IEC 62153-4-7

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REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Metallic ~~communication~~ cables and other passive components test methods – Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies ~~up to and above 3 GHz~~ – Triaxial tube in tube method

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Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies ~~up to and above 3 GHz~~ – Triaxial tube in tube method

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 62153-4-7:2015+AMD1:2018 CSV. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 62153-4-7 has been prepared by IEC technical committee 46: Cables, wires, waveguides, RF connectors, RF and microwave passive components and accessories. It is an International Standard.

This third edition cancels and replaces the second edition published in 2015 and its Amendment 1:2018. This edition constitutes a technical revision.

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

The document is revised and updated. It now includes IEC 62153-4-7:2015/COR1:2016 and IEC 62153-4-7:2015/AMD1:2018. Furthermore, the changes of the revised IEC 62153-4-9:2018 are included.

Measurements of the coupling attenuation can be achieved now by using a mixed mode network analyser (virtual balun). The following new annexes have been added:

– Annex E contains informative information about the direct measurement of screening effectiveness of connectors;
– Annex F gives normative information about mixed mode parameters;
– Annex G contains normative information about accessories for measuring coupling attenuation;
– Annex H discusses the low frequency screening attenuation.

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

FDIS	Report on voting
46/812/FDIS	46/820/RVD

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

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

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

A list of all parts of the IEC 62153 series, under the general title *Metallic cables and other passive components test methods* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

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INTRODUCTION

The shielded screening attenuation test set-up according to IEC 62153-4-3 and IEC 62153-4-4 have been extended to take into account the particularities of electrically short elements like connectors and cable assemblies. Due to the concentric outer tube of the triaxial set-up, measurements are independent of irregularities on the circumference and outer electromagnetic fields.

With the use of an additional resonator tube (inner tube respectively tube in tube), a system is created where the screening effectiveness of an electrically short device is measured in realistic and controlled conditions. Also, a lower cut off frequency for the transition between electrically short (transfer impedance Z_T) and electrically long (screening attenuation a_S) can be achieved.

A wide dynamic and frequency range can be applied to test even super screened connectors and assemblies with normal instrumentation from low frequencies up to the limit of defined transversal waves in the outer circuit at approximately 4 GHz.

METALLIC ~~COMMUNICATION~~ CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies ~~up to and above 3 GHz~~ – Triaxial tube in tube method

1 Scope

This part of IEC 62153 deals with the triaxial tube in tube method. This triaxial method is suitable to determine the surface transfer impedance and/or screening attenuation and coupling attenuation of mated screened connectors (including the connection between cable and connector) and cable assemblies. This method could also be extended to determine the transfer impedance, coupling or screening attenuation of balanced or multipin connectors and multicore cable assemblies. For the measurement of transfer impedance and screening- or coupling attenuation, only one test set-up is needed.

2 Normative references

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

IEC TS 62153-4-1:2014, *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic screening measurements*

IEC 62153-4-3, *Metallic communication cable test methods – Part 4-3: Electromagnetic Compatibility (EMC) − Surface transfer impedance − Triaxial method*

IEC 62153-4-4, *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, triaxial method*

IEC 62153-4-8, *Metallic cables and other passive components – Test methods – Part 4-8: Electromagnetic compatibility (EMC) – Capacitive coupling admittance*

IEC 62153-4-9:2018, *Metallic communication cable test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method*

IEC 62153-4-10, *Metallic communication cable test methods – Part 4-10: Electromagnetic compatibility (EMC) – Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets - Double coaxial test method*

IEC 62153-4-15:2015, *Metallic communication cable test methods – Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell*

IEC 62153-4-16, *Metallic communication cable test methods – Part 4-16: Electromagnetic compatibility (EMC) – Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up*

EN 50117-9-2:2019, *Coaxial cables – Part 9-2: Sectional specification for coaxial cables for analogue and digital transmission – Indoor droop cables for systems operating at 5 MHz – 3 000 MHz*

3 Terms and definitions

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

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

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

3.1
surface transfer impedance
Z_T
for an electrically short screen, quotient of the longitudinal voltage U_1 induced to the inner circuit by the current I_2 fed into the outer circuit or vice versa

Note 1 to entry: The surface transfer impedance is expressed in ohms.

Note 2 to entry: The value Z_T of an electrically short screen is expressed in ohms [Ω] or decibels in relation to 1 Ω.

Note 3 to entry: See Figure 1.

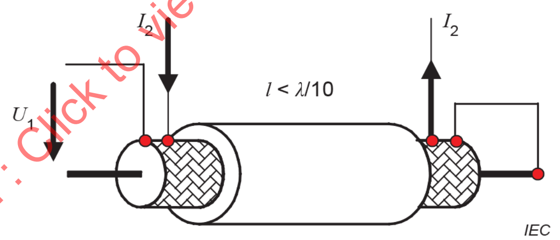


Figure 1 – Definition of Z_T

$$Z_T = \frac{U_1}{I_2} \tag{1}$$

$$Z_T \ \text{dB}(\Omega) = +20 \times \log_{10}\left(\frac{|Z_T|}{1\,\Omega}\right) \tag{2}$$

3.2
effective transfer impedance
Z_{TE}
~~effective transfer impedance, defined as:~~
maximum absolute value of the sum or difference of the capacitive coupling impedance Z_F and the transfer impedance Z_T at every frequency:

$$Z_{TE} = \max\left|Z_F \pm Z_T\right| \tag{3}$$

3.3
screening attenuation
a_S
for electrically long devices, i.e. above the cut-off frequency, logarithmic ratio of the feeding power P_1 and the periodic maximum values of the coupled power $P_{r,max}$ in the outer circuit

$$a_S = -10 \times \log_{10}\left(\mathrm{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \tag{4}$$

~~where~~

~~Env is the minimum envelope curve of the measured values in dB~~

Note 1 to entry: The screening attenuation of an electrically short device is defined as:

$$a_S = 20 \times \log_{10} \frac{150\,\Omega}{Z_{TE}} \tag{5}$$

where

150 Ω is the standardized impedance of the outer circuit.

3.4
coupling attenuation
a_C
for a screened balanced device, the sum of the unbalance attenuation a_U of the symmetric pair and the screening attenuation a_S of the screen of the device under test

Note 1 to entry: For electrically long devices, i.e. above the cut-off frequency, the coupling attenuation a_C is defined as the logarithmic ratio of the feeding power P_1 and the periodic maximum values of the coupled power $P_{r,max}$ in the outer circuit.

3.5
coupling length
~~length of cable inside the test jig between the end of the extension tube and the screening cap (see Figure 2)~~
length of device under test

Note 1 to entry: The coupling length is electrically short, if

$$\frac{\lambda_o}{l} > 10 \times \sqrt{\varepsilon_{r1}} \quad \text{or} \quad f < \frac{c_o}{10 \times l \times \sqrt{\varepsilon_{r1}}} \tag{6}$$

or electrically long, if

~~$$\lambda_o/l \le 2 \cdot \left|\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right| \quad \text{or} \quad f > \frac{c_o}{2 \cdot l \cdot \left|\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right|} \tag{7}$$~~

$$\frac{\lambda_o}{l} \le \pi \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right| \quad \text{or} \quad f \ge \frac{c_o}{\pi \times l \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right|} \tag{7}$$

where

l is the effective coupling length, in m;

λ_0 is the free space wavelength, in m;

ε_{r1} is the resulting relative permittivity of the dielectric of the cable;

ε_{r2} is the resulting relative permittivity of the dielectric of the secondary circuit;

f is the frequency, in Hz;

c_o is the velocity of light in free space.

3.6
device under test
DUT
device consisting of the mated connectors with their attached cables

4 Physical background

See respective clauses of IEC TS 62153-4-1, IEC 62153-4-3, IEC 62153-4-4, IEC 62153-4-9 and Annex C and Annex D.

5 Principle of the test methods

5.1 General

IEC 62153-4 (all parts) describes different test procedures to measure screening effectiveness on communication cables, connectors and components with triaxial test set-up.

Table 1 gives an overview about IEC 62153-4 (all parts) test procedures with triaxial test set-up.

Table 1 – IEC 62153, Metallic communication cable test methods – Test procedures with triaxial test set-up

	Metallic communication cable test methods – Electromagnetic compatibility (EMC)
IEC ~~TR~~ TS 62153-4-1	Introduction to electromagnetic (EMC) screening measurements
IEC 62153-4-3	Surface transfer impedance – Triaxial method
IEC 62153-4-4	~~Shielded screening attenuation,~~ Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method
IEC 62153-4-7	~~Shielded screening attenuation~~ Test method for measuring the transfer impedance Z_T and the screening attenuation a_s or coupling attenuation a_C of RF-connectors and assemblies up to and above 3 GHz – Triaxial tube in tube method
IEC 62153-4-9	Coupling attenuation of screened balanced cables, triaxial method
IEC 62153-4-10	~~Shielded screening attenuation test method for measuring the screening effectiveness of feedtroughs and electromagnetic gaskets double coaxial method~~ Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets – Double coaxial test method
IEC 62153-4-15	Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell ~~(under consideration)~~
IEC 62153-4-16	~~Technical report on the relationship between transfer impedance and screening attenuation (under consideration)~~ Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up

Usually, RF connectors have mechanical dimensions in the longitudinal axis in the range of 20 mm to maximum 50 mm. With the definition of electrical short elements, we get cut off or corner frequencies for the transition between electrically short and long elements of about 1 GHz or higher for usual RF-connectors.

