มาตรฐานผลิตภัณฑ์อุตสาหกรรม

THAI INDUSTRIAL STANDARD

มอก. 1441 เล่ม 2–2548

CISPR 16–1–2(2004–06)

ข้อกำหนดสำหรับอุปกรณ์และวิธีการวัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน

เล่ม 1–2 อุปกรณ์วัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน – บริภัณฑ์ช่วย – สัญญาณรบกวนที่นำตามสาย

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS–

PART 1–2 : RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS – ANCILLARY EQUIPMENT – COMDUCTED DISTRUBANCES

สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

กระทรวงอุตสาหกรรม

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สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

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ประกาศในราชกิจจานุเบกษา ฉบับประกาศและงานทั่วไป เล่ม 123 ตอนที่ 60ง

วันที่ 22 มิถุนายน พุทธศักราช 2549

บริภัณฑ์ไฟฟ้าและอิเล็กทรอนิกส์ ตลอดจนบริภัณฑ์เทคโนโลยีสารสนเทศในขณะใช้งานจะต้องไม่ส่งสัญญาณรบกวนเข้าสู่ระบบไฟฟ้าหรือรบกวนการทำงานของบริภัณฑ์ข้างเคียง รวมทั้งตัวบริภัณฑ์เองก็ต้องมีภูมิคุ้มกันในระดับเพียงพอที่จะทำงานในสภาวะแวดล้อมทางแม่เหล็กไฟฟ้าในระดับหนึ่งได้ จึงกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม ข้อกำหนดสำหรับอุปกรณ์และวิธีการวัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน เล่ม 1-2 อุปกรณ์วัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน - บริภัณฑ์ช่วย - สัญญาณรบกวนที่นำตามสาย ขึ้น

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นโดยรับ CISPR 16-1-2(2004-06) Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-2 : Radio disturbance and immunity measuring apparatus - Ancillary equipment - Conducted disturbances มาใช้ในระดับเหมือนกันทุกประการ(identical) โดยใช้ CISPR ฉบับ ภาษาอังกฤษเป็นหลัก

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นเพื่อใช้ในการอ้างอิง และเพื่อให้ทันกับความต้องการของผู้ใช้มาตรฐาน ซึ่งจะได้แปลเป็นภาษาไทยในโอกาสอันสมควรต่อไป หากมีข้อสงสัยโปรดติดต่อสอบถามสำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

คณะกรรมการมาตรฐานผลิตภัณฑ์อุตสาหกรรมได้พิจารณามาตรฐานนี้แล้ว เห็นสมควรเสนอรัฐมนตรีประกาศตามมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511

ประกาศกระทรวงอุตสาหกรรม

ฉบับที่ 3467 (พ.ศ. 2549)

ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม

พ.ศ. 2511

เรื่อง กำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม

ข้อกำหนดสำหรับอุปกรณ์และวิธีการวัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน

เล่ม 1-2 อุปกรณ์วัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน-

บริภัณฑ์ช่วย-สัญญาณรบกวนที่นำตามสาย

อาศัยอำนาจตามความในมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511 รัฐมนตรีว่าการกระทรวงอุตสาหกรรมออกประกาศกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม ข้อกำหนดสำหรับอุปกรณ์และวิธีการวัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน เล่ม 1-2อุปกรณ์วัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน-บริภัณฑ์ช่วย-สัญญาณรบกวนที่นำตามสาย มาตรฐานเลขที่ มอก. 1441 เล่ม 2-2548 ไว้ ดังมีรายละเอียดต่อท้ายประกาศนี้

ประกาศ ณ วันที่ 8 กุมภาพันธ์ พ.ศ. 2549

สุริยะ จึงรุ่งเรืองกิจ

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

มาตรฐานผลิตภัณฑ์อุตสาหกรรม
ข้อกำหนดสำหรับอุปกรณ์และวิธีการวัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน
เล่ม 1-2 อุปกรณ์วัดสัญญาณรบกวนวิทยุและภูมิคุ้มกัน - บริภัณฑ์ช่วย - สัญญาณรบกวนที่นำตามสาย

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มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้ได้รับการระบุให้เป็นมาตรฐานพื้นฐาน ซึ่งกำหนดลักษณะเฉพาะและสมรรถนะของบริภัณฑ์สำหรับวัดแรงดันไฟฟ้ารบกวนวิทยุ และกระแสไฟฟ้ารบกวนวิทยุ ในพิสัยความถี่ 9 กิโลเฮิรตซ์ ถึง 1 จิกะเฮิรตซ์

ข้อกำหนดสำหรับเครื่องสำเร็จช่วยถูกรวมไว้สำหรับ : โครงข่ายแหล่งจ่ายกำลังไฟฟ้าประธานเทียม โพรบกระแส โพรบแรงดัน และหน่วยเชื่อมต่อสำหรับป้อนกระแสเข้าสายเคเบิล

คุณลักษณะที่ต้องการตามมาตรฐานเล่มนี้ต้องเป็นไปตามที่กำหนดที่ทุกความถี่และทุกระดับแรงดันไฟฟ้ารบกวนวิทยุ และกระแสไฟฟ้ารบกวนวิทยุ ภายในพิสัยแสดงค่าของบริภัณฑ์วัด

วิธีการวัดครอบคลุมโดยเล่ม 2 และสารสนเทศเพิ่มเติมเกี่ยวกับสัญญาณรบกวนวิทยุให้ไว้ในเล่ม 3

รายละเอียดให้เป็นไปตาม CISPR 16-1-2(2004 - 06)

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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

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard CISPR 16-1-2 has been prepared by CISPR subcommittee A: Radio interference measurements and statistical methods.

This consolidated version of CISPR 16-1-2 is based on the first edition (2003) and its amendment 1 (2004) [documents CIS/A/503/FDIS and CIS/A/521/RVD].

It bears the edition number 1.1.

A vertical line in the margin shows where the base publication has been modified by amendment 1.

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

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the maintenance result 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.

INTRODUCTION

CISPR 16-1, CISPR 16-2, CISPR 16-3 and CISPR 16-4 have been reorganised into 14 parts, to accommodate growth and easier maintenance. The new parts have also been renumbered. See the list given below.

Old CISPR 16 publications		New CISPR 16 publications	
CISPR 16-1	Radio disturbance and immunity measuring apparatus	CISPR 16-1-1	Measuring apparatus
		CISPR 16-1-2	Ancillary equipment – Conducted disturbances
		CISPR 16-1-3	Ancillary equipment – Disturbance power
		CISPR 16-1-4	Ancillary equipment – Radiated disturbances
		CISPR 16-1-5	Antenna calibration test sites for 30 MHz to 1 000 MHz
CISPR 16-2	Methods of measurement of disturbances and immunity	CISPR 16-2-1	Conducted disturbance measurements
		CISPR 16-2-2	Measurement of disturbance power
		CISPR 16-2-3	Radiated disturbance measurements
		CISPR 16-2-4	Immunity measurements
CISPR 16-3	Reports and recommendations of CISPR	CISPR 16-3	CISPR technical reports
		CISPR 16-4-1	Uncertainties in standardised EMC tests
		CISPR 16-4-3	Statistical considerations in the determination of EMC compliance of mass-produced products
		CISPR 16-4-4	Statistics of complaints and a model for the calculation of limits
CISPR 16-4	Uncertainty in EMC measurements	CISPR 16-4-2	Measurement instrumentation uncertainty

More specific information on the relation between the 'old' CISPR 16-1 and the present 'new' CISPR 16-1-2 is given in the table after this introduction (TABLE RECAPITULATING CROSS REFERENCES).

Measurement instrumentation specifications are given in five new parts of CISPR 16-1, while the methods of measurement are covered now in four new parts of CISPR 16-2. Various reports with further information and background on CISPR and radio disturbances in general are given in CISPR 16-3. CISPR 16-4 contains information related to uncertainties, statistics and limit modelling.

CISPR 16-1 consists of the following parts, under the general title *Specification for radio disturbance and immunity measuring apparatus and methods – Radio disturbance and immunity measuring apparatus:*

- Part 1-1: Measuring apparatus,
- Part 1-2: Ancillary equipment – Conducted disturbances,
- Part 1-3: Ancillary equipment – Disturbance power,
- Part 1-4: Ancillary equipment – Radiated disturbances,
- Part 1-5: Antenna calibration test sites for 30 MHz to 1 000 MHz.

TABLE RECAPITULATING CROSS-REFERENCES

Second edition of CISPR 16-1	First edition of CISPR 16-1-2
Clauses, subclauses	**Clauses, subclauses**
2	2
3.8, …, 3.10	3.1, …, 3.3
3.20, .., 3.23	3.4, …, 3.7
5.1	4
5.2	5
5.8	6
5.10	7
5.11	8
Annexes	**Annexes**
F	A
I	B
M	C
N	D
Q	E
Z	F
Tables	**Tables**
18, 22	1, 2
Figures	**Figures**
7, 8, 9, 23, 24	1, 2, 3, 4, 5
10, 20, 52, 53, 54	6, 7, 8, 9, 10
25, …, 29	A.1, …, A.5
F.1	A.6
30, …, 37	B.1, …, B.8
44, …, 48	C.1, …, C.5
49, 50	D.1, D.2
Q.1, …, Q.6	E.1, …, E.6

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 1-2: Radio disturbance and immunity measuring apparatus – Ancillary equipment – Conducted disturbances

1 Scope

This part of CISPR 16 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.

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

The requirements of this publication shall be complied with 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 Part 2, and further information on radio disturbance is given in Part 3 of CISPR 16.

2 Normative references

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

CISPR 14-1:2000, *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 1: Emission*

CISPR 16-1-1:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-2-1:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of immunity and disturbance – 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, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainties*

IEC 60050(161):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

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

3 Definitions

For the purpose of this part of CISPR 16, the following definitions apply. Also see IEC 60050 (161).

3.1
symmetric voltage
in a two-wire circuit, such as a single-phase mains supply, the symmetric voltage is the radio-frequency disturbance voltage appearing between the two wires. This is sometimes called the differential mode voltage. If *Va* is the vector voltage between one of the mains terminals and earth and *Vb* is the vector voltage between the other mains terminal and earth, the symmetric voltage is the vector difference (*Va*-*Vb*)

3.2
asymmetric voltage
the asymmetric voltage is the radio-frequency disturbance voltage appearing between the electrical mid-point of the mains terminals and earth. It is sometimes called the common mode voltage and is half the vector sum of *Va* and *Vb*, i.e., (*Va* + *Vb*)/2

3.3
unsymmetric voltage
the amplitude of the vector voltage, *Va* or *Vb* defined in 3.1 and 3.2. This is the voltage measured by the use of an artificial mains V-network

3.4
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 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

3.6
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

3.7
longitudinal conversion loss (LCL)
in a one- or two-port network, a measure (a ratio expressed in dB) 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
(definition from ITU-T Recommendation O.9[1)])

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1) ITU-T Recommendation O.9, *Measuring arrangements to assess the degree of unbalance about earth*.

4 Artificial mains networks

An artificial mains network is required to provide a defined impedance at radio frequencies at the terminals of the equipment under test, 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 artificial mains networks, the V-network which couples the unsymmetric voltages, and the delta-network 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 equipment under test, and the disturbance output terminal for connection to the measuring equipment.

NOTE Examples of circuits of artificial mains networks are given in annex A.

4.1 Network impedance

The impedance of an artificial mains network is the magnitude of the impedance with respect to reference earth measured at an equipment terminal when the corresponding disturbance output terminal is terminated with 50 Ω.

The impedance at the equipment terminals of the artificial mains network defines the termination impedance presented to the equipment under test. For this reason, when a disturbance output terminal is not connected to the measuring receiver, it shall be terminated by 50 Ω.

The impedance of each of the mains conductors of the network shall comply with 4.2, 4.3, 4.4, 4.5 or 4.6 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 earth. 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.

4.2 50 Ω/50 μH + 5 Ω artificial mains V-network (for use in the frequency range 9 kHz to 150 kHz)

The network shall have the impedance versus frequency characteristic shown in figure 1a in the relevant frequency range. A tolerance of ±20 % is permitted.

NOTE This network may be constructed such that it can meet the combined impedance requirements of this subclause and 4.3.

4.3 50 Ω/50 μH artificial mains V-network (for use in the frequency range 0,15 MHz to 30 MHz)

The network shall have the impedance versus frequency characteristic shown in figure 1b in the relevant frequency range. A tolerance of ±20 % is permitted.

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

4.4 50 Ω/5 μH + 1 Ω artificial mains V-network (for use in the frequency range 150 kHz to 100 MHz)

The network shall have the impedance versus frequency characteristic shown in figure 2. A tolerance of ±20 % is permitted.

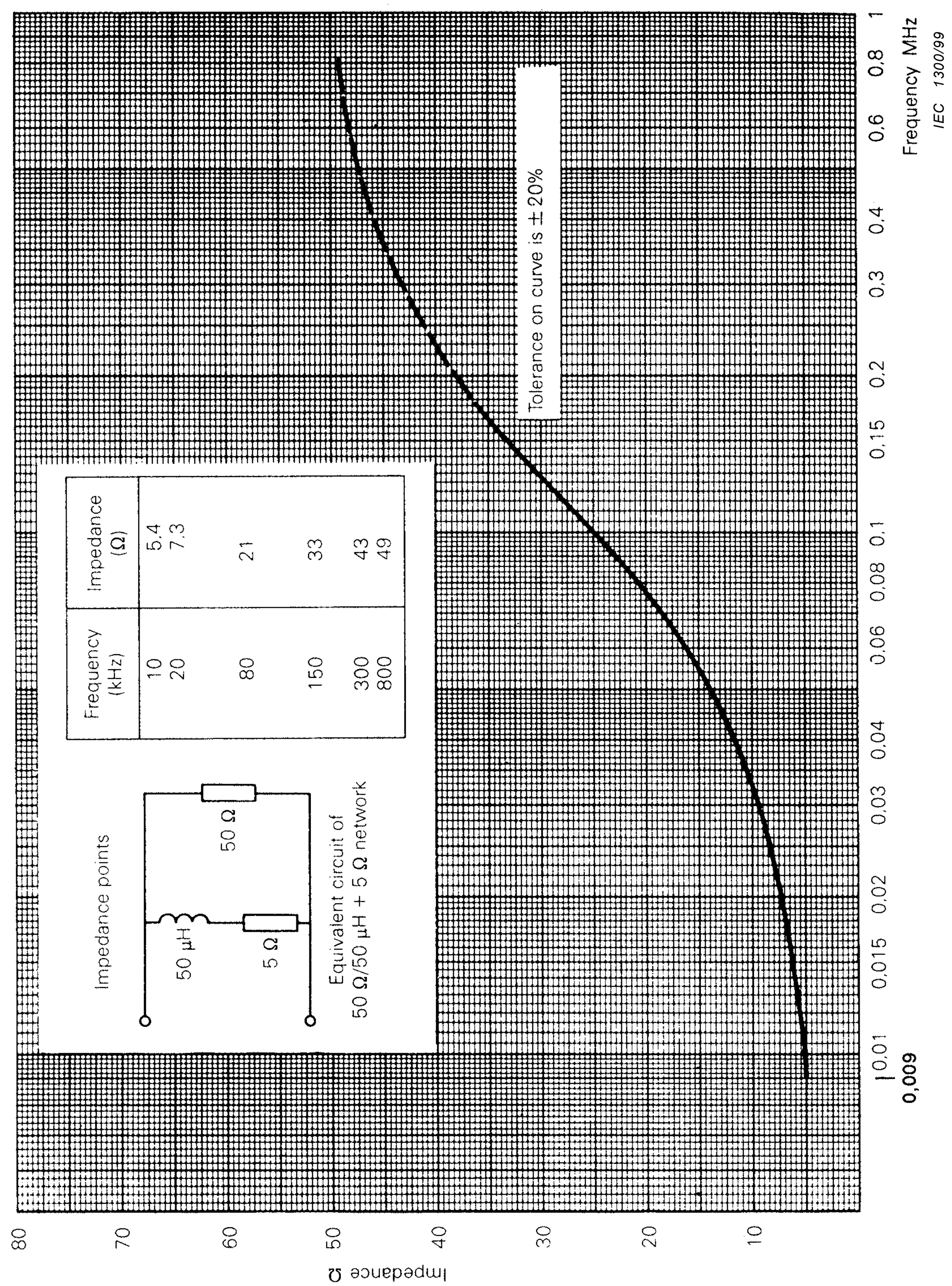


Figure 1a – Impedance of artificial mains network for band A (see 4.2)

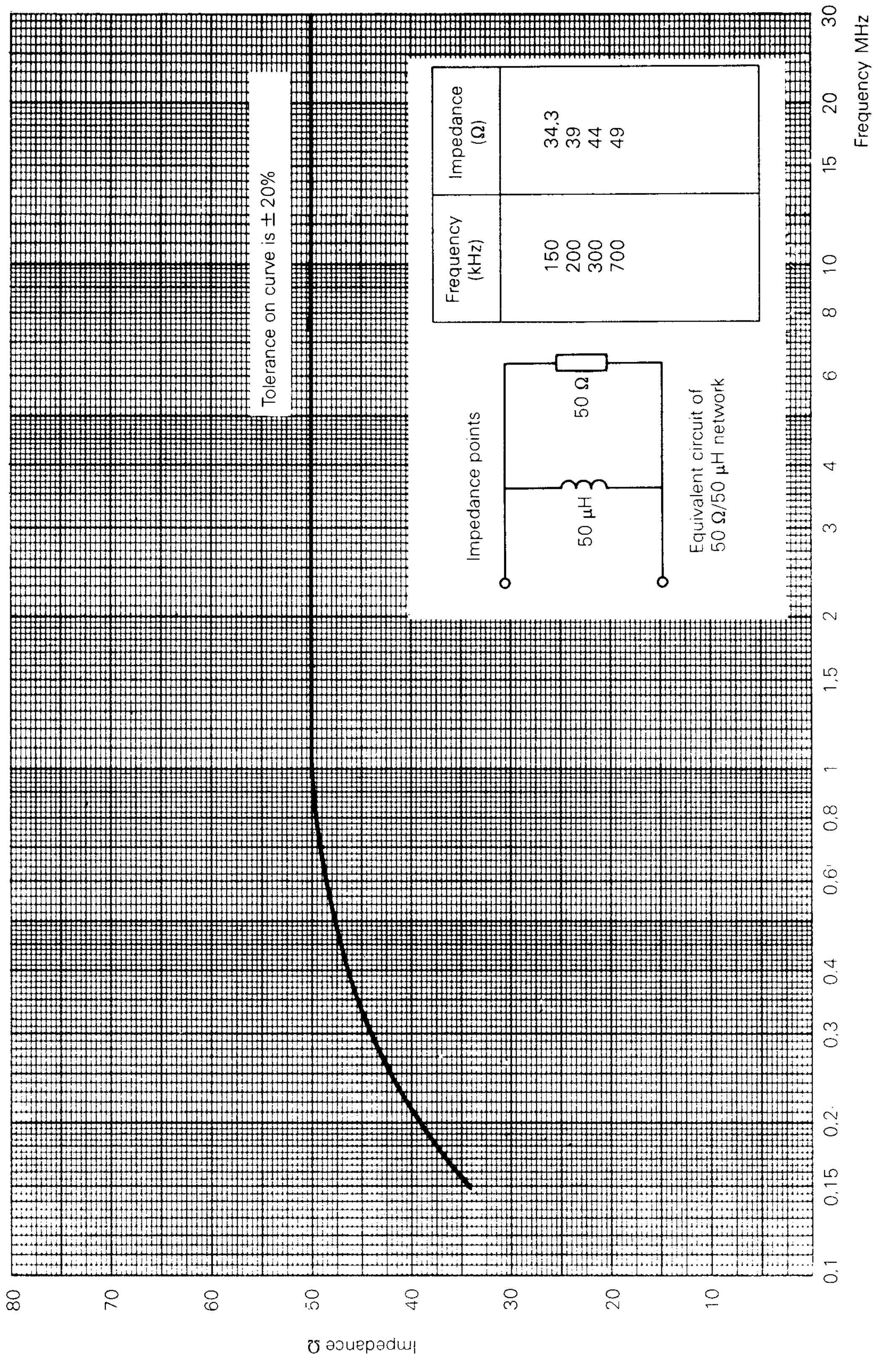


Figure 1b – Impedance of artificial mains network for band B (see 4.3)

