

INTERNATIONAL STANDARD



INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

BASIC EMC PUBLICATION

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



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INTERNATIONAL ELECTROTECHNICAL COMMISSION
INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

**SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY
MEASURING APPARATUS AND METHODS –**

**Part 1-2: Radio disturbance and immunity measuring apparatus –
~~Ancillary equipment – Conducted disturbances~~
Coupling devices for conducted disturbance measurements**

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International Standard CISPR 16-1-2 has been prepared by subcommittee A: Radio-interference measurements and statistical methods, of IEC technical committee CISPR: International special committee on radio interference.

This second edition cancels and replaces the first edition published in 2003 and its Amendment 1 (2004) and Amendment 2 (2006). This edition constitutes a technical revision.

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

- a) requirements from CISPR 22 for the AAN have been copied to this standard;
- b) the CDNE for measurement of disturbance voltage in the frequency range 30 MHz to 300 MHz is added;
- c) additional maintenance is included.

It has the status of a basic EMC publication in accordance with IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*.

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

FDIS	Report on voting
CISPR/A/1051/FDIS	CISPR/A/1059/RVD

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

A list of all parts of CISPR 16 series, under the general title *Specification for radio disturbance and immunity measuring apparatus and methods*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 1-2: Radio disturbance and immunity measuring apparatus – ~~Ancillary equipment – Conducted disturbances~~ Coupling devices for conducted disturbance measurements

1 Scope

This part of the CISPR 16 series ~~is designated a basic standard, which~~ specifies the characteristics and performance of equipment for the measurement of radio disturbance voltages and currents in the frequency range 9 kHz to 1 GHz.

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.

Specifications for ancillary apparatus are included for artificial mains networks, current and voltage probes and coupling units for current injection on cables.

~~It is intended that~~ the requirements of this publication ~~shall be complied with~~ are fulfilled at all frequencies and for all levels of radio disturbance voltages and currents within the CISPR indicating range of the measuring equipment.

Methods of measurement are covered in the CISPR 16-2 series, and further information on radio disturbance is given in CISPR 16-3, ~~while uncertainties, statistics and limit modelling are covered in the CISPR 16-4 series.~~

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 1:2000, Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 1: Emission~~

CISPR 16-1-1:20032010, Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus

CISPR 16-2-1:20032014, Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements

~~CISPR 16 3:2003, Specification for radio disturbance and Immunity measuring apparatus and methods – Part 3: CISPR Technical reports~~

~~CISPR 16 4 1:2003, Specification for radio disturbance and immunity measuring apparatus and methods – Part 4 1: Uncertainties, statistics and limit modelling – Uncertainties in standardized EMC tests~~

CISPR 16-4-2:2003/2011, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainty*

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

~~IEC 60050(161):1990, International Electrotechnical Vocabulary (IEV) — Chapter 161: Electromagnetic compatibility~~

IEC 61000-4-6:2008, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

~~International Vocabulary of Basic and General Terms in Metrology, International Organization for Standardization, Geneva, 2nd edition, 1993~~

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050, as well as the following apply. ~~Also see IEC 60050(161).~~

3.1.1

ancillary equipment

transducers 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

Note 1 to entry: Examples of transducers are current and voltage probes and artificial networks.

3.1.2

associated equipment

AE

apparatus that is not part of the system under test but is required for the functioning of the EUT

3.1.3

asymmetric voltage

radio-frequency disturbance voltage appearing between the electrical mid-point of the mains terminals and ground, sometimes called the common mode voltage ~~and is half the vector sum of V_a and V_b , i.e., $(V_a + V_b)/2$~~

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. $(V_a + V_b)/2$.

3.1.4

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. ~~If V_a is the vector voltage between one of the mains terminals and earth and V_b is the vector voltage between the other mains terminal and earth,~~

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

3.1.5**unsymmetric voltage**

amplitude of the vector voltage, V_a or V_b defined in 3.1.3 and 3.1.4

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 3.1.3 and 3.1.4 for details on V_a and V_b .

3.1.6**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.

3.1.7**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: The term "Y-network" is a synonym for AAN.

3.5**impedance stabilization network (ISN)**

generally an artificial network that provides a stabilized impedance to the EUT; often (e.g. in CISPR 22) used as a synonym for AAN

3.1.8**auxiliary equipment****AuxEq**

peripheral equipment that is part of the system under test

3.1.9**coupling/decoupling network****CDN**

artificial network for the measurement or injection of signals on one circuit while preventing signals from being measured or injected on another circuit

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 "Sx" for screened cable with x internal wires

Note 1 to entry: See Annex J for further details on the CDNE-X.

3.1.11

equipment under test

EUT

equipment (devices, appliances and systems) subjected to EMC (emission) compliance tests

3.1.12

impedance measurement adaptor

IMA

metallic vertical plane, 0,1 m by 0,1 m, bonded to the reference ground plane, which contains connection ports for a network analyzer and a CDNE

3.1.13

longitudinal conversion loss

LCL

in a one- or two-port network, a measure of the degree of unwanted transverse (symmetric mode) signal produced at the terminals of the network due to the presence of a longitudinal (asymmetric mode) signal on the connecting leads

Note 1 to entry: LCL is a ratio expressed in dB.

[SOURCE: ITU-T Recommendation O.9 [8] ¹⁾]

3.1.14

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 emission measurements, and serves as reference ground for the measurement of unsymmetrical and asymmetrical disturbance voltages.

3.2 Abbreviations

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

AN	Artificial network
CVP	Capacitive voltage probe
E.m.f.	Electromotive force
ISN	Impedance stabilization network
ITE	Information technology equipment
LCL	Longitudinal conversion loss
NWA	Network analyser
PE	Protective earth
RF	Radio frequency

¹⁾ Numbers in square brackets refer to the Bibliography.

4 Artificial mains networks

4.1 General

An artificial mains network is required to provide a defined impedance at radio frequencies at the terminals of the EUT, to isolate the test circuit from unwanted radio-frequency signals on the supply mains, and to couple the disturbance voltage to the measuring receiver.

There are two basic types of AMN, the V-network AMN (V-AMN), which couples the unsymmetric voltages, and the delta-network AMN (Δ -AMN), which couples the symmetric and the asymmetric voltages separately.

For each mains conductor, there are three terminals: the mains terminal for connection to the supply mains, the equipment terminal for connection to the EUT, and the disturbance output terminal for connection to the measuring equipment.

NOTE 1 Examples of circuits of AMNs are given in Annex A.

NOTE 2 This clause specifies impedance and isolation requirements for the AMN including the corresponding measurement methods. Some background and rationale on the AMN related uncertainties are given in 6.2.3 of CISPR/TR 16-4-1:2009 and in CISPR 16-4-2.

4.1 Network impedance

4.2 AMN impedance

The specification of the impedance of an AMN includes the magnitude and the phase of the impedance measured at an EUT terminal with respect to the reference ground, when the corresponding disturbance output terminal receiver port is terminated with 50 Ω .

The impedance at the EUT terminals of the AMN defines the termination impedance presented to the EUT. For this reason, when a disturbance output terminal is not connected to the measuring receiver, it shall be terminated by 50 Ω . To assure accurate termination into 50 Ω of the receiver port, a 10 dB attenuator shall be used either inside or external to the network, the VSWR of which (seen from either side) shall be less than or equal to 1,2 to 1. The attenuation shall be included in the measurement of the voltage division factor (see 4.11).

The impedance of between each conductor (except PE) of the mains conductors of the network EUT terminal and the reference ground shall comply with the provisions of 4.3, 4.4, 4.5, 4.6 or 4.7, as appropriate, for any value of external impedance, including a short circuit or the RF filter described in 4.7, connected between the corresponding mains terminal and reference ground. This requirement shall be met at all temperatures which the network may reach under normal conditions for continuous currents up to the specified maximum. The requirement shall also be met for peak currents up to the specified maximum.

Where the phase requirement cannot be met, the measured phase angles shall be taken into account in the uncertainty budget according to CISPR 16-4-2. Annex I gives guidelines for the calculation of the uncertainty contribution of the phase if the tolerance is exceeded.

NOTE Because EUT connectors are not optimized for radio frequencies up to 30 MHz, the measurement of the network impedance is carried out with special measurement adaptors to enable short-length connections. The OSM (open/short/matched) calibration of the network analyzer is used to characterize the adaptors, taking the insertion loss and the conductor lengths of the adaptors into account.

4.24.3 50 Ω /50 μ H + 5 Ω artificial mains V-network (V-AMN) for use in the frequency range 9 kHz to 150 kHz

The AMN shall have the impedance (magnitude and phase) versus frequency characteristic shown in Table 1 and Figure 1 in the relevant frequency range. Tolerances of $\pm 20\%$ for the magnitude and $\pm 11,5^\circ$ for the phase are permitted.

Table 1 – Magnitudes and phase angles of the V-network (see Figure 1)

Frequency MHz	Impedance magnitude Ω	Phase angle Degrees
0,009	5,22	26,55
0,015	6,22	38,41
0,020	7,25	44,97
0,025	8,38	49,39
0,030	9,56	52,33
0,040	11,99	55,43
0,050	14,41	56,40
0,060	16,77	56,23
0,070	19,04	55,40
0,080	21,19	54,19
0,090	23,22	52,77
0,100	25,11	51,22
0,150	32,72	43,35

NOTE ~~This network may be constructed such that it can~~ If this AMN meets the combined impedance requirements of 4.3 and 4.4, it can be used in the frequency range 150 kHz to 30 MHz as well.

4.34.4 50 Ω /50 μ H artificial mains V-network (V-AMN) for use in the frequency range 0,15 MHz to 30 MHz

The AMN shall have the impedance (magnitude and phase) versus the frequency characteristic shown in Table 2 and Figure 2 in the relevant frequency range. Tolerances of $\pm 20\%$ for the magnitude and $\pm 11,5^\circ$ for the phase are permitted.

Table 2 – Magnitudes and phase angles of the V-network (see Figure 2)

Frequency MHz	Impedance magnitude Ω	Phase angle Degrees
0,15	34,29	46,70
0,17	36,50	43,11
0,20	39,12	38,51
0,25	42,18	32,48
0,30	44,17	27,95
0,35	45,52	24,45
0,40	46,46	21,70
0,50	47,65	17,66
0,60	48,33	14,86
0,70	48,76	12,81
0,80	49,04	11,25
0,90	49,24	10,03
1,00	49,38	9,04
1,20	49,57	7,56
1,50	49,72	6,06
2,00	49,84	4,55
2,50	49,90	3,64
3,00	49,93	3,04
4,00	49,96	2,28
5,00	49,98	1,82
7,00	49,99	1,30
10,00	49,99	0,91
15,00	50,00	0,61
20,00	50,00	0,46
30,00	50,00	0,30

NOTE — The 50 Ω /50 μ H + 5 Ω artificial mains V-network of 4.2 may also meet the impedance requirement of this subclause.

4.44.5 50 Ω /5 μ H + 1 Ω artificial mains V-network (V-AMN) for use in the frequency range 150 kHz to ~~100~~ 108 MHz

The AMN shall have the impedance (magnitude and phase) versus the frequency characteristic shown in Table 3 and Figure 3. Tolerances of $\pm 20\%$ for the magnitude and $\pm 11,5^\circ$ for the phase are permitted.

Table 3 – Magnitudes and phase angles of the V-network (see Figure 3)

Frequency MHz	Impedance magnitude Ω	Phase angle Degrees
0,15	4,70	72,74
0,20	6,19	73,93
0,30	9,14	73,47
0,40	12,00	71,61
0,50	14,75	69,24
0,70	19,82	64,07
1,00	26,24	56,54
1,50	33,94	46,05
2,00	38,83	38,15
2,50	41,94	32,27
3,00	43,98	27,81
4,00	46,33	21,63
5,00	47,56	17,62
7,00	48,71	12,80
10,00	49,35	9,04
15,00	49,71	6,06
20,00	49,84	4,55
30,00	49,93	3,04
50,00	49,97	1,82
100,00	49,99	0,91
108,00	49,99	0,84

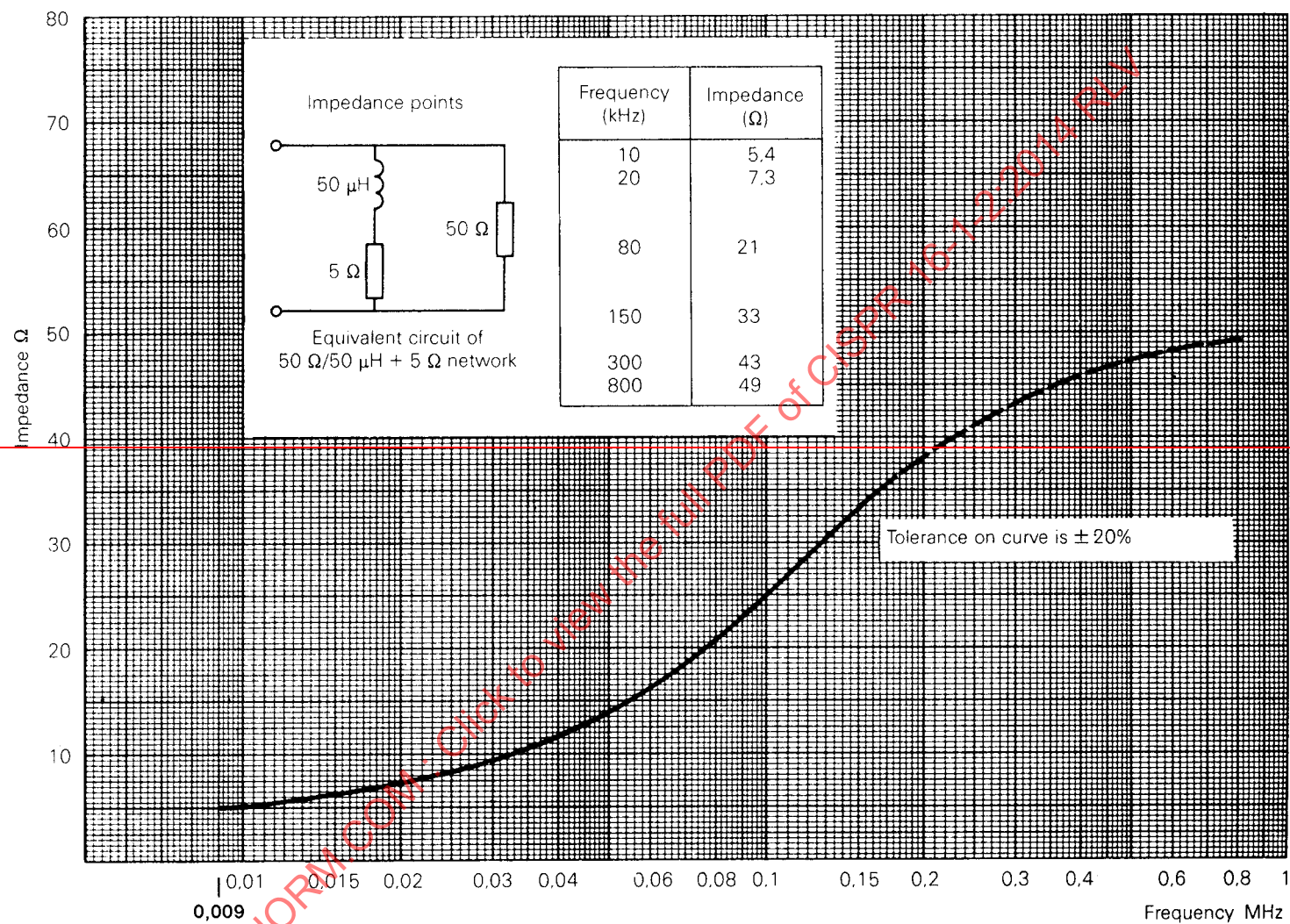


Figure 1a — Impedance of artificial mains network for band A (see 4.2)

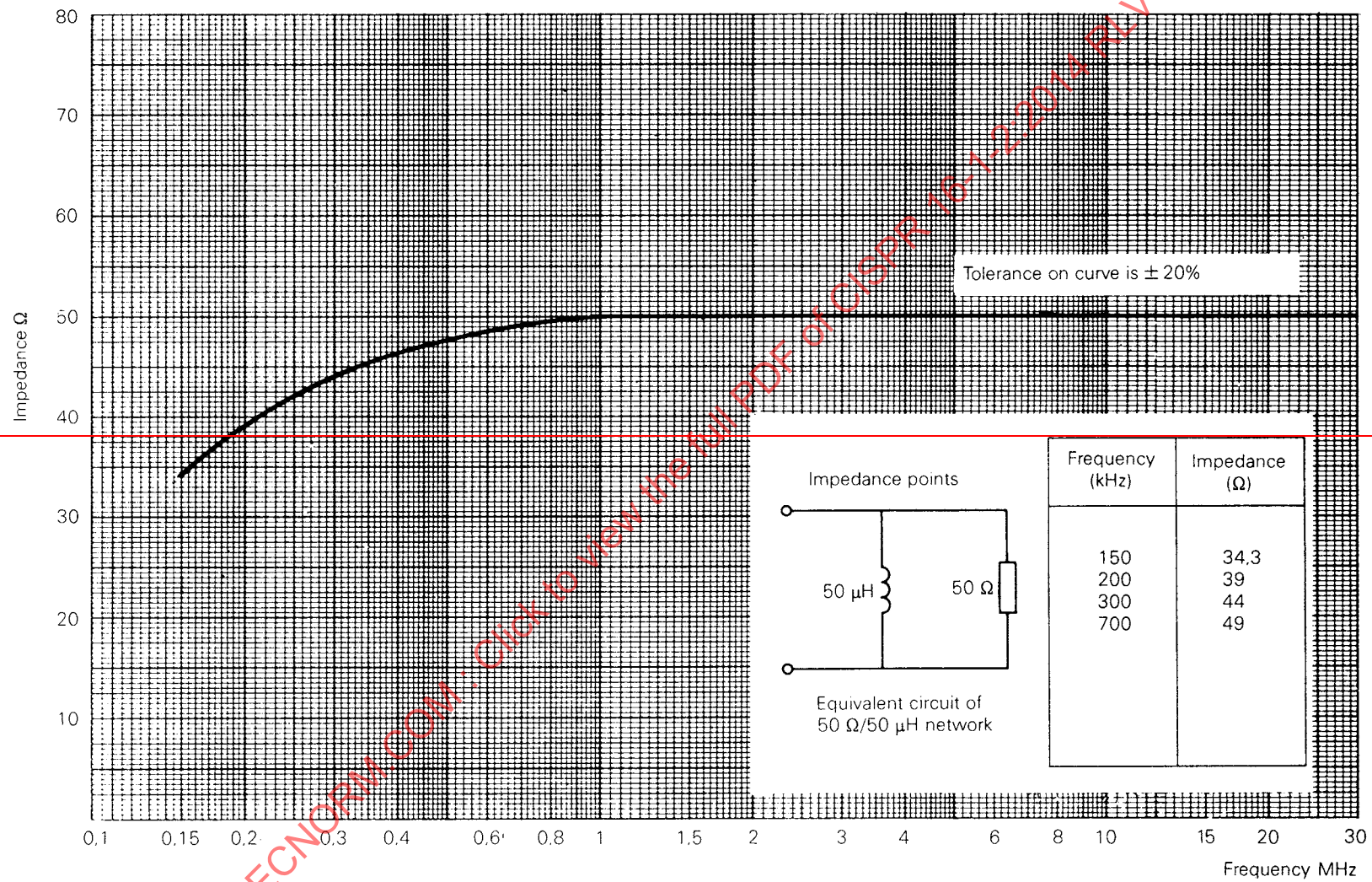


Figure 1b — Impedance of artificial mains network for band B (see 4.3)

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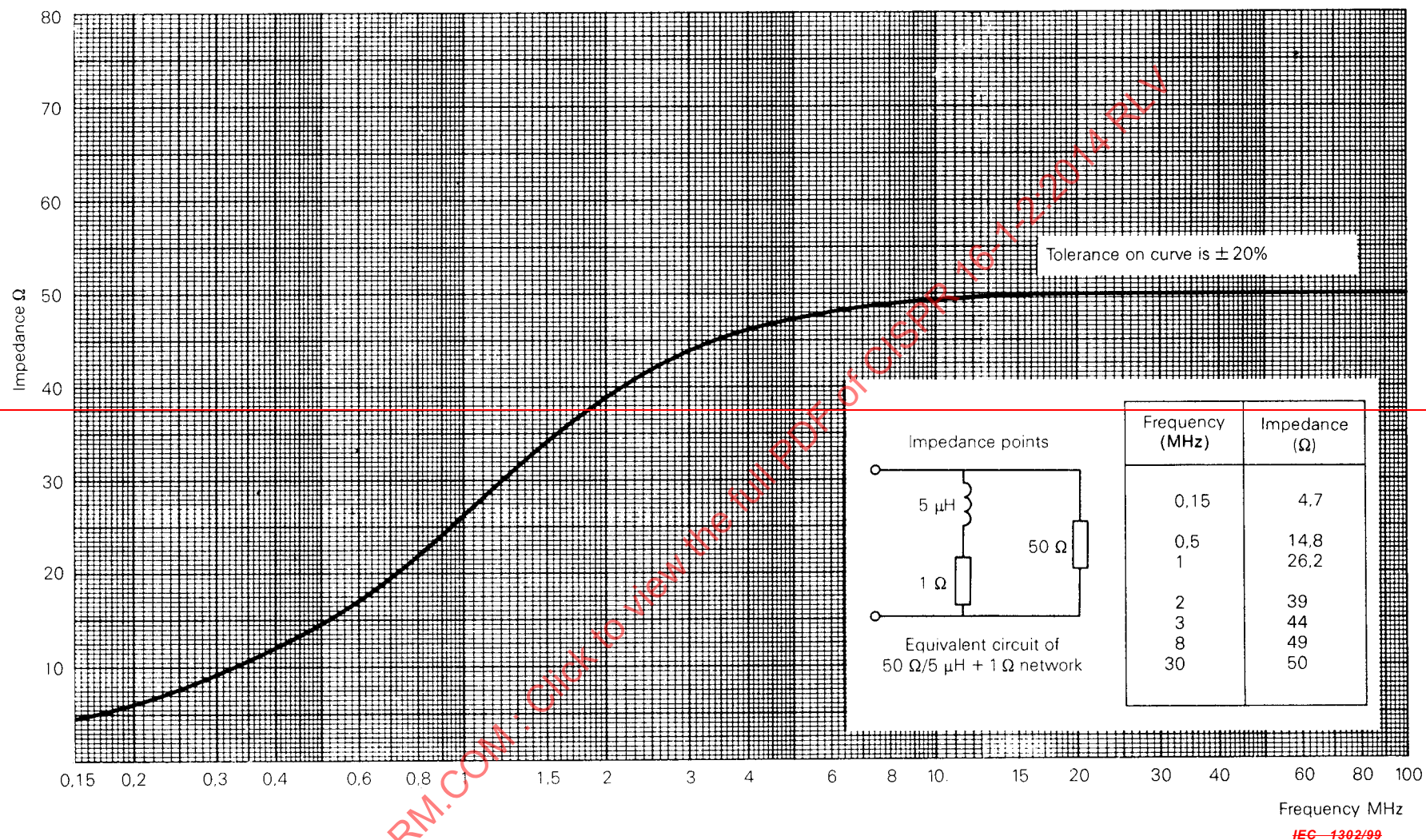


Figure 2 — Impedance of artificial mains network for band B, 0,15 MHz to 30 MHz or band C, 30 MHz to 100 MHz (see 4.4)

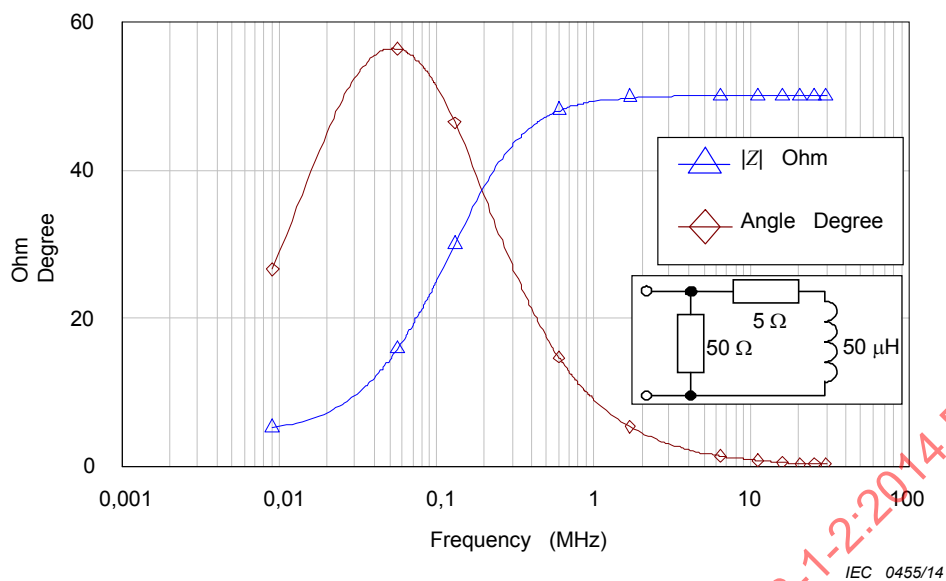


Figure 1 – Impedance (magnitude and phase) of the V-network for Band A (see 4.3, the relevant frequency range is from 9 kHz to 150 kHz)

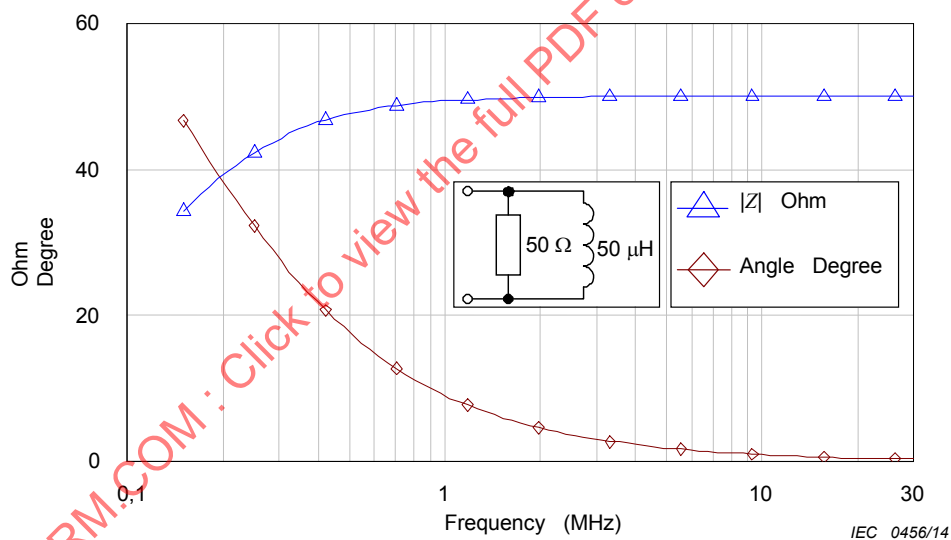


Figure 2 – Impedance (magnitude and phase) of the V-network for Band B (see 4.4)

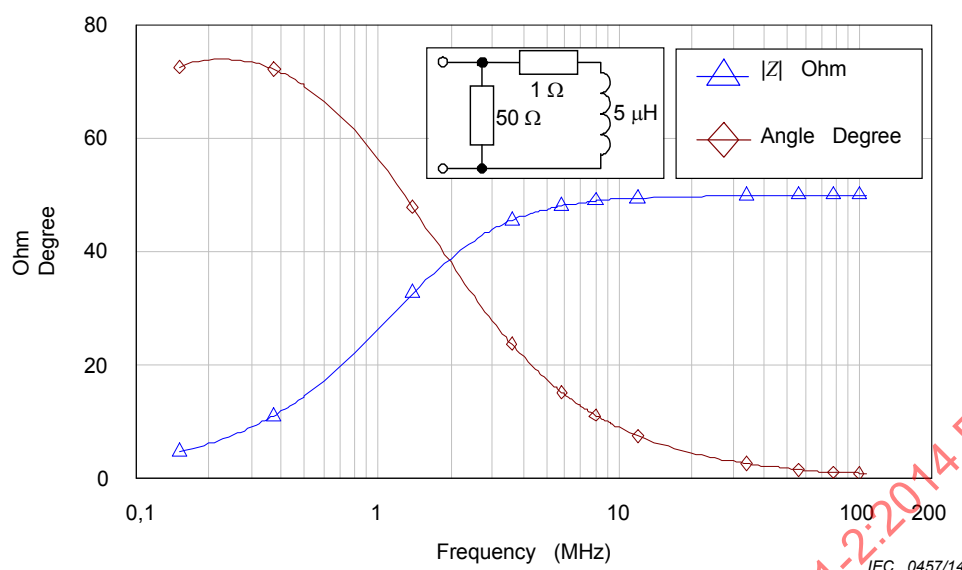


Figure 3 – Impedance (magnitude and phase) of the V-network for Bands B and C (from 150 kHz to 108 MHz; see 4.5)

4.54.6 150 Ω artificial mains V-network (V-AMN) for use in the frequency range 150 kHz to 30 MHz

The network shall have an impedance of magnitude $(150 \pm 20) \Omega$ with a phase angle not exceeding 20° .

4.64.7 150 Ω artificial mains delta-network (Δ -AMN) for use in the frequency range 150 kHz to 30 MHz

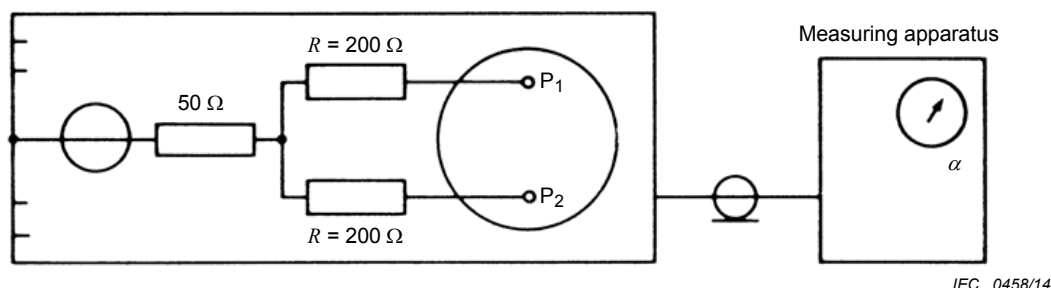
4.7.1 General parameters

The network shall have an impedance of magnitude $(150 \pm 20) \Omega$ with a phase angle not exceeding 20° , both between the equipment terminals and between the two equipment terminals joined together and the reference ground.

For the measurement of the symmetric voltage, a screened and balanced transformer is required. To avoid appreciable modification of the impedance of the network, the input impedance of the transformer shall be not less than $1\,000 \Omega$ at all frequencies concerned. The voltage measured by the measuring receiver depends on the network component values and the transformer ratio. The network shall be calibrated.

4.6.14.7.2 Balance of the 150 Ω artificial mains delta-network

The balance of the system comprising the network and the measuring receiver connected thereto via the transformer shall be such that the measurement of symmetric voltage shall be substantially unaffected by the presence of an asymmetric voltage. The balance shall be measured using the circuit shown in Figure 4.



R are resistors of $200\ \Omega$ equal to each other within 1 %

P_1 and P_2 are terminals of network for connection of device

Figure 3 4 – Method for checking the balance of the arrangement for the measurement of symmetrical voltages

A voltage U_a is injected from a generator having an internal impedance of $50\ \Omega$, between reference ground and the common point of two resistors each $200\ \Omega \pm 1\ %$. The other end of these resistors is connected to the equipment terminals of the AMN.

A voltage U_s is measured in the position for symmetric voltage measurement. The ratio U_a/U_s shall be greater than 20:1 (26 dB).

4.74.8 Isolation

4.8.1 Requirement

To ensure that at any test frequency unwanted signals existing on the supply mains do not affect the measurement, an additional RF low pass filter may be required, inserted between the artificial mains network and the supply mains. With this filter inserted, the impedance requirements given in 4.2, 4.3, 4.4, 4.5 and 4.6 shall be met. The components forming this filter shall be enclosed in a metallic screen directly connected to the reference earth of the measuring system.

To ensure that at any test frequency, unwanted signals existing on the mains side and the unknown impedance of the supply mains do not affect the measurement, a minimum isolation (decoupling factor) between each mains terminal and the receiver port for a given termination of the relevant terminal of the EUT port shall be met. See Table 4. The requirement applies to the V-AMN itself excluding additional external cables and filters.

Additional filtering external to the AMN may be required for the suppression of disturbance on the mains port (see CISPR 16-2-1 for practical requirements).

Table 4 – Values of minimum isolation for V-networks

Subclause	Type of V-network	Frequency range MHz	Minimum isolation dB
4.3	$50\ \Omega / 50\ \mu\text{H} + 5\ \Omega$	0,009 to 0,05	0 to 40 ^a
		0,05 to 30	40
4.4	$50\ \Omega / 50\ \mu\text{H}$	0,15 to 30	40
4.5	$50\ \Omega / 5\ \mu\text{H} + 1\ \Omega$	0,15 to 3	0 to 40 ^a
		3 to 108	40

^a These values indicate that the minimum isolation rises linearly with the logarithm of frequency

4.8.2 Measurement procedure

The test setup is shown in Figure H.1. For the measurement, first a signal V_1 is measured across a load impedance of $50\ \Omega$ with a source impedance of $50\ \Omega$. Then this signal source shall be connected between the relevant mains terminal and reference ground, the relevant EUT terminals shall be terminated with $50\ \Omega$, and the output voltage V_2 shall be measured at the receiver port (terminated with an impedance of $50\ \Omega$). The attenuation of the 10 dB attenuator described in 4.2 shall be added to the isolation requirement. The isolation requirement shall be met for all mains and EUT terminals. If the termination of the other mains terminals affects the measurement result, then the requirement shall be met with the other mains terminals open and shorted.

The following equation shall be met:

$$V_1 - V_2 \geq F_D + A \quad (1)$$

where

- V_1 is the reference voltage at the mains terminals in dB(μ V);
- V_2 is the output voltage at the receiver port in dB(μ V);
- F_D is the minimum isolation (decoupling factor) requirement in dB;
- A is the attenuation of the built-in attenuator in dB.

NOTE Because EUT connectors are not optimized for radio frequencies up to 30 MHz, the measurement of the network isolation are carried out with special measurement adaptors to enable short-length connections. The measurement of V_1 is made with the adaptor connected to the source.

4.8.9 Current carrying capacity and series voltage drop

The maximum continuous currents and the maximum peak current shall be specified. The voltage applied to the EUT when passing continuous currents up to the maximum shall be not less than 95 % of the mains voltage at the mains terminals of the AMN.

4.8.10 Modified reference ground connection

The measurement of some types of equipment may require the insertion of an impedance in the reference ground conductor in the AMNs in 4.3 and 4.4, following the requirements of the related product publications. This is inserted at point X marked in the reference ground lead in Figures 5 and 6, respectively. The impedance to be inserted is either a 1,6 mH inductor, or an impedance conforming to the impedance requirement of 4.3 or 4.4, as appropriate for the frequency range.

NOTE For safety reasons, the 5 Ω resistor mentioned in 4.2 should be omitted. When considering the frequency range 9 kHz to 150 kHz, for safety reasons the 5 Ω resistor of the artificial mains V-network is not inserted.

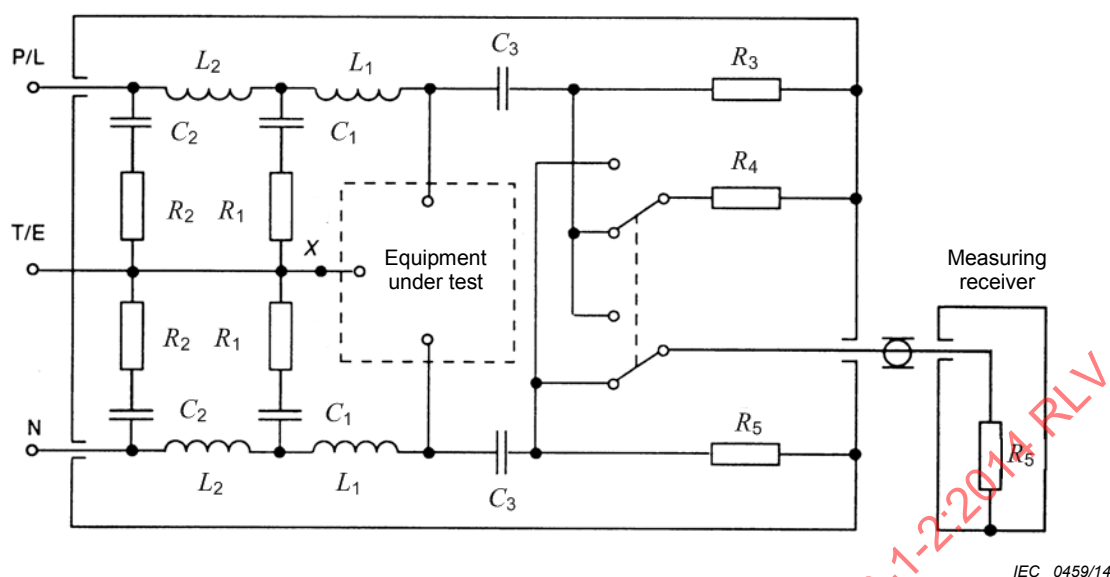


Figure 4.5 – Example of artificial mains $50\ \Omega/50\ \mu\text{H} + 5\ \Omega$ V-network (see 4.3 and A.2)

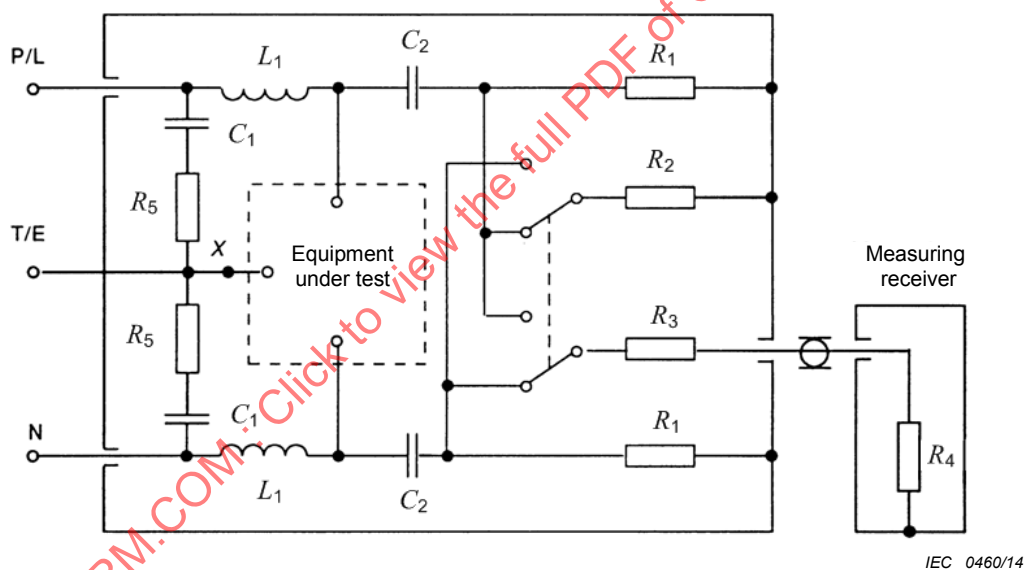


Figure 5.6 – Example of artificial mains V-networks, $50\ \Omega/50\ \mu\text{H}$, $50\ \Omega/5\ \mu\text{H} + 1\ \Omega$ or $150\ \Omega$ (see 4.4, 4.5, 4.6, A.3, A.4 and A.5, respectively)

4.104.11 Measurement of the voltage division factor of artificial mains V-networks

The voltage division factor between the EUT port of the V-network and the RF output port shall be measured and taken into consideration during the measurement of the disturbance voltage. A procedure to measure the voltage division factor is contained in A.8.

5 Current and voltage probes

5.1 Current probes

5.1.1 General

The asymmetrical disturbance currents of cables can be measured, without making direct conductive contact with the source conductor and without modification of its circuit, by use of specially developed clamp-on current transformers. The utility of this method is self-evident; complex wiring systems, electronic circuits, etc., may be measured without interruption of the normal operation or configuration. The current probe is constructed so that it may be conveniently clamped around the conductor to be measured. The conductor represents a one-turn primary winding. The secondary winding is contained within the current probe.

Current probes can be constructed for measurements in the frequency range 30 Hz to 1 000 MHz, although the primary measurement range is 30 Hz to 100 MHz. Beyond 100 MHz the standing currents in conventional power systems require that the current probe location be optimized for detection of the maximum current.

Current probes are designed to provide a flat frequency response over a passband. At frequencies below this flat passband, accurate measurements can still be made but with decreased sensitivity due to reduced transfer impedances. At frequencies above the flat passband, measurements are not accurate due to resonances in the current probe.

With an additional shielding structure, a current probe may be used to measure either the asymmetrical (common mode) or symmetrical (differential mode) current. Some construction details are provided in B.5.

5.1.1.2 Construction

The current probe shall be constructed so as to enable the measurement of the current without disconnecting the lead under measurement.

Annex B contains some typical constructions of current probes.

5.1.1.3 Characteristics

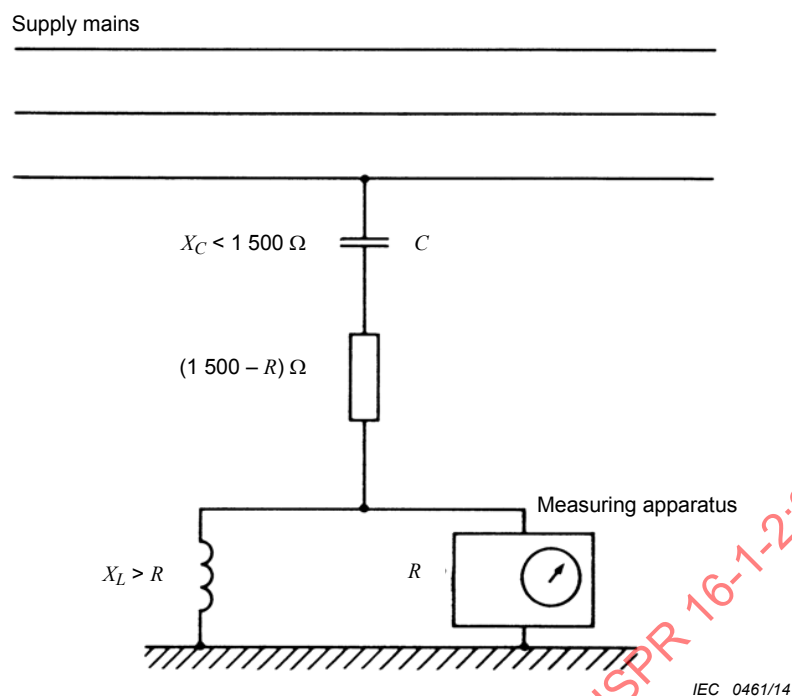
Insertion impedance	1 Ω impedance maximum
Transfer impedance	0,1 Ω to 5 Ω in the flat linear range; 0,001 Ω to 0,1 Ω below the flat linear range (current probe terminated into 50 Ω load)
	NOTE The reciprocal transfer admittance [in dB(S)] ~~may~~ can be used instead. When expressed in decibels, the admittance is added to the reading of the measuring receiver. For the calibration of the transfer impedance or admittance, ~~it may be necessary to use~~ a jig designed for the purpose ~~is used~~ . See Annex B.
Added shunt capacitance	Less than 25 pF between the current probe housing and measured conductor.
Frequency response	Transfer impedance is measured over a specified frequency range ~~to calibrate the probe~~ ; the range of individual probes is typically 100 kHz to 100 MHz, 100 MHz to 300 MHz, and 200 MHz to 1 000 MHz.
Pulse response	Under consideration.

Magnetic saturation	The maximum d.c. or a.c. mains current in the primary lead for a measurement error less than 1 dB shall be specified.
Transfer impedance tolerance	Under consideration.
Influence of external magnetic fields	40 dB reduction in indication when a current carrying conductor is removed from the current probe opening to a position adjacent to the probe.
Influence of electric fields	Not susceptible to fields < 10 V/m.
Influence of orientation	Less than 1 dB up to 30 MHz and 2,5 dB from 30 MHz to 1 000 MHz, when used on a conductor of any size placed anywhere inside the aperture.
Current probe opening	At least 15 mm.

5.2 Voltage probe

5.2.1 High impedance voltage probe

Figure 7 shows a circuit that is used to make voltage measurements between a mains conductor and the reference ground. The probe consists of a blocking capacitor C and a resistor, such that the total resistance between line and ground is 1 500 Ω . The probe may also be used to make measurements on other lines, and for certain applications its impedance may need to be increased to avoid excessive loading of high impedance circuits. An inductor may have to be connected across the input of the measuring apparatus, for safety reasons; its inductive ~~reactive, X_C , to reactance, X_L~~ , should be much greater than R .



NOTE $V = \frac{1\,500}{R} U_{Vm}$

where

V is the disturbing voltage;

U_{Vm} is the voltage at the input of the measuring apparatus.

Figure 6 7 – Circuit for RF voltage measurement on supply mains

~~The insertion loss~~ For calibration of voltage probes, the voltage division factor shall be measured in a 50 Ω system over the frequency range of 9 kHz to 30 MHz. The effect on the accuracy of measurement of any device that may be used for protection should either be less than 1 dB, or be allowed for in calibration. Care shall be taken to ensure that the level of disturbance is accurately measured in the presence of the ambient noise, to make the measurement meaningful.

The loop formed by the lead connected to the probe, the mains conductor tested and reference ground should be minimized, to reduce the effects of any strong magnetic fields.

5.2.2 Capacitive voltage probe

5.2.2.1 General

The asymmetrical disturbance voltages of cables can be measured without making direct conductive contact with the source conductor, and without modification of its circuit by the use of a clamp-on capacitive coupling device. The usefulness of this method is self-evident; complex wiring systems, electronic circuits, etc., may be measured without interruption of the normal operation or configuration of the EUT or the need to cut the cable to insert a measuring device. The capacitive voltage probe (CVP) is constructed so that it may be conveniently clamped around the conductor to be measured.

The CVP is used for measurements of conducted disturbances in the frequency range 150 kHz to 30 MHz with an almost flat frequency response in the frequency range of interest. The voltage division factor, which is defined as the ratio of the disturbance voltage on the cable to the input voltage at the measuring receiver, depends on the type of cable. This

parameter should be calibrated over a specified frequency range for each cable type, using the method described in Annex G.

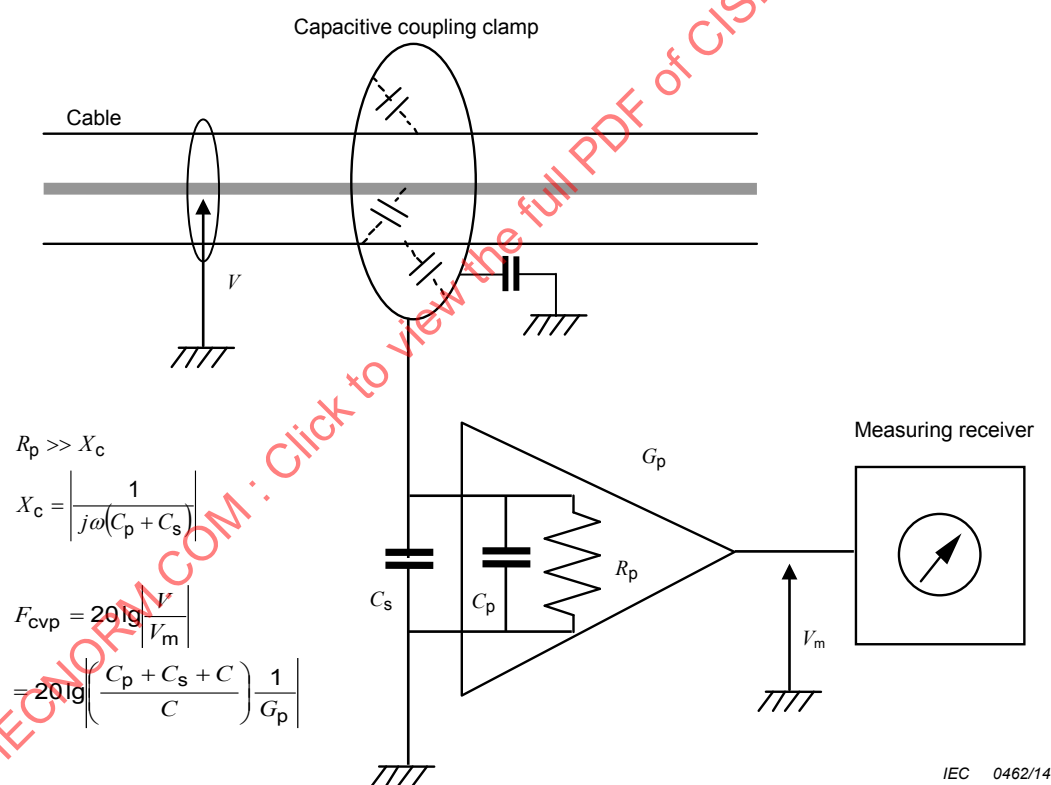
The CVP may need additional shielding to provide sufficient isolation from the asymmetrical (common mode) signal around the cable (see 5.2.2.3). Annex G contains an example of the construction and a method of measurement for the isolation.

This CVP can be used to measure the disturbances at telecommunication ports. The minimum measurable level is typically up to 44 dB(μV).

5.2.2.2 Construction

The CVP shall be constructed so as to enable the measurement of the voltage without disconnecting the cable under measurement. Figure 8 shows a circuit that is used to make voltage measurements between a cable and reference ground. The probe consists of a capacitive coupling clamp which is connected to a trans-impedance amplifier. The input resistance R_p of this amplifier shall be large enough compared to the reactance X_c to obtain a flat frequency response.

Annex G provides instructions for the typical construction and verification of the CVP.



Key

C	Capacitance between cable and clamp
C_p	Capacitance of trans-impedance amplifier
C_s	Capacitance between probe and ground
F_{CVP}	Voltage division factor
G_p	Gain of trans-impedance amplifier
R_p	Resistance of trans-impedance amplifier
V	Disturbance voltage
V_m	Voltage at the input of the measuring receiver

Figure 8 – Circuit used to make voltage measurements between a cable and reference ground

5.2.2.3 Requirements

Added shunt capacitance	Less than 10 pF between the grounding terminal of CVP and the cable under test.
Frequency response	Voltage division factor, $F_{CVP} = 20 \lg V/V_m $ in dB (see Figure 8), is measured over a specified frequency range.
Pulse response	Maintain linearity for the pulse determined by the method in Annexes B and C of CISPR 16-1-1:2010 for Band B.
Influence of electric field (influence caused by electrostatic coupling with other cables near the probe)	The voltage indication is reduced by more than 20 dB when a cable is removed from the CVP. The measurement method is described in Annex G.
CVP aperture or opening [aperture when the two coaxial electrodes open at the slot (see Figure G.1)]	At least 30 mm.

6 Coupling units for conducted current immunity measurement

6.1 General

The coupling units are designed to inject the disturbance current on to the leads under test and to isolate the other leads and any apparatus which is connected to the EUT from the effects of these currents. With a 150Ω source impedance, there is a useful correlation between the RF disturbance field strength acting on a real installation and the e.m.f. that ~~must be~~ is applied in the current injection method to produce the same degree of impairment, at least for frequencies up to 30 MHz. The immunity of an apparatus is expressed by this e.m.f. value. Annexes C and D give the principles of operation and examples of types of units and their construction.

6.16.2 Characteristics

6.2.1 General

The performance checks of the coupling units are done for impedance in the frequency range 0,15 MHz to 30 MHz and for insertion loss in the frequency range 30 MHz to 150 MHz.

6.1.16.2.2 Impedance

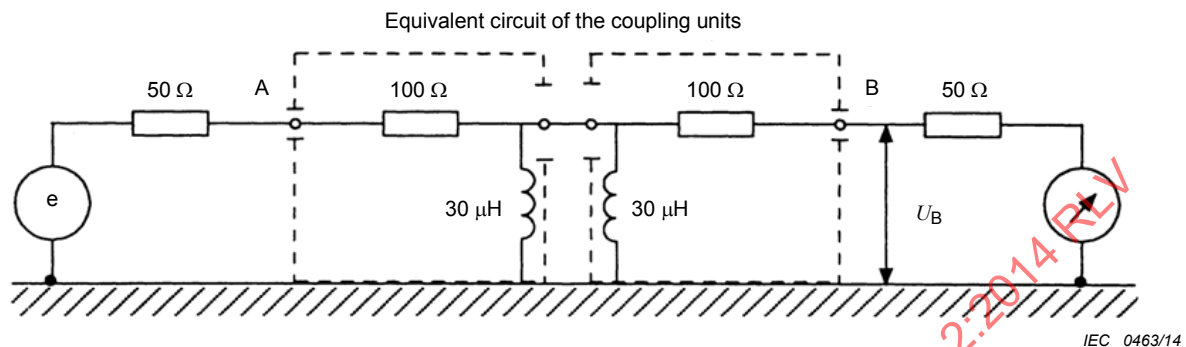
In the frequency range 0,15 MHz to 30 MHz, the total asymmetric impedance (RF choke coil in parallel with the 150Ω resistive disturbance source impedance) measured between the point of injection of the disturbance signal to the EUT and the ground of the unit shall have a magnitude of $150 \Omega \pm 20 \Omega$ and a phase angle less than $\pm 20^\circ$ (this impedance is the same as the CISPR 150Ω artificial mains V-network; see 4.5).

For example, for coupling units type A and S, the point of injection is the shield of the output connector; for types M and L, the point of injection is the joint output terminals.

6.1.16.2.3 Insertion loss

In the frequency range 30 MHz to 150 MHz, the insertion loss of two identical coupling units in tandem shall be within the range 9,6 dB to 12,6 dB, measured as shown in Figure 9. ~~The two units shall be connected together with very short wires (≤ 1 cm).~~

The insertion loss U_G/U_B of two identical coupling units measured according to the setup of Figure 9 should be within 9,6 dB and 12,6 dB in the frequency range 30 MHz to 150 MHz; U_G is the reading of the receiver when the generator and receiver are directly connected together.



NOTE The two units shall be connected together with very short wires (≤ 1 cm).

Figure 7-9 – Measuring set-up to check the insertion loss of the coupling units in the frequency range 30 MHz to 150 MHz

7 Coupling devices for measuring signal lines

7.1 General

The interference potential (and immunity) of signal lines may be assessed by measurement (or injection) of the conducted disturbance voltage or current. For this purpose, coupling devices are needed to measure the disturbance component while rejecting the intentional signal on the line. The devices included are to measure the electromagnetic emission and immunity (common and differential mode, current and voltage). Typical devices for these kinds of measurements are current probes and asymmetric artificial networks (AANs or Y-networks).

NOTE 1 Requirements for AANs for conducted immunity tests on signal lines ~~may can~~ be found in IEC 61000-4-6 (AANs are special versions of “coupling and decoupling devices” [so-called coupling/decoupling networks (CDNs)]). An AAN that meets the requirements for emission measurements may also meet the requirements for immunity testing.

NOTE 2 Signal lines include telecommunication lines and terminals of equipment intended to be connected to these lines.

NOTE 3 The terms “asymmetric voltage” and “common mode voltage” as well as “symmetric voltage” and “differential mode voltage” are synonyms, as defined in Clause 3.

NOTE 4 The term “asymmetric artificial network (AAN)” is used as synonym for “Y-network”, which is in contrast to V-networks and delta-networks. The T-network is a special version of the Y-network.

When a current probe is used and the limit value is specified in volts, the voltage value ~~must be~~ is divided by the impedance of the signal line or termination impedance, as specified by the detailed measurement procedure, to obtain the limit value for the current. This impedance may be common mode, as required by the detailed measurement procedure.

The specification for AANs is provided in 7.2. The differential mode to common mode rejection (V_{dm}/V_{cm}) is crucial to the usability of the AAN. This parameter is related to the longitudinal conversion loss (LCL). Examples of AANs and the required test and calibration procedures are given in Annex E.

7.47.2 Requirements for AANs (or Y-networks)

AANs are 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—In CISPR 22 this type of network is called impedance stabilization network (ISN).

An AAN shall include the following properties when calibrated in accordance with the methods of Annex E. In addition, the attenuation distortion or other deterioration shall not affect the normal operation of the EUT.

- a) AAN for measurements at ports intended for connection to category 6 (or better) unscreened balanced pair cables:

The variation of the longitudinal conversion loss (a_{LCL}) with frequency f (in MHz) shall be defined by the following equation:

$$a_{LCL} = 75 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right]$$

$$f < 2 \text{ MHz: } a_{LCL} \leq \pm 3 \text{ dB}$$

$$2 \text{ MHz} \leq f \leq 30 \text{ MHz: } a_{LCL} \leq \begin{matrix} +6 \\ -3 \end{matrix} \text{ dB}$$

- b) AAN for measurements at ports intended for connection to category 5 (or better) unscreened balanced pair cables.

The variation of the longitudinal conversion loss (a_{LCL}) with frequency f (in MHz) shall be defined by the following equation:

$$a_{LCL} = 65 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right]$$

$$f < 2 \text{ MHz: } a_{LCL} \leq \pm 3 \text{ dB}$$

$$2 \text{ MHz} \leq f \leq 30 \text{ MHz: } a_{LCL} \leq \begin{matrix} +4,5 \\ -3 \end{matrix} \text{ dB}$$

- c) AAN for measurements at ports intended for connection to category 3 (or better) unscreened balanced cables.

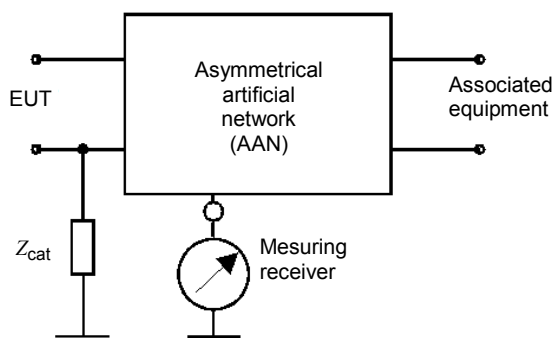
The variation of the longitudinal conversion loss (a_{LCL}) with frequency f (in MHz) shall be defined by the following equation:

$$a_{LCL} = 55 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right] \text{ in dB}$$

$$a_{LCL} \leq \pm 3 \text{ dB}$$

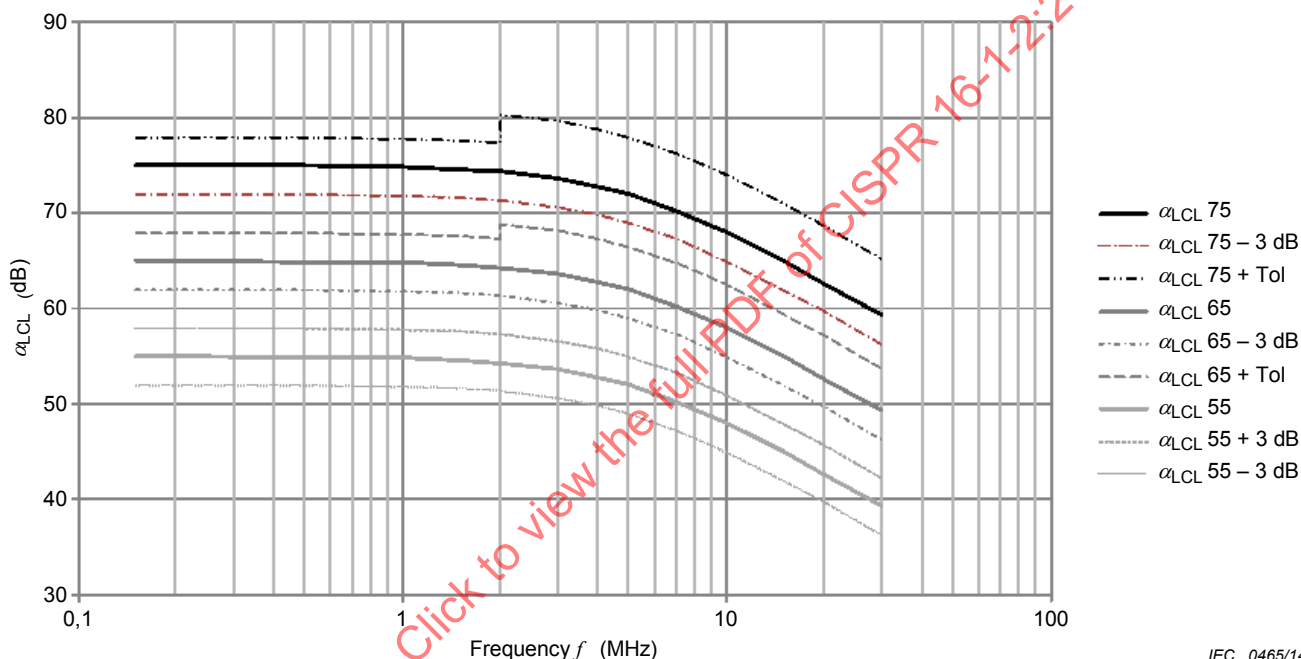
NOTE The above specifications of a_{LCL} versus frequency are approximations of a_{LCL} of typical unscreened balanced cables in representative environments. The specification in list item c) of 7.2 for category 3 cables is considered representative of the a_{LCL} of typical telecommunication access networks.

Figure 10 shows the general circuit diagram and graphical representation of a_{LCL} requirements for an AAN.



IEC 0464/14

a) Principal circuit of the AAN (or Y-network) and its ports consisting of a basic highly symmetric network and an (optional) unbalanced network Z_{cat}



IEC 0465/14

NOTE 1 The definition equation can e.g. be

$$\pm Tol \text{ (in dB)}$$

LCL_{lf} is the LCL at low frequencies, e.g. 50 dB,

f is the frequency,

f_{corner} is the corner frequency, e.g. 5 MHz, and

Tol is the LCL tolerance, e.g. 3 dB

NOTE 2 The ideal values for "50 dB", "60 dB" and "70 dB" are given as bold lines, whereas tolerance lines are drawn as thin lines.

NOTE 1 This graph is derived from the equations in 7.2, list items a), b), and c). The ideal values for 55 dB, 65 dB, and 75 dB are shown as bold lines, while tolerance values are shown above and below the ideal values.

NOTE 2 "Tol" is the tolerance specified in 7.2, list items a), b), and c).

b) Graph of requirements for a_{LCL} of the AAN (Y-network)

Figure 8 10 – Principal circuit and example LCL requirements of an AAN

The characteristics of the AAN for the measurement of asymmetric (common mode) disturbances shall cover the frequency range of the asymmetric disturbance voltages, as well as the frequency range used for the transmission of the intentional signal. These characteristics are given in Table 5.

Table 4 5 – Characteristics of the AAN for the measurement of asymmetric disturbance voltage

1)	Termination impedance of basic network for asymmetric disturbance voltage ^a • magnitude • phase	150 $\Omega \pm 20 \Omega$ 0° $\pm 20^\circ$
2)	Longitudinal conversion loss (LCL) at the EUT port of the network ^b	(9 kHz to 150 kHz: to be defined); 0,15 MHz to 30 MHz: defined by the relevant product standard, e.g. as shown in Figure 8b depending on cable category as defined in 7.2^c
3)	Decoupling attenuation for asymmetric signals between AE port and EUT port	(9 kHz to 150 kHz: to be defined) 0,15 MHz to 1,5 MHz: > 35 dB to 55 dB increasing linearly with the log of frequency > 1,5 MHz: > 55 dB
4)	Insertion loss of the symmetric circuit between EUT and AE ports	< 3 dB ^d
5)	Voltage division factor of the asymmetric circuit between EUT and measuring receiver ports, to be added to the reading of the measuring receiver	Typically 9,5 dB ^e ± 1 dB
6)	Symmetric load impedance of the network	Depending on the system specifications, e.g. 100 Ω or 600 Ω ; to be defined by the relevant product standards ^f
7)	Transmission bandwidth for the intentional signal (analog or digital)	Depending on the system specifications for the symmetric insertion loss, e.g. up to 2 MHz or up to 100 MHz; to be defined by the relevant product standards
8)	Frequency range ^{hf} (1) Emission (2) Immunity	(0,009 MHz) 0,15 MHz to 30 MHz See e.g. IEC 61000-4-6 CISPR 22 [5]

- a The asymmetric impedance of the AAN will normally be influenced by the addition of an unbalanced network Z_{cat} according to Figure 10 a). This standard specifies the impedance tolerance for the basic network. ~~If the influence of the unbalanced network on impedance and phase is negligible, the given tolerance may apply including the unbalanced network. If this is not the case~~ The unbalanced network for the AANs defined in list items a), b), and c) of 7.2 nominally changes the impedance by less than $10\ \Omega$, and the phase by less than 10° , so the given tolerance applies including the unbalanced network. If a product standard specifies lower LCL values, e.g. if the unbalanced network changes the impedance nominally by more than $10\ \Omega$, or the phase by more than 10° , the product standard shall take this into account when specifying tolerances for impedance and phase, because a certain tolerance should be left to the AAN manufacturer.
- b Different concepts for determination of conformance of equipment are in use, i.e. use an LCL of the AAN higher than the available LCL values of signal lines, or use the LCL to simulate available telecommunication line categories. ~~CISPR has decided to use the LCL to simulate the asymmetry of cable categories for emission tests, whereas IEC Sub-Committee 77B recommends the use of an LCL of the AAN higher than the cable category for immunity tests.~~
- c ~~The values of LCL in Figure 8b have been taken — with modified tolerances — from a draft of the amendment to CISPR 22:1997. Other values may be defined by future product standards. Therefore the LCL requirements given in this publication are examples only.~~ Generally, three factors have to be considered for LCL tolerances: the residual LCL of the basic AAN, the deviation of the ~~unsymmetry unbalanced~~ network Z_{cat} from nominal, and the uncertainty of LCL measurement. The tolerances given in a product standard ~~deviating from the values of 7.2~~ should take into account that acceptable tolerances should increase with the required LCL and with frequency. ~~Figure 8b shows an example of reasonable tolerances.~~
- d The actual requirements will depend on the specifications of the transmission system. Some transmission systems allow insertion losses of up to 6 dB. The insertion loss caused by an AAN is dependent on source and load impedances of the whole symmetric circuit. For lower/higher impedances the insertion loss will be lower/higher, and should be given by the manufacturer, e.g. for $100\ \Omega$ ~~impedance~~. In addition, it will be useful if manufacturers specify the phase characteristics of the AAN in its symmetric circuit.
- e The AAN shall be calibrated by measuring the voltage division factor in a test set-up according to Figure E.6.
- f More than one network may be used to cover the complete frequency range.

7.27.3 Requirements for artificial networks for coaxial and other screened cables

Artificial networks (ANs) for coaxial and other screened cables are used to measure (or inject) unsymmetric (common mode) voltages on the shield of (e.g. telecommunication or RF) cables while passing the communication or RF signal through. The required characteristics are given in Table 6.

NOTE In CISPR 22 [5] this type of network is called coaxial or screened cable impedance stabilization network (ISN).

Table 2 6 – Characteristics of artificial networks for coaxial and other screened cables

1)	Termination impedance of basic network for unsymmetric disturbance voltage: ^a • magnitude • phase	150 $\Omega \pm 20 \Omega$ 0° $\pm 20^\circ$
2)	Decoupling attenuation ^b for unsymmetric signals between AE port and EUT port.	(9 kHz to 150 kHz: to be defined) 0,15 MHz to 30 MHz: $\square 40$ dB
3)	Insertion loss and transmission bandwidth for the intentional (communication or r.f.) signal between EUT and AE ports, including characteristic impedance(s)	Defined by system requirements ^c
4)	Voltage division factor of the unsymmetric circuit between EUT and measuring receiver ports, to be added to the reading of the measuring receiver.	Typically 9,5 dB ^d
	Frequency range (1) Emission (2) Immunity	(0,009 MHz) 0,15 MHz to 30 MHz See e.g. IEC 61000-4-6
a The asymmetric impedance of the AN will be determined by the 150-Ω resistor in parallel with the choke and the capacitance of the bulkhead connector to ground. b Since the coaxial cable shield at the AE port is directly connected to the AN metal case, the decoupling attenuation will not be a problem of the AN itself. The emission (or immunity) test set-up shall be such that the minimum decoupling attenuation can be guaranteed. c Insertion loss and transmission bandwidth for the intentional (communication or RF) signal between EUT and AE ports as well as the characteristic impedances between shield and inner conductor(s) are not in the scope of this standard. They should be defined according to system requirements. d The AN shall be calibrated by measuring the voltage division factor in a test set-up according to Figure F.2.		

8 The artificial hand and series RC element

8.1 General

In some product specifications the artificial hand is required for EUTs which do not have an earth ground connected to the metallic parts of the EUT and which in normal use are hand-held. Housings of plastic with a conductive coating may also require the use of the artificial hand. The artificial hand is used in conducted emission tests in the frequency range of 150 ~~Hz~~ kHz to 30 MHz (the most critical frequencies are 5 MHz to 30 MHz) to simulate the influence of the operator's hands on the measurement results. The types of equipment to be evaluated with the artificial hand are: electric tools, household appliances, such as hand-held mixers, telephone handsets, joysticks, keyboards, etc.

8.2 Construction of the artificial hand and RC element

The artificial hand consists of a (strip of) metal foil of specified dimensions, which is placed on or wrapped around that part of the equipment normally touched by the user's hand, in a specific configuration, described as follows.

The metal foil is connected in a specific configuration to the reference point of the disturbance measuring system via an RC element consisting of a capacitor $C = 220 \text{ pF} \pm 20 \%$ in series with a resistor $R = 510 \Omega \pm 10 \%$; see Figure 11 a).

The strips of metal foil used to simulate the influence of a user's hand around an equipment handle or an equipment body are typically 60 mm wide. In the case of a keyboard EUT, a metal foil, or more practically a metal plate of maximum dimensions 100 mm by 300 mm, may be placed on top of the keys. Examples are given in Figures 11 and 12.

The lead length between the RC element and the metal foil shall be 1 m. If the test set-up requires a longer lead length, the total inductance of the lead shall be less than 1,4 µH if the frequency of measurement is near 30 MHz.

