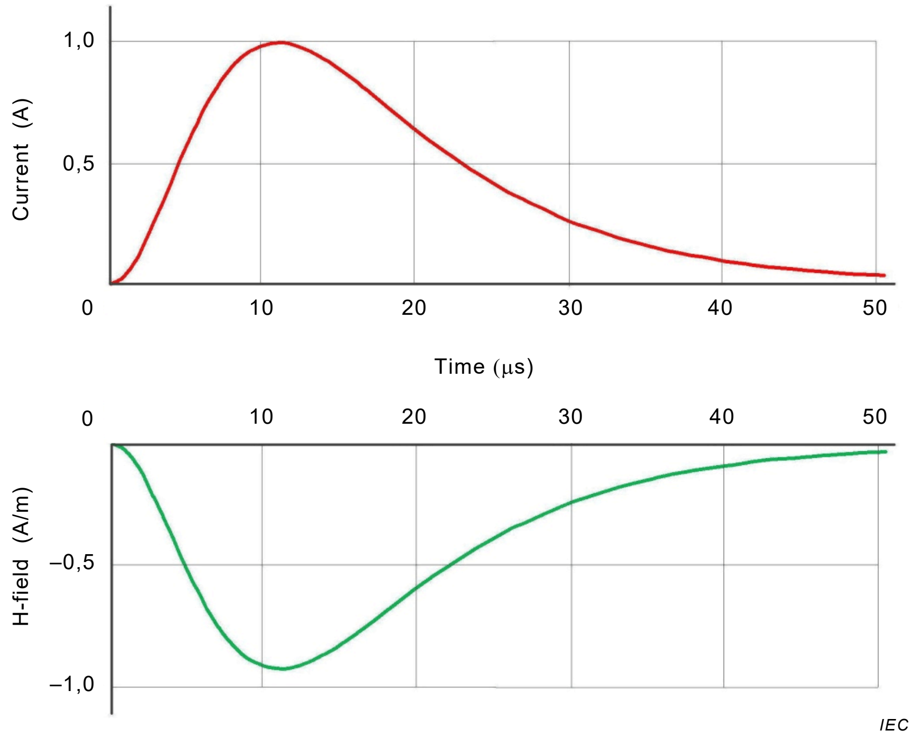
The simulations of Figures G.1 to G.12 are performed as follows:

