

BS EN 61000-4-4:2012



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Electromagnetic compatibility (EMC)

Part 4-4: Testing and measurement
techniques — Electrical fast transient/burst
immunity test

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National foreword

This British Standard is the UK implementation of EN 61000-4-4:2012. It is identical to IEC 61000-4-4:2012. It supersedes

BS EN 61000-4-4:2004+A1:2010 which will be withdrawn on 4 June 2015.

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

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English version

**Electromagnetic compatibility (EMC) -
Part 4-4: Testing and measurement techniques -
Electrical fast transient/burst immunity test**

(IEC 61000-4-4:2012)

Compatibilité électromagnétique (CEM) -
Partie 4-4: Techniques d'essai
et de mesure -
Essai d'immunité aux transitoires
électriques rapides en salves
(CEI 61000-4-4:2012)

Elektromagnetische Verträglichkeit (EMV) -
Teil 4-4: Prüf- und Messverfahren -
Prüfung der Störfestigkeit gegen schnelle
transiente elektrische Störgrößen/Burst
(IEC 61000-4-4:2012)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

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

Management Centre: Avenue Marnix 17, B - 1000 Brussels

Foreword

The text of document 77B/670/FDIS, future edition 3 of IEC 61000-4-4, 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 61000-4-4:2012.

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) 2013-05-09
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2015-06-04

This document supersedes EN 61000-4-4:2004 + A1:2010.

EN 61000-4-4:2012 includes the following significant technical changes with respect to EN 61000-4-4:2004 + A1:2010:

This edition improves and clarifies simulator specifications, test criteria and test setups.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 61000-4-4:2012 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61000-4-2:2008	NOTE	Harmonised as EN 61000-4-2:2009 (not modified).
IEC 61000-4-4:2004	NOTE	Harmonised as EN 61000-4-4:2004 (not modified).
IEC 61000-4-4:2004/A1:2010	NOTE	Harmonised as EN 61000-4-4:2004/A1:2010 (not modified).
IEC 61000-4-5:2005	NOTE	Harmonised as EN 61000-4-5:2006 (not modified).

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 When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-161	1990	International Electrotechnical Vocabulary (IEV) Chapter 161: Electromagnetic compatibility	-	-

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INTRODUCTION

IEC 61000 is published in separate parts, according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (in so far as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as international standards or as technical specifications or technical reports, some of which have already been published as sections. Others are 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 electrical fast transients/bursts.

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test

1 Scope

This part of IEC 61000 relates to the immunity of electrical and electronic equipment to repetitive electrical fast transients. It gives immunity requirements and test procedures related to electrical fast transients/bursts. It additionally defines ranges of test levels and establishes test procedures.

The object of this standard is to establish a common and reproducible reference in order to evaluate the immunity of electrical and electronic equipment when subjected to electrical fast transient/bursts on supply, signal, control and earth ports. 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.¹

The standard defines:

- test voltage waveform;
- range of test levels;
- test equipment;
- calibration and verification procedures of test equipment;
- test setups;
- test procedure.

The standard gives specifications for laboratory and in situ tests.

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 60050-161:1990, *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions of IEC 60050-161, as well as the following apply.

¹ TC 77 and its subcommittees are prepared to co-operate with product committees in the evaluation of the value of particular immunity tests for their products.

NOTE Several of the most relevant terms and definitions from IEC 60050-161 are presented among the definitions below.

3.1.1
auxiliary equipment
AE

equipment necessary to provide the equipment under test (EUT) with the signals required for normal operation and equipment to verify the performance of the EUT

3.1.2
burst

sequence of a limited number of distinct pulses or an oscillation of limited duration

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

3.1.3
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]

3.1.4
coupling

interaction between circuits, transferring energy from one circuit to another

3.1.5
common mode (coupling)

simultaneous coupling to all lines versus the ground reference plane

3.1.6
coupling clamp

device of defined dimensions and characteristics for common mode coupling of the disturbance signal to the circuit under test without any galvanic connection to it

3.1.7
coupling network

electrical circuit for the purpose of transferring energy from one circuit to another

3.1.8
decoupling network

electrical circuit for the purpose of preventing EFT voltage applied to the EUT from affecting other devices, equipment or systems which are not under test

3.1.9
degradation (of performance)

undesired departure in the operational performance of any device, equipment or system from its intended performance

Note 1 to entry: The term "degradation" can apply to temporary or permanent failure.

[SOURCE: IEC 60050-161:1990, 161-01-19]

3.1.10
EFT/B

electrical fast transient/burst

3.1.11
electromagnetic compatibility
EMC

ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[SOURCE: IEC 60050-161:1990, 161-01-07]

3.1.12
EUT

equipment under test

3.1.13
ground reference plane
GRP

flat conductive surface whose potential is used as a common reference

[SOURCE: IEC 60050-161:1990, 161-04-36]

3.1.14
immunity (to a disturbance)

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]

3.1.15
port

particular interface of the EUT with the external electromagnetic environment

3.1.16
pulse width

interval of time between the first and last instants at which the instantaneous value reaches 50 % value of the rising and falling edge of the pulse

[SOURCE: IEC 60050-702:1992, 702-03-04, modified]

3.1.17
rise time

interval of time between the instants at which the instantaneous value of a pulse first reaches 10 % value and then the 90 % value

[SOURCE: IEC 60050-161:1990, 161-02-05, modified]

3.1.18
transient

pertaining to or designating a phenomenon or a quantity which varies between two consecutive steady states during a time interval which is short compared with the time-scale of interest

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

3.1.19
unsymmetric mode (coupling)

single line coupling versus the ground reference plane

3.1.20 verification

set of operations which is used to check the test equipment system (e.g. the test generator and the interconnecting cables) and to gain confidence that the test system is functioning within the specifications given in Clause 6

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

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

3.2 Abbreviations

AE	Auxiliary Equipment
CDN	Coupling/Decoupling Network
EFT/B	Electrical Fast Transient/Burst
EMC	ElectroMagnetic Compatibility
ESD	ElectroStatic Discharge
EUT	Equipment Under Test
GRP	Ground Reference Plane
MU	Measurement Uncertainty
PE	Protective Earth
TnL	Terminator non Linearity

4 General

The repetitive fast transient test is a test with bursts consisting of a number of fast transients, coupled into power, control, signal and earth ports of electrical and electronic equipment. Significant for the test are the high amplitude, the short rise time, the high repetition frequency, and the low energy of the transients.

The test is intended to demonstrate the immunity of electrical and electronic equipment when subjected to types of transient disturbances such as those originating from switching transients (interruption of inductive loads, relay contact bounce, etc.).

5 Test levels

The preferred test levels for the electrical fast transient test, applicable to power, control, signal and earth ports of the equipment are given in Table 1.

Table 1 – Test levels

Open circuit output test voltage and repetition frequency of the impulses				
Level	Power ports, earth port (PE)		Signal and control ports	
	Voltage peak kV	Repetition frequency kHz	Voltage peak kV	Repetition frequency kHz
1	0,5	5 or 100	0,25	5 or 100
2	1	5 or 100	0,5	5 or 100
3	2	5 or 100	1	5 or 100
4	4	5 or 100	2	5 or 100
X ^a	Special	Special	Special	Special

The use of 5 kHz repetition frequency is traditional, however, 100 kHz is closer to reality. Product committees should determine which frequencies are relevant for specific products or product types.

With some products, there may be no clear distinction between power ports and signal ports, in which case it is up to product committees to make this determination for test purposes.

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

For selection of test levels, see Annex B.

6 Test equipment

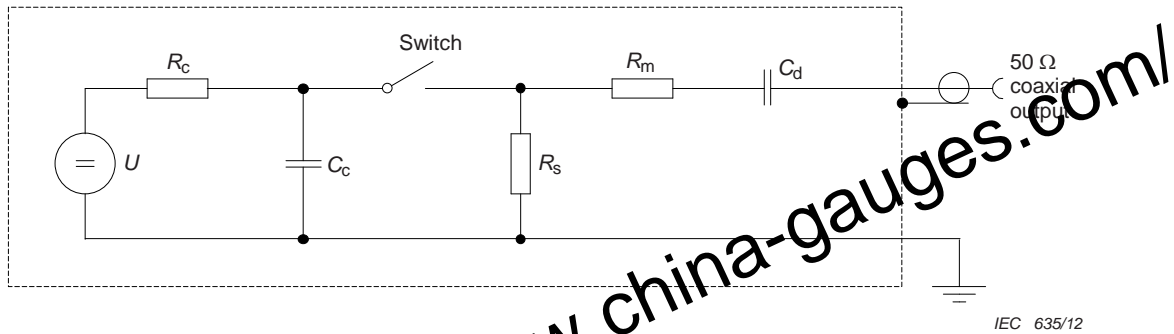
6.1 Overview

The calibration procedures of 6.2.3, 6.3.2 and 6.4.2 ensure the correct operation of the test generator, coupling/decoupling networks, and other items making up the test setup so that the intended waveform is delivered to the EUT.

6.2 Burst generator

6.2.1 General

The simplified circuit diagram of the generator is given in Figure 1. The circuit elements C_c , R_s , R_m , and C_d are selected so that the generator delivers a fast transient under open circuit conditions and with a 50Ω resistive load. The effective output impedance of the generator shall be 50Ω .



IEC 635/12

Components

U	high-voltage source
R_c	charging resistor
C_c	energy storage capacitor
R_s	impulse duration shaping resistor
R_m	impedance matching resistor
C_d	d.c. blocking capacitor
Switch	high-voltage switch

NOTE The characteristics of the switch together with stray elements (inductance and capacitance) of the layout shape the required rise time.

Figure 1 – Simplified circuit diagram showing major elements of a fast transient/burst generator

6.2.2 Characteristics of the fast transient/burst generator

The characteristics of the fast transient/burst generator are the following.

- Output voltage range with 1 000 Ω load shall be at least 0,24 kV to 3,8 kV.
- Output voltage range with 50 Ω load shall be at least 0,125 kV to 2 kV.

The generator shall be capable of operating under short-circuit conditions without being damaged.