When considering the total effect of the interconnecting wires as a single wire in free space, the inductance L of the wire shall be less than 1,4 µH if the upper limit of the frequency range in the conducted emission test is 30 MHz. For a given single-wire length, this requirement allows calculating the minimum diameter d (in m) of the wires to be used by Equation (2):

$$L = \frac{\mu l}{2\pi} \left[\ln\left(\frac{4l}{d}\right) - 1 \right] \text{ H} \quad (2)$$

where

$$\mu = 4\pi \times 10^{-7} \text{ H/m};$$

l is the length of the wire in m;

d is the diameter of the wire in m.

NOTE When complying with the inductance requirement of 1,4 µH, the impedance of the RC network sufficiently dominates at 30 MHz.

8.3 The use of the artificial hand

The maximum length of wire between the RC element and the reference ground is generally met when the wire length does not exceed 1 m. The RC element may, for example, be placed either as close as possible to the metal foil, or as close as possible to the reference point. The correct choice largely depends on the (generally unknown) internal common mode impedance of the disturbance source in the presence of the metal foil, and the characteristic impedance of the transmission line formed by the connecting wire and its environment. If the upper frequency range of the emission measurements is limited to 30 MHz, the position of the RC element is not critical, and a practical position (also from a reproducibility point of view) of the RC element is inside the AMN or the LISN.

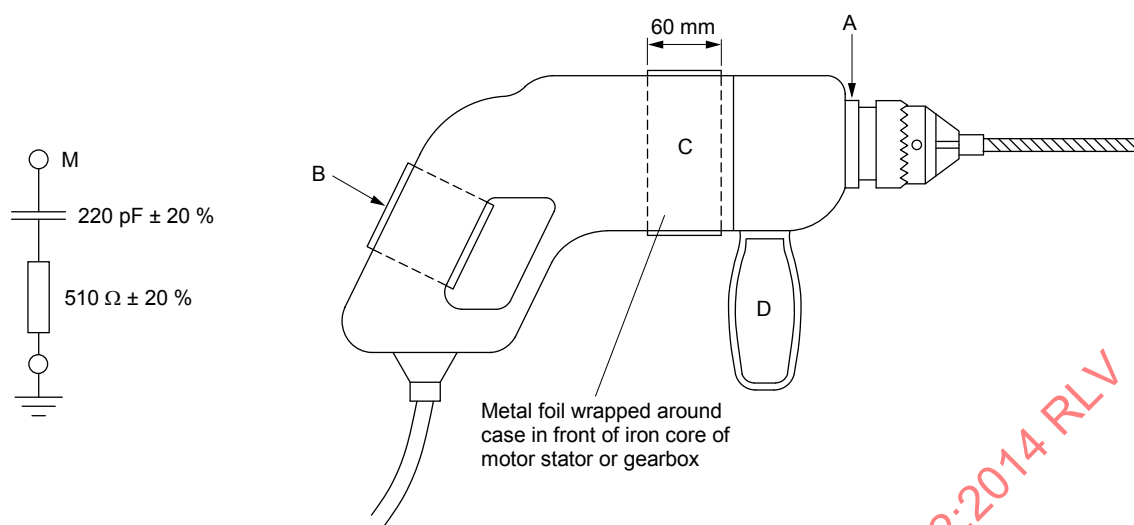
When the conducted emission at the mains port is measured, the reference point is the reference ground in the AMN. When this emission is measured on a signal or control line, the reference point is the reference ground of the ~~line impedance simulation network (LISN)~~ AN. The general principle to be followed in the application of the artificial hand is that terminal M of the RC element shall be connected to any exposed non-rotating metalwork and to metal foil wrapped around all handles, both fixed and detachable, supplied with the appliance. Metalwork which is covered with paint or lacquer is considered exposed metalwork and shall be directly connected to the RC element.

The following items specify the detailed application of an artificial hand:

- a) When the housing of the appliance is constructed entirely of metal and is earth-grounded, an artificial hand is not required.
- b) When the case of the appliance is constructed of insulating material, metal foil shall be wrapped around the handle B as in Figure 11 b) and c), and also around the second handle D, if present. Metal foil 60 mm wide shall also be wrapped around the body C, as in Figure 11 b) and c) at the point where the iron core of the motor stator is located; or around the gearbox, if the latter gives a higher disturbance level. All these pieces of metal foil, and the metal ring or bushing A, if present, shall be connected together, and to the terminal M of the RC element.

- c) When the case **construction** of the appliance is partly metal and partly insulating material, and has insulating handles, metal foil shall be wrapped around the handles B and D as in Figure 11 b). 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 the point where the iron core of the motor stator is located; or alternatively around the gearbox, if this is **constructed** of insulating loading material and a higher disturbance level is obtained. The metal part of the body, the point A, the metal foil around 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 a Class II appliance (**i.e. double insulated**, without ground wire) has two handles of insulating material A and B, and a case of metal C, for example an electric saw as in Figure 11 c), 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 terminal M of the RC element.
- e) Figure 12 gives examples for a telephone handset and a keyboard. For the handset, the 60 mm wide foil is wrapped around the handle with some overlap of the foil. In the case of a keyboard the foil or the PCB should fully cover the keys as far as possible. Using a PCB, the metal side has to be placed on the keyboard; it does not, however, need to exceed the dimensions of 300 mm by 100 mm.

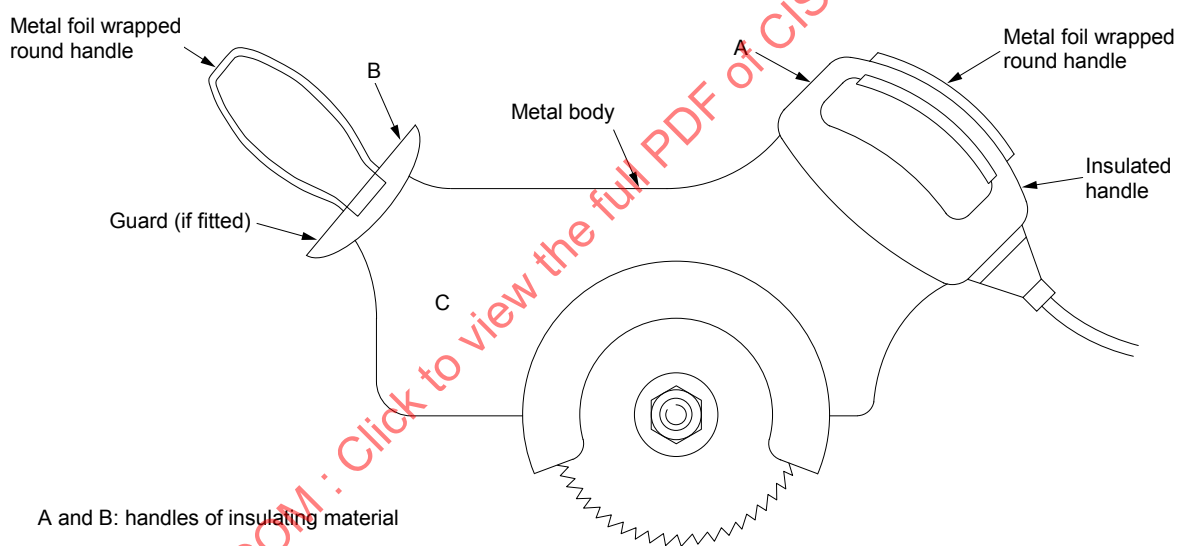
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IEC 0466/14

a) RC element

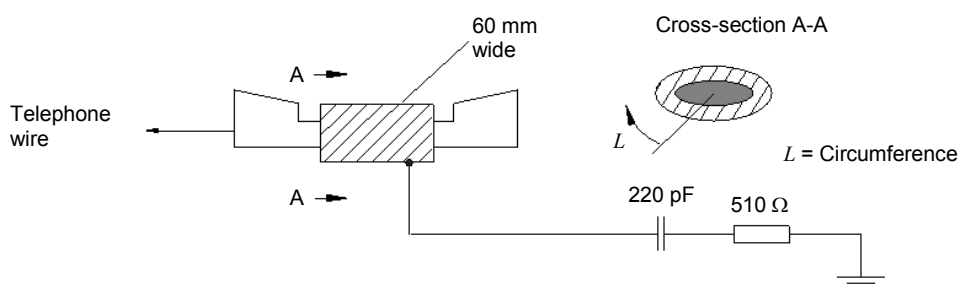
b) Portable electric drill



IEC 0467/14

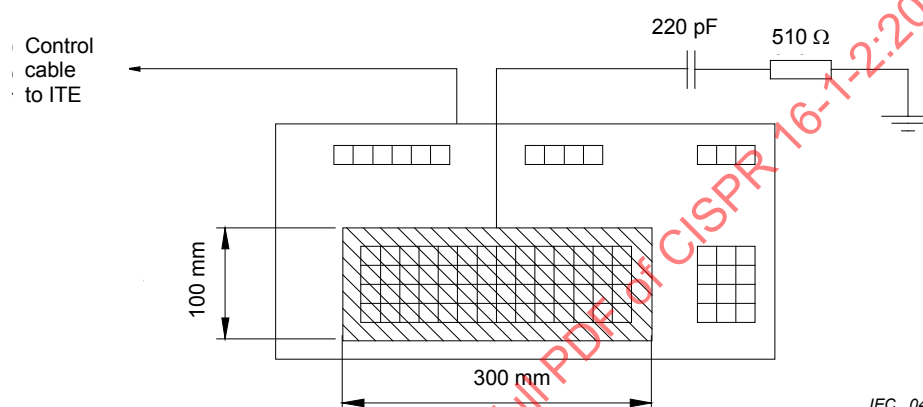
c) Portable electric saw

Figure 911 – Application of the artificial hand



IEC 0468/14

a) Application of artificial hand to telephone handset



IEC 0469/14

b) Application of artificial hand to typical keyboard

The artificial hand incorporates a metal foil, with the following dimensions:

a) 60 mm wide and greater than L in length:	for parts of the equipment that are hand-held during operation, or at a maximum of four parts of a system under test.
b) 300 mm by 100 mm:	for keyboards, whereby the metal foil is to be sized to cover the total number of keys, or to partially cover the keyboard, when the keyboard dimensions are greater than the maximum foil size.

Figure 1012 – Examples of application of artificial hand to ITE

9 CDNE for measurement of disturbance voltage in frequency range 30 MHz to 300 MHz

9.1 Instrumentation

9.1.1 General

The measurement method is described in Clause 9 of CISPR 16-2-1:2014.

The measurement method uses the following equipment:

- a CDNE- X and,
- an RGP.

The technical requirements for this equipment are described in this subclause.

The CDNE couples asymmetric (common-mode) disturbance voltage from the EUT into the input lead of the measuring receiver, and decouples that lead from any emissions or influences present in the test environment. Any symmetric (differential-mode) disturbance coming from the EUT is loaded either by a symmetric impedance of 100 Ω at the EUT mains port (CDNE-M2 and CDNE-M3), or by the symmetric load at the AE port of the CDNE-S_x (see Annex J). The CDNE cannot be used for the measurement on mains lines which carry intentional symmetric (differential mode) signals.

The RGP is the reference for the measured asymmetric (common-mode) disturbance voltage.

9.1.2 Description of the CDNE measurement

9.1.2.1 Range of application

The CDNE is intended for the measurement of conducted disturbances in the frequency range from 30 MHz to 300 MHz from an electrically small EUT with one or two connected cables. Further the CDNE can be arranged between EUT and AE to decouple asymmetric disturbances from the AE and to stabilize the impedance.

NOTE An EUT is seen as electrically small if fulfils the conditions of 9.1 of CISPR 16-2-1:2014.

9.1.2.2 Measurement of disturbance voltage

The CDNE allows measurement of the asymmetric disturbance voltage V_{dis} generated by the EUT on the connected cable(s). This measurement takes into account the measuring receiver reading V_{meas} and the voltage division factor F_{CDNE} . The voltage division factor F_{CDNE} in dB, includes the internal attenuator a_{meas} of at least 6 dB, which is used to reduce the uncertainty contributed by the mismatch between the CDNE and the measuring receiver.

The result of the measurement is calculated as follows:

$$V_{\text{dis}} = V_{\text{meas}} + F_{\text{CDNE}} \text{ in dB}(\mu\text{V}) \quad (3)$$

9.1.2.3 Termination impedance of the CDNE

The internal impedance of the EUT at the connection point is generally unknown. For this reason both the reading and the reproducibility of the measurement results are highly dependent on the CDNE termination impedance. The asymmetric (common-mode) termination impedance was chosen to be 150 Ω , giving the lowest uncertainty contribution relative to the established test method.

The CDNE-M2 and CDNE-M3 for the mains port of the EUT provides a symmetric impedance of 100 Ω , which represents the symmetric impedance of most a.c. mains networks.

9.1.2.4 Decoupling attenuation of the CDNE

The unknown impedance of the AE and any emission from the AE can influence the measurement result. This influence can be reduced by using an asymmetric attenuation between the AE port and the EUT port. This asymmetric attenuation is typically realized with a choke.

9.1.3 Description of the RGP

The RGP serves as the reference for the measured asymmetric disturbance voltage. The set-up is placed on the RGP that is connected to the protective earth for safety of personnel and equipment. The CDNE is placed in direct contact (good electrical bonding) with this plane, to ensure that it meets the specification for the asymmetric impedance. The EUT is positioned at a defined distance above the RGP.

9.2 Technical requirements for the CDNE-X

9.2.1 Mechanical and electrical parameters

The CDNE is contained in a metallic case. The centre of the CDNE EUT port is 30 mm $^{+10}_0$ mm above the RGP. This height allows for a typical impedance of 150 Ω for the connected cable.

For guidance, figures in Annex J provide examples of the construction of CDNEs.

Table 7 provides the electrical parameters and their specifications in the frequency range from 30 MHz to 300 MHz.

Table 7 – Electrical parameters of the CDNE-X

Parameter	Value for CDNE-M2 and CDNE-M3	Value for CDNE-Sx
Asymmetric (common-mode) impedance Z_{CM} at the EUT port	150 Ω $^{+10}_{-20}$ Phase angle: $0^\circ \pm 25^\circ$	150 Ω $^{+10}_{-20}$ Phase angle: $0^\circ \pm 25^\circ$
Symmetric (differential-mode) impedance Z_{DM} at the EUT port	100 $\Omega \pm 20 \Omega$	not defined
Longitudinal conversion loss (LCL)	≥ 20 dB	not defined
Tolerance of the voltage division factor F_{CDNE} including a_{meas}	$\pm 1,5$ dB	$\pm 1,5$ dB
Decoupling attenuation a_{decoup}	≥ 30 dB	> 30 dB

In general the level of asymmetric voltage is higher than the level of unintentional symmetric voltage. Therefore a minimum LCL value of 20 dB is adequate to prevent any influences of the symmetric voltage on the measurement results. In contrast, the assessment of EUTs using the differential-mode for communication on unscreened leads requires specific LCL values (minimum and maximum value) of the CDNE.

NOTE 1 For the EUT port of CDNE-M3, the minimum LCL value is not defined for L and PE, or N and PE.

NOTE 2 Reproducible LCL measurements above 100 MHz are under consideration.

NOTE 3 The CDNE cannot be used for applications on a mains network with intentional differential mode signals, e.g. where transmitting of a wanted differential signal would require a specific LCL, minimum and maximum value, to take the network quality into account.

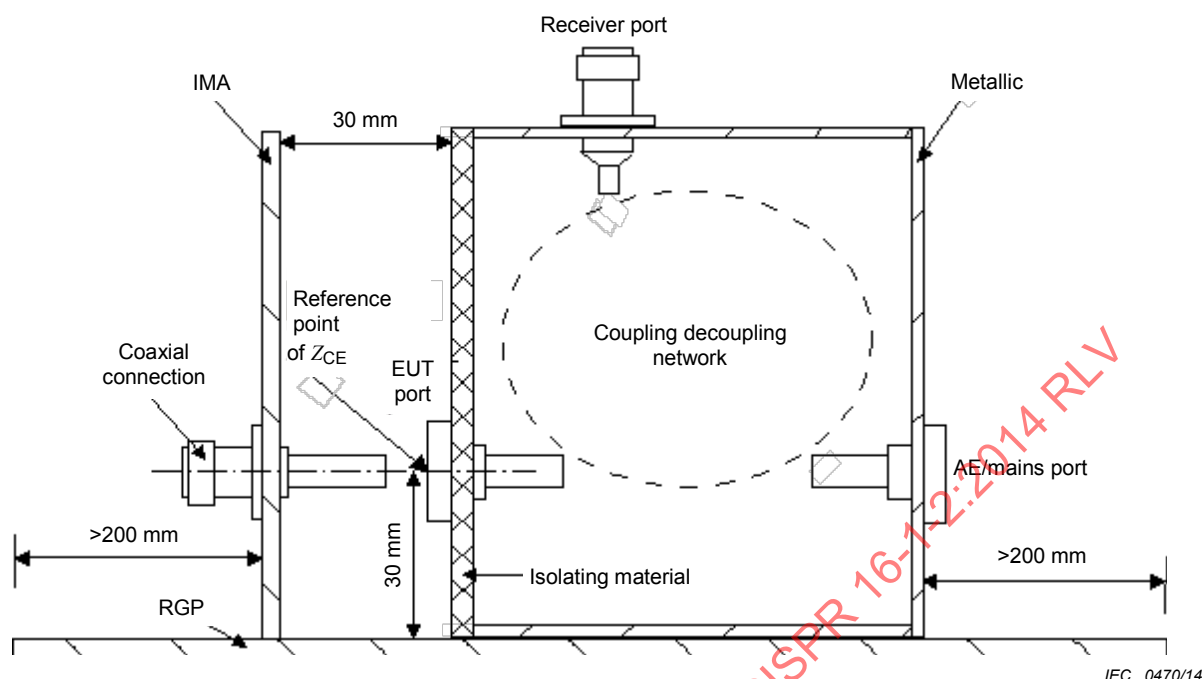
The attenuation a_{meas} at the receiver port is used to reduce the measurement uncertainty contributed by the mismatch between the CDNE and the measuring receiver. This attenuation is preferably an internal component of the CDNE. If an external attenuator is used, it shall be directly mounted on the CDNE receiver port, and this attenuator needs to be present during calibration and measurement. The attenuation of a_{meas} should be at least 6 dB.

9.2.2 Validation of the CDNE

9.2.2.1 General requirements

For the validation measurement, the CDNE shall be placed on an RGP, and its enclosure bonded to this RGP.

All measurements of the asymmetrical voltage refer to this RGP. The measurement arrangement shall be as specified in Figure 7 of Clause 10 of IEC 61000-4-6:2008, and is shown in Figure 13 with a different reference point of Z_{CE} in front of the EUT port.



NOTE "AE/mains" can include a.c. mains, d.c. supply as well as control/communication lines.

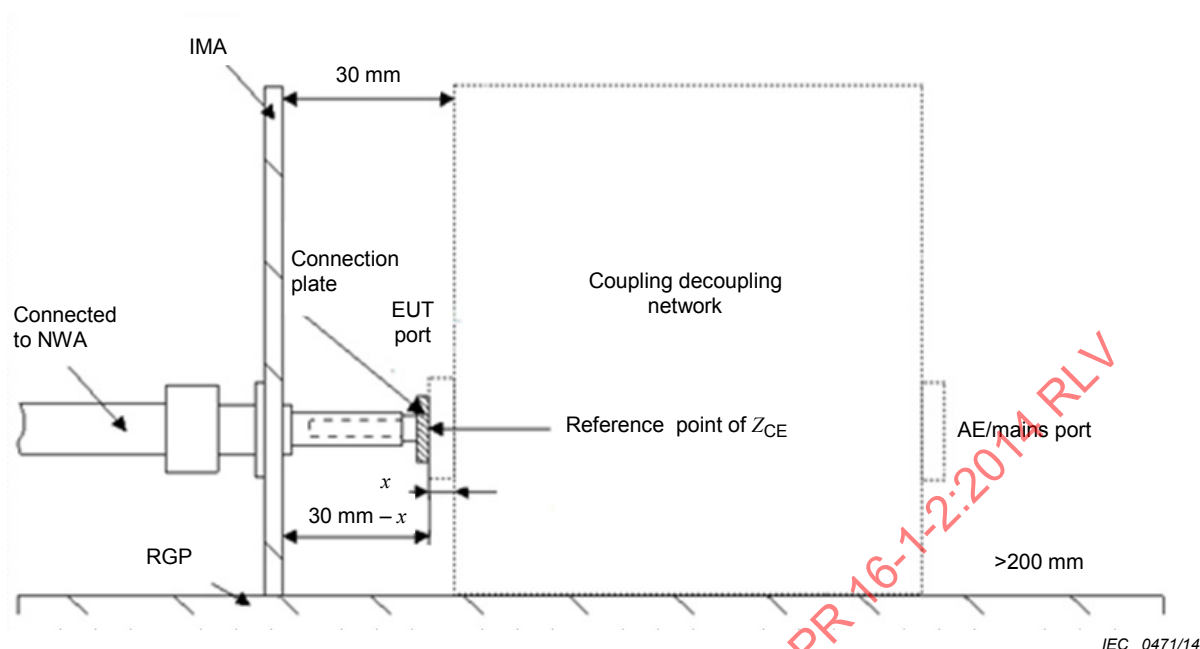
Figure 13 – Arrangement for validation of a CDNE

9.2.2.2 Calibration of the network analyzer (NWA) at the reference point

For the measurement of the asymmetric impedance at the reference point of Z_{CE} in Figure 13, the following calibration procedure shall be used:

The effect of the measurement cable (between the IMA and the NWA) is taken into account by calibrating the NWA using the OPEN-, SHORT-, and MATCH-error-correction method. The next step requires connection of the IMA with the previously calibrated cable to the NWA. The other side of the IMA shall be fitted with a connection plate including all adaptor parts that are between the IMA and CDNE during the measurement of the asymmetric impedance and phase angle (see Figure 14). Excluded are all parts that will be inserted into the connectors of the CDNE. This arrangement takes into account the electrical load between the calibrated cable and the measurement point at the input of the CDNE.

The electrical length shall be corrected by a delay time, which may be adjusted automatically or manually depending on the measurement equipment used.



The length x is related to the design of the EUT port connector and shall be as short as possible. Safety banana connectors have a typical x value of 3 mm.

The coupling decoupling network is not part of the set-up and is shown only for the positioning of the connection plate.

This set-up requires a connection plate without any parts that will be inserted into the connectors of the EUT port. In principle the connection plate will be upgraded to a asymmetric-mode adaptor (electrical connection between IMA and all lines of the EUT port) for the measurement of the asymmetric impedance and phase angle.

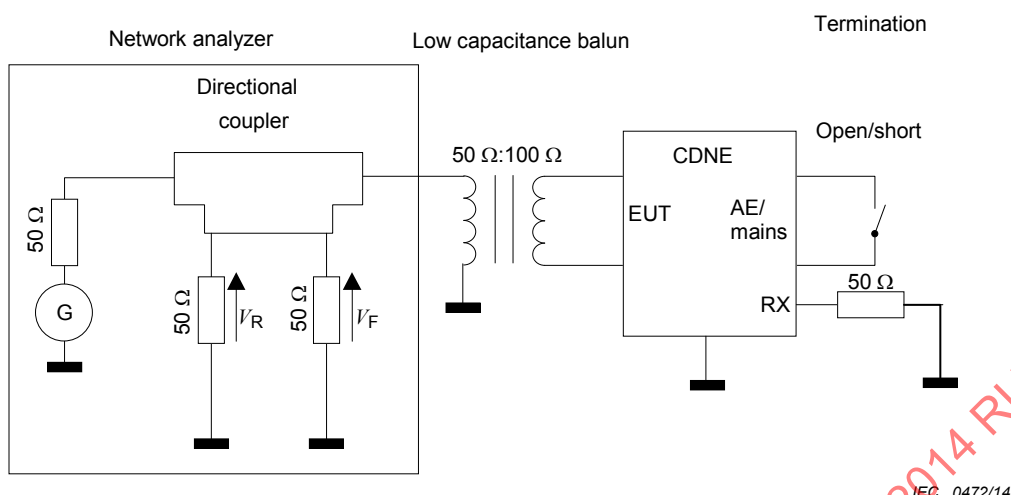
Figure 14 – IMA arrangement for correcting the electrical length

9.2.2.3 Asymmetric impedance Z_{CM}

The asymmetric impedance Z_{CM} at the CDNE EUT port shall be measured with the arrangement provided in Figure E.2.

9.2.2.4 Symmetric impedance of Z_{DM}

The symmetric impedance Z_{DM} at the CDNE-M2 and CDNE-M3 EUT port shall be measured according to Figure 15. The test arrangement with the low capacitance balun shall be calibrated using a 50 Ω network analyzer with OPEN, SHORT, and MATCH using 100 Ω on the symmetric port of the balun. The reflection coefficient ρ shall then be determined after connecting the CDNE to the symmetric port of the balun.



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

Figure 15 – Test arrangement for the measurement of the symmetric impedance (Z_{DM})

The symmetric impedance shall be calculated according to Equation (4) or will be displayed on the network analyzer.

$$Z_{DM} = Z_0 \frac{1+\rho}{1-\rho} = Z_0 \frac{1+(V_R/V_F)}{1-(V_R/V_F)} \quad (4)$$

where ρ is the reflection coefficient and Z_0 is 100 Ω .

9.2.2.5 Voltage division factor

The voltage division factor F_{CDNE} of the CDNE is measured according to Figure E.6.

NOTE 1 For this measurement, F_{CDNE} is the same as the term a_{vdiv} used in Figure E.6.

NOTE 2 The generator impedance of 150 Ω is typically accomplished with an additional 100 Ω impedance in series with the generator impedance. Because of the frequency range, this additional 100 Ω is described by S-parameters that are used for the specification of the voltage at the CDNE input.

9.2.2.6 Decoupling attenuation

The decoupling attenuation a_{decoup} of the CDNE is measured using the set-up as shown in Figure E.4. For a CDNE with two or more wires, all wire ports shall be measured between the EUT port and the AE port.

NOTE For this measurement, F_{CDNE} is the same as the term a_{vdiv} used in Figure E.6.

9.2.2.7 LCL

The LCL of the CDNE is measured according to Annex E.

9.3 Technical requirement for the RGP

The only requirement for the metallic RGP is for size and its arrangement in the environment. The RGP shall be at least 0,2 m larger at each side than the area determined by the test set-up comprising the CDNE and EUT. The surface of the RGP shall also be such that it enables a good electrical bonding of the CDNE, i.e. not painted or anodized.

Annex A (normative)

AMNs (~~clause 4~~)

A.1 General

This annex sets forth information and data concerning AMNs used in the measurement of radio-frequency (RF) voltages over the frequency range 9 kHz to 100 MHz and having current-carrying capabilities of up to 500 A. ~~This annex supplements the provisions of Clause 4.~~ Included are V-networks for voltage measurements between each conductor of the supply mains and reference ground, and delta-networks for voltage measurements between conductors of the supply mains (symmetric) and between the ~~electrical~~ mid-point of the conductors of the supply mains and reference ground (asymmetric).

An AMN circuit ~~has to~~ **shall** provide firstly the specified impedance over the working frequency range. It ~~has to~~ **shall** provide sufficient isolation to spurious signals in the mains supply (the spurious signals generally should be at least 10 dB below the measurement level at the measuring receiver). Also it ~~has to~~ **shall** prevent the mains voltage from being applied to the measuring receiver. It should have these provisions for each conductor of the mains (two-wire in single-phase and four-wire in three-phase), a switch to connect the measuring receiver to the mains conductor under measurement and to provide the correct termination to the other mains conductors. The circuits given in this annex have these features. These circuits are given for the case of two-wire single-phase mains; extension to four-wire three-phase use is simply done.

A.2 An example of the 50 Ω /50 μ H + 5 Ω artificial mains V-network

Figure 5 shows a suitable circuit with the component values listed in Table A.1. The parameters L_1 , C_1 , R_1 , R_4 and R_5 define the impedance; L_2 , C_2 and R_2 provide the isolation to spurious mains signals and mains impedance variations, and C_3 decouples the measuring receiver from mains voltage. The network may be constructed for use with currents up to 100 A.

Table A.1 – Component values of 50 Ω /50 μ H + 5 Ω V-network

Component	Value
R_1	5 Ω
R_2	10 Ω
R_3	1 000 Ω
R_4	50 Ω
R_5	50 Ω (input impedance the measuring receiver)
C_1	8 μ F
C_2	4 μ F
C_3	0,25 μ F
L_1	50 μ H
L_2	250 μ H

At the lowest frequencies of the range 9 kHz to 150 kHz, the 0,25 μF capacitance of C_3 does not have a negligible impedance. Unless otherwise specified, it will be necessary to make a correction for this impedance.

Since C_1 and C_2 have high capacitances, for safety reasons the network case should either be solidly bonded to reference ground or a mains isolating transformer should be used.

The inductance L_2 should have a Q -factor not less than 10 over the 9 kHz to 150 kHz frequency range. In practice, it is advantageous to use inductors coupled in series opposition in the live and neutral lines (common-core choke).

A suitable construction for the inductor L_1 is described in Clause A.7. For equipment requiring currents greater than 25 A, difficulties may be encountered in the construction of L_2 . In this case the isolating section L_2 , C_2 and R_2 may be omitted. The effects will be that the impedance of the network at frequencies below 150 kHz may be outside the tolerance specified in 4.3, and the isolation of mains noise may not be sufficient.

This circuit may also satisfy the requirements of the 50 Ω /50 μH artificial mains V-network specified in 4.4.

A.3 An example of the 50 Ω /50 μH artificial mains V-network

Figure 6 shows the circuit with the component values as listed in Table A.2. Components L_1 , C_1 , R_2 , R_3 and R_4 define the impedance. Unlike the previous example (i.e. see A.2), there is no isolating section because the circuit is able to meet the impedance specification. However, in cases of high ambient mains noise, a filter is required to reduce the spurious signal level. This network may be constructed for use with currents up to 100 A.

Table A.2 – Component values of 50 Ω /50 μH V-network

Component	Value
R_1	1 000 Ω
R_2	50 Ω
R_3	0 Ω
R_4	50 Ω (input impedance of the measuring receiver)
R_5	0 Ω
C_1	1 μF
C_2	0,1 μF
L_1	50 μH

Because C_1 has a high capacitance, for safety reasons the network case shall either be solidly bonded to reference ground or a mains isolating transformer shall be used.

A suitable construction for the inductor L_1 is described in Clause A.7.

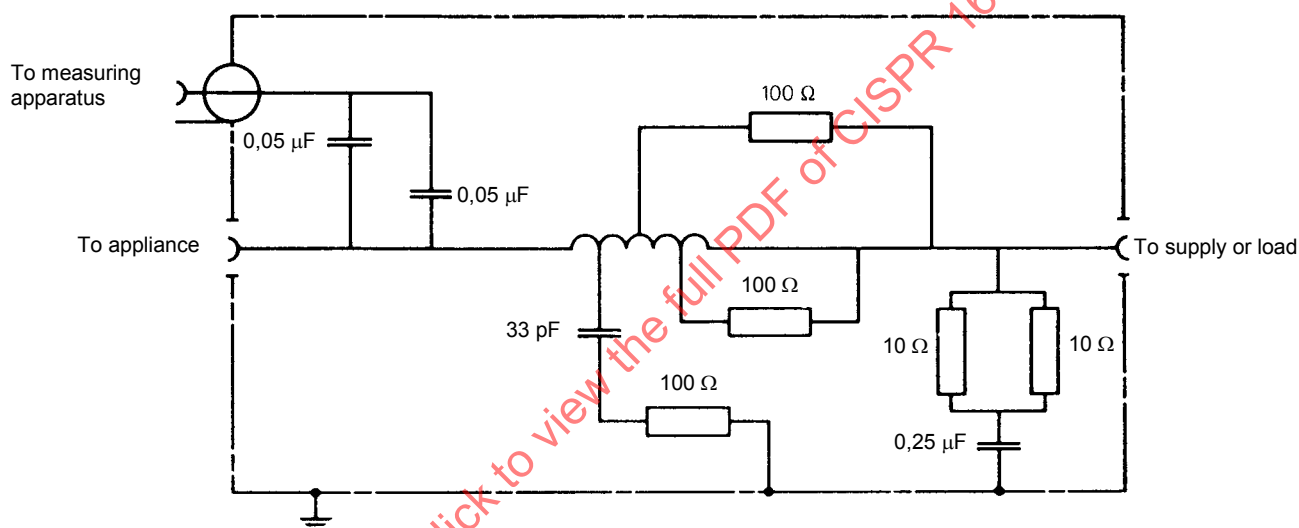
A.4 Examples of the 50 Ω /5 μH + 1 Ω artificial mains V-network

The circuit of Figure 6 with the component values given in Table A.3 is suitable for frequencies 150 kHz to 30 MHz, and currents up to 400 A.

Table A.3 – Component values of 50 Ω /5 μ H + 1 Ω V-network

Component	Value
R_1	1 000 Ω
R_2	50 Ω
R_3	0 Ω
R_4	50 Ω (input impedance of the measuring receiver)
R_5	1 Ω
C_1	2 μ F (minimum)
C_2	0,1 μ F
L_1	5 μ H

An alternative circuit with component values is shown in Figure A.1. It is suitable for the frequency range 150 kHz to 100 MHz, and for currents up to 500 A.



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Coil details: 5 μ H, 18 turns, $\varnothing$ 6 mm wound on 50 mm diameter ~~former~~ coilformer. Tapping points at 3, 5, 9 and 13,5 turns.

Figure A.1 – Example of an alternative 50 Ω /5 μ H + 1 Ω V-AMN for devices used with low impedance power sources

A.5 An example of the 150 Ω artificial mains V-network

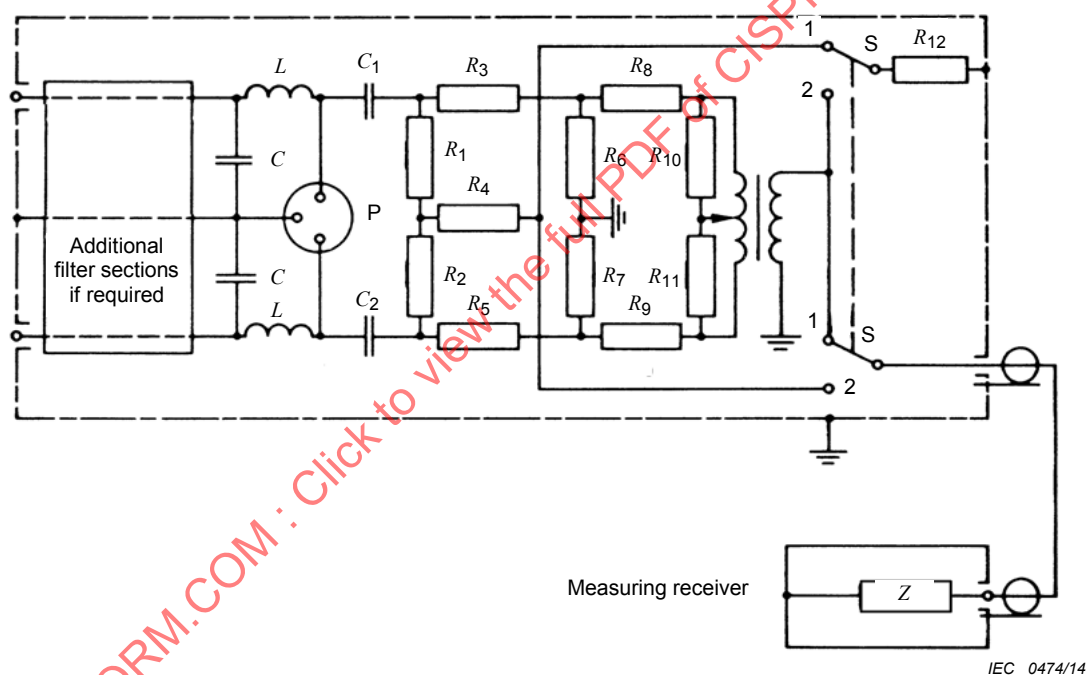
Figure 6 shows a suitable circuit. The component values are given in Table A.4.

Table A.4 – Component values of the 150 Ω V-network

Component	Value
R_1	1 000 Ω
R_2	150 Ω
R_3	100 Ω
R_4	50 Ω (input impedance of the measuring receiver)
R_5	0 Ω
C_1	1 μF
C_2	0,1 μF
L_1	Suitable value to achieve the specified impedance

A.6 Example of the 150 Ω artificial mains delta-network

Figure A.2 shows a suitable circuit. The component values are given in Table A.5.



Key

- P is the connection for apparatus under test
- 1 for the symmetric component
- 2 for the asymmetric component
- S double pole double throw switch
- Z measuring receiver input impedance

Figure A.2 – Example of a Δ -AMN for a measuring ~~apparatus~~ receiver with unbalanced input

Table A.5 – Component values of the 150 Ω delta-network

Component	Value
R_1, R_2	118,7 (120) Ω
R_3, R_5	152,9 (150) Ω
R_4	390,7 (390) Ω
R_6, R_7	275,7 (270) Ω
R_8, R_9	22,8 (22) Ω
R_{10}, R_{11}	107,8 (110) Ω
R_{12}	50 Ω
C_1, C_2	0,1 μF
L, C	suitable value to achieve the specified impedance
NOTE 1 The turns ratio of the balanced to unbalanced transformer is assumed to be 1:2,5 with centre tap.	
NOTE 2 Resistance values shown in brackets are the nearest preferred values ($\pm 5\%$ tolerance).	

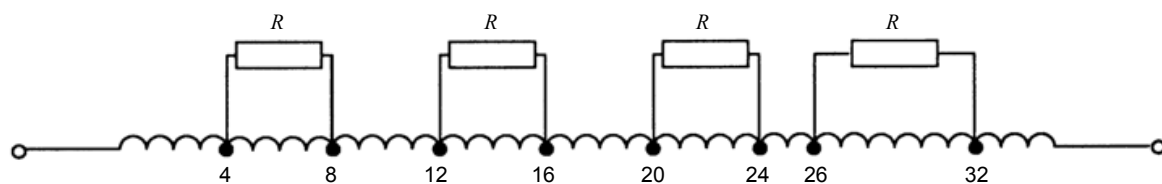
Calculations give the following network performance. Values in brackets are based on the resistance values in brackets.

Attenuation:	Symmetric	20	(20) dB
	Asymmetric	20	(19,9) dB
Network impedance:	Symmetric	150	(150) Ω
	Asymmetric	150	(148) Ω

A.7 Example design for an AMN with a 50 μH inductor

A.7.1 The inductor

The solenoidal winding of the inductor shown in Figure A.3 consists of 35 turns of a single layer of 6 mm diameter copper wire with an 8 mm pitch wound on a coilformer of an insulating material. Its inductance is greater than 50 μH outside the metal case, and 50 μH inside the metal case.



IEC 0475/14

NOTE Resistors R ($430 \, \Omega \pm 10 \, \%$) are connected to taps at turns 4 and 8, 12 and 16, 20 and 24, 26 and 32. Inductance is $50 \, \mu\text{H} \pm 10 \, \%$.

Figure A.3 – Schematic of $50 \, \mu\text{H}$ inductor

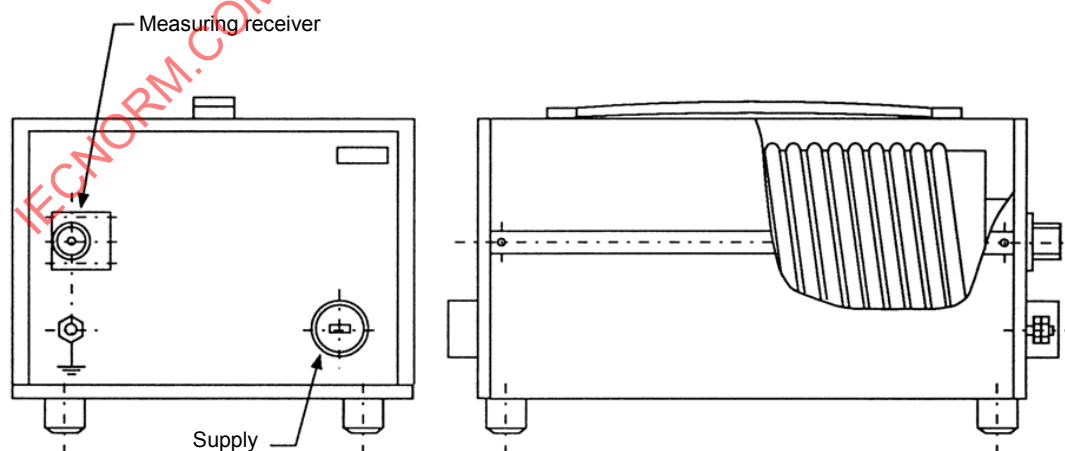
The diameter of the inductor is 130 mm. To improve the electrodynamic stability of the winding, a 3 mm deep spiral groove is made in the coilformer, and the wire is laid in this groove.

The higher frequency characteristics of the inductor are improved by sectionalizing the winding. Alternate sections, each of 4 turns, are each shunted by a $430 \, \Omega$ resistor. These act to suppress internal resonances in the inductor, which otherwise would cause the input impedance to deviate from the specified value at certain frequencies.

A.7.2 The case of the inductor

The inductor and the other components of the network are mounted on a metal frame, which is then closed by metal lids. The bottom and side lids are perforated to improve the heat dissipation. The dimensions of the case are 360 mm by 300 mm by 180 mm. Figure A.4 shows a general view.

NOTE It is recommended that the load-end terminals of the network be located as near as possible to a corner of that end of the case, so that two or more networks may be assembled with short leads from these terminals to the socket to be used for attachment of the EUT.

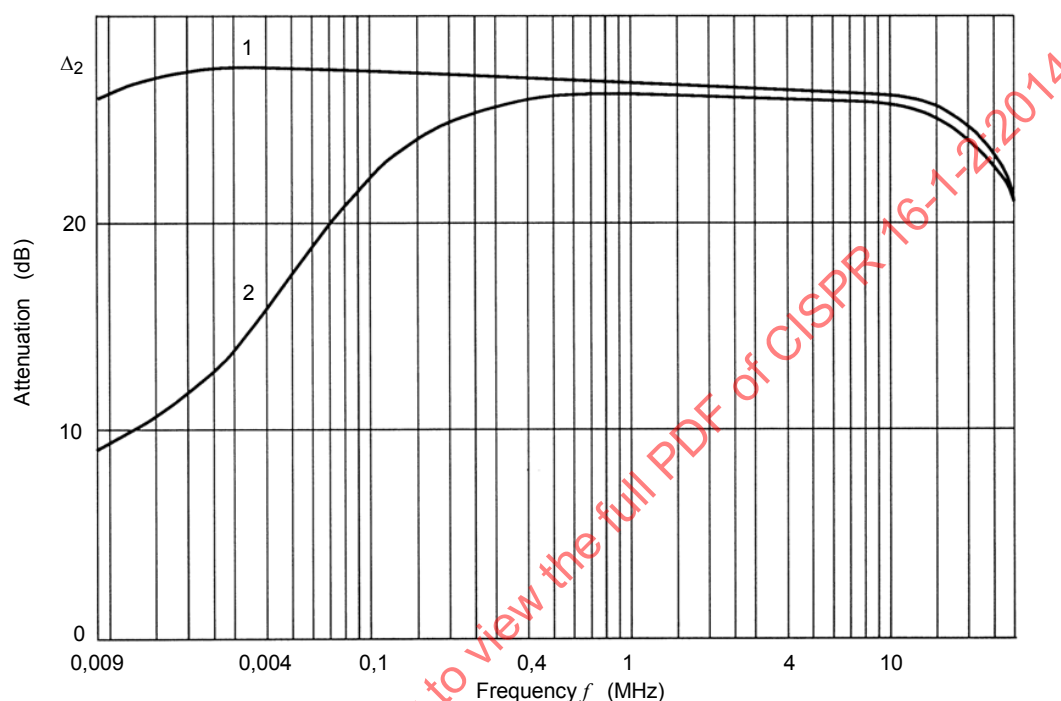


IEC 0476/14

Figure A.4 – General view of an AMN

A.7.3 Isolation of the inductor

Figure A.5 shows the attenuation to signals on the mains supply when the inductor is used in the circuit of Figure 5 but without the isolation section L_2 , C_2 , and R_2 . The attenuation is determined as that between the supply mains terminal and the ~~radio-disturbance-measuring apparatus~~ measuring receiver terminal. For curve 1, the internal impedance of the signal generator at the mains terminal is $50\ \Omega$ resistive. In curve 2, the internal impedance of the generator is varied in accordance with the nominal value of the magnitude of input impedance of the AMN, as given in Figure A.5.



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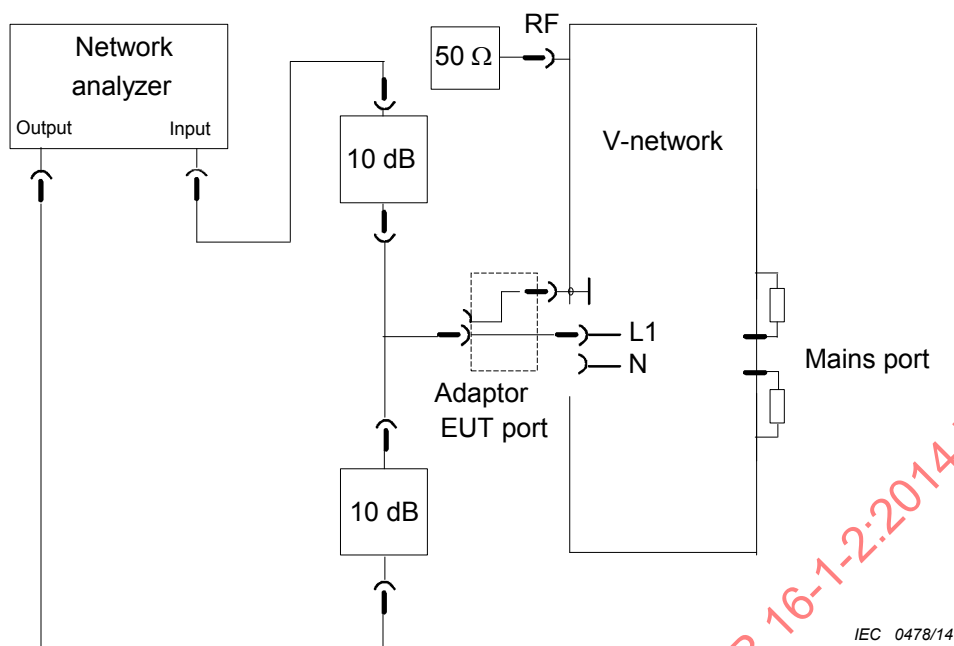
Key

- 1 $Z_{\text{gen}} = R_{\text{gen}} = 50\ \Omega$
 2 $Z_{\text{gen}} = |Z_{\text{in AMN}}|$

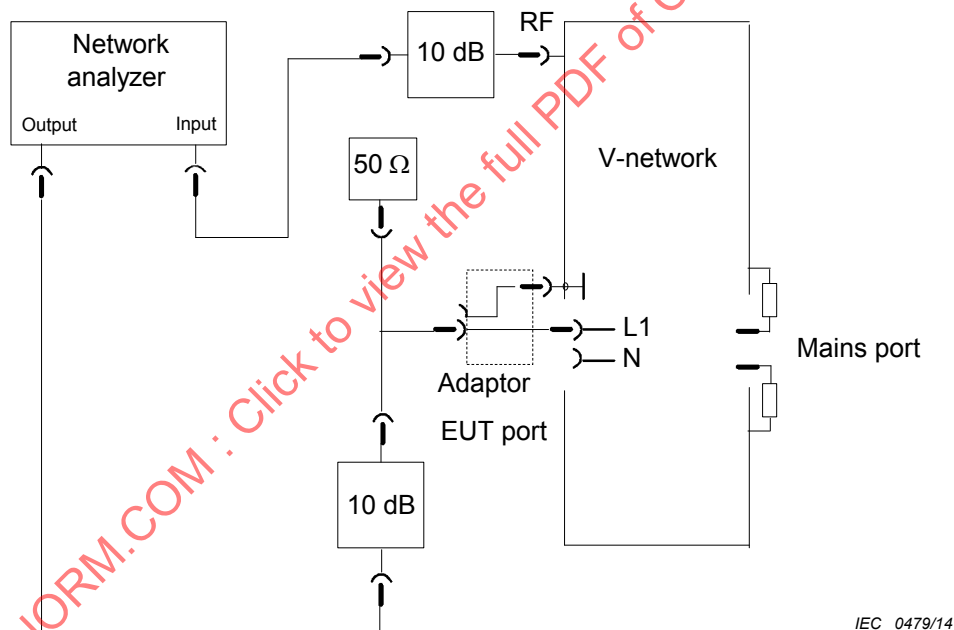
Figure A.5 – Attenuation of an AMN filter

A.8 Measurement of the voltage division factor of an artificial mains V-network

The voltage division factor may be determined using a test set-up as given by Figures A.6 for each test configuration of a V-network. The voltage division factor shall be measured on each line with each internal connection (e.g. with manual or remote switching configurations) using a network analyser, or using a signal generator and a measuring receiver or an RF voltmeter with a high impedance (low capacitance) probe. All lines of the EUT port which are not connected to the RF port shall be terminated with $50\ \Omega$ loads.



a) Test set-up for normalization (calibration) of the network analyzer



b) Test set-up for measurement of the voltage division factor using a network analyzer

Figure A.6 – Test set-up for determining the voltage division factor

Because the EUT port presents a frequency-dependent input impedance, the network analyzer needs to be normalized (i.e. calibrated), using the measured voltage level at the EUT port.

If a signal generator and an RF-voltmeter with a high-impedance probe are used, the EUT port is fed via a 50 Ω pad, and the RF port is terminated with a 50 Ω load while determining the voltage division factor by two subsequent measurements on the EUT and RF ports.

The construction of the adaptor used at the EUT port is critical for the calibration. Accordingly, the connections ~~must~~ **should** provide low impedance, and the T-connector ~~must~~ **should** be placed as close as possible to the EUT port and ground terminals. The 10 dB pads are used to provide exact 50 Ω source and load impedances for accurate measurements.

Furthermore, each line of the mains port ~~shall~~ **should** be terminated with 50 Ω relative to the chassis.

For a 150 Ω V-network the voltage division between the EUT port and the measuring receiver port, i.e. 150 Ω /50 Ω , ~~must~~ **should** be considered.

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Annex B (informative)

Construction, frequency range, and calibration of current probes

~~(clause 5)~~

NOTE This annex supplements the provisions of Clause 5.

B.1 Physical and electrical considerations for current probes

The physical size of the current probe is a function of the maximum cable size to be measured, the maximum ~~power~~ current flowing in the cable, and the range of signal frequencies to be measured.

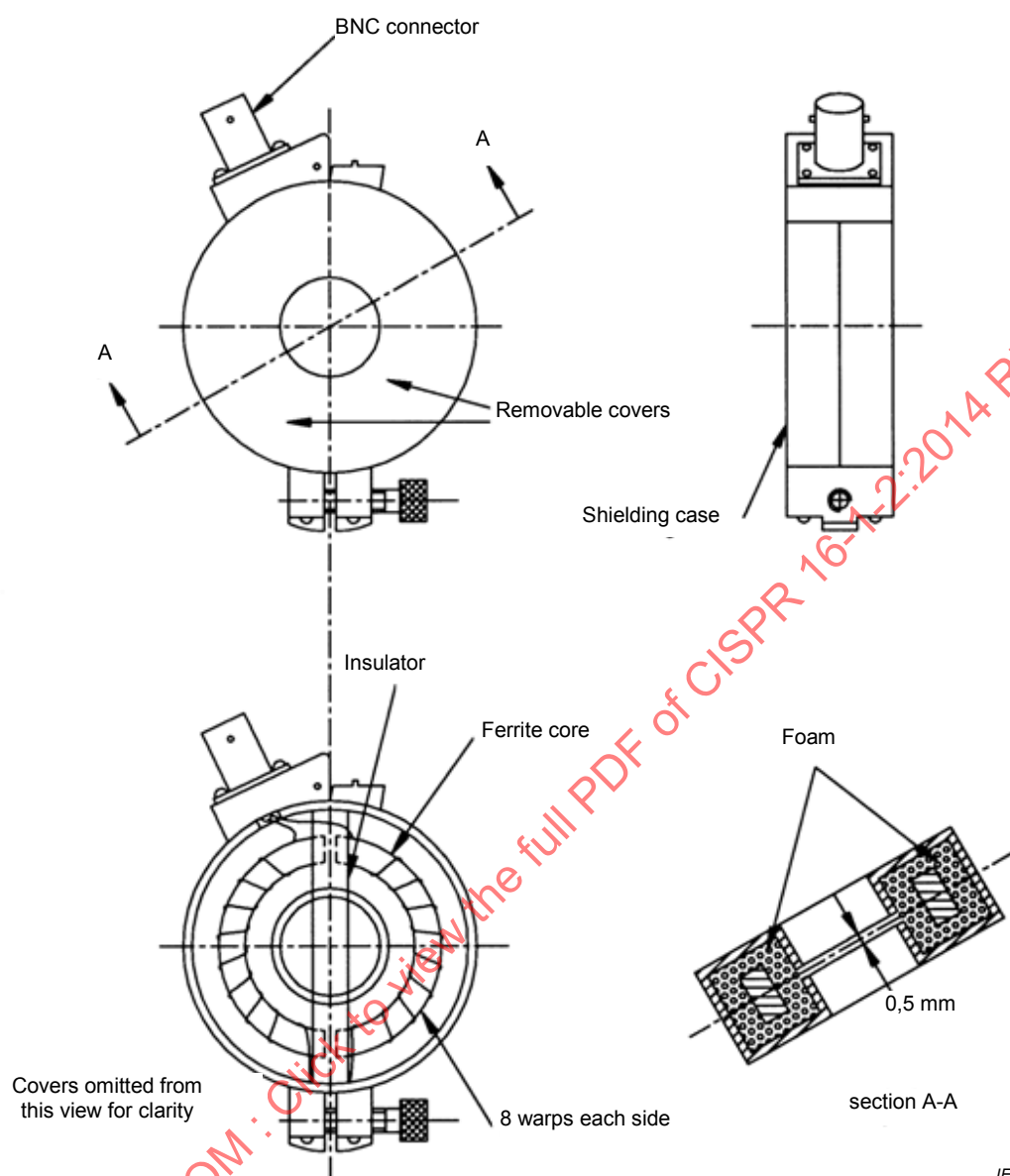
A current probe is usually a toroid with the conductor to be measured placed within the centre opening. Existing requirements and manufacturers' specifications show that the centre opening may vary from 2 mm to 30 cm in diameter. The secondary winding is placed on the toroid in such a manner as to facilitate the clamp-on function of the probe. The core and winding are enclosed in a shield to prevent electrostatic pick-up. The shield has a gap to prevent it from being a shorted turn on the transformer.

Typical current probes for disturbance measurements use seven to eight secondary turns. This number of turns is an optimized turns-ratio to ensure a maximized flat frequency range and an insertion impedance of 1 Ω or less. For frequencies below 100 kHz, laminated silicon steel cores are used. Ferrite cores are used between 100 kHz to 400 MHz and air cores are used between 200 MHz to 1 000 MHz, with a balanced coil to unbalanced 50 Ω output transformer. Figure B.1 shows the configuration of a typical current probe.

The current probe is generally used as a pick-up device for disturbance measurements. Therefore, it is designed to transfer the disturbance current to a voltage which can be detected by the meter. The sensitivity of the current probe may be expressed conveniently in terms of transfer impedance. Transfer impedance is defined as the ratio of secondary voltage (generally across a 50 Ω resistive load) to the primary current. The transfer admittance is sometimes used instead.

Overall sensitivity of the current probe and disturbance **measuring** receiver is also a function of the receiver sensitivity. Minimum detectable disturbance current in a conductor is the ratio of receiver sensitivity (V) to current probe transfer impedance (Ω). For instance, if a one microvolt (1 μ V) receiver and a current probe with a transfer impedance of 10 Ω are used, then the minimum measurable disturbance current is 0,1 μ A. However, if a 10 μ V receiver and a current probe with a transfer impedance of 1 Ω are used, then the minimum measurable current is 10 μ A. To obtain maximum sensitivity, the transfer impedance should be as high as possible.

The transfer impedance Z_T is often expressed in terms of decibels (dB) above 1 Ω . This is a convenient unit in reference to the more general disturbance units of decibels above 1 μ V or 1 μ A (Z_T in terms of decibels above 1 Ω is taken as $20 \lg Z_T$).



IEC 0480/14

Figure B.1 – Typical current probe configuration

B.2 Equivalent electrical circuit of current probe

The current probe may be represented by an exact equivalent circuit from general transformer theory. It is not necessary to repeat the circuit here since it is shown in many standard textbooks, see Reference [10]. After considerable simplification of the exact circuit and derived equations, the following equations for the transfer impedance result:

High-frequency
condition:

$$Z_T = \frac{\omega M}{\left[(\omega L / R_L)^2 + (\omega^2 LC - 1)^2 \right]^{1/2}} \quad (\text{B.1})$$

Mid-frequency
condition:

$$Z_T = MR_L \text{ when } (\omega^2 LC = 1) \quad (\text{B.2})$$

Low frequency
condition:

$$Z_T = \frac{\omega M}{\left[(\omega L / R_L)^2 + 1 \right]^{1/2}} \quad (\text{B.3})$$

where

- Z_T is the transfer impedance;
- M is the mutual inductance between primary and secondary windings;
- L is the inductance of secondary winding;
- R_L is the load impedance of secondary (usually 50 Ω);
- C is the distributed capacitance of secondary;
- ω is the angular frequency in radian/second.

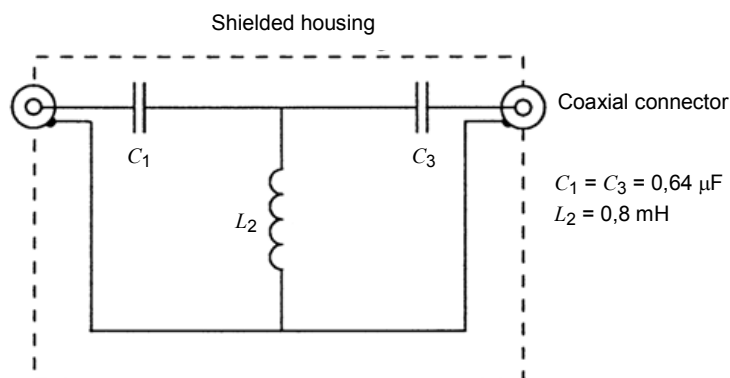
The following conclusions result from Equations (B.1) to (B.3):

- a) The maximum transfer impedance at mid-frequency, for a constant load impedance, is directly proportional to the ratio of mutual inductance to secondary inductance (R_L being constant).
- b) The high-frequency half-power point occurs when the reactance of the secondary distributed capacitance is equal to the load resistance.

B.3 Detrimental effects of current probe measurements

The current probe is essentially a toroidal transformer and therefore reflects the secondary impedance into the primary. For an 8-turn secondary winding and a 50 Ω load, typically the insertion impedance is approximately 1 Ω . As long as the combination of source and load impedances of the circuit to be measured is greater than 1 Ω , the application of the current probe will not greatly alter the primary current flow. However, if the sum of the circuit source and load impedances is less than the insertion impedance, the application of the current probe may alter the primary current considerably.

One intended current probe application is the measurement of disturbance current on primary power lines which may carry up to 300 A d.c. or 100 A a.c. The current probe may also be used in the vicinity of devices which generate strong external magnetic fields. The current probe transfer impedance shall not be altered by these power currents or flux densities. Therefore, the magnetic circuit shall be designed so that it will not saturate. Because the a.c. power currents may be in the frequency range of 20 Hz to 15 kHz, the current probe output at these power frequencies may damage the input circuit of the associated receiver. A possible solution is the insertion of power-frequency rejection filters between the current probe and the receiver. Figure B.2 shows a high-pass filter with 9 kHz cut-off frequency.

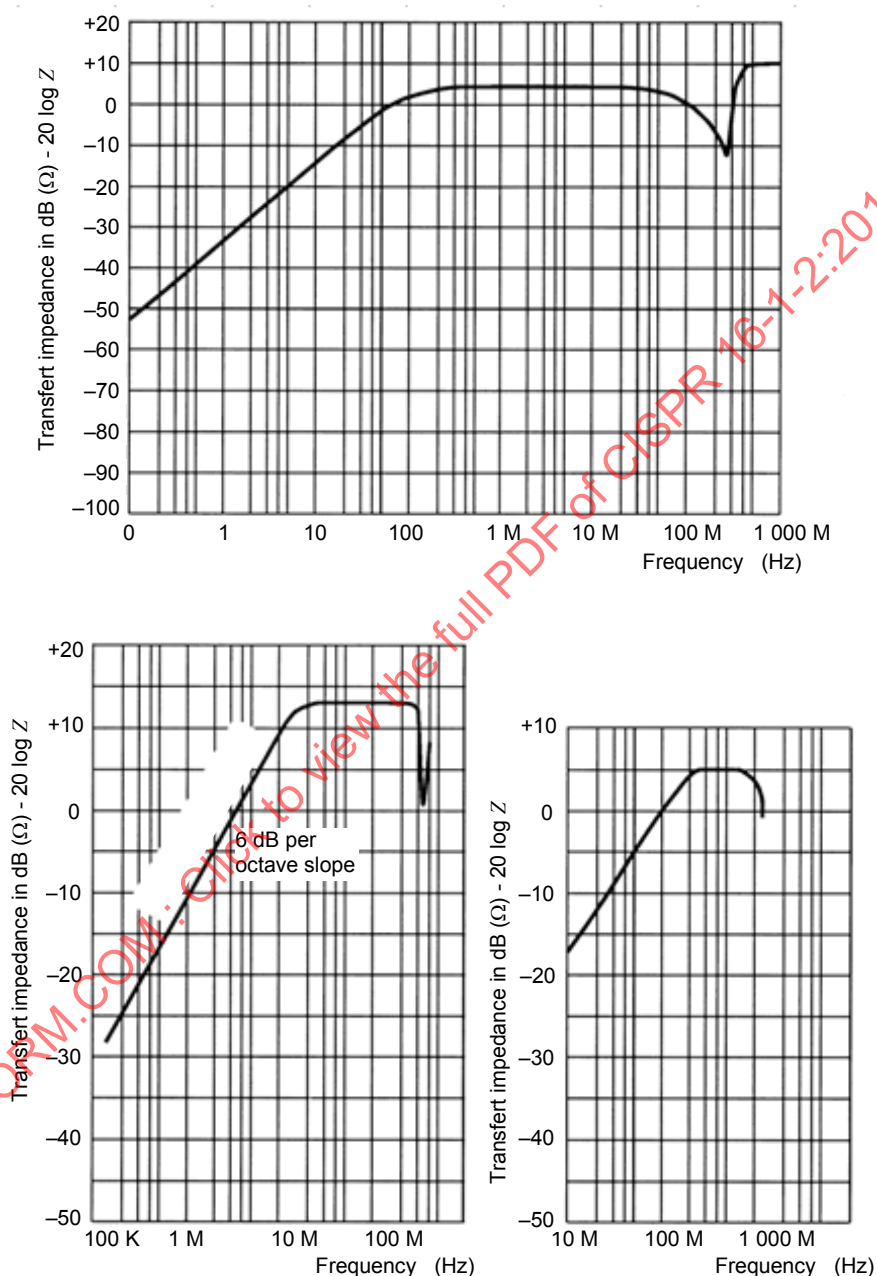


IEC 0481/14

Figure B.2 – High-pass filter with cut-off frequency of 9 kHz

B.4 Typical frequency response characteristics of current probes

Figure B.3 shows the typical frequency response characteristics of current probes, with flat passbands of: a) 100 kHz to 100 MHz; b) 30 MHz to 300 MHz; and c) 200 MHz to 1 000 MHz.



IEC 0482/14

Figure B.3 – Transfer impedance of typical current probes

B.5 A shielding structure for use with current probes

B.5.1 General

A current probe with the addition of a conductive (e.g. copper, brass, etc.) shielding structure may be used to measure either asymmetric (common mode) or symmetric (differential mode) disturbance current. The method is usable from 100 kHz to 20 MHz. The essential feature of this method is a modified RF current probe combined with a high-pass filter. The purpose of the high-pass filter is to enhance the rejection of the power frequency current in the output of the current probe. The test arrangement is described in CISPR 16-2-1.

B.5.2 Theoretical model

The set-up for current measurement using the AMN is shown in Figure B.4 a). The components of the disturbance currents are:

I_1 current in the live mains conductor

I_2 current in the neutral mains conductor

I_C asymmetric (common mode) current

I_D symmetric (differential mode) current

NOTE The phase angle between I_1 and I_2 is assumed to be zero. This is the case for leads of less than 1 m and frequencies below 30 MHz.

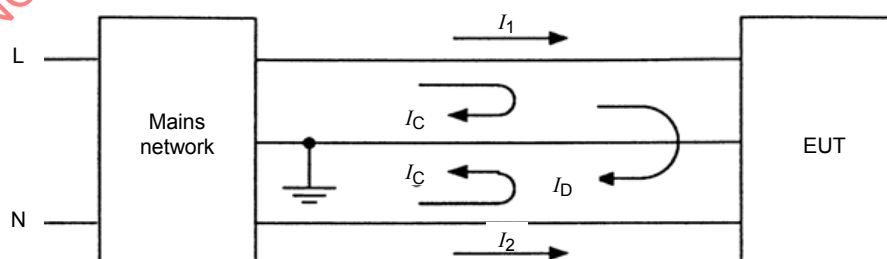
It can be seen from Figures B.4 a) and B.4 b) that the currents have the following relations:

$$I_1 = I_C + I_D \quad (\text{B.4})$$

$$I_2 = I_C - I_D \quad (\text{B.5})$$

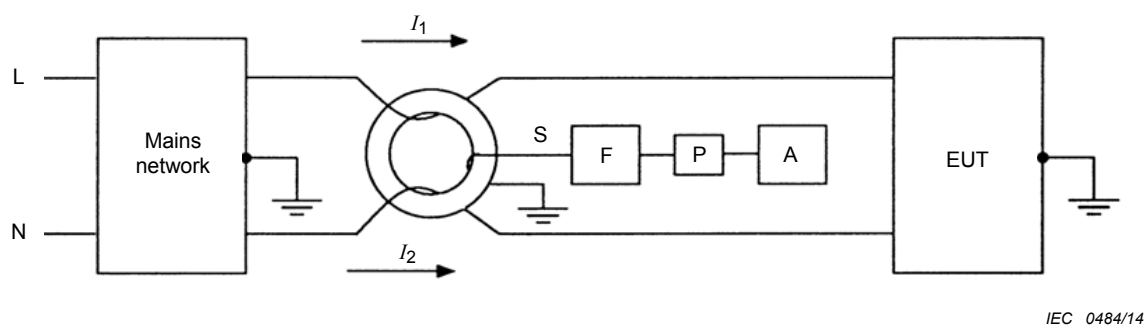
$$2I_C = I_1 + I_2 \quad (\text{B.6})$$

$$I_D = I_1 - I_2 \quad (\text{B.7})$$



IEC 0483/14

a) CISPR test circuit with disturbance currents



IEC 0484/14

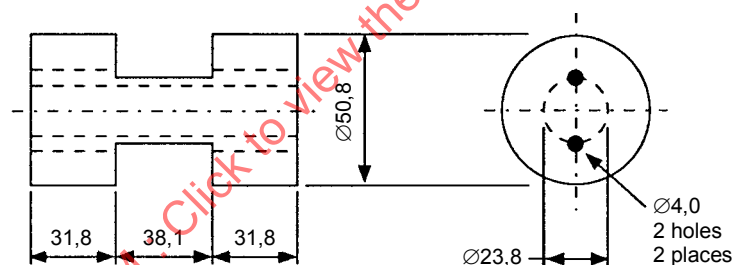
b) Test circuit which differentiates asymmetric (common) mode and symmetric (differential) mode noise

Figure B.4 – Set-up for current measurement using the AMN

Thus a current probe clamped around the conductors so that I_1 and I_2 would add gives an output due solely to the asymmetric current; whereas, subtraction of the currents would yield an output related only to the symmetric current. A 6 dB correction of the measured value only for the asymmetric current is required, due to the factor of 2 in the equation for the asymmetric current (see Figure B.4 b).

B.5.2B.5.3 Construction of the shielding structure

The additional shield required is shown in Figure B.5. The dimensions shown are for a current probe with a centre core of 51 mm diameter. For other sizes of current probes the dimensions are scaled accordingly.



IEC 0485/14

The material should be highly conductive, e.g. copper or brass.

Figure B.5 – Shield configuration used with current transformer

This structure serves to position the unshielded conductors in the current probe, and to provide additional shielding from any external linkage when the output is grounded at one end. Insulated (0,75 mm²), stranded wire is passed through the hole and fitted at each end with terminals to accept the shielded leads from the mains network and to the EUT. The diameter of the centre of the shield is built up with insulating tape so that the wires are firmly held in the slots, and so that this portion of the assembly fits snugly in the current probe when it is closed.

The shield is positioned in the current probe such that the plane of the leads is perpendicular to the plane of the gaps in the core halves of the probe. It is important to ensure that the shielding structure as shown in Figure B.5 is insulated from the current probe housing so that the gap in the housing is not shorted.

B.5.3B.5.4 High-pass filter

A high-pass filter, if needed, is inserted between the output of the current probe and the measuring receiver. This filter may be part of the measuring receiver [see Figures B.2 and B.4 b)].

B.6 Calibration of current probes

Calibration of current probes may be done by a jig which is made of two halves of a coaxial adaptor. When assembled with the current probe in place, the jig forms a coaxial line the outer conductor of which encloses the current probe and the inner conductor passes through the probe aperture (see Figure B.9).