- 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

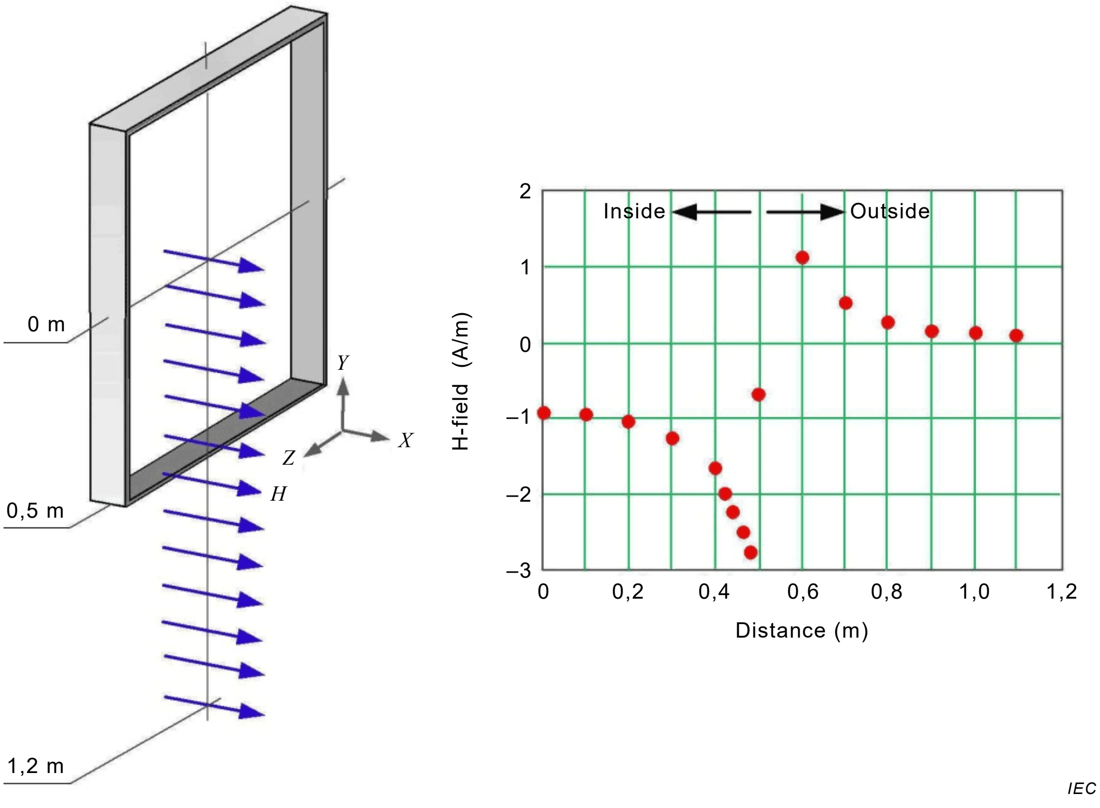


Figure G.2 – *Hx*-field along the side of 1 m × 1 m induction coil in A/m

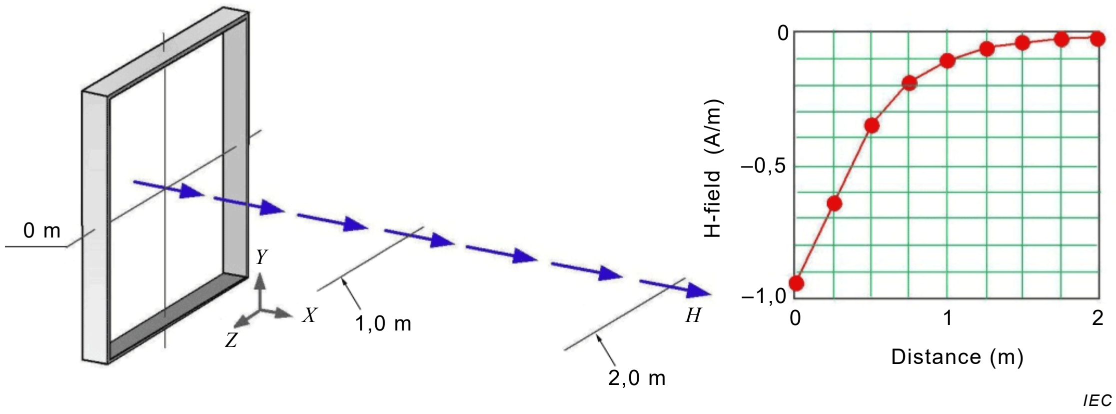


Figure G.3 – Hx-field in direction x perpendicular to the plane of the 1 m × 1 m induction coil

