IEC 62153-4-3

Edition 2.0 2013-10

INTERNATIONAL STANDARD

colour inside

Metallic communication cable test methods –
Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method

IEC 62153-4-3:2013(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

Useful links:

IEC publications search - www.iec.ch/searchpub

The advanced search enables you to find IEC publications by a variety of criteria (reference number, text, technical committee,…).
It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available on-line and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary (IEV) on-line.

Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IEC 62153-4-3

Edition 2.0 2013-10

INTERNATIONAL STANDARD

colour inside

Metallic communication cable test methods – Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRICE CODE X

ICS 33.120.10; 33.100

ISBN 978-2-8322-1179-3

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method

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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
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 IEC 62153-4-3 has been prepared by IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This second edition cancels and replaces the first edition published in 2006. This edition constitutes a technical revision.

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

a) now three different test configurations are described;
b) formulas to calculate the maximum frequency up to which the different test configurations can be used are included (Annex E: Cut-off frequency of the triaxial set-up for the measurement of the transfer impedance);
c) the effect of ground loops is described (Annex F: impact of ground loops on low frequency measurements).

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

FDIS	Report on voting
46/471/FDIS	46/482/RVD

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

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

A list of all parts in the IEC 62153 series, published under the general title *Metallic communication cable test methods*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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

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

A bilingual version of this publication may be issued at a later date.

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

INTRODUCTION

IEC 62153 consists of the following parts, under the general title *Metallic communication cable test methods:*

Part 1-1: *Metallic communication cables test methods – Part 1-1: Electrical – Measurement of the pulse/step return loss in the frequency domain using the Inverse Discrete Fourier Transformation (IDFT)*

Part 1-2: *Metallic communication cables test methods – Part 1-2: Electrical – Reflection measurement correction*[1]

Part 4-0: *Metallic communication cable test methods – Part 4-0: Electromagnetic compatibility (EMC) – Relationship between surface transfer impedance and screening attenuation, recommended limits*

Part 4-1: *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements*

Part 4-2: *Metallic communication cable test methods – Part 4-2: Electromagnetic compatibility (EMC) – Screening and coupling attenuation – Injection clamp method*

Part 4-3: *Metallic communication cable test methods – Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method*

Part 4-4: *Metallic communication cable test methods – Part 4-4: Electromagnetic compatibility (EMC) – Shielded screening attenuation, test method for measuring of the screening attenuation as up to and above 3 GHz*

Part 4-5: *Metallic communication cables test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing clamp method*

Part 4-6: *Metallic communication cable test methods – Part 4-6: Electromagnetic compatibility (EMC) – Surface transfer impedance – Line injection method*

Part 4-7: *Metallic communication cable test methods – Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring the transfer impedance and the screening – or the coupling attenuation – Tube in tube method*

Part 4-8: *Metallic communication cable test methods – Part 4-8: Electromagnetic compatibility (EMC) – Capacitive coupling admittance*

Part 4-9: *Metallic communication cable test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method*

Part 4-10: *Metallic communication cable test methods – Part 4-10: Electromagnetic compatibility (EMC) – Shielded screening attenuation test method for measuring the screening effectiveness of feed-throughs and electromagnetic gaskets double coaxial method*

Part 4-11: *Metallic communication cable test methods – Part 4-11: Electromagnetic compatibility (EMC) – Coupling attenuation or screening attenuation of patch cords, coaxial cable assemblies, pre-connectorized cables – Absorbing clamp method*

---

1 Under consideration.

Part 4-12: *Metallic communication cable test methods – Part 4-12: Electromagnetic compatibility (EMC) – Coupling attenuation or screening attenuation of connecting hardware – Absorbing clamp method*

Part 4-13: *Metallic communication cable test methods – Part 4-13: Electromagnetic compatibility (EMC) – Coupling attenuation of links and channels (laboratory conditions) – Absorbing clamp method*

Part 4-14: *Metallic communication cable test methods – Part 4-14: Electromagnetic compatibility (EMC) – Coupling attenuation of cable assemblies (Field conditions) absorbing clamp method*

METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method

1 Scope

This part of IEC 62153 determines the screening effectiveness of a cable shield by applying a well-defined current and voltage to the screen of the cable and measuring the induced voltage in order to determine the surface transfer impedance. This test measures only the magnetic component of the transfer impedance.

NOTE The measurement of the electrostatic component (the capacitance coupling impedance) is described in IEC 62153-4-8 [1][2].

The triaxial method of measurement is in general suitable in the frequency range up to 30 MHz for a 1 m sample length and up to 100 MHz for a 0,3 m sample length, which corresponds to an electrical length less than about 1/6 of the wavelength in the sample.

2 Normative references

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

IEC/TR 62153-4-1:2010, *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) screening measurements*

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

3 Terms and definitions

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

3.1
inner circuit
circuit consisting of the screens and the conductor(s) of the test specimen

Note 1 to entry: Quantities relating to the inner circuit are denoted by the subscript “1”. See Figure 1 and Figure 2.

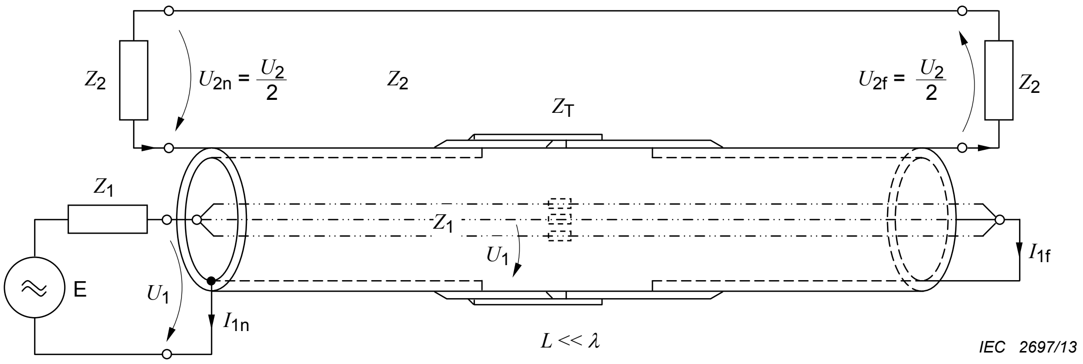
3.2
outer circuit
circuit consisting of the screen surface and the inner surface of a surrounding test jig

[2] Numbers in square brackets refer to the bibliography.

Note 1 to entry: Quantities relating to the outer circuit are denoted by the subscript "2". See Figure 1 and Figure 2.

3.3
transfer impedance
Z**T**

quotient of the longitudinal voltage induced in the matched outer circuit – formed by the screen under test and the measuring jig – and the current fed into the inner circuit or vice versa (see Figure 1)



$$Z_T = \frac{U_2}{I_1}$$

where

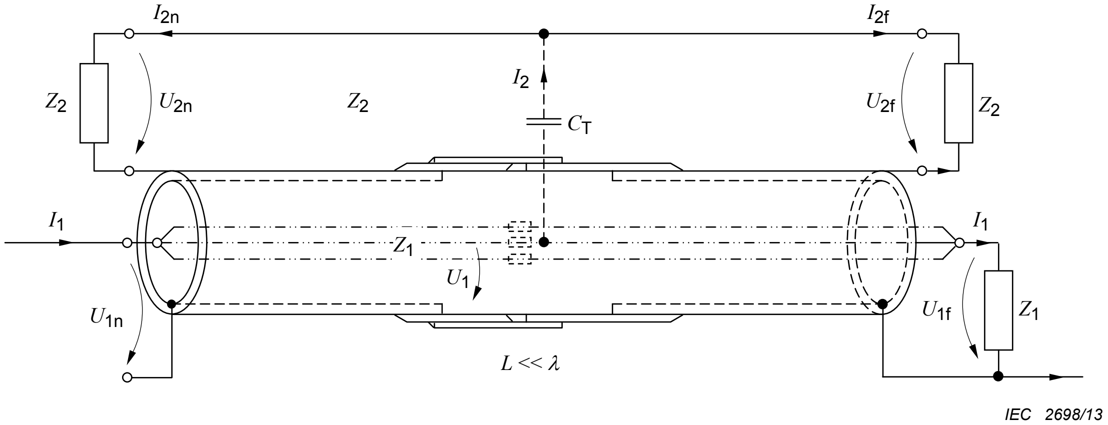
Z_1, Z_2	is the characteristic impedance of the inner and the outer circuits;
U_1, U_2	are the voltages in the inner and the outer circuits (n: near end, f: far end);
I_1	is the current in the inner circuit (n: near end, f: far end);
L	is the length of the cable, respectively the length of the screen under test;
λ	is the wavelength in free space.

Figure 1 – Definition of Z_T

Note 1 to entry: Transfer impedance is expressed in mΩ/m.

3.4
capacitive coupling impedance
Z**F**

quotient of twice the voltage induced to the terminating impedance Z_2 of the matched outer circuit by a current I_1 fed (without returning over the screen) to the inner circuit and the current I_1 or vice versa (see Figure 2)



$I_{2n} = I_{2f}$

$U_{1n} = U_{1f}$

$I_{2n} = I_{2f} = (1/2) \times I_2 = I_2/2$

$I_2 = I_{2n} + I_{2f}$

$$Z_F = \frac{U_{2n} + U_{2f}}{I_1} = \frac{2U_{2f}}{I_1} = Z_1 Z_2 \times j\omega C_T$$

where

Z_1, Z_2	is the characteristic impedance of the inner and the outer circuits;
U_1, U_2	are the voltages in the inner and the outer circuits (n: near end, f: far end);
I_1	is the current in the inner circuit (n: near end, f: far end);
I_2	is the current in the outer circuit (n: near end, f: far end);
C_T	is the coupling capacitance;
L	is the length of the cable, respectively the length of the screen under test;
λ	is the wavelength in free space.

Figure 2 – Definition of Z_F

Note 1 to entry: Capacitive coupling impedance is expressed in mΩ/m

3.5
effective transfer impedance
$\boldsymbol{Z_{TE}}$

3.5.1
effective transfer impedance
$\boldsymbol{Z_{TE}}$
maximum absolute value of the sum or difference of the Z_F and Z_T at every frequency

$$Z_{TE} = \max\left|Z_F \pm Z_T\right|$$

Note 1 to entry: The effective transfer impedance is expressed in Ω.

3.5.2
effective transfer impedance related to a reference impedance of 1 Ω
$\boldsymbol{Z_{TE}}$
maximum absolute value of the sum or difference of the Z_F and Z_T at every frequency expressed in dB (Ω)

$$Z_{TE} = +20 \times \log_{10}\left(\frac{|Z_{TE}|}{Z_{T,ref}}\right)$$

where

$Z_{T,ref}$ is the reference transfer impedance with a value of 1 Ω.

Note 1 to entry: The effective transfer impedance is expressed in dB (Ω).

3.6
coupling length
L_c
length of cable which is inside the test jig, i.e. the length of the screen under test

Note 1 to entry: The coupling length together with the test method has an impact on the maximum frequency up to which the transfer impedance could be measured. A detailed description can be found in Clause 8 of IEC/TR 62153-4-1:2010.

3.7
cut-off frequency
maximum frequency up to which the transfer impedance can be measured

Note 1 to entry: The cut-off frequency varies with the coupling length and the used test method. A detailed description can be found in Clause 8 of IEC/TR 62153-4-1:2010. The calculation of the cut-off frequency is described in Annex E.

4 Principle

The test determines the screening effectiveness of a shielded cable by applying a well-defined current and voltage to the screen of the cable and measuring the induced voltage in a secondary circuit in order to determine the surface transfer impedance. This test measures only the magnetic component of the transfer impedance. The measurement of the electrostatic component (the capacitance coupling impedance) is described in IEC 62153-4-8.

The triaxial method of measurement is in general suitable in the frequency range up to 30 MHz for a 1 m sample length and up to 100 MHz for a 0,3 m sample length, which corresponds to an electrical length less than 1/6 of the wavelength in the sample. A detailed description can be found in Clause 8 of IEC/TR 62153-4-1:2010.

5 Test methods

5.1 General

The measurements shall be carried out at the temperature of (23 ± 3) °C.

The test method determines the transfer impedance of a cable by measuring the cable in a triaxial test set-up. The triaxial set-up can be realised by a rigid tube or by using a milked on braid. Different methods using different load conditions are possible and are described below. All the different methods give the same results up to their corresponding cut-off frequency.

5.2 Test equipment

The measurements can be performed using a vector network analyser (VNA) or alternatively a separate signal generator and a selective measuring receiver.

The measuring equipment consists of the following:

a) a vector network analyser (with an S-parameter test set); or alternatively

- a signal generator with the same characteristic impedance as the coaxial system of the cable under test or with an impedance adapter and complemented with a power amplifier if necessary for very high screening attenuation;
- a receiver with optional low noise amplifier for very high screening attenuation;
- the generator and receiver shall have the same system impedance:

  $Z_G = Z_R = Z_0$

b) impedance matching circuit if necessary

- primary side: nominal impedance of generator;
- secondary side: nominal impedance of the inner circuit;
- return loss: >10 dB.

