IEC 61000-4-6

Edition 5.0 2023-06

INTERNATIONAL STANDARD

BASIC EMC PUBLICATION

Electromagnetic compatibility (EMC) –
Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields

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ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields

FOREWORD

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IEC 61000-4-6 has been prepared by subcommittee 77B: High frequency phenomena, of IEC technical committee 77: Electromagnetic compatibility. It is an International Standard.

It forms Part 4-6 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107.

This fifth edition cancels and replaces the fourth edition published in 2013. This edition constitutes a technical revision.

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

a) selection of injection devices revised;
b) need of AE impedance check for clamp injection removed and Annex H deleted;
c) saturation check revised;
d) new Annex H on testing with multiple signals;

e) level-setting only with feedback loop.

The text of this International Standard is based on the following documents:

Draft	Report on voting
77B/863/FDIS	77B/865/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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 document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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

IMPORTANT – The "colour inside" logo on the cover page of this document 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 (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 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 conducted disturbances induced by radio-frequency fields.

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields

1 Scope

This part of IEC 61000 relates to the conducted immunity requirements of electrical and electronic equipment to electromagnetic disturbances coming from intended radio-frequency (RF) transmitters in the frequency range 150 kHz up to 80 MHz.

NOTE 1 Product committees might decide to use the methods described in this document also for frequencies up to 230 MHz (see Annex B) although the methods and test instrumentation are intended to be used in the frequency range up to 80 MHz.

Equipment not having at least one conducting wire or cable (such as mains supply, signal line or earth connection) which can couple the equipment to the disturbing RF fields is excluded from the scope of this document.

NOTE 2 Test methods are specified in this part of IEC 61000 to assess the effect that conducted disturbing signals, induced by electromagnetic radiation, have on the equipment concerned. The simulation and measurement of these conducted disturbances are not adequately exact for the quantitative determination of effects. The test methods specified are structured for the primary objective of establishing adequate repeatability of results at various facilities for quantitative analysis of effects.

The object of this document is to establish a common reference for evaluating the functional immunity of electrical and electronic equipment when subjected to conducted disturbances induced by RF fields. The test method in this document describes a consistent method to assess the immunity of an equipment or system against a specified phenomenon.

NOTE 3 As described in IEC Guide 107, this document 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 should be applied or not, and if applied, they are responsible for determining the appropriate test levels and performance criteria.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CISPR 16-1-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Coupling devices for conducted disturbance measurements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
artificial hand
AH
electrical network simulating the impedance of the human body under average operational conditions between a hand-held electrical appliance and earth

Note 1 to entry: The construction should be in accordance with CISPR 16-1-2.

[SOURCE: IEC 60050-161:1990, 161-04-27, modified – the note has been added.]

3.2
auxiliary equipment
AE
equipment necessary to provide the equipment under test (EUT) with the signals required for normal operation

Note 1 to entry: Auxiliary equipment can be useful for monitoring the EUT.

3.3
clamp injection
method of injecting signals onto cables using a clamp injection device

3.4
clamp injection device
clamp-on signal injecting device that is either a current clamp or an electromagnetic clamp

3.4.1
current clamp
transformer, the secondary winding of which consists of the cable into which the injection is made

3.4.2
electromagnetic clamp
EM clamp
injection device with combined capacitive and inductive coupling

3.5
common-mode impedance
ratio of the common-mode voltage and the common-mode current at a certain port

Note 1 to entry: This common-mode impedance can be determined by applying a unity common-mode voltage between the terminal(s) or screen of that port and a reference plane (point). The resulting common-mode current is then measured as the vectoral sum of all currents flowing through these terminal(s) or screen (see also Figure 15a) and Figure 15b)).

3.6
coupling factor
ratio determined by the open-circuit voltage (e.m.f.) obtained at the EUT port of the coupling (and decoupling) device divided by the open-circuit voltage obtained at the output of the test generator

3.7
coupling network
coupling device
electrical circuit or device for transferring energy from one circuit to another with a specified impedance

Note 1 to entry: Coupling and decoupling devices can be integrated into one box (coupling and decoupling network (CDN)) or they can be in separate networks.

3.8
coupling/decoupling network
CDN
electrical circuit incorporating the functions of both the coupling and decoupling networks

3.9
decoupling network
decoupling device
electrical circuit or device for preventing test signals applied to the EUT from affecting other devices, equipment or systems that are not under test

3.10
test generator
generator (RF generator, modulation source, attenuators, broadband power amplifier and filters) capable of generating the required test signal

SEE: Figure 4.

3.11
electromotive force
e.m.f.
voltage at the terminals of the ideal voltage source in the representation of an active element

3.12
measurement result
U_{mr}
voltage reading of the measurement equipment

3.13
voltage standing wave ratio
VSWR
ratio of a maximum to an adjacent minimum voltage magnitude along the line

4 General

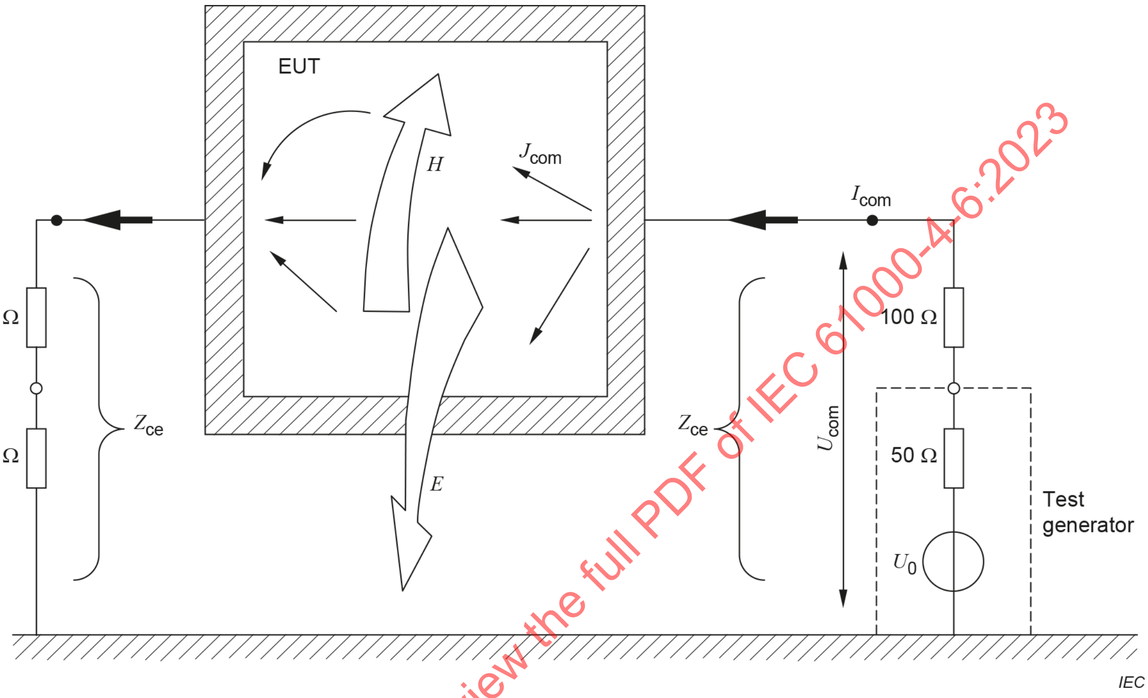
The source of disturbance covered by this document is basically an electromagnetic field, coming from intended RF transmitters, that can act on the whole length of cables connected to installed equipment. The dimensions of the disturbed equipment, mostly a sub-part of a larger system, are assumed to be small compared with the wavelengths of the interfering signals. The leads entering and exiting the EUT (e.g. mains, communication lines, interface cables) behave as passive receiving antenna networks and signal conduction paths for both intentional and unintentional signals.

Between those cable networks, the susceptible equipment is exposed to currents flowing "through" the equipment. Cable systems connected to an equipment are assumed to be in resonant mode ($\lambda/4$, $\lambda/2$ open or folded dipoles) and as such are represented by coupling and decoupling devices having a common-mode impedance of 150 Ω with respect to a reference ground plane. For the method described herein, the EUT is connected between two 150 Ω common-mode impedance connections: one providing an RF source and the other providing a return path for the current.

This test method subjects the EUT to a source of disturbance comprising electric and magnetic fields, simulating those coming from intentional RF transmitters. These disturbing fields (E and H) are approximated by the electric and magnetic near-fields resulting from the voltages and currents caused by the test setup as shown in Figure 1.

The use of coupling and decoupling devices to apply the disturbing signal to one cable at a time, while keeping all other cables nonexcited (see Figure 2), can only approximate the real situation where disturbing sources act on all cables simultaneously, with a range of different amplitudes and phases.

Coupling and decoupling devices are specified in 6.2. Any coupling and decoupling device fulfilling these characteristics can be used. The CDNs in Annex C are only examples of commercially available networks.



Z_{ce} Common-mode impedance of the CDN, Z_{ce} = 150 Ω

U_0 Test generator source voltage (e.m.f.)

U_{com} Common-mode voltage between EUT and reference plane

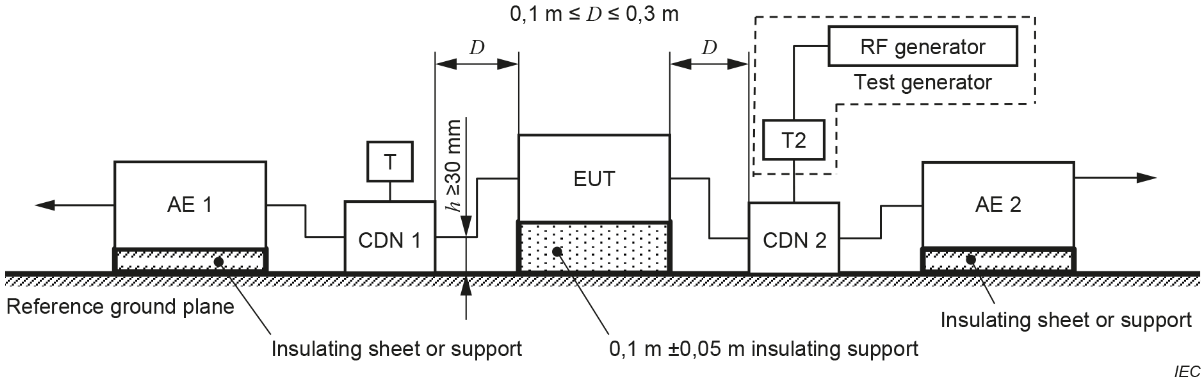
I_{com} Common-mode current through the EUT

J_{com} Current density on conducting surface or current on other conductors of the EUT

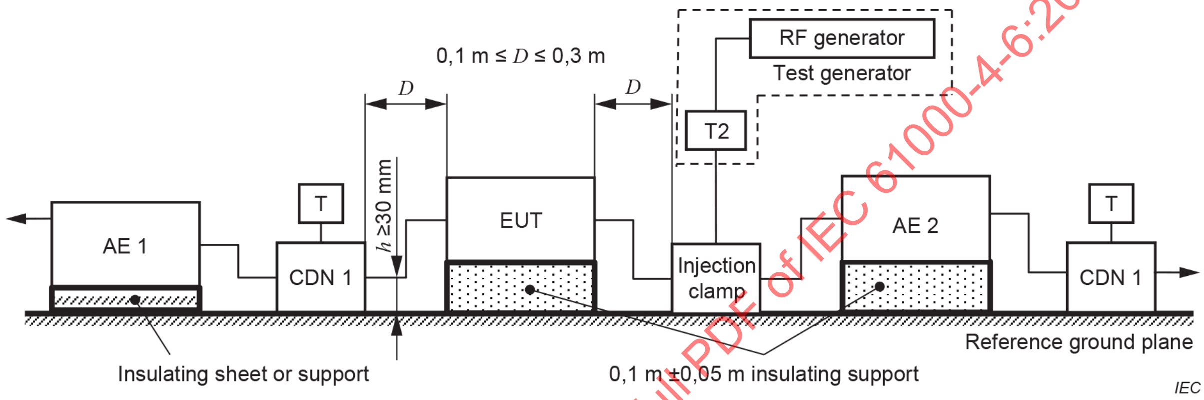
E, H Electric and magnetic fields

NOTE The 100 Ω resistors are included in the CDNs. The left input is loaded by a (passive) 50 Ω load and the right input is loaded by the source impedance of the test generator.

Figure 1 – Diagram showing EM fields near the EUT due to common-mode currents on its cables



a) Schematic setup for immunity test used for CDN



b) Schematic setup for immunity test used for injection clamp

T:	Termination 50 Ω
T2:	Attenuator (6 dB)
CDN:	Coupling and decoupling network
Injection clamp:	Current clamp or EM clamp
Insulating sheet or support:	A non-conductive coating, foot, roller and/or caster may be used as an alternative to an insulating support. The height shall be as specified. The height of the insulating sheet or support under a decoupled AE need not be specified

Figure 2 – Schematic setup for immunity test to RF conducted disturbances

5 Test levels

According to this document, tests are required for induced disturbances caused by electromagnetic fields coming from intentional RF transmitters in the frequency range 150 kHz to 80 MHz.

The open circuit test levels (e.m.f.) of the unmodulated disturbing signal, expressed in RMS (root mean square), are specified in Table 1.

Table 1 – Test levels

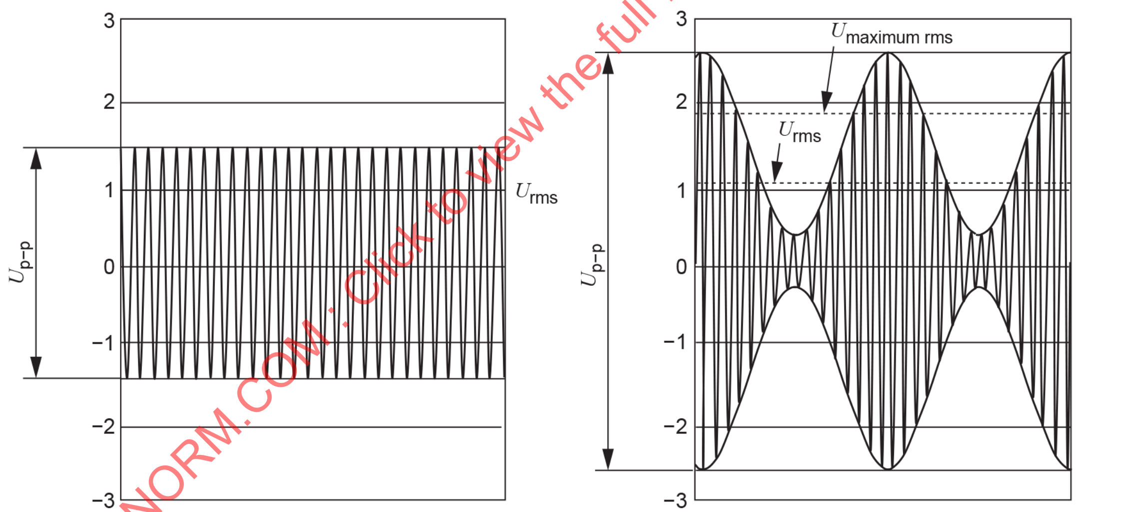
Frequency range 150 kHz to 80 MHz		
Level	**Voltage level (e.m.f.)**	
	U_0 **V**	U_0 **dB(μV)**
1	1	120
2	3	129,5
3	10	140
X [a]	Special	

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

The test levels are set at the EUT port of the coupling devices (see 6.4). For testing of the equipment, this signal is 80 % amplitude modulated with a 1 kHz sine wave to simulate actual threats. The effective amplitude modulation is shown in Figure 3. Annex C provides guidance for selecting test levels.

NOTE 1 IEC 61000-4-3 also specifies test methods for establishing the immunity of electrical and electronic equipment against radiated electromagnetic energy. It covers frequencies above 80 MHz. Product committees can decide to choose a lower or higher transition frequency than 80 MHz (see Annex B).

NOTE 2 Product committees can select alternative modulation schemes.



a) Unmodulated RF signal
U_{p-p} = 2,82 V
U_{rms} = 1,00 V

b) Modulated RF signal 80 % AM
U_{p-p} = 5,09 V
U_{rms} = 1,15 V
$U_{maximum\ rms} = U_{unmodulated\ rms} \times (100 + m) / 100 = 1,8$ V

IEC

Figure 3 – Example of unmodulated and modulated RF signal

6 Test equipment and level adjustment procedure

6.1 Test generator

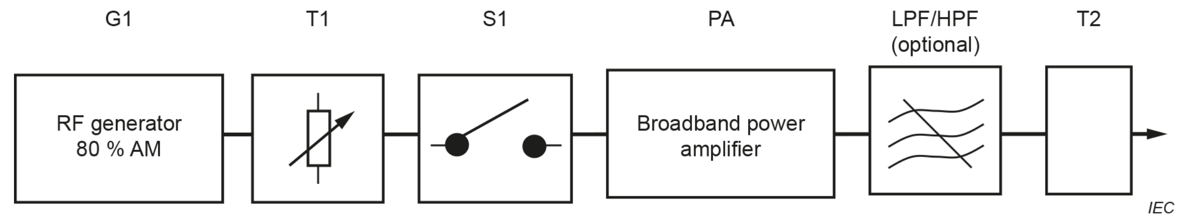
The test generator includes all equipment and components for supplying the input port of each coupling device with the disturbing signal at the required signal level at the appropriate injection point. A typical arrangement comprises the following items which can be separate or integrated into one or more test instruments (see 3.10, Figure 4, and Figure 5):

- RF generator(s), G1, capable of covering the frequency band of interest and of being amplitude modulated by a 1 kHz sine wave with a modulation depth of 80 %. They shall have manual control (e.g. frequency, amplitude, modulation index) or in the case of RF synthesizers, they shall be programmable with frequency-dependent step sizes and dwell times;
- attenuator T1, (typically 0 dB to 40 dB) of adequate frequency rating to control the disturbing test source output level. T1 can be included in the RF generator and is optional;
- RF switch S1, by which the disturbing test signal can be switched on and off when measuring the immunity of the EUT. S1 can be included in the RF generator and is optional;
- broadband power amplifier(s), PA, might be necessary to amplify the signal if the output power of the RF generator is insufficient;
- low-pass filters (LPFs) or high-pass filters (HPFs), or both, can be used to avoid interference caused by (higher order or sub-) harmonics with some types of EUT, for example RF receivers. When required, they shall be inserted between the broadband power amplifier PA and the attenuator T2;
- attenuator T2, fixed attenuation (6 dB ± 0,5 dB), with sufficient power ratings. T2 is provided to reduce the VSWR at the output of the power amplifier. Larger attenuation values may be used.

The characteristics of the test generator are specified in Table 2.

Table 2 – Characteristics of the test generator

Nominal output impedance	50 Ω
Harmonics and distortion	Within 150 kHz and 80 MHz, any spurious signal shall be at least 15 dB below the carrier level, measured directly at the output of the test generator.
Amplitude modulation	Internal or external, $m = \left(80\ {}^{+5}_{-20}\right)\ \%$, with $m = 100 \times \frac{U_{\text{pp,max}} - U_{\text{pp,min}}}{U_{\text{pp,max}} + U_{\text{pp,min}}}$ 1 kHz ± 0,1 kHz sine wave
Output level	Sufficiently high to cover test level (see also Annex E).
NOTE The harmonics and distortion are measured in continuous wave (CW) at 1,8 times the test level without modulation.	



G1	RF generator	T1	Variable attenuator
PA	Broadband power amplifier	T2	Attenuator (see 6.1)
LPF/HPF	Low pass filter and/or high pass filter (optional)	S1	RF switch

Figure 4 – Test generator setup

6.2 Coupling and decoupling devices

6.2.1 General

Coupling and decoupling devices shall be used for appropriate coupling of the disturbing signal (over the entire frequency range, with a defined common-mode impedance at the EUT port) to the various cables connected to the EUT and for preventing applied test signals from affecting other devices, equipment and systems that are not under test.

The coupling and decoupling devices can be combined into one box (e.g. CDN) or can consist of several parts (e.g. current clamp and decoupling clamp).

The preferred coupling and decoupling devices are the CDNs, for reasons of test reproducibility and protection of the AE. The main coupling and decoupling device parameter, the common mode impedance seen at the EUT port, is specified in Table 3. If CDNs are not applicable, for example the attenuation of the CDN adversely affects the intentional operation of the EUT, or not available on the market, other injection methods can be used. Rules for selecting the appropriate injection method are specified in 7.4. Other injection methods, due to their electrical properties, are unlikely to meet the parameters of Table 3.

Table 3 – Main parameter of the combination of the coupling and decoupling device

	Frequency band	
Parameter	0,15 MHz to 24 MHz	24 MHz to 80 MHz
$\lvert Z_{ce} \rvert$	150 Ω ± 20 Ω	150^{+60}_{-45} Ω
Neither the argument of Z_{ce} nor the decoupling factor between the EUT port and the AE port are specified separately. These factors are embodied in the requirement that the tolerance of $\lvert Z_{ce} \rvert$ shall be met with the AE port open or short-circuited to the reference ground plane		

NOTE Details regarding clamps are specified in Annex A.

