BS EN 55016-2-1:2014

BSI Standards Publication

Specification for radio disturbance and immunity measuring apparatus and methods

Part 2-1: Methods of measurement of disturbances and immunity — Conducted disturbance measurements

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This British Standard is the UK implementation of EN 55016-2-1:2014. It is identical to CISPR 16-2-1:2014. It supersedes BS EN 55016-2-1:2009+A2:2013, which will be withdrawn on 2 April 2017.

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

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Anforderungen an Geräte und Einrichtungen sowie Festlegung der Verfahren zur Messung der hochfrequenten Störaussendung (Funkstörungen) und Störfestigkeit - Teil 2-1: Verfahren zur Messung der hochfrequenten Störaussendung (Funkstörungen) und Störfestigkeit - Messung der leitungsgeführten Störaussendung
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Foreword

The text of document CISPR/A/1053/FDIS, future edition 3 of CISPR 16-2-1, prepared by SC A "Radio-interference measurements and statistical methods" of IEC/TC CISPR "International special committee on radio interference" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 55016-2-1:2014.

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This document supersedes EN 55016-2-1:2009.

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The text of the International Standard CISPR 16-2-1:2014 was approved by CENELEC as a European Standard without any modification.

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

CISPR 11:2003 + A1:2004	NOTE	Harmonized as EN 55011:2007 [1)] (modified).
CISPR 16-1-4:2010	NOTE	Harmonized as EN 55016-1-4:2010 (not modified).
CISPR 16-2-3:2010	NOTE	Harmonized as EN 55016-2-3:2010 (not modified).
IEC 60364-4 Series	NOTE	Harmonized as HD 60364-4 Series (modified).
IEC 61000-4-6:2008	NOTE	Harmonized as EN 61000-4-6:2009 (modified).
IEC 61010-1:2001	NOTE	Harmonized as EN 61010-1:2001 (modified).

[1)] Superseded by EN 55011:2009 (CISPR 11:2009, mod.)

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

Publication	Year	Title	EN/HD	Year
CISPR 14-1	-	Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission	EN 55014-1	-
CISPR 16-1-1	2010	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus	EN 55016-1-1	2010
CISPR 16-1-2	2014	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	EN 55016-1-2	2014
CISPR 16-4-2	-	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty	EN 55016-4-2	-
IEC 60050	Series	International Electrotechnical Vocabulary	-	-

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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements

1 Scope

This part of CISPR 16 is designated a basic standard, which specifies the methods of measurement of disturbance phenomena in general in the frequency range 9 kHz to 18 GHz and especially of conducted disturbance phenomena in the frequency range 9 kHz to 30 MHz. With a CDNE, the frequency range is 9 kHz to 300 Hz.

NOTE In accordance with IEC Guide 107, CISPR 16 is a basic EMC standard for use by product committees of the IEC. As stated in Guide 107, product committees are responsible for determining the applicability of the EMC standard. CISPR and its sub-committees are prepared to co-operate with product committees in the evaluation of the value of particular EMC tests for specific products.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CISPR 14-1, *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 1: Emission*

CISPR 16-1-1:2010, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-1-2:2014, *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*

CISPR 16-4-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Uncertainty in EMC measurements*

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <http://www.electropedia.org>)

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
ancillary equipment
transducers (e.g. current and voltage probes and artificial networks) connected to a measuring receiver or (test) signal generator and used in the disturbance signal transfer between the EUT and the measuring or test equipment

3.1.2
artificial network
AN
agreed reference load (simulation) impedance presented to the EUT by actual networks (e.g. extended power or communication lines) across which the RF disturbance voltage is measured

Note 1 to entry: This note applies to the French language only.

3.1.3
artificial mains network
AMN
network that provides a defined impedance to the EUT at radio frequencies, couples the disturbance voltage to the measuring receiver, and decouples the test circuit from the supply mains

Note 1 to entry: There are two basic types of this network, the V-network (V-AMN) which couple the unsymmetric voltages, and the delta-network (Δ-AMN), which couple the symmetric and the unsymmetric voltages separately.

Note 2 to entry: The terms line impedance stabilization network (LISN) and V-AMN are used interchangeably .

Note 3 to entry: This note applies to the French language only.

3.1.4
associated equipment
AE
apparatus, which is not part of the system under test, but needed to help exercise the EUT

Note 1 to entry: This note applies to the French language only.

3.1.5
asymmetric artificial network
AAN
network used to measure (or inject) asymmetric (common mode) voltages on unshielded symmetric signal (e.g. telecommunication) lines while rejecting the symmetric (differential mode) signal

Note 1 to entry: An AAN is an AN (artifical network) that provides a simulation of the asymmetric load realized by the telecommunication network.

Note 2 to entry: The term “Y-network” is a synonym for AAN.

Note 3 to entry: The AAN can also be used for immunity testing, where the receiver measurement port becomes the disturbance injection port.

Note 4 to entry: This note applies to the French language only.

3.1.6
asymmetric voltage
radio-frequency disturbance voltage appearing between the electrical mid-point of the mains terminals and ground, sometimes called the common mode voltage

Note 1 to entry: If V_a is the vector voltage between one of the mains terminals and ground, and V_b is the vector voltage between the other mains terminal and ground, the asymmetric voltage is half the vector sum of V_a and V_b, i.e. $(V_a + V_b)/2$.

3.1.7
symmetric voltage
radio-frequency disturbance voltage appearing between the two wires in a two-wire circuit, such as a single-phase mains supply, sometimes called the differential mode voltage

Note 1 to entry: The symmetric voltage is the vector difference $(V_a - V_b)$.

3.1.8
unsymmetric mode voltage
amplitude of the vector voltage, V_a or V_b (defined in 3.6 and 3.7)

Note 1 to entry: The unsymmetric voltage is the voltage measured by the use of an artificial mains V-network.

Note 2 to entry: See notes in 3.6 and 3.7 for details on V_a and V_b.

3.1.9
auxiliary equipment
AuxEq
peripheral equipment which is part of the system under test

Note 1 to entry: This note applies to the French language only.

3.1.10
CDNE-*X*
coupling decoupling network for emission measurement in the frequency range 30 MHz to 300 MHz; where the "*X*" suffix can be "M2" for unscreened two-wire mains, DC or control ports, "M3" for unscreened three-wire mains, DC or control ports, and "S*x*" for screened cable with *x* internal wires

Note 1 to entry: See Annex J in CISPR 16-1-2: 2014 for example CDNE-*X* set-up diagrams.

3.1.11
coaxial cable
cable containing one or more coaxial lines, typically used for a matched connection of ancillary equipment to the measuring equipment or (test-)signal generator providing a specified characteristic impedance and a specified maximum allowable cable transfer impedance

3.1.12
common mode current
vector sum of the currents flowing through two or more conductors at a specified cross-section of a "mathematical" plane intersected by these conductors

3.1.13
continuous disturbance
RF disturbance with a duration of more than 200 ms at the IF-output of a measuring receiver, which causes a deflection on the meter of a measuring receiver in quasi-peak detection mode which does not decrease immediately

3.1.14
differential mode current
half the vector difference of the currents flowing in any two of a specified set of active conductors at a specified cross-section of a "mathematical" plane intersected by these conductors

3.1.15
discontinuous disturbance
for counted clicks, disturbance with a duration of less than 200 ms at the IF-output of a measuring receiver, which causes a transient deflection on the meter of a measuring receiver in quasi-peak detection mode

Note 1 to entry: For impulsive disturbance, see IEC 60050-161:1990, 161-02-08.

3.1.16
(electromagnetic) emission
phenomenon by which electromagnetic energy emanates from a source

[SOURCE: IEC 60050-161:1990, 161-01-08]

3.1.17
emission limit (from a disturbance source)
specified maximum emission level of a source of electromagnetic disturbance

[SOURCE: IEC 60050-161:1990, 161-03-12]

3.1.18
equipment under test
EUT
equipment (devices, appliances and systems) subjected to EMC (emission) compliance tests

Note 1 to entry: This note applies to the French language only.

3.1.19 Measurement, scan and sweep times

3.1.19.1

measurement
process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity

[SOURCE: JCGM 200:2012, 2.1 [12][1]]

3.1.19.2

measurement time
T_{m}
effective, coherent time for a measurement result at a single frequency (in some areas also called dwell time)

– for the peak detector, the effective time to detect the maximum of the signal envelope,
– for the quasi-peak detector, the effective time to measure the maximum of the weighted envelope
– for the average detector, the effective time to average the signal envelope
– for the r.m.s. detector, the effective time to determine the r.m.s. of the signal envelope

1 Numbers in square brackets refer to the Bibliography.

3.1.19.3

scan
continuous or stepped frequency variation over a given frequency span

3.1.19.4

span
Δf
difference between stop and start frequencies of a sweep or scan

3.1.19.5

sweep
continuous frequency variation over a given frequency span

3.1.19.6

sweep time
scan time
T_s
time between start and stop frequencies of a sweep or scan

3.1.19.7

sweep rate
scan rate
frequency span divided by the sweep time or scan time

3.1.19.8

observation time
T_o
sum of measurement times T_m on a certain frequency in case of multiple sweeps

Note 1 to entry: If n is the number of sweeps or scans, then $T_o = n \times T_m$.

3.1.19.9

total observation time
T_{tot}
effective time for an overview of the spectrum (either single or multiple sweeps)

Note 1 to entry: If c is the number of channels within a scan or sweep, then $T_{tot} = c \times n \times T_m$.

3.1.20
measuring receiver

instrument such as a tunable voltmeter, an EMI receiver, a spectrum analyzer or an FFT-based measuring instrument, with or without preselection, that meets the relevant clauses of CISPR 16-1-1

Note 1 to entry: See Annex I of CISPR 16-1-1:2010 for further information.

3.1.21
number of sweeps per time unit
n_s
1/(sweep time + retrace time)

Note 1 to entry: For example, sweeps per second.

3.1.22
product standard
publication specifying EMC requirements for a product or product family, taking into account specific aspects of such a product or product family

3.1.23
protective earthing
earthing a point or points in a system or in an installation or in equipment, for purposes of electrical safety

[SOURCE: IEC 60050-195:1998, 195-01-11]

3.1.24
reference ground
reference potential connecting point

Note 1 to entry: There can only be one reference ground in a conducted disturbance measurement system.

3.1.25
reference ground plane
RGP
flat conductive surface that is used as a common reference and that allows a defined parasitic capacitance to the surroundings of an EUT

Note 1 to entry: A reference ground plane is needed for conducted disturbance measurements, and serves as reference ground for the measurement of unsymmetric and asymmetric disturbance voltage.

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

3.1.26
test
technical operation that consists of the determination of one or more characteristics of a given product, process or service according to a specified procedure

Note 1 to entry: A test is carried out to measure or classify a characteristic or a property of an item by applying to the item a set of environmental and operating conditions and/or requirements.

[SOURCE: IEC 60050-151:2001, 151-16-13]

3.1.27
test configuration
combination that gives the specified measurement arrangement of the EUT in which a disturbance level is measured

3.1.28
total common mode impedance
TCM impedance
impedance between the cable attached to the EUT port under test and the RGP

Note 1 to entry: The complete cable is seen as one wire of the circuit and the ground plane as the other wire of the circuit. The TCM wave is the transmission mode of electrical energy, which can lead to radiation of electrical energy if the cable is exposed in the real application. Vice versa, this is also the dominant mode, which results from exposure of the cable to external electromagnetic fields.

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

3.1.29
weighting
pulse-repetition-frequency (PRF) dependent conversion (mostly reduction) of a peak-detected impulse voltage level to an indication that corresponds to the interference effect on radio reception

Note 1 to entry: For the analogue receiver, the psychophysical annoyance of the interference is a subjective quantity (audible or visual, usually not a certain number of misunderstandings of a spoken text).

Note 2 to entry: For the digital receiver, the interference effect is an objective quantity that may be defined by the critical bit error ratio (BER) or bit error probability (BEP) for which perfect error correction can still occur or by another, objective and reproducible parameter.

3.1.29.1

weighted disturbance measurement
measurement of disturbance using a weighting detector

3.1.29.2

weighting characteristic
peak voltage level as a function of PRF for a constant effect on a specific radiocommunication system, i.e. the disturbance is weighted by the radiocommunication system itself

3.1.29.3

weighting detector
detector that provides an agreed weighting function

3.1.29.4

weighting factor
value of the weighting function relative to a reference PRF or relative to the peak value

Note 1 to entry: The weighting factor is expressed in dB.

3.1.29.5

weighting function
weighting curve
relationship between input peak voltage level and PRF for constant level indication of a measuring receiver with a weighting detector, i.e. the curve of response of a measuring receiver to repeated pulses

3.2 Abbreviations

The following abbreviations, not already provided in 3.1, are used in this standard.

CCM	Converted common mode
CM	Common mode
CMAD	Common mode absorption device
CVP	Capacitive voltage probe
CW	Continuous wave
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
FFT	Fast Fourier transform
IF	Intermediate frequency
ISM	Industrial, scientific and medical
LCL	Longitudinal conversion loss
OATS	Open area test site
PE	Protective earth
PRF	Pulse-repetition frequency
RC	Resistor-capacitor

RF	Radio frequency
SOLT	Short-open-load-through (calibration method)
VDF	Voltage division factor
VDU	Video display unit

4 Types of disturbance to be measured

4.1 General

Clause 4 describes the classification of different types of disturbance and the detectors appropriate for their measurement.

4.2 Types of disturbance

For physical and psychophysical reasons, dependent on the spectral distribution, measuring receiver bandwidth, the duration, rate of occurrence, and degree of annoyance during the assessment and measurement of radio disturbance, distinction is made between the following types of disturbance:

a) *narrowband continuous disturbance*, i.e. disturbance on discrete frequencies as, for example, the fundamentals and harmonics generated with the intentional application of RF energy with ISM equipment, constituting a frequency spectrum consisting only of individual spectral lines whose separation is greater than the bandwidth of the measuring receiver so that during the measurement only one line falls into the bandwidth, in contrast to b);

b) *broadband continuous disturbance,* which normally is unintentionally produced by the repeated impulses of, for example, commutator motors, and which has a repetition frequency which is lower than the bandwidth of the measuring receiver so that during the measurement more than one spectral line falls into the bandwidth; and

c) *broadband discontinuous disturbance* is also generated unintentionally by mechanical or electronic switching procedures, for example by thermostats or programme controls with a repetition rate lower than 1 Hz (click-rate less than 30/min).

The frequency spectra described in b) and c) are characterized by having a continuous spectrum in the case of individual (single) impulses and a discontinuous spectrum in case of repeated impulses, both spectra being characterized by having a frequency range which is wider than the bandwidth of the measuring receiver specified in CISPR 16-1-1.

4.3 Detector functions

Depending on the types of disturbance, measurements may be carried out using a measuring receiver with:

a) an average detector generally used in the measurement of narrowband disturbance and signals, and particularly to discriminate between narrowband and broadband disturbance;

b) a quasi-peak detector provided for the weighted measurement of broadband disturbance for the assessment of audio annoyance to a radio listener, but also usable for narrowband disturbance;

c) an r.m.s.-average detector provided for the weighted measurement of broadband disturbance for the assessment of the effect of impulsive disturbance to digital radio communication services but also useable for narrowband disturbance;

d) a peak detector which may be used for either broadband or narrowband disturbance measurement.

Measuring receivers incorporating these detectors are specified in CISPR 16-1-1.

5 Connection of measuring equipment

5.1 General

Clause 5 describes the connection of measuring equipment, measuring receivers and ancillary equipment such as artificial networks (AN) and voltage and current probes.

5.2 Connection of ancillary equipment

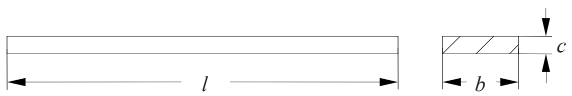
The connecting cable between the measuring receiver and the ancillary equipment shall be shielded and its characteristic impedance shall be matched to the input impedance of the measuring receiver. The measurement result shall account for the attenuation of the connecting cable.

The output of the ancillary equipment shall be terminated with the prescribed impedance. A minimum attenuation of 10 dB between the AN output and the measuring receiver input is required in order to fulfill the specified tolerance of the AN impedance at its EUT port. This attenuation may be incorporated in the AN. The use of a transient limiter is recommended for the protection of the receiver input circuits. It shall be designed to provide signals of maximum receiver input level without creating nonlinear effects.

5.3 Connections to RF reference ground

The artificial network (AN) shall be connected to the reference ground by a low RF impedance, e.g. by direct bonding of the case of the AN to the reference ground of a shielded room, or with a low impedance conductor as short and as wide as practical (the maximum length to width ratio of which is 3:1, and the inductance of which is less than approximately 50 nH corresponding to an impedance of less than approximately 10 Ω at 30 MHz). An in situ test of the voltage division factor as explained in Annex E is recommended. This will help to find, e.g. a ground strap resonance in the AN grounding.

NOTE 1 A conductor with rectangular cross section (see drawing below) with: length l = 30 cm, width b = 3 cm, thickness c = 0,02 cm will cause an inductance L of approximately 210 nH (X_L = 40 Ω at 30 MHz), which is excessive. The value of L was calculated using the following equation:



$$L = 2l\left(\ln\frac{2l}{b+c} + 0,5 + 0,22\frac{b+c}{l}\right)$$

where

L	is the inductance of the conductor in nH
l, b, c	are the dimensions of the conductor in cm

If such a length cannot be avoided, a width as large as possible will minimize the inductance.

Terminal voltage measurements shall be referenced only to the reference ground. Ground loops (common impedance coupling) shall be avoided. Ground loops will negatively affect repeatability of measurement and can, e.g. be detected if grounded components of a test set-up are touch-sensitive. This should also be observed for measuring apparatus (e.g. measuring receivers and connected ancillary equipment, such as oscilloscopes, analyzers, recorders, etc.) fitted with a protective earth conductor (PE) of safety class I equipment. The measuring instrumentation shall be provided with RF isolation so that the AN has only one RF connection to ground. This can be accomplished by RF chokes and isolation transformers, or by powering the measuring apparatus from batteries. Figure 1 shows an example of a recommended test set-up with three AMNs and PE chokes for the avoidance of ground loops. In this figure, also the receiver RF connecting cable to the AMN can act as a ground connection if the receiver is grounded. Therefore, either a PE choke is needed at the receiver power input, or, if the receiver is outside a shielded room, a sheath current suppressor is needed on the connecting cable. Each AMN is thus RF-grounded only once.

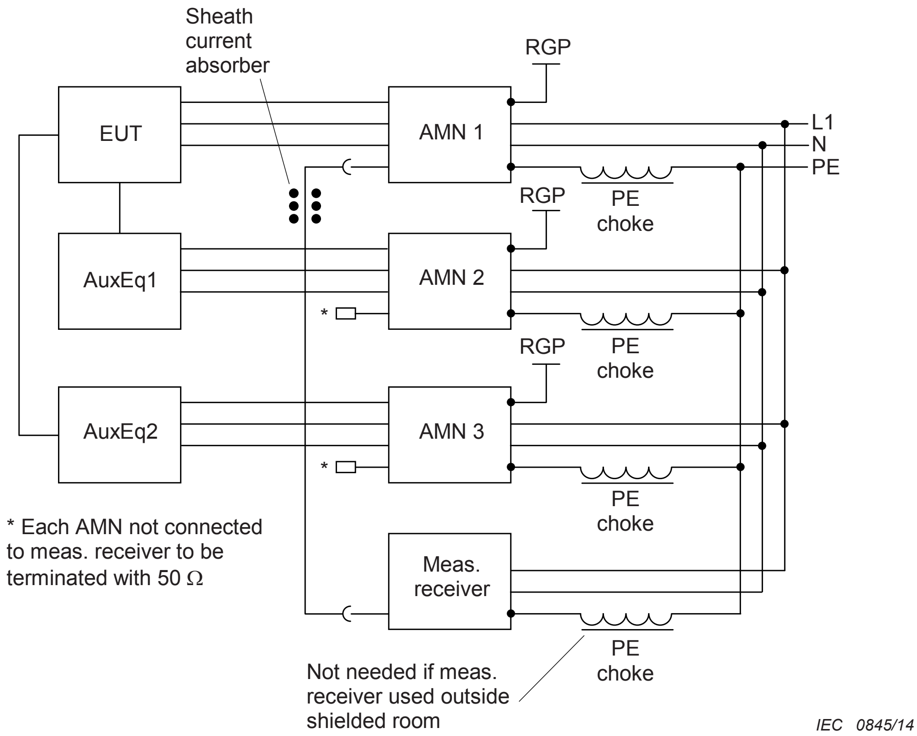


Figure 1 – Example of a recommended test set-up with PE chokes with three AMNs and a sheath current absorber on the RF cable

For safety reasons, PE chokes shall exhibit a low impedance for the power supply voltage at the power frequency and voltage in case of any defect. The short-circuit voltage across the PE choke shall be below 4 V. PE chokes may be incorporated inside the AMN.

The RF impedance of PE chokes and sheath current absorbers in the measurement frequency range should be high compared with the impedance of the AMN connection to the RGP. Commercially available PE chokes have, e.g. an inductance of 1,6 mH at nominal currents up to 36 A but they are not standardized in CISPR 16-1-2. The attenuation can be tested in accordance with Annex E. Some AMNs are available with built-in PE chokes. The difference in potential between PE and RGP shall be minimized to avoid saturation of PE chokes from the resulting DC or low frequency current flowing through the chokes. If the current is unknown, it may have to be measured.

NOTE 2 Sheath currents are RF currents flowing on the shield of shielded (e.g. coaxial) cables, and are a source of measurement uncertainty. Sheath current absorbers serve the purpose of reducing these currents.

For the treatment of PE connection of the EUT to the reference ground, see Clause A.4.

Stationary test configurations of the AMN do not require a connection with the protective earth conductor if the reference ground is connected directly and meets the safety requirements for protective earth conductors (PE connections).

5.4 Connection between the EUT and the artificial mains network

General guidelines for the selection of grounded and non-grounded connections of the EUT to the AMN are discussed in Annex A.

6 General measurement requirements and conditions

6.1 General

Radio disturbance measurements, within the uncertainties allowed by CISPR 16-4-2, shall be:

- reproducible, i.e. independent of the measurement location and environmental conditions, especially ambient noise;
- free from interactions, i.e. the connection of the EUT to the measuring equipment shall neither influence the function of the EUT nor the accuracy of the measurement equipment.

These requirements may be met by observing the following conditions:

a) existence of a sufficient signal-to-noise ratio at the desired measurement level, e.g. the level of the relevant disturbance limit;

b) having a defined measuring set-up, termination and operating conditions of the EUT;

c) in the case of voltage probe measurements on the supply mains, the probe shall have an impedance of 1,5 kΩ as specified in CISPR 16-1-2; for measurements on other circuits, the impedance may need to be increased (as provided by active voltage probes) to avoid excessive loading of high impedance circuits;

d) in the case of current probe measurements, the probe shall have an impedance in the measuring circuit of 1 Ω maximum, as specified in CISPR 16-1-2.

6.2 Disturbance not produced by the equipment under test

6.2.1 General

The measurement signal-to-noise ratio with respect to ambient noise shall meet the following requirements. Should the ambient noise level exceed the required level, it shall be recorded in the test report.

6.2.2 Compliance testing

A test site shall permit emissions from the EUT to be distinguished from ambient noise. The ambient noise level should be at least 20 dB below the specified limit. For in situ tests the ambient noise level should be at least 6 dB below the specified limit. In in situ cases, the disturbance plus ambient shall not exceed the limit. If the disturbance plus ambient exceeds the limit, then other methods need to be applied, for example, reduce the bandwidth, apply ambient cancellation, change frequency, etc. The suitability of the site for the permitted ambient level may be determined by measuring the ambient noise level with the EUT in place but not operating.

NOTE Annex A of CISPR 16-2-3:2010 [3] provides recommendations for measurement of disturbances in the presence of ambient emissions.

6.3 Measurement of continuous disturbance

6.3.1 Narrowband continuous disturbance

The measuring receiver shall be kept tuned to the discrete frequency under investigation and retuned if the frequency fluctuates.

6.3.2 Broadband continuous disturbance

For the assessment of broadband continuous disturbance the level of which is fluctuating, the maximum reproducible measurement value shall be found; see 6.5.1 for further details.

6.3.3 Use of spectrum analyzers and scanning receivers

Spectrum analyzers and scanning receivers are useful for disturbance measurements, particularly in order to reduce measuring time. However, special consideration shall be given to certain characteristics of these instruments, which include: overload, linearity, selectivity, normal response to pulses, frequency scan rate, signal interception, sensitivity, amplitude accuracy and peak, average and quasi-peak detection. These characteristics are considered in Annex B.

6.4 EUT arrangement and measurement conditions

6.4.1 EUT arrangement

6.4.1.1 General

Where not specified in the product standard, the EUT shall be configured as described in the following paragraphs.

The EUT shall be installed, arranged and operated in a manner consistent with typical applications. Where the manufacturer has specified or recommended an installation practice, such practice shall be used in the test arrangement, where possible. This arrangement shall be typical of the normal installation practice. Interface cables, loads and devices shall be connected to at least one of each type of interface port of the EUT, and where practical, each cable shall be terminated in a device typical of actual usage.

Where there are multiple interface ports of the same type, additional interconnecting cables, loads and devices may need to be added to the EUT depending upon the results of preliminary tests. The number of additional cables or wires of the same type should be limited to the condition where the addition of another cable or wire does not significantly affect the disturbance level, i.e. varies by less than 2 dB, provided that the EUT remains compliant. The rationale for the selection of the configuration and loading of ports shall be included in the test report.

Interconnecting cables should be of the type and length specified in the individual equipment requirements. If the length can be varied, the length shall be selected to produce maximum disturbance.

If shielded or special cables are used during the tests to achieve compliance, a note shall be included in the instruction manual advising of the need to use such cables.

Excess lengths of cables shall be bundled at the approximate centre of the cable with the bundles 30 cm to 40 cm in length. If it is impractical to do so because of cable bulk or stiffness, the disposition of the excess cable shall be precisely noted in the test report.

Where there are multiple interface ports all of the same type, connecting a cable to just one of that type of port is sufficient, provided it can be shown that the additional cables would not significantly affect the results.

Any set of results shall be accompanied by a complete description of the cable and equipment orientation so that results can be reproduced. If specific conditions of use are required to meet the limits, those conditions shall be specified and documented, for example cable length, cable type, shielding and grounding. These conditions shall be included in the instructions to the user.

Equipment that is populated with multiple modules (such as drawers and plug-in cards) shall be tested with a mix and number representative of that used in a typical installation. The number of additional boards or plug-in cards of the same type should be limited to the condition where the addition of another board or plug-in card does not significantly affect the disturbance level, i.e. varies by less than 2 dB, provided that the EUT remains compliant. The rationale used for selecting the number and type of modules should be stated in the test report.

A system that consists of a number of separate units shall be configured to form a minimum representative configuration. The number and mix of units included in the test configuration shall normally be representative of that used in a typical installation. The rationale used for selecting units should be stated in the test report.

One module of each type shall be operational in each equipment evaluated in an EUT. For an EUT comprising a system, one of each type of equipment that can be included in the possible system configuration shall be included in the EUT.

The results of an evaluation of EUTs having one of each type of module can be applied to configurations having more than one of each of those modules.

NOTE It has been found that disturbances from identical modules are generally not additive in practice.

The EUT position relative to the RGP shall be equivalent to that occurring in use. Therefore, floor-standing equipment is placed on, but insulated from, an RGP, and tabletop equipment is placed on a non-conductive table.

Equipment designed for wall-mounted operation shall be tested as tabletop EUT. The orientation of the equipment shall be consistent with normal installation practice.

Combinations of the equipment types identified above shall also be arranged in a manner consistent with normal installation practice. Equipment designed for both tabletop and floor standing operation shall be tested as tabletop equipment unless the usual installation is floor standing, then that arrangement shall be used.

The ends of signal cables attached to the EUT that are not connected to another unit or auxiliary equipment (AuxEq) shall be terminated using the correct terminating impedance defined in the product standard. If no product standard can be applied to the particular configuration, the termination shall be defined by the EUT manufacturer and noted in the test report.

Cables or other connections to auxiliary equipment located outside the test site shall drape to the floor, and then be routed to the place where they leave the test site.

Installation of AuxEq shall be in accordance with normal installation practice. Where this means that the AuxEq is located on the test site, it shall be arranged using the same conditions applicable for the EUT (for example, distance from the ground plane and insulation from the ground plane if floor standing, layout of cabling).

6.4.1.2 Arrangement of tabletop equipment

Equipment intended for tabletop use shall be placed on a non-conductive table. The size of the table will nominally be 1,5 m by 1,0 m but may ultimately be dependent on the horizontal dimensions of the EUT.

Intra-unit cables shall be draped over the back of the table. If a cable hangs closer than 0,4 m from the horizontal ground plane (or floor), the excess shall be folded at the cable centre into a bundle no longer than 0,4 m, such that the part of the bundle closest to the horizontal RGP is at least 0,4 m above the plane.

Cables shall be positioned as for normal usage.

If the mains port input cable is less than 0,8 m long (including power supplies integrated in the mains plug), an extension cable shall be used such that the external power supply unit is placed on the tabletop. The extension cable shall have characteristics similar to the mains cable (including the number of conductors and the presence of a ground connection). The extension cable shall be treated as part of the mains cable.

In the above arrangements, the cable between the EUT and the power accessory shall be arranged on the tabletop in the same manner as other cables connecting components of the EUT.

6.4.1.3 Arrangement of floor-standing equipment

The EUT shall be placed on the horizontal RGP, orientated for normal use, but separated from metallic contact with the RGP by up to 15 cm of insulation.

The cables shall be insulated (by up to 15 cm) from the horizontal RGP. If the equipment requires a dedicated ground connection, then this shall be provided and bonded to the horizontal RGP.

Intra-unit cables (between units forming the EUT or between the EUT and any auxiliary equipment) shall drape to, but remain insulated from, the horizontal RGP. Any excess cable shall either be folded at the cable centre into a bundle no longer than 0,4 m or arranged in a serpentine fashion. If an intra-unit cable length is not long enough to drape to the horizontal RGP but drapes closer than 0,4 m, then the excess shall be folded at the cable centre into a bundle no longer than 0,4 m. The bundle shall be positioned such that it is either 0,4 m above the horizontal RGP or at the height of the cable entry or connection point if this is within 0,4 m of the horizontal RGP.

For equipment with a vertical cable riser, the number of risers shall be typical of installation practice. Where the riser is made of non-conductive material, a minimum spacing of at least 0,2 m shall be maintained between the closest part of the equipment and the nearest vertical cable. Where the riser structure is conductive, the minimum spacing of 0,2 m shall be between the closest parts of the equipment and riser structure.

6.4.1.4 Arrangement for combinations of tabletop and floor-standing equipment

Intra-unit cables between a tabletop unit and a floor-standing unit shall have the excess cable folded into a bundle no longer than 0,4 m. The bundle shall be positioned such that it is either 0,4 m above the horizontal RGP or at the height of the cable entry or connection point if this is within 0,4 m of the horizontal RGP.

6.4.2 Normal load conditions

The normal load conditions shall be as defined in the product standard relevant to the EUT, and for EUTs not covered by a product standard, as indicated in the manufacturer's instructions.

6.4.3 Duration of operation

The duration of operation (during which the disturbance can be measured) shall be, in the case of EUTs with a given rated operating time, in accordance with the marking; in all other cases, the time is not restricted.

6.4.4 Running-in/warm-up time

No specific running-in/warm-up time, prior to testing, is given, but the EUT shall be operated for a sufficient period to ensure that the modes and conditions of operation (e.g. operating temperature is reached, software loading is completed and EUT is ready to perform its intended operation) are typical of those during the life of the equipment. The term “running-in time” relates to EUTs that include electrical motors. For some EUTs, special test conditions may be prescribed in the relevant product publications.

6.4.5 Supply

The EUT shall be operated from a supply having the rated voltage of the EUT. EUTs with more than one rated voltage shall be tested at the rated voltage which causes maximum disturbance. Product standards may call out additional measurements, if, for example, the levels of disturbances vary considerably with the supply voltage.

6.4.6 Mode of operation

The EUT shall be operated under conditions of use intended by the manufacturer which cause the maximum disturbance at the measurement frequency.

6.4.7 Operation of multifunction equipment

Multifunction equipment that is subjected simultaneously to different clauses of a product standard and/or different standards shall be tested with each function operated in isolation, if this can be achieved without modifying the equipment internally. The equipment thus tested shall be deemed to have complied with the requirements of all clauses/standards when each function has satisfied the requirements of the relevant clause/standard.

For equipment that it is not practical to test with each function operated in isolation, or where the isolation of a particular function would result in the equipment being unable to fulfil its primary function, or where the simultaneous operation of several functions would result in saving measurement time, the equipment shall be deemed to have complied if it meets the provisions of the relevant clause/standard with the necessary functions operated.

6.4.8 Determination of EUT arrangement(s) that maximize(s) emissions

Initial testing shall identify the frequency that has the highest disturbance relative to the limit. This identification shall be performed whilst operating the EUT in typical modes of operation and with cable positions in a test arrangement that is representative of typical installation practice.

The frequency of highest disturbance with respect to the limit shall be found by investigating disturbances at a number of significant frequencies. This provides confidence that the probable frequency of maximum disturbance has been found and that the associated cable, EUT arrangement and mode of operation have been identified.

For initial testing, the EUT should be arranged in accordance with the product standards as appropriate.

6.4.9 Recording of measurement results

Of those disturbances above (L – 20 dB), where L is the limit level in dB(μV) or dB(μA), the disturbance levels and the frequencies of at least the six disturbances having the smallest margin to the limit L shall be recorded.

In addition, the test report shall include the value of the measurement instrumentation uncertainty corresponding to the used test set-up, calculated as per the requirements of CISPR 16-4-2.

6.5 Interpretation of measuring results

6.5.1 Continuous disturbance

The following steps shall be applied when interpreting the results for continuous disturbance measurements:

a) At each frequency for which the level of disturbance is close to the limit and not steady, the reading on the measuring receiver is observed for at least 15 s for each measurement; the highest readings shall be recorded. Some product standards allow the exclusion of isolated clicks, which shall be ignored (e.g. CISPR 14-1).

b) If the general level of the disturbance is not steady, but shows a continuous rise or fall of more than 2 dB in the 15 s period, then the disturbance voltage levels shall be observed for a further period and the levels shall be interpreted according to the conditions of normal use of the EUT, as follows:

   1) if the EUT is one which may be switched on and off frequently, or the direction of rotation of which can be reversed, then at each frequency of measurement the EUT should be switched on or reversed just before each measurement, and switched off just after each measurement. The maximum level obtained during the first minute at each frequency of measurement shall be recorded;

   2) if the EUT is one which in normal use runs for longer periods, then it should remain switched on for the period of the complete test, and at each frequency the level of disturbance shall be recorded only after a steady reading (subject to the provision that item a) has been obtained).

c) If the pattern of the disturbance from the EUT changes from a steady to a random character part way through a test, then that EUT shall be tested in accordance with item b).

d) Measurements are taken throughout the complete spectrum and are recorded at least at the frequency with maximum reading and as required by the relevant CISPR publication.

6.5.2 Discontinuous disturbance

Measurement of discontinuous disturbance may be performed at a restricted number of frequencies; for further details, see CISPR 14-1.

6.5.3 Measurement of the duration of disturbances

The duration of a disturbance shall be known in order to measure it correctly and to determine if it is discontinuous. The duration of a disturbance may be measured in one of the following ways:

- through the connection of an oscilloscope to a measuring receiver’s IF output to allow monitoring of the disturbance in the time-domain;
- through the tuning of either an EMI receiver or a spectrum analyzer to the disturbance frequency without frequency scanning (i.e. ‘zero-span’ mode) to allow monitoring of the disturbance in the time-domain; or
- through the use of the time-domain output of an FFT-based measuring receiver.

Guidance for the determination of the appropriate measurement time can be found in 8.3.

6.6 Measurement times and scan rates for continuous disturbance

6.6.1 General

For manual and automated or semi-automated measurements, measurement times and scan rates of measuring and scanning receivers shall be set such that the maximum emissions are measured. Especially, where a peak detector is used for prescans, the measurement times and scan rates have to take the timing of the disturbance under test into account. More detailed guidance on the execution of automated measurements can be found in Clause 8.

6.6.2 Minimum measurement times

The minimum measurement (dwell) times are given in Table 2. The minimum measurement (dwell) times for scanning receivers and FFT-based measuring instruments in Table 2 and the scan times for spectrum analyzers in Table 1 apply to CW signals. The minimum scan times of Table 1 were derived to perform measurements in the entire CISPR band.