Optional equipments are:

1) time domain reflectometer (TDR) with a rise time of less than 200 ps or a network analyser with maximum frequency up to 5 GHz and time domain capability;
2) plotter.

5.3 Calibration procedure

The calibration shall be established at the same frequency points at which the measurement of the transfer impedance is done, i.e. in a logarithmic frequency sweep over the whole frequency range, which is specified for the transfer impedance.

When using a vector network analyser with an S-parameter test set, a full two-port calibration shall be established including the connecting cables used to connect the test set-up to the test equipment. The reference planes for the calibration are the connector interface of the connecting cables.

When using a (vector) network analyser without an S-parameter test set, i.e. by using a power splitter, a THRU calibration shall be established including the connecting cables used to connect the test set-up to the test equipment.

When using a separate signal generator and receiver, the composite loss of the connecting cables shall be measured and the calibration data shall be saved, so that the results may be corrected.

$$a_{cal} = 10\log_{10}\left(\frac{P_1}{P_2}\right) = -20\log_{10}(S_{21}) \qquad (1)$$

where

P_1 is the power fed during the calibration procedure;

P_2 is the power at the receiver during the calibration procedure.

If amplifiers are used, their gain shall be measured over the above-mentioned frequency range and the data shall be saved.

If an impedance matching adapter is used, the attenuation shall be measured over the above-mentioned frequency range and the data shall be saved (see Annex B).

5.4 Sample preparation

The test sample shall have a length not more than 50 % longer than the coupling length.

Coaxial cables are prepared as shown in Figure 3.

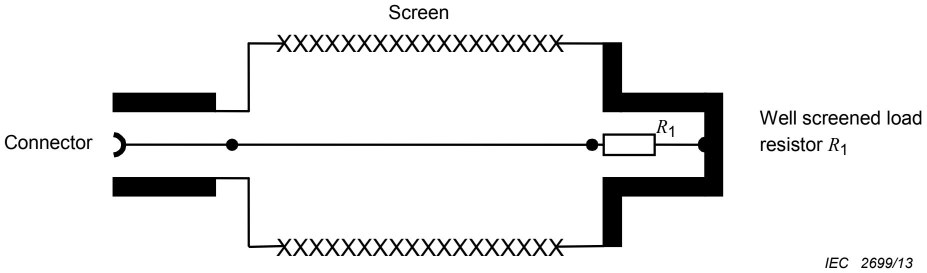


Figure 3 – Preparation of test sample for coaxial cables

One end of the coaxial cable is loaded with a well-screened resistor, R_1. The value of R_1 depends on the test method used (as detailed below), i.e. either a short circuit or equal to the characteristic impedance of the inner circuit, Z_1, or equal to the generator impedance. R_1 is chosen as a standard value resistor, whose resistance is close (within 10 %) to Z_1.

The other end is prepared with a connector to make a connection to the generator or the impedance matching adapter (depending on the used method). All connections shall be made so that the R.F.-contact resistance can be neglected with respect to the results.

Screened symmetrical cables are treated as a quasi-coaxial system. Therefore, the conductors of all pairs/quads shall be connected together at both ends (other configurations of connection are under study). All screens, including those of individually screened pairs/quads, shall be connected together at both ends. The screens shall be connected over the whole circumference. See also Figure 4.

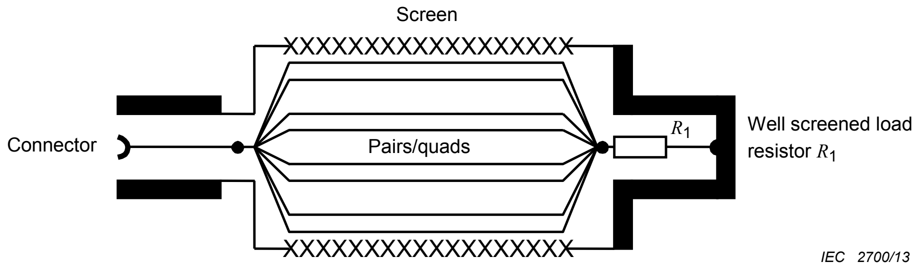


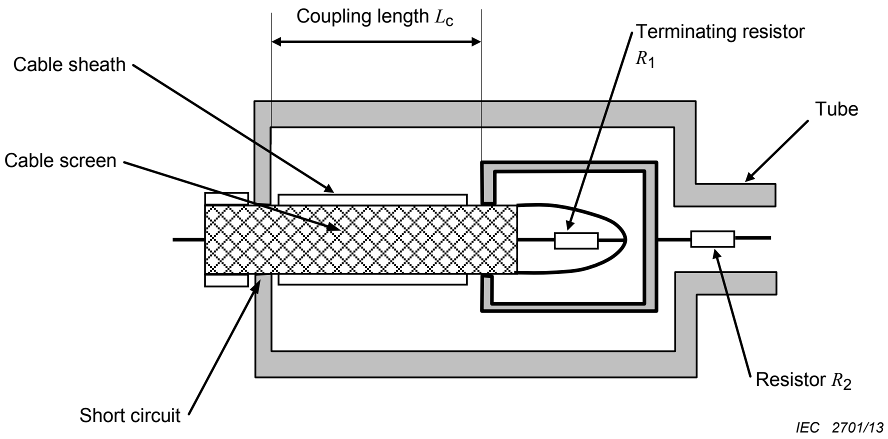
Figure 4 – Preparation of test sample for symmetrical cables

5.5 Test set-up

The test sample shall be fitted to the test set-up. The test set-up is an apparatus of a triple coaxial form. The cable screen forms both the outer conductor of the inner circuit and the inner conductor of the outer circuit.

In the rigid set-up, the outer conductor of the outer circuit is a well-conductive tube of non-ferromagnetic metal (for example brass, copper or aluminium) with a short circuit to the screen on the fed side of the cable (see Figure 5).

In the flexible set-up, the outer conductor of the outer circuit is a tinned copper braid having a coverage >70 % and braid angle <30° which is pulled over the entire length of the cable under test (see Annex C).



R_1 is the terminating resistor. The value of R_1 depends on the test method used, i.e. either a short circuit or equal to the characteristic impedance of the inner circuit, Z_1 or equal to the generator impedance as detailed in the corresponding test method.

R_2 is the damping resistor. The value of R_2 depends on the test method used, i.e. either a short circuit or a value as a function of the impedance of the outer circuit as detailed in the corresponding test method.

Figure 5 – Connection to the tube

5.6 Test configurations

5.6.1 General

Depending on the available test equipment, different test configurations are available which may – depending on the test method used – have an impact on how to convert the measured values into the transfer impedance (see Annex D).

5.6.2 Vector network analyser with S-parameter test set

Nowadays, the common test configuration is to use a vector network analyser with an S-parameter test set (see Figure 6).

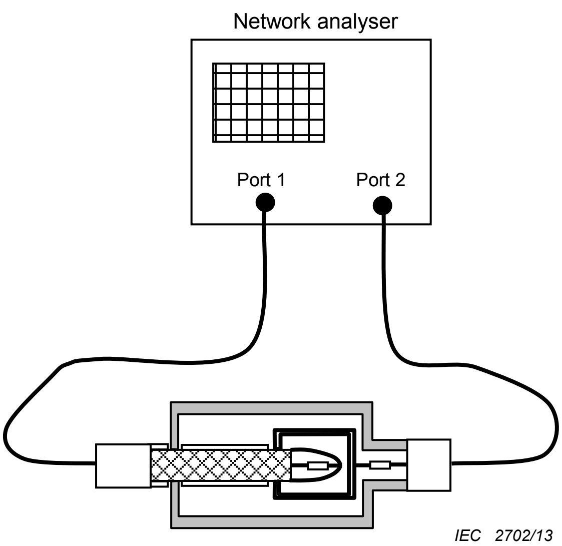


Figure 6 – Test set-up using a vector network analyser with the S-parameter test set

5.6.3 (Vector) network analyser with power splitter

If an S-parameter test set is not available, one can use a power splitter (see Figure 8). Power splitters can be either a 2-resistor or a 3-resistor type (see Figure 7). When using the test method feeding into a short (see Clause 8), the conversion from the measured scattering parameter S_{21} to the transfer impedance will depend on the power splitter type used.

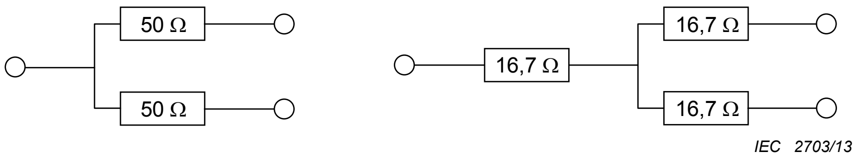


Figure 7 – 50 Ω power splitter, 2- and 3-resistor types

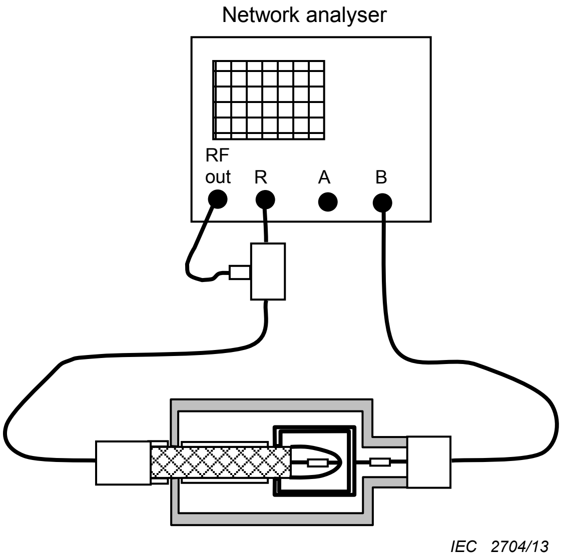


Figure 8 – Test set-up using a network analyser (NA) and a power splitter

5.6.4 Separate signal generator and receiver

When measuring very good screens having very low transfer impedance, the test results could be prone to error at low frequencies due to ground loops. To avoid those ground loops, one could use a separate generator and receiver which are either battery-driven or connected to the power supply using disconnecting transformers (see Figure 9).

When using the test methods where the power is fed into a short (see Clause 8), one can feed the power via a feeding resistor (the value of which is equal to the generator impedance) in order to avoid damage of the generator (see Figure 10).

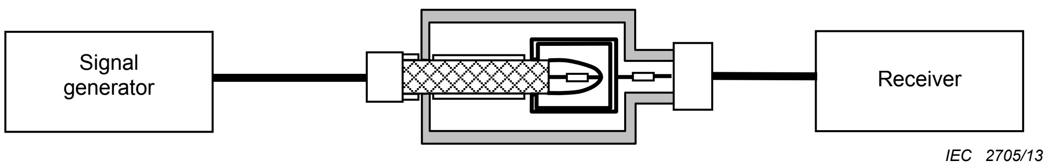


Figure 9 – Test set-up using a signal generator and a receiver

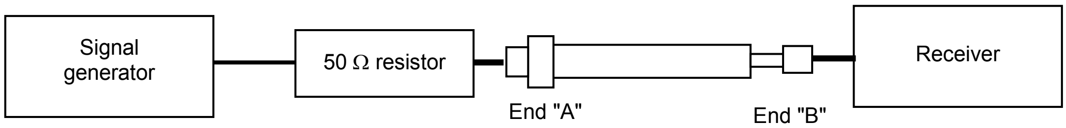


Figure 10 – Test set-up using a signal generator and a receiver with feeding resistor

5.7 Expression of test results

5.7.1 Expression

The values of the transfer impedance are expressed as mΩ/m at the frequencies for which requirements are specified in the relevant cable specifications.

5.7.2 Test report

The test report shall record the test results and shall conclude if the requirements of the relevant cable specification are met.

6 Test method A: Matched inner circuit with damping resistor in outer circuit

6.1 General

In this method, the inner circuit (cable) is terminated on a matched termination ($R_1 = Z_1$) and is considered as the disturbing circuit (i.e. it is fed by the generator). If the impedance of the inner circuit is unknown, it may be measured as described in Annex A.

The outer circuit is short-circuited on the near-end side on the cable shield and connected to the receiver on the far end via a damping resistor R_2.

If the impedance of the inner circuit is different from the generator impedance, then an impedance matching adapter is used (see Annex B).

The advantage of this method is that it has a high cut-off frequency. However, the use of the damping resistor and impedance matching adapters reduces the dynamic range.

NOTE This method is usually used with the rigid set-up.

6.2 Damping resistor R_2

To obtain the maximum flat bandwidth of the set-up by means of critical damping, the resistor R_2 should be incorporated at the far end of the outer circuit. The value of the resistor is:

$$R_2 = A \times 60 \ln\left(\frac{D}{d}\right) - 50 \qquad (2)$$

$$A = \sqrt{2} \text{ or } A = \sqrt{\frac{\varepsilon_{r1}}{\varepsilon_{r2}}}$$

where

D is the inner diameter of the tube;

d is the outer diameter of the cable screen;

ε_{r1} is the permittivity of the inner circuit;

ε_{r2} is the permittivity of the outer circuit.