The calibration equivalent circuit is shown in Figure B.6. When the coaxial line is well matched the current I_P through the inner conductor may be calculated from a measurement of the voltage V_1 on the line. The body, if metal, or shield of the probe should be taken into account in the design of the jig, to achieve a good coaxial line. If the voltage output of the current probe is V_2 the transfer admittance may be calculated using the following equation:

$$k Y_T = V_1 - V_2 - 34 \quad (\text{B.8})$$

where

$k Y_T$ is the transfer admittance in dB(S);

V_1 is the RF voltage on the coaxial line in dB(μ V);

V_2 is the RF output voltage of the probe in dB(μ V);

34 is a factor related to the 50 Ω load impedance.

The transfer admittance $k Y_T$ in dB(S) is used to calculate the value of the measured current I_P in dB(μ A) using the equation:

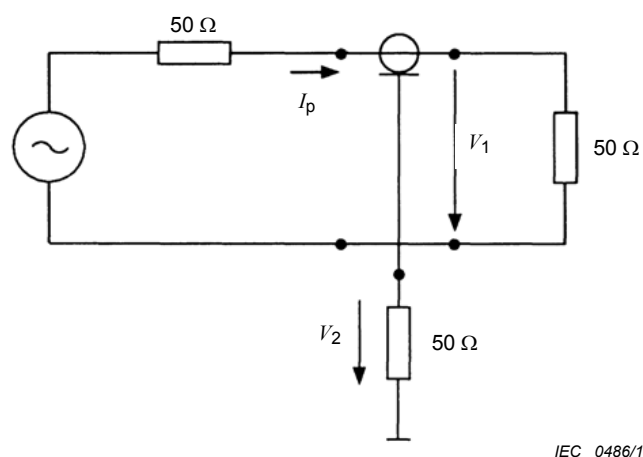
$$I_P = V_2 + k Y_T \quad (\text{B.9})$$

where V_2 is in dB(μ V).

I_P is in dB(μ A), and

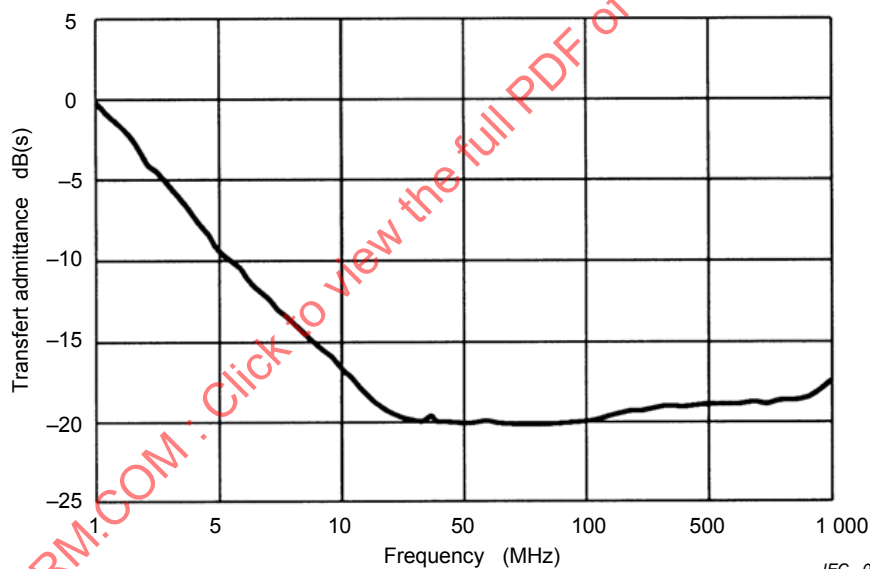
k is in dB(s)

Figure B.7 shows a typical calibration result, Figure B.8 shows the return loss, and Figure B.9 provides a photograph of a coaxial adaptor jig.



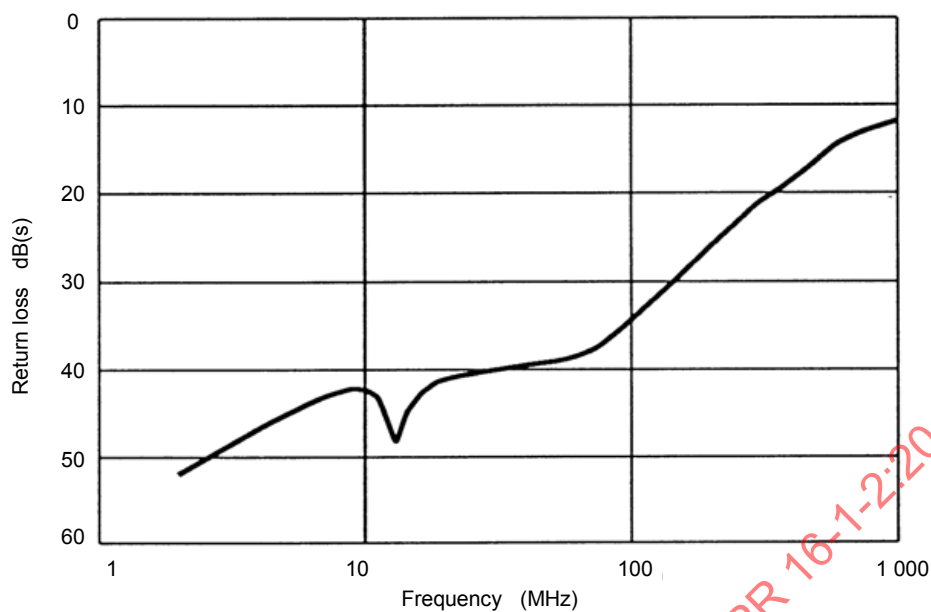
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Figure B.6 – Schematic diagram of circuit with coaxial adaptor and current probe
~~Current probe factor k~~ transfer admittance Y_T measurement



IEC 0487/14

Figure B.7 – ~~Current probe factor k~~ Transfer admittance Y_T as a function of frequency



IEC 0488/14

Figure B.8 – Return loss of the coaxial adaptor terminated with 50 Ω and with the current probe (also terminated with 50 Ω) inside



IEC 0489/14

Figure B.9 – Current probe between the two halves of the coaxial adaptor

Annex C (informative)

Construction of the coupling units for current injection for the frequency range 0,15 MHz to 30 MHz

~~(clause 6)~~

NOTE This annex supplements the provisions of Clause 6.

C.1 Coupling unit type A for coaxial antenna input

The circuit diagram and construction are similar to the type A unit shown in Figure C.1, except that the inductance value is 280 μH .

Construction of the 280 μH inductor:

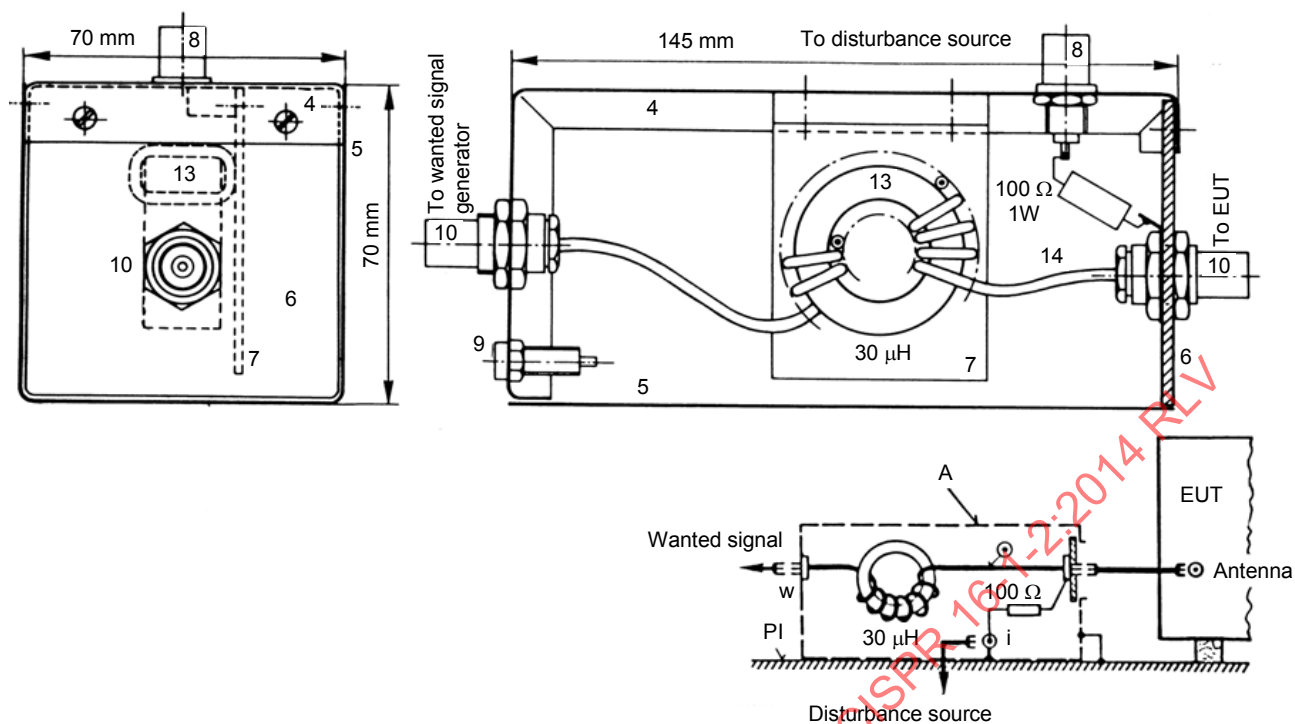
- Core: Two ferrite rings, material 4C6 or equivalent, placed together, dimensions 36 mm outer diameter, 23 mm inner diameter, 30 mm thick.
- Winding: 28 turns of a fully screened miniature coaxial cable, e.g. UT-34, wire diameter 0,9 mm, with an outer insulation plastic tubing of 1,5 mm outer diameter.

C.2 Coupling unit type M, for mains leads

The circuit diagram and construction are similar to the type M unit shown in Figure C.2, except that the two inductors are 560 μH each, and $C_1 = 0,1 \mu\text{F}$ and $C_2 = 0,47 \mu\text{F}$.

Construction of the 560 μH inductor:

- Core: Two ferrite rings, material 4C6 or equivalent, placed together, dimensions 36 mm outer diameter, 23 mm inner diameter, 30 mm thick.
- Winding: 40 turns of insulated copper wire, 1,5 mm outer diameter.

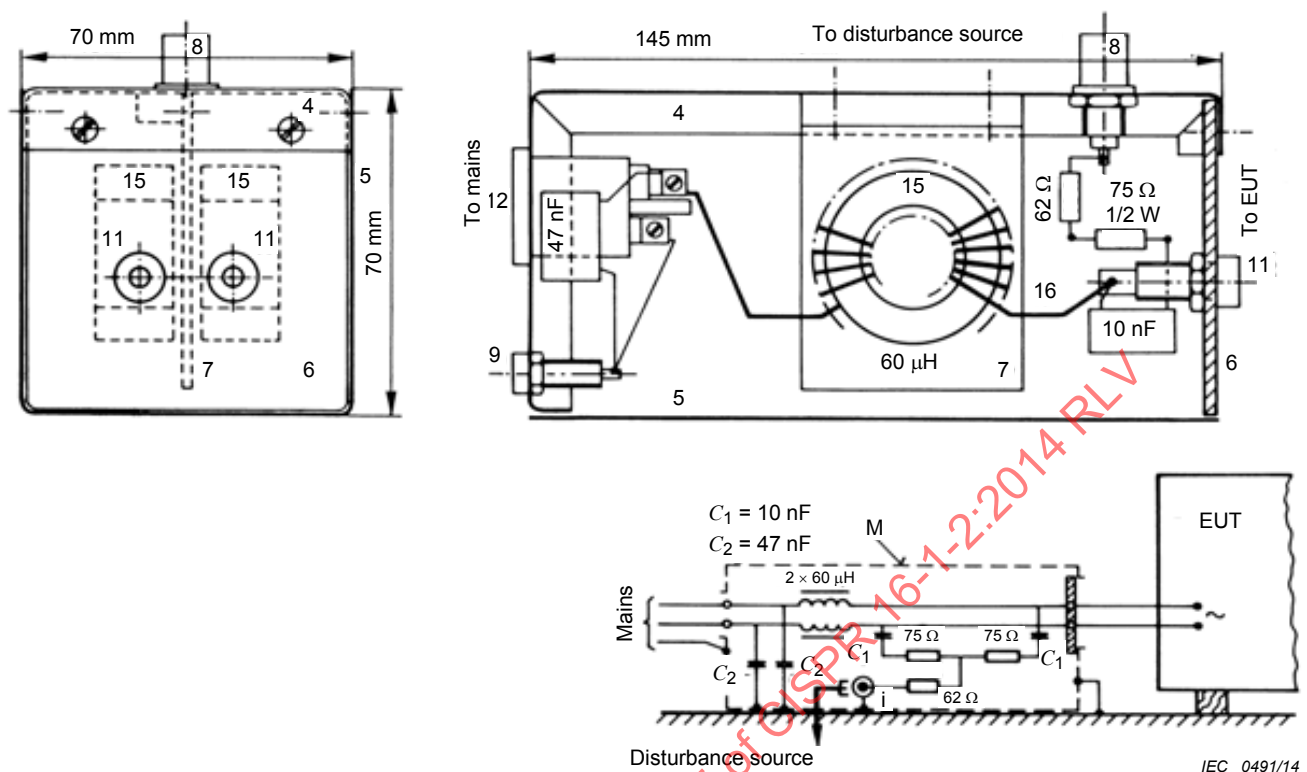


IEC 0490/14

Key

- 4-5 metallic case 145 mm by 70 mm by 70 mm (parts 5 placed on the ground plane P1)
- 6 front plate (insulating material)
- 7 supporting plate for chokes (insulating material)
- 8 coaxial connector, BNC, 50 Ω
- 9 group jack
- 10 coaxial connector, BNC
- 13 ferrite ring type 4C6, $\varnothing$ 36 mm, 15 mm, with 14 turns of coaxial cable
- 14 coaxial cable, outer $\varnothing$ 2,4 mm

**Figure C.1 – Example of coupling unit type A, for coaxial input
schematic diagram and construction details (see C.1 and D.2)**



Key

- 4-9 see Figure C.1
- 11 is the mains socket for EUT (two insulated banana jacks)
- 12 is the mains plug (2P + ground)
- 15 are two ferrite rings type 4C6, $\varnothing 36 \text{ mm} \times 23 \text{ mm} \times 15 \text{ mm}$, with 20 turns each
- 16 is an insulated 0,8 mm copper wire, outer $\varnothing 0,8 \text{ mm}$

Figure C.2 – Example of coupling unit type M, for mains leads, schematic diagram and construction details (see C.2 and D.2)

C.3 Coupling unit type L, for loudspeaker leads

The circuit diagram and construction are similar to the type L unit shown in Figure C.3 with two separate inductors of $560 \mu\text{H}$ each, and $C_1 = 47 \text{ nF}$ and $C_2 = 0,22 \mu\text{F}$.

Construction of each $560 \mu\text{H}$ choke:

Core: One ferrite ring, material 4C6 or equivalent, dimensions 36 mm outer diameter, 23 mm inner diameter, 15 mm thick.

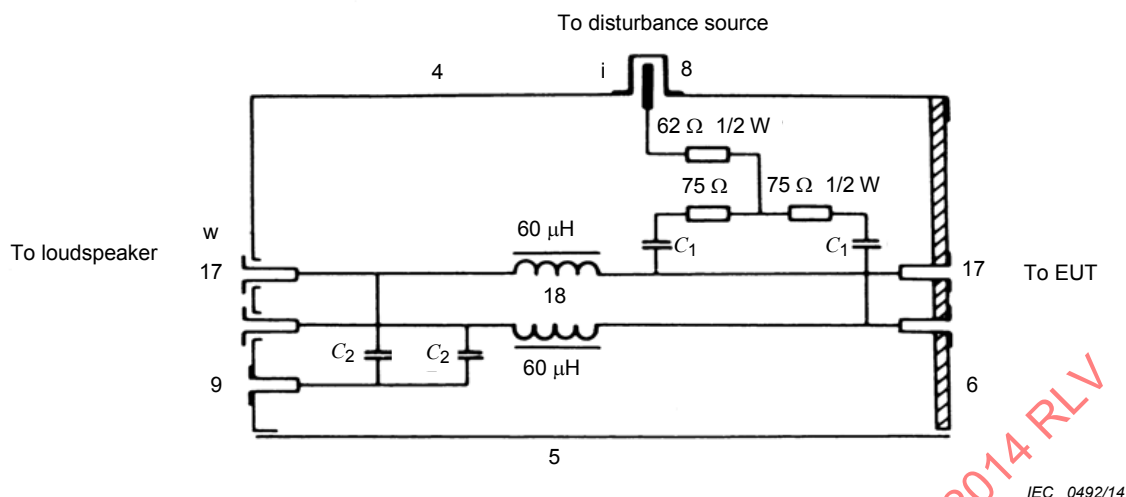
Winding: 56 turns of varnish insulated copper wires, 0,4 mm diameter.

NOTE Characteristics of magnetic ferrite type 4C6:

Relative initial permeability $\mu_i = 120$

Loss factor $\tan \delta \mu_i < 40$ at 2 MHz, < 100 at 10 MHz

Resistivity $\rho = 10 \text{ k } \Omega\text{-m}$



Key

4-9 see unit type A

17 are insulated banana jacks

18 two inductances 60 μH each

For each inductance:

Core: one ferrite ring, type 4C6,
 $\varnothing$ 36 mm by $\varnothing$ 23 mm by 15 mm

Winding: 20 turns copper wire insulated
 outer $\varnothing$ 1,2 mm

Mounting of the inductances: see unit type M

C_1 10 nF each

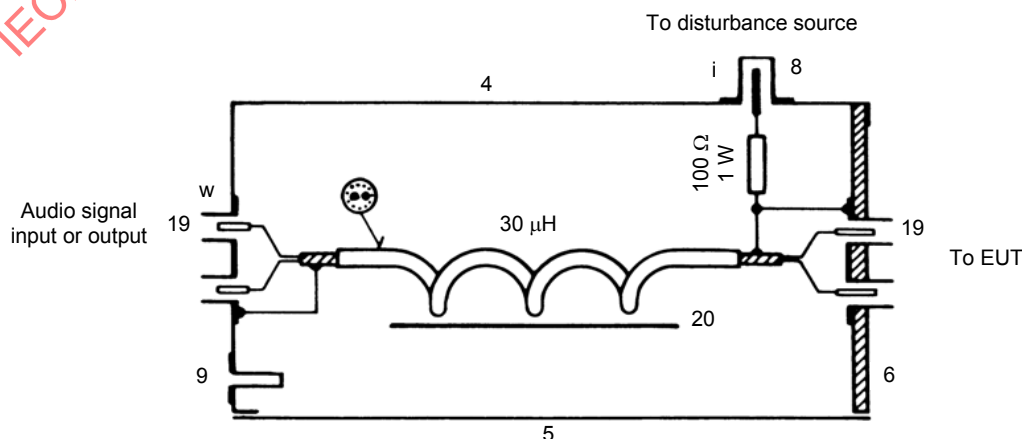
C_2 47 nF each

Figure C.3 – Example of coupling unit type L for loudspeaker leads, schematic diagram and simplified construction drawing (see D.2)

C.4 Coupling unit type Sw, for audio-frequency signals

The circuit diagram and construction are similar to the type Sw unit shown in Figure C.4, except with the 280 μH inductor described in C.1. The screened cable may be an audio-frequency type, and its diameter shall be not larger than 2,1 mm.

NOTE The type A coupling unit described in C.1 may can be used for this purpose, if the two stereo signal cables of the EUT are connected together.



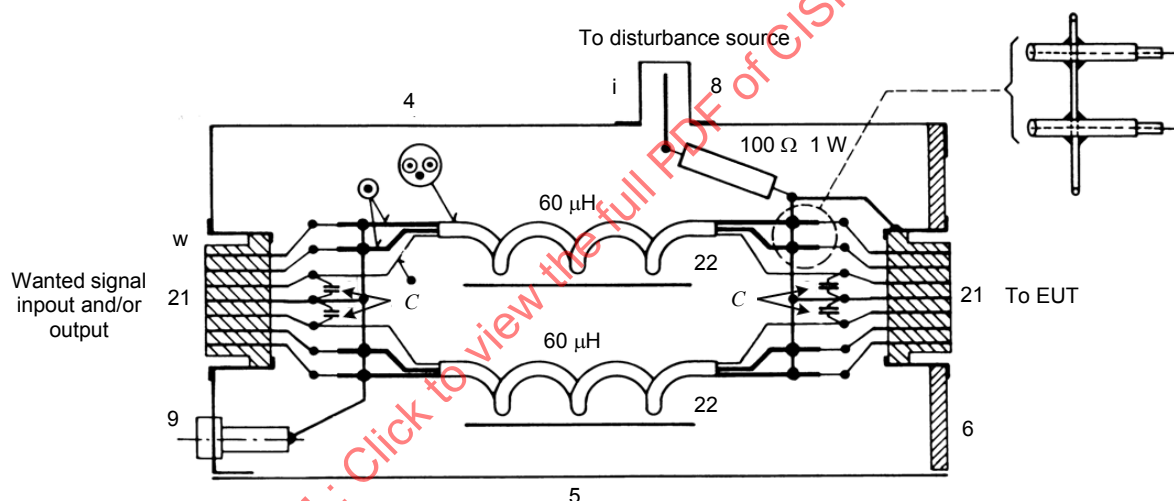
Key

- 4-9 see unit type A
- 19 Cinch or DIN sockets
- 20 inductance of 30 μH :
 Core: one ferrite ring, type 4C6,
 $\varnothing$ 36 mm by $\varnothing$ 23 mm by 15 mm
 Winding: 14 turns with a screened twisted pair:
 outer diameter of cable insulation 2,8 mm
 Mounting of the inductance: see unit type A

**Figure C.4 – Example of coupling unit type Sw, for audio signals.
 Schematic diagram and simplified construction drawing (see D.2)**

C.5 Coupling unit type Sw, for audio, video, and control signals

The circuit diagram and construction are similar to the type Sw unit shown in Figure C.5, except with two 560 μH inductors constructed as described in C.2. The cable with three conductors shall have an outer diameter not larger than 1,5 mm. This may be achieved using two micro-coaxial cables type UT-20 (0,6 mm diameter) and a varnish insulated copper wire of 0,3 mm diameter.



IEC 0494/14

Key

- 4-9 see unit type A
- 21 multiple pins connector (e.g. 7 pins DIN-socket)
- 22 two inductances 60 μH each; for each inductance:
 Core: one ferrite ring, type 4C6,
 $\varnothing$ 36 mm by $\varnothing$ 23 mm by 15 mm
 Winding: 20 turns with a three-lead cable
 Cable: Two micro-coaxial cables, UT-34,
 outer $\varnothing$ 0,9 mm + one copper wire
 $\varnothing$ 0,4 mm, varnish insulated
 outer insulation: tube outer $\varnothing$ 2,4 mm
 Mounting of the inductances: see unit type M
 $C = 1 \text{ nF}$ (or more, if it is acceptable by the signal source)

**Figure C.5 – Example of coupling unit type Sw, for audio, video and control signals,
 schematic diagram and simplified construction drawing (see D.2)**

Annex D (informative)

Principle of operation and examples of coupling units for conducted current immunity measurements

~~(clause 6)~~

NOTE This annex supplements the provisions of Clause 6.

D.1 Principle of operation

The principle of operation is illustrated in Figure D.1. The inductance L presents a high impedance to the injected disturbance current. The filter L/C_2 isolates the test apparatus (wanted signal generator or auxiliary equipment); C_1 and C_2 may be replaced by a short circuit if the a.c./d.c. conditions permit. The disturbance signal delivered from a generator with $50\ \Omega$ internal resistance is injected via a $100\ \Omega$ resistor R_1 and a blocking capacitor C_1 (if required) on to the leads or on to the shield of a coaxial cable.

D.2 Types of unit and their construction

The following types of coupling units are used:

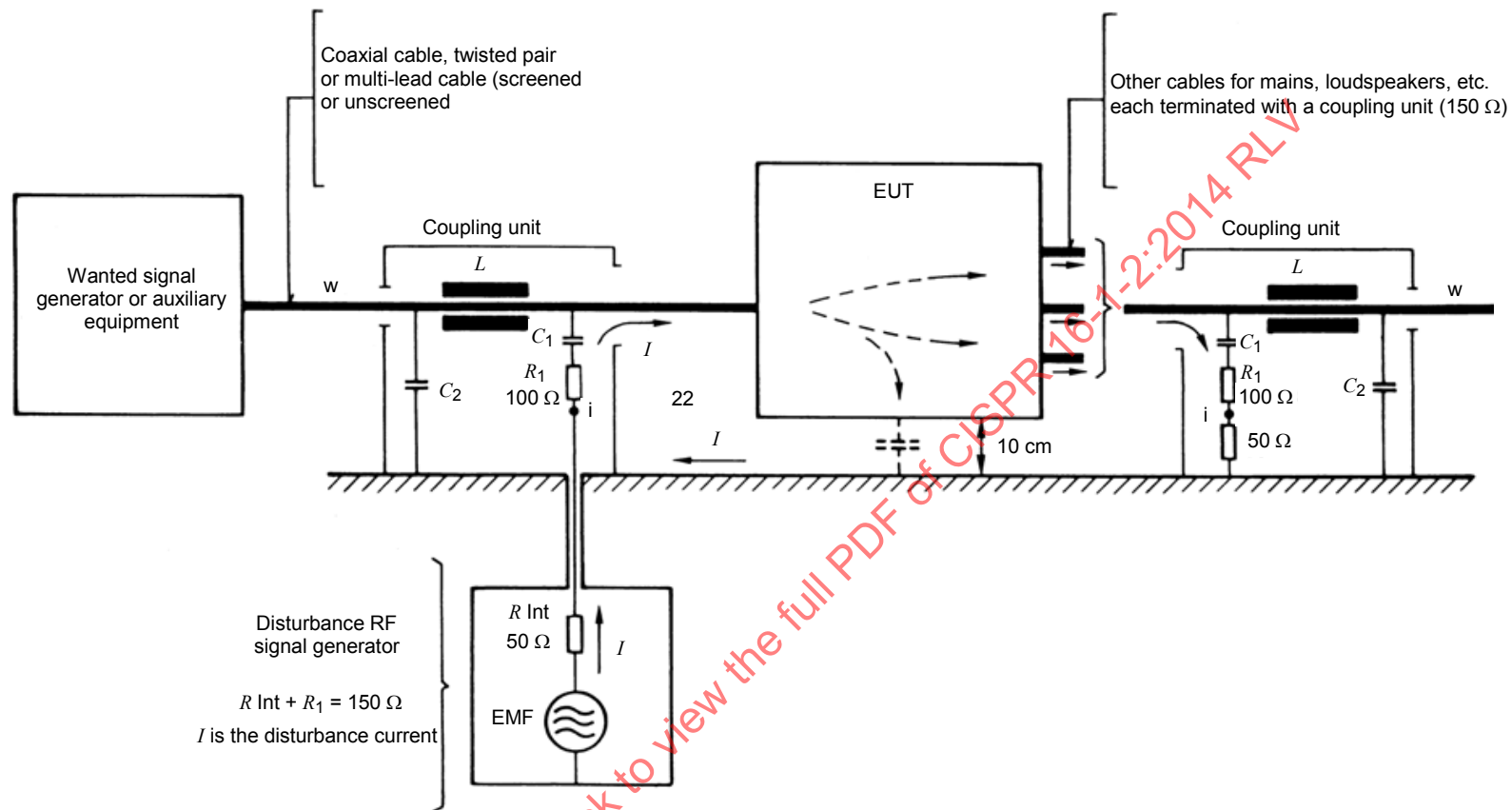
- Type A:** The RF coaxial units are to be used for coaxial leads carrying wanted signals in the RF frequency range. The construction details are shown in Figure C.1. The $100\ \Omega$ resistor (to make up the $150\ \Omega$ source impedance from a $50\ \Omega$ disturbance signal source) is bonded to the shield of the coaxial output connector in the unit.
- Type M:** These are for use with mains leads. The construction details are shown in Figure C.2. The injection of the disturbance current is done asymmetrically on both wires through an equivalent resistance of $100\ \Omega$. This unit is like an artificial mains delta network, and as seen from the EUT terminals, a symmetric and asymmetric equivalent resistive impedance of $150\ \Omega$.
- Type L:** These are for use with loudspeaker leads. The construction details are shown in Figure C.3. The impedance of the disturbance source is arranged as for Type M units.
- Type Sr and Sw:** These are designed for use with audio, video and other auxiliary leads. They are multi-pin units which have to be adapted to a variety of pin numbers and connector configurations, as follows:
- Type Sw:** These units provide a through path for audio, video, control or other signals, in which case filtering is required to ensure that the disturbance signal is directed towards the EUT. The construction details shown in Figure C.4, indicate the simple filtering provided for audio signals with a screened pair wound on a toroid. In the case of multi-lead cables it may be necessary, for construction reasons, to separate the cable leads before winding upon a toroid shown in Figure C.5. In both cases the disturbance current is injected via a $100\ \Omega$ resistor on to the screen and the ground pins of the output connector, the screens of the shielded leads, and through capacitor on to the other (unshielded) leads.
- Type Sr:** These are designed for the case where there is no requirement to provide a through signal path. All leads of the cable are terminated with a matched load resistance. The construction details are shown in Figure D.2. The disturbance current is injected via a $100\ \Omega$ resistor on to the screen (grounding) and the ground pins of the connector, to which point all the load resistors (R_1 to R_n) are connected also. It should be noted that a coupling unit of the type indicated in Figures C.4 or C.5 terminated with a correct load impedance could be used for this purpose.

If the source impedance of the disturbance generator is not $50\ \Omega$, the value of the series resistor is adjusted accordingly to make up the required $150\ \Omega$ impedance.

The RF choke coils shown in Figures C.1 to D.2 have inductance values $30\ \mu\text{H}$ or two $60\ \mu\text{H}$ chokes in parallel, and are satisfactory for the frequency range $1,5\ \text{MHz}$ to $150\ \text{MHz}$. For the frequency range $0,15\ \text{MHz}$ to $30\ \text{MHz}$, the inductance values are $280\ \mu\text{H}$ or two $560\ \mu\text{H}$ chokes in parallel respectively. Annex C describes their construction.

Precautions ~~have to~~ should be taken in the layout to keep parasitic capacitance to the output terminals of the units as low as possible. It should be noted that the metal cases of the units are to be carefully connected to the ground plane using large section copper braid and unpainted cases.

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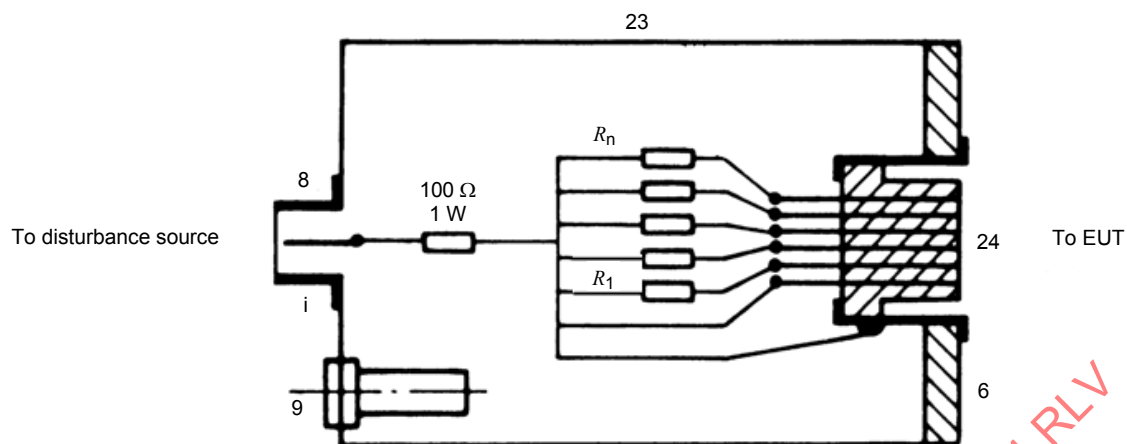
IEC 0495/14

Key

L isolating inductance

C_1, C_2 capacitors with low RF impedance (if the a.c. d.c. conditions allow this, capacitors should be replaced by a direct connection)

Figure D.1 – General principle of the current-injection method (see D.1)



IEC 0496/14

Key

- 6, 8, 9 see unit type A
 23 is the metallic case 100 mm by 55 mm by 55 mm
 24 is the multiple-pin conductor or DIN-socket
 R_1 to R_n are the matched load resistances.

Example – Coupling units type Sr for audio equipment

Phonograph	Magnetic: $2 \times 2,2\ \text{k}\Omega$ Crystal: $2 \times 470\ \text{k}\Omega$
Microphone	$2 \times 600\ \Omega$
Tuner	$2 \times 47\ \text{k}\Omega$
Tape recorder	$4 \times 47\ \text{k}\Omega$
Audio in/out	$4 \times 47\ \text{k}\Omega$

Figure D.2 – Coupling unit type Sr with load resistances – Schematic diagram and simplified construction drawing (see D.2)

Annex E (normative)

Example and measurement of the parameters of the asymmetric artificial network (AAN)

E.1 Description of an example of an AAN: the T-network

Figure E.1 gives an example of an AAN, the T-network, having terminals a_1 and b_1 for connection to a conductor pair in a signal port of an EUT and RG for connection to the reference ground and, if applicable, to the safety earth or other ground connector of the EUT.

The symmetric signal which may be needed to have the EUT operating correctly is connected to the terminals a_2 and b_2 . The double choke L_1 allows separate measurement of the asymmetric component of the disturbance. The two windings are designed such that the symmetric currents are suppressed by a high impedance, whereas the impedance for asymmetric currents (passing to R_M) shall be negligible.

The termination impedance of the network for the asymmetric disturbance voltage of $150\ \Omega$ is determined by the two resistors R_T ($200\ \Omega$), in parallel for the asymmetric current, in series with the resistor R_M ($50\ \Omega$). The resistor R_M is usually the input impedance of a measuring receiver. In this case the meter reading is typically 9,5 dB lower than the actual asymmetric value at the terminal of the EUT. The capacitor C_T blocks d.c. currents, thus allowing for d.c. supply voltages on the network leads without damaging the resistors and without affecting the properties of L_1 , due to saturation.

Normally an AAN is inserted between an EUT and its associated equipment.

E.2 Measurements of the parameters of an asymmetric artificial network (AAN)

For the determination of compliance with the requirements of 7.1, the procedures for the measurement of the specified parameters described below are used.

a) Termination impedance

This impedance between the terminals a_1 and b_1 connected together, and terminal RG shall be checked with terminals a_2 and b_2 being alternatively open and short-circuited to the ground terminal RG (see Figure E.2).

b) Longitudinal conversion loss (LCL)

This rejection of the Y-network shall be measured in accordance with Figure E.5. The network analyzer (NWA) applies its output signal to an LCL probe, which ~~must~~ shall have a residual longitudinal conversion loss (LCL) at least 10 dB higher than the required LCL of the AAN. For LCL probe verification, see Figure E.3, and for calibration, see Figure E.4.

c) Decoupling attenuation

The decoupling attenuation shall be measured in accordance with Figure E.6.

d) Insertion loss of the symmetric circuit

The insertion loss of the symmetric circuit shall be measured in accordance with Figure E.7.

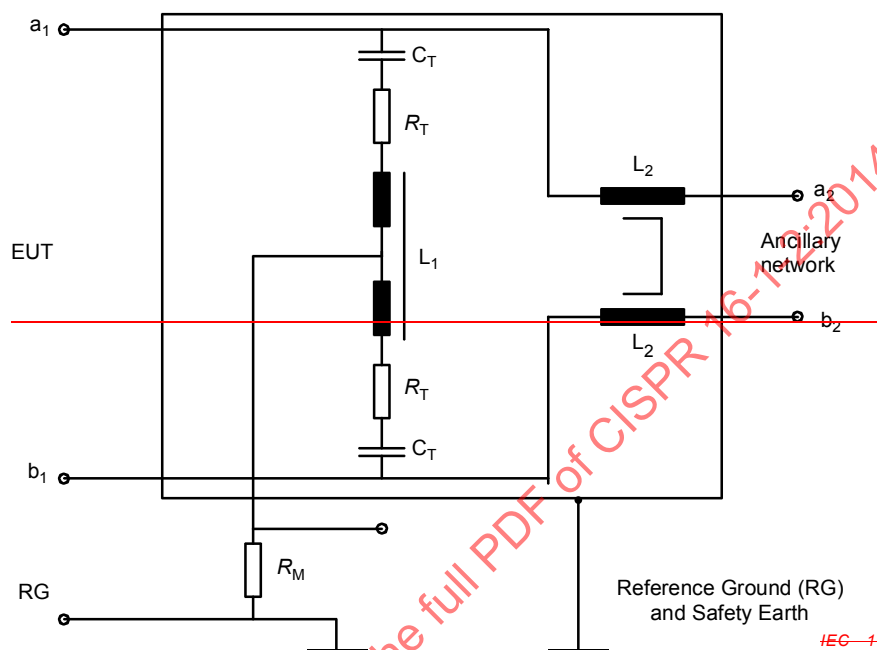
Two LCL probes can be used as baluns for the insertion loss test of the Y-network. Two identical baluns may be connected in series for the determination of their own insertion loss. Baluns can be designed such that the combined insertion loss of two baluns is less than 1 dB in the frequency range from 0,15 MHz to 30 MHz.

e) **Voltage division factor of the asymmetric circuit (calibration of the Y-network)**

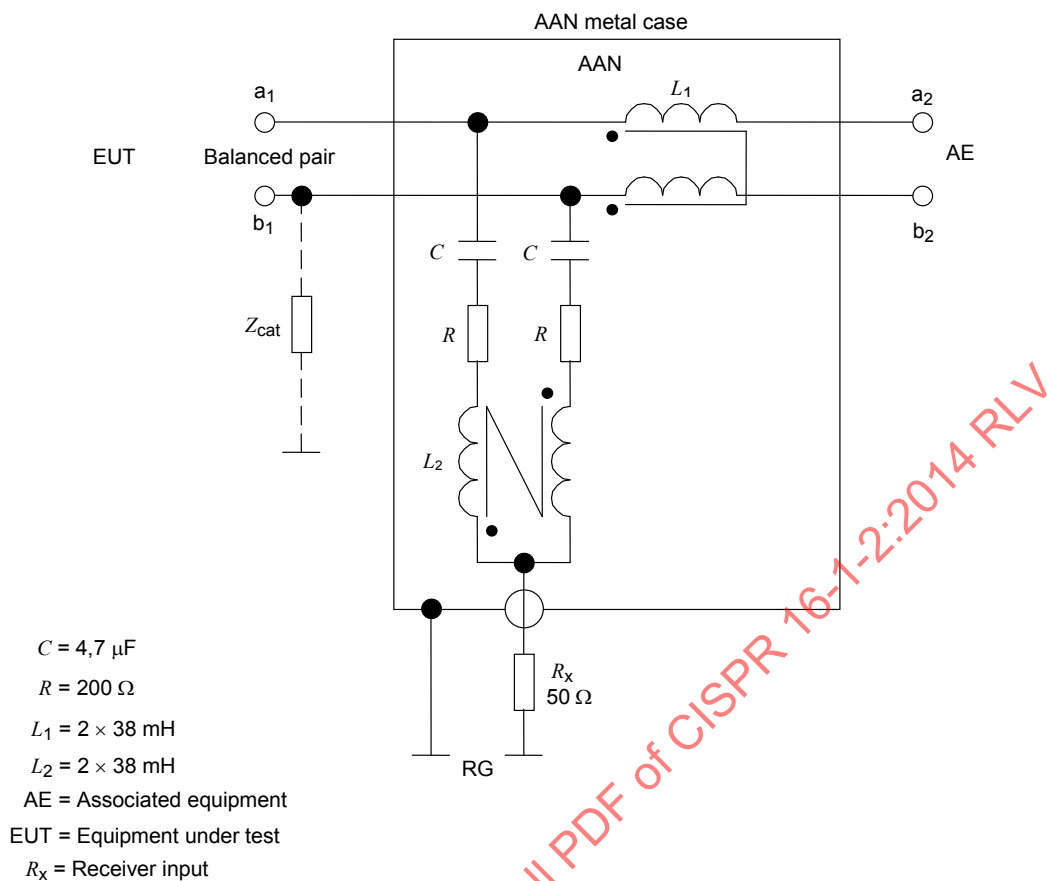
The voltage division factor of the asymmetric circuit shall be measured in accordance with Figure E.8.

f) **Symmetric load impedance and transmission bandwidth**

This parameter is defined by the system. Y-networks may be optimized for a certain impedance with respect to transmission bandwidth. The transmission bandwidth may be measured for a certain symmetric load impedance using the test set-up of Figure E.7.



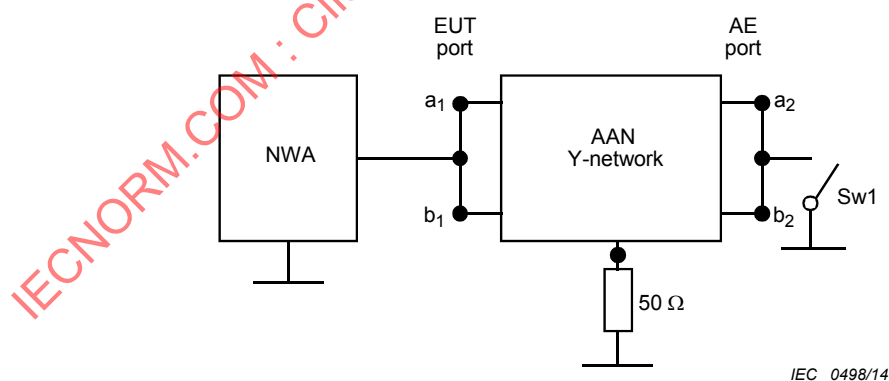
IEC-1116/03



NOTE 1 Nominal voltage division = 9,5 dB.

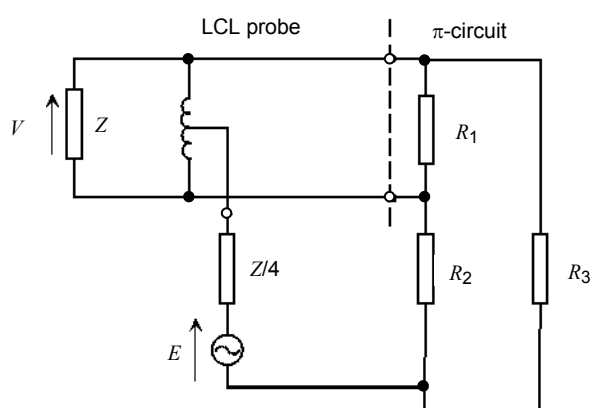
NOTE 2 Z_{cat} represents the unbalance network used to adjust the LCL.

Figure E.1 – Example of a T-network circuit for one pair of wires



NOTE If the AAN is of higher order (i.e. more than one pair of wires), then all wires of the EUT port, respectively all wires of the AE port, are connected together.

Figure E.2 – Arrangement for the termination impedance measurement



IEC 0499/14

NOTE 1 When terminated with a minimum LCL π -circuit consisting of R_1 , R_2 and R_3 ($R_2 \neq R_3$), which includes both the nominal symmetric impedance $Z (= \frac{R_1(R_2 + R_3)}{R_1 + R_2 + R_3})$ of the AAN and the asymmetric impedance of $150 \Omega (=$

$\frac{R_2 R_3}{R_2 + R_3}$), the probe ~~should~~ ideally shows a residual LCL of 20 dB or higher than the highest LCL to be measured.

For $Z = 100 \Omega$: $R_1 = 120 \Omega$ and $R_2 = R_3 = 300 \Omega$.

NOTE 2 The LCL probe ~~should be operated~~ operates with an asymmetric source impedance of $Z/4$.

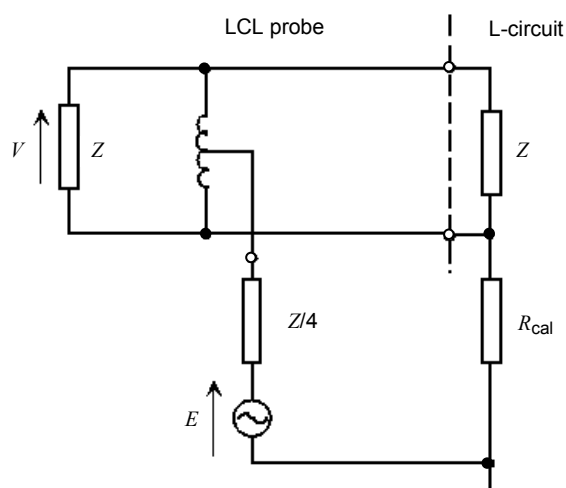
NOTE 3 For $Z = 100 \Omega$, $Z/4$ equals 25Ω .

NOTE 4 For optimum reproducibility, the LCL of the probe ~~should be~~ is maximized for both orientations of the π -circuit relative to the balanced terminals of the LCL probe.

NOTE 5 Definition: longitudinal conversion loss (LCL) $= 20 \lg \left| \frac{E}{V} \right|$ in dB (according to ITU-T Recommendation G.117 [7])

The LCL probe ~~should be~~ is so constructed that the LCL can be measured using ordinary network analyzers. An example LCL probe is described in [9].

Figure E.3 – Arrangement for LCL probe verification



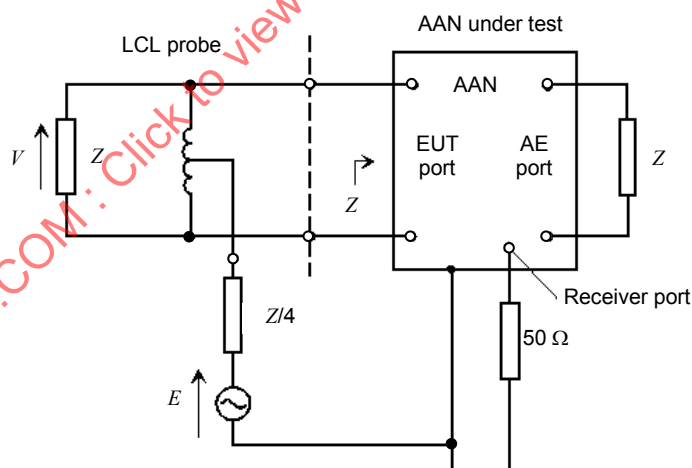
NOTE 1 LCL of the L-circuit: $a_{LCL} = 20 \lg \left| \frac{(R_{sym} // Z) + 4R_{cal} + Z}{2(R_{sym} // Z)} \right| \text{ dB}$

NOTE 2 The LCL measurement uncertainty per Figure E.5 is influenced by the accuracy of the L-circuit and the amount of the residual LCL of the probe. Changing the orientation of the LCL probe relative to the L-circuit will show some uncertainty of calibration.

NOTE 3 Example of an L-circuit:

For an impedance $Z = 100 \, \Omega$ and $R_{sym} = 100 \, \Omega$, a value $R_{cal} = 750 \, \Omega$ will give an LCL of 29,97 dB, i.e. approximately 30 dB.

Figure E.4 – Test Arrangement for the LCL probe calibration using an L-circuit

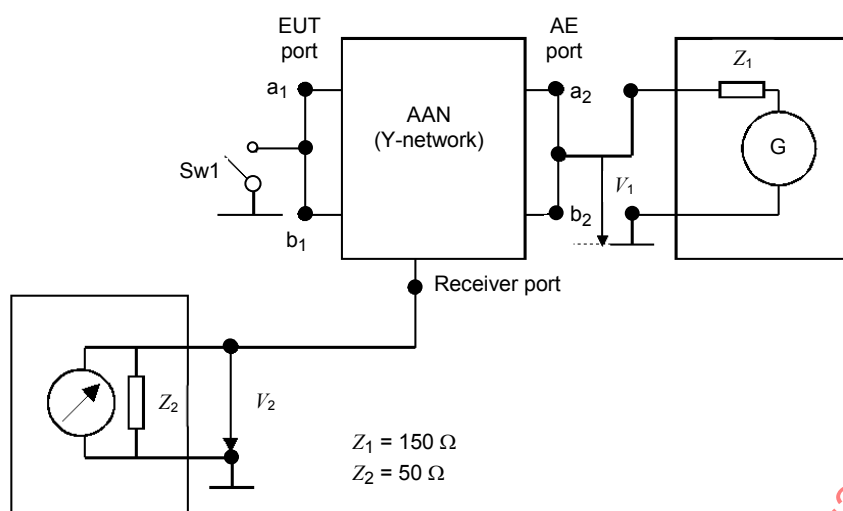


NOTE 1 For the definition of LCL, see Figure E.3a3.

NOTE 2 Depending on the closeness between the LCL to be measured and the residual LCL of the probe, a measurement with both orientations of the LCL probe, relative to the EUT port terminals and the determination of the mean value of the two results, ~~may~~ can improve the accuracy of the test.

NOTE 3 If the AAN is of higher order (i.e. more than one pair of wires), then the LCL of each pair is tested, while the other pair(s) is (are) terminated with the common mode impedance Z in case of any influence on the measured pair.

Figure E.5 – Test arrangement for the LCL measurement of the AAN



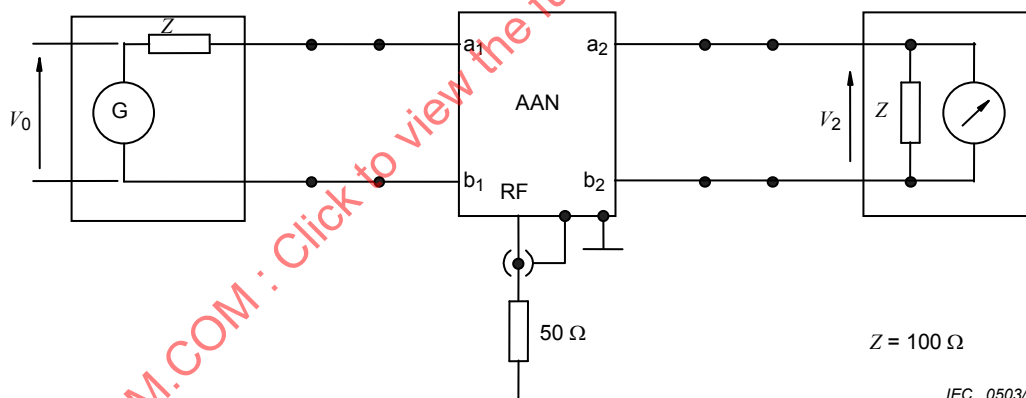
IEC 0502/14

The decoupling attenuation specification shall be met in both positions of Sw1 (short and open). If the AAN is of higher order (i.e. more than 1 pair of wires), then all wires of the EUT port, respectively all wires of the AE port, are connected together. ~~a_{vdiv} is the voltage division factor as measured in accordance with Figure E.6.~~

NOTE — If the AAN is of higher order (i.e. more than 1 pair of wires), then each pair shall be tested separately.

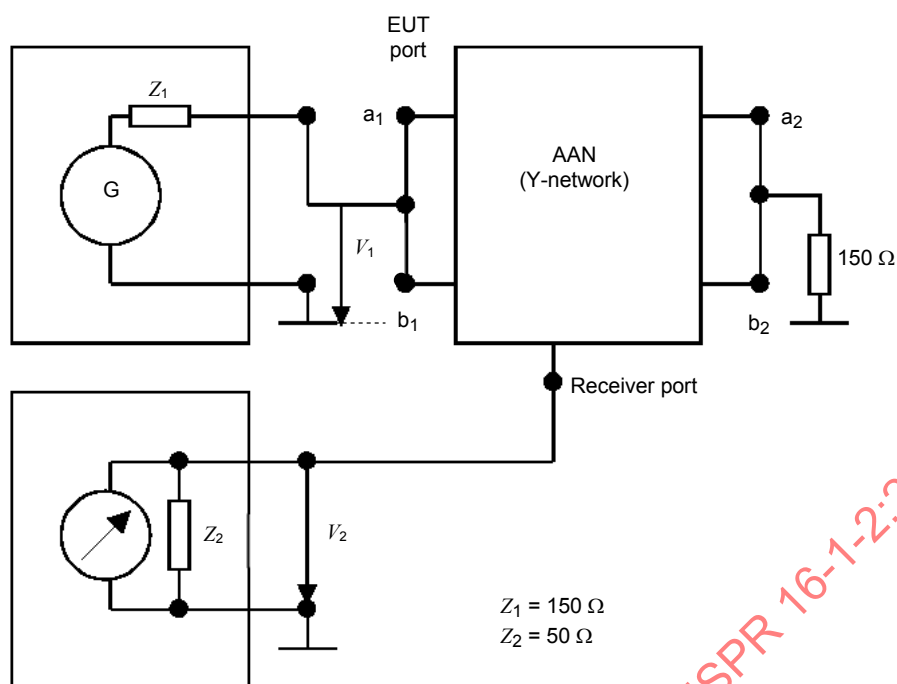
Figure E.6 – Test set-up for the decoupling attenuation (isolation) of the AAN

$$a_{\text{decoup}} = 20 \lg \left| \frac{V_1}{V_2} \right| - a_{\text{vdiv}} \text{ in dB for asymmetric signals between AE port and EUT port}$$



IEC 0503/14

Figure E.7 – Test set-up for the insertion loss (symmetric) of the AAN



IEC 0504/14

NOTE If the AAN is of higher order (i.e. more than one pair of wires), then all wires of the EUT port respectively all wires of the AE port are connected together.

Figure E.8 – Calibration test set-up for the AAN voltage division factor

of the asymmetric circuit: $F_{\text{AAN}} = a_{\text{vdiv}} = 20 \lg \left| \frac{V_1}{V_2} \right|$ in dB

E.3 Reference documents

- [1] [1] — MACFARLANE, J.P. A Probe for the Measurement of Electrical Unbalance of Networks and Devices. *IEEE Trans. EMC*, Feb. 1999, Vol.41, No.1, p.3-14.

Annex F (normative)

Example and measurement of the parameters of the AN for coaxial and other screened cables

F.1 Description of ANs for coaxial and other screened cables

Figure F.1 gives an example of a coaxial cable AN employing internal common-mode chokes created by miniature coaxial cable (miniature semi-rigid solid copper screen or miniature double-braided screen coaxial cable) wound on ferrite toroids.

In cases where high shielding attenuation is not required, the internal common-mode choke(s) can also be created using bifilar windings of an insulated centre-conductor wire and an insulated screen-conductor wire on a common magnetic core (e.g. a ferrite toroid).

For multi-conductor screened cables, the internal common-mode choke can be created using either multifilar windings of insulated signal wires and an insulated screen-conductor wire, or by winding a multi-conductor screened cable on a common-mode magnetic core.

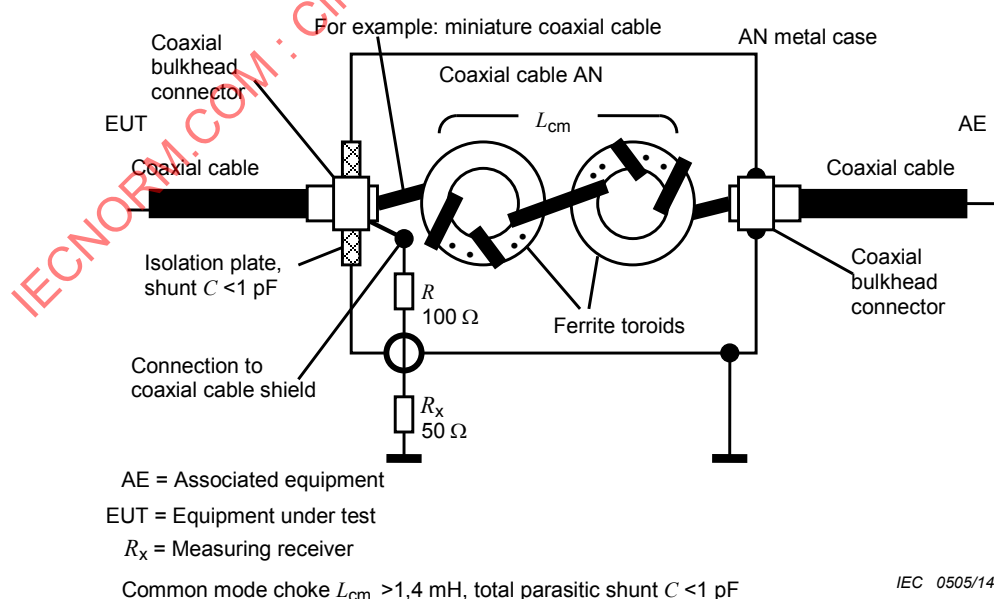
F.2 Measurements of parameters of an AN for coaxial and other screened cables

a) Termination impedance

The impedance between the coaxial screen on the bulkhead connector (with no EUT cable attached) and the reference-ground connector shall be measured with the receiver port terminated with 50 Ω load.

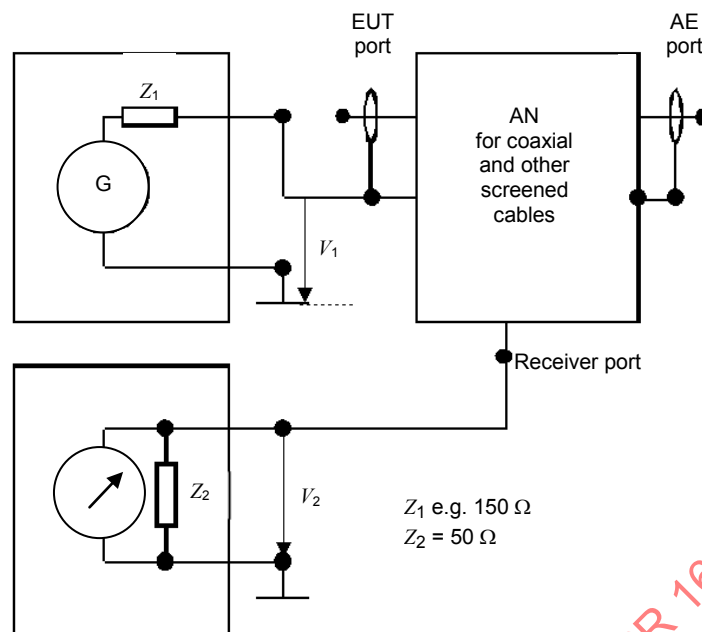
b) Voltage-division factor

The voltage division factor of the AN shall be measured in accordance with the set-up of Figure F.2.



IEC 0505/14

Figure F.1 – Example of a coaxial cable AN



IEC 0506/14

Figure F.2 – Test set-up for the coaxial and screened cable AN

voltage division factor $a_{\text{div}, \text{AN}} = 20 \lg \left| \frac{V_1}{V_2} \right|$ in dB

Annex G (informative)

Construction and evaluation of capacitive voltage probe

NOTE This annex supplements the provisions of 5.2.2.

G.1 General

This annex provides an example of a method for the calibration of the capacitive voltage probe (CVP). Other calibration methods can be used if their uncertainty is considered to be equivalent to that of the method shown in this annex.

G.2 Physical and electrical considerations for CVP

Figure G.1 shows the configuration of a CVP. A CVP consists of two coaxial electrodes, a grounding terminal, a cable fixture, and a trans-impedance amplifier. The outer electrode is used as an electrostatic shield to reduce the measurement error caused by electrostatic coupling from cables running alongside.

The equivalent circuit of the probe is shown in Figure G.2. When a voltage exists between the cable and the ground, an induced voltage occurs between the inner electrode and the outer electrode as a result of electrostatic induction. This voltage is detected by a high impedance input amplifier and converted to low impedance by a trans-impedance amplifier. The output is measured by a measuring receiver.

G.3 Determination of the frequency response of the voltage division factor

Figure G.3 shows the test set-up used to determine the frequency response of a CVP. A CVP is verified according to the following procedures.

- a) Prepare the same type of cable that is used with the EUT.

NOTE 1 If several types of cable are used with the CVP, a representative variety of cable types is used in the calibration, and the spread of results determined. The voltage division factor (F_{CVP}) can be estimated by using Equation (G.3), however, the F_{CVP} for each cable is measured.

- b) Place the calibration fixture on the reference ground plane, as shown in Figure G.3.
- c) Connect both ends of the cable to the inner ports of the calibration fixture (port-1, port-2) (see Figure G.3).
- d) Place the CVP in the calibration unit and adjust the position of the cable to pass through the centre.

NOTE 2 If the ends of plates of the calibration fixture are too close to the ends of the CVP, the stray capacitance is increased, which can adversely affect the calibration at higher frequencies. If the end plates of the calibration fixture get too far from the ends of the CVP, a standing wave can be formed within the calibration fixture at higher frequencies. These standing waves can adversely affect the calibration.

- e) Connect the grounding port of the CVP to the inner grounding port of the calibration fixture. Connect the outer grounding port of the calibration fixture to the reference ground plane. The grounding strip should have low inductance, be as short as possible and kept away from the CVP aperture.
- f) Connect a signal generator, with an output impedance of 50 Ω , to the outer port of the port-1 through a 10 dB attenuator.
- g) Connect a level meter, with an input impedance of 50 Ω , to the outer port of port-2 and terminate the output port of the CVP in 50 Ω load. Measure the level V over a specified frequency range.

- h) Connect the level meter to the output port of the CVP and terminate the outer port of the port-2 by a $50\ \Omega$ load. Measure the level V_m over a specified frequency range.
- i) Calculate the voltage division factor $F_{CVP} = 20 \lg |V/V_m|$ in dB from the measured values.

G.4 Method of measurement to determine the influence of external electric fields

G.4.1 Influence of external electric field

The influence of the external electric field appears via electrostatic coupling with other cables close to the probe. Figure G.4 shows the electrostatic coupling models and their equivalent circuits. Both the asymmetric voltage V_x on cable 2 and the voltage V on cable 1 appear at the input terminal of the high impedance voltage probe through the capacitance C_x and C as shown in Figure G.4 a). An electrostatic shield shall be used to reduce the coupling due to C_x . However, the influence of the external electric field due to the electrostatic coupling between the outer electrode and other cable (C_x') still remains because of the imperfection of the electrostatic shield, as shown in Figure G.4 b). Subclause G.4.2 provides the measurement procedure for evaluating the influence of the electrostatic coupling between outer electrode and other cable. Furthermore, it should be noted that the voltage V is affected by V_x unless $|Z_s| \ll |1/(j\omega C_c)|$.

G.4.2 Method of measurement to determine the influence of the external electric field

The influence of an external electric field caused by electrostatic coupling due to limited electrostatic shielding is measured using the test set-up shown in Figure G.5. The measurement procedure is as follows;

- a) Measure the voltage division factor, $F_{CVP} = 20 \lg |V/V_m|$, using the method in G.3.
- b) Place the CVP beside the cable, at a distance “s” equal to 1 cm (see Figure G.5).
- c) Connect the grounding port of the probe to the inner grounding port of the unit. Connect the outer grounding port of the unit to the reference ground plane.
- d) Connect a signal generator with a $50\ \Omega$ output impedance to the outer port of the port-1 through a 10 dB attenuator.
- e) Connect a measuring receiver with a $50\ \Omega$ input impedance to the outer port of the port-2 and terminate the output port of the probe by $50\ \Omega$. Measure the level V_s over a specified frequency range.
- f) Connect the measuring receiver to the output port of the probe and terminate the outer port of the port-2 by $50\ \Omega$. Measure the level V_{sm} over a specified frequency range.
- g) The reduction of the influence is defined as $F_s = F_{CVP}/(V_s/V_{sm})$ from the measured values.

G.5 Pulse response

A CVP is constructed as part of the measuring system which includes the measuring receiver. It does not affect the performance of the measuring receiver described in Clause 4. The probe response to pulses shall be measured because a CVP contains an active circuit. The response is measured using the pulse generator as described in Annexes B and C of CISPR 16-1-1:2010 for Band B.

It is difficult to measure the pulse response using a pulse generator. The pulse capability of the probe is tested to measure the linearity using a CW signal whose peak value is the same as the peak value of the pulse. This can be accomplished because the probe does not contain a detector and band-pass filter. The attenuator can be necessary to minimize the amplitude of the reflected signal, due to the use of coaxial cable between the signal generator and the test fixture. If it is not necessary to stabilize the frequency response, the attenuator is not needed.

The impulse area of the pulse generator signal is 0,316 mVs from 0,15 MHz to 30 MHz as shown in Table B.1 of CISPR 16-1-1:2010. The spectrum of the pulse generator signal is practically constant up to 30 MHz. The pulse width, τ , is approximately given by

$$\tau = \frac{1}{\pi f_m} \quad (G.1)$$

With $f_m = 30$ MHz, $\tau = 0,0106 \mu\text{s}$.

The amplitude of the pulse, A , is given by

$$A = 0,316/\tau = 29,8 \text{ V} \quad (G.2)$$

This indicates that the CVP should maintain linearity up to 30 V.

The linearity is tested by measuring the voltage division factor, F_{CVP} , when the amplitude of the signal generator is varied up to 30 V.

G.6 Voltage division factor dependence

The voltage division factor of the CVP depends on the radius and the position of the cable under test in the inner electrode of the CVP. Although the value of the voltage division factor is needed for disturbances measurements, calculation of the factor for any type of cable may be difficult. An investigation was performed to evaluate the influence of the cable configuration on the voltage division factor, and is described in the following paragraphs.

The voltage division factor dependencies were investigated using measurements and a theoretical analysis. Figure G.6 shows the voltage division factor deviation when the cable position changes in the electrode. The cable is replaced with a copper rod in the experiment. The horizontal axis indicates the separation ratio, $g/(b-a)$. The solid line represents the calculation results obtained from the capacitance variation between the inner electrode and cable, and the dots are the measured values. As a result, the measurement data agrees well with the calculated data. The sensitivity of the CVP, however, does not depend on the variation of the cable position in the inner electrode up to a separation ratio of 0,8. Thus, to minimize measurement errors, the cable under test shall be adjusted to pass the centre of the CVP.

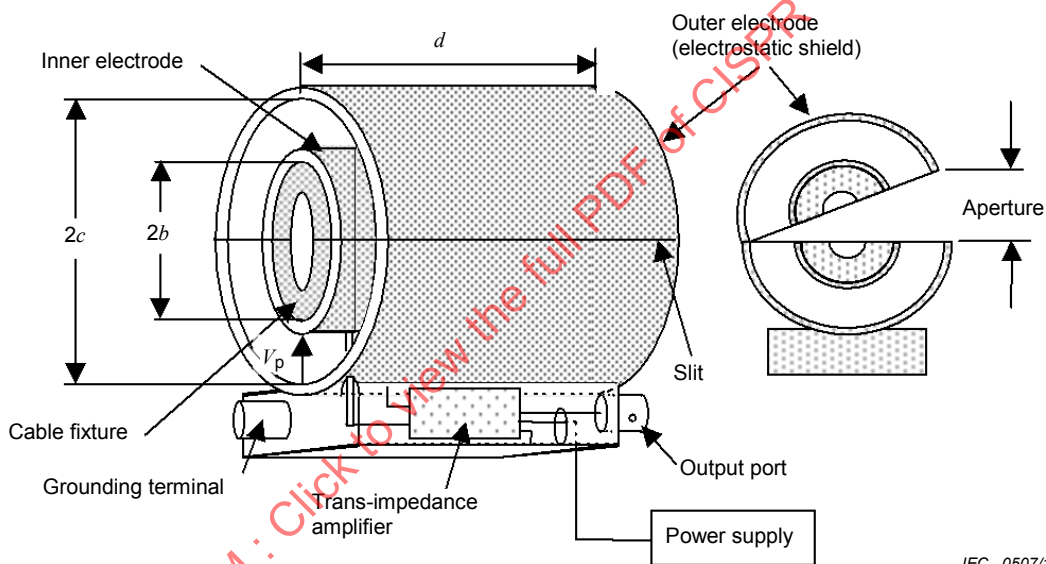
Figure G.7 shows the cable radius dependence. The vertical axis shows the deviation of the voltage division factor F_{CVP} . The solid line shows the calculated results using the following equation:

$$F_{\text{CVP}} = \frac{\left\{ 1 + \frac{1}{C_p} \frac{2\pi\epsilon}{\ln(b/a)} d \right\}}{\left\{ 1 + \frac{1}{C_p} \frac{2\pi\epsilon}{\ln(b/a_{\text{ref}})} d \right\}} \quad (G.3)$$

where

- ε is the dielectric constant;
- a_{ref} is the cable radius used for reference;
- C_p is the gain of the trans-impedance amplifier, obtained from the measurement;
- b and d are defined in Figure G.1.

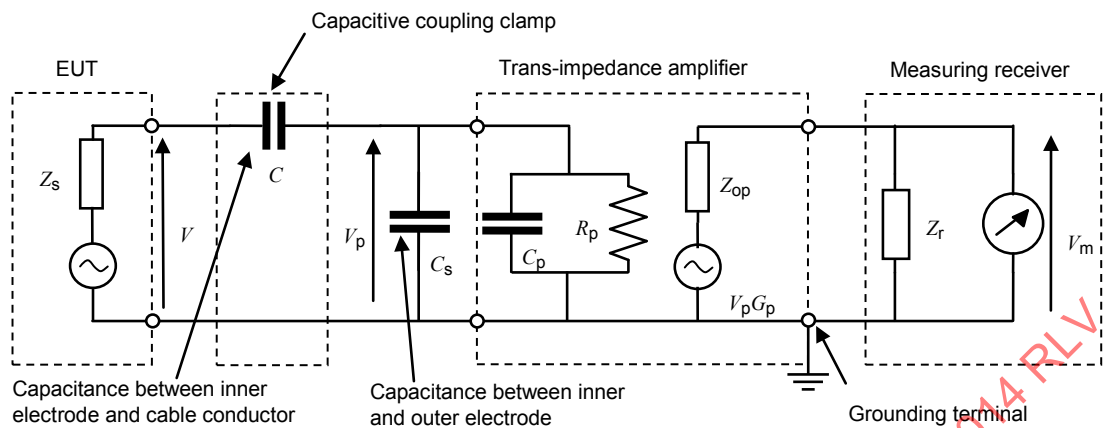
The plotted values show the measurement results for several cables. The equivalent radius of each cable is evaluated with respect to the surface area of each wire included in the cable and compared to the surface area of a copper rod. The number of wires in the cable was changed from 1 to 12. Figure G.7 indicates that the calculated results agree well with the measured result using the copper rod. Thus the deviation between the measured results for actual cable and the calculated value is within 2 dB. This result shows that the voltage division factor can be approximately calculated by Equation (G.3) using the surface area of each cable.