Table 1 – Minimum scan times for the three CISPR bands with peak and quasi-peak detectors

Frequency band		Scan time T_s for peak detection	Scan time T_s for quasi-peak detection
A	9 kHz to 150 kHz	14,1 s	2 820 s = 47 min
B	0,15 MHz to 30 MHz	2,985 s	5 970 s = 99,5 min = 1 h 39 min
C and D	30 MHz to 1 000 MHz	0,97 s	19 400 s = 323,3 min = 5 h 23 min

Table 2 – Minimum measurement times for the four CISPR bands

Frequency band		Minimum measurement time T_m
A	9 kHz to 150 kHz	10,00 ms
B	0,15 MHz to 30 MHz	0,50 ms
C and D	30 MHz to 1 000 MHz	0,06 ms
E	1 GHz to 18 GHz	0,01 ms

Depending on the type of disturbance, the scan time may have to be increased, especially for swept quasi-peak measurements. In extreme cases, the measurement time T_m at a certain frequency may have to be increased to 15 s, if the level of the observed disturbance is not steady (see 6.5.1).

Scan rates and measurement times for use with the average detector will be found in Annex D.

Most product standards call out for quasi-peak detection for compliance measurements which is very time consuming, if no time-saving procedures are applied (see Clause 8). Before time-saving procedures can be applied, the disturbance is detected in a prescan. To ensure that e.g. intermittent signals are not overlooked during an automatic scan, the considerations in 6.6.3 to 6.6.5 need to be taken into account.

6.6.3 Scan rates for scanning receivers and spectrum analyzers

One of two conditions need to be met to ensure that signals are not missed during automatic scans over frequency spans:

a) for a single sweep: the measurement time at each frequency shall be larger than the intervals between pulses for intermittent signals;

b) for multiple sweeps with maximum hold: the observation time at each frequency should be sufficient for intercepting intermittent signals.

The frequency scan rate is limited by the instrument’s resolution bandwidth, and video bandwidth settings. If the scan rate is chosen too fast for the given instrument state, erroneous measurement results will be obtained. Therefore, a sufficiently long sweep time as defined below needs to be chosen for the selected frequency span. Intermittent signals may be intercepted by either a single sweep with sufficient observation time at each frequency or by multiple sweeps with maximum hold. Usually for an overview of unknown emissions, the latter will be highly efficient: as long as the spectrum display changes, there may still be intermittent signals to discover. The observation time is selected according to the periodicity at which interfering signals occur. In some cases, the sweep time may have to be varied in order to avoid synchronization effects.

When determining the minimum sweep time for measurements with a spectrum analyzer or scanning EMI receiver, based on a given instrument setting and using peak detection, two different cases have to be distinguished. If the video bandwidth is selected to be wider than the resolution bandwidth, the following expression can be used to calculate the minimum sweep time:

$$T_{\mathrm{s\,min}} = (k \times \Delta f)/(B_{\mathrm{res}})^2 \tag{1}$$

where

$T_{\mathrm{s\,min}}$ is the minimum sweep time

Δf is the frequency span

B_{res} is the resolution bandwidth

k is the constant of proportionality, related to the shape of the resolution filter; this constant assumes a value between 2 and 3 for synchronously-tuned, near-Gaussian filters. For nearly rectangular, stagger-tuned filters, k has a value between 10 and 15.

NOTE Actual values of k are available from instrument manufacturers. The actual values are normally taken into consideration in the coupled mode of the receiver or spectrum analyzer firmware.

If the video bandwidth is selected to be equal to or smaller than the resolution bandwidth, the following expression can be used to calculate the minimum sweep time:

$$T_{\mathrm{s\,min}} = (k \times \Delta f)/(B_{\mathrm{res}} \times B_{\mathrm{video}}) \tag{2}$$

where B_{video} is the video bandwidth.

Most spectrum analyzers and scanning EMI receivers automatically couple the sweep time to the selected frequency span and the bandwidth settings. Sweep time is adjusted to maintain a calibrated display. The automatic sweep time selection can be overwritten if longer observation times are required, e.g. to intercept slowly varying signals.

In addition, for repetitive sweeps, the number of sweeps per second will be determined by the sweep time $T_{\mathrm{s\,min}}$ and the retrace time (time needed to retune the local oscillator and to store the measurement results, etc.).

6.6.4 Scan times for stepping receivers

Stepping EMI receivers are consecutively tuned to single frequencies using predefined step sizes. While covering the frequency range of interest in discrete frequency steps, a minimum dwell time at each frequency is required for the instrument to accurately measure the input signal.

For the actual measurement, a frequency step size of roughly 50 % or less of the resolution bandwidth used (depending on the resolution filter shape) is required to reduce measurement uncertainty for narrowband signals due to the stepwidth. Under these assumptions the scan time $T_{\mathrm{s\,min}}$ for a stepping receiver can be calculated using the following equation:

$$T_{\mathrm{s\,min}} = T_{\mathrm{m\,min}} \times \Delta f / (B_{\mathrm{res}} \times 0{,}5) \tag{3}$$

where $T_{\mathrm{m\,min}}$ is the minimum measurement (dwell) time at each frequency.

In addition to the measurement time, some time is needed for the synthesizer to switch to the next frequency and for the firmware to store the measurement result, which in most measuring receivers is automatically done so that the selected measurement time is the effective time for the measurement result. Furthermore, the selected detector, e.g. peak or quasi-peak, determines this time period as well.

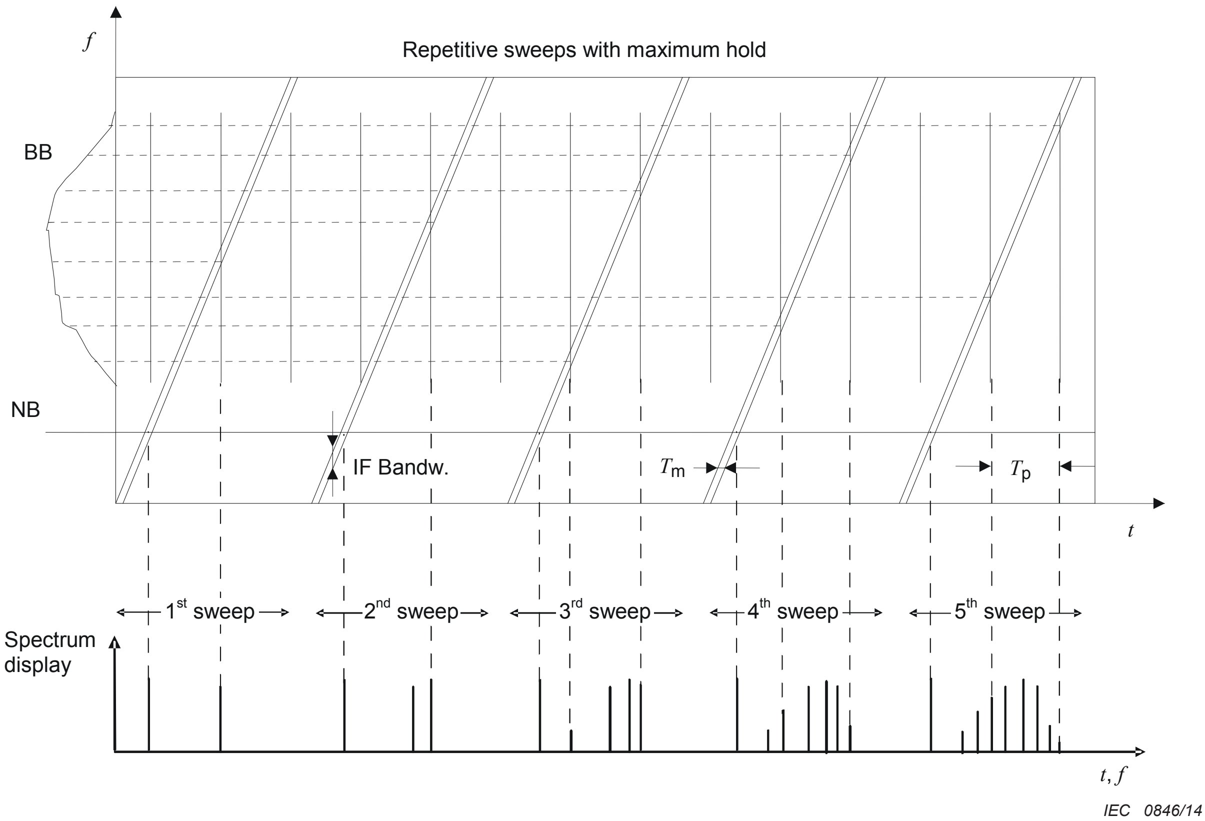
For purely broadband emissions, the frequency step size may be increased. In this case the objective is to find the maxima of the disturbance spectrum only.

6.6.5 Strategies for obtaining a spectrum overview using the peak detector

For each prescan measurement, the probability of intercepting all critical spectral components of the EUT spectrum shall be as close to 100 % as possible. Depending on the type of measuring receiver and the characteristics of the disturbance, which may contain narrowband and broadband elements, two general approaches are proposed:

- stepped scan: the measurement (dwell) time shall be long enough at each frequency to measure the signal peak, e.g. for an impulsive signal the measurement (dwell) time should be longer than the reciprocal of the repetition frequency of the signal;
- swept scan: the measurement time shall be larger than the intervals between intermittent signals (single sweep) and the number of frequency scans during the observation time should be maximized to increase the probability of signal interception.

Figures 2, 3, 4 and 5 show examples of the relationship between various time-varying disturbance spectra and the corresponding display on a measuring receiver. In the cases of Figures 2, 4, and 5, the upper part of the figure shows the position of the receiver bandwidth as it either sweeps or steps through the spectrum.

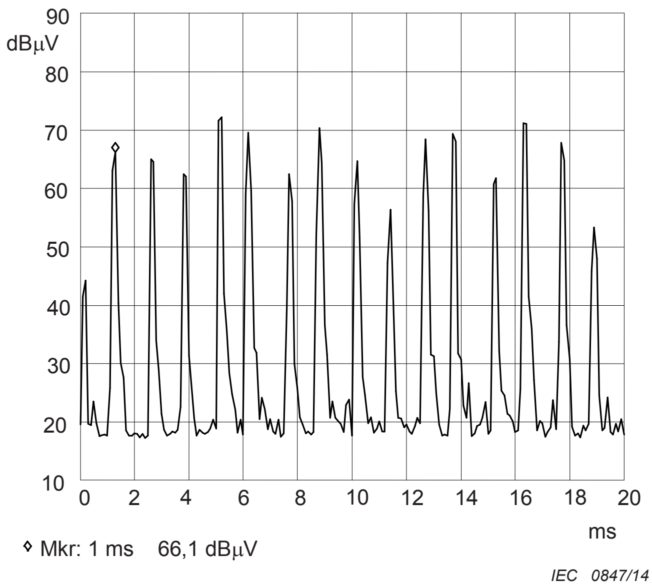


T_p is the pulse-repetition interval of the impulsive signal. A pulse occurs at each vertical line of the spectrum-versus-time display (upper part of the figure).

Figure 2 – Measurement of a combination of a CW signal ("NB") and an impulsive signal ("BB") using multiple sweeps with maximum hold

If the type of disturbance is unknown, multiple sweeps with the shortest possible sweep time and peak detection allow the spectrum envelope to be determined. A short single sweep is sufficient to measure the continuous narrowband signal content of the EUT spectrum. For continuous broadband and intermittent narrowband signals, multiple sweeps at various scan rates using a “maximum hold” function may be necessary to determine the spectrum envelope. For low repetition impulsive signals, many sweeps will be necessary to fill up the spectrum envelope of the broadband component.

The reduction of measurement time requires a timing analysis of the signals to be measured. This can be done either with a measuring receiver which provides a graphical signal display, used in zero-span mode or using an oscilloscope connected to the receiver’s IF or video output as shown for example in Figure 3.



Example results for disturbance from a DC collector motor. Due to the number of collector segments the pulse repetition frequency is high (approximately 800 Hz) and the pulse amplitude varies strongly. Therefore for this example, the recommended measurement (dwell) time with the peak detector is > 10 ms.

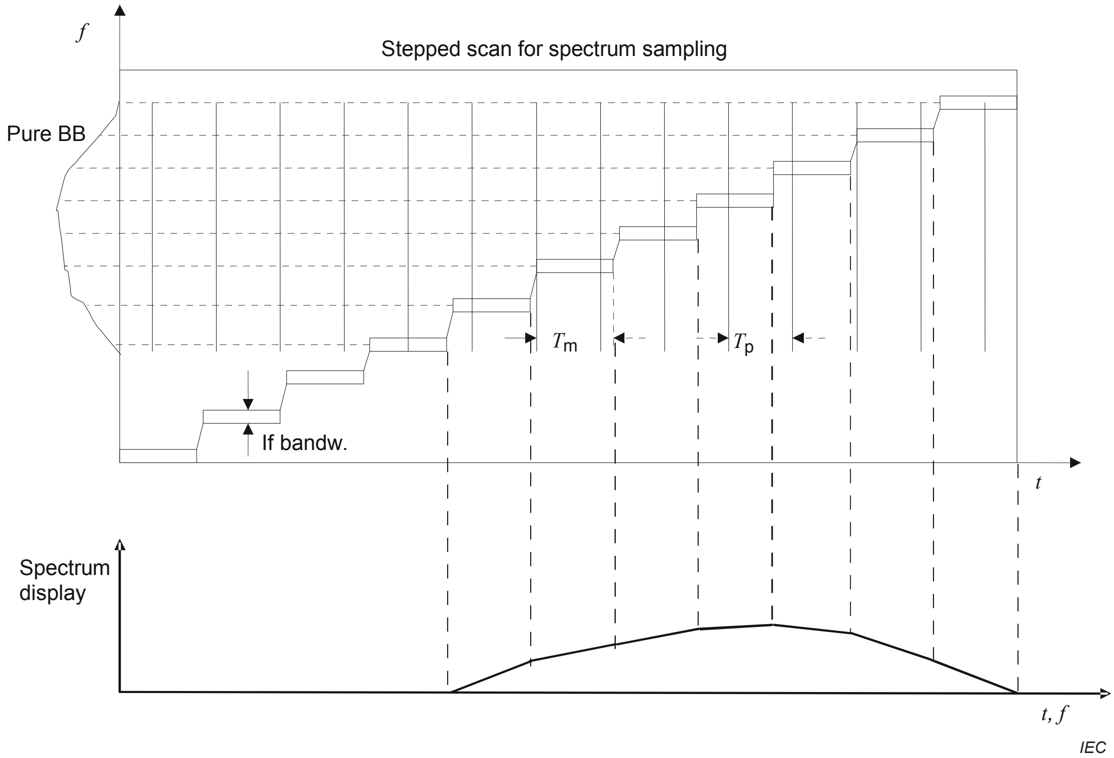
Figure 3 – Example of a timing analysis

From the timing analysis, pulse durations and pulse repetition frequencies can be determined and scan rates or dwell times selected accordingly:

– for **continuous unmodulated narrowband** disturbances, the fastest scan time possible for the selected instrument settings may be used;
– for **pure continuous broadband** disturbances, e.g. from ignition motors, arc welding equipment, and collector motors, a stepped scan (with peak or even quasi-peak detection) for sampling of the disturbance spectrum may be used. In this case, the knowledge of the type of disturbance is used to draw a polyline curve as the spectrum envelope (see Figure 4). The step size is chosen so that no significant variations in the spectrum envelope are missed. A single swept measurement – if performed slowly enough – will also yield the spectrum envelope;
– for **intermittent narrowband** disturbances with unknown frequencies either fast short sweeps involving a “maximum hold” function (see Figure 5) or a slow single sweep may be used. A timing analysis may be required prior to the actual measurement to ensure proper signal interception.

Intermittent broadband disturbances shall be measured with a disturbance analyzer that complies with CISPR 16-1-1. For explanation of related measurement procedures, see CISPR 14-1.

NOTE In the example of Figure 5, five sweeps are required until all spectral components are intercepted. The number of sweeps required or the sweep time may have to be increased, depending on pulse duration and pulse repetition interval.



The measurement (dwell) time T_m should be longer than the pulse repetition interval T_p, which is the inverse of the pulse repetition frequency.

Figure 4 – A broadband spectrum measured with a stepped receiver

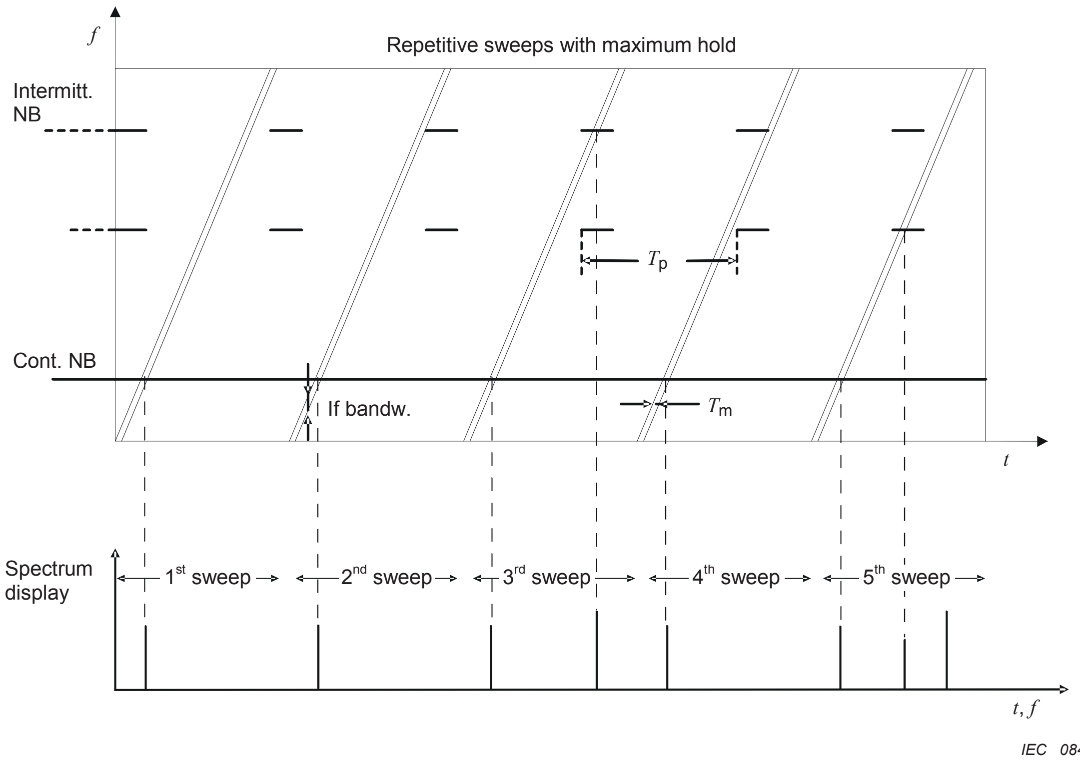


Figure 5 – Intermittent narrowband disturbances measured using fast short repetitive sweeps with maximum hold function to obtain an overview of the disturbance spectrum

6.6.6 Timing considerations using FFT-based instruments

FFT-based measuring instruments may combine the parallel calculation at N frequencies and a stepped scan. For this purpose, the frequency range of interest is subdivided into a number of segments N_{seg} that are scanned sequentially. The procedure is shown in Figure 6 for three segments. The total scan time for the frequency range of interest T_{scan} is calculated as:

$$T_{scan} = T_m N_{seg} \tag{4}$$

where

T_m is the measurement time for each segment, and

N_{seg} is the number of segments.

FFT-based measuring instruments may also provide methods to improve the frequency resolution across a given frequency range. In general, an FFT-based measuring instrument will have a fixed frequency step $f_{step\ FFT}$ that is determined by the number of frequencies of the FFT. Increased frequency resolution is achieved by performing repeat calculations over a given frequency range. For each repeat calculation, the lowest frequency is incremented by a step ratio, $f_{step\ final}$.

Hence the first calculation over the given frequency range considers the following frequencies:

f_{min},
$f_{min} + f_{step\ FFT}$,
$f_{min} + 2f_{step\ FFT}$,
$f_{min} + 3f_{step\ FFT}$…

The second calculation over the given frequency range considers the following frequencies:

$f_{min} + f_{step\ final}$,
$f_{min} + f_{step\ final} + f_{step\ FFT}$,
$f_{min} + f_{step\ final} + 2f_{step\ FFT}$,
$f_{min} + f_{step\ final} + 3f_{step\ FFT}$…

This procedure, applied for a step ratio of 3, is displayed in Figure 7.

The scan time T_{scan} is calculated as:

$$T_{scan} = T_m \frac{f_{step\ FFT}}{f_{step\ final}} \tag{5}$$

where

T_m is the measurement time, and

$\frac{f_{step\ FFT}}{f_{step\ final}}$ is the step ratio.

For a system that combines both methods, the scan time T_{scan} is calculated as:

$$T_{scan} = T_m N_{seg} \frac{f_{step\ FFT}}{f_{step\ final}} \tag{6}$$

NOTE 1 FFT-based measuring instruments may combine both methods, i.e. the stepped scan as well as a method to improve the frequency resolution.

NOTE 2 Additional background information is provided in CISPR/TR 16-3 [4].

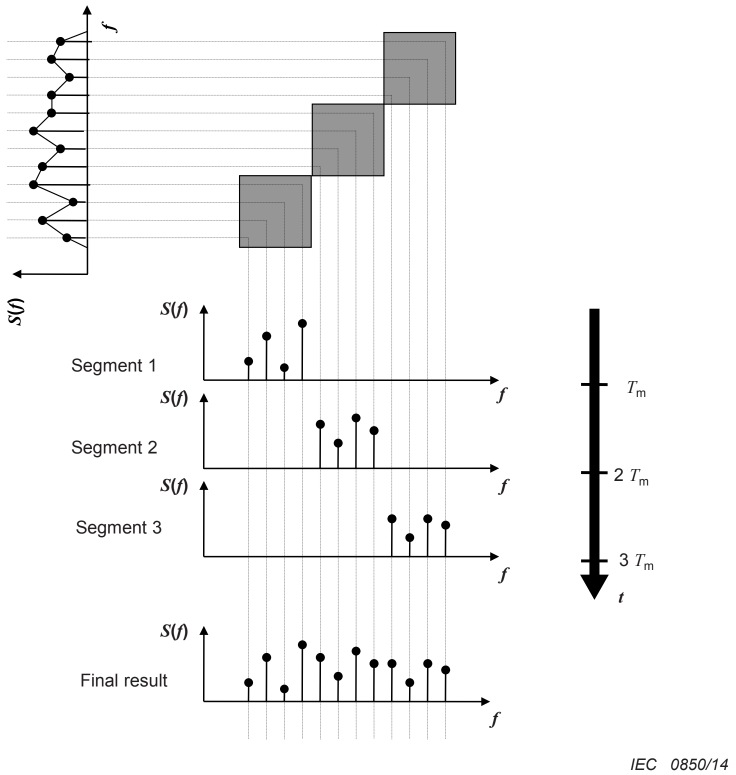


Figure 6 – FFT scan in segments

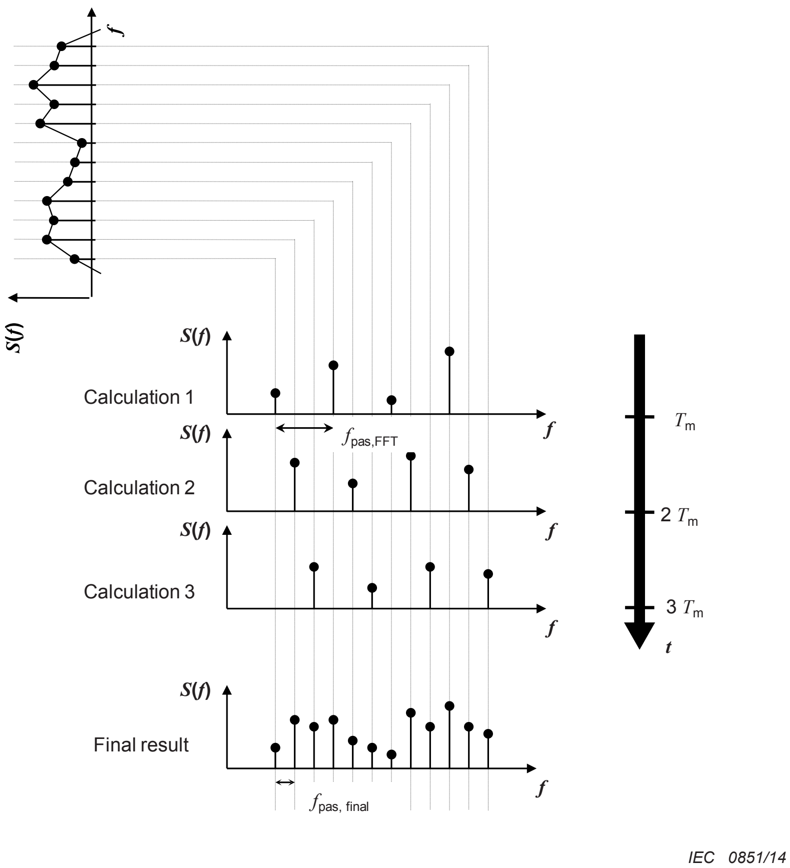


Figure 7 – Frequency resolution enhanced by FFT-based measuring instrument

7 Measurement of disturbances conducted along leads, 9 kHz to 30 MHz

7.1 General

When testing for compliance with disturbance limits for electromagnetic disturbances conducted along leads, the following items shall be considered as minimum, both in the standardized situation (type tests) and at the place of installation (in situ tests):

a) *the types of disturbance:* there are two methods of measuring conducted disturbances, either as a voltage (prevailing method for CISPR measurements) or as a current. Both methods can be used to measure the three types of conducted disturbance, i.e.:
   - common mode (also called asymmetric mode, i.e. the vector sum of voltages/currents in bundle or group of wires);
   - differential mode (also called symmetric mode);
   - unsymmetric mode (voltage between terminal and reference ground).

   NOTE The unsymmetric mode voltage is primarily measured at the power port. The common mode voltage (or current) is measured primarily at telecommunication, signal and control ports.
b) *the measuring equipment:* the type of measuring equipment is chosen in relation to the disturbance properties to be determined (see 7.2);
c) *the ancillary equipment:* the type of ancillary equipment, i.e. artificial networks, current probes or voltage probes, is chosen in accordance with the type of disturbance to be measured in accordance with 7.1 a). Each type of ancillary equipment presents RF loading to the measured signals and ports (see 7.3);
d) *RF load conditions of the disturbance source:* the test set-up will present certain RF load impedances to the disturbance source(s) in the EUT. These impedances are standardized in type tests or might depend on the conditions at the place of installation in the case of in situ tests (see 7.3 and 7.4);
e) *the test configuration of EUT:* a standardized test configuration shall specify the reference ground, the position of the EUT and ancillary measuring equipment with respect to that reference ground, connections to that reference ground and interconnections of the EUT with the associated equipment in an unambiguous way (see 7.4 and 7.5).

7.2 Measuring equipment (receivers, etc.)

7.2.1 General

In general, a distinction is drawn between continuous and discontinuous disturbances. Continuous radio-frequency disturbances are predominantly measured in terms of frequency domain parameters. Discontinuous disturbances are also measured in terms of frequency domain parameters but may need additional time domain measurements.

The measuring receivers and other measuring equipment specified in CISPR 16-1-1 shall be used. For time domain measurements oscilloscopes etc. may be used.

7.2.2 Use of detectors for conducted disturbance measurements

CISPR 16-1-1 specifies the characteristics of detectors that are required to perform measurements per product specifications. Several of these product specifications require the use of both quasi-peak and average detectors for conducted disturbance measurements. The time constants of these two detectors are very long and make automated measurements time-consuming.

A peak detector with shorter time constants may be used to make initial measurements and to determine compliance with a limit. But if the measured disturbance levels are above a limit they shall be followed by measurements with the quasi-peak and average detectors.

Annex C provides guidance on how these measurements may be performed efficiently.

7.3 Ancillary measuring equipment

7.3.1 General

Ancillary measuring equipment for conducted disturbance measurement is divided into two categories:

a) voltage measuring sensors, such as artificial networks (ANs) and voltage probes;

NOTE Some standards use the terms impedance stabilization network (ISN) for ANs for disturbance measurements on telecommunication ports (i.e. AANs or Y-networks).

b) current measuring sensors, such as current probes.

7.3.2 Artificial networks (ANs)

7.3.2.1 General

The common mode, differential and unsymmetric mode impedances of actual networks, such as of power mains and telecommunication networks, are location dependent and, in general, time varying. Therefore, type testing of disturbance requires standardized impedance simulation networks, referred to as artificial networks (ANs). The AN provides standardized RF load impedances to the EUT. For this purpose, the AN is inserted in series with the terminals of the EUT and the actual network or signal simulator. In this way, the AN simulates extended networks (long lines) with defined impedances.

7.3.2.2 Types of artificial networks

The ANs specified in CISPR 16-1-2 shall be used, unless specific reasons call for another construction. In general three types of AN can be distinguished:

a) *the V-type AN (typically used as V-AMN, or LISN):* in a defined frequency range, the RF impedances between each of the EUT terminals to be measured and the reference ground have a defined value, whereas no impedance component is connected directly between these terminals. The construction defines (indirectly) the measurement of the vector sum of both the differential and common mode voltage. In principle, there is no limit for the number of EUT terminals, i.e. for the number of lines to be measured by V-type ANs;
b) *the delta-type AN (actually not used in product publications but could be used as delta-AMN for power lines or as delta-network for signal lines):* in a defined frequency range, the RF impedance between a pair of EUT terminals to be measured and between these terminals and the reference ground have defined value. This construction defines directly both the differential and the common mode RF load impedances. Addition of a balance/unbalance transformer makes it possible to measure the symmetric and asymmetric disturbance voltage;
c) *the Y-type AN (also called the asymmetric artificial network, AAN, or ISN):* in a defined frequency range, the common mode RF impedance between a pair of EUT terminals to be measured and a reference ground has a defined value. In general, no defined differential load impedance is included in a Y-type AN as such. The defined differential mode impedance shall then be provided by the external circuit connected to the supply (line) terminals of the Y-type AN. This type of AN is used to measure common mode disturbance voltages only.

7.3.3 Voltage probes

For specifications of voltage probes, see CISPR 16-1-2.

Disturbance voltages on terminals which are not to be measured with an AN can be measured with a voltage probe. Examples of such terminals are connecting jacks for antennas, control lines, signal lines and load lines. In general the voltage probe is used to measure the unsymmetric disturbance voltage. The probe presents a high RF impedance between the terminal to be measured and the reference ground.

The capacitive voltage probe (CVP) is used to measure the asymmetric (common mode) voltage of a number of conductors without making direct conductive contact. It is constructed so that it can be clamped around the conductors to be measured. Clamping the CVP around an individual conductor will allow the measurement of the unsymmetric disturbance voltage.

7.3.4 Current probes

Current probes or current transformers allow the measurement of all three types of disturbance current (see 7.1 and CISPR 16-1-2) on mains leads, signal lines, load lines, etc. A clip-on construction of the probe will facilitate its use.

The common mode current on leads is measured when the current probe is clipped around those leads, regardless of the number of wires. In this situation, the differential mode currents on the leads will induce signals with equal magnitude but opposite sign, so that these signals cancel to a high degree. The latter effect allows the measurement of a common mode current with a small amplitude in the presence of differential mode (operating) currents with large amplitude.

The current probe cannot be used for the measurement of the converted common mode (CCM) current between an AAN and the EUT. The CCM shall only be measured by the voltage at the output of the AAN (see 7.3.2.2 c)).

For already defined (and standardized) current probes, see CISPR 16-1-2.

NOTE The purpose of the AAN is to simulate the disturbance potential of the network cabling that is attached to the telecommunication port of the EUT. Thus, in response to the differential-mode voltage launched onto the network at the telecommunication port of the EUT, the AAN generates an internal common-mode voltage that represents the converted common-mode (CCM) voltage that would be generated by the attached network cabling. This internally generated common-mode voltage has an associated common-mode current (I_{CCM} in Figure 8). This current undergoes current division within the AAN (into I_{CCM1} and I_{CCM2} in Figure 8). The current division is determined by the common mode impedance of the AAN output (Z_T on Figure 8) and the common mode impedance presented at the AAN's EUT terminal (Z_E in Figure 8). The common-mode impedance of the AAN output is controlled and hence the common-mode voltage at the AAN output (V_{CCM} in Figure 8) is the measure of the disturbance potential of the connected network. The common mode impedance presented at the AAN's EUT port is not controlled: rather, it varies with frequency and depends upon the EUT size and the EUT arrangement. Hence this CCM current (I_{CCM2} in Figure 8) cannot be measured with a current probe because, for IT equipment of typical size, the magnitude of Z_E varies from around 2 kΩ to around 200 Ω, in the frequency range from 150 kHz to 30 MHz.

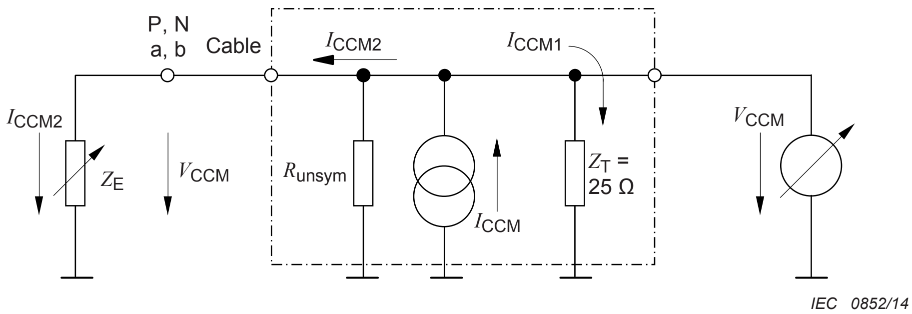


Figure 8 – Illustration of current I_{CCM}

7.4 Equipment under test configuration

7.4.1 Arrangement of the EUT and its connection to the AN

For measurement of the disturbance voltage, the EUT is connected to the power supply mains and any other extended network via one or more AN(s) (in general, the V-type network is used as an AMN for the power port, see Figure 9), in accordance with the following requirements. CISPR product publications supply additional test details relevant to particular EUTs.

An EUT, whether intended to be grounded or not, and which is to be used on a table is configured as follows:

– either the bottom or the rear of the EUT shall be at a controlled distance of 40 cm from an RGP. This ground plane is normally the wall or floor of a shielded room. It may also be a grounded metal sheet with dimensions of at least 2 m by 2 m. This is physically accomplished as follows:
  - place the EUT on a table of non-conducting material which is at least 80 cm high; place the EUT so that it is 40 cm from the wall of the shielded room, or
  - place the EUT on a table of non-conducting material which is 40 cm high so that the bottom of the EUT is 40 cm above the ground plane;
– all other conductive surfaces of the EUT shall be more than 40 cm away from the RGP;
– the ANs are placed on the floor as shown in Figure 9 in such a way that one side of the AN housing is 40 cm from the vertical RGP and other metallic parts. V-networks (AMNs) and Y-networks (AANs) are shown in Figures 9 and 10.
– the EUT cable connections shall be as shown in Figure 9;
– the optional test configuration for table-top EUT with only a power cord attached is shown in Figure 11.

NOTE The configuration in Figure 11 may cause an ambiguity due to the fact that with some EUTs, the metallic disturbance source is not in the center of the nonmetallic housing (see CISPR 16-4-1 [5]).