Characteristics:

- polarity: positive/negative
- output type: coaxial, 50 Ω
- d.c. blocking capacitor (10 \pm 2) nF
- repetition frequency: (see Table 2) \pm 20 %
- relation to a.c. mains: asynchronous
- burst duration: (15 \pm 3) ms at 5 kHz
(see Figure 2) (0,75 \pm 0,15) ms at 100 kHz
- burst period: (300 \pm 60) ms
(see Figure 2)
- wave shape of the pulse
 - into 50 Ω load
 - rise time $t_r = (5 \pm 1,5)$ ns
 - pulse width $t_w = (50 \pm 15)$ ns
 - peak voltage = according to Table 2, \pm 10 %

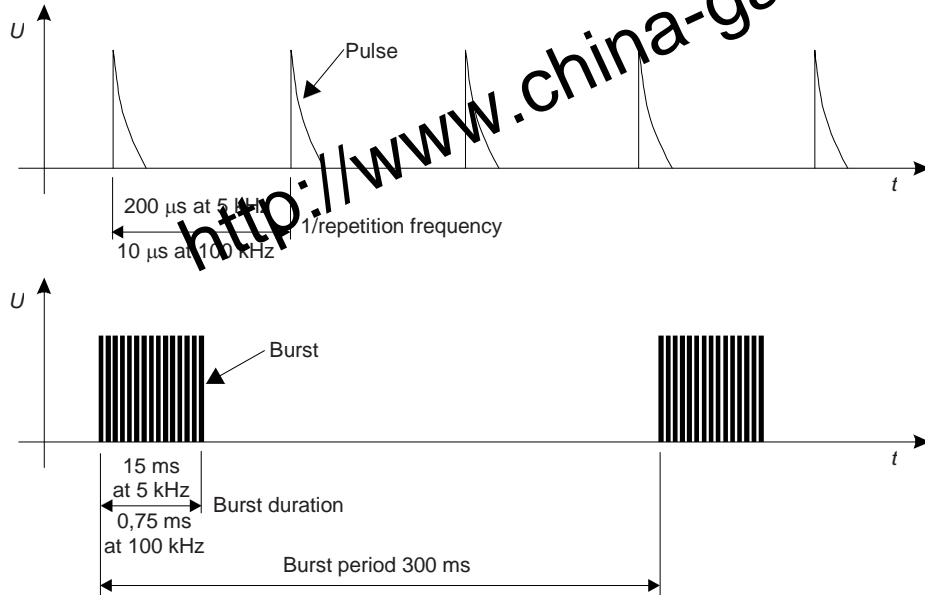
- into 1 000 Ω load

(see Figure 3 for the 50 Ω wave shape)

rise time $t_r = (5 \pm 1,5)$ ns

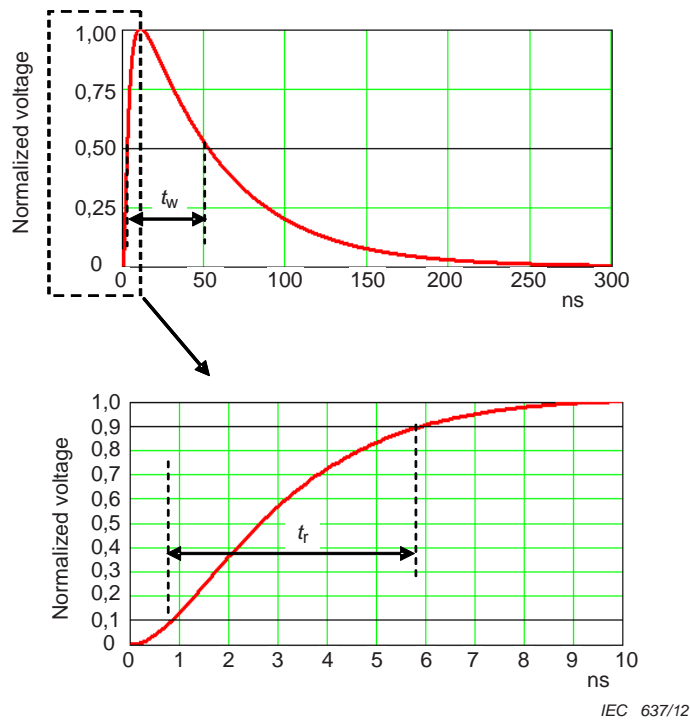
pulse width $t_w = 50$ ns, with a tolerance of -15 ns to +100 ns

peak voltage = according to Table 2, +20% (see Note 1 of Table 2)



IEC 636/12

Figure 2 – Representation of an electrical fast transient/burst



IEC 637/12

Figure 3 – Ideal waveform of a single pulse into a 50 Ω load with nominal parameters $t_r = 5$ ns and $t_w = 50$ ns

The formula of the ideal waveform of Figure 3, $v_{\text{EFT}}(t)$, is as follows:

$$v_{\text{EFT}}(t) = k_v \left[\frac{v_1}{k_{\text{EFT}}} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{n_{\text{EFT}}}}{1 + \left(\frac{t}{\tau_1}\right)^{n_{\text{EFT}}}} \cdot e^{-\frac{t}{\tau_2}} \right]$$

where

$$k_{\text{EFT}} = e^{-\frac{\tau_1}{\tau_2} \left(\frac{n_{\text{EFT}} \cdot \tau_2}{\tau_1}\right)^{n_{\text{EFT}}}}$$

and

k_v is maximum or peak value of the open-circuit voltage ($k_v = 1$ means normalized voltage)

$$v_1 = 0,92 \quad \tau_1 = 3,5 \text{ ns} \quad \tau_2 = 51 \text{ ns} \quad n_{\text{EFT}} = 1,8$$

NOTE The origin of this formula is given in IEC 62305-1:2010, Annex B.

6.2.3 Calibration of the characteristics of the fast transient/burst generator

The test generator characteristics shall be calibrated in order to establish that they meet the requirements of this standard. For this purpose, the following procedure shall be undertaken.

The test generator output shall be connected to a 50 Ω and 1 000 Ω coaxial termination respectively and the voltage monitored with an oscilloscope. The -3 dB bandwidth of the oscilloscope shall be at least 400 MHz. The test load impedance at 1 000 Ω is likely to become a complex network. The characteristics of the test load impedance are:

- (50 \pm 1) Ω ;
- (1 000 \pm 20) Ω ; the resistance measurement is made at d.c.

The tolerance of the insertion loss of both test loads shall not exceed as follows:

- ± 1 dB up to 100 MHz
- ± 3 dB from 100 MHz up to 400 MHz.

The following parameters shall be measured:

- peak voltage;
For each of the set voltages of Table 2, measure the output voltage with a 50 Ω load [V_p (50 Ω)]. This measured voltage shall be V_p (50 Ω), with a tolerance of ± 10 %.
With the same generator setting (set voltage), measure the voltage with a 1 000 Ω load [V_p (1 000 Ω)]. This measured voltage shall be V_p (1 000 Ω), with a tolerance of ± 20 %.
- rise time for all set voltages;
- pulse width for all set voltages;
- repetition frequency of the pulses within one burst for any one set voltage;
- burst duration for any one set voltage;
- burst period for any one set voltage.

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Table 2 – Output voltage peak values and repetition frequencies

Set voltage kV	V_p (open circuit) kV	V_p (1 000 Ω) kV	V_p (50 Ω) kV	Repetition frequency kHz
0,25	0,25	0,24	0,125	5 or 100
0,5	0,5	0,48	0,25	5 or 100
1	1	0,95	0,5	5 or 100
2	2	1,9	1	5 or 100
4	4	3,8	2	5 or 100

Measures should be taken to ensure that stray capacitance is kept to a minimum.

NOTE 1 Use of a 1 000 Ω load resistor will automatically result in a voltage reading that is 5 % lower than the set voltage, as shown in column V_p (1 000 Ω). The reading V_p at 1 000 Ω = V_p (open circuit) multiplied times 1 000/1 050 (the ratio of the test load to the total circuit impedance of 1 000 Ω plus 50 Ω).

NOTE 2 With the 50 Ω load, the measured output voltage is 0,5 times the value of the unloaded voltage as reflected in the table above.

6.3 Coupling/decoupling network for a.c./d.c. power port

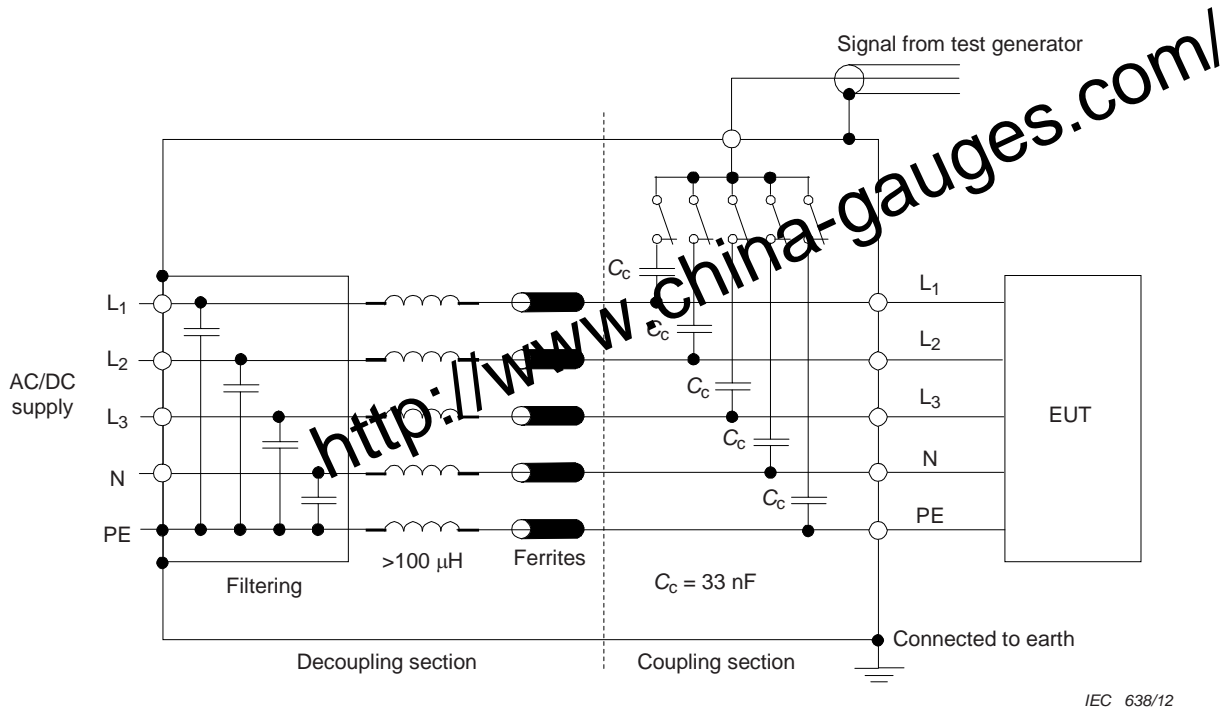
6.3.1 Characteristics of the coupling/decoupling network

The coupling/decoupling network is used for tests of a.c./d.c. power ports.

The circuit diagram (example for a three-phase power port) is given in Figure 4.

The typical characteristics of the coupling/decoupling network are the following:

- decoupling inductor with ferrite: >100 μ H;
- coupling capacitors: 33 nF.