6.3 Cut-off frequency

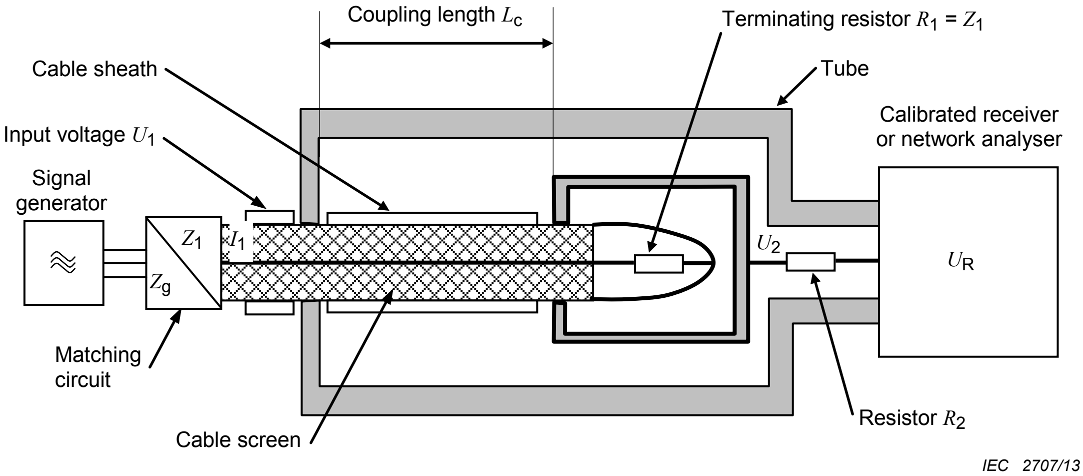
The cut-off frequency length product of this test method is (for details, see Clause 8 of IEC/TR 62153-4-1:2010):

$$f_{\mathrm{cut}} \times L \approx 80\,\mathrm{MHz} \times \mathrm{m} \qquad (3)$$

i.e. for a coupling length of 0,5 m the maximum frequency up to which the transfer impedance could be measured is 160 MHz.

6.4 Block diagram of the set-up

A block diagram of the test set-up is shown in Figure 11.



Key

Z_g impedance of the generator
Z_1 impedance of the cable under test
U_1 input voltage in the inner circuit
U_2 voltage in the outer circuit
U_R voltage measured by the receiver
L_c coupling length
R_1 terminating resistor in the inner circuit
R_2 damping resistor
I_1 current in the cable screen

Figure 11 – Test set-up (principle)

6.5 Measuring procedure

The test sample shall be connected to the generator and the outer circuit (tube) to the receiver.

The attenuation, a_{meas}, shall be preferably measured in a logarithmic frequency sweep over the whole frequency range, which is specified for the transfer impedance and at the same frequency points as for the calibration procedure:

$$a_{\mathrm{meas}} = 10\log_{10}\left(\frac{P_1}{P_2}\right) = -20\log_{10}\left(S_{21}\right) \qquad (4)$$

where

P_1 is the power fed to inner circuit;

P_2 is the power in the outer circuit.

6.6 Evaluation of test results

The conversion from the measured attenuation to the transfer impedance is given by the following formula:

$$Z_T = \frac{R_1(Z_0 + R_2)}{Z_0 L_c} 10^{-\left\{\frac{a_{meas} - a_{cal} - \left(a_{pad} + 10\log_{10}\left(\frac{Z_0}{Z_1}\right)\right)}{20}\right\}} \quad (5)$$

where

Z_0 is the system impedance (in general 50 Ω);

Z_1 is the characteristic impedance of the inner circuit;

Z_T is the transfer impedance;

a_{meas} is the attenuation measured at the measuring procedure;

a_{cal} is the attenuation of the connection cables if not eliminated by the calibration procedure of the test equipment;

a_{pad} is the attenuation of the impedance matching adapter;

L_c is the coupling length;

R_1 is the terminating resistor in the inner circuit;

R_2 is the series resistor in the outer circuit.

7 Test method B: Inner circuit with load resistor and outer circuit without damping resistor

7.1 General

This method is the same as Clause 6, however without the use of the impedance matching adapter and without the damping resistor R_2. It has a higher dynamic range.

The load resistor shall be either equal to the impedance of the inner circuit or be equal to the generator impedance. The latter case is of interest when using a network analyser with power splitter instead of S-parameter test set.

7.2 Cut-off frequency

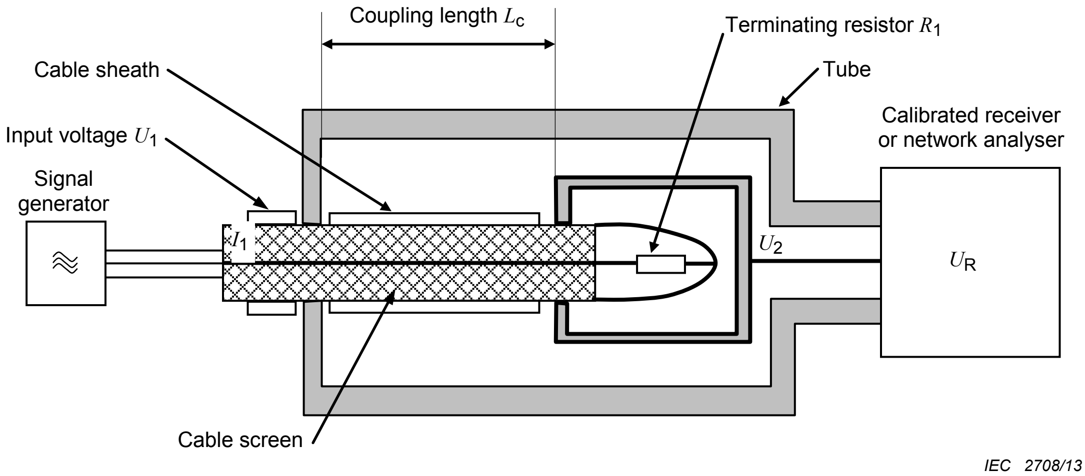
The cut-off frequency length product of this test method is:

$$f_{cut} \times L \approx 25 \text{MHz} \times \text{m} \quad (6)$$

i.e. for a coupling length of 0,5 m the maximum frequency up to which the transfer impedance could be measured is 50 MHz.

7.3 Block diagram of the set-up

A block diagram of the test set-up is shown in Figure 12.



Key

U_1 input voltage in the inner circuit

U_2 voltage in the outer circuit

U_R voltage measured by the receiver

L_c coupling length

R_1 terminating resistor in the inner circuit

I_1 current in the cable screen

Figure 12 – Test set-up (principle)

7.4 Measuring procedure

The test sample shall be connected to the generator and the outer circuit (tube) to the receiver.

The attenuation, a_{meas}, shall be preferably measured in a logarithmic frequency sweep over the whole frequency range, which is specified for the transfer impedance and at the same frequency points as for the calibration procedure:

$$a_{meas} = 10\log_{10}\left(\frac{P_1}{P_2}\right) = -20\log_{10}\left(S_{21}\right) \tag{7}$$

where

P_1 is the power fed to the inner circuit;

P_2 is the power in the outer circuit.

7.5 Evaluation of test results

The conversion from the measured attenuation to the transfer impedance is given by the following formula:

$$Z_T = \frac{R_1 + Z_0}{2L_c} 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}} \tag{8}$$

where

Z_T is the transfer impedance;

Z_0 is the system impedance (in general 50 Ω);

a_{meas} is the attenuation measured at measuring procedure;

a_{cal} is the attenuation of the connection cables if not eliminated by the calibration procedure of the test equipment;

L_c is the coupling length;

R_1 is the terminating resistor in inner circuit (either equal to the impedance of the inner circuit or the impedance of the generator).

8 Test method C: (Mismatched)-Short-Short without damping resistor

8.1 General

In this method, both the inner and the outer circuits are short-circuited on one side, i.e. the damping resistor R_2 and the terminating resistor R_1 (see Figure 5) are replaced by short circuits. An impedance matching adapter is not used.

The generator feeds the outer circuit at the near end and the inner circuit (the cable under test) is connected to the receiver at the far end. In this set-up, the influence of the capacitive coupling is suppressed by the short circuits in the primary and secondary circuit. It is also very sensitive and thus suitable to measure very low values of the transfer impedance (down to 1 μΩ/m and less). Using a milked on braid as described below allows the measurement of the transfer impedance of cable under test before, during and after mechanical tests.

NOTE This method can be used either with the rigid or the flexible (milked on braid) set-up.

8.2 Cut-off frequency

The cut-off frequency length product of this test method is for the rigid set-up:

$$f_{cut} \times L \approx 30\,\text{MHz} \times \text{m} \tag{9}$$

i.e. for a coupling length of 0,5 m, the maximum frequency up to which the transfer impedance could be measured is 60 MHz.

The cut-off frequency length product of this test method is for the flexible (milked on braid) set-up:

$$f_{cut} \times L \approx 20\,\text{MHz} \times \text{m} \tag{10}$$

i.e. for a coupling length of 0,5 m the maximum frequency up to which the transfer impedance could be measured is 40 MHz.

8.3 Block diagram of the set-up

A block diagram of the test set-up is shown in Figure 13.

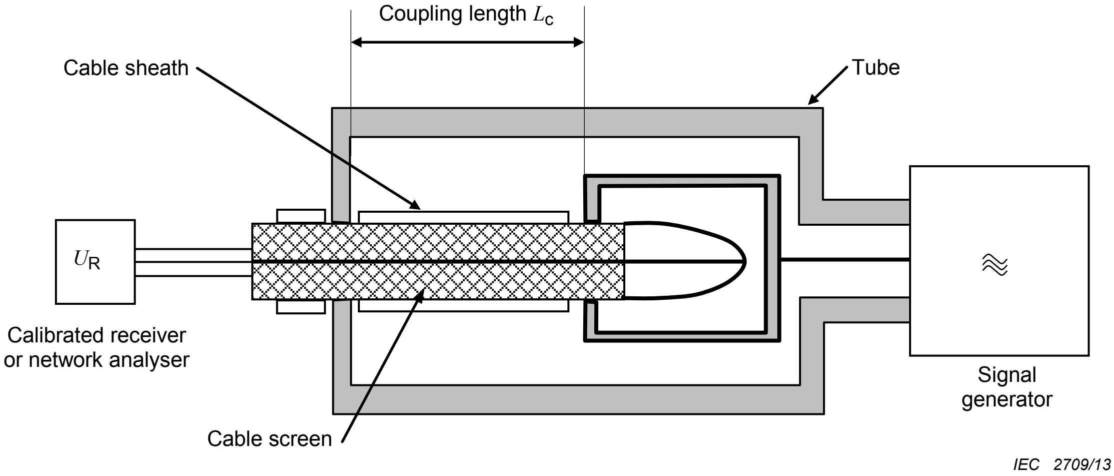


Figure 13 – Test set-up (principle)

8.4 Measuring procedure

The outer circuit (tube) shall be connected to the generator and the inner circuit (cable) to the receiver. In the flexible (milked on braid) set-up, the outer circuit corresponds to end “A” and the inner circuit to end “B” (see Annex C).

The attenuation, a_{meas}, shall be preferably measured in a logarithmic frequency sweep over the whole frequency range, which is specified for the transfer impedance and at the same frequency points as for the calibration procedure:

$$a_{meas} = 10\log_{10}\left(\frac{P_1}{P_2}\right) = -20\log_{10}(S_{21}) \tag{11}$$

where

P_1 is the power fed to the inner circuit;

P_2 is the power in the outer circuit.

8.5 Evaluation of test results

The conversion from the measured attenuation to the transfer impedance depends on the test configuration:

Vector network analyser with S-parameter test set without additional feeding resistors:

$$Z_T = \frac{Z_0}{2L_c} 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}} \tag{12}$$

(Vector) network analyser with 2-resistor power splitter on the generator side:

$$Z_T = \frac{Z_0}{2L_c} 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}} \tag{13}$$

(Vector) network analyser with 3-resistor power splitter on the generator side:

$$Z_T = \frac{Z_0}{4L_c} 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}} \tag{14}$$

Feeding of the power via a feeding resistor (having a value equal to the impedance of the generator), either with a separate signal generator and receiver or with a vector network analyser with an S-parameter test set or with a power splitter:

$$Z_T = \frac{Z_0}{L_c} 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}} \tag{15}$$

where

Z_T is the transfer impedance;

Z_0 is the system impedance (in general 50 Ω);

a_{meas} is the attenuation measured at measuring procedure;

a_{cal} is the attenuation of the connection cables if not eliminated by the calibration procedure of the test equipment;

L_c is the coupling length.

Annex A
(normative)

Determination of the impedance of the inner circuit

A.1 Impedance of inner circuit

If the impedance Z_1 of the inner circuit is not known, it may be determined using a TDR or using the following method with a (vector) network analyser (VNA).

One end of the prepared sample is connected to the VNA, which is calibrated for impedance measurements at the connector interface reference plane. The test frequency shall be the approximately the frequency for which the length of the sample is 1/8 λ, where λ is the wavelength.

$$f_{\text{test}} \approx \frac{c}{8 \times L_{\text{sample}} \times \sqrt{\varepsilon_{\text{r1}}}} \tag{A.1}$$

where

f_{test} is the test frequency;

c is the speed of light 3×10^8 m/s;

ε_{r1} is the permittivity of the inner circuit;

L_{sample} is the length of sample.