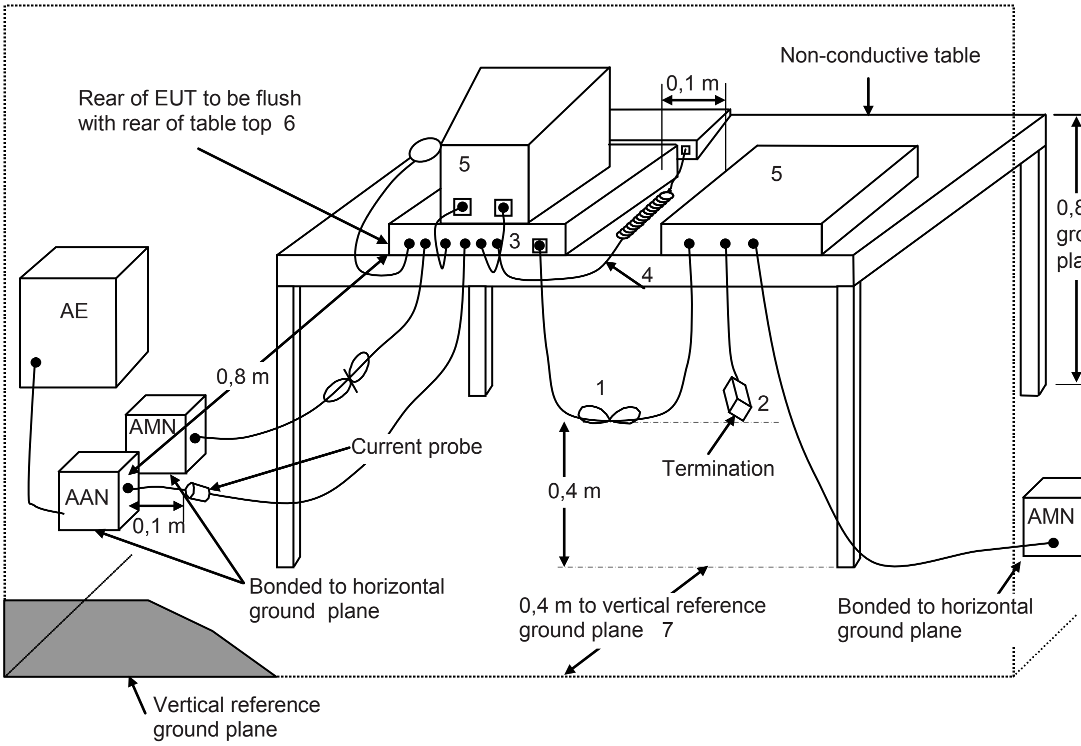
Floor-standing EUTs are subject to the same provisions as above with the exception that they shall be placed on a floor, the points of contact being consistent with normal use. A ground-connected floor of metal shall be used which shall not make metallic contact with the floor support(s) of the EUT, but which shall make contact with intentional ground conductors of the EUT. The metal floor may be used as the RGP and shall extend at least 50 cm beyond the boundaries of the EUT and have minimum dimensions of 2 m by 2 m. For examples of test configurations, see Figures 12 and 13.

The AN is RF bonded to the RGP by a low RF impedance connection (as explained in 5.2). The "low" RF impedance value should preferably be less than 10 Ω at 30 MHz. This can, for example, be achieved if the housing of the AN is mounted directly to the RGP or its connection strap has a length-to-width ratio not more than 3:1. Resonances in the AN grounding can be identified by an in situ test of the voltage division factor (see Annex E).

The EUT is arranged as shown in Figures 9 through 13. The reference distance between the boundary of the EUT and the closest surface of the AN is 80 cm. A good approach for table-top EUTs as in Figures 9 and 13 is the AN mounted in the ground plane – the front panel being flush with the ground plane.

The power mains leads to an AN and the connecting cable from the network to the measuring receiver should be arranged in such a way that their locations do not influence the measurement results. EUTs, which are not equipped with fixed connecting leads, are connected to the AN with a 1 m long lead or as specified in the relevant equipment documentation. The 1 m length is preferred as it gives a lower standard compliance uncertainty.

Unless the EUT has specific requirements for ground lead impedance, the following instructions shall apply. If the EUT is to be connected to a reference ground, this shall be done by means of a lead running parallel to the EUT mains lead and of the same length at a distance of not more than 10 cm from it, unless a ground conductor is contained in the mains lead itself. If a fixed lead is attached to the EUT it shall be 1 m long, or if in excess of 1 m, part of the lead is folded back and forth in the shape of a meander between 30 cm and 40 cm in length, and arranged in the form of a non-inductive serpentine in such a way that the total length of the lead does not exceed 1 m (see also Figure 14). However, when the bundled lead may influence the measurement results, a shortening of the length to 1 m is recommended.



Key

1 Interconnecting cables that hang closer than 40 cm to the ground plane shall be folded back and forth forming a bundle 40 cm long or less, hanging approximately in the middle between the ground plane and the table. The minimum bend radius of the cable shall not be exceeded. If the bend radius causes the bundle length to exceed 40 cm, the bend radius shall determine the bundle length.

2 I/O cables that are connected to a peripheral shall be bundled in the centre. The end of the cable may be terminated if required using correct terminating impedance. The total length shall not exceed 1 m – if possible.

3 The EUT is connected to one AMN. Measurement terminals of AMNs and AANs shall be terminated with 50 Ω if not connected to the measuring receiver. AMNs are placed directly on the horizontal ground plane 0,8 m from the EUT and 40 cm from vertical ground plane if the vertical ground plane is the RGP (see also Figure 10 a)). Alternatively (as shown in Figure 10 b)), AMNs are placed on the vertical ground plane 0,8 m from the EUT, if the horizontal ground plane is the RGP, which is 40 cm below the EUT. To reach the 0,8 m distance, the AMNs may have to be moved to the side. All auxiliary equipment is connected to a second AMN if this second AMN is capable of supplying the necessary power. In cases where a single AMN is not capable of supplying the necessary power, several AMNs may be used to supply the auxiliary equipment. AANs are used for unshielded twisted pair cables containing 1, 2, 3 or 4 pairs, and current probes may be used for other cables (unshielded or shielded).

4 Cables of hand-operated devices, such as keyboards, mouses, etc., shall be placed as close as possible to the host.

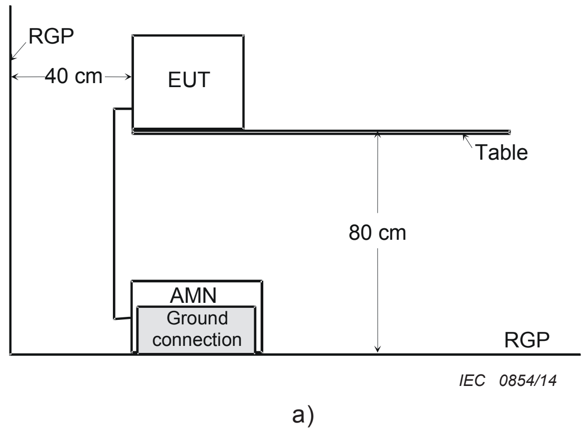
5 Non-EUT components being tested.

6 Rear of EUT, including peripherals, shall all be aligned and flush with rear of table-top.

7 Rear of table-top shall be at a distance of 40 cm from a vertical conducting plane that is bonded to the floor ground plane.

Tolerances of cable lengths and distances are as practical as possible.

Figure 9 – Test configuration: table-top equipment for conducted disturbance measurements on power mains



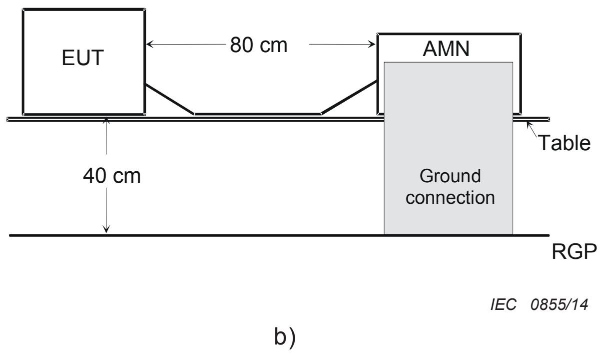
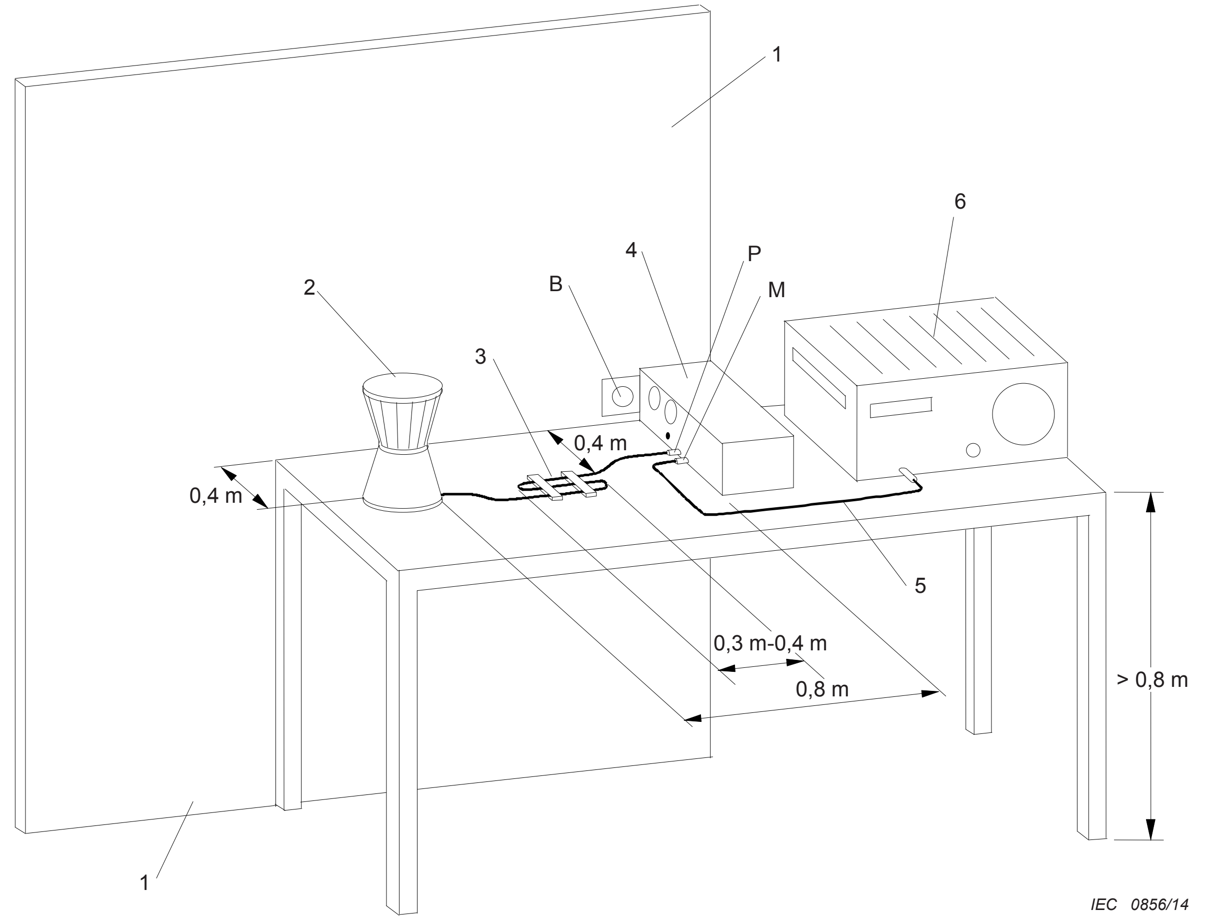


Figure 10 – Arrangement of EUT and AMN at 40 cm distance, with a) vertical RGP and b) horizontal RGP

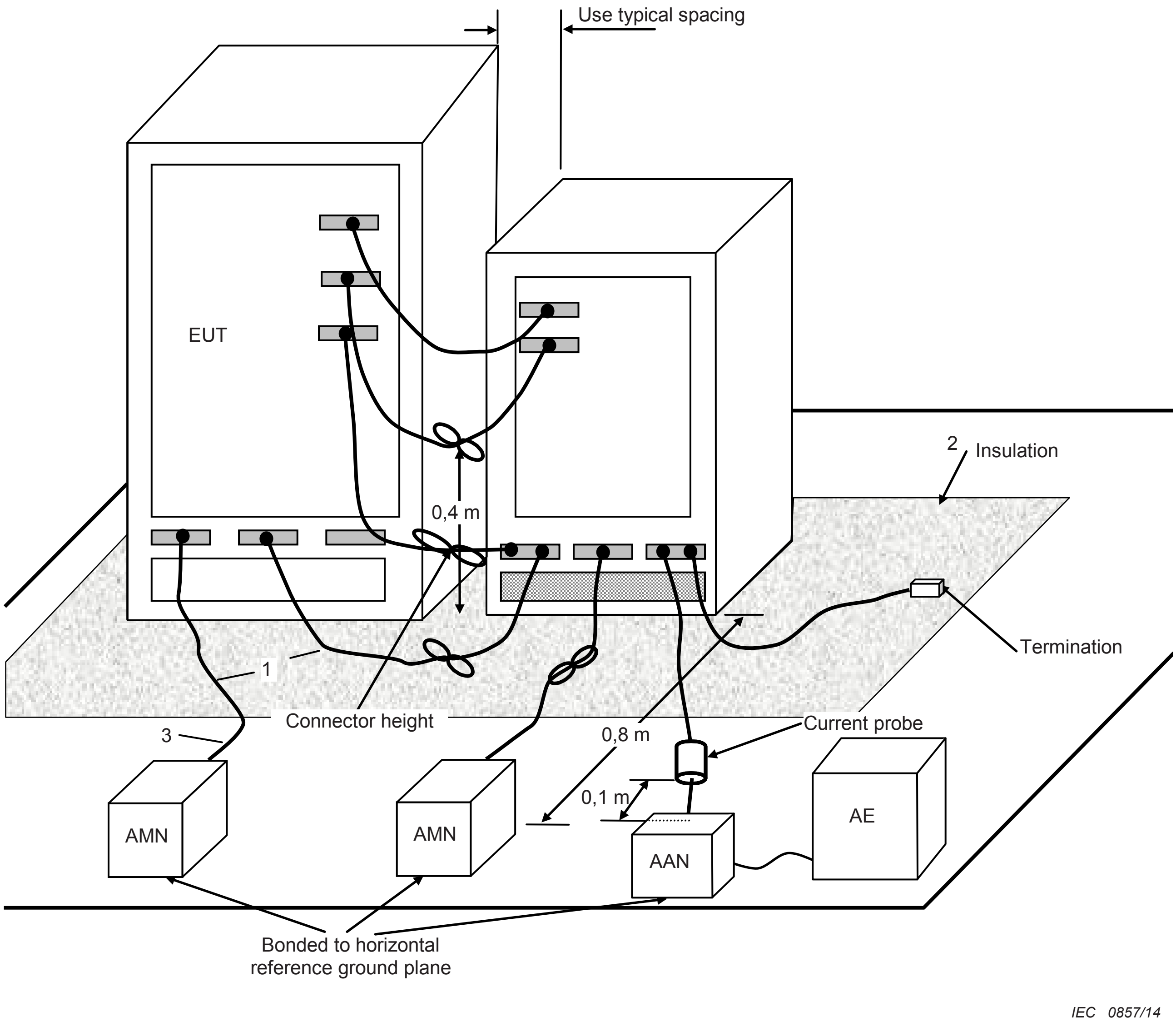


Key

1 Metallic wall 2 m by 2 m
2 EUT
3 Excess power cord (e.g. 0,02 m by 0,3 m forming a meander)
4 AMN
5 Coaxial cable
6 Measuring receiver
B Reference ground connection
M Measuring receiver port
P Power to EUT

Tolerances of cable lengths and distances are as practical as possible.

Figure 11 – Optional example test configuration for an EUT with only a power cord attached



Key

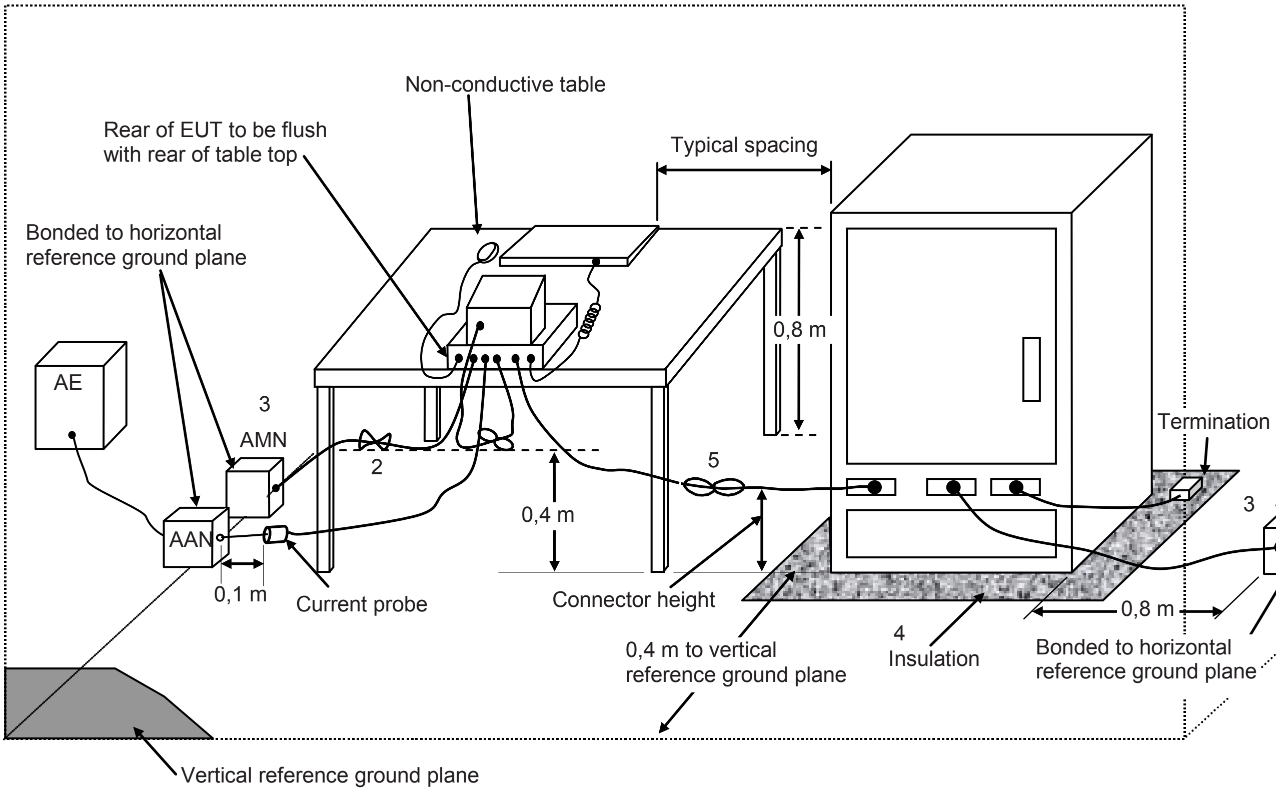
1 Excess cables shall be bundled in the centre or shortened to appropriate length.

2 The EUT and cables shall be insulated (up to 15 cm) from the ground plane.

3 The EUT is connected to one AMN. The AMN can be placed on top of or immediately beneath the ground plane. All other equipment is powered from the second AMN. Refer also to comment 3 in Figure 9.

Tolerances of cable lengths and distances are as practical as possible.

Figure 12 – Test configuration: floor-standing equipment (see 7.4.1 and 7.5.2.3)



Key

1 The interconnecting cables which hang closer than 40 cm to the ground plane shall be folded back and forth forming a bundle 30 cm to 40 cm long or less, hanging approximately in the middle between the ground plane and the table.

2 Excess power cords shall be bundled in the centre or shortened to appropriate length.

3 The EUT is connected to one AMN. The AMN may alternatively be connected to the vertical reference plane. All other equipment is powered from the second AMN. To reach the 0,8 m distance, the AMNs may have to be moved to the side. Refer also to comment 3 in Figure 9.

4 The EUT and the cables shall be insulated (up to 15 cm) from the ground plane.

5 The I/O cable to the floor standing unit drapes to the ground plane and the excess is bundled. Cables not reaching the ground plane are dropped to the height of the connector or 40 cm, whichever is lower.

Tolerances of cable lengths and distances are as practical as possible.

Figure 13 – Example test configuration: floor-standing and table-top equipment (see 7.4.1 and 7.5.2.3)

7.4.2 Procedure for the measurement of unsymmetric disturbance voltages with V-networks (AMNs)

7.4.2.1 General

Generally, the measurement of disturbance voltages using ANs is the preferred CISPR measurement method. If, e.g. an AMN causes the EUT not to work, then measurements with current probes or voltage probes should be made.

7.4.2.2 Arrangement of equipment with ground connection

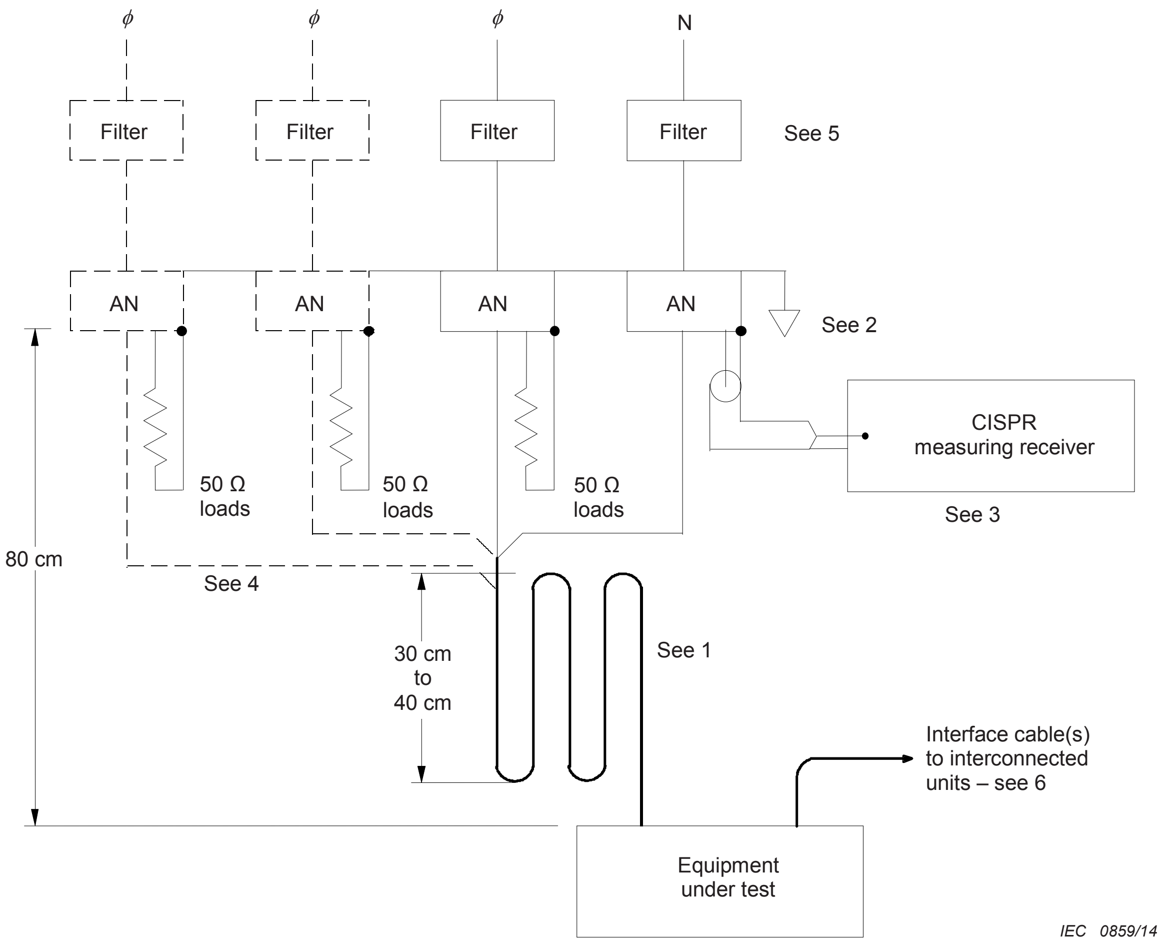
For equipment under test which is required to be grounded during its operation, or the conductive housing of which can come into contact with ground, the unsymmetric radio disturbance voltage of the individual mains lead is measured with reference to the reference metal wall (general ground of the measuring equipment) to which the housing of the equipment under test is connected via its protective ground conductor and the ground connection of the artificial mains network (see the equivalent circuit in Figure 15).

The parameters determining the interference potential of grounded test units are discussed in A.3.

For EUTs with two or more power and safety conductors or special ground connections, the measurement result depends much on the termination conditions of the mains terminals and the grounding conditions (refer also to 7.5 on measurement in systems).

As the ground safety conductors in the actual mains power supply installation may have a considerable length, and therefore do not guarantee a ground impedance as low and effective as in the standard test set-up with only a 1 m long ground wire connection to the reference ground, and moreover, because safety conductors need not be used on every product per IEC 60364-4 [8], disturbance voltage measurements on pluggable safety-class I appliances shall be carried out according to 7.4.2.3, also without the safety or ground wire being connected (non-grounded measurement). If however for safety reasons it is necessary to maintain the safety function of ground wires, this can be achieved by the use of a PE choke or impedance equal to the network impedance of a V-network in the safety wire path.

Exceptions may be made for non-radiating or well-screened EUTs which have to be grounded according to special requirements or instructions (see A.2.1 and A 4.1).



Key

1 The length of the EUT power cord in excess of 80 cm shall be folded into a serpentine-like bundle and not coiled.

2 Connection of the AN to the ground plane shall provide a low impedance path at high frequencies. It shall be made using a solid flat metal conductor that has a length-to-width ratio of not more than 3:1.

3 The CISPR measuring receiver shall be isolated from the AMN using a sheath current absorber on the coaxial cable (example in E.2).

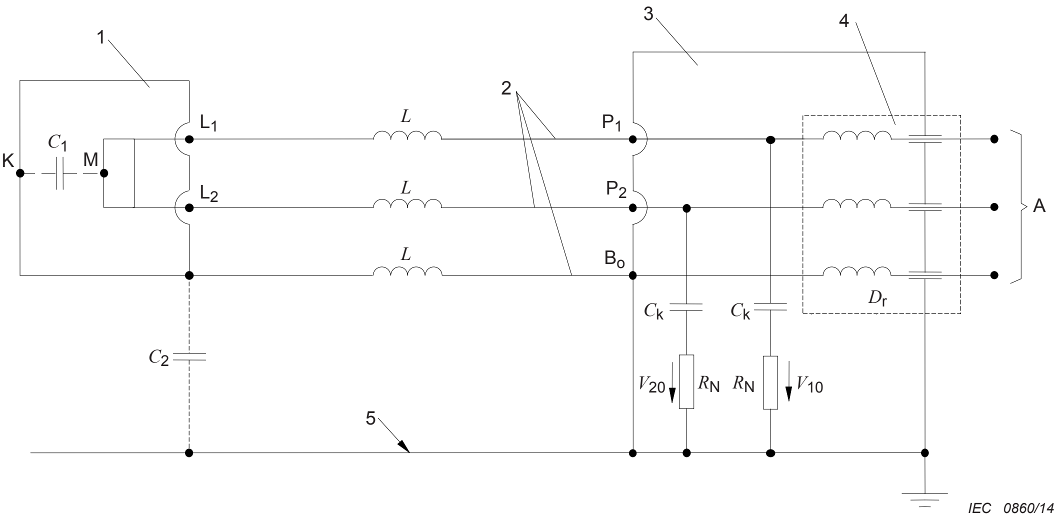
4 Dotted lines represent the test set-up for the three-phase power.

5 Optional filter hook-up; replace with shorts if not used.

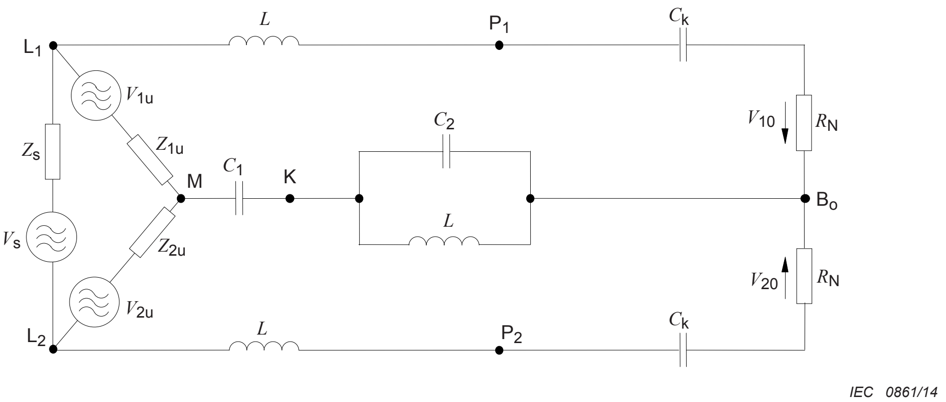
6 Interconnected units may be attached to a single AN via a power junction strip or box.

7 A table mounted or handheld EUT shall be 40 cm from any grounded conducting surface of at least 2 m square and at least 80 cm from any other conductive objects, including devices that are part of the system or instrumentation.

Figure 14 – Schematic of disturbance voltage measurement configuration (see also 7.5.2.3)



a) Schematic for measurement and power circuit



b) Equivalent voltage source and measurement circuit

Key

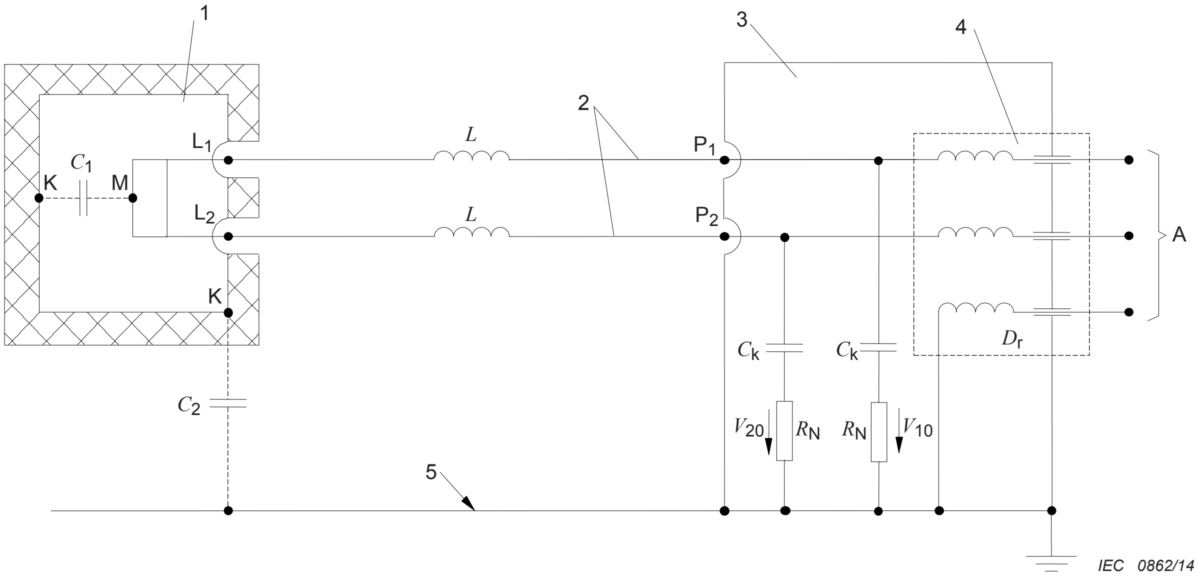
1	EUT
2	Power cord
3	AMN
4	Inductor and decoupling capacitor
5	Metallic wall
A	Power input
B_0	Reference ground connection
L_1, L_2	Power cord connection (100 cm)
P_1, P_2	EUT plug to mains network
C_1	Stray capacitance within EUT to metallic parts
C_2	Stray capacitance of EUT to metallic wall (ground)
C_K	Coupling capacitors within mains network
D_r	Inductor (PE choke) for safety ground wire
K	Conductive structural parts of the EUT
L	Inductance of connecting wires
M	Fictitious mid-point of the internal voltages
R_N	Simulation resistances (50 Ω or 150 Ω)
Z_s	Symmetric internal impedance of EUT
Z_{1u}, Z_{2u}	Internal impedances of the EUT
V_s	Symmetric internal voltage of the EUT
V_{1u}, V_{2u}	Internal voltages of the EUT
V_{10}, V_{20}	External measurable unsymmetric voltage

Figure 15 – Equivalent circuit for measurement of unsymmetric disturbance voltage for safety-class I (grounded) EUT

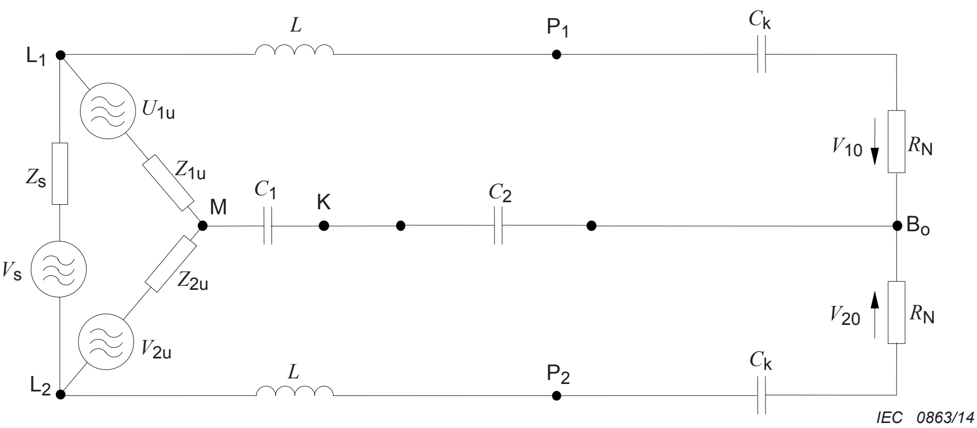
7.4.2.3 Arrangement of equipment without ground connection

Devices without ground connection comprise electrical devices with protective insulation (safety-class II) and devices which can be operated without ground or safety conductor (device of safety-class III) and also pluggable safety-class I devices connected via an isolating transformer. For these devices, the unsymmetric disturbance voltage of the individual conductors shall be measured with respect to the metal reference ground of the measurement arrangement as shown in the equivalent circuit of Figure 16.

Because in the long-wave and medium-wave bands (0,15 MHz to 2 MHz) the results of measurement can be considerably influenced by the low series capacitance C_2 between the EUT and the reference ground, and because the capacitance is determined by the specified distance, the arrangement shall be exactly followed and other external influences such as body and hand capacitance, for example, should be avoided.



a) Schematic for power and measurement circuit



b) Equivalent RFI source and measurement circuit

NOTE Refer to Figure 15 for explanation of symbols.

Figure 16 – Equivalent circuit for measurement of unsymmetric disturbance voltage for safety-class II (ungrounded) EUT

7.4.2.4 Arrangement of handheld equipment without a ground connection

Measurements shall first be made in accordance with 7.4.2.3. Additional measurements shall then be made using the artificial hand (other details are described in CISPR 16-1-2).

The general principle to be followed in the application of the artificial hand is shown in Figure 18. Terminal M of the RC element shall be connected to any exposed non-rotating metal work and to metal foil wrapped around all handles, both fixed and detachable, supplied with the EUT. Metalwork which is covered with paint or lacquer is considered as exposed metalwork and shall be directly connected to the RC element.

The artificial hand shall consist of metal foil wrapped around the case, or part thereof, as specified below. The foil shall be connected to one terminal (terminal M) of an RC element (see Figure 17) consisting of a capacitor of 220 pF ± 20 % in series with a resistor of 510 Ω ± 10 %; the other terminal of the RC element shall be connected to the reference ground of the measuring system.

The artificial hand is to be applied in the following way:

a) when the case of the EUT is entirely of metal, no metal foil is needed, but the terminal M of the RC element shall be connected directly to the body of the EUT;
b) when the case of the EUT is of insulating material, metal foil shall be wrapped around the handle B (Figure 18), and also around the second handle D, if present. Metal foil 60 mm wide shall also be wrapped around the body C at that point where the iron core of the motor stator is located or around the gearbox if this gives a higher disturbance level. All these pieces of metal foil, and the ring or bushing A, if present, shall be connected together and to the terminal M of the RC element;
c) when the case of the EUT is partly metal and partly insulating material, and has insulating handles, metal foil shall be wrapped around the handles B and D (Figure 18). If the case is non-metallic at the location of the motor, a metal foil 60 mm wide shall be wrapped around the body C at that point where the iron core of the motor stator is located, or alternatively around the gearbox, if this is of insulating material and a higher disturbance level is obtained. The metal part of the body, the point A, the metal foil round the handles B and D and the metal foil on the body C shall be connected together and to the terminal M of the RC element;
d) when the EUT has two handles of insulating material A and B and a case of metal C, for example an electric saw (Figure 19), metal foil shall be wrapped around the handles A and B. The metal foil at A and B and the metal body C shall be connected together and to the terminal M of the RC element.