IEC 638/12

Components

L1, L2, L3,	phases
N	neutral
PE	protective earth
C_c	coupling capacitors

Figure 4 – Coupling/decoupling network for a.c./d.c. power mains supply ports/terminals

6.3.2 Calibration of the coupling/decoupling network

Measurement equipment that is specified as suitable to perform the calibrations defined in 6.2.3 shall also be used for the calibration of the characteristics of the coupling/decoupling network.

The coupling/decoupling network shall be calibrated with a generator, which has been shown to be compliant with the requirements of 6.2.3.

The waveform shall be calibrated in common mode coupling, this means to couple the transients to all lines simultaneously. The waveform shall be individually calibrated for each coupling line at each output terminal (L1, L2, L3, N and PE) of the coupling/decoupling network with a single 50 Ω termination to reference ground. Figure 5 shows one of the five calibration measurements, the calibration of L1 to reference ground.

NOTE 1 Verifying each coupling line separately is done to ensure that each line is properly functioning and calibrated.

Care should be taken to use coaxial adapters to interface with the output of the CDN.

The connection between the output of the CDN and the coaxial adapter should be as short as possible; but not to exceed 0,1 m.

The calibration is performed with the generator output at a set voltage of 4 kV. The generator is connected to the input of the coupling/decoupling network. Each individual output of the CDN (normally connected to the EUT) is terminated in sequence with a 50 Ω load while the other outputs are open. The peak voltage and waveform are recorded for each polarity.

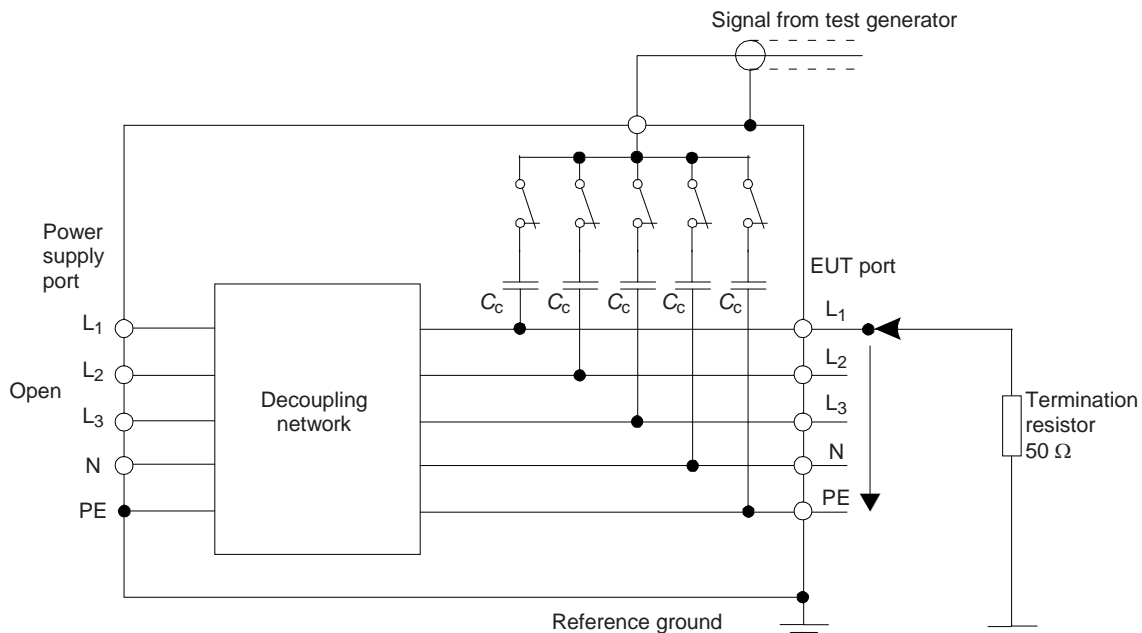
Rise time of the pulses shall be $(5,5 \pm 1,5)$ ns.

Pulse width shall be (45 ± 15) ns.

Peak voltage shall be $(2 \pm 0,2)$ kV, according to Table 2.

NOTE 2 The values shown above are the result of the calibration method of the CDN.

The residual test pulse voltage on the power inputs of the coupling/decoupling network when the EUT and the power network are disconnected shall not exceed 400 V when measured individually at each input terminal (L1, L2, L3, N to PE) with a single 50 Ω termination and when the generator is set to 4 kV and the coupling/decoupling network is set in common mode coupling, this means to couple the transients to all lines simultaneously.



IEC 639/12

Figure 5 – Calibration of the waveform at the output of the coupling/decoupling network

6.4 Capacitive coupling clamp

6.4.1 General

The clamp provides the ability of coupling the fast transients/bursts to the circuit under test without any galvanic connection to the terminals of the EUT's ports, shielding of the cables or any other part of the EUT.

The coupling capacitance of the clamp depends on the cable diameter, material of the cables and cable shielding (if any).

The device is composed of a clamp unit (made, for example, of galvanized steel, brass, copper or aluminium) for housing the cables (flat or round) of the circuits under test and shall

be placed on a ground reference plane. The ground reference plane shall extend beyond the clamp by a least 0,1 m on all sides.

The clamp shall be provided at both ends with a high-voltage coaxial connector for the connection of the test generator at either end. The generator shall be connected to that end of the clamp which is nearest to the EUT.

When the coupling clamp has only one HV coaxial connector, it should be arranged so that the HV coaxial connector is closest to the EUT.

The clamp itself shall be closed as much as possible to provide maximum coupling capacitance between the cable and the clamp.

An example of the mechanical arrangement of the coupling clamp is given in Figure 6. The following dimensions shall be used:

- Lower coupling plate height: (100 ± 5) mm
- Lower coupling plate width: (140 ± 7) mm
- Lower coupling plate length: $(1\ 000 \pm 50)$ mm

The coupling method using the clamp is used for tests on lines connected to signal and control ports. It may also be used on power ports only if the coupling/decoupling network defined in 6.3 cannot be used (see 7.3.2.1).

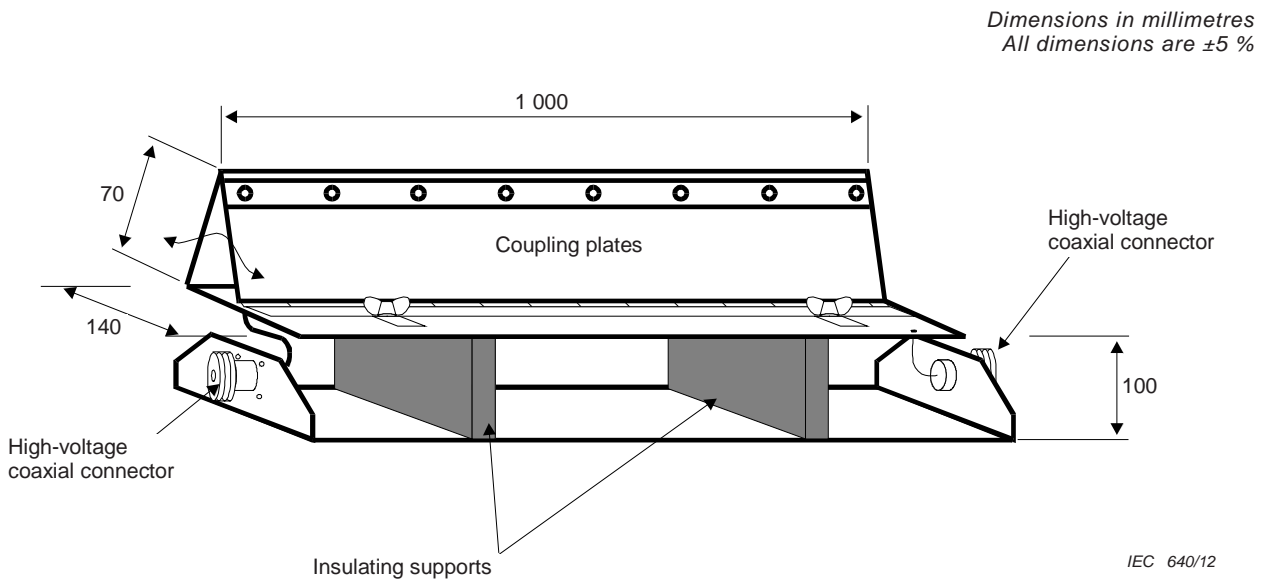


Figure 6 – Example of a capacitive coupling clamp

6.4.2 Calibration of the capacitive coupling clamp

Measurement equipment that is specified as suitable to perform the calibrations defined in 6.2.3 shall also be used for the calibration of the characteristics of the capacitive coupling clamp.

A transducer plate (see Figure 7) shall be inserted into the coupling clamp and a connecting adapter with a low inductance bond to ground shall be used for connection to the measurement terminator/attenuator. A setup is given in Figure 8.

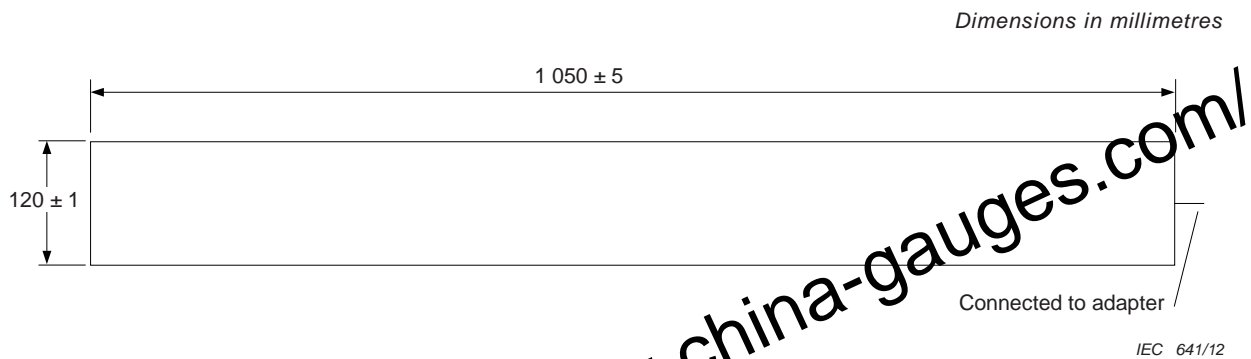


Figure 7 – Transducer plate for coupling clamp calibration

The transducer plate shall consist of a metallic sheet 120 mm × 1 050 mm of maximum 0,5 mm thickness, insulated on top and bottom by a dielectric sheet of 0,5 mm. Insulation of at least 2,5 kV on all sides shall be guaranteed in order to avoid the clamp contacting the transducer plate. At one end it is connected by a maximum of 30 mm long low impedance connection to the connecting adapter. The transducer plate shall be placed in the capacitive coupling clamp such that the end with the connection is aligned with the end of the lower coupling plate. The connecting adapter shall support a low impedance connection to ground reference plane for grounding of the 50 Ω coaxial measurement terminator/attenuator. The distance between the transducer plate and the 50 Ω measurement terminator/attenuator shall not exceed 0,1 m.