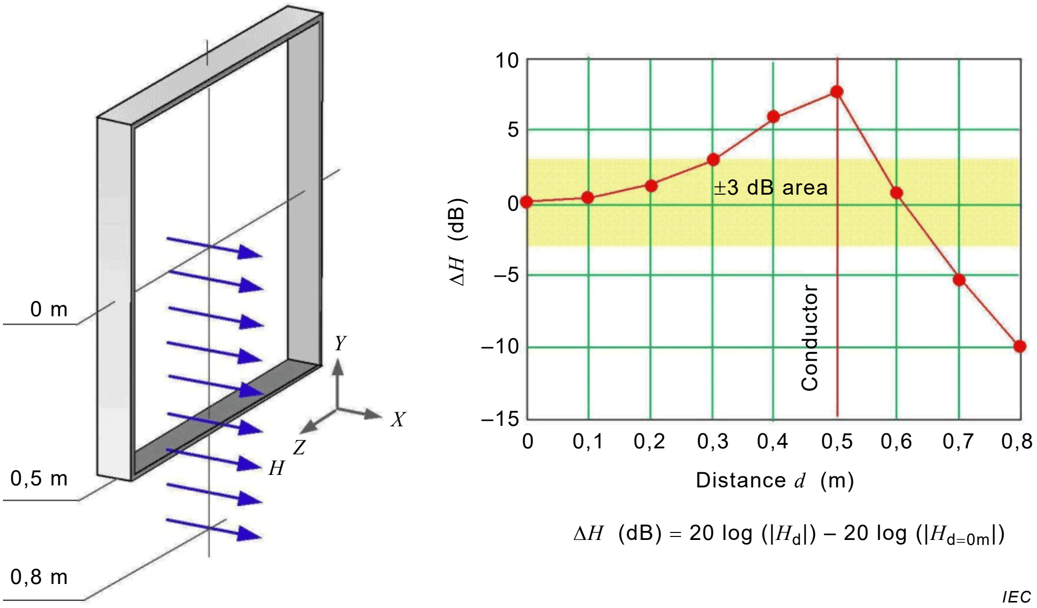


Figure G.4 – Hx-field along the side in dB for the 1 m × 1 m induction coil

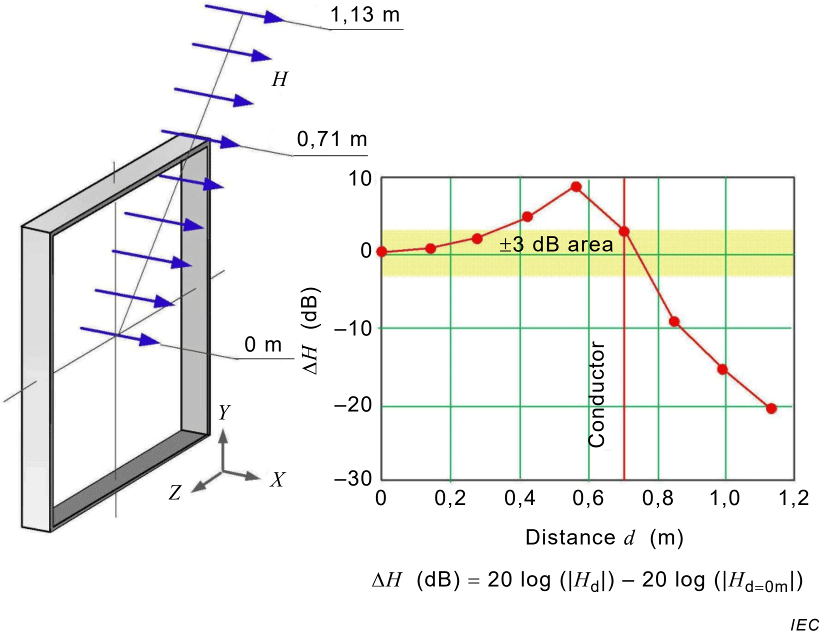
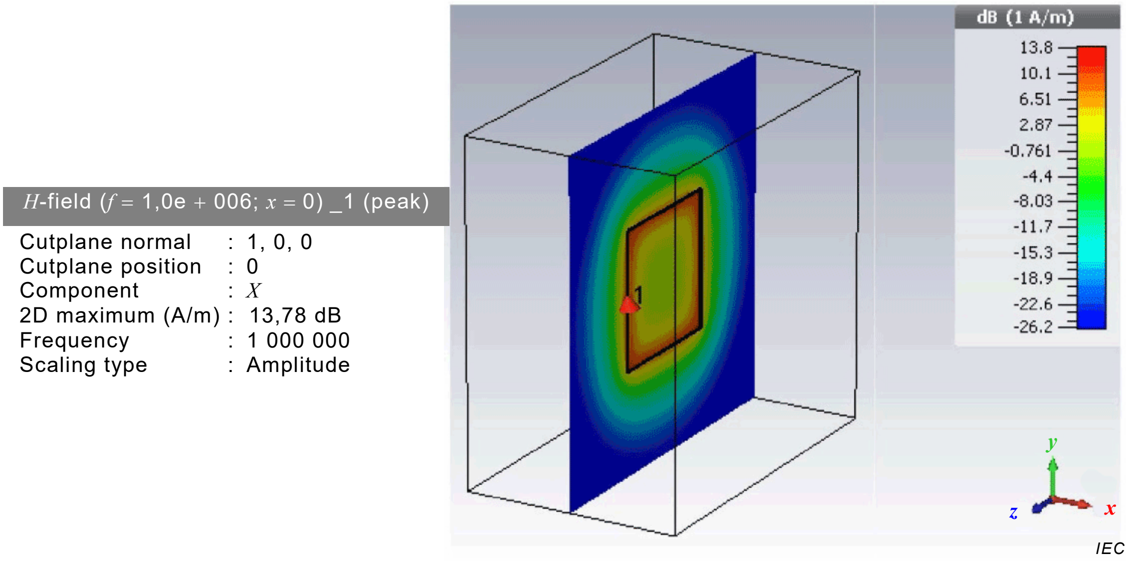