To measure the screening attenuation instead of transfer impedance also in the lower frequency range, the tube in tube procedure was designed. The electrically length of the RF-connector is extended by a RF-tightly closed metallic extension tube (tube in tube). See Figure 2.

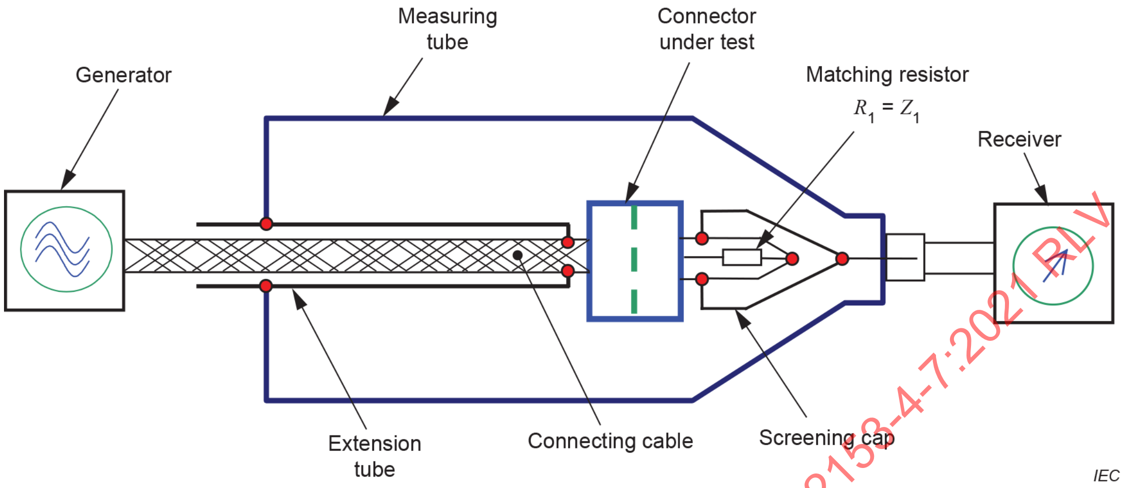


Figure 2 – Principle of the test set-up to measure transfer impedance and screening or coupling attenuation of connectors with tube in tube

The tube in tube test set up is based on the triaxial system according to IEC 62153-4-3 and IEC 62153-4-4 consisting of the DUT, a solid metallic tube and (optional) a RF-tight extension tube. The matched device under test, DUT, which is fed by a generator, forms the disturbing circuit which may also be designated as the inner or the primary circuit. The connecting cables to the DUT are additionally screened by the tube in tube.

The disturbed circuit, which may also be designated as the outer or the second circuit, is formed by the outer conductor of the device under test (and the extension tube), connected to the connecting cable and a solid metallic tube, having the DUT under test in its axis.

5.2 Transfer impedance

The test determines the screening effectiveness of a shielded cable by applying a well-defined current and voltage to the screen of the cable, the assembly or the device under test and measuring the induced voltage in secondary circuit in order to determine the surface transfer impedance. This test measures only the magnetic component of the transfer impedance. To measure the electrostatic component (the capacitance coupling impedance), the method described in IEC 62153-4-8 should be used.

The triaxial method of the measurement is in general suitable in the frequency range up to 30 MHz for a 1 m sample length and 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 is found in Clause 9 of IEC TS 62153-4-1:2014 as well as in IEC 62153-4-3.

5.3 Screening attenuation

The disturbing or primary circuit is the matched cable, assembly or device under test. The disturbed or secondary circuit consists of the outer conductor (or the outermost layer in the case of multiscreen cables or devices) of the cable or the assembly or the device under test and a solid metallic housing, having the device under test in its axis (see Figure 3).

The voltage peaks at the far end of the secondary circuit ~~have to~~ shall be measured. The near end of the secondary circuit is short-circuited. For this measurement, a matched receiver is not necessary. The expected voltage peaks at the far end are not dependent on the input impedance of the receiver, provided that it is lower than the characteristic impedance of the secondary circuit. However, it is an advantage to have a low mismatch, for example, by selecting of housings of sufficient size. A detailed description ~~could~~ can be found in Clause 10 of IEC TS 62153-4-1:2014 as well as in IEC 62153-4-4. Additional Information on the interpretation of screening attenuation test results at frequencies below the cut-off frequency can be found in Annex H.

5.4 Coupling attenuation

Balanced cables, connectors, assemblies or devices which are driven in the differential mode may radiate a small part of the input power, due to irregularities in the symmetry. For unscreened balanced cables, connectors, assemblies or devices, this radiation is related to the unbalance attenuation a_u. For screened balanced cables, connectors or assemblies, the unbalance causes a current in the screen which is then coupled by the transfer impedance and capacitive coupling impedance into the outer circuit. The radiation is attenuated by the screen of the component and is related to the screening attenuation a_S.

Consequently, the effectiveness against electromagnetic disturbances of shielded balanced cables, connectors or assemblies is the sum of the unbalance attenuation a_U of the pair and the screening attenuation a_S of the screen. Since both quantities usually are given in a logarithmic ratio, they may simply be added to form the coupling attenuation a_C:

$$a_C = a_U + a_S \quad (8)$$

Coupling attenuation a_C is determined from the logarithmic ratio of the feeding power P_1 and the periodic maximum values of the power $P_{r,max}$ (which may be radiated due to the peaks of voltage U_2 in the outer circuit):

$$a_C = -10 \times \log_{10}\left(\text{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \quad (9)$$

~~where~~

~~Env is the minimum envelope curve of the measured values in dB.~~

The relationship of the radiated power P_r to the measured power P_2 received on the input impedance R is:

$$\frac{P_R}{P_2} = \frac{P_{Rmax}}{P_{2max}} = \frac{R}{2 \times Z_S} \quad (10)$$

There will be a variation of the voltage U_2 on the far end, caused by the electromagnetic coupling through the screen and superposition of the partial waves caused by the surface transfer impedance Z_T, the capacitive coupling impedance Z_F (travelling to the far and near end) and the totally reflected waves from the near end.

To feed the balanced device under test, a differential mode signal is necessary. This can be achieved with a two-port network analyser (generator and receiver) and a balun or a multiport network analyser. ~~The procedure to measure coupling attenuation with a multiport network analyser is under consideration.~~ The procedures to measure coupling attenuation are described in Clause 10. Annex G gives normative information on accessories for coupling attenuation measurements.

6 Test procedure

6.1 General

The measurements shall be carried out at the temperature of (23 ± 3) °C. The test method determines the transfer impedance or the screening attenuation or the coupling attenuation of a DUT by measuring in a triaxial test set-up according to IEC 62153-4-3, IEC 62153-4-4 and IEC 62153-4-9.

6.2 Tube in tube procedure

Usually, RF connectors have mechanical dimensions in the longitudinal axis in the range of 20 mm to maximum 50 mm. With the definition of electrically short elements, we get cut off or corner frequencies or corner for the transition between electrically short and long elements of about 1 GHz or higher for usual RF-connectors.

In the frequency range up to the cut off frequency, where the device under test (DUT) is electrically short, the transfer impedance of the DUT can be measured. For frequencies above the cut-off frequency, where the DUT is electrically long, the screening attenuation can be measured.

By extending the electrically length of the RF-connector by a RF-tightly closed metallic extension tube (tube in tube), the tested combination becomes electrically long and the cut-off frequency is moved towards the lower frequency range. In this way, also in the lower frequency range, the screening attenuation may be measured and the effective transfer impedance of electrical short devices calculated.

The test set up is a triaxial system consisting of the DUT, a solid metallic tube and a RF-tight extension tube. The matched device under test, DUT, which is fed by a generator forms the disturbing circuit which may also be designated as the inner or the primary circuit.

The disturbed circuit, which may also be designated as the outer or the second circuit, is formed by the outer conductor of the device under test, connected to the extension tube and a solid metallic tube having the DUT under test in its axis.

The principle of the test set-up is shown in Figure 2 and Figure 3. The set-up is the same for measuring the transfer impedance and the screening- or the coupling attenuation, whereas the length of the inner and the outer tube may vary.