Caution:

- 1) The cable fixture is used to centre the cable under test inside the probe. This item can act as a dielectric, which will increase capacitance between the cable under test and the voltage probe inner electrode.
- 2) Isolation from the external electric field is needed to keep pickup on the power supply leads from coupling into the voltage probe circuitry.

Figure G.1 – Configuration of a CVP



IEC 0508/14

Typical values for the configuration shown in Figure G.1

b 25 mm

c 55 mm

d 100 mm

C 8 pF

(Cable diameter is 26 mm)

C_s 7 pF

C_p 5 pF

R_p 1 M Ω

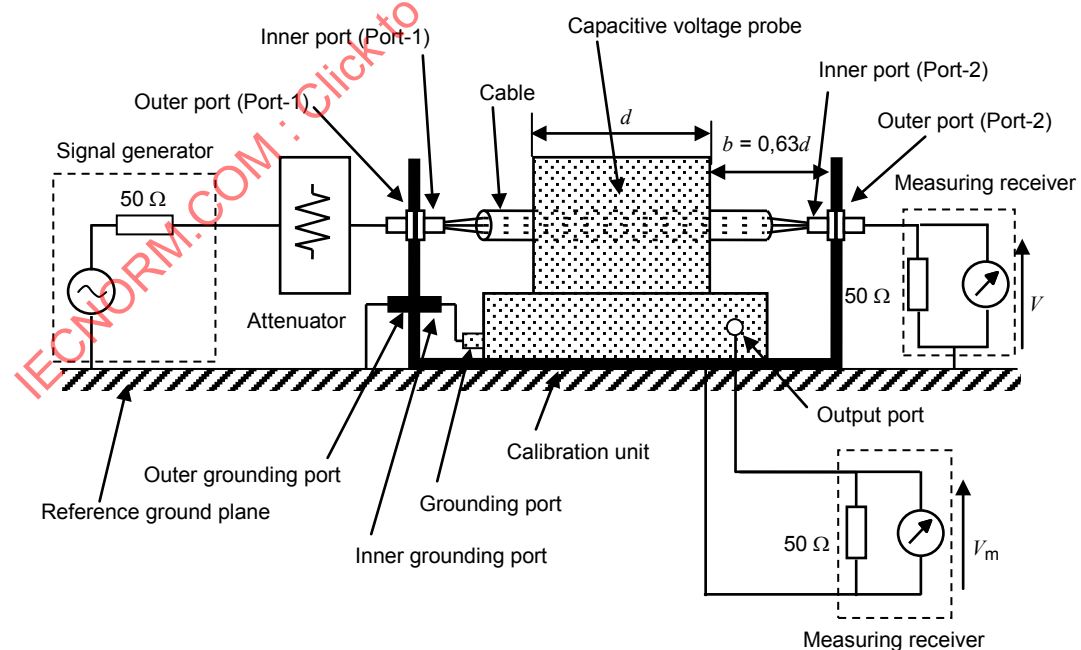
$|Z_s| \ll |1/(j\omega C)|$

$R_p \gg |1/(j\omega(C_s + C_p))|$

$Z_{op} = Z_r = 50 \Omega$

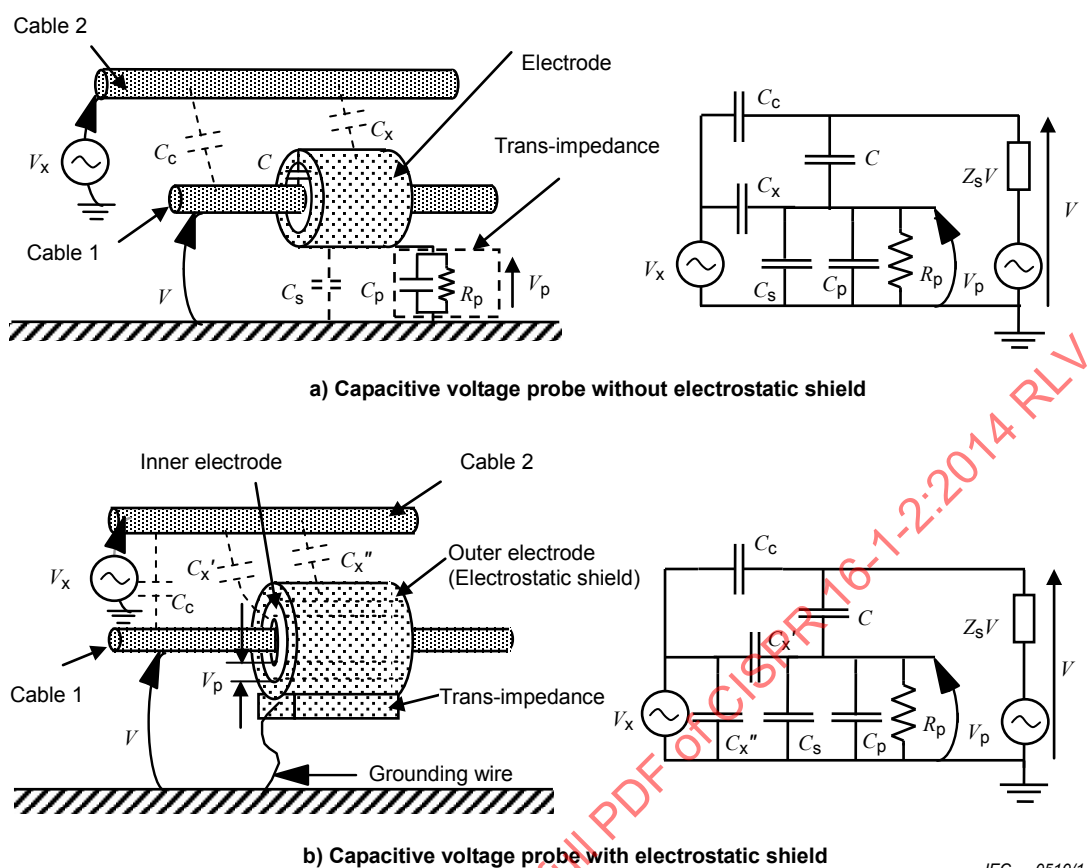
Typical values are not required/specified values, and other combinations consistent with "Characteristics" of 5.1.3 are acceptable.

Figure G.2 – Equivalent circuit of a CVP



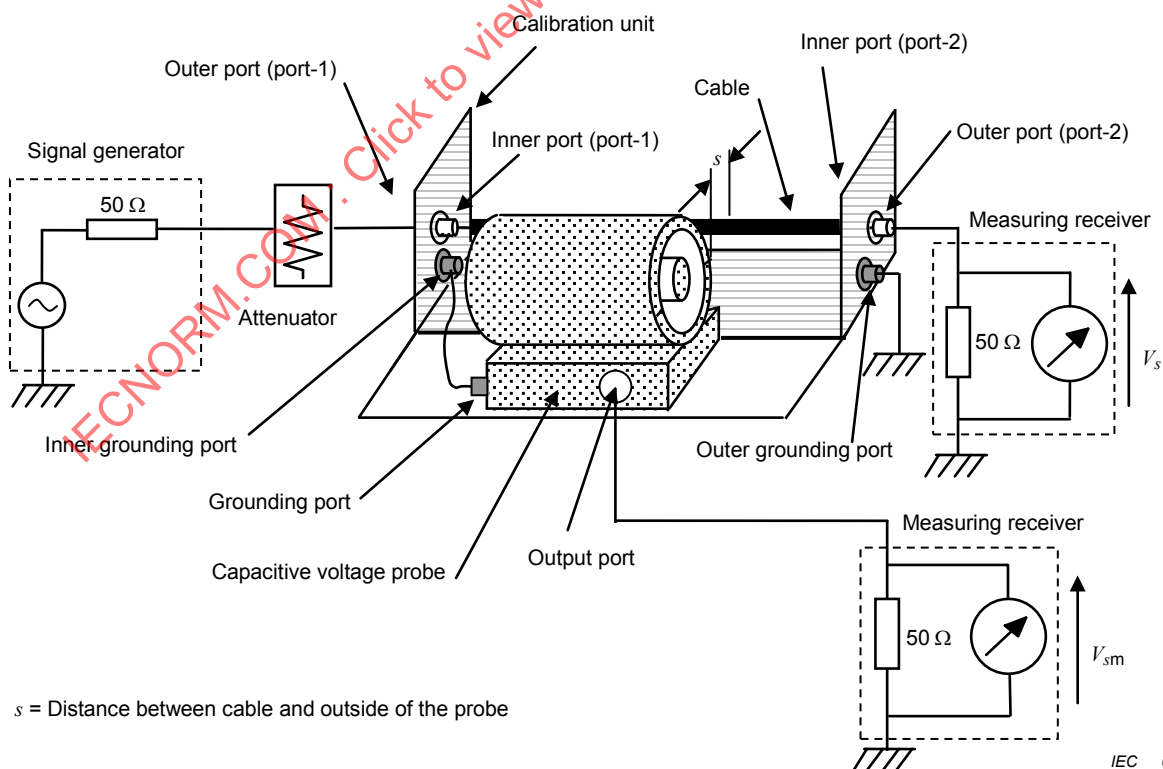
IEC 0509/14

Figure G.3 – Test set-up to measure the frequency response



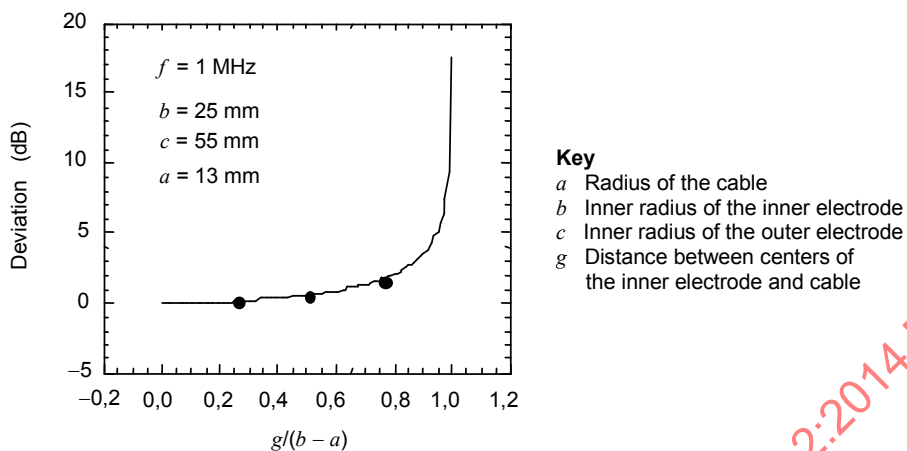
IEC 0510/14

Figure G.4 – Electrostatic coupling model and its equivalent circuit



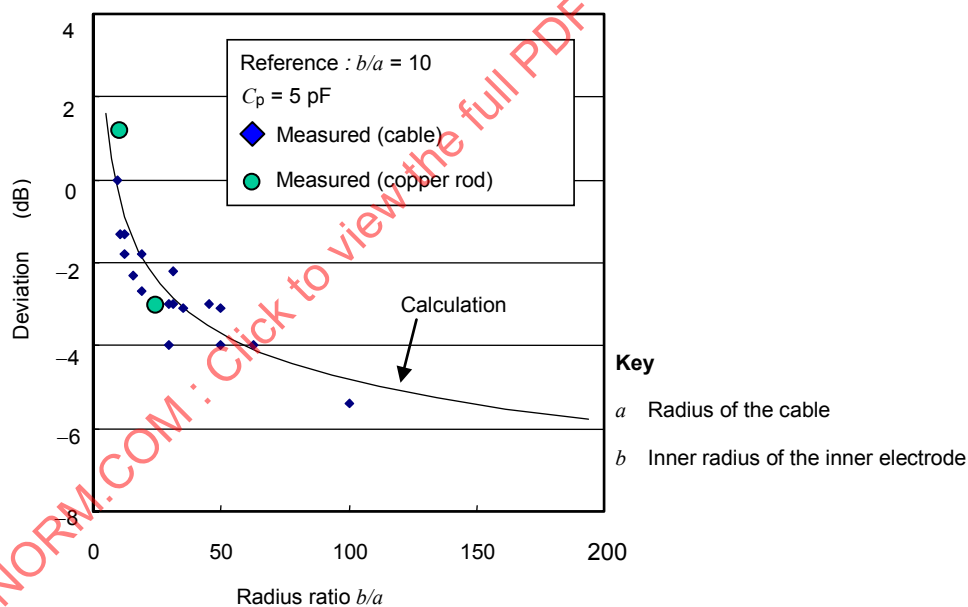
IEC 0511/14

Figure G.5 – Test set-up to measure the reduction, through the shielding effect, of the influence of the external electric field caused by electrostatic coupling



IEC 0512/14

Figure G.6 – Conversion factor deviation when cable position is changed



IEC 0513/14

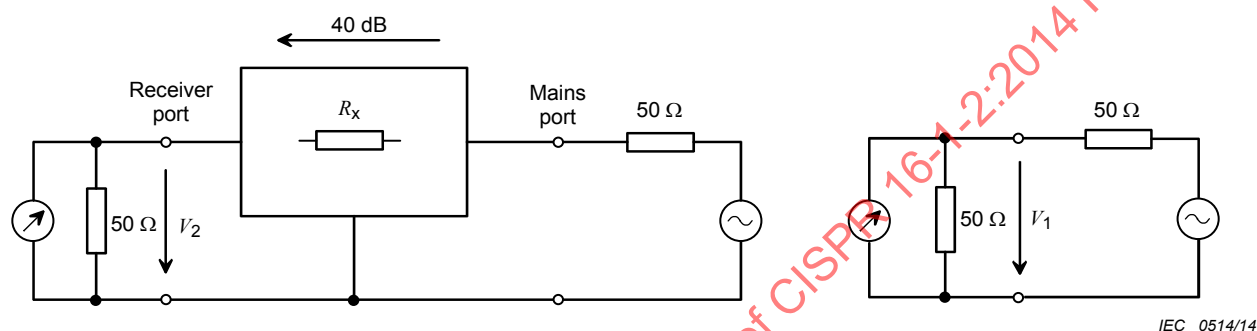
NOTE The vertical axis shows the deviation of the voltage division factor (F_{CVP}) from the calculated value when b/a is 10.

Figure G.7 – Investigation result of the cable radius dependence

Annex H (informative)

Rationale for the introduction of a minimum decoupling factor between mains and EUT/receiver ports for the V-AMN

For the purpose of reducing the influence of the unknown actual mains impedance on the V-AMN impedance, a minimum decoupling factor (isolation) between the mains port and the receiver port for a given termination of the EUT port may be specified. Differences between the various types of V-AMN have to be taken into consideration.



NOTE V_1 is measured separately by terminating the source with 50 Ω. V_2 could be defined either at the EUT port or at the receiver port; in 4.8.2 it was decided to be defined at the receiver port.

Figure H.1 – Isolation measurement arrangement

A value of 40 dB of isolation [$20 \lg (V_1/V_2)$] is fulfilled if e.g. $R_x = 4\,950\, \Omega$. If the impedance at the power port is then short or open, the impedance variation at the EUT port will be 1 %. Consequently, to keep the influence of the mains impedance on the AMN impedance below 1 %, a 40 dB isolation is needed (the detailed measurement procedure is given in 4.8). The uncertainty calculations in CISPR 16-4-2 are based on an impedance tolerance of 20 % and no influence from the mains port. It is not possible to guarantee no influence. However with 40 dB isolation, 1 % of the tolerance is left for the influence of the mains port, i.e. if, for example, the uncertainty contribution of the AMN impedance tolerance is 2,6 dB, the uncertainty contribution of the unknown mains port termination is in the order of 0,13 dB (included in the amount of 2,6 dB – not to be added).

In addition, the 40 dB isolation helps to limit the effect of the mains port termination on the voltage division factor and helps to keep disturbance from the mains port below a critical level. Further suppression can be achieved by additional filtering.

Remarks from manufacturers have shown that the value of 40 dB can easily be achieved if not yet fulfilled by the addition of e.g. a capacitor between the mains port terminal and ground.

Annex I (informative)

Rationale for the introduction of a phase tolerance for the V-AMN input impedance

For CISPR 16-4-2, the amount of U_{CISPR} was calculated based on the assumption of an “uncertainty circle” ΔZ_{in} (see Figure I.1), which can also be redefined as an impedance tolerance circle.

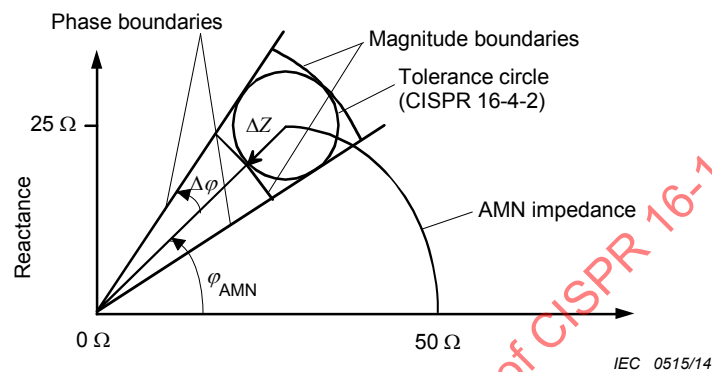


Figure I.1 – Definition of impedance magnitude and phase tolerances

Existing network analyzers however do not allow specification of a tolerance circle for the impedance. Additional software would be required for that purpose. Therefore the use of the existing specification of the magnitude tolerance and the addition of a specification of the phase tolerance are advisable. Using trigonometric functions, a value of $\Delta\varphi = 11,54^\circ$ follows from $\Delta|Z|/|Z| = 0,2$.

CISPR/TR 16-4-1 can be taken as a theoretical basis for uncertainty and reproducibility of conducted emission measurements using a V-AMN. For the purpose of explaining the influence of deviations from the specified phase of a V-AMN, Equation (15) of CISPR/TR 16-4-1:2009 can be used:

$$\frac{\Delta V_m}{V_{mt}} = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \left(\frac{\Delta\alpha}{\alpha_0} + \frac{\Delta U_d}{V_{d0}} \right) + \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} - \frac{\Delta Z_d}{Z_{d0}} \right) \quad (\text{I.1})$$

where

V_{mt} is the true voltage reading at the CISPR receiver in the ideal situation;

Z_{13} is the ideal impedance of the V-AMN;

$Z_{in} = Z_{13} + \Delta Z_{in}$

Z_{d0}, V_{d0} are the true values of the disturbance source (i.e. the EUT) parameters;

α_0 is the true value of the V-AMN voltage division factor;

$\Delta V_m, \Delta\alpha,$ are deviations from the true or ideal values.

$\Delta V_d, \Delta Z_{in},$
 ΔZ_d

Because we are interested in the effect of the phase tolerance on the uncertainty, the contributions $\Delta\alpha$, ΔV_d and ΔZ_d may be set to zero and based on Equation (17) of CISPR/TR 16-4-1:2009 we get:

$$\frac{\Delta V_m}{V_{mt}} = \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} \right) = c_2 \frac{\Delta Z_{in}}{Z_{13}} \quad (I.2)$$

The absolute value of the coefficient c_2 is shown as a function of the phase angle difference $\varphi = \varphi_{Z_{in}} - \varphi_{d0} = \varphi_{AMN} - \varphi_{EUT}$ of the impedances of Z_{in} and $Z_{d0} = Z_{EUT}$ in Figure 17 of CISPR/TR 16-4-1:2009 for several values of the ratio $|Z_{13}/Z_{d0}|$.

The absolute value of c_2 has been calculated using a spread sheet for several values of φ_{EUT} (0° , -45° , -90°), φ_{AMN} (0° , 30° , 46°), $|Z_{13}/Z_{d0}|$ (0,1; 0,2; 0,4; 0,8; 1,0; 1,4) and for $\Delta\varphi_{AMN}$ (-23° ; $-11,5^\circ$; $11,5^\circ$; 23°). For the purpose of this investigation, the absolute value of the factor $\Delta Z_{in}/Z_{13}$ has been set to 0,2 (i.e. to the maximum of the impedance magnitude tolerance), i.e.

$$\frac{\Delta V_m}{V_{mt}} = |c_2| \times 0,2 \quad (I.3)$$

For a comparison of the voltage level deviations due to phase deviations, the logarithms have been calculated as follows:

$$\text{Level deviation} = 20 \lg \left(1 - \frac{\Delta V_m}{V_{mt}} \right) \quad (I.4)$$

The level deviations have been compared for the results with $\Delta\varphi_{AMN} = -23^\circ$ and $-11,5^\circ$, as well as for $\Delta\varphi_{AMN} = 11,5^\circ$ and 23° , e.g. level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ}$.

The results thus obtained are:

For $\varphi_{EUT} = 0^\circ$ and $\varphi_{AMN} = 0^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 0,018$ dB (max.)

For $\varphi_{EUT} = -45^\circ$ and $\varphi_{AMN} = 46^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 0,27$ dB (max.)

For $\varphi_{EUT} = -45^\circ$ and $\varphi_{AMN} = 30^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 0,86$ dB (max.)

For $\varphi_{EUT} = -90^\circ$ and $\varphi_{AMN} = 46^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 3,07$ dB (max.)

Comment: the comparison of level deviations for $\Delta\varphi_{AMN} = 11,5^\circ$ and 23° shows that the reproducibility of measurements is not only influenced by the V-AMN impedance but also by the frequency (which determines φ_{AMN}) and by the phase angle φ_{EUT} . The reader can easily understand this by looking at Figure 17 of CISPR/TR 16-4-1:2009.

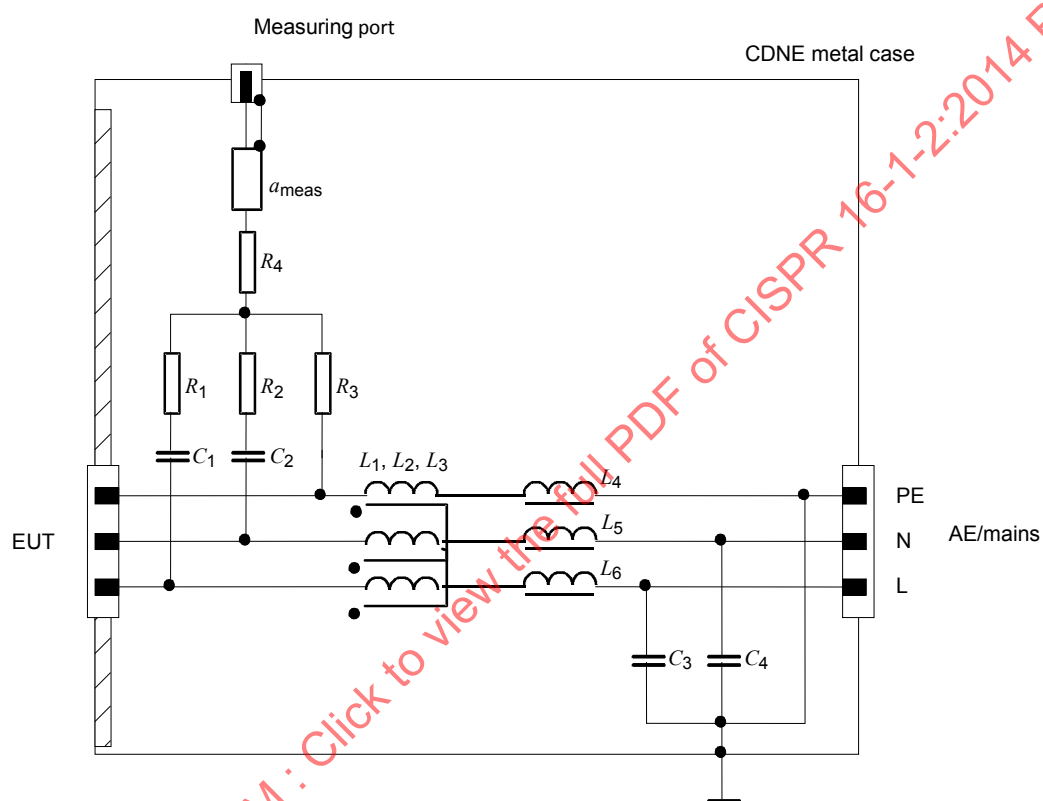
Conclusion: The investigation above shows that it is not sufficient to specify a tolerance of the magnitude of the V-AMN input impedance. Limiting the phase tolerance of the V-AMN input impedance by using $|\Delta\varphi_{AMN \text{ MAX}}| = 11,5^\circ$ does not cause a manufacturing problem for the V-AMN, but improves the reproducibility of measurement for identical EUTs.

Annex J (informative)

Example CDNE set-up diagrams

J.1 CDNE-M2 and CDNE-M3

Examples of CDNEs for the mains connection of protection class I and class II are shown in Figures J.1 and J.2.



IEC 0516/14

Key

$C_1, C_2, C_3, C_4 = 1 \text{ nF}$

$L_1, L_2, L_3 > 10 \text{ } \mu\text{H}$

$L_4, L_5, L_6 > 5 \text{ } \mu\text{H}$

$R_1, R_2, R_3 = 50 \text{ } \Omega$

$R_4 = 83,3 \text{ } \Omega$

$a_{\text{meas}} \geq 6 \text{ dB}$

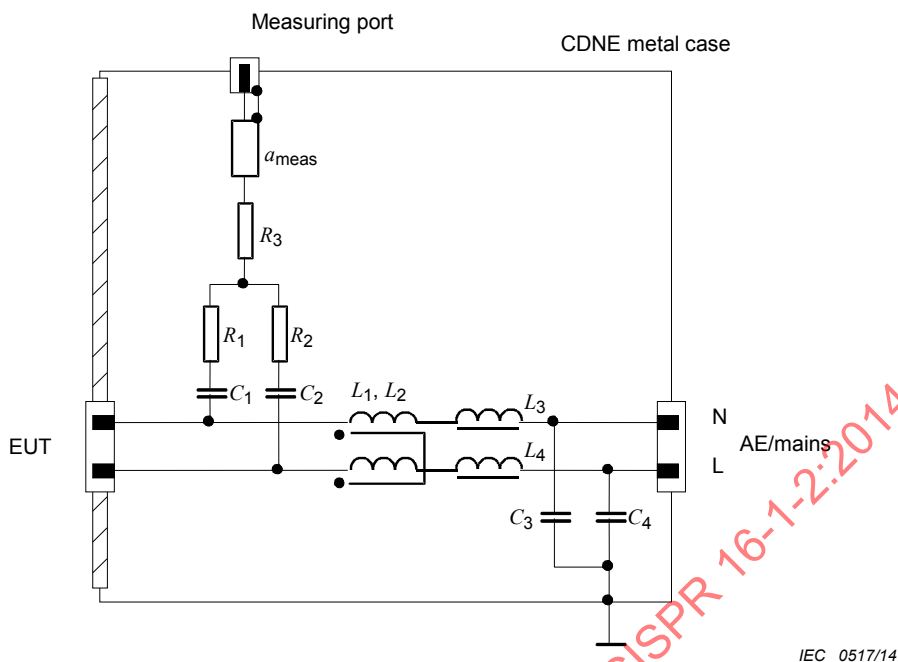
PE = protective earth

N = neutral

L = line

NOTE "AE/mains" can include a.c. mains, d.c. supply as well as control/communication lines.

Figure J.1 – CDNE-M3 with internal attenuator a_{meas} of at least 6 dB



Key

$C_1, C_2, C_3, C_4 = 1 \text{ nF}$

$L_1, L_2 > 10 \text{ } \mu\text{H}$

$L_3, L_4 > 5 \text{ } \mu\text{H}$

$R_1, R_2 = 50 \text{ } \Omega$

$R_3 = 75 \text{ } \Omega$

$a_{\text{meas}} \geq 6 \text{ dB}$

N = neutral

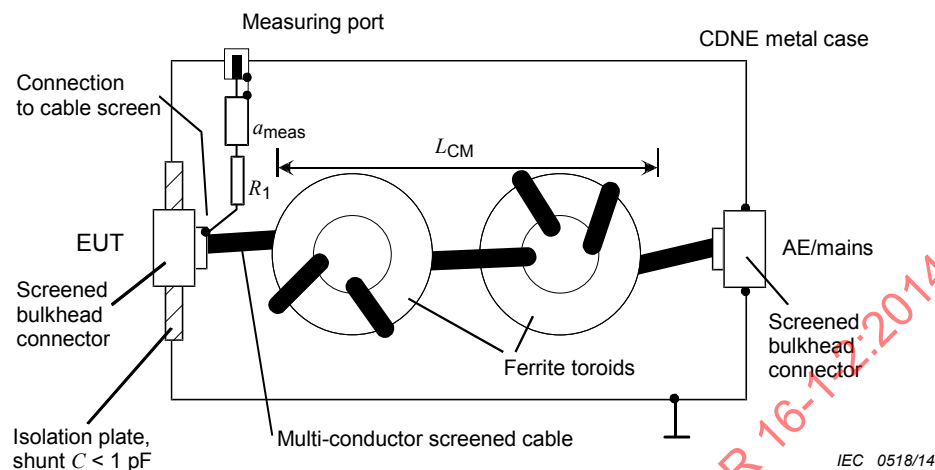
L = line

NOTE "AE/mains" can include a.c. mains, d.c. supply as well as control/communication lines.

Figure J.2 – CDNE-M2 with internal attenuator a_{meas} of at least 6 dB

J.2 CDNE-S_x

Figure J.3 shows an example of a CDNE-S_x for screened cables.



Key

$$R_1 = 100 \, \Omega$$

$$L_{CM} > 10 \, \mu\text{H}$$

$$a_{\text{meas}} \geq 6 \, \text{dB}$$

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

Figure J.3 – CDNE-S_x for screened cable with x internal wires and an internal attenuator of at least 6 dB

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INTERNATIONAL STANDARD

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BASIC EMC PUBLICATION
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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

Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques –

Partie 1-2: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Dispositifs de couplage pour la mesure des perturbations conduites

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INTERNATIONAL ELECTROTECHNICAL COMMISSION
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**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**

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International Standard CISPR 16-1-2 has been prepared by subcommittee A: Radio-interference measurements and statistical methods, of IEC technical committee CISPR: International special committee on radio interference.

This second edition cancels and replaces the first edition published in 2003 and its Amendment 1 (2004) and Amendment 2 (2006). This edition constitutes a technical revision.

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

- a) requirements from CISPR 22 for the AAN have been copied to this standard;
- b) the CDNE for measurement of disturbance voltage in the frequency range 30 MHz to 300 MHz is added;
- c) additional maintenance is included.

It has the status of a basic EMC publication in accordance with IEC Guide 107, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*.

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

FDIS	Report on voting
CISPR/A/1051/FDIS	CISPR/A/1059/RVD

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

A list of all parts of CISPR 16 series, under the general title *Specification for radio disturbance and immunity measuring apparatus and methods*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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

1 Scope

This part of the CISPR 16 series specifies the characteristics and performance of equipment for the measurement of radio disturbance voltages and currents in the frequency range 9 kHz to 1 GHz.

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.

Specifications for ancillary apparatus are included for artificial mains networks, current and voltage probes and coupling units for current injection on cables.

It is intended that the requirements of this publication are fulfilled at all frequencies and for all levels of radio disturbance voltages and currents within the CISPR indicating range of the measuring equipment.

Methods of measurement are covered in the CISPR 16-2 series, and further information on radio disturbance is given in CISPR 16-3, while uncertainties, statistics and limit modelling are covered in the CISPR 16-4 series.

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 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 16-2-1:2014, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements*

CISPR 16-4-2:2011, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainty*

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

IEC 61000-4-6:2008, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1

ancillary equipment

transducers 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

Note 1 to entry: Examples of transducers are current and voltage probes and artificial networks.

3.1.2

associated equipment

AE

apparatus that is not part of the system under test but is required for the functioning of the EUT

3.1.3

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. $(V_a + V_b)/2$.

3.1.4

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 $(V_a - V_b)$.

3.1.5

unsymmetric voltage

amplitude of the vector voltage, V_a or V_b defined in 3.1.3 and 3.1.4

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 3.1.3 and 3.1.4 for details on V_a and V_b .

3.1.6

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.

3.1.7**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: The term “Y-network” is a synonym for AAN.

3.1.8**auxiliary equipment****AuxEq**

peripheral equipment that is part of the system under test

3.1.9**coupling/decoupling network****CDN**

artificial network for the measurement or injection of signals on one circuit while preventing signals from being measured or injected on another circuit

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 for further details on the CDNE-X.

3.1.11**equipment under test****EUT**

equipment (devices, appliances and systems) subjected to EMC (emission) compliance tests

3.1.12**impedance measurement adaptor****IMA**

metallic vertical plane, 0,1 m by 0,1 m, bonded to the reference ground plane, which contains connection ports for a network analyzer and a CDNE

3.1.13**longitudinal conversion loss****LCL**

in a one- or two-port network, a measure of the degree of unwanted transverse (symmetric mode) signal produced at the terminals of the network due to the presence of a longitudinal (asymmetric mode) signal on the connecting leads

Note 1 to entry: LCL is a ratio expressed in dB.

[SOURCE: ITU-T Recommendation O.9 [8] ¹⁾]

1) Numbers in square brackets refer to the Bibliography.

3.1.14

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 emission measurements, and serves as reference ground for the measurement of unsymmetrical and asymmetrical disturbance voltages.

3.2 Abbreviations

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

AN	Artificial network
CVP	Capacitive voltage probe
E.m.f.	Electromotive force
ISN	Impedance stabilization network
ITE	Information technology equipment
LCL	Longitudinal conversion loss
NWA	Network analyser
PE	Protective earth
RF	Radio frequency

4 Artificial mains networks

4.1 General

An artificial mains network is required to provide a defined impedance at radio frequencies at the terminals of the EUT, to isolate the test circuit from unwanted radio-frequency signals on the supply mains, and to couple the disturbance voltage to the measuring receiver.

There are two basic types of AMN, the V-network AMN (V-AMN), which couples the unsymmetric voltages, and the delta-network AMN (Δ -AMN), which couples the symmetric and the asymmetric voltages separately.

For each mains conductor, there are three terminals: the mains terminal for connection to the supply mains, the equipment terminal for connection to the EUT, and the disturbance output terminal for connection to the measuring equipment.

NOTE 1 Examples of circuits of AMNs are given in Annex A.

NOTE 2 This clause specifies impedance and isolation requirements for the AMN including the corresponding measurement methods. Some background and rationale on the AMN related uncertainties are given in 6.2.3 of CISPR/TR 16-4-1:2009 and in CISPR 16-4-2.

4.2 AMN impedance

The specification of the impedance of an AMN includes the magnitude and the phase of the impedance measured at an EUT terminal with respect to the reference ground, when the receiver port is terminated with 50 Ω .

The impedance at the EUT terminals of the AMN defines the termination impedance presented to the EUT. For this reason, when a disturbance output terminal is not connected to the measuring receiver, it shall be terminated by 50 Ω . To assure accurate termination into 50 Ω of the receiver port, a 10 dB attenuator shall be used either inside or external to the network, the VSWR of which (seen from either side) shall be less than or equal to 1,2 to 1. The attenuation shall be included in the measurement of the voltage division factor (see 4.11).

The impedance between each conductor (except PE) of the EUT terminal and the reference ground shall comply with the provisions of 4.3, 4.4, 4.5, 4.6 or 4.7, as appropriate, for any value of external impedance, including a short circuit connected between the corresponding mains terminal and reference ground. This requirement shall be met at all temperatures which the network may reach under normal conditions for continuous currents up to the specified maximum. The requirement shall also be met for peak currents up to the specified maximum.

Where the phase requirement cannot be met, the measured phase angles shall be taken into account in the uncertainty budget according to CISPR 16-4-2. Annex I gives guidelines for the calculation of the uncertainty contribution of the phase if the tolerance is exceeded.

NOTE Because EUT connectors are not optimized for radio frequencies up to 30 MHz, the measurement of the network impedance is carried out with special measurement adaptors to enable short-length connections. The OSM (open/short/matched) calibration of the network analyzer is used to characterize the adaptors, taking the insertion loss and the conductor lengths of the adaptors into account.

4.3 50 Ω /50 μ H + 5 Ω artificial mains V-network (V-AMN) for use in the frequency range 9 kHz to 150 kHz

The AMN shall have the impedance (magnitude and phase) versus frequency characteristic shown in Table 1 and Figure 1 in the relevant frequency range. Tolerances of ± 20 % for the magnitude and $\pm 11,5^\circ$ for the phase are permitted.

Table 1 – Magnitudes and phase angles of the V-network (see Figure 1)

Frequency MHz	Impedance magnitude Ω	Phase angle Degrees
0,009	5,22	26,55
0,015	6,22	38,41
0,020	7,25	44,97
0,025	8,38	49,39
0,030	9,56	52,33
0,040	11,99	55,43
0,050	14,41	56,40
0,060	16,77	56,23
0,070	19,04	55,40
0,080	21,19	54,19
0,090	23,22	52,77
0,100	25,11	51,22
0,150	32,72	43,35

NOTE If this AMN meets the combined impedance requirements of 4.3 and 4.4., it can be used in the frequency range 150 kHz to 30 MHz as well.

4.4 50 Ω /50 μ H artificial mains V-network (V-AMN) for use in the frequency range 0,15 MHz to 30 MHz

The AMN shall have the impedance (magnitude and phase) versus the frequency characteristic shown in Table 2 and Figure 2 in the relevant frequency range. Tolerances of ± 20 % for the magnitude and $\pm 11,5^\circ$ for the phase are permitted.

Table 2 – Magnitudes and phase angles of the V-network (see Figure 2)

Frequency MHz	Impedance magnitude Ω	Phase angle Degrees
0,15	34,29	46,70
0,17	36,50	43,11
0,20	39,12	38,51
0,25	42,18	32,48
0,30	44,17	27,95
0,35	45,52	24,45
0,40	46,46	21,70
0,50	47,65	17,66
0,60	48,33	14,86
0,70	48,76	12,81
0,80	49,04	11,25
0,90	49,24	10,03
1,00	49,38	9,04
1,20	49,57	7,56
1,50	49,72	6,06
2,00	49,84	4,55
2,50	49,90	3,64
3,00	49,93	3,04
4,00	49,96	2,28
5,00	49,98	1,82
7,00	49,99	1,30
10,00	49,99	0,91
15,00	50,00	0,61
20,00	50,00	0,46
30,00	50,00	0,30

4.5 50 Ω /5 μ H + 1 Ω artificial mains V-network (V-AMN) for use in the frequency range 150 kHz to 108 MHz

The AMN shall have the impedance (magnitude and phase) versus the frequency characteristic shown in Table 3 and Figure 3. Tolerances of $\pm 20\%$ for the magnitude and $\pm 11,5^\circ$ for the phase are permitted.

Table 3 – Magnitudes and phase angles of the V-network (see Figure 3)

Frequency MHz	Impedance magnitude Ω	Phase angle Degrees
0,15	4,70	72,74
0,20	6,19	73,93
0,30	9,14	73,47
0,40	12,00	71,61
0,50	14,75	69,24
0,70	19,82	64,07
1,00	26,24	56,54
1,50	33,94	46,05
2,00	38,83	38,15
2,50	41,94	32,27
3,00	43,98	27,81
4,00	46,33	21,63
5,00	47,56	17,62
7,00	48,71	12,80
10,00	49,35	9,04
15,00	49,71	6,06
20,00	49,84	4,55
30,00	49,93	3,04
50,00	49,97	1,82
100,00	49,99	0,91
108,00	49,99	0,84

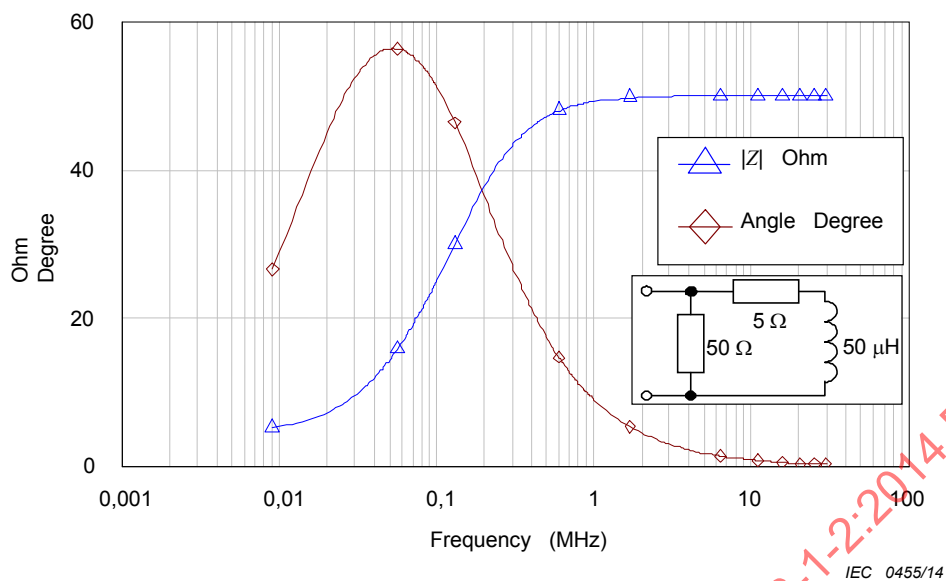


Figure 1 – Impedance (magnitude and phase) of the V-network for Band A (see 4.3, the relevant frequency range is from 9 kHz to 150 kHz)

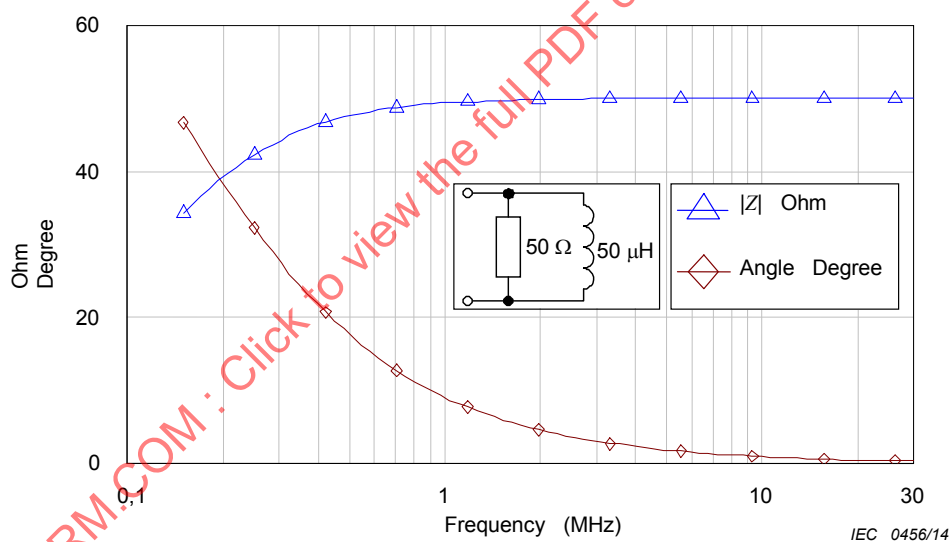


Figure 2 – Impedance (magnitude and phase) of the V-network for Band B (see 4.4)

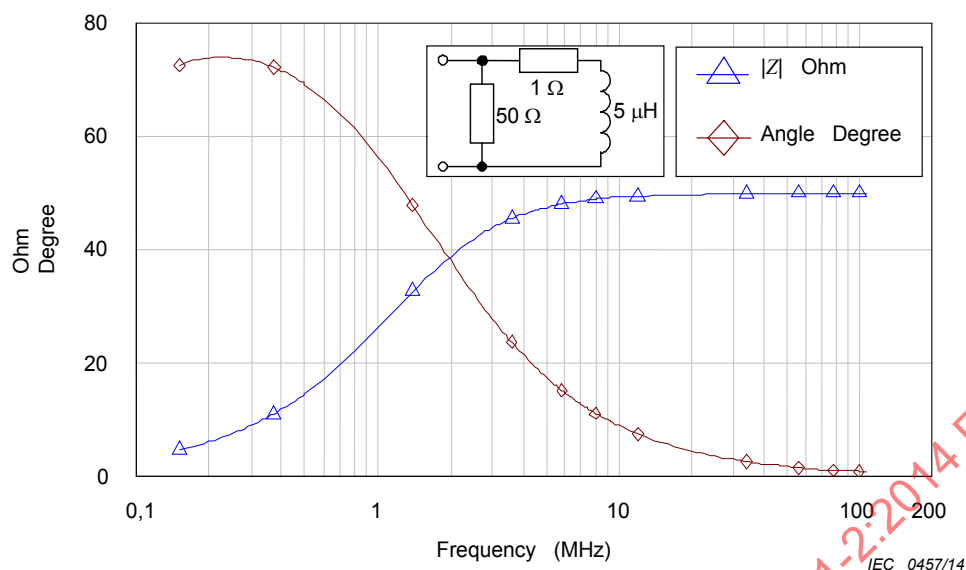


Figure 3 – Impedance (magnitude and phase) of the V-network for Bands B and C (from 150 kHz to 108 MHz; see 4.5)

4.6 150 Ω artificial mains V-network (V-AMN) for use in the frequency range 150 kHz to 30 MHz

The network shall have an impedance of magnitude $(150 \pm 20) \Omega$ with a phase angle not exceeding 20° .

4.7 150 Ω artificial mains delta-network (Δ -AMN) for use in the frequency range 150 kHz to 30 MHz

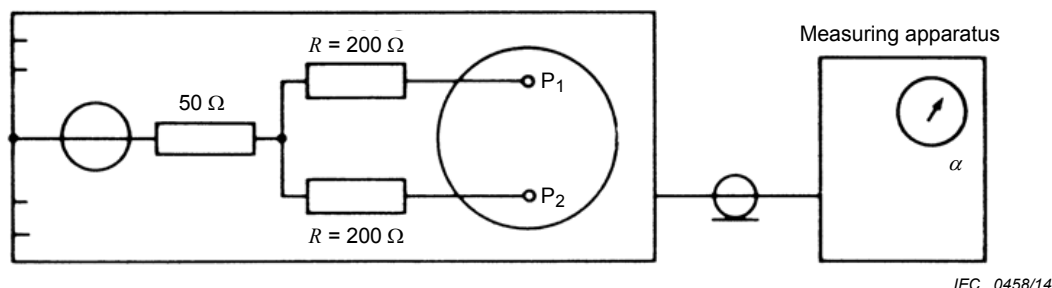
4.7.1 General parameters

The network shall have an impedance of magnitude $(150 \pm 20) \Omega$ with a phase angle not exceeding 20° , both between the equipment terminals and between the two equipment terminals joined together and the reference ground.

For the measurement of the symmetric voltage, a screened and balanced transformer is required. To avoid appreciable modification of the impedance of the network, the input impedance of the transformer shall be not less than $1\,000 \Omega$ at all frequencies concerned. The voltage measured by the measuring receiver depends on the network component values and the transformer ratio. The network shall be calibrated.

4.7.2 Balance of the 150 Ω artificial mains delta-network

The balance of the system comprising the network and the measuring receiver connected thereto via the transformer shall be such that the measurement of symmetric voltage shall be substantially unaffected by the presence of an asymmetric voltage. The balance shall be measured using the circuit shown in Figure 4.



R are resistors of $200\ \Omega$ equal to each other within 1 %

P_1 and P_2 are terminals of network for connection of device

Figure 4 – Method for checking the balance of the arrangement for the measurement of symmetrical voltages

A voltage V_a is injected from a generator having an internal impedance of $50\ \Omega$, between reference ground and the common point of two resistors each $200\ \Omega \pm 1\%$. The other end of these resistors is connected to the equipment terminals of the AMN.

A voltage V_s is measured in the position for symmetric voltage measurement. The ratio V_a/V_s shall be greater than 20:1 (26 dB).

4.8 Isolation

4.8.1 Requirement

To ensure that at any test frequency, unwanted signals existing on the mains side and the unknown impedance of the supply mains do not affect the measurement, a minimum isolation (decoupling factor) between each mains terminal and the receiver port for a given termination of the relevant terminal of the EUT port shall be met. See Table 4. The requirement applies to the V-AMN itself excluding additional external cables and filters.

Additional filtering external to the AMN may be required for the suppression of disturbance on the mains port (see CISPR 16-2-1 for practical requirements).

Table 4 – Values of minimum isolation for V-networks

Subclause	Type of V-network	Frequency range MHz	Minimum isolation dB
4.3	$50\ \Omega / 50\ \mu\text{H} + 5\ \Omega$	0,009 to 0,05	0 to 40 ^a
		0,05 to 30	40
4.4	$50\ \Omega / 50\ \mu\text{H}$	0,15 to 30	40
4.5	$50\ \Omega / 5\ \mu\text{H} + 1\ \Omega$	0,15 to 3	0 to 40 ^a
		3 to 108	40

^a These values indicate that the minimum isolation rises linearly with the logarithm of frequency

4.8.2 Measurement procedure

The test setup is shown in Figure H.1. For the measurement, first a signal V_1 is measured across a load impedance of $50\ \Omega$ with a source impedance of $50\ \Omega$. Then this signal source shall be connected between the relevant mains terminal and reference ground, the relevant EUT terminals shall be terminated with $50\ \Omega$, and the output voltage V_2 shall be measured at the receiver port (terminated with an impedance of $50\ \Omega$). The attenuation of the 10 dB attenuator described in 4.2 shall be added to the isolation requirement. The isolation

requirement shall be met for all mains and EUT terminals. If the termination of the other mains terminals affects the measurement result, then the requirement shall be met with the other mains terminals open and shorted.

The following equation shall be met:

$$V_1 - V_2 \geq F_D + A \quad (1)$$

where

V_1 is the reference voltage at the mains terminals in dB(μ V);

V_2 is the output voltage at the receiver port in dB(μ V);

F_D is the minimum isolation (decoupling factor) requirement in dB;

A is the attenuation of the built-in attenuator in dB.

NOTE Because EUT connectors are not optimized for radio frequencies up to 30 MHz, the measurement of the network isolation are carried out with special measurement adaptors to enable short-length connections. The measurement of V_1 is made with the adaptor connected to the source.

4.9 Current carrying capacity and series voltage drop

The maximum continuous currents and the maximum peak current shall be specified. The voltage applied to the EUT when passing continuous currents up to the maximum shall be not less than 95 % of the mains voltage at the mains terminals of the AMN.

4.10 Modified reference ground connection

The measurement of some types of equipment may require the insertion of an impedance in the reference ground conductor in the AMNs in 4.3 and 4.4, following the requirements of the related product publications. This is inserted at point X marked in the reference ground lead in Figures 5 and 6, respectively. The impedance to be inserted is either a 1,6 mH inductor, or an impedance conforming to the impedance requirement of 4.3 or 4.4, as appropriate for the frequency range.

NOTE When considering the frequency range 9 kHz to 150 kHz, for safety reasons the 5 Ω resistor of the artificial mains V-network is not inserted.

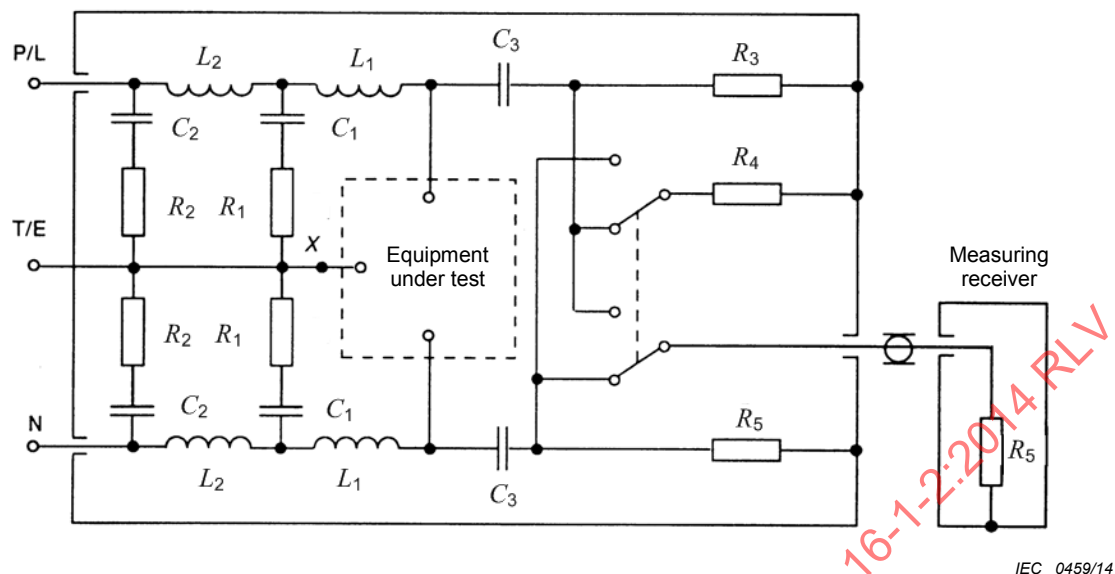


**Figure 5 – Example of artificial mains 50 Ω/50 μH + 5 Ω V-network
(see 4.3 and A.2)**

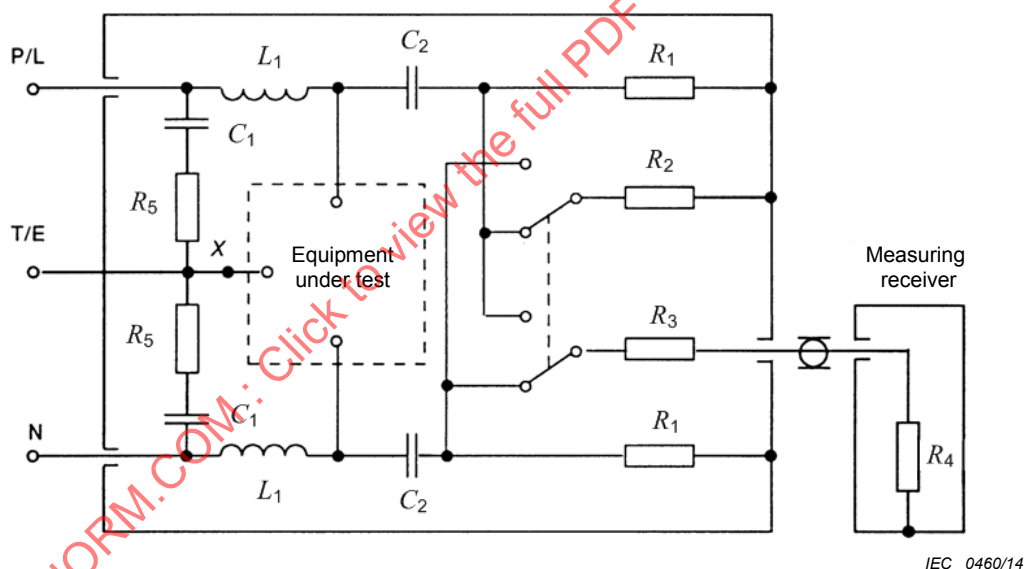


**Figure 6 – Example of artificial mains V-networks, 50 Ω/50 μH, 50 Ω /5 μH + 1 Ω or 150 Ω
(see 4.4, 4.5, 4.6, A.3, A.4 and A.5, respectively)**

4.11 Measurement of the voltage division factor of artificial mains V-networks

The voltage division factor between the EUT port of the V-network and the RF output port shall be measured and taken into consideration during the measurement of the disturbance voltage. A procedure to measure the voltage division factor is contained in A.8.

5 Current and voltage probes

5.1 Current probes

5.1.1 General

The asymmetrical disturbance currents of cables can be measured, without making direct conductive contact with the source conductor and without modification of its circuit, by use of specially developed clamp-on current transformers. The utility of this method is self-evident; complex wiring systems, electronic circuits, etc., may be measured without interruption of the normal operation or configuration. The current probe is constructed so that it may be conveniently clamped around the conductor to be measured. The conductor represents a one-turn primary winding. The secondary winding is contained within the current probe.

Current probes can be constructed for measurements in the frequency range 30 Hz to 1 000 MHz, although the primary measurement range is 30 Hz to 100 MHz. Beyond 100 MHz the standing currents in conventional power systems require that the current probe location be optimized for detection of the maximum current.

Current probes are designed to provide a flat frequency response over a passband. At frequencies below this flat passband, accurate measurements can still be made but with decreased sensitivity due to reduced transfer impedances. At frequencies above the flat passband, measurements are not accurate due to resonances in the current probe.

With an additional shielding structure, a current probe may be used to measure either the asymmetrical (common mode) or symmetrical (differential mode) current. Some construction details are provided in B.5.

5.1.2 Construction

The current probe shall be constructed so as to enable the measurement of the current without disconnecting the lead under measurement.

Annex B contains some typical constructions of current probes.

5.1.3 Characteristics

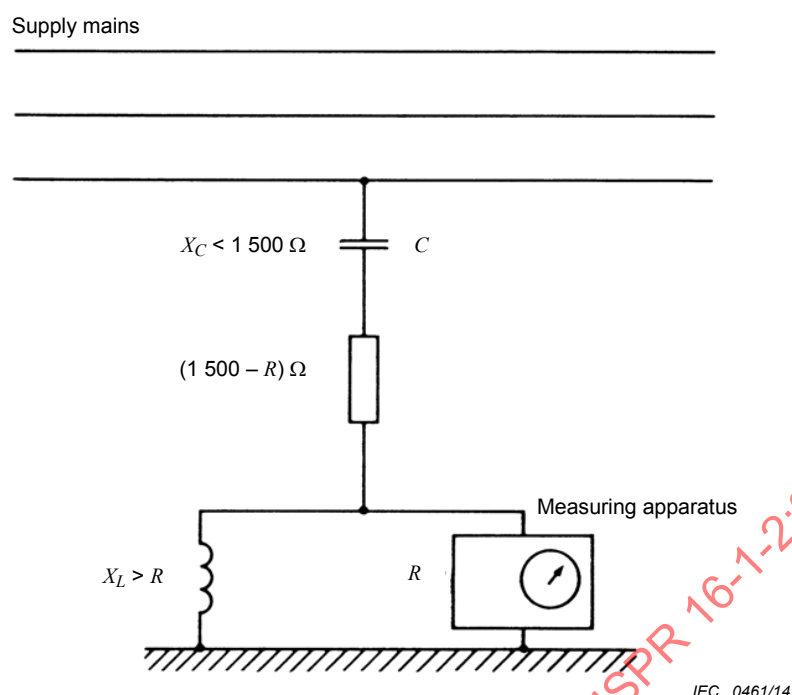
Insertion impedance	1 Ω impedance maximum
Transfer impedance	0,1 Ω to 5 Ω in the flat linear range; 0,001 Ω to 0,1 Ω below the flat linear range (current probe terminated into 50 Ω load)
NOTE The reciprocal transfer admittance [in dB(S)] can be used instead. When expressed in decibels, the admittance is added to the reading of the measuring receiver. For the calibration of the transfer impedance or admittance, a jig designed for the purpose is used. See Annex B.	
Added shunt capacitance	Less than 25 pF between the current probe housing and measured conductor.
Frequency response	Transfer impedance is measured over a specified frequency range to calibrate the probe; the range of individual probes is typically 100 kHz to 100 MHz, 100 MHz to 300 MHz, and 200 MHz to 1 000 MHz.
Pulse response	Under consideration.

Magnetic saturation	The maximum d.c. or a.c. mains current in the primary lead for a measurement error less than 1 dB shall be specified.
Transfer impedance tolerance	Under consideration.
Influence of external magnetic fields	40 dB reduction in indication when a current carrying conductor is removed from the current probe opening to a position adjacent to the probe.
Influence of electric fields	Not susceptible to fields < 10 V/m.
Influence of orientation	Less than 1 dB up to 30 MHz and 2,5 dB from 30 MHz to 1 000 MHz, when used on a conductor of any size placed anywhere inside the aperture.
Current probe opening	At least 15 mm.

5.2 Voltage probe

5.2.1 High impedance voltage probe

Figure 7 shows a circuit that is used to make voltage measurements between a mains conductor and the reference ground. The probe consists of a blocking capacitor C and a resistor, such that the total resistance between line and ground is 1 500 Ω . The probe may also be used to make measurements on other lines, and for certain applications its impedance may need to be increased to avoid excessive loading of high impedance circuits. An inductor may have to be connected across the input of the measuring apparatus, for safety reasons; its inductive reactance, X_L , should be much greater than R .



NOTE $V = \frac{1500}{R} V_m$

where

V is the disturbing voltage;

V_m is the voltage at the input of the measuring apparatus.

Figure 7 – Circuit for RF voltage measurement on supply mains

For calibration of voltage probes, the voltage division factor shall be measured in a 50 Ω system over the frequency range of 9 kHz to 30 MHz. The effect on the accuracy of measurement of any device that may be used for protection should either be less than 1 dB, or be allowed for in calibration. Care shall be taken to ensure that the level of disturbance is accurately measured in the presence of the ambient noise, to make the measurement meaningful.

The loop formed by the lead connected to the probe, the mains conductor tested and reference ground should be minimized, to reduce the effects of any strong magnetic fields.

5.2.2 Capacitive voltage probe

5.2.2.1 General

The asymmetrical disturbance voltages of cables can be measured without making direct conductive contact with the source conductor, and without modification of its circuit by the use of a clamp-on capacitive coupling device. The usefulness of this method is self-evident; complex wiring systems, electronic circuits, etc., may be measured without interruption of the normal operation or configuration of the EUT or the need to cut the cable to insert a measuring device. The capacitive voltage probe (CVP) is constructed so that it may be conveniently clamped around the conductor to be measured.

The CVP is used for measurements of conducted disturbances in the frequency range 150 kHz to 30 MHz with an almost flat frequency response in the frequency range of interest. The voltage division factor, which is defined as the ratio of the disturbance voltage on the cable to the input voltage at the measuring receiver, depends on the type of cable. This

parameter should be calibrated over a specified frequency range for each cable type, using the method described in Annex G.

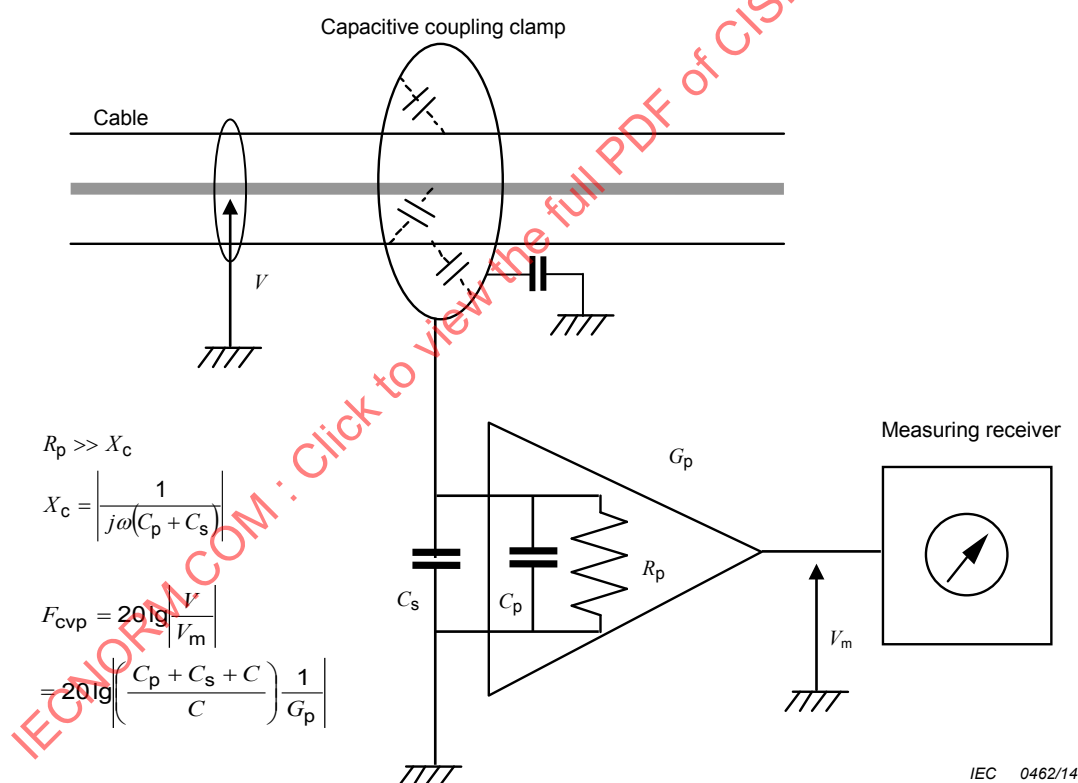
The CVP may need additional shielding to provide sufficient isolation from the asymmetrical (common mode) signal around the cable (see 5.2.2.3). Annex G contains an example of the construction and a method of measurement for the isolation.

This CVP can be used to measure the disturbances at telecommunication ports. The minimum measurable level is typically up to 44 dB(μV).

5.2.2.2 Construction

The CVP shall be constructed so as to enable the measurement of the voltage without disconnecting the cable under measurement. Figure 8 shows a circuit that is used to make voltage measurements between a cable and reference ground. The probe consists of a capacitive coupling clamp which is connected to a trans-impedance amplifier. The input resistance R_p of this amplifier shall be large enough compared to the reactance X_c to obtain a flat frequency response.

Annex G provides instructions for the typical construction and verification of the CVP.



Key

C	Capacitance between cable and clamp
C_p	Capacitance of trans-impedance amplifier
C_s	Capacitance between probe and ground
F_{CVP}	Voltage division factor
G_p	Gain of trans-impedance amplifier
R_p	Resistance of trans-impedance amplifier
V	Disturbance voltage
V_m	Voltage at the input of the measuring receiver

Figure 8 – Circuit used to make voltage measurements between a cable and reference ground

5.2.2.3 Requirements

Added shunt capacitance	Less than 10 pF between the grounding terminal of CVP and the cable under test.
Frequency response	Voltage division factor, $F_{CVP} = 20 \lg V/V_m $ in dB (see Figure 8), is measured over a specified frequency range.
Pulse response	Maintain linearity for the pulse determined by the method in Annexes B and C of CISPR 16-1-1:2010 for Band B.
Influence of electric field (influence caused by electrostatic coupling with other cables near the probe)	The voltage indication is reduced by more than 20 dB when a cable is removed from the CVP. The measurement method is described in Annex G.
CVP aperture or opening [aperture when the two coaxial electrodes open at the slot (see Figure G.1)]	At least 30 mm.

6 Coupling units for conducted current immunity measurement

6.1 General

The coupling units are designed to inject the disturbance current on to the leads under test and to isolate the other leads and any apparatus which is connected to the EUT from the effects of these currents. With a 150Ω source impedance, there is a useful correlation between the RF disturbance field strength acting on a real installation and the e.m.f. that is applied in the current injection method to produce the same degree of impairment, at least for frequencies up to 30 MHz. The immunity of an apparatus is expressed by this e.m.f. value. Annexes C and D give the principles of operation and examples of types of units and their construction.

6.2 Characteristics

6.2.1 General

The performance checks of the coupling units are done for impedance in the frequency range 0,15 MHz to 30 MHz and for insertion loss in the frequency range 30 MHz to 150 MHz.

6.2.2 Impedance

In the frequency range 0,15 MHz to 30 MHz, the total asymmetric impedance (RF choke coil in parallel with the 150Ω resistive disturbance source impedance) measured between the point of injection of the disturbance signal to the EUT and the ground of the unit shall have a magnitude of $150 \Omega \pm 20 \Omega$ and a phase angle less than $\pm 20^\circ$ (this impedance is the same as the CISPR 150Ω artificial mains V-network; see 4.5).

For example, for coupling units type A and S, the point of injection is the shield of the output connector; for types M and L, the point of injection is the joint output terminals.

6.2.3 Insertion loss

In the frequency range 30 MHz to 150 MHz, the insertion loss of two identical coupling units in tandem shall be within the range 9,6 dB to 12,6 dB, measured as shown in Figure 9. The two units shall be connected together with very short wires (≤ 1 cm).

The insertion loss U_G/U_B of two identical coupling units measured according to the setup of Figure 9 should be within 9,6 dB and 12,6 dB in the frequency range 30 MHz to 150 MHz; U_G

is the reading of the receiver when the generator and receiver are directly connected together.

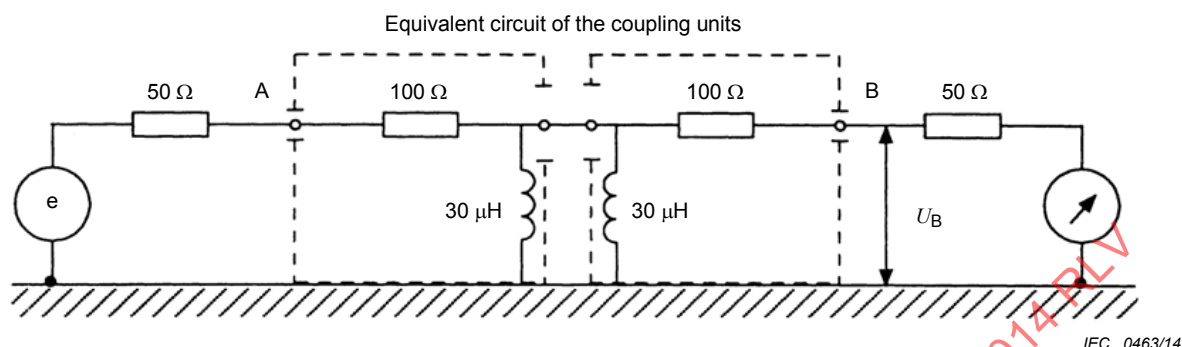


Figure 9 – Measuring set-up to check the insertion loss of the coupling units in the frequency range 30 MHz to 150 MHz

7 Coupling devices for measuring signal lines

7.1 General

The interference potential (and immunity) of signal lines may be assessed by measurement (or injection) of the conducted disturbance voltage or current. For this purpose, coupling devices are needed to measure the disturbance component while rejecting the intentional signal on the line. The devices included are to measure the electromagnetic emission and immunity (common and differential mode, current and voltage). Typical devices for these kinds of measurements are current probes and asymmetric artificial networks (AANs or Y-networks).

NOTE 1 Requirements for AANs for conducted immunity tests on signal lines can be found in IEC 61000-4-6 (AANs are special versions of “coupling and decoupling devices” [so-called coupling/decoupling networks (CDNs)]). An AAN that meets the requirements for emission measurements may also meet the requirements for immunity testing.