The sample is short-circuited at the far end. The impedance Z_{short} is measured.

The sample is left open at the same point where it was shorted. The impedance Z_{open} is measured.

Z_1 is calculated as:

$$Z_1 = \sqrt{Z_{\text{short}} \times Z_{\text{open}}} \tag{A.2}$$

Annex B
(normative)

Impedance matching adapter

B.1 Design of the impedance matching circuit

B.1.1 General

An impedance matching circuit shall be implemented as a two-resistor circuit with one series resistor, R_s and one parallel resistor, R_p (commercial adapters are available for some impedance combinations, for example 50/75 Ω).

B.1.2 Secondary impedance Z_2 lower than primary impedance Z_1

If the secondary impedance Z_2 is lower than the primary impedance Z_1, the formulae below are used:

$$R_s = Z_1\sqrt{1-\frac{Z_2}{Z_1}} \tag{B.1}$$

$$R_p = \frac{Z_2}{\sqrt{1-\frac{Z_2}{Z_1}}} \tag{B.2}$$

The configuration is depicted in Figure B.1.

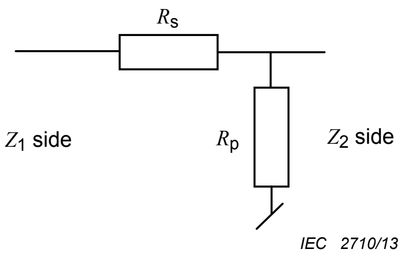


Figure B.1 – Impedance matching for $Z_2 < Z_1$

The voltage gain, k_m, of the circuit is:

$$k_m = \frac{Z_2 R_p}{Z_2 R_p + R_p R_s + Z_2 R_s} \tag{B.3}$$

The scattering parameter S_{21} of the circuit is:

$$S_{21} = \frac{2R_p\sqrt{Z_1 Z_2}}{(R_s + R_p + Z_1)(R_p + Z_2) - R_p^2} \tag{B.4}$$

B.1.3 Secondary impedance Z_2 higher than primary impedance Z_1

If the secondary impedance Z_2 is higher than the primary impedance Z_1, the formulae below are used:

$$R_s = Z_2\sqrt{1-\frac{Z_1}{Z_2}} \tag{B.5}$$

$$R_p = \frac{Z_1}{\sqrt{1-\frac{Z_1}{Z_2}}} \tag{B.6}$$

The configuration is depicted in Figure B.2.

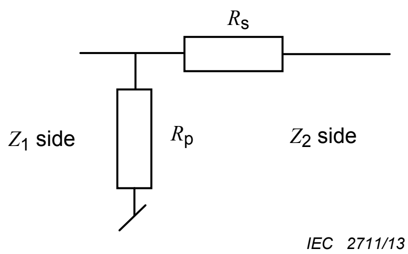


Figure B.2 – Impedance matching for $Z_2 > Z_1$

The voltage gain, k_m, of the circuit is:

$$k_m = \frac{Z_2}{R_s + Z_2} \tag{B.7}$$

The scattering parameter S_{21} of the circuit is:

$$S_{21} = \frac{2R_p\sqrt{Z_1Z_2}}{(R_s + R_p + Z_2)(R_p + Z_1) - R_p^2} \tag{B.8}$$

B.2 Frequency response of the impedance matching circuit

B.2.1 General

The formulae given above ((B.3), (B.4), (B.7), (B.8)) for the calculation of the voltage gain and scattering parameter give sufficient results at low frequencies. However, at higher frequencies, one has to take into account stray inductances and capacitances. Therefore the parameters of the impedance matching adapter may not just be calculated but need to be measured over the frequency range of interest.

B.2.2 Measurement using two identical impedance matching adapters

In the case where two identical impedance matching adapters are available – for example when using commercial available coaxial impedance matching adapters from 50 Ω to 75 Ω – one may obtain the attenuation of one adapter by measuring the scattering parameter S_{21} of two adapters connected together. The attenuation of one adapter is then the half of the measured S_{21}.

B.2.3 Measurement using the open/short method

In general – especially when using homemade impedance matching adapters – it is difficult (impossible) to build two identical adapters. In this case, the attenuation of an adapter may be obtained from an open/short measurement, i.e. by measuring the input impedance on the primary side of the adapter when a) the secondary side is open and b) the secondary side is short-circuited. The attenuation can be obtained from the following formula:

$$\gamma = \alpha + j\beta = ar\tanh\sqrt{\frac{Z_s}{Z_o}} \tag{B.9}$$

where

γ is the wave propagation constant of the impedance matching adapter;

α is the attenuation constant of the impedance matching adapter in Nepers;

β is the phase constant of the impedance matching adapter in radians;

Z_o is the input impedance on the primary side of the adapter when the secondary side is open-circuited;

Z_s is the input impedance on the primary side of the adapter when the secondary side is short-circuited.

B.2.4 Example of a coaxial 50 Ω to 75 Ω impedance matching adapter

Coaxial impedance matching adapters from 50 Ω to 75 Ω are commercially available with an indicated attenuation of 5,75 dB. They are built using R_p of 87 Ω and R_s of 44 Ω as shown in Figure B.3:

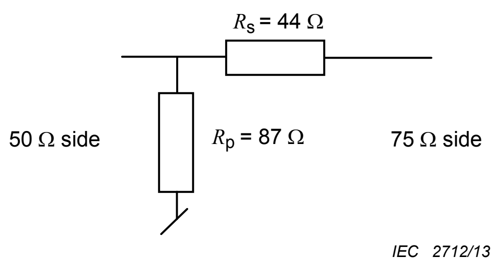


Figure B.3 – Coaxial impedance matching adapters (50 Ω to 75 Ω)

The calculation of the scattering parameter S_{21} using the equations of B.1.3 results in:

S_{21} = 0,516 or S_{21} = –5,75 dB.

The calculation of the attenuation using the open/short approach results in:

Z_o = 87 Ω, Z_s = 29,22 Ω and α = 0,662, Np = 5,75 dB.

The measurement of the attenuation using the methods described in B.2.2 and B.2.3 is shown in Figure B.4:

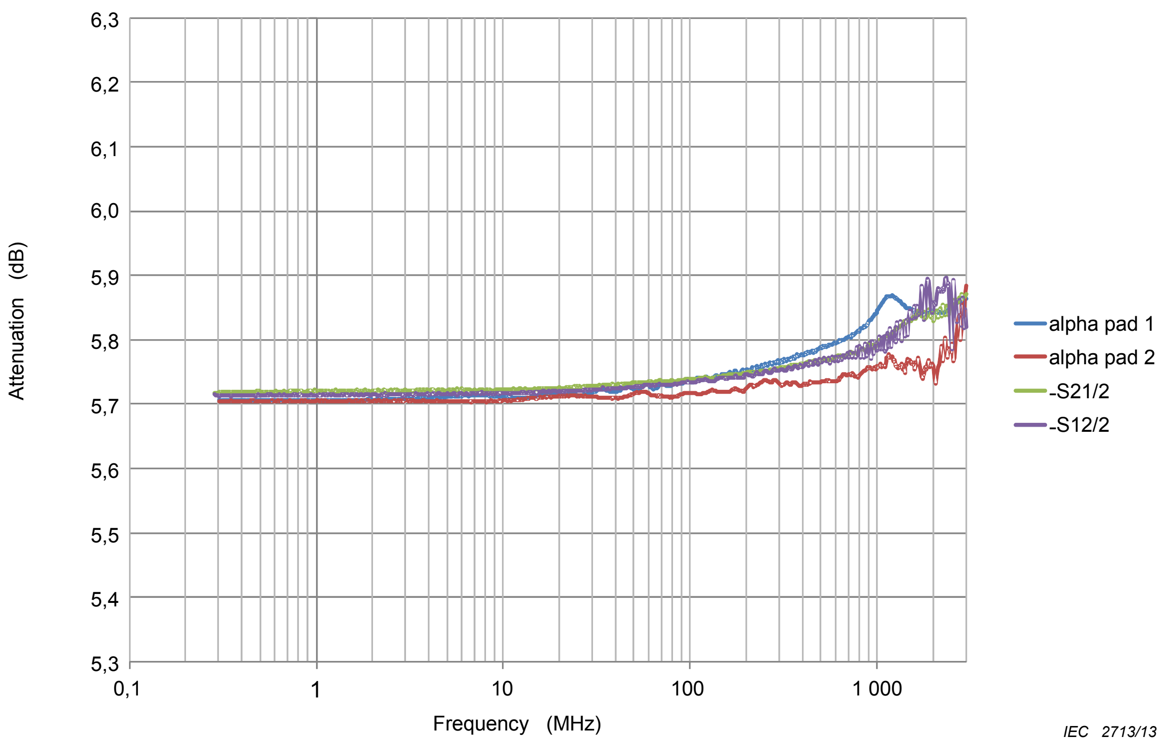


Figure B.4 – Attenuation of 50 Ω to 75 Ω impedance matching adapter

where the curve

alpha pad 1 is the attenuation constant of the first impedance matching adapter obtained from an open/short measurement;

alpha pad 2 is the attenuation constant of the second impedance matching adapter obtained from an open/short measurement;

–S21/2 is half of the measured S_{21} multiplied by minus 1 when two adapters are connected together;

–S12/2 is half of the measured S_{12} multiplied by minus 1 when two adapters are connected together.

The results of both methods are in good concordance as the two measured impedance matching adapters are almost identical.

One may observe that the measured attenuation (at low frequencies) is slightly different from the calculated one, i.e. 5,72 dB instead of 5,75 dB. At higher frequencies, the measured attenuation is slightly increasing from 5,7 dB to 5,9 dB.

Annex C
(normative)

Sample preparation for “milked on braid” method

C.1 General

In the configuration with the “milked on” braid, the latter forms the outer conductor of the outer coaxial system.

The screen to be measured is short-circuited with the inner conductor(s) of the cable providing the contact resistance is minimised. Special attention shall be paid in the case of a foil-braid screen that a good electrical connection between foil and the inner conductor be made.

The screen shall completely enclose the insulated conductor(s), shall be soldered around 360° of the conductor(s), and all the disturbed portion of the screen shall be well soldered. The conductor(s) shall not extend beyond the soldered joint and shall be trimmed. A piece of heat-shrinkable tubing or other appropriate materials shall be applied over the soldered joint to insulate it.

Around the short circuit, in order to carry the disturbing current to the screen under test, a shielding case made of copper foil of a suitable thickness shall be placed (a self-adhesive copper tape shall be avoided) and shall be soldered to the screen under test in such a way that the short circuit between the inner conductor(s) and the screen is inside. The other side of the shielding box shall be formed around a piece of conductor to connect the shielding box to the central pin of a suitable connector (for example N type)[3].

This end will be referred to as an “A” end.

A tinned copper braid having a coverage >70 % and a braid angle <30° shall be pulled over the entire length of the cable and over the connector. The outer braid shall be firmly connected to the connector, making sure that a 360° contact is formed (for example using a hose clamp). Heat-shrinkable tubing or other appropriate materials shall be applied over the entire length of the outer braid ensuring that the outer braid is pressed firmly and consistently to the jacket of the cable.

At the distance of 1 m (or 0,3 m) from the location of the soldering between the shielding box and the screen under test, the outer braid and the screen of the cable under test shall be soldered together for the full 360 °. Any excess of the outer braid shall be removed. The joint between the outer braid and the screen shall be insulated with heat-shrinkable tubing or suitable materials. The length between the shielding box to the screen and the outer braid to cable screen joints is the coupling length.

The protruding cable shall be provided with a suitable connector (for example N type). The length of the protruding part shall be as short as possible.

This end will be referred to as a “B” end.

A TDR (or alternatively a VNA with time domain capability) can be used to check whether the connectors themselves have been inadvertently shorted out (see Clause C.4 for details).

---

3 In case of foil screens, one may use a tinned conductor to make a coil on the foils and inner conductors which are then soldered together.

C.2 Coaxial cables

The preparation procedure steps of a coaxial sample are given in Figure C.1 and Figure C.2.