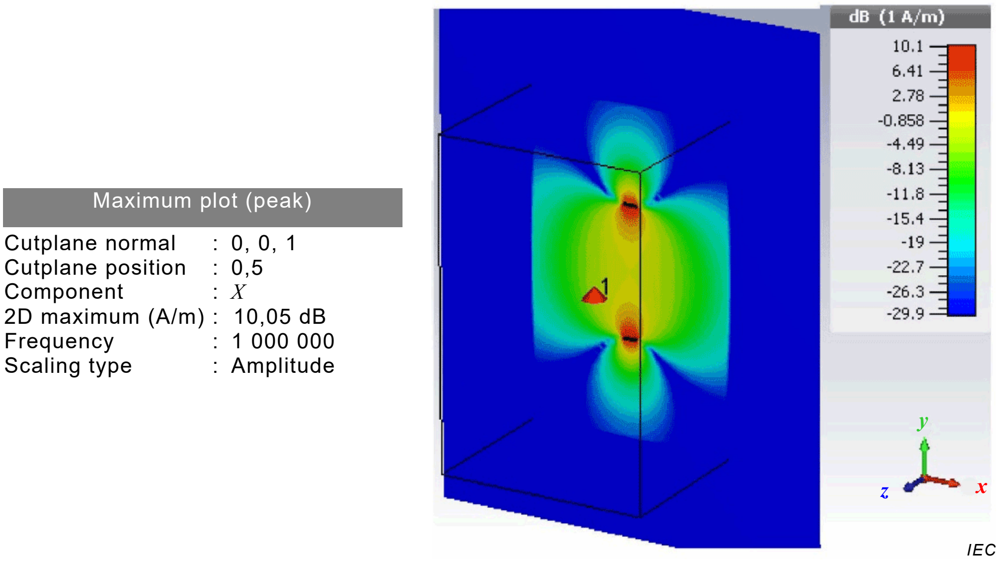
Figure G.5 – Hx-field along the diagonal in dB for the 1 m × 1 m induction coil



H-field (f = 1,0e + 006; x = 0) _1 (peak)

Cutplane normal : 1, 0, 0
Cutplane position : 0
Component : *X*
2D maximum (A/m) : 13,78 dB
Frequency : 1 000 000
Scaling type : Amplitude