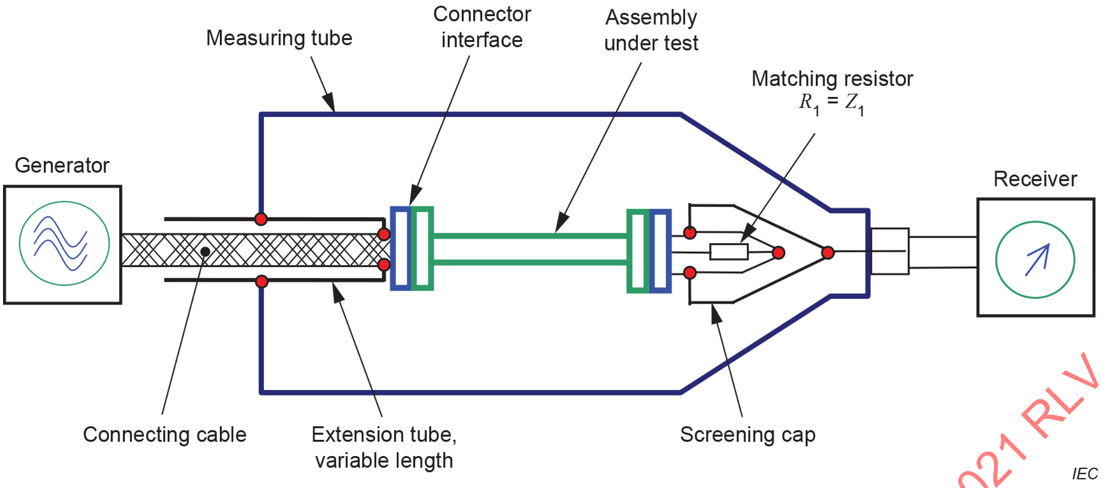


Figure 3 – Principle of the test set-up to measure transfer impedance and screening attenuation of a cable assembly

The voltage ratio of the voltage at the near end (U_1) of the inner circuit (generator) and the voltage at the far end (U_2) of the secondary circuit (receiver) shall be measured (U_1/U_2). The near end of the secondary circuit is short-circuited.

Depending on the electrical length of the tested combination, the DUT and the extension tube, the result may be expressed either by the transfer impedance, the effective transfer impedance or the screening attenuation (or the coupling attenuation).

For this measurement, a matched receiver is not necessary. The likely voltage peaks at the far end are not dependent on the input impedance of the receiver, provided that it is lower than the characteristic impedance of the secondary circuit. However, it is an advantage to have a low mismatch, for example by selecting a range of tube diameters for ~~several~~ various sizes of ~~coaxial cables~~ DUTs.

6.3 Test equipment

The principle of the test set-up is shown in Figure 2 and Figure 3 and consists of:

- an apparatus of a triple coaxial form with a length sufficient to produce a superimposition of waves in narrow frequency bands which enable the envelope curve to be drawn,
- tubes with variable lengths, e.g. by different parts of the tubes and/or by a movable tube in tube. In case of larger connectors or components, the triaxial tubes may be replaced by a triaxial cell according to IEC 62153-4-15.
- a RF-tight extension tube (tube in tube), variable in length, which should preferably have a diameter such that the characteristic impedance to the outer tube is 50 Ω or equal to the nominal characteristic wave impedance of the network analyser or the generator and receiver. The material of the extension tube shall be non-ferromagnetic and well conductive (copper or brass) and shall have a thickness ≥1 mm such that the transfer impedance is negligible compared to the transfer impedance of the device under test,
- a signal generator and a receiver with a calibrated step attenuator and a power amplifier if necessary for very high screening attenuation. The generator and the receiver may be included in a network analyser,
- a balun for impedance matching of the unbalanced generator output signal to the characteristic wave impedance of balanced cables for measuring the coupling attenuation. Requirements for the balun are given in IEC 62153-4-9:~~2008~~2018, 6.3. ~~Alternatively to a balun, a VNA with mixed mode option may be used (procedures with mixed mode VNAs are under consideration).~~ Alternatively, instead of a balun, a Vector Network analyser

(VNA) with mixed mode option and a twisted-pair (TP) connecting unit may be used. The requirements for the TP connecting unit are given in IEC 62153-4-9:2018, 6.4.

Optional equipment is:

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

6.4 Calibration procedure

The calibration shall be established at the same frequency points at which the measurement 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 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 S-parameter test-set, i.e. by using a power splitter, a THRU calibration shall be established including the test leads used to connect the test set-up to the test equipment.

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

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

where

P_1 is the power fed during calibration procedure;

P_2 is the power at the receiver during 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. This can be achieved e.g. by connecting two impedance matching adapters of the same type and the same manufacturer “back to back” together and measure:

$$2 \times a_{\text{imd}} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \tag{12}$$

Further information on impedance matching adapters is given in IEC 62153-4-3, Annex B.

6.5 Connection between extension tube and device under test

The connection between the extension tube and the attached cables of the device under test shall be such that the contact resistance is negligible. A possible connection technique as well as a description of the influence of contact resistances is given in Annex D. Annex E gives information about the direct connection of the extension tube to connectors under test.

6.6 Dynamic range respectively noise floor

With the verification test, the residual transfer impedance respectively the noise floor due to the connection of the feeding cable to the extension tube shall be determined.

The feeding cable is matched with its characteristic impedance and connected to the test head. The extension tube shall then be connected to the feeding cable (without DUT), using the same connection technique as during the test. The piece of cable between the connection points shall be as short as possible (see Figure 4).

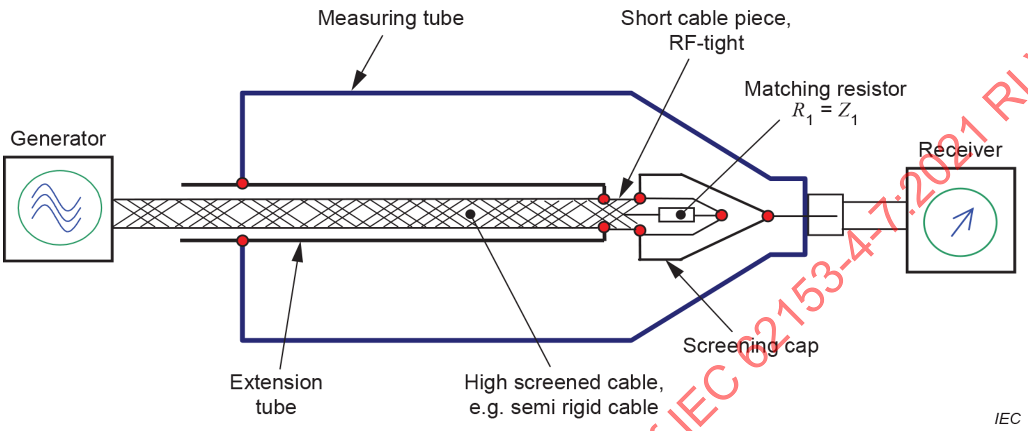


Figure 4 – Principle set-up for verification test

The voltage ratio U_1/U_2 shall be measured with the ~~VNA~~ NWA.

The noise floor a_n of the connection of the extension tube to the feeding cable is then given by:

$$a_n = 20 \times \log_{10}(U_1 / U_2) \tag{12}$$

The noise floor shall be at least 10 dB better than the measured value.

The residual transfer impedance of the connection of the extension tube to the feeding cable is given by:

$$Z_{Tr} = Z_1 \times \left| \frac{U_2}{U_1} \right| \tag{13}$$

6.7 Impedance matching

If unknown, the nominal characteristic impedance of the (quasi-)coaxial system can either be measured by using a TDR with maximum 200 ps rise time or using the method described in Annex A. An impedance matching adapter to match the impedance of the generator and the impedance of the (quasi-)coaxial system is not recommended as it reduces the dynamic range of the test set-up and may have sufficient matching (return loss) only up to 100 MHz ~~when using self-made adapters which are necessary for impedances other than 60 Ω or 75 Ω~~ (see Annex B).

6.8 Influence of adapters

When measuring transfer impedance and screening attenuation or coupling attenuation on connectors or cable assemblies, test adapters are required if no mating connectors to the connectors of the DUT are available.

Test adapters and/or mating connectors may limit the sensitivity of the test set up and may influence the measurement.

The type and/or the design of the test adapter shall be stated in the test report.

A more detailed description on the design and the influence of test adapters is under consideration.

7 Sample preparation

7.1 Coaxial connector or device

A feeding cable shall be mounted to the connector under test and it's mating part according to the specification of the manufacturer. One end shall be connected to the test head where the feeding cable is matched with the nominal characteristic impedance of the device under test. It may be short circuited, when measuring the transfer impedance with ~~method C:~~ (mismatched)-short-short without damping resistor according to IEC 62153-4-3.

The other end of the connecting cable shall be passed through the extension tube and connected to the generator. On the side of the device under test, the screen of the feeding cable shall be connected to the extension tube with low contact resistance (see 6.2 and Annex B). On the generator side, the screen of the feeding cable shall not be connected to the extension tube.

7.2 Balanced or multiconductor device

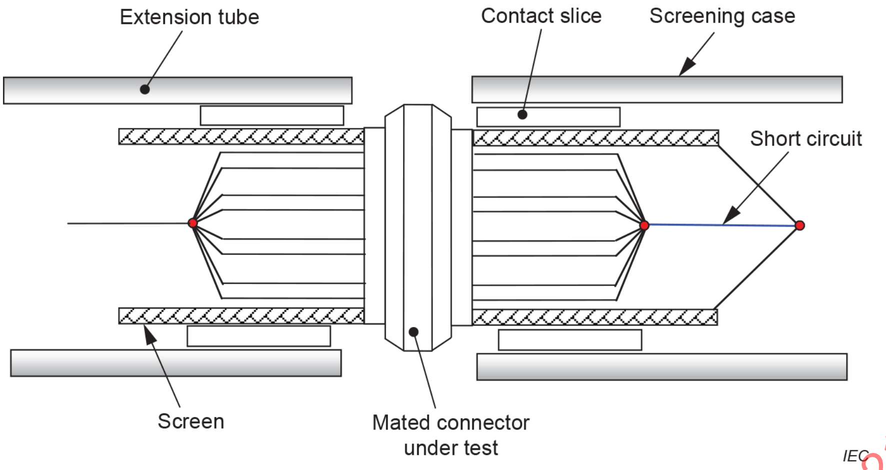
A balanced or multiconductor cable which is usually used with the connector under test shall be mounted each to the connector under test and it's mating part according to the specification of the manufacturer.