NOTE 2 Signal lines include telecommunication lines and terminals of equipment intended to be connected to these lines.

NOTE 3 The terms “asymmetric voltage” and “common mode voltage” as well as “symmetric voltage” and “differential mode voltage” are synonyms, as defined in Clause 3.

NOTE 4 The term “asymmetric artificial network (AAN)” is used as synonym for “Y-network”, which is in contrast to V-networks and delta-networks. The T-network is a special version of the Y-network.

When a current probe is used and the limit value is specified in volts, the voltage value is divided by the impedance of the signal line or termination impedance, as specified by the detailed measurement procedure, to obtain the limit value for the current. This impedance may be common mode, as required by the detailed measurement procedure.

The specification for AANs is provided in 7.2. The differential mode to common mode rejection (V_{dm}/V_{cm}) is crucial to the usability of the AAN. This parameter is related to the longitudinal conversion loss (LCL). Examples of AANs and the required test and calibration procedures are given in Annex E.

7.2 Requirements for AANs (or Y-networks)

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

An AAN shall include the following properties when calibrated in accordance with the methods of Annex E. In addition, the attenuation distortion or other deterioration shall not affect the normal operation of the EUT.

- a) AAN for measurements at ports intended for connection to category 6 (or better) unscreened balanced pair cables:

The variation of the longitudinal conversion loss (a_{LCL}) with frequency f (in MHz) shall be defined by the following equation:

$$a_{LCL} = 75 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right]$$

$$f < 2 \text{ MHz: } a_{LCL} \leq \pm 3 \text{ dB}$$

$$2 \text{ MHz} \leq f \leq 30 \text{ MHz: } a_{LCL} \leq \begin{matrix} +6 \\ -3 \end{matrix} \text{ dB}$$

- b) AAN for measurements at ports intended for connection to category 5 (or better) unscreened balanced pair cables.

The variation of the longitudinal conversion loss (a_{LCL}) with frequency f (in MHz) shall be defined by the following equation:

$$a_{LCL} = 65 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right]$$

$$f < 2 \text{ MHz: } a_{LCL} \leq \pm 3 \text{ dB}$$

$$2 \text{ MHz} \leq f \leq 30 \text{ MHz: } a_{LCL} \leq \begin{matrix} +4.5 \\ -3 \end{matrix} \text{ dB}$$

- c) AAN for measurements at ports intended for connection to category 3 (or better) unscreened balanced cables.

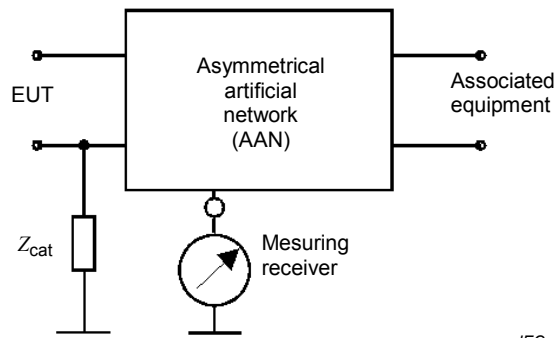
The variation of the longitudinal conversion loss (a_{LCL}) with frequency f (in MHz) shall be defined by the following equation:

$$a_{LCL} = 55 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right] \text{ in dB}$$

$$a_{LCL} \leq \pm 3 \text{ dB}$$

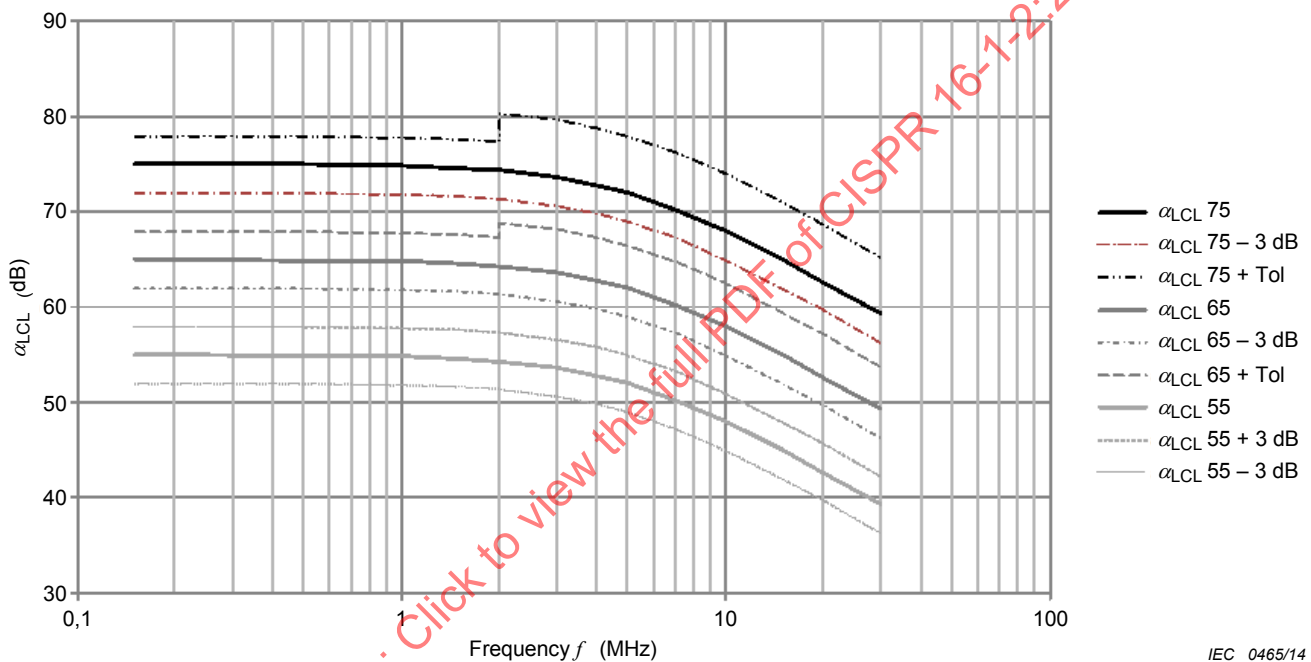
NOTE The above specifications of a_{LCL} versus frequency are approximations of a_{LCL} of typical unscreened balanced cables in representative environments. The specification in list item c) of 7.2 for category 3 cables is considered representative of the a_{LCL} of typical telecommunication access networks.

Figure 10 shows the general circuit diagram and graphical representation of a_{LCL} requirements for an AAN.



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a) Principal circuit of the AAN (or Y-network) and its ports consisting of a basic highly symmetric network and an (optional) unbalanced network Z_{cat}



IEC 0465/14

NOTE 1 This graph is derived from the equations in 7.2, list items a), b), and c). The ideal values for 55 dB, 65 dB, and 75 dB are shown as bold lines, while tolerance values are shown above and below the ideal values.

NOTE 2 "Tol" is the tolerance specified in 7.2, list items a), b), and c).

b) Graph of requirements for a_{LCL} of the AAN (Y-network)

Figure 10 – Principal circuit and LCL requirements of an AAN

The characteristics of the AAN for the measurement of asymmetric (common mode) disturbances shall cover the frequency range of the asymmetric disturbance voltages, as well as the frequency range used for the transmission of the intentional signal. These characteristics are given in Table 5.

Table 5 – Characteristics of the AAN for the measurement of asymmetric disturbance voltage

1)	Termination impedance of basic network for asymmetric disturbance voltage ^a • magnitude • phase	150 $\Omega \pm 20 \Omega$ 0° $\pm 20^\circ$
2)	Longitudinal conversion loss (LCL) at the EUT port of the network ^b	(9 kHz to 150 kHz: to be defined); 0,15 MHz to 30 MHz: depending on cable category as defined in 7.2 ^c
3)	Decoupling attenuation for asymmetric signals between AE port and EUT port	(9 kHz to 150 kHz: to be defined) 0,15 MHz to 1,5 MHz: > 35 dB to 55 dB increasing linearly with the log of frequency > 1,5 MHz: > 55 dB
4)	Insertion loss of the symmetric circuit between EUT and AE ports	< 3 dB ^d
5)	Voltage division factor of the asymmetric circuit between EUT and measuring receiver ports, to be added to the reading of the measuring receiver	Typically 9,5 dB ^e ± 1 dB
6)	Symmetric load impedance of the network	Depending on the system specifications, e.g. 100 Ω or 600 Ω ; to be defined by the relevant product standards ^f
7)	Transmission bandwidth for the intentional signal (analog or digital)	Depending on the system specifications for the symmetric insertion loss, e.g. up to 2 MHz or up to 100 MHz; to be defined by the relevant product standards
8)	Frequency range ^f (1) Emission (2) Immunity	(0,009 MHz) 0,15 MHz to 30 MHz See e.g. CISPR 22 [5]
^a The asymmetric impedance of the AAN will normally be influenced by the addition of an unbalanced network Z_{cat} according to Figure 10 a). This standard specifies the impedance tolerance for the basic network. The unbalanced network for the AANs defined in list items a), b), and c) of 7.2 nominally changes the impedance by less than 10 Ω, and the phase by less than 10°, so the given tolerance applies including the unbalanced network. If a product standard specifies lower LCL values, e.g. if the unbalanced network changes the impedance nominally by more than 10 Ω, or the phase by more than 10°, the product standard shall take this into account when specifying tolerances for impedance and phase, because a certain tolerance should be left to the AAN manufacturer. ^b Different concepts for determination of conformance of equipment are in use, i.e. use an LCL of the AAN higher than the available LCL values of signal lines, or use the LCL to simulate available telecommunication line categories. CISPR has decided to use the LCL to simulate the asymmetry of cable categories for emission tests, whereas IEC Sub-Committee 77B recommends the use of an LCL of the AAN higher than the cable category for immunity tests. ^c Generally, three factors have to be considered for LCL tolerances: the residual LCL of the basic AAN, the deviation of the unbalanced network Z_{cat} from nominal, and the uncertainty of LCL measurement. The tolerances given in a product standard deviating from the values of 7.2 should take into account that acceptable tolerances should increase with the required LCL and with frequency. ^d The actual requirements will depend on the specifications of the transmission system. Some transmission systems allow insertion losses of up to 6 dB. The insertion loss caused by an AAN is dependent on source and load impedances of the whole symmetric circuit. For lower/higher impedances the insertion loss will be lower/higher, and should be given by the manufacturer, e.g. for 100 Ω impedance. In addition, it will be useful if manufacturers specify the phase characteristics of the AAN in its symmetric circuit. ^e The AAN shall be calibrated by measuring the voltage division factor in a test set-up according to Figure E.6. ^f More than one network may be used to cover the complete frequency range.		

7.3 Requirements for artificial networks for coaxial and other screened cables

Artificial networks (ANs) for coaxial and other screened cables are used to measure (or inject) unsymmetric (common mode) voltages on the shield of (e.g. telecommunication or RF) cables while passing the communication or RF signal through. The required characteristics are given in Table 6.

NOTE In CISPR 22 [5] this type of network is called coaxial or screened cable impedance stabilization network (ISN).

Table 6 – Characteristics of artificial networks for coaxial and other screened cables

1)	Termination impedance of basic network for unsymmetric disturbance voltage: ^a • magnitude • phase	150 $\Omega \pm 20 \Omega$ 0° $\pm 20^\circ$
2)	Decoupling attenuation ^b for unsymmetric signals between AE port and EUT port.	(9 kHz to 150 kHz: to be defined) 0,15 MHz to 30 MHz: >40 dB
3)	Insertion loss and transmission bandwidth for the intentional (communication or r.f.) signal between EUT and AE ports, including characteristic impedance(s)	Defined by system requirements ^c
4)	Voltage division factor of the unsymmetric circuit between EUT and measuring receiver ports, to be added to the reading of the measuring receiver.	Typically 9,5 dB ^d
5)	Frequency range (1) Emission (2) Immunity	(0,009 MHz) 0,15 MHz to 30 MHz See e.g. IEC 61000-4-6
^a The asymmetric impedance of the AN will be determined by the 150-Ω resistor in parallel with the choke and the capacitance of the bulkhead connector to ground. ^b Since the coaxial cable shield at the AE port is directly connected to the AN metal case, the decoupling attenuation will not be a problem of the AN itself. The emission (or immunity) test set-up shall be such that the minimum decoupling attenuation can be guaranteed. ^c Insertion loss and transmission bandwidth for the intentional (communication or RF) signal between EUT and AE ports as well as the characteristic impedances between shield and inner conductor(s) are not in the scope of this standard. They should be defined according to system requirements. ^d The AN shall be calibrated by measuring the voltage division factor in a test set-up according to Figure F.2.		

8 The artificial hand and series RC element

8.1 General

In some product specifications the artificial hand is required for EUTs which do not have an earth ground connected to the metallic parts of the EUT and which in normal use are hand-held. Housings of plastic with a conductive coating may also require the use of the artificial hand. The artificial hand is used in conducted emission tests in the frequency range of 150 kHz to 30 MHz (the most critical frequencies are 5 MHz to 30 MHz) to simulate the influence of the operator's hands on the measurement results. The types of equipment to be evaluated with the artificial hand are: electric tools, household appliances, such as hand-held mixers, telephone handsets, joysticks, keyboards, etc.

8.2 Construction of the artificial hand and RC element

The artificial hand consists of a (strip of) metal foil of specified dimensions, which is placed on or wrapped around that part of the equipment normally touched by the user's hand, in a specific configuration, described as follows.

The metal foil is connected in a specific configuration to the reference point of the disturbance measuring system via an RC element consisting of a capacitor $C = 220 \text{ pF} \pm 20 \%$ in series with a resistor $R = 510 \Omega \pm 10 \%$; see Figure 11 a).

The strips of metal foil used to simulate the influence of a user's hand around an equipment handle or an equipment body are typically 60 mm wide. In the case of a keyboard EUT, a metal foil, or more practically a metal plate of maximum dimensions 100 mm by 300 mm, may be placed on top of the keys. Examples are given in Figures 11 and 12.

The lead length between the RC element and the metal foil shall be 1 m. If the test set-up requires a longer lead length, the total inductance of the lead shall be less than $1,4 \mu\text{H}$ if the frequency of measurement is near 30 MHz.

When considering the total effect of the interconnecting wires as a single wire in free space, the inductance L of the wire shall be less than $1,4 \mu\text{H}$ if the upper limit of the frequency range in the conducted emission test is 30 MHz. For a given single-wire length, this requirement allows calculating the minimum diameter d (in m) of the wires to be used by Equation (2):

$$L = \frac{\mu l}{2\pi} \left[\ln\left(\frac{4l}{d}\right) - 1 \right] \text{ H} \quad (2)$$

where

μ = $4\pi \times 10^{-7} \text{ H/m}$;

l is the length of the wire in m;

d is the diameter of the wire in m.

NOTE When complying with the inductance requirement of $1,4 \mu\text{H}$, the impedance of the RC network sufficiently dominates at 30 MHz.

8.3 The use of the artificial hand

The maximum length of wire between the RC element and the reference ground is generally met when the wire length does not exceed 1 m. The RC element may, for example, be placed either as close as possible to the metal foil, or as close as possible to the reference point. The correct choice largely depends on the (generally unknown) internal common mode impedance of the disturbance source in the presence of the metal foil, and the characteristic impedance of the transmission line formed by the connecting wire and its environment. If the upper frequency range of the emission measurements is limited to 30 MHz, the position of the RC element is not critical, and a practical position (also from a reproducibility point of view) of the RC element is inside the AMN or the LISN.

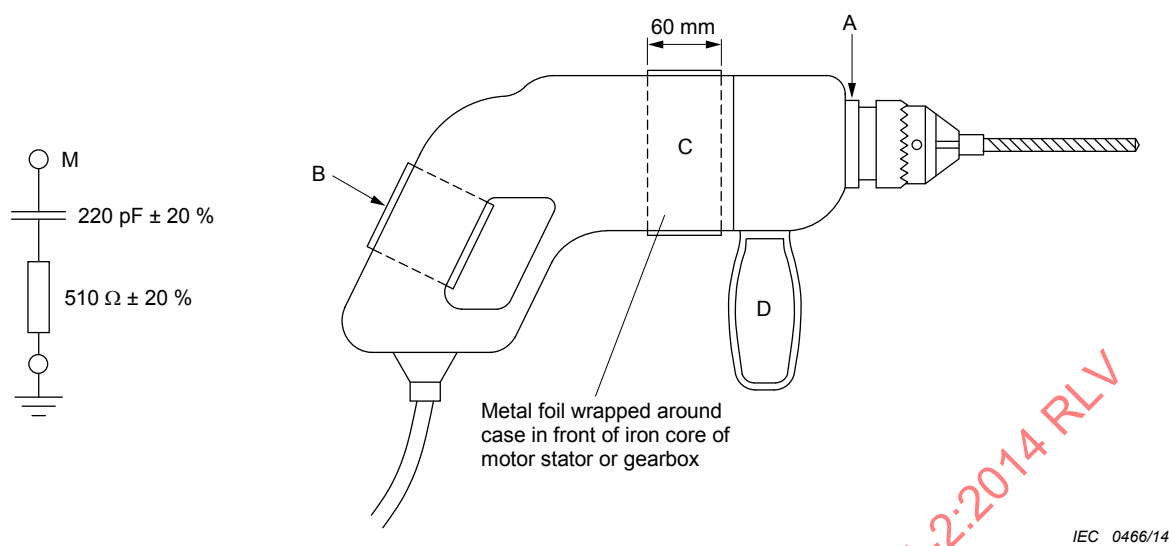
When the conducted emission at the mains port is measured, the reference point is the reference ground in the AMN. When this emission is measured on a signal or control line, the reference point is the reference ground of the AN. The general principle to be followed in the application of the artificial hand is that terminal M of the RC element shall be connected to any exposed non-rotating metalwork and to metal foil wrapped around all handles, both fixed and detachable, supplied with the appliance. Metalwork which is covered with paint or lacquer is considered exposed metalwork and shall be directly connected to the RC element.

The following items specify the detailed application of an artificial hand:

- a) When the housing of the appliance is constructed entirely of metal and is earth-grounded, an artificial hand is not required.

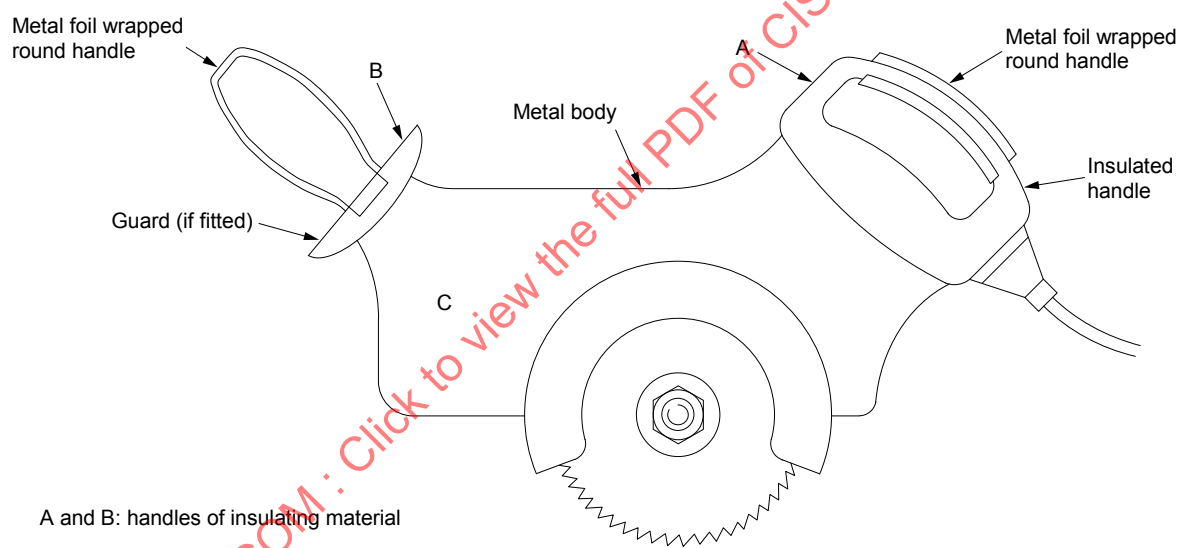
- b) When the case of the appliance is constructed of insulating material, metal foil shall be wrapped around the handle B as in Figure 11 b) and c), and also around the second handle D, if present. Metal foil 60 mm wide shall also be wrapped around the body C, as in Figure 11 b) and c) at the point where the iron core of the motor stator is located; or around the gearbox, if the latter gives a higher disturbance level. All these pieces of metal foil, and the metal ring or bushing A, if present, shall be connected together, and to the terminal M of the RC element.
- c) When the case construction of the appliance is partly metal and partly insulating material, and has insulating handles, metal foil shall be wrapped around the handles B and D as in Figure 11 b). 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 the point where the iron core of the motor stator is located; or alternatively around the gearbox, if this is constructed of insulating loading material and a higher disturbance level is obtained. The metal part of the body, the point A, the metal foil around 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 a Class II appliance (i.e. double insulated, without ground wire) has two handles of insulating material A and B, and a case of metal C, for example an electric saw as in Figure 11 c), 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 terminal M of the RC element.
- e) Figure 12 gives examples for a telephone handset and a keyboard. For the handset, the 60 mm wide foil is wrapped around the handle with some overlap of the foil. In the case of a keyboard the foil or the PCB should fully cover the keys as far as possible. Using a PCB, the metal side has to be placed on the keyboard; it does not, however, need to exceed the dimensions of 300 mm by 100 mm.

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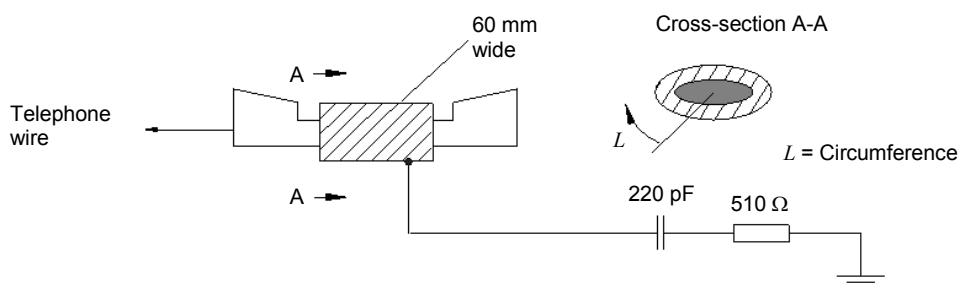
a) RC element

b) Portable electric drill



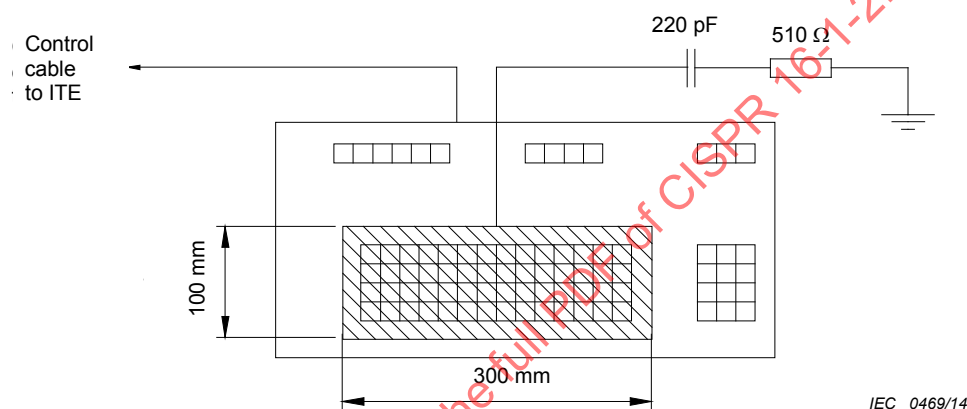
c) Portable electric saw

Figure 11 – Application of the artificial hand



IEC 0468/14

a) Application of artificial hand to telephone handset



IEC 0469/14

b) Application of artificial hand to typical keyboard

The artificial hand incorporates a metal foil, with the following dimensions:

a) 60 mm wide and greater than L in length:	for parts of the equipment that are hand-held during operation, or at a maximum of four parts of a system under test.
b) 300 mm by 100 mm:	for keyboards, whereby the metal foil is to be sized to cover the total number of keys, or to partially cover the keyboard, when the keyboard dimensions are greater than the maximum foil size.

Figure 12 – Examples of application of artificial hand to ITE

9 CDNE for measurement of disturbance voltage in frequency range 30 MHz to 300 MHz

9.1 Instrumentation

9.1.1 General

The measurement method is described in Clause 9 of CISPR 16-2-1:2014.

The measurement method uses the following equipment:

- a CDNE- X and,

– an RGP.

The technical requirements for this equipment are described in this subclause.

The CDNE couples asymmetric (common-mode) disturbance voltage from the EUT into the input lead of the measuring receiver, and decouples that lead from any emissions or influences present in the test environment. Any symmetric (differential-mode) disturbance coming from the EUT is loaded either by a symmetric impedance of 100 Ω at the EUT mains port (CDNE-M2 and CDNE-M3), or by the symmetric load at the AE port of the CDNE-S_x (see Annex J). The CDNE cannot be used for the measurement on mains lines which carry intentional symmetric (differential mode) signals.

The RGP is the reference for the measured asymmetric (common-mode) disturbance voltage.

9.1.2 Description of the CDNE measurement

9.1.2.1 Range of application

The CDNE is intended for the measurement of conducted disturbances in the frequency range from 30 MHz to 300 MHz from an electrically small EUT with one or two connected cables. Further the CDNE can be arranged between EUT and AE to decouple asymmetric disturbances from the AE and to stabilize the impedance.

NOTE An EUT is seen as electrically small if fulfils the conditions of 9.1 of CISPR 16-2-1:2014.

9.1.2.2 Measurement of disturbance voltage

The CDNE allows measurement of the asymmetric disturbance voltage V_{dis} generated by the EUT on the connected cable(s). This measurement takes into account the measuring receiver reading V_{meas} and the voltage division factor F_{CDNE} . The voltage division factor F_{CDNE} in dB, includes the internal attenuator a_{meas} of at least 6 dB, which is used to reduce the uncertainty contributed by the mismatch between the CDNE and the measuring receiver.

The result of the measurement is calculated as follows:

$$V_{\text{dis}} = V_{\text{meas}} + F_{\text{CDNE}} \text{ in dB}(\mu\text{V}) \quad (3)$$

9.1.2.3 Termination impedance of the CDNE

The internal impedance of the EUT at the connection point is generally unknown. For this reason both the reading and the reproducibility of the measurement results are highly dependent on the CDNE termination impedance. The asymmetric (common-mode) termination impedance was chosen to be 150 Ω , giving the lowest uncertainty contribution relative to the established test method.

The CDNE-M2 and CDNE-M3 for the mains port of the EUT provides a symmetric impedance of 100 Ω , which represents the symmetric impedance of most a.c. mains networks.

9.1.2.4 Decoupling attenuation of the CDNE

The unknown impedance of the AE and any emission from the AE can influence the measurement result. This influence can be reduced by using an asymmetric attenuation between the AE port and the EUT port. This asymmetric attenuation is typically realized with a choke.

9.1.3 Description of the RGP

The RGP serves as the reference for the measured asymmetric disturbance voltage. The set-up is placed on the RGP that is connected to the protective earth for safety of personnel and

equipment. The CDNE is placed in direct contact (good electrical bonding) with this plane, to ensure that it meets the specification for the asymmetric impedance. The EUT is positioned at a defined distance above the RGP.

9.2 Technical requirements for the CDNE-X

9.2.1 Mechanical and electrical parameters

The CDNE is contained in a metallic case. The centre of the CDNE EUT port is 30 mm $^{+10}_0$ mm above the RGP. This height allows for a typical impedance of 150 Ω for the connected cable.

For guidance, figures in Annex J provide examples of the construction of CDNEs.

Table 7 provides the electrical parameters and their specifications in the frequency range from 30 MHz to 300 MHz.

Table 7 – Electrical parameters of the CDNE-X

Parameter	Value for CDNE-M2 and CDNE-M3	Value for CDNE-Sx
Asymmetric (common-mode) impedance Z_{CM} at the EUT port	150 Ω $^{+10}_{-20}$ Ω Phase angle: $0^\circ \pm 25^\circ$	150 Ω $^{+10}_{-20}$ Ω Phase angle: $0^\circ \pm 25^\circ$
Symmetric (differential-mode) impedance Z_{DM} at the EUT port	100 $\Omega \pm 20 \Omega$	not defined
Longitudinal conversion loss (LCL)	≥ 20 dB	not defined
Tolerance of the voltage division factor F_{CDNE} including a_{meas}	$\pm 1,5$ dB	$\pm 1,5$ dB
Decoupling attenuation a_{decoup}	> 30 dB	> 30 dB

In general the level of asymmetric voltage is higher than the level of unintentional symmetric voltage. Therefore a minimum LCL value of 20 dB is adequate to prevent any influences of the symmetric voltage on the measurement results. In contrast, the assessment of EUTs using the differential-mode for communication on unscreened leads requires specific LCL values (minimum and maximum value) of the CDNE.

NOTE 1 For the EUT port of CDNE-M3, the minimum LCL value is not defined for L and PE, or N and PE.

NOTE 2 Reproducible LCL measurements above 100 MHz are under consideration.

NOTE 3 The CDNE cannot be used for applications on a mains network with intentional differential mode signals, e.g. where transmitting of a wanted differential signal would require a specific LCL, minimum and maximum value, to take the network quality into account.

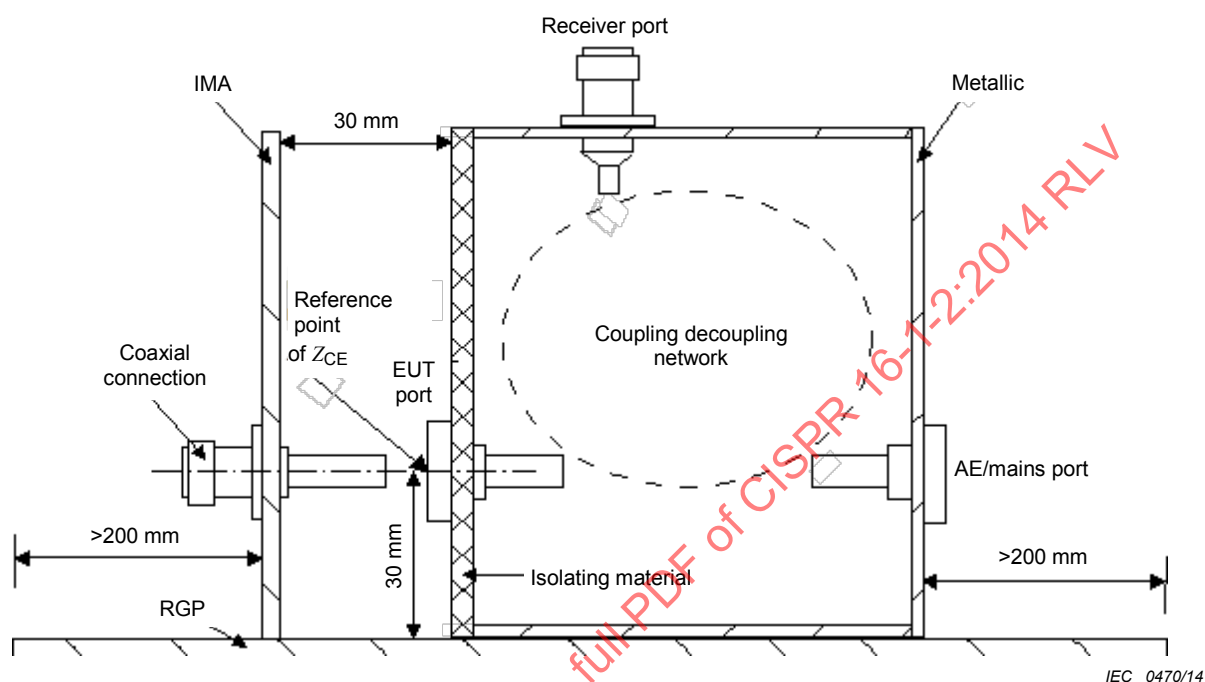
The attenuation a_{meas} at the receiver port is used to reduce the measurement uncertainty contributed by the mismatch between the CDNE and the measuring receiver. This attenuation is preferably an internal component of the CDNE. If an external attenuator is used, it shall be directly mounted on the CDNE receiver port, and this attenuator needs to be present during calibration and measurement. The attenuation of a_{meas} should be at least 6 dB.

9.2.2 Validation of the CDNE

9.2.2.1 General requirements

For the validation measurement, the CDNE shall be placed on an RGP, and its enclosure bonded to this RGP.

All measurements of the asymmetrical voltage refer to this RGP. The measurement arrangement shall be as specified in Figure 7 of Clause 10 of IEC 61000-4-6:2008, and is shown in Figure 13 with a different reference point of Z_{CF} in front of the EUT port.



NOTE "AE/mains" can include a.c. mains, d.c. supply as well as control/communication lines.

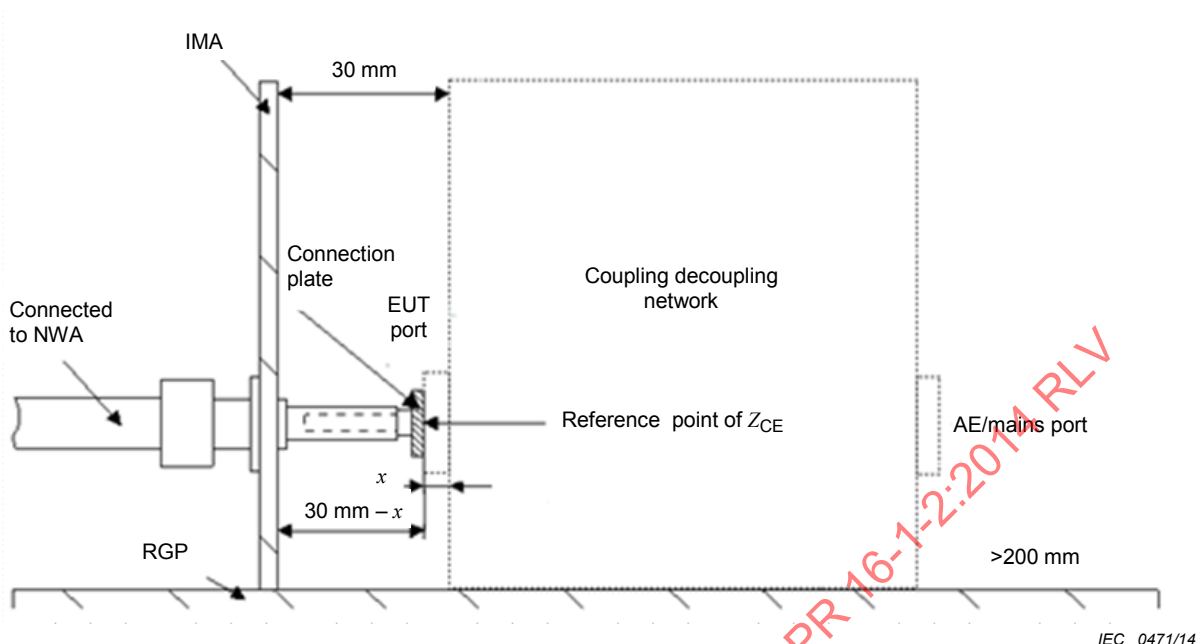
Figure 13 – Arrangement for validation of a CDNE

9.2.2.2 Calibration of the network analyzer (NWA) at the reference point

For the measurement of the asymmetric impedance at the reference point of Z_{CE} in Figure 13, the following calibration procedure shall be used:

The effect of the measurement cable (between the IMA and the NWA) is taken into account by calibrating the NWA using the OPEN-, SHORT-, and MATCH-error-correction method. The next step requires connection of the IMA with the previously calibrated cable to the NWA. The other side of the IMA shall be fitted with a connection plate including all adaptor parts that are between the IMA and CDNE during the measurement of the asymmetric impedance and phase angle (see Figure 14). Excluded are all parts that will be inserted into the connectors of the CDNE. This arrangement takes into account the electrical load between the calibrated cable and the measurement point at the input of the CDNE.

The electrical length shall be corrected by a delay time, which may be adjusted automatically or manually depending on the measurement equipment used.



The length x is related to the design of the EUT port connector and shall be as short as possible. Safety banana connectors have a typical x value of 3 mm.

The coupling decoupling network is not part of the set-up and is shown only for the positioning of the connection plate.

This set-up requires a connection plate without any parts that will be inserted into the connectors of the EUT port. In principle the connection plate will be upgraded to a asymmetric-mode adaptor (electrical connection between IMA and all lines of the EUT port) for the measurement of the asymmetric impedance and phase angle.

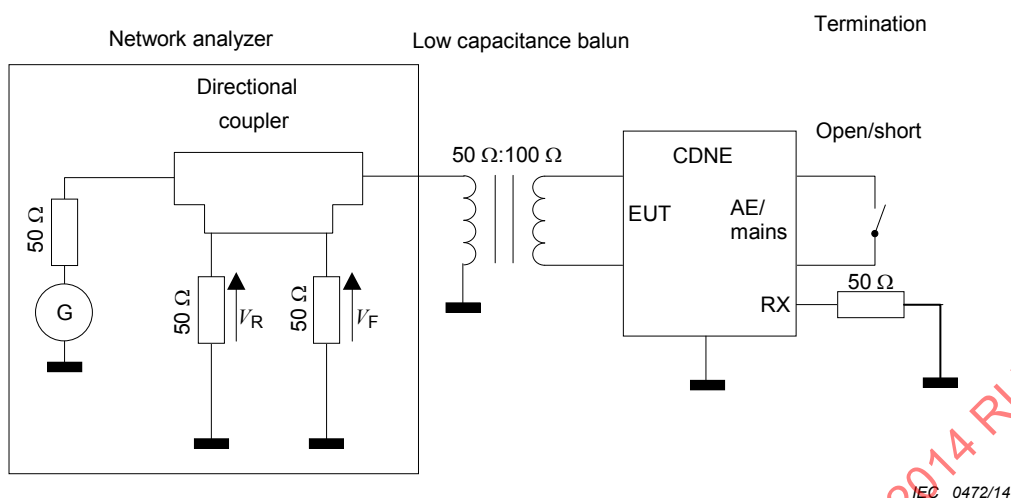
Figure 14 – IMA arrangement for correcting the electrical length

9.2.2.3 Asymmetric impedance Z_{CM}

The asymmetric impedance Z_{CM} at the CDNE EUT port shall be measured with the arrangement provided in Figure E.2.

9.2.2.4 Symmetric impedance of Z_{DM}

The symmetric impedance Z_{DM} at the CDNE-M2 and CDNE-M3 EUT port shall be measured according to Figure 15. The test arrangement with the low capacitance balun shall be calibrated using a 50 Ω network analyzer with OPEN, SHORT, and MATCH using 100 Ω on the symmetric port of the balun. The reflection coefficient ρ shall then be determined after connecting the CDNE to the symmetric port of the balun.



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

Figure 15 – Test arrangement for the measurement of the symmetric impedance (Z_{DM})

The symmetric impedance shall be calculated according to Equation (4) or will be displayed on the network analyzer.

$$Z_{DM} = Z_0 \frac{1 + \rho}{1 - \rho} = Z_0 \frac{1 + (V_R/V_F)}{1 - (V_R/V_F)} \quad (4)$$

where ρ is the reflection coefficient and Z_0 is 100 Ω .

9.2.2.5 Voltage division factor

The voltage division factor F_{CDNE} of the CDNE is measured according to Figure E.6.

NOTE 1 For this measurement, F_{CDNE} is the same as the term a_{vdiv} used in Figure E.6.

NOTE 2 The generator impedance of 150 Ω is typically accomplished with an additional 100 Ω impedance in series with the generator impedance. Because of the frequency range, this additional 100 Ω is described by S-parameters that are used for the specification of the voltage at the CDNE input.

9.2.2.6 Decoupling attenuation

The decoupling attenuation a_{decoup} of the CDNE is measured using the set-up as shown in Figure E.4. For a CDNE with two or more wires, all wire ports shall be measured between the EUT port and the AE port.

NOTE For this measurement, F_{CDNE} is the same as the term a_{vdiv} used in Figure E.6.

9.2.2.7 LCL

The LCL of the CDNE is measured according to Annex E.

9.3 Technical requirement for the RGP

The only requirement for the metallic RGP is for size and its arrangement in the environment. The RGP shall be at least 0,2 m larger at each side than the area determined by the test set-up comprising the CDNE and EUT. The surface of the RGP shall also be such that it enables a good electrical bonding of the CDNE, i.e. not painted or anodized.

Annex A (normative)

AMNs

A.1 General

This annex sets forth information and data concerning AMNs used in the measurement of radio-frequency (RF) voltages over the frequency range 9 kHz to 100 MHz and having current-carrying capabilities of up to 500 A. This annex supplements the provisions of Clause 4. Included are V-networks for voltage measurements between each conductor of the supply mains and reference ground, and delta-networks for voltage measurements between conductors of the supply mains (symmetric) and between the electrical mid-point of the conductors of the supply mains and reference ground (asymmetric).

An AMN circuit shall provide firstly the specified impedance over the working frequency range. It shall provide sufficient isolation to spurious signals in the mains supply (the spurious signals generally should be at least 10 dB below the measurement level at the measuring receiver). Also it shall prevent the mains voltage from being applied to the measuring receiver. It should have these provisions for each conductor of the mains (two-wire in single-phase and four-wire in three-phase), a switch to connect the measuring receiver to the mains conductor under measurement and to provide the correct termination to the other mains conductors. The circuits given in this annex have these features. These circuits are given for the case of two-wire single-phase mains; extension to four-wire three-phase use is simply done.

A.2 An example of the 50 Ω /50 μ H + 5 Ω artificial mains V-network

Figure 5 shows a suitable circuit with the component values listed in Table A.1. The parameters L_1 , C_1 , R_1 , R_4 and R_5 define the impedance; L_2 , C_2 and R_2 provide the isolation to spurious mains signals and mains impedance variations, and C_3 decouples the measuring receiver from mains voltage. The network may be constructed for use with currents up to 100 A.

Table A.1 – Component values of 50 Ω /50 μ H + 5 Ω V-network

Component	Value
R_1	5 Ω
R_2	10 Ω
R_3	1 000 Ω
R_4	50 Ω
R_5	50 Ω (input impedance the measuring receiver)
C_1	8 μ F
C_2	4 μ F
C_3	0,25 μ F
L_1	50 μ H
L_2	250 μ H

At the lowest frequencies of the range 9 kHz to 150 kHz, the 0,25 μF capacitance of C_3 does not have a negligible impedance. Unless otherwise specified, it will be necessary to make a correction for this impedance.

Since C_1 and C_2 have high capacitances, for safety reasons the network case should either be solidly bonded to reference ground or a mains isolating transformer should be used.

The inductance L_2 should have a Q -factor not less than 10 over the 9 kHz to 150 kHz frequency range. In practice, it is advantageous to use inductors coupled in series opposition in the live and neutral lines (common-core choke).

A suitable construction for the inductor L_1 is described in Clause A.7. For equipment requiring currents greater than 25 A, difficulties may be encountered in the construction of L_2 . In this case the isolating section L_2 , C_2 and R_2 may be omitted. The effects will be that the impedance of the network at frequencies below 150 kHz may be outside the tolerance specified in 4.3, and the isolation of mains noise may not be sufficient.

This circuit may also satisfy the requirements of the 50 Ω /50 μH artificial mains V-network specified in 4.4.

A.3 An example of the 50 Ω /50 μH artificial mains V-network

Figure 6 shows the circuit with the component values as listed in Table A.2. Components L_1 , C_1 , R_2 , R_3 and R_4 define the impedance. Unlike the previous example (i.e. see A.2), there is no isolating section because the circuit is able to meet the impedance specification. However, in cases of high ambient mains noise, a filter is required to reduce the spurious signal level. This network may be constructed for use with currents up to 100 A.

Table A.2 – Component values of 50 Ω /50 μH V-network

Component	Value
R_1	1 000 Ω
R_2	50 Ω
R_3	0 Ω
R_4	50 Ω (input impedance of the measuring receiver)
R_5	0 Ω
C_1	1 μF
C_2	0,1 μF
L_1	50 μH

Because C_1 has a high capacitance, for safety reasons the network case shall either be solidly bonded to reference ground or a mains isolating transformer shall be used.

A suitable construction for the inductor L_1 is described in Clause A.7.

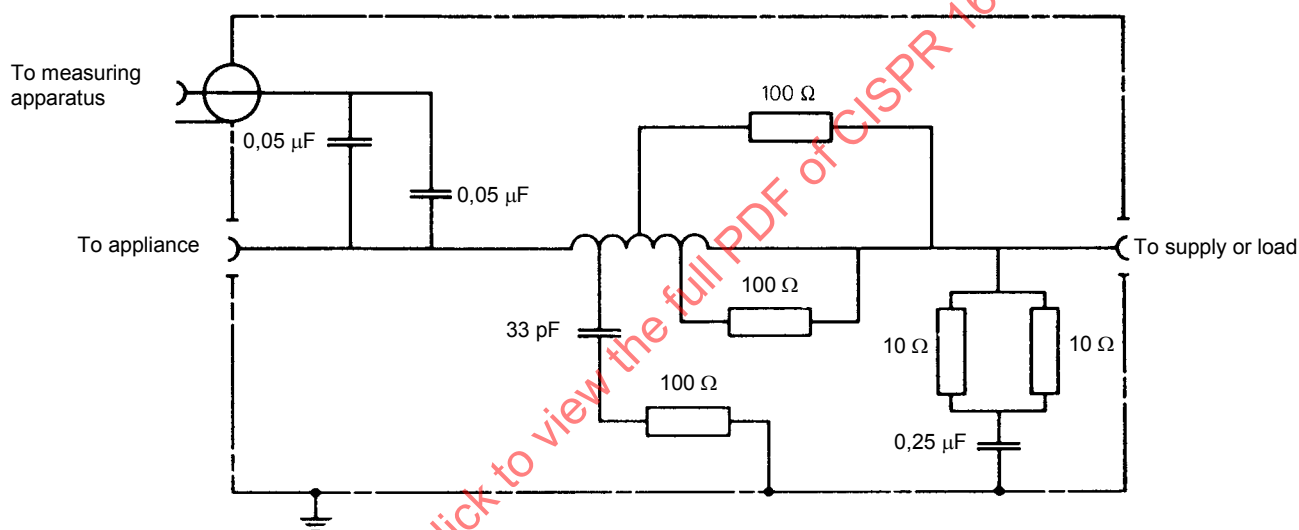
A.4 Examples of the 50 Ω /5 μH + 1 Ω artificial mains V-network

The circuit of Figure 6 with the component values given in Table A.3 is suitable for frequencies 150 kHz to 30 MHz, and currents up to 400 A.

Table A.3 – Component values of 50 Ω/5 μH + 1 Ω V-network

Component	Value
R_1	1 000 Ω
R_2	50 Ω
R_3	0 Ω
R_4	50 Ω (input impedance of the measuring receiver)
R_5	1 Ω
C_1	2 μF (minimum)
C_2	0,1 μF
L_1	5 μH

An alternative circuit with component values is shown in Figure A.1. It is suitable for the frequency range 150 kHz to 100 MHz, and for currents up to 500 A.



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Coil details: 5 μH, 18 turns, Ø 6 mm wound on 50 mm diameter coilformer. Tapping points at 3, 5, 9 and 13,5 turns.

Figure A.1 – Example of an alternative 50 Ω/5 μH + 1 Ω V-AMN for devices used with low impedance power sources

A.5 An example of the 150 Ω artificial mains V-network

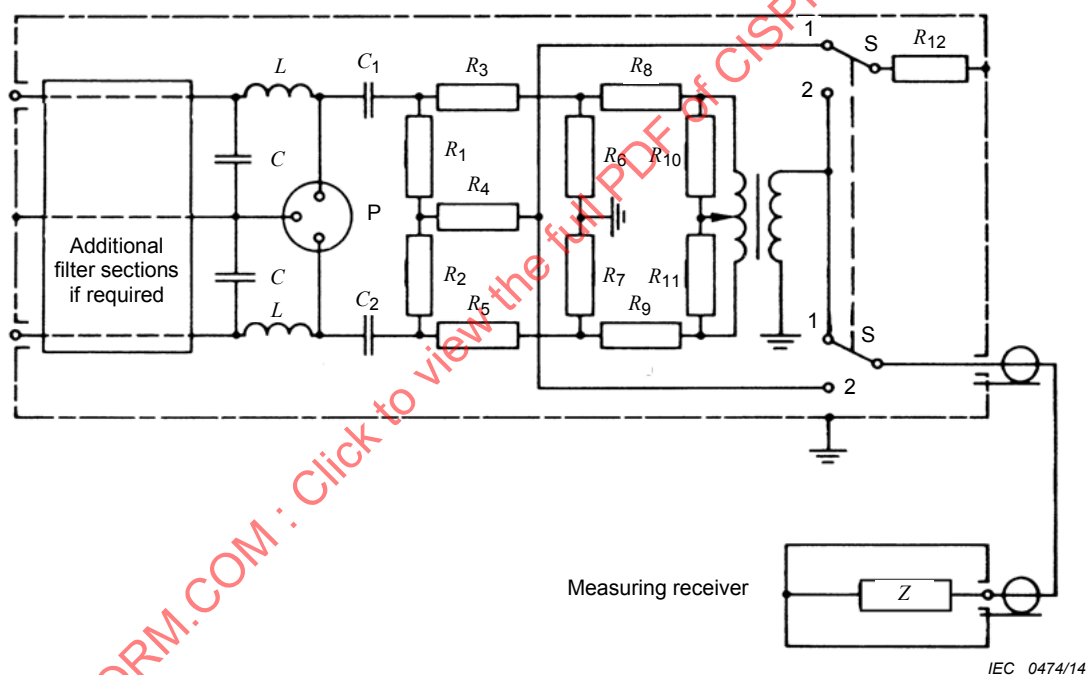
Figure 6 shows a suitable circuit. The component values are given in Table A.4.

Table A.4 – Component values of the 150 Ω V-network

Component	Value
R_1	1 000 Ω
R_2	150 Ω
R_3	100 Ω
R_4	50 Ω (input impedance of the measuring receiver)
R_5	0 Ω
C_1	1 μF
C_2	0,1 μF
L_1	Suitable value to achieve the specified impedance

A.6 Example of the 150 Ω artificial mains delta-network

Figure A.2 shows a suitable circuit. The component values are given in Table A.5.

**Key**

- P is the connection for apparatus under test
- 1 for the symmetric component
- 2 for the asymmetric component
- S double pole double throw switch
- Z measuring receiver input impedance

Figure A.2 – Example of a Δ -AMN for a measuring receiver with unbalanced input

Table A.5 – Component values of the 150 Ω delta-network

Component	Value
R_1, R_2	118,7 (120) Ω
R_3, R_5	152,9 (150) Ω
R_4	390,7 (390) Ω
R_6, R_7	275,7 (270) Ω
R_8, R_9	22,8 (22) Ω
R_{10}, R_{11}	107,8 (110) Ω
R_{12}	50 Ω
C_1, C_2	0,1 μF
L, C	suitable value to achieve the specified impedance
NOTE 1 The turns ratio of the balanced to unbalanced transformer is assumed to be 1:2,5 with centre tap.	
NOTE 2 Resistance values shown in brackets are the nearest preferred values ($\pm 5\%$ tolerance).	

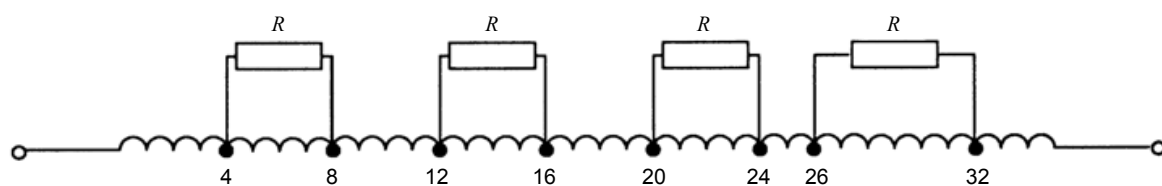
Calculations give the following network performance. Values in brackets are based on the resistance values in brackets.

Attenuation:	Symmetric	20	(20) dB
	Asymmetric	20	(19,9) dB
Network impedance:	Symmetric	150	(150) Ω
	Asymmetric	150	(148) Ω

A.7 Example design for an AMN with a 50 μH inductor

A.7.1 The inductor

The solenoidal winding of the inductor shown in Figure A.3 consists of 35 turns of a single layer of 6 mm diameter copper wire with an 8 mm pitch wound on a coilformer of an insulating material. Its inductance is greater than 50 μH outside the metal case, and 50 μH inside the metal case.



IEC 0475/14

NOTE Resistors R ($430\ \Omega \pm 10\%$) are connected to taps at turns 4 and 8, 12 and 16, 20 and 24, 26 and 32. Inductance is $50\ \mu\text{H} \pm 10\%$.

Figure A.3 – Schematic of $50\ \mu\text{H}$ inductor

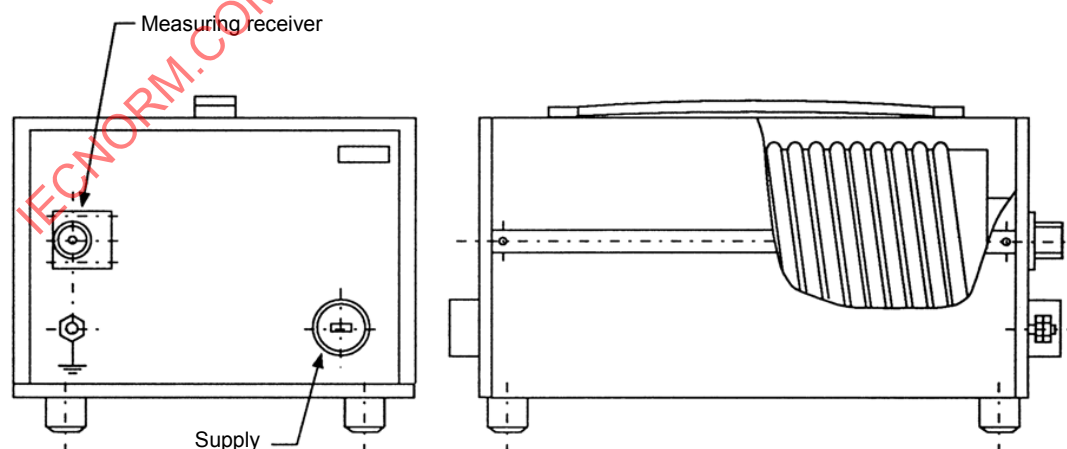
The diameter of the inductor is 130 mm. To improve the electrodynamic stability of the winding, a 3 mm deep spiral groove is made in the coilformer, and the wire is laid in this groove.

The higher frequency characteristics of the inductor are improved by sectionalizing the winding. Alternate sections, each of 4 turns, are each shunted by a $430\ \Omega$ resistor. These act to suppress internal resonances in the inductor, which otherwise would cause the input impedance to deviate from the specified value at certain frequencies.

A.7.2 The case of the inductor

The inductor and the other components of the network are mounted on a metal frame, which is then closed by metal lids. The bottom and side lids are perforated to improve the heat dissipation. The dimensions of the case are 360 mm by 300 mm by 180 mm. Figure A.4 shows a general view.

It is recommended that the load-end terminals of the network be located as near as possible to a corner of that end of the case, so that two or more networks may be assembled with short leads from these terminals to the socket to be used for attachment of the EUT.

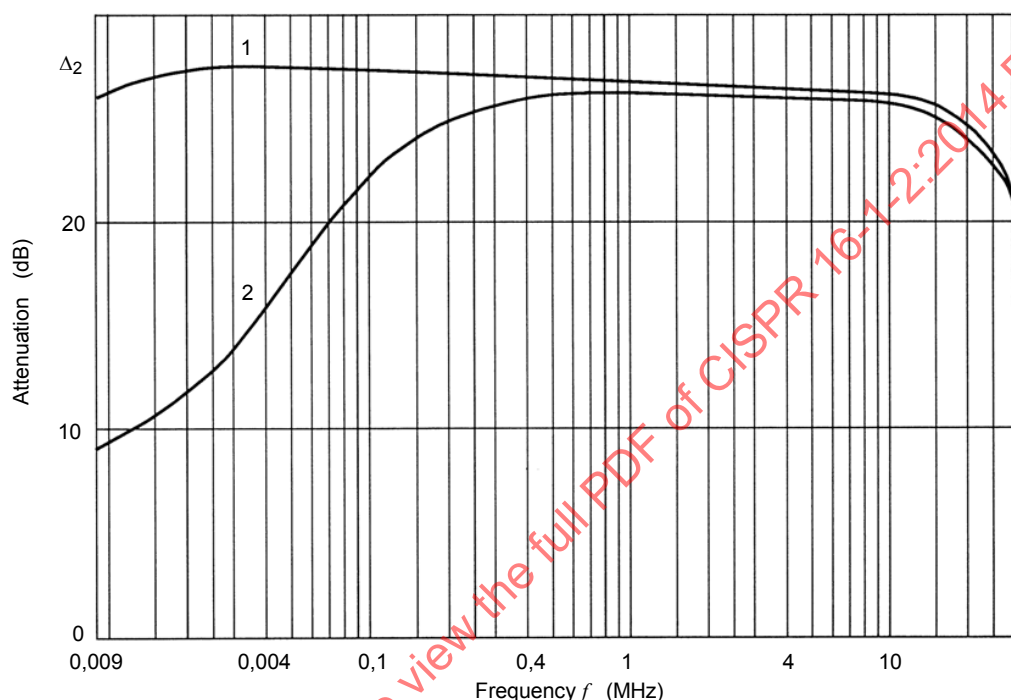


IEC 0476/14

Figure A.4 – General view of an AMN

A.7.3 Isolation of the inductor

Figure A.5 shows the attenuation to signals on the mains supply when the inductor is used in the circuit of Figure 5 but without the isolation section L_2 , C_2 , and R_2 . The attenuation is determined as that between the supply mains terminal and the measuring receiver terminal. For curve 1, the internal impedance of the signal generator at the mains terminal is $50\ \Omega$ resistive. In curve 2, the internal impedance of the generator is varied in accordance with the nominal value of the magnitude of input impedance of the AMN, as given in Figure A.5.



IEC 0477/14

Key

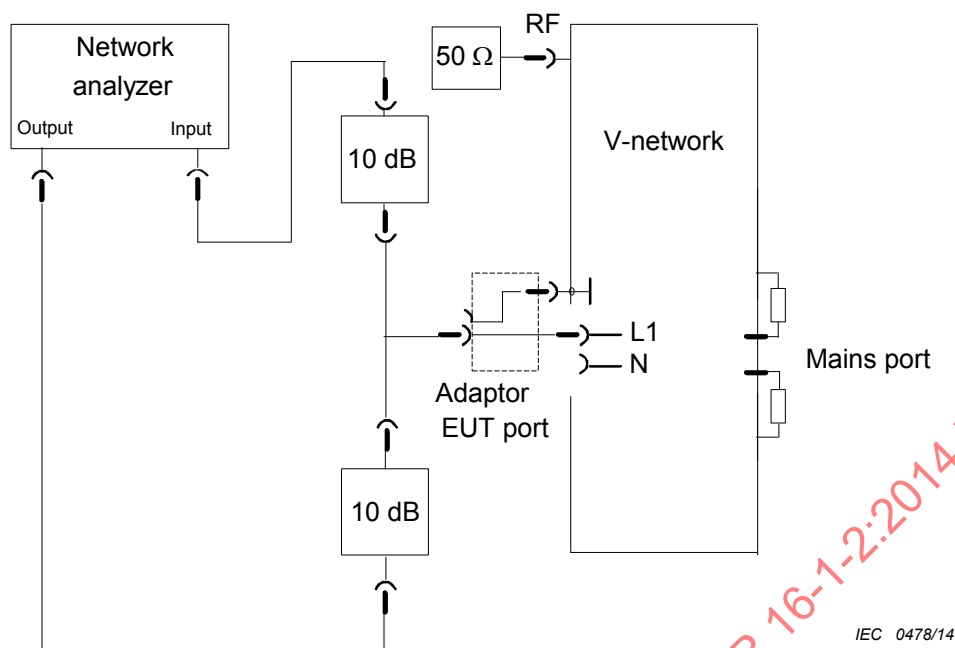
1 $Z_{\text{gen}} = R_{\text{gen}} = 50\ \Omega$

2 $Z_{\text{gen}} = |Z_{\text{in AMN}}|$

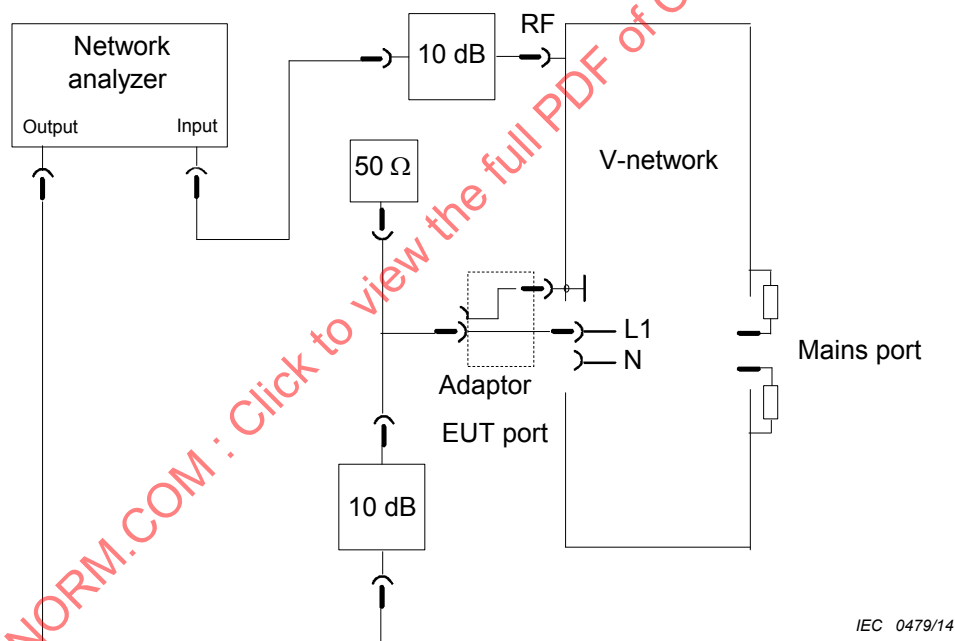
Figure A.5 – Attenuation of an AMN filter

A.8 Measurement of the voltage division factor of an artificial mains V-network

The voltage division factor may be determined using a test set-up as given by Figures A.6 for each test configuration of a V-network. The voltage division factor shall be measured on each line with each internal connection (e.g. with manual or remote switching configurations) using a network analyser, or using a signal generator and a measuring receiver or an RF voltmeter with a high impedance (low capacitance) probe. All lines of the EUT port which are not connected to the RF port shall be terminated with $50\ \Omega$ loads.



a) Test set-up for normalization (calibration) of the network analyzer



b) Test set-up for measurement of the voltage division factor using a network analyzer

Figure A.6 – Test set-up for determining the voltage division factor

Because the EUT port presents a frequency-dependent input impedance, the network analyzer needs to be normalized (i.e. calibrated), using the measured voltage level at the EUT port.

If a signal generator and an RF-voltmeter with a high-impedance probe are used, the EUT port is fed via a 50 Ω pad, and the RF port is terminated with a 50 Ω load while determining the voltage division factor by two subsequent measurements on the EUT and RF ports.

The construction of the adaptor used at the EUT port is critical for the calibration. Accordingly, the connections should provide low impedance, and the T-connector should be placed as close as possible to the EUT port and ground terminals. The 10 dB pads are used to provide exact 50 Ω source and load impedances for accurate measurements.

Furthermore, each line of the mains port should be terminated with 50 Ω relative to the chassis.

For a 150 Ω V-network the voltage division between the EUT port and the measuring receiver port, i.e. 150 Ω /50 Ω , should be considered.

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Annex B (informative)

Construction, frequency range, and calibration of current probes

NOTE This annex supplements the provisions of Clause 5.

B.1 Physical and electrical considerations for current probes

The physical size of the current probe is a function of the maximum cable size to be measured, the maximum current flowing in the cable, and the range of signal frequencies to be measured.

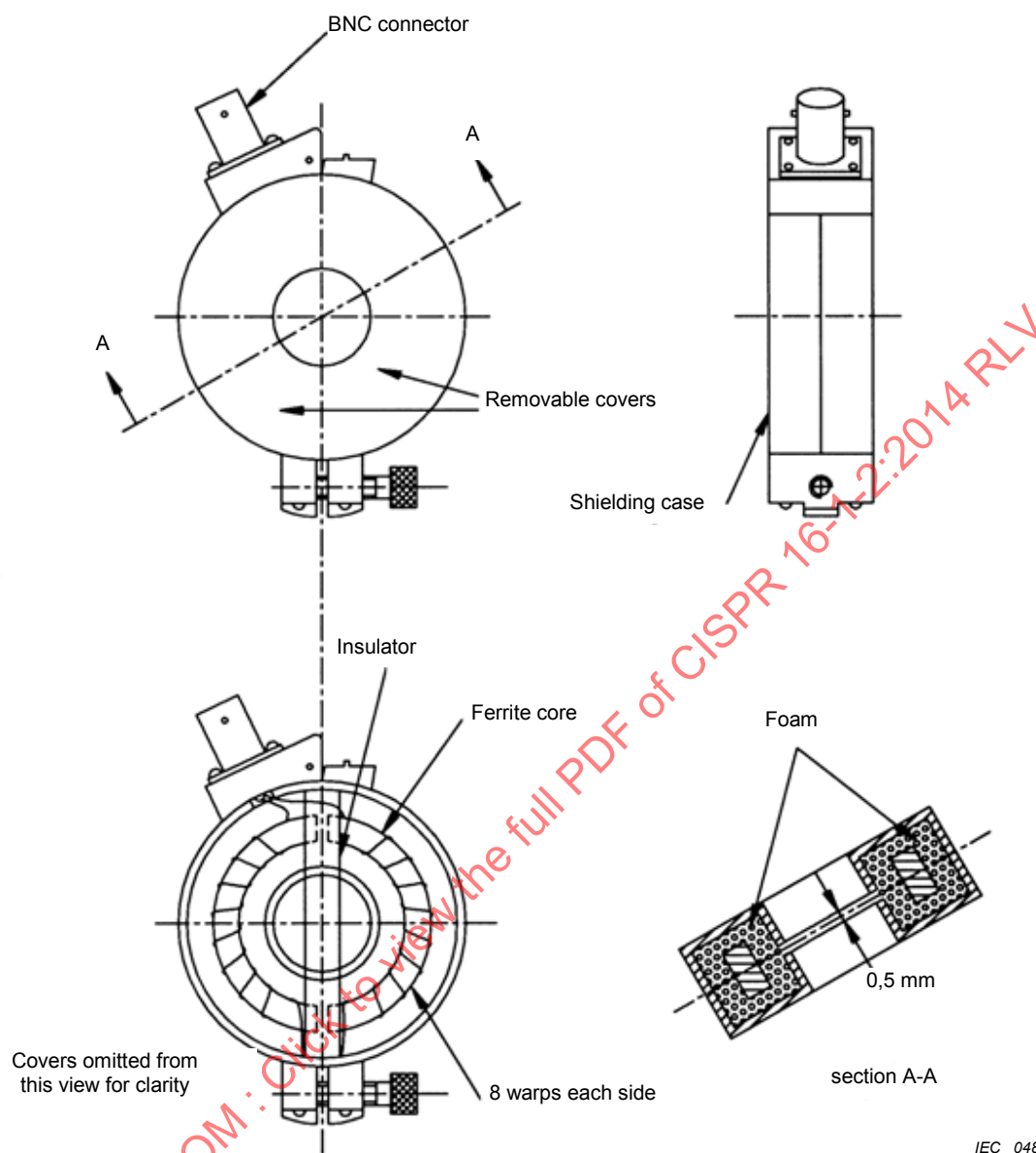
A current probe is usually a toroid with the conductor to be measured placed within the centre opening. Existing requirements and manufacturers' specifications show that the centre opening may vary from 2 mm to 30 cm in diameter. The secondary winding is placed on the toroid in such a manner as to facilitate the clamp-on function of the probe. The core and winding are enclosed in a shield to prevent electrostatic pick-up. The shield has a gap to prevent it from being a shorted turn on the transformer.

Typical current probes for disturbance measurements use seven to eight secondary turns. This number of turns is an optimized turns-ratio to ensure a maximized flat frequency range and an insertion impedance of 1 Ω or less. For frequencies below 100 kHz, laminated silicon steel cores are used. Ferrite cores are used between 100 kHz to 400 MHz and air cores are used between 200 MHz to 1 000 MHz, with a balanced coil to unbalanced 50 Ω output transformer. Figure B.1 shows the configuration of a typical current probe.

The current probe is generally used as a pick-up device for disturbance measurements. Therefore, it is designed to transfer the disturbance current to a voltage which can be detected by the meter. The sensitivity of the current probe may be expressed conveniently in terms of transfer impedance. Transfer impedance is defined as the ratio of secondary voltage (generally across a 50 Ω resistive load) to the primary current. The transfer admittance is sometimes used instead.

Overall sensitivity of the current probe and disturbance measuring receiver is also a function of the receiver sensitivity. Minimum detectable disturbance current in a conductor is the ratio of receiver sensitivity (V) to current probe transfer impedance (Ω). For instance, if a one microvolt (1 μ V) receiver and a current probe with a transfer impedance of 10 Ω are used, then the minimum measurable disturbance current is 0,1 μ A. However, if a 10 μ V receiver and a current probe with a transfer impedance of 1 Ω are used, then the minimum measurable current is 10 μ A. To obtain maximum sensitivity, the transfer impedance should be as high as possible.

The transfer impedance Z_T is often expressed in terms of decibels (dB) above 1 Ω . This is a convenient unit in reference to the more general disturbance units of decibels above 1 μ V or 1 μ A (Z_T in terms of decibels above 1 Ω is taken as 20 lg Z_T).