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

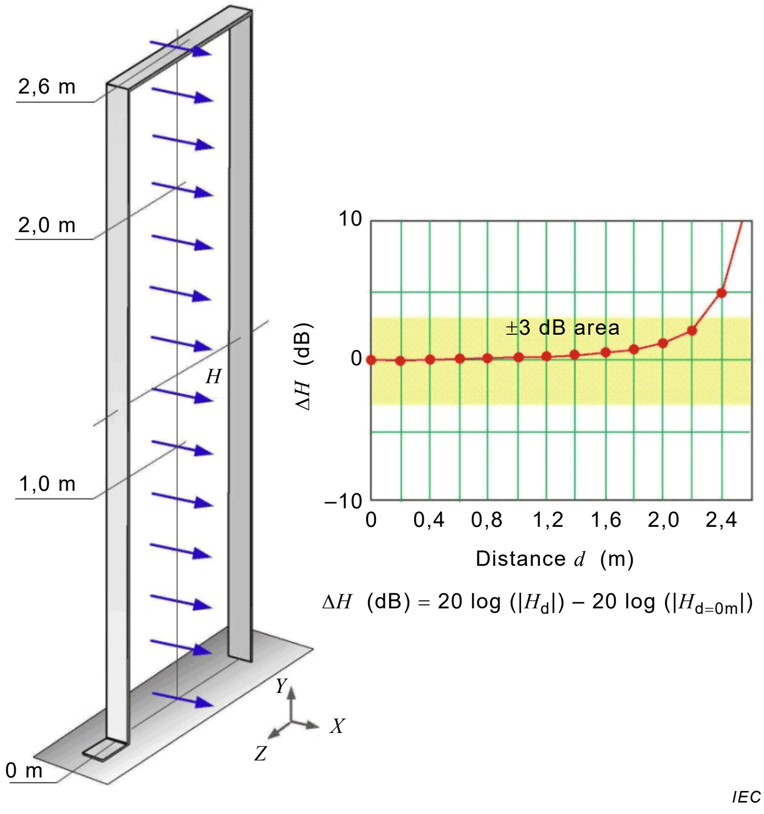


Figure G.8 – Hx-field along the vertical middle line in dB for the 1 m × 2,6 m induction coil

Maximum plot (peak)

Cutplane normal : 1, 0, 0
Cutplane position : 0
Component : *X*
2D maximum (A/m) : 17,6 dB
Frequency : 1 000 000
Scaling type : Amplitude

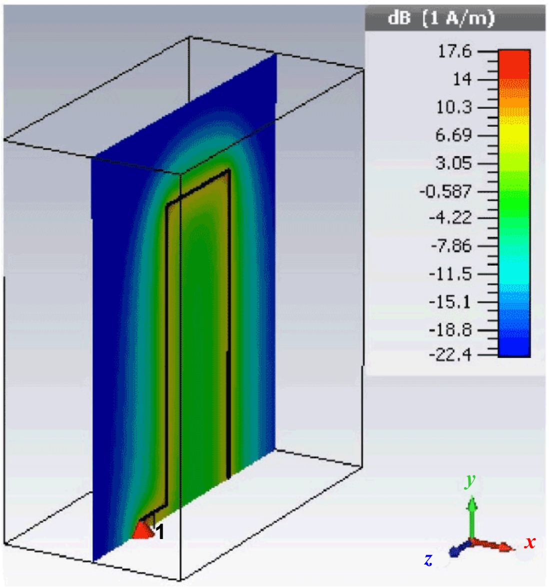


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Figure G.9 – *Hx*-field 2D plot on *y*-*z* plane for the 1 m × 2,6 m induction coil

H-field (*f* = 1,0e + 006; *z* = 0,5) _1 (peak)

Cutplane normal : 0, 0, 1
Cutplane position : 0,5
Component : *X*
2D maximum (A/m) : 9,403 dB
Frequency : 1 000 000
Scaling type : Amplitude