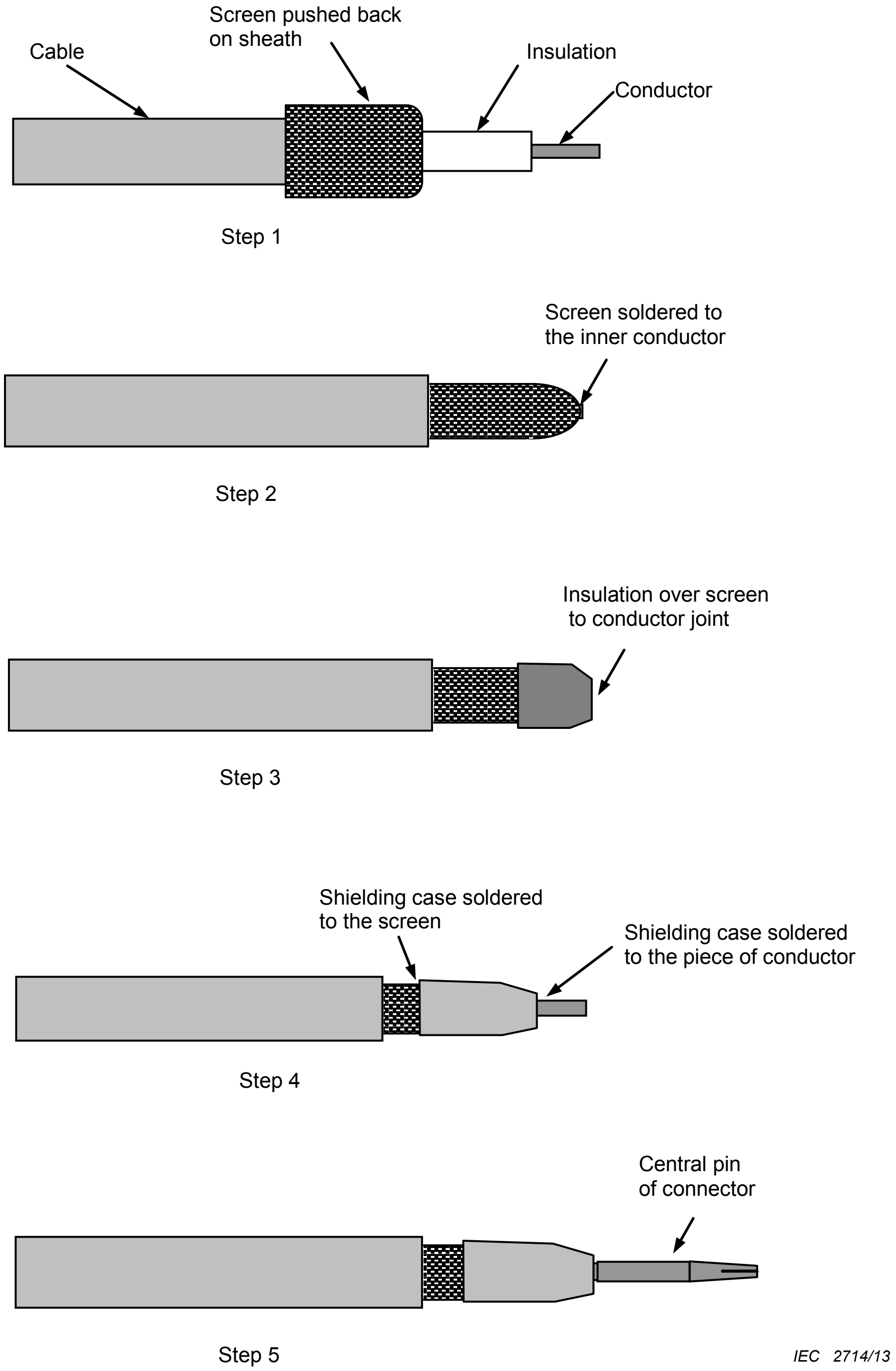


Figure C.1 – Coaxial cables: preparation of cable end “A” *(1 of 2)*

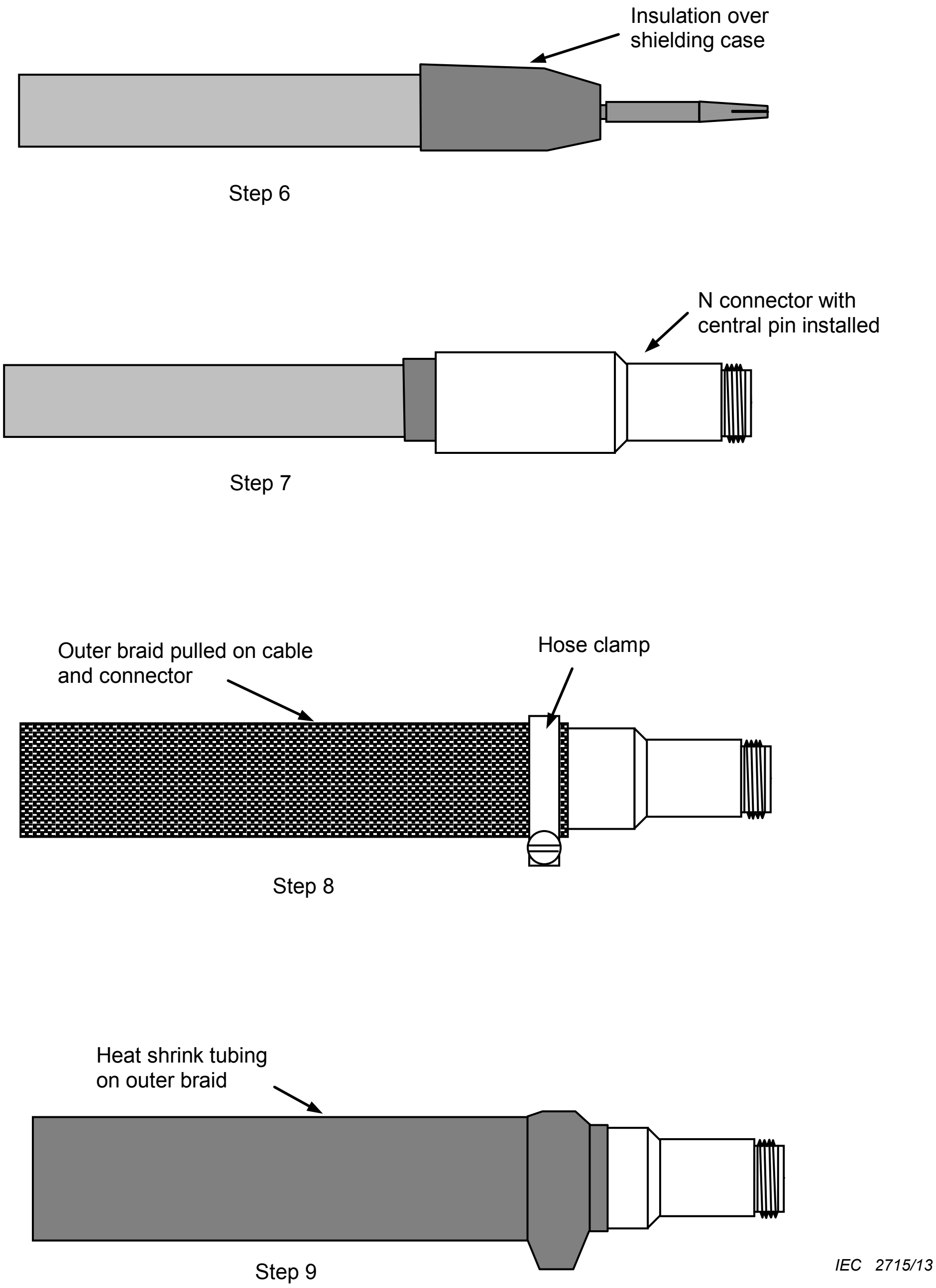


Figure C.1 – Coaxial cables: preparation of cable end “A” *(2 of 2)*

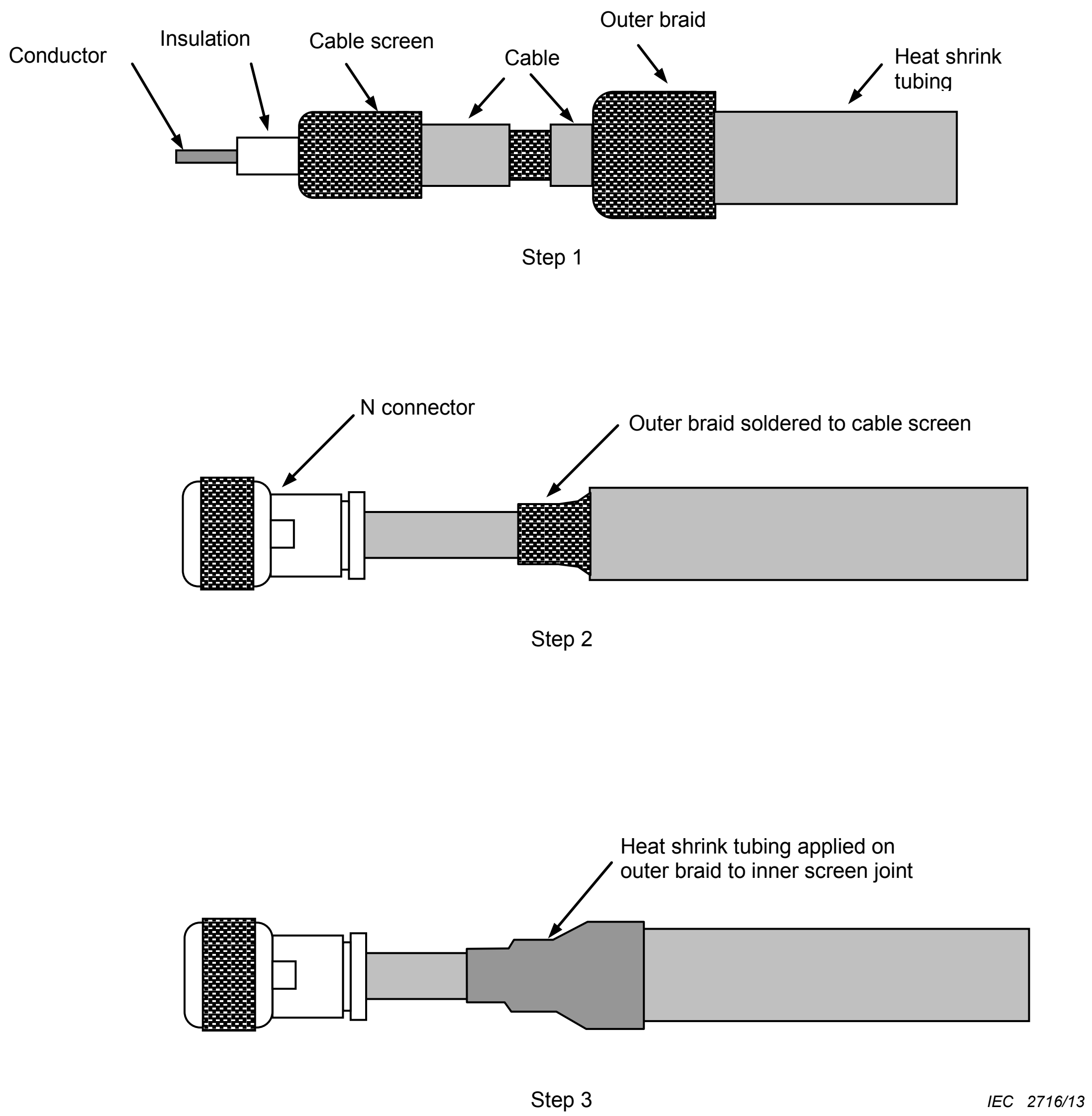


Figure C.2 – Coaxial cables: preparation of cable end “B”

C.3 Symmetrical and multiconductor cables

The preparation procedure steps of a symmetrical or multiconductor sample are given in Figure C.3 and Figure C.4.