IEC 0480/14

Figure B.1 – Typical current probe configuration

B.2 Equivalent electrical circuit of current probe

The current probe may be represented by an exact equivalent circuit from general transformer theory. It is not necessary to repeat the circuit here since it is shown in many standard textbooks, see Reference [10]. After considerable simplification of the exact circuit and derived equations, the following equations for the transfer impedance result:

High-frequency condition:

$$Z_T = \frac{\omega M}{\left[(\omega L / R_L)^2 + (\omega^2 LC - 1)^2 \right]^{1/2}} \quad (\text{B.1})$$

Mid-frequency condition:

$$Z_T = MR_L \text{ when } (\omega^2 LC = 1) \quad (\text{B.2})$$

Low frequency condition:

$$Z_T = \frac{\omega M}{\left[(\omega L / R_L)^2 + 1 \right]^{1/2}} \quad (\text{B.3})$$

where

- Z_T is the transfer impedance;
- M is the mutual inductance between primary and secondary windings;
- L is the inductance of secondary winding;
- R_L is the load impedance of secondary (usually 50 Ω);
- C is the distributed capacitance of secondary;
- ω is the angular frequency in radian/second.

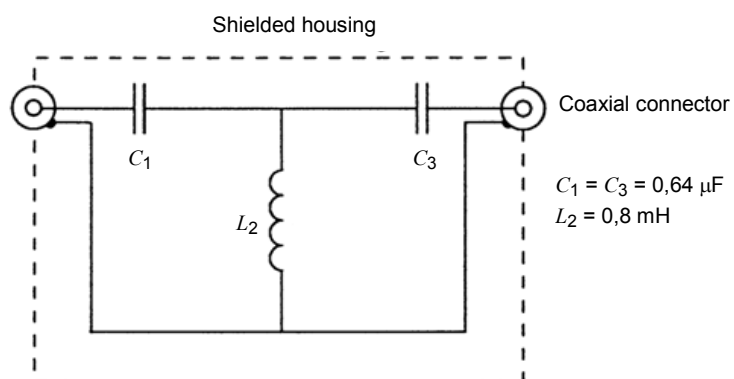
The following conclusions result from Equations (B.1) to (B.3):

- a) The maximum transfer impedance at mid-frequency, for a constant load impedance, is directly proportional to the ratio of mutual inductance to secondary inductance (R_L being constant).
- b) The high-frequency half-power point occurs when the reactance of the secondary distributed capacitance is equal to the load resistance.

B.3 Detrimental effects of current probe measurements

The current probe is essentially a toroidal transformer and therefore reflects the secondary impedance into the primary. For an 8-turn secondary winding and a 50 Ω load, typically the insertion impedance is approximately 1 Ω . As long as the combination of source and load impedances of the circuit to be measured is greater than 1 Ω , the application of the current probe will not greatly alter the primary current flow. However, if the sum of the circuit source and load impedances is less than the insertion impedance, the application of the current probe may alter the primary current considerably.

One intended current probe application is the measurement of disturbance current on primary power lines which may carry up to 300 A d.c. or 100 A a.c. The current probe may also be used in the vicinity of devices which generate strong external magnetic fields. The current probe transfer impedance shall not be altered by these power currents or flux densities. Therefore, the magnetic circuit shall be designed so that it will not saturate. Because the a.c. power currents may be in the frequency range of 20 Hz to 15 kHz, the current probe output at these power frequencies may damage the input circuit of the associated receiver. A possible solution is the insertion of power-frequency rejection filters between the current probe and the receiver. Figure B.2 shows a high-pass filter with 9 kHz cut-off frequency.



IEC 0481/14

Figure B.2 – High-pass filter with cut-off frequency of 9 kHz

B.4 Typical frequency response characteristics of current probes

Figure B.3 shows the typical frequency response characteristics of current probes, with flat passbands of: a) 100 kHz to 100 MHz; b) 30 MHz to 300 MHz; and c) 200 MHz to 1 000 MHz.

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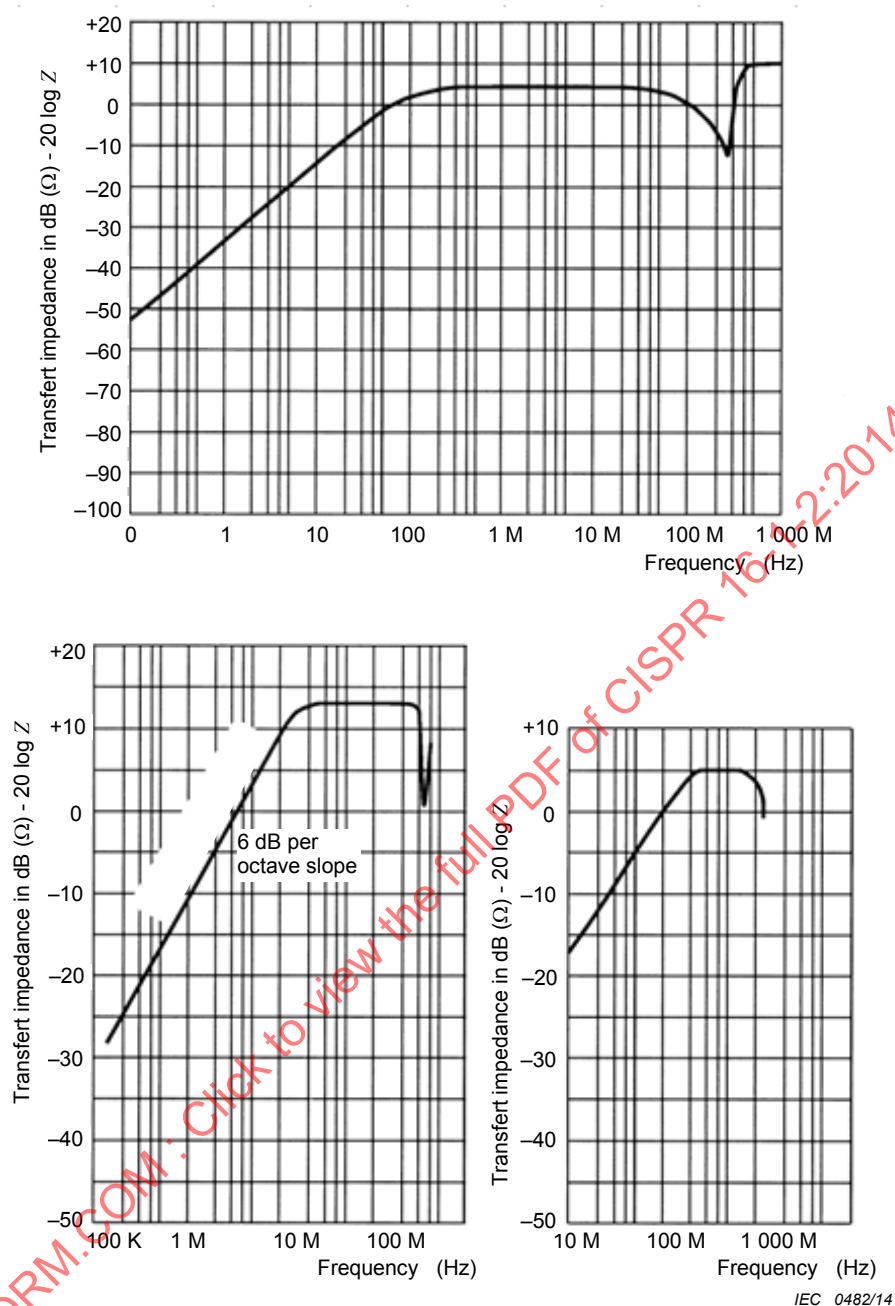


Figure B.3 – Transfer impedance of typical current probes

B.5 A shielding structure for use with current probes

B.5.1 General

A current probe with the addition of a conductive (e.g. copper, brass, etc.) shielding structure may be used to measure either asymmetric (common mode) or symmetric (differential mode) disturbance current. The method is usable from 100 kHz to 20 MHz. The essential feature of this method is a modified RF current probe combined with a high-pass filter. The purpose of the high-pass filter is to enhance the rejection of the power frequency current in the output of the current probe. The test arrangement is described in CISPR 16-2-1.

B.5.2 Theoretical model

The set-up for current measurement using the AMN is shown in Figure B.4 a). The components of the disturbance currents are:

I_1 current in the live mains conductor

I_2 current in the neutral mains conductor

I_C asymmetric (common mode) current

I_D symmetric (differential mode) current

NOTE The phase angle between I_1 and I_2 is assumed to be zero. This is the case for leads of less than 1 m and frequencies below 30 MHz.

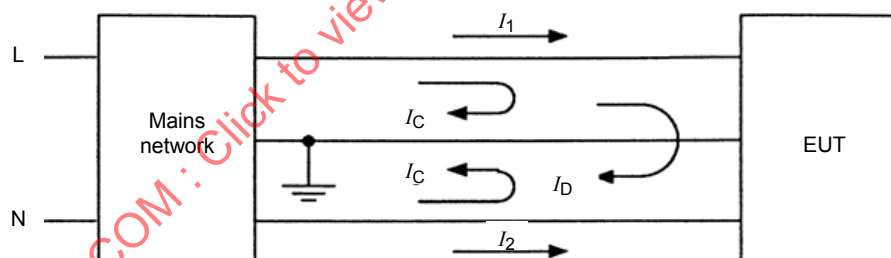
It can be seen from Figures B.4 a) and B.4 b) that the currents have the following relations:

$$I_1 = I_C + I_D \quad (B.4)$$

$$I_2 = I_C - I_D \quad (B.5)$$

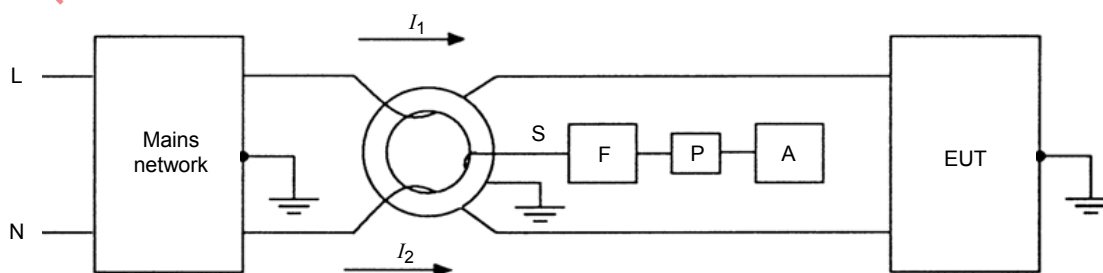
$$2I_C = I_1 + I_2 \quad (B.6)$$

$$I_D = I_1 - I_2 \quad (B.7)$$



IEC 0483/14

a) CISPR test circuit with disturbance currents



IEC 0484/14

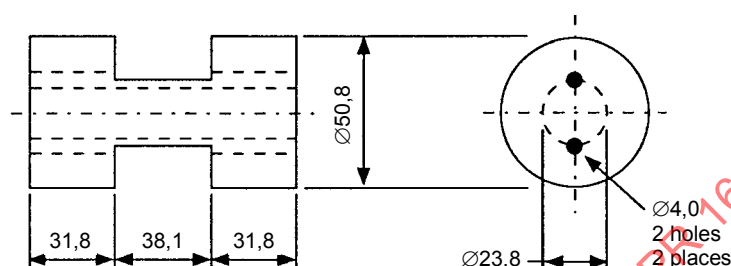
b) Test circuit which differentiates asymmetric (common) mode and symmetric (differential) mode noise

Figure B.4 – Set-up for current measurement using the AMN

Thus a current probe clamped around the conductors so that I_1 and I_2 would add gives an output due solely to the asymmetric current; whereas, subtraction of the currents would yield an output related only to the symmetric current. A 6 dB correction of the measured value only for the asymmetric current is required, due to the factor of 2 in the equation for the asymmetric current (see Figure B.4 b).

B.5.3 Construction of the shielding structure

The additional shield required is shown in Figure B.5. The dimensions shown are for a current probe with a centre core of 51 mm diameter. For other sizes of current probes the dimensions are scaled accordingly.



IEC 0485/14

The material should be highly conductive, e.g. copper or brass.

Figure B.5 – Shield configuration used with current transformer

This structure serves to position the unshielded conductors in the current probe, and to provide additional shielding from any external linkage when the output is grounded at one end. Insulated (0,75 mm²), stranded wire is passed through the hole and fitted at each end with terminals to accept the shielded leads from the mains network and to the EUT. The diameter of the centre of the shield is built up with insulating tape so that the wires are firmly held in the slots, and so that this portion of the assembly fits snugly in the current probe when it is closed.

The shield is positioned in the current probe such that the plane of the leads is perpendicular to the plane of the gaps in the core halves of the probe. It is important to ensure that the shielding structure as shown in Figure B.5 is insulated from the current probe housing so that the gap in the housing is not shorted.

B.5.4 High-pass filter

A high-pass filter, if needed, is inserted between the output of the current probe and the measuring receiver. This filter may be part of the measuring receiver [see Figures B.2 and B.4 b)].

B.6 Calibration of current probes

Calibration of current probes may be done by a jig which is made of two halves of a coaxial adaptor. When assembled with the current probe in place, the jig forms a coaxial line the outer conductor of which encloses the current probe and the inner conductor passes through the probe aperture (see Figure B.9).

The calibration equivalent circuit is shown in Figure B.6. When the coaxial line is well matched the current I_p through the inner conductor may be calculated from a measurement of the voltage V_1 on the line. The body, if metal, or shield of the probe should be taken into

account in the design of the jig, to achieve a good coaxial line. If the voltage output of the current probe is V_2 the transfer admittance may be calculated using the following equation:

$$Y_T = V_1 - V_2 - 34 \quad (\text{B.8})$$

where

- Y_T is the transfer admittance in dB(S);
- V_1 is the RF voltage on the coaxial line in dB(μ V);
- V_2 is the RF output voltage of the probe in dB(μ V);
- 34 is a factor related to the 50 Ω load impedance.

The transfer admittance Y_T in dB(S) is used to calculate the value of the measured current I_P in dB(μ A) using the equation:

$$I_P = V_2 + Y_T \quad (\text{B.9})$$

where V_2 is in dB(μ V).

Figure B.7 shows a typical calibration result, Figure B.8 shows the return loss, and Figure B.9 provides a photograph of a coaxial adaptor jig.

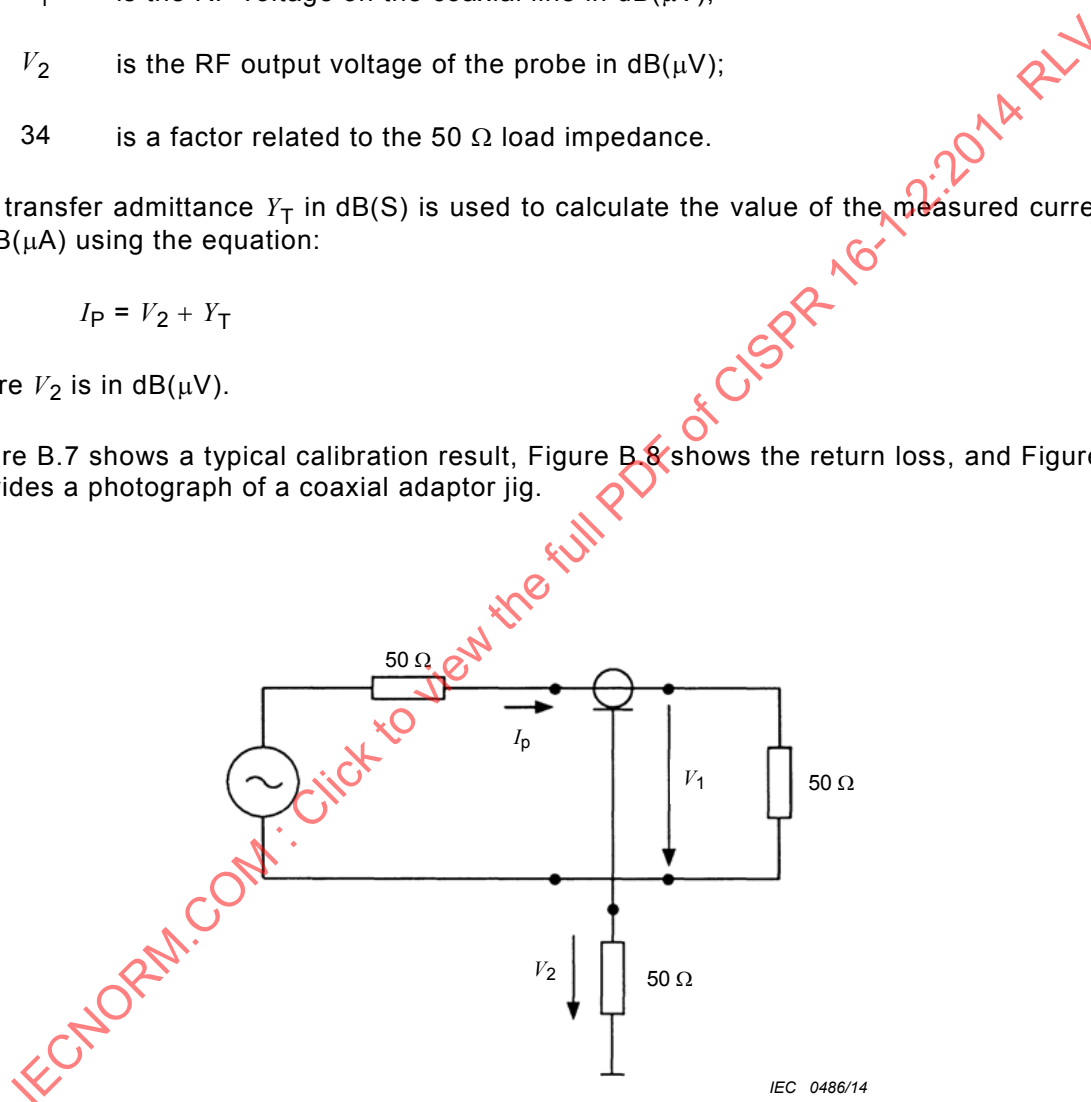


Figure B.6 – Schematic diagram of circuit with coaxial adaptor and current probe transfer admittance Y_T measurement

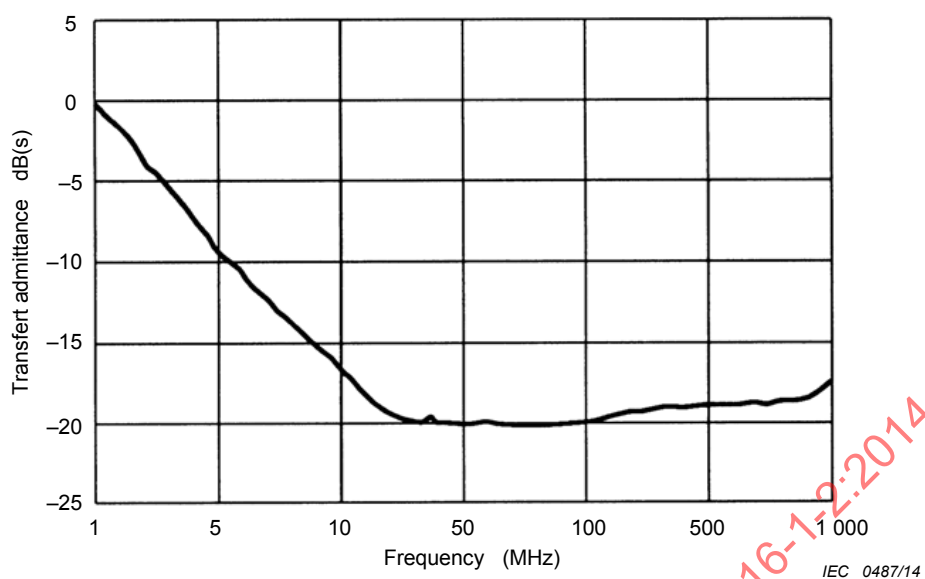


Figure B.7 – Transfer admittance Y_T as a function of frequency

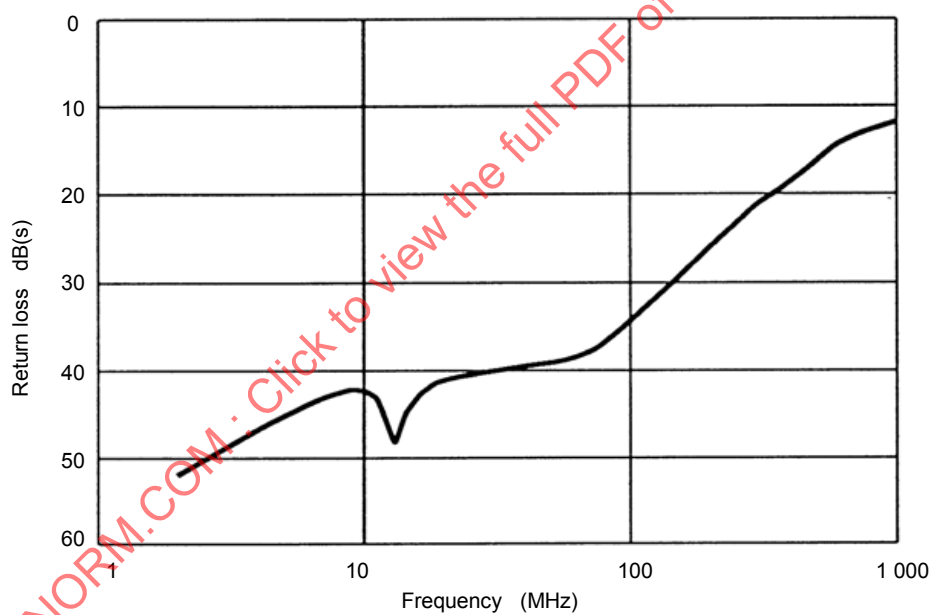
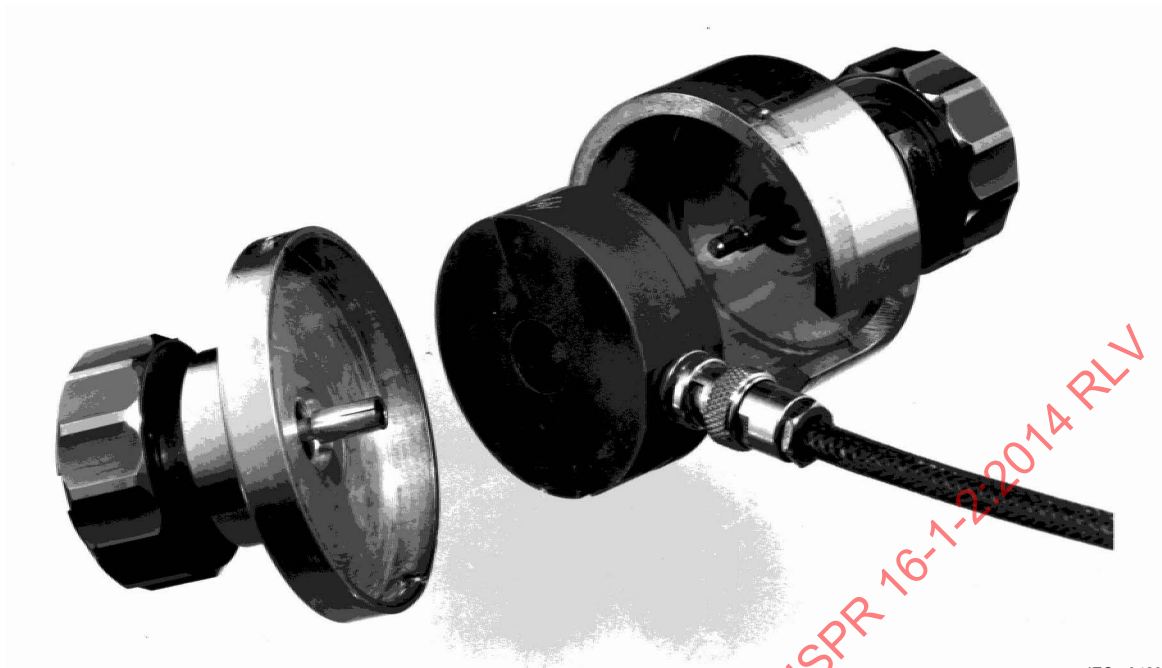


Figure B.8 – Return loss of the coaxial adaptor terminated with 50 Ω and with the current probe (also terminated with 50 Ω) inside



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Figure B.9 – Current probe between the two halves of the coaxial adaptor

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Annex C (informative)

Construction of the coupling units for current injection for the frequency range 0,15 MHz to 30 MHz

NOTE This annex supplements the provisions of Clause 6.

C.1 Coupling unit type A for coaxial antenna input

The circuit diagram and construction are similar to the type A unit shown in Figure C.1, except that the inductance value is 280 μH .

Construction of the 280 μH inductor:

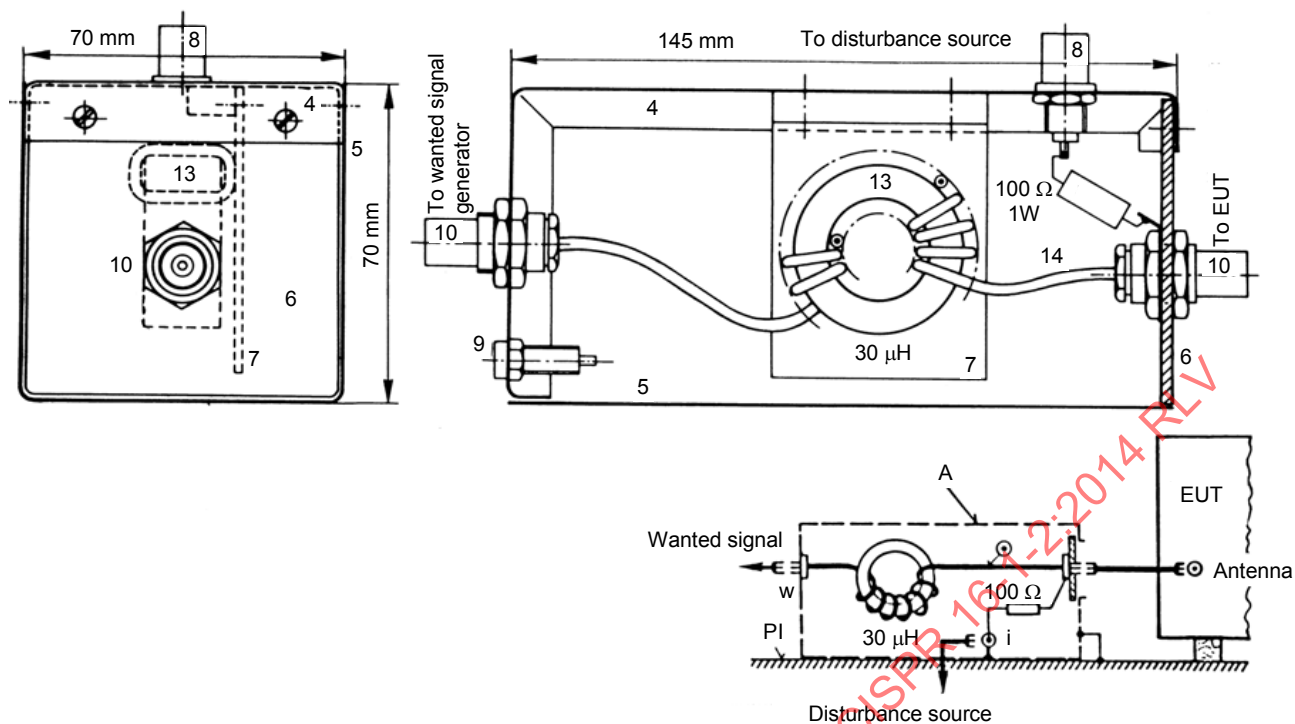
- Core: Two ferrite rings, material 4C6 or equivalent, placed together, dimensions 36 mm outer diameter, 23 mm inner diameter, 30 mm thick.
- Winding: 28 turns of a fully screened miniature coaxial cable, e.g. UT-34, wire diameter 0,9 mm, with an outer insulation plastic tubing of 1,5 mm outer diameter.

C.2 Coupling unit type M, for mains leads

The circuit diagram and construction are similar to the type M unit shown in Figure C.2, except that the two inductors are 560 μH each, and $C_1 = 0,1 \mu\text{F}$ and $C_2 = 0,47 \mu\text{F}$.

Construction of the 560 μH inductor:

- Core: Two ferrite rings, material 4C6 or equivalent, placed together, dimensions 36 mm outer diameter, 23 mm inner diameter, 30 mm thick.
- Winding: 40 turns of insulated copper wire, 1,5 mm outer diameter.

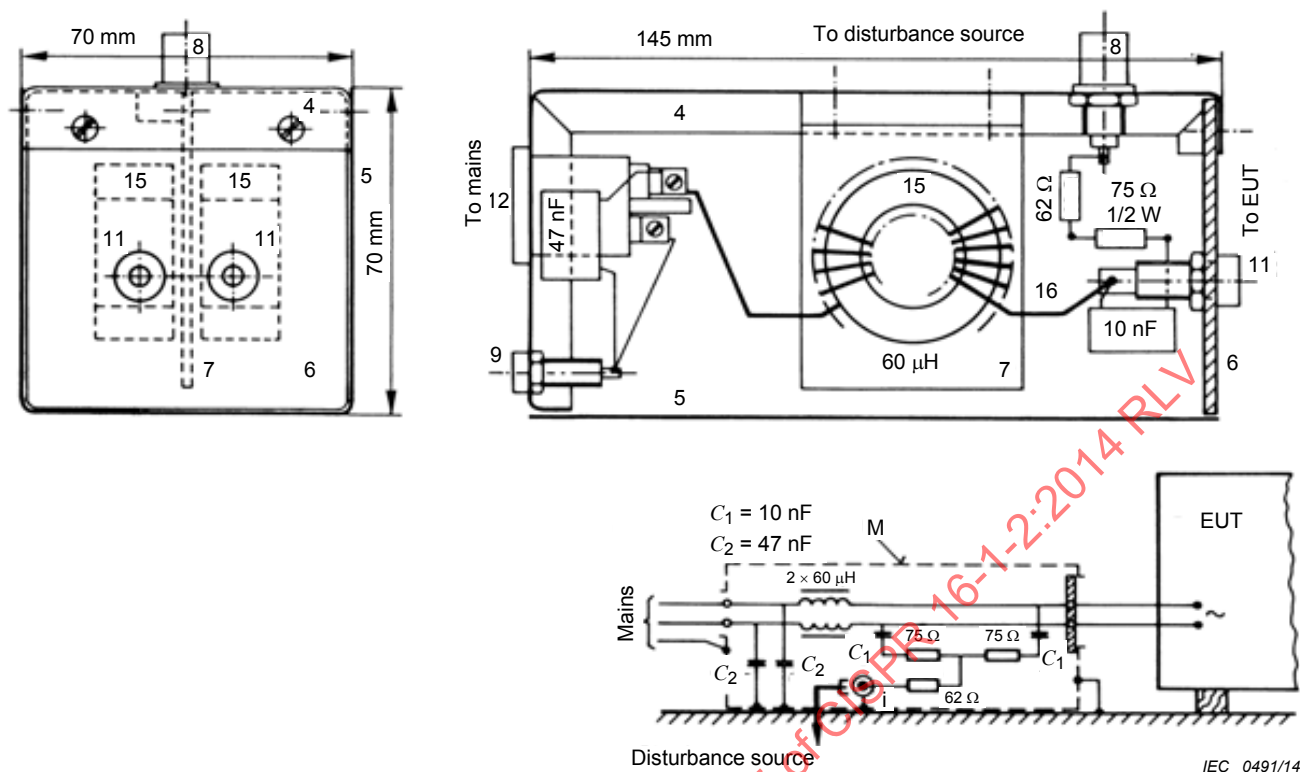


IEC 0490/14

Key

- 4-5 metallic case 145 mm by 70 mm by 70 mm (parts 5 placed on the ground plane P1)
- 6 front plate (insulating material)
- 7 supporting plate for chokes (insulating material)
- 8 coaxial connector, BNC, 50 Ω
- 9 group jack
- 10 coaxial connector, BNC
- 13 ferrite ring type 4C6, $\varnothing$ 36 mm, 15 mm, with 14 turns of coaxial cable
- 14 coaxial cable, outer $\varnothing$ 2,4 mm

**Figure C.1 – Example of coupling unit type A, for coaxial input
schematic diagram and construction details (see C.1 and D.2)**

**Key**

- 4-9 see Figure C.1
- 11 is the mains socket for EUT (two insulated banana jacks)
- 12 is the mains plug (2P + ground)
- 15 are two ferrite rings type 4C6, $\varnothing$ 36 mm $\times$ 23 mm $\times$ 15 mm, with 20 turns each
- 16 is an insulated 0,8 mm copper wire, outer $\varnothing$ 0,8 mm

Figure C.2 – Example of coupling unit type M, for mains leads, schematic diagram and construction details (see C.2 and D.2)

C.3 Coupling unit type L, for loudspeaker leads

The circuit diagram and construction are similar to the type L unit shown in Figure C.3 with two separate inductors of 560 μH each, and $C_1 = 47 \text{ nF}$ and $C_2 = 0,22 \mu\text{F}$.

Construction of each 560 μH choke:

Core: One ferrite ring, material 4C6 or equivalent, dimensions 36 mm outer diameter, 23 mm inner diameter, 15 mm thick.

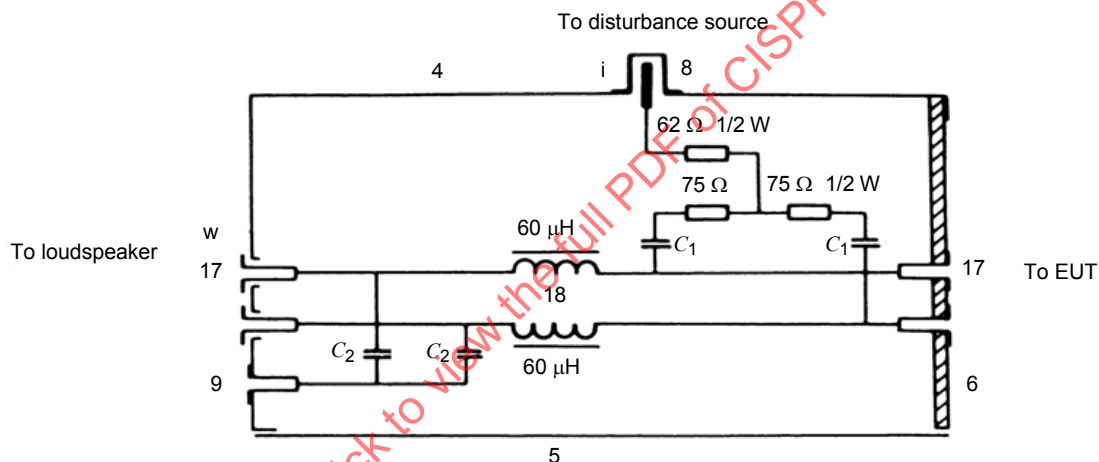
Winding: 56 turns of varnish insulated copper wires, 0,4 mm diameter.

NOTE Characteristics of magnetic ferrite type 4C6:

Relative initial permeability $\mu_i = 120$

Loss factor $\tan \delta \mu_i < 40$ at 2 MHz, < 100 at 10 MHz

Resistivity $\rho = 10 \text{ k } \Omega\text{-m}$



IEC 0492/14

Key

4-9 see unit type A

18 two inductances 60 μH each

For each inductance:

Core: one ferrite ring, type 4C6,
 $\varnothing 36 \text{ mm}$ by $\varnothing 23 \text{ mm}$ by 15 mm

Winding: 20 turns copper wire insulated
outer $\varnothing 1,2 \text{ mm}$

Mounting of the inductances: see unit type M

C_1 10 nF each

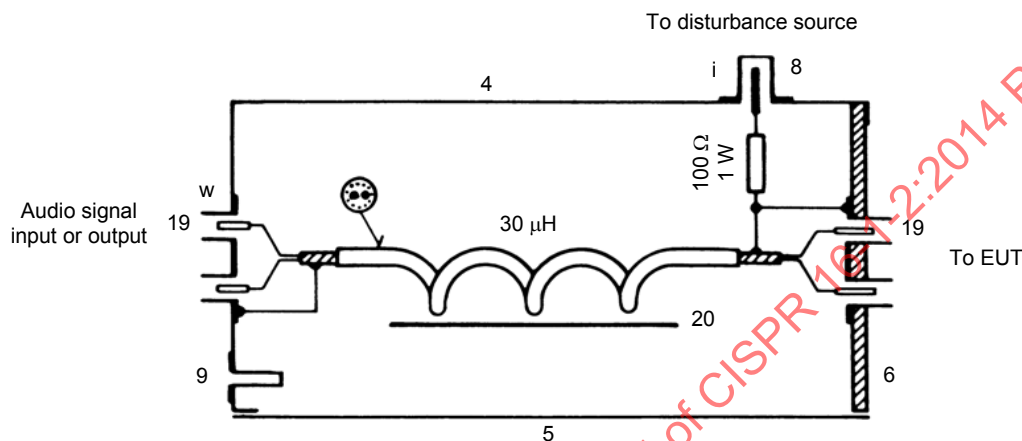
C_2 47 nF each

Figure C.3 – Example of coupling unit type L for loudspeaker leads, schematic diagram and simplified construction drawing (see D.2)

C.4 Coupling unit type Sw, for audio-frequency signals

The circuit diagram and construction are similar to the type Sw unit shown in Figure C.4, except with the 280 μH inductor described in C.1. The screened cable may be an audio-frequency type, and its diameter shall be not larger than 2,1 mm.

NOTE The type A coupling unit described in C.1 can be used for this purpose if the two stereo signal cables of the EUT are connected together.



IEC 0493/14

Key

4-9 see unit type A

19 Cinch or DIN sockets

20 inductance of 30 μH :

Core: one ferrite ring, type 4C6,
 $\varnothing$ 36 mm by $\varnothing$ 23 mm by 15 mm

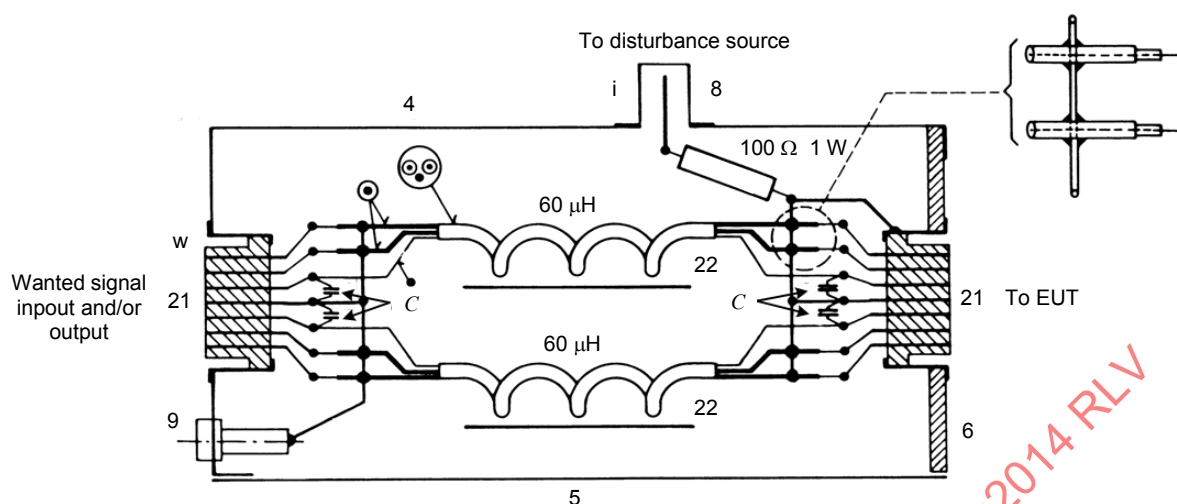
Winding: 14 turns with a screened twisted pair:
 outer diameter of cable insulation 2,8 mm

Mounting of the inductance: see unit type A

**Figure C.4 – Example of coupling unit type Sw, for audio signals.
 Schematic diagram and simplified construction
 drawing (see D.2)**

C.5 Coupling unit type Sw, for audio, video, and control signals

The circuit diagram and construction are similar to the type Sw unit shown in Figure C.5, except with two 560 μH inductors constructed as described in C.2. The cable with three conductors shall have an outer diameter not larger than 1,5 mm. This may be achieved using two micro-coaxial cables type UT-20 (0,6 mm diameter) and a varnish insulated copper wire of 0,3 mm diameter.



IEC 0494/14

Key

4-9 see unit type A

21 multiple pins connector (e.g. 7 pins DIN-socket)

22 two inductances 60 µH each; for each inductance:

Core: one ferrite ring, type 4C6,

Ø 36 mm by Ø 23 mm by 15 mm

Winding: 20 turns with a three-lead cable

Cable: Two micro-coaxial cables, UT-34,

outer Ø 0,9 mm + one copper wire

Ø 0,4 mm, varnish insulated

outer insulation: tube outer Ø 2,4 mm

Mounting of the inductances: see unit type M

C = 1 nF (or more, if it is acceptable by the signal source)

Figure C.5 – Example of coupling unit type Sw, for audio, video and control signals, schematic diagram and simplified construction drawing (see D.2)

Annex D (informative)

Principle of operation and examples of coupling units for conducted current immunity measurements

NOTE This annex supplements the provisions of Clause 6.

D.1 Principle of operation

The principle of operation is illustrated in Figure D.1. The inductance L presents a high impedance to the injected disturbance current. The filter L/C_2 isolates the test apparatus (wanted signal generator or auxiliary equipment); C_1 and C_2 may be replaced by a short circuit if the a.c./d.c. conditions permit. The disturbance signal delivered from a generator with $50\ \Omega$ internal resistance is injected via a $100\ \Omega$ resistor R_1 and a blocking capacitor C_1 (if required) on to the leads or on to the shield of a coaxial cable.

D.2 Types of unit and their construction

The following types of coupling units are used:

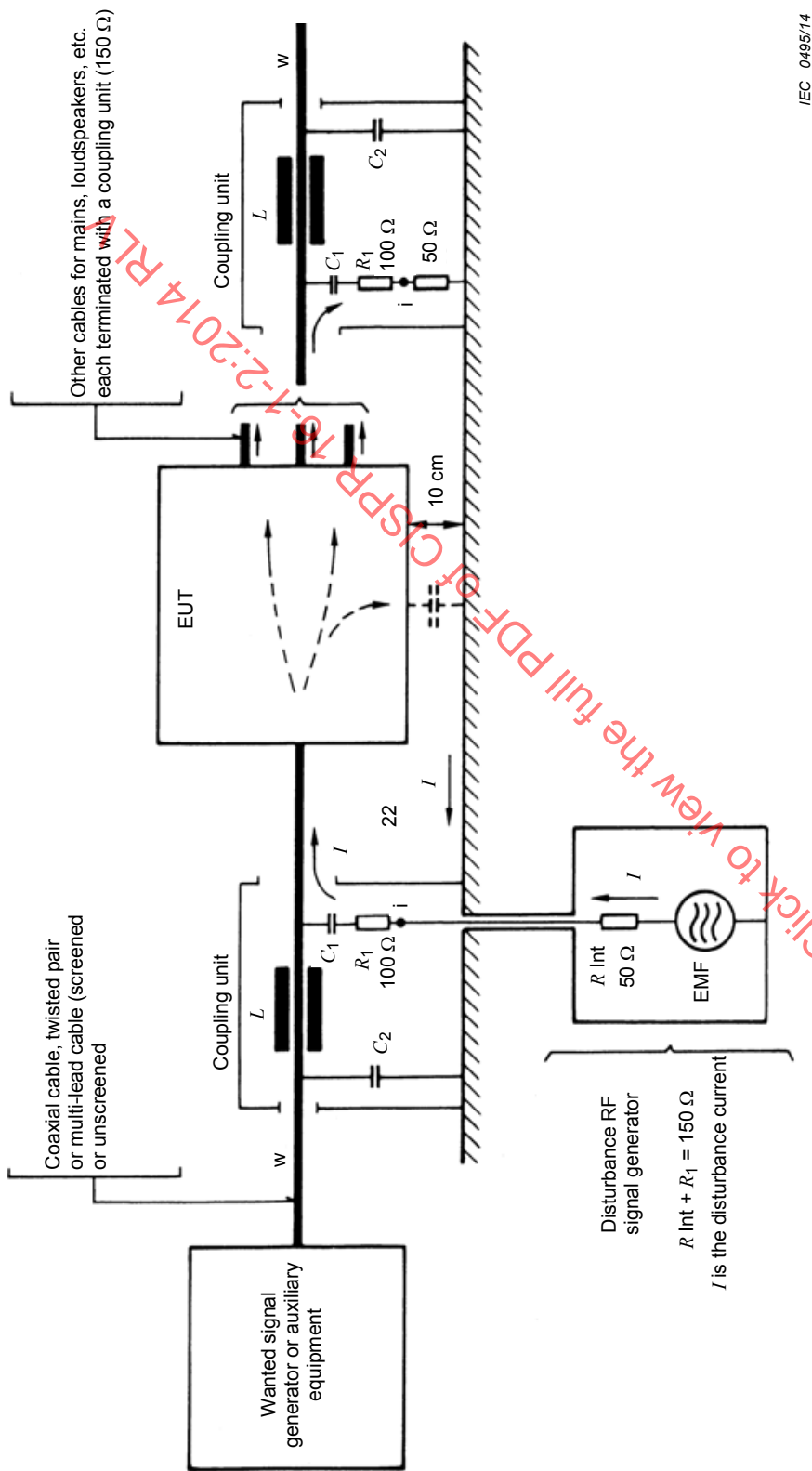
- Type A: The RF coaxial units are to be used for coaxial leads carrying wanted signals in the RF frequency range. The construction details are shown in Figure C.1. The $100\ \Omega$ resistor (to make up the $150\ \Omega$ source impedance from a $50\ \Omega$ disturbance signal source) is bonded to the shield of the coaxial output connector in the unit.
- Type M: These are for use with mains leads. The construction details are shown in Figure C.2. The injection of the disturbance current is done asymmetrically on both wires through an equivalent resistance of $100\ \Omega$. This unit is like an artificial mains delta network, and as seen from the EUT terminals, a symmetric and asymmetric equivalent resistive impedance of $150\ \Omega$.
- Type L: These are for use with loudspeaker leads. The construction details are shown in Figure C.3. The impedance of the disturbance source is arranged as for Type M units.
- Type Sr and Sw: These are designed for use with audio, video and other auxiliary leads. They are multi-pin units which have to be adapted to a variety of pin numbers and connector configurations, as follows:
- Type Sw: These units provide a through path for audio, video, control or other signals, in which case filtering is required to ensure that the disturbance signal is directed towards the EUT. The construction details shown in Figure C.4, indicate the simple filtering provided for audio signals with a screened pair wound on a toroid. In the case of multi-lead cables it may be necessary, for construction reasons, to separate the cable leads before winding upon a toroid shown in Figure C.5. In both cases the disturbance current is injected via a $100\ \Omega$ resistor on to the screen and the ground pins of the output connector, the screens of the shielded leads, and through capacitor on to the other (unshielded) leads.
- Type Sr: These are designed for the case where there is no requirement to provide a through signal path. All leads of the cable are terminated with a matched load resistance. The construction details are shown in Figure D.2. The disturbance current is injected via a $100\ \Omega$ resistor on to the screen (grounding) and the ground pins of the connector, to which point all the load resistors (R_1 to R_n) are connected also. It should be noted that a coupling unit of the type indicated in Figures C.4 or C.5 terminated with a correct load impedance could be used for this purpose.

If the source impedance of the disturbance generator is not $50\ \Omega$, the value of the series resistor is adjusted accordingly to make up the required $150\ \Omega$ impedance.

The RF choke coils shown in Figures C.1 to D.2 have inductance values $30\ \mu\text{H}$ or two $60\ \mu\text{H}$ chokes in parallel, and are satisfactory for the frequency range 1,5 MHz to 150 MHz. For the frequency range 0,15 MHz to 30 MHz, the inductance values are $280\ \mu\text{H}$ or two $560\ \mu\text{H}$ chokes in parallel respectively. Annex C describes their construction.

Precautions should be taken in the layout to keep parasitic capacitance to the output terminals of the units as low as possible. It should be noted that the metal cases of the units are to be carefully connected to the ground plane using large section copper braid and unpainted cases.

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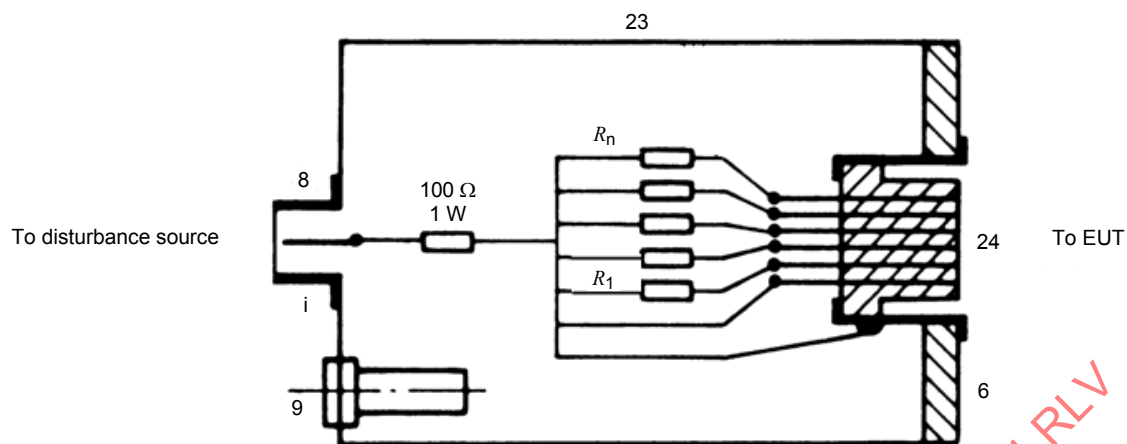


Key

L Isolating inductance

C_1, C_2 capacitors with low RF impedance (if the a.c. d.c. conditions allow this, capacitors should be replaced by a direct connection)

Figure D.1 – General principle of the current-injection method (see D.1)



IEC 0496/14

Key

- 6, 8, 9 see unit type A
- 23 is the metallic case 100 mm by 55 mm by 55 mm
- 24 is the multiple-pin conductor or DIN-socket
- R₁ to R_n are the matched load resistances.

Example – Coupling units type Sr for audio equipment

Phonograph	Magnetic: 2 × 2,2 kΩ
	Crystal: 2 × 470 kΩ
Microphone	2 × 600 Ω
Tuner	2 × 47 kΩ
Tape recorder	4 × 47 kΩ
Audio in/out	4 × 47 kΩ

Figure D.2 – Coupling unit type Sr with load resistances – Schematic diagram and simplified construction drawing (see D.2)

Annex E (normative)

Example and measurement of the parameters of the asymmetric artificial network (AAN)

E.1 Description of an example of an AAN: the T-network

Figure E.1 gives an example of an AAN, the T-network, having terminals a_1 and b_1 for connection to a conductor pair in a signal port of an EUT and RG for connection to the reference ground and, if applicable, to the safety earth or other ground connector of the EUT.

The symmetric signal which may be needed to have the EUT operating correctly is connected to the terminals a_2 and b_2 . The double choke L_1 allows separate measurement of the asymmetric component of the disturbance. The two windings are designed such that the symmetric currents are suppressed by a high impedance, whereas the impedance for asymmetric currents (passing to R_M) shall be negligible.

The termination impedance of the network for the asymmetric disturbance voltage of $150\ \Omega$ is determined by the two resistors R_T ($200\ \Omega$), in parallel for the asymmetric current, in series with the resistor R_M ($50\ \Omega$). The resistor R_M is usually the input impedance of a measuring receiver. In this case the meter reading is typically 9,5 dB lower than the actual asymmetric value at the terminal of the EUT. The capacitor C_T blocks d.c. currents, thus allowing for d.c. supply voltages on the network leads without damaging the resistors and without affecting the properties of L_1 , due to saturation.

Normally an AAN is inserted between an EUT and its associated equipment.

E.2 Measurements of the parameters of an asymmetric artificial network (AAN)

For the determination of compliance with the requirements of 7.1, the procedures for the measurement of the specified parameters described below are used.

a) Termination impedance

This impedance between the terminals a_1 and b_1 connected together, and terminal RG shall be checked with terminals a_2 and b_2 being alternatively open and short-circuited to the ground terminal RG (see Figure E.2).

b) Longitudinal conversion loss (LCL)

This rejection of the Y-network shall be measured in accordance with Figure E.5. The network analyzer (NWA) applies its output signal to an LCL probe, which shall have a residual longitudinal conversion loss (LCL) at least 10 dB higher than the required LCL of the AAN. For LCL probe verification, see Figure E.3, and for calibration, see Figure E.4.

c) Decoupling attenuation

The decoupling attenuation shall be measured in accordance with Figure E.6.

d) Insertion loss of the symmetric circuit

The insertion loss of the symmetric circuit shall be measured in accordance with Figure E.7.

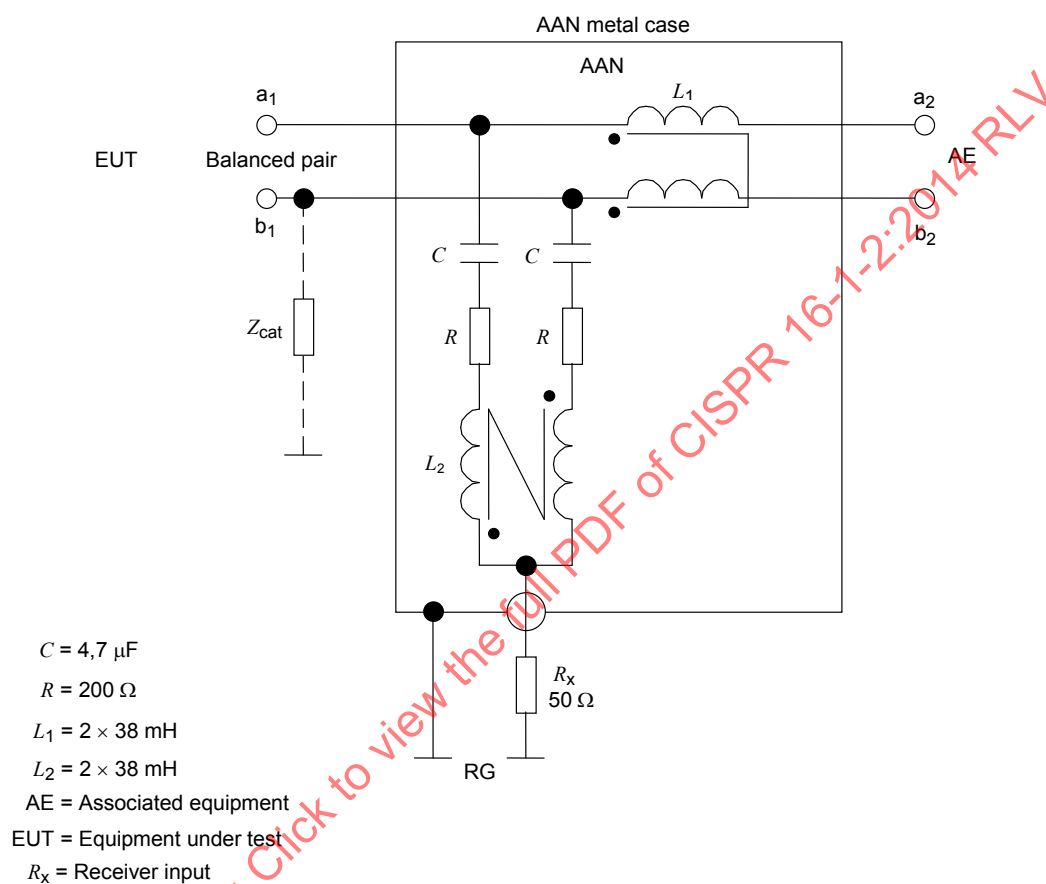
Two LCL probes can be used as baluns for the insertion loss test of the Y-network. Two identical baluns may be connected in series for the determination of their own insertion loss. Baluns can be designed such that the combined insertion loss of two baluns is less than 1 dB in the frequency range from 0,15 MHz to 30 MHz.

e) Voltage division factor of the asymmetric circuit (calibration of the Y-network)

The voltage division factor of the asymmetric circuit shall be measured in accordance with Figure E.8.

f) **Symmetric load impedance and transmission bandwidth**

This parameter is defined by the system. Y-networks may be optimized for a certain impedance with respect to transmission bandwidth. The transmission bandwidth may be measured for a certain symmetric load impedance using the test set-up of Figure E.7.

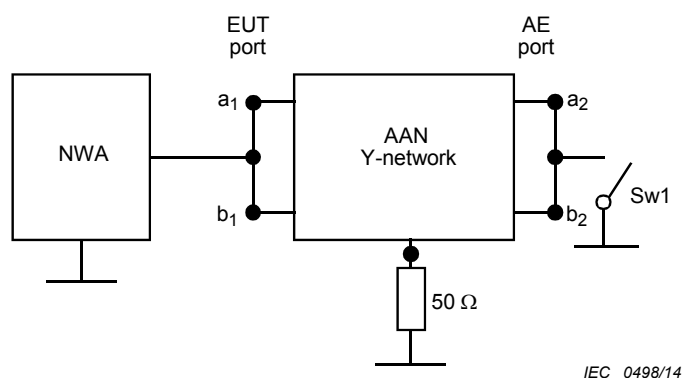


IEC 0497/14

NOTE 1 Nominal voltage division = 9,5 dB.

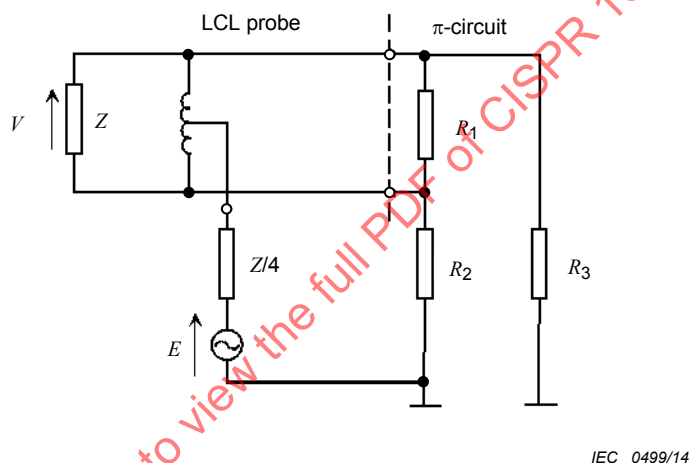
NOTE 2 Z_{cat} represents the unbalance network used to adjust the LCL.

Figure E.1 – Example of a T-network circuit for one pair of wires



NOTE If the AAN is of higher order (i.e. more than one pair of wires), then all wires of the EUT port, respectively all wires of the AE port, are connected together.

Figure E.2 – Arrangement for the termination impedance measurement



NOTE 1 When terminated with a minimum LCL π -circuit consisting of R_1 , R_2 and R_3 ($R_2 = R_3$), which includes both the nominal symmetric impedance $Z (= \frac{R_1(R_2 + R_3)}{R_1 + R_2 + R_3})$ of the AAN and the asymmetric impedance of $150 \Omega (=$

$\frac{R_2 R_3}{R_2 + R_3})$, the probe ideally shows a residual LCL of 20 dB or higher than the highest LCL to be measured. For $Z = 100 \Omega$: $R_1 = 120 \Omega$ and $R_2 = R_3 = 300 \Omega$.

NOTE 2 The LCL probe operates with an asymmetric source impedance of $Z/4$.

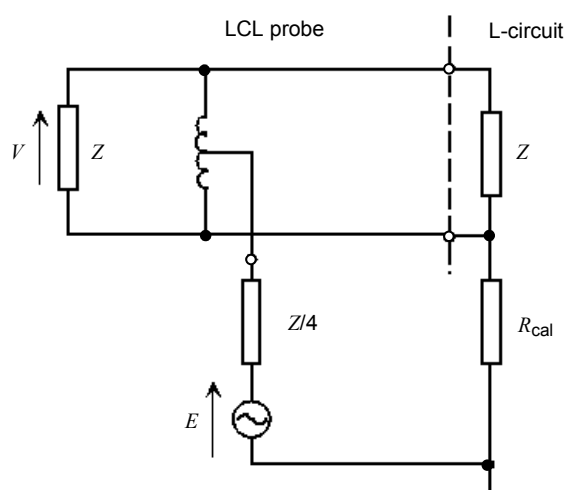
NOTE 3 For $Z = 100 \Omega$, $Z/4$ equals 25Ω .

NOTE 4 For optimum reproducibility, the LCL of the probe is maximized for both orientations of the π -circuit relative to the balanced terminals of the LCL probe.

NOTE 5 Definition: longitudinal conversion loss (LCL) $= 20 \lg \left| \frac{E}{V} \right|$ in dB (according to ITU-T Recommendation G.117 [7])

The LCL probe is so constructed that the LCL can be measured using ordinary network analyzers. An example LCL probe is described in [9].

Figure E.3 – Arrangement for LCL probe verification



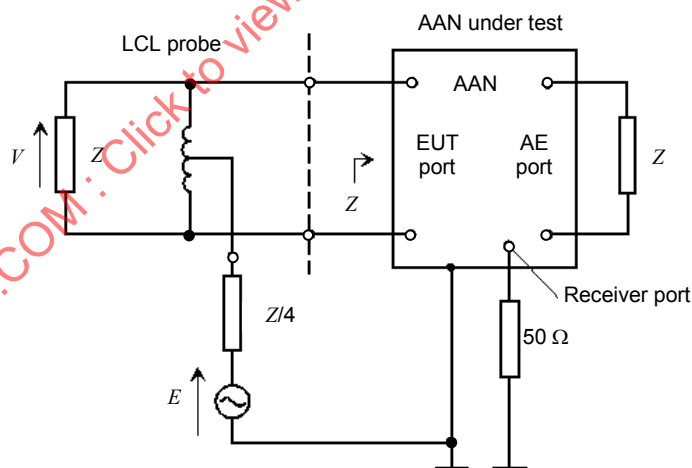
NOTE 1 LCL of the L-circuit: $a_{LCL} = 20 \lg \left| \frac{(R_{sym} // Z) + 4R_{cal} + Z}{2(R_{sym} // Z)} \right| \text{ dB}$

NOTE 2 The LCL measurement uncertainty per Figure E.5 is influenced by the accuracy of the L-circuit and the amount of the residual LCL of the probe. Changing the orientation of the LCL probe relative to the L-circuit will show some uncertainty of calibration.

NOTE 3 Example of an L-circuit:

For an impedance $Z = 100 \, \Omega$ and $R_{sym} = 100 \, \Omega$, a value $R_{cal} = 750 \, \Omega$ will give an LCL of 29,97 dB, i.e. approximately 30 dB.

Figure E.4 – Arrangement for the LCL probe calibration using an L-circuit

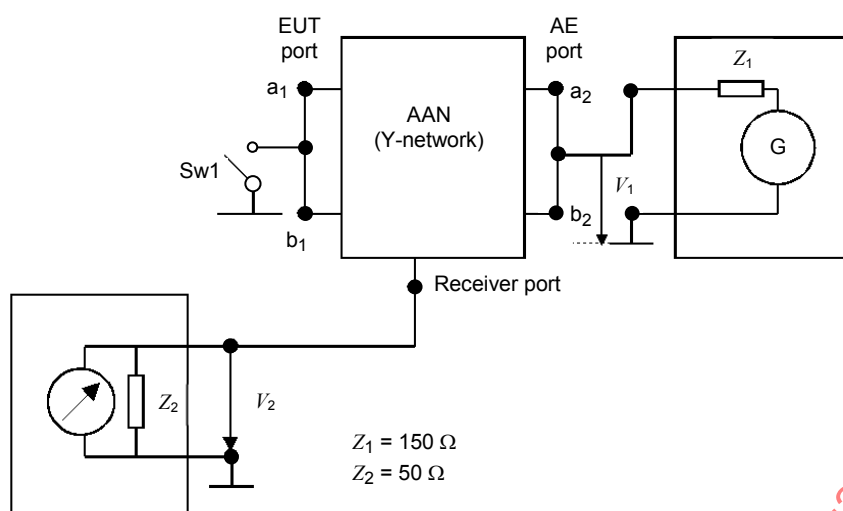


NOTE 1 For the definition of LCL, see Figure E.3.

NOTE 2 Depending on the closeness between the LCL to be measured and the residual LCL of the probe, a measurement with both orientations of the LCL probe, relative to the EUT port terminals and the determination of the mean value of the two results, can improve the accuracy of the test.

NOTE 3 If the AAN is of higher order (i.e. more than one pair of wires), then the LCL of each pair is tested, while the other pair(s) is (are) terminated with the common mode impedance Z in case of any influence on the measured pair.

Figure E.5 – LCL measurement of the AAN using an LCL probe

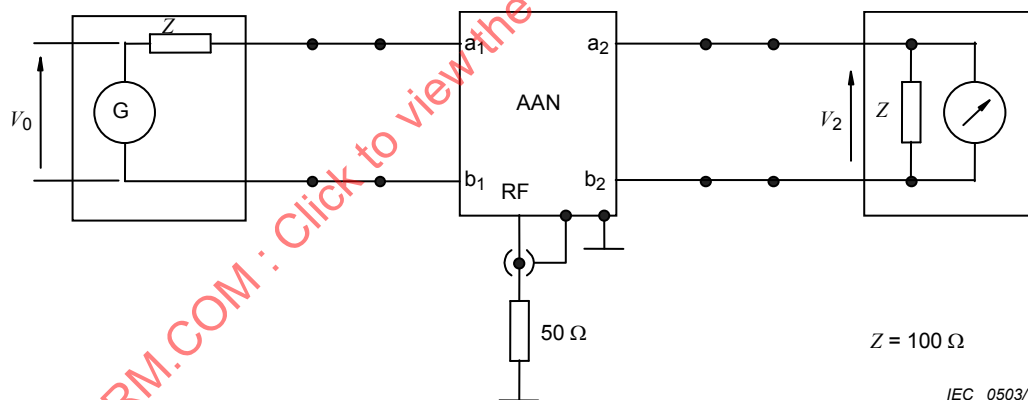


IEC 0502/14

The decoupling attenuation specification shall be met in both positions of Sw1 (short and open). If the AAN is of higher order (i.e. more than 1 pair of wires), then all wires of the EUT port, respectively all wires of the AE port, are connected together.

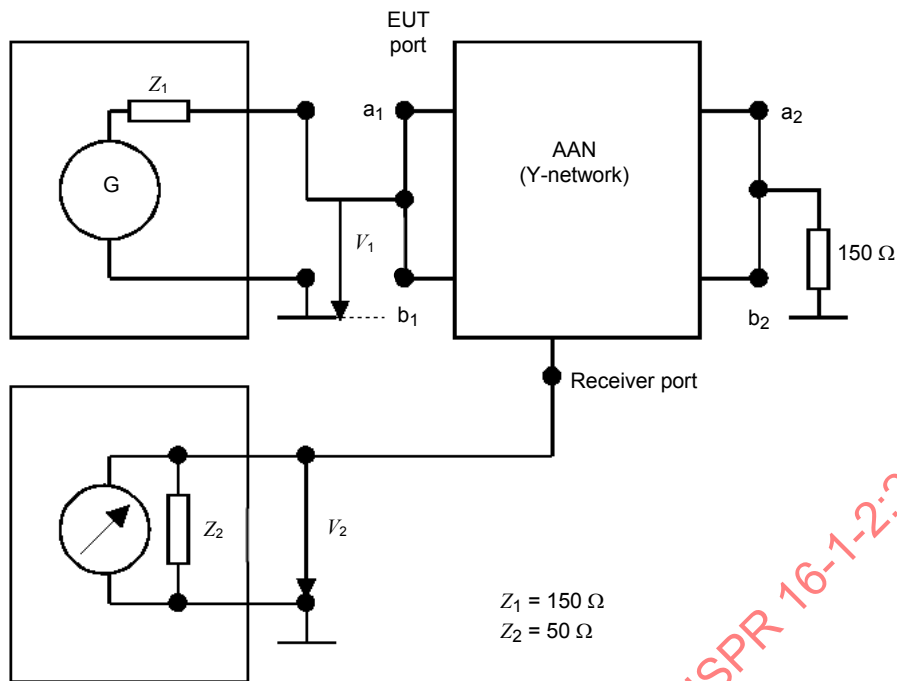
Figure E.6 – Test set-up for the decoupling attenuation (isolation) of the AAN

$$a_{\text{decoup}} = 20 \lg \left| \frac{V_1}{V_2} \right| - a_{\text{vdiv}} \quad \text{in dB for asymmetric signals between AE port and EUT port}$$



IEC 0503/14

Figure E.7 – Test set-up for the insertion loss (symmetric) of the AAN



IEC 0504/14

NOTE If the AAN is of higher order (i.e. more than one pair of wires), then all wires of the EUT port respectively all wires of the AE port are connected together.

Figure E.8 – Calibration test set-up for the AAN voltage division factor of the asymmetric circuit.

$$F_{\text{AAN}} = a_{\text{vdiv}} = 20 \lg \left| \frac{V_1}{V_2} \right| \text{ in dB}$$

Annex F (normative)

Example and measurement of the parameters of the AN for coaxial and other screened cables

F.1 Description of ANs for coaxial and other screened cables

Figure F.1 gives an example of a coaxial cable AN employing internal common-mode chokes created by miniature coaxial cable (miniature semi-rigid solid copper screen or miniature double-braided screen coaxial cable) wound on ferrite toroids.

In cases where high shielding attenuation is not required, the internal common-mode choke(s) can also be created using bifilar windings of an insulated centre-conductor wire and an insulated screen-conductor wire on a common magnetic core (e.g. a ferrite toroid).

For multi-conductor screened cables, the internal common-mode choke can be created using either multifilar windings of insulated signal wires and an insulated screen-conductor wire, or by winding a multi-conductor screened cable on a common-mode magnetic core.

F.2 Measurements of parameters of an AN for coaxial and other screened cables

a) Termination impedance

The impedance between the coaxial screen on the bulkhead connector (with no EUT cable attached) and the reference-ground connector shall be measured with the receiver port terminated with $50\ \Omega$ load.

b) Voltage-division factor

The voltage division factor of the AN shall be measured in accordance with the set-up of Figure F.2.

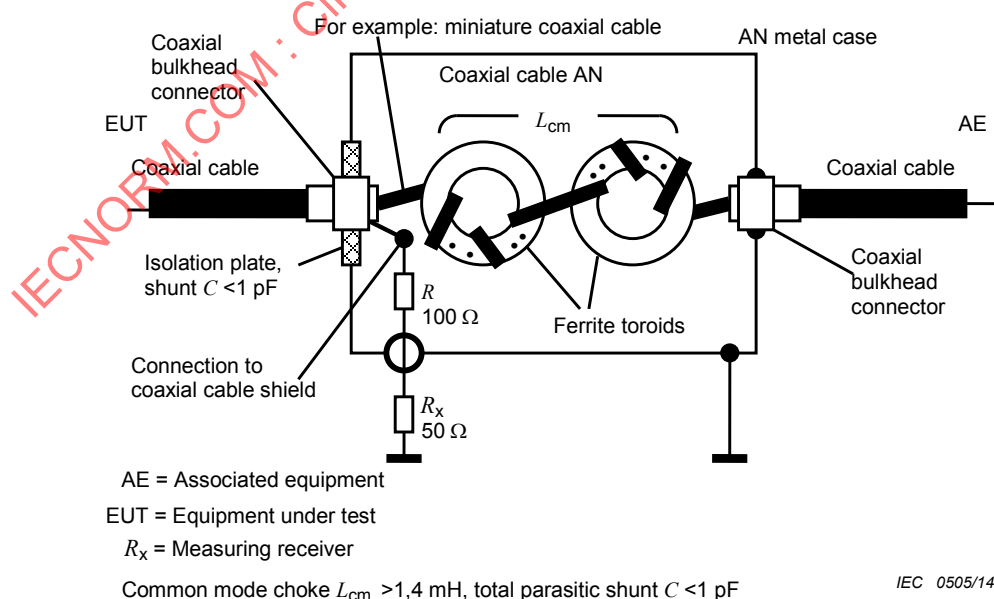
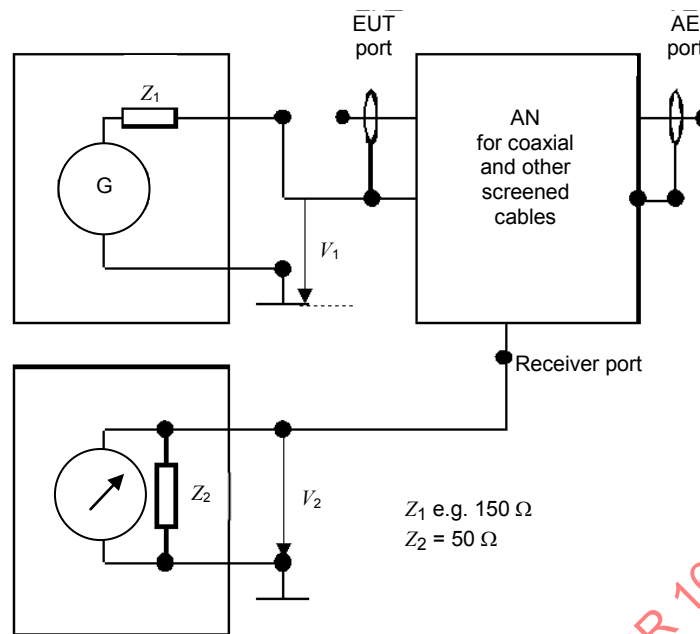


Figure F.1 – Example of a coaxial cable AN



IEC 0506/14

Figure F.2 – Test set-up for the coaxial and screened cable AN

voltage division factor $F_{AN} = 20 \lg \left| \frac{V_1}{V_2} \right|$ in dB

Annex G (informative)

Construction and evaluation of capacitive voltage probe

NOTE This annex supplements the provisions of 5.2.2.

G.1 General

This annex provides an example of a method for the calibration of the capacitive voltage probe (CVP). Other calibration methods can be used if their uncertainty is considered to be equivalent to that of the method shown in this annex.

G.2 Physical and electrical considerations for CVP

Figure G.1 shows the configuration of a CVP. A CVP consists of two coaxial electrodes, a grounding terminal, a cable fixture, and a trans-impedance amplifier. The outer electrode is used as an electrostatic shield to reduce the measurement error caused by electrostatic coupling from cables running alongside.

The equivalent circuit of the probe is shown in Figure G.2. When a voltage exists between the cable and the ground, an induced voltage occurs between the inner electrode and the outer electrode as a result of electrostatic induction. This voltage is detected by a high impedance input amplifier and converted to low impedance by a trans-impedance amplifier. The output is measured by a measuring receiver.

G.3 Determination of the frequency response of the voltage division factor

Figure G.3 shows the test set-up used to determine the frequency response of a CVP. A CVP is verified according to the following procedures.

- a) Prepare the same type of cable that is used with the EUT.

NOTE 1 If several types of cable are used with the CVP, a representative variety of cable types is used in the calibration, and the spread of results determined. The voltage division factor (F_{CVP}) can be estimated by using Equation (G.3), however, the F_{CVP} for each cable is measured.

- b) Place the calibration fixture on the reference ground plane, as shown in Figure G.3.
- c) Connect both ends of the cable to the inner ports of the calibration fixture (port-1, port-2) (see Figure G.3).
- d) Place the CVP in the calibration unit and adjust the position of the cable to pass through the centre.

NOTE 2 If the ends of plates of the calibration fixture are too close to the ends of the CVP, the stray capacitance is increased, which can adversely affect the calibration at higher frequencies. If the end plates of the calibration fixture get too far from the ends of the CVP, a standing wave can be formed within the calibration fixture at higher frequencies. These standing waves can adversely affect the calibration.

- e) Connect the grounding port of the CVP to the inner grounding port of the calibration fixture. Connect the outer grounding port of the calibration fixture to the reference ground plane. The grounding strip should have low inductance, be as short as possible and kept away from the CVP aperture.
- f) Connect a signal generator, with an output impedance of $50\ \Omega$, to the outer port of the port-1 through a 10 dB attenuator.
- g) Connect a level meter, with an input impedance of $50\ \Omega$, to the outer port of port-2 and terminate the output port of the CVP in $50\ \Omega$ load. Measure the level V over a specified frequency range.

- h) Connect the level meter to the output port of the CVP and terminate the outer port of the port-2 by a $50\ \Omega$ load. Measure the level V_m over a specified frequency range.
- i) Calculate the voltage division factor $F_{CVP} = 20 \lg |V/V_m|$ in dB from the measured values.

G.4 Method of measurement to determine the influence of external electric fields

G.4.1 Influence of external electric field

The influence of the external electric field appears via electrostatic coupling with other cables close to the probe. Figure G.4 shows the electrostatic coupling models and their equivalent circuits. Both the asymmetric voltage V_x on cable 2 and the voltage V on cable 1 appear at the input terminal of the high impedance voltage probe through the capacitance C_x and C as shown in Figure G.4 a). An electrostatic shield shall be used to reduce the coupling due to C_x . However, the influence of the external electric field due to the electrostatic coupling between the outer electrode and other cable (C_x') still remains because of the imperfection of the electrostatic shield, as shown in Figure G.4 b). Subclause G.4.2 provides the measurement procedure for evaluating the influence of the electrostatic coupling between outer electrode and other cable. Furthermore, it should be noted that the voltage V is affected by V_x unless $|Z_s| \ll |1/(j\omega C_c)|$.

G.4.2 Method of measurement to determine the influence of the external electric field

The influence of an external electric field caused by electrostatic coupling due to limited electrostatic shielding is measured using the test set-up shown in Figure G.5. The measurement procedure is as follows;

- a) Measure the voltage division factor, $F_{CVP} = 20 \lg |V/V_m|$, using the method in G.3.
- b) Place the CVP beside the cable, at a distance " s " equal to 1 cm (see Figure G.5).
- c) Connect the grounding port of the probe to the inner grounding port of the unit. Connect the outer grounding port of the unit to the reference ground plane.
- d) Connect a signal generator with a $50\ \Omega$ output impedance to the outer port of the port-1 through a 10 dB attenuator.
- e) Connect a measuring receiver with a $50\ \Omega$ input impedance to the outer port of the port-2 and terminate the output port of the probe by $50\ \Omega$. Measure the level V_s over a specified frequency range.
- f) Connect the measuring receiver to the output port of the probe and terminate the outer port of the port-2 by $50\ \Omega$. Measure the level V_{sm} over a specified frequency range.
- g) The reduction of the influence is defined as $F_s = F_{CVP}/(V_s/V_{sm})$ from the measured values.

G.5 Pulse response

A CVP is constructed as part of the measuring system which includes the measuring receiver. It does not affect the performance of the measuring receiver described in Clause 4. The probe response to pulses shall be measured because a CVP contains an active circuit. The response is measured using the pulse generator as described in Annexes B and C of CISPR 16-1-1:2010 for Band B.

It is difficult to measure the pulse response using a pulse generator. The pulse capability of the probe is tested to measure the linearity using a CW signal whose peak value is the same as the peak value of the pulse. This can be accomplished because the probe does not contain a detector and band-pass filter. The attenuator can be necessary to minimize the amplitude of the reflected signal, due to the use of coaxial cable between the signal generator and the test fixture. If it is not necessary to stabilize the frequency response, the attenuator is not needed.

The impulse area of the pulse generator signal is 0,316 mVs from 0,15 MHz to 30 MHz as shown in Table B.1 of CISPR 16-1-1:2010. The spectrum of the pulse generator signal is practically constant up to 30 MHz. The pulse width, τ , is approximately given by

$$\tau = \frac{1}{\pi f_m} \quad (G.1)$$

With $f_m = 30$ MHz, $\tau = 0,0106 \mu s$.

The amplitude of the pulse, A , is given by

$$A = 0,316/\tau = 29,8 \text{ V} \quad (G.2)$$

This indicates that the CVP should maintain linearity up to 30 V.

The linearity is tested by measuring the voltage division factor, F_{CVP} , when the amplitude of the signal generator is varied up to 30 V.

G.6 Voltage division factor dependence

The voltage division factor of the CVP depends on the radius and the position of the cable under test in the inner electrode of the CVP. Although the value of the voltage division factor is needed for disturbances measurements, calculation of the factor for any type of cable may be difficult. An investigation was performed to evaluate the influence of the cable configuration on the voltage division factor, and is described in the following paragraphs.

The voltage division factor dependencies were investigated using measurements and a theoretical analysis. Figure G.6 shows the voltage division factor deviation when the cable position changes in the electrode. The cable is replaced with a copper rod in the experiment. The horizontal axis indicates the separation ratio, $g/(b-a)$. The solid line represents the calculation results obtained from the capacitance variation between the inner electrode and cable, and the dots are the measured values. As a result, the measurement data agrees well with the calculated data. The sensitivity of the CVP, however, does not depend on the variation of the cable position in the inner electrode up to a separation ratio of 0,8. Thus, to minimize measurement errors, the cable under test shall be adjusted to pass the centre of the CVP.

Figure G.7 shows the cable radius dependence. The vertical axis shows the deviation of the voltage division factor F_{CVP} . The solid line shows the calculated results using the following equation:

$$F_{CVP} = \frac{\left\{ 1 + \frac{1}{C_p} \frac{2\pi\epsilon}{\ln(b/a)} d \right\}}{\left\{ 1 + \frac{1}{C_p} \frac{2\pi\epsilon}{\ln(b/a_{ref})} d \right\}} \quad (G.3)$$

where

ϵ is the dielectric constant;

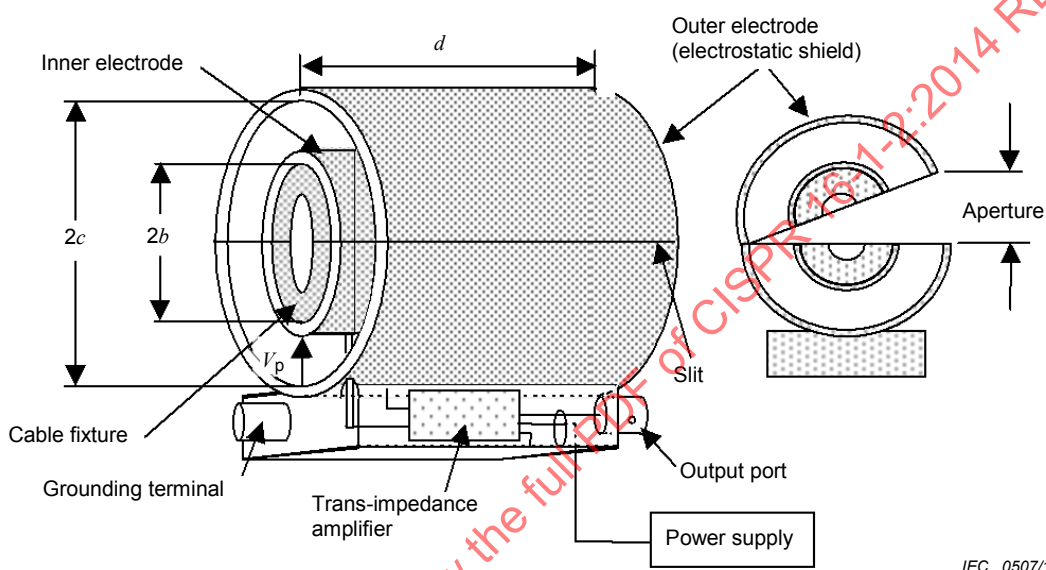
a_{ref} is the cable radius used for reference;

C_p is the gain of the trans-impedance amplifier, obtained from the

measurement;

b and d are defined in Figure G.1.

The plotted values show the measurement results for several cables. The equivalent radius of each cable is evaluated with respect to the surface area of each wire included in the cable and compared to the surface area of a copper rod. The number of wires in the cable was changed from 1 to 12. Figure G.7 indicates that the calculated results agree well with the measured result using the copper rod. Thus the deviation between the measured results for actual cable and the calculated value is within 2 dB. This result shows that the voltage division factor can be approximately calculated by Equation (G.3) using the surface area of each cable.

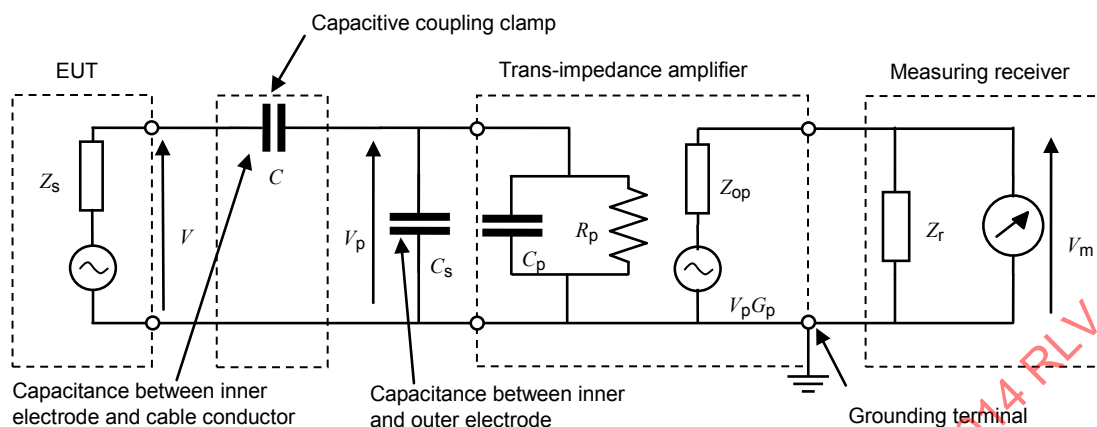


IEC 0507/14

Caution:

- 1) The cable fixture is used to centre the cable under test inside the probe. This item can act as a dielectric, which will increase capacitance between the cable under test and the voltage probe inner electrode.
- 2) Isolation from the external electric field is needed to keep pickup on the power supply leads from coupling into the voltage probe circuitry.

Figure G.1 – Configuration of a CVP



IEC 0508/14

Typical values for the configuration shown in Figure G.1

b 25 mm

c 55 mm

d 100 mm

C 8 pF

(Cable diameter is 26 mm)

C_s 7 pF

C_p 5 pF

R_p 1 M Ω

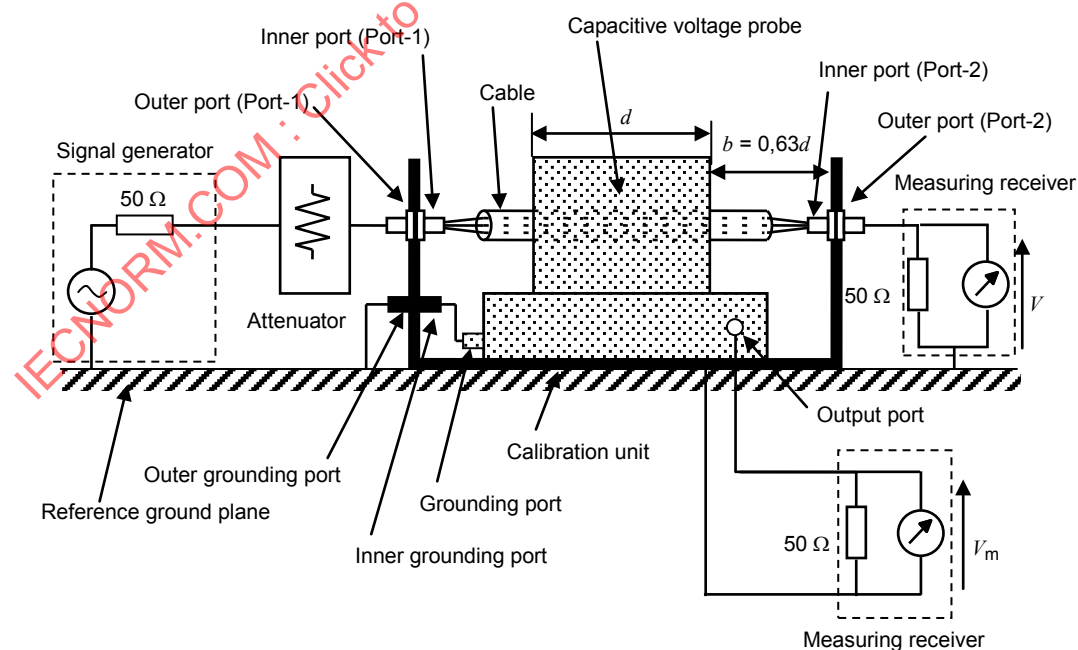
$|Z_s| \ll |1/(j\omega C)|$

$R_p \gg |1/(j\omega(C_s + C_p))|$

$Z_{op} = Z_r = 50 \Omega$

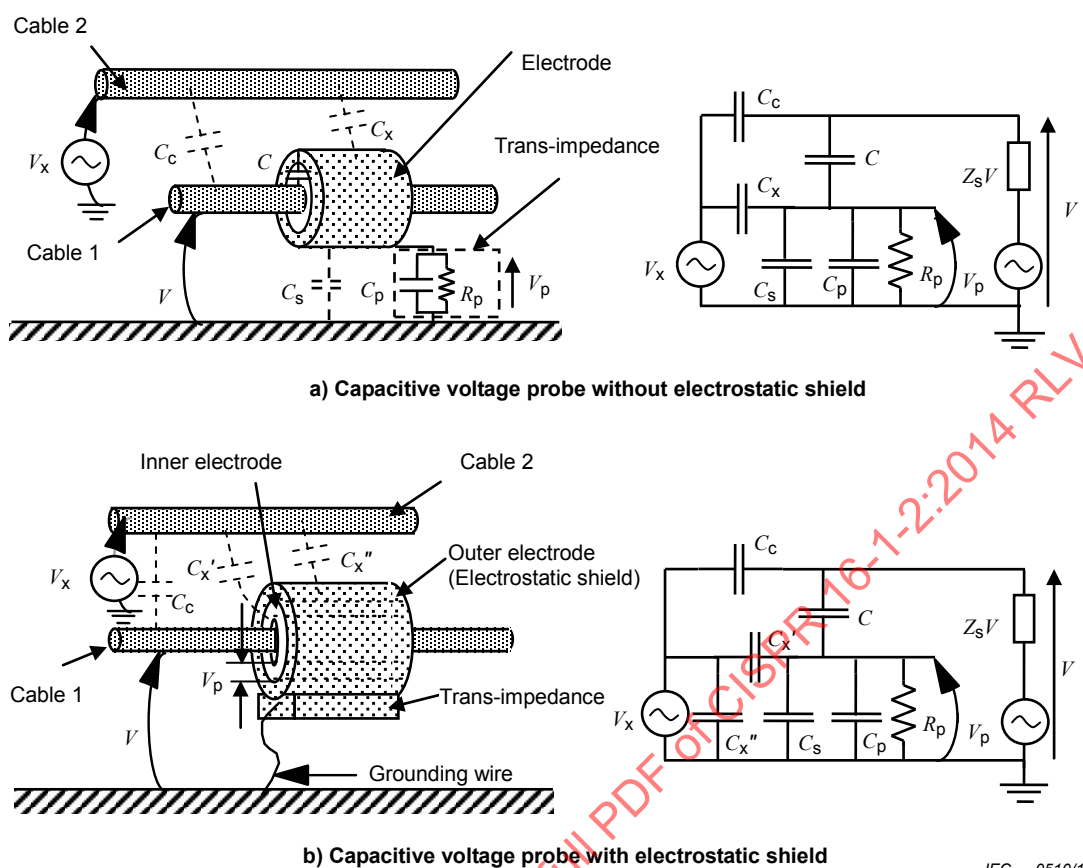
Typical values are not required/specified values, and other combinations consistent with "Characteristics" of 5.1.3 are acceptable.

Figure G.2 – Equivalent circuit of a CVP



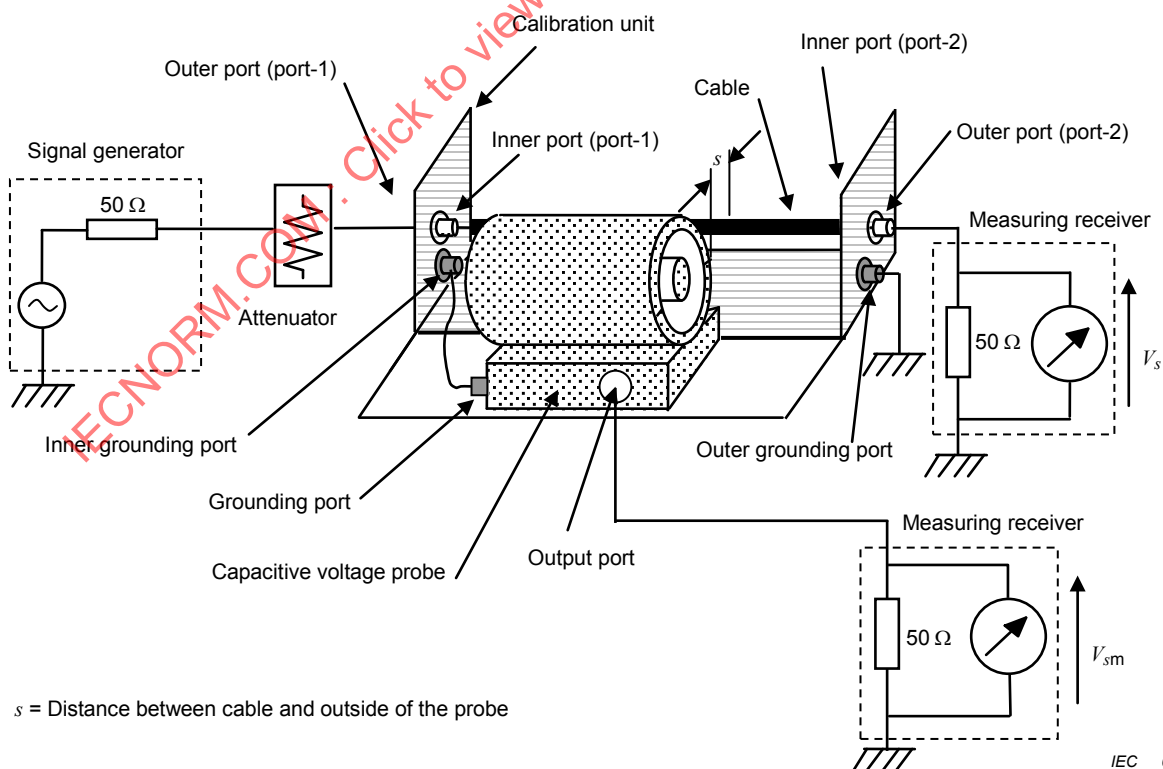
IEC 0509/14

Figure G.3 – Test set-up to measure the frequency response



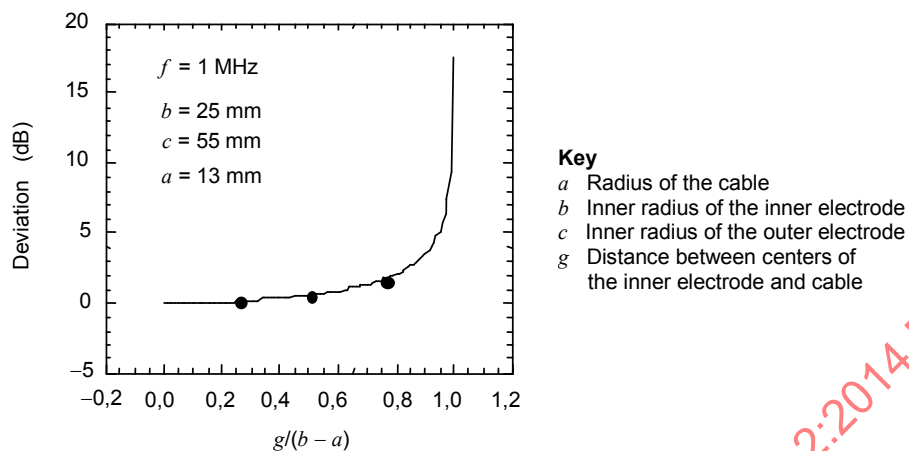
IEC 0510/14

Figure G.4 – Electrostatic coupling model and its equivalent circuit



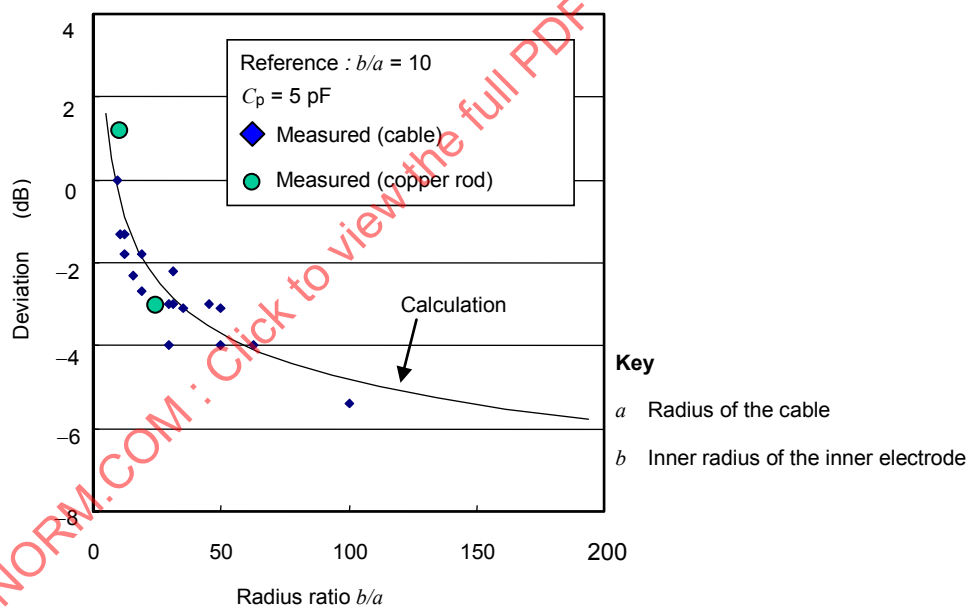
IEC 0511/14

Figure G.5 – Test set-up to measure the reduction, through the shielding effect, of the influence of the external electric field caused by electrostatic coupling



IEC 0512/14

Figure G.6 – Conversion factor deviation when cable position is changed



IEC 0513/14

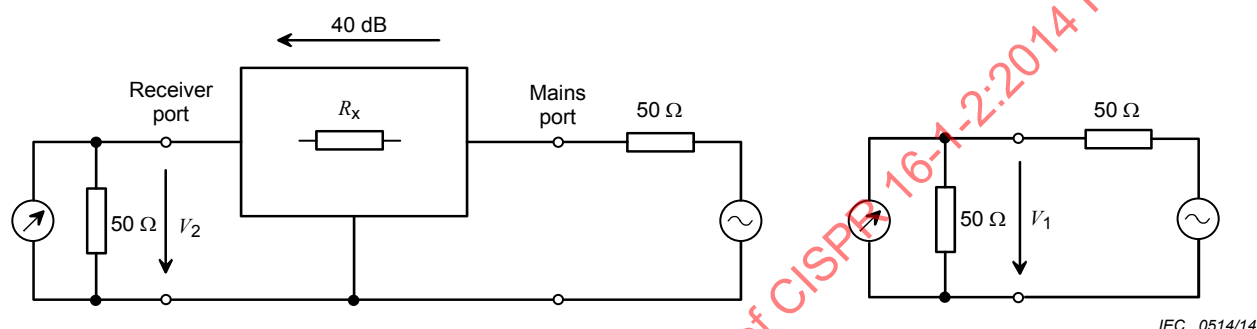
NOTE The vertical axis shows the deviation of the voltage division factor (F_{CVP}) from the calculated value when b/a is 10.

Figure G.7 – Investigation result of the cable radius dependence

Annex H (informative)

Rationale for the introduction of a minimum decoupling factor between mains and EUT/receiver ports for the V-AMN

For the purpose of reducing the influence of the unknown actual mains impedance on the V-AMN impedance, a minimum decoupling factor (isolation) between the mains port and the receiver port for a given termination of the EUT port may be specified. Differences between the various types of V-AMN have to be taken into consideration.



NOTE V_1 is measured separately by terminating the source with $50\ \Omega$. V_2 could be defined either at the EUT port or at the receiver port; in 4.8.2 it was decided to be defined at the receiver port.

Figure H.1 – Isolation measurement arrangement

A value of 40 dB of isolation [$20 \lg (V_1/V_2)$] is fulfilled if e.g. $R_x = 4\ 950\ \Omega$. If the impedance at the power port is then short or open, the impedance variation at the EUT port will be 1 %. Consequently, to keep the influence of the mains impedance on the AMN impedance below 1 %, a 40 dB isolation is needed (the detailed measurement procedure is given in 4.8). The uncertainty calculations in CISPR 16-4-2 are based on an impedance tolerance of 20 % and no influence from the mains port. It is not possible to guarantee no influence. However with 40 dB isolation, 1 % of the tolerance is left for the influence of the mains port, i.e. if, for example, the uncertainty contribution of the AMN impedance tolerance is 2,6 dB, the uncertainty contribution of the unknown mains port termination is in the order of 0,13 dB (included in the amount of 2,6 dB – not to be added).

In addition, the 40 dB isolation helps to limit the effect of the mains port termination on the voltage division factor and helps to keep disturbance from the mains port below a critical level. Further suppression can be achieved by additional filtering.

Remarks from manufacturers have shown that the value of 40 dB can easily be achieved if not yet fulfilled by the addition of e.g. a capacitor between the mains port terminal and ground.

Annex I (informative)

Rationale for the introduction of a phase tolerance for the V-AMN input impedance

For CISPR 16-4-2, the amount of U_{CISPR} was calculated based on the assumption of an “uncertainty circle” ΔZ_{in} (see Figure I.1), which can also be redefined as an impedance tolerance circle.

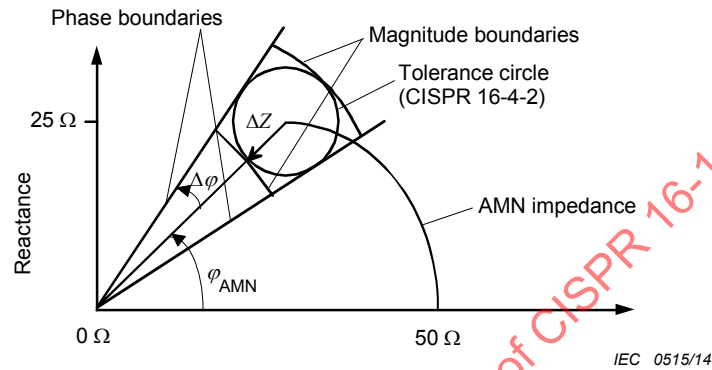


Figure I.1 – Definition of impedance magnitude and phase tolerances

Existing network analyzers however do not allow specification of a tolerance circle for the impedance. Additional software would be required for that purpose. Therefore the use of the existing specification of the magnitude tolerance and the addition of a specification of the phase tolerance are advisable. Using trigonometric functions, a value of $\Delta\phi = 11,54^\circ$ follows from $\Delta|Z|/|Z| = 0,2$.

CISPR/TR 16-4-1 can be taken as a theoretical basis for uncertainty and reproducibility of conducted emission measurements using a V-AMN. For the purpose of explaining the influence of deviations from the specified phase of a V-AMN, Equation (15) of CISPR/TR 16-4-1:2009 can be used:

$$\frac{\Delta V_m}{V_{mt}} = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \left(\frac{\Delta\alpha}{\alpha_0} + \frac{\Delta U_d}{V_{d0}} \right) + \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} - \frac{\Delta Z_d}{Z_{d0}} \right) \quad (\text{I.1})$$

where

- V_{mt} is the true voltage reading at the CISPR receiver in the ideal situation;
- Z_{13} is the ideal impedance of the V-AMN;
- $Z_{in} = Z_{13} + \Delta Z_{in}$
- Z_{d0}, V_{d0} are the true values of the disturbance source (i.e. the EUT) parameters;
- α_0 is the true value of the V-AMN voltage division factor;
- $\Delta V_m, \Delta\alpha, \Delta V_d, \Delta Z_{in}, \Delta Z_d$ are deviations from the true or ideal values.

Because we are interested in the effect of the phase tolerance on the uncertainty, the contributions $\Delta\alpha$, ΔV_d and ΔZ_d may be set to zero and based on Equation (17) of CISPR/TR 16-4-1:2009 we get:

$$\frac{\Delta V_m}{V_{mt}} = \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} \right) = c_2 \frac{\Delta Z_{in}}{Z_{13}} \quad (I.2)$$

The absolute value of the coefficient c_2 is shown as a function of the phase angle difference $\varphi = \varphi_{Z_{in}} - \varphi_{d0} = \varphi_{AMN} - \varphi_{EUT}$ of the impedances of Z_{in} and $Z_{d0} = Z_{EUT}$ in Figure 17 of CISPR/TR 16-4-1:2009 for several values of the ratio $|Z_{13}/Z_{d0}|$.

The absolute value of c_2 has been calculated using a spread sheet for several values of φ_{EUT} (0° , -45° , -90°), φ_{AMN} (0° , 30° , 46°), $|Z_{13}/Z_{d0}|$ (0,1; 0,2; 0,4; 0,8; 1,0; 1,4) and for $\Delta\varphi_{AMN}$ (-23° ; $-11,5^\circ$; $11,5^\circ$; 23°). For the purpose of this investigation, the absolute value of the factor $\Delta Z_{in}/Z_{13}$ has been set to 0,2 (i.e. to the maximum of the impedance magnitude tolerance), i.e.

$$\frac{\Delta V_m}{V_{mt}} = |c_2| \times 0,2 \quad (I.3)$$

For a comparison of the voltage level deviations due to phase deviations, the logarithms have been calculated as follows:

$$\text{Level deviation} = 20 \lg \left(1 - \frac{\Delta V_m}{V_{mt}} \right) \quad (I.4)$$

The level deviations have been compared for the results with $\Delta\varphi_{AMN} = -23^\circ$ and $-11,5^\circ$, as well as for $\Delta\varphi_{AMN} = 11,5^\circ$ and 23° , e.g. level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ}$.

The results thus obtained are:

For $\varphi_{EUT} = 0^\circ$ and $\varphi_{AMN} = 0^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 0,018$ dB (max.)

For $\varphi_{EUT} = -45^\circ$ and $\varphi_{AMN} = 46^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 0,27$ dB (max.)

For $\varphi_{EUT} = -45^\circ$ and $\varphi_{AMN} = 30^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 0,86$ dB (max.)

For $\varphi_{EUT} = -90^\circ$ and $\varphi_{AMN} = 46^\circ$: level deviation $_{23^\circ}$ – level deviation $_{11,5^\circ} = 3,07$ dB (max.)

Comment: the comparison of level deviations for $\Delta\varphi_{AMN} = 11,5^\circ$ and 23° shows that the reproducibility of measurements is not only influenced by the V-AMN impedance but also by the frequency (which determines φ_{AMN}) and by the phase angle φ_{EUT} . The reader can easily understand this by looking at Figure 17 of CISPR/TR 16-4-1:2009.

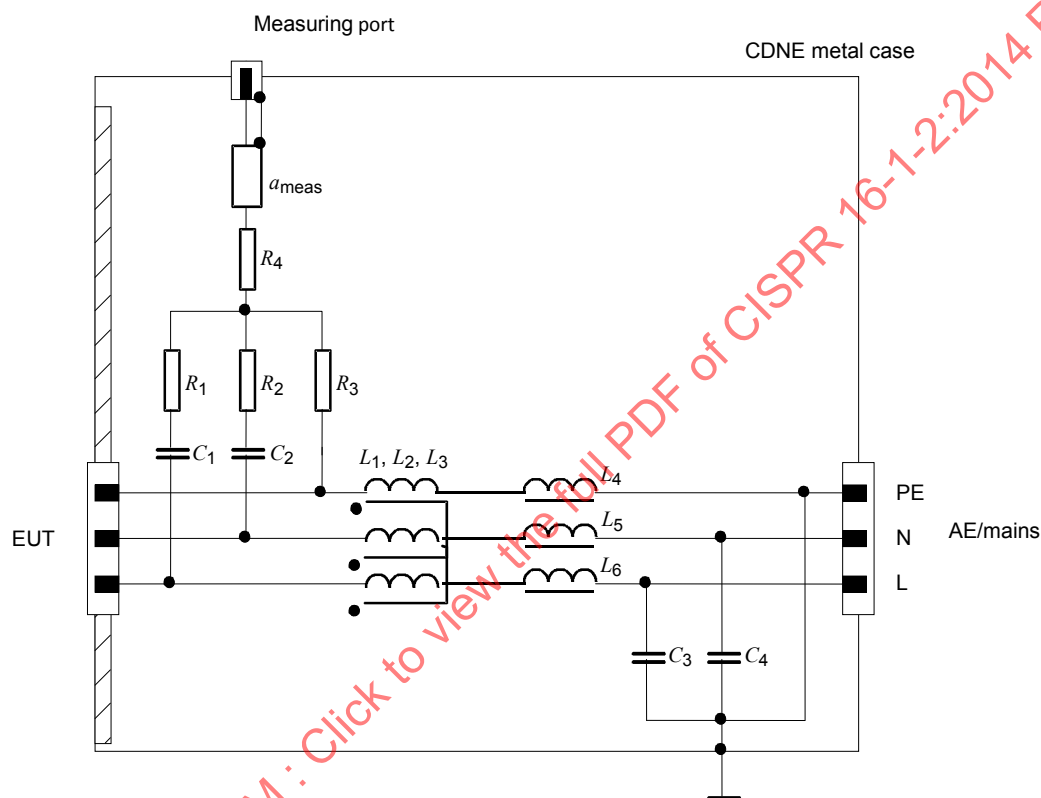
Conclusion: The investigation above shows that it is not sufficient to specify a tolerance of the magnitude of the V-AMN input impedance. Limiting the phase tolerance of the V-AMN input impedance by using $|\Delta\varphi_{AMN \text{ MAX}}| = 11,5^\circ$ does not cause a manufacturing problem for the V-AMN, but improves the reproducibility of measurement for identical EUTs.

Annex J (informative)

Example CDNE set-up diagrams

J.1 CDNE-M2 and CDNE-M3

Examples of CDNEs for the mains connection of protection class I and class II are shown in Figures J.1 and J.2.



IEC 0516/14

Key

$C_1, C_2, C_3, C_4 = 1 \text{ nF}$

$L_1, L_2, L_3 > 10 \text{ } \mu\text{H}$

$L_4, L_5, L_6 > 5 \text{ } \mu\text{H}$

$R_1, R_2, R_3 = 50 \text{ } \Omega$

$R_4 = 83,3 \text{ } \Omega$

$a_{\text{meas}} \geq 6 \text{ dB}$

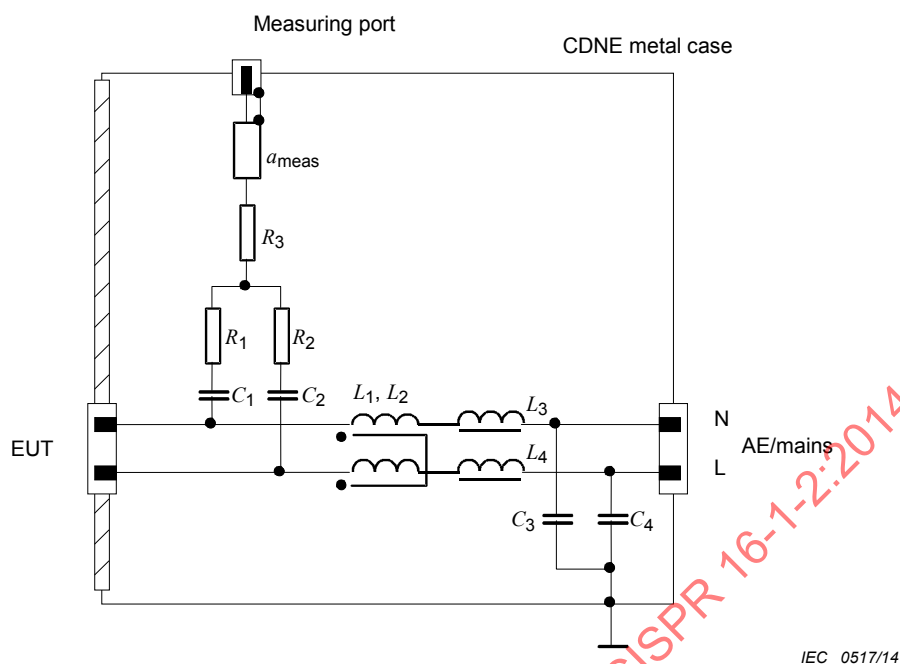
PE = protective earth

N = neutral

L = line

NOTE "AE/mains" can include a.c. mains, d.c. supply as well as control/communication lines.

Figure J.1 – CDNE-M3 with internal attenuator a_{meas} of at least 6 dB



Key

$C_1, C_2, C_3, C_4 = 1 \text{ nF}$

$L_1, L_2 > 10 \text{ } \mu\text{H}$

$L_3, L_4 > 5 \text{ } \mu\text{H}$

$R_1, R_2 = 50 \text{ } \Omega$

$R_3 = 75 \text{ } \Omega$

$a_{\text{meas}} \geq 6 \text{ dB}$

N = neutral

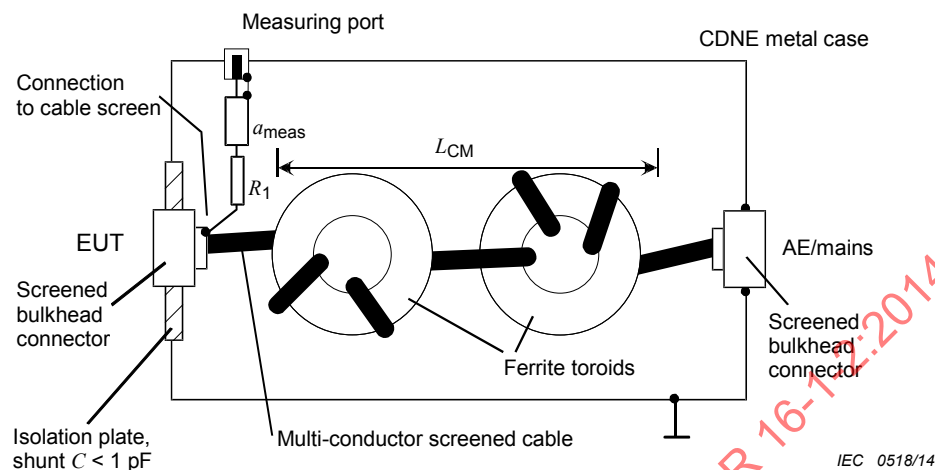
L = line

NOTE "AE/mains" can include a.c. mains, d.c. supply as well as control/communication lines.

Figure J.2 – CDNE-M2 with internal attenuator a_{meas} of at least 6 dB

J.2 CDNE-S_x

Figure J.3 shows an example of a CDNE-S_x for screened cables.



Key

$$R_1 = 100 \, \Omega$$

$$L_{\text{CM}} > 10 \, \mu\text{H}$$

$$a_{\text{meas}} \geq 6 \, \text{dB}$$

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

Figure J.3 – CDNE-S_x for screened cable with x internal wires and an internal attenuator of at least 6 dB

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE
COMITÉ INTERNATIONAL SPÉCIAL DES PERTURBATIONS RADIOÉLECTRIQUES

**SPÉCIFICATIONS DES MÉTHODES ET DES APPAREILS DE MESURE
DES PERTURBATIONS RADIOÉLECTRIQUES ET DE L'IMMUNITÉ
AUX PERTURBATIONS RADIOÉLECTRIQUES –**

**Partie 1-2: Appareils de mesure des perturbations
radioélectriques et de l'immunité aux perturbations radioélectriques –
Dispositifs de couplage pour la mesure des perturbations conduites**

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La Norme internationale CISPR 16-1-2 a été établie par le sous-comité A de la CISPR: Mesures des perturbations radioélectriques et méthodes statistiques, du comité d'études CISPR de la CEI: Comité international spécial des perturbations radioélectriques.

Cette deuxième édition annule et remplace la première édition parue en 2003, l'Amendement 1 (2004) et l'Amendement 2 (2006). Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- a) des exigences de la CISPR 22 relatives aux AAN ont été copiées dans la présente norme;
- b) le CDNE pour la mesure de la tension perturbatrice dans la gamme de fréquences de 30 MHz à 300 MHz a été ajouté;
- c) une maintenance supplémentaire est incluse.

Elle a le statut d'une publication fondamentale en CEM (Compatibilité Electromagnétique) conformément au Guide 107 de la CEI, *Compatibilité électromagnétique – Guide pour la rédaction des publications sur la compatibilité électromagnétique*.

Le texte de la présente norme est issu des documents suivants:

FDIS	Rapport de vote
CISPR/A/1051/FDIS	CISPR/A/1059/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette norme.

Une liste de toutes les parties de la série CISPR 16, publiées sous le titre général *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques*, peut être consultée sur le site web de la CEI.

La présente publication a été rédigée selon les Directives ISO/CEI, Partie 2.

Le comité a décidé que le contenu de la présente publication ne sera pas modifié avant la date de stabilité indiquée sur le site web de la CEI à l'adresse «<http://webstore.iec.ch>» dans les données relatives à la publication recherchée. A cette date, la publication sera

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

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

SPÉCIFICATIONS DES MÉTHODES ET DES APPAREILS DE MESURE DES PERTURBATIONS RADIOÉLECTRIQUES ET DE L'IMMUNITÉ AUX PERTURBATIONS RADIOÉLECTRIQUES –

Partie 1-2: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Dispositifs de couplage pour la mesure des perturbations conduites

1 Domaine d'application

La présente partie de la série CISPR 16 spécifie les caractéristiques et les performances des appareils de mesure de tensions et de courants perturbateurs radioélectriques dans la plage de fréquences comprises entre 9 kHz et 1 GHz.

NOTE Selon le Guide 107 de la CEI, la présente partie de la CISPR 16 constitue une norme fondamentale en CEM destinée à l'usage des comités de produits de la CEI. Comme mentionné dans le Guide 107, les comités de produits sont responsables de la détermination de l'applicabilité de la norme CEM. Le CISPR et ses sous-comités sont prêts à coopérer avec les comités de produits à l'évaluation de la valeur des essais CEM spécifiques à certains produits.

Les spécifications relatives aux matériels d'appoint sont incluses pour les réseaux fictifs, les sondes de courant et de tension et les boîtiers de couplage pour injection de courant au niveau des câbles.

Il est prévu que les exigences de la présente publication satisfassent à toutes les fréquences et à tous les niveaux de tension et de courant radioélectriques perturbateurs, dans les limites de la plage de lecture des appareils de mesure de la CISPR.

Les méthodes de mesure sont traitées dans la série CISPR 16-2, et des informations supplémentaires relatives aux perturbations radioélectriques sont communiquées par la série CISPR 16-3, alors que les incertitudes, les statistiques et la modélisation des limites sont fournies dans la série CISPR 16-4.

2 Références normatives

Les documents suivants sont cités en référence de manière normative, en intégralité ou en partie, dans le présent document et sont indispensables pour son application. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

CISPR 16-1-1:2010, *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 1-1: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Appareils de mesure*

CISPR 16-2-1:2014, *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 2-1: Méthodes de mesure des perturbations et de l'immunité – Mesures des perturbations conduites*

CISPR 16-4-2:2011, *Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Partie 4-2: Incertitudes, statistiques et modélisation des limites – Incertitudes de mesure de l'instrumentation*

CEI 60050 (toutes les parties), *Vocabulaire Electrotechnique International* (disponible sur «<http://www.electropedia.org>»)

CEI 61000-4-6:2008, *Compatibilité électromagnétique (CEM) – Partie 4-6: Techniques d'essai et de mesure – Immunité aux perturbations conduites, induites par les champs radioélectriques*

3 Termes, définitions et abréviations

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions donnés dans la CEI 60050, ainsi que les suivants s'appliquent.

3.1.1

matériel d'appoint

transducteurs connectés au récepteur de mesure ou au générateur de signal (d'essai) et utilisés dans le transfert du signal perturbateur entre le matériel en essai (EUT) et le matériel de mesure ou d'essai

Note 1 à l'article: Des exemples de transducteurs sont les sondes de courant et de tension, et les réseaux fictifs.

Note 2 à l'article: L'abréviation «EUT» est dérivée du terme anglais développé correspondant «Equipment Under Test».

3.1.2

matériel associé

AE

matériel nécessaire pour aider au fonctionnement du matériel en essai qui ne fait pas partie du système soumis à essai

Note 1 à l'article: L'abréviation «AE» est dérivée du terme anglais développé correspondant «associated equipment».

3.1.3

tension asymétrique

tension perturbatrice radioélectrique apparaissant entre le point milieu électrique des bornes d'alimentation et la terre, quelquefois appelée tension de mode commun

Note 1 à l'article: Si V_a désigne la tension vectorielle entre l'une des bornes d'alimentation et la terre, et que V_b désigne la tension vectorielle entre les bornes d'alimentation restantes et la terre, alors la tension asymétrique correspond à la moitié de la somme vectorielle de V_a et de V_b , soit $(V_a + V_b)/2$.

3.1.4

tension symétrique

tension perturbatrice radioélectrique apparaissant entre les deux fils d'un circuit bifilaire, tel qu'une alimentation monophasée, quelquefois appelée tension de mode différentiel

Note 1 à l'article: La tension symétrique correspond à la différence vectorielle ($V_a - V_b$).

3.1.5

tension dissymétrique

amplitude de la tension vectorielle, V_a ou V_b définie en 3.1.3 et 3.1.4

Note 1 à l'article: La tension dissymétrique correspond à la tension mesurée en utilisant un réseau fictif en V.

Note 2 à l'article: Voir les notes en 3.1.3 et 3.1.4 pour en savoir plus sur V_a et V_b .

3.1.6**réseau fictif d'alimentation****AMN**

réseau permettant d'envoyer une impédance RF définie à l'EUT, de coupler la tension perturbatrice au récepteur de mesure et de découpler le circuit d'essai de l'alimentation

Note 1 à l'article: Il existe deux types principaux de réseau fictif: le réseau en V (AMN en V) qui délivre les tensions dissymétriques, et le réseau en delta (AMN en Δ) qui délivre les tensions symétriques et asymétriques séparément.

Note 2 à l'article: Les termes «réseau de stabilisation d'impédance de ligne» (RSIL) et «AMN en V» sont interchangeables.

Note 3 à l'article: L'abréviation «AMN» est dérivée du terme anglais développé correspondant «artificial mains network».

3.1.7**réseau fictif asymétrique****AAN**

réseau utilisé pour mesurer (ou injecter) des tensions asymétriques (mode commun) sur des lignes de signal symétrique non blindées (par exemple de télécommunication) tout en rejetant le signal symétrique (mode différentiel)

Note 1 à l'article: Le terme «réseau en Y» est un synonyme de réseau fictif asymétrique (AAN).

Note 2 à l'article: L'abréviation «AAN» est dérivée du terme anglais développé correspondant «Asymmetric Artificial Network».

3.1.8**matériel auxiliaire****AuxEq**

périphérique faisant partie du système soumis à essai

Note 1 à l'article: L'abréviation «AuxEq» est dérivée du terme anglais développé correspondant «auxiliary equipment».

3.1.9**réseau de couplage/découplage****CDN**

réseau fictif pour la mesure ou l'injection de signaux sur un circuit tout en évitant que des signaux soient mesurés ou injectés dans un autre circuit

Note 1 à l'article: L'abréviation «CDN» est dérivée du terme anglais développé correspondant «coupling/decoupling network».

3.1.10**CDNE-X**

réseau de couplage/découplage dédié aux émissions pour la mesure de la tension perturbatrice dans la gamme de fréquences de 30 MHz à 300 MHz, où le suffixe «X» peut être «M2» pour une alimentation à deux fils non blindée, un courant continu ou des ports de commande, «M3» pour une alimentation à trois fils non blindée, un courant continu ou des ports de commande, et «S_x» pour un câble blindé avec *x* fils internes

Note 1 à l'article: Voir l'Annexe J pour en savoir plus sur le CDNE-X.

3.1.11**matériel en essai****EUT**

matériel (dispositifs, appareils et systèmes) soumis aux essais de conformité en matière de CEM (émission)

Note 1 à l'article: L'abréviation «EUT» est dérivée du terme anglais développé correspondant «equipment under test».

3.1.12

adaptateur de mesure d'impédance

IMA

plan vertical métallique de 0,1 m sur 0,1 m raccordé au plan de masse de référence et doté de ports de connexion pour un analyseur de réseau et un CDNE

Note 1 à l'article: L'abréviation «IMA» est dérivée du terme anglais développé correspondant «impedance measurement adaptor».

3.1.13

affaiblissement de conversion longitudinale

ACL

pour un réseau à un ou à deux ports, mesure du degré du signal transversal non désiré (mode symétrique) qui apparaît aux bornes dudit réseau du fait de la présence d'un signal longitudinal (mode asymétrique) sur les conducteurs

Note 1 à l'article: L'ACL est un rapport exprimé en dB.

[SOURCE: Recommandation UIT-T O.9 [8]¹]

3.1.14

plan de masse de référence

RGP

surface conductrice linéaire utilisée comme référence commune et permettant d'obtenir une capacité parasite définie autour d'un EUT

Note 1 à l'article: Un plan de masse de référence est nécessaire pour les mesures d'émissions conduites, et sert de terre de référence pour les mesures de tensions perturbatrices dissymétriques et asymétriques.

Note 2 à l'article: L'abréviation «RGP» est dérivée du terme anglais développé correspondant «reference ground plane».

3.2 Abréviations

Les abréviations suivantes sont utilisées dans la présente norme et n'ont pas été fournies en 3.1.

ACL	Longitudinal conversion loss (Affaiblissement de conversion longitudinale)
AN	Artificial network (réseau fictif)
CVP	Capacitive voltage probe (Sonde de tension à couplage capacitif)
f.é.m	Force électromotrice
ISN	Impedance stabilization network (Réseau de stabilisation d'impédance)
ITE	Information technology equipment (Appareil de traitement de l'information)
NWA	Network analyser (Analyseur de réseau)
PE	Protective earth (Terre de protection)
RF	Radiofréquence

¹ Les chiffres entre crochets se réfèrent à la Bibliographie.

4 Réseaux fictifs d'alimentation

4.1 Généralités

Un réseau fictif est nécessaire pour fournir une impédance RF définie aux bornes de l'EUT, afin d'isoler le circuit d'essai des signaux RF indésirables issus du réseau d'alimentation, et pour coupler la tension perturbatrice au récepteur de mesure.

Il existe deux principaux types de réseau fictif: le réseau en V (AMN en V) qui délivre les tensions dissymétriques, et le réseau en delta (AMN en Δ) qui délivre les tensions symétriques et asymétriques séparément.

Chaque type de conducteur d'alimentation est doté de trois bornes: la borne d'alimentation permettant le branchement au réseau d'alimentation, la borne appareil permettant le branchement à l'EUT, et la borne de sortie de perturbation permettant le branchement à l'appareil de mesure.

NOTE 1 Des exemples de circuits d'AMN sont fournis en Annexe A.

NOTE 2 Le présent Article définit les exigences d'impédance et d'isolation pour l'AMN, y compris les méthodes de mesures associées. Des éléments de contexte et de justification relatifs aux incertitudes liées à l'AMN sont fournis en 6.2.3 de la CISPR/TR 16-4-1:2009 et dans la CISPR 16-4-2.

4.2 Impédance de l'AMN

La spécification de l'impédance d'un AMN comprend l'amplitude et la phase de l'impédance mesurée sur une borne d'un EUT par rapport à la terre de référence, lorsque l'accès du récepteur est terminé par une résistance de 50 Ω .

L'impédance sur les bornes d'un EUT de l'AMN détermine l'impédance de charge au niveau dudit EUT. C'est pourquoi, lorsqu'une borne de sortie de perturbation n'est pas connectée au récepteur de mesure, celui-ci doit être terminé par une résistance de 50 Ω . Afin de garantir une terminaison de 50 Ω au niveau de l'accès du récepteur, un atténuateur de 10 dB doit être utilisé à l'intérieur ou à l'extérieur du réseau, son RPS (relevé depuis l'autre côté) devant être inférieur ou égal à une valeur comprise entre 1,2 et 1. L'affaiblissement doit être pris en compte dans la mesure du facteur de division en tension (voir 4.11).

L'impédance entre chaque conducteur (à l'exception de celui de protection PE) des bornes de l'EUT et la terre de référence doit être conforme aux dispositions spécifiées en 4.3, 4.4, 4.5, 4.6 ou 4.7 selon le cas, pour chaque valeur d'impédance externe, y compris dans le cas d'un court-circuit entre la borne maîtresse correspondante et la masse de référence. Cette exigence doit être satisfaite à toutes les températures que le réseau peut atteindre dans des conditions normales de fonctionnement pour des courants permanents jusqu'au maximum spécifié. Cette exigence doit aussi être satisfaite pour les courants de crête jusqu'au maximum spécifié.

Lorsque les exigences en termes de phase ne peuvent être satisfaites, les angles de phase mesurés dans le bilan d'incertitude doivent être pris en compte conformément à la CISPR 16-4-2. L'Annexe I fournit des directives de calcul de l'incidence d'incertitude de la phase lorsque les limites de tolérance ne sont pas respectées.

NOTE Comme les connecteurs des EUT ne sont pas optimisés pour les fréquences radioélectriques jusqu'à 30 MHz, la mesure de l'impédance du réseau est effectuée avec des adaptateurs de mesure spécifiques permettant des connexions courtes. L'étalonnage OSM (ouverture/court-circuit/correspondance, de l'anglais *Open/Short/Matched*) de l'analyseur de réseau est utilisé pour qualifier les adaptateurs en prenant en compte les pertes d'insertion et les longueurs des conducteurs desdits adaptateurs.

4.3 Réseau fictif en V (AMN en V) de $50 \Omega/50 \mu\text{H} + 5 \Omega$ pour une utilisation dans la plage de fréquences comprises entre 9 kHz et 150 kHz

L'AMN doit offrir une caractéristique d'impédance (amplitude et phase) qui dépend de la fréquence indiquée au Tableau 1 et en Figure 1 pour la plage de fréquences correspondante. Des tolérances de $\pm 20 \%$ pour l'amplitude et de $\pm 11,5^\circ$ pour la phase sont autorisées.

Tableau 1 – Amplitudes et angles de phase du réseau en V (voir Figure 1)

Fréquence en MHz	Amplitude de l'impédance en Ω	Angle de phase en degrés
0,009	5,22	26,55
0,015	6,22	38,41
0,020	7,25	44,97
0,025	8,38	49,39
0,030	9,56	52,33
0,040	11,99	55,43
0,050	14,41	56,40
0,060	16,77	56,23
0,070	19,04	55,40
0,080	21,19	54,19
0,090	23,22	52,77
0,100	25,11	51,22
0,150	32,72	43,35

NOTE Si ce réseau AMN satisfait aux exigences d'impédance spécifiées en 4.3 et 4.4, il peut être aussi utilisé dans la plage de fréquences comprises entre 150 kHz et 30 MHz.

4.4 Réseau fictif en V (AMN en V) de 50 Ω /50 μ H pour une utilisation dans la plage de fréquences comprises entre 0,15 MHz et 30 MHz

L'AMN doit offrir une caractéristique d'impédance (amplitude et phase) en fonction de la fréquence indiquée au Tableau 2 et en Figure 2 pour la plage de fréquences correspondante. Des tolérances de ± 20 % pour l'amplitude et de $\pm 11,5^\circ$ pour la phase sont autorisées.

Tableau 2 – Amplitudes et angles de phase du réseau en V (voir Figure 2)

Fréquence en MHz	Amplitude de l'impédance en Ω	Angle de phase en degrés
0,15	34,29	46,70
0,17	36,50	43,11
0,20	39,12	38,51
0,25	42,18	32,48
0,30	44,17	27,95
0,35	45,52	24,45
0,40	46,46	21,70
0,50	47,65	17,66
0,60	48,33	14,86
0,70	48,76	12,81
0,80	49,04	11,25
0,90	49,24	10,03
1,00	49,38	9,04
1,20	49,57	7,56
1,50	49,72	6,06
2,00	49,84	4,55
2,50	49,90	3,64
3,00	49,93	3,04
4,00	49,96	2,28
5,00	49,98	1,82
7,00	49,99	1,30
10,00	49,99	0,91
15,00	50,00	0,61
20,00	50,00	0,46
30,00	50,00	0,30

4.5 Réseau fictif en V (AMN en V) de $50 \Omega/5 \mu\text{H} + 1 \Omega$ pour une utilisation dans la plage de fréquences comprises entre 150 kHz et 108 MHz

L'AMN doit offrir une caractéristique d'impédance (amplitude et phase) en fonction de la fréquence indiquée au Tableau 3 et en Figure 3. Des tolérances de $\pm 20 \%$ pour l'amplitude et de $\pm 11,5^\circ$ pour la phase sont autorisées.

Tableau 3 – Amplitudes et angles de phase du réseau en V (voir Figure 3)

Fréquence en MHz	Amplitude de l'impédance en Ω	Angle de phase en degrés
0,15	4,70	72,74
0,20	6,19	73,93
0,30	9,14	73,47
0,40	12,00	71,61
0,50	14,75	69,24
0,70	19,82	64,07
1,00	26,24	56,54
1,50	33,94	46,05
2,00	38,83	38,15
2,50	41,94	32,27
3,00	43,98	27,81
4,00	46,33	21,63
5,00	47,56	17,62
7,00	48,71	12,80
10,00	49,35	9,04
15,00	49,71	6,06
20,00	49,84	4,55
30,00	49,93	3,04
50,00	49,97	1,82
100,00	49,99	0,91
108,00	49,99	0,84

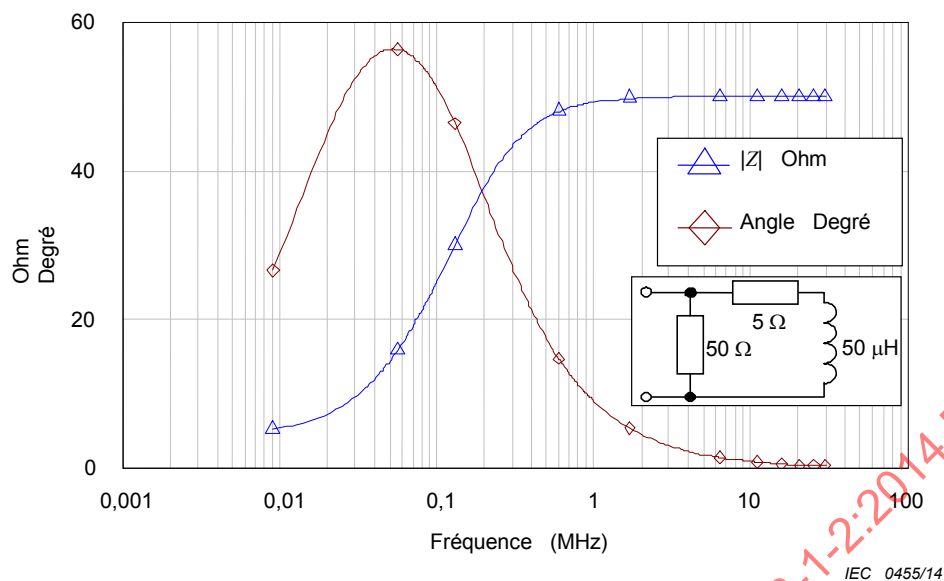


Figure 1 – Impédance (amplitude et phase) du réseau en V pour la bande A (de 9 kHz à 150 kHz) (voir 4.3)

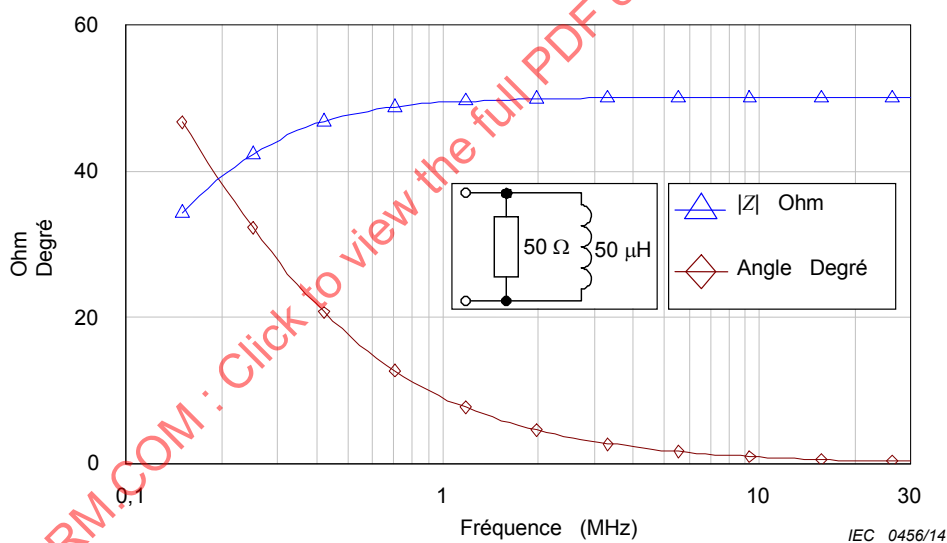


Figure 2 – Impédance (amplitude et phase) du réseau en V pour la bande B (voir 4.4)

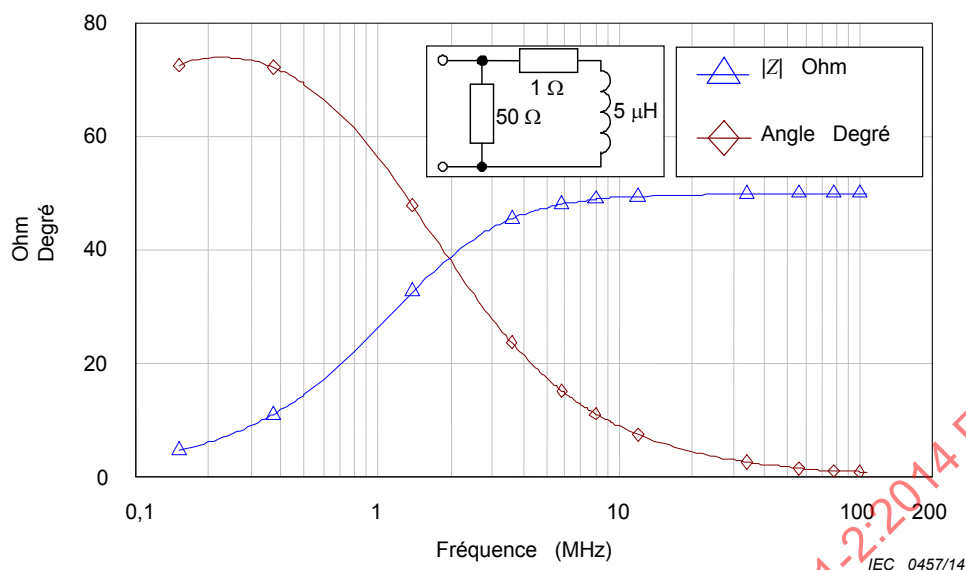


Figure 3 – Impédance (amplitude et phase) du réseau en V pour les bandes B et C (de 150 kHz to 108 MHz) (voir 4.5)

4.6 Réseau fictif en V (AMN en V) de 150 Ω pour une utilisation dans la plage de fréquences comprises entre 150 kHz et 30 MHz

Le réseau doit offrir une impédance d'amplitude de $(150 \pm 20) \Omega$, avec un angle de phase ne dépassant pas 20° .

4.7 Réseau fictif en delta (AMN en Δ) de 150 Ω pour une utilisation dans la plage de fréquences comprises entre 150 kHz et 30 MHz

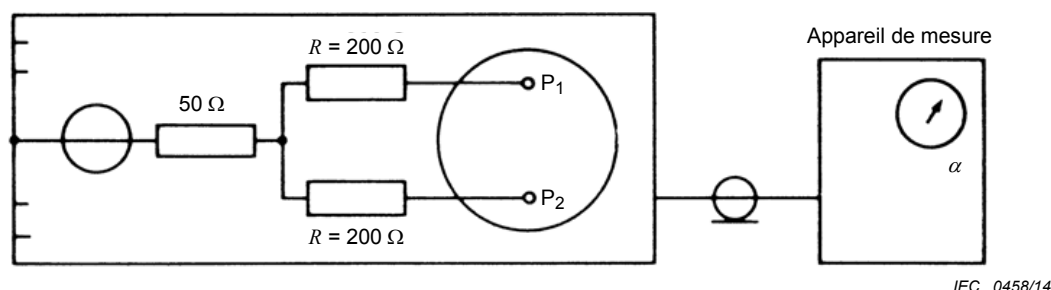
4.7.1 Paramètres généraux

Le réseau doit offrir une impédance d'amplitude de $(150 \pm 20) \Omega$, avec un angle de phase ne dépassant pas 20° entre les deux bornes appareil, et entre ces dernières réunies et la terre de référence.