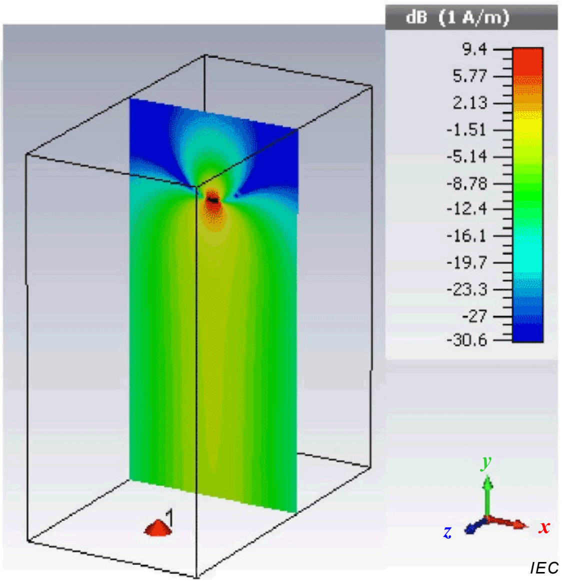

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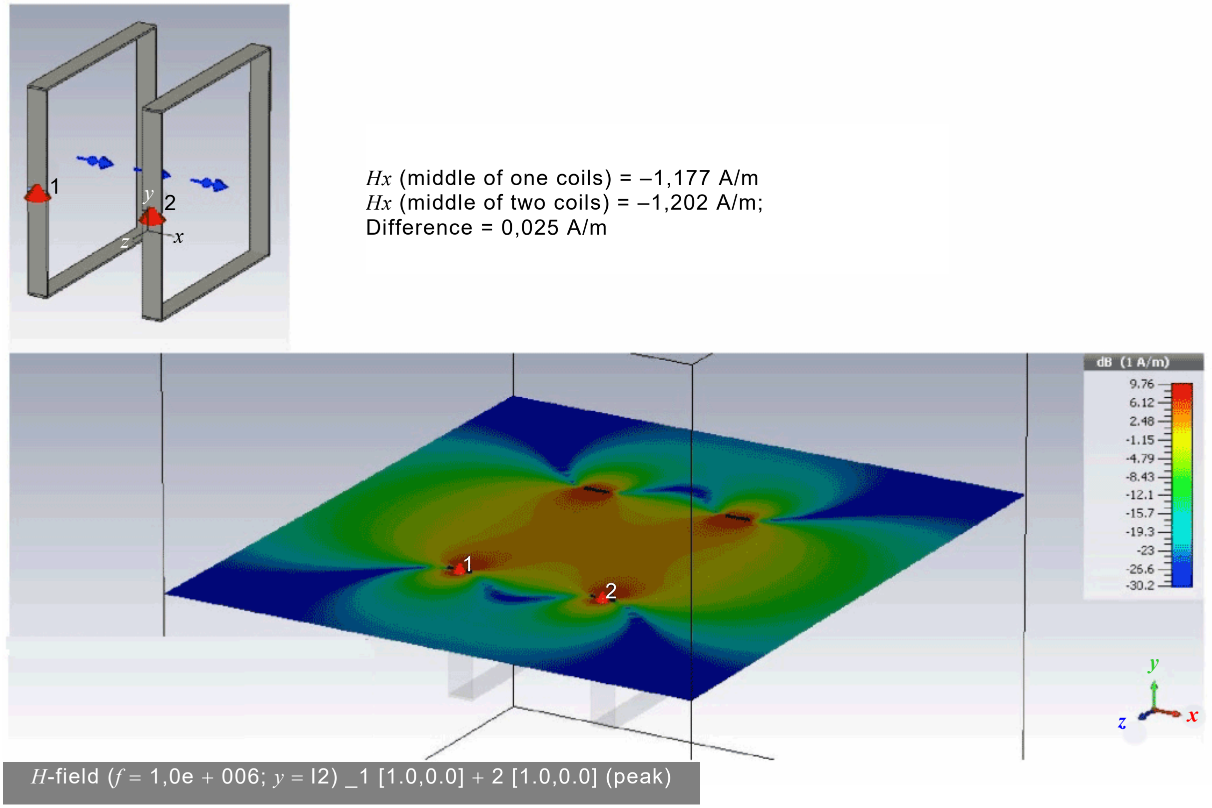
Figure G.10 – *Hx*-field 2D plot on *x*-*y* plane at *z* = 0,5 m for the 1 m × 2,6 m induction coil



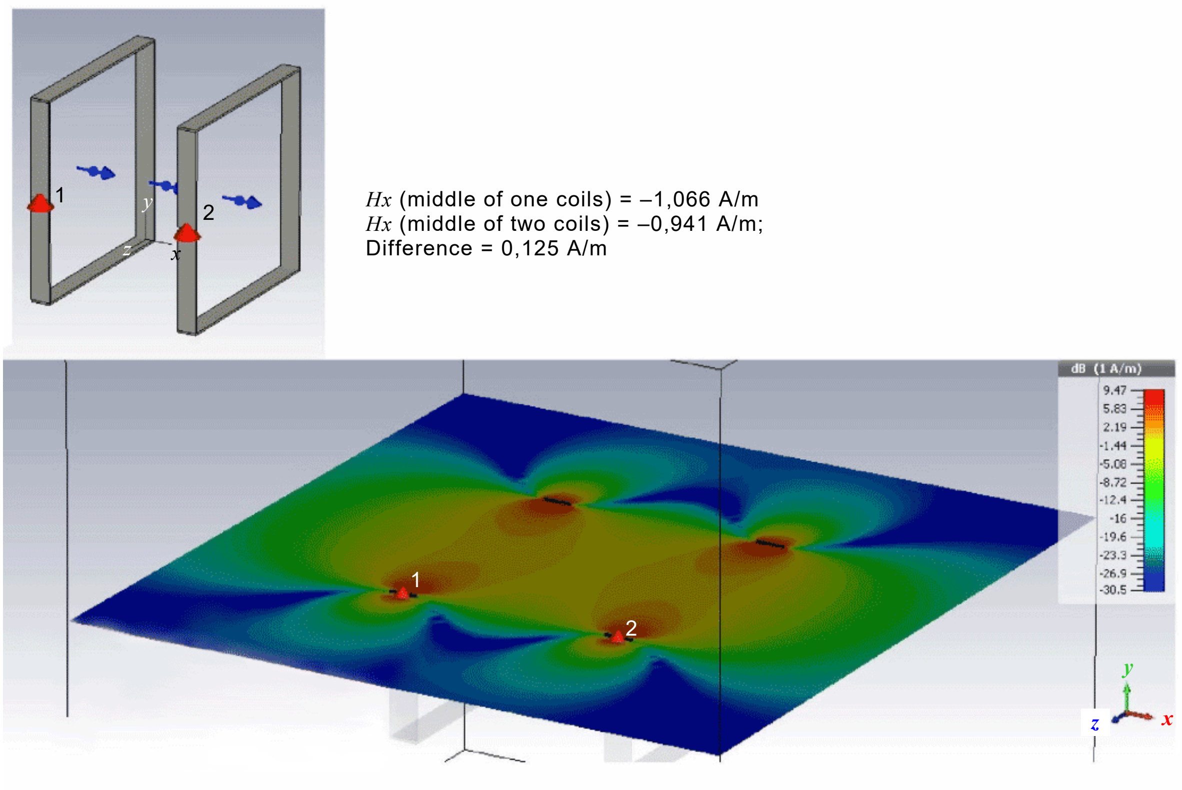
Hx (middle of one coils) = –1,177 A/m
Hx (middle of two coils) = –1,202 A/m;
Difference = 0,025 A/m

H-field (f = 1,0e + 006; y = I2) _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) : 9,756 dB
Frequency : 1 000 000
Scaling type : Amplitude

IEC

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 = I2) _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

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