When measuring transfer impedance or screening attenuation, screened balanced or multiconductor cables are treated as a quasi-coaxial system. Therefore, at the open ends of the feeding cable, all conductors of all pairs shall be connected together. All screens, including those of individually screened pairs or quads, shall be connected together at both ends. All screens shall be connected over the whole circumference (see Figure 5 and Figure 5b).

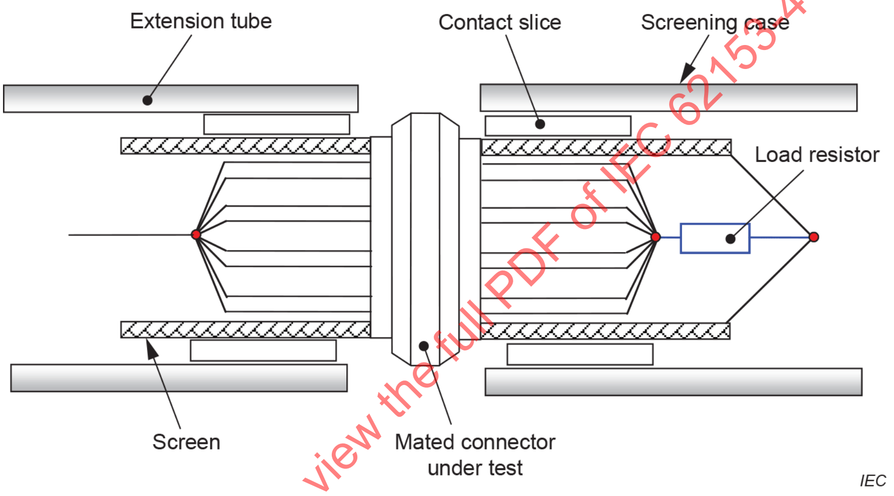
One end shall then be connected to the test head where the feeding cable is matched with the characteristic impedance (screening attenuation and transfer impedance with short/matched procedure) or with a short circuit (transfer impedance with short/short procedure).

~~One end of the connecting cable shall then be connected to the test head where the connecting cable is matched with the characteristic impedance of the DUT.~~

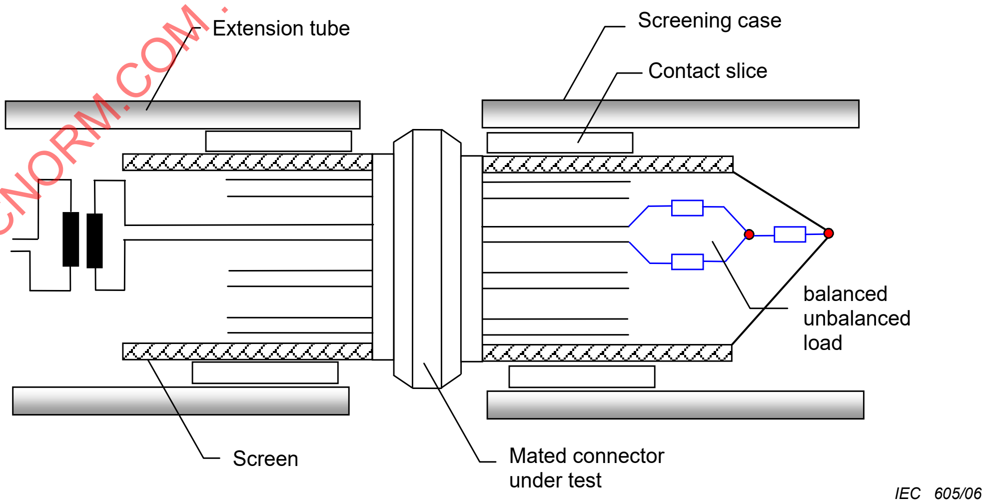
The other end shall be led through the extension tube and shall be connected to the feeding port (VNA or generator) by the use of an appropriate adapter.



a) Principle preparation of balanced or multiconductor connectors for transfer impedance (short/short)

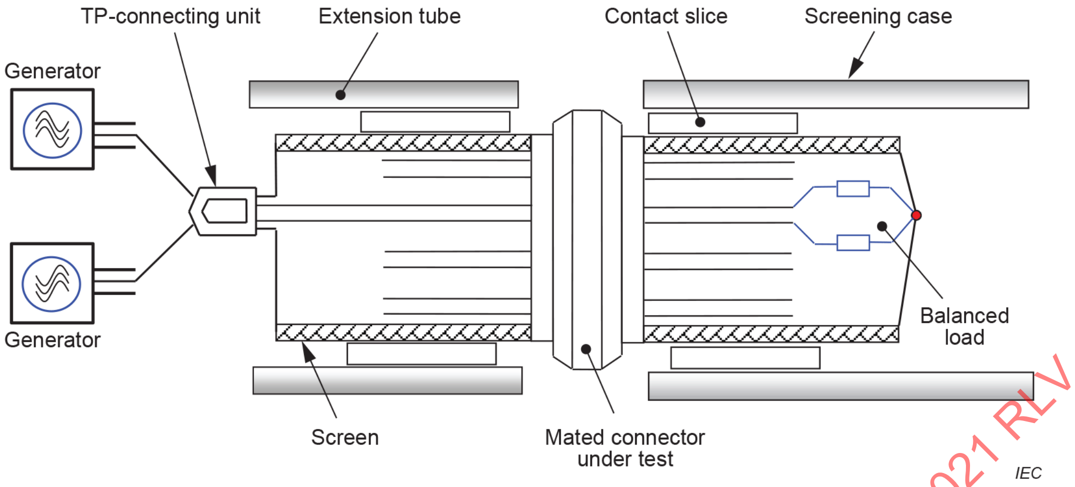


b) Principle preparation of balanced or multiconductor connectors for transfer impedance (short/matched) and screening attenuation



c) Principle preparation of balanced or multiconductor connectors for coupling attenuation using a balun

NOTE 1 Add terminations for all pairs if the cable is not pair screened. If a pair screen is added, the termination of all pairs is not mandatory but preferred.



d) Principle preparation of balanced or multiconductor connectors for coupling attenuation using a virtual balun

NOTE 2 Add terminations for all pairs if the cable is not pair screened. If a pair screen is added, the termination of all pairs is not mandatory but preferred.

Figure 5 – Preparation of balanced or multiconductor connectors

7.3 Cable assembly

If the cable assembly fits into the tube, it shall be measured according to Figure 3. Longer cable assemblies can be cut, and each side measured separately.

8 Measurement of transfer impedance

8.1 General

IEC 62153-4-3 describes three different triaxial test procedures:

– ~~Test method A:~~ matched inner circuit with damping resistor in outer circuit,

– ~~Test method B:~~ inner circuit with load resistor and outer circuit without damping resistor,

– ~~Test method C:~~ (mismatched)-short-short without damping resistor.

The procedure described herein is in principle the same as ~~test method B~~ in IEC 62153-4-3 with matched inner circuit without the use of the impedance matching adapter and without the damping resistor R_2. It has a higher dynamic range than ~~test method A of IEC 62153-4-3~~ testing with damping resistor in outer circuit.

The load resistor R_1 could 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.

NOTE Other procedures of 62153-4-3 ~~may~~ can be applied accordingly if required.

8.2 Principle block diagram of transfer impedance

A block diagram of the test set-up to measure transfer impedance according to test method ~~B~~ of IEC 62153-4-3 with load resistor in inner circuit and without damping resistor in outer circuit is shown in Figure 6.

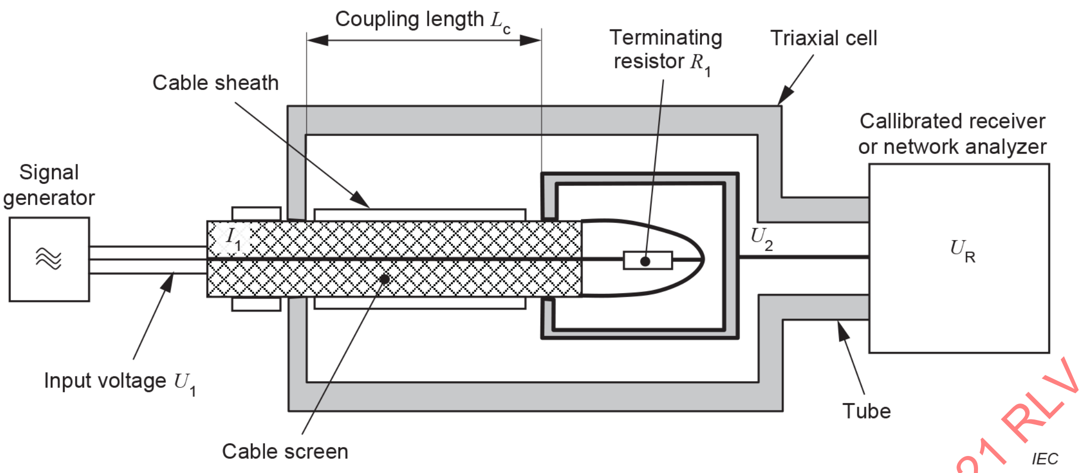


Figure 6 – Test set-up (principle) for transfer impedance measurement according to test ~~method B~~ of IEC 62153-4-3 with load resistor in inner circuit and without damping resistor in outer circuit

8.3 Measuring procedure – Influence of connecting cables

When measuring a connector or a component without tube in tube, the transfer impedance of the connecting cables inside the tube to connect the DUT shall be measured.