NOTE The clearance between the upper coupling plate and transducer plate is not significant.

The waveform shall be calibrated with a single 50 Ω termination.

The clamp shall be calibrated with a generator, which has been shown to be compliant with the requirements of 6.2.2 and 6.2.3.

The calibration is performed with the generator output voltage set to 2 kV.

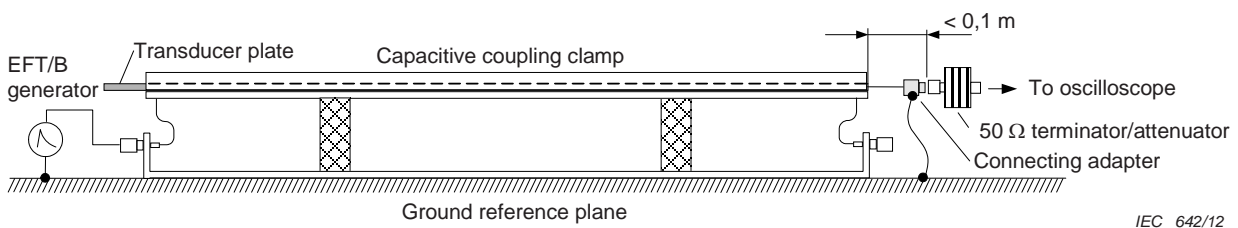


Figure 8 – Calibration of a capacitive coupling clamp using the transducer plate

The generator is connected to the input of the coupling clamp.

The peak voltage and waveform parameters are recorded at the transducer plate output located at the opposite end of the clamp.

The waveform characteristics shall meet the following requirements:

- rise time ($5 \pm 1,5$) ns;
- pulse width (50 ± 15) ns;
- peak voltage ($1\ 000 \pm 200$) V.

7 Test setup

7.1 General

Different types of tests are defined based on test environments. These are:

- type (conformance) tests performed in laboratories;
- in situ tests performed on equipment in its final installed condition.

The preferred test method is that of type tests performed in laboratories.

The EUT shall be arranged in accordance with the manufacturer's instructions for installation (if any).

7.2 Test equipment

7.2.1 General

The test setup includes the following equipment (see Figure 9):

- ground reference plane;
- coupling device (network or clamp);
- decoupling network, if appropriate;
- test generator.

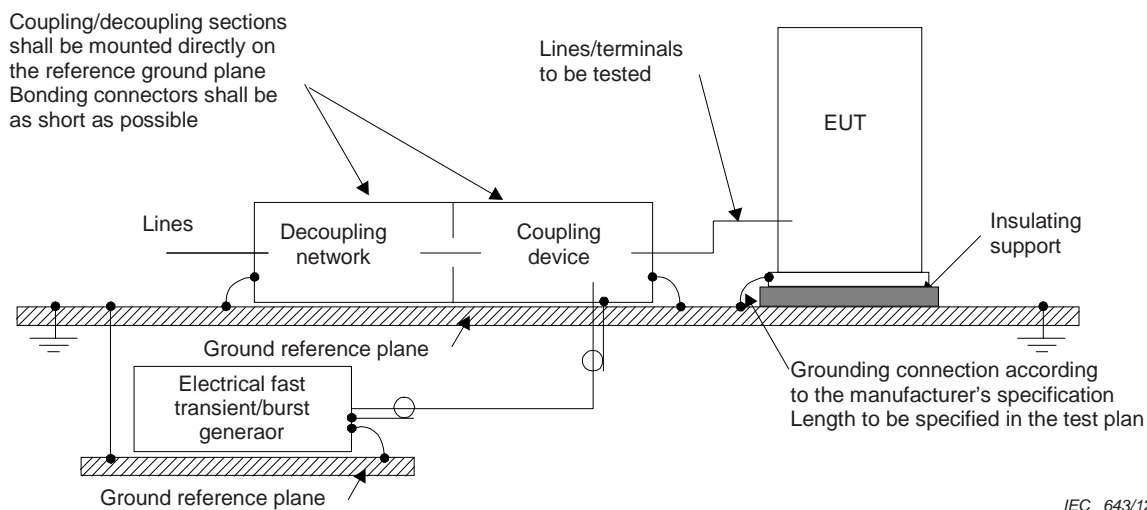


Figure 9 – Block diagram for electrical fast transient/burst immunity test

7.2.2 Verification of the test instrumentation

The purpose of verification is to ensure that the EFT/B test setup is operating correctly between calibrations. The EFT/B test setup includes:

- EFT/B generator;
- CDN;
- capacitive coupling clamp;
- interconnection cables.

To verify that the system functions correctly, the following signals should be checked:

- EFT/B signal present at the output terminal of the CDN;
- EFT/B signal present at the capacitive coupling clamp.

It is sufficient to verify that burst transients (see Figure 2) are present at any level by using suitable measuring equipment (e.g. oscilloscope) without an EUT connected to the system.

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

An example of the verification procedure of the capacitive coupling clamp is given in Figure 10.

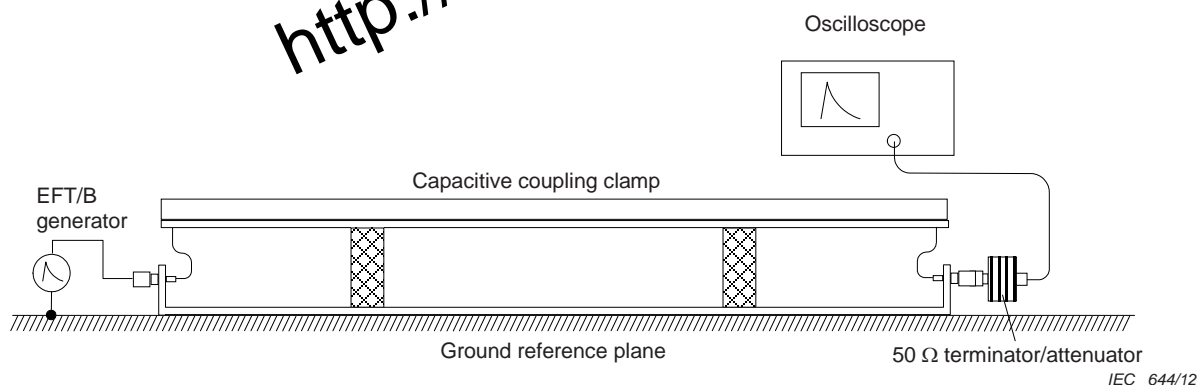


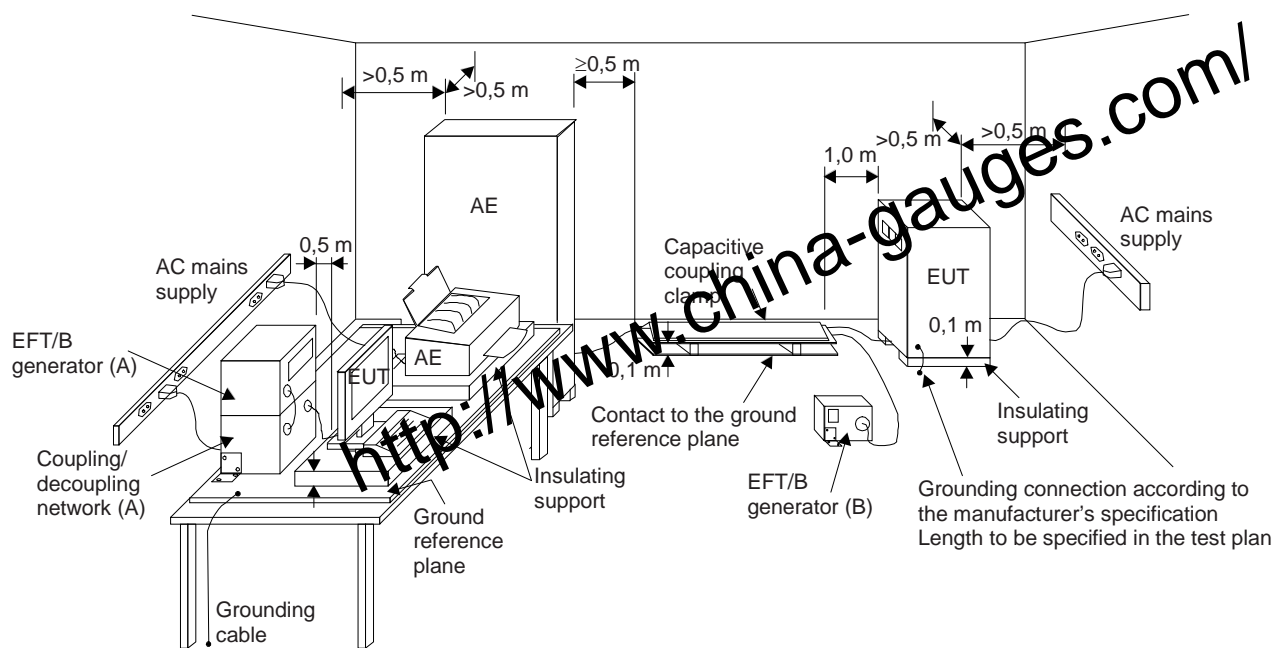
Figure 10 – Example of a verification setup of the capacitive coupling clamp

7.3 Test setup for type tests performed in laboratories

7.3.1 Test conditions

The following requirements apply to tests performed in laboratories with the environmental reference conditions specified in 8.1.

Floor standing EUTs and equipment designed to be mounted in other configurations, unless otherwise mentioned, shall be placed on a ground reference plane and shall be insulated from it by an insulating support with a thickness of $(0,1 \pm 0,05)$ m including non conductive roller/castors (see Figure 11).



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- (A) location for supply line coupling
- (B) location for signal lines coupling

Figure 11 – Example of a test setup for laboratory type tests

Table-top equipment and equipment normally mounted on ceilings or walls as well as built-in equipment shall be tested with the EUT located $(0,1 \pm 0,01)$ m above the ground reference plane.

Testing of large table-top equipment or multiple systems can be performed on the floor; maintaining the same distances as for the test setup of table-top equipment.

The test generator and the coupling/decoupling network shall be bonded to the ground reference plane.

The ground reference plane shall be a metallic sheet (copper or aluminium) of 0,25 mm minimum thickness; other metallic materials may be used, but they shall have at least 0,65 mm minimum thickness.