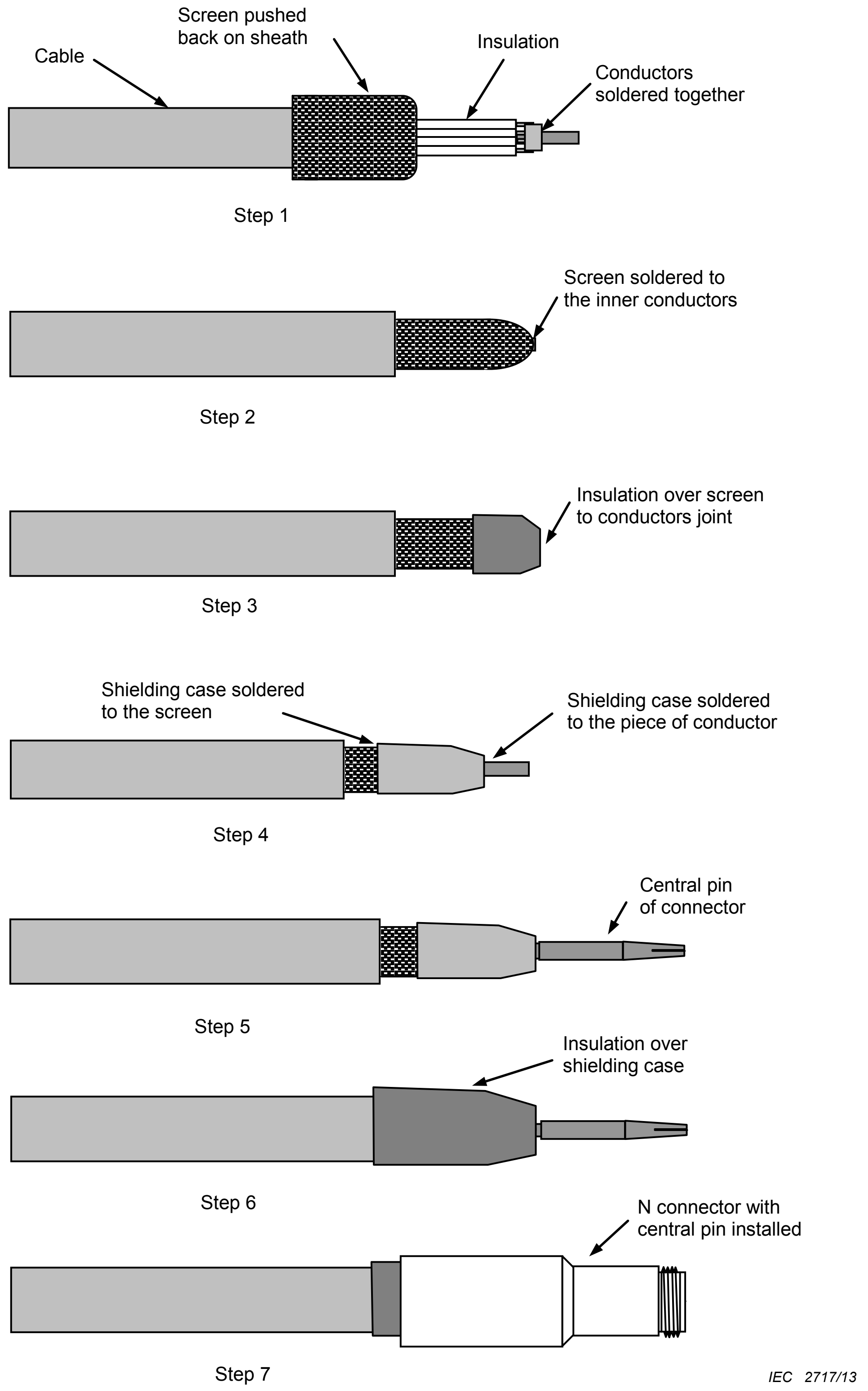


Figure C.3 – Symmetrical cables: preparation of cable end "A" *(1 of 2)*

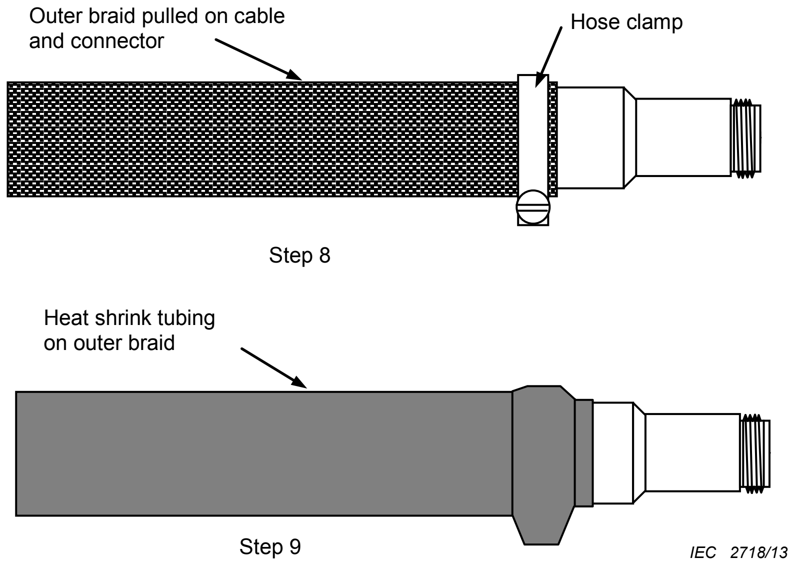


Figure C.3 – Symmetrical cables: preparation of cable end "A" *(2 of 2)*

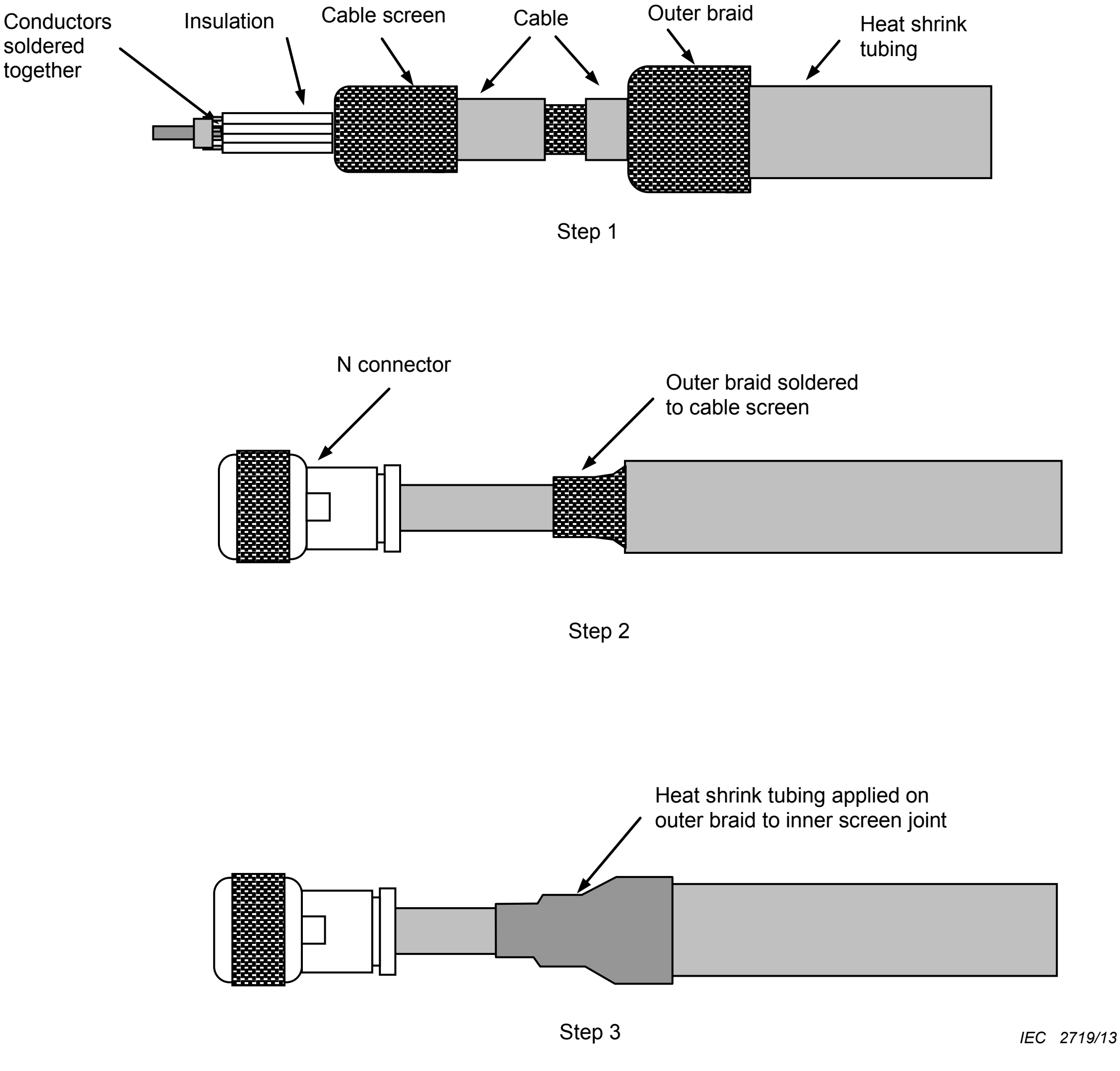


Figure C.4 – Symmetrical cables: preparation of cable end "B"

C.4 Verification of the sample preparation with TDR

A TDR or a network analyser with time domain capability can be used to check the sample preparation of method B:

The typical response when end "A" is connected to the TDR is shown in Figure C.5. The beginning and the end of the sample can be easily determined. It is possible also to check whether the connector in "A" has been inadvertently shorted out.

The typical response when end "B" is connected to the TDR is shown in Figure C.6. The beginning and the end of the sample can be easily determined.

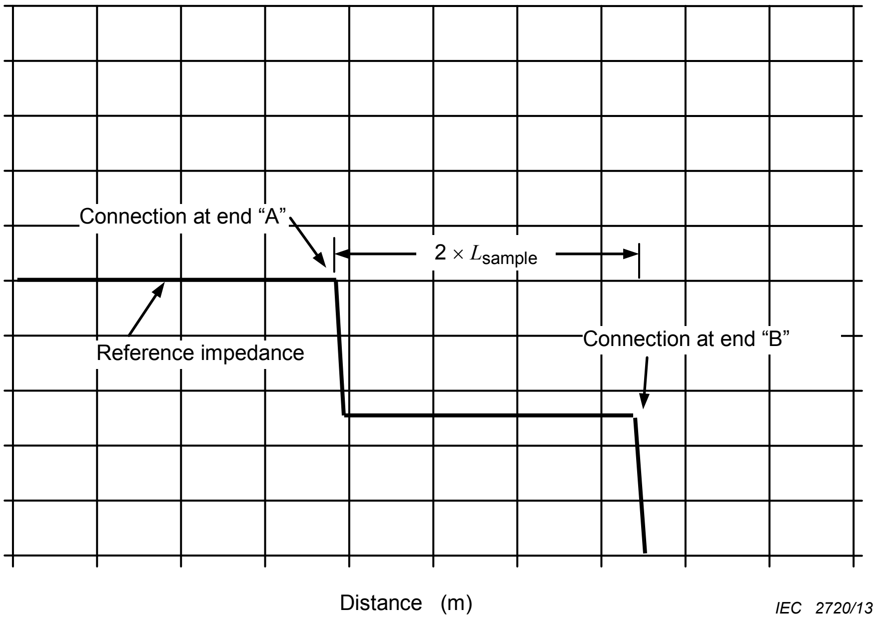


Figure C.5 – Typical resonance of end "A"

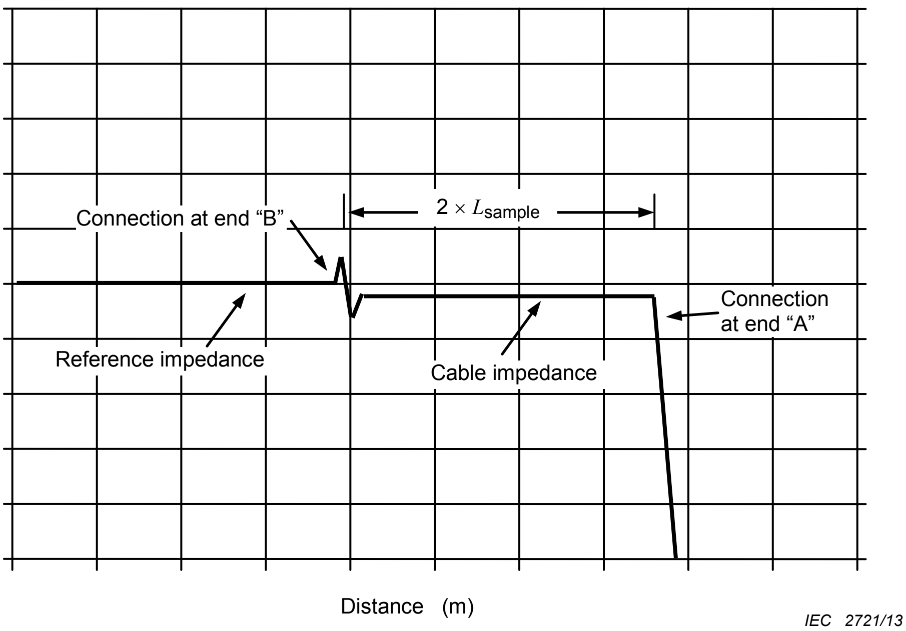


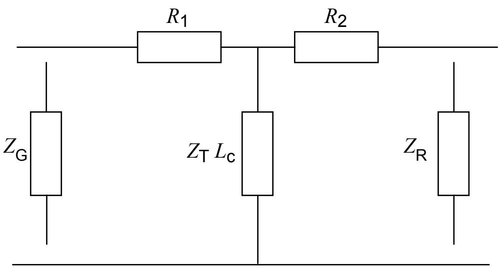
Figure C.6 – Typical resonance of end "B"

Annex D
(informative)

Triaxial test set-up depicted as a T-circuit

D.1 General

The load conditions of the inner and outer circuit have an influence on how to convert the measured scattering parameter S_{21} to the transfer impedance. This can be explained by approximating the test set-up by concentrated elements using the T-circuit as depicted in Figure D.1.