The transfer impedance of the connecting cables which connects the DUT shall be measured according to IEC 62153-4-3. The measured value shall be related to the length of the connecting cables inside the test set-up to connect the DUT, the result is the transfer impedance of the connecting cables, Z_{con}.

8.4 Measuring

The DUT 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:

$$a_{meas} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \quad (15)$$

where

P_1 is the power fed to inner circuit;

P_2 is the power received in the outer circuit.

8.5 Evaluation of test results

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

$$Z_T = \frac{R_1 + Z_0}{2} \times 10^{-\left(\frac{a_{meas} - a_{cal}}{20}\right)} - Z_{con} \quad (16)$$

or

$$Z_{\mathrm{T}} = \frac{R_1 + Z_0}{2} \times 10^{-(\frac{a_{\mathrm{meas}} - a_{\mathrm{cal}}}{20})} - Z_{\mathrm{Tr}} \quad (17)$$

when using the tube in tube method.

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;
R_1	is the terminating resistor in inner circuit (either equal to the impedance of the inner circuit or the impedance of the generator);
Z_{con}	is the transfer impedance of connecting cables;
Z_{Tr}	is the residual transfer impedance, see 6.6.

NOTE Contrary to the measurement of the transfer impedance of cable screens, the transfer impedance of connectors or assemblies is not related to length.

8.6 Test report

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

The use and the design of test adapters (if any) shall be described.

9 Screening attenuation

9.1 General

This method is in principle the same as described in IEC 62153-4-4.

9.2 Impedance matching

9.2.1 General

Measuring of screening attenuation can be achieved with or without impedance matching.

If the characteristic impedance of the DUT is unknown, the nominal characteristic impedance of the quasi-coaxial system can either be measured by using a TDR with maximum 200 ps rise time or using the method described in Annex A ~~of IEC 62153-4-4~~.

An impedance matching adapter to match the impedance of the generator and the impedance of the system device under test (see Figure 7) is not recommended as it reduces the dynamic range of the test set-up and may have sufficient matching (return loss) only up to 100 MHz when using self-made adapters which are necessary for impedances other than ~~50~~ 60 Ω or 75 Ω (see Annex B ~~of IEC 62153-4-4~~).

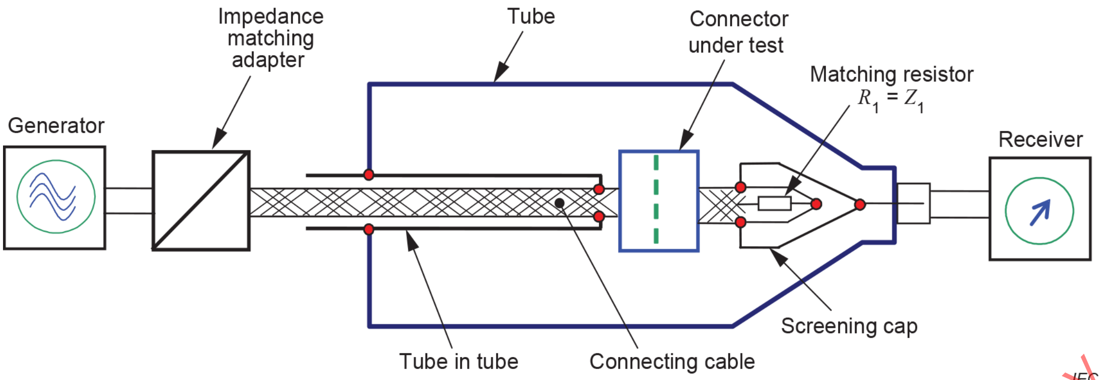


Figure 7 – Measuring the screening attenuation with tube in tube with impedance matching device

The DUT with the connected extension tube shall be installed in the measuring tube. The extension tube shall be short circuited to the measuring tube at the near end of the generator. The feeding cable shall be connected to the generator (via an impedance matching device if necessary) and the output of the measuring tube shall be connected to the receiver.

The scattering parameter S_{21} shall be measured.

Only the peak values of the obtained screening attenuation graph are used to determine the envelope curve.

9.2.2 Evaluation of test results with matched conditions

The screening attenuation a_S shall be calculated with the arbitrary determined normalised value Z_S = 150 Ω[1].

$$a_S = 10 \times \log_{10}\left|\frac{P_1}{P_{r,max}}\right| = 10 \times \log_{10}\left|\frac{P_1}{P_{2,max}} \times \frac{2 \times Z_S}{R}\right| - a_{imd} \quad (18)$$

$$= \text{Env}\left\{-20 \times \log_{10}\left|S_{21}\right| + 10 \times \log_{10}\left|\frac{300\,\Omega}{Z_1}\right| - a_{imd}\right\} \quad (19)$$

where

a_S is the screening attenuation related to the radiating impedance of 150 Ω, in dB;
a_{imd} is the attenuation of the impedance matching device (if appropriate);
Env is the minimum envelope curve of the measured values, in dB;
S_{21} is the scattering parameter S_{21} (complex quantity) of the set-up where the primary side of the two port is the DUT and the secondary side is the tube;
Z_1 is the characteristic impedance of the cable under test, in Ω.

1 Z_S is the normalized value of the characteristic impedance of the environment of a typical cable installation. It is not in relation to the impedance of the outer circuit of the test set-up.

At frequencies lower than the limit of the electrically long coupling length, the measurement will be similar to that for surface transfer impedance.

9.2.3 Measuring with mismatch

The DUT shall be connected to port 1 and the test head of the set-up shall be connected to port 2 of the vector network analyser.

If not known, the characteristic impedance Z_1 of the DUT shall be measured (see 9.2).

The scattering parameter S_{21} shall be measured.

Only the peak values of the obtained screening attenuation graph are used to determine the envelope curve.

9.2.4 Evaluation of test results

The screening attenuation a_S which is comparable to the results of the absorbing clamp method shall be calculated with the arbitrary determined normalised value Z_S = 150 Ω[1].

$$a_S = 10 \times \log_{10} \left| \frac{P_1}{P_{r,max}} \right| = 10 \times \log_{10} \left| \frac{P_1}{P_{2,max}} \cdot \frac{2 \times Z_S}{R} \right| \quad (20)$$

$$= \text{Env}\left\{ -20 \times \log_{10} \left| S_{21} \right| + 10 \times \log_{10} \left| 1 - r^2 \right| + 10 \times \log_{10} \left| \frac{300\,\Omega}{Z_1} \right| \right\} \quad (21)$$

where

a_S	is the screening attenuation related to the radiating impedance of 150 Ω, in dB;
Env	is the minimum envelope curve of the measured values, in dB;
S_{21}	is the scattering parameter S_{21} (complex quantity) of the set-up where the primary side of the two port is the DUT and the secondary side is the tube;
r	is the reflection coefficient $= \left| \left(\frac{Z_0 - Z_1}{Z_0 + Z_1} \right) \right|$;
Z_0	is the characteristic impedance of system, in Ω (usually 50 Ω);
Z_1	is the characteristic impedance (in complex form) of the device under test, in Ω.

9.3 Test report

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

The use and the design of test adapters (if any) shall be described.

10 Coupling attenuation

10.1 General

Coupling attenuation of balanced transmission devices including differential pairs describes the overall effect against electromagnetic interference (EMI) considering both the unbalance attenuation of the pair and the screening attenuation of the screen. Subclause 5.4 of this document gives additional information on coupling attenuation. The principles of measuring the coupling attenuation of balanced cables are described in IEC 62153-4-9. Parts of the information given therein as well as the specific information needed for measuring connectors and cable assemblies is given in the following subclauses.

10.2 Procedure for testing connectors

The coupling attenuation measurements of connectors can be performed with either a two-port VNA (or a generator and a receiver) and a balun (see Figure 8) or with a multiport (or mixed mode) VNA and a TP-connecting unit (see Figure 9) in both cases with the use of the tube-in tube procedure.

The DUT is connected to the connecting cables at the near end according to the instructions of the manufacturer and terminated at the far end by differential and common mode terminations according to Figure 5c. The sample is then centred in the tube and fed by either a generator in the differential mode via a balun, see Figure 8 (or port 1 of a 2-port VNA with the balun to provide the differential mode (Figure 8) or it is fed by 2 ports building up a differential pair of a multiport VNA with the TP-connecting unit (Figure 9). Alternatively, the DUT may be fed by a multiport VNA, see Figure 10 (procedure is under consideration).

The quotient of the voltages at the output of the outer circuit and the input of the cable is measured, either directly by a network analyser or with a calibrated step attenuator [assuming that the receiver has the same input impedance as the output impedance of the signal generator ($R = Z_1$)] which is inserted as an alternative to the triaxial apparatus.