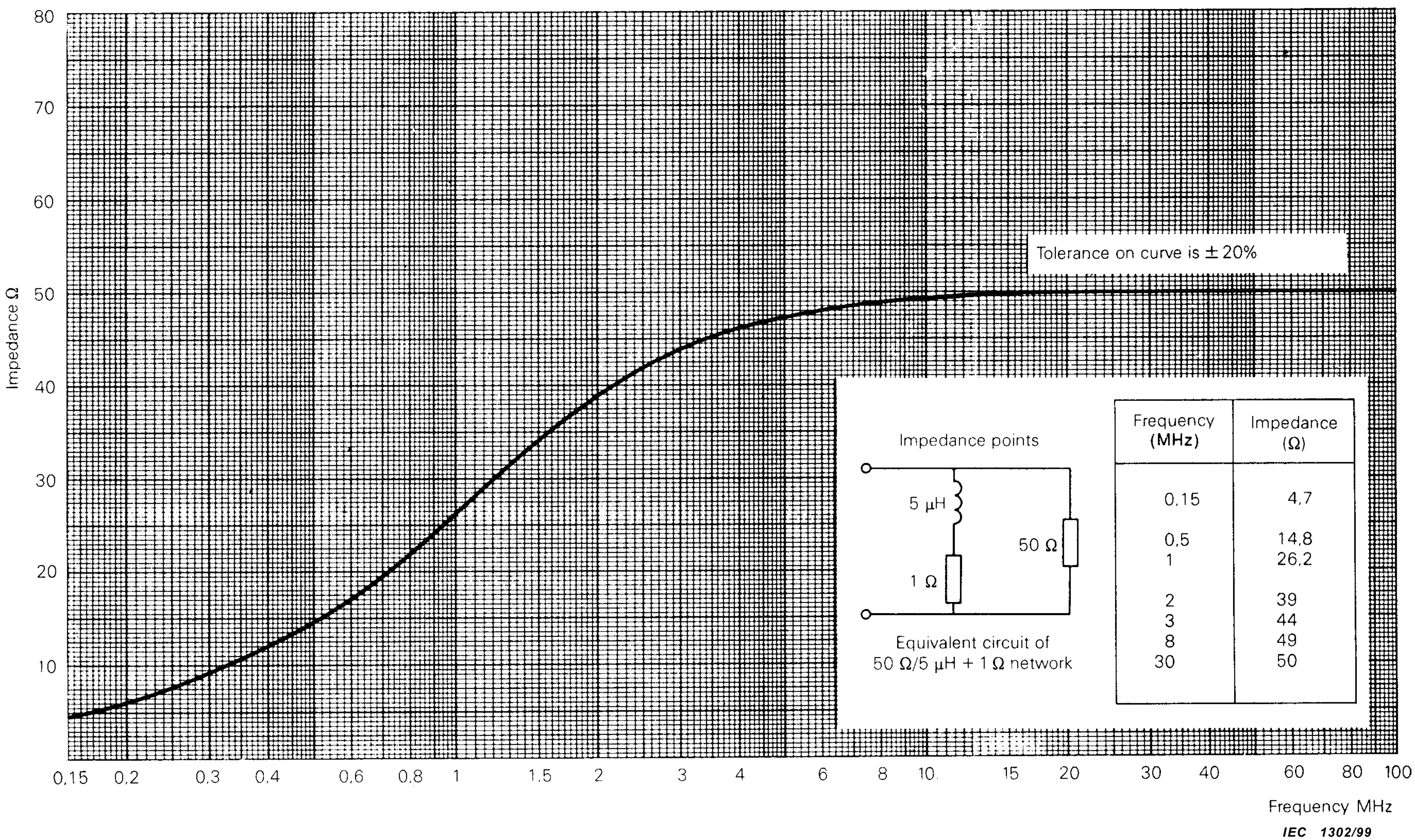


Figure 2 – Impedance of artificial mains network for band B, 0,15 MHz to 30 MHz or band C, 30 MHz to 100 MHz (see 4.4)

4.5 150 Ω artificial mains V-network (for use in the frequency range 150 kHz to 30 MHz)

The network shall have an impedance of magnitude 150 ± 20 Ω with a phase angle not exceeding 20°.

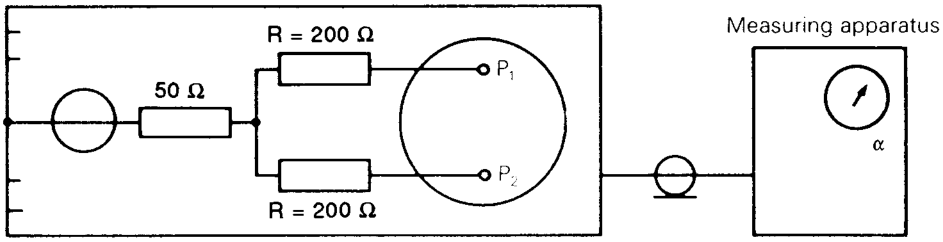
4.6 150 Ω artificial mains delta-network (for use in the frequency range 150 kHz to 30 MHz)

The network shall have an impedance of magnitude 150 ± 20 Ω with a phase angle not exceeding 20°, both between the equipment terminals and between the two equipment terminals joined together and reference earth.

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 Ω 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.

4.6.1 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 3.



R are the resistors of 200 Ω equal to each other within 1 %

P_1 P_2 are the terminals of network for connection of device

Figure 3 – 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 Ω, between reference earth and the common point of two resistors each 200 Ω ± 1 %. The other end of these resistors is connected to the equipment terminals of the artificial mains network.

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).

4.7 Isolation

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.

4.8 Current carrying capacity and series voltage drop

The maximum continuous currents and the maximum peak current shall be specified. The voltage applied to the equipment under test when passing continuous currents up to the maximum shall be not less than 95 % of the mains voltage at the mains terminals of the artificial mains network.

4.9 Modified reference earth connection

The measurement of some types of equipment may require the insertion of an impedance in the reference earth conductor in the artificial mains networks in 4.2 and 4.3 following the requirements of the related product publications. This is inserted at point X marked in the reference earth lead in figures 4 and 5, respectively. The impedance to be inserted is either a 1,6 mH inductor or an impedance conforming to the impedance requirement of 4.2 or 4.3, as appropriate for the frequency range.

NOTE For safety reasons, the 5 Ω resistor mentioned in 4.2 should be omitted.

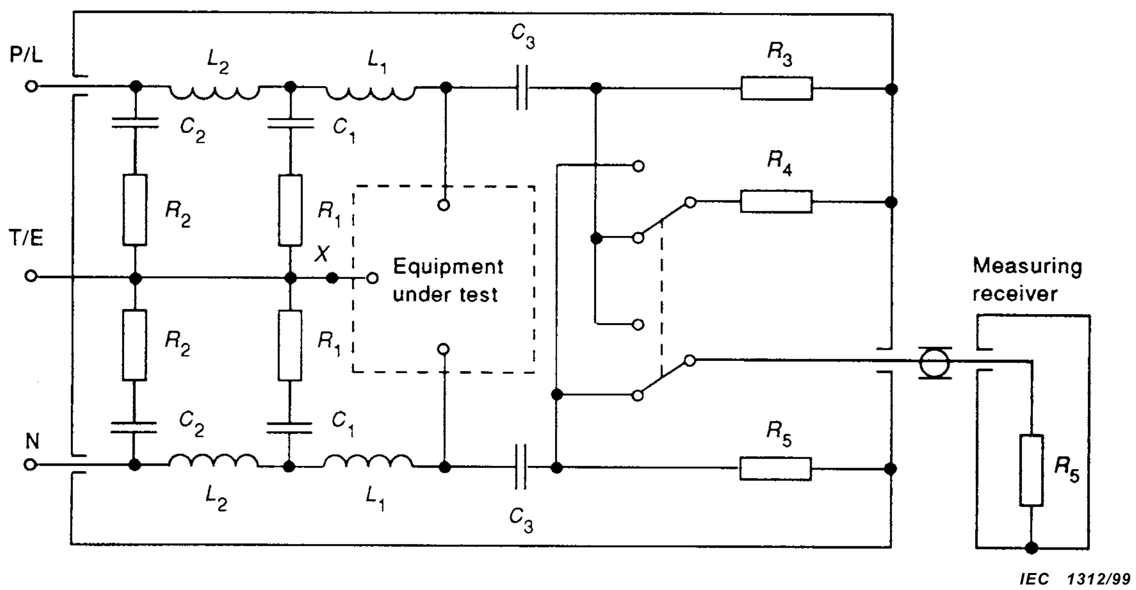


Figure 4 – Example of artificial mains 50 Ω/50 μH + 5 Ω V-network (see 4.2 and clause A.2)

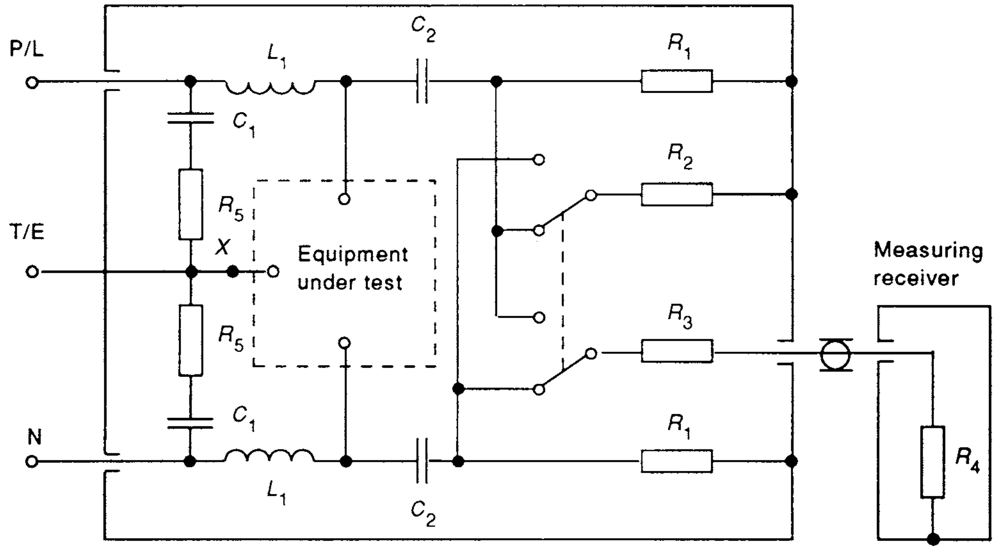


Figure 5 – Example of artificial mains V-networks, 50 Ω/50 µH, 50 Ω/5 µH + 1 Ω or 150 Ω (see 4.3, 4.4, 4.5 and clauses A.3, A.4 and A.5, respectively)

4.10 Calibration 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 clause A.8.

5 Current and voltage probes

5.1 Current probes

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. Clause B.5 of annex B contains some construction details.

5.1.1 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.

5.1.2 Characteristics

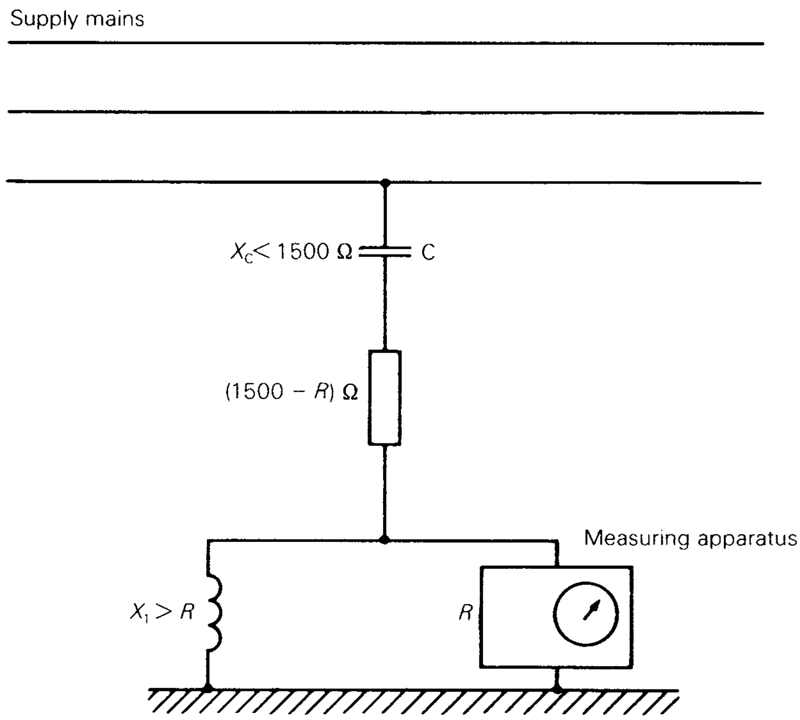
Insertion impedance	1 Ω impedance maximum
Transfer impedance*	0,1 to 5 Ω in the flat linear range; 0,001 to 0,1 Ω below the flat linear range (current probe terminated into 50 Ω)
Added shunt capacitance	Less than 25 pF between the current probe housing and measured conductor
Frequency response	Transfer impedance is calibrated over a specified frequency range; 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 carry ing 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 6 shows a circuit which is used to make voltage measurements between a mains conductor and reference ground. The probe consists of a blocking capacitor C and a resistor such that the total resistance between line and earth 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 be much greater than R.

* The reciprocal transfer admittance, (in dB(S)), may 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. See annex B.



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

where

V is the disturbing voltage

U is the voltage at the input of the measuring apparatus

Figure 6 – Circuit for RF voltage measurement on supply mains (see 5.2.1)

The insertion loss of voltage probes shall be calibrated 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 which 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

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 is constructed so that it may be conveniently clamped around the conductor to be measured.

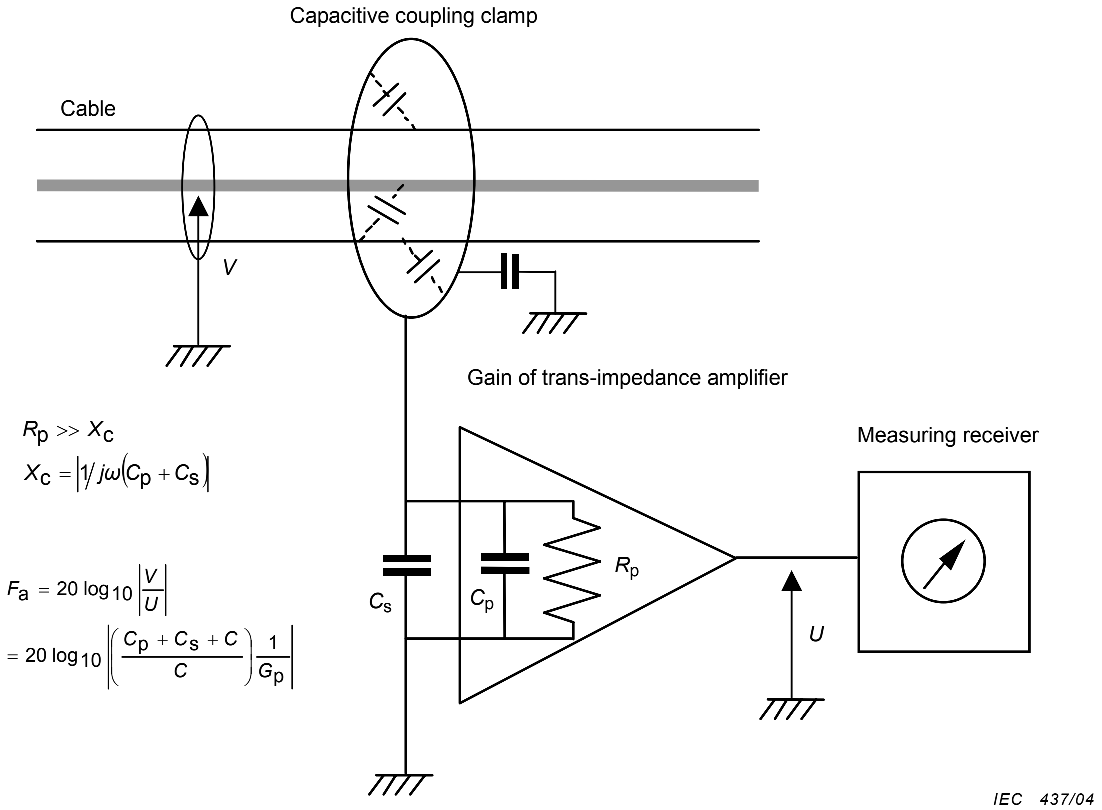
The capacitive voltage probe is used for measurements of conducted disturbances in the frequency range 150 kHz to 30 MHz with an almost flat frequency response in the frequency range of interest. The voltage division factor, which is defined as the ratio of the disturbance voltage on the cable to the 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 capacitive voltage probe may need additional shielding to provide sufficient isolation from the asymmetrical (common mode) signal around the cable (see "Influence of electric field" in 5.2.2.2). Annex G contains an example of the construction and a method of measurement for the isolation.

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

5.2.2.1 Construction

The capacitive voltage probe shall be constructed so as to enable the measurement of the voltage without disconnecting the cable under measurement. Figure 11 shows a circuit that is used to make voltage measurements between a cable and a 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.



Key

G_p Gain of trans-impedance amplifier

C Capacitance between the cable and the clamp

C_s Capacitance between probe and ground

C_p Capacitance of trans-impedance amplifier

R_p Resistance of trans-impedance amplifier

V Disturbance voltage

U Voltage at the input of the measuring receiver

Figure 11 – Circuit used to make voltage measurement between a cable and a reference ground

Annex G provides instructions for the typical construction and verification of the capacitive voltage probe.

5.2.2.2 Requirements

Added shunt capacitance:	Less than 10 pF between the grounding terminal of capacitive voltage probe and the cable under test.
Frequency response:	Voltage division factor, $F_a = 20 \log_{10}\lvert V/U \rvert$ in dB (see Figure 11), is calibrated 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 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 capacitive voltage probe. The measurement method is described in Annex G.
Capacitive voltage probe 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

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 equipment under test from the effects of these currents. With a 150 Ω 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 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 principle of operation and examples of types of units and their construction.

6.1 Characteristics

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

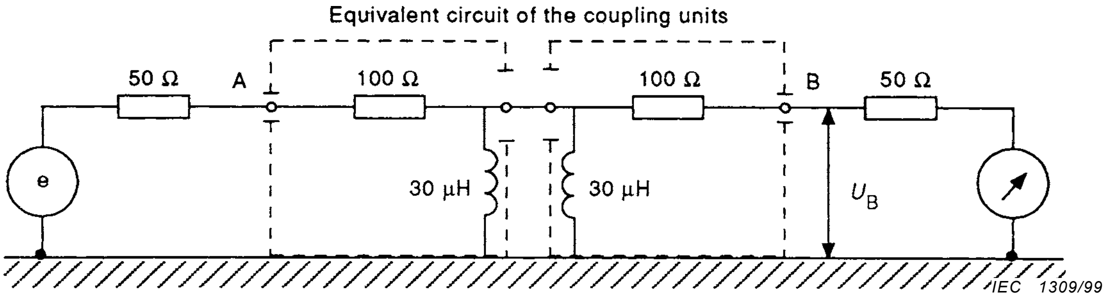
6.1.1 Impedance

In the frequency range 0,15 MHz to 30 MHz, the total asymmetric impedance (RF choke coil in parallel with the 150 Ω resistive disturbance source impedance) measured between the point of injection of the disturbance signal to the equipment under test and the ground of the unit shall have a modulus of 150 Ω ± 20 Ω and a phase angle less than ±20° (this impedance is the same as the CISPR 150 Ω artificial mains V-network, see 4.4).