The minimum size of the ground reference plane is $0,8 \text{ m} \times 1 \text{ m}$. The actual size depends on the dimensions of the EUT.

The ground reference plane shall project beyond the EUT by at least 0,1 m on all sides.

The ground reference plane shall be connected to protective earth (PE) for safety reasons.

The EUT shall be arranged and connected to satisfy its functional requirements, according to the equipment installation specifications.

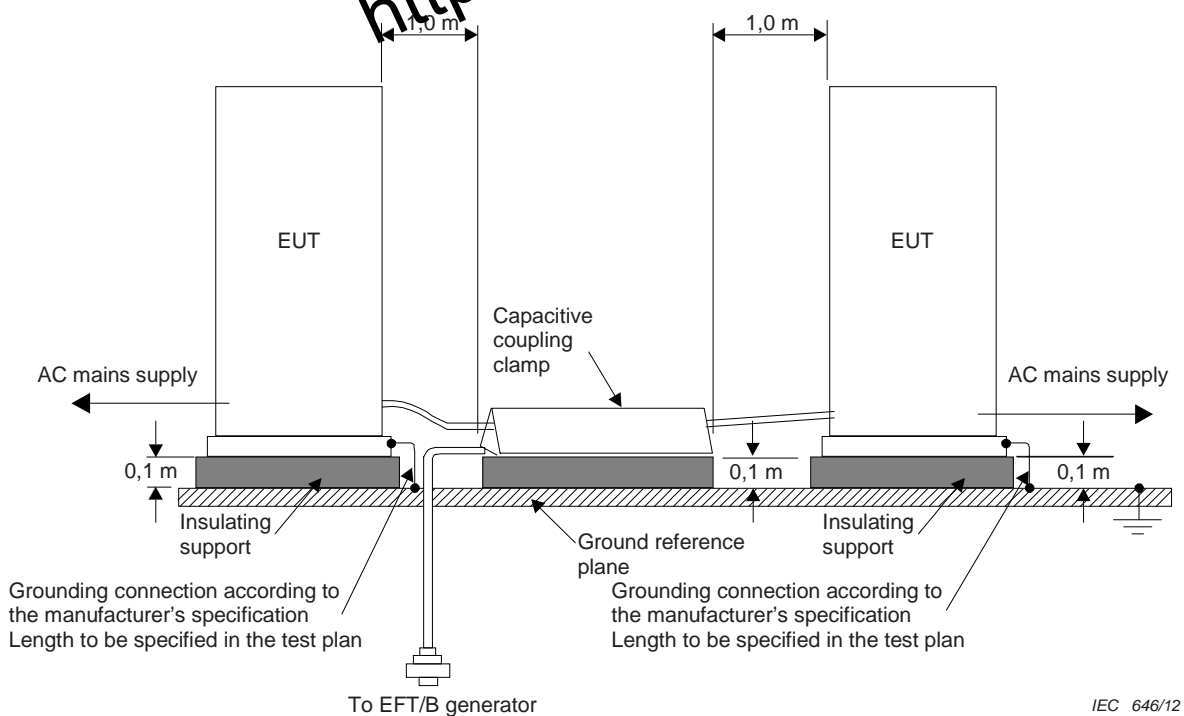
The minimum distance between the EUT and all other conductive structures (including the generator, AE and the walls of a shielded room), except the ground reference plane, shall be more than 0,5 m.

All cables to the EUT shall be placed on the insulation support 0,1 m above the ground reference plane. Cables not subject to electrical fast transients shall be routed as far as possible from the cable under test to minimize the coupling between the cables.

The EUT shall be connected to the earthing system in accordance with the manufacturer's installation specifications; no additional earthing connections are allowed.

The connection impedance of the coupling/decoupling network earth cables to the ground reference plane and all bondings shall provide a low inductance.

Either a direct coupling network or a capacitive clamp shall be used for the application of the test voltages. The test voltages shall be coupled to all of the EUT ports in turn including those between two units of equipment involved in the test, unless the length of the interconnecting cable makes it impossible to test (see Figure 12).



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Equipment without cables provided should be tested according to the operating/installation instruction or with a worst case scenario.

NOTE The cable length to be tested is usually specified by product committees.

Figure 12 – Example of test setup using a floor standing system of two EUTs

Equipment with elevated cable entries shall be set up as outlined in Figure 13.

Decoupling networks or common mode absorbing devices shall be used to protect auxiliary equipment and public networks.

When using the coupling clamp, the minimum distance between the coupling plates and all other conductive surfaces (including the generator), except the ground reference plane beneath the coupling clamp and beneath the EUT, shall be at least 0,5 m.

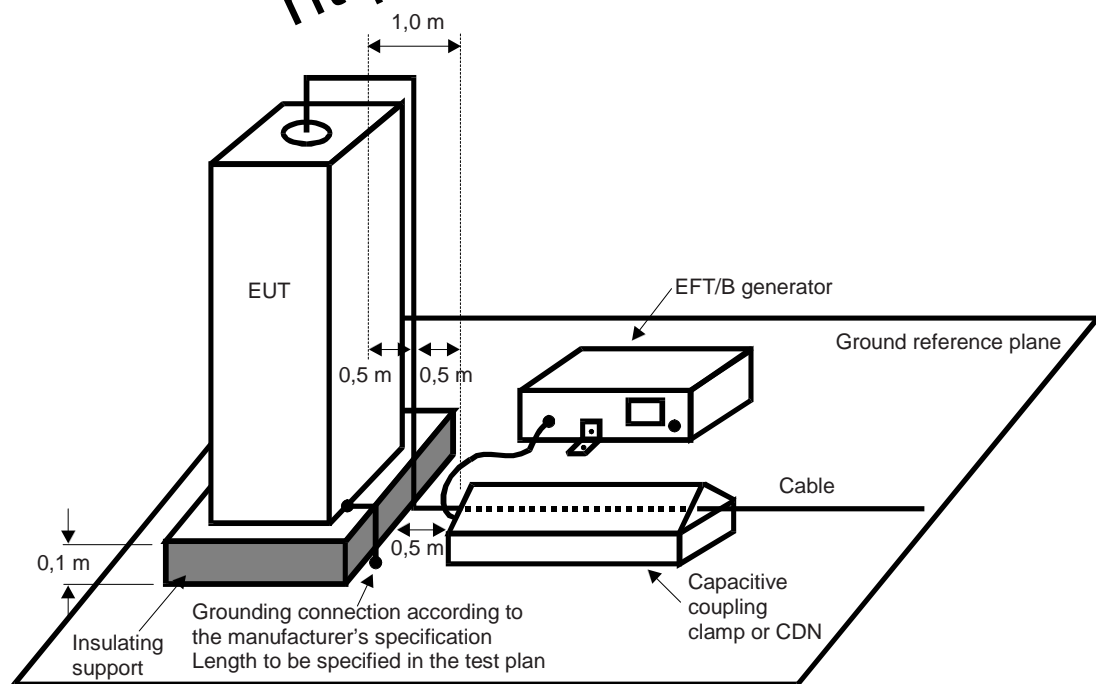
The distance between any coupling devices and the EUT shall be (0,5 – 0/+0,1) m for table-top equipment testing, and (1,0 ± 0,1) m for floor standing equipment, unless otherwise

specified in product standards. When it is not physically possible to apply the distances mentioned above, other distances can be used and shall be recorded in the test report.

The cable between the EUT and the coupling device, if detachable, shall be as short as possible to comply with the requirements of this clause. If the manufacturer provides a cable exceeding the distance between the coupling device and the point of entry of the EUT, the excess length of this cable shall be bundled and situated at a distance of 0,5 m above the ground reference plane. When a capacitive clamp is used as a coupling device, the excess cable length shall be bundled at the AE side.

Parts of the EUT with interconnecting cables of a length less than 3 m, which are not tested, shall be placed on the insulating support. The parts of the EUT shall have a distance of 0,5 m between them. Excess cable length shall be bundled.

Examples of the test setup for laboratory tests are given in Figure 11 to 14.



IEC 647/12

Figure 13 – Example of a test setup for equipment with elevated cable entries

7.3.2 Methods of coupling the test voltage to the EUT

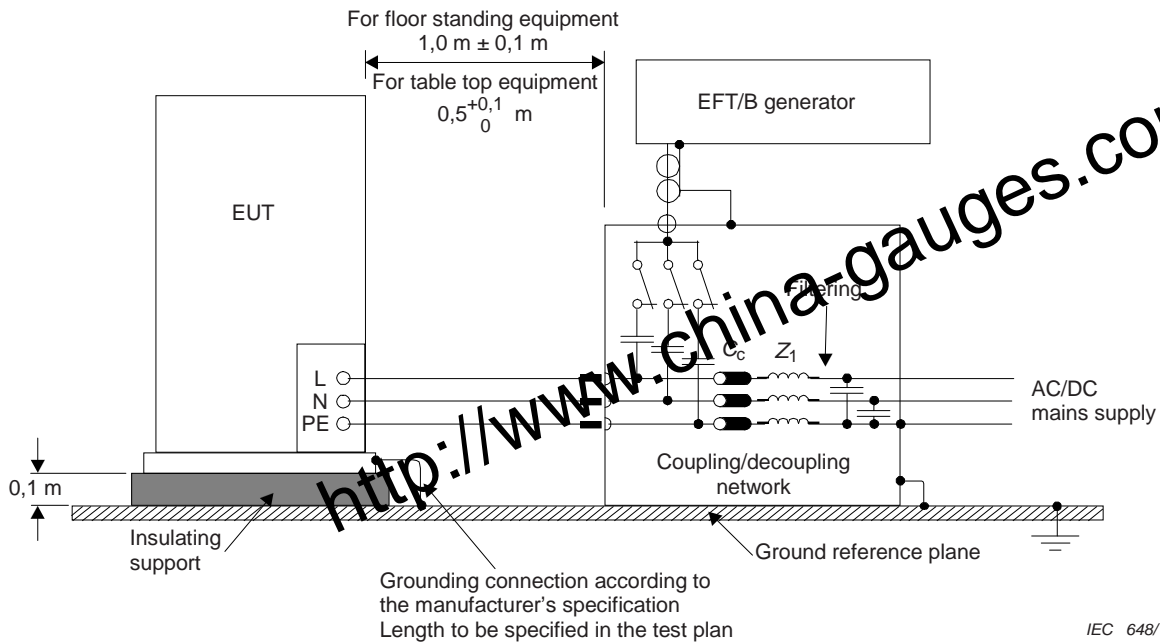
7.3.2.1 General

The method of coupling the test voltage to the EUT is dependent on the type of EUT port (as indicated below).