Only the peak values of the maximum of the voltage ratio or the minimum of the attenuation must shall be measured and recorded as a function of the frequency in order to determine the envelope curve. Attenuation introduced by the inclusion of adapters, instead of direct connection, must shall be taken into account when calibrating the triaxial apparatus. The voltage ratio measured is not dependent on the diameter of the outer tube of the triaxial test set-up or on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

NOTE The procedure to measure with a VNA with mixed mode option instead of using a balun is under consideration.

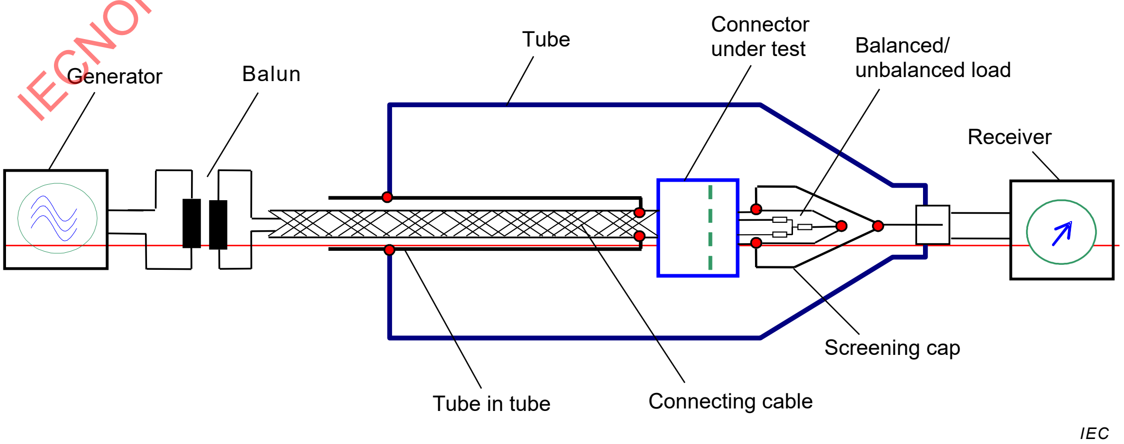


Figure 8 – Measuring the coupling attenuation with tube in tube and balun

The evaluation of the test result is given in 10.4.

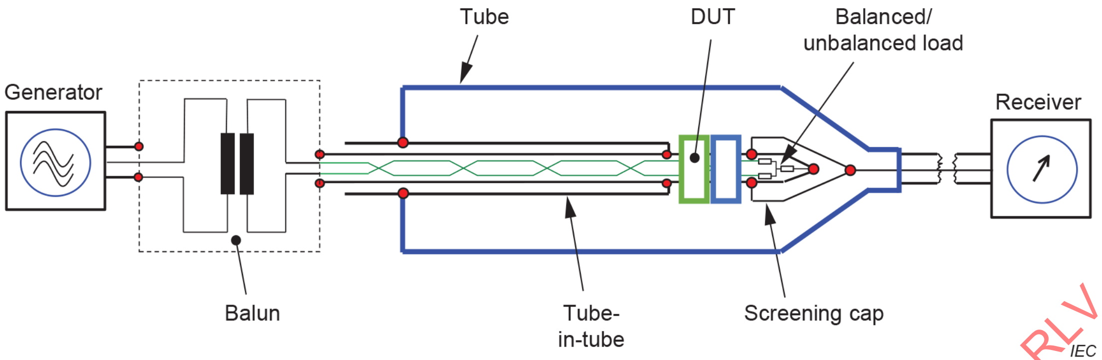


Figure 8 – Coupling attenuation, principle test set-up with 2-port VNA and balun

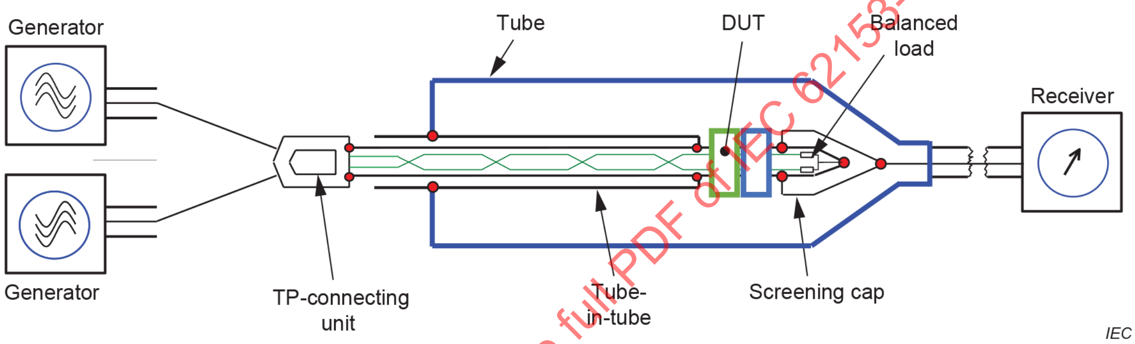


Figure 9 – Coupling attenuation, principle set-up with multiport VNA and TP-connecting unit

10.3 Procedure for testing cable assemblies

Most of the basics of the procedure for testing cable assemblies are comparable to the test of connectors which are described in 10.2. The following additional precautions shall be taken. The measurement of cable assemblies can be divided in two different problems depending on the length of the test objects. If the assembly is shorter than the length of the outer tube, the complete cable assembly can be tested at once as shown in Figure 10. The near end of the cable assembly is connected to an adapter that contains the mating counterpart of the cable assemblies near end. This adapter provides the test signals (near end or feeding adapter). At the far end, the cable assembly is connected to a second adapter (far end or matching adapter) that contains the mating counterpart of the cable assemblies far end connector. The far end adapter includes the matching resistors of the differential pairs according to Figure 5c.

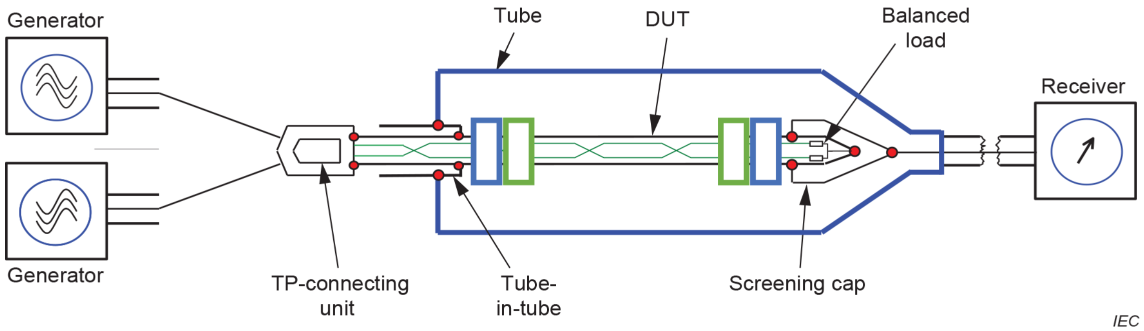


Figure 10 – Coupling attenuation, principle test set-up with multiport VNA and TP-connecting unit for measuring complete cable assemblies

If the cable assembly which is to be tested is longer than the outer tube, it shall be cut into two halves which shall be measured separately without the use of the tub-in-tube process. This situation is depicted in Figure 11. The near end of the measured halve is connected via the TP-connection unit to the generators (2-ports of the multiport VNA) building the differential pair. The screen of the halved cable assembly at the near end is connected to the tube by removing the cable sheath. The far end of the measured cable assembly halve is containing the connector. It is connected to the far end adapter containing the matching resistors of the differential signal pairs according to Figure 5c.

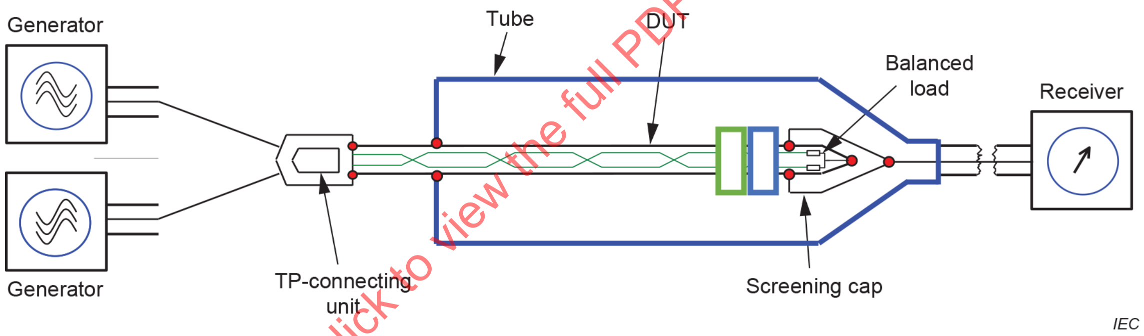


Figure 11 – Coupling attenuation, principle test set-up with multiport VNA and TP-connecting unit for measuring halved cable assemblies

10.4 ~~Expression of results~~ Evaluation of test results when using a balun

The attenuation of the balun shall be subtracted from the measuring results. The coupling attenuation a_C shall be calculated with the normalised value Z_S = 150 Ω:

$$a_C = 10 \times \log_{10} \left| \frac{P_1}{P_{r,max}} \right| = 10 \times \log_{10} \left| \frac{P_1}{P_{2,max}} \times \frac{2 \times Z_S}{R} \right| \quad (22)$$