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.

6.1.2 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 7.



The insertion loss U_G/U_B of two identical coupling units measured according to this figure 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 – 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

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 be found in IEC 61000-4-6[2] (AANs are special versions of "coupling and decoupling devices" [so called coupling/decoupling networks (CDNs)]). An AAN which meets the requirement 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 Δ-networks. The T-network is a special version of the Y-network.

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

When a current probe is used and the limit value is specified in volts, the voltage value must be 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.

Subclause 7.1 states the specification for asymmetric (common mode) artificial networks (AANs). The differential mode to common mode rejection (V_{dm}/V_{cm}) is crucial to the useability of the AAN. This parameter is related to the longitudinal conversion loss (LCL). An example of asymmetric artificial networks and the required test and calibration procedures are given in Annex E.

7.1 Requirements for asymmetric artificial networks (AANs or Y-networks)

Asymmetric artificial 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).

Figure 8a shows the general circuit diagram of an asymmetric artificial network.

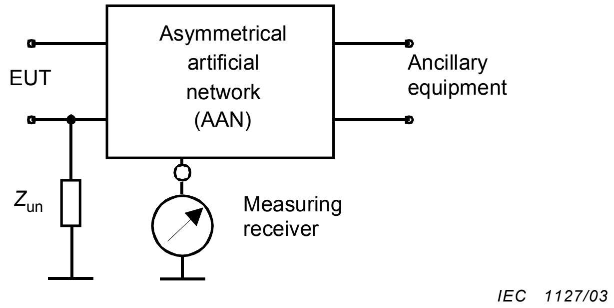
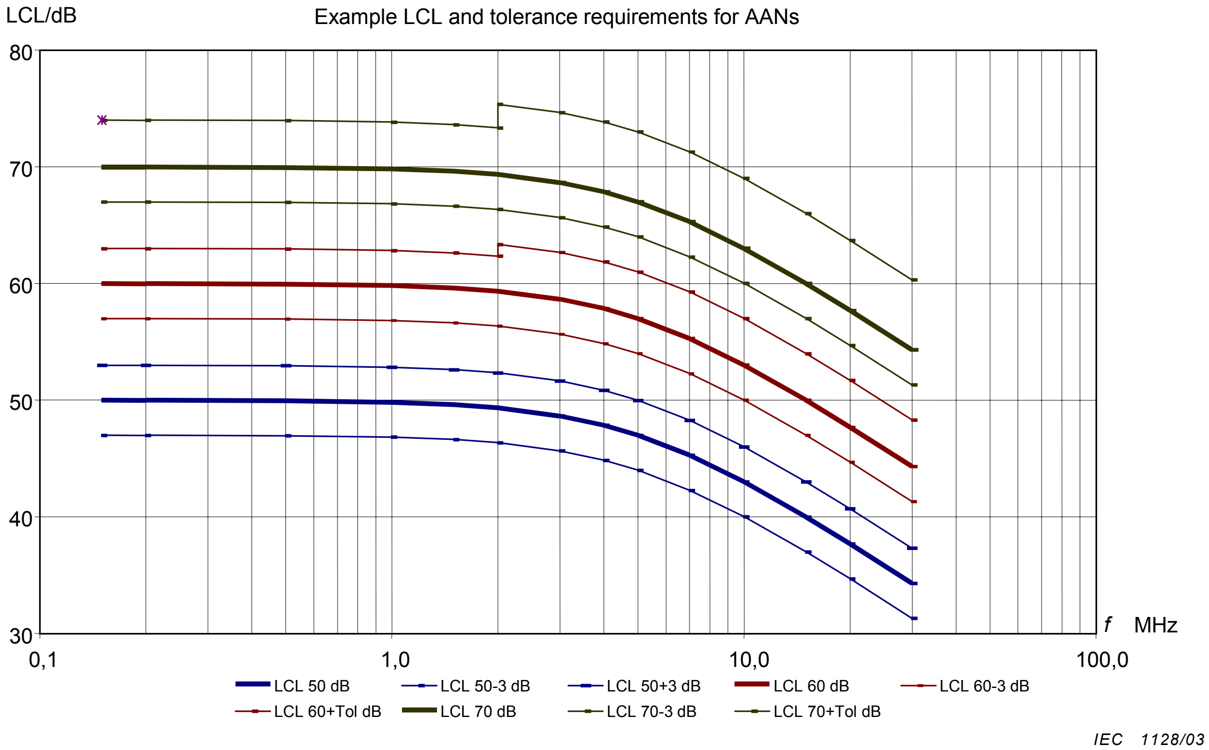


Figure 8a – Principle circuit of the asymmetric artificial network (AAN or Y-network) and its ports consisting of a basic highly symmetric network and an (optional) unbalance network Z_{un}



NOTE 1 The definition equation can e.g. be

$$LCL = LCL_{lf} - 10\lg\left[1+\left(\frac{f}{f_{corner}}\right)^2\right] \pm Tol \text{ (in dB)}$$

where

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.

Figure 8b – Graph showing example requirements for the longitudinal conversion loss (LCL) of the AAN (Y-network))

Figure 8 – Principle circuit and example LCL requirements of an AAN

The characteristics of the AAN for the measurement of asymmetric (common mode) disturbances shall be covering 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 1.

Table 1 – Characteristics of the asymmetric artificial network for the measurement of asymmetric disturbance voltage

a.	**Termination impedance** of basic network for asymmetric disturbance voltage[a] • magnitude • phase		 150 Ω ± 20 Ω 0° ± 20°
b.	**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[c]
c.	**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
d.	**Insertion loss of the symmetric circuit** between EUT and AE ports		<3 dB[d]
e.	**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]
f.	**Symmetric load impedance** of the network		t.b.d.[f]
g.	**Transmission bandwidth** for the intentional signal (analog or digital)		t.b.d.[g]
h.	**Frequency range**[h]	(1) Emission (2) Immunity	(0,009) 0,15 MHz to 30 MHz See e.g. IEC 61000-4-6

[a] The asymmetric impedance of the AAN will normally be influenced by the addition of an unbalanced network according to Figure 8a. 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, e.g. if the unbalanced network changes the impedance 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, since a certain tolerance should be left to the AAN manufacturer.

[b] Different concepts for determination of conformance of equipment are in use: 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.

[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, 3 factors have to be considered for LCL tolerances: the residual LCL of the basic AAN, the deviation of the unsymmetry network Z_{un} from nominal and the uncertainty of LCL measurement. The tolerances given in a product standard 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 Ω. 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] t.b.d. = to be defined, i.e. depending on the system specifications, e.g. 100 Ω or 600 Ω

[g] t.b.d. = to be defined, i.e. depending on the system specifications for the symmetric insertion loss, e.g. up to 2 MHz or up to 100 MHz

[h] More than one network may be used to cover the complete frequency range.

7.2 Requirements for artificial networks for coaxial and other screened cables

Artificial networks for coaxial and other screened cables are used to measure (or inject) unsymmetric (common mode) voltages on the shield of (e.g. telecommunication or r.f.) cables while passing the communication or r.f. signal through. The required characteristics are given in Table 2.

NOTE 1 In CISPR 22 this type of network is called coaxial or screened cable impedance stabilization network (ISN).

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

a.	**Termination impedance** of basic network for unsymmetric disturbance voltage:[a] • magnitude • phase	 150 Ω ± 20 Ω 0° ± 20°
b.	**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
c.	**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]
d.	**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]
e.	**Frequency range** (1) Emission (2) Immunity	(0,009) 0,15MHz 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 so that the minimum decoupling attenuation can be guaranteed.

[c] Insertion loss and transmission bandwidth for the intentional (communication or r.f.) signal between EUT and AE ports as well as the characteristic impedances between shield and inner conductor(s) are not the purpose 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 Introduction

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 to 30 MHz (the most critical frequencies are 5 MHz–30 MHz) to simulate the influence of the operator's hands on the measurements. The types of equipment to be evaluated with the artificial hand are: electric tools, household equipment, 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 specified way.

The metal foil is connected in a specified way to the reference point of the disturbance measuring system via an RC element consisting of a capacitor C = 220 pF ± 20 % in series with a resistor R = 510 Ω ± 10 % (see figure 9a).

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 a metal foil, or more practically a metal plate of maximum dimensions 100 mm × 300 mm, may be placed on top of the keys. Examples are given in figures 9 and 10.

The lead length between the RC element and the metal foil shall be 1 m long. 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 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 the calculation of the minimum diameter d (in metres) of the wires to be used from:

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

where

μ = 4π × 10⁻⁷ H/m;

l is the length of the wire, in metres

d is the diameter of the wire, in metres

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 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 the reproducibility point of view) of the RC element is inside the artificial mains network or the line impedance simulation network.

When the conducted emission to the mains is measured, the reference point is the reference ground in the artificial mains network (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). 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 an exposed metalwork and shall be directly connected to the RC element.

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

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

b) When the case of the appliance is of insulating material, metal foil shall be wrapped around the handle B (figure 9c) and also around the second handle D, if present. Metal foil 60 mm wide shall also be wrapped around the body C (see figure 9c) at the point where the iron core of the motor stator is located, or around the gearbox if this gives a higher interference 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 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 (figure 9c). 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 of insulating loading material and a higher interference 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 (without ground wire) has two handles of insulating material A and B and a case of metal C, for example an electric saw (figure 9c), 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 10 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 × 100 mm.

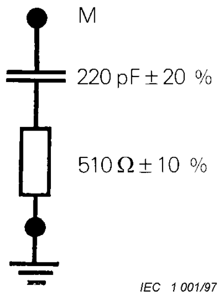


Figure 9a – RC element

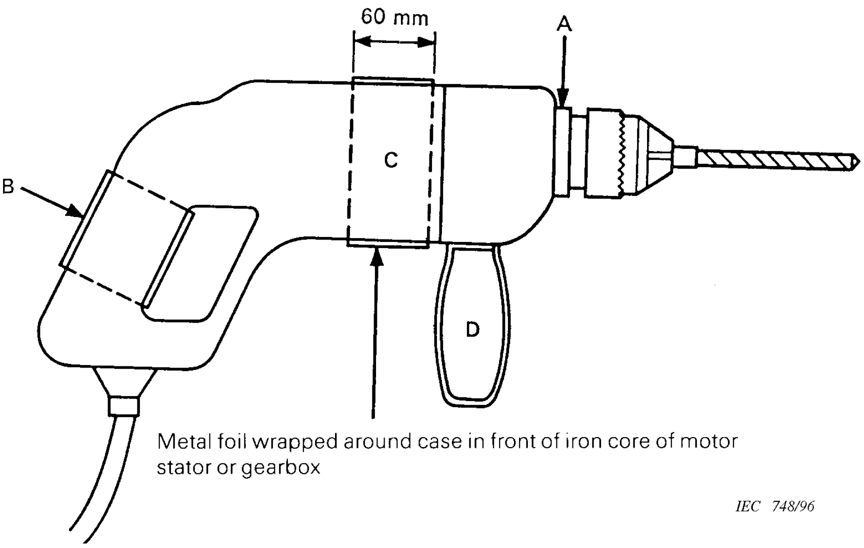


Figure 9b – Portable electric drill

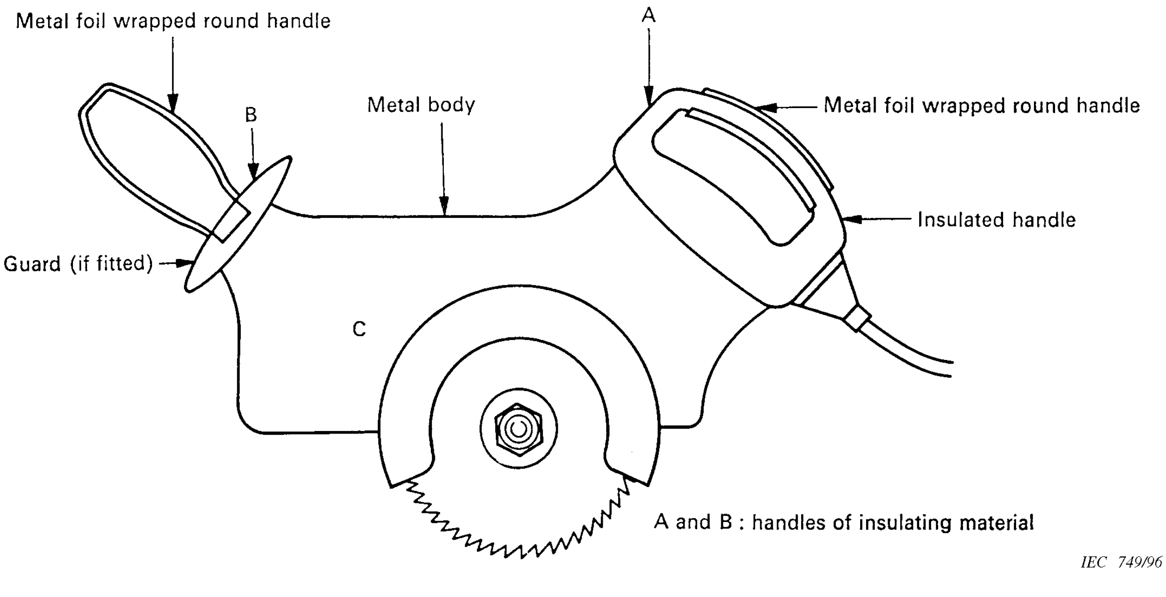


Figure 9c – Portable electric saw

Figure 9 – Application of the artificial hand

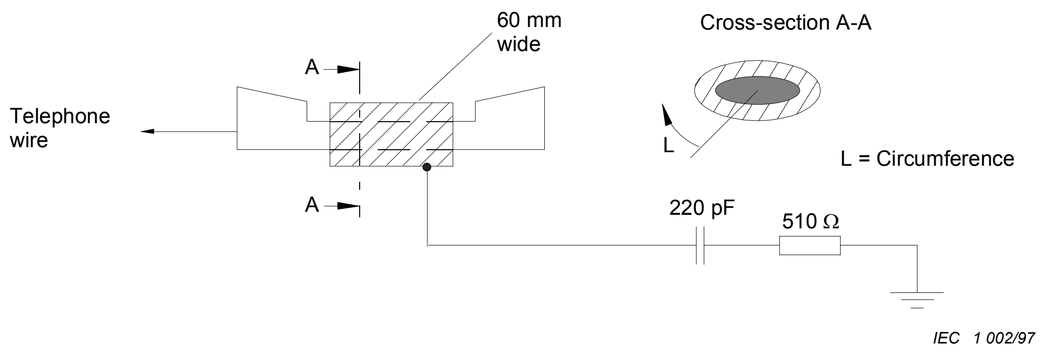


Figure 10a – Application of artificial hand to telephone handset

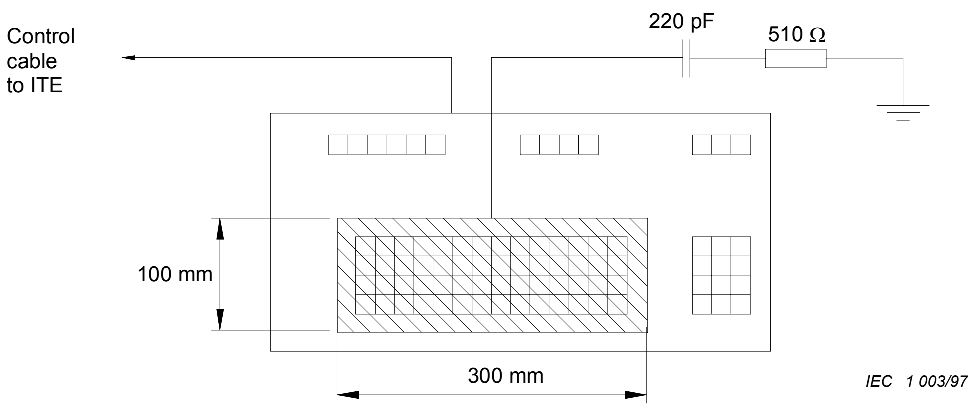


Figure 10b – Application of artificial hand to typical keyboard

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 4
b) 300 mm × 100 mm	for keyboards, whereby the metal foil is to be sized in order 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 10 – Examples of application of artificial hand to ITE

Annex A
(normative)

Artificial mains networks
(clause 4)

This annex sets forth information and data concerning artificial mains networks 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. Included are V-networks for voltage measurements between each conductor of the supply mains and reference earth, and delta-networks for voltage measurements between conductors of the supply mains (symmetrical) and between the mid-point of the conductors of the supply mains and reference earth (asymmetrical).

A.1 General

An artificial mains network circuit has to provide firstly the specified impedance over the working frequency range. It has to 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 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 the following have these facilities. They are given for the case of two-wire single-phase mains. The extension to four-wire three-phase use is simply done.

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

Figure 4 shows a suitable circuit with the component values listed in table A.1. L1, C1, R1, R4 and R5 define the impedance; L2, C2 and R2 provide the isolation to spurious mains signals and mains impedance variations, and C3 decouples the measuring receiver from mains voltage. It may be constructed for use with currents up to 100 A.

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

Component	Value
R1	5 Ω
R2	10 Ω
R3	1000 Ω
R4	50 Ω
R5	50 Ω (input impedance the measuring receiver)
C1	8 μF
C2	4 μF
C3	0,25 μF
L1	50 μH
L2	250 μH

At the lowest frequencies of the range 9 kHz to 150 kHz, the 0,25 μF capacitance of C3 does not have a negligible impedance. Unless otherwise specified, it will be necessary to make a correction for this impedance.

Since C1 and C2 have high capacitances, for safety reasons the network case should either be solidly bonded to reference earth or a mains isolating transformer should be used.

The inductance L2 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).

Clause A.7 describes a suitable construction for the inductor L1. For equipment requiring currents greater than 25 A, difficulties may be encountered in the construction of L2. In this case the isolating section L2, C2 and R2 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 4.2, 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 4.3.

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

Figure 5 shows the circuit with the components values as listed in the table A.2. L1, C1, R2, R3 and R4 define the impedance. Unlike the previous example, there is no isolating section since 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 network

Component	Value
R1	1000 Ω
R2	50 Ω
R3	0 Ω
R4	50 Ω (input impedance of the measuring receiver)
R5	0 Ω
C1	1 μF
C2	0,1 μF
L1	50 μH

Since C1 has a high capacitance, for safety reasons the network case shall either be solidly bonded to reference earth or a mains isolating transformer shall be used.

Clause A.7 describes a suitable construction for the inductor L1.

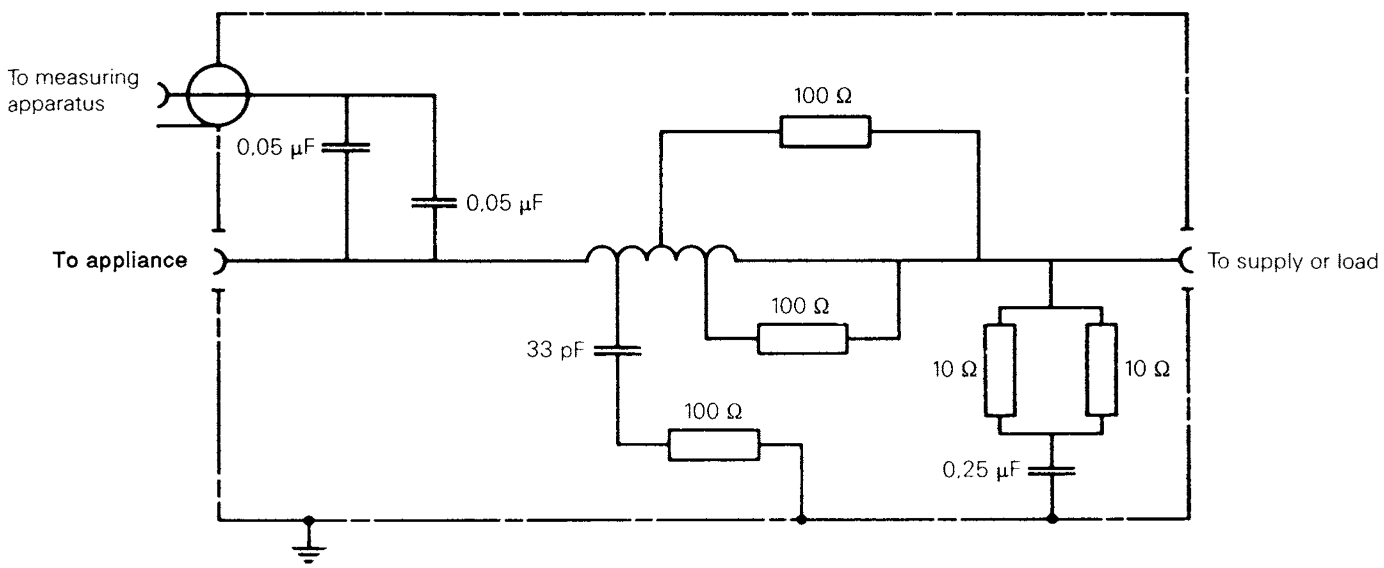
A.4 Examples of the 50 Ω/5 μH + 1 Ω artificial mains V-network

The circuit of figure 5 with the component values given in the 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 network

Component	Value
R1	1 000 Ω
R2	50 Ω
R3	0 Ω
R4	50 Ω (input impedance of the measuring receiver)
R5	1 Ω
C1	2 μF (minimum)
C2	0,1 μF
L1	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.



Coil details:

5 μH, 18 turns, ∅ 6 mm wound on 50 mm diameter former. Tapping points at 3, 5, 9 and 13,5 turns.

Figure A.1 – Example of an alternative 50 Ω/5 μH + 1 Ω artificial mains network for devices used with low impedance power sources

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

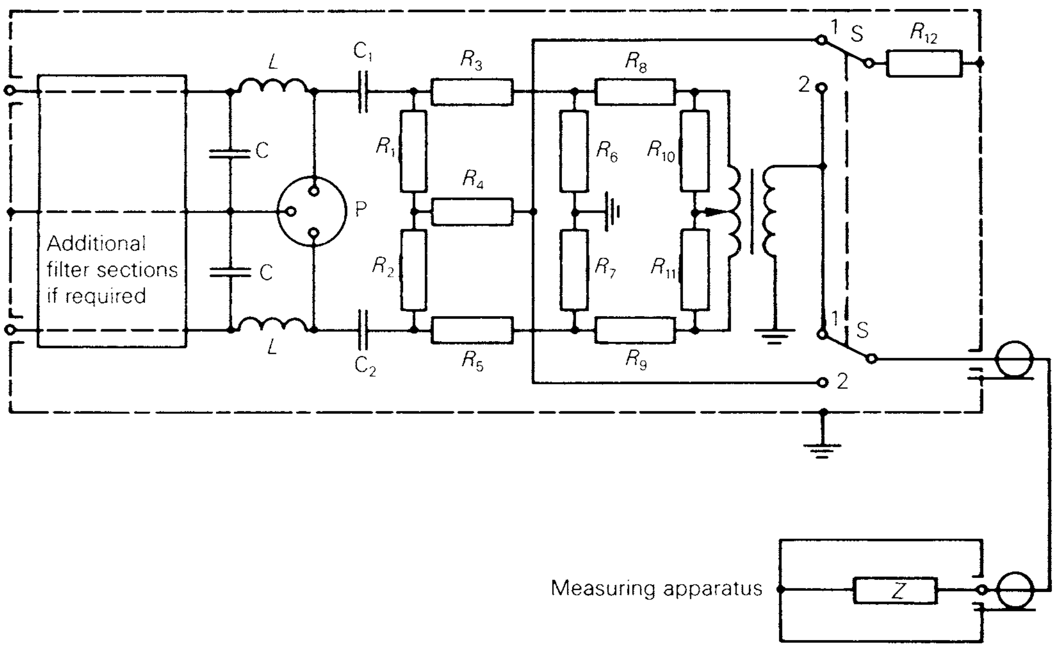
Figure 5 shows a suitable circuit. The component values are given in table A.4.

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

Component	Value
R1	1 000 Ω
R2	150 Ω
R3	100 Ω
R4	50 Ω (input impedance of the measuring receiver)
R5	0 Ω
C1	1 µF
C2	0,1 µF
L1	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.



P is the connection for apparatus under test
1 for the symmetrical component
2 for the asymmetrical component

Figure A.2 – Example of an artificial mains network (delta) for measuring apparatus with unbalanced input

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

Component	Value
R1, R2	118,7 (120) Ω
R3, R5	152,9 (150) Ω
R4	390,7 (390) Ω
R6, R7	275,7 (270) Ω
R8, R9	22,8 (22) Ω
R10, R11	107,8 (110) Ω
R12	50 Ω
C1, C2	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 center tap. NOTE 2 Resistance values shown in brackets are the nearest preferred values (±5 % tolerance).	

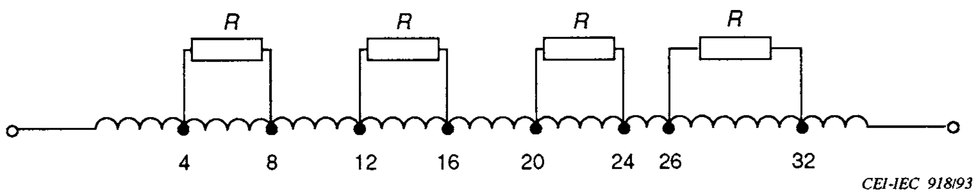
Calculations give the following network performance. Values in brackets are based on the resistance values in brackets.

Attenuation:	Symmetrical	20	(20) dB
	Asymmetrical	20	(19,9) dB
Network impedance:	Symmetrical	150	(150) Ω
	Asymmetrical	150	(148) Ω

A.7 An example of a design for an artificial mains network 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 coil former of an insulating material. Its inductance is greater than 50 μH outside the metal case and 50 μH inside the metal case.



Resistors R (430 Ω ± 10 %) are connected to taps at turns 4 and 8, 12 and 16, 20 and 24, 26 and 32. Inductance is 50 μH ± 10 %.

Figure A.3 – Schematic of 50 μH inductor

The diameter of the inductor is 130 mm. In order to improve the electrodynamic stability of the winding, a 3 mm deep spiral groove is made in the coil former, 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 Ω 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 in order to improve the heat dissipation. The dimensions of the case are 360 × 300 × 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 equipment under test.

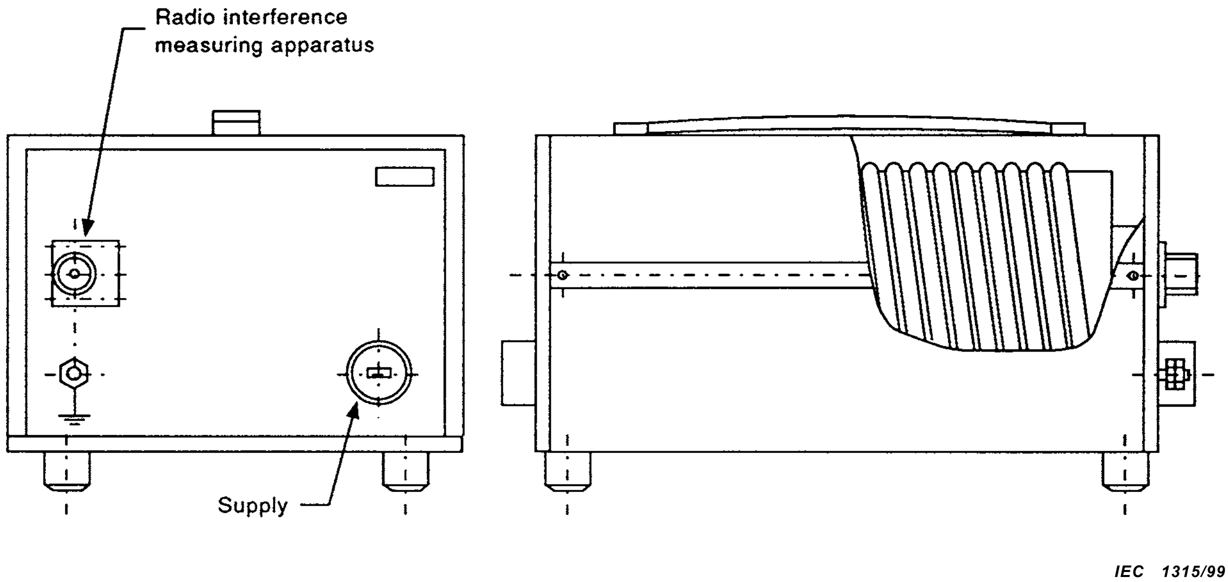


Figure A.4 – A general view of the artificial mains network

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 4 but without the isolation section L2, C2, and R2. The attenuation is determined as that between the supply mains terminal and the radio disturbance measuring apparatus terminal. In the case of curve 1, the internal impedance of the signal generator at the mains terminal is 50 Ω 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 artificial mains network as given in figure A.5.

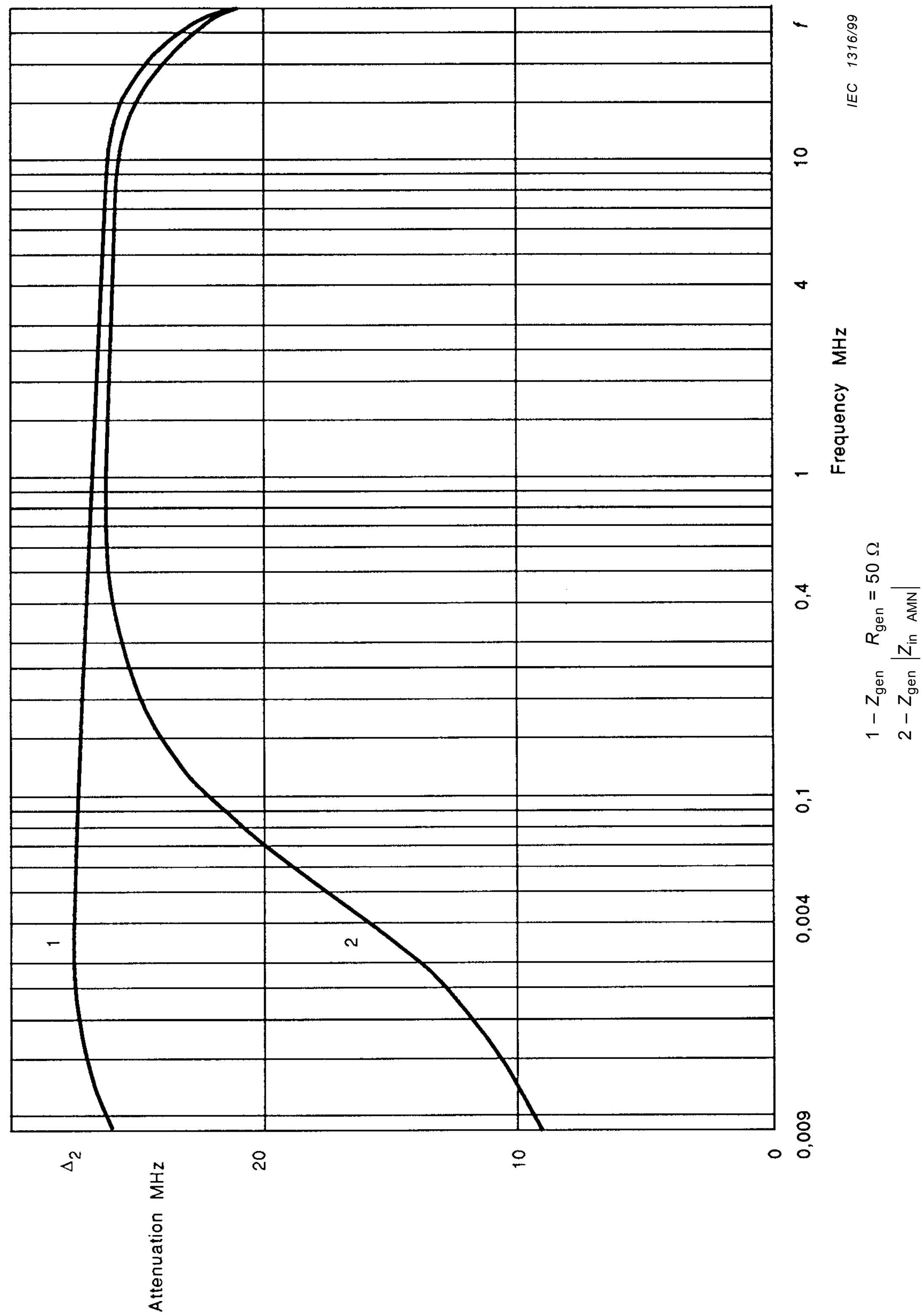


Figure A.5 – Attenuation of an artificial mains network filter

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.6a and A.6b for each test configuration of a V-network. It shall be measured on each line with each internal connection (e.g. with manual or remote switching configurations) using a network analyzer 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 Ω.

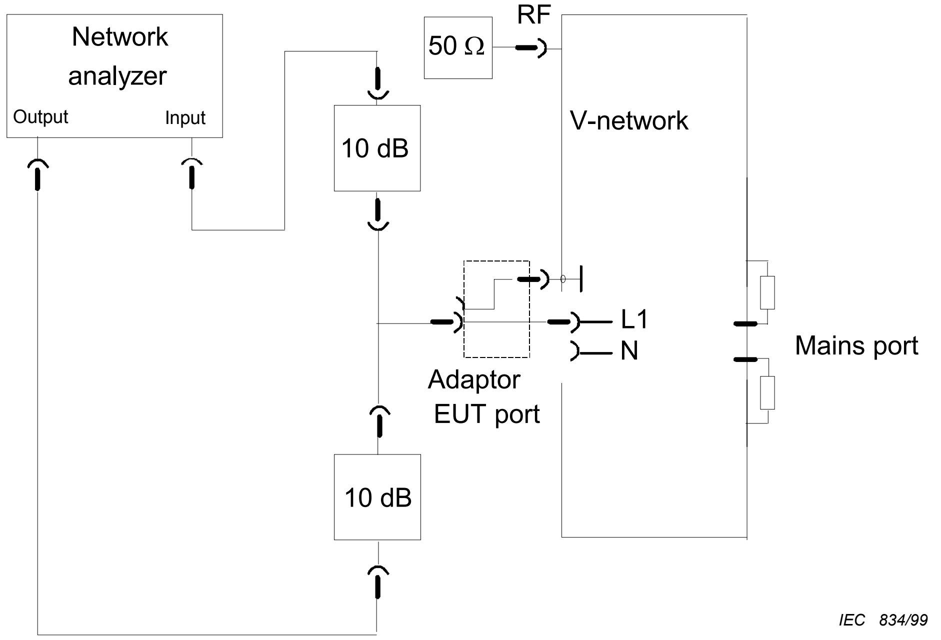


Figure A.6a – Test set-up for normalization of the network analyzer

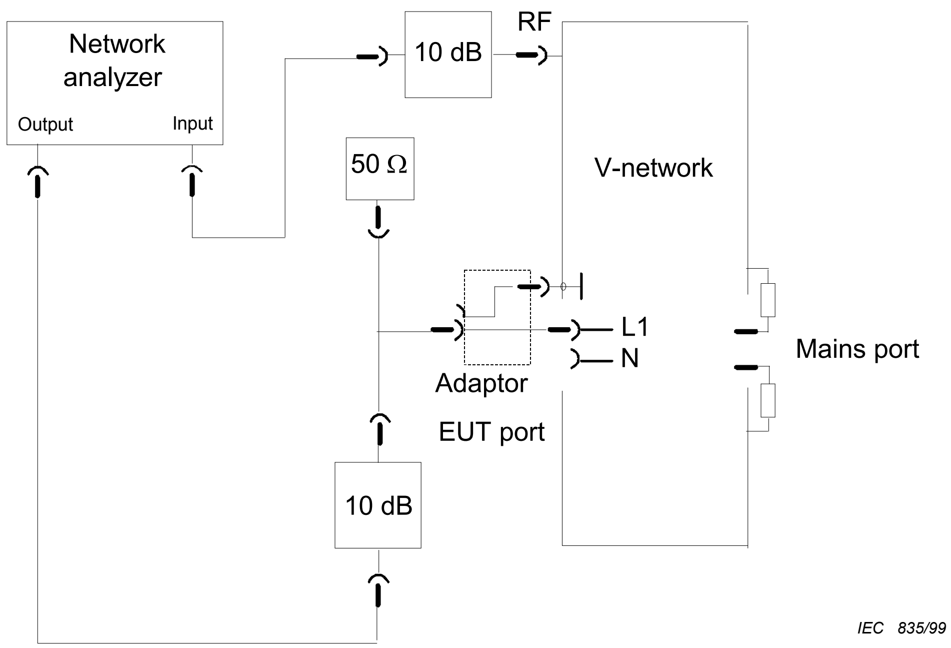


Figure A.6b – Test set-up for measurement of the voltage division factor using a network analyzer

Since the EUT port presents a frequency-dependant input impedance, the network analyzer needs to be normalized, 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. The connections must provide low impedance and the T-connector must be placed as close as possible to the EUT port and earth terminals. The 10 dB pads are used to provide exact 50 Ω source and load impedances for accurate measurements.

Each line of the mains port shall 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 be taken into consideration.

Annex B
(informative)

Construction, frequency range, and calibration of current probes
(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.

The current probe is usually of toroidal shape with the conductor to be measured placed within the centre opening of the toroid. 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 toroidal core and winding is enclosed with 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 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 μV) receiver and a current probe with a transfer impedance of 10 Ω are used, then the minimum measurable disturbance current is 0,1 μA. However, if a 10 μV receiver and a current probe with a transfer impedance of 1 Ω are used, then the minimum measurable current is 10 μA. 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 μV or 1 μA (Z_T in terms of decibels above 1 Ω is taken as 20 log Z_T).

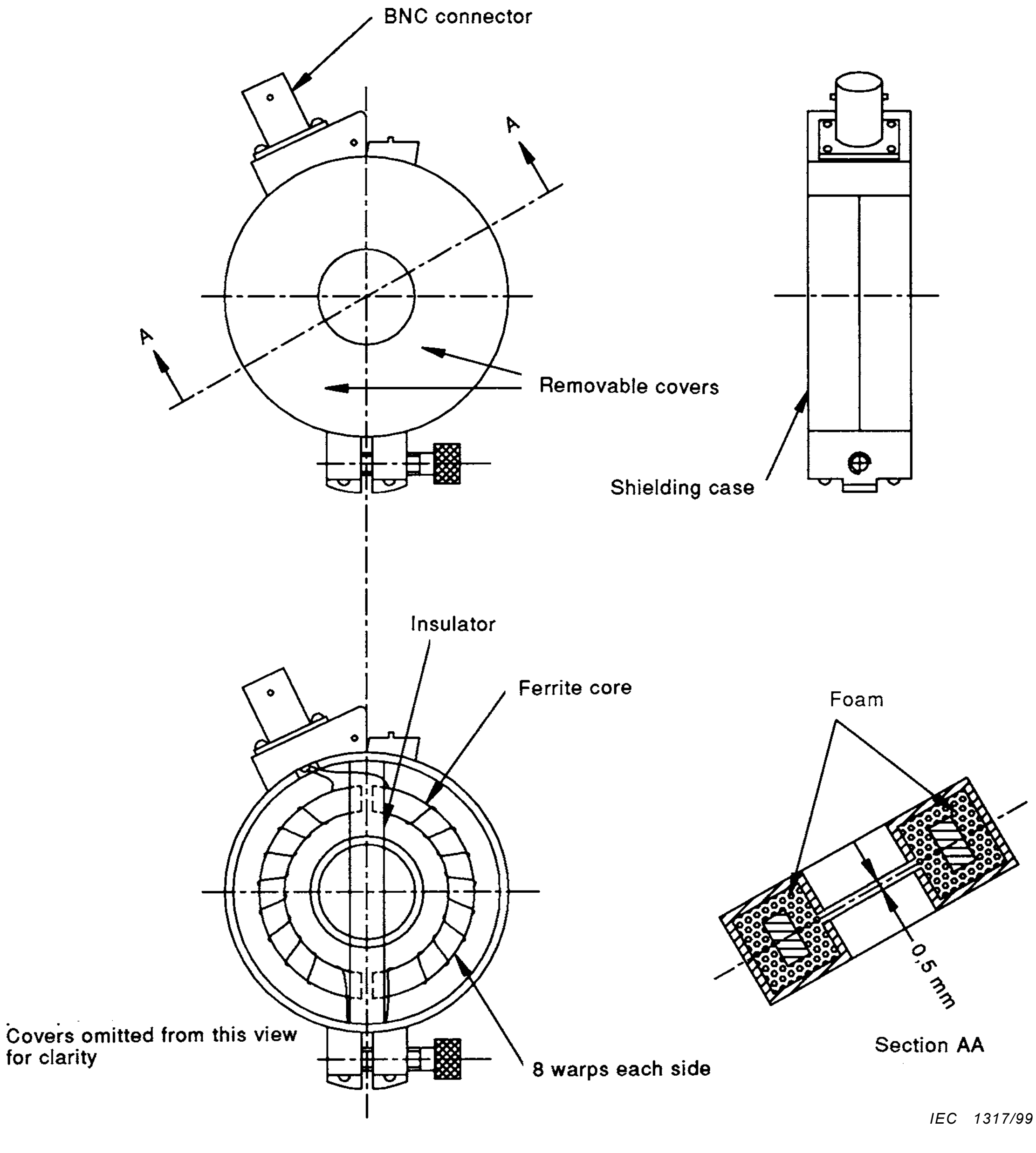


Figure B.1 – Typical current probe configuration

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*. After considerable simplification of the exact circuit and derived equations, the following equations for the transfer impedance result:

High-frequency case: $$Z_T = \frac{\omega M}{\left[(\omega L / R_L)^2 + (\omega^2 LC - 1)^2\right]^{1/2}}$$

Mid-frequency case: $Z_T = MR_L/L$ when $(\omega^2 LC = 1)$

Low frequency case: $$Z_T = \frac{\omega M}{\left[(\omega L / R_L)^2 + 1\right]^{1/2}}$$

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 these equations:

1) 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).
2) The high-frequency half-power point occurs when the reactance of the secondary distributed capacitance is equal to the load resistance.

B.3 Deleterious 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 of d.c. or 100 A of 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. Since 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.

* MIT Staff: *Magnetic Circuits and Transformers,* John Wiley & Sons, Inc., New York, N.Y., 1947.

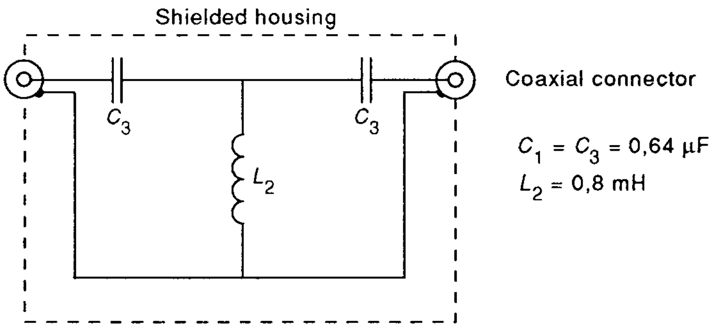


Figure B.2 – High-pass filter with cut-off frequency of 9 kHz

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.

B.5 A shielding structure for use with current probes

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.5.1 Theoretical model

The set-up for current measurement using the artificial mains network is shown in figure B.4a. 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 current

I_D symmetric current

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

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

$I_1 = I_C + I_D$

$I_2 = I_C - I_D$

$2\ I_C = I_1 + I_2$

$I_D = I_1 - I_2$

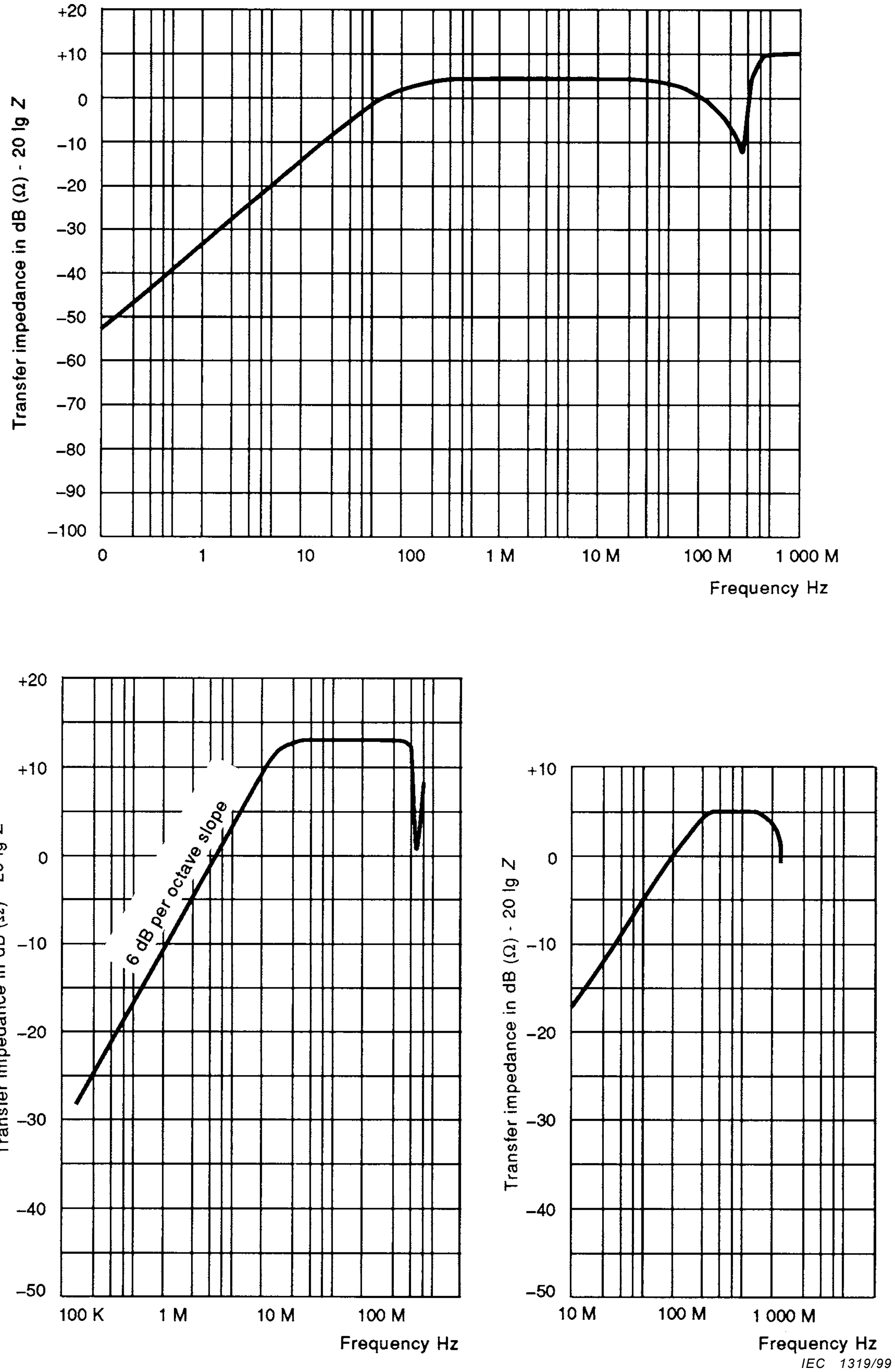


Figure B.3 – Transfer impedance of typical current probes (see clause B.4)

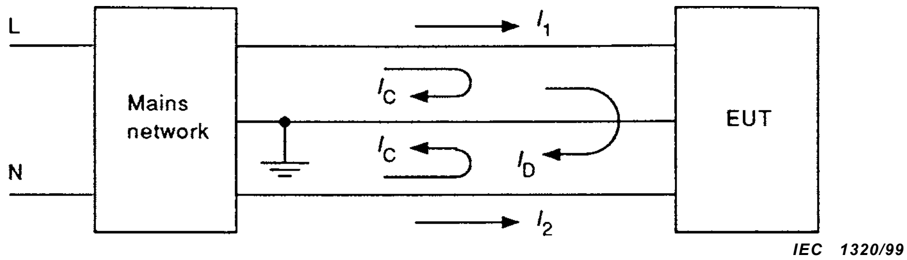


Figure B.4a – CISPR test circuit with interference currents

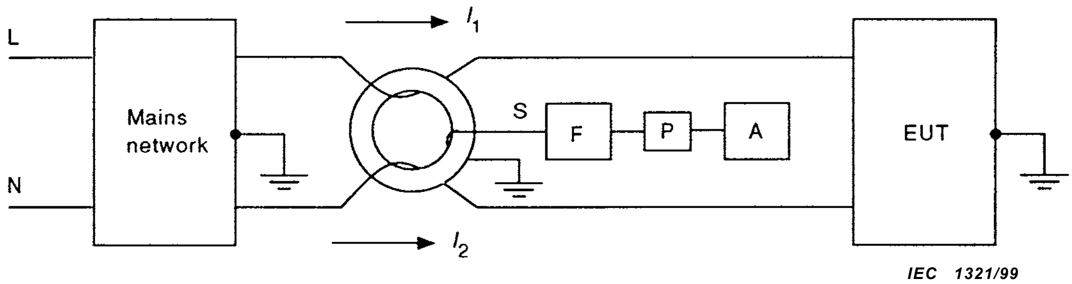


Figure B.4b – Test circuit which differentiates common (asymmetrical mode and differential (symmetrical) mode noise

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

B.5.2 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.

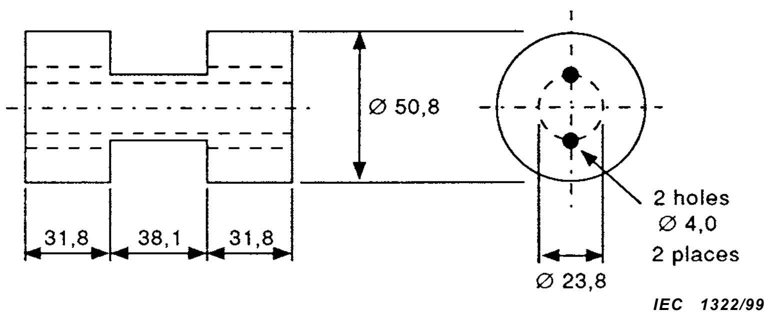


Figure B.5 – Shield configuration used with current transformer (The material should be highly conductive, e.g. copper or brass)

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 equipment under test. The diameter of the centre of the shield is the 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.5.3 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.4b).

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 adapter. When assembled with the current probe in place, it 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.8).

The equivalent calibration 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 formula:

$$k = V_1 - V_2 - 34$$

where

k is the transfer admittance in dB(S);

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

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

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

The transfer admittance k is used to calculate the value of the measured current I_P by the formula:

$$I_P = V_2 + k$$

where

I_P is in dB(μA), and

V_2 is in dB(μV)

k is in dB(s)

Figure B.7 shows a typical calibration result, figure B.8a shows the return loss and figure B.8b shows picture of the coaxial adapter jig.

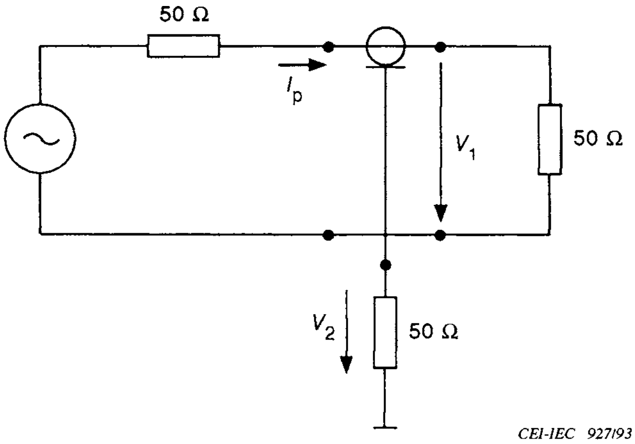


Figure B.6 – Schematic diagram of circuit with coaxial adapter and current probe Current probe factor k measurement

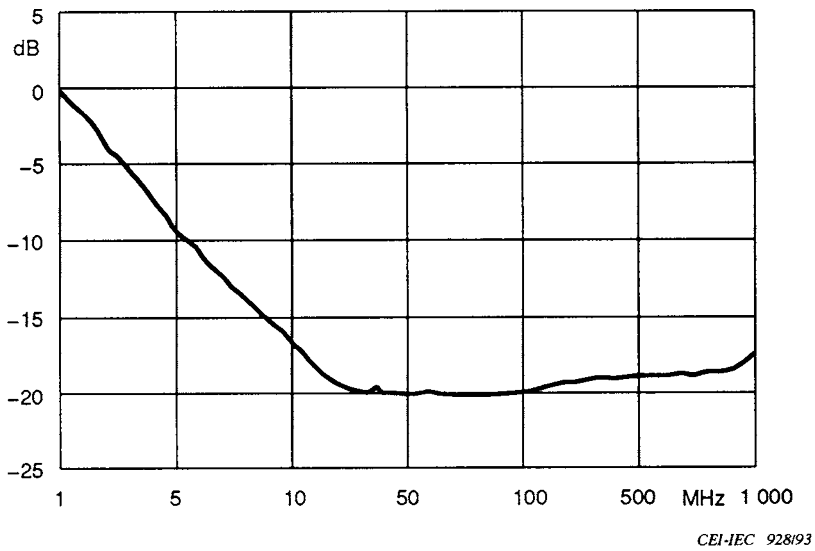


Figure B.7 – Current probe factor k as a function of frequency

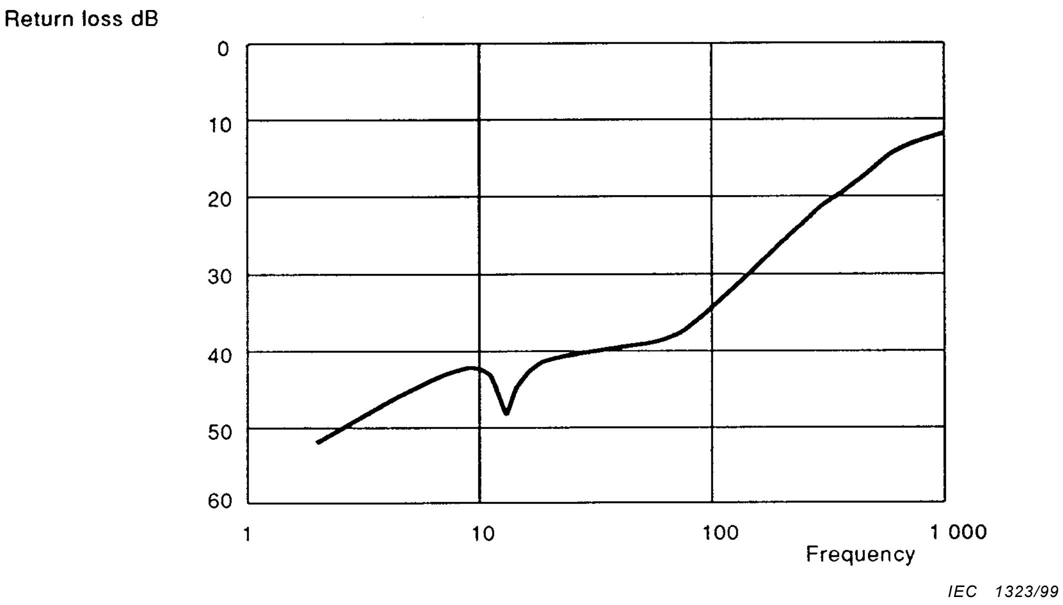


Figure B.8a – Return loss

Return loss of the coaxial adapter (see below) terminated with 50 Ω and with the current probe inside. The current probe is also terminated with 50 Ω.

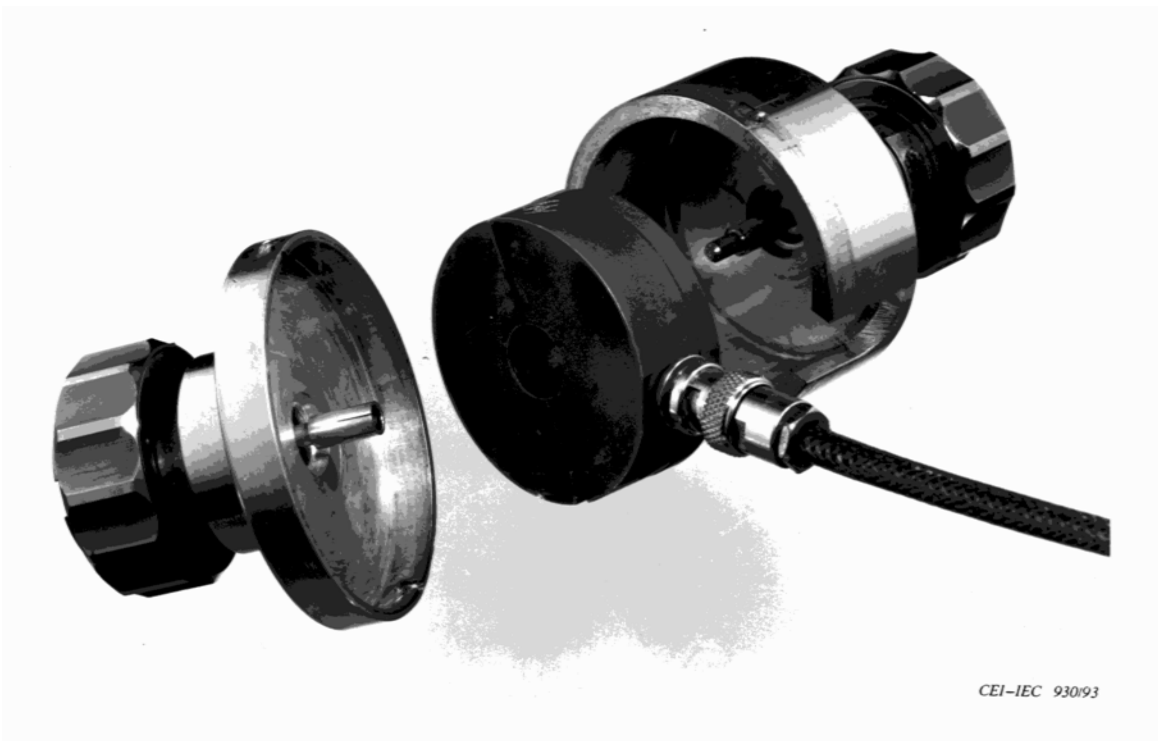


Figure B.8b – Current probe between the two halves of the coaxial adapter

Annex C
(informative)

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

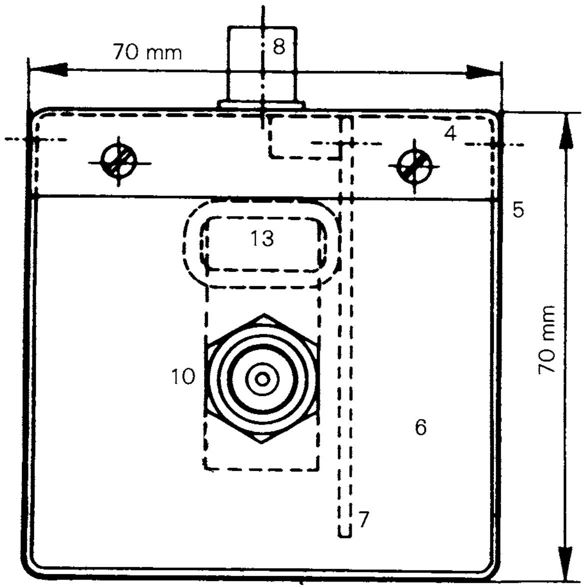
C.2 Coupling unit type M, for mains leads

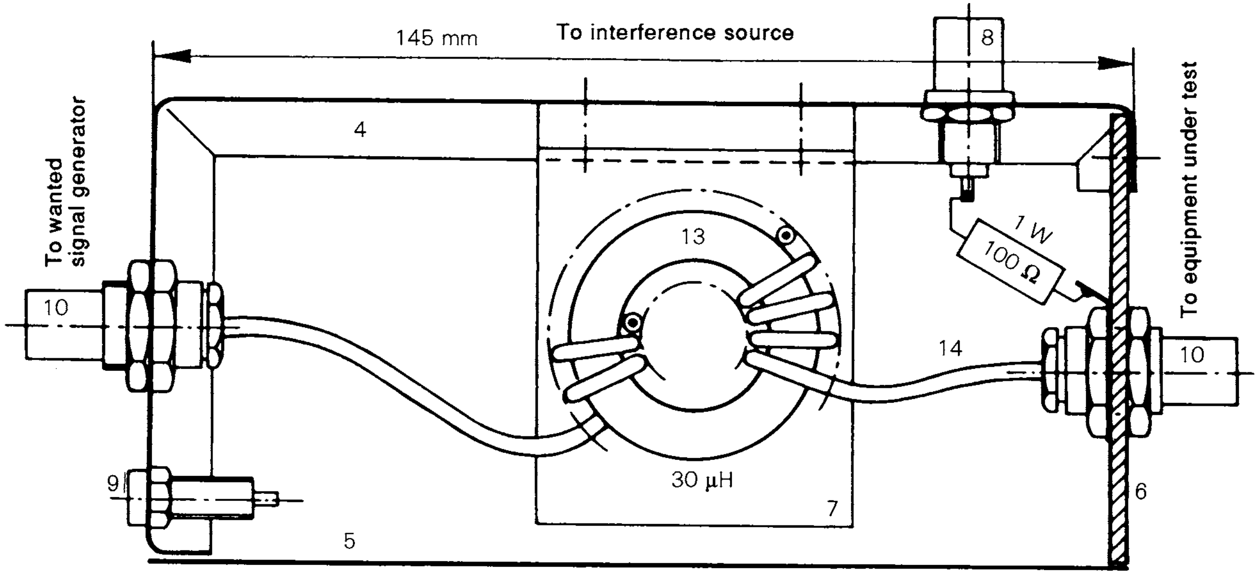
The circuit diagram and construction are similar to the type M unit shown in figure C.2, except that the two inductors are 560 μH each, and $C1$ = 0,1 μF and $C2$ = 0,47 μF.

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.





4-5 is the metallic case 145 mm × 70 mm × 70 mm (parts 5 placed on the ground plane P1)

6 is the front plate (insulating material)

7 is the supporting plate for chokes (insulating material)

8 is a coaxial connector, BNC, 50 Ω

9 is the group jack

10 is a coaxial connector, BNC

13 is a ferrite ring type 4C6, ∅ 36 mm, 15 mm, with 14 turns of coaxial cable

14 is a coaxial cable, outer ∅ 2,4 m

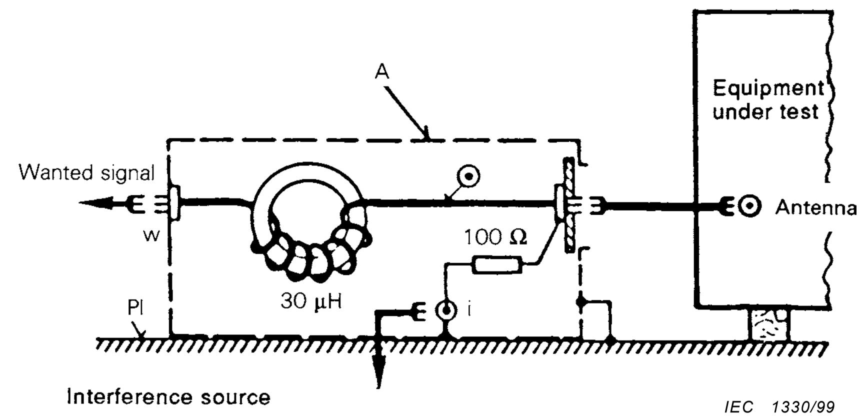
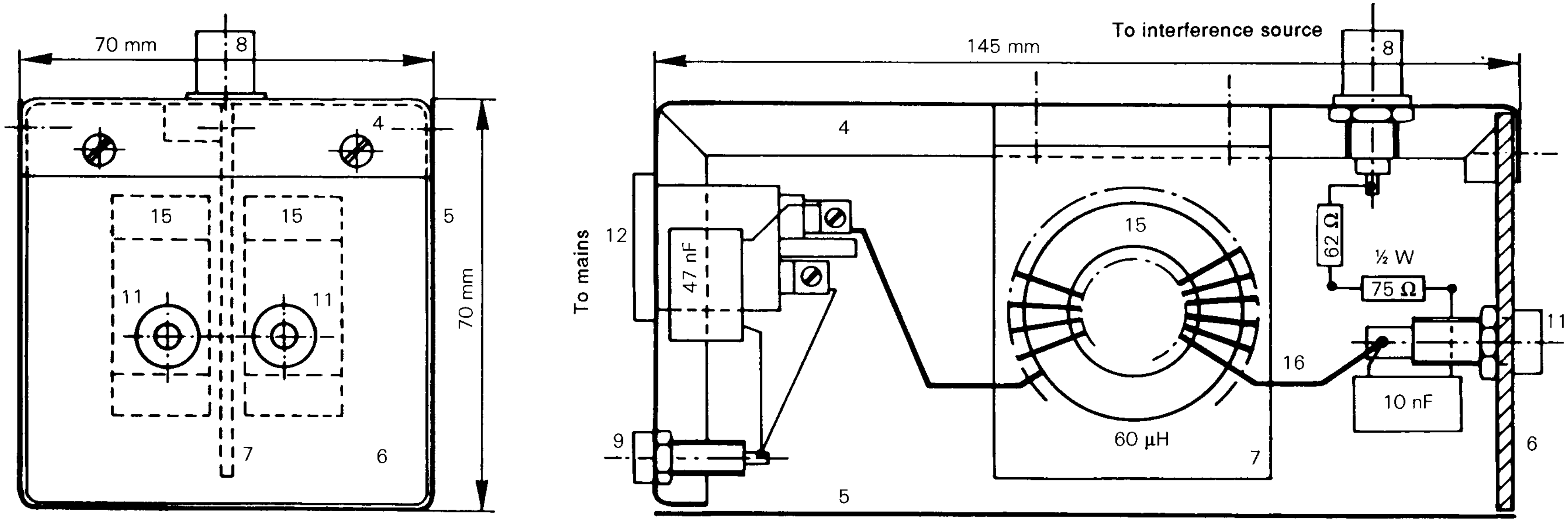


Figure C.1 – Example of coupling unit A, for coaxial input
Schematic diagram and construction details (see clause C.1 and clause D.2)



Parts 4 to 9: see unit type A

11 is the mains socket for equipment under test (two insulated banana jacks)

12 is the mains plug (2P + ground)

15 are two ferrite rings type 4C6, ∅ 36 mm × 23 mm × 15 mm, with 20 turns each

16 is a 0.8 mm copper wire insulated, outer ∅ 0.8 mm

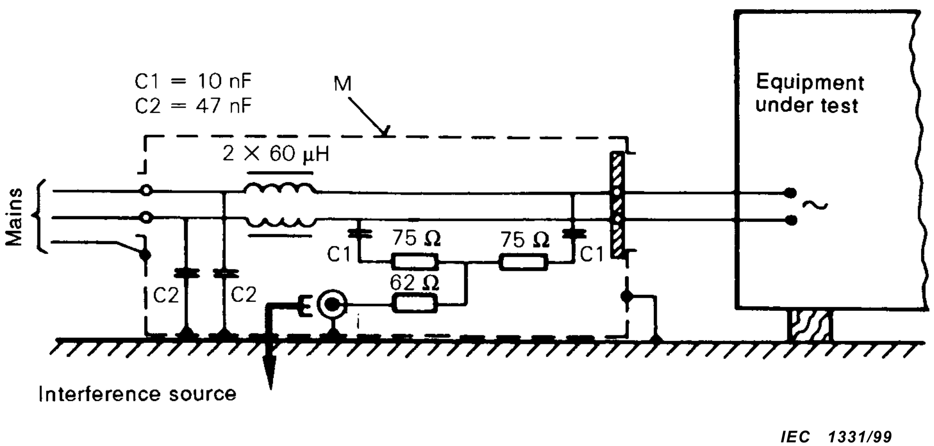


Figure C.2 – Example of coupling unit type M, for mains leads. Schematic diagram and construction details (see clause C.2 and clause D.2)

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 *C1* = 47 nF and *C2* = 0,22 μF.

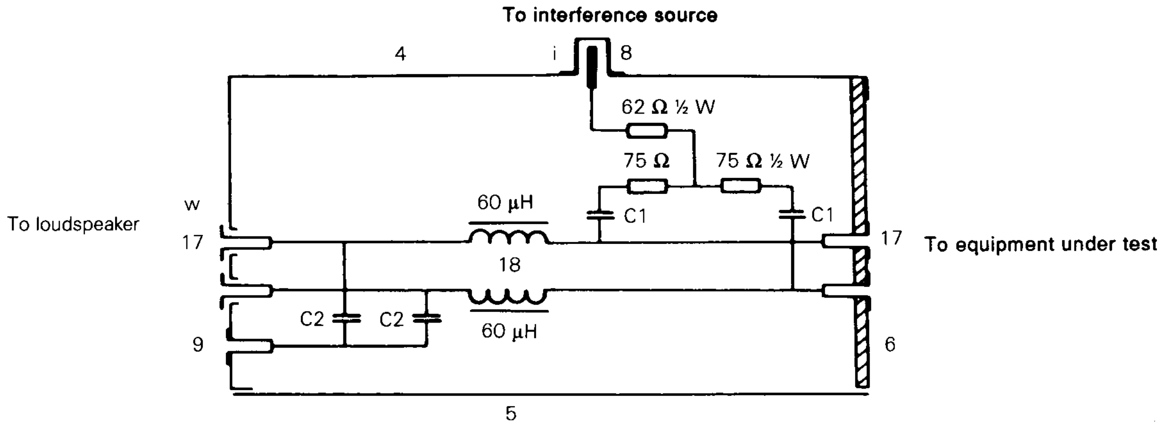
Construction of each 560 μH choke:

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	μ_i	= 120
Loss factor	$\tan\delta/\mu_i$	< 40 at 2 MHz, < 100 at 10 MHz
Resistivity	ρ	= 10 kΩm



Parts 4-5-6-8-9: see unit type A.

17 are insulated banana jacks

18 are two inductances 60 μH each.
For each inductance:

Core: one ferrite ring, type 4C6, ∅ 36 mm × ∅ 23 mm × 15 mm
Winding: 20 turns copper wire insulated outer ∅ 1,2 mm
Mounting of the inductances: see unit type M

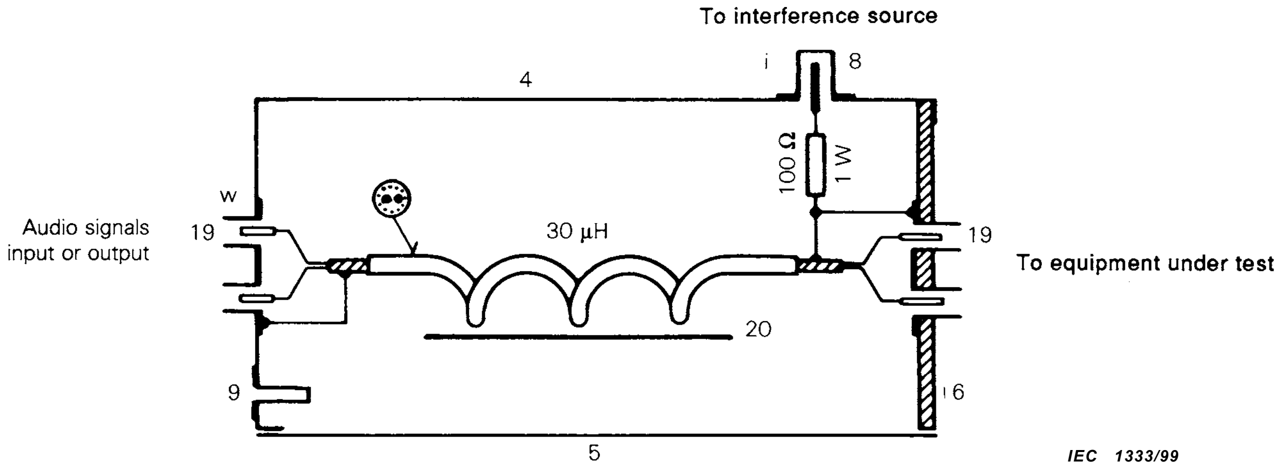
C1 = 10 nF
C2 = 47 nF

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 clause 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 be used for this purpose, if the two stereo signal cables of the equipment under test are connected together.



Parts 4-5-6-8-9: see unit type A.

19 are Cinch or DIN sockets

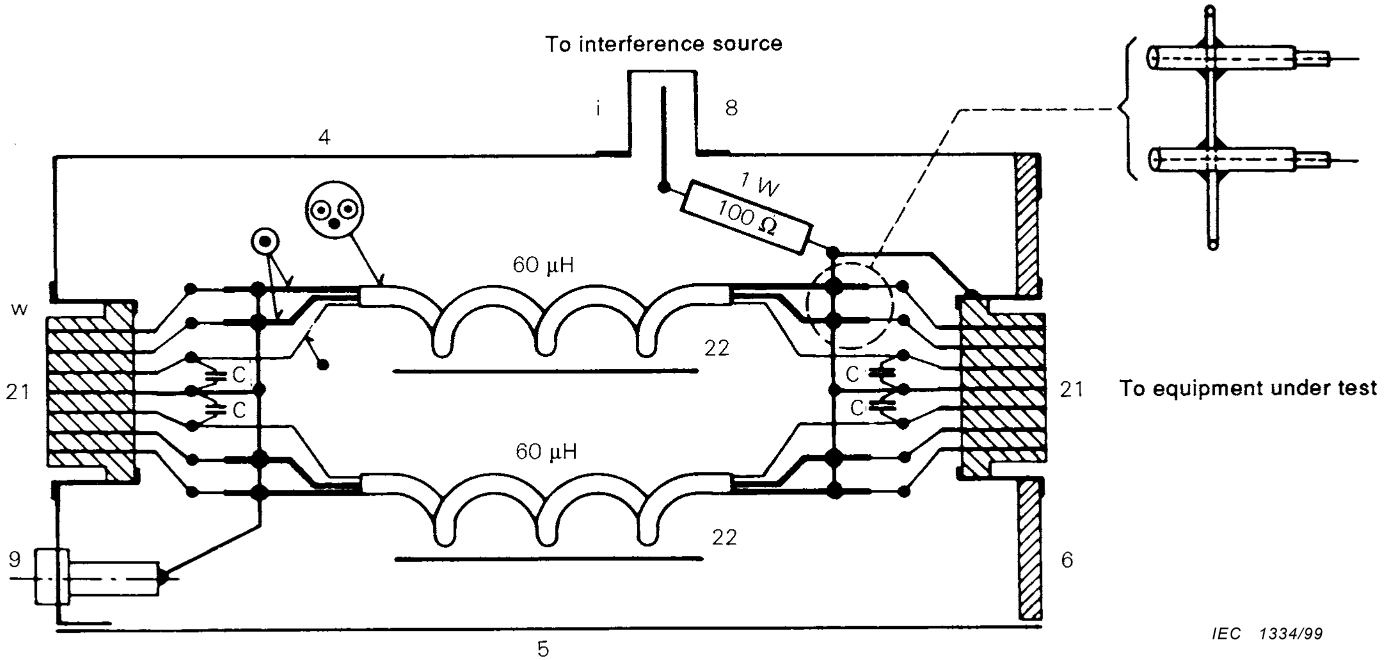
20 is the inductance 30 μH:

Core: one ferrite ring, type 4C6,
∅ 36 mm × ∅ 23 mm × 15 mm
Winding: 14 turns with a screeened 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 clause 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.



Parts 4-5-6-8-9: see unit type A.

21 are multiple pins connector (e.g. 7 pins DIN-socket)

22 are two inductances 60 µH each. For each inductance:

Core: one ferrite ring, type 4C6,
∅ 36 mm × ∅ 23 mm × 15 mm
Winding: 20 turns with a three-lead cable
Cable: Two micro-coaxial cables, UT-34,
outer ∅ 0,9 mm + one copper wire
∅ 0,4 mm, varnish insulated
outer insulation: tube outer ∅ 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
(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 Ω internal resistance is injected via a 100 Ω 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 Ω resistor (to make up the 150 Ω source impedance from a 50 Ω interference 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 Ω. This unit is like an artificial mains delta network and presents, as seen from the equipment under test terminals, a symmetrical and asymmetrical equivalent resistive impedance of 150 Ω.

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:

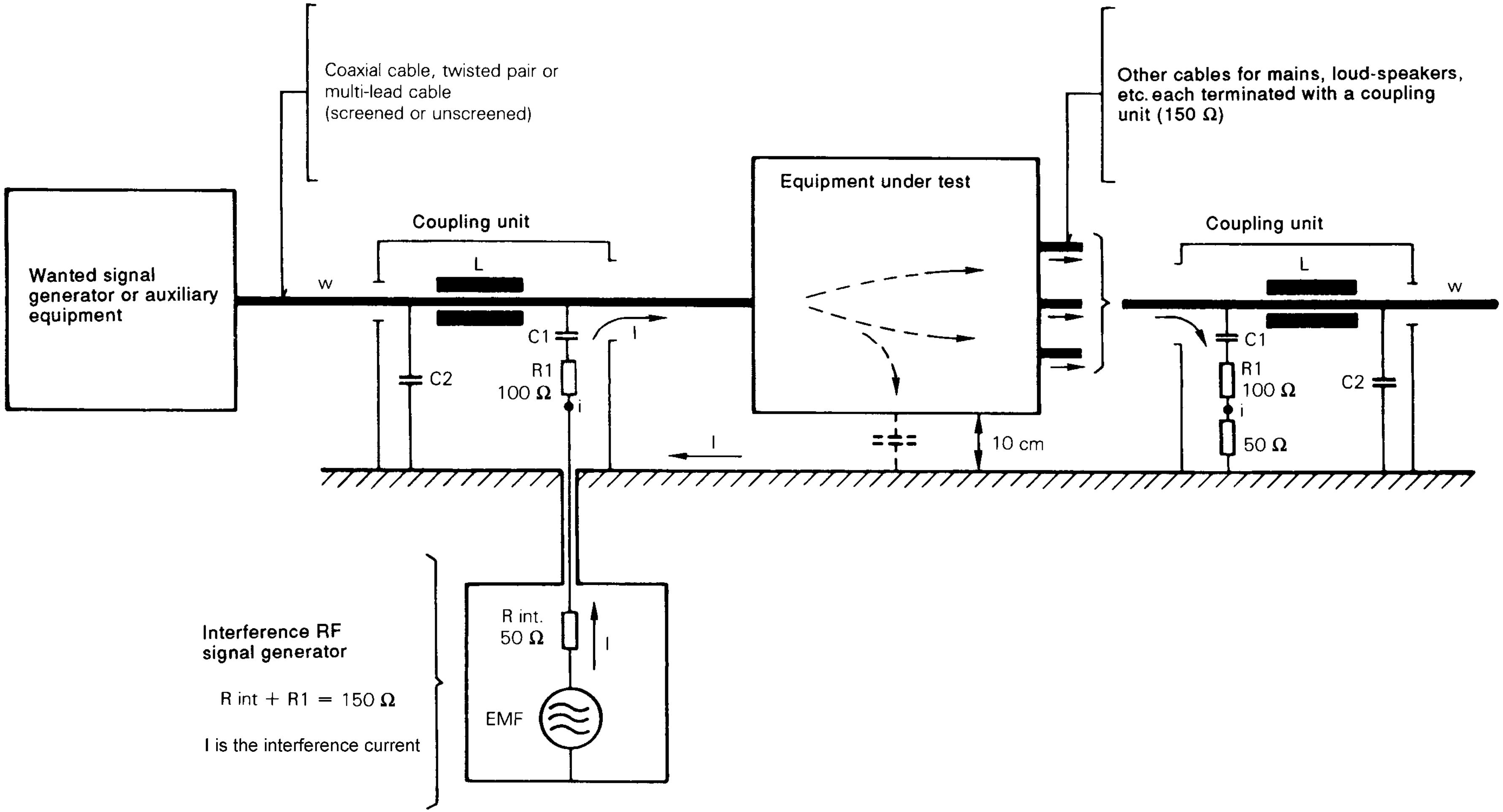
Type Sw: These units provide a through path for audio, video, control or other signals, in which case filtering is required to ensure that the disturbance signal is directed towards the equipment under test. The construction details shown in figure C.4, indicate the simple filtering provided for audio 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 Ω resistor on to the screen and the earth 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 Ω resistor on to the screen (earthing) and the earth 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 Ω, the value of the series resistor is adjusted accordingly to make up the required 150 Ω impedance.

The RF choke coils shown in figures C.1 to D.2 have inductance values 30 µH or 2 x 60 µH 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 µH or 2 x 560 µH in parallel respectively. Annex C describes their construction.

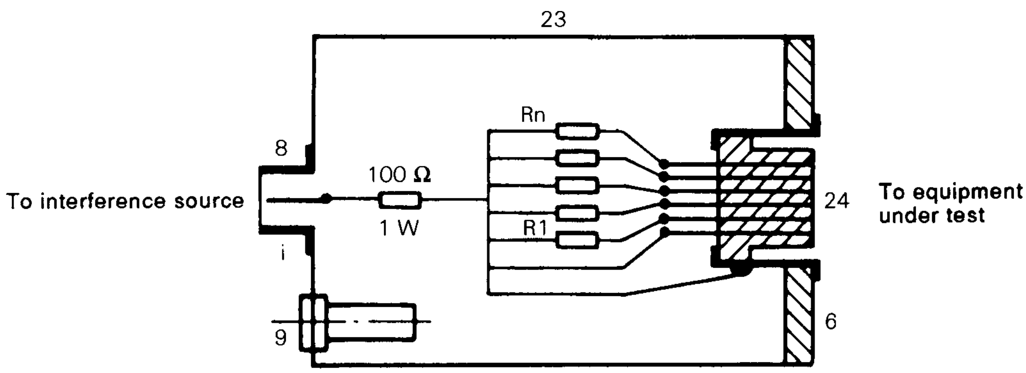
Precautions have to be taken in the layout in order to keep parasitic capacitance to the output terminals of the units as low as possible. It should be noted that the metal cases of the units are to be carefully connected to the ground plane using large section copper braid and unpainted cases.



L is the isolating inductance

C1, C2 are the capacitors with low RF impedance (if the ac. dc conditions allow this, capacitors should be replaced by a direct connection)

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



6-8-9: see unit type A

23 is the metallic case 100 mm × 55 mm × 55 mm

24 is the multiple-pin conductor or DIN-socket

R1 to Rn are the matched load resistances.

Examples: Coupling units 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 clause 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 Ω is determined by the two resistors R_T (200 Ω), in parallel for the asymmetric current, in series with the resistor R_M (50 Ω). 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 is blocking 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 earth 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.3c. The network analyzer (NWA), applies its output signal to an LCL probe, which must 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.3a and for calibration, see Figure E.3b.

c) **Decoupling attenuation**

The decoupling attenuation shall be measured in accordance with Figure E.4.

d) **Insertion loss of the symmetric circuit**

The insertion loss of the symmetric circuit shall be measured in accordance with Figure E.5.

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 2 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.6.

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.5.

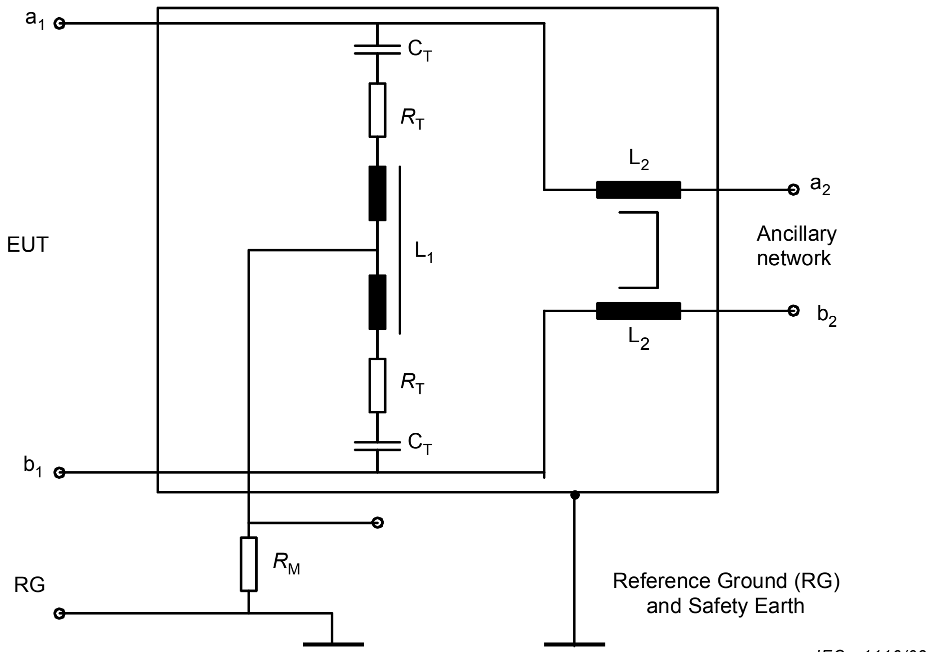
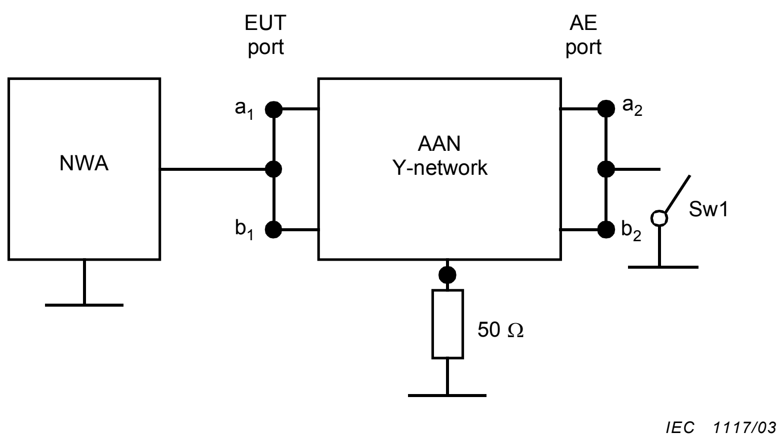
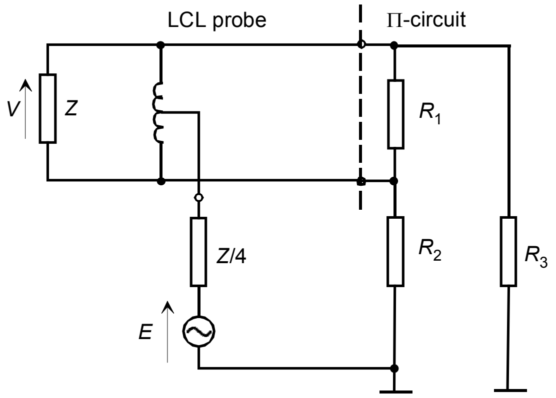


Figure E.1 – Example of a T-network circuit for one pair of wires



NOTE If the AAN is of higher order (i.e. more than 1 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 When terminated with a minimum LCL Π-circuit consisting of R_1, R_2 and R_3 (R_2 = R_3) which include both the nominal symmetric impedance Z (= $\frac{R_1 \cdot (R_2 + R_3)}{R_1 + R_2 + R_3}$) of the AAN and the asymmetric impedance of 150 Ω (= $\frac{R_2 \cdot R_3}{R_2 + R_3}$), the probe should ideally show a residual LCL of 20 dB or higher than the highest LCL to be measured.
For Z = 100 Ω: R_1 = 120 Ω and R_2 = R_3 = 300 Ω.

The LCL probe should be operated with an asymmetric source impedance of Z/4.

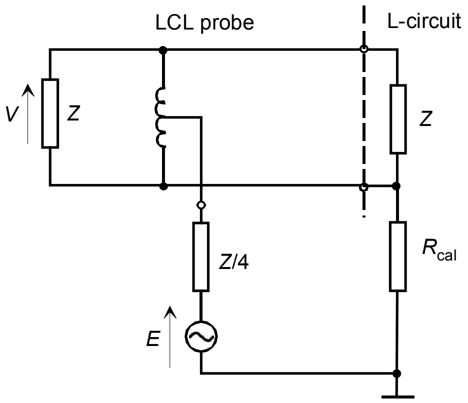
For Z = 100 Ω, Z/4 equals 25 Ω.

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

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

The LCL probe should be so constructed that the LCL can be measured using ordinary network analyzers. An example LCL probe is described in [1][3].

Figure E.3a – Arrangement for the LCL probe verification



NOTE $LCL_L = 20\ \lg\left|\frac{(R_{sym} \mathbin{/\!/} Z) + 4R_{cal} + Z}{2(R_{sym} \mathbin{/\!/} Z)}\right|$ dB

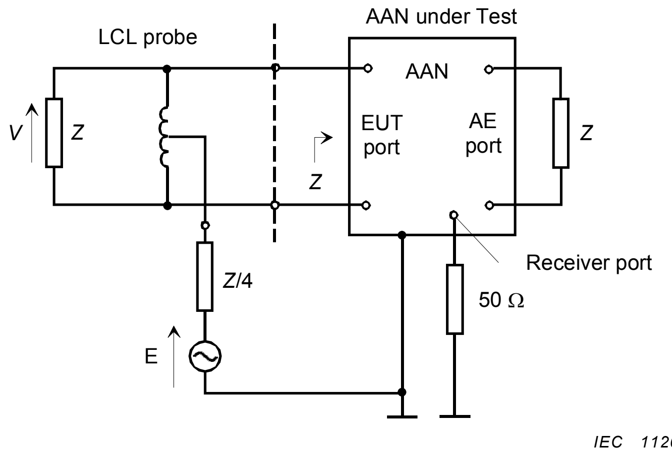
The LCL measurement uncertainty per Figure E.3c is influenced by the accuracy of the L-circuit and the amount of the residual LCL of the probe. Changing the orientation of the LCL probe relative to the L-circuit will show some uncertainty of calibration.

Example of an L-circuit: For an impedance Z = 100 Ω and R_{sym} = 100 Ω, a value

R_{cal} = 750 Ω will give an LCL of 29,97 dB i.e. approximately 30 dB.

Figure E.3b – Test arrangement for the LCL probe calibration (L-circuit)

3) Figures in brackets refer to the reference documents at the end of this annex.



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

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 improve the accuracy of the test.

NOTE 3 If the AAN is of higher order (i.e. more than 1 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.3c –Test arrangement for the LCL measurement of the AAN

Figure E.3 – LCL measurement using an LCL probe including verification and calibration of the probe

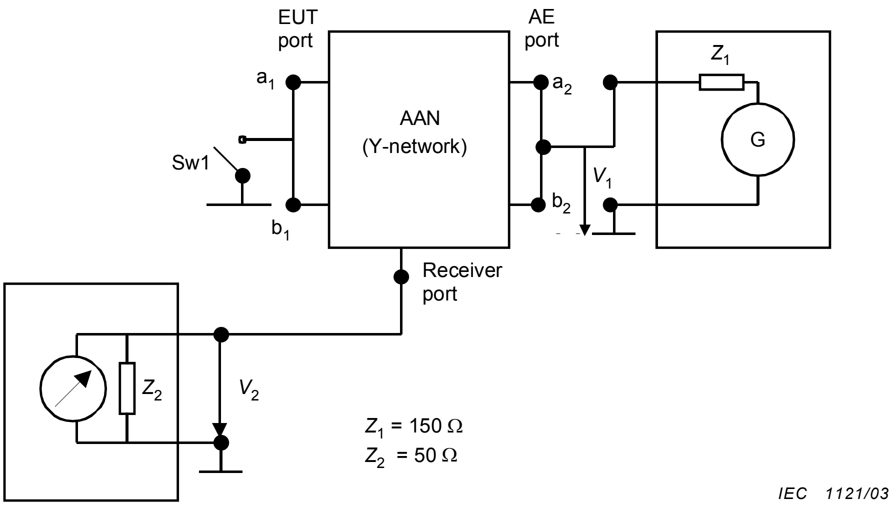
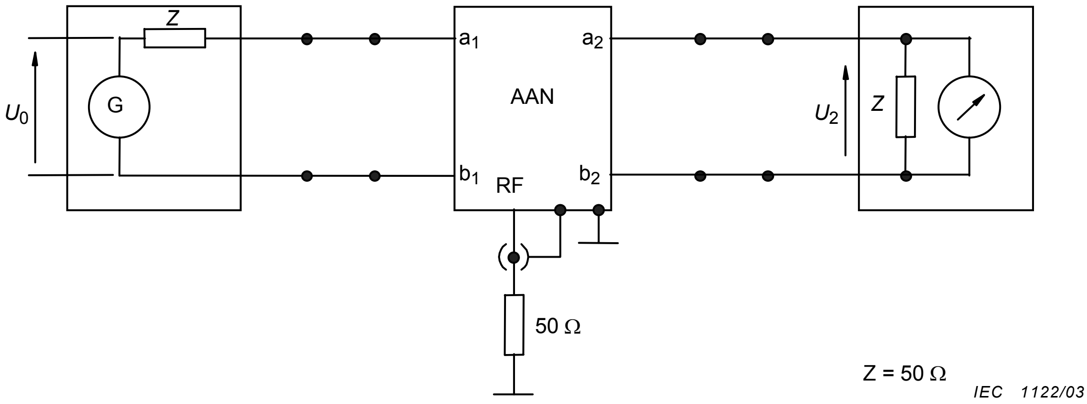


Figure E.4 – Test set-up for the decoupling attenuation (isolation) of the AAN

$$a_{\text{decoup}} = 20 \lg \left| \frac{V_1}{V_2} \right| - a_{\text{vdiv}} \quad \text{in dB}$$

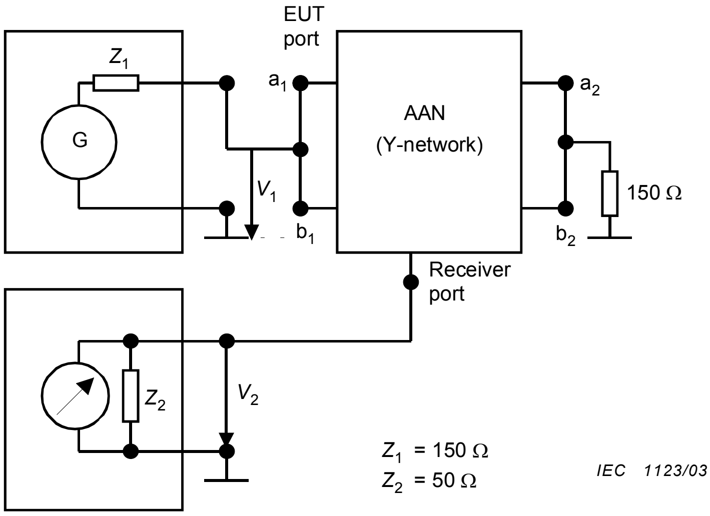
for asymmetric signals between AE port and EUT port



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.5 – Test set-up for the insertion loss (symmetric) of the AAN



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.6 – Calibration test set-up for the AAN voltage division factor

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

E.3 Reference documents

[1] MACFARLANE, IP. 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 no high shielding attenuation is 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.

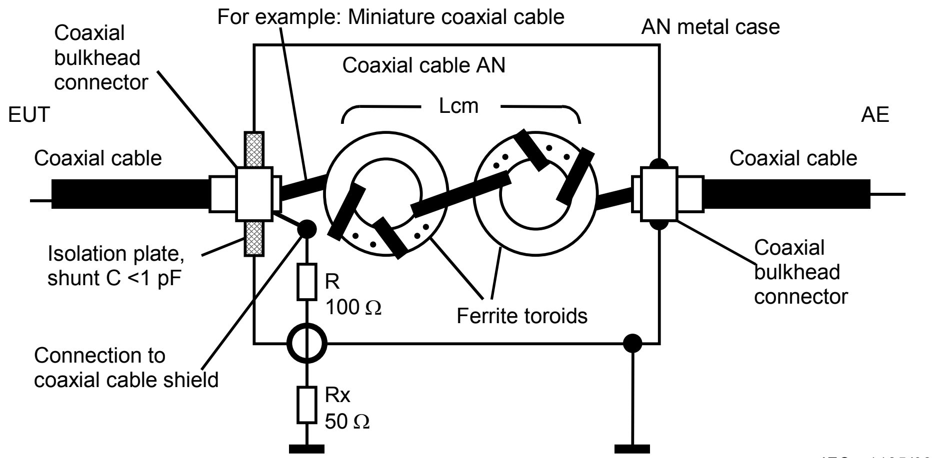
F.2 Measurements of parameters of an AN for coaxial and other screened cables

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.

b) **Voltage-division factor**

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



AE = Associated equipment

EUT = Equipment under test

Rx = Measuring receiver

Common mode choke Lcm >1,4 mH, total parasitic shunt C <1 pF

Figure F.1 – Example of a coaxial cable AN

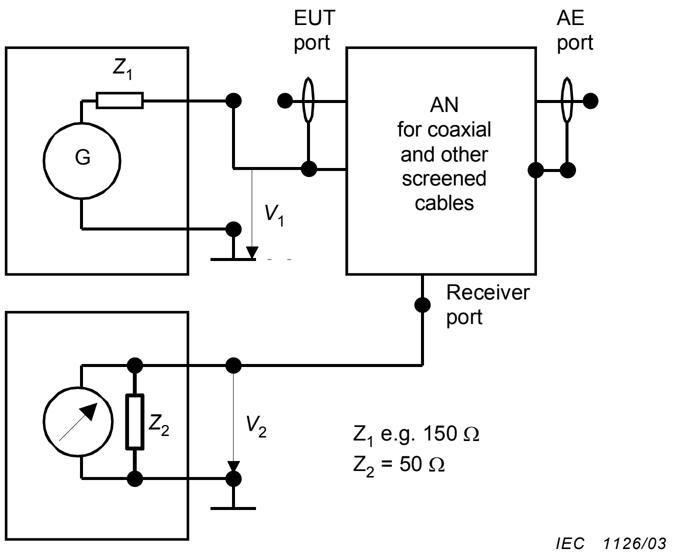


Figure F.2 – Test set-up for the coaxial and screened cable AN voltage division factor $a_{\mathrm{vdiv}} = 20 \lg \left| \frac{V_1}{V_2} \right|$ in dB

Annex G
(informative)

Construction and evaluation of capacitive voltage probe (subclause 5.2.2)

G.0 Introduction

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.1 Physical and electrical considerations for capacitive voltage probe

Figure G.1 shows the configuration of a capacitive voltage probe. It is made up 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.2 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 the capacitive voltage probe. The probe is verified according to the following procedures.

a) Prepare the same type of cable which is used with the equipment under test (EUT).

NOTE If several types of cable are used with the probe, a representative variety of cable types shall be used in the calibration and the spread of results determined. The voltage division factor (F_a) can be estimated by using equation (G.3), however, it is recommended to measure the F_a for each cable.

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 probe in the calibration unit and adjust the position of the cable to pass through the centre.

Caution: If the end of plates of the calibration fixture are too close to the ends of the voltage probe, 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 voltage probe, a standing wave may be formed within the calibration fixture at higher frequencies. These standing waves can adversely affect the calibration.

e) Connect the grounding port of the probe 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 voltage probe 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 probe in 50 Ω. Measure the level *V* over a specified frequency range.

h) Connect the level meter to the output port of the probe and terminate the outer port of the port-2 by 50 Ω. Measure the level *U* over a specified frequency range.

i) Calculate the voltage division factor $F_a = 20 \log_{10}|V/U|$ in dB from the measured values.

G.3 Method of measurement to determine the influence of external electric fields

G.3.1 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 common-mode 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.3.2 shows 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 the V_x unless $|Z_s| << |1/(j\omega C_c)|$.

G.3.2 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, $F_a = 20 \log_{10}|V/U|$, using the method in Clause G.2.

b) Place the capacitive voltage probe 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 Ω output impedance to the outer port of the port-1 through a 10 dB attenuator.

e) Connect a measuring receiver with a 50 Ω input impedance to the outer port of the port-2 and terminate the output port of the probe by 50 Ω. 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 Ω. Measure the level U_s over a specified frequency range.

g) The reduction of the influence is defined as $F_s = F_a/(V_s/U_s)$ from the measured values.

G.4 Pulse response

The capacitive voltage probe is constructed as part of the measuring system which includes the disturbance receiver. It does not affect the performance of the measuring receiver described in Clause 4. The probe response to pulses shall be measured since the capacitive voltage probe contains an active circuit. The response is measured using the pulse generator as described in Annexes B and C of CISPR 16-1-1 for band B.

NOTE 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 may be required 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 response of the pulse generator is 0,316 (mVs) from 0,15 MHz to 30 MHz as shown in Table B.1 of CISPR 16-1-1. The spectrum of the pulse generator signal is practically constant up to 30 MHz. The pulse width, τ, is approximately given by

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

where f_m is 30 MHz. Then, we get τ of 0,0106 μs.

The amplitude of the pulse, A, is given by

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

This indicates that the capacitive voltage probe should maintain linearity up to 30 V.

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

G.5 Voltage division factor dependence

The voltage division factor of the capacitive voltage probe 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.

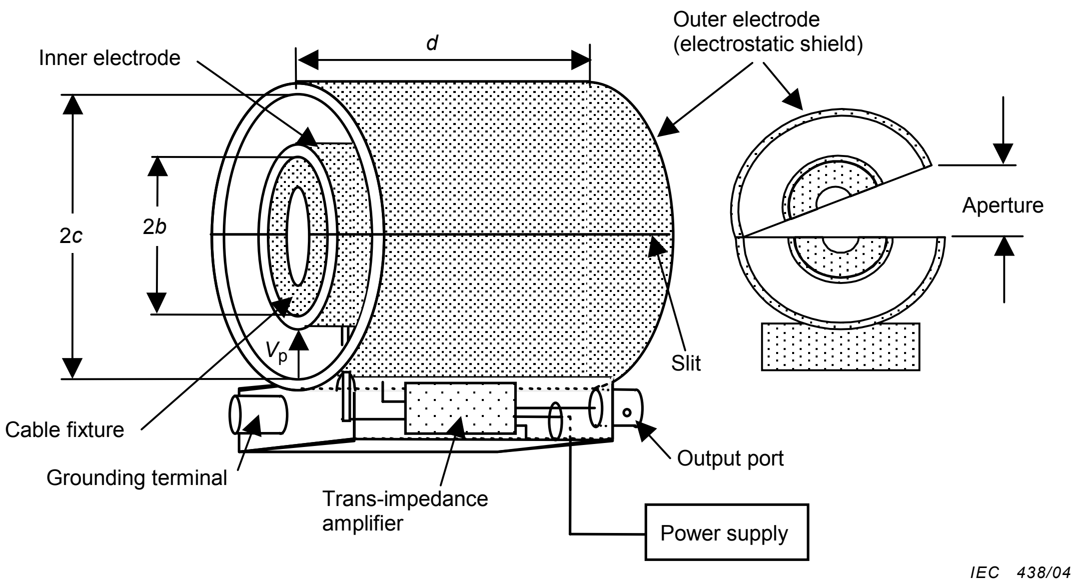
The voltage division factor dependencies were investigated using measurements and a theoretical analysis. Figure G.6 shows the voltage division factor deviation when the cable position changes in the electrode. In Figure G.6, "*a*" is the radius of the cable, "*b*" is the inner radius of the inner electrode, "*c*" is the inner radius of the outer electrode (electrostatic shield), and "*g*" is the distance between the centre of the inner electrode and the centre of the cable. 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 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 capacitive voltage probe, however, does not depend on the variation of the cable position in the inner electrode up to a separation ratio of 0,8. Thus, in order to minimize measurement errors, the cable under test shall be adjusted to pass the centre of the probe.

Figure G.7 shows the cable radius dependence. The vertical axis shows the deviation of the voltage division factor F_a. The solid line shows the calculated results using the following equations:

$$F_a = \frac{\left\{1 + \frac{1}{C_p} \frac{2\pi\varepsilon}{\log_e \frac{b}{a}} d\right\}}{\left\{1 + \frac{1}{C_p} \frac{2\pi\varepsilon}{\log_e \frac{b}{a_{ref}}} d\right\}} \quad \text{(G.3)}$$

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

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. The figure 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.

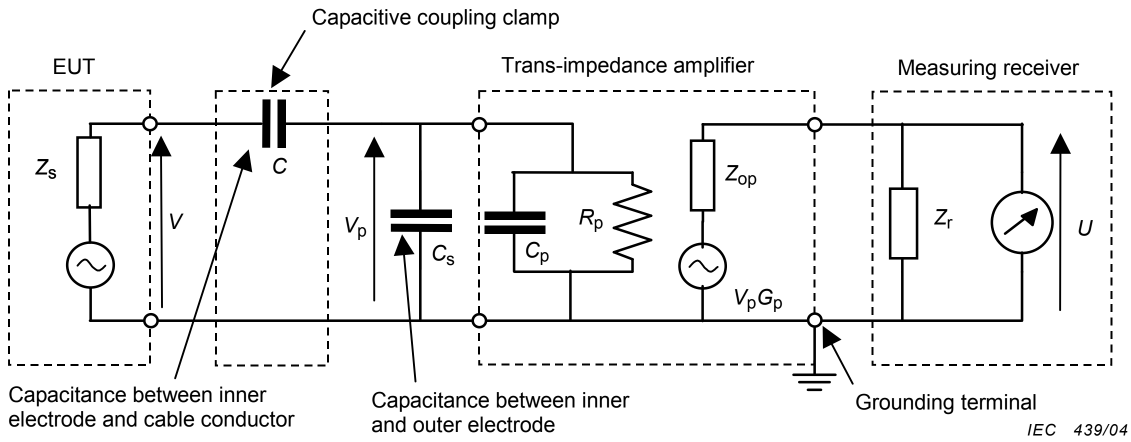


Caution:

1) 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 capacitive voltage probe



Typical values for the configuration shown in Figure G.1

b 25 mm	C_p 5 pF
c 55 mm	R_p 1 MΩ
d 100 mm	$\lvert Z_s \rvert << \lvert 1/(j\omega C) \rvert$
C 8 pF (Cable diameter is 26 mm)	$R_p >> \lvert 1/(j\omega(Cs+Cp)) \rvert$
C_s 7 pF	$Z_{op} = Z_r = 50\ \Omega$

Typical values are not required/specified values, and other combinations consistent with "Characteristics" of 5.1.2 are acceptable.

Figure G.2 – Equivalent circuit of the capacitive voltage probe

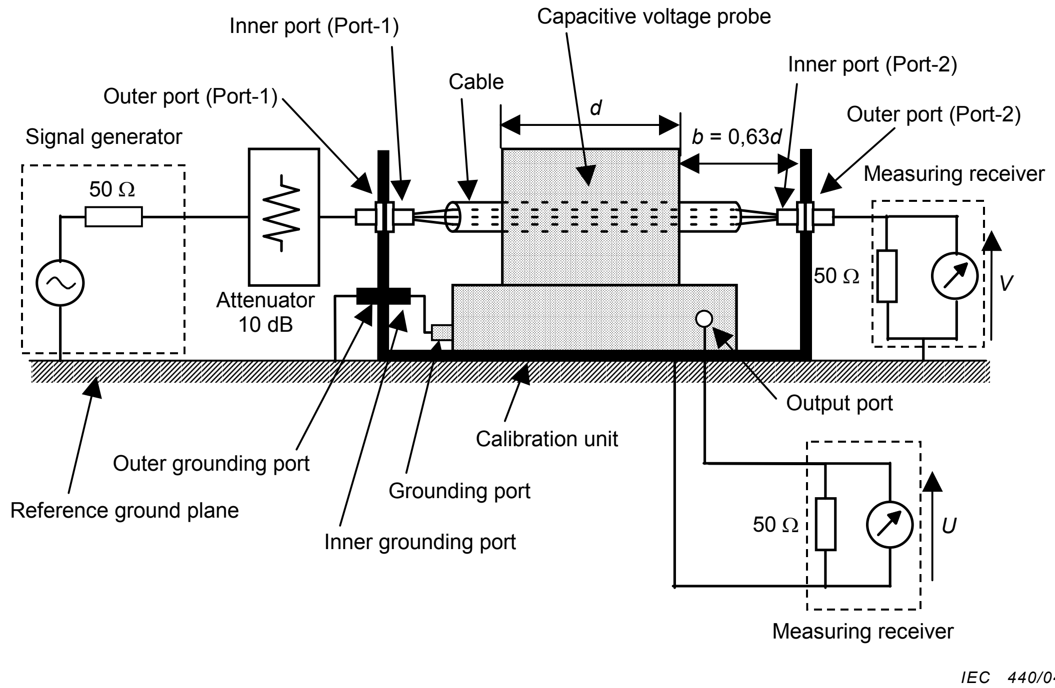
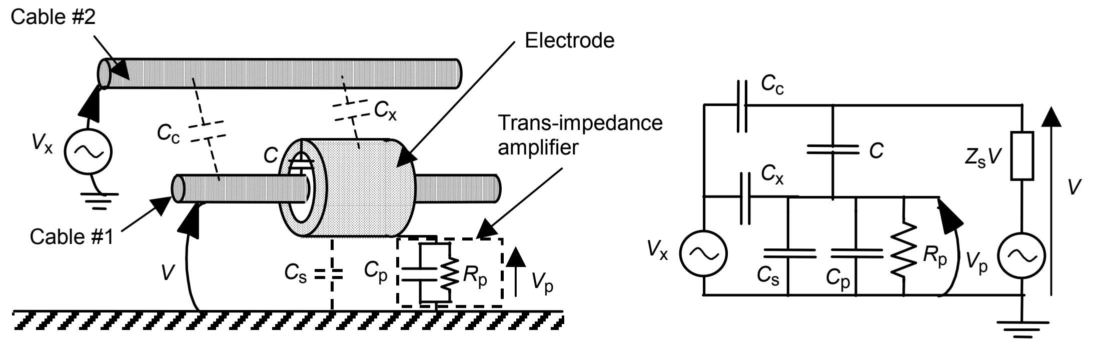
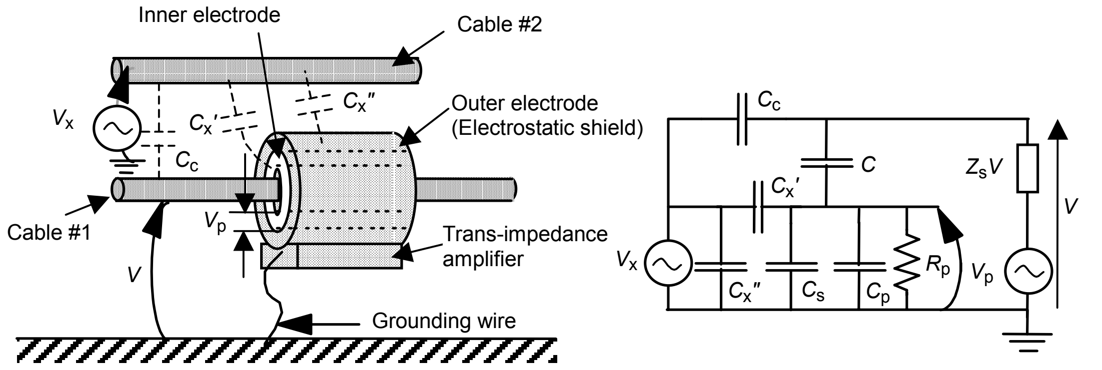


Figure G.3 – Test set-up to calibrate frequency response



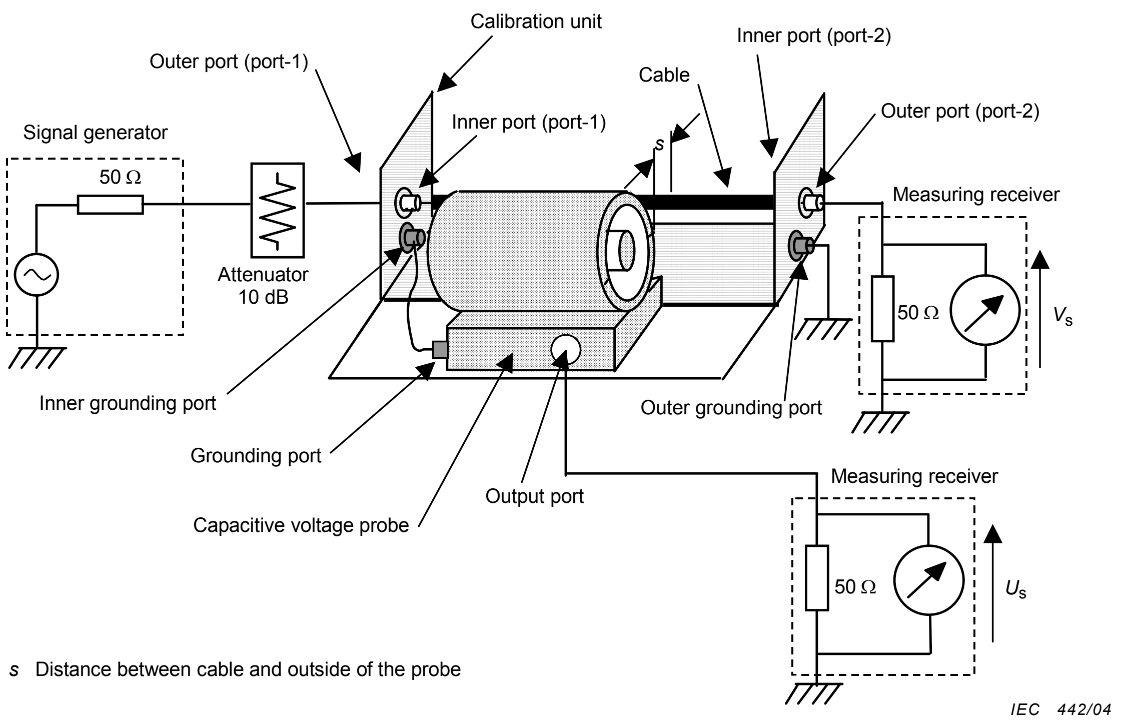
(a) Capacitive voltage probe without electrostatic shield



(b) Capacitive voltage probe with electrostatic shield

IEC 441/04

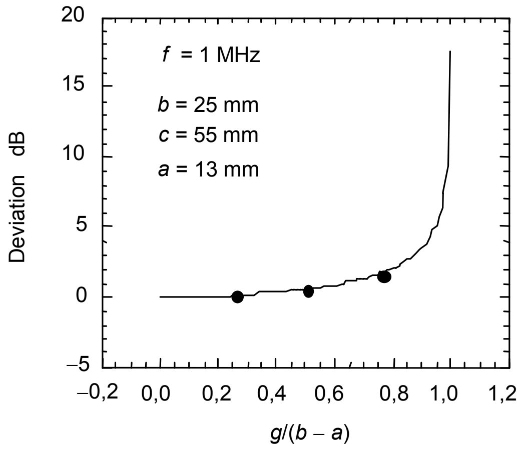
Figure G.4 – Electrostatic coupling model and its equivalent circuit



s Distance between cable and outside of the probe

IEC 442/04

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



Key

a Radius of the cable

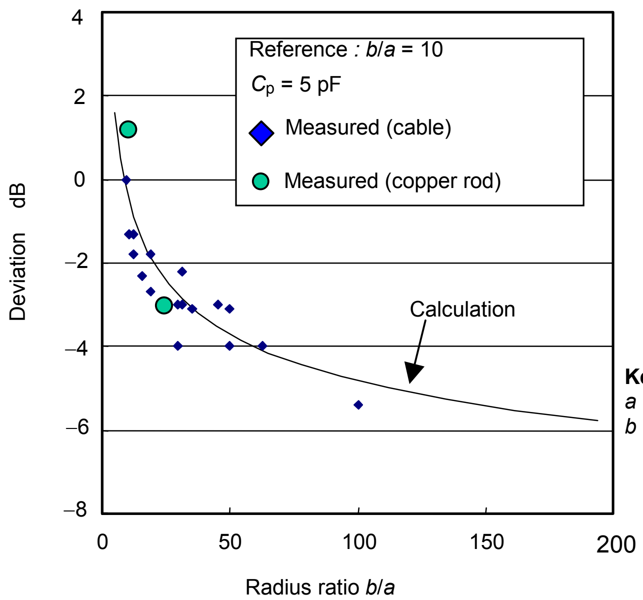
b Inner radius of the inner electrode

c Inner radius of the outer electrode

g Distance between centers of the inner electrode and cable

IEC 443/04

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



Key

a Radius of the cable

b Inner radius of the inner electrode

IEC 444/04

NOTE Vertical axis shows the deviation of the voltage division factor (F_a) from the calculated value when *b/a* is 10.

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