Pour la mesure de la tension symétrique, un transformateur blindé et symétrique est nécessaire. Afin d'éviter une modification importante de l'impédance du réseau, l'impédance d'entrée du transformateur ne doit pas être inférieure à 1 000 Ω , peu importe la fréquence concernée. La tension relevée par le récepteur de mesure dépend des valeurs des composants du réseau et du rapport du transformateur. Le réseau doit être étalonné.

4.7.2 Symétrie d'un réseau fictif en delta de 150 Ω

Du fait de la nature symétrique que doit offrir le système comprenant le réseau et le récepteur de mesure connecté à celui-ci par l'intermédiaire du transformateur, la mesure de la tension symétrique ne doit pas être considérablement affectée par la présence d'une tension asymétrique. La symétrie doit être mesurée à l'aide du circuit présenté en Figure 4.



R correspond aux résistances de 200Ω identiques à 1 % près

P_1 et P_2 correspondent aux bornes du réseau dédiées à la connexion du dispositif

Figure 4 – Méthode de vérification de la symétrie de l'installation pour la mesure de tensions symétriques

Une tension V_a est injectée à partir d'un générateur d'impédance interne de 50Ω entre la terre de référence et le point milieu de deux résistances de $200 \Omega \pm 1 \%$ chacune. L'autre extrémité de ces résistances est raccordée aux bornes appropriées de l'AMN.

Une tension V_s est relevée en position de mesure de la tension symétrique. Le rapport V_a/V_s doit être supérieur à 20:1 (26 dB).

4.8 Isolation

4.8.1 Exigence

Afin de garantir que des signaux non désirés existants du côté de l'alimentation et l'impédance inconnue du réseau d'alimentation n'affectent pas la mesure de chacune des fréquences d'essai, une isolation minimale (facteur de découplage) doit être respectée entre chaque borne maîtresse et l'accès du récepteur d'une terminaison donnée de l'accès de l'EUT. Voir Tableau 4. Cette exigence s'applique à l'AMN en V (AMN en V), à l'exclusion des câbles et filtres externes complémentaires.

Un filtrage additionnel externe à l'AMN peut s'avérer nécessaire pour supprimer les interférences au niveau de l'accès d'alimentation (voir les exigences pratiques de la CISPR 16-2-1).

Tableau 4 – Valeurs d'isolation minimale pour les réseaux en V

Paragraphe	Type de réseau en V	Plage de fréquences en MHz	Isolation minimale en dB
4.3	50 Ω /50 μ H + 5 Ω	0,009 à 0,05	0 à 40 ^a
		0,05 à 30	40
4.4	50 Ω /50 μ H	0,15 à 30	40
4.5	50 Ω /5 μ H + 1 Ω	0,15 à 3	0 à 40 ^a
		3 à 108	40

^a Ces valeurs signifient que l'isolation minimale augmente linéairement avec le logarithme de fréquence

4.8.2 Procédure de mesure

La configuration d'essai est représentée en Figure H.1. À des fins de mesure, un signal V_1 est relevé pour une impédance de charge de 50Ω avec une impédance de source de résistance

identique. Cette source de signal doit ensuite être connectée aux bornes maîtresses correspondantes et à la terre de référence, les bornes de l'EUT associées devant être terminées par une résistance de 50 Ω. La tension de sortie V_2 doit être mesurée au niveau de l'accès du récepteur (lequel est terminé par une résistance identique). L'affaiblissement provenant de l'atténuateur de 10 dB (décrit en 4.2) doit être ajouté à l'exigence d'isolation. L'exigence d'isolation doit être satisfaite pour toutes les bornes d'alimentation et de l'EUT. Si la terminaison des autres bornes d'alimentation influence le résultat de mesure, l'exigence doit être satisfaite avec les autres bornes d'alimentation ouvertes et court-circuitées.

L'équation suivante doit être satisfaite:

$$V_1 - V_2 \geq F_D + A \quad (1)$$

où

- V_1 est la tension de référence aux bornes maîtresses en dB(μV);
- V_2 est la tension de sortie au niveau de l'accès du récepteur en dB(μV);
- F_D est l'exigence minimale d'isolation (facteur de découplage) en dB;
- A est l'affaiblissement de l'atténuateur intégré en dB.

NOTE Comme les connecteurs des EUT ne sont pas optimisés pour les fréquences radioélectriques jusqu'à 30 MHz, la mesure de l'isolation du réseau est effectuée avec des adaptateurs de mesure spécifiques permettant des connexions courtes. Il est nécessaire d'effectuer la mesure de V_1 avec l'adaptateur raccordé à la source.

4.9 Courants maximaux et chute de tension série

Les courants permanents maximaux et le courant de crête maximal doivent être spécifiés. La tension appliquée à l'EUT lors du passage de courants continus jusqu'aux valeurs maximales ne doit pas être inférieure à 95 % de la tension d'alimentation au niveau des bornes d'alimentation de l'AMN.

4.10 Prise de terre de référence modifiée

La mesure de certains types d'appareils peut nécessiter l'insertion d'une impédance dans le conducteur de terre de référence des AMN spécifiée en 4.3 et 4.4, conformément aux exigences des publications relatives à ces produits. Ladite insertion est réalisée au point X indiqué sur le conducteur de terre de référence des Figures 5 et 6 respectives. L'impédance à insérer est soit une inductance de 1,6 mH, soit une impédance conforme à l'exigence spécifiée en 4.3 ou 4.4, selon la plage de fréquences appropriée.

NOTE Lorsque l'on considère la plage de fréquences qui s'étend de 9 kHz à 150 kHz, il ne faut pas insérer la résistance de 5 Ω du réseau fictif en V pour des raisons de sécurité.

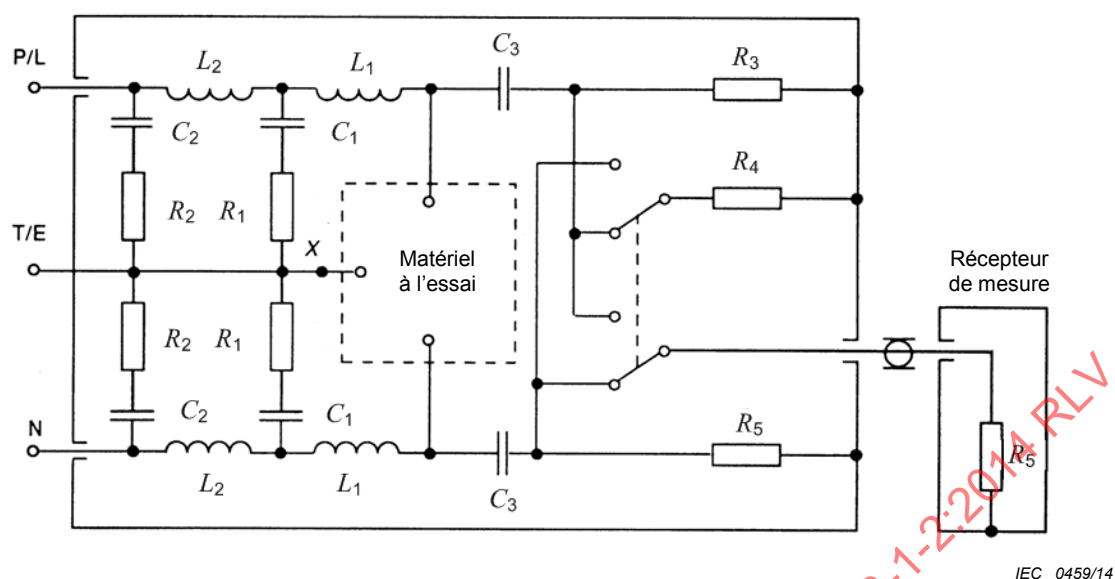


Figure 5 – Exemple de réseau fictif en V de $50 \Omega/50 \mu\text{H} + 5 \Omega$ (voir 4.3 et A.2)

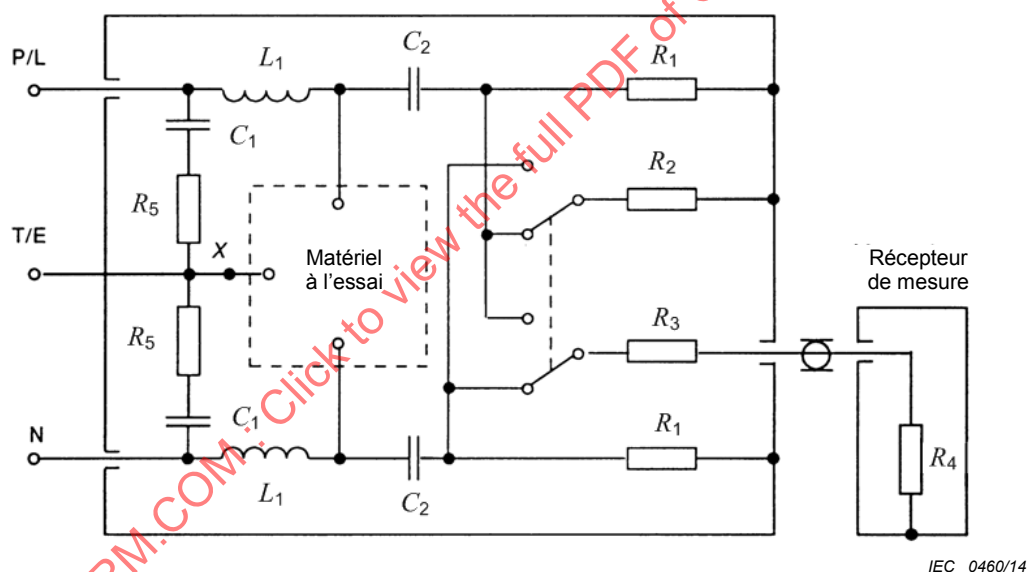


Figure 6 – Exemple de réseau fictif en V de $50 \Omega/50 \mu\text{H}$, $50 \Omega/5 \mu\text{H} + 1 \Omega$ ou 150Ω (voir 4.4, 4.5, 4.6, A.3, A.4 et A.5 respectives)

4.11 Mesure du facteur de division en tension des réseaux fictifs en V

Le facteur de division en tension entre les accès de l'EUT et de la sortie RF du réseau fictif en V doit être mesuré et pris en compte lors de la mesure de la tension perturbatrice. Une procédure de mesure du facteur de division en tension est fournie en A.8.

5 Sondes de courant et de tension

5.1 Sondes de courant

5.1.1 Généralités

Il est possible de mesurer les courants perturbateurs asymétriques des câbles sans produire de contact électrique direct avec le conducteur source ni modifier son circuit, en utilisant des

pincés-transformateurs de courant, conçues spécialement à cet effet. L'utilité de cette méthode est évidente: des solutions complexes (systèmes de câblage, circuits électroniques, etc.) peuvent être mesurées sans interruption du fonctionnement ni modification de la configuration. La sonde de courant est conçue de façon à pouvoir se refermer correctement autour du conducteur à mesurer. Le conducteur représente un bobinage primaire à une spire. Le bobinage secondaire se trouve dans la sonde de courant.

Bien que la plage de mesure primaire s'étende de 30 Hz à 1 000 MHz, les sondes de courant peuvent être conçues pour des mesures réalisées dans une plage de fréquences comprises entre 30 Hz et 100 MHz. Au-delà de 100 MHz, les courants à ondes stationnaires des systèmes de puissance classiques exigent que la position de la sonde de courant soit optimisée en vue de détecter le courant maximal.

Les sondes de courant sont conçues pour fournir une réponse en fréquence linéaire sur toute la bande passante. Il est possible d'effectuer des mesures précises à des fréquences inférieures à cette plage linéaire. Le cas échéant, la sensibilité est toutefois réduite du fait de la valeur plus faible des impédances de transfert. Les mesures réalisées à des fréquences supérieures à cette plage linéaire sont imprécises en raison des résonances existant dans la sonde de courant.

Avec une structure de blindage supplémentaire, une sonde de courant peut être utilisée pour mesurer des courants asymétriques (mode commun) ou symétriques (mode différentiel). Quelques informations de conception sont fournies en B.5.

5.1.2 Conception

La sonde de courant doit être conçue de manière à permettre la mesure du courant sans qu'il soit nécessaire de débrancher le conducteur à mesurer.

L'Annexe B présente quelques configurations standard des sondes de courant.

5.1.3 Caractéristiques

Impédance d'insertion	Impédance maximale de 1 Ω
Impédance de transfert	De 0,1 Ω à 5 Ω dans la plage de réponse linéaire; de 0,001 Ω à 0,1 Ω en dessous de la plage de réponse linéaire (la sonde étant bouclée par une charge de 50 Ω).
NOTE Il est également possible d'utiliser la valeur inverse, c'est-à-dire l'admittance de transfert [en dB(S)]. Lorsqu'elle est exprimée en décibels, l'admittance s'ajoute à la valeur relevée sur le récepteur de mesure. Pour l'étalonnage de l'impédance ou de l'admittance de transfert, un gabarit spécialement conçu à cet effet est utilisé (voir Annexe B).	
Capacité parallèle supplémentaire	Inférieure à 25 pF entre le boîtier de la sonde de courant et le conducteur mesuré.
Réponse en fréquence	L'impédance de transfert est mesurée sur une plage de fréquences déterminée. La plage de fréquences des sondes individuelles s'étend habituellement de 100 kHz à 100 MHz, de 100 MHz à 300 MHz, et de 200 MHz à 1 000 MHz.
Réponse impulsionnelle	A l'étude.
Saturation magnétique	Le courant d'alimentation maximal CC ou CA dans le conducteur primaire permettant d'obtenir une erreur

de mesure inférieure à 1 dB doit être spécifié.

Tolérance d'impédance de transfert A l'étude.

Influence des champs magnétiques externes Réduction de 40 dB de la valeur lue lorsqu'un conducteur porteur de courant est déplacé de l'ouverture de la sonde de courant jusqu'à une position proche de la sonde.

Influence des champs électriques Immunité aux champs < à 10 V/m.

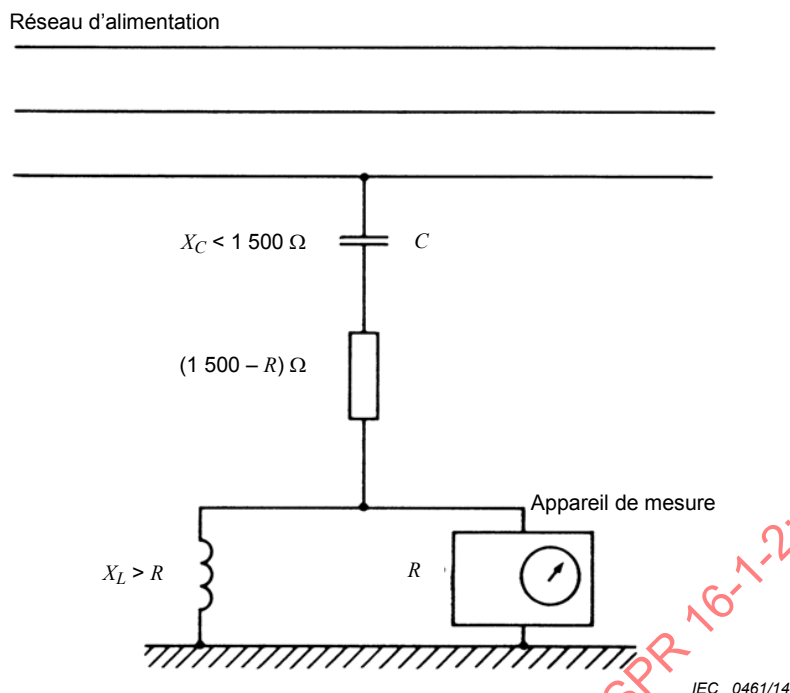
Influence de l'orientation Inférieure à 1 dB jusqu'à 30 MHz et 2,5 dB de 30 MHz à 1 000 MHz, dans le cas d'une utilisation sur un conducteur, quelle que soit sa dimension et son emplacement dans l'ouverture.

Ouverture de la sonde de courant Au moins 15 mm.

5.2 Sonde de tension

5.2.1 Sonde de tension à haute impédance

La Figure 7 représente un circuit utilisé pour réaliser des mesures de tension entre un conducteur d'alimentation et la terre de référence. La sonde est composée d'un condensateur de blocage C et d'une résistance de sorte que la résistance totale entre la ligne et la terre soit de 1 500 Ω . La sonde peut également être utilisée pour effectuer des mesures sur d'autres lignes et, avec certaines applications, son impédance peut devoir être augmentée de manière à éviter une charge excessive sur les circuits à haute impédance. Pour des raisons de sécurité, il est permis de connecter une inductance en parallèle sur l'entrée de l'appareil de mesure. Il convient que sa réactance inductive, X_L , soit largement supérieure à R .



NOTE $V = \frac{1500}{R} V_m$

où

V est la tension perturbatrice;

V_m est la tension à l'entrée de l'appareil de mesure.

Figure 7 – Dispositif pour la mesure de tensions RF sur le réseau d'alimentation

Pour l'étalonnage des sondes de tension, le facteur de division en tension doit être mesuré sur un système de 50 Ω pour une plage de fréquences comprises entre 9 kHz et 30 MHz. Il convient que les effets sur la précision de la mesure de tout dispositif pouvant être utilisé à des fins de protection soient inférieurs à 1 dB, ou pris en compte au moment de l'étalonnage. On doit veiller à ce que le niveau de perturbation faisant l'objet de la mesure soit suffisamment élevé par rapport au bruit ambiant pour que la mesure soit significative.

Il convient de réduire la boucle formée par le conducteur connecté à la sonde, le conducteur d'alimentation mesuré et la terre de référence afin d'éviter les effets des champs magnétiques forts.

5.2.2 Sonde de tension à couplage capacitif

5.2.2.1 Généralités

Il est possible de mesurer les tensions perturbatrices asymétriques des câbles sans produire de contact électrique direct avec le conducteur source ni modifier son circuit, en utilisant une pince de couplage capacitif. L'utilité de cette méthode est évidente: des solutions complexes (systèmes de câblage, circuits électroniques, etc.) peuvent être mesurées sans interruption du fonctionnement ni modification de la configuration de l'EUT, et ce sans devoir couper le câble afin d'y insérer un dispositif de mesure. La sonde de tension à couplage capacitif (CVP, de l'anglais «capacitive voltage probe») est conçue de façon à pouvoir se refermer correctement autour du conducteur à mesurer.

La CVP est utilisée pour mesurer les perturbations conduites dans la plage de fréquences comprises entre 150 kHz et 30 MHz avec une réponse quasi linéaire sur la plage prise en

compte. Le facteur de division en tension, qui est défini par le rapport de la tension perturbatrice sur le câble avec la tension d'entrée au niveau du récepteur de mesure, dépend du type de câble. Il convient que celui-ci soit étalonné sur une plage de fréquences propre à chaque type de câble à partir de la méthode décrite en Annexe G.

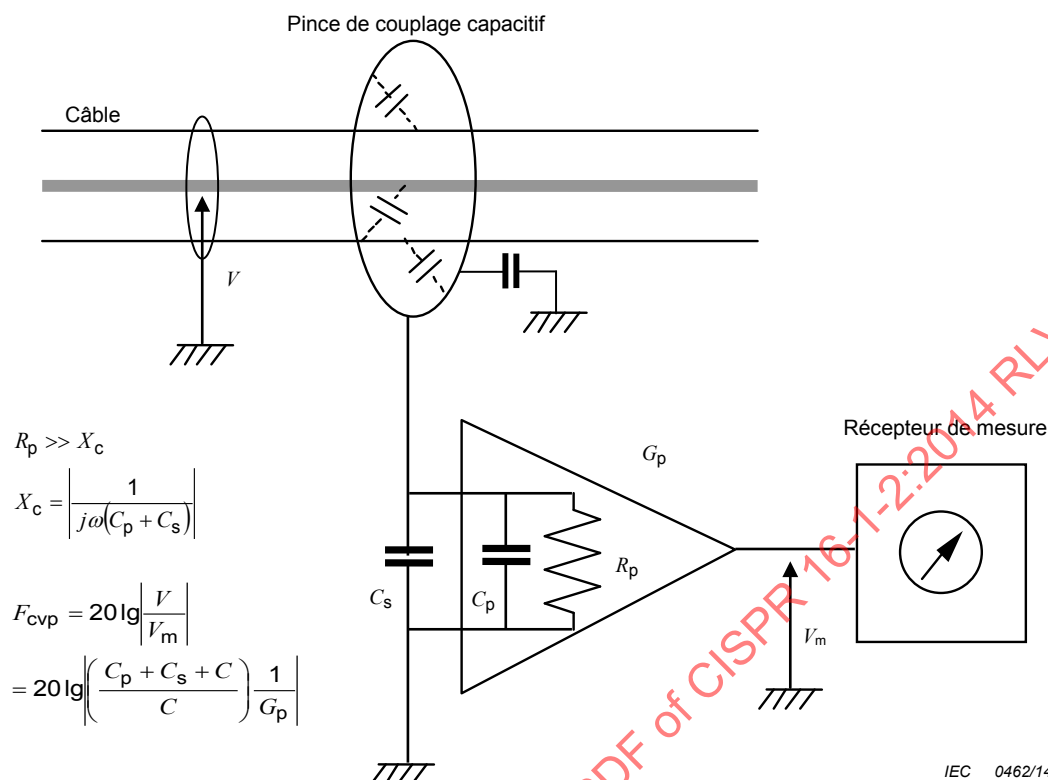
Il peut être nécessaire d'assurer un blindage supplémentaire au niveau de la CVP afin de fournir une isolation suffisante par rapport au signal asymétrique (mode commun) présent dans l'environnement du câble (voir 5.2.2.3). L'Annexe G propose un exemple de conception ainsi qu'une méthode de mesure pour l'isolation.

Cette CVP peut être utilisée pour mesurer les perturbations au niveau des ports de télécommunication. Le niveau mesurable minimal atteint généralement 44 dB(μ V).

5.2.2.2 Conception

La CVP doit être conçue de manière à permettre la mesure de la tension sans déconnecter le câble à mesurer. La Figure 8 présente un circuit utilisé pour réaliser des mesures de tension entre un câble et une terre de référence. La sonde est composée d'une pince de couplage capacitif connectée à un amplificateur à transimpédance. La résistance d'entrée R_p de cet amplificateur doit être suffisamment grande par rapport à la réactance X_C pour obtenir une réponse linéaire en fréquence.

L'Annexe G fournit des instructions pour la réalisation et la vérification standard de la CVP.



Légende

C	Capacité entre le câble et la pince
C_p	Capacité de l'amplificateur à transimpédance
C_s	Capacité entre la sonde et la terre
F_{CVP}	Facteur de division en tension
G_p	Gain de l'amplificateur à transimpédance
R_p	Résistance de l'amplificateur à transimpédance
V	Tension perturbatrice
V_m	Tension à l'entrée du récepteur de mesure

Figure 8 – Circuit utilisé pour réaliser des mesures de tension entre un câble et la terre de référence

5.2.2.3 Exigences

Capacité parallèle supplémentaire	Inférieure à 10 pF entre la borne de mise à la terre de la CVP et le câble en essai.
Réponse en fréquence	Le facteur de division en tension, $F_{CVP} = 20 \lg V/V_m $ en dB (voir Figure 8), est étalonné sur une plage de fréquences spécifique.
Réponse impulsionnelle	Maintenir la linéarité pour l'impulsion déterminée à partir de la méthode spécifiée dans les Annexes B et C de la CISPR 16-1-1:2010 pour la bande B.
Influence du champ électrique (influence due au couplage électrostatique avec d'autres câbles près de la sonde)	L'indication de la tension est réduite de plus de 20 dB lorsqu'un câble est retiré de la CVP. La méthode de mesure est décrite en Annexe G.

Entrebâillement ou ouverture de la CVP [entrebâillement lorsque les deux électrodes coaxiales s'ouvrent au niveau de l'encoche (voir Figure G.1)]

Au moins 30 mm.

6 Boîtiers de couplage pour la mesure de l'immunité aux courants conduits

6.1 Généralités

Les boîtiers de couplage sont conçus pour injecter le courant perturbateur sur les conducteurs en essai et pour isoler ceux restants, ainsi que les appareils branchés à l'EUT, des effets de tels courants. Avec une impédance de source de $150\ \Omega$, il existe une corrélation utile entre la force du champ perturbateur RF agissant sur une installation réelle et la f.é.m. qu'il faut appliquer dans la méthode d'injection de courant en vue de produire le même degré de dégradation, au moins jusqu'à des fréquences de 30 MHz. L'immunité d'un appareil est exprimée par cette valeur f.é.m. L'Annexe C et l'Annexe D présentent les principes de fonctionnement ainsi que des exemples de boîtiers et de leur conception.

6.2 Caractéristiques

6.2.1 Généralités

Les contrôles de fonctionnement des boîtiers de couplage sont effectués pour une impédance à une plage de fréquences comprises entre 0,15 MHz et 30 MHz et pour une perte d'insertion à une plage de fréquences comprises entre 30 MHz et 150 MHz.

6.2.2 Impédance

Avec la plage de fréquences comprises entre 0,15 MHz et 30 MHz, l'impédance asymétrique totale (bobine d'arrêt RF parallèle à l'impédance résistive de la source de perturbations de $150\ \Omega$) mesurée entre le point d'injection du signal perturbateur dans l'EUT et la terre du boîtier doit offrir une amplitude de $150\ \Omega \pm 20\ \Omega$, ainsi qu'un angle de phase inférieur à $\pm 20^\circ$ (cette impédance est identique à celle du réseau fictif en V de $150\ \Omega$ de la CISPR) (voir 4.5).

Par exemple, pour les boîtiers de couplage de type A et S, le point d'injection correspond au blindage du connecteur de sortie. Pour les boîtiers de type M et L, le point d'injection correspond aux bornes de sortie rassemblées.

6.2.3 Pertes d'insertion

Avec la plage de fréquences comprises entre 30 MHz et 150 MHz, la perte d'insertion de deux boîtiers de couplage identiques en tandem doit s'étendre de 9,6 dB à 12,6 dB, mesurée conformément à la Figure 9. Ces deux boîtiers doivent être interconnectés avec des fils très courts ($\leq 1\text{ cm}$).

Il convient que la perte d'insertion U_G/U_B des deux boîtiers de couplage identiques mesurée conformément à la configuration en Figure 9 se trouve entre 9,6 dB et 12,6 dB pour une plage de fréquences comprises entre 30 MHz et 150 MHz. U_G correspond au relevé du récepteur lorsque celui-ci est directement connecté au générateur.

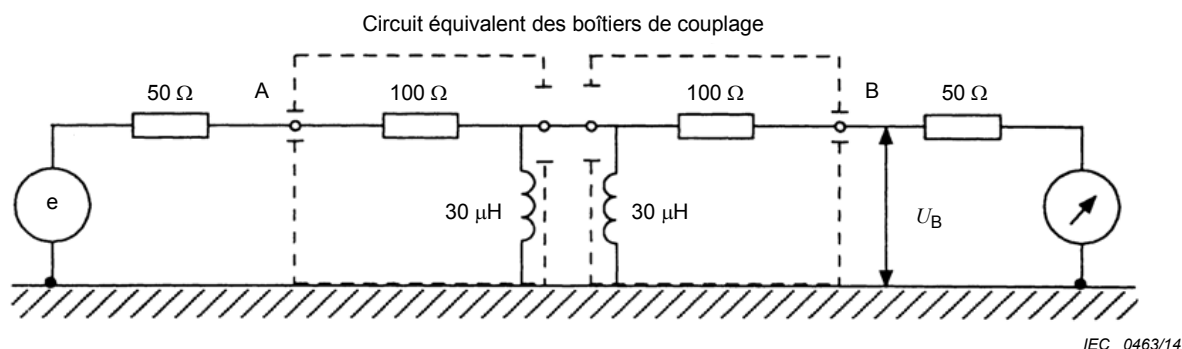


Figure 9 – Dispositif de mesure pour la vérification de la perte d'insertion des boîtiers de couplage dans la gamme de fréquences de 30 MHz à 150 MHz

7 Dispositifs de couplage pour la mesure des lignes de signaux

7.1 Généralités

Le potentiel de brouillage (et l'immunité) des lignes de signaux peut être évalué en mesurant (ou en injectant) la tension ou le courant perturbateur(trice) conduit(e). Des dispositifs de couplage sont donc nécessaires pour mesurer la perturbation tout en rejetant le signal utile présent sur la ligne. Les dispositifs considérés doivent mesurer l'émission et l'immunité électromagnétique (mode commun et mode différentiel, courant et tension). Avec ce genre de mesures, les dispositifs types sont les sondes de courant et les réseaux fictifs asymétriques (AAN ou réseau en Y).

NOTE 1 Les exigences applicables aux AAN en matière d'essais d'immunité conduits sur les lignes de signaux sont disponibles dans la CEI 61000-4-6 [les AAN constituent des versions spéciales des «dispositifs de couplage et de découplage», à savoir les réseaux de couplage/découplage (CDN)]. Un AAN qui respecte les exigences en matière de mesures d'émission peut également répondre aux exigences applicables aux essais d'immunité.

NOTE 2 Les lignes de signaux comprennent les lignes de télécommunications et les bornes des appareils destinés à y être connectés.

NOTE 3 Les termes «tension asymétrique» et «tension de mode commun», ainsi que «tension symétrique» et «tension de mode différentiel», sont synonymes, comme définis à l'Article 3.

NOTE 4 Le terme «réseau fictif asymétrique (AAN)» est utilisé comme synonyme de «réseau en Y», lequel est différent des réseaux en V et en D. Le réseau en T constitue une version spéciale du réseau en Y.

Lorsqu'une sonde de courant est utilisée et que la valeur limite est indiquée en volts, la valeur de la tension est divisée par l'impédance de la ligne de signaux ou par l'impédance de charge en vue d'obtenir la valeur limite en courant, conformément aux instructions de la procédure de mesure détaillée. Cette impédance peut être en mode commun, comme exigé par ladite procédure.

Les spécifications relatives aux AAN sont fournies en 7.2. La réjection de mode différentiel par rapport à celle de mode commun (V_{dm}/V_{cm}) est essentielle à l'utilisation d'un AAN. Ce paramètre est lié à l'affaiblissement de conversion longitudinal (ACL). L'Annexe E intègre des exemples d'AAN ainsi que les essais et les procédures d'étalonnage requis.

7.2 Exigences applicables aux AAN (ou réseaux en Y)

Les AAN sont utilisés pour mesurer (ou injecter) des tensions asymétriques (mode commun) sur des lignes de signal symétrique non blindées (par exemple de télécommunication) tout en rejetant le signal symétrique (mode différentiel).

Un AAN doit inclure les propriétés suivantes lorsqu'il est étalonné conformément aux méthodes de l'Annexe E. De plus, la distorsion d'affaiblissement ou autre détérioration ne doit pas affecter le fonctionnement normal de l'EUT.

- a) AAN pour les mesures aux accès prévus pour la connexion de câbles à paires symétriques non blindés de catégorie 6 (ou plus).

La variation de l'affaiblissement de conversion longitudinal (a_{ACL}) en fonction de la fréquence f (en MHz) doit être définie selon l'équation suivante:

$$a_{ACL} = 75 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right]$$

$$f < 2 \text{ MHz: } a_{ACL} \leq \pm 3 \text{ dB}$$

$$2 \text{ MHz} \leq f \leq 30 \text{ MHz: } a_{ACL} \leq \begin{matrix} +6 \\ -3 \end{matrix} \text{ dB}$$

- b) AAN pour les mesures aux accès prévus pour la connexion de câbles à paires symétriques non blindés de catégorie 5 (ou plus).

La variation de l'affaiblissement de conversion longitudinal (a_{ACL}) en fonction de la fréquence f (en MHz) doit être définie selon l'équation suivante:

$$a_{ACL} = 65 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right]$$

$$f < 2 \text{ MHz: } a_{ACL} \leq \pm 3 \text{ dB}$$

$$2 \text{ MHz} \leq f \leq 30 \text{ MHz: } a_{ACL} \leq \begin{matrix} +4,5 \\ -3 \end{matrix} \text{ dB}$$

- c) AAN pour les mesures aux accès prévus pour la connexion de câbles symétriques non blindés de catégorie 3 (ou plus).

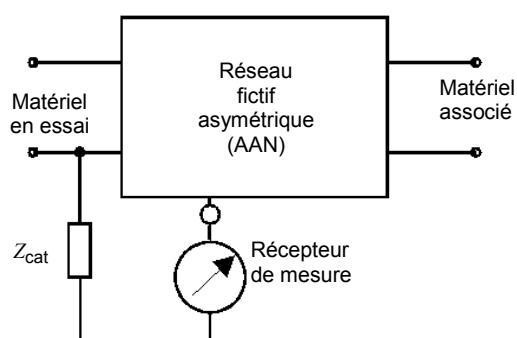
La variation de l'affaiblissement de conversion longitudinal (a_{ACL}) en fonction de la fréquence f (en MHz) doit être définie selon l'équation suivante:

$$a_{ACL} = 55 - 10 \lg \left[1 + \left(\frac{f}{5} \right)^2 \right] \text{ en dB}$$

$$a_{ACL} \leq \pm 3 \text{ dB}$$

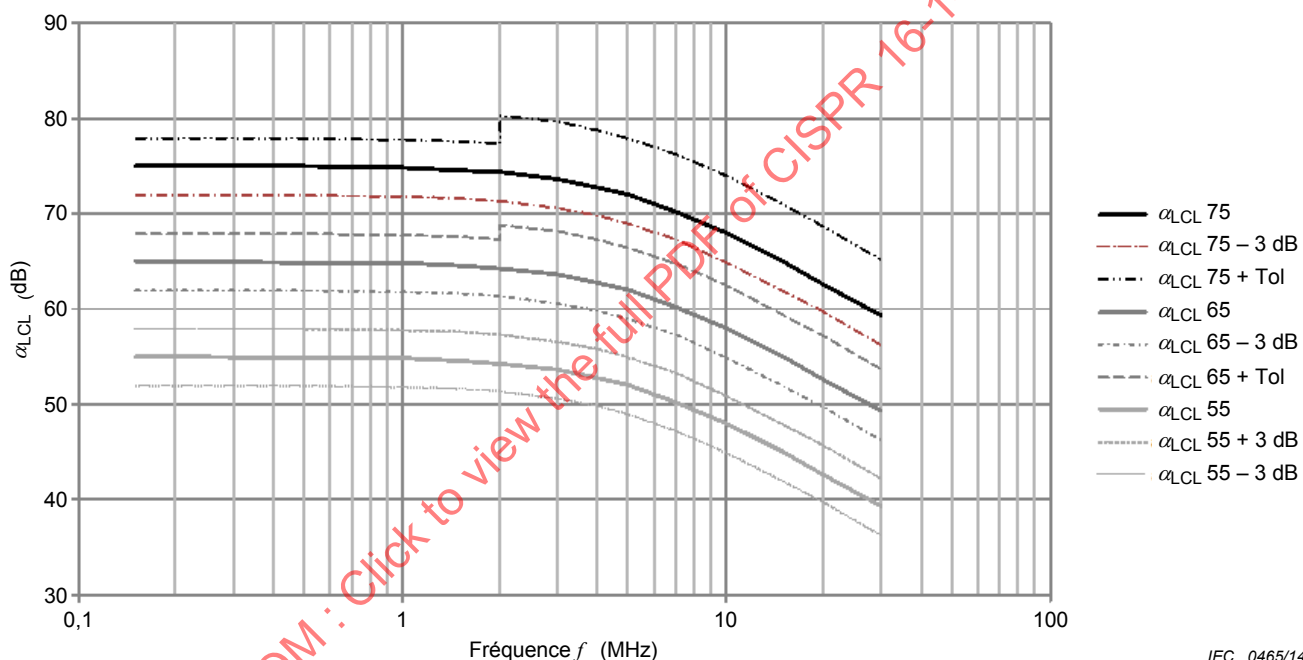
NOTE Les spécifications susmentionnées de a_{ACL} en fonction de la fréquence représentent des estimations de a_{ACL} pour des câbles symétriques non blindés standard utilisés dans des environnements représentatifs. La spécification spécifiée en 7.2 c) pour les câbles de catégorie 3 est considérée comme représentative de l'élément a_{ACL} pour les réseaux d'accès standard aux télécommunications.

La Figure 10 fournit le diagramme général du circuit ainsi qu'une représentation graphique des exigences a_{ACL} pour un AAN.



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a) Circuit principal de l'AAN (ou du réseau en Y) et de ses accès constitués d'un réseau de base hautement symétrique et d'un réseau non symétrique (facultatif) Z_{cat}



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NOTE 1 Ce graphique est obtenu à partir des équations décrites en 7.2 a), b) et c). Les lignes des valeurs idéales pour 55 dB, 65 dB et 75 dB sont présentées en gras alors que les valeurs de tolérance apparaissent de part et d'autre de ces dernières.

NOTE 2 «Tol» correspond à la tolérance indiquée en 7.2 a), b) et c).

b) Graphique des exigences applicables à l'élément a_{ACL} de l'AAN (ou au réseau en Y)

Figure 10 – Circuit principal et exigences en matière d'ACL d'AAN

Les caractéristiques de l'AAN en termes de mesure des perturbations asymétriques (mode commun) doivent couvrir la plage de fréquences correspondant à celle des tensions perturbatrices asymétriques et à celle transmettant le signal utile. Ces caractéristiques sont fournies au Tableau 5.

Tableau 5 – Caractéristiques de l'AAN pour la mesure de la tension perturbatrice asymétrique

1)	Impédance de charge du réseau de base pour la tension perturbatrice asymétrique ^a • amplitude • phase	150 $\Omega \pm 20 \Omega$ 0° $\pm 20^\circ$
2)	Affaiblissement de conversion longitudinale (ACL) au niveau de l'accès de l'EUT du réseau ^b	(9 kHz à 150 kHz: à définir); 0,15 MHz à 30 MHz: en fonction de la catégorie de câble définie en 7.2 ^c
3)	Affaiblissement de découplage pour signaux asymétriques entre l'accès de l'AE et celui de l'EUT	(9 kHz à 150 kHz: à définir); 0,15 MHz à 1,5 MHz: > 35 dB à 55 dB, augmentation linéaire avec le logarithme de fréquence > 1,5 MHz: > 55 dB
4)	Perte d'insertion du circuit symétrique entre l'accès de l'EUT et celui de l'AE	< 3 dB ^d
5)	Facteur de division en tension du circuit asymétrique entre l'accès de l'EUT et celui de du récepteur de mesure, à ajouter au relevé de ce dernier	Habituellement 9,5 dB ^e ± 1 dB
6)	Impédance de charge symétrique du réseau	Dépend des spécifications du système, par exemple 100 Ω ou 600 Ω . A définir en fonction des normes de produits applicables ^f
7)	Largeur de bande de transmission pour le signal utile (analogique ou numérique).	Dépend des spécifications du système en matière de perte d'insertion symétrique (par exemple jusqu'à 2 MHz ou jusqu'à 100 MHz). A définir en fonction des normes de produits applicables
8)	Plage de fréquences ^f (1) Emission (2) Immunité	(0,009 MHz) 0,15 MHz à 30 MHz Voir par exemple la CISPR 22 [5]

^a L'impédance asymétrique de l'AAN sera normalement influencée par l'ajout d'un réseau non symétrique Z_{cat} conformément à la Figure 10 a). La présente norme spécifie la tolérance d'impédance pour le réseau de base. Le réseau non symétrique pour les AAN définis en 7.2 a), b) et c) change nominalement l'impédance de moins de 10 Ω , et la phase de moins de 10°. La tolérance indiquée peut ainsi s'appliquer aux réseaux non symétriques. Si une norme de produit fait état de valeurs ACL inférieures (par exemple si le réseau non symétrique change nominalement l'impédance de plus de 10 Ω ou la phase de plus de 10°), celle-ci doit en tenir compte lors de la spécification des tolérances en matière d'impédance et de phase puisqu'il convient de laisser une certaine tolérance au constructeur de l'AAN.

^b Différents concepts sont adoptés en vue de déterminer la conformité de l'appareil: utilisation d'un ACL d'AAN plus élevé que les valeurs d'ACL disponibles pour les lignes de signaux ou utilisation de l'ACL afin de simuler les catégories de lignes de télécommunication disponibles. La CISPR a décidé d'utiliser l'ACL pour simuler l'asymétrie des catégories de câbles pour les essais d'émission, alors que le sous-comité 77B de la CEI recommande l'utilisation d'un ACL d'AAN plus élevé que la catégorie de câble pour les essais d'immunité.

^c En général, trois facteurs doivent être pris en compte pour déterminer les tolérances en matière d'ACL: l'ACL résiduel de l'AAN de base, la variation de Z_{cat} du réseau non symétrique par rapport à sa valeur nominale et l'incertitude de mesure de l'ACL. Il convient que les tolérances indiquées par une norme de produits qui s'écartent des valeurs définies en 7.2 tiennent compte du fait suivant: il convient que les valeurs acceptables augmentent avec l'ACL requis et avec la fréquence.

^d Les exigences réelles dépendront des spécifications du système de transmission. Certains d'entre eux autorisent des pertes d'insertion jusqu'à 6 dB. La perte d'insertion provoquée par un AAN dépend des impédances de source et de charge de l'ensemble du circuit symétrique. Pour les impédances plus faibles/élevées, la perte d'insertion sera plus petite/grande. Il convient qu'elle soit indiquée par le fabricant (par exemple pour une impédance de 100 Ω). De plus, il sera utile que les fabricants spécifient les caractéristiques de phase de l'AAN dans son circuit symétrique.

^e L'AAN doit être étalonné en mesurant le facteur de division en tension dans une configuration d'essai conformément à la Figure E.6.

^f Plusieurs réseaux peuvent être utilisés pour couvrir l'ensemble de la plage de fréquences.

7.3 Exigences relatives aux réseaux fictifs pour câbles coaxiaux et autres câbles blindés

Les réseaux fictifs (AN) pour câbles coaxiaux et autres câbles blindés sont utilisés pour mesurer (ou injecter) des tensions dissymétriques (mode commun) sur le blindage des câbles (de télécommunication ou RF par exemple) tout en transmettant le signal de télécommunication ou le signal RF. Les caractéristiques requises sont fournies au Tableau 6.

NOTE Dans la CISPR 22 [5], ce type de réseau est appelé réseau de stabilisation d'impédance (ISN) pour câble coaxial ou blindé.

Tableau 6 – Caractéristiques des réseaux fictifs pour câbles coaxiaux et autres câbles blindés

1)	Impédance de charge du réseau de base pour la tension perturbatrice dissymétrique ^a : • amplitude • phase	150 $\Omega \pm 20 \Omega$ 0° $\pm 20^\circ$
2)	Affaiblissement de découplage ^b pour signaux dissymétriques entre l'accès de l'AE et celui de l'EUT	(9 kHz à 150 kHz: à définir); 0,15 MHz à 30 MHz: > 40 dB
3)	Perte d'insertion et bande de transmission pour le signal utile (de communication ou RF) entre l'accès de l'EUT et celui de l'AE, impédance(s) caractéristique(s) comprises	Définies dans les exigences système ^c
4)	Facteur de division en tension du circuit dissymétrique entre l'accès de l'EUT et celui de du récepteur de mesure, à ajouter au relevé de ce dernier	En général < 9,5 dB ^d
5)	Plage de fréquences (1) Emission (2) Immunité	(0,009 MHz) 0,15 MHz à 30 MHz Voir par exemple la CEI 61000-4-6
^a L'impédance asymétrique de l'AN sera déterminée par la résistance de 150 Ω parallèle à la bobine d'arrêt et la capacité de la connexion de cloison avec la terre. ^b Étant donné que le blindage du câble coaxial au niveau de l'accès de l'AE est directement connecté au boîtier métallique de l'AN, l'affaiblissement de découplage ne constitue pas un problème pour l'AN. La configuration de l'essai d'émission (ou d'immunité) doit permettre de garantir un affaiblissement de découplage minimal. ^c La perte d'insertion et bande de transmission pour le signal utile (de communication ou RF) entre l'accès de l'EUT et celui de l'AE ainsi que les impédances caractéristiques entre le blindage et le(s) conducteur(s) interne(s) ne relèvent pas du domaine d'application de la présente norme. Il convient de les définir d'après les exigences système. ^d L'AN doit être étalonné en mesurant le facteur de division en tension dans une configuration d'essai conformément à la Figure F.2.		

8 Main fictive et élément RC série

8.1 Généralités

Dans certaines spécifications de produit, une main fictive est requise pour les EUT qui ne possèdent pas de mise à la terre connectée à ses parties métalliques, lesquelles sont habituellement en contact avec la main. Les boîtiers en plastique recouverts d'un revêtement conducteur peuvent également nécessiter l'utilisation d'une main fictive. Une main fictive est utilisée avec les essais d'émissions conduites dans la plage de fréquences qui s'étend de 150 kHz à 30 MHz (les fréquences les plus critiques étant comprises entre 5 MHz et 30 MHz) afin de simuler l'influence de la main de l'utilisateur sur les mesures. Les types d'appareils à évaluer avec la main fictive sont: les outils électriques, les appareils domestiques (tels que les mixeurs manuels), les combinés téléphoniques, les manettes de jeux, les claviers, etc.

8.2 Conception d'une main fictive et d'un élément RC en série

Une main fictive est constituée d'une feuille métallique (en bande) de dimensions précises, laquelle est placée sur (ou enroulée autour de) la partie de l'appareil normalement en contact avec la main de l'utilisateur selon le processus suivant.

La feuille métallique est connectée selon une configuration précise au point de référence du système de mesure de perturbation à travers un élément RC constitué d'un condensateur $C = 220 \text{ pF} \pm 20 \%$ en série avec une résistance $R = 510 \Omega \pm 10 \%$ (voir Figure 11 a).

Les bandes de feuille métallique utilisées en vue de simuler l'influence de la main de l'utilisateur autour de la poignée ou de la structure d'un appareil présentent habituellement une largeur de 60 mm. Avec un EUT à clavier, une feuille métallique (ou, plus pratique, une plaque métallique ne dépassant pas 100 mm par 300 mm) peut être placée au-dessus des touches. Des exemples sont fournis aux Figures 11 et 12.

La longueur du conducteur qui rallie l'élément RC et la feuille métallique doit être de 1 m. Lorsque la configuration d'essai impose une dimension supérieure, l'inductance totale du conducteur doit être inférieure à $1,4 \mu\text{H}$ lorsque la fréquence de mesure avoisine les 30 MHz.

Si l'on considère l'effet total des fils d'interconnexion comme celui d'un fil unique en espace libre, l'inductance L du fil doit être inférieure à $1,4 \mu\text{H}$ lorsque la limite supérieure de la plage de fréquences pour l'essai d'émission conduite est 30 MHz. Pour une longueur de fil spécifique, cette exigence permet de calculer le diamètre minimal d (en m) des fils à utiliser dans l'Équation (2):

$$L = \frac{\mu l}{2\pi} \left[\ln\left(\frac{4l}{d}\right) - 1 \right] \text{ H} \quad (2)$$

où

μ = $4\pi \times 10^{-7} \text{ H/m}$;

l est la longueur du fil, en m;

d est le diamètre du fil, en m.

NOTE Lorsque l'exigence relative à une inductance de $1,4 \mu\text{H}$ est satisfaite, l'impédance du réseau RC est suffisamment importante à 30 MHz.

8.3 Utilisation de la main fictive

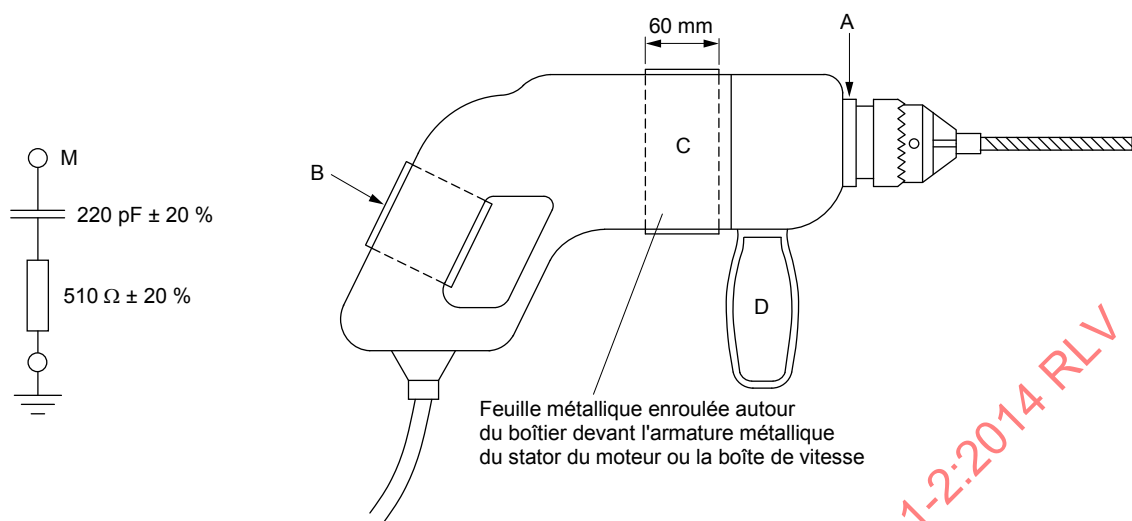
La longueur maximale du fil qui rallie l'élément RC et la terre de référence est généralement satisfaisante lorsque celle-ci ne dépasse pas 1 m. L'élément RC peut, par exemple, être positionné au plus près de la feuille métallique ou du point de référence. Le choix correct dépend en grande partie de l'impédance interne en mode commun (généralement inconnue) de la source de perturbation en présence de la feuille métallique et de l'impédance caractéristique de la ligne de transmission constituée du fil de connexion et de son environnement. Si la plage de fréquences supérieure pour les mesures d'émission est limitée à 30 MHz, la position de l'élément RC n'est pas critique et s'avère pratique (notamment en termes de reproductibilité) d'insérer ledit élément à l'AMN ou au RSIL.

Pour les mesures d'émission conduite réalisées au niveau de l'accès d'alimentation, le point de référence correspond à la terre de référence de l'AMN. Lorsque cette émission est relevée sur une ligne de signaux ou de commande, le point de référence correspond à la terre de référence de l'AN. Le principe général à respecter en matière d'utilisation d'une main fictive est le suivant: la borne M de l'élément RC doit être connectée à l'ensemble des parties métalliques exposées et non pivotantes, ainsi qu'à la feuille métallique enroulée autour des

poignées (fixes et amovibles) fournies avec l'appareil. Les parties métalliques couvertes de peinture ou de laque sont considérées comme des parties métalliques exposées et doivent être directement connectées à l'élément RC.

Les points suivants décrivent précisément l'utilisation d'une main fictive:

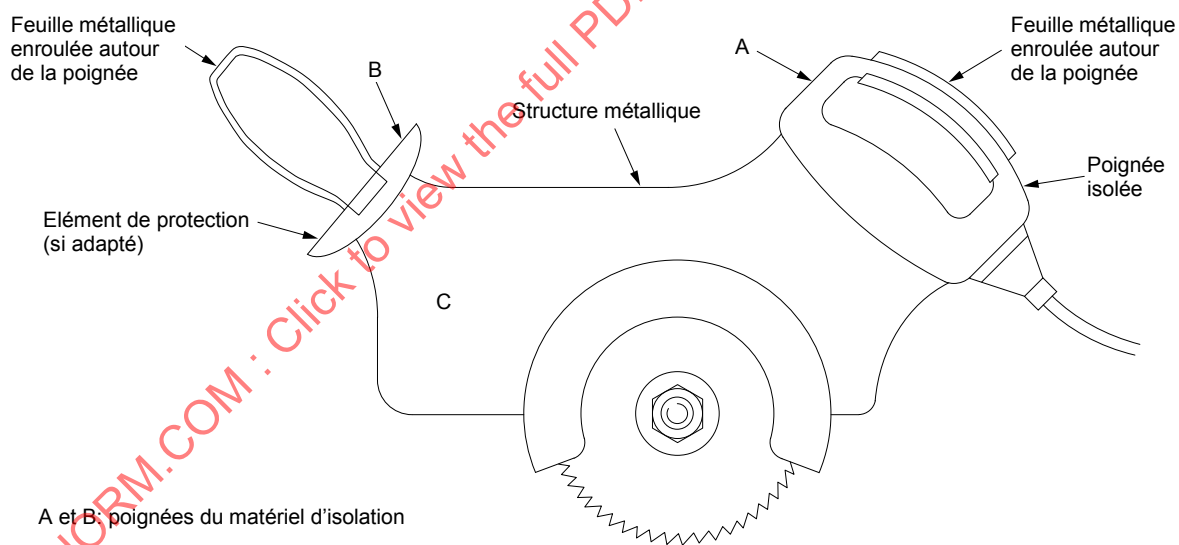
- a) Lorsque le boîtier de l'appareil est entièrement composé de métal et relié à la terre, une main fictive n'est pas nécessaire.
- b) Lorsque le boîtier de l'appareil est constitué de matériau isolant, la feuille métallique doit être enroulée autour de la poignée B [comme sur les Figures 11 b) et c)] et autour de la seconde poignée D, le cas échéant. Une feuille métallique d'une largeur de 60 mm doit également être enroulée autour de la structure C [comme sur les Figures 11 b) et c)], là où se situe l'armature métallique du stator du moteur, ou autour de la boîte de vitesse lorsque le niveau de perturbation de celle-ci est plus élevé. Toutes les parties de la feuille métallique, ainsi que les bagues/manchons métalliques A (le cas échéant), doivent être reliés entre eux et à la borne M de l'élément RC.
- c) Lorsque la composition du boîtier de l'appareil est en partie métallique et en partie isolant, et qu'il possède des poignées isolantes, la feuille métallique doit être enroulée autour des poignées B et D [comme sur la Figure 11 b)]. Si le boîtier n'est pas métallique au niveau du moteur, une feuille métallique d'une largeur de 60 mm doit être enroulée autour de la structure C, là où se situe l'armature métallique du stator du moteur, ou autour de la boîte de vitesse lorsque celle-ci est composée d'un matériau isolant et que son niveau de perturbation est plus élevé. La partie métallique de la structure, le point A, la feuille métallique autour des poignées B et D, ainsi que celle qui entoure la structure C doivent être reliés entre eux et à la borne M de l'élément RC.
- d) Lorsqu'un appareil de Classe II (c'est-à-dire à double isolation, sans câble de garde) possède deux poignées en matériau isolant A et B, et un boîtier en métal C [une scie électrique identique à celle de la Figure 11 c) par exemple], la feuille métallique doit être enroulée autour des poignées A et B. Celle-ci et la structure métallique C doivent être reliées entre elles et à la borne M de l'élément RC.
- e) La Figure 12 fournit un exemple de combiné téléphonique et de clavier. Pour le combiné téléphonique, une feuille d'une largeur de 60 mm est enroulée autour de la poignée et offre un certain recouvrement. Dans le cas d'un clavier, il convient que la feuille métallique ou la PCB (plaque de circuit imprimé, de l'anglais *Printed Circuit Board*) recouvre au maximum les touches. La plaque métallique doit être positionnée sur le clavier à l'aide de la PCB. En revanche, il n'est pas nécessaire qu'elle dépasse 300 mm par 100 mm.



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a) Élément RC

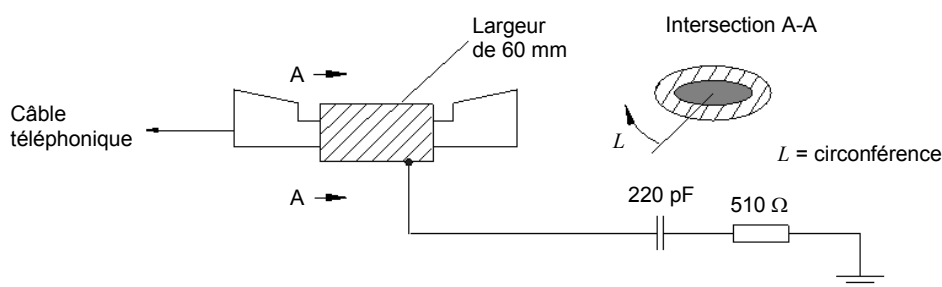
b) Perceuse électrique sans fil



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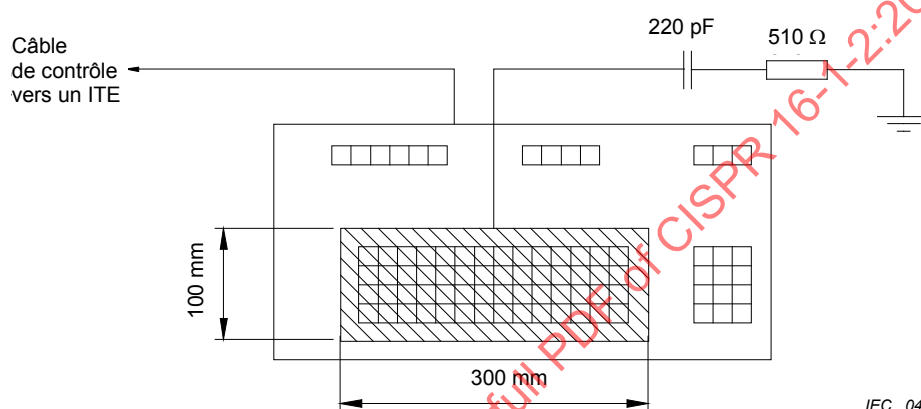
c) Scie électrique sans fil

Figure 11 – Utilisation d'une main fictive



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a) Utilisation d'une main fictive avec un combiné téléphonique



IEC 0469/14

b) Utilisation d'une main fictive avec un clavier standard

La main fictive comporte une feuille métallique présentant les dimensions suivantes:

a) largeur de 60 mm et longueur supérieure à L	pour les parties de l'appareil en contact avec la main lors du fonctionnement; quatre parties maximum pour chaque système en essai.
b) 300 mm par 100 mm	pour les claviers, les dimensions de la feuille métallique devant permettre de recouvrir l'ensemble des touches ou une partie du clavier lorsque celui-ci est supérieur à la taille maximale de la feuille.

Figure 12 – Exemples d'utilisation d'une main fictive avec un ITE

9 CDNE pour la mesure de la tension perturbatrice à une plage de fréquences comprises entre 30 MHz et 300 MHz

9.1 Instrumentation

9.1.1 Généralités

La méthode de mesure est décrite dans l'Article 9 de la CISPR 16-2-1:2014.

Ladite méthode utilise le matériel suivant:

- un CDNE- X et
- un RGP.

Les exigences techniques relatives à ces équipements sont décrites dans le présent paragraphe.

Le CDNE couple la tension perturbatrice asymétrique (mode commun) de l'EUT au niveau du conducteur d'entrée du récepteur de mesure, et découple cette dernière de toutes émissions ou influences présentes dans l'environnement d'essai. Toute perturbation symétrique (mode différentiel) provenant de l'EUT est chargée avec une impédance symétrique de $100\ \Omega$ au niveau des accès d'alimentation correspondants (CDNE-M2 et CDNE-M3) OU avec une charge symétrique au niveau des accès de l'AE d'un CDNE-S x (voir Annexe J). Le CDNE ne peut être utilisé pour réaliser des mesures sur des lignes d'alimentation transportant des signaux utiles symétriques (mode différentiel).

Le RGP sert de référence pour la tension perturbatrice asymétrique (mode commun).

9.1.2 Description de la mesure du CDNE

9.1.2.1 Domaine d'application

Le CDNE est destiné à la mesure des perturbations conduites dans la plage de fréquences comprises entre 30 MHz et 300 MHz d'un petit EUT électrique connecté avec un ou deux câbles. De plus, le CDNE peut être disposé entre l'EUT et l'AE pour découpler les perturbations asymétriques de ce dernier, et pour stabiliser l'impédance.

NOTE Un petit EUT électrique renvoie aux conditions spécifiées en 9.1 de la CISPR 16-2-1:2014.

9.1.2.2 Mesure de la tension perturbatrice

Le CDNE permet de mesurer la tension perturbatrice asymétrique V_{dis} générée par l'EUT sur le(s) câble(s) connecté(s). Cette mesure prend en compte les valeurs du récepteur de mesure V_{meas} et le facteur de division en tension F_{CDNE} . Le facteur de division en tension F_{CDNE} (en dB) comprend l'atténuateur interne a_{meas} d'au moins 6 dB, utilisé pour réduire l'incidence d'incertitude liée à l'écart entre le CDNE et le récepteur de mesure.

Le résultat de la mesure est calculé comme suit:

$$V_{\text{dis}} = V_{\text{meas}} + F_{\text{CDNE}} \text{ en dB}(\mu\text{V}) \quad (3)$$

9.1.2.3 Impédance de charge du CDNE

L'impédance de charge de l'EUT au niveau du point de connexion est généralement inconnue. C'est pourquoi la lecture comme la reproductibilité des résultats de mesure dépendent fortement de l'impédance de charge du CDNE. L'impédance de la charge asymétrique (mode commun) a été fixée à $150\ \Omega$ de manière à obtenir une incidence d'incertitude optimale à partir de la méthode d'essai établie.

Le CDNE-M2 et le CDNE-M3 dédiés aux accès d'alimentation de l'EUT fournissent une impédance symétrique de $100\ \Omega$, laquelle est représentative de celle de la plupart des réseaux d'alimentation en courant alternatif.

9.1.2.4 Affaiblissement de découplage du CDNE

L'impédance inconnue de l'AE et toute émission correspondante peut influencer le résultat de mesure. Une telle influence peut être réduite à l'aide d'un affaiblissement asymétrique entre

l'accès de l'AE et celui de l'EUT. En général, cet affaiblissement asymétrique est réalisé avec une bobine d'arrêt.

9.1.3 Description du RGP

Le RGP sert de référence pour la tension perturbatrice asymétrique mesurée. Pour des raisons de sécurité à la fois personnelle et matérielle, la configuration apparaît sur le RGP connecté à la terre de protection. Le CDNE est placé en contact direct avec ledit plan (grâce à une liaison électrique adaptée) afin d'en garantir la conformité aux spécifications relatives à l'impédance asymétrique. L'EUT est installé à une distance définie au-dessus du RGP.

9.2 Exigences techniques relatives au CDNE-X

9.2.1 Paramètres mécaniques et électriques

Le CDNE est contenu dans une enveloppe métallique. Le centre de l'accès de l'EUT du CDNE se situe à 30 mm^{+10}_0 mm au-dessus du RGP. En général, cette hauteur permet une impédance de 150Ω pour le câble connecté.

Les Figures de l'Annexe J fournissent des exemples de conception de CDNE à titre informatif.

Le Tableau 7 décrit les paramètres électriques et leurs spécifications dans la plage de fréquences comprises entre 30 MHz et 300 MHz.

Tableau 7 – Paramètres électriques du CDNE-X

Paramètre	Valeurs pour CDNE-M2 et CDNE-M3	Valeur pour CDNE-Sx
Impédance asymétrique (mode commun) Z_{CM} au niveau de l'accès de l'EUT	$150 \Omega^{+10}_{-20}$ Angle de phase: $0^\circ \pm 25^\circ$	$150 \Omega^{+10}_{-20}$ Angle de phase: $0^\circ \pm 25^\circ$
Impédance symétrique (mode différentiel) Z_{DM} au niveau de l'accès de l'EUT	$100 \Omega \pm 20 \Omega$	Non défini
Affaiblissement de conversion longitudinal (ACL)	$\geq 20 \text{ dB}$	Non défini
Tolérance du facteur de division en tension F_{CDNE} incluant a_{meas}	$\pm 1,5 \text{ dB}$	$\pm 1,5 \text{ dB}$
Affaiblissement de découplage a_{decoup}	$> 30 \text{ dB}$	$> 30 \text{ dB}$

En général, le niveau de tension asymétrique est supérieur au niveau de tension symétrique non intentionnelle. 20 dB constitue donc une valeur minimale appropriée pour l'ACL en vue d'éviter toute influence de la tension symétrique sur les résultats des mesures. En revanche, l'évaluation de l'EUT en mode différentiel pour la communication avec des conducteurs non blindés nécessite des valeurs d'ACL spécifiques (minimale et maximale) pour le CDNE.

NOTE 1 Avec l'accès de l'EUT du CDNE-M3, la valeur minimale d'ACL n'est pas définie pour L et PE, ni pour N et PE.

NOTE 2 Des mesures d'ACL reproductibles supérieures à 100 MHz sont à l'étude.

NOTE 3 Le CDNE ne peut être utilisé sur un réseau d'alimentation avec des signaux utiles en mode différentiel (lorsque la transmission d'un signal différentiel désiré pourrait nécessiter des valeurs minimale et maximale d'ACL spécifiques par exemple) afin de prendre en compte la qualité du réseau.

L'affaiblissement a_{meas} au niveau de l'accès du récepteur permet de réduire l'incidence d'incertitude liée à l'écart entre le CDNE et le récepteur de mesure. De préférence, cet affaiblissement est un composant interne du CDNE. Lorsqu'un atténuateur externe est utilisé, il doit être directement monté sur l'accès du récepteur du CDNE, et être pris en compte lors

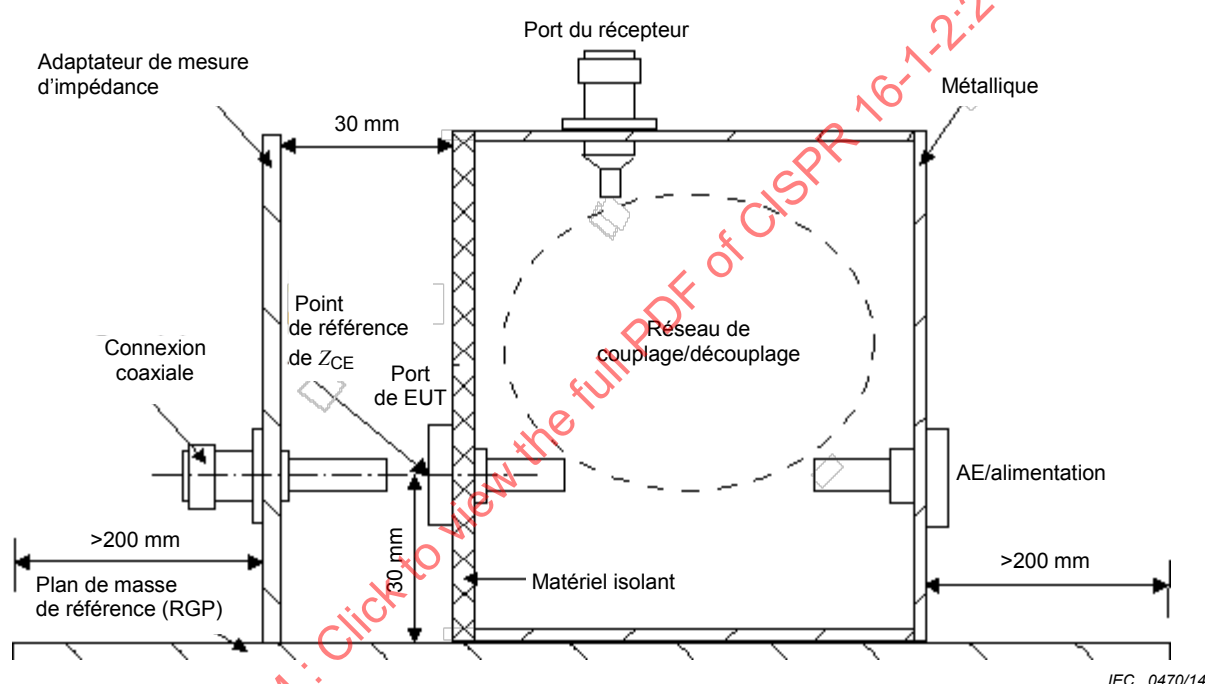
de l'étalonnage et des mesures. Il convient que l'affaiblissement de a_{meas} soit d'au moins 6 dB.

9.2.2 Validation du CDNE

9.2.2.1 Exigences générales

Pour les mesures de validation, le CDNE doit être monté sur un RGP, lequel est connecté à son enveloppe.

Toutes les mesures de la tension asymétrique font référence à ce RGP. L'installation de mesure doit être conforme à la Figure 7 de l'Article 10 de la CEI 61000-4-6:2008, lequel est représenté en Figure 13 avec un point de référence Z_{CE} différent en face de chaque accès de l'EUT.



NOTE «AE/alimentation» peut désigner une alimentation alternative, une alimentation continue ou encore des lignes de commande/communication.

Figure 13 – Installation pour la validation d'un CDNE

9.2.2.2 Étalonnage de l'analyseur de réseau (NWA) au niveau du point de référence

Pour mesurer l'impédance asymétrique au point de référence Z_{CE} de la Figure 13, la procédure d'étalonnage suivante doit être appliquée:

L'effet du câble de mesure (entre l'IMA et le NWA) est pris en compte dans l'étalonnage du NWA à partir de la méthode de correction des erreurs OPEN (ouverture), SHORT (court-circuit) et MATCH (correspondance). L'étape suivante implique la connexion de l'IMA avec le câble précédemment étalonné d'après le NWA. L'autre partie de l'IMA doit être dotée d'une plaque de connexion comprenant toutes les sections de l'adaptateur qui se trouvent entre l'IMA et le CDNE au cours de la mesure de l'impédance asymétrique et de l'angle de phase (voir Figure 14). Toutes les parties qui seront insérées dans les connecteurs du CDNE sont exclues. Cette installation prend en compte la charge électrique entre le câble étalonné et le point de mesure à l'entrée du CDNE.

La longueur électrique doit être corrigée selon un délai, lequel peut être ajusté automatiquement ou manuellement selon le matériel de mesure utilisé.