~~$$= 20 \cdot \log_{10} \left| \frac{U_1}{U_{2max}} \right| + 10 \cdot \log_{10} \left| \frac{300\ \Omega}{Z_1} \right| \quad (23)$$~~

~~$$= a_{m,min} - a_z + 10 \cdot \log_{10} \left| \frac{300\ \Omega}{Z_1} \right| \quad (24)$$~~

$$a_C = 20 \times \log_{10}\left|\frac{U_1}{U_{2max}}\right| + 10 \times \log_{10}\left|\frac{2 \times Z_S}{Z_1}\right| \quad (23)$$

$$a_C = a_{m,min} - a_z + 10 \times \log_{10}\left|\frac{2 \times Z_S}{Z_1}\right| \quad (24)$$

where

a_C	is the coupling attenuation related to the normalised radiating impedance of 150 Ω, in dB;
$a_{m,min}$	is the attenuation recorded as minimum envelope curve of the measured values, in dB;
a_z	is the additional attenuation of an inserted balun, if not otherwise eliminated e.g. by the calibration, in dB;
U_1	is the input voltage of the primary circuit formed by the cable, in V;
U_2	is the output voltage of the secondary circuit, in V;
Z_1	is the (differential mode) characteristic impedance of the cable under test, in Ω.

10.5 Evaluation of test results when using a multiport VNA

The voltage ratio U_{diff}/U_{2max} shall be measured with a calibrated multiport VNA (or calibrated generator and receiver) and corrected with regard to the influence of test leads and connecting units.

NOTE The voltage ratio U_{diff}/U_{2max} corresponds to the invers of the mixed mode S-parameters S_{sd21} and S_{ds12}, respectively according to the conventions shown in Annex F.

The coupling attenuation a_C which is comparable to the results of the absorbing clamp method shall be calculated with the arbitrary determined normalized value Z_S = 150 Ω:

$$a_C = 20 \times \log_{10}\left|\frac{U_{diff}}{U_{2max}}\right| + 10 \times \log_{10}\left|\frac{2 \times Z_S}{Z_{diff}}\right| \quad (25)$$

where

a_C	is the coupling attenuation related to the normalised radiating impedance of 150 Ω, in dB;
U_{diff}	is the differential voltage at the calibrated generator ports;
U_{2max}	is the output voltage of the secondary circuit, in V;
Z_S	is the arbitrary determined normalised impedance (150 Ω);
Z_{diff}	is the (differential mode) characteristic impedance of the cable under test, in Ω.

The envelope curve over the minimum values shall be used as result.

10.6 Test report

The test report shall indicate whether the results of minimum coupling attenuation comply with the value indicated in the relevant cable specification.

If a limiting value of the radiating power is specified for a cable system operating with a defined power level, the difference between the power level and the limit of radiating power shall not be greater than the coupling attenuation of the cable provided for the system.

The use and the design of test adapters (if any) shall be described.

A typical measurement graph of a connector is given in Figure 12.

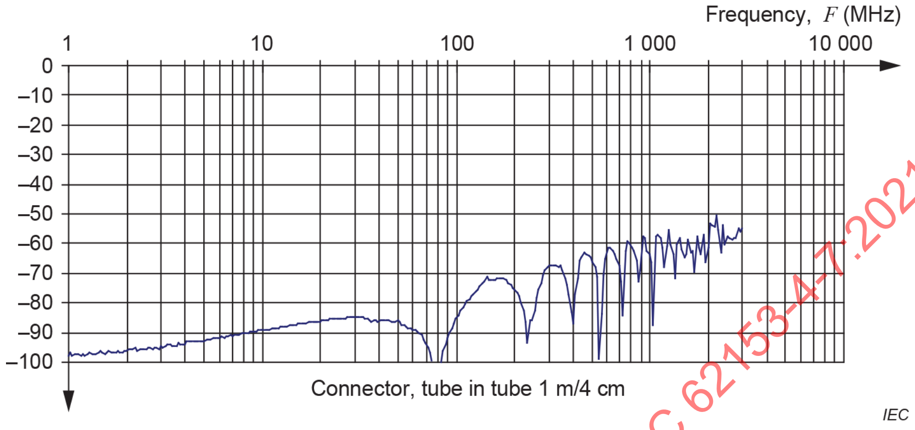


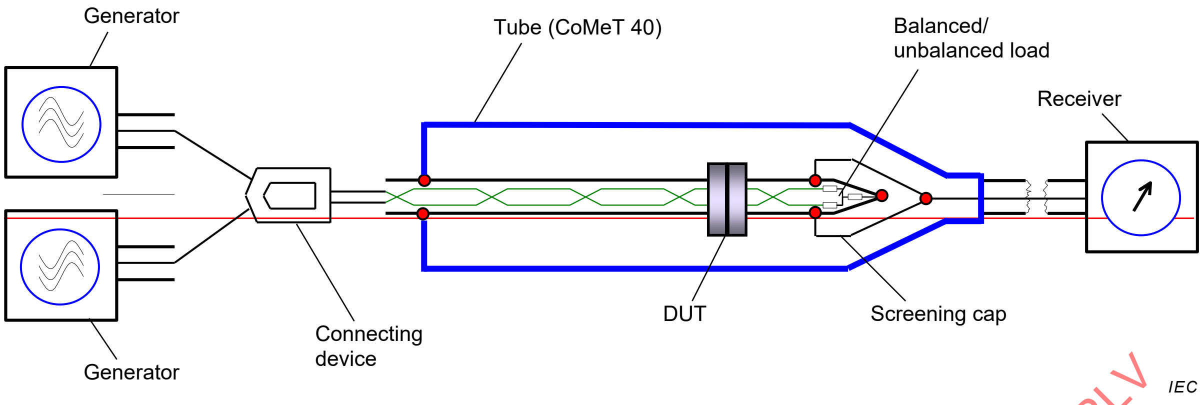
Figure 12 – Typical measurement of a connector of 0,04 m length with 1 m extension tube

~~10.4 Balunless procedure~~

~~To measure the coupling attenuation as well as to measure the unbalance attenuation a differential signal is required. This can, for example, be generated using a balun which converts the unbalanced signal of a 50 Ω network analyser into a balanced signal. Commercial baluns, however, are available up to 1,2 GHz only.~~

~~Alternatively, a balanced signal may be obtained with a network analyser having two generators with a phase shift of 180°. Another alternative is to measure with a multi-port VNA (virtual balun).~~

~~The balunless test procedure is under consideration.~~



~~**Figure 10 – Measuring the coupling attenuation with multiport VNA (balunless procedure is under consideration)**~~

Annex A
(normative)

Determination of the impedance of the inner circuit

If the impedance Z_1 of the inner circuit is not known, it may be determined using a TDR with maximum 200 ps rise time 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 approximately the frequency for which the length of the sample is 1/8 λ, where λ is the wavelength.

$$f_{\text{test}} \approx \frac{c_0}{8 \times L_{\text{sample}} \times \sqrt{\varepsilon_{r1}}} \quad \text{(A.1)}$$

where

f_{test} is the test frequency;

c_0 is the speed of light (3×10^8 m/s);

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:

$$Z_1 = \sqrt{Z_{\text{short}} \times Z_{\text{open}}} \quad \text{(A.2)}$$

Annex B
(informative)

Example of a self-made impedance matching adapter

The graphs in Figure B.1 and Figure B.2 show the attenuation and return loss of a 50 Ω to 5 Ω impedance matching adapter. A DUT impedance of 5 Ω is typical when measuring multipair cables with individually screened pairs or when measuring high voltage cables for electrical vehicles.

The attenuation and return loss were obtained from an open/short measurement. One can obtain that the matching adapter only works up to 10 MHz.

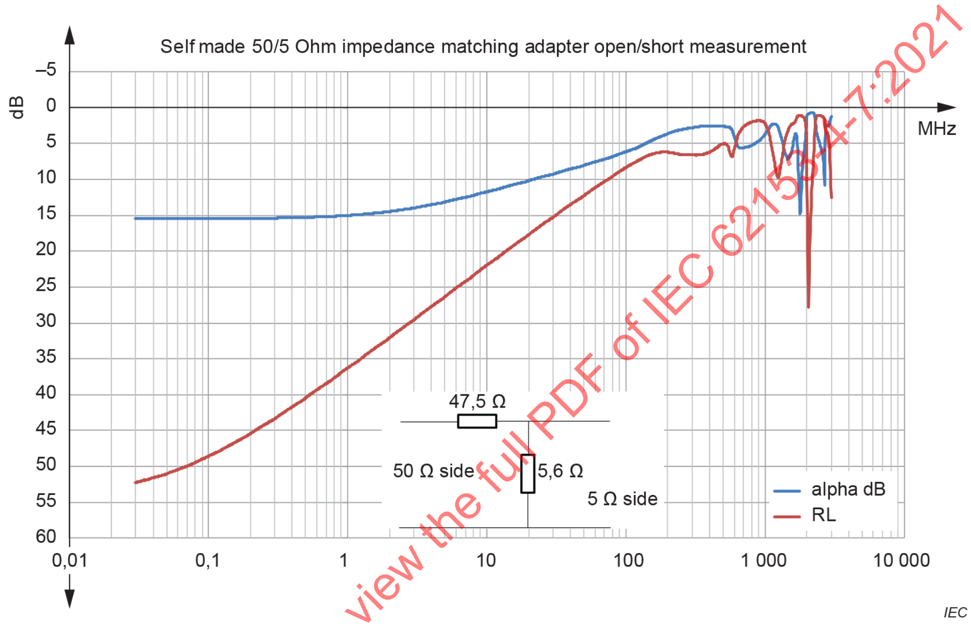


Figure B.1 – Attenuation and return loss of a 50 Ω to 5 Ω impedance matching adapter, log scale