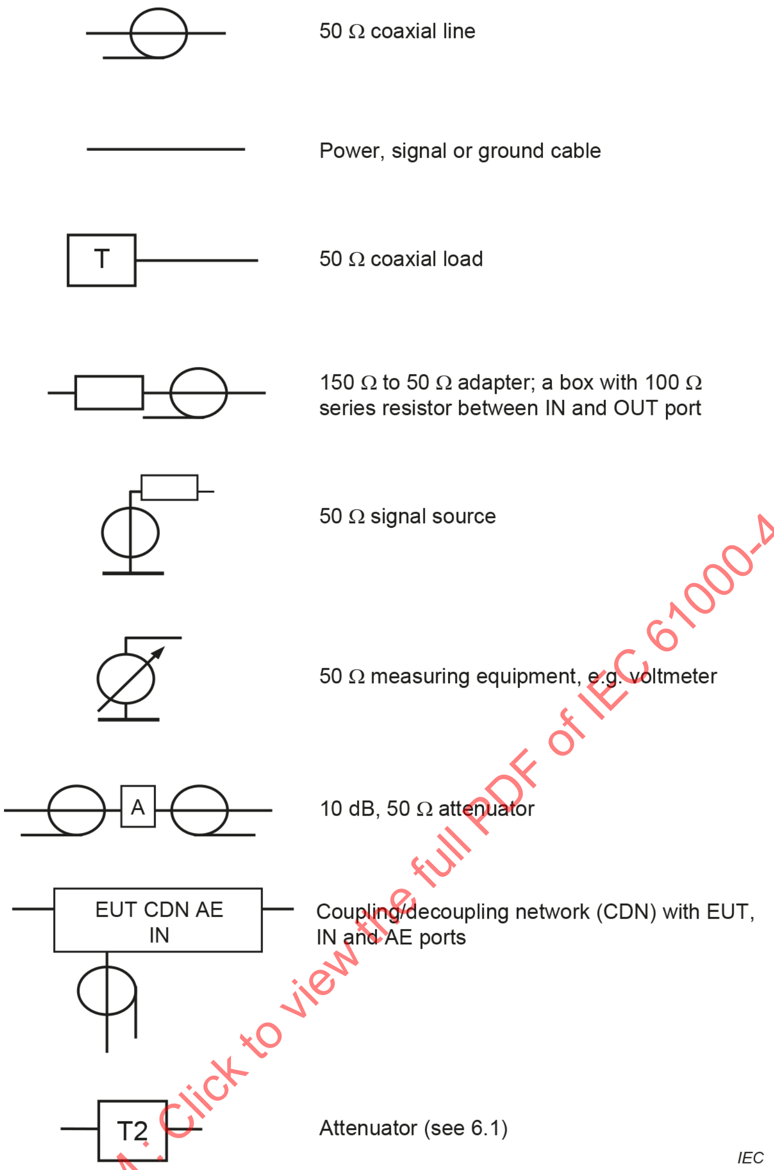


Figure 5 – Principle of coupling and decoupling – Symbols used for the indicated setup principles

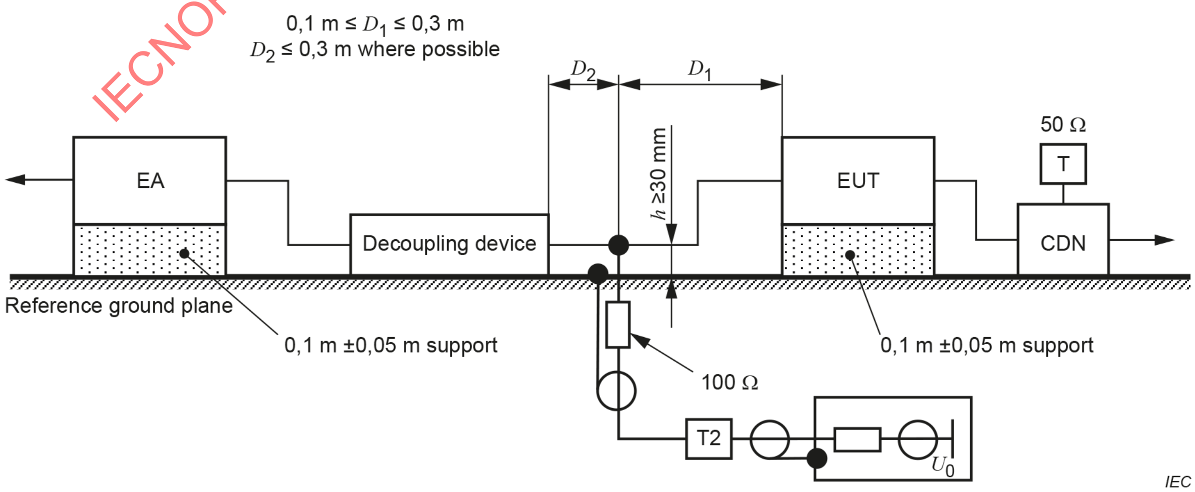


Figure 6 – Principle of coupling and decoupling – Principle of direct injection to screened cables

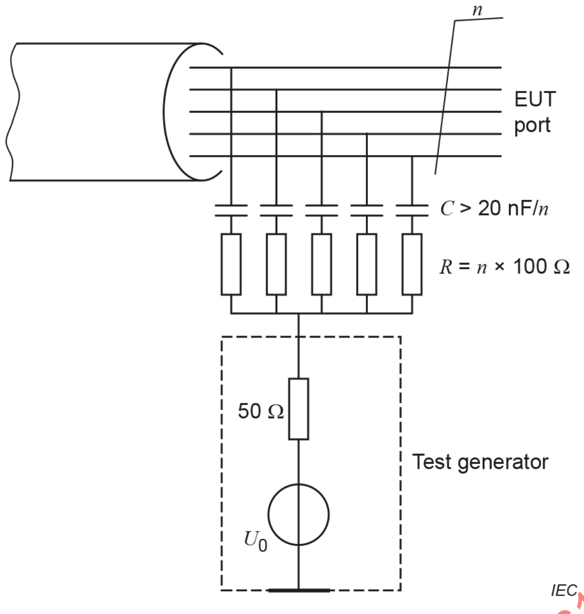
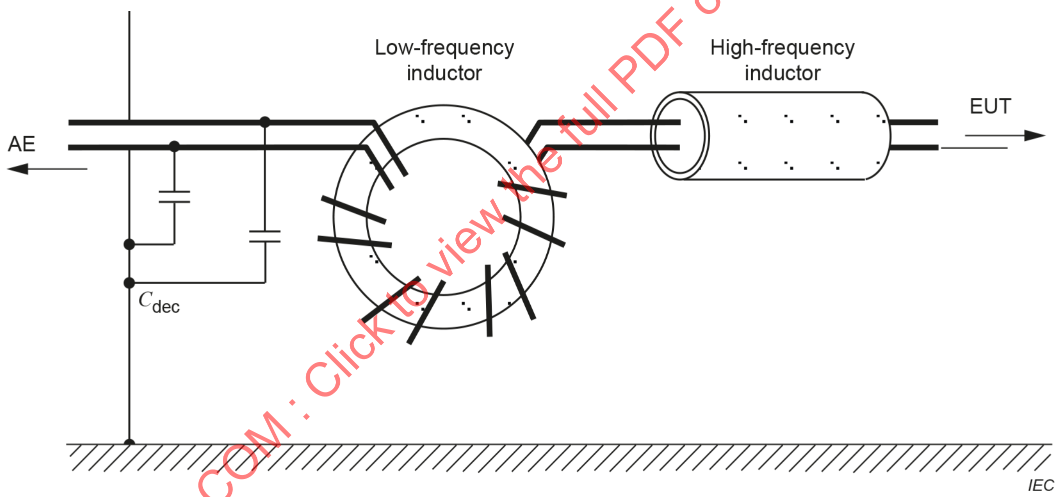


**Figure 7 – Principle of coupling and decoupling –
Principle of coupling to unscreened cables according to the CDN method**



Example: Typically C_{dec} = 47 nF (only on unscreened cables), $L_{(150\ kHz)}$ ≥ 280 µH

Low frequency inductor: 17 turns on a ferrite toroid material: NiZn, μ_R = 1 200

High frequency inductor: 2 to 4 ferrite toroids (forming a tube), material: NiZn, μ_R = 700

Figure 8 – Principle of coupling and decoupling – Principle of decoupling

6.2.2 Coupling/decoupling networks (CDNs)

6.2.2.1 General

These networks comprise the coupling and decoupling circuits in one box. Typical concepts of the CDNs are shown in Figure 7 and Figure 8. Table 4 summarizes the usage of the different types of CDNs as specified in Annex D. The CDNs selected shall not unduly affect the functional signals. Constraints on such effects may be specified in the product standards.

Guidance is given in 6.2.2.2 to 6.2.2.5 for the selection of CDNs. CDNs shall be selected to match the number of wires in the EUT port to be tested, for example for a port with three data lines a CDN-AF3 shall be used.

NOTE Attention is drawn to potential non-linear behaviour of CDNs containing non-linear devices (e.g. clipping devices).

Table 4 – Usage of CDNs

Line type	Examples	CDN type
Power supply (AC and DC) and earth connection	AC mains, DC in industrial installations, earth connection	CDN-Mx (see Figure D.2)
Screened cables	Coaxial cables, cables used for LAN and USB connections, cables for audio systems	CDN-Sx (see Figure D.1)
Unscreened balanced lines	ISDN lines, telephone lines	CDN-Tx (see Figure D.4, Figure D.5, Figure D.7 and Annex H)
Unscreened unbalanced lines	Any line not belonging to other groups	CDN-AFx or CDN-Mx (see Figure D.3 and Figure D.6)

6.2.2.2 CDNs for power supply lines

CDNs are recommended for all power supply connections. However, for high-power (current ≥ 16 A) or complex supply systems (multi-phase or various parallel supply voltages), other injection methods may be selected.

The disturbing signal shall be coupled to the supply lines, using type CDN-M1 (single wire), CDN-M2 (two wires) or CDN-M3 (three wires), or equivalent networks (see Annex D). Similar networks can be specified for a three-phase mains system. The coupling circuit is shown in Figure 7.

NOTE The performance of the CDN can be degraded by saturation of the magnetic material due to current drawn by the EUT, especially when using CDN-M1. This can be avoided if the magnetizing effect of the forward current is cancelled by that due to the return current.

WARNING — The capacitors used within the CDNs bridge live parts. As a result, high leakage currents can occur and safety connections from the CDN to the reference ground plane are mandatory (in some cases, these connections might be provided by the construction of the CDN).

6.2.2.3 CDNs for unscreened balanced lines

For coupling and decoupling disturbing signals to an unscreened cable with balanced lines, a CDN-T2, CDN-T4 or CDN-T8 shall be used as a CDN. Figure D.4, Figure D.5 and Figure D.7 show these possibilities:

– CDN-T2 for a cable with one symmetrical pair (two wires);
– CDN-T4 for a cable with two symmetrical pairs (four wires);
– CDN-T8 for a cable with four symmetrical pairs (eight wires).

The number of symmetrical pairs is determined by the cable connected to the port.

Other CDN-Tx networks may be used if they are suitable for the intended frequency range and satisfy the requirements of 6.2.1. For example, the differential-to-common-mode conversion loss of the CDNs should have a larger value than the specified conversion ratio of the cable to be installed or equipment connected to the installed cable. If different conversion ratios are specified for cable and equipment, then the smaller value applies. Often, the clamp injection needs to be applied to multi-pair balanced cables if suitable CDNs are not available.

6.2.2.4 CDNs for unscreened unbalanced lines

For coupling and decoupling disturbing signals to an unscreened cable with unbalanced lines, an AFx or Mx CDN shall be used. Figure D.3 is an example for a two-wire CDN (AF2) and Figure D.6 for an eight-wire CDN (AF8).

If no CDN for the unscreened unbalanced line is applicable, follow the decision chart in Figure 20.

6.2.2.5 CDNs for screened cables

For coupling and decoupling disturbing signals to a screened cable, an Sx-type CDN shall be used. Figure D.1 is the example for a coaxial cable (S1).

To be able to treat a cable as a screened cable using CDNs for coupling of the disturbing signal, the screen shall be connected to appropriate ground (e.g. metallic housing, large ground structure on a printed circuit board) at both ends of the cable. If this condition is not met, the cable shall be treated as an unscreened cable.

6.2.3 Clamp injection devices

6.2.3.1 General

With clamp injection devices, the coupling and decoupling functions are separated. Coupling is provided by the clamp-on device, while the common-mode impedance and the decoupling functions are established at the AE. As such, the AE becomes part of the coupling and decoupling devices. With clamp injection devices, the AE is subject to the same injected current as the EUT and therefore needs to be immune to the test level used.

NOTE The EM clamp provides some decoupling above 10 MHz (see Annex A).

Instructions for proper application are specified in 7.6.

6.2.3.2 Current clamp

This device establishes an inductive coupling to the cable connected to the EUT.

The current clamp shall not induce significant attenuation. The increase of the transmission loss of the test jig when inserting the current clamp shall not exceed 1,6 dB. A circuit of the transmission loss verification setup is shown in Figure 10.

NOTE 1 The verification of such performance can be done in two steps. During the first step, the current clamp is omitted, and the voltage is recorded. During the second step, the current clamp is inserted and terminated at its input port by a 50 Ω load, and the voltage is measured. The difference between these two measurements is compared to the 1,6 dB requirement above.

NOTE 2 For example, with a 5:1 turns ratio, the transformed common-mode series impedance can be neglected with respect to the 150 Ω established by the AE. In this case, the test generator's output impedance (50 Ω) is transformed into 2 Ω. Other turns ratios can be used.

The signal level applied to the current injection clamp is set prior to the test. The test level-setting procedure is specified in 6.4.2 and Figure 10.

NOTE 3 The cable is generally positioned through the centre of the clamp to minimize capacitive coupling.

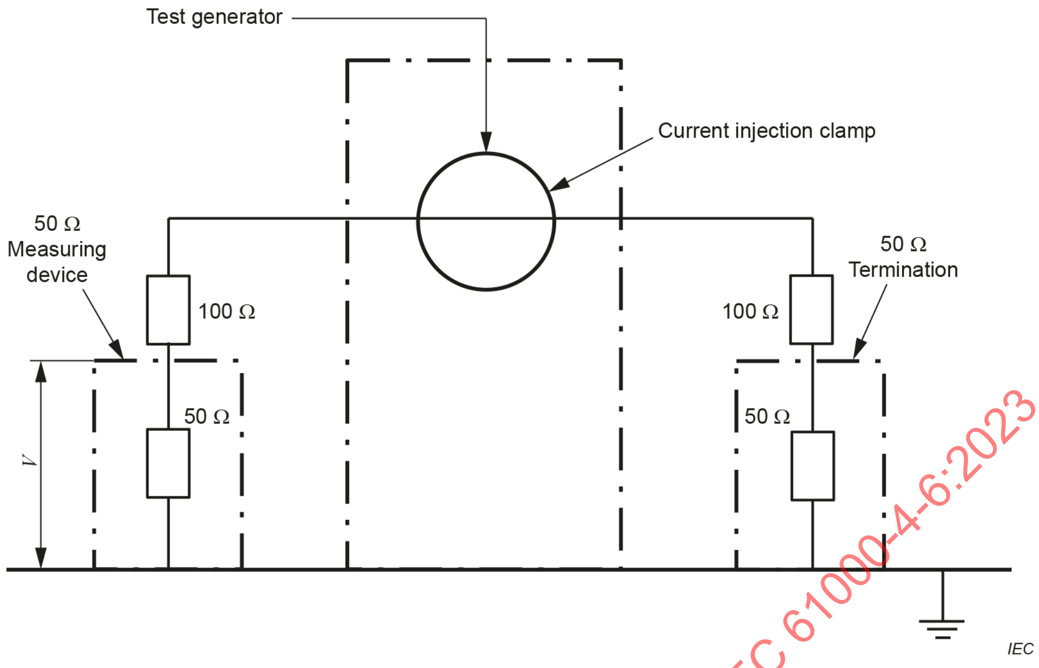


Figure 9 – Example of circuit for level-setting setup in a 150 Ω test jig

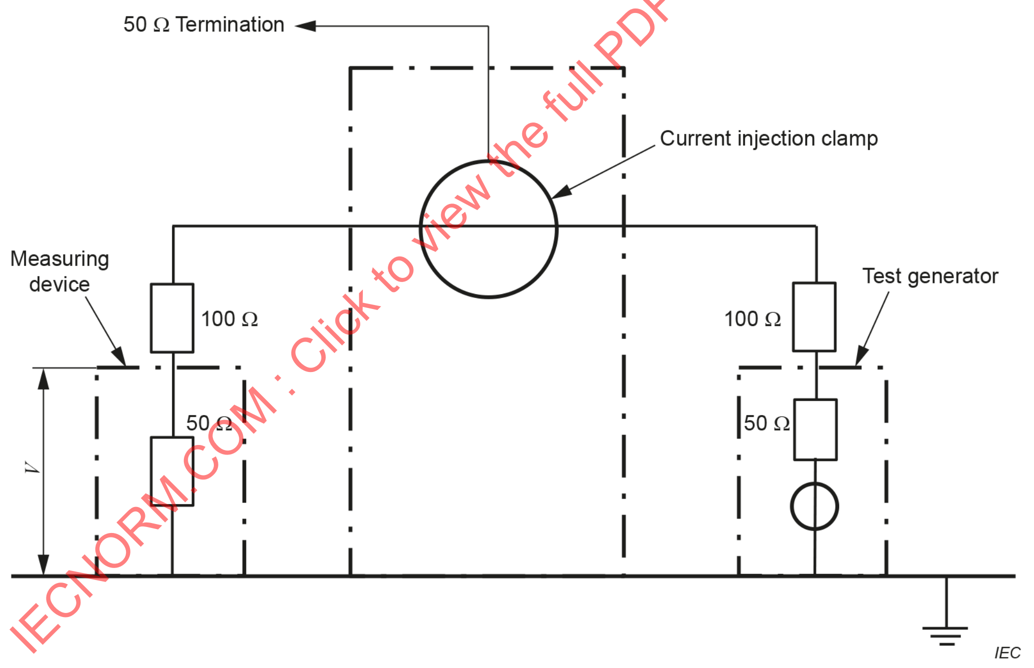


Figure 10 –Example of circuit for evaluating the transmission loss of the current clamp level-setting

6.2.3.3 EM clamp

The EM clamp establishes both capacitive and inductive coupling to the cable connected to the EUT. The construction and performance of the EM clamp are described in Clause A.2 and Clause A.3.

6.2.4 Direct injection devices

Direct injection is only applicable to screened or coaxial cables. When using direct injection, the disturbing signal is injected onto the screen via a 100 Ω resistor (even if the screen is ungrounded or grounded at one end only). Between the AE and the injection point, a decoupling clamp as specified in Clause A.3 shall be inserted as close as possible to the injection point (see Figure 6). A ground connection shall be made from the screen of the direct injection device's input port to the reference ground plane.

If the screen is intended to be grounded at the AE side, a connection from the screen of the cable under test to the reference ground plane (RGP) should be made at the AE side of the decoupling element to improve decoupling and reproducibility unless this connection would significantly deviate from practical application (e.g. remote sensor with screened cable).

When making direct connection to foil screens, ensure a good contact for reliable test results.

6.2.5 Decoupling networks

Normally, the decoupling network comprises several inductors to create a high impedance over the frequency range. This is determined by the ferrite material used, and an inductance of at least 280 µH is required at 150 kHz. The reactance shall remain high, ≥ 260 Ω up to 24 MHz and ≥ 150 Ω above 24 MHz. The inductance can be achieved either by having a number of windings on ferrite toroids (see Figure 8) or by using a number of ferrite toroids over the cable (usually as a clamp-on tube).

NOTE Decoupling clamps are specified in Clause A.3.

The CDNs as specified in Annex D can be used as decoupling networks with the RF input port left unloaded, unless stated otherwise elsewhere in this document. When CDNs are used in this way, they shall meet the requirements of 6.2. The use of CDNs as decoupling devices is the preferred choice. If CDNs are not applicable, decoupling clamps as specified in Clause A.3 shall be used.

The decoupling networks shall be used on all cables not selected for the test, but connected to the EUT or AEs, or both. For exceptions, see 7.3. Although the preferred choice is to decouple each cable individually, more cables may be routed in the same decoupling clamp, if the dimension of the clamp allows that.

6.3 Verification of the common-mode impedance at the EUT port of coupling and decoupling devices

6.3.1 General

Coupling and decoupling devices are characterized by the common-mode impedance seen at the EUT port, $|Z_{ce}|$. Its correct value ensures the reproducibility of the test results.

NOTE The common-mode impedance of coupling and decoupling devices is calibrated using the setup shown in Figure 11 to Figure 14.

The coupling and decoupling devices and the impedance reference plane (Figure 11) shall be placed on a reference ground plane. The size of the reference ground plane shall exceed the projected geometry of the setup on all sides by at least 0,2 m.

The impedance reference point shall be connected to the EUT port of the CDN as shown in Figure 11. The magnitude of the common-mode impedance seen at the connector on the impedance reference plane shall be measured.

The CDNs shall meet the impedance requirements of Table 3 while the input port is terminated with a 50 Ω load and the AE port is sequentially loaded in common mode with a short-circuit and an open circuit condition as shown in Figure 12. This requirement ensures sufficient attenuation and makes the setup of the AE, for example open or short-circuited inputs, insignificant.

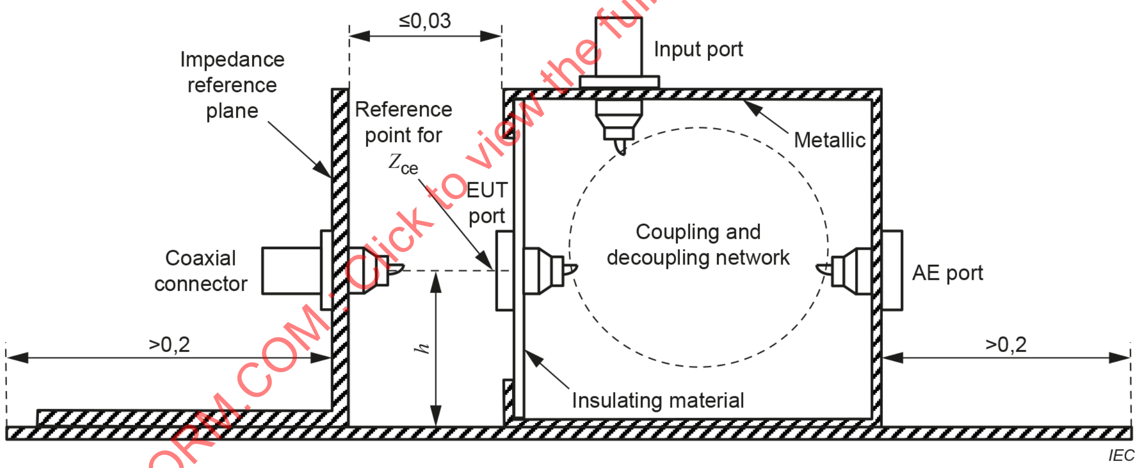
If clamp injection or direct injection is used, it is unrealistic to verify the common-mode impedance for each AE setup connected to the EUT. For clamp injection it is generally sufficient to follow the procedure specified in 7.6. For direct injection it is generally sufficient to follow the procedure specified in 7.7.

6.3.2 Insertion loss of the 150 Ω to 50 Ω adapters

When the test generator is set up prior to testing, the test level shall be verified in a 150 Ω common-mode impedance environment. This is achieved by connecting the appropriate common-mode point to a 50 Ω measurement device via a 150 Ω to 50 Ω adapter as shown in Figure 14a). The construction of the adapter is shown in Figure 14b).

The adapters shall be placed on a reference ground plane, the size of which exceeds the projected geometry of this setup on all sides by at least 0,2 m. The insertion loss is measured according to the principle of Figure 13. Its value shall be in the range of (9,5 ± 0,5) dB (theoretical value of 9,5 dB caused by the additional series impedance when measured in a 50 Ω system). Attenuators with suitable VSWR (suggested: VSWR ≤ 1,2) at the inputs of receivers and outputs of generators are recommended.

Dimensions in meters



– The reference ground plane shall exceed the projection of the coupling and decoupling devices and other components by at least 0,2 m.

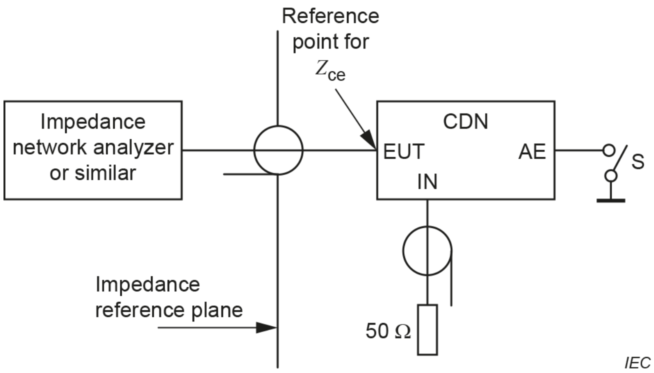
– The coaxial connector shall be connected horizontally to the EUT port.

– The height h of the EUT port depends on the individual CDN, which can vary from 0,03 m to 0,10 m; particular large current CDNs have an EUT port located higher above the reference ground plane.

– The impedance reference plane (with the coaxial connector): 0,1 m × 0,1 m for h = 0,03 m and 0,15 m × 0,15 m for other values of h.

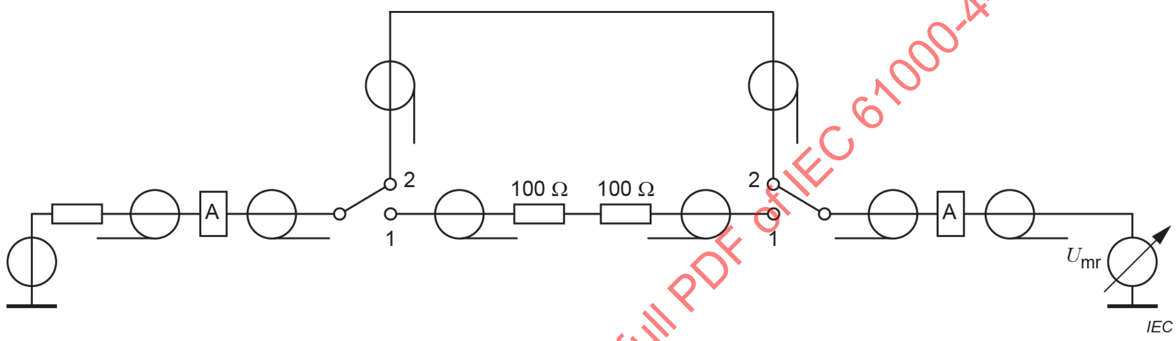
– The impedance reference plane and CDN shall have a good RF contact to the reference ground plane.