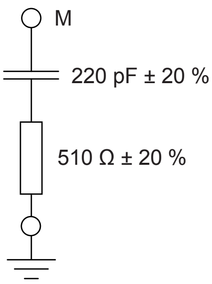


Figure 17 – RC element for artificial hand

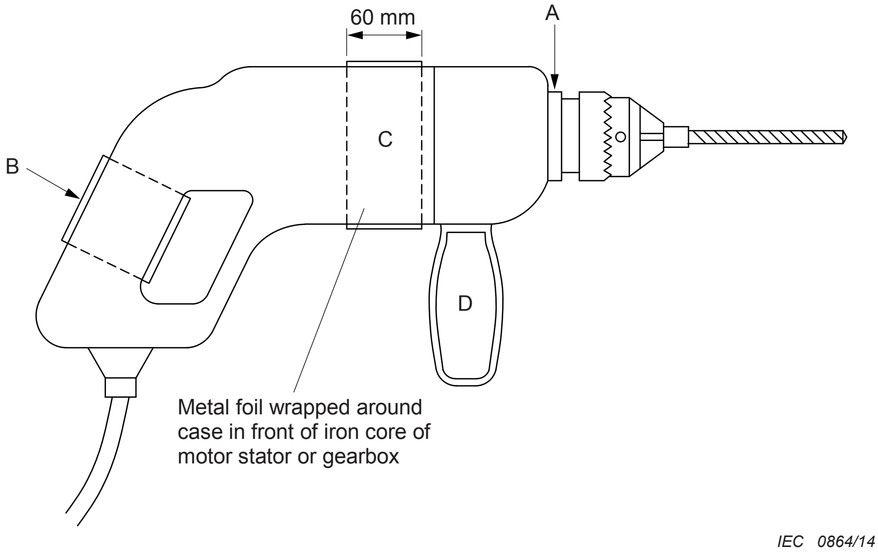


Figure 18 – Portable electric drill with artificial hand

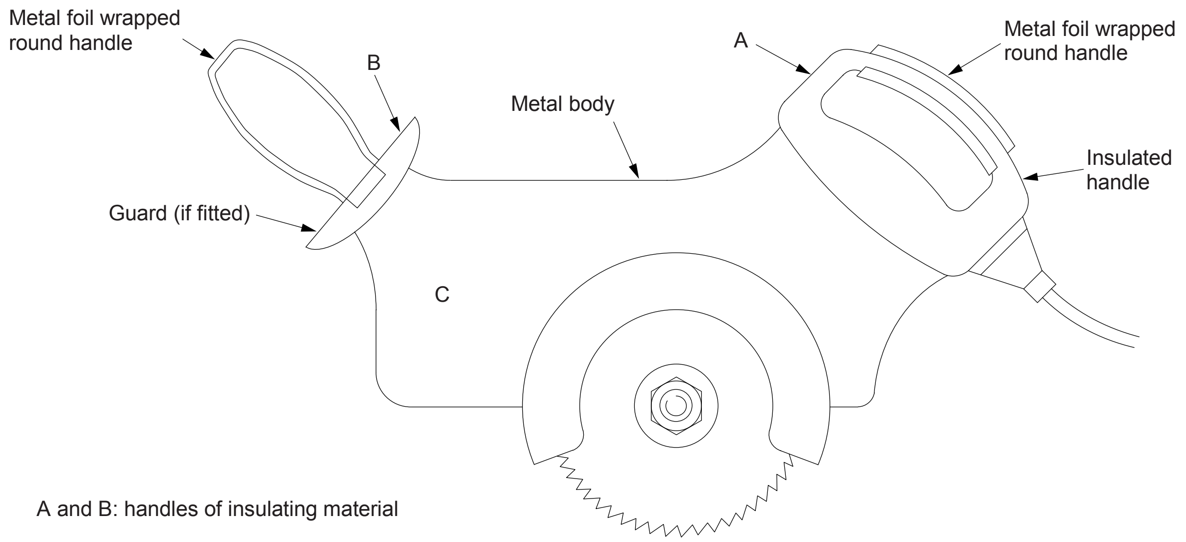


Figure 19 – Portable electric saw with artificial hand

7.4.2.5 Arrangement of keyboards, electrodes and other equipment sensitive to human touch

For keyboards, electrodes and other equipment sensitive to human touch, the artificial hand shall be applied as required by the product standards, and in general according to 7.4.2.4.

7.4.2.6 Arrangement of equipment with external suppression components

If interference suppression devices are attached outside the EUT (e.g. in a plug device for connection to the mains) or as an element inserted in the connecting cable (power cord disturbance suppression device), or if shielded power cords are used, an additional 1 m long unshielded cable shall be connected between the suppression device and the AN for measurement of the disturbance voltage. The line between the AN and the disturbance suppression device shall be placed in the direct proximity of the EUT.

7.4.2.7 Arrangement of equipment having auxiliary equipment (AuxEq) connected at the end of a lead other than the mains lead

Regulating controls incorporating semiconductor devices are excluded from 7.4.2.7; the provisions of 7.4.4.1 shall apply.

When the AuxEq is not essential to the operation of the EUT and has a separate test procedure specified elsewhere, 7.4.2.7 does not apply. The main EUT is tested as an individual EUT.

The ultimate decision whether to measure and apply limits is to be made in the relevant CISPR product publication.

Connecting leads exceeding 1 m in length shall be bundled in accordance with 7.4.1.

Measurements are not required when the connecting lead between the EUT and the AuxEq is permanently fixed on both ends and is either shorter than 2 m or is shielded, provided that in the latter case the shielded lead is connected at both ends to the metal housing of the EUT and to that of the AuxEq. Leads with removable plugs and sockets are considered to be extendable to a length of more than 2 m and measurements are required.

The EUT shall be arranged in accordance with 7.4.2.1 through 7.4.2.6, with the following additional requirements:

a) the AuxEq shall be placed at the same height as, and at the same distance from, the grounded conducting surface and if the lead is long enough it is to be treated in accordance with 7.4.1. If the auxiliary lead is shorter than 0,8 m, its length shall be maintained, and the AuxEq shall be placed as far away as possible from the main EUT. When the AuxEq is a control unit, the arrangements for its operation shall not affect the level of disturbance;
b) if an EUT having an AuxEq is grounded, no artificial hand shall be connected. If the EUT itself is made to be held in the hand, the artificial hand shall be connected to the EUT and not to any AuxEq;
c) if the EUT is not made to be held in the hand, an AuxEq which is not grounded and is made to be held in the hand shall be connected to the artificial hand. If the AuxEq is not made to be held in the hand either, it shall be placed in relation to a grounded conducting surface as described in 7.4.1.

In addition to the measurement on the terminals for the mains connection, measurements are performed on all other terminals for incoming and outgoing leads (e.g. control and load lines) using a voltage probe connected to the input of the measuring receiver.

The AuxEq, control, or load is connected to allow measurements to be made under all provided operating conditions, and during interactions between the EUT and the AuxEq.

Measurements are performed both on the power input terminals of the EUT and the power input terminals of the AuxEq.

7.4.3 Measurement of common mode voltages at differential mode signal terminals

7.4.3.1 General

Generally, the measurement of disturbance voltages using ANs is the preferred CISPR measurement method. If e.g. an AN causes the EUT not to work, then measurements with current probes or capacitive voltage probes should be made.

7.4.3.2 Measurement using the delta-type network

The common mode disturbance voltage at the terminals for differential mode signal lines of telecommunication, data processing and other equipment is measured with delta-networks in accordance with CISPR 16-1-2, in the frequency range 150 kHz to 30 MHz. The delta-networks specified in CISPR 16-1-2 could be constructed so as to allow signal and d.c. current paths needed for the proper functioning of the EUT, as long as the requirements on differential mode and common mode impedances of CISPR 16-1-2 are complied with.

When using the delta-network for measurements on signal terminals, the differential mode rejection shall be as high as needed so as not to give erroneous results when measuring a common mode disturbance voltage at the same frequency as the operational differential mode signal.

When the EUT is to be measured on its power supply terminals using an AMN, all voltage measurements shall be carried out with both networks connected simultaneously. The provisions prescribed in 7.4.1 and 7.4.2 shall be observed.

NOTE The frequency range of the delta-network can be extended to 9 kHz using the same network impedance if decoupling of the connected signal line and coupling to the measuring receiver are designed accordingly.

7.4.3.3 Measurements using the Y-type network

Alternatively an asymmetric (common mode) artificial network (AAN), i.e. a Y-type network according to CISPR 16-1-2, can be used for the measurement of common mode disturbance voltages in the frequency range 9 kHz to 30 MHz.

NOTE Y-type networks are frequently (e.g. in CISPR 22) called impedance stabilization networks (ISNs).

In contrast to the delta-network, which provides a differential mode and a common mode termination with equal simulation impedances of 150 Ω, the Y-network provides only a common mode termination of 150 Ω, and with the communication line terminated with its characteristic impedance and a differential to common mode rejection characteristic of the telecommunication network to which the EUT is intended to be connected.

At the supply side of the Y-type network, a signal simulator, load circuits for d.c. or the operational signal frequency of the EUT, or other circuits needed for the operation of the EUT can be connected. These circuits shall either themselves provide a differential mode RF resistance of 100 Ω to 150 Ω, as required for the particular EUT, or with a termination to provide this resistance. When no external circuit is specified for the operation of the EUT, a resistor of 150 Ω shall be connected as differential mode RF termination to the Y-type network. If no suitable Y-network is available, the telecommunication port is terminated with AuxEq.

When an EUT with telecommunication port is to be measured on its power supply terminals using an AMN, the disturbance voltage measurements shall be carried out with AMN connected to the power port and Y-network connected to the telecommunication port simultaneously, or with the associated equipment directly connected to the EUT. Figure 9 shows the measurement arrangement with AMNs and Y-networks (ISNs). The provisions prescribed in 7.4.1 and 7.4.2 shall be observed.

7.4.4 Measurements using voltage probes

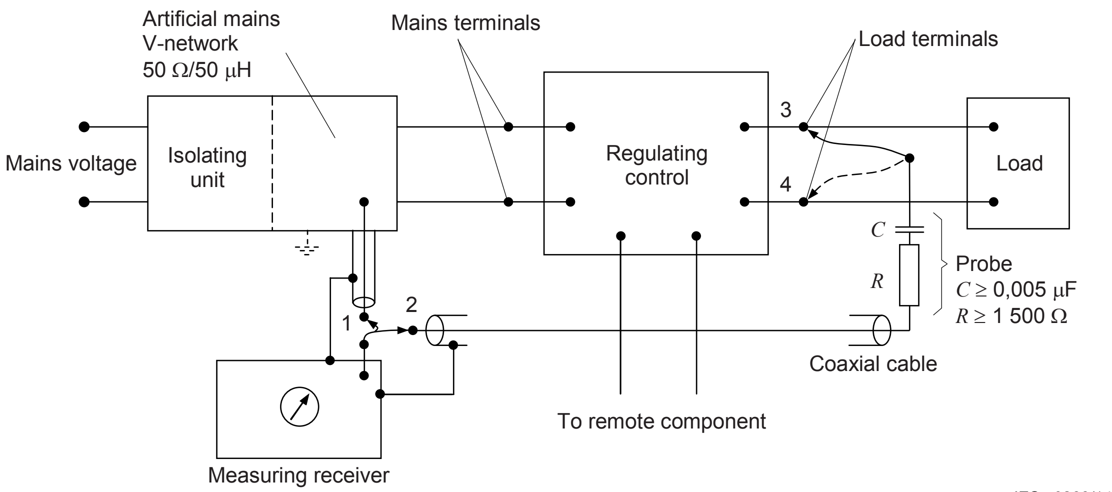
7.4.4.1 With an AMN

To test devices and systems with several connected or connectable lines, the disturbance voltage at the line connections that cannot be measured with AMN (e.g. for connecting lines between parts of components which are separated from the mains), as well as at the connecting jacks for antennas, control and load lines, shall be measured with a voltage probe (see 7.3.3) with a high input impedance (1 500 Ω or more) to ensure that the lines are not loaded by the probe.

For these cases, however, the primary power input wires shall be isolated and RF terminated with the AMN. For the remaining lines, also those not to be measured with the probe, the corresponding conditions of 7.4.1 and the operating conditions laid down for the individual devices in the respective product standards (e.g. CISPR 11 [1] and CISPR 14-1) shall be observed in regard to arrangement and length. The voltage probe is connected to the measuring receiver via a coaxial cable, the screen of which is connected to the reference ground and the case of the voltage probe. No connection shall be made directly from this case to live parts of the EUT.

If the measuring receiver is connected to the voltage probe, the AMN shall be terminated with 50 Ω.

Figures 20 and 21 (from CISPR 14-1) show an example for a test set-up for measuring the disturbance voltage of a semi-conductor regulating control.



Switch positions:

1 For mains measurements

2 For load measurements

3 and 4 Successive connections during load measurements

NOTE 1 The ground of the measuring receiver is connected to the AMN.

NOTE 2 The length of the coaxial cable from the probe does not exceed 2 m.

NOTE 3 When the switch is in position 2, the output of the AMN at terminal 1 is terminated by an impedance equivalent to that of the CISPR measuring receiver.

NOTE 4 Where a two-terminal regulating control is inserted in one lead only of the supply, measurements are made by connecting the second supply lead as indicated in Figure 21.

Figure 20 – Measuring example for voltage probes

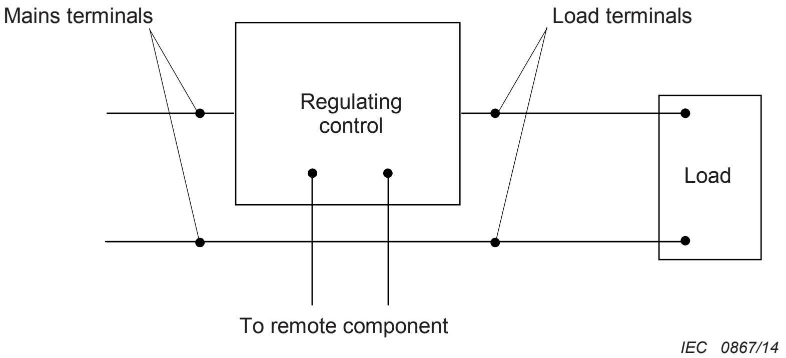


Figure 21 – Measurement arrangement for two-terminal regulating controls

7.4.4.2 Measurements without an AMN

During testing of EUTs which are not to be measured with AMNs, the disturbance voltage is measured across a defined simulation resistance (e.g. artificial fence simulation in CISPR 14-1 or under open-circuit conditions with an exactly defined arrangement and line layout taking into consideration the specifications of 7.4.1). The disturbance voltage is measured with a high-impedance voltage probe.

This is valid also for e.g. power electronic devices which are fed from their own separate power supplies or battery-powered devices to which separately installed lines are connected which are not to be loaded.

In the case of disturbance voltage measurements on separate individual power sources for currents of more than 25 A (e.g. battery, generator, converter), an impedance measurement shall be applied to ascertain that the tolerance of the simulated resistance, in accordance with CISPR 16-1-2 is not exceeded.

The flexible ground connection for probes with an input impedance R_x of more than 1 500 Ω should not be longer than 1/10 of the wave-length at the maximum measurement frequency and shall be connected in the shortest possible way to the metal surface serving as reference ground. In order to avoid additional capacitive loading of the test point by the screening of the probe, the tip of the probe should not exceed a length of approximately 3 cm. The screened connections to the measuring receiver shall be arranged in such a way that the capacitance of the test object is not altered with respect to the reference ground.

7.4.4.3 AMN as a voltage probe

Where the current rating of an EUT exceeds the rating of available AMNs, the AMN can be used as a voltage probe. The EUT port of the AMN is connected to each of the supply lines of the EUT (single phase or three-phase).

Prior to connecting an AMN to the mains supply, it shall be safely connected to the local physical earth (PE).

> **WARNING:** Before disconnecting the PE, the AMN should be disconnected from the mains supply. The mains port of the AMN is left open. When the AMN is connected as a voltage probe, the pins on the AMN power input connector/plug will be energized by the supply voltage. The pins on the plug shall be made safe with an insulated protective cover or other means.

In the frequency range of 150 kHz to 30 MHz, the supply lines of the EUT shall be connected to the mains via an inductance of 30 μH to 50 μH (see Figure A.8, configuration 2). The inductance may be realized by a choke, a line of 50 m length, or a transformer. In the frequency range of 9 kHz to 150 kHz, a greater inductance will normally be required for decoupling from the mains. This guarantees also a reduction of noise from the mains network (see A.5).

Because measurements are preferable with AMNs in their standard configuration, the AMN as a voltage probe should only be used for in situ tests and where practical current limitations are exceeded. The AMN as a voltage source shall not be used for testing according to a product standard unless it is referred to in the product standard as an alternative measuring method.

7.4.5 Measurement using a capacitive voltage probe (CVP)

Disturbance voltage measurements on unshielded signal and telecommunication cables with more than four symmetrical pairs can be made using a CVP. The measurement can be combined with a current probe measurement to measure disturbance voltage and current simultaneously. The disadvantage of this method is a lack of isolation between the EUT and the actual network or simulator.

The CVP body shall be bonded to the RGP using a ground connection as short as possible.

7.4.6 Measurements using current probes

Disturbance current measurements may be useful for several reasons. The first is that in some devices it may not be possible to insert an AN. This is particularly true when tests are performed on installed systems, or where the EUT has very high currents. A second reason for the use of the current probe is that at the lower end of the frequency range the mains impedance becomes very low, so the disturbance source is a current generator. The measurement of this current can be made by means of a current transformer, without interrupting or disconnecting the mains connection.

Current probes shall conform to the requirements of CISPR 16-1-2.

Current probes enable the direct measurement of the common mode components of the disturbance current by enclosing the cable containing all leads. Therefore, common mode disturbance currents can be easily separated from differential mode operating currents.

If measurements are performed with known load and source impedances, the disturbance voltage can be calculated.

If only one conductor is enclosed, the superposition of the differential and common mode disturbance current components is measured. If, in this case, any extremely high (above 200 A) operating current exists, there is a risk of false data because the magnetic core of the current probe may saturate.

7.5 System test configuration for conducted emissions measurements

7.5.1 General approach to system measurements

The general objective of defining a system test configuration for conducted disturbance measurements has the following key points:

- avoiding common mode disturbance ground loops;
- defining a configuration which is easily duplicated;
- decoupling of lines not being measured from the line being measured;
- placing of lines to achieve decoupling;
- arrangement of lines to minimize the influence of magnetic fields on disturbance measurements;
- duplicating requirements in 7.1 to 7.4 for the system test to the maximum extent possible.

Whenever possible, the disturbance voltage on a system line shall be measured with an AN. For currents up to 50 A, AMNs can be used quite easily. The AN shall be installed within 80 cm of the system equipment being measured, where practical. Each wire of a multi-wire power mains circuit shall be routed through an AMN. Each AN shall be terminated with a 50 Ω resistor at the measurement terminal.

The EUT shall be arranged and connected with cables terminated in accordance with the manufacturer's instructions.

For some measurements, relevant product publications may state a specific load to be used together with load voltage probes, instead of an AMN. A voltage probe may also be used for conducted measurements, when the mains current is above 50 A and an appropriate AMN is not available. However, in this latter case, test results with an AMN shall be preferred.

For some measurements, the use of current probes may be specified in the relevant product publication.

7.5.2 System configuration

7.5.2.1 General

The system shall be carefully configured, installed, arranged and operated in a manner that is most representative of the system as typically used (i.e. as specified in the instruction manual), or as specified herein. Equipment that typically operates within a system made up of multiple interconnected units should be tested as part of such a typical operational system.

Generally, the system that is tested shall be of the same type that is supplied to the end user. If the marketing information is not available, or it is not practical to assemble extraordinary amounts of equipment to replicate a complete product installation, the test shall be performed using the best judgement of the test engineer, in consultation with the design engineering staff. The results of any such discussion and decision process shall be documented in the test report.

The selection and placement of cables, a.c. line cords, host and peripherals depends on the type of EUT and shall be representative of expected equipment installation. The separation between different units shall be 10 cm, unless this is not possible due to their construction. Then the units should be placed as closely together as possible (greater than 10 cm), and the set-up shall be documented in the test report. Three types of set-ups are distinguished. First, there are systems normally used entirely on one table-top; see e.g. Figure 9. A second type of system consists of equipment normally used in a floor-standing configuration. These include systems mounted over a specially designed raised floor which facilitates intra-system connection under the raised floor. Equipment making up the floor-standing system can be interconnected with cabling lying on the floor, under the floor in a raised floor installation, or overhead according to normal installation. Third, there are systems that are a combination of floor-standing and table-top systems. The remainder of 7.5.2 provides instructions for the testing of each of these systems. In addition, the specific requirements in 7.1 to 7.4 shall be observed.

Equipment in a system, normally being floor-standing, shall be placed on a floor in accordance with 7.4.1. Equipment designed for both table-top and floor operation shall be tested only in the table-top configuration.

7.5.2.2 Operating conditions

The system shall be operated at the rated (nominal) operating voltage and typical load conditions – mechanical or electrical, or both – for which it is designed. Loads may be actual or simulated, as described in the individual equipment requirements. For some systems, it may be necessary to develop a set of explicit requirements specifying the test conditions, operations, etc., to be used in testing a specific system.

If the system includes a visual display unit or monitor, the following operating conditions apply, unless the product standard specifies otherwise:

a) set the contrast control to maximum;
b) set the brightness control to maximum, or at raster extinction if raster extinction occurs at less than maximum brightness;
c) for colour monitors, use white letters on a black background to represent all colours;
d) select the worst case of positive or negative video, if both are available;
e) set character size and number of characters per line so that the maximum number of characters per screen is displayed;
f) for a monitor that has no graphics capabilities, regardless of the video card used, a pattern consisting of random text shall be displayed;
g) for a monitor with graphics capabilities, even though another video card may be needed to accomplish a graphic display, a pattern consisting of a line of scrolling Hs should be displayed;
h) if a monitor has no text capabilities, use a typical display.

7.5.2.3 Interfacing equipments, simulators and cables

Compliance testing is performed with peripheral and cable placement which is judged realistic and likely to be found in the final installation. Figures 9, 12 and 13 describe standardized test set-ups which will provide a basis for reproducibility among testing laboratories and is consistent with the requirement for a realistic system and cable orientation. Therefore, measurements with an actual interfacing unit shall be preferred. Because a system is required to interact functionally with other units, the actual interfacing units should be used. Simulators may be used to provide representative operating conditions, provided the effects of the simulator used in lieu of an actual interfacing unit properly represent the electrical, and in some cases the mechanical, characteristics of the interfacing units, especially concerning RF signals, impedances, and shield terminations. Because of the added degree of uncertainty when a simulator is used, such use should be avoided if possible. Accordingly, measurements made with an actual interfacing unit shall be preferred. If a device is designed for use with only a specific host computer or peripheral, it should be tested with that computer or peripheral.

Interfacing cables should be typical of normal use as supplied with the normal system, and at least 2 m long, unless the manufacturer's user manual specifies shorter cables. The same type of cable (that is, non-shielded, braided shield, foil shield, etc.) specified in the user manual should be used throughout the tests. Excessive lengths of cable shall be folded into a serpentine-like bundle at the approximate centre of the cable, with the bundles 40 cm or less in length so that the effective length between EUT and AE does not exceed 1 m, if possible.

If shielded or special cables are used during the tests to achieve compliance, then a statement shall be included in the test report and in the instruction manual advising of the need to use those types of cables.

If magnetic fields are generated by components of the system (e.g. by VDUs), loops between ground connections and measurement lines may pick up these fields, and measurement results may be erroneous due to voltages coupled into these loops. To avoid magnetic field pickup, connecting lines (ground and measurement lines) should be as short as possible and twisted.

Interface ports (connectors) shall have a cable connected to one of each type of functional interface port of the system, and each cable shall be terminated in a device typical of actual usage. Where there are multiple interface ports all of the same type, additional connecting cables shall be added to the system to determine the effect these cables have on emissions from the system. Measurements on power ports using V-networks shall be made with telecommunication ports simultaneously terminated with Y-networks (see 7.4.3.3).

Normally, the loading of similar ports is limited to the following:

a) availability of multiple loads (for large systems);
b) reasonableness of multiple loads representing a typical installation.

The rationale for the selection of the configuration and loading of ports shall be included in the test report; that is, 25 % of possible cables were connected and the emissions did not increase by more than 2 dB when one or more cables were added. Additional ports on support units, interfacing units, or simulators, other than those associated with the system or the minimum required system, need not be connected or used during testing.

7.5.2.4 Mains connection

If the system is an assembly of equipment each having its own power cords, the point of connection for the AMNs is determined from the following rules:

a) each power cord which terminates in a mains supply plug of a standard design (e.g. IEC/TR 60083 [7]) shall be tested separately;
b) power cords or terminals which are not specified by the manufacturer to be connected via a host unit shall be tested separately;
c) power cords or field wiring terminals that are specified by the manufacturer to be connected to a host unit or other power-supplying equipment, shall be connected to that host unit or other power-supplying equipment, and the terminals or cords of that host unit or other power-supplying equipment are connected to the AMNs and tested;
d) where a special mains connection is specified, the necessary connection hardware to the AMN shall be supplied by the manufacturer for the purpose of the test.

The ground safety conductor of units separately powered shall be isolated from the equipment under test by a 50 μH AN in the frequency range 0,15 MHz to 30 MHz. The normal AMN mains input is connected to the reference ground in this use of the AMN as a filter.

7.5.3 Measurements of interconnecting lines

In addition to the measurement on the terminals for the mains connection, measurements may need to be performed with a voltage probe on other terminals for incoming and outgoing leads (for example control and load lines). If the function of the equipment under test is affected by the 1 500 Ω impedance of the probe, the impedance at 50 Hz/60 Hz and at radio frequencies may need to be increased (for example 15 k Ω in series with 500 pF). In place of a voltage measurement, a current measurement with a current probe may also be used, if required (or offered as an option) in the product specification.

During the measurement, the ANs on the mains lead remain in place, to provide a defined mains isolation and a defined RF termination. The auxiliary apparatus (control, load) is connected to allow measurements to be made under all provided operating conditions and during interactions between components of the equipment. Measurements are made on the specified terminals of each piece of equipment.

If the connecting lines between components of the equipment are permanently fixed on both ends, and are either shorter than 2 m or are shielded, no measurements are necessary, provided that in the latter case the shielded cable is connected at both ends to the reference ground, that is the metal housing of the equipment. Non-shielded connecting lines with plug(s) or socket(s) are considered to be extendable to a length of more than 2 m, and therefore shall be extended by at least 2 m and shall be tested. Shielded cables shall be at least 2 m long, unless the user manual specifies shorter cables.

7.5.4 Decoupling of system components

One of the sources of inaccurate conducted measurements in a system is any ground-circulating current. This ground current may be interrupted by installing a 50 μH AN (PE choke) in the frequency range 0,15 MHz to 30 MHz in the ground safety conductor to the EUT.

An additional source of circulating currents can be the shields of interconnecting cables between units. Therefore, the ground safety conductor to these units shall also be isolated by a 50 μH AN.

The measurement receiver should be referenced to ground only at the measurement point, to prevent ground loops. (Caution: shock hazard may exist if the measuring receiver is not supplied with an isolation transformer.)

7.6 In situ measurements

7.6.1 General

Where allowed by the relevant product standard, in situ measurements may be made for the evaluation of compliance, if technical reasons prohibit disturbance measurement on a standard test site. Such technical reasons may include excessive size and/or weight of the EUT, or situations where the interconnection to the infrastructure for the EUT is too expensive for the measurement on standard test sites. In situ measurement results of an EUT type will likely deviate from site to site, or from results obtained on a standard test site, and should therefore not be used for type testing. The applicable product standard takes precedence.

The disturbance voltage shall be measured under the existing conduction conditions with non-reactive pick-up devices (high resistance voltage probes). The conduction conditions and measurement results are affected by:

– the existing reference ground used during measurement. Neither a conducting ground plane nor an AN shall be installed for user's installation testing, unless one or both are to be a permanent part of the installation;
– the RF characteristics and loading conditions for the power mains conduction;
– the ambient RF environment;
– the input impedance of the pick-up device; and
– the magnetic fields caused by the EUT or in the vicinity.

7.6.2 Reference ground

The existing ground at the place of installation should be used as reference ground. This should be selected by taking high-frequency (RF) criteria into consideration. Generally, this is accomplished by connecting the EUT via wide straps, with a length-to-width ratio not exceeding a factor of three, to structural conductive parts of buildings that are connected to earth. These include metallic water pipes, central heating pipes, lightning wires to earth, concrete reinforcing steel, and steel beams.

In general, the safety and neutral conductors of the power installation are not suitable as reference ground because these may carry extraneous disturbance voltages and can have undefined RF impedances.

If no suitable reference ground is available in the surroundings of the test object or at the place of measurement, sufficiently large conductive structures such as metal foils, metal sheets or wire meshes set up in the proximity, can be used as reference ground for measurement.

The general requirements of 7.4.2.2 and of Annex A should be observed.

7.6.3 Measurement with voltage probes

Testing of conducted disturbance voltage is made with the voltage probe. Special precautions shall be taken to establish a reference ground for the measurements.

Any voltage decrease caused by loading of the circuit to be measured can be determined qualitatively by varying the voltage probe input impedance. If the input impedance of the voltage probe is high compared to the internal impedance of the test point or of the tested network, then only slight differences in the measurement of the disturbance voltage occur when the probe input impedance is increased. The input impedance of the probe can be doubled by series connection of a 1 500 Ω resistor. If the disturbance voltage is then reduced by an amount between 5 dB and 6 dB, then the 1 500 Ω probe can be used to measure the disturbance voltage.

7.6.4 Selection of measuring points

7.6.4.1 General

Radio disturbance voltage measurements at the place of installation are carried out at the boundaries of the user's premises, of industrial areas, or at points to be specified within the influence area of the receiving system.

7.6.4.2 Measurements on mains and other supply leads

In power supply networks it is sufficient to measure the unsymmetric disturbance voltage with the voltage probe at accessible power outlets near the power entrance to the building.

7.6.4.3 Measurements on unshielded and shielded cables

In the case of non-shielded and shielded signal, control and load leads with non-grounded shield leaving the boundaries, the unsymmetric disturbance voltage shall be measured with a high-impedance voltage probe on the individual wires or the shields with respect to the reference ground. Common mode disturbance voltage can be measured with a capacitive voltage probe.

In the case of shielded cables with grounded shield, the common mode disturbance current is measured at a distance greater than one-tenth wavelength from the connecting and grounding points using a current probe.

8 Automated measurement of disturbances

8.1 Precautions for automating measurements

Much of the tedium of making repeated EMI measurements can be removed by automation. Operator errors in reading and recording measurement values are minimized. By using a computer to collect data, however, new forms of error can be introduced that may have been detected by an operator. Automated testing can lead, in some situations, to greater measurement uncertainty in the collected data than manual measurements performed by a skilled operator. Fundamentally, there is no difference in the accuracy with which a disturbance value is measured whether manually or under software control. In both cases the measurement uncertainty is based on the accuracy specifications of the equipment used in the test set-up. Difficulties may arise, however, when the current measurement situation is different from the scenarios the software was configured for.

For example, an EUT disturbance adjacent in frequency to a high level ambient signal may not be measured accurately, if the ambient signal is present during the time of the automated test. A knowledgeable tester, however, is more likely to distinguish between the actual disturbance and the ambient signal; therefore the method for measuring the EUT disturbance can be adapted as required. However, valuable test time can be saved by performing ambient scans prior to the actual disturbance measurement with the EUT turned off to record ambient signals present on the OATS. In this case the software may be able to warn the operator of the potential presence of ambient signals at certain frequencies by applying appropriate signal identification algorithms.

Operator interaction is recommended if the EUT disturbance is slowly varying, if the EUT disturbance has a low on-off cycle or when transient ambient signals (e.g. arc welding transients) may occur.

8.2 Generic measurement procedure

Signals need to be intercepted by the EMI receiver before they can be maximized and measured. The use of the quasi-peak detector during the disturbance maximization process for all frequencies in the spectrum of interest leads to excessive test times (see 6.6.2). Time-consuming processes like antenna height scans are not required for each disturbance frequency. They should be limited to frequencies at which the measured peak amplitude of the disturbance is above or near the emission limit. Therefore, only the disturbances at critical frequencies whose amplitudes are close to or exceed the limit will be maximized and measured.

The following generic process will yield a reduction in measurement time (see Figure 22):

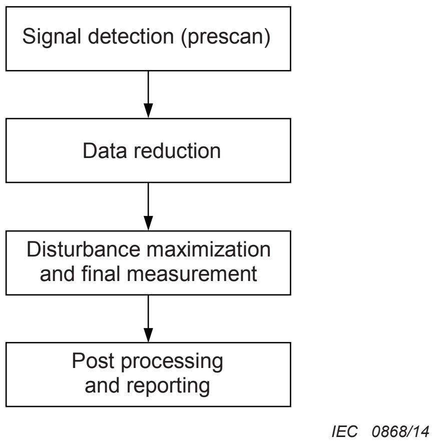


Figure 22 – Generic process to help reduce measurement time

8.3 Prescan measurements

This initial step in the overall measurement procedure serves multiple purposes. Prescan places the least number of restrictions and requirements upon the test system because its main purpose is to gather a minimal amount of information upon which the parameters of additional testing or scanning will be based. This measurement mode can be used to test a new product, where the familiarity with its disturbance spectrum is very low. In general, prescan is a data acquisition procedure used to determine where in the frequency range of interest, significant signals are located. Improved frequency accuracy and data reduction through amplitude comparison may be necessary. These factors define the measurement sequence during the execution of prescan. In any case, the results will be stored in a signal list for further processing.

When a prescan measurement is made to quickly obtain information on an EUT’s unknown disturbance spectrum, frequency scanning can be performed by applying the considerations of 6.6.

Determination of the required measurement time:

If the disturbance spectrum and especially the maximum pulse repetition interval T_p of the EUT is not known, the measurement time T_m is investigated to assure it is not shorter than T_p. The intermittent character of the EUT's disturbance is especially relevant for critical peaks of the disturbance spectrum. First should be determined at which frequencies the amplitude of the disturbance is not steady. This can be done by comparing the max-hold with a min-hold or clear/write function of the measuring equipment or software, and observing the disturbance for a period of 15 s. During this period no change of lead should be made. Signals with e.g. more than 2 dB difference between the max-hold result and min-hold result are marked as intermittent signals. (Care should be taken not to mark noise as intermittent signals.) The measurement is repeated, to reduce the risk that certain intermittent peaks are not found because they remain below noise level. From each intermittent signal, the pulse repetition period T_p can be measured, by applying zero span or using an oscilloscope connected to the IF-output of the measurement receiver. The correct measurement time can also be determined by increasing it until the difference between max-hold and clear/write displays is below e.g. 2 dB. During further measurements (maximization and final measurement), it has to be assured for each part of the frequency range that the measuring time T_m is not smaller than the applicable pulse repetition period T_p.

For **conducted disturbance measurements,** the prescan is defined as either performed on a representative lead, for example lead “L” of the power line, or on each lead using peak detection and the fastest scan time possible. If multiple leads are measured, a “maximum hold” function should be used to retain the highest emissions found during the measurement.

8.4 Data reduction

The second step in the overall measurement procedure is used to reduce the number of signals collected during prescan and thus aimed at further reduction of the overall measurement time. These processes can accomplish different tasks, e.g. determination of significant signals in the spectrum, discrimination between ambient or auxiliary equipment signals and EUT emissions, comparison of signals to limit lines, or data reduction based on user-definable rules. Another example of data-reduction methods involving the sequential use of different detectors and amplitude versus limit comparisons is given by the decision tree in Annex C of this standard. Data reduction may be performed fully automated or interactively, involving software tools or manual operator interaction. It need not be a separate section of the automated test, i.e. it may be part of a prescan.

In certain frequency ranges, an acoustic ambient discrimination is very effective. This requires signals to be demodulated to be able to listen to their modulation content. If an output list of prescan contains a large number of signals and acoustic discrimination is needed, it can be a rather lengthy process. However, if the frequency ranges for tuning and listening can be specified, only signals within these ranges will be demodulated. The results of the data reduction process are stored in a separate signal list for further processing.

8.5 Disturbance maximization and final measurement

During the final test the emissions are maximized to determine their highest level. After the maximization of the signals, the disturbance amplitude is measured using quasi-peak detection and/or average detection, allowing for the appropriate measurement time (at least 15 s if the reading shows fluctuations close to the limit).

For **conducted disturbance** measurements: the maximization process is defined by comparison of the disturbance amplitudes on the different leads of the EUT power cord and retention of the maximum levels.

NOTE Using an FFT-based measuring instrument, the final measurement will be performed at several frequencies in parallel.

8.6 Post processing and reporting

The last part of the test procedure addresses documentation requirements. The functionality for defining sorting and comparison routines which then can be automatically or interactively applied to signal lists supports a user in compiling the necessary reports and documentation. The corrected peak, quasi-peak or average signal amplitudes should be available as sorting or selection criteria. The results of these processes are stored in separate output lists or can be combined in a single list and are available for documentation or further processing.

Results shall be available in tabular or graphics format, or a combination of both, for use in a test report. Furthermore, information about the test system itself, e.g. transducers used, measuring instrumentation, and documentation of the EUT set-up as required by the product standard should also be part of the test report.

8.7 Disturbance measurement strategies with FFT-based measuring instruments

Depending on the implementation, FFT-based measuring instruments may perform weighted measurements significantly faster than the tuneable selective voltmeters. A weighted measurement over the frequency range of interest may then be faster than a measurement consisting of a prescan and final scan performed with a superheterodyne receiver (as described in 8.2).

9 Test set-up and measurement procedure using the CDNE in the frequency range 30 MHz to 300 MHz

9.1 General

Clause 9 contains requirements for the test set-ups and the procedure for measurement of the asymmetric disturbance voltage V_{dis} in the frequency range from 30 MHz to 300 MHz using the CDNE described in CISPR 16-1-2.

The CDNE method can be used for disturbance measurements if the radiation via connected cables is dominant.

The method is not applicable to an EUT under the following conditions:

a) when the largest dimension of the EUT enclosure is larger than a quarter wavelength at the highest frequency of measurement, unless otherwise specified by the product committee;
b) with a rated supply voltage exceeding 600 V;
c) with more than two cables.

The interference potential of an EUT having only one mains lead and no other external leads can be assessed by the asymmetric voltage on this lead. This asymmetric voltage is nearly equal to that supplied by the EUT to a suitable CDNE. Direct radiation from the EUT enclosure is not taken into account.

Equipment having one additional external lead other than a mains lead can radiate interfering energy from this shielded or unshielded lead in the same manner as radiation from the mains lead. CDNE measurements can be performed on this lead as well. The precise measuring procedure and its applicability have to be specified for each category of products in the product standard.

In general the level of asymmetric voltage is higher than the level of unintentional symmetric voltage. Therefore a minimum longitudinal conversion loss (LCL) value of 20 dB is adequate to prevent any influences of the symmetric voltage on the measurement results. The CDNE, with a defined minimum LCL of 20 dB, is not appropriate for EUTs with an intentional differential mode on the mains network.

9.2 Test set-up

The test set-up is placed on the RGP, which is connected to the protective earth for safety of personnel and equipment. The distance of the EUT to any other metallic object shall be ≥ 0,8 m. For a shorter distance, but not less than 0,4 m, an additional uncertainty of 0,2 dB shall be added.

NOTE 1 The conductive floor of a shielded room is an example of an implementation of the RGP.

The CDNE is connected to the RGP via its metallic enclosure. RF grounding can be improved by using additional pressure on the enclosure. In addition a reliable connection to protective earth is needed for safety purposes, and therefore shall be made using screws or similar means. The back of the CDNE shall be positioned at least 200 mm from the edge of the ground plane.

The EUT is positioned 100 mm ± 2 mm above the RGP and supported by non-conductive material that has relative permittivity ε_r less than 1,05 (e.g. polystyrene foam). The edge of the RGP shall be at least 200 mm beyond the perimeter of the EUT.

A distance of 200 mm ± 20 mm shall be maintained between the CDNE and EUT. The CDNE shall be positioned on the side of the EUT at which the cable under test is connected, to minimize the cable length. The cable shall not be meandered or bundled.

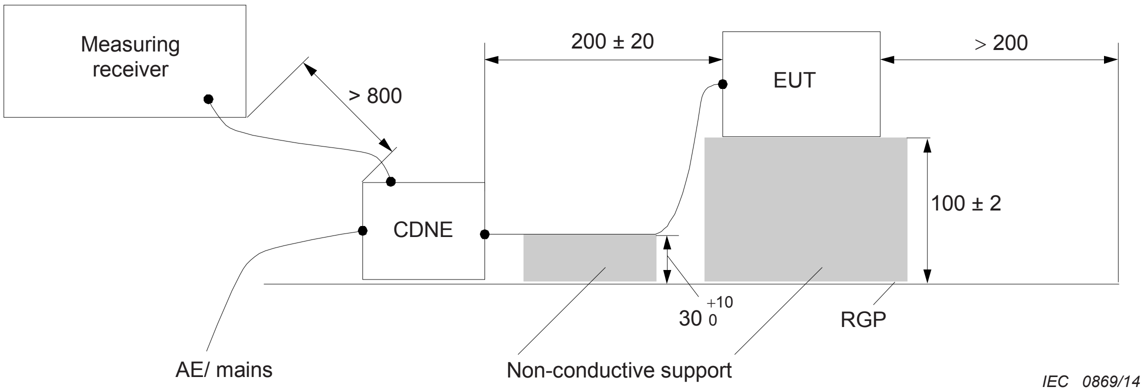
The cable connected to the EUT shall run down vertically from the EUT for a distance of about 30 mm to the RGP, and horizontally to the EUT port of the CDNE (see Figure 23).

The AE/mains port of the CDNE connects to the associated equipment, i.e. the mains for the CDNE-M2 and CDNE-M3, and a control unit for CDNE-Sx. The receiver port of the CDNE connects to the input port of the measuring receiver.

Figure 24 shows a test set-up for an EUT with two connected cables. Actual set-ups will depend on which EUT surfaces the cables are connected to; Figure 24 illustrates an arrangement of an EUT with cable connections on adjacent sides.

When two cables are connected to an EUT on the same surface, the two CDNEs shall be positioned next to this side of the EUT (see Figure 25). The CDNEs are positioned 2 cm ± 1 cm from each other. For the cable that is not under test, the receiver port of the CNDE that is not connected to the measuring receiver is terminated with a 50 Ω load.

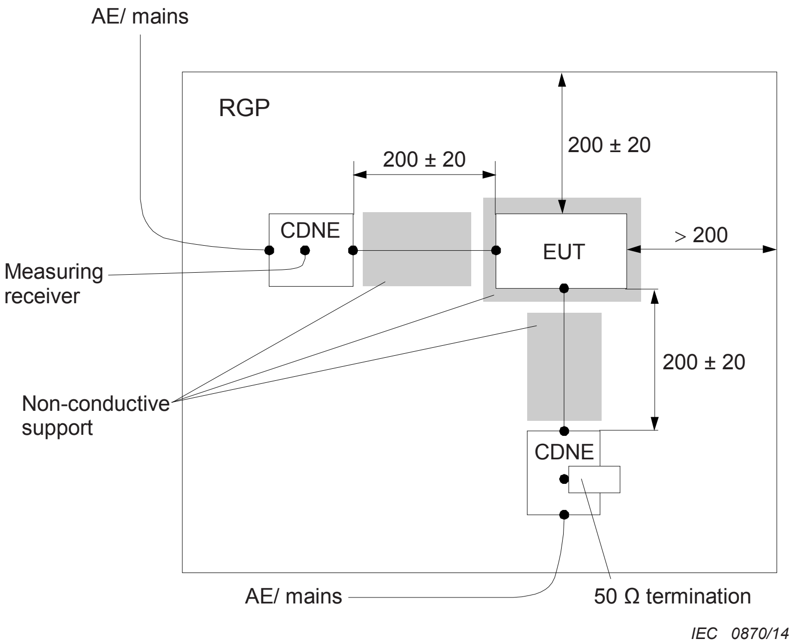
NOTE 2 The measurement set-ups shown in Figures 24 and 25 are not applicable on a mains network with dominant differential-mode signals. Differential mode cross-talk components will cause significant measurement errors.



"AE/mains" may include AC mains, DC supply as well as control/communication lines.

NOTE All dimensions are in mm.

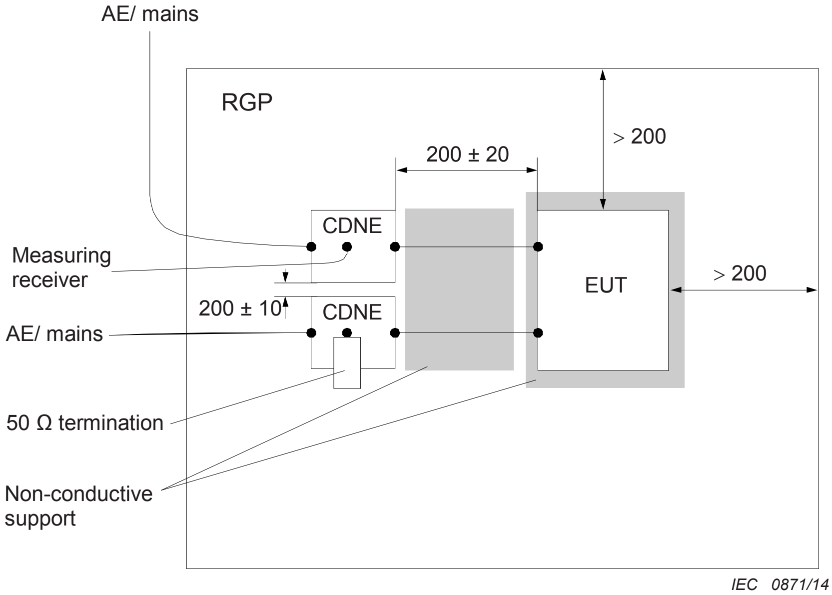
Figure 23 – Test set-up for measurement of an EUT with one cable



"AE/mains" may include AC mains, DC supply as well as control/communication lines.

NOTE All dimensions are in mm.

Figure 24 – Test set-up for measurement of an EUT with two cables connected adjacent surfaces of the EUT



“AE/mains” may include AC mains, DC supply as well as control/communication lines.

NOTE All dimensions are in mm.

Figure 25 – Test set-up for measurement of an EUT with two cables connected on the same surface of the EUT

9.3 Measurement procedure

Clause 6 as well as 6.2 shall be taken into account for measurements using a CDNE. Accordingly, the following provisions are applicable:

a) The operating conditions of the EUT shall be selected as described by the manufacturer.

b) The necessary warm-up time for the EUT shall be selected and monitored.

c) For the verification of the measurement result, the ambient emissions shall be checked to ensure that the ratio of disturbance signal to ambient emission is larger than 20 dB.

d) The detector, as specified in 7.2.2, and measurement time selected for the measuring receiver, shall be determined from the preliminary and final measurements. For the preliminary measurement, at least the peak detector shall be used. During the final measurement, the asymmetric disturbance voltage V_{dis} shall be measured with a detector as specified in the product standard.

e) The CDNE voltage division factor F_{CDNE}, in dB, shall be added to the measuring receiver reading V_{meas}, in dB(μV), for measurement of the disturbance voltage V_{dis}, i.e.

   $V_{\text{dis}} = V_{\text{meas}} + F_{\text{CDNE}}$ in dB(μV).

f) For an EUT with two connected cables, each cable is measured separately, then the maximum reading of the two cables shall be taken as the measurement result of V_{dis}.

Annex A
(informative)

Guidelines for connection of electrical equipment to the artificial mains network

NOTE Annex A supplements the provisions of Clause 5.

A.1 General

Annex A is intended to give general guidance on the techniques which can be used to evaluate the disturbance generated by certain electrical equipment in the frequency range 9 kHz to 30 MHz. It provides information on methods of connection of such equipment to the artificial mains network for the measurement of terminal voltages. A table is provided giving a general presentation of various cases encountered in practice, for such cases, enabling a suitable technique to be selected.

The cases described in Clause A.2 identify propagation of the EUT disturbance either:

a) by **conduction** along the connected mains leads (designated with E_1 and I_1 in the equivalent circuit diagrams), or
b) by **radiation** and coupled to the connected mains lead (designated with E_2 and I_2 in the equivalent circuit diagrams).

Whether conducted or radiated disturbance dominates is partly dependent on the arrangement of the EUT with respect to the reference ground (including the type of connection to the reference ground) and on the type of connection from the EUT to the artificial mains network (shielded or non-shielded cable).

A.2 Classification of the possible cases

A.2.1 Well-shielded but poorly filtered EUT (Figures A.1 and A.2)

In this case, the conducted disturbance component represented by the current I_1 dominates. The disturbance current I_1 is fed from the EUT to the artificial mains network Z. Consequently, the voltage U_1 increases when capacitance C_1 between the EUT shield and the reference ground increases (see Figure A.1). The voltage U_1 is maximized ($U_1 = ZI_1 = E_1$) when the impedance of the current return path is minimized by short-circuiting C_1, either directly or by using shielded cables to supply the EUT (see Figure A.2). (Also, see the discussion in Clause A.3.)

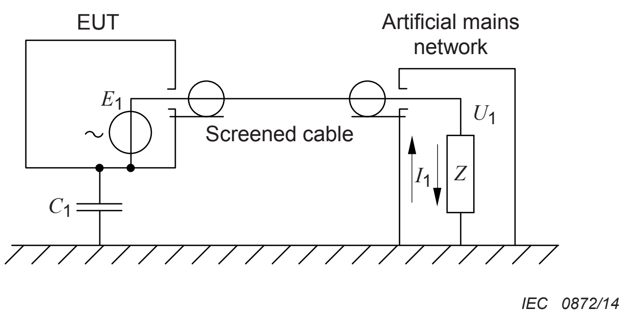


Figure A.1 – Basic schematic of well-shielded but poorly filtered EUT

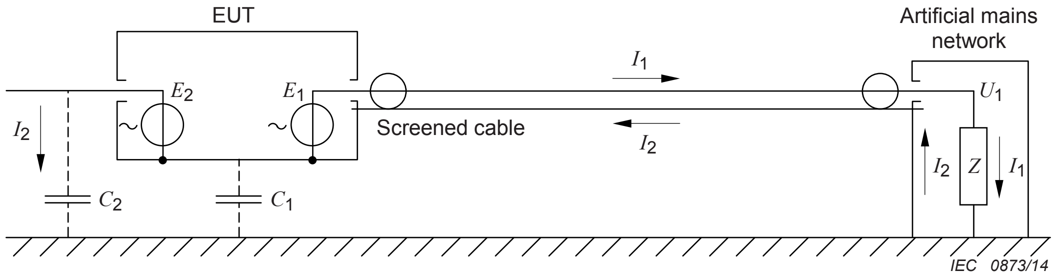


Figure A.2 – Detail of well-shielded but poorly filtered EUT

A.2.2 Well-filtered but incompletely shielded EUT (Figures A.3 and A.4)

In this case, the disturbance current fed to the mains is reduced practically to zero, and the voltage across the artificial mains network may be dominated by undesirable radiation, either from gaps in an incomplete shield or from a protruding conductor acting as an antenna. Such leakage can be represented schematically by an external capacitor C_2 connected between an internal disturbance source of e.m.f., E_2 and the reference ground. This capacitance C_2 passes a current I_2. Part of the current I_2, which flows through C_2 to the reference ground, returns via C_1 and a part of I_2 returns via the artificial mains network. If the supply leads are unshielded (see Figure A.3), and the impedance of C_1 is large compared with the artificial mains impedance Z ($ZC_1\ \omega$ << 1), then I'_2 is nearly equal to I_2 and the voltage U_2 is nearly equal to I_2Z ($U_2 = ZI_2$).

If C_1 is increased, Z is shunted and U_2 will decrease. At the limit, when C_1 is short-circuited by supplying the EUT through shielded cables (see Figure A.4), so that no part of I_2 flows through Z, then U_2 will be zero.

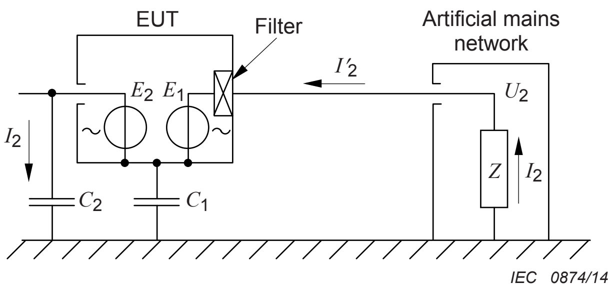


Figure A.3 – Well-filtered but incompletely shielded EUT

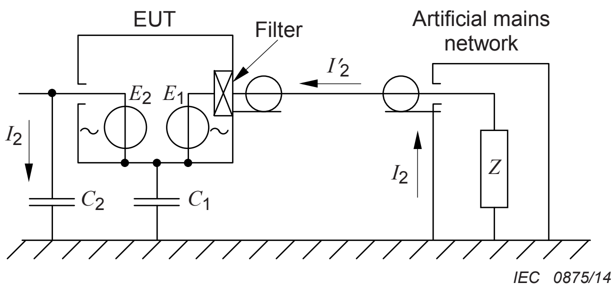


Figure A.4 – Well-filtered but incompletely shielded EUT, with U_2 reduced to zero

A.2.3 Practical general case

A.2.3.1 General

In practice, neither the shielding nor the filtering described in the preceding subclauses are perfect; the two effects then occur simultaneously and are additive. Under these conditions, the three following cases may be encountered.

A.2.3.2 Supply through shielded conductors (Figure A.5)

The current I_1 caused by leakage due to radiation flows in a circuit closed through the ground and the external surfaces of the screening of the artificial mains network and of the supply conductors; it has no effect on Z.

The voltage U_1, which may be measured across Z, is solely due to the current I_1 injected into the supply conductors and returning through the internal surfaces of the screening of the artificial mains network and these conductors. The voltage U_1 is then maximum:

$$U_1 = ZI_1 \approx E_1$$

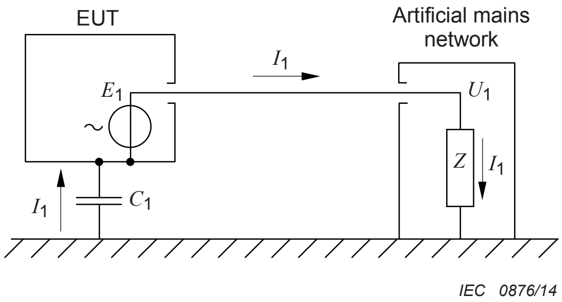


Figure A.5 – Disturbance supply through shielded conductors

A.2.3.3 Supply through unshielded but filtered conductors (Figure A.6)

If a highly efficient low-pass filter is connected to the input of the EUT, with its screening directly connected to the screening of the EUT, the current I_1 fed by source E_1 to the mains conductors will be stopped by the filter.

As in the case represented in Figure A.6, the current I_2 due to the radiation returns through Z and the conductors (if $ZC_1\omega$ << 1); the voltage U_2 measured across Z is then produced solely by the radiation.

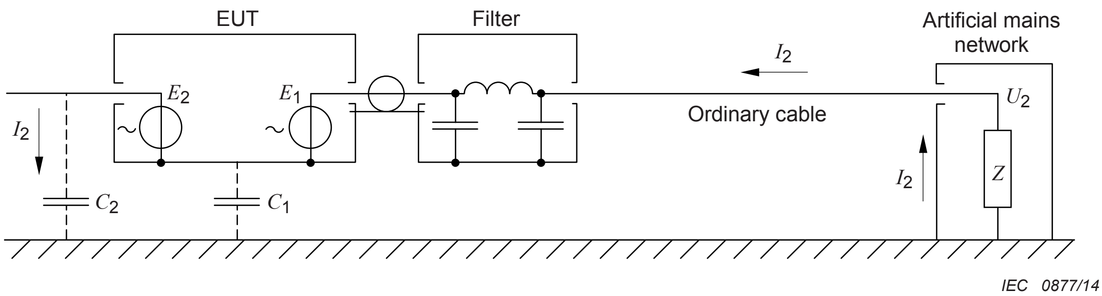


Figure A.6 – Disturbance supply through unshielded but filtered conductors

A.2.3.4 Supply through ordinary conductors (Figure A.7)

Should the filter in Figure A.6 be removed, the current I_1 from source E_1 reappears on the conductors (Figure A.7). In comparison to Figure A.5 (with the maximum possible value of I_1 for the supply of a non-filtered EUT through shielded conductors) the value of I_1 in Figure A.7 (supply of a non-filtered EUT through ordinary, i.e. unshielded conductors) is reduced to a minimum value in the ratio of I_1 (EUT unshielded) / I_1 (EUT shielded) = $ZC_1\omega$ referred to its minimum value (Figure A.2), if $ZC_1\omega$ << 1. The current I_2 is the same as in the previous cases, but because the conductors are not shielded, it also passes through Z and the mains conductors.

The voltage U across the artificial mains network results then from the superposition of currents I_1 and I_2. When electromotive forces E_1 and E_2 are themselves produced by a common internal source, these currents are synchronous, and the voltage U depends not only on the current values but also on their phases. For certain frequencies, it may occur that currents I_1 and I_2 are in opposition, and if they are also of approximately the same magnitude, the voltage U may become very small even if I_1 and I_2 are individually quite large. Moreover, if the frequency of the source varies, the phase opposition may not remain constant, and voltage U may show rapid and considerable variations.

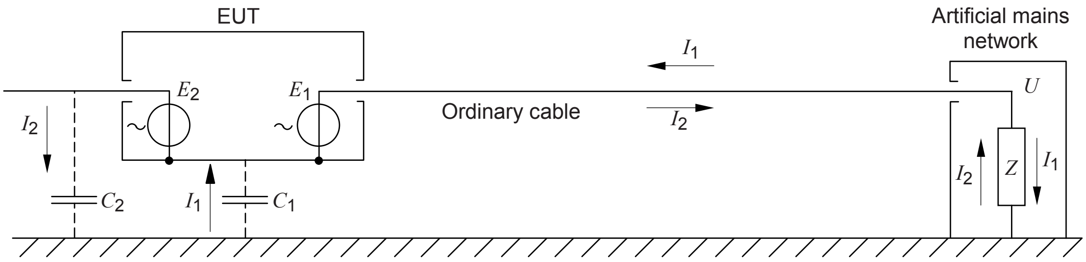


Figure A.7 – Disturbance supply through ordinary conductors

A.3 Method of grounding

In the preceding subclauses, the connection to ground of the EUT was assumed to be made through connection of the shielding of the supply conductors to the reference ground.

This is the only correct solution to obtain a grounding allowing a clear distinction between the two kinds of currents I_1 and I_2, as indicated above. It may be applied, without exception, to all frequencies.

For frequencies below 1,6 MHz practically the same result may be achieved by grounding through a straight lead of small length (1 m maximum), running parallel to the mains lead, and not more than 10 cm distant from it.

For frequencies above a few MHz, this simplified solution should only be used with care, especially at the higher frequencies. It is then strongly recommended that screened conductors be used in all cases. At the higher frequencies, it may be necessary to take into account the characteristic impedance of the conductor.

A.4 Conditions of grounding

A.4.1 General

A.4.1.1 General rules

It appears from the considerations in the preceding subclauses that the behaviour of the measuring circuit for the voltage across the artificial mains network and hence the result of these measurements, is largely dependent on how the frame of the EUT being tested is connected to ground. It is therefore essential to specify these conditions closely.

Essentially, the principal effect of grounding is to separate the two currents I_1 and I_2, and possibly to cause opposing variations of their respective actions on the measuring apparatus (which measures voltage U across Z). In the limiting case of a direct connection from the body of the EUT to ground, which short-circuits C_1, the values of current I_1, and thus of voltage $U_1 = ZI_1 \approx E_1$, are maximum; on the contrary, the current I_2 due to radiation passes entirely through this short-circuit, and the corresponding voltage U_2 is reduced to zero.

From these considerations, the following general rules are drawn.

Direct grounding should always be used when testing:

a) a non-radiating EUT (e.g. a motor) because in such a case, the measurement yields the maximum value of the disturbance voltage which may be met in practice;

b) a poorly filtered radiating EUT when, without troubling to measure the radiation, it is wished to measure solely the disturbance voltage due to direct injection into the supply conductors:

   1) either for assessing the efficiency of the filter (for instance, for the time base circuits of television receivers);

   2) or for evaluating, in the laboratory, the actual disturbance produced by an apparatus whose radiation in normal operation will be suppressed by shielding (e.g. a transformer for the ignition system of fuel for boilers).

A.4.1.2 Direct grounding

Direct grounding should not be used when testing under item b) 1) of A.4.1.1 for a very well-filtered EUT that generates considerable radiation (e.g. ozonizer, medical apparatus with damped oscillations, arc welder). In all these cases, the voltage across the artificial mains network becomes very small with direct grounding, while without such grounding the voltage may be quite large or unsteady. The measurement may then be meaningless, and it may become necessary to make the grounding through a specified impedance to simulate the actual impedance of the safety ground (protective earth) conductor, e.g. by a protective ground choke which additionally provides some RF isolation from the "polluted" and therefore "poor" protective earth (see the lower part of Table A.2).

The impedance of such an "electrically long" conductor is in case of an EUT of safety-class I normally equal to the mains simulation impedance specified as termination for the mains terminals of the EUT provided by the artificial mains network (constituted by the network of 50 µH + 1 Ω which, due to thermal problems in case of high current loads, may be reduced to a network of 50 µH).

A.4.1.3 No grounding

Without any grounding, the voltage across the artificial mains network results from the addition of both currents I_1 and I_2. A measurement can only be obtained when one of these currents is reduced to zero, either with a very well-screened shielded but poorly filtered EUT (e.g. a motor) or with a very well-filtered but radiating EUT (e.g. a television receiver, an ozonizer, etc.).

If in case of an EUT of safety-class I for the purpose of analysis of I_2, for the reduction of I_1 the impedance according to the note under A.4.1.2 is not sufficient; a high impedance RF choke (1,6 mH) may be inserted into the ground conductor path.

The measurement usually yields only the value of the total disturbance, without allowing any discrimination, the results being only valid for the conditions used during the test. Such conditions should then be very well defined, namely the values of the capacitance to the ground plane of the various elements of the EUT (for instance, the capacitance of the transmission line from the antenna in the case of a television receiver). Moreover, a single measurement for one arbitrary frequency has no significance if, for this frequency, the currents I_1 and I_2 are in opposition. As a matter of principle, then, it is necessary to make measurements at a number of frequencies.

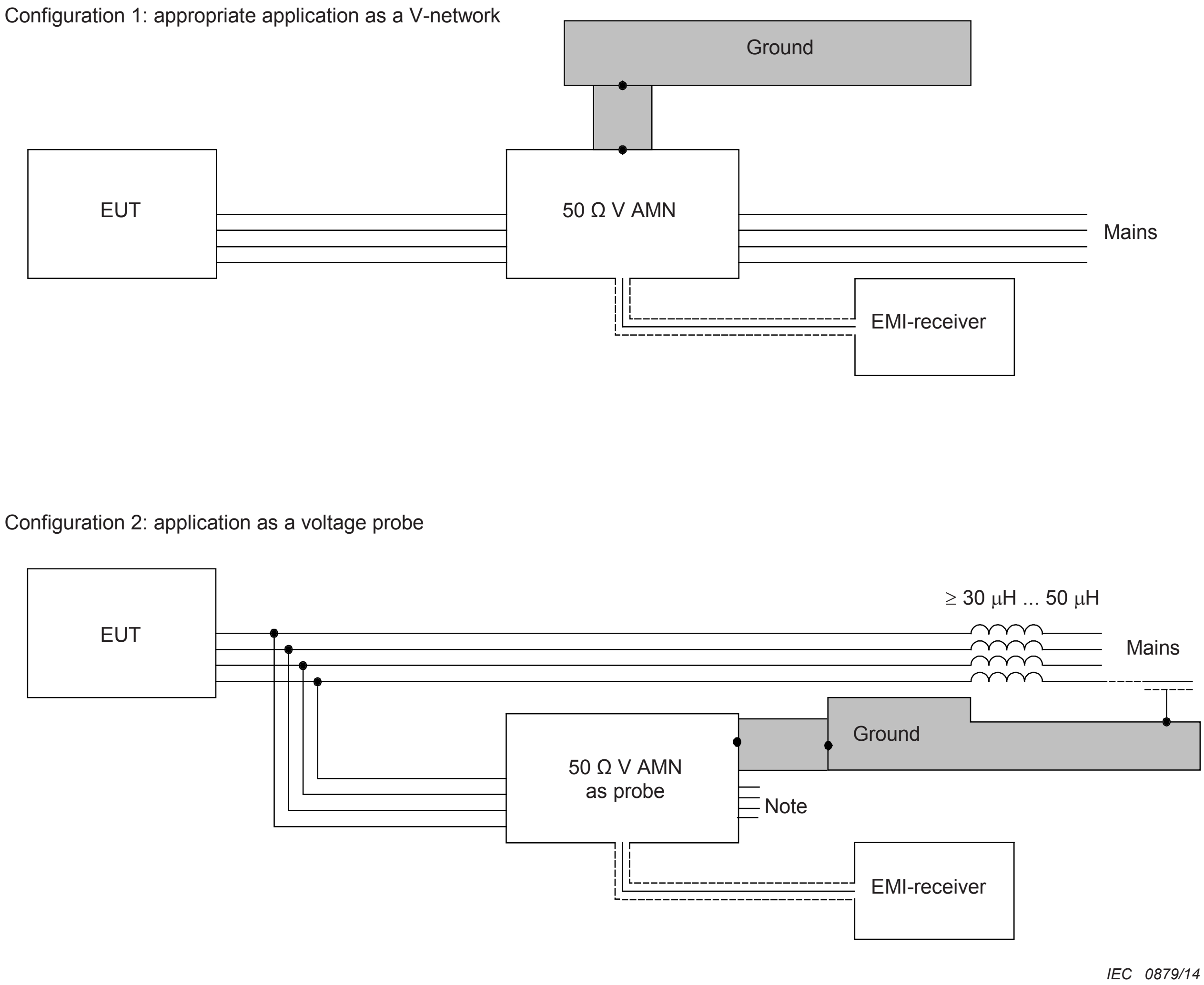
A.4.2 Classification of typical testing conditions

Tables A.1 and A.2 summarize the various testing conditions and the types of EUTs for which they are suitable. These tables also give the meaning of the measurement, that is, the physical quantity which corresponds to the voltage U measured across the artificial mains network Z, and also the precautions to be taken when making the measurement.

A.5 Connection of the AMN as a voltage probe

Conducted disturbance measurements of EUTs with high operational currents may cause difficulties. AMNs for the frequency range 9 kHz to 150 kHz (30 MHz) are available for up to approximately 25 A nominal current. AMNs for the frequency range 150 kHz to 30 MHz (50 µH parallel to 50 Ω) are available for up to approximately 200 A.

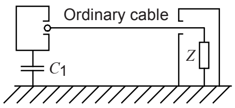
EUTs with higher current rating may be tested using the AMN as a voltage probe. This alternative solution is also helpful for in situ measurement, if referred to in the applicable product standard.



NOTE Exposed pins are made safe.

Figure A.8 – AMN configurations

Table A.1 – Testing conditions for types of EUTs – Ordinary cable

<table>
<tr><th rowspan="3">Method of connection</th><th colspan="4">Types of apparatus</th><th rowspan="3">Quantity measured</th><th rowspan="3">Details of the measurement</th></tr>
<tr><th rowspan="2">Examples</th><th colspan="3">Essential characteristics</th></tr>
<tr><th>Grounding</th><th>Radiation</th><th>Filtering</th></tr>
<tr><td rowspan="5">

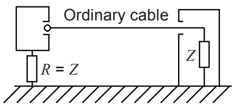
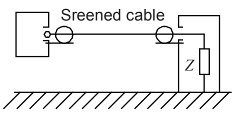
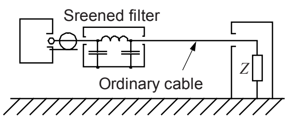

</td><td>Motors, electro-domestic appliances</td><td rowspan="4">Without</td><td>Weak</td><td>Moderate</td><td>Actual disturbance (reduced) solely due to injected current C_1</td><td>The disturbance depends on C_1</td></tr>
<tr><td rowspan="4">Ozonizers
Medical apparatus
Arc-welders
Television receivers (time-base)</td><td rowspan="4">Strong</td><td>Very good</td><td>Actual disturbance solely due to radiation current I_2</td><td rowspan="2">It is necessary to state accurately the position of the appliance with regard to ground or to quote the value of C_1</td></tr>
<tr><td rowspan="2">Moderate</td><td>Total overall disturbance resulting from the superposition of the two preceding effects (I_1 and I_2)</td></tr>
<tr><td>These two effects (I_1 and I_2) may be in phase opposition at certain frequencies</td><td>Measurement should be repeated, the frequency being varied</td></tr>
<tr><td>With</td><td>Very good</td><td>Actual disturbance produced with a ground connection of usual length</td><td>The position of the appliance with regard to ground should be specified in order that $RC_1\omega$ <1</td></tr>
</table>

Table A.2 – Testing conditions for types of EUTs – Screened cable

<table>
<tr><th>Method of connection</th><th>Types of apparatus</th><th>Quantity measured</th><th>Examples</th><th>Details of the measurement</th></tr>
<tr><td rowspan="3">
</td><td>Non-radiating appliances provided with an ground terminal</td><td>Maximum actual disturbance as C_1 is short-circuited</td><td>All motors provided with an ground terminal</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Radiating appliances when it is desired to measure only the disturbance caused by current feed to mains</td><td>Check on the efficiency of the screening</td><td>Television receivers, medical apparatus, ozonizers, arc-welders</td></tr>
<tr><td>Actual disturbance caused by an appliance which, in normal use, must be carefully screened</td><td>Transformer for the ignition system of oil burners; part of a screened assembly separately tested</td></tr>
<tr><td rowspan="2">
</td><td rowspan="2">Poorly filtered appliances when it is desired to measure only the disturbance caused by radiation</td><td>Check on the efficiency of the screening</td><td>Television receivers; high-frequency industrial apparatus</td><td rowspan="2">The position of the appliance with regard to ground should be specified in order that $ZC_1\omega$ <1</td></tr>
<tr><td>Actual disturbance caused by an appliance which, in normal use, is provided with a good filter</td><td>Fluorescent lighting</td></tr>
</table>

Annex B
(informative)

Use of spectrum analyzers and scanning receivers

NOTE Annex B supplements the provisions of Clause 6.

B.1 General

The following characteristics should be taken into account when using spectrum analyzers and scanning measuring receivers.

B.2 Overload

Most spectrum analyzers have no RF preselection in the frequency range up to 2 000 MHz; that is, the input signal is directly fed to a broadband mixer. To avoid overload, to prevent damage, and to operate a spectrum analyzer linearly, the signal amplitude at the mixer should typically be less than 150 mV peak. RF attenuation, or additional RF preselection, may be required to reduce the input signal to this level.

B.3 Linearity test

Linearity can be measured by measuring the level of the specific signal under investigation, then repeating this measurement after an X dB attenuator has been inserted at the input of the measuring receiver or, if used, at the input of the preamplifier ($X \geq 6$ dB), if used. The new reading of the measuring receiver display should differ by X dB not more than ± 0,5 dB from the first reading when the measuring system is linear.

B.4 Selectivity

The spectrum analyzer and scanning measuring receiver should have the bandwidth specified in CISPR 16-1-1, to correctly measure broadband and impulsive signals and narrowband disturbance with several spectrum components within the standardized bandwidth.

B.5 Normal response to pulses

The response of a spectrum analyzer and scanning measuring receiver with quasi-peak detection can be verified with the calibration test pulses specified in CISPR 16-1-1. The large peak voltage of the calibration test pulses typically requires an insertion of RF attenuation of 40 dB or more to satisfy the linearity requirements. This decreases the sensitivity, and makes the measurement of low repetition rate and isolated calibration test pulses impossible for bands B, C and D. If a preselecting filter is used ahead of the measuring receiver, then the RF attenuation can be decreased. The filter limits the spectrum width of the calibration test pulse as seen by the mixer.

B.6 Peak detection

The normal (peak) detection mode of spectrum analyzers provides a display indication which, in principal, is never less than the quasi-peak indication. It is convenient to measure emissions using peak-detection, because it allows faster frequency scans than quasi-peak detection. Then those signals that are close to the emission limits need to be remeasured using quasi-peak detection, to record quasi-peak amplitudes.

B.7 Frequency scan rate

The scan rate of a spectrum analyzer or a scanning measuring receiver should be adjusted for the CISPR frequency band and the detection mode used. The minimum sweep time/frequency, or the fastest scan rate, is listed in Table B.1:

Table B.1 – Sweep time/frequency or fastest scan rate

Band	Peak-detection	Quasi-peak detection
A	100 ms/kHz	20 s/kHz
B	100 ms/MHz	200 s/MHz
C and D	1 ms/MHz	20 s/MHz

For a spectrum analyzer or scanning measuring receiver used in a fixed tuned non-scanning mode, the display sweep time may be adjusted independently of the detection mode, and according to the needs for observing the behaviour of the disturbance. If the level of disturbance is not steady, the reading on the measuring receiver should be observed for at least 15 s to determine the maximum (see 6.5.1).