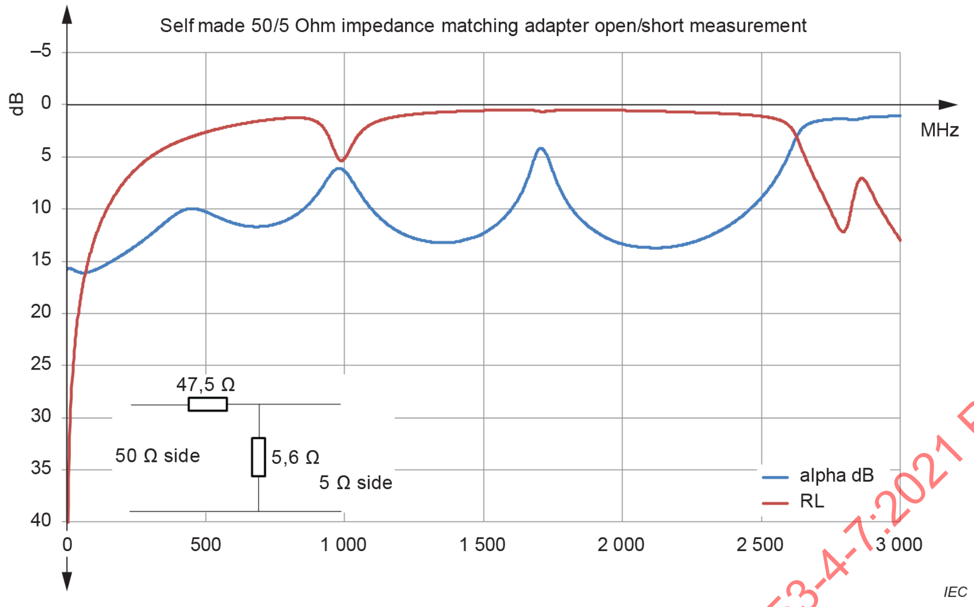


Figure B.2 – Attenuation and return loss of a 50 Ω to 5 Ω impedance matching adapter, lin scale

Annex C
(informative)

Measurements of the screening effectiveness of connectors and cable assemblies

C.1 General

Due to the increasing use of all kinds of electric or electronic equipment, electromagnetic pollution is on the increase. To reduce this electromagnetic pollution, all components of a system, especially the connecting cables (assemblies) shall be screened. It is obvious that one needs standardised measuring procedures to compare the screening effectiveness of different screen designs. The basic screening parameters are the transfer impedance Z_T and the screening attenuation a_S or coupling attenuation a_C. Either the triaxial or the line injection method can be used to obtain the transfer impedance Z_T of cables, connectors and cable assemblies. However, for the measurement of the screening a_S or coupling a_C attenuation of connectors and cable assemblies, an easy and cost effective method does not exist.

The following new method, which fills this gap, is described hereafter. It is based on the recently introduced shielded screening attenuation (long triaxial) test method for the measurement of the screening or coupling attenuation of cables [7], [8][2].

C.2 Physical basics

C.2.1 General coupling equation

For the measurement of the coupling, it is expedient to use the concept of operational attenuation with the square root of power waves, as in the definition of scattering parameters [9], [10]. The general coupling transfer function is then defined as:

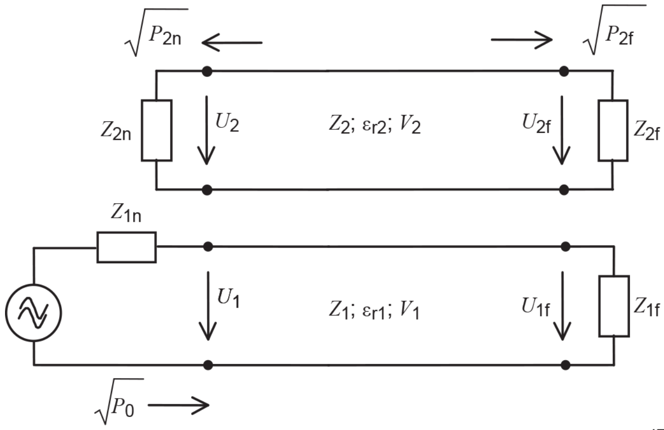
$$T_{n,f} = \frac{\underline{U}_{2n,f} \big/ \sqrt{Z_2}}{\underline{U}_1 \big/ \sqrt{Z_1}} = \frac{\sqrt{\underline{P}_{2n,f}}}{\sqrt{\underline{P}_0}} \qquad (C.1)$$

The electromagnetic influence between the sample under test and the surrounding is in principle the crosstalk between two lines and is caused by capacitive and magnetic coupling. At the near end, the magnetic and capacitive coupling adds whereas at the far end they subtract [10], [11]. The coupling along the sample length is obtained by integrating the infinitesimal coupling distribution along the sample with the correct phase. The phase effect, when summing up the infinitesimal couplings along the line is expressed by the summing function S [10]. When the sample attenuation is neglected, then S could be expressed by the following equation, where $\beta_{1,2}$ are the phase velocities of the primary respectively the secondary circuit and l the coupling length. The indices n and f denote the near respectively the far end.

The equivalent circuit for two coupled lines is given in Figure C.1.

$$S_{n,f}(lf) = \frac{\sin\left[(\beta_2 \pm \beta_1)\cdot l/2\right]}{(\beta_2 \pm \beta_1)\cdot l/2} \exp\left(-j(\beta_2 + \beta_1)\cdot l/2\right) \qquad (C.2)$$

2 Figures in square brackets refer to the Bibliography.



Key

$\sqrt{P_0}$	square root of the feeding power
$\sqrt{P_{2n}}$	square root of the coupled power, near end
$\sqrt{P_{2f}}$	square root of the coupled power, far end
Z_{nm}	matching resistors, 1 = primary circuit, 2 = secondary circuit, n = near end, f = far end
Z_n	characteristic impedance, 1 = primary circuit, 2 = secondary circuit
ε_{rn}	dielectric constant, 1 = primary circuit, 2 = secondary circuit
V_n	velocity of propagation, 1 = primary circuit, 2 = secondary circuit

Figure C.1 – Equivalent circuit of coupled transmission lines

Figure C.2 shows the summing function which is in principle a sin (x)/x function. For high frequencies, the asymptotic value becomes:

$$\left|S_{\substack{n\\f}}\right| \to \frac{2}{(\beta_1 \pm \beta_2)\times l} \qquad \text{(C.3)}$$

And for low frequencies, the summing function becomes:

$$\left|S_{\substack{n\\f}}\right| \to 1 \qquad \text{(C.4)}$$

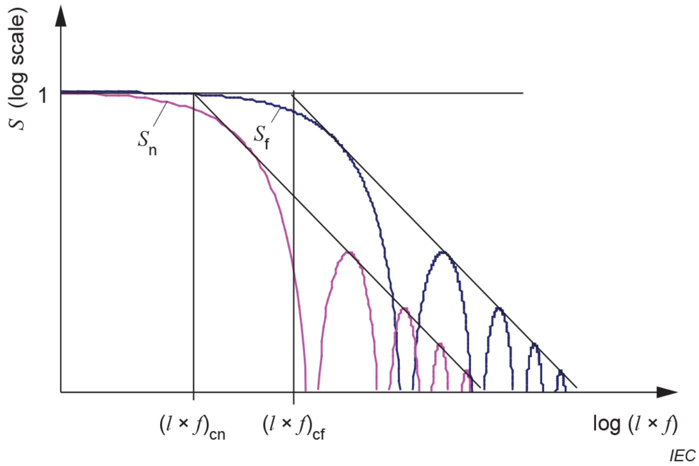


Figure C.2 – Summing function S

The point of intersection between the asymptotic values for low and high frequencies is the so called cut-off frequency f_c. This frequency gives the condition for electrical long samples:

$$f_{\text{c,}\substack{\text{n}\\\text{f}}} \times l \geq \frac{c_0}{\pi \times \left| \sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}} \right|} \quad \text{(C.5)}$$

where

ε_{r1} is the relative dielectric permittivity of the inner system;

ε_{r2} is the relative dielectric permittivity of the outer system;

l is the cable length.

C.2.2 Coupling transfer function

C.2.2.1 Homogenous screens

The primary screening quantities of a screen are the surface transfer impedance Z_T and the capacitive coupling impedance Z_F or the effective transfer impedance Z_{TE}. For homogeneous screens such as for connectors or cables, they can be assumed to be constant along the length. The integration could then be easily solved. The coupling between the sample and the surrounding could be expressed by the following coupling transfer function. For matched