7.3.2.2 Power ports

An example for the test setup for direct coupling of the EFT/B disturbance voltage via a coupling/decoupling network is given in Figure 14. This is the preferred method of coupling to power ports.

For equipment having a power port with no earth terminal, the test voltage is only applied to L and N lines.



Components

- PE protective earth
- N neutral
- L phase
- Z_1 decoupling inductive
- C_c coupling capacitor

Figure 14 – Example of a test setup for direct coupling of the test voltage to a.c./d.c. power ports for laboratory type tests

If a suitable coupler/decoupler is not available, e.g. for a.c. mains currents >100 A, alternative methods can be employed, as follows:

- in case of common and unsymmetric modes, direct injection using the $(33 \pm 6,6)$ nF capacitors is the preferred coupling mode;
- if direct injection is not practical, the capacitive clamp is used.

7.3.2.3 Signal and control ports

The examples in Figure 11 and Figure 12 show how to use the capacitive coupling clamp for application of the disturbance test voltage to signal and control ports. The cable shall be placed in the centre of the coupling clamp. Non-tested or auxiliary equipment connected may be appropriately decoupled.

7.3.2.4 Earth terminal

The test point on the metallic enclosure of equipment having a power port with earth terminal shall be the terminal of the protective earth conductor.

In case a CDN cannot be used, the test voltage shall be applied to the protective earth (PE) connection through a $(33 \pm 6,6)$ nF coupling capacitor

7.4 Test setup for in situ tests

7.4.1 Overview

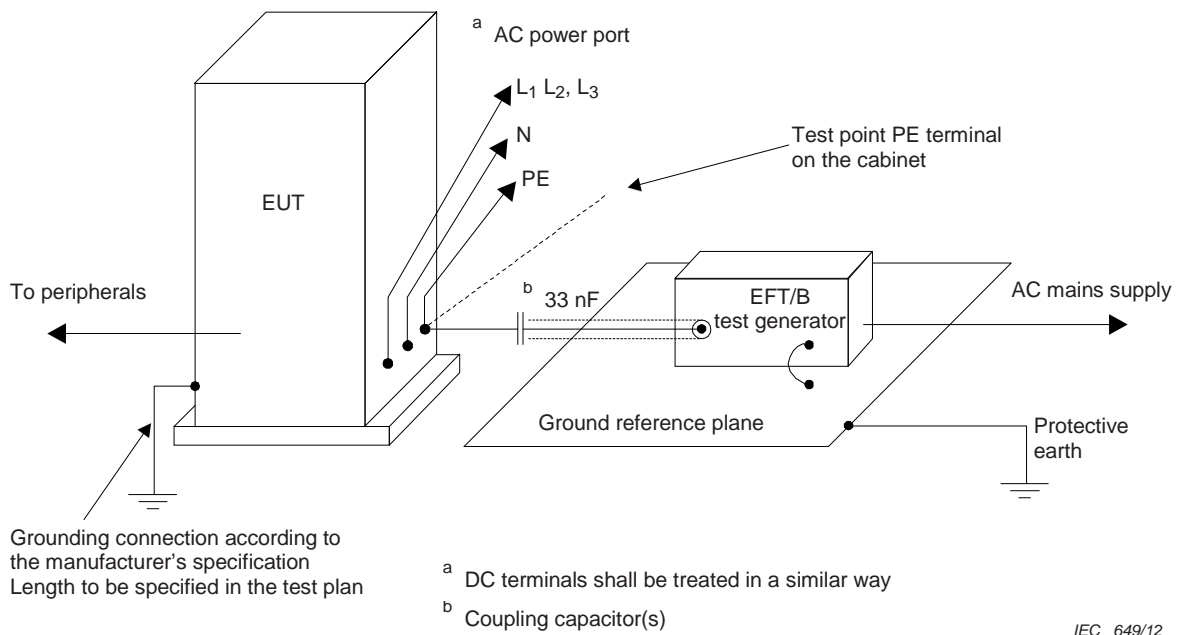
In situ tests may be applied only when agreed between manufacturer and customer. It has to be considered that the test itself may be destructive to the EUT and other co-located equipment may be damaged or otherwise unacceptably affected.

The equipment or system shall be tested in the final installed condition. In situ tests shall be performed without coupling/decoupling networks in order to simulate the actual electromagnetic environment as closely as possible.

If equipment or system other than the EUT is unduly affected during the test, decoupling networks shall be used by agreement between the user and the manufacturer.

7.4.2 Test on power ports and earth ports

The test voltage shall be applied simultaneously between a ground reference plane and the power supply terminals, a.c. or d.c., and the protective or functional earth port on the EUT cabinet (see Figure 15).



Components

- PE protective earth
- N neutral
- L1, L2, L3 phases

Figure 15 – Example for in situ test on a.c./d.c. power ports and protective earth terminals for stationary, floor standing EUT

A ground reference plane as described in 7.3.1 shall be mounted near the EUT and connected to the protective earth conductor at the power mains.

The EFT/B generator shall be located on the ground reference plane and connected to the coupling capacitor(s) by a coaxial cable. The shield of the coaxial cable shall not be

connected at the capacitor end. The length of the connection from the coupling capacitor to the ports on the EUT shall be as short as possible. This connection shall be unshielded but well insulated. Coupling capacitors shall have a value of $(33 \pm 6,6)$ nF. All other connections of the EUT should be in accordance with its functional requirements.

7.4.3 Test on signal and control ports

The capacitive coupling clamp is the preferred method for coupling the test voltage into signal and control ports. The cable shall be placed in the centre of the coupling clamp. If the clamp cannot be used due to mechanical reasons (e.g. size, cable routing), in the cabling, it shall be replaced by a tape or a conductive foil enveloping the lines under test.

An alternative method is to couple the EFT/B generator to the terminals of the lines via discrete (100 ± 20) pF capacitors instead of the distributed capacitance of the clamp or of the foil or tape arrangement.

Earthing of the coaxial cable from the test generator shall be made in the vicinity of the coupling point. Application of the test voltage to the connectors (hot wires) of coaxial or shielded lines is not permitted.

The test voltage should be applied in a way that the shielding protection of the equipment is not reduced (see Figure 16 for the test configuration).

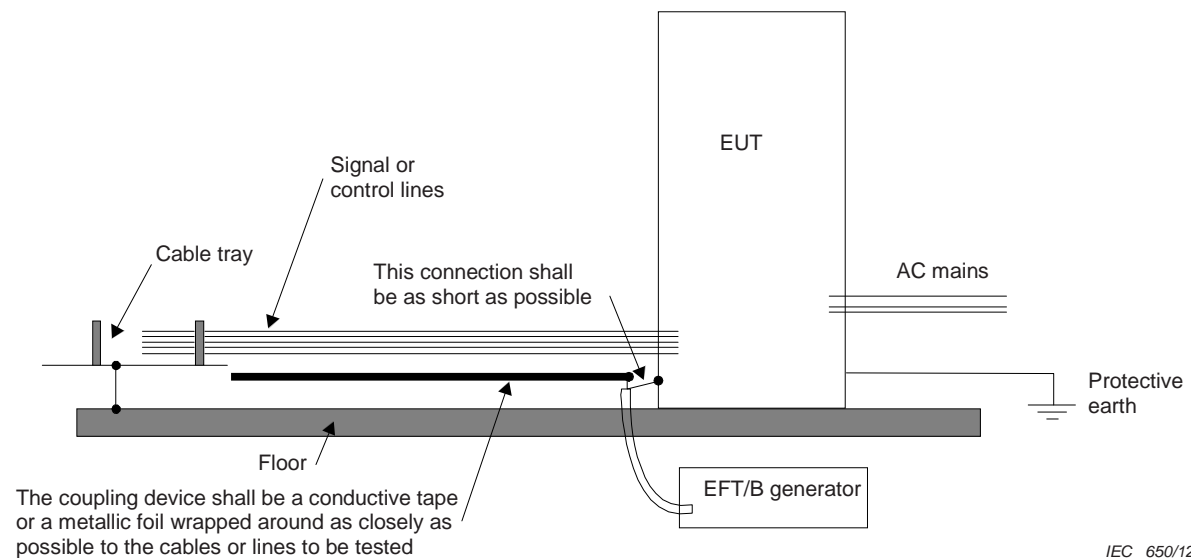


Figure 16 – Example of in situ test on signal and control ports without the capacitive coupling clamp

The test results obtained with the discrete capacitor coupling arrangement are likely to be different from those obtained with the coupling clamp or the foil coupling. Therefore, the test levels specified in Clause 5 may be amended by a product committee in a product standard in order to take significant installation characteristics into consideration.

In the in situ test, it can be agreed between manufacturer and user that external cables can be tested by routing all cables simultaneously in the coupling clamp.

8 Test procedure

8.1 General

The test procedure includes:

- the verification of the test instrumentation according to 7.2.2.
- the verification of the laboratory reference conditions;
- the verification 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 by the committee responsible for the generic or product standard, 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

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

The EUT shall operate in its normal operating conditions.

The test plan shall specify:

- type of test (laboratory or in situ);
- test level;
- coupling mode (common mode, and unsymmetric mode in the case of in-situ testing or when no CDN is available);
- polarity of the test voltage (both polarities are mandatory);
- duration of the test per port (shall not be less than the time necessary for the EUT to be exercised and to respond but in no case it shall be less than 1 min. Product committees may choose other test durations);
- repetition frequency;
- EUT ports to be tested;
- representative operating conditions of the EUT;
- sequence of application of the test voltage to the ports of the EUT;
- auxiliary equipment (AE).

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 the 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, due 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.

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, e.g. brand name, product type, serial number;
- identification of the test equipment, e.g. brand name, product type, serial number;
- any special environmental conditions in which the test was performed, e.g. shielded enclosure;
- any specific conditions necessary to enable the test to be performed;
- drawing and/or pictures of the test setup and EUT arrangement;
- 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;
- all types of cables, including their length, and the interface port of the EUT to which they were connected;
- 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.

Annex A (informative)

Information on the electrical fast transients

A.1 General

The electrical fast transient burst (EFT/B) is generated by the switching of inductive loads. This switching transient is commonly referred to as fast transient and may be described in terms of:

- the duration of the burst (which is predominately determined by the energy stored in the inductance prior to switching);
- the repetition frequency of the individual transients;
- the varying amplitude of the transients composing a burst, determined mainly by the mechanical and electrical characteristics of the switching contact (speed of the contacts in the opening operation, voltage withstand capability of the contacts in their open condition).

Generally, the EFT/B has no unique parameters that depend upon the characteristics of the switching contact or the switched load.

A.2 Spike amplitude

The level of the spikes measured on the conductors of a line may have the same value as galvanic connection of this line with the switching contact. In the case of power supply and some control circuits, this may also be true in the proximity (distance of the order of 1 m) of the contacts. In this case, the disturbance is transferred by induction (e.g. capacitive). The amplitude is a fraction of the level measured at the contacts.

A.3 Rise time

It should be noted that as the distance from the source increases, the waveform is modified due to propagation losses, dispersion, and reflections due to distortions caused by the connected loads. The rise time of 5 ns assumed for the specifications of the test generator is a compromise that takes into account the effect of the attenuation of the high frequency components in the spike propagation.

A shorter rise time, e.g. 1 ns, would give more severe test results, and its appropriateness is mainly related to equipment having short connections in the field with reference to the EFT/B source.

NOTE The rise time of the EFT at the source, for voltage range 500 V to 4 kV or more, is very close to the rise time of an electrostatic discharge (in air), the discharge mechanism being the same.

A.4 Spike duration

The real duration differs significantly from that specified in all editions of the standard. The duration specified here is consistent with the duration of the spikes measured as induced in the victim circuits due to less relevance of the low frequency components of the spikes.

A.5 Spike repetition frequency

The repetition frequency depends on many parameters. For example:

- time constant of the charging circuit (resistance, inductance and distributed capacity of the switched inductive load);
- time constant of the switching circuit, including the impedance of the line connecting this load to the switching contact;
- speed of the contact in the opening action;
- withstanding voltage of the switching contact.

The repetition frequency is therefore variable, and the range of one decade or more is quite common.

NOTE In practice, the repetition frequencies of 5 kHz and 100 kHz are selected for testing as the compromise repetition frequencies because of the need to include in one test the range of the most significant parameters of the EFT/B.

A.6 Number of spikes per burst and burst duration

This (these) parameter(s) depend(s) on the energy stored by the switched inductive load as well as the withstand voltage of the switching contact.

The number of spikes per burst is directly related to the spike repetition frequency and burst duration. From measured results, most of the duration of bursts are very near to 2 ms, with the exception of the mercury wetted relay, the use of which is not as common as for the other types considered here.

NOTE The 0,75 ms duration was chosen as the reference time for testing at 100 kHz. Accordingly, 75 is the resultant number of spikes per burst. When testing at 5 kHz the burst duration is 15 ms.

Annex B (informative)

Selection of the test levels

The test levels should be selected in accordance with the most realistic installation and environmental conditions. These levels are outlined in Clause 5 of this standard.

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.

For testing signal and control ports, the test voltage values are half of the applied voltages on power ports.

Based on common installation practices, the recommended selection of test levels for EFT/B testing according to the requirements of the electromagnetic environment is the following:

a) Level 1: Well-protected environment

The installation is characterized by the following attributes:

- suppression of all EFT/B in the switched power supply and control circuits;
- separation between power supply lines (a.c. and d.c.) and control and measurement circuits coming from other environments belonging to higher severity levels;
- shielded power supply cables with the screens earthed at both ends on the reference ground of the installation, and power supply protection by filtering.

A computer room may represent this environment.

The applicability of this level for testing the equipment is limited to the power supply circuits for type tests, and particularly to the earthing circuits and equipment cabinets for in situ tests.

b) Level 2: Protected environment

The installation is characterized by the following attributes:

- partial suppression of EFT/B in the power supply and control circuits which are switched only by relays (no contactors);
- poor separation of the industrial circuits belonging to the industrial environment from other circuits associated with environments of higher severity levels;
- physical separation of unshielded power supply and control cables from signal and communication cables.

The control room or terminal room of industrial and electrical plants may represent this environment.

c) Level 3: Typical industrial environment

The installation is characterized by the following attributes:

- no suppression of EFT/B in the power supply and control circuits which are switched only by relays (no contactors);
- poor separation of the industrial circuits from other circuits associated with environments of higher severity levels;
- dedicated cables for power supply, control, signal and communication lines;

- poor separation between power supply, control, signal and communication cables;
- availability of earthing system represented by conductive pipes, earth conductors in the cable trays (connected to the protective earth system) and by a ground mesh.

The area of industrial process equipment may represent this environment.

d) Level 4: Severe industrial environment

The installation is characterized by the following attributes:

- no suppression of EFT/B in the power supply and control and power circuits which are switched by relays and contactors;
- no separation of the industrial circuits belonging to the severe industrial environment from other circuits associated with environments of higher severity levels;
- no separation between power supply, control, signal and communication cables;
- use of multi-core cables in common for control and signal lines.

The outdoor area of industrial process equipment where no specific installation practice has been adopted, power plants, the relay rooms of open-air HV substations and gas insulated substations of up to 500 kV operating voltage (with typical installation practice) may represent this environment.

e) Level X: Special situations to be analysed

The minor or major electromagnetic separation of disturbance sources from equipment circuits, cables, lines etc., and the quality of the installations may require the use of a higher or lower environmental level than those described above. It should be noted that equipment lines of a higher environmental level can penetrate a lower severity environment.

Annex C (informative)

Measurement uncertainty (MU) considerations

C.1 General

The reproducibility of EMC tests relies on many factors or influences, that affect the test results. These influences may be categorized as random or systematic effects. 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 an impulse with an oscilloscope by using attenuators). 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.

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.

In immunity tests estimates and uncertainties are evaluated for the parameters of the disturbance quantity (e.g. rise time, peak and pulse width). As such, they describe the degree of agreement of the disturbance quantity with the relevant specifications of this basic standard.

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

Since the effect of the parameters of the disturbance quantity on the EUT is a priori unknown and in most cases the EUT shows a nonlinear behavior, a single estimate and uncertainty number 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 more than one uncertainty budget.

This annex focuses on the uncertainty of calibration for calibration laboratories and test laboratories, which perform their own calibration.

C.2 Uncertainty contributors of EFT/B

Uncertainties can also be specified for the parameters of the disturbance quantity. As such, they describe the degree of agreement of the specified instrumentation with the specifications of this basic standard.

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

- reading of the peak value;

- reading of the 10 % level;
- reading of the 90 % level;
- reading of the 50 % level
- attenuation ratio;
- mismatch chain – oscilloscope;
- termination-attenuator-cable chain;
- oscilloscope horizontal measurement contribution;
- oscilloscope vertical measurement contribution;
- measurement system repeatability (type A);
- variation in test setup (type A);
- calibration of oscilloscope, attenuator.

It shall be recognized that the contributions which apply for calibration and for test may not be the same. This leads to different uncertainty budgets for each process.

C.3 Uncertainty of calibration

C.3.1 General

It is necessary to produce independent uncertainty budgets for each calibration item; that is V_p, t_r, t_w . For an EFT/B test, the disturbance quantity is the pulse energy and spectrum from the EFT generator that is applied to the EUT. As described in Clause C.1, an independent uncertainty budget should be calculated for each of these parameters.

The general approach for pulse MU is described below. Tables C.1 to C.3 give examples of calculated uncertainty budgets for these parameters. The tables include the contributors to the uncertainty budget that are considered most significant for these examples, the details (numerical values, type of distribution, etc.) of each contributor and the results of the calculations required for determining each uncertainty budget.

C.3.2 Rise time of the EFT/B voltage

The measurand is the rise time of the EFT/B voltage across a 50 Ω load and calculated by using the functional relationship

$$t_r = \sqrt{(T_{90\%} - T_{10\%} + \delta R)^2 - T_{MS}^2}$$

where

$$T_{MS} = \frac{\alpha}{B}$$

and

- | | |
|------------|----------------------------------------------------------------------------------|
| $T_{10\%}$ | is the time at 10 % of the peak amplitude; |
| $T_{90\%}$ | is the time at 90 % of the 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 %); |
| B | is –3 dB bandwidth of the measuring system; |
| α | is the coefficient whose value is 360 ± 40 (B in MHz and T_{MS} in ns). |

Table C.1 – Example of uncertainty budget for voltage rise time (t_r)

Symbol	Estimate	Unit	Error bound	Unit	PDF ^a	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
$T_{10\%}$	0,85	ns	0,10	ns	triangular	2,45	0,041	-1,02	1	0,041	ns
$T_{90\%}$	6,1	ns	0,10	ns	triangular	2,45	0,041	1,02	1	0,041	ns
δR	0	ns	0,15	ns	normal ($k = 1$)	1,00	0,150	1,00	1	0,152	ns
A	360	ns-MHz	40	ns-MHz	rectangular	1,73	$23,09 \cdot 10^{-5}$	-2	1/MHz	0,010	ns
B	400	MHz	30	MHz	rectangular	1,73	$17,32 \cdot 10^{-5}$	2	ns/MHz	$6,78 \cdot 10^{-3}$	ns
^a Probability Density Function							$u_c(y) = \sqrt{\sum u_i(y)^2}$		0,16		ns
							$U(y) = 2 u_c(y)$		0,33		ns
							Y		5,33		ns
							Expressed in % of 5,33 ns		6,2		%

$T_{10\%}$, $T_{90\%}$: is the time reading at 10 % or 90 % of the peak amplitude. The error bound is obtained assuming a sampling frequency of 5 GS/s and trace interpolation capability of the oscilloscope (triangular probability density function). Would this not be 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 C.3.5. The readings are assumed to be $T_{10\%} = 0,85$ ns and $T_{90\%} = 6,1$ ns.

T_{MS} : is the calculated rise time of the step response of the measuring system. The coefficient α 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 C.3.6 and Table C.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 voltage probe, a cable and a oscilloscope) by using the following formula:

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

An estimate of 400 MHz and a 30 MHz 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 $T_{90\%}$ to $T_{10\%}$ due to the measuring instrumentation, the layout of the measurement setup and the EFT/B 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

$$s(q_k) = \sqrt{\frac{1}{n-1} \sum_{j=1}^n (q_j - \bar{q})^2}$$

where \bar{q} is the arithmetic mean of the q_j values. An error bound $s(q_k) = 150$ ps (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

NOTE For the voltage across a 1 k Ω load, the budget may be similarly obtained. In that case the bandwidth of the measuring system with the 1 k Ω transducer is used in place of that with the 50 Ω transducer.

C.3.3 Peak voltage of the EFT/B

The measurand is the peak voltage of the EFT/B across a 50 Ω load and calculated by using the functional relationship

$$V_p = \frac{V_{PR}(1 + \delta R + \delta V)}{1 - \left(\frac{\beta}{B}\right)^2} A$$

where

- V_{PR} is the voltage peak reading;
 A is the DC attenuation of the voltage probe;
 δR is the correction for non-repeatability (relative);
 δV is the DC vertical accuracy of the oscilloscope (relative);
 B is the –3 dB bandwidth of the measuring system;
 β is the coefficient whose value is (7,0 ± 0,8) MHz.

Table C.2 – Example of uncertainty budget for EFT/B peak voltage value (V_p)

Symbol	Estimate	Unit	Error bound	Unit	PDF ^a	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit
V_{PR}	3,75	V	0,007 3	V	triangular	2,45	0,003 0	1 000	1	2,99	V
A	1 000	1	50	1	rectangular	1,73	28,9	3,75	V	108	V
δR	0	1	0,03	1	normal ($k = 1$)	1,00	0,030	3 751	V	112,5	V
δV	0	1	0,02	1	rectangular	1,73	0,012	3 751	V	43,3	V
β	7,0	MHz	0,8	MHz	rectangular	1,73	0,462	0,328	V/MHz	0,152	V
B	400	MHz	30	MHz	rectangular	1,73	17,32	–0,005 8	V/MHz	0,099 5	V
^a Probability Density Function							$u_c(y) = \sqrt{\sum u_i(y)^2}$			0,162	kV
							$U(y) = 2 u_c(y)$			0,32	kV
							y			3,75	kV
							Expressed in % of 3,75 kV			8,6	%

V_{PR} : is the voltage peak reading. The error bound is obtained assuming that the oscilloscope has 8-bit vertical resolution with interpolation capability (triangular probability density function).

A : is the DC attenuation of the voltage probe. An estimated value of 1 000 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 voltage. 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 oscilloscope 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 C.3.7). The

interval $7,0 \pm 0,8$ is representative of a wide class of systems, each having a different shape of the impulse response.

B: see C.3.2, same meaning and same values both for the estimate and error bound.

For the voltage across a 1 kΩ load, the budget may be similarly obtained. In that case the bandwidth of the measuring system with the 1 kΩ transducer is used in place of that with the 50 Ω transducer.

C.3.4 Pulse width of the EFT/B voltage

The measurand is the pulse width of the EFT/B voltage across a 50 Ω load and calculated by using the functional relationship

$$t_w = (T_{50\%,F} - T_{50\%,R} + \delta R) \left[1 - \left(\frac{\beta}{B} \right)^2 \right]$$

where

- $T_{50\%,R}$ is the time at 50 % of peak amplitude at the rising edge of the EFT/B;
- $T_{50\%,F}$ is the time at 50 % of peak amplitude at the falling edge of the EFT/B;
- δR is the correction for non-repeatability;
- B is the -3 dB bandwidth of the measuring system;
- β is the coefficient whose value is $(7,0 \pm 0,8)$ MHz.

Table C.3 – Example of uncertainty budget for EFT/B voltage pulse width (t_w)

Symbol	Estimate	Unit	Error bound	Unit	PDF ^a	Divisor	$u(x_i)$	c_i	Unit	$u_i(y)$	Unit	
$T_{50\%,R}$	3,5	ns	0,10	ns	triangular	2,45	0,041	-1,00	ns	0,040 8	ns	
$T_{50\%,F}$	54,5	ns	0,10	ns	triangular	2,45	0,041	1,00	ns	0,040 8	ns	
δR	0	ns	1,5	ns	normal ($k = 1$)	1,00	1,50	1,00	ns	1,50	ns	
β	7,0	MHz	0,8	MHz	rectangular	1,73	0,462	-0,004 5	ns/MHz	0,002 1	ns	
B	400	MHz	30	MHz	rectangular	1,73	17,32	$8,0 \cdot 10^{-5}$	ns/MHz	0,001 4	ns	
^a Probability Density Function							$u_c(y) = \sqrt{\sum u_i(y)^2}$			1,502	ns	
							$U(y) = 2 u_c(y)$				3,00	ns
							Y				51,0	ns
							Expressed in % of 51,0 ns				5,9	%

$T_{50\%,R}, T_{50\%,F}$: is the time reading at 50 % of the peak amplitude on the rising or falling edge of the EFT/B voltage. The error bound is obtained assuming a sampling frequency of 5 GS/s (the same as in C.3.2) and trace interpolation capability of the oscilloscope (triangular probability density function). Would this not be the case, a rectangular probability density function should be assumed. Only the contributor to MU due to sampling rate is considered here. For additional contributors, see C.3.5. The readings are assumed to be $T_{50\%,R} = 3,5$ ns and $T_{50\%,F} = 54,5$ ns.

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 EFT/B 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 $s(q_k) = 1,5 \text{ ns}$ (1 standard deviation of a normal probability density function) and an estimate of 0 ns are assumed.

β : see C.3.3, same meaning and same values both for the estimate and error bound.

B : see C.3.2, same meaning and same values both for the estimate and error bound.

For the voltage across a 1 k Ω load, the budget may be similarly obtained. In that case, the bandwidth of the measuring system with the 1 k Ω transducer is used in place of that with the 50 Ω transducer.

C.3.5 Further MU contributions to the measurements

Sampling rate: usually, the value of this uncertainty is the half of the inverse of the oscilloscope sampling frequency. The distribution may be assumed as triangular ($k = 2,45$) if trace interpolation is performed to obtain the time for a given trace level (see the oscilloscope manual). Would this not be the case, rectangular distribution with $k = 1,73$ has to be assumed.

Time base error and jitter: the oscilloscope specifications may be taken as uncertainties, with rectangular distributions. 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) triangular distribution is used, otherwise rectangular distribution is used. This contribution is often negligible.

C.3.6 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.

$$t_{rd} = \sqrt{t_r^2 + T_{MS}^2} \quad (\text{C.1})$$

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 (C.1) is based on the following definition of the rise time

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

where

$h_0(t)$ is the impulse response of the measuring system having normalized area, i.e.

$$\int_0^{\infty} h_0(t) dt = 1;$$

and T_s is the delay time given by

$$T_s = \int_0^{\infty} t h_0(t) dt \quad (C.3)$$

Definition (C.2) is much easier to handle, from the mathematical point of view, than the usual one based on the 10 % and 90 % threshold levels. Nevertheless, in the technical applications, the 10 % to 90 % rise times are usually combined through Equation (C.1). Given the bandwidth of the system the two definitions lead to comparable rise times. Indeed, if we define

$$\alpha = T_{MS} B \quad (C.4)$$

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 C.4. It is evident from Table C.4 that it is not possible to identify a unique value of α since α depends both on the adopted definition of the rise time (e.g. based on thresholds or on equation (C.2)) 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 1, that is 360×10^{-3} . Further, it can be assumed that, if no information is available about the measuring system apart from its bandwidth, any value of α between 321×10^{-3} and 399×10^{-3} is equally probable. Differently stated, α is assumed to be a random variable having a rectangular probability density function with lower and upper bounds 321×10^{-3} and 399×10^{-3} , respectively. The standard uncertainty of α quantifies both

- a) the indifference to the mathematical model adopted for the definition of the rise time, and
- b) the indifference to the shape of the impulse response of the system.

Table C.4 – α factor (Equation (C.4)) of different unidirectional impulse responses corresponding to the same bandwidth of the system B

Values of α are multiplied by 10^3	Gaussian	I order	II order (critical damping)	Rectangular	Triangular
α : using Equation (C.2)	332	399	363	321	326
α : 10 % to 90 %	339	350	344	354	353

C.3.7 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

$$v_{out}(t) = \int_0^t v_{in}(\tau) h(t - \tau) d\tau \quad (C.5)$$

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 DC attenuation of the measuring system. The input waveform can be approximated by its Taylor series expansion about the time instant t_p when the input reaches its peak value V_p .

$$v_{in}(t) = V_p + \frac{v_{in}''(t_p)}{2}(t-t_p)^2 + \frac{v_{in}'''(t_p)}{6}(t-t_p)^3 + \dots \quad (C.6)$$

Note that the first order term is missing from (C.6) since $v_{in}'(t_p) = 0$. 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 (C.6) into (C.5) and after simplifications, valid when the bandwidth of the measuring system is large with respect to the bandwidth of the input signal (so that the power series terms whose order is greater than two are negligible), we obtain

$$V_{pd} = \frac{V_p}{A} \left[1 - \left(\frac{\beta}{B} \right)^2 \right] \quad (C.7)$$

where

V_{pd} is the output impulse peak,

A is the DC attenuation of the measuring system and

$$\beta = \alpha \sqrt{\frac{|v_{in}''(t_p)|}{4\pi V_p}} \quad (C.8)$$

Note that the parameter β depends on the second derivative of the standard input waveform and on the parameter α defined and derived in C.3.6. Since the mathematical expression for the standard EFT/B waveform is given in 6.2.2, the value of β can be numerically calculated and its value is $(7,0 \pm 0,8)$ MHz.

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 DC attenuation A . Therefore

$$V_p t_w = A V_{pd} t_{wd} \quad (C.9)$$

where t_{wd} is the output impulse width.

Hence

$$t_{wd} = \frac{V_p}{A V_{pd}} t_w = \frac{1}{1 - \left(\frac{\beta}{B} \right)^2} t_w \quad (C.10)$$

C.4 Calibration of a coupling device

The calibration of EFT/B parameters at the output of coupling / decoupling devices uses the same equipment (attenuators, oscilloscopes, etc...) plus some adapters to connect the measuring equipment to the specific terminals of the coupling / decoupling device.

NOTE Due to the very poor high frequency behaviour of these adapters, it is very difficult to perform reliable high frequency measurements of these adapters and therefore properly determine the uncertainty contributions.

The following procedure is recommended to qualify the adapters:

- DC measurements of the ground connection: it shall be smaller than 0,4 Ω ;
- DC measurements of the inner conductor: it shall be smaller than 0,4 Ω ;
- DC measurements between the conductor and the ground. This shall have “infinite” value; enough insulation shall be provided to hold the applied EFT/B (2 kV or more);
- characterise the influence of these adapters. For this purpose, establish a reference, by connecting a 50 Ω coaxial termination to the coaxial EFT/B generator output (not to the coupling/decoupling network output) and measure the pulse parameters. Then insert between the generator output and the 50 Ω termination 2 adapters, connected face to face and measure the pulse parameters again. The value of pulse parameters with and without the adaptor pair in the line is estimated on a sufficient number of pulses. The difference between the measured pulse parameters (which represent the insertion losses of the adapters which may be compensated) is finally a measure of the additional uncertainty caused by the adapters. Estimated values are 4 % for voltage amplitudes, 60 ps for rise time, and 4 ns for pulse duration;
- finally, consider the uncertainty of the burst adaptor being equal to the worst observed difference (rectangular distribution assumed). Despite the fact that the influence of the adapters has been obtained using 2 pieces of them, the division by 2 of the observed difference (with and without adapters) is not recommended for the moment.

C.5 Application of uncertainties in the EFT/B generator compliance criterion

Generally, in order to be sure the generator is within its specifications, the calibration results should be within the specified limits of this standard (tolerances are not reduced by MU).

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