B.8 Signal interception

The spectrum of intermittent emissions may be captured with peak-detection, and digital display storage if provided. Multiple, fast frequency scans reduce the time to intercept a disturbance, compared to a single, slow frequency scan. The starting time of the scans should be varied to avoid any synchronism with the disturbance and thereby hiding it. The total observation time for a given frequency range should be longer than the time between the emissions. Depending upon the kind of disturbance being measured, the peak detection measurements can replace all or part of the measurements needed using quasi-peak detection. Re-tests using a quasi-peak detector should then be made at frequencies where disturbance maxima have been found.

B.9 Average detection

Average detection with a spectrum analyzer is obtained by reducing the video bandwidth until no further smoothing of the displayed signal is observed. The sweep time should be increased with reductions in video bandwidth, to maintain amplitude calibration. For such measurements, the measuring receiver shall be used in the linear mode of the detector. After linear detection is made, the signal may be processed logarithmically for display, in which case the value is corrected even though it is the logarithm of the linearly detected signal.

A logarithmic amplitude display mode may be used, for example, to distinguish more easily between narrowband and broadband signals. The displayed value is the average of the logarithmically distorted IF signal envelope. A logarithmic amplitude display mode results in a larger attenuation of broadband signals than in the linear detection mode without affecting the display of narrowband signals. Video filtering in log-mode is, therefore, especially useful for estimating the narrowband component in a spectrum containing both.

B.10 Sensitivity

Sensitivity can be increased with low noise RF pre-amplification ahead of the spectrum analyzer. The input signal level to the amplifier should be adjustable with an attenuator to test the linearity of the overall system for the signal under examination.

The sensitivity to extremely broadband emissions, which require large RF attenuation for system linearity, is increased with RF pre-selecting filters ahead of the spectrum analyzer. The filters reduce the peak amplitude of the broadband emissions and less RF attenuation can be used. Such filters may also be necessary to reject or attenuate strong out-of-band signals and the intermodulation products they cause. If such filters are used, they should be calibrated with broadband signals.

B.11 Amplitude accuracy

The amplitude accuracy of a spectrum analyzer or a scanning measuring receiver may be verified by using a signal generator, power meter, and precision attenuator. The characteristics of these instruments, cable and mismatch losses have to be analyzed, to estimate the errors in the verification test.

Annex C
(informative)

Decision tree for use of detectors for conducted disturbance measurements

NOTE Annex C supplements the provisions of Clause 6.

The following decision tree and text provide guidance on the pass/fail criteria and the use of detectors for conducted disturbance measurements when the product standard requires measurements with both the quasi-peak and average detectors. For efficiency in performing these measurements, path 1 in Figure C.1 showing the use of the peak detector is recommended.

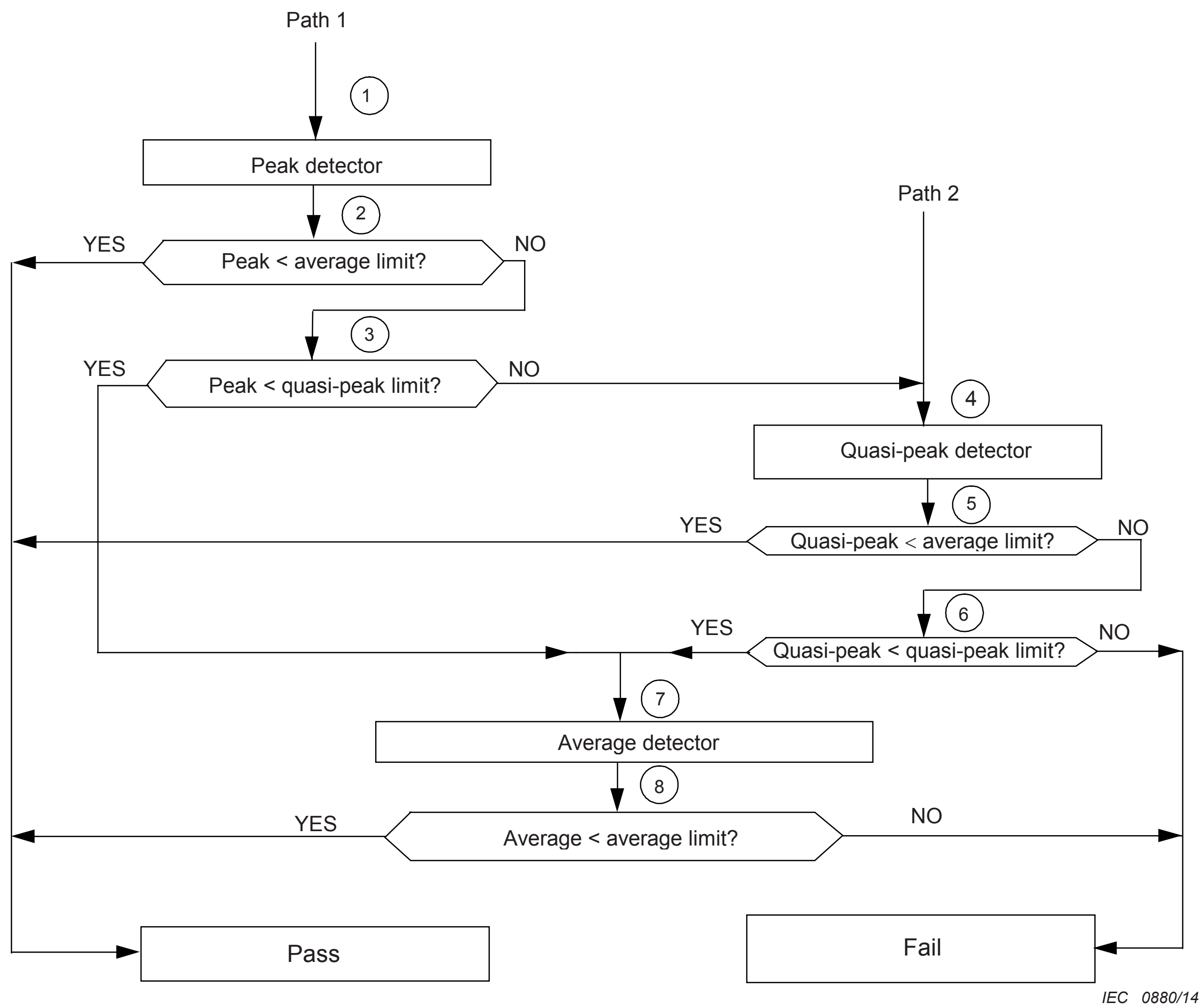


Figure C.1 – Decision tree for optimizing speed of conducted disturbance measurements with peak, quasi-peak and average detectors

For the EUT to pass, the measured conducted disturbance should comply with both the quasi-peak and average limits. The tests may be performed using either path 1 or path 2; however, to optimize the speed of conducted disturbance measurements path 1 is recommended. Path 2, starting with a quasi-peak measurement, is slower in situations where compliance with the quasi-peak limit could already be determined from a peak measurement.

1) Start measurement with peak detector for rapid measurement.
2) Compare peak disturbance level to average limit.
   If emissions are above limit: go to step 3).
   If emissions are below limit: EUT passes.
3) Compare peak disturbance level with quasi-peak limit.
   If emissions are above limit: go to step 4).
   If emissions are below limit: go to step 7).
4) Measurement with quasi-peak detector.
5) Compare quasi-peak disturbance level to the average limit.
   If emissions are above limit: go to step 6).
   If emissions are below limit: EUT passes.
6) Compare quasi-peak disturbance level to the quasi-peak limit.
   If emissions are above limit: EUT fails.
   If emissions are below limit: go to step 7).
7) Measurement with average detector.
8) Compare average disturbance level to the average limit.
   If emissions are above limit: EUT fails.
   If emissions are below limit: EUT passes.

When frequency scanning is used during the peak measurement, the scan rate of the spectrum analyzer or scanning receiver should be adjusted not to exceed the fastest scan rate listed in Annex B.

Annex D
(informative)

Scan rates and measurement times for use with the average detector

D.1 General

Annex B is intended to give guidance on the selection of scan rates and measurement times when measuring impulsive disturbance with the average detector.

The average detector serves the following purposes:

a) to suppress impulsive noise and thus to enhance the measurement of CW components in disturbance signals to be measured;
b) to suppress amplitude modulation (AM) in order to measure the carrier level of amplitude modulated signals;
c) to show the weighted peak reading for intermittent, unsteady or drifting narrowband disturbances using a standardized meter time constant.

CISPR 16-1-1 defines the average measuring receiver for the frequency range 9 kHz to 1 GHz.

In order to select the proper video bandwidth and the corresponding scan rate or measurement time, the following considerations apply.

D.2 Suppression of impulsive disturbance

D.2.1 General

The pulse duration T_p of impulsive disturbance is often determined by the IF bandwidth B_res: T_p = 1/B_res. For the suppression of such noise, the suppression factor a is then determined by the video bandwidth B_video relative to the IF bandwidth: a = 20 lg (B_res/B_video). B_video is determined by the bandwidth of the lowpass filter following the envelope detector. For longer pulses, the suppression factor will be lower than a. The minimum scan time $T_\mathrm{s\ min}$ (and maximum scan rate $R_\mathrm{s\ max}$) is determined using:

$$T_\mathrm{s\,min} = (k \times \Delta f)/(B_\mathrm{res} \times B_\mathrm{video}) \quad \text{(D.1)}$$

$$R_\mathrm{s\,max} = \Delta f / T_\mathrm{s\,min} = (B_\mathrm{res} \times B_\mathrm{video})/k \quad \text{(D.2)}$$

where Δf is the frequency span and k is a proportionality factor which depends on the speed of the measuring receiver.

For the longer scan times, k is very close to 1. If a video bandwidth of 100 Hz is selected, the maximum scan rates and pulse suppression factors in Table D.1 will be obtained.

This suppression can be applied for product standards calling out quasi-peak and average limits in Bands B (and C) if short pulses are expected in the disturbance signal. Compliance of the EUT with both limits shall be demonstrated. If the pulse repetition frequency is greater than 100 Hz and the quasi-peak limit is not exceeded by the impulsive disturbance, then the short pulses are sufficiently suppressed for average detection with a video bandwidth of 100 Hz.

Table D.1 – Pulse suppression factors and scan rates for a 100 Hz video bandwidth

	Band A	Band B	Bands C and D
Frequency range	9 kHz to 150 kHz	150 kHz to 30 MHz	30 MHz to 1 000 MHz
IF bandwidth B_{res}	200 Hz	9 kHz	120 kHz
Video bandwidth B_{video}	100 Hz	100 Hz	100 Hz
Max. scan rate	17,4 kHz/s	0,9 MHz/s	12 MHz/s
Max. suppression factor	6 dB	39 dB	61,5 dB

D.2.2 Suppression of impulsive disturbance by digital averaging

Average detection may be done by digital averaging of the signal amplitude. An equivalent suppression effect can be achieved if the averaging time is equal to the inverse of the video filter bandwidth. In this case, the suppression factor is $a = 20 \lg (T_{av} \times B_{res})$, where T_{av} is the averaging (or measuring) time at a certain frequency. Consequently a measurement time of 10 ms will result in the same suppression factor as the video bandwidth of 100 Hz. Digital averaging has the advantage of zero delay time, when switching from one frequency to another. On the other hand, for averaging of a certain pulse repetition frequency f_p, the result may vary depending on whether n or n+1 pulses are averaged. This effect is less than 1 dB, if $T_{av} \times f_p > 10$.

D.3 Suppression of amplitude modulation

To measure the carrier of a modulated signal, the modulation is suppressed by signal averaging over a sufficiently long time, or by using a video filter of sufficient attenuation at the lowest frequency. If f_m is the lowest modulation frequency, and if for the case that the maximum measurement error due to the 100 % modulation is limited to 1 dB, then the measurement time T_m should be $T_m = 10 / f_m$.

D.4 Measurement of slowly intermittent, unsteady or drifting narrowband disturbances

In CISPR 16-1-1, the response to intermittent, unsteady, or drifting narrowband disturbances is defined using the peak reading with meter time constants of 160 ms (for bands A and B) and 100 ms (for bands C and D). These time constants correspond to second order video filter bandwidths of 0,64 Hz or 1 Hz respectively. For correct measurements, these bandwidths would require very long measurement times (see Table D.2).

This applies however only for pulse repetition frequencies of 5 Hz or less. For all higher pulse widths and modulation frequencies, higher video filter bandwidths may be used (see D.2.1). Figures D.1 and D.2 show the weighting function of a pulse with 10 ms pulse duration versus pulse repetition frequency f_p with peak reading (“CISPR AV”) and with true averaging (“AV”) for meter time constants of 160 ms (Figure D.1) and 100 ms (Figure D.2).

Figures D.1 and D.2 imply that the difference between average with peak reading (“CISPR AV”) and without peak reading (“AV”) is increasing as the pulse repetition frequency f_p decreases. Figures D.3 and D.4 show the difference for f_p = 1 Hz as a function of pulse width.

Table D.2 – Meter time constants and the corresponding video bandwidths and maximum scan rates

	Band A	Band B	Bands C and D
Frequency range	9 kHz to 150 kHz	150 kHz to 30 MHz	30 MHz to 1 000 MHz
IF bandwidth B_{res}	200 Hz	9 kHz	120 kHz
Meter time constant	160 ms	160 ms	100 ms
Video bandwidth B_{video}	0,64 Hz	0,64 Hz	1 Hz
Maximum scan rate	8,9 s/kHz	172 s/MHz	8,3 s/MHz

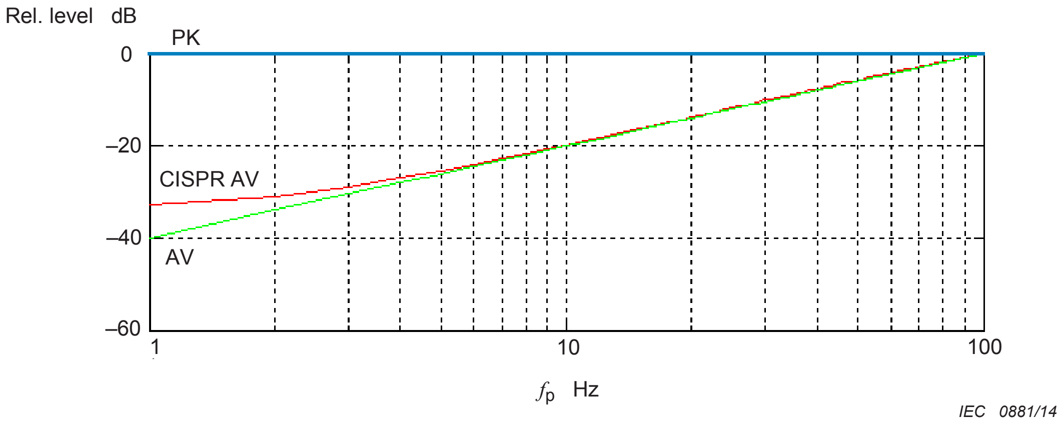


Figure D.1 – Weighting function of a 10 ms pulse for peak ("PK") and average detections with ("CISPR AV") and without ("AV") peak reading; meter time constant 160 ms

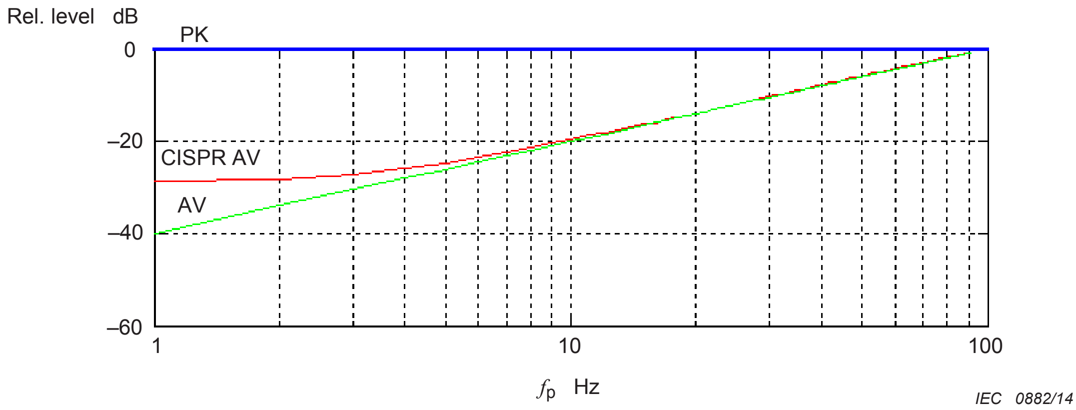


Figure D.2 – Weighting functions of a 10 ms pulse for peak ("PK") and average detections with ("CISPR AV") and without ("AV") peak reading; meter time constant 100 ms

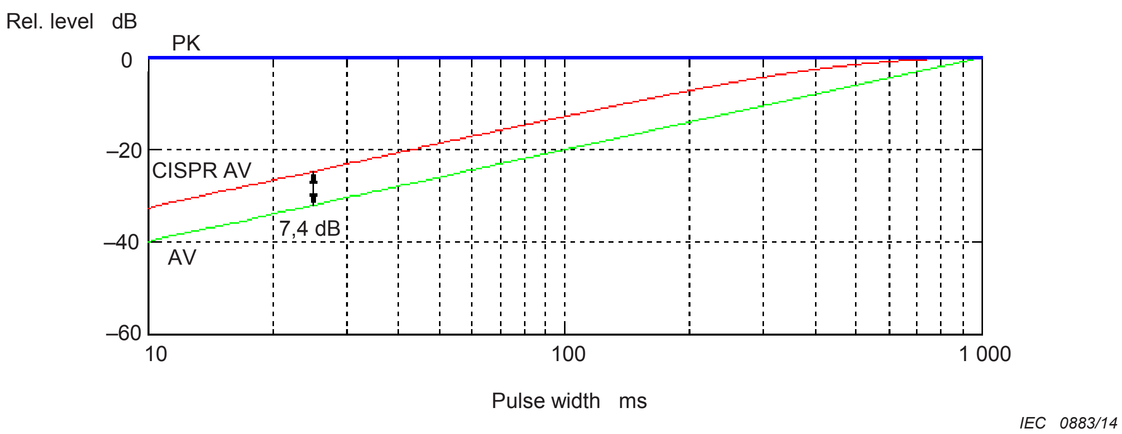


Figure D.3 – Example of weighting functions (of a 1 Hz pulse) for peak (“PK”) and average detections as a function of pulse width; meter time constant 160 ms

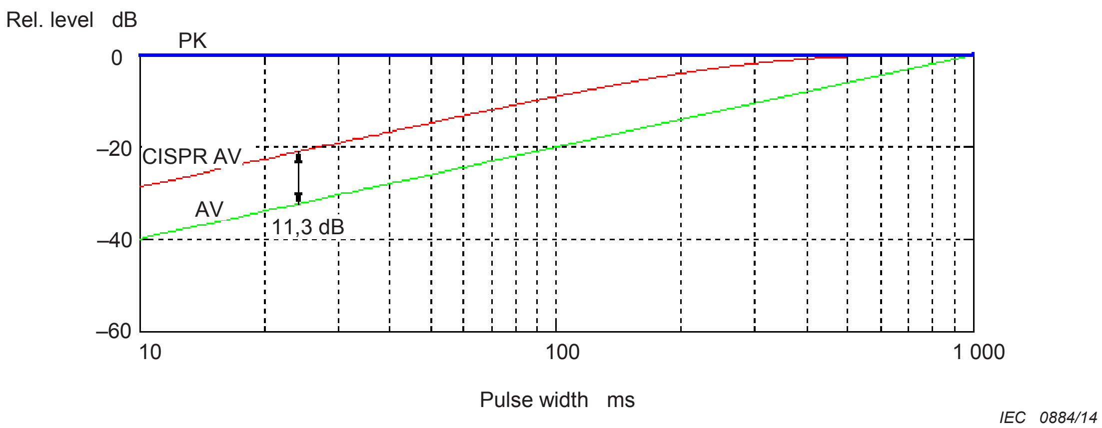


Figure D.4 – Example of weighting functions (of a 1 Hz pulse) for peak (“PK”) and average detections as a function of pulse width; meter time constant 100 ms

D.5 Recommended procedure for automated or semi-automated measurements

When measuring EUTs which do not emit slowly intermittent, unsteady, or drifting narrowband disturbances, it is recommended to measure with the average detector using a video filter bandwidth of e.g. 100 Hz, i.e. a short averaging time during a prescan procedure. At frequencies where the disturbance is found to be close to the average limit, it is recommended to make a final measurement using a lower video filter bandwidth, i.e. a longer averaging time. (For the prescan/final measurement procedure, see also Clause 8 of this standard).

For slowly intermittent, unsteady, or drifting narrowband disturbances, manual measurements are the preferred solution.

Annex E
(informative)

Guidelines for the improvement of the test set-up with ANs

E.1 In situ verification of the AN impedance and voltage division factor

To minimize resonances in the AN grounding, it is recommended to verify the AN impedance (if a vector network analyzer is available) and/or the voltage division factor (VDF) in situ. This can be done by measuring these parameters relative to the RGP instead of measuring relative to the ground connection of the AN itself. A description of the VDF measurement can be found in CISPR 16-1-2.

If the AN is bonded to the RGP using a ground strap of significant inductance, which appears in parallel to the AN enclosure capacitance relative to the ground plane, a parallel resonance may result within the frequency range below 30 MHz (see Figure E.1)

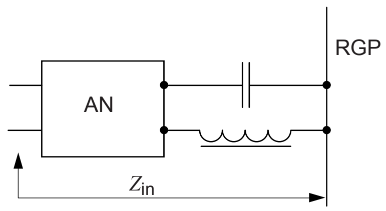


Figure E.1 – Parallel resonance of enclosure capacitance and ground strap inductance

Using in situ measurements of the impedance and the VDF, solutions can be found as shown in Figure E.2, where an AMN was used as an example of an AN. The AMN impedance is shown in Figure E.3, and the VDF shown in Figure E.4. In this example, the AMN was connected to a vertical wall-mounted RGP, to give a distance of 40 cm between the centre of the power plug and the RGP, as required especially by Figure 11, but generally also in other test configurations. The impedance measurements into the AMN were made:

a) with reference to the front panel measurement ground (see Figure E.2),
b) with reference to a measurement ground on the grounding sheet (Figure E.2), and
c) with reference to the vertical RGP (see Figure E.5). In this case it is important to use a low-impedance measurement ground.

The impedance does not differ between cases a) and b). Only for case c) does the phase show a significant increase at 30 MHz, where the effect on the VDF is in the order of 0,7 dB. The measurement results are shown in Figure E.6.

The phase increase at 30 MHz is due both to the length of the connecting plate and the length of the measurement ground plate. The ideal impedance ends at 50 Ω (i.e. in the centre of the Smith diagram). Both the impedance and VDF do not show resonances.

In Figure E.7, VDF is shown for a ground connection with resonances as in Figure E.1.

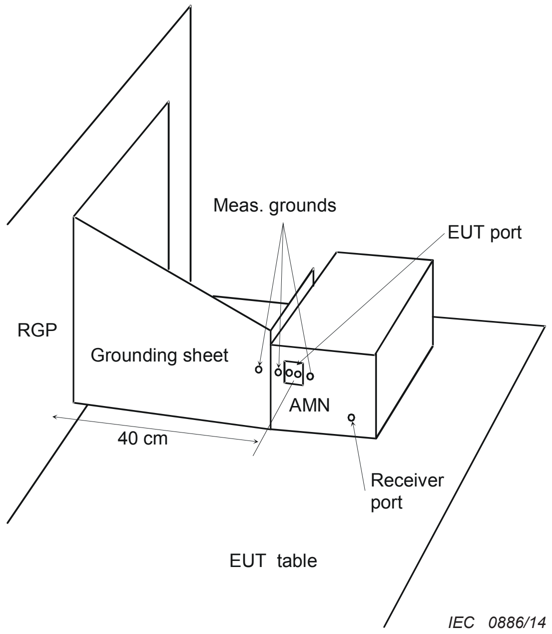


Figure E.2 – Connection of an AMN to RGP using a wide grounding sheet for low inductance grounding

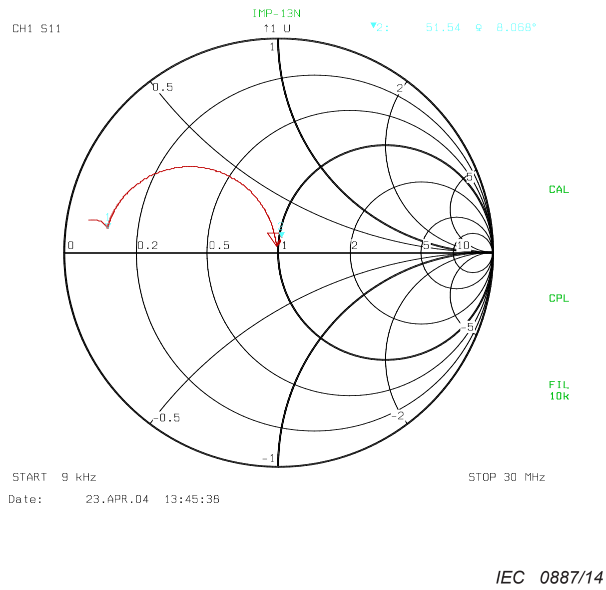
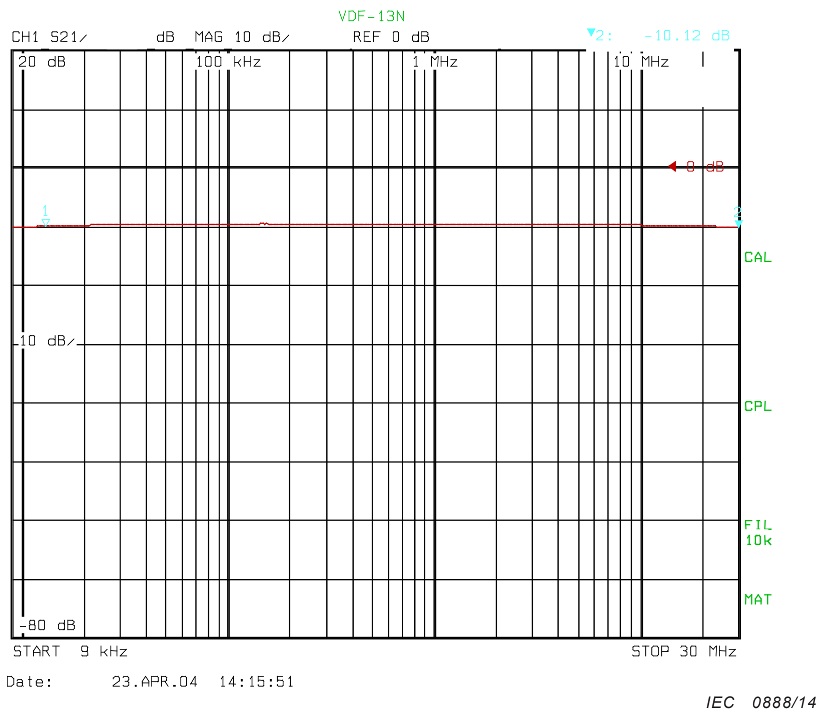
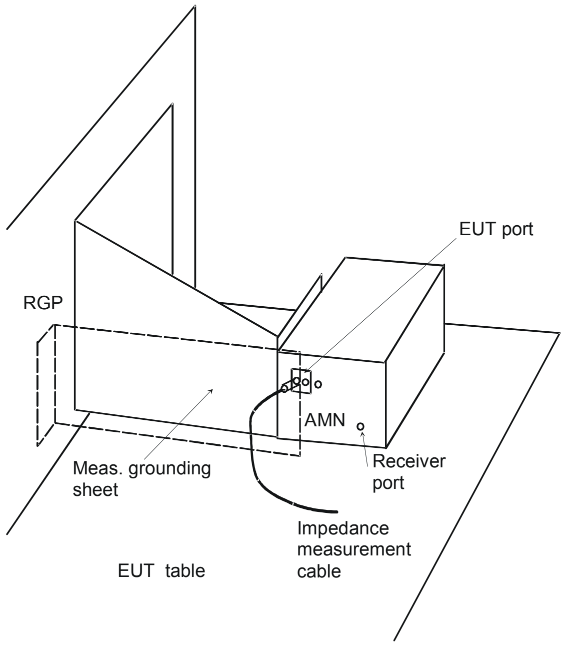


Figure E.3 – Impedance measured with the arrangement of Figure E.2 both with reference to the front panel ground and to the grounding sheet

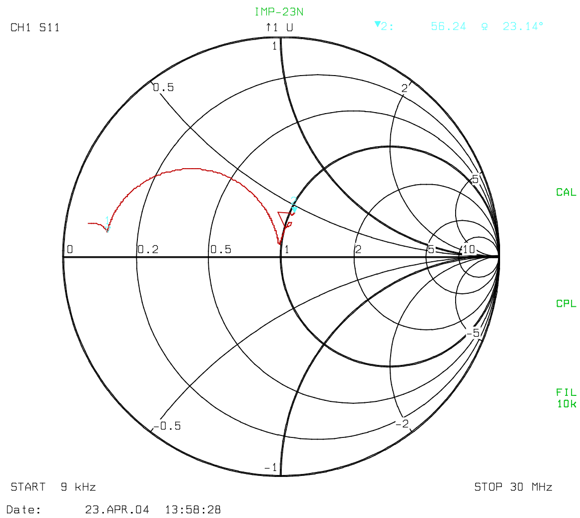


The AMN used has a flat frequency response of the VDF, which may be different for other AMNs.

Figure E.4 – VDF in the configuration of Figure E.2 measured with reference to the front panel ground and to the grounding sheet



IEC 0889/14

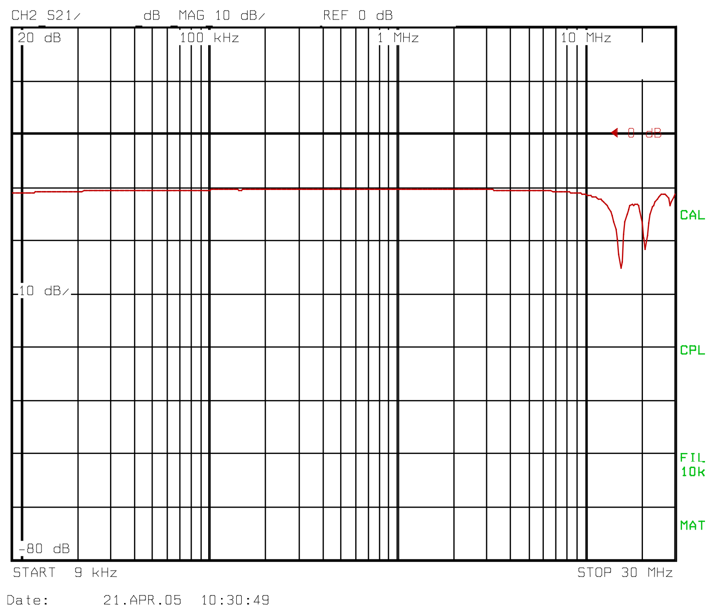


IEC 0890/14

The impedance measurement cable ground is connected to the measurement grounding sheet, whereas the inner conductor is connected to the EUT port pin.

Figure E.5 – Arrangement showing the measurement grounding sheet (shown with dotted lines) when measuring the impedance with reference to RGP

Figure E.6 – Impedance measured with the arrangement of Figure E.5 with reference to the RGP



IEC 0891/14

Figure E.7 – VDF measured with parallel resonances in the AMN grounding

E.2 PE chokes and sheath current absorbers for the suppression of ground loops

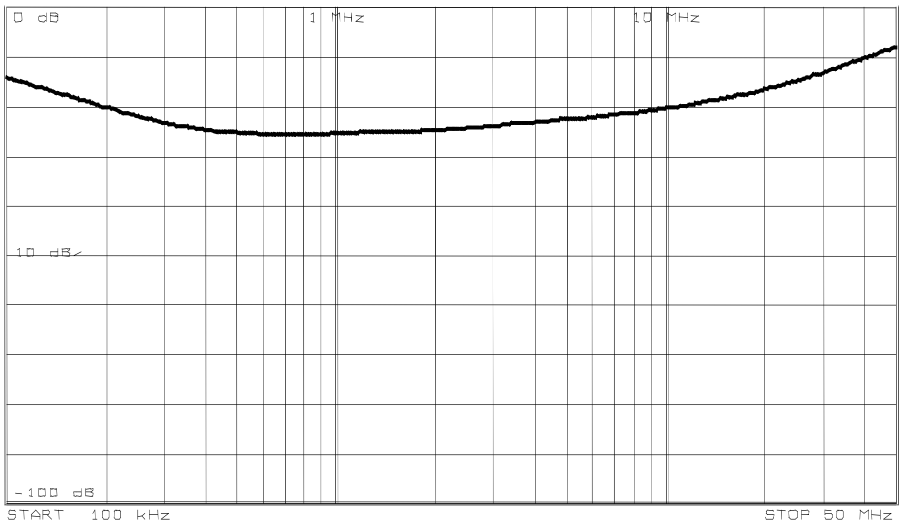
To suppress effects resulting from ground loops, it is recommended that coaxial cables be inductively wound around ferrite rings to provide a sheath current absorber.

Figure E.8 shows the attenuation of a sheath current absorber with the following characteristics:

Material:	N30; Al = 5 400 nH
Size:	Toroidal core 58 mm by 40 mm by 17 mm
Number of turns:	20 (cable terminated with BNC connectors)

The measurements can be taken in the test set-up of Figure E.9. The EUT is a wire, wound around a core as described above, or similar. It may also consist of two such high impedance circuits for the sheath current, with a connection to ground in between for high insertion loss.

The transmitter and receiver can be replaced by a network analyzer. For a system with higher or lower impedance, the resistors in the transmit box and the load box may be replaced by other values. As a reference for the attenuation, the EUT is replaced by a simple wire (as shown in Figure E.9). The measurement arrangement can be replaced by the arrangement used with the SOLT calibration used for the verification of common-mode absorption devices (CMAD, see CISPR 16-1-4 [2] and CISPR 16-3 [4]).



Attenuation caused by the sheath current absorber made with a toroidal core with 20 turns of cable, measured with the test set-up given in Figure E.9 (150 Ω system). An attenuation of 20 dB means that the impedance of the sheath current suppressor is in the order of 1 500 Ω.

Figure E.8 – Attenuation of a sheath current absorber measured in a 150 Ω test arrangement

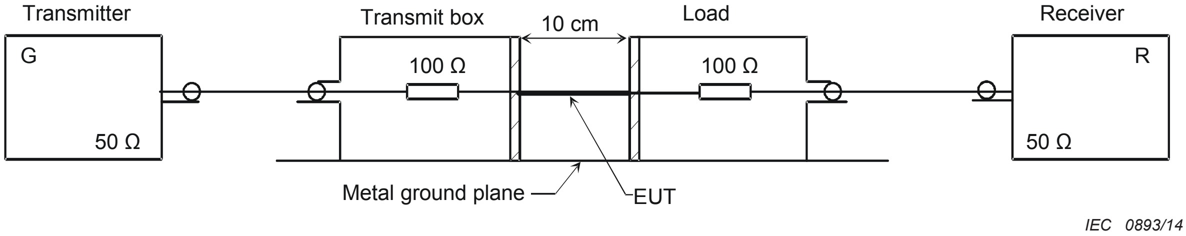


Figure E.9 – Arrangement for the measurement of attenuation due to PE chokes and sheath current absorbers

Annex F
(normative)

Determination of suitability of spectrum analyzers for compliance tests

The user of a spectrum analyzer shall be able to demonstrate – using either specifications from the manufacturer or by measurement – that the analyzer meets the quasi-peak detection requirements for pulse-repetition frequencies greater than 20 Hz, in the frequency range of use. For the average detector, the response to pulses is called out in 6.5 of CISPR 16-1-1:2010.

Because the measurement of the pulse repetition frequency of a disturbance may not always be possible, a simple method to confirm the validity of the quasi-peak measurement shall be applied when a spectrum analyzer is used. This method is based on a comparison of measurement results with the peak and quasi-peak detectors. From the quasi-peak weighting functions, the amplitude differences shown in Table F.1 are the results of measurements for a signal with a pulse repetition frequency of 20 Hz.

The comparison measurement is to be made at signal frequencies that show amplitudes close to the applicable limit in quasi-peak detection. If the difference between the peak and quasi-peak detected amplitude is smaller than the value in Table F.1, the quasi-peak measurement is valid, and the result obtained with a spectrum analyzer can be used to demonstrate compliance. If the amplitude difference is larger than the stated values in Table F.1, a measuring receiver that fully complies with the low-prf requirements of CISPR 16-1-1:2010, Clause 4 shall be used for the quasi-peak measurement, instead of a spectrum analyzer. This comparison measurement requires an adequate signal-to-noise ratio to ensure proper results.

Table F.1 – Maximum amplitude difference between peak and quasi-peak detected signals

Band A	Band B	Band C/D
7 dB	13 dB	21 dB

Annex G
(informative)

Basic guidance for measurements on telecommunications ports

G.1 Limits

The disturbance voltage (or current) limit is defined for a TCM load impedance of 150 Ω (as seen by the EUT at the AE port during the measurement). This standardization is necessary to obtain reproducible measurement results, independent of the indeterminate TCM impedance at the AE and at the EUT.

NOTE 1 The common mode disturbances created from the wanted signal can be controlled at the design stage of the interface technology by giving proper consideration to the factors explained in CISPR/TR 16-3.

In general, the TCM impedance seen by the EUT at the AE port is not defined unless an AAN/CDN is used. If the AE is located outside the shielded room, the TCM impedance seen by the EUT at the AE port can be determined by the TCM impedance of the feed-through filter between the measurement set-up and the outside world. A Π-type filter has low TCM impedance, whilst a T-type filter has high TCM impedance.

NOTE 2 CDNs are described in IEC 61000-4-6 [9].

AAN/CDNs do not exist for all types of cables used by EUTs. Therefore it is also necessary to define alternative test methods that do not use AAN/CDNs (i.e. “non-invasive” test methods).

Only the cable attached to the EUT port under test is shown in the measurements specifics figures of Annex H. Normally, there are several other cables (or ports) present at the EUT. At least the connection to the mains terminal is represented in most cases. The TCM impedance of these other connections (including a possible ground connection), and the presence or absence of these connections during the test, can influence the measurement result significantly, in particular for small EUTs. Therefore, the TCM impedance of the non-measured connections should be specified for the test of small EUTs. In addition to the port under test, it is sufficient to have at least two additional ports connected to a TCM impedance of 150 Ω (normally by using an AAN or CDN, with the RF measurement port terminated with 50 Ω load) to reduce this influence effect to a negligible amount.

Coupling devices for unshielded balanced pairs should also simulate the typical LCL (longitudinal conversion loss) of the lowest cabling category (worst case LCL) specified for the telecom port under test. The intent of this requirement is to account for the transformation of the symmetric signal into a CM (common mode) signal, which might contribute to the radiation when the EUT is in the end-use application. Asymmetry is built-in to an AAN to yield the specified LCL; this asymmetry may enhance or cancel the asymmetry of the EUT. To establish the worst case emissions and optimize test repeatability, consideration should therefore be given to repeating the testing with the LCL imbalance on each wire of a balanced pair when using the appropriate AAN.

Because imbalance on each balanced pair may contribute to the total common mode conducted disturbance, all combinations of imbalance on all balanced pairs should be considered. For a single balanced pair, this is a relatively minor impact on test effort – i.e. the two wires are reversed. However, for two balanced pairs, the number of LCL loading combinations is four (i.e. four test configurations). For four balanced pairs, the number of loading combinations grows to sixteen. Such numbers will have a significant impact on test time and test documentation. Such testing should be undertaken with care, and properly documented if implemented.

The RF measurement port of an AAN/CDN not connected to the measuring receiver shall be terminated in a 50 Ω load.

Table G.1 summarizes the advantages and disadvantages of the measurement methods described in Annex H.

Table G.1 – Summary of advantages and disadvantages of the methods described in the specific subclauses of Annex H

	Subclause H.5.2 (AAN)	Subclause H.5.3 (150 Ω load and cable shield)	Subclause H.5.4 (current probe and CVP)
Advantages	Smallest measurement uncertainty (Possible only if AAN/CDNs with appropriate transmission properties are available) LCL shall be known and shall be taken into account	– Non-invasive (except for the removal of the insulation of the shielded cable) – Always applicable for shielded cables – Small measurement uncertainty for higher frequencies	Non-invasive
Disadvantages	– Not applicable in all cases (needs appropriate AAN/CDNs) – Invasive (needs appropriate cable connections) – Needs an individual AAN/CDN for each cable type (results in a high number of different AAN/CDNs) – No isolation to symmetric signals from the AE is provided by an AAN	– Increased measurement uncertainty for very low frequencies (< 1 MHz) – Destruction of the cable insulation is necessary – Reduced isolation against disturbances from the AE side (compared to H.5.2) – Does not evaluate the interference potential that arises from the conversion of the symmetric signal into a common mode signal due to the limited LCL of the cable network to which the EUT port will be connected	– No isolation against disturbances from the AE side (compared to H.5.2) – Does not evaluate the interference potential that arises from the conversion of the symmetric signal into a common mode signal due to the limited LCL of the cable network to which the EUT port will be connected

G.2 Combination of current probe and capacitive voltage probe (CVP)

The method described in H.5.4 has the advantage of being applicable in a non-invasive way to all types of cables. However, unless the TCM impedance seen by the EUT at the AE connection is 150 Ω, the method of H.5.4 in general will show a result which is too high, but never too low (i.e. worst case estimation of the disturbance).

G.3 Basic ideas of the capacitive voltage probe

The set-up of Figure H.3 uses a capacitive voltage probe to measure the CM voltage. There are two approaches to the construction of a capacitive voltage probe. For either approach, if a TCM impedance of 150 Ω is present, the capacitance of the capacitive voltage probe to the cable attached to the EUT port under test will appear as a load in parallel with the 150 Ω TCM impedance.

NOTE 1 A CVP does not simulate the differential to common mode conversion that takes place in telecommunication networks (whereas an AAN does), and therefore a CVP cannot be used to measure the converted common mode voltage. For the same reason, a combination of a CVP and a current probe cannot replace the AAN.

The TCM impedance tolerance is ± 20 Ω over the frequency range of 0,15 MHz to 30 MHz. If the capacitive voltage probe loading acts to reduce the 150 Ω TCM impedance at most down to 130 Ω, the capacitance of the capacitive voltage probe to the cable attached to the EUT port under test should be < 5 pF at 30 MHz (i.e. the worst case frequency). At 30 MHz, 5 pF is an impedance of approximately $-j1\ 061\ \Omega$, which in parallel with 150 Ω yields a combined TCM of approximately 148 Ω. Refer to Figure G.2 of CISPR 16-1-2: 2014 for further background information.

The first approach to construction of a capacitive voltage probe is to have the probe be a single device that relies on physical distance from the cable attached to the EUT port under test to achieve the < 5 pF loading. This style of capacitive voltage probe is described in 5.2.2 of CISPR 16-1-2: 2014.

The second approach to construction of a CVP uses a capacitive coupling device in close proximity to the cable attached to the EUT port under test (the device is actually in physical contact with the insulation of the cable attached to the EUT port under test). A standard oscilloscope-type voltage probe having an impedance > 10 M Ω, with a probe capacitance < 5 pF, is placed in series with the capacitive coupling device. The theory is that the probe capacitance in series with the capacitance of the capacitive coupling device will present only the probe capacitance to the cable attached to the EUT port under test. In practice, given the physical size of the capacitive coupling device, it is possible to have a large stray capacitance in parallel with the probe capacitance. If this occurs, the total capacitive loading will be greater than that of the probe itself, and the requirement to have loading < 5 pF may be violated. If this technique is employed, the capacitive loading should be verified by measurement, i.e. not rely only on theory.

This capacitance measurement can be made with any capacitance meter that can operate over the 150 kHz to 30 MHz frequency range. The capacitance is measured between the cable attached to the EUT port under test (all wires in the cable are connected together at the connection point to the meter) and the RGP. The same type of cable used in the conducted disturbance measurement should be used for this capacitance measurement.

NOTE 2 The uncertainty of this method is lowest if the length of cable between the EUT and AE is less than 1,25 m. Significantly longer cables are subject to standing waves, which can adversely affect voltage and current measurements.

G.4 Combination of current limit and voltage limit

If the TCM impedance is not 150 Ω, the measurement of the voltage or the current alone is not acceptable, because of a very high measurement uncertainty due to the undefined and unknown TCM impedances. However, if both voltage and current are measured, with limits on current and voltage applied simultaneously, the result is a worst case estimation of the disturbance, as explained below.

The basic circuit for which the limits are defined is shown in Figure G.1. This circuit is the reference for which the limits expressed in terms of current and voltage are derived; any other measurement should be compared to this basic circuit. In Figure G.1, Z_1 is an unknown parameter of the EUT; Z_2 is 150 Ω in the reference measurement.

If the measurement is performed without specifying the TCM impedance seen by the EUT, the simplified circuit is as shown in Figure G.2, where the TCM impedance Z_2 seen by the EUT is defined by the AE, and can have any value. Therefore, Z_1 as well as Z_2 are unknown parameters of the measurement.

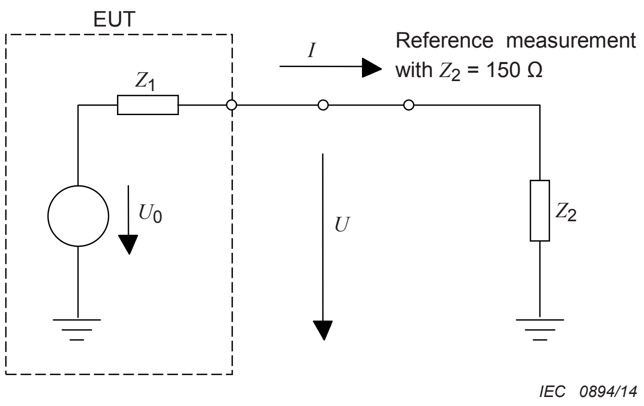


Figure G.1 – Basic circuit for considering the limits with a defined TCM impedance of 150 Ω

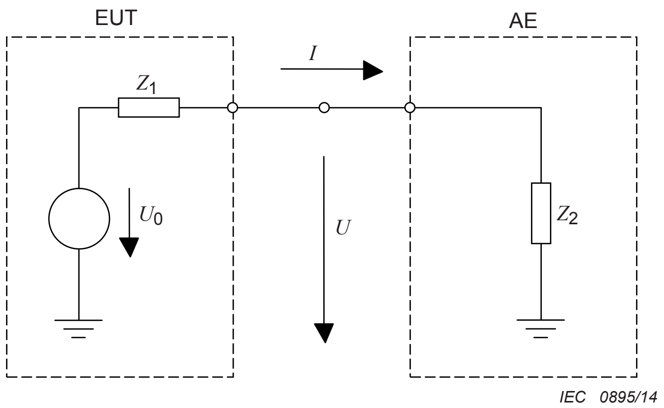


Figure G.2 – Basic circuit for the measurement with unknown TCM impedance

If the measurement is performed using the circuit of Figure G.1, the current limit and the voltage limit are equivalent. The relation between current and voltage will always be 150 Ω, and either can be used to determine compliance. However, this is not the case if Z_2 is not 150 Ω (i.e. see Figure G.2).

It is important to note that compliance with the limit is not solely determined by the source voltage U_0. The disturbance voltage measured should use a standardized Z_2 of 150 Ω, and depends on Z_1, Z_2 and U_0 together. For example, for the set-up of Figure G.1, the voltage limit value can be reached with an EUT containing a high impedance Z_1 and a high source voltage U_0, or with a lower U_0 combined with a lower impedance Z_1.

In the more general case of Figure G.2, where Z_2 is not defined, it is not possible to measure the exact value of the disturbance voltage. Because Z_1 and U_0 are not known, it is not possible to derive the disturbance voltage, even if the value of Z_2 is known (or is measured or calculated from I and U). For example, if an EUT with disturbance above the limit is evaluated only by measuring the voltage in a test set-up with low Z_2 ($Z_2 < 150$ Ω) at the AE side, the EUT might still seem to comply with the limits. In contrast, if the same EUT is measured only by measuring the current in a test set-up with high Z_2 (for example by adding ferrites), the EUT might again seem to comply with the limits.

However, it can be shown that if the current limit and the voltage limit are applied simultaneously, an EUT with disturbance results exceeding the limits will always be identified by exceeding either the current limit (if Z_2 is $<$ 150 Ω) or the voltage limit (if Z_2 is $>$ 150 Ω).

If the TCM impedance of the AE (Z_2) differs significantly from 150 Ω, it is possible that an EUT which would comply with the limits if measured with Z_2 = 150 Ω may be deemed non-compliant. However, it will never happen that an EUT not complying with the limits is deemed to be compliant. A measurement according to H.5.4 is therefore a worst case estimation of the disturbance. If an EUT exceeds the limit with the H.5.4 method, it is possible the EUT would comply with the limits if it could be measured with Z_2 = 150 Ω.

G.5 Adjusting the TCM impedance with ferrites

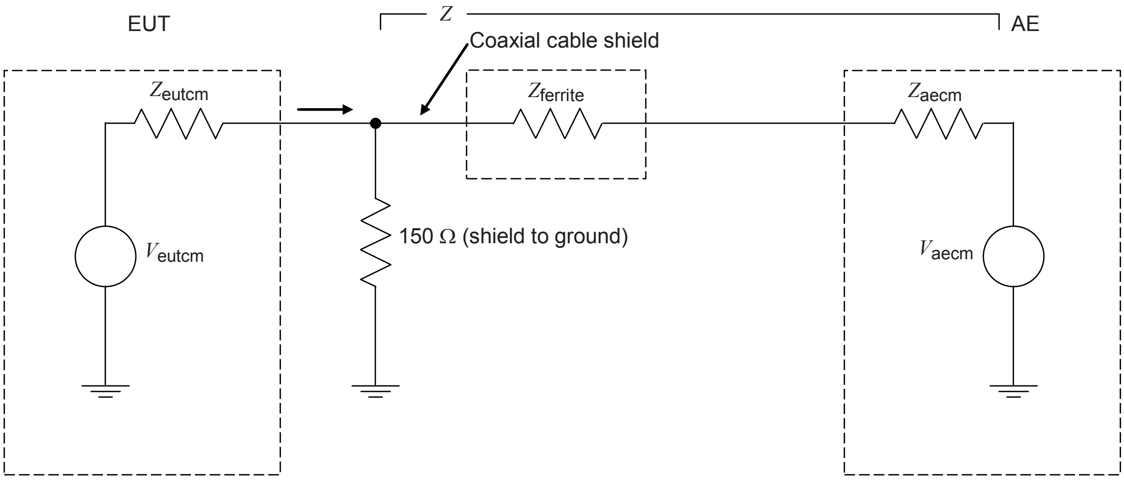
In some cases (i.e. if the TCM impedance at the AE side is originally lower than 150 Ω), it is possible to adjust the impedance by adding ferrites on the cable attached to the EUT port under test. Subclause H.5.5 requires measurement of the TCM impedance, and adjustment of the ferrites at each frequency to be measured, until the TCM impedance is 150 Ω ± 20 Ω. Therefore, the method is relatively complicated and time-consuming if applied for the full frequency spectrum. If the TCM impedance at the AE side is originally higher than 150 Ω, there is no way to adjust the impedance to 150 Ω by adding ferrites or shifting the position of the ferrites for frequencies below 30 MHz (though other methods to adjust the TCM impedance for specific frequencies could be used instead).

G.6 Ferrite specifications for use with methods of Annex H

Subclause H.5.3 defines a test set-up for measuring the common mode conducted disturbance on the shield of a coaxial cable. A load impedance of 150 Ω is connected between the coaxial shield and the RGP, as shown in Figure H.2. Ferrites are shown placed over the coaxial shield between the 150 Ω load and the AE. The following paragraphs present methods for verifying that the ferrites satisfy the requirements of H.5.3.

Figure G.3 shows all of the basic impedances involved in Figure H.2. The ferrites are specified in H.5.3 to provide high impedance such that the common mode impedance towards the right of the 150 Ω resistor shall be sufficiently large so as to not affect the measurement (Z in Figure G.3).

The previous paragraph infers that the combined series impedance of Z_{ferrite} and Z_{aecm} should not load down the 150 Ω resistor. The general approach in the CISPR 16 series is for a tolerance of ± 20 Ω on 150 Ω common mode loads over the frequency range of 0,15 MHz to 30 MHz. Combining these two concepts, the combined series impedance of Z_{ferrite} and Z_{aecm} in parallel with the 150 Ω resistor (Z in Figure G.3) should be no lower than 130 Ω. This in turn implies that this relationship should hold regardless of the value of Z_{aecm}.



Key

V_{eutcm}	common mode voltage generated by the EUT
Z_{eutcm}	common mode source impedance of the EUT
V_{aecm}	common mode voltage generated by the AE
Z_{aecm}	common mode source impedance of the AE
$Z_{ferrite}$	impedance of the ferrites
Z	combined impedance of the 150 Ω load, $Z_{ferrite}$, and Z_{aecm}

Figure G.3 – Impedance layout of the components used in Figure H.2

To establish the impedance characteristics of the ferrites, only two cases need to be considered, i.e. Z_{aecm} = open circuit, and Z_{aecm} = short-circuit. If the ferrites can be selected to satisfy these requirements, any value of Z_{aecm} will be acceptable.

- Case 1: Z_{aecm} = open circuit

  The combined series impedance of $Z_{ferrite}$ and Z_{aecm} is also an open circuit. An open circuit in parallel with the 150 Ω load yields 150 Ω. $Z_{ferrite}$ can be of any value.

- Case 2: Z_{aecm} = short-circuit

  The combined series impedance of $Z_{ferrite}$ and Z_{aecm} is equal to $Z_{ferrite}$. The value of $Z_{ferrite}$ in parallel with the 150 Ω resistor shall then be no lower than 130 Ω. In equation form:

$$\frac{150 Z_{ferrite}}{150 + Z_{ferrite}} \geq 130\ \Omega$$

  Solving for $Z_{ferrite}$ yields a value of 975 Ω. This implies that the ferrites selected for this application shall have a minimum impedance of 975 Ω over the frequency range of 0,15 MHz to 30 MHz. For a given set of ferrites, the minimum impedance ($j\omega L$) will occur at the minimum frequency of 0,15 MHz.

Combining the two conditions described above, it is seen that the second condition at 0,15 MHz sets the minimum requirements for the impedance of the ferrites. Any value of impedance for the ferrites above this value would be acceptable.

In order to establish that the selected ferrites will accomplish the intended function, use of the test set-up shown in Figure G.4 is suggested. A traditional impedance meter/analyzer can be used to measure the impedance between point Z (I and V in Figure G.4) and the reference ground. Another approach is to measure the individual voltage and current at point Z, then calculate the impedance. At a minimum, the impedance measurement should be made at 0,15 MHz. However, it is advisable to measure the impedance across the entire 0,15 MHz to 30 MHz range, to ensure that any stray capacitance associated with the ferrites and the coaxial cable does not degrade the ferrite impedance. This effect is of concern because laboratory data have shown that it is unlikely that the desired impedance can be achieved with only a single pass of the coaxial cable through the ferrites – i.e. multiple passes through the ferrites are necessary. This arrangement increases the chances of stray capacitance adversely affecting the impedance of the ferrites. It has been demonstrated that in the laboratory that the desired impedance versus frequency can be achieved.

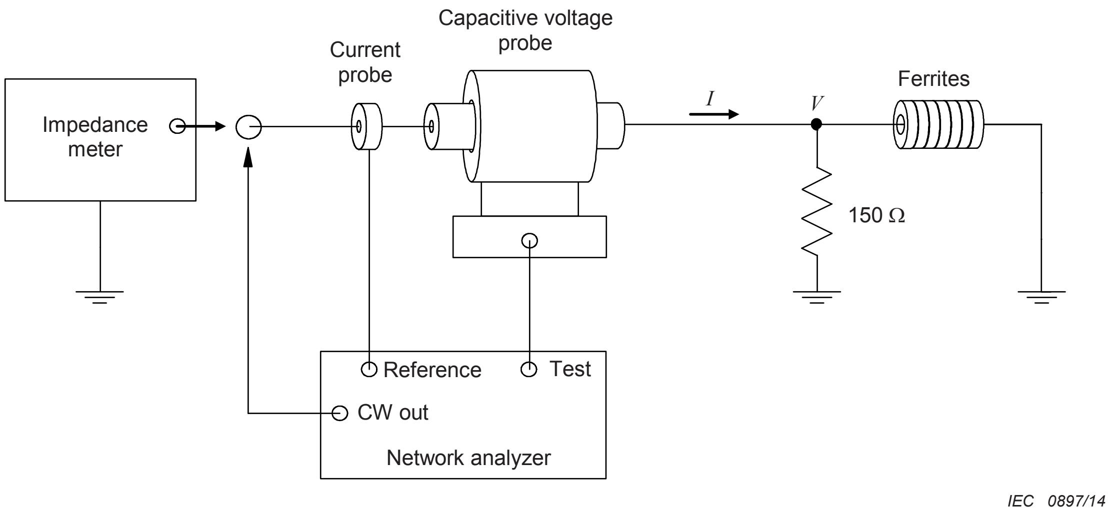


Figure G.4 – Basic test set-up to measure combined impedance of the 150 Ω and ferrites

Annex H
(normative)

Specific guidance for conducted disturbance measurements on telecommunication ports

H.1 General

The purpose of Annex H is to define methods of measurement of the unwanted common mode disturbance at the telecommunication ports of an EUT. Various measurement procedures can be used, as summarized in Table H.1.

Where there are multiple similar ports on an EUT, it shall be shown by pre-scanning or some other technique that the ports are similar in their emissions performance, and that the conducted disturbance on the selected port is representative of the other similar ports.

Table H.1 – Telecommunication port disturbance measurement procedure selection

	Cable type	Number of pairs	Example ANs	Measurement type	Procedures
1	Balanced, unscreened	1 (2 wires) 2 (4 wires) 3 (6 wires) 4 (8 wires)	Figure I.1 Figure I.2 Figure I.3 Figure I.3	Voltage	H.5.2
2	Balanced, unscreened	1 (2 wires) 2 (4 wires) 3 (6 wires) 4 (8 wires) > 4 (> 8 wires)	Not applicable	Voltage and current	H.5.4 Adjustment of the matching network (CMAD) may be required to achieve the specified impedance.
3	Screened or coaxial	Not applicable	Figure I.10 Figure I.8	Voltage	H.5.2
4	Screened or coaxial	Not applicable	Not applicable	Current or voltage	H.5.3
5	Unbalanced cables	Not applicable	Not applicable	Voltage and current	H.5.4 Adjustment of the matching network (CMAD) may be required to achieve the specified impedance.
6	Unbalanced mains	Not applicable	Relevant AMN	Voltage	The AMN shall be used as a voltage probe.

Further details:

a) Where used, an AAN shall satisfy all the requirements defined in Clause H.2.

b) Where used, the current probe shall satisfy the requirements defined in Clause H.3 and the voltage probe shall satisfy the requirements defined in Clause H.4.

c) When measuring the mains terminal disturbance voltages, the mains voltage shall be supplied to the EUT via the AMN used.

d) The procedure described in H.5.2 gives results with the lowest measurement uncertainty.

e) Each EUT unscreened symmetric telecommunication port shall be tested with the example AAN applicable to the total number of balanced pairs in that EUT port (for example, a four-pair EUT port shall use the example AAN shown in Figures I.3, I.6 or I.7), provided that at least one pair is used for balanced telecommunication and is independent of how the other pairs in the cable are used.

f) The AANs shown in Figures I.2 and I.3 can be used for any number of pairs up to the maximum; remaining AANs from Annex I are appropriate only for use with the stated number of pairs in the cable.

H.2 Characteristics of AANs

Measurement of common mode (asymmetric mode) current or voltage emissions at wired network ports for attachment of unscreened balanced pairs shall be performed with the wired network port connected by a cable to an AAN; thus, the AAN shall define the common mode termination impedance seen by the wired network port during the disturbance measurements.

The AAN (as calibrated including all appropriate adapters required to connect to the EUT and AE) shall have the following properties:

a) The common mode termination impedance in the frequency range 0,15 MHz to 30 MHz shall be 150 Ω ± 20 Ω, phase angle 0° ± 20°.

b) The AAN shall provide sufficient isolation against emissions from an AE or load connected to the wired network port being measured. The attenuation of the AAN, for common mode emissions originating from the AE, shall be such that the measured level of these emissions at the measuring receiver input shall be at least 10 dB below the relevant emission limit.

   The preferred isolation is:

   - 150 kHz to 1,5 MHz, isolation > 35 dB to 55 dB, increasing linearly with the logarithm of the frequency;
   - 1,5 MHz to 30 MHz, isolation > 55 dB.

   NOTE Isolation is the decoupling of common mode disturbance originating in an AE and subsequently appearing at the EUT port of the AAN. Certain parameters of the test system are considered in determining the adequate requirement for disturbance levels.

c) The AAN shall meet the longitudinal conversion loss (a_{LCL}) requirements from 150 kHz to 30 MHz stated in Table H.2. Actual LCL values to simulate different cable categories are defined in Table H.2.

Table H.2 – a_{LCL} values

Cable type	a_{LCL} dB	Tolerance dB
Cat 3 (or better)	$a_{\mathrm{LCL}} = 55 - 10\lg\left[1 + \left(\frac{f}{5}\right)^2\right]$	± 3
Cat 5 (or better)	$a_{\mathrm{LCL}} = 65 - 10\lg\left[1 + \left(\frac{f}{5}\right)^2\right]$	± 3 for $f < 2$ MHz −3 /+4,5 for 2 MHz ≤ f ≤ 30 MHz
Cat 6 (or better)	$a_{\mathrm{LCL}} = 75 - 10\lg\left[1 + \left(\frac{f}{5}\right)^2\right]$	± 3 for $f < 2$ MHz −3 /+6 for 2 MHz ≤ f ≤ 30 MHz
NOTE 1 The equations provide the variation of LCL (a_{LCL}) in dB with frequency f in MHz. NOTE 2 LCL versus frequency is an approximation of the LCL of typical unscreened balanced cables in representative environments. The specification for category 3 is considered representative of the LCL of typical telecommunication access networks.		

d) The insertion loss, or other deterioration of the signal quality in the wanted signal frequency band caused by the presence of the AAN, shall not significantly affect the normal operation of the EUT.

e) The voltage division factor (F_{AAN}) shall be ± 1 dB from 150 kHz to 30 MHz. The AAN voltage division factor is calculated as follows:

$$F_{\mathrm{AAN}} = 20\lg\left|\frac{V_{\mathrm{cm}}}{V_{\mathrm{mp}}}\right| \mathrm{dB}$$

where V_{cm} is the common mode voltage appearing across the common mode impedance presented to the EUT by the AAN, and V_{mp} is the resulting receiver voltage measured directly at the voltage measuring port. The voltage division factor shall be added to the receiver voltage measured directly at the voltage measuring port, and the result compared with the voltage limits as applicable. The voltage division factor is a calibrated quantity with an uncertainty and no tolerance.

H.3 Characteristics of current probe

The current probe shall have a uniform frequency response without resonances (over the frequency range of interest), and shall be capable of operating without saturation effects caused by the operating currents in the primary winding.

During measurements of currents, where an AAN is used to terminate the line, a current probe is inadequate for determining the converted common mode, and therefore shall not be used.

The insertion impedance of the current probe shall not be larger than 1 Ω (see 5.1 of CISPR 16-1-2: 2014).

H.4 Characteristics of capacitive voltage probe

The capacitive voltage probe defined in 5.2.2 of CISPR 16-1-2: 2014 shall be used.

H.5 Procedures for common mode measurements

H.5.1 General

Clause H.5 describes the measurement procedures that can be used to measure the CM conducted disturbance of wired network ports. Depending on the cable type, different procedures can be used, each with its advantages and disadvantages (see also Annex G).

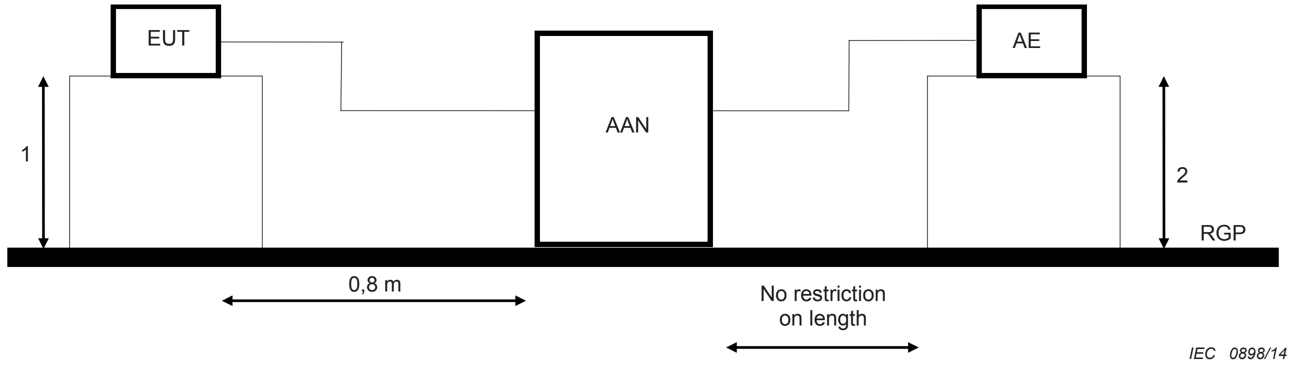
H.5.2 Measurement procedure using AANs

Measurement is made at wired network ports using AANs with longitudinal conversion losses as defined in Table H.2 The EUT shall not exceed the applicable limits when measured with the AN according to the cable category specified by the equipment documentation provided to the user.

When disturbance voltage measurements are performed, an AAN providing a voltage measuring port suitable for connection to a measuring receiver, while satisfying the wired network port common mode termination impedance requirements, shall be used.

For unscreened cables containing balanced pairs, the AAN according to Clause H.2 shall be used. The LCL values of the AAN shall be within the tolerance in Table H.2 of an AAN appropriate to the cable category connected to the EUT.

a) Arrange the EUT as per Figure H.1.
b) Measure the voltage at the measurement port of the AAN, then correct the reading by adding the AAN voltage division factor (F_{AAN}) defined in list item e) of Clause H.2, then compare to the limit.



Key

1 Distance to the horizontal RGP: 40 cm for tabletop equipment; up to 15 cm for floor standing equipment. Alternatively, tabletop EUT can be 40 cm from a vertical RGP.

2 Distance to the RGP is not critical if the AAN provides sufficient isolation against emissions from an AE.

Figure H.1 – Measurement set-up using an AAN

H.5.3 Measurement procedure using a 150 Ω load connected to the outside surface of the cable screen

This procedure can be used for all types of coaxial cables, metallic screens or strength members on fibre optic cables or shielded multi-pair cables.

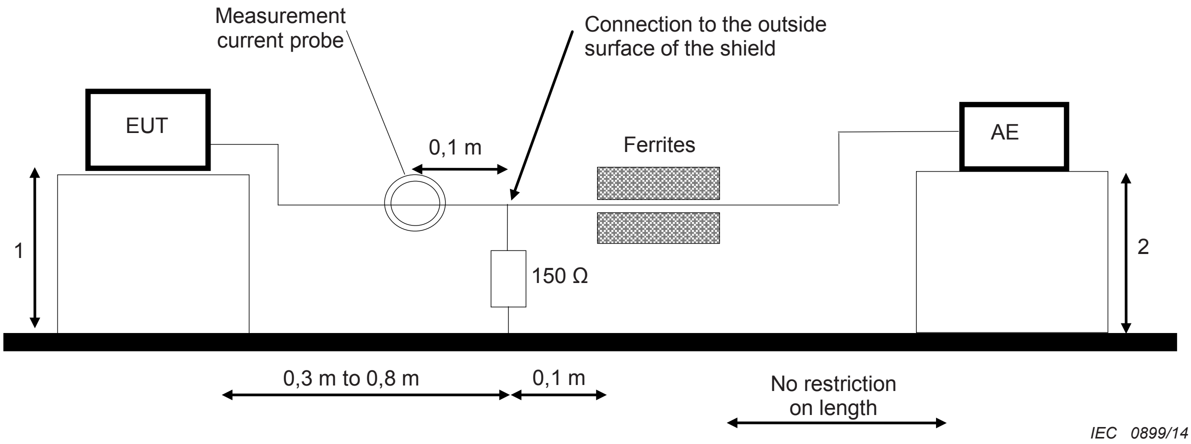
a) Arrange the EUT as per Figure H.2.

b) Break the external protective insulation (exposing the shield), and connect a 150 Ω resistor using an electrical connection from the cable screen to the RGP (through the 150 Ω resistor). The length of this electrical connection shall be ≤ 0,3 m from the outside surface of the screen to the RGP.

c) Apply a ferrite tube or clamp between the 150 Ω connection and AE.

d) Measure the current with a current probe and compare to the current limit. The common mode impedance towards the right of the 150 Ω resistor shall be sufficiently large so as not to affect the measurement. Use the method of H.5.5 to measure this impedance, which should be much larger than 150 Ω so as not to affect the measurement for frequencies emitted by the EUT.

   Voltage measurement may also be performed in parallel with the 150 Ω resistor with a high impedance probe, or by using a "50 Ω to 150 Ω adaptor" (described in IEC 61000-4-6 [9] as a 150 Ω load) and applying the appropriate correction factor (9,5 dB in case of the "50 Ω to 150 Ω adaptor").



Key

1 Distance to the horizontal RGP: 40 cm for tabletop equipment; up to 15 cm for floor standing equipment. Alternatively, tabletop EUT can be 40 cm from a vertical RGP.

2 Distance to the RGP is not critical if the impedance of the ferrite is higher than that given in G.6.

Figure H.2 – Measurement set-up using a 150 Ω load to the outside surface of the shield

H.5.4 Measurement procedure using a combination of current probe and capacitive voltage probe

Because an AAN is not used in the procedure, the common mode impedance is not stabilized; therefore the EUT is measured against both the voltage and the current limits, as defined in the following steps:

a) Arrange the EUT as per Figure H.3.

b) Measure the current with a current probe, and compare the results against the current limits.

c) Measure the voltage with a capacitive voltage probe as specified in H.4.

   1) Adjust the measured voltage as follows:

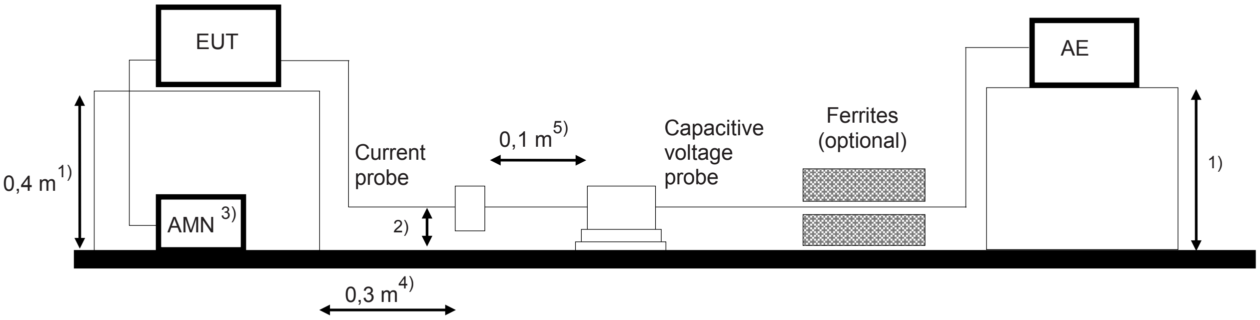
      i) Current margin ≤ 6 dB: subtract the actual current margin from the measured voltage.

      ii) Current margin > 6 dB: subtract 6 dB from the measured voltage.

   2) Compare the adjusted voltage with the applicable voltage limit.

   3) Both the measured current and the adjusted voltage shall be below the applicable current and voltage limits.

d) If the EUT has met both limits at all frequencies, then the EUT is compliant.



It is not required to place both the current probe and the capacitive voltage probe in the measurement set-up at the same time unless simultaneous current and voltage measurements are to be made.

1) Distance to the horizontal RGP: 40 cm for tabletop equipment; up to 15 cm for floor standing equipment. Alternatively, a tabletop EUT can be 40 cm from a vertical RGP.

2) The cable used in testing shall drop directly from the EUT to a position 4 cm ± 1 cm from the RGP, and run at this position between the EUT and AE tables. This restriction does not apply to the section of the cable passing through the voltage probe.

3) Unless battery operated, the EUT shall be powered using an AMN placed on the RGP at > 10 cm from the nearest edge of the RGP. The EUT power cord shall be routed away from the cable used in testing, to minimize coupling or crosstalk effects.

4) The horizontal projection of the EUT to the measurement device shall be 30 cm ± 1 cm.

5) The current and voltage probes shall be separated by 10 cm ± 1 cm. Either the current probe (as shown) or the capacitive voltage probe may be placed on the EUT side.

Figure H.3 – Measurement set-up using current and capacitive voltage probes

H.5.5 Measurement of cable, ferrite and AE common mode impedance

One of the following three procedures is used to measure the total common mode (TCM) impedance of cable, ferrite, and AE.

a) Procedure using two current probes

   1) Characterize the "drive" probe and measurement probe 50 Ω system; see Figure H.4. Insert a drive voltage (V_1) from a signal generator into the "drive" probe, and record the resulting current (I_1) in the measurement probe.

   2) Remove the cable from the EUT and short it to ground at the EUT end.

   3) Apply the same drive voltage (V_1) to the cable with the same "drive" probe.

   4) Measure the current with the same measurement probe and calculate the common mode impedance of the cable, ferrite, and AE combination by comparing the current (I2) read by the measurement probe with that in the first step (common mode impedance = 50 × I_1/I_2). For example, if I_2 is half I_1, then the common mode impedance is 100 Ω.

   5) This TCM impedance measurement technique shall be used only under the following conditions:

      The loop length (circumference) in the 50 Ω characterization set-up of Figure H.4 shall be within 0,9 times to 1,1 times the total loop length in Figure H.2 and both loop lengths shall be less than 1,25 m. These conditions are necessary to minimize loop resonance(s) that could affect the impedance measurement and increase measurement uncertainty.

b) Procedure using an impedance analyzer

   Connect the impedance analyzer between the cable attached to the EUT port being measured and the RGP. The EUT is disconnected for this measurement, and all wires in the cable attached to the EUT port being measured, including the shield if present, are connected together at the point where they are connected to the impedance analyzer. The cable length conditions cited above shall be applied for this measurement. This measurement set-up is similar to that shown in Figure G.4.

c) Procedure using a network analyzer

Using a network analyzer, a current probe, and a capacitive voltage probe, measure the common mode voltage and current. The ratio of the voltage to the current on the cable attached to the EUT port under test, as measured with the network analyzer, defines the TCM impedance. This measurement test set-up is similar to that shown in Figure G.4. All wires in the tested cable, including the shield if present, shall be connected together at the EUT end of the cable, similar to the procedure described in item b).

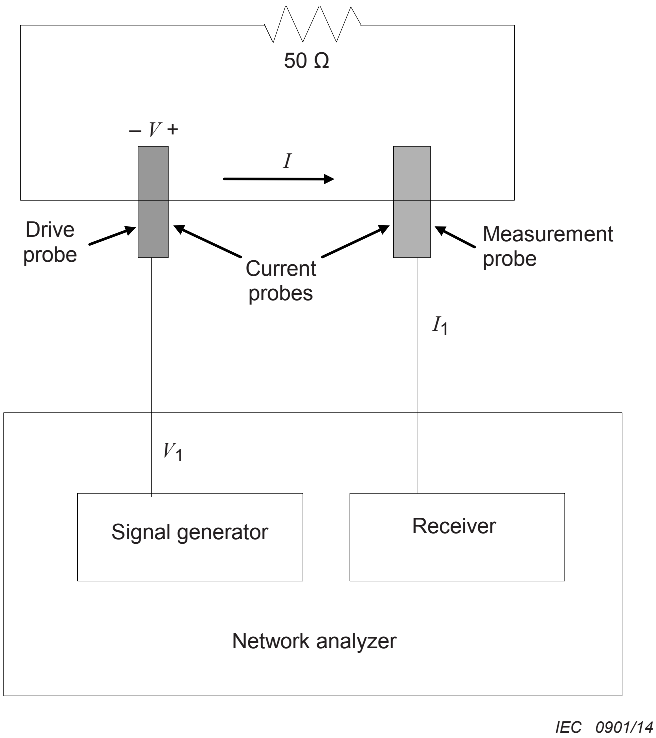
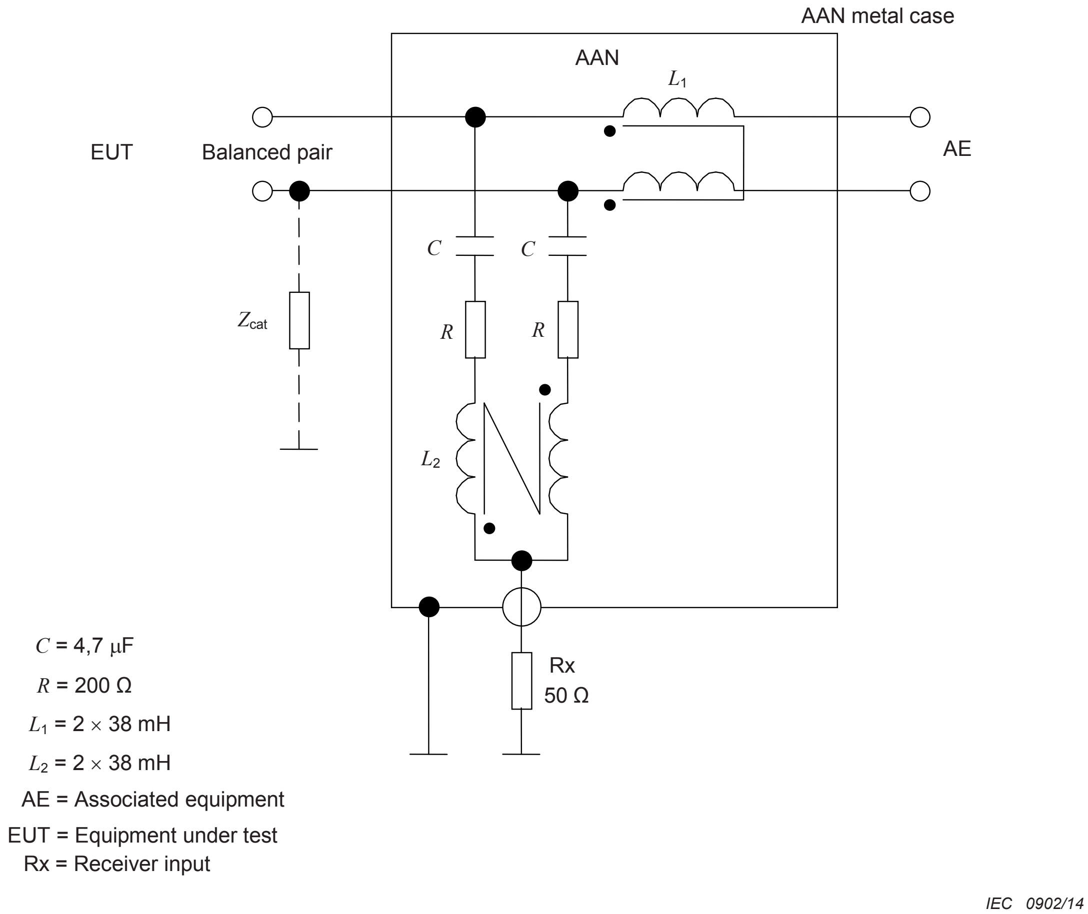


Figure H.4 – Characterization set-up

Annex I
(informative)

Examples of AANs and ANs for screened cables

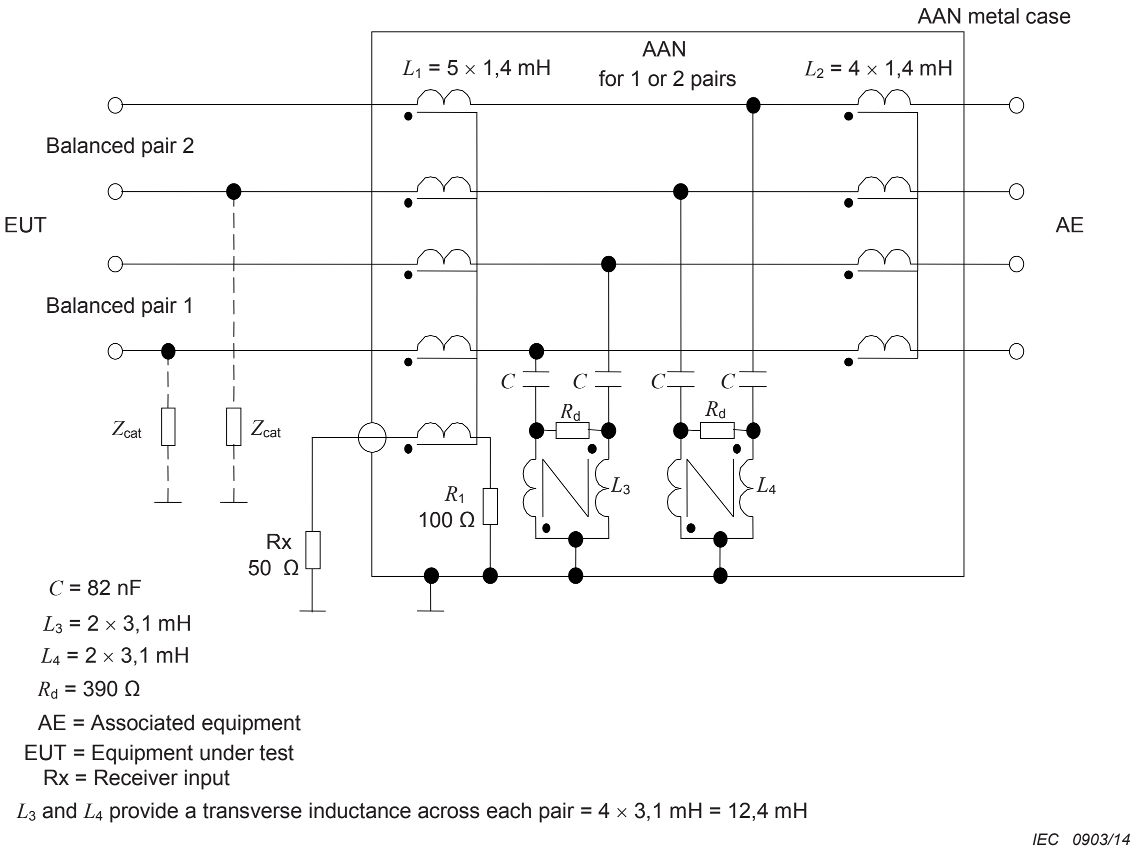
Figures I.1 through I.7 provide schematic diagrams of examples of AANs. Figures I.8 through I.11 provide diagrams of examples of ANs for screened cables.



NOTE 1 Nominal voltage division factor = 9,5 dB.

NOTE 2 Z_{cat} represents the unbalanced network required to adjust the LCL.

Figure I.1 – Example AAN for use with unscreened single balanced pairs

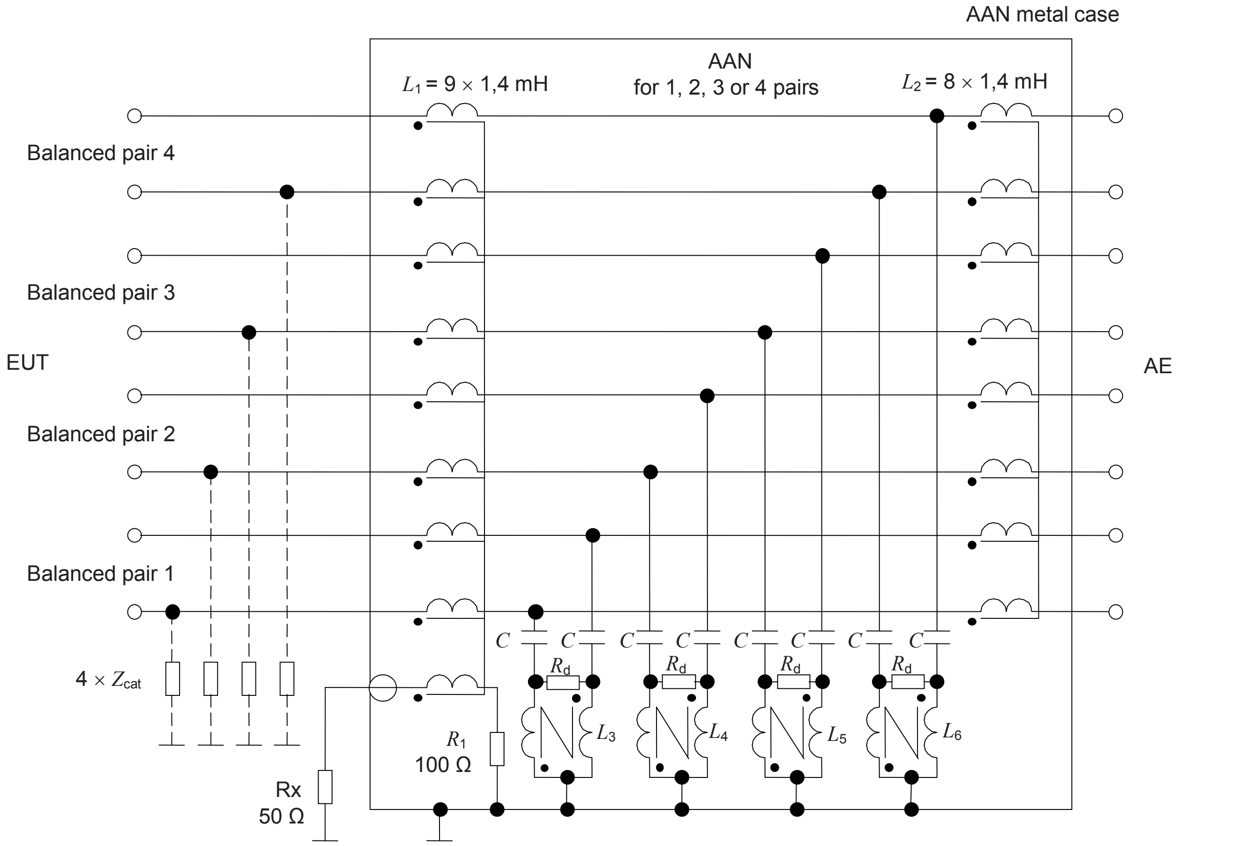


NOTE 1 Nominal voltage division factor = 9,5 dB.

NOTE 2 Z_{cat} represents the unbalanced network required to adjust the applicable LCL.

NOTE 3 This AAN can be used to measure common mode disturbance equally well on a single unscreened balanced pair, or on two unscreened balanced pairs.

Figure I.2 – Example AAN with high LCL for use with either one or two unscreened balanced pairs



C = 82 nF
R_d = 390 Ω
AE = Associated equipment
EUT = Equipment under test
Rx = Receiver input
L_3, L_4, L_5 and L_6 = 2 × 3,1 mH
L_3, L_4, L_5 and L_6, provide a transverse inductance across each pair = 4 × 3,1 mH = 12,4 mH

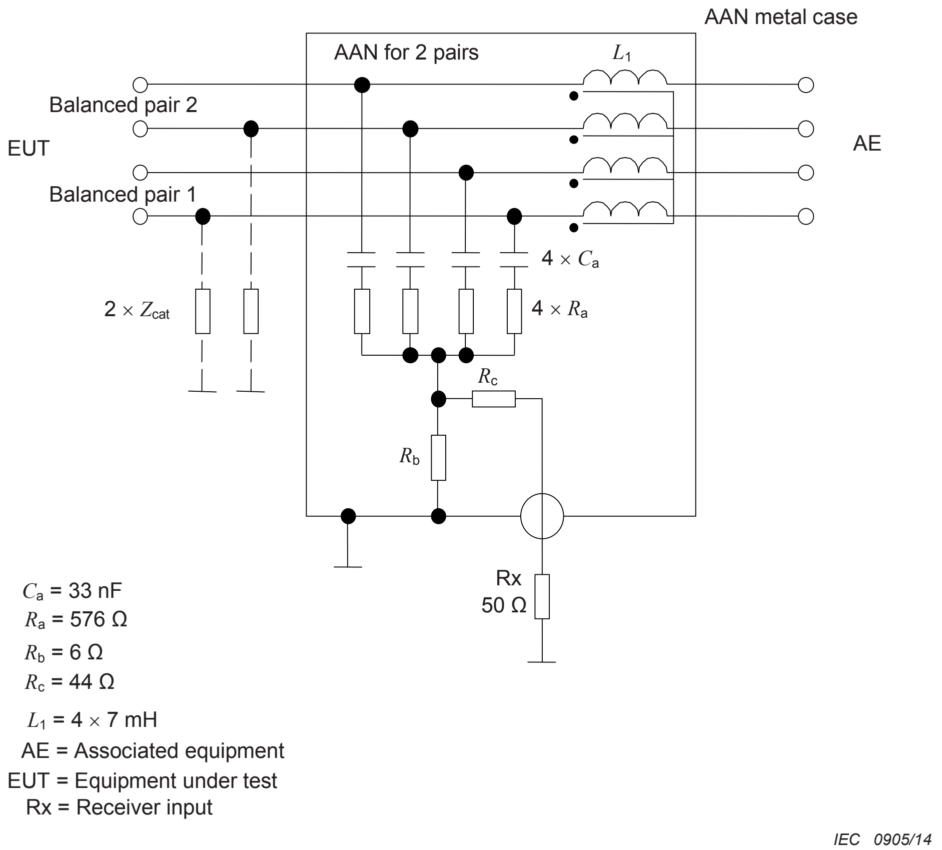
IEC 0904/14

NOTE 1 Nominal voltage division factor = 9,5 dB.

NOTE 2 Z_{cat} represents the unbalance network required to adjust the applicable LCL.

NOTE 3 This AAN can be used to measure common mode emissions equally well on a single unscreened balanced pair, or on two, three or four unscreened balanced pairs.

Figure I.3 – Example AAN with high LCL for use with one, two, three, or four unscreened balanced pairs

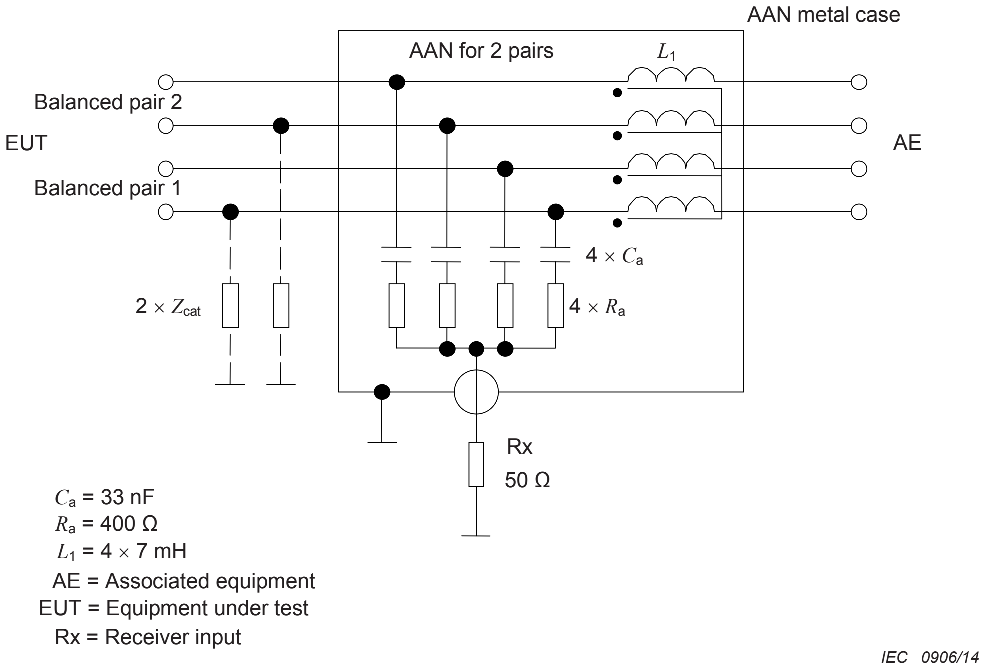


CAUTION – Due to the possibility of erroneous measurement results, this AAN should not be used to measure common mode emissions on unscreened pair cables connected to telecommunication ports that contain only one active unscreened balanced pair.

NOTE 1 Nominal voltage division factor = 34 dB.

NOTE 2 Z_{cat} represents the unbalance network required to adjust the applicable LCL.

Figure I.4 – Example AAN, including a 50 Ω source matching network at the voltage measuring port, for use with two unscreened balanced pairs

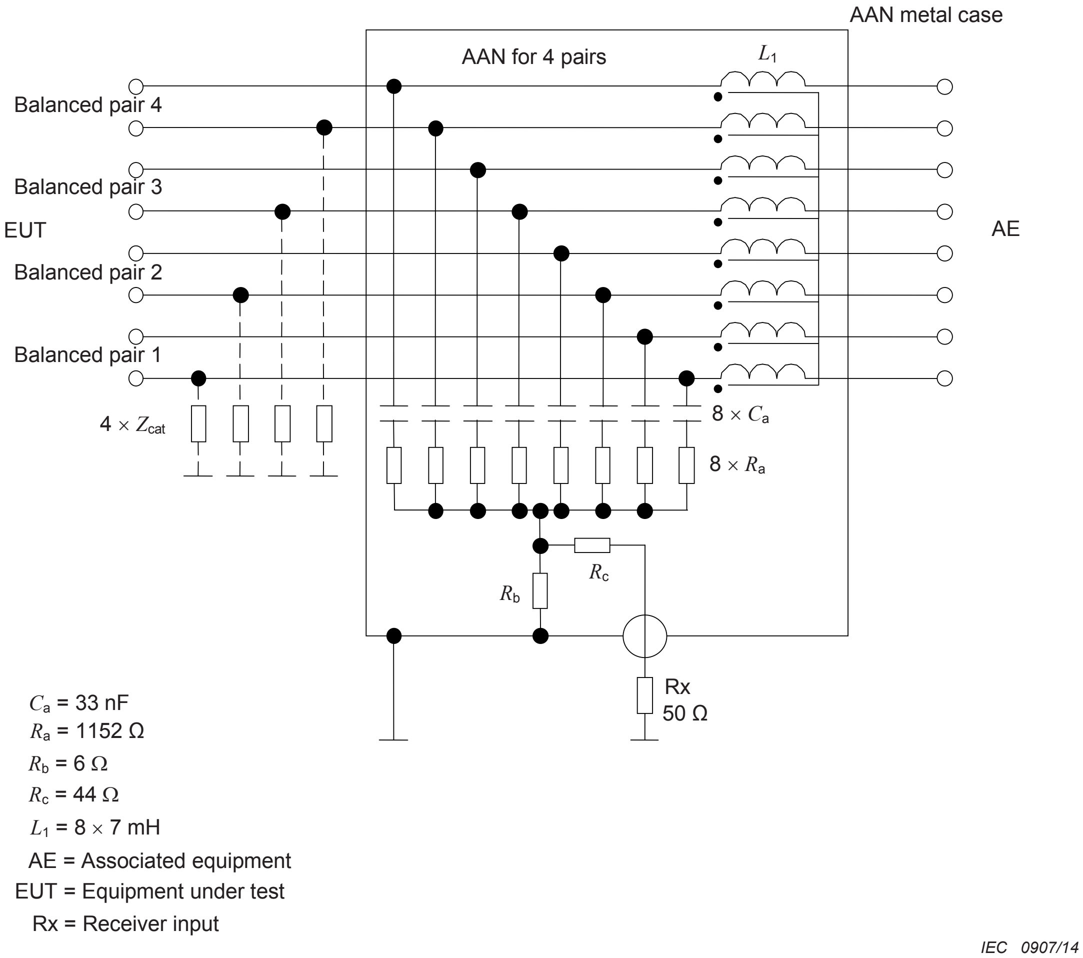


NOTE 1 Nominal voltage division factor = 9,5 dB.

NOTE 2 Z_{cat} represents the unbalance network required to adjust the applicable LCL.

NOTE 3 CAUTION – Due to the possibility of erroneous measurement results, this AAN cannot be used to measure common mode emissions on unscreened pair cables connected to wired network ports that employ only one active unscreened balanced pair.

Figure I.5 – Example AAN for use with two unscreened balanced pairs

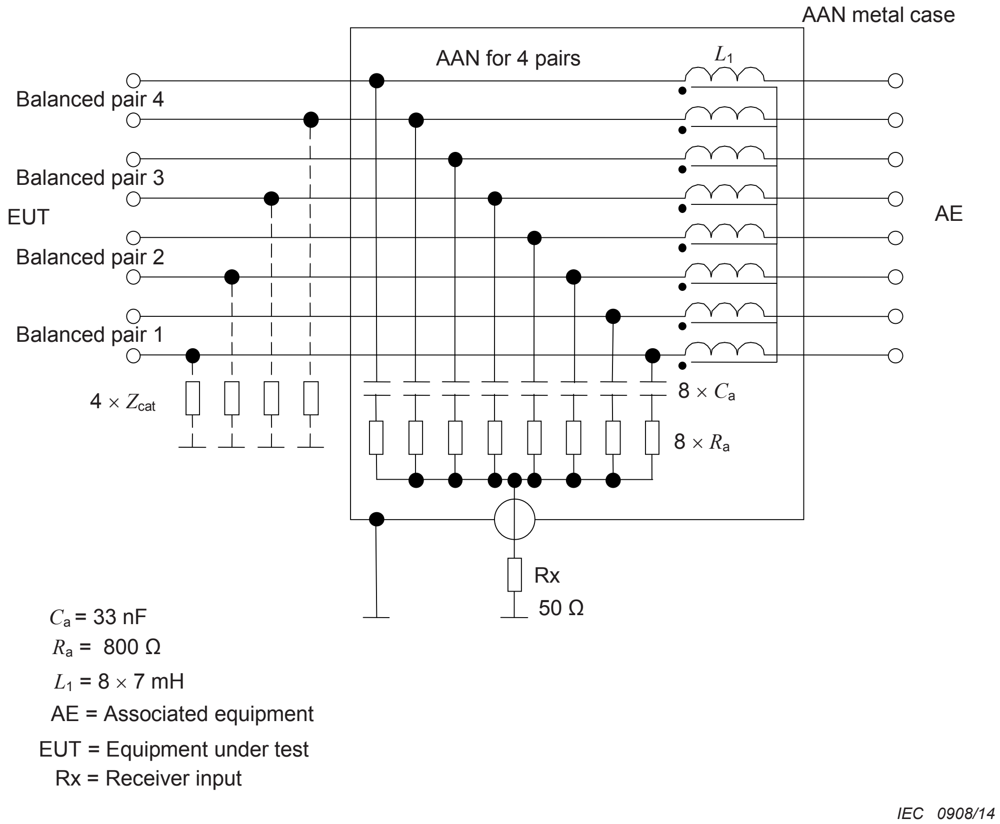


NOTE 1 Nominal voltage division factor = 34 dB.

NOTE 2 Z_{cat} represents the unbalance network required to adjust the applicable LCL.

NOTE 3 CAUTION – Due to the possibility of erroneous measurement results, this AAN cannot be used to measure common mode emissions on unscreened pair cables connected to wired network ports that employ less than four active unscreened balanced pair.

Figure I.6 – Example AAN, including a 50 Ω source matching network at the voltage measuring port, for use with four unscreened balanced pairs

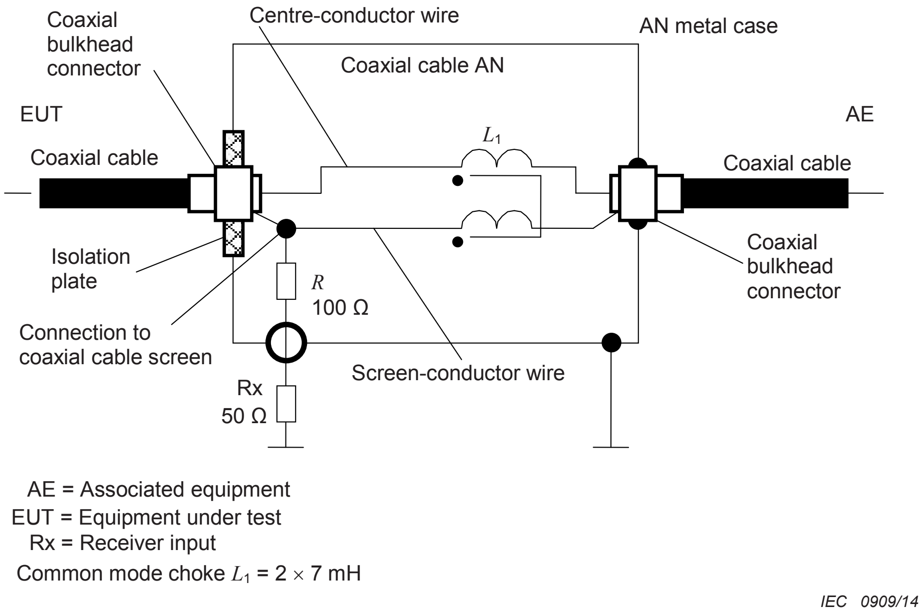


NOTE 1 Nominal voltage division factor = 9,5 dB.

NOTE 2 Z_{cat} represents the unbalance network required to adjust the applicable LCL.

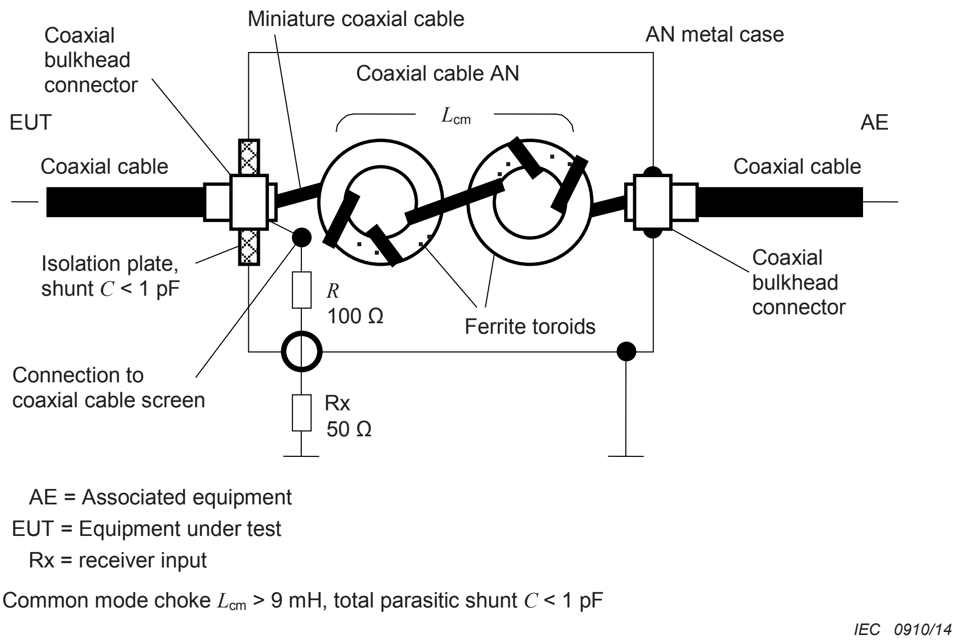
NOTE 3 CAUTION – Due to the possibility of erroneous measurement results, this AAN cannot be used to measure common mode emissions on unscreened pair cables connected to telecommunication ports that employ less than four unscreened balanced pairs.

Figure I.7 – Example AAN for use with four unscreened balanced pairs



NOTE Nominal voltage division factor = 9,5 dB.

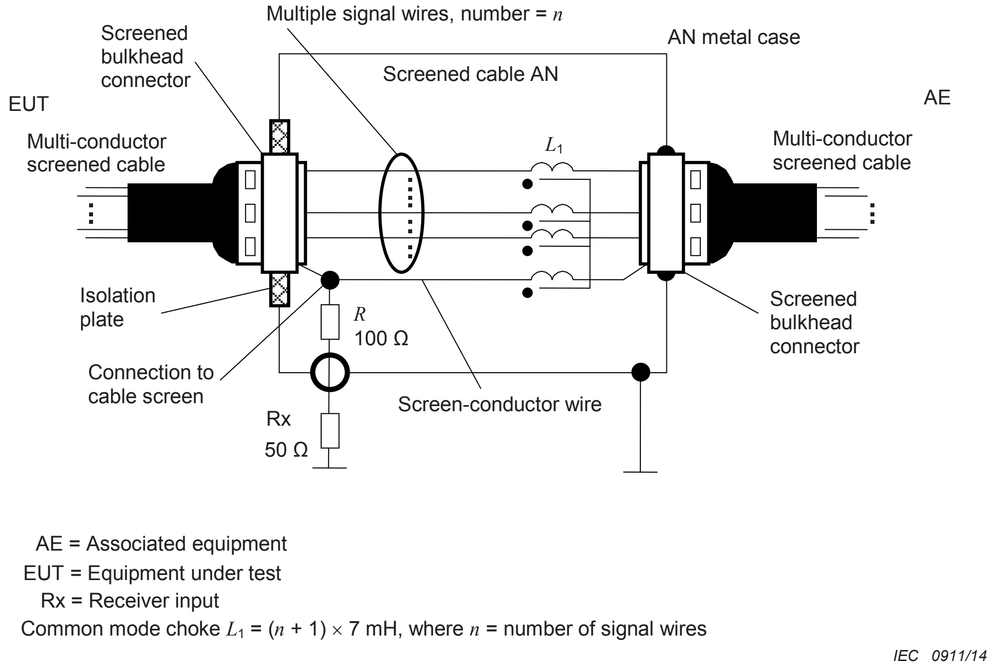
Figure I.8 – Example AN for use with coaxial cables, employing an internal common mode choke created by bifilar winding an insulated centre-conductor wire and an insulated screen-conductor wire on a common magnetic core (for example, a ferrite toroid)



NOTE 1 Nominal voltage division factor = 9,5 dB.

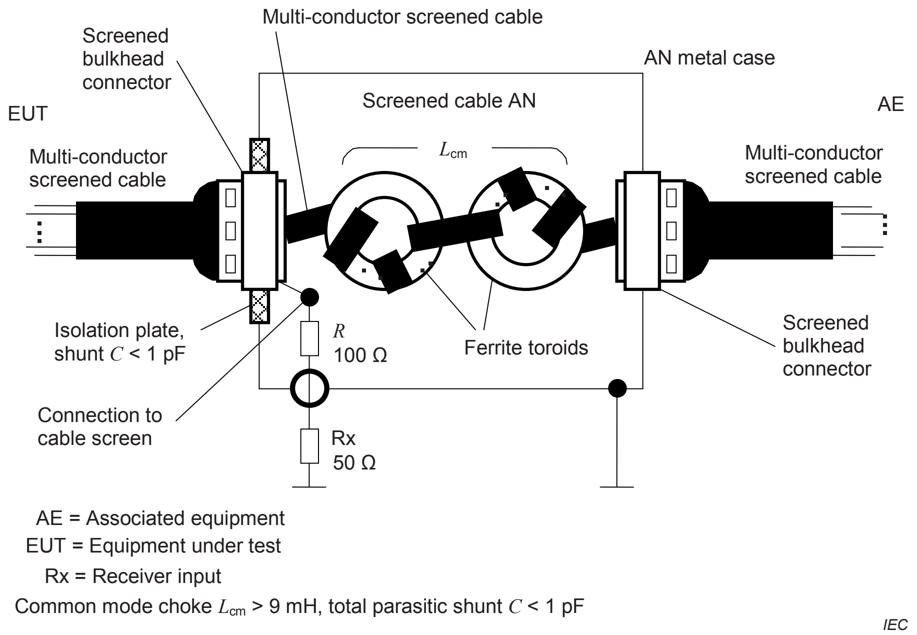
NOTE 2 More toroids may be needed to fully meet the requirements for ANs.

Figure I.9 – Example AN for use with coaxial cables, employing an internal common mode choke created by miniature coaxial cable (miniature semi-rigid solid copper screen or miniature double-braided screen coaxial cable) wound on ferrite toroids



NOTE Nominal voltage division factor = 9,5 dB.

Figure I.10 – Example AN for use with multi-conductor screened cables, employing an internal common mode choke created by bifilar winding multiple insulated signal wires and an insulated screen-conductor wire on a common magnetic core (for example, a ferrite toroid)



NOTE 1 Nominal voltage division factor = 9,5 dB.

NOTE 2 More toroids may be needed to fully meet the requirements for ANs.

Figure I.11 – Example AN for use with multi-conductor screened cables, employing an internal common mode choke created by winding a multi-conductor screened cable on ferrite toroids

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