Figure 11 – Example of the setup geometry to verify the impedance characteristics of the coupling and decoupling devices



The impedance requirement shall be met with the open and closed switch S (see 6.3).

Figure 12 – Setup principle to verify Z_{ce} of the coupling and decoupling device

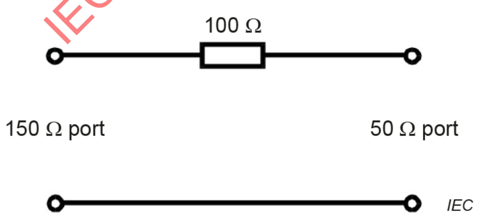


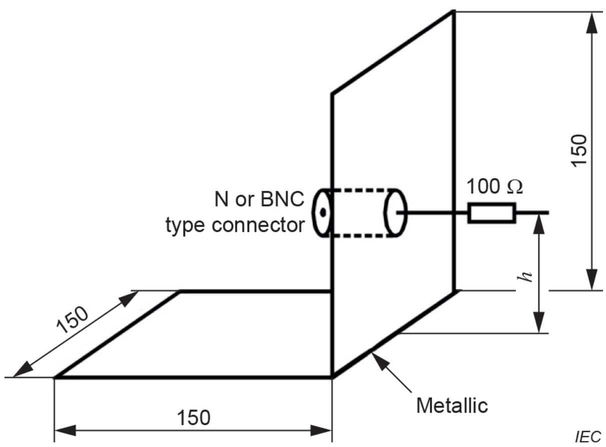
Insertion loss = U_{mr} (switches position 2) – U_{mr} (switches position 1)

dB dB(μV) dB(μV)

Figure 13 – Setup principle for measuring the insertion loss of two 150 Ω to 50 Ω adapters

Dimensions in millimetres





NOTE Low inductance resistor:
Power rating ≥ 2,5 W.

a) Circuit of the 150 Ω to 50 Ω adapter

NOTE Identical to Figure 11 (connector plate), but with 100 Ω low inductance resistor added.

b) Example of construction diagram of the 150 Ω to 50 Ω adapter (150 mm × 150 mm example)

Figure 14 – Circuit and construction of the 150 Ω to 50 Ω adapter

6.4 Setting of the test generator

6.4.1 General

For the correct setting of the unmodulated test level the procedure in 6.4.2 shall be applied. It is assumed that the test generator, the coupling and decoupling devices and the 150 Ω to 50 Ω adapter comply with the requirements of 6.1, 6.2.1 and 6.3.1. The output power of the test generator can be determined by measurement of the amplifier output power (forward power, as measured using a directional coupler).

6.4.2 Setting of the output level at the EUT port of the coupling device

The test generator shall be connected to the RF input port of the coupling device. The EUT port of the coupling device shall be connected in common mode (see Figure 15) through the 150 Ω to 50 Ω adapter to a measuring equipment having a 50 Ω input impedance. The AE port of the coupling device shall be loaded in common mode with a 150 Ω to 50 Ω adapter, terminated with 50 Ω. The setup is shown in Figure 16 for all coupling and decoupling devices.

NOTE 1 With clamp injection, current clamps are generally bi-directional and hence do not have an EUT port and AE port. These devices are calibrated by using a test jig as shown in Figure 9.

Using the above-mentioned setup and the following measurement procedure, the test generator shall be adjusted to yield the following reading on the measuring equipment.

Procedure to be followed for each coupling device starting at the lowest frequency:

a) Apply a forward power (without modulation) to the coupling device so that the voltage obtained equals U_{mr} at the output port of the 150 Ω to 50 Ω adapter.

   Record the level of the forward power at the output of the power amplifier P_{for} and the voltage U_{mr} at the output port of the 150 Ω to 50 Ω adapter.

b) Increase the frequency by a maximum of 1 % of the present frequency.

c) Repeat steps a) and b) until the next frequency in the sequence exceeds the highest frequency (for example 80 MHz) in the range of the test. The stop frequency shall be included.

The laboratory shall ensure that the amplifier is not saturated. This should be demonstrated by applying the following procedure:

1) Determine, across all used coupling devices, the highest forward power P_{formax} required during the level-setting process at each frequency step.

2) For each frequency, repeat the following steps:

   i) set the output level of the power amplifier to P_{formax};

   ii) increase the control level of the RF signal generator by 5,1 dB;

   iii) record the new forward power $P_{formax,\ inc}$;

   iv) if the difference $P_{formax,inc} - P_{formax}$ is between 3,1 dB and 7,1 dB for all frequency steps, then the amplifier is in tolerance and the test system is sufficient for testing at the selected test level. If the difference is less than 3,1 dB or more than 7,1 dB then the amplifier is non-linear and is not suitable for testing.

Alternatively, the saturation verification procedure specified above may be directly included in the level-setting process of each CDN.

Annex J provides information on test generator compression and amplifier non-linearity.

In the step a) setting process the voltage U_{mr} shall be:

$$U_{mr} = U_0/6 \begin{pmatrix} +19\% \\ -16\% \end{pmatrix}, \text{ in linear quantities, or}$$

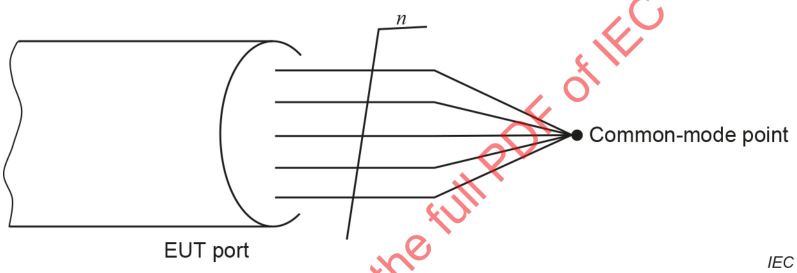
$$U_{mr} = U_0 - 15{,}6 \text{ dB} \pm 1{,}5 \text{ dB}, \text{ in logarithmic quantities.}$$

NOTE 2 U_0 is the test voltage specified in Table 1 and U_{mr} is the measured voltage as defined in 3.12 and shown in Figure 16. To minimize testing errors, the output level of the test generator is set by setting U_{mr} with 150 Ω loads (for instance with the 150 Ω to 50 Ω adapter and 50 Ω termination) and not by setting U_0.

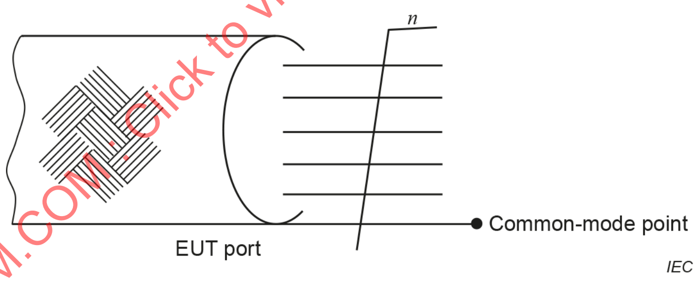
NOTE 3 The factor 6 (15,6 dB) arises from the e.m.f. value specified for the test level. The matched load level is half the e.m.f. level and the further 3:1 voltage division is caused by the 150 Ω to 50 Ω adapter terminated by the 50 Ω measuring equipment.

The control parameters of the test generator setting shall be recorded and used for testing.

It is intended that the test generator setting process should be carried out at least annually and when significant changes are made to the test generator or its relevant equipment (RF generator, amplifier, CDN, coupling device, etc.), or both.



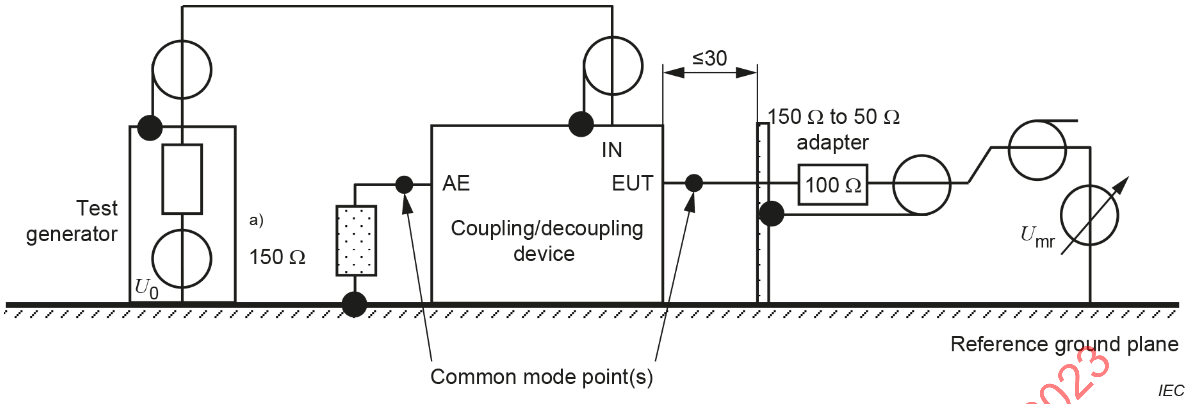
a) **Definition of a common-mode point with unscreened cables containing *n* wires**



b) **Definition of a common-mode point with screened cables containing *n* wires**

Figure 15 – Definition of a common-mode point for unscreened and screened cables

Dimensions in millimetres



Coupling/decoupling devices:

- CDNs;
- direct injection network (with decoupling);
- clamp injection device (e.g. EM clamp, current clamp with decoupling device).

a) The 150 Ω loading, for example a 150 Ω to 50 Ω adapter terminated with a 50 Ω load at the AE port, shall only be applied to unscreened cables (screened cables have their screens connected to the reference ground plane at the AE side).

Figure 16 – Setup for level-setting at the EUT port of the coupling/decoupling devices

7 Test setup and injection methods

7.1 Test setup

The equipment to be tested is placed on an insulating support of 0,1 m ± 0,05 m height above a reference ground plane. A non-conductive roller/caster in the range of 0,1 m ± 0,05 m above the reference ground plane can be used as an alternative to an insulating support. All cables exiting the EUT shall be supported at a height of at least 30 mm above the reference ground plane.

If the equipment is designed to be mounted in a panel, rack or cabinet, then it shall be tested in this configuration.

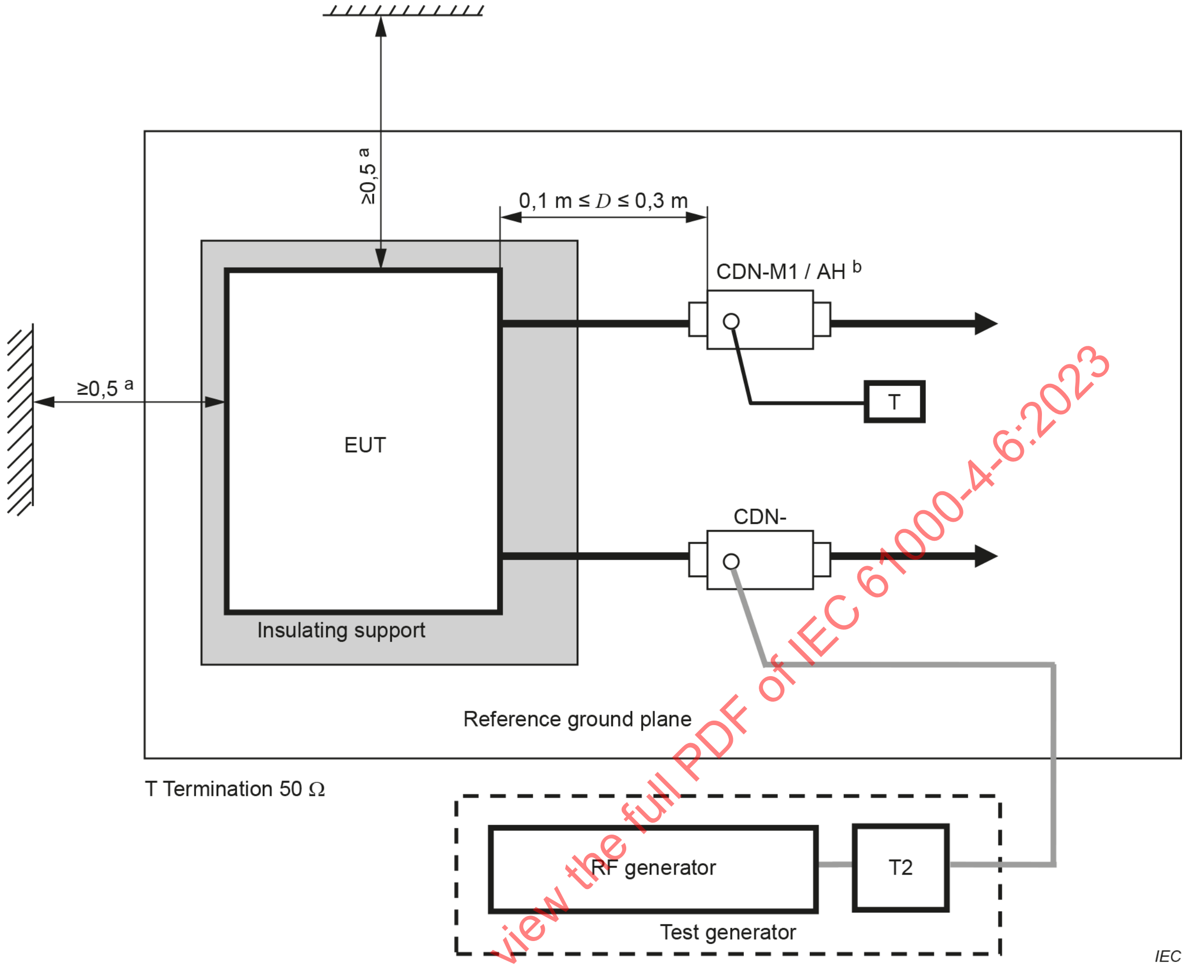
Grounding of the equipment shall be consistent with the EUT's installation instructions.

Where coupling or decoupling devices, or both, are required, they shall be located between 0,1 m and 0,3 m from the EUT (this distance is denoted D in this document). This distance is to be measured horizontally from the projection of the EUT onto the reference ground plane to the coupling or decoupling device, or both. See Figure 18, Figure 19 and Figure 22. Subclauses 7.2 to 7.7 provide more detailed information. Annex F shows a test setup example of a large EUT.

NOTE Distance D is not required to be the same on all sides of the EUT, but is between 0,1 m and 0,3 m.

If the EUT is provided with a human interface device (i.e. keyboard, or any hand-held accessory), then the artificial hand shall be placed on this human interface device or wrapped around the accessory and connected to the reference ground plane. Details on construction, application and use of the artificial hand can be found in CISPR 16-1-2.

Dimensions in metres



[a] The EUT clearance from any metallic objects other than test equipment shall be at least 0,5 m.

[b] The CDN not used for injection shall be terminated with 50 Ω, providing only a single return path. An artificial hand (AH) can also be used, depending on the kind of EUT.

Figure 17 – Example of test setup with a single unit EUT with only one CDN for injection (top view)

7.2 EUT comprising a single unit

The EUT shall be placed on an insulating support 0,1 m above the reference ground plane. The reference ground plane may be placed on a table (see Figure 18).

On all cables to be tested, coupling and decoupling devices shall be inserted (see 7.4.3). The coupling and decoupling devices shall be placed on the reference ground plane, making direct contact with it at a distance of 0,1 m to 0,3 m from the EUT. The cables between the coupling and decoupling devices and the EUT shall be as short as possible and shall not be bundled or wrapped. Their height above the reference ground plane shall be at least 30 mm.

Custom length of cables can be necessary, i.e. shortened or modified to a length to fulfill the setup requirements.

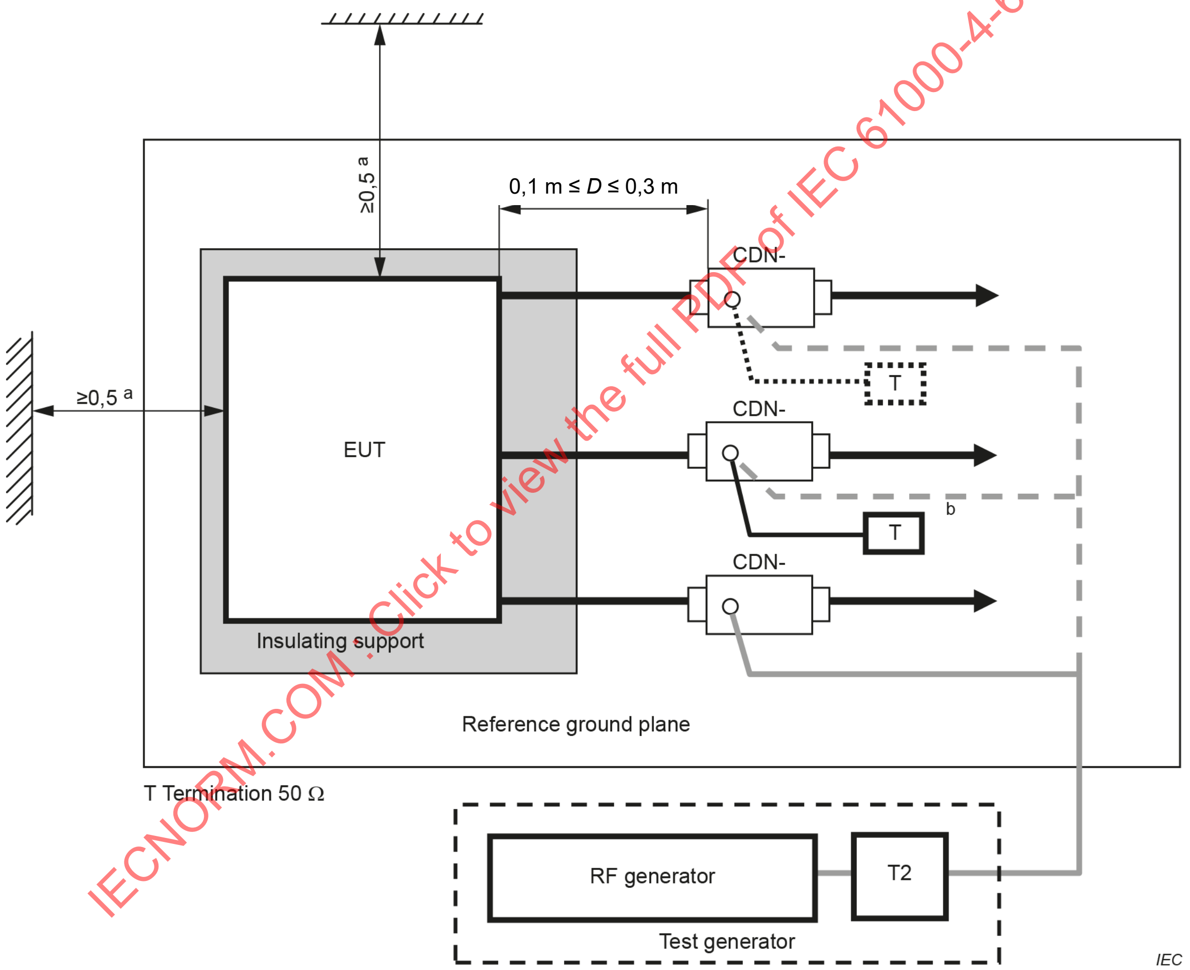
The preferred length of cable between EUT and CDN is less than 0,3 m. In case the cables cannot be shortened to this length, the setup shall be stretched out up to a cable length of maximum 2 m to allow a straight layout of the cable. In case of cable lengths exceeding 2 m, the excess cable length shall be laid out in serpentines if the cable is flexible enough to do so. The excess length of the cable shall be kept at least 30 mm above the reference ground plane, and not bundled or wrapped.

All deviations exceeding the preferred cable lengths of maximum 30 cm shall be stated in the test report.

If the EUT is provided with other earth terminals in addition to the dedicated PE, they all shall be bonded together and then connected to the reference ground plane through CDN-M1 (unless this would significantly deviate from the intended installation in practice), see 6.2.2.2 and Figure 17 (i.e. the AE port of the CDN-M1 is then connected to the reference ground plane).

AE required for the operation of the EUT according to the specifications of the product committee, for example communication equipment, modem, printer, sensor, as well as AE necessary for ensuring any data transfer and assessment of the functions, shall be connected to the EUT through coupling or decoupling devices, or both. The number of cables to be tested can be limited; however, at least one of each physical type port shall be submitted to injection.

Dimensions in metres



[a] The EUT clearance from any metallic objects other than test equipment shall be at least 0,5 m.

[b] Only one of the CDNs not used for injection shall be terminated with 50 Ω, providing only a single return path. All other CDNs shall be configured as decoupling networks.

Figure 18 – Example of test setup with a single unit EUT (top view) using multiple CDNs

7.3 EUT comprising several units

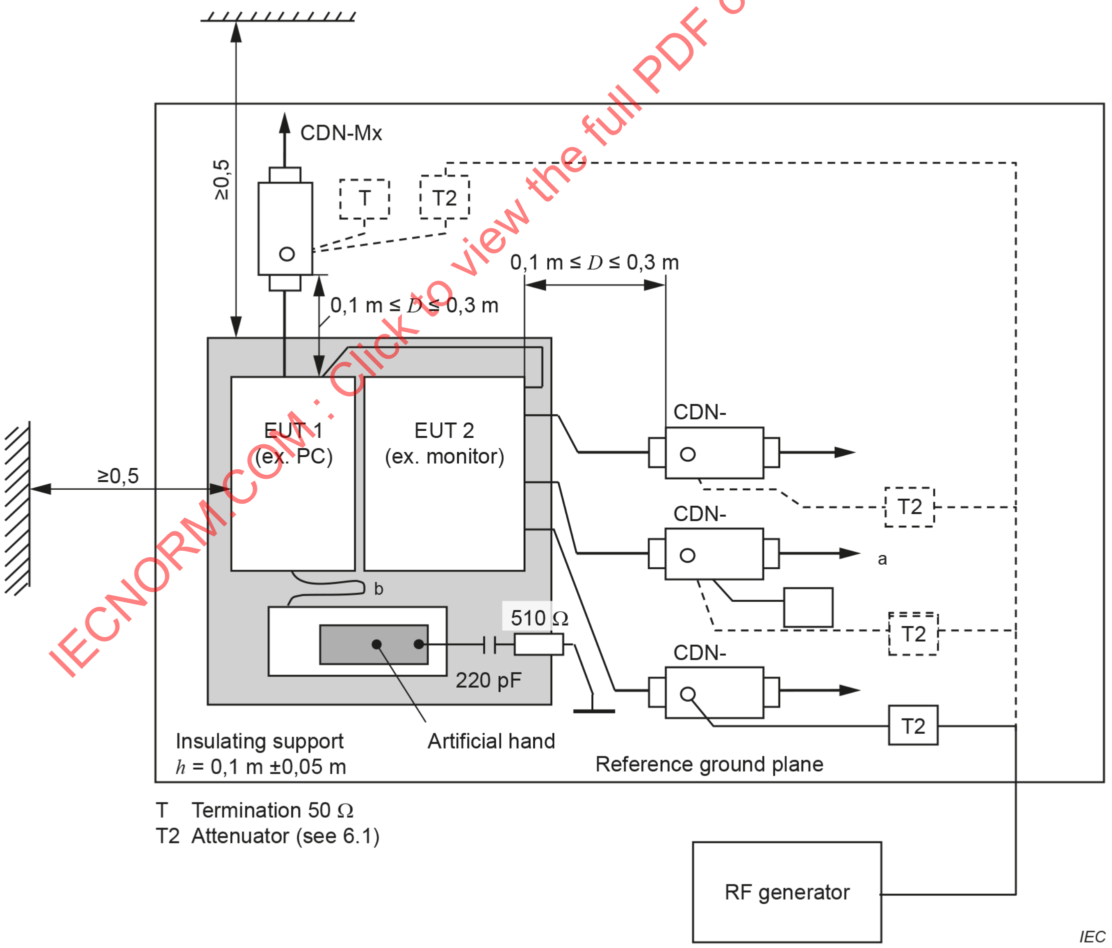
Equipment comprising several units, which are interconnected, shall be tested using one of the following methods.

- Preferred method: Each sub-unit shall be treated and tested separately as an EUT (see 7.2), considering all others as AE. Coupling and decoupling devices (or CDNs) shall be placed on the cables (according to 7.4.1) of the sub-units considered as the EUT. All sub-units shall be tested in turn.
- Alternative method: Sub-units that are always connected together by short cables, i.e. ≤ 0,4 m, and that are part of the equipment to be tested, can be considered as one EUT. No conducted immunity test shall be performed on their interconnecting cables, these cables being regarded as internal cables of the system. See Figure 19.

The units being part of such an EUT shall be placed as close as possible to each other without making contact, all on the insulating support. The interconnecting cables of these units shall also be placed on the insulating support. All other cables shall be tested according to the rules of 7.4 to 7.7.

The EUT clearance from any metallic obstacles other than the test equipment shall be at least 0,5 m.

Dimensions in metres



[a] Only one of the CDNs not used for injection shall be terminated with 50 Ω, providing only one return path. All other CDNs shall be configured as decoupling networks.

[b] Interconnecting cables (≤ 0,4 m) belonging to the EUT shall remain on the insulating support.

Figure 19 – Example of a test setup with a multi-unit EUT (top view)

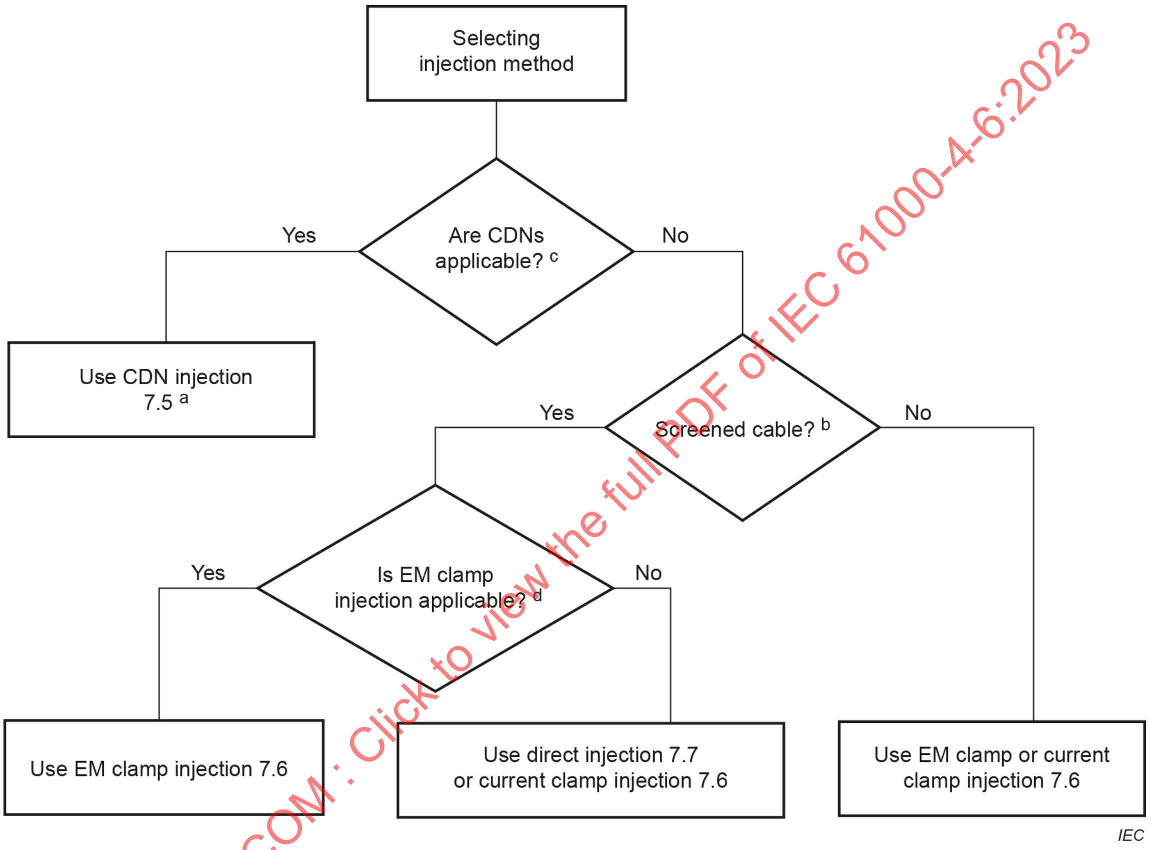
7.4 Rules for selecting injection methods and test points

7.4.1 General

To select the type and number of cables to be provided with coupling and decoupling devices, the physical configuration of typical installation conditions shall be considered, for example the likely length of the longest cables.

7.4.2 Injection method

Figure 20 gives rules for selecting the injection method.



[a] See Table 4.

[b] See 6.2.3.

[c] See 6.2.1.

[d] "Applicable" means that the EM clamp can technically accommodate the cable.

NOTE The decision path in the flowchart prefers test methods using a coupling device, for example CDN or EM clamp over direct injection, because the use of a coupling device is usually more prescriptive and leaves less room for individual setups, like direct injection.

Figure 20 – Rules for selecting the injection method

Testing shall be performed with the EUT, including selected cables for testing, installed, arranged and operated in a manner consistent with typical applications. CDNs not listed in this document, but meeting the requirements of this document, may also be used.

Where several cables coming from the EUT are in close proximity over a length of more than 10 m or are routed from the EUT to other equipment in a cable tray or conduit, they should be treated as one cable, regardless of cable types present. If the bundle of cables is too large for testing as one cable, they should be separated by cable type or function (e.g. signal, mains, screened, etc.) and at least one cable of each type or function tested individually.

If a product committee decides that a certain kind of coupling and decoupling device is more appropriate for cables connected to a particular family of products, then that choice (justified on a technical basis) takes precedence. These devices shall be described in the product standard. Examples of CDNs are described in Annex D.

7.4.3 Ports to be tested

In any one test, only two 150 Ω networks are required, one for signal injection, one for signal return path. It is not necessary to connect unterminated CDNs to all other EUT ports which are not yet undergoing RF test signal injection or return path. These other ports can instead be left open (unless the technical function of the EUT requires a treatment of these ports for operation) until they shall be used for injection of the test signal. At that time the suitable CDN can be connected and used for injection on each of such ports in turn. The CDN used for injection of the test signal can be moved between different ports as they are tested. When a CDN is removed from a port, it may be replaced by a decoupling network.

If the EUT has multiple identical ports (same input or output electronic circuits, loads, connected equipment, etc.), at least one of these ports shall be selected for testing to ensure that all different types of ports are covered.

7.5 CDN injection application

When using the CDN injection, the following measures shall be taken.

a) If the AE is directly connected to the EUT (e.g. no decoupling on the connection between them as shown in Figure 21a)) then it is to be placed on an insulating support 0,1 m ± 0,05 m above the reference ground plane and grounded via a terminated CDN.

   If the EUT has multiple AEs directly connected to it, only one AE shall be terminated in this manner. Other directly connected AEs shall have all other connections decoupled. This ensures that there is only one loop terminated with 150 Ω at each end.

b) If the AE is connected to the EUT via a CDN, then its arrangement is not generally critical and it can be connected to the reference ground plane in accordance with the AE's and EUT's installation requirements.

c) One CDN shall be connected to the port intended to be tested and one CDN with 50 Ω termination shall be connected to another port. Decoupling networks shall be installed on all other ports to which cables are attached. In this manner there is only one loop terminated with 150 Ω at each end.

d) The CDN to be terminated shall be chosen according to the following priority:

   1) CDN-M1 used for connection of the earth terminal;

   2) CDN-M3, CDN-M4, or CDN-M5 used for mains (class I equipment);

   3) CDN-Sn (n = 1,2,3…): if the EUT has several CDN-Sn ports, the port which is closest to the port selected for injection (shortest geometrical distance) shall be used;

   4) CDN-M2 used for AC or DC mains (class II equipment);

   5) Other CDN connected to the port which is the closest to the port selected for injection (shortest geometrical distance).

   NOTE 1 Annex I gives guidance for an alternative CDN injection process for specific products.

e) If the EUT has only one port, that port is connected to the CDN used for injection.

   NOTE 2 The capacitive coupling path from the EUT to the reference ground plane provides the return path for the test signal.

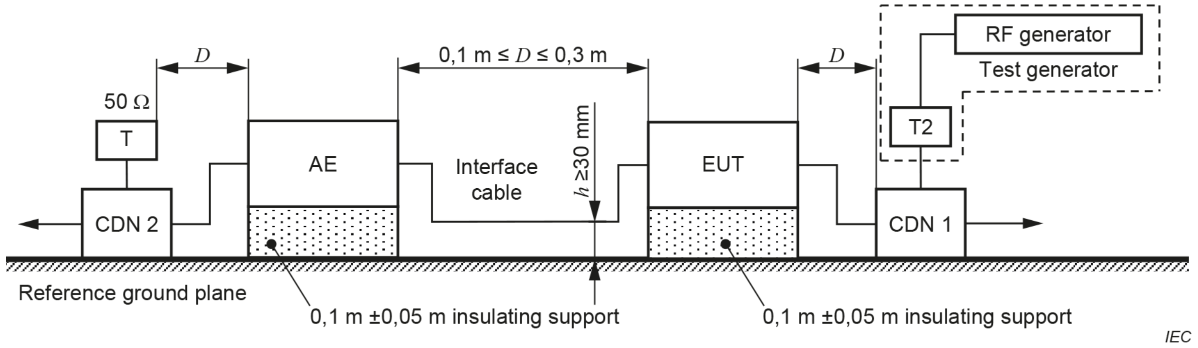
f) If the EUT has two ports and only one CDN can be connected to the EUT, the other port shall be connected to an AE that has one of its other ports connected to a CDN terminated with 50 Ω in accordance with the above-mentioned priority. All other connections of the AE shall be decoupled (see Figure 21a)). If an AE connected to the EUT shows an error during the test, a terminated EM clamp may be connected between the EUT and AE (see Figure 21b)). The interface cable should have enough length to add the terminated EM clamp without changing the setup.

g) If the EUT has more than two ports and only one CDN can be connected to the EUT, it shall be tested as described for two ports but all other EUT ports shall be decoupled. If an AE connected to the EUT shows an error during the test, a terminated EM clamp may be connected between EUT and AE, as mentioned above.

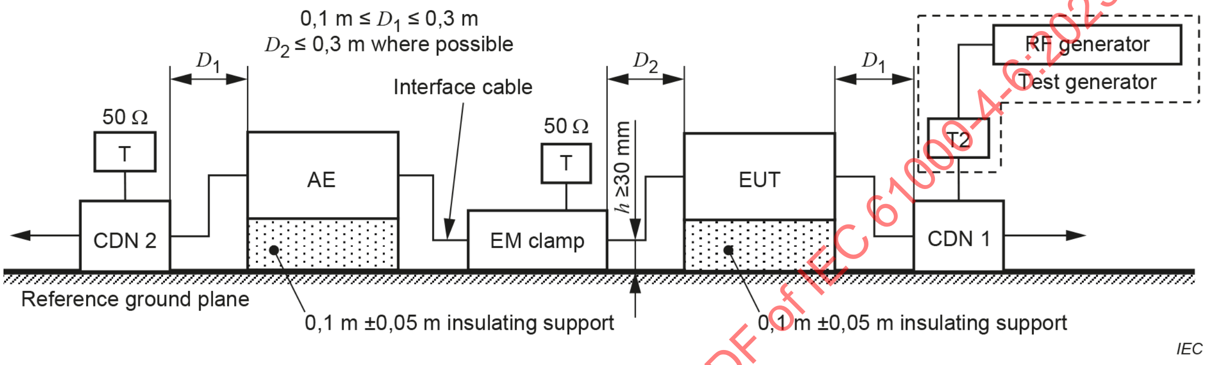
If in actual installations the supply wires are individually routed, separate CDN-M1 CDNs shall be used. All input ports shall be treated separately.

If the EUT is provided with functional earth terminals (e.g. for RF purposes or high leakage currents), they shall be connected to the reference ground plane:

– through the CDN-M1 when the characteristics or specification of the EUT permit. In this case, the (power) supply shall be provided through an appropriate CDN-Mx type network;
– when the characteristics or specification of the EUT do not permit the presence of a CDN-M1 network in series with the earth terminal for RF or other reasons (for example, if this would significantly deviate from the intended installation in practice), the earth terminal shall be directly connected to the reference ground plane. In this case the CDN-M3 network shall be replaced by a CDN-M2 network to prevent an RF short-circuit by the protective earth conductor. When the equipment was already supplied via CDN-M1 or CDN-M2 networks, these shall remain in operation;
– for a three-phase supply, a similar adjustment shall be done regarding the use of an appropriate CDN-Mx type network.



a) Schematic setup for a two-port EUT connected to only 1 CDN



b) Example: schematic setup when AE shows errors during the test

T: Termination 50 Ω

T2: Attenuator (see 6.1)

CDN: Coupling and decoupling network

Figure 21 – Immunity test for two-port EUT (when only one CDN can be used)

7.6 Clamp injection application

When using clamp injection, each AE shall represent the functional installation conditions as closely as possible. The following measures shall be taken:

– Each AE used with clamp injection shall be placed on an insulating support 0,1 m ± 0,05 m above the reference ground plane.

– The clamp shall be placed on the cable to be tested. The clamp shall be supplied with the test generator level previously established during the level-setting procedure.

– A decoupling network shall be installed on each cable between the EUT and AE except the cable under test.

– All cables connected to each AE, other than those being connected to the EUT, shall be provided with decoupling networks, see 6.2.5. Custom lengths of cables can be necessary, that is, shortened or modified to a length to fulfil the setup requirements. If a longer cable has to be used due to functional requirements, the excess length of the cable shall be kept at least 30 mm above the reference ground plane, and not bundled or wrapped.

– The decoupling networks connected to each AE (except those on cables between the EUT and AE) shall be applied no further than 0,3 m from the AE. The cable(s) between the AE and the decoupling network(s) or between the AE and the injection clamp shall not be bundled nor wrapped and shall be kept at a height of 30 mm or more above the reference ground plane.

– At one end of the cable under test is the EUT, and at the opposite end is the AE. Multiple CDNs can be connected to the EUT and to the AE; however, only one CDN on each of the EUT and AE shall be terminated in 50 Ω. The termination of the CDN shall be chosen according to the priority in 7.5.

– When several clamps are used, the injection is performed on each cable selected for testing one by one. The cables which are selected for testing with the injection clamp, but not actually exercised, shall be decoupled in accordance with 6.2.5.

– Each AE and EUT used with clamp injection shall represent the functional installation conditions as closely as possible, for example the EUT shall either be connected to the reference ground plane or placed on an insulating support (see Figure 22 and Figure 23).

– The common-mode impedance of the AE should be less than or equal to the common mode impedance of the EUT port being tested. If the AE impedance cannot be lowered without changing the usual installation practice, there is no need to make a special connection to lower the impedance for this test. In this case, the test is performed with a setup representing the actual use.

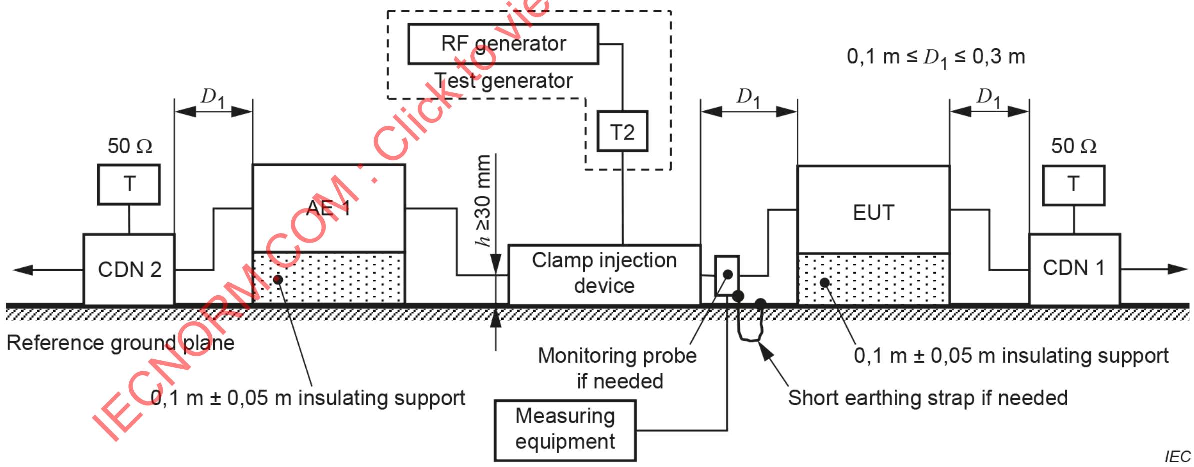
– The induced voltage is set in the same way as specified in 6.4.2.

– By means of a current monitoring probe inserted between the injection clamp and the EUT, the current (without modulation) resulting from the induced voltage (set according to 6.4.1) can be monitored. This probe should be kept in close proximity to the injection clamp. If the current is monitored and exceeds the nominal circuit value I_{max} given below, the test generator level may be reduced until the measured current is equal to the I_{max} value given below. If the test generator level is reduced, then this reduced level shall be recorded in the test report. In case of dispute, the test method limiting the current to I_{max} will take precedence.

$$I_{max} = U_0/150\ \Omega$$

– During a test, a ground connection shall be made from the earth bar of the EM clamp to the reference ground plane. If the monitoring probe has a ground bar, it shall also be connected to the reference ground plane (see Figure 22 and Figure 23).

To ensure reproducibility, the test setup shall be fully described in the test report.



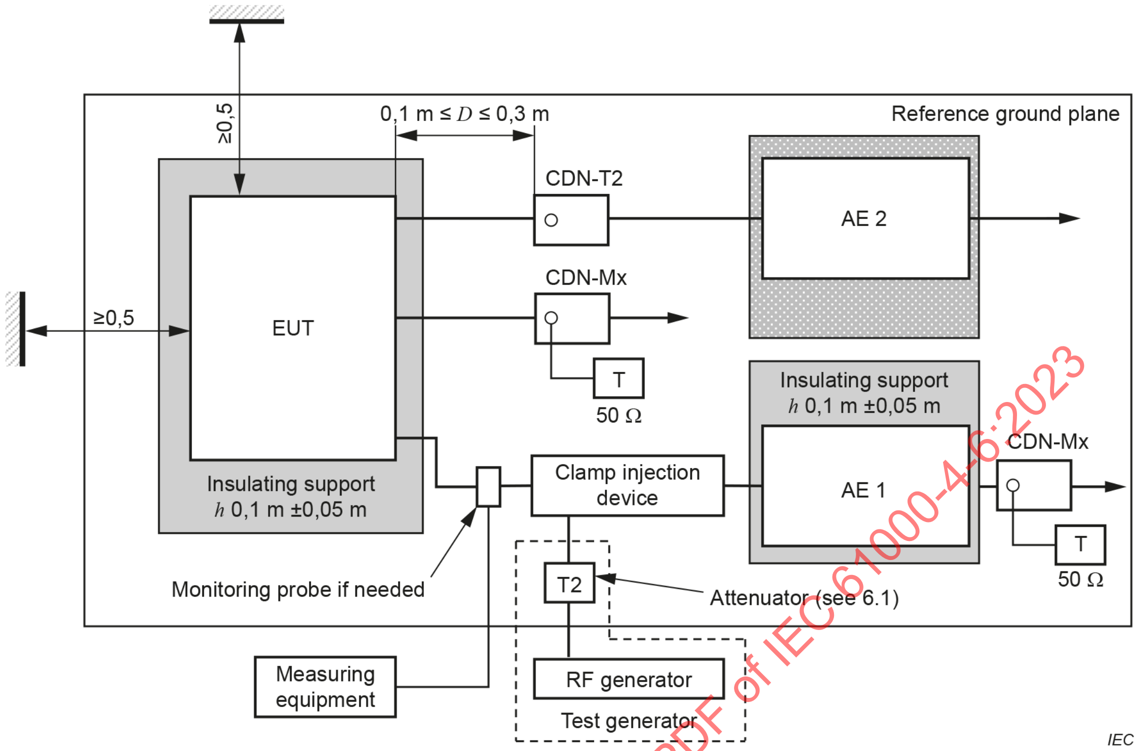
T: Termination 50 Ω

T2: Attenuator (see 6.1)

CDN: Coupling and decoupling network

Figure 22 – General principle of a test setup using clamp injection devices

Dimensions in metres



T: Termination 50 Ω

T2: Attenuator (see 6.1)

CDN: Coupling and decoupling network

Figure 23 – Example of the test unit locations on the ground plane when using injection clamps (top view)

7.7 Direct injection application

When using direct injection to screened cables, the following measures shall be taken.

– The EUT shall be placed on an insulating support of 0,1 m height above the reference ground plane.

– On the cable being tested, a decoupling clamp as specified in Clause A.3 shall be placed between the injection point and the AE, as close as possible to the injection point. A second port of the EUT shall be loaded with 150 Ω (see 7.5 and Figure 6 for details). On all other cables attached to the EUT decoupling networks shall be installed. When left open, a CDN is considered a decoupling network. See also 6.2.5.

– The injection point shall be located between 0,1 m and 0,3 m from the geometric projection of the EUT onto the reference ground plane.

– The test signal shall be injected directly onto the shield of the cable through a 100 Ω resistor (see 6.2.4).

8 Test procedure

The EUT shall be tested within its intended operating and climatic conditions.

The radiation from the test setup can be subject to local interference regulations. If the radiated energy exceeds the permitted level, the test shall be performed in a shielded enclosure.

NOTE 1 Generally, this test can be performed without using a shielded enclosure. This is because the disturbance levels applied and the geometry of the setups are not likely to radiate a high amount of energy, especially at the lower frequencies.

The test shall be performed with the test generator connected to each of the coupling devices (CDN, EM clamp, current clamp) in turn. All other cables not under test shall either be provided with decoupling networks or unterminated CDNs, or disconnected when setup conditions cannot be met.

A low-pass filter (LPF) or a high-pass filter (HPF), or both, for example 100 kHz cut-off frequency, can be required at the output of the test generator to prevent (higher order or sub-) harmonics from disturbing the EUT. The band-stop characteristics of the LPF shall be sufficient to suppress the harmonics so that they do not affect the results. These filters shall be inserted after the test generator before setting the test level (see 6.1 and 6.4.1).

The frequency range is swept from 150 kHz to 80 MHz, using the signal levels (forward power) established during the setting process, and with the disturbance signal 80 % amplitude modulated with a 1 kHz sine wave, pausing to adjust the RF signal level or to change coupling devices as necessary. Where the frequency is swept incrementally, the step size shall not exceed 1 % of the preceding frequency value. The dwell time of the amplitude modulated carrier at each frequency shall not be less than the time necessary for the EUT to be exercised and to respond, but shall in no case be less than 0,5 s. Potentially sensitive frequencies shall be tested in addition to the maximum 1 % step size.

NOTE 2 Since the EUT can be disturbed by transients occurring during frequency stepping, provisions will be made to avoid such disturbance. For example, before the frequency change, the strength of the signal can be decreased a few dB below the test level.

Attempts shall be made to fully exercise the EUT during testing, and to fully interrogate all exercise modes selected for testing.

The use of a special exercising program is recommended.

Testing shall be performed according to a test plan.

It can be necessary to carry out some investigatory testing in order to establish some aspects of the test plan.

In order to reduce test time, more than one frequency may be applied simultaneously (multiple signal testing) during a single dwell time, provided the linearity requirements of 6.4.2 are met on the aggregate signal. At each of the signal frequencies, the test levels shall be the ones resulting from the level-setting procedure for testing with one frequency at a time. The same modulation is applied simultaneously to each signal. Intermodulation signals shall be treated like harmonics and checked to ensure they are not causing a significant effect (see Annex H regarding modulation effects and Clause 9 regarding the evaluation of the test result). The phase of the modulation signal during AM modulation shall be identical for all simultaneous test frequencies.

9 Evaluation of the test results

The following classification may be used as a guide in formulating performance criteria, by committees responsible for generic, product and product-family standards.

The test results shall be evaluated during the dwell time and classified in terms of the loss of function or degradation of performance of the EUT, relative to a performance level derived from the accompanying documents, for example specification sheets, manuals, user guides.

The recommended classification is as follows:

a) normal performance within limits specified in the accompanying documents;
b) temporary loss of function or degradation of performance which ceases after the disturbance ceases, and from which the EUT 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 EUT's accompanying documents may specify effects on the EUT which are considered insignificant, and therefore acceptable.

EUT performance evaluation should be based on a single cause-and-effect basis. If multiple test signals were used during testing, ensure that any recorded performance degradation was caused by a single test signal and was not caused by the combination of multiple test signals. In case of dispute the single signal test takes precedence.

10 Test report

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

– identification of the EUT and any associated equipment, for example brand name, product type, serial number, software, etc.;
– the size of the EUT;
– representative operating conditions of the EUT;
– whether the EUT is tested as a single or multiple unit;
– the types of interconnecting cables, including their length, and the interface port of the EUT to which they were connected;
– any specific conditions for use, for example cable length or type, shielding or grounding, or EUT operating conditions, which are required to achieve compliance;
– the recovery time of the EUT if necessary;
– the type of test facility used and the position of the EUT, AE(s) and coupling and decoupling devices;
– identification of the test equipment, for example brand name, product type, serial number, software, etc.;
– the coupling and decoupling devices used on each cable;
– for each injection port, indicate which decoupling devices were terminated in 50 Ω;
– a description of the EUT exercising method;
– any specific conditions necessary to enable the test to be performed;
– the frequency range of application of the test;
– the rate of sweep frequency, dwell time and frequency steps;
– the test level set;
– the number of tones and grouping used (if applicable);
– the performance level specified by the accompanying documents;
– the performance criteria that have been applied;
– any effects on the EUT observed during or after application of the test disturbance and the duration for which these effects persist;
– the rationale for the pass/fail decision.

Annex A
(normative)

EM and decoupling clamps

A.1 EM clamps

A.1.1 General

Annex A deals with the requirements of EM clamps. The EM clamp (in contrast to the conventional current injection clamp) has directivity above several tens of MHz. The construction and concept of the EM clamp are shown in Figure A.1 and Figure A.2. Typical characteristics of impedance can be found in Figure A.7. Typical characteristics of the decoupling factor can be found in Figure A.8. Typical characteristics of the coupling factor can be found in Figure A.11. These characteristics were measured using the procedure described in Clause A.2.

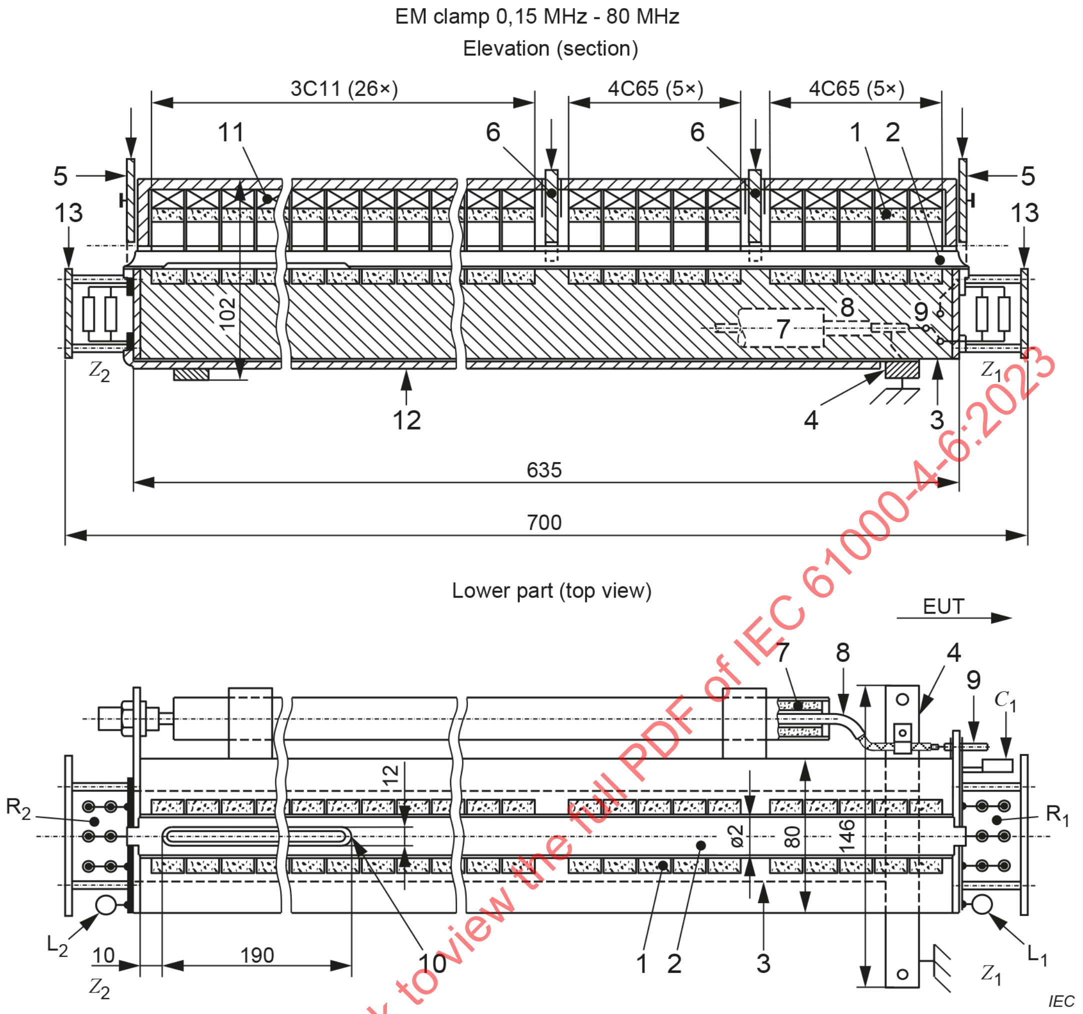
A.1.2 Specification of EM clamps

EM clamps are used for injection into cables. The requirements are:

– operating frequency range: 0,15 MHz to 80 MHz;
– length: 650 mm ± 50 mm;
– height of clamp opening centre above ground plane: 50 mm to 70 mm;
– clamp opening diameter: 20 mm ± 2 mm;
– clamp reference point (distance from outer dimension to first core): < 30 mm.

NOTE The electrical characteristics shown in Figure A.7, Figure A.8 and Figure A.11 can also be achieved using other physical dimensions (e.g. to test larger diameter cables).

Dimensions in millimetres



Components

1 Ferrite ring cores ∅ 36 mm × ∅ 23 mm × 15 mm
10 rings, NiZn, μ ≈ 100
26 rings, MnZn, μ ≈ 4 300

2 Semi-cylinder of copper foil glued to the groove

3 Lower conductor plate

4 Earth bar

5/6 Devices for pressing the cable under test into the groove
Parts from insulating material with pressure springs (not shown)

7 Ferrite tube, 4C65

8 Coaxial cable, 50 Ω with BNC connector

9 Switch for the disconnection of Z_1

10 Slot for part no. 2

11 Elastic fixing of ferrite (upper semi-ring)

12 Lower insulating plate

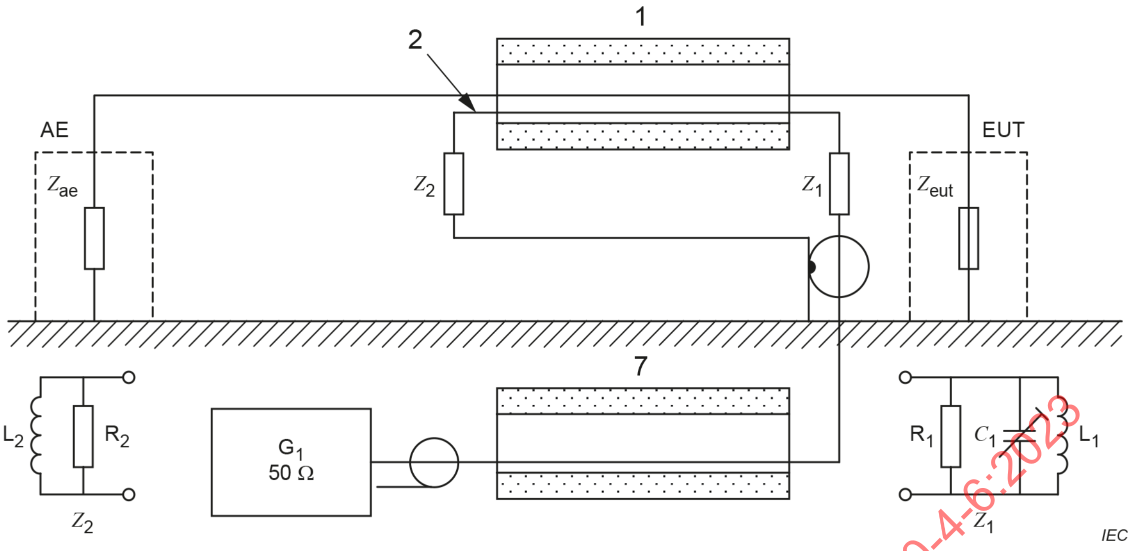
13 Protection plate for Z_1, Z_2

EUT Equipment under test

Z_1 Series impedance: C_1: 20 pF to 100 pF, L_1: 0,15 μH, R_1: 50 Ω / 12 W

Z_2 Series impedance: L_2: 0,8 μH, R_2: 50 Ω / 12 W

Figure A.1 – Example: Construction details of the EM clamp



Components

1	Ferrite tube (clamp) length 0,6 m, ∅ 20 mm, consisting of 10 rings, 4C65 (μ ≈ 100) at the EUT side and 26 rings 3C11 (μ ≈ 4 300) at the AE side
2	Semi cylinder of copper foil
7	Ferrite tube (μ ≈ 100) included in the EM clamp construction
Z_1, Z_2	Built-in to optimize the frequency response and directivity
G_1	Test generator

Principle of the EM clamp:

– magnetic coupling by the ferrite tube (item 1);

– electric coupling by close proximity between EUT cable and copper foil (item 2).

Figure A.2 – Example: Concept of the EM clamp

A.2 EM clamp characterization

A.2.1 Specification of the clamp test jig

A test jig used for measuring the S-parameters of clamps shall have a cylindrical metal rod above a metal plate (reference ground plane) as shown in Figure A.4 and Figure A.5. The test jig consists of three sections: one section forming a transmission line in the jig between the two reference planes, and two reference planes with lossless 50 Ω adapters, see Figure A.3, Figure A.4 and Figure A.5. For the characterization of the EM clamp, a single metal rod is used. The length of the metal rod ($L_A + L_B + L_{reference}$) is set to allow the dimensions of Figure A.5 to be satisfied.

The diameter d of the cylindrical rod shall be 4 mm. The height h above the ground plane is constrained by the dimensions of the clamp. Typical values are 50 mm up to 70 mm. The measurement shall be performed at the height given by the construction of the clamp using the centre position of the clamp opening.

The distance between the clamp reference point (1st core) and the vertical flange of the jig L_A and L_B shall be 30 mm ± 5 mm (see Figure A.5). The size of the reference ground plane shall exceed the projected geometry of the setup on all sides by at least 0,2 m.

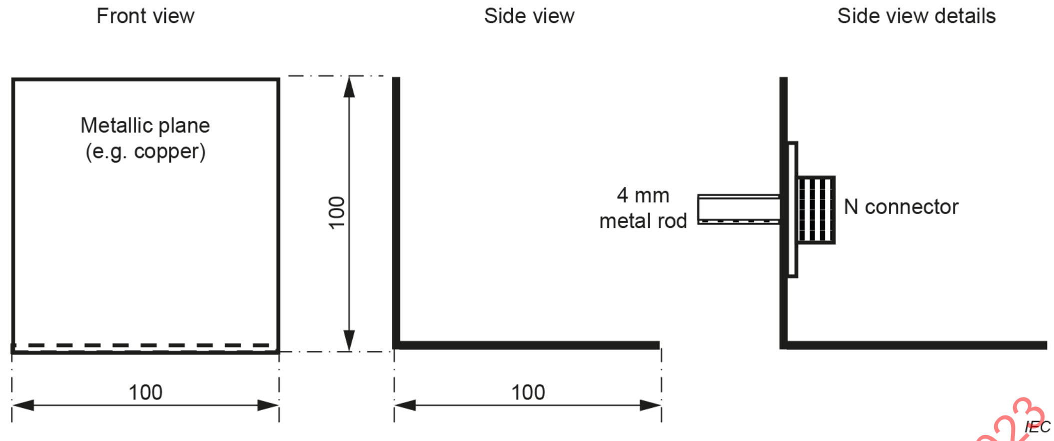


Figure A.3 – Dimension of a reference plane

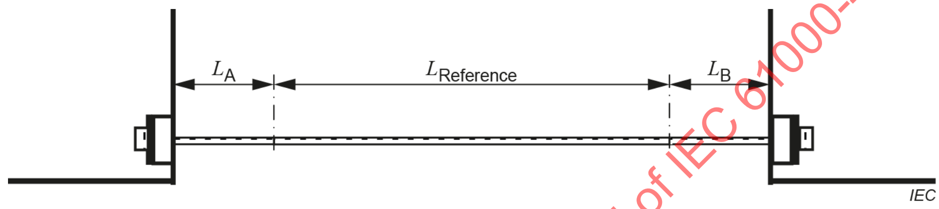


Figure A.4 – Test jig

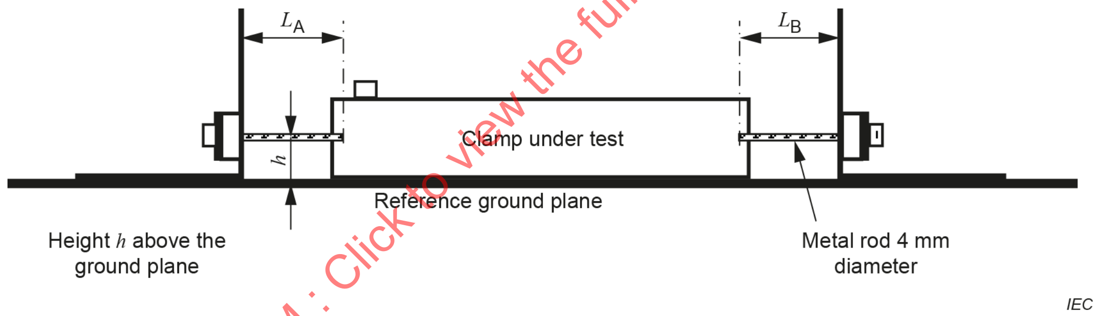


Figure A.5 – Test jig with inserted clamp

A.2.2 Clamp characterization

A.2.2.1 Impedance

A.2.2.1.1 Measurement setup

The test jig as specified in A.2.1 shall be used for the impedance measurement. The clamp (i.e. injection port) shall be terminated with a 50 Ω load and placed into the test jig, see Figure A.6. For impedance measurement the EM clamp is treated as a two-port device which can be characterized by its S-parameters S_{11}, S_{12}, S_{21} and S_{22} measured in a 50 Ω system using a network analyzer. Prior to the measurement the network analyzer shall be normalized at the cable ends (to be connected to the jig) using a standard through-open-short-matched (TOSM) method with an appropriate calibration kit. The length between the cable end and the clamp reference point shall be respected by a port offset of the vector network analyzer (VNA) or by other means.

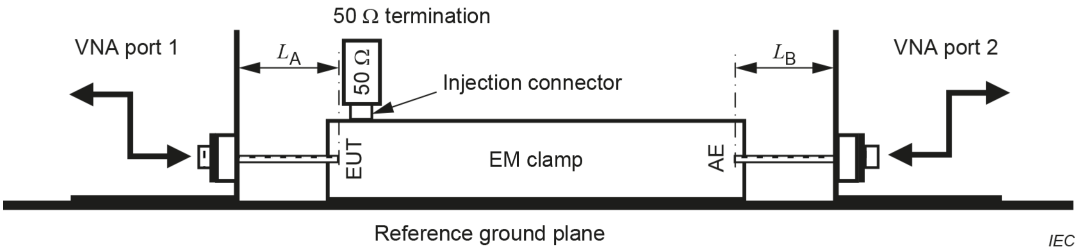


Figure A.6 – Impedance / decoupling factor measurement setup

A.2.2.1.2 Transformation

The S-parameters obtained from the network analyzer measurement as described in A.2.2.1.1 are measured in a 50 Ω system. However, the characteristic impedance Z'_{ref} of the test jig is typically different from 50 Ω. It is determined by the height of the clamp opening above the ground plane. Using $ABCD$ transformation, a set of transformed parameters independent from Z_{ref} can be obtained using the following formulae:

NOTE All calculations are performed with complex numbers.

$$Z_{ref} = 50\ \Omega \tag{A.1}$$

$$A = \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}} \tag{A.2}$$

$$B = \frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}} Z_{ref} \tag{A.3}$$

$$C = \frac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}} / Z_{ref} \tag{A.4}$$

$$D = \frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{2S_{21}} \tag{A.5}$$

Based on the $ABCD$ parameters a set of S-parameters based on the characteristic impedance Z'_{ref} of the test jig can be calculated.

$$Z'_{ref} = 60\ \Omega \times \cosh^{-1}\left(\frac{2h}{d}\right) \tag{A.6}$$

where

d is the jig conductor diameter (specified to be 4 mm);

h is the height of the centre of the jig conductor above the ground plane.

$$B' = B / Z'_{\text{ref}} \tag{A.7}$$

$$C' = C \cdot Z'_{\text{ref}} \tag{A.8}$$

$$S'_{11} = \frac{A + B' - C' - D}{A + B' + C' + D} \tag{A.9}$$

$$S'_{12} = \frac{2(AD - BC)}{A + B' + C' + D} \tag{A.10}$$

$$S'_{21} = \frac{2}{A + B' + C' + D} \tag{A.11}$$

$$S'_{22} = \frac{-A + B' - C' + D}{A + B' + C' + D} \tag{A.12}$$

A.2.2.1.3 Impedance calculation

The input impedance is given by

$$Z_{\text{in}} = Z'_{\text{ref}} \frac{1 + S'_{11}}{1 - S'_{11}} \tag{A.13}$$

Figure A.7 gives typical examples of the impedance curve for three different EM clamps.

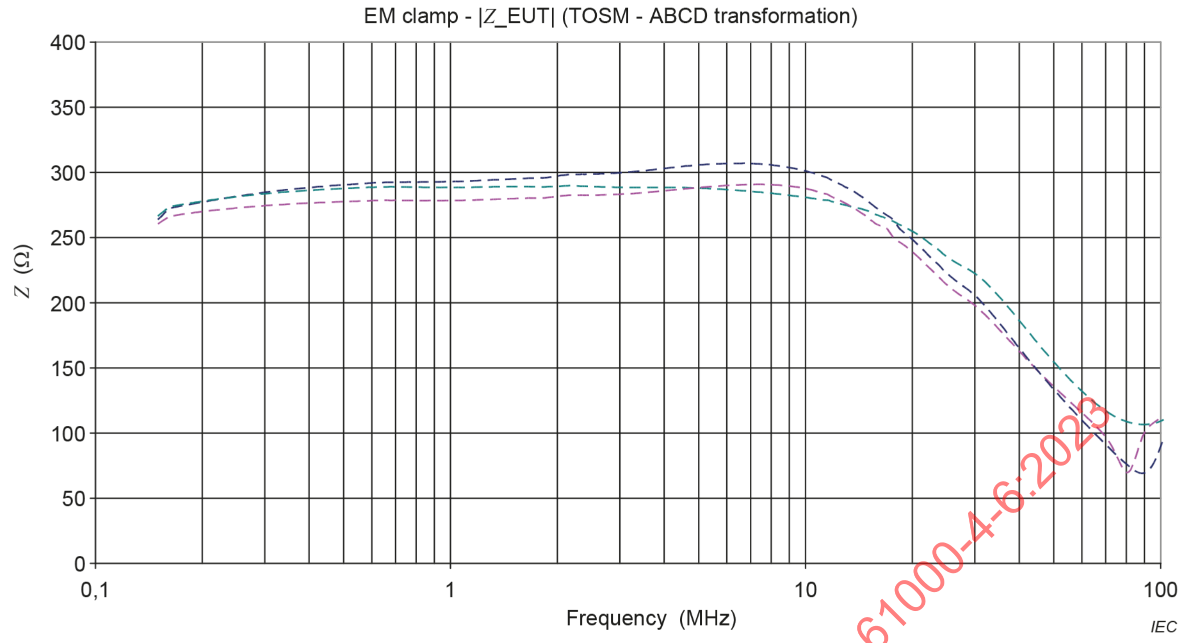


Figure A.7 – Typical examples for clamp impedance, three typical clamps

NOTE The impedance measured according to this procedure is valid for the case where the far end of the device is terminated by Z_{ref}. This value can be different when using the clamp in immunity test setups due to the real AE impedance.

A.2.2.2 Decoupling factor between EUT and AE

The measurement setup and the transformation shall be applied as described in A.2.2.1.1 and A.2.2.1.2. The decoupling factor is calculated by

$$\alpha[\mathrm{dB}] = 20\log_{10}\left(\left| S'_{21}\right|\right) \quad \text{(A.14)}$$

Figure A.8 gives typical examples of the decoupling factor curve for three different EM clamps.

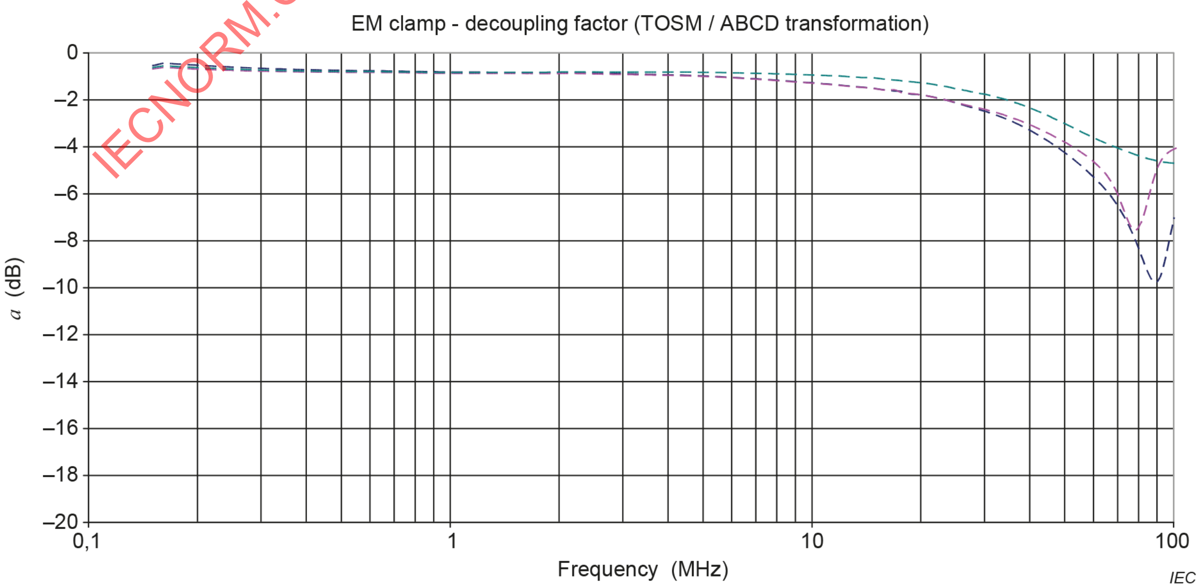


Figure A.8 – Typical examples for decoupling factors, three typical clamps

A.2.2.3 Coupling factor

The coupling factor shall be measured in a 150 Ω system according to the setup shown in Figure A.10. The test jig as described in A.2.1 shall be used with the following modifications: The height of the cylindrical rod shall be adjusted to be in the bottom position of the clamp opening. Furthermore 150 Ω to 50 Ω adapters shall be inserted in the reference planes. Prior to the measurement the setup shall be normalized by connecting the reference planes of the jig back to back, see Figure A.9. The use of two 10 dB attenuators as shown in Figure A.9 and Figure A.10 is recommended.

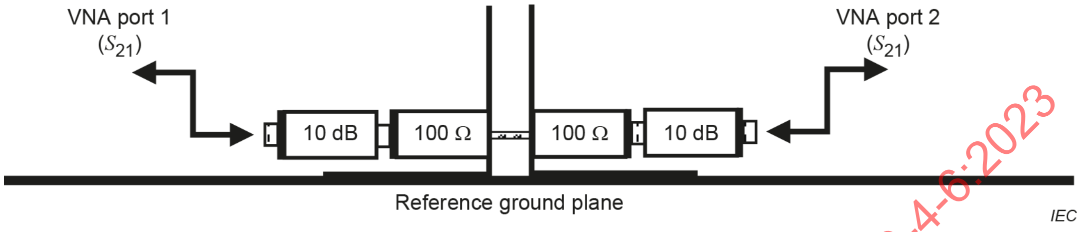


Figure A.9 – Normalization setup for coupling factor measurement

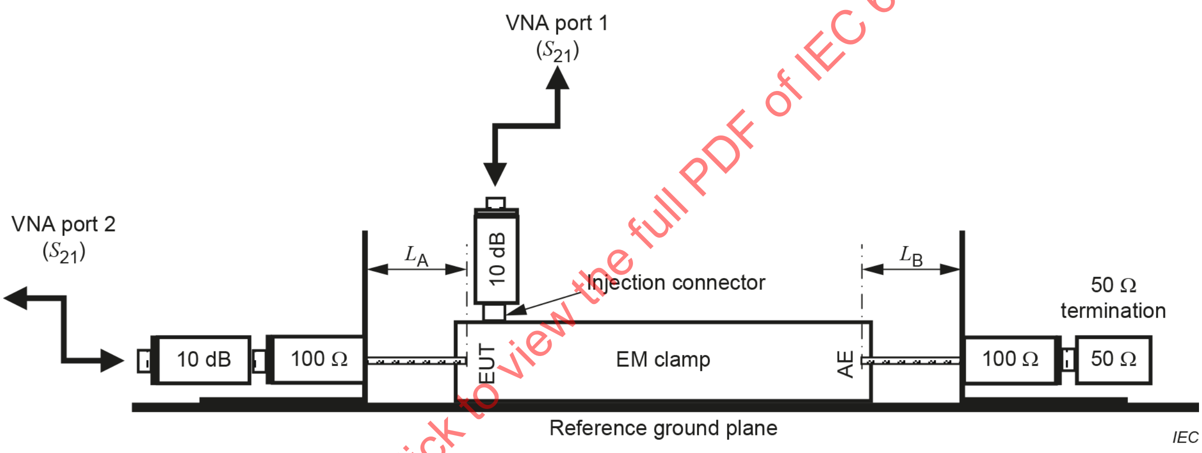


Figure A.10 – S_{21} coupling factor measurement setup

Figure A.11 gives typical examples of the coupling factor curve for three different EM clamps.

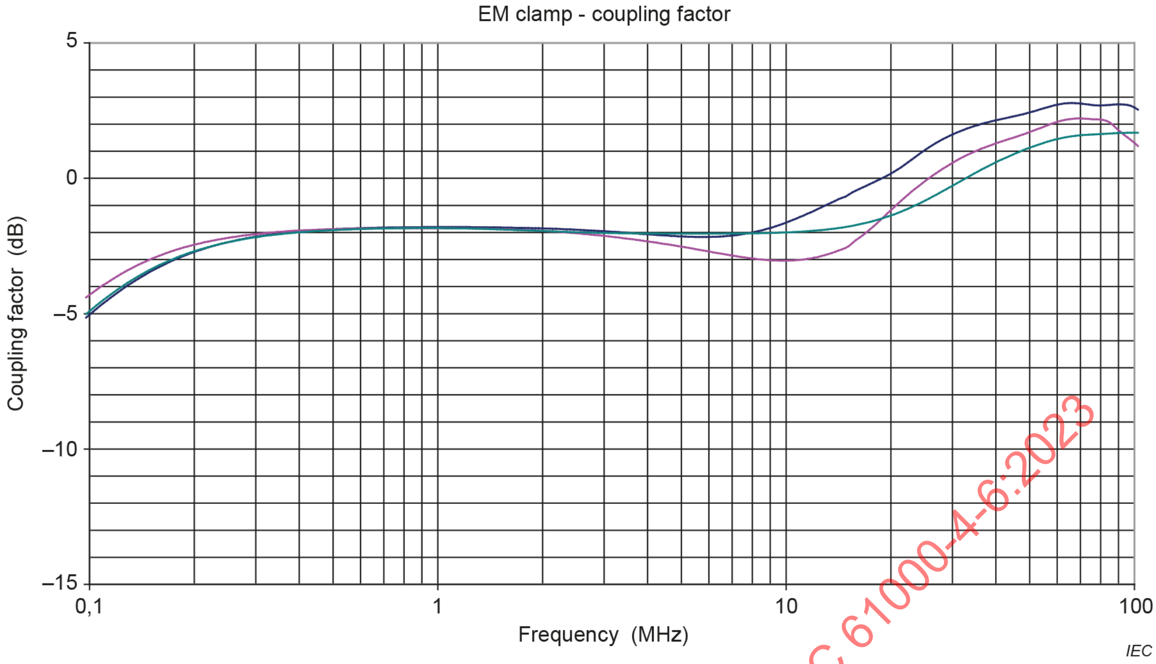


Figure A.11 – Typical examples for coupling factor, three typical clamps

A.3 Decoupling clamp characterization

A.3.1 General

Decoupling clamps are used for decoupling. Typical characteristics of impedance can be found in Figure A.13. Typical characteristics of the decoupling factor can be found in Figure A.14. These characteristics were measured using the procedures described in A.3.3 and A.3.4.

A.3.2 Specification of decoupling clamps

The requirements are:

– operating frequency range: 0,15 MHz to 80 MHz;

– decoupling > 5 dB in the frequency range above 1 MHz (measured in $ABCD$ transformation, corresponds to > 14 dB measured in a 50 Ω system);

– height of the centre of the clamp opening above the ground plane: 35 mm to 70 mm;

– clamp reference point (distance from outer dimension to first core): < 30 mm.

A.3.3 Impedance

A.3.3.1 Measurement setup

The test jig as specified in A.2.1 shall be used for the impedance measurement. The decoupling clamp shall be placed into the test jig, see Figure A.12. For impedance measurement the decoupling clamp is treated as a two-port device which can be characterized by its S-parameters S_{11}, S_{12}, S_{21} and S_{22} measured in a 50 Ω system using a network analyzer. Prior to the measurement the network analyzer shall be normalized at the cable ends (to be connected to the jig) using a standard TOSM method with an appropriate calibration kit. The length between the cable end and the decoupling clamp reference point shall be respected by a port offset of the network analyzer or by other means.

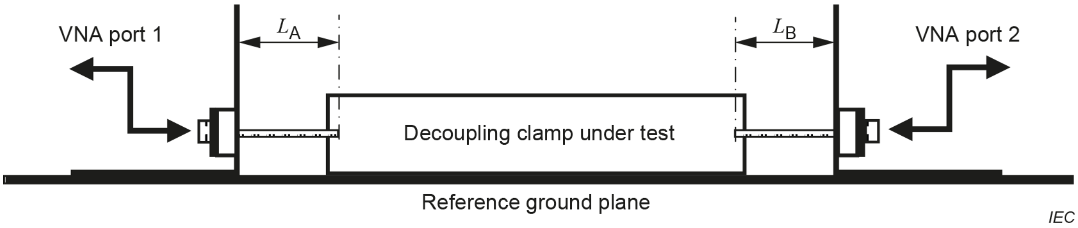


Figure A.12 – Decoupling clamp characterization measurement setup

A.3.3.2 Impedance calculation

The transformation as described in A.2.2.1.2 shall be applied. The input impedance is given by

$$Z_{in} = Z'_{ref} \frac{1+S'_{11}}{1-S'_{11}} \tag{A.15}$$

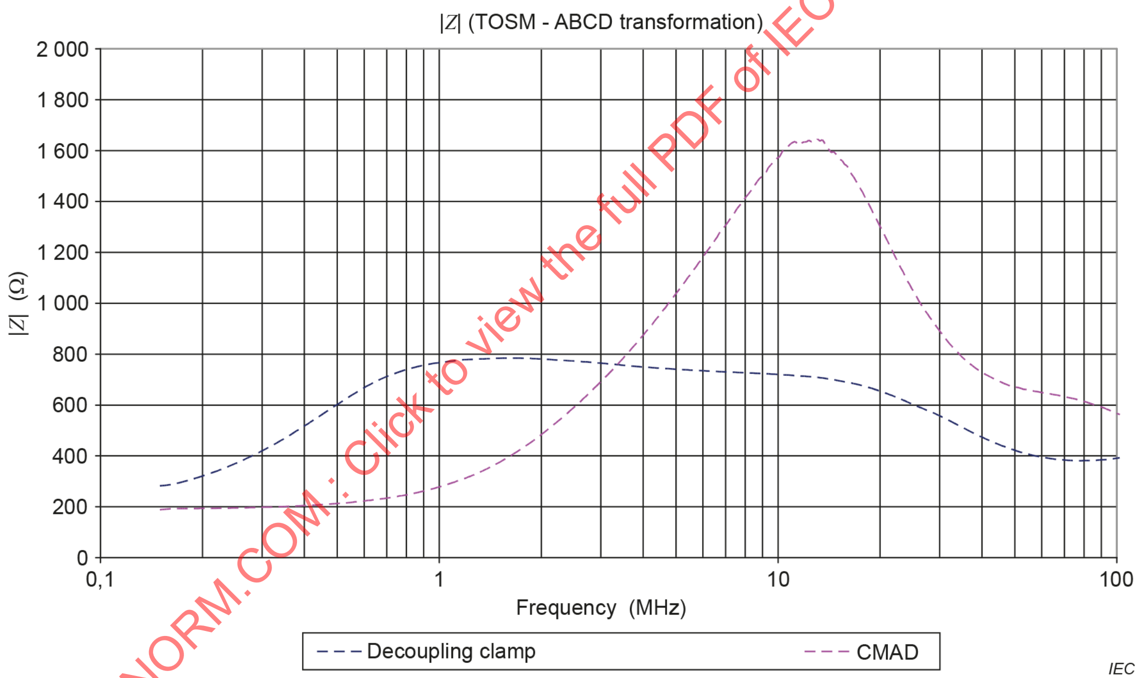


Figure A.13 – Typical examples for the decoupling clamp impedance

NOTE The impedance measured according to this procedure is valid for the case where the far end of the device is terminated by Z_{ref}. This value can be different when using the clamp in immunity test setups due to the real AE impedance.

A.3.4 Decoupling factor

The measurement setup and the transformation shall be applied as described in A.3.3.1 and A.2.2.1.2. The decoupling factor is calculated by Formula (A.14).

NOTE Decoupling devices used for other applications are possibly not suitable for this document. For example, the common-mode absorption device (CMAD) (CISPR 16-1-4) is designed for good decoupling between 30 MHz and 200 MHz and is therefore less suitable for the lower frequency range indicated in this document.

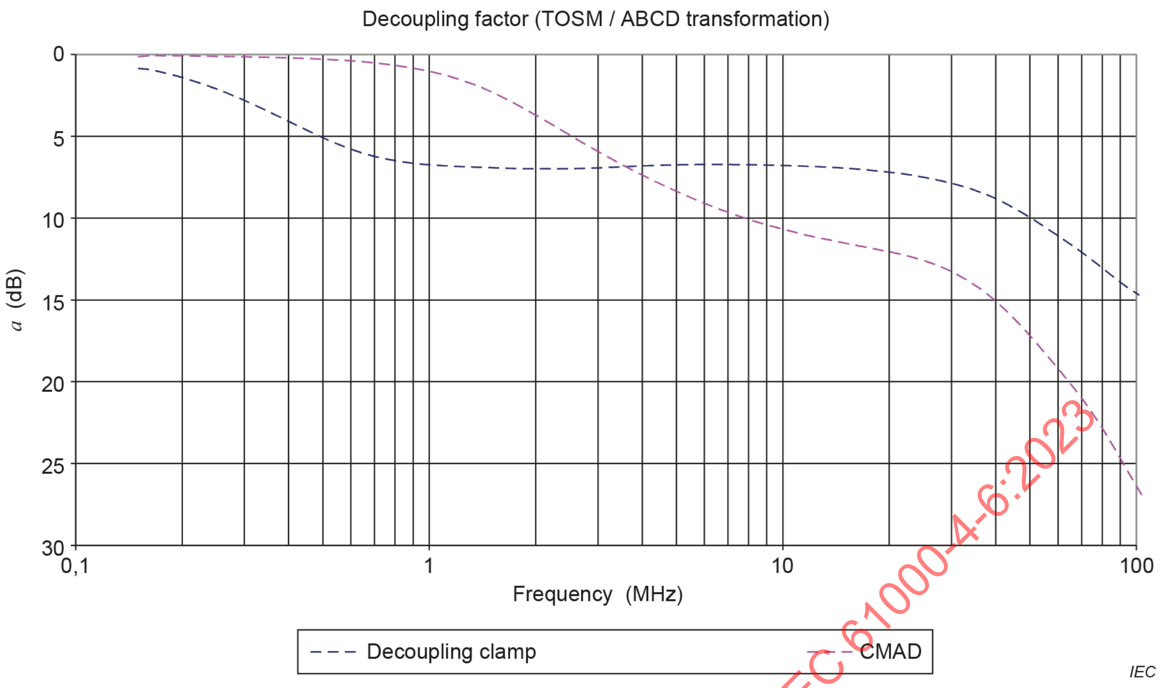


Figure A.14 – Typical examples for decoupling factors

Annex B
(informative)

Selection criteria for the frequency range of application

Annex B is provided for guidance to the product committee. Although the requirements in this document are specified for the frequency range 150 kHz up to 80 MHz, the applicable frequency range depends on the normal installation and operation conditions of the equipment to be tested. For example, a small battery-powered equipment with total dimensions less than 0,4 m and without any metallic cable(s) connected thereto, does not need to be tested below 80 MHz because it is unlikely that the induced RF energy resulting from the disturbing EM field will upset the device.

In general, the stop frequency will be 80 MHz. In some cases, where small sized equipment is considered (dimension < λ/10), dedicated product standards may specify that the stop frequency is extended up to a maximum of 230 MHz. The coupling and decoupling devices in this case shall then meet the parameter of common-mode impedance seen at the EUT port specified in Table B.1. When using this test method up to higher frequencies, results are influenced by the size of equipment, the type(s) of interconnecting cables used, and the availability of special CDNs, etc. Further guidance for proper application should be supplied in the dedicated product standards.

Table B.1 – Main parameter of the combination of the coupling and decoupling device when the frequency range of the test is extended above 80 MHz

	Frequency band		
Parameter	0,15 MHz to 24 MHz	24 MHz to 80 MHz	80 MHz to 230 MHz
$\lvert Z_{ce} \rvert$	150 Ω ± 20 Ω	150^{+60}_{-45} Ω	150 Ω ± 60 Ω
Neither the argument of Z_{ce} nor the decoupling factor between the EUT port and the AE port are specified separately. These factors shall be met with the AE port open or short-circuited to the reference ground plane.			

If a product committee decides to use CDNs for frequencies between 9 kHz and 150 kHz the specification for the impedance for the frequency range 0,15 MHz to 24 MHz shall also be met in the frequency range from 9 kHz to 150 kHz.

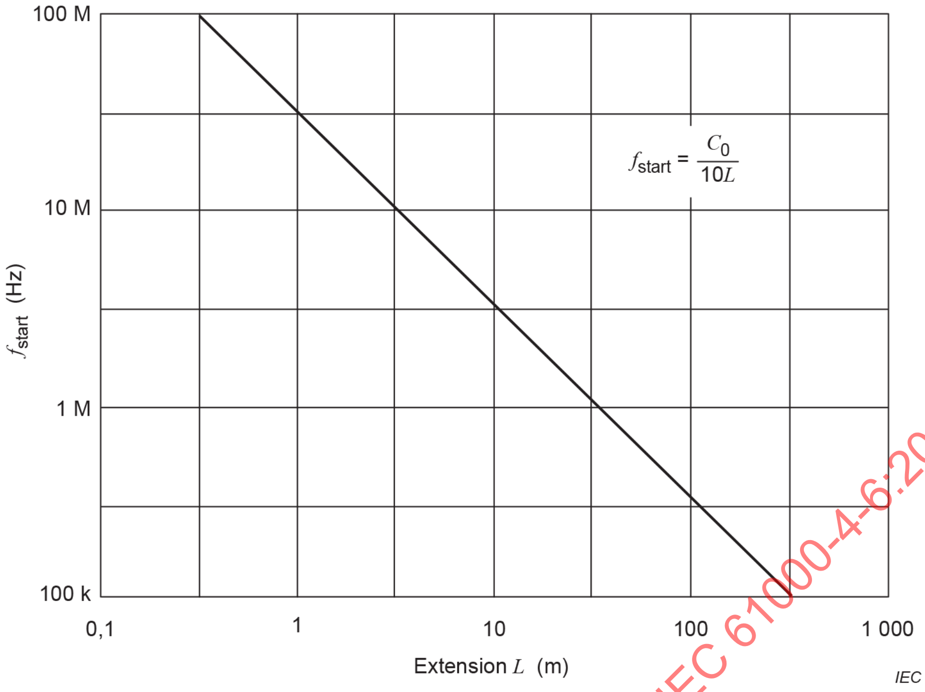
The start frequency depends on whether the equipment including its connected cables is capable of receiving a large amount of RF energy from the disturbing EM field.

Three different situations are considered.

a) Battery-powered equipment (dimension < λ/10) which has no connection(s) to ground nor to any other equipment and which is not used during battery charging, does not need to be tested according to this document. If the equipment will be operated during battery charging, case b) or c) applies.
   For battery-powered equipment (dimension ≥ λ/10), its size, including the maximum length of the cables connected, determines the start frequency, as shown in Figure B.1.

b) Equipment connected to a (power) mains network but not connected to any other equipment or cables.
   The power supply is provided via a coupling and decoupling device and the equipment is loaded by an artificial hand. The start frequency is 150 kHz.

c) Equipment connected to a (power) mains network which is also connected via control and I/O or telecommunication cables to other insulated or non-insulated equipment.
   The start frequency is 150 kHz.



c_0 = 3×10^8 m/s

L = cable length + equipment size

The following is a list of examples:

– For a cable only connected to a keyboard (extended dimension ≥ λ/10) powered from a battery-operated personal computer, with a coiled cable having a length of 4 m, the start frequency should be 6,67 MHz. The keyboard should be covered by the artificial hand. For a mouse having just 2 m of cable, the start frequency would be 15 MHz, etc.

– A pocket calculator with an AC/DC adapter option, should be tested on the mains side of the adapter from 150 kHz upwards. The pocket calculator should be covered by the artificial hand.

– A hand-held battery-supplied multimeter which can have connections to ground should be tested on its cables from 150 kHz upwards. The multimeter should be covered by the artificial hand.

– A double insulated (mains) compact disc player which can be connected to an audio receiver, connected to insulated loudspeaker boxes, but also having an antenna input terminal which can be connected to ground should be tested on both mains supply and audio cable(s) from 150 kHz upwards.

– A burglar alarm having various insulated sensors distributed through a building, of which the maximum length of cable may extend 200 m (EUT's specification) should be tested on these cables from 150 kHz upwards.

Figure B.1 – Start frequency as function of cable length and equipment size

Annex C
(informative)

Guidelines for selecting test levels

The test levels should be selected in accordance with the electromagnetic radiation environment to which the EUT and cables can be exposed when finally installed. The consequences of failure should be kept in mind in selecting the test level to be used. A higher level should be considered if the consequences of failure are large.

If the EUT is to be installed at a few sites only, then inspection of the local RF sources enables a calculation of field strengths likely to be encountered. If the powers of the sources are not known it can be possible to measure the actual field strength at the location(s) concerned.

For equipment intended for operation in a variety of locations, the following guidelines can be followed in selecting the test level to be used.

The following classes are related to the levels listed in Clause 5; they are considered as general guidelines for the selection of the appropriate levels:

Class 1: Low-level electromagnetic radiation environment. Typical level where radio/ television stations are located at a distance of more than 1 km and typical level for low-power transceivers.

Class 2: Moderate electromagnetic radiation environment. Low-power portable transceivers (typically less than 1 W rating) are in use, but with restrictions on use in close proximity to the equipment. A typical commercial environment.

Class 3: Severe electromagnetic radiation environment. Portable transceivers (2 W and more) are in use relatively close to the equipment but at a distance not less than 1 m. High-powered broadcast transmitters are in close proximity to the equipment and ISM equipment can be located close by. A typical industrial environment.

Class X: X is an open level which can be negotiated and specified in the dedicated equipment specifications or equipment standards.

The test levels described are typical values which are rarely exceeded in the locations described. At some locations these values are exceeded, for example in the proximity of high-power transmitters or ISM equipment located in the same building. In such cases, it can be preferable to shield the room or building, and filter the signal and power wires to the equipment, rather than specifying all equipment to be immune to such levels.

Annex D
(informative)

Information on coupling and decoupling networks

D.1 Basic features of the coupling and decoupling networks

The CDN should provide:

- coupling of the disturbing signal to the EUT;
- stable impedance, seen from the EUT, independent of the AE common-mode impedance;
- decoupling of the AE from the disturbing signal to prevent interference of the AE;
- transparency to the wanted signal.

The required parameters for the CDNs in the frequency range 150 kHz to 80 MHz are specified in 6.2.1 and examples are given in Clause D.2.

In Figure D.1 to Figure D.7, the common-mode impedance, Z_{ce}, is formed by the sum of the internal resistance of the test generator (50 Ω) and the parallel combination of the resistors from the conductors of the cable under test (100 Ω). With the use of a suitable inductor L ($|\omega L| >> 150$ Ω), the decoupling elements, C_2, should not influence Z_{ce}.

The centre of the EUT port on the CDN should be located 30 mm above the reference ground plane. The cable between the CDN and the EUT can then represent a transmission line with a characteristic impedance of about 150 Ω if located 30 mm above the reference ground plane.

The impedance of capacitors C_1, providing DC and LF separation of the test generator and the individual wires of the CDN, should be much less than 150 Ω in the frequency range of interest.

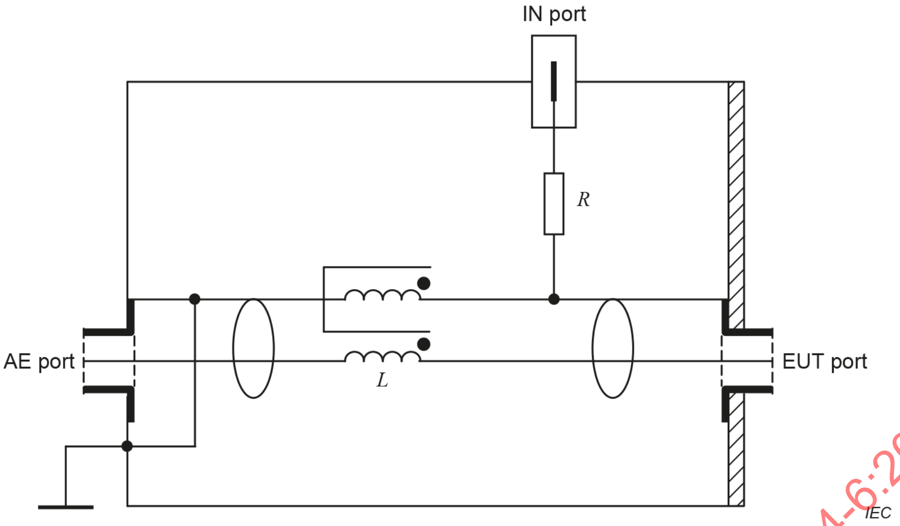
The AE is decoupled by a common-mode inductor L, and by the capacitors C_2 for unscreened cables or by a common-mode inductor L only. For screened cables, the capacitors C_2 are not needed as the screen will be connected to the reference ground plane at the AE side.

It is essential for unscreened cable that the value of C_2 is chosen such that the wanted signal is not unduly affected. It is not permissible for CDN parameters to be unduly affected by the wanted signal, for example in CDN-M1, saturation of the ferrite(s).

WARNING – Since C_1 and C_2 bridge live parts in the mains CDNs, suitable Y capacitors shall be used. Due to the high leakage current, the CDN shall have an earth terminal which shall be connected to the reference ground plane under all test conditions, and the reference ground plane shall be appropriately connected to the protective earth.

D.2 Examples of coupling and decoupling networks

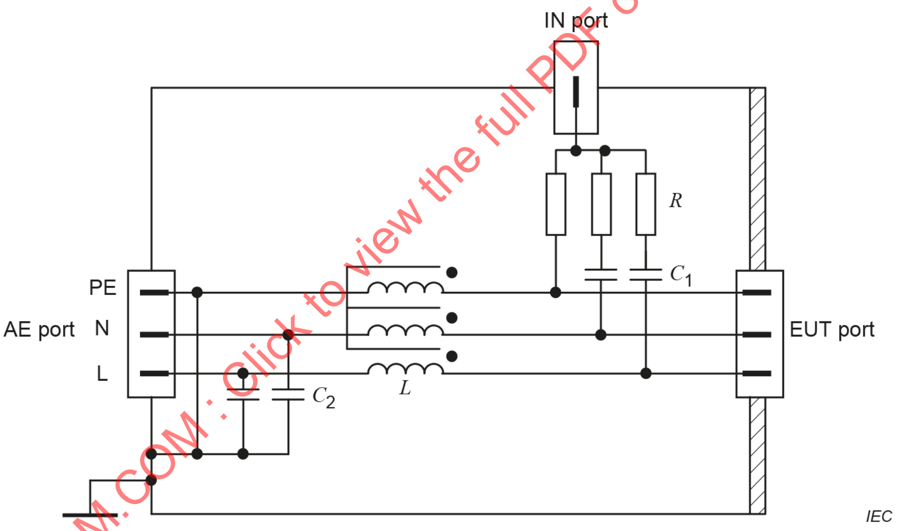
A number of possibilities are shown in Figure D.1 to Figure D.7 because it is impossible to cover all functional requirements with one CDN.



R = 100 Ω

L ≥ 280 µH at 150 kHz

Figure D.1 – Example of a simplified diagram for the circuit of CDN-S1 used with screened cables (see 6.2.2.5)

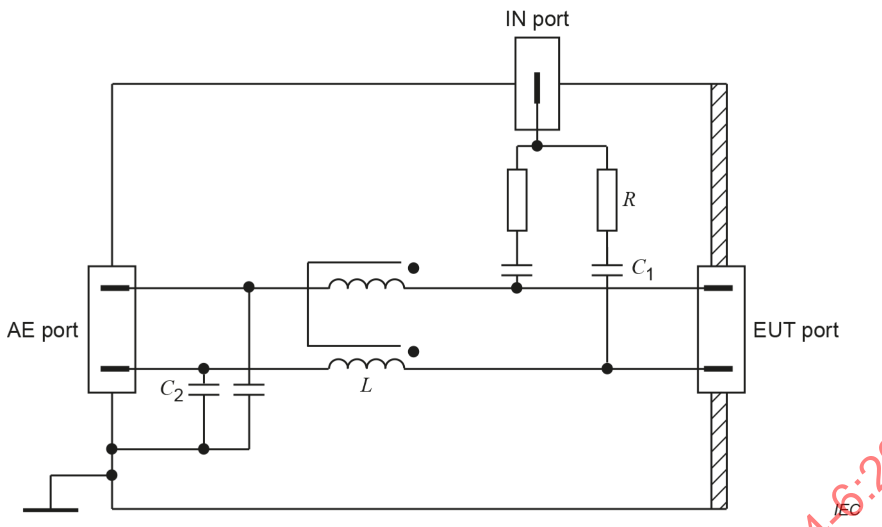


CDN-M3, C_1 (typical) = 10 nF, C_2 (typical) = 47 nF, R = 300 Ω, L ≥ 280 µH at 150 kHz

CDN-M2, C_1 (typical) = 10 nF, C_2 (typical) = 47 nF, R = 200 Ω, L ≥ 280 µH at 150 kHz

CDN-M1, C_1 (typical) = 22 nF, C_2 (typical) = 47 nF, R = 100 Ω, L ≥ 280 µH at 150 kHz

Figure D.2 – Example of simplified diagram for the circuit of CDN-M1, CDN-M2 and CDN-M3 used with unscreened supply (mains) lines (see 6.2.2.2)



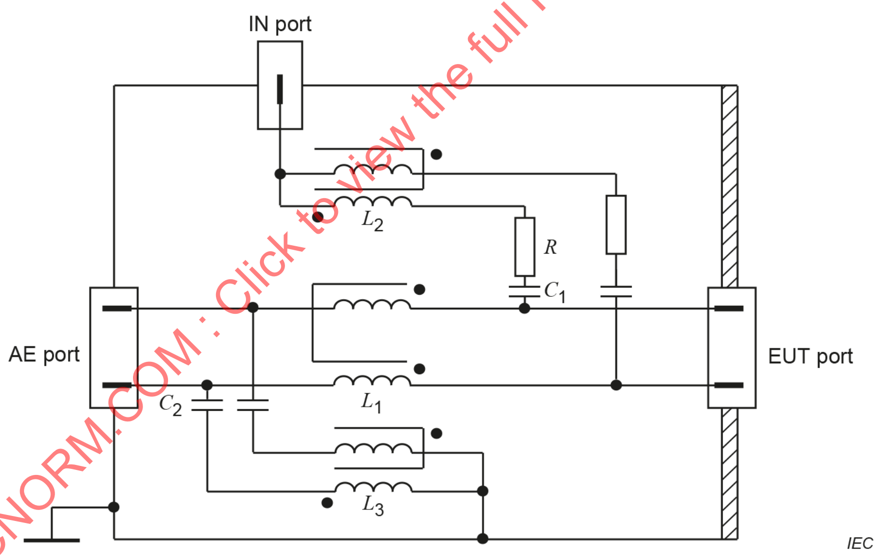
C_1 (typical) = 10 nF

C_2 (typical) = 47 nF

R = 200 Ω

L ≥ 280 µH at 150 kHz

Figure D.3 – Example of a simplified diagram for the circuit of CDN-AF2 used with unscreened unbalanced lines (see 6.2.2.4)



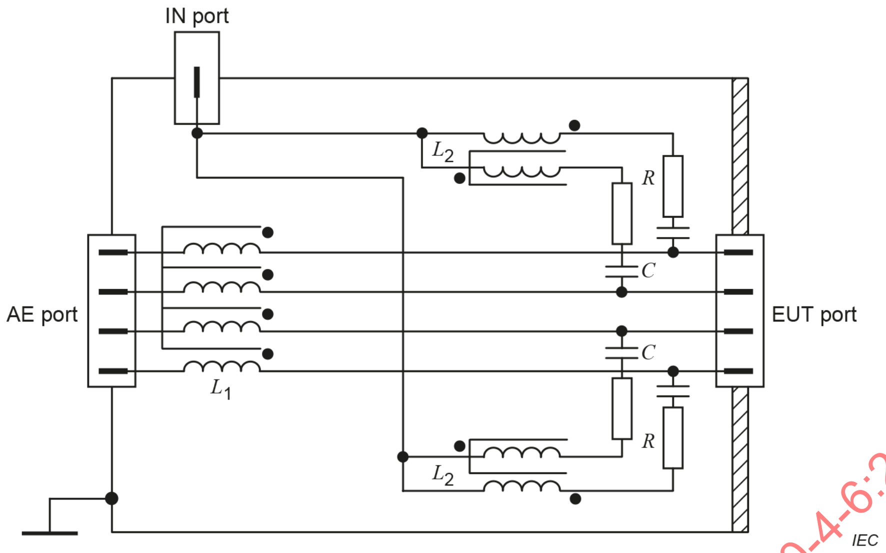
C_1 (typical) = 10 nF,

C_2 (typical) = 47 nF, R = 200 Ω

L_1 ≥ 280 µH at 150 kHz

$L_2 = L_3$ = 6 mH (when C_2 and L_3 are not used, L_1 ≥ 30 mH)

Figure D.4 – Example of a simplified diagram for the circuit of CDN-T2, used with an unscreened balanced pair (see 6.2.2.3)



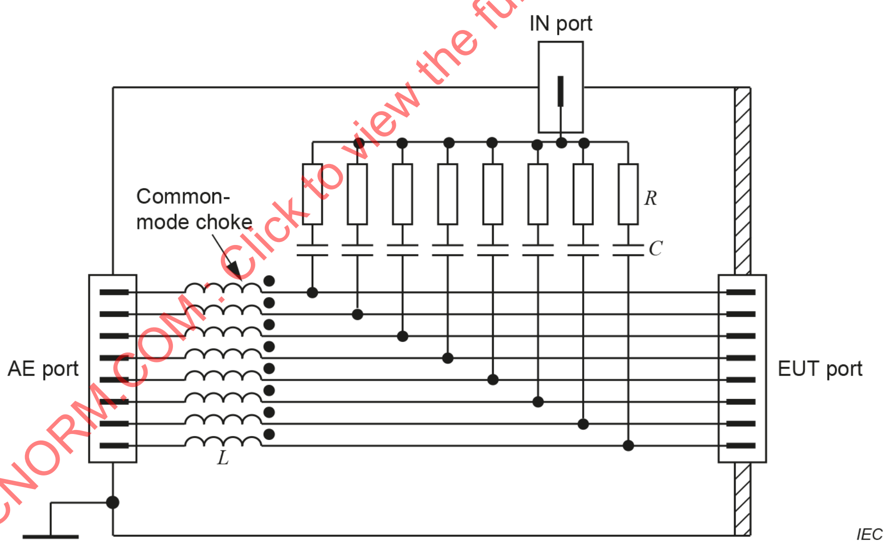
C (typical) = 5,6 nF

R = 400 Ω

$L_1 \gg$ 280 µH at 150 kHz

L_2 = 6 mH

Figure D.5 – Example of a simplified diagram of the circuit of CDN-T4 used with unscreened balanced pairs (see 6.2.2.3)

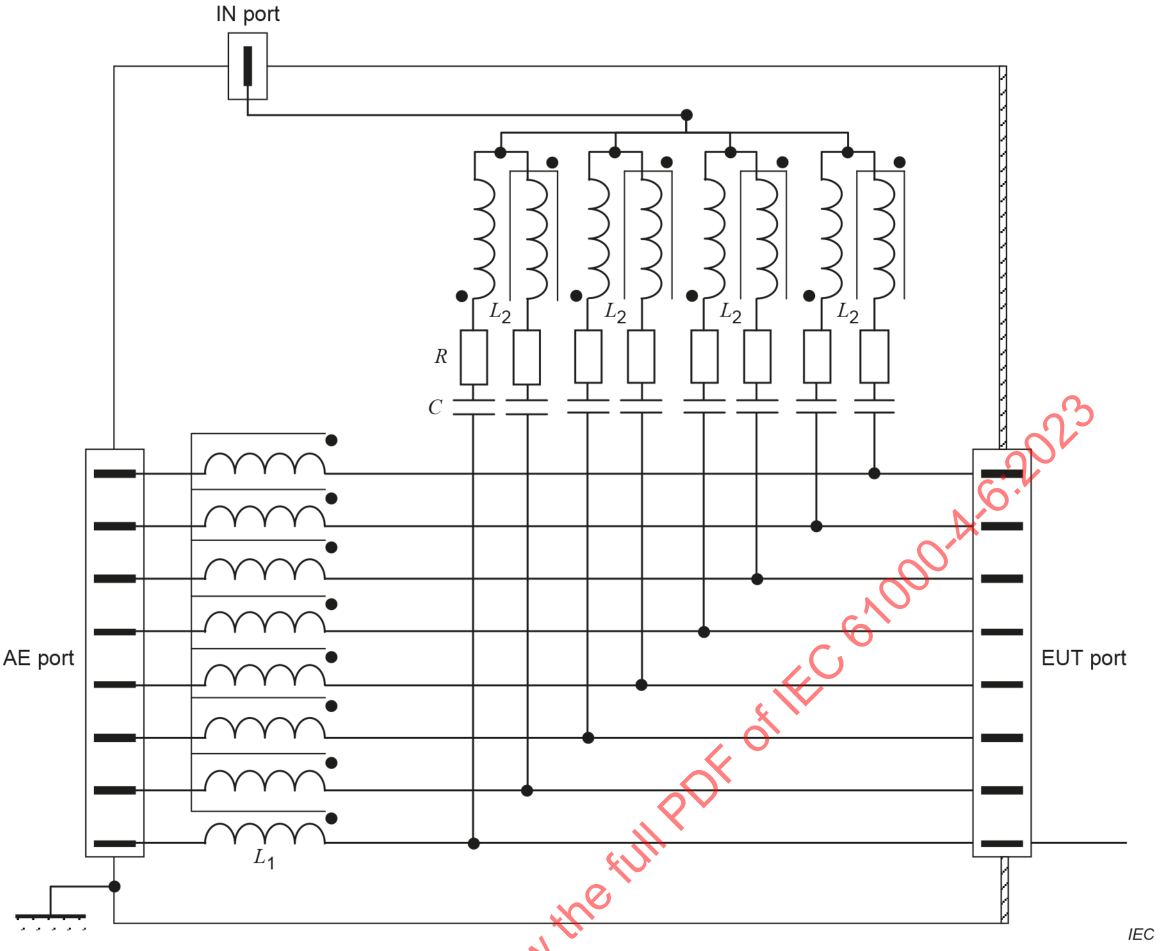


C (typical) = 2,2 nF

R = 800 Ω

$L \gg$ 280 µH at 150 kHz

Figure D.6 – Example of a simplified diagram of the circuit of CDN AF8 used with unscreened unbalanced lines (see 6.2.2.4)



C (typical) = 2,2 nF

R = 800 Ω

$L_1 \gg$ 280 μH at 150 kHz

$L_2 \gg$ 6 mH at 150 kHz

Figure D.7 – Example of a simplified diagram of the circuit of CDN-T8 used with unscreened balanced pairs (see 6.2.2.3)

Annex E
(informative)

Information for the test generator specification

The required output power of the power amplifier, PA (see Figure 4), is determined by taking into account the attenuator T2 (see 6.1), the amplitude modulation depth (80 % – see Figure 3), and the minimum coupling factor of the CDN or clamp used (see Table E.1).

Table E.1 – Required power amplifier output power to obtain a test level of 10 V

Injection device	Minimum coupling factor ± 1,5 dB dB	Required power at output of PA W
CDN	0	7
Current clamp winding (ratio 5:1)	–14	176
EM clamp	–6	28
NOTE The coupling factor is defined in 3.6. It can be measured by using the output level-setting circuit (see Figure 16). The coupling factor is the ratio between the output voltage U_{mr}, obtained when using a coupling and decoupling device in series with a 150 Ω to 50 Ω adapter, and the output voltage when using two 150 Ω to 50 Ω adapters in series.		

Annex F
(informative)

Test setup for large EUTs

F.1 General

The test setup as described in the main body of this document (see Clause 7) is not fully sufficient to cover the needs of some large EUTs with cables entering or exiting the EUT at heights greater than 1 m. As the upper frequency of the test signal is 80 MHz, EUT size can be considerable compared to the wavelength, and resonance effects can be present with cables that are connected to such EUTs.

In this case, Annex F provides an alternative test method applicable to large EUTs that places the coupling device near to the cable entry, resulting in a small loop area with reduced resonance effects.

Examples of large EUTs to which Annex F may apply include, but are not limited to, the following:

– rack-mounted telecommunication switching systems;
– electrical machinery;
– rack-mounted switch and control gear.

F.2 Test setup for large EUTs

Examples of the test setup for large EUTs are shown in Figure F.1 and Figure F.2.

The elevated reference ground plane shown in Figure F.1 is the reference ground plane for this test setup. The purpose of the elevated reference ground plane is to reduce the length of cable between the EUT and CDN, thereby controlling or reducing the effects of resonances in the cables.

The size of the elevated reference ground plane shall be large enough to extend a minimum of 0,2 m beyond all CDNs used in the test.

The elevated reference ground plane shall be electrically connected to earth for safety reasons. This connection is not significant from an RF point of view.

NOTE 1 The physical construction of the elevated reference ground plane and its support structure to ensure a mechanically safe condition are important.

If the EUT is provided with other earth terminals than a PE lead in the power input, they all shall be bonded together and then connected to the reference ground plane through CDN-M1 (unless this would significantly deviate from the intended installation in practice).

The equipment to be tested should be placed on an insulating support of 0,1 m ± 0,05 m in height above the ground plane. In case the equipment is delivered on a transport pallet, and if due to its excessive weight or size it cannot be safely removed from its transport pallet, then the EUT may be left on its pallet for testing even if its height exceeds 0,1 m ± 0,05 m. In case the equipment, because of size or weight, cannot be elevated 0,1 m ± 0,05 m, thinner insulation may be used provided the EUT is electrically isolated from the ground plane. Any variation from the standard method of testing shall be recorded in the test report.

The AE may be located on the elevated reference ground plane but does not need to be located on it provided the AE is connected to the EUT via a CDN. When direct injection is used, the AE may be located off of the elevated reference ground plane provided proper decoupling is used. In the case where clamp injection is used instead of injection via a CDN, the AE shall be located on the elevated reference ground plane.

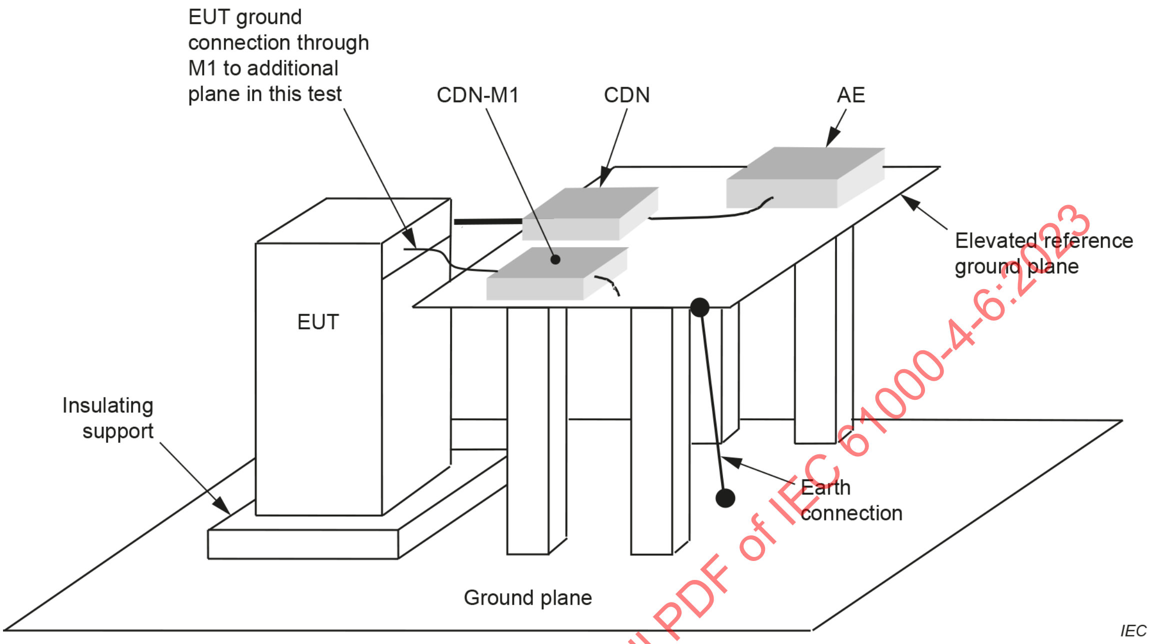


Figure F.1 – Example of large EUT test setup with elevated horizontal reference ground plane

The vertical reference ground plane shown in Figure F.2 is the reference ground plane for this test setup. The purpose of the vertical reference ground plane is to reduce the length of cable between the EUT and CDN, thereby controlling or reducing the effects of resonances in the cables.

NOTE 2 The vertical reference ground plane can be more applicable than the horizontal elevated reference ground plane in cases where cables enter/exit the EUT at multiple heights or where only one CDN is applied.

The vertical reference ground plane shall be electrically connected to earth for safety reasons. This connection is not significant from an RF point of view.

The size of the vertical reference ground plane shall be large enough to extend a minimum of 0,2 m beyond all CDNs used in the test. In case of an EUT having only one line, the horizontal reference ground plane shall be bonded to the floor with low inductivity. The length of cable under test between the EUT and CDN shall be a maximum of 0,3 m. The distance between the EUT and the vertical reference ground plane shall be such that the 0,3 m cable length requirement can be satisfied. A wall of a shielded room can be used as the vertical reference ground plane.

The CDNs shall be mounted to the vertical reference ground plane at a height that allows cables from the EUT to pass to the CDNs in a horizontal alignment.

The specifications for the test setup using a horizontal elevated reference ground plane (i.e., insulating support and location of AE) apply for the test setup using a vertical reference ground plane accordingly.

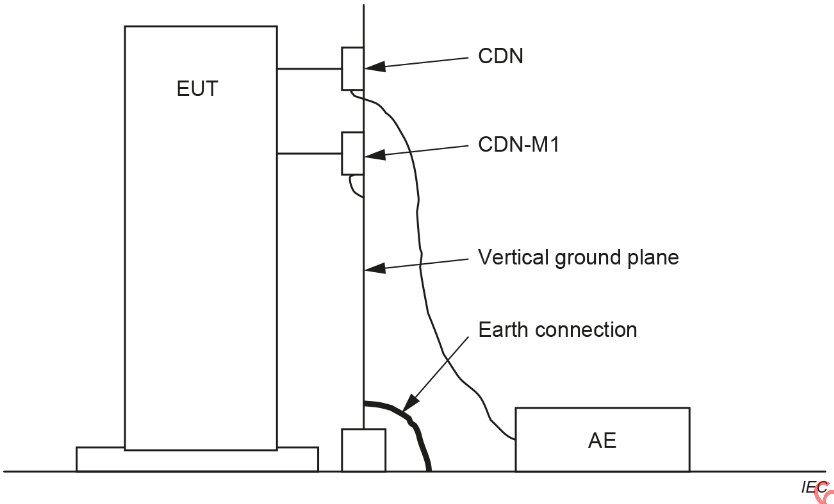


Figure F.2 – Example of large EUT test setup with vertical reference ground plane

Annex G
(informative)

Measurement uncertainty of the voltage test level

G.1 General

Annex G gives information related to measurement uncertainty (MU) of the voltage generated by the test instrumentation according to the particular needs of the test method contained in the main body of this document. Further information about MU can be found in the publications listed in the Bibliography.

Annex G focuses on the uncertainties for level-setting as an example and shows how an uncertainty budget can be prepared based both on the measurement instrumentation uncertainty and the voltage test level-setting procedure described in 6.4. Other parameters of the disturbance quantity (e.g. modulation frequency, modulation depth, etc.) can be of equal importance and should also be considered by the test laboratory as appropriate. The methodology shown in Annex G is considered to be applicable to all parameters of the disturbance quantity.

The subject of Annex G is the evaluation of MU of the voltage level set in the case of 150 Ω EUT impedance as required by the test level-setting procedure in 6.4. The analysis of non-reproducibility issues related to tests made by different laboratories on the same EUT are out of the scope of Annex G.

G.2 General symbols

The general symbols that appear in Table G.1 and that are listed below are a subset of those defined in IEC TR 61000-1-6:

X_i input quantity;

x_i estimate of X_i;

$u(x_i)$ standard uncertainty of x_i;

c_i sensitivity coefficient;

y result of a measurement (the estimate of the measurand), corrected for all recognized significant systematic effects;

$u_c(y)$ (combined) standard uncertainty of y;

$U(y)$ expanded uncertainty of y;

k coverage factor;

δX_i correction for the influence quantity X_i.

G.3 Uncertainty budgets for test methods

G.3.1 Definition of the measurand

The measurand is the open circuit test level U_0 as defined in Clause 5.

NOTE U_0 is the voltage supplied through a coupling device to a 150 Ω load at a specific frequency comprised between 150 kHz and 80 MHz. For the purpose of measurement uncertainties, it is expressed in dB(μV).

G.3.2 MU contributors of the measurand

The following influence diagrams (Figure G.1, Figure G.2, Figure G.3 and Figure G.4) give examples of influence quantities upon voltage test level. The diagrams are not exhaustive. The most important contributors from the influence diagrams have been selected for the uncertainty budget calculation examples shown in Table G.1 to Table G.8. At a minimum, these contributors listed in Table G.1 to Table G.8 shall be used for the calculation of MU in order to obtain comparable budgets for different test sites or laboratories. It is noted that a laboratory may include additional contributors (for example, type A) in the calculation of the MU, on the basis of its particular circumstances.

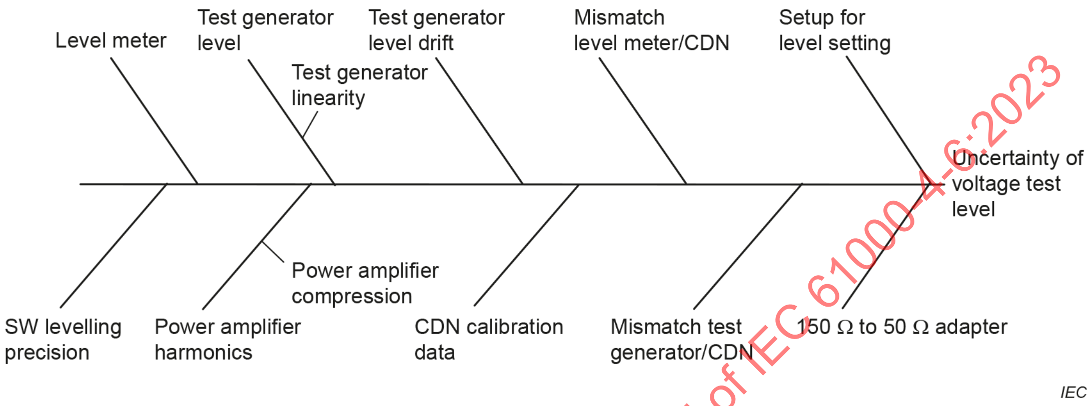


Figure G.1 – Example of influences upon voltage test level using CDN

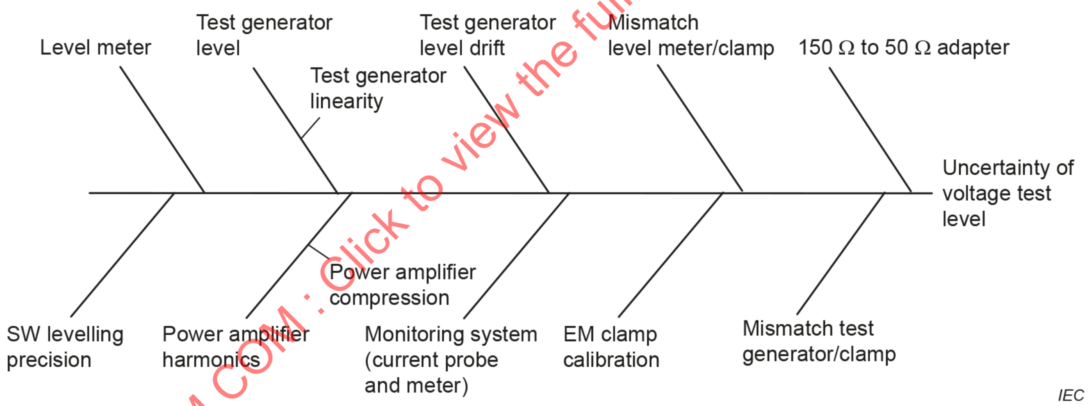


Figure G.2 – Example of influences upon voltage test level using EM clamp

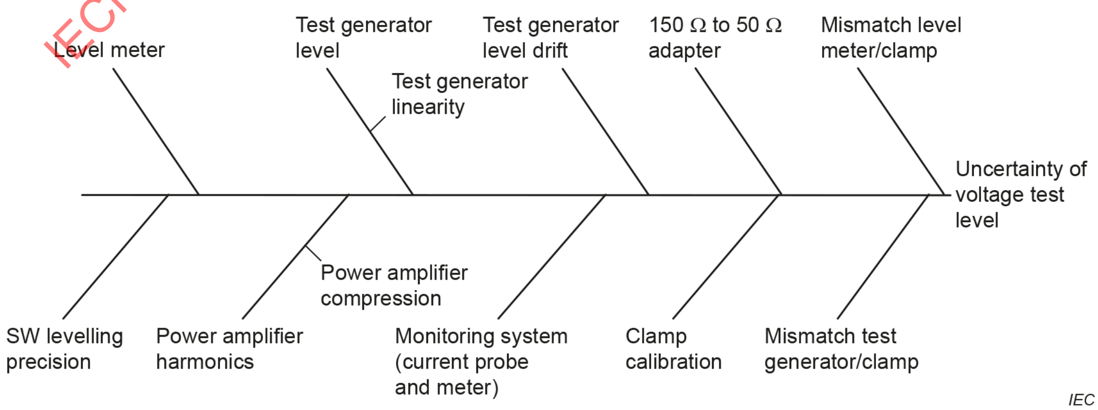


Figure G.3 – Example of influences upon voltage test level using current clamp

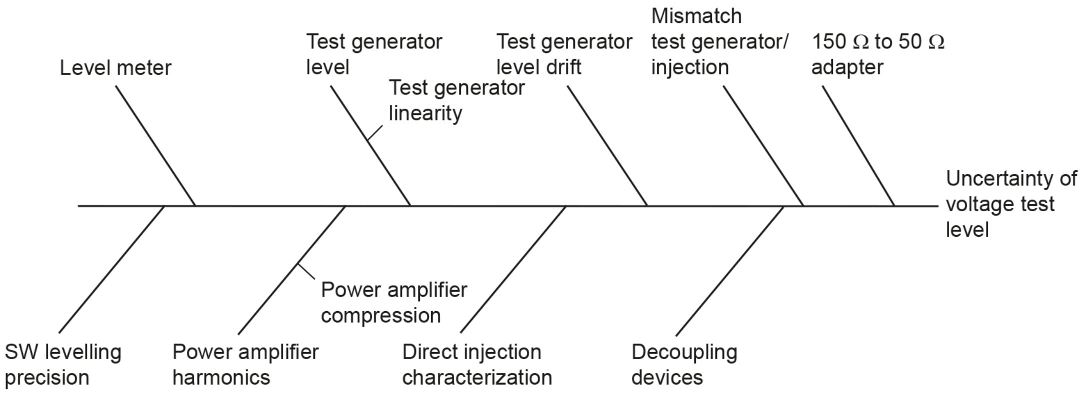


Figure G.4 – Example of influences upon voltage test level using direct injection

G.3.3 Input quantities and calculation examples for expanded uncertainty

The examples below assume that the same instrumentation used in the test level-setting procedure is used for generating the voltage test level (the measurement setup for the test level-setting is that depicted in Figure 16 and Figure G.5), except for the measuring instrument, which is absent during the test. However, the uncertainty contributions that would exist, if different instrumentation is used, are shown in Table G.1 to Table G.8 but their values can be set to zero (see notes below Table G.1 to Table G.8).

Therefore, it has to be recognized that the contributions which apply for the level-setting process and for the test will possibly not be the same. This leads to (slightly) different uncertainty budgets for each process.

Table G.1 to Table G.8 give examples of an uncertainty budget for voltage level-setting. Each uncertainty budget consists of two parts, the uncertainty for level-setting and the uncertainty for test. The level-setting process determines the relation between U_x and U_{mr} (see Figure G.1.) During the test process, U_x is reproduced.

1) Uncertainty budget when using CDN

Table G.1 and Table G.2 give examples of an uncertainty budget for voltage level-setting and an uncertainty budget for the test using CDN.

Model function for CDN voltage level-setting process (all quantities in logarithmic units):

$$U_0 = U_{LMc} + 15{,}6\ \text{dB} + \delta LM_c + \delta RCAL + \delta SETUP + \delta SW_c + \delta ML$$

Explanation of contributions:

U_{LMc} voltage indication U_{mr} from the power meter directly in or converted to dB(μV).

NOTE 1 The other symbols are included in the explanation of terms below.

Model function for CDN test process (all quantities in logarithmic units):

$$U_0 = U_x + 20\ \log\ (6/5) + \delta LMC_t + \delta CAL + \delta SW_t$$

$$U_x = U_{LMc} + 20\log(5)$$

NOTE 2 The symbols are included in the explanation of terms below.

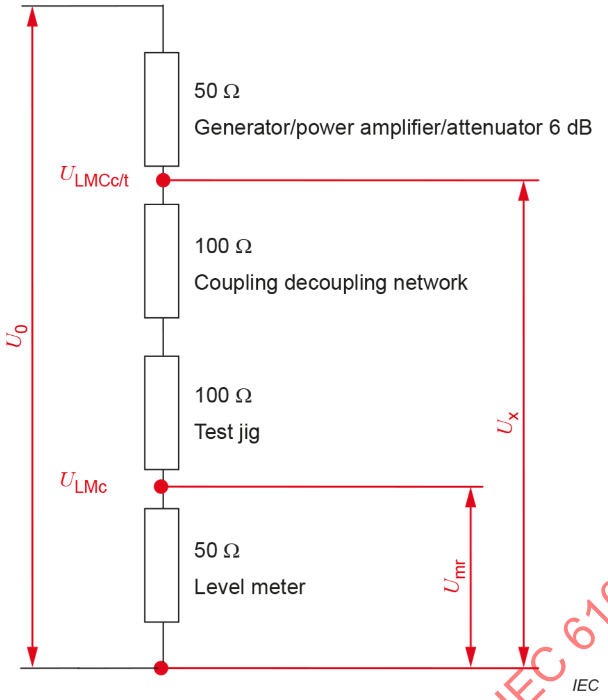


Figure G.5 – Circuit for level-setting setup of CDN

Table G.1 – CDN level-setting process

Symbol	Uncertainty Source X_i	$U(x_i)$	Unit	Distribution	Divisor	$u(x_i)$	Unit	c_i	$u_i(y)$	Unit	$u_i(y)^2$
$\delta RCAL$	150 Ω - 50 Ω adapter, deviation	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
	150 Ω - 50 Ω adapter, calibration	0,2	dB	normal k=2	2	0,10	dB	1	0,10	dB	0,01
$\delta SETUP$	Setup for level setting	0,4	dB	normal k=1	1	0,35	dB	1	0,35	dB	0,12
δLM_c	Level meter	0,5	dB	rectangular	1,73	0,29	dB	1	0,29	dB	0,08
δSW_c	SW levelling precision	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
δLMC_c (3,4)	Level meter in control loop	0	dB	rectangular	1,73	0,00	dB	1	0,00	dB	0,00
δTG_c (3,4)	Test generator	0	dB	rectangular	1,73	0,00	dB	1	0,00	dB	0,00
δMT_c (5)	Mismatch test generator/CDN	0	dB	U-shaped	1,41	0,00	dB	1	0,00	dB	0,00
δML	Mismatch level meter/CDN	0,5	dB	U-shaped	1,41	0,35	dB	1	0,35	dB	0,13
				$\Sigma u_i(y)^2$							0,40
				Combined uncertainty $u(y) = \sqrt{\Sigma u_i(y)^2}$							0,63
				Expanded uncertainty (CAL) $U = u(y) \times k$, k = 2							**1,27 dB**

Table G.2 – CDN test process

Symbol	Uncertainty Source X_i	$U(x_i)$	Unit	Distribution	Divisor	$u(x_i)$	Unit	c_i	$u_i(y)$	Unit	$u_i(y)^2$
δCAL	Level setting	1,27	dB	normal k=2	2	0,63	dB	1	0,63	dB	0,40
δLMCt (3,4)	Level meter in control loop	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
δTGt (3,4)	Test generator	0	dB	rectangular	1,73	0,00	dB	1	0,00	dB	0,00
δMTt (5)	Mismatch test generator/CDN	0,3	dB	U-shaped	1,41	0,21	dB	1	0,21	dB	0,05
δSWt	SW levelling precision	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
				$\Sigma u_i(y)^2$							0,51
				Combined uncertainty $u(y) = \sqrt{\Sigma u_i(y)^2}$							0,71
				Expanded uncertainty $U = u(y) \times k$, k = 2							**1,42 dB**

NOTE 3 Either LMC or the test generator (TG) contributions enter into Table G.1 and Table G.2 for level-setting or test, or both, depending on whether a control loop for the signal generator and amplifier output level is used or not. In this example, the test generator does not contribute to the uncertainty budget because it is part of the control loop. The contribution from the control loop is established by the level meter (see also Note 4). However, the test generator is included in Table G.1 and Table G.2 to remind the test labs that they can consider this item depending on the labs' particular test setup. The explanation of terms provides explanation and guidance on analysis of the TG contribution.

NOTE 4 If the same equipment is used for level-setting and testing, then only the contributions of repeatability and linearity enter into Table G.2 for the test process. The contribution for the level-setting can be neglected.

NOTE 5 This contribution is normally zero in Table G.1 since it is incorporated in the result of the level setting process due to the control loop. If a different circuit is used for level setting and test, the impact of the different setups and the reproducibility of the test setup are contributing to this uncertainty source in Table G.2. If the same circuit is used for level-setting and testing, then these contributions can be neglected.

Explanation of terms:

$RCAL$ – is the uncertainty of the 150 Ω to 50 Ω adapter. This contribution can normally be obtained from the calibration report. Alternatively, the insertion loss can be measured using a network analyzer (see Figure 13). The maximum deviation from the specified loss (9,5 dB) and its calibration uncertainty should be included in Table G.1 and Table G.2. It is recommended that 0,5 dB be used if the calibration certificate states only the compliance to the tolerance.

NOTE 6 Deviations can be corrected in the software. In this case, the maximum deviation can be reduced to the interpolation uncertainty and calibration uncertainty.

NOTE 7 The impedance of the 150 Ω to 50 Ω adapter can also be measured directly, for example, using a network analyzer or taken from the calibration certificate. In this case, the deviation from 100 Ω and the calibration uncertainty can be inserted in Table G.1 and Table G.2. The sensitivity coefficient c_i for this contribution is changed accordingly.

$SETUP$ – is a combination of uncertainties introduced by the setup for level-setting, i.e., calibration fixture, the connection between the CDN and the CDN adapter and the reference ground plane impacts, for example, contact to the reference ground plane. This contribution can be derived from reproducibility tests with changing conditions or estimated on the basis of experience as shown in the example.

LM_c – is the uncertainty of the level meter, i.e., the voltmeter or power meter used for measurement of the level at the output of the CDN. It is taken from the EUT's specifications in the example but can be determined from other sources as well.

SW_c – is the uncertainty derived from the discrete level step size of the signal generator and software windows for level-setting during the level-setting process. The software window can usually be adjusted by the test lab.

LMC_c – is the uncertainty of the level meter, i.e., the voltmeter or power meter used for the control loop for the signal generator and amplifier output level. It can be taken from the EUT's specifications or determined from other sources.

TG_c – is the uncertainty of the test generator including frequency generator, power amplifier and attenuator. It can be taken from the EUT's specifications or determined from other sources.

NOTE 8 The uncertainty of the individual components of the test generator (for example, signal generator, power amplifier stability, power amplifier rapid gain variation, attenuator, etc.) can be assessed separately, especially where a control loop is not used in the test setup.

MT_c – is a combination of the mismatches between the amplifier, the attenuator and the CDN.

ML – is the mismatch between the CDN and the level meter.

CAL – is the expanded uncertainty of the test voltage level in the level-setting process.

LMC_t – is the uncertainty of the level meter, for example, the voltmeter, used at the output of the power amplifier taken from the EUT's specification. Alternatively, a power meter can be used in order to obtain a lower uncertainty.

TG_t – is the uncertainty of the test generator including the frequency generator, the power amplifier and the attenuator. It can be taken from the EUT's specifications or determined from other sources.

NOTE 9 The uncertainty of the individual components of the test generator (for example, signal generator, power amplifier stability, power amplifier rapid gain variation, attenuator) can be assessed separately, especially where a control loop is not used in the test setup.

MT_t – is a combination of the mismatches between the amplifier, the attenuator and the CDN. This contribution can be neglected if the same setup, i.e., the attenuator and cables, is used for level-setting and test.

SW_t – is the uncertainty derived from the discrete level step size of the signal generator and software windows for level-setting during the test process. The software window can usually be adjusted by the test laboratory.

2) Uncertainty budget when using an EM clamp

Table G.3 and Table G.4 give examples of an uncertainty budget for voltage level-setting and an uncertainty budget for test using an EM clamp.

Model function for an EM clamp voltage level-setting process (all quantities in logarithmic units):

$$U_0 = U_{\mathrm{LMc}} + 15{,}6\ \mathrm{dB} + \delta LM_{\mathrm{c}} + \delta RCAL + \delta SETUP + \delta SW_{\mathrm{c}} + \delta ML$$

Explanation of contributions:

U_{LMc} voltage indication U_{mr} from the power meter directly in or converted to dB(μV).

NOTE 10 The other symbols are included in the explanation of terms below.

Model function for EM clamp test process (all quantities in logarithmic units):

$$U_0 = U_{\mathrm{x}} + 20\log(6/5) + \delta LMC_{\mathrm{t}} + \delta CAL + \delta SW_{\mathrm{t}} + \delta AETERM$$

$$U_{\mathrm{x}} = U_{\mathrm{LMc}} + 20\log(5)$$

NOTE 11 The symbols are included in the explanation of terms below.

Table G.3 – EM clamp level-setting process

Symbol	Uncertainty Source X_i	$U(x_i)$	Unit	Distribution	Divisor	$u(x_i)$	Unit	c_i	$u_i(y)$	Unit	$u_i(y)^2$
$\delta RCAL$	150 Ω - 50 Ω adapter, deviation	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
	150 Ω - 50 Ω adapter, calibration	0,2	dB	normal k=2	2	0,10	dB	1	0,10	dB	0,01
$\delta SETUP$	Setup for level setting	0,35	dB	normal k=1	1	0,35	dB	1	0,35	dB	0,12
δLM_c	Level meter	0,5	dB	rectangular	1,73	0,29	dB	1	0,29	dB	0,08
δSW_c	SW levelling precision	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
δLMC_c (12,13)	Level meter in control loop	0	dB	rectangular	1,73	0,00	dB	1	0,00	dB	0,00
δTG_c (12,13)	Test generator	0	dB	rectangular	1,73	0,00	dB	1	0,00	dB	0,00
δMT_c (14)	Mismatch test generator/clamp	0	dB	U-shaped	1,41	0,00	dB	1	0,00	dB	0,00
δML	Mismatch level meter/clamp	0,5	dB	U-shaped	1,41	0,35	dB	1	0,35	dB	0,13
				$\Sigma u_i(y)^2$							0,40
				Combined uncertainty $u(y) = \sqrt{\Sigma u_i(y)^2}$							0,63
				Expanded uncertainty (CAL) $U = u(y) \times k$, k = 2							**1,27** dB

Table G.4 – EM clamp test process

Symbol	Uncertainty Source X_i	$U(x_i)$	Unit	Distribution	Divisor	$u(x_i)$	Unit	c_i	$u_i(y)$	Unit	$u_i(y)^2$
δCAL	Level setting	1,27	dB	normal k=2	2	0,63	dB	1	0,63	dB	0,40
δLMC_t (12,13)	Level meter in control loop	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
δTG_t (12,13)	Test generator	0	dB	rectangular	1,73	0,00	dB	1	0,00	dB	0,00
δMT_t (14)	Mismatch test generator/clamp	0,3	dB	U-shaped	1,41	0,21	dB	1	0,21	dB	0,05
δSW_t	SW levelling precision	0,3	dB	rectangular	1,73	0,17	dB	1	0,17	dB	0,03
$\delta AETERM$	AE termination	2,5	dB	rectangular	1,73	1,45	dB	1	1,45	dB	2,09
				$\Sigma u_i(y)^2$							2,60
				Combined uncertainty $u(y) = \sqrt{\Sigma u_i(y)^2}$							1,61
				Expanded uncertainty $U=u(y) \times k$, k = 2							**3,22** dB

NOTE 12 Either the LMC or the test generator (TG) contributions enter into Table G.3 and Table G.4 for level-setting or test, or both, depending on whether a control loop for the signal generator and amplifier output level is used or not. In this example, the test generator does not contribute to the uncertainty budget because it is part of the control loop. The contribution from the control loop is established by the level meter (see also Note 13). However, the test generator is included in Table G.3 and Table G.4 to remind the test labs that they can consider this item depending on the labs' particular test setup. The explanation of terms provides explanation and guidance on analysis of the TG contribution.

NOTE 13 If the same equipment is used for level-setting and testing, then only the contributions of repeatability and linearity enter into Table G.4 for the test process. The contribution for the level-setting can be neglected.

NOTE 14 This contribution is normally zero in Table G.3 since it is incorporated in the result of the level setting process due to the control loop. If a different circuit is used for level setting and test, the impact of the different setups and the reproducibility of the test setup are contributing to this uncertainty source in Table G.4. If the same circuit is used for level-setting and testing, then these contributions can be neglected.

Explanation of terms:

Several items apply in principle as in the previous example (CDN method). These items are not explained here; the previous example should be consulted.

NOTE 15 Uncertainty related to 7.4.1, where a monitoring probe is used and current limitation is applied, is not considered in Annex G. In this case, the value of U_0 is no longer the same as that determined in the level-setting procedure, but it is reduced to an unknown value. Therefore, no uncertainty can be assigned to U_0 in this case.

AETERM – is the effect of the AE impedance, which should be maintained at 150 Ω (assumed ideal impedance of the EUT). Deviations from this value have significant influence especially in the lower frequency range (below 10 MHz), where the directivity of the EM clamp is weak. This impedance deviation can have a significant effect on the actual test level. The impedance mismatch will in practice determine the percentage of test signal going to the EUT or AE. If the AE impedance is higher than the EUT impedance, more test voltage is going to the AE rather than to the EUT. A lower value may be used for frequencies above 10 MHz.

This contribution can be investigated experimentally using a network analyzer. The coupling factor of the clamp can be measured for a 150 Ω AE impedance and compared to different AE impedances.

3) Uncertainty budget when using a current clamp

Table G.5 and Table G.6 give examples of an uncertainty budget for voltage level-setting and an uncertainty budget for test using a current clamp.

Model function for current clamp voltage level-setting process (all quantities in logarithmic units):

$$U_0 = U_{\mathrm{LMc}} + 15{,}6\ \mathrm{dB} + \delta LM_{\mathrm{c}} + \delta RCAL + \delta JIG + \delta SW_{\mathrm{c}} + \delta ML$$