IEC 2722/13

Key

R_1 terminating resistor of the inner circuit

R_2 terminating resistor of the outer circuit

Z_T transfer impedance of the cable screen

Z_G impedance of the generator

Z_R impedance of the receiver

L_C coupling length

Figure D.1 – Triaxial set-up depicted as a T-circuit

D.2 Scattering parameter S_{21} of the T-circuit

The formulae for the scattering parameter of a T-circuit can be found in the literature (e.g. Vierpoltheorie, Wilhelm Klein [2]). Using the elements defined in the key to Figure D.1 and taking into account that $Z_T << Z_G$, Z_R we get:

$$S_{21} = Z_T L_C \frac{2\sqrt{Z_R Z_G}}{(R_1 + Z_G)(R_2 + Z_R)} \tag{D.1}$$

And consequently we get for the transfer impedance

$$Z_T = \frac{(R_1 + Z_G)(R_2 + Z_R)}{2\sqrt{Z_R Z_G}} \frac{S_{21}}{L_c} \tag{D.2}$$

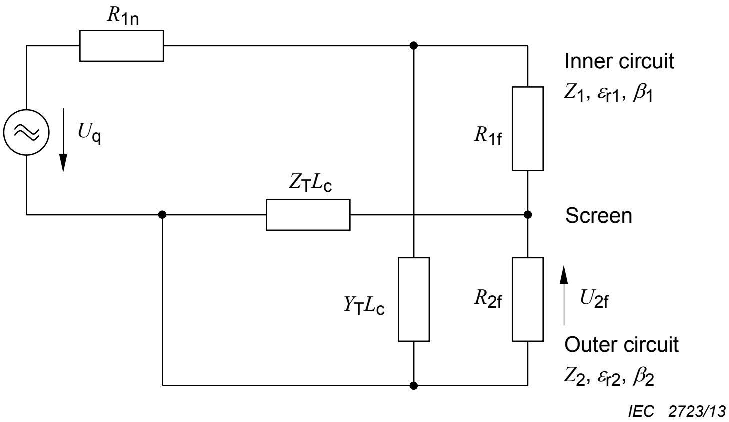
This formula is the general formula which can be used for all triaxial test methods for the conversion of the measured S_{21} to transfer impedance.

Annex E
(informative)

Cut-off frequency of the triaxial set-up for the measurement of the transfer impedance

E.1 Equivalent circuit

The equivalent circuit of the triaxial set-up is depicted in Figure E.1.



Key

$Z_{1,2}$	characteristic impedance of the inner circuit (cable), respectively outer circuit (tube)
$\varepsilon_{r1,2}$	dielectric permittivity of the inner circuit (cable), respectively outer circuit (tube)
$\beta_{1,2}$	phase constant of the inner circuit (cable), respectively outer circuit (tube)
L_C	coupling length
Z_T	transfer impedance
Y_T	capacitive coupling admittance
R_{1n}	load resistance at the near end of the inner circuit (cable). Equal to the output impedance of the generator, respectively input impedance of the receiver including an eventually used feeding resistor
R_{1f}	load resistance at the far end of the inner circuit (cable). Depending on the method used, either equal to the characteristic impedance of the cable or a short circuit
R_{2f}	load resistance at the far end of the outer circuit (tube). Equal to the output impedance of the generator respectively input impedance of the receiver including an eventually used feeding resistor
U_q	EMF of the generator
U_{2f}	voltage at the far end of the outer circuit

Figure E.1 – Equivalent circuit of the triaxial set-up

E.2 Coupling equations

By taking into account the short circuit at the near end of the outer circuit (between the cable screen and the measuring tube), neglecting the attenuation of the disturbing and disturbed line, neglecting the capacitive coupling admittance (which is possible due to the short circuit between the cable screen and the tube), assuming non ferromagnetic materials and introducing further variables, one gets following equations describing the coupling between the primary and secondary circuit [3] (see also IEC/TR 62153-4-1):

$$\frac{U_{2f}}{U_q} = \frac{Z_T L_c}{R_{1,f} + R_{1,n}} g \tag{E.1}$$

$$g = -\frac{1}{N}\frac{j\beta_1}{(\beta_1^2 - \beta_Z^2)\cdot L_c}\left\{\frac{R_{1f}}{Z_1}\left[\cos(\beta_1 L_c) - \cos(\beta_2 L_c)\right] - j\frac{\beta_2}{\beta_1}\sin(\beta_2 L_c) + j\sin(\beta_1 L_c)\right\} \tag{E.2}$$

$$N = \left\{\cos(\beta_1 L_c) + j\frac{\sin(\beta_1 L_c)}{R_{1f} + R_{1n}}\left[Z_1 + \frac{R_{1f} R_{1n}}{Z_1}\right]\right\}\left\{\cos(\beta_2 L_c) + j\frac{Z_2}{R_{2f}}\sin(\beta_2 L_c)\right\} \tag{E.3}$$

$$\beta_{1,2} L_c = 2\pi \frac{L_c}{\lambda_{1,2}} \frac{2\pi \cdot f \cdot L_c \sqrt{\varepsilon_{r1,2}}}{c} \tag{E.4}$$

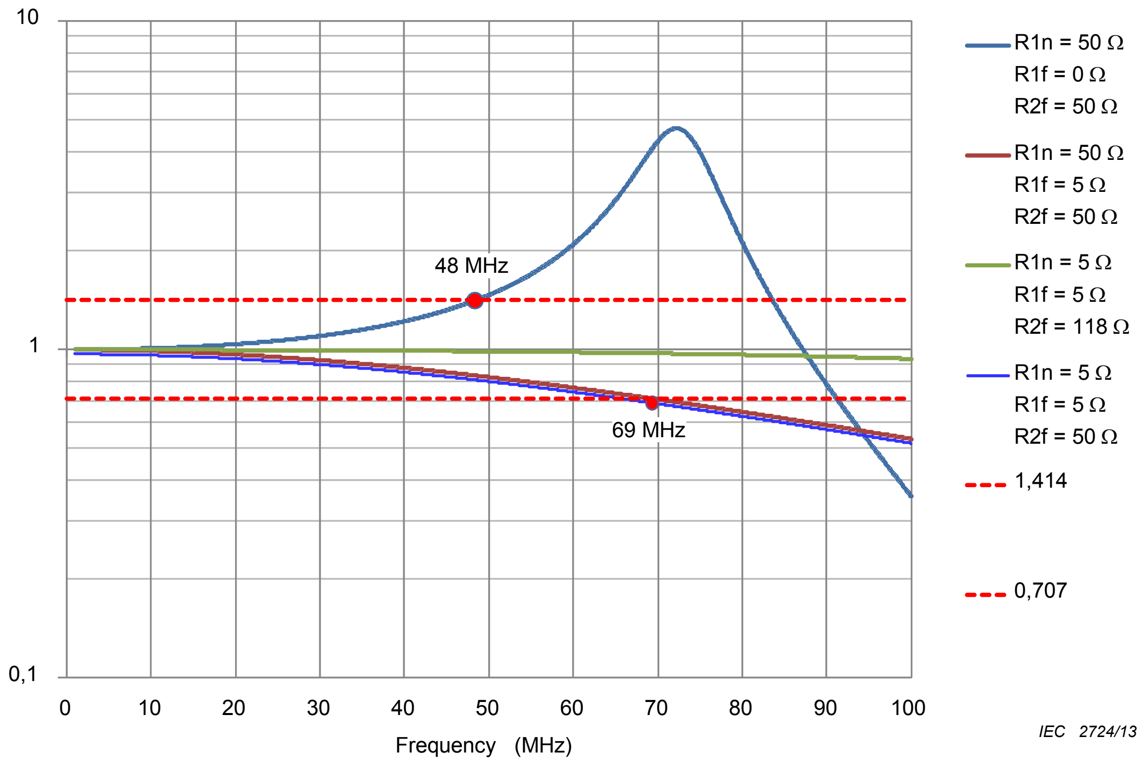
where

$Z_{1,2}$	is the characteristic impedance of the inner circuit (cable), respectively outer circuit (tube);
$\varepsilon_{r1,2}$	is the dielectric permittivity of the inner circuit (cable), respectively outer circuit (tube);
$\beta_{1,2}$	is the phase constant of the inner circuit (cable), respectively outer circuit (tube);
$\lambda_{1,2}$	is the wavelength in the inner circuit (cable), respectively outer circuit (tube);
L_c	is the coupling length;
Z_T	is the transfer impedance;
R_{1n}	is the load resistance at the near end of the inner circuit (cable). Equal to the output impedance of the generator, respectively input impedance of the receiver including an eventually used feeding resistor;
R_{1f}	is the load resistance at the far end of the inner circuit (cable). Depending on the method used, either equal to the characteristic impedance of the cable or a short circuit;
R_{2f}	is the load resistance at the far end of the outer circuit (tube). Equal to the output impedance of the generator, respectively input impedance of the receiver including an eventually used feeding resistor;
U_q	is the EMF of the generator;
U_{2f}	is the voltage at the far end of the outer circuit;
c	is the speed of light;
g	is the factor describing the frequency response of the triaxial test set-up;
f	is the frequency.

E.3 Cut-off frequency

The factor g describes the frequency response of the test set-up. At low frequencies, when $\lambda >> L$, the factor g is equal to 1. With increasing frequency however the factor g starts to oscillate and thus also the measurement results. The cut-off frequency is the maximum frequency at which the transfer impedance could be measured without oscillations, caused by the set-up, and is defined as the 3 dB deviation from the linear interpolation of the measurement results, or in other words, if the factor g becomes $>\sqrt{2}$ respectively $<1/\sqrt{2}$.

Figure E.2 shows the graph of the frequency response of the triaxial set-up for different load conditions. The cut-off frequency is obtained from the intersection of the frequency response with the horizontal line of either √2 or 1/√2 (i.e. ± 3 dB).



Calculated frequency response of the triaxial set-up with:

- coupling length is 39 cm;
- impedance of the inner circuit (cable under test) is 5 Ω;
- impedance of the outer circuit (tube) is 71 Ω;
- permittivity of the inner circuit (cable under test) is 7;
- permittivity of the outer circuit (tube) is 1,46.

where the curve

R1n=50 Ω R1f=0 Ω R2f=50 Ω	Is the calculation for test conditions according to Clause 8 (Test method C: (Mismatched)-Short-Short without damping resistor)
R1n=50 Ω R1f=5 Ω R2f=50 Ω	Is the calculation for test conditions according to Clause 7 (Test method B: Inner circuit with load resistor and outer circuit without damping resistor)
R1n=5 Ω R1f=5 Ω R2f=118 Ω	Is the calculation for test conditions according to Clause 6 (Test method A: Matched inner circuit with damping resistor in outer circuit)
R1n=5 Ω R1f=5 Ω R2f=50 Ω	Is the calculation for test conditions according to Clause 6 (Test method A: Matched inner circuit with damping resistor in outer circuit) but without the damping resistor

Figure E.2 – Frequency response of the triaxial set-up for different load conditions

E.4 Determination of the dielectric permittivity and impedance

For the calculation of the cut-off frequency, it is necessary to know the dielectric permittivity and impedance of the inner and outer circuit. The dielectric permittivity and impedance of the inner circuit (DUT) is in general known or may be obtained from an open/short measurement (see also B.2.3).

For the determination of the impedance and dielectric permittivity of the outer circuit (tube), it is possible to use the theory of the transformation characteristics of a line. The input impedance of a line can be expressed by the following equation (neglecting the attenuation):

$$Z_{\text{in}} = Z_{\text{c}} \frac{\dfrac{Z_{\text{load}}}{Z_{\text{c}}} + j\tan(\beta L)}{1 + \dfrac{Z_{\text{load}}}{Z_{\text{c}}} j\tan(\beta L)} \tag{E.5}$$

where

Z_{in}	is the input impedance of the transmission line;
Z_{load}	is the load impedance of the transmission line;
Z_{c}	is the characteristic impedance of the transmission line;
β	is the phase constant of the transmission line;
L	is the length of the transmission line;
j	is the imaginary unit $\sqrt{(-1)}$.

The input impedance varies periodically as a function of βL. This becomes clearer by introducing the wavelength:

$$\tan(\beta L) = \tan\left(2\pi \frac{L}{\lambda}\right) \tag{E.6}$$

where λ is the wavelength of the transmission line.

For even multiples of the half wavelength ($\lambda/2$) one gets $\tan\beta L = 0$, and for odd multiples of the quarter wavelength ($\lambda/4$) one gets $\tan\beta L = \infty$. Thus one gets for the input impedance of the line:

$Z_{\text{in}} = Z_2$ when $L = n\ \lambda/2$

respectively

$Z_{\text{in}} = \dfrac{Z_{\text{c}}^2}{Z_2}$ when $L = (2n+1)\ \lambda/4$

For even multiples of the half wavelength ($\lambda/2$), the input impedance is equal to the load impedance, and for odd multiples of the quarter wavelength ($\lambda/4$), the transmission line acts as a dual transformer.

With the short circuit in the outer circuit of the triaxial set-up one gets:

$Z_{in} = 0$ or $S_{11} = -1$ when $L = n\ \lambda/2$

$Z_{in} = \infty$ or $S_{11} = +1$ when $L = (2n+1)\ \lambda/4$

So by measuring the scattering parameter S_{11} and observing two successive resonances where the real part $Re(S_{11}) = -1$ (and $Im(S_{11}) = 0$), or two successive resonances where the real part $Re(S_{11}) = +1$ (and $Im(S_{11}) = 0$) one can obtain the dielectric permittivity:

When $Re(S_{11}) = -1$ or $Re(S_{11}) = +1$

$$\varepsilon_r = \left[\frac{c}{2 \cdot L \cdot \Delta f}\right]^2 \tag{E.7}$$

It is recommended to take the average frequency spacing of at least 5 successive resonances as shown in Figure E.3.

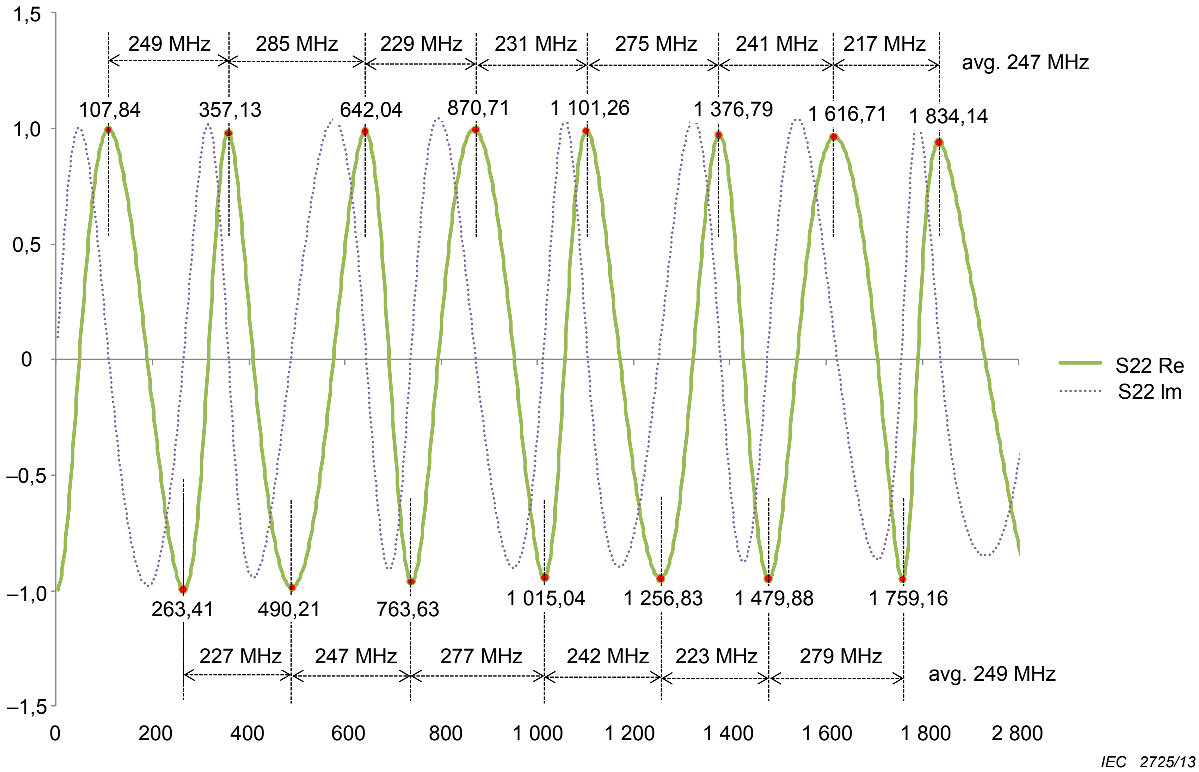


Figure E.3 – Measurement of S_{11} of the outer circuit (tube) having a length of 50 cm

In the example in Figure E.3, the average frequency spacing of two successive resonances is 248 MHz resulting in a dielectric permittivity in the outer circuit of ε_{r2} = 1,46.

Knowing the dimension of the cable and the tube and having determined the dielectric permittivity of the outer circuit, it is possible to calculate the impedance of the outer circuit:

$$Z_2 = \frac{60}{\sqrt{\varepsilon_{r2}}} \ln\left(\frac{D}{d}\right) \tag{E.8}$$

where

Z_2 is the characteristic impedance of the outer circuit in Ω;

ε_{r2} is the dielectric permittivity of the outer circuit;

D is the inner diameter of the tube in mm;

d is the outer diameter of the cable screen in mm.

Annex F
(informative)

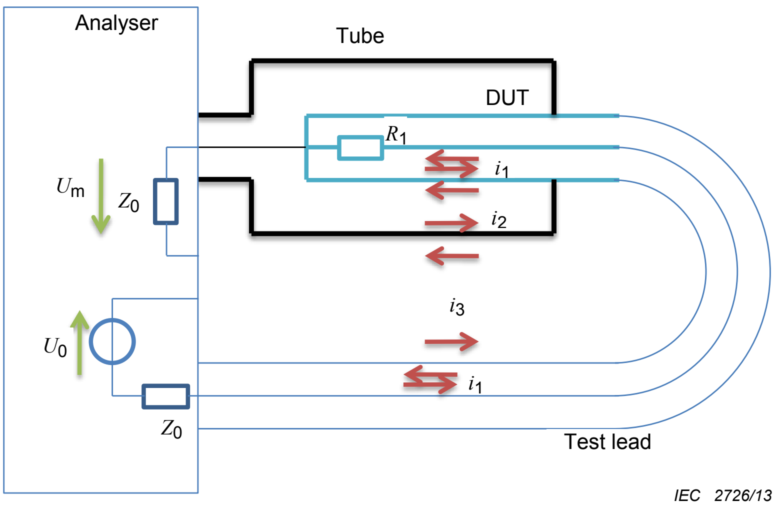
Impact of ground loops on low frequency measurements

F.1 General

In general test configurations, the generator and the receiver have the same ground potential. This is not only valid when using a network analyser but also when using a separate generator and receiver, as long as both are connected directly to the power supply (due to the earthing conductor). This ground loop leads to measurement errors especially at lower frequencies.

F.2 Analysis of the test set-up [3]

Figure F.1 shows a usual triaxial test set-up for the measurement of the transfer impedance.



Key

U_m measured voltage in the outer circuit

U_0 voltage of the generator

R_1 load impedance at the far end of the inner circuit (DUT)

$i_{1,2,3}$ currents in loop 1,2,3

Z_0 system impedance (of generator and receiver)

Figure F.1 – Triaxial test set-up

The set-up consists of three coupled loops:

loop 1: device under test (DUT) with test lead;

loop 2: between cable screen and tube;

loop 3: between tube and test lead.

The equivalent circuits of the 3 loops are shown in Figure F.2 under the assumption of a test lead, DUT and outer circuit of the triaxial set-up without loss:

where

Z_T is the transfer impedance of the DUT;

$Z_{T,L}$ is the transfer impedance of the test lead;

$Z_{T,t}$ is the transfer impedance of the tube;

L_L is the length of the test lead;

L is the length of the DUT (coupling length);

Z_0 is the system impedance (of generator and receiver);

Z_3 is the longitudinal impedance of loop 3;

L_3 is the length of loop 3.

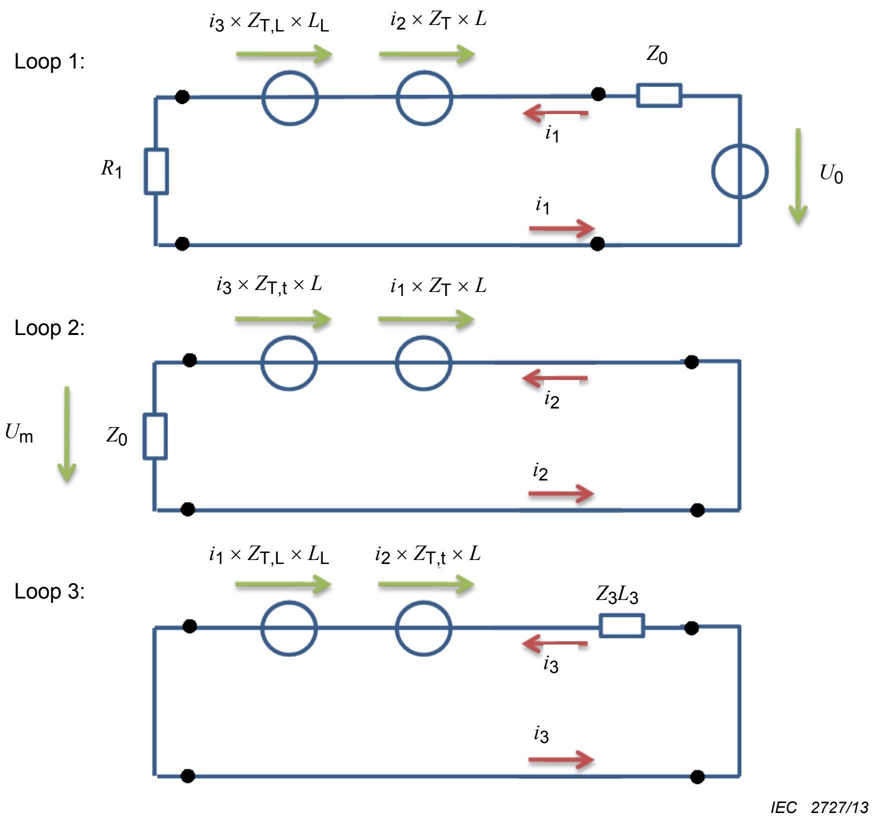


Figure F.2 – Equivalent circuits of the triaxial set-up

For low frequencies where the wave propagation effect can be neglected we get:

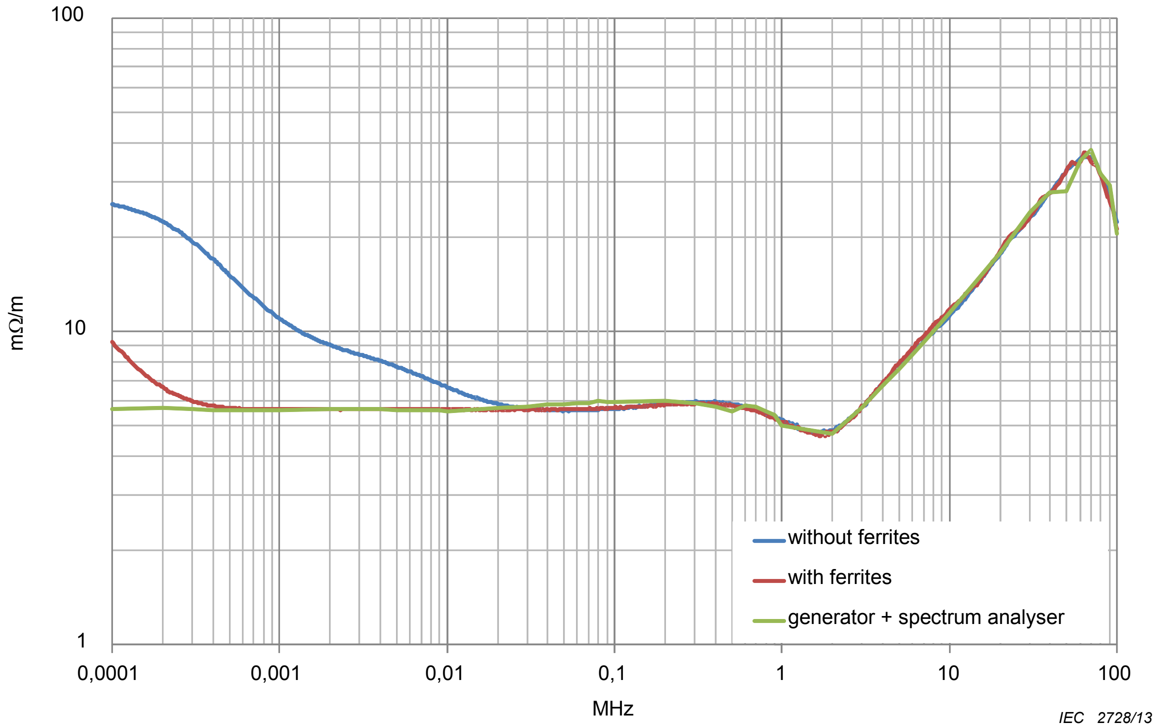
$$\frac{U_m}{U_0}\frac{R_1+Z_0}{L} \approx Z_T + \frac{Z_{T,t} \times Z_{T,L} \times L_L}{Z_3 \times L_3}$$

The second term shows the measurement error. It can be reduced by:

- using a test tube and test lead with low transfer impedance;
- using a short test lead;
- increasing the longitudinal impedance of loop 3.

The impedance of loop 3 can be increased by using ferrites on the test lead or by using a generator and receiver which are not on the same ground potential, i.e. using a separate generator and receiver which are battery-driven or connected to the power supply using a separation transformer.

The effect of the measurement error is shown in Figure F.3.



Test results of the transfer impedance of a high voltage car cable:

- test method C according to Clause 8;
- coupling length 39 cm;
- impedance of the inner circuit (cable under test) 5 Ω,

where the curve

without ferrites	is the measurement with a vector network analyser without the use of ferrites on the test leads;
with ferrites	is the measurement with a vector network analyser with the use of ferrites on the test leads;
generator +spectrum analyser	is the measurement with a separate generator and spectrum analyser where the spectrum analyser is connected to the power supply via a separation transformer.

Figure F.3 – Example showing the impact of the measurement error

Bibliography

[1] IEC 62153-4-8, *Metallic communication cable test methods – Part 4-8: Electromagnetic compatibility (EMC) − Capacitive coupling admittance*

[2] KLEIN Wilhelm, Vierpoltheorie, Wissenschaftsverlag – Bibliographisches Institut, 1972

[3] KLEY Thomas, “Optimierte Kabelschirme Theorie und Messung“, Diss. ETH Nr. 9354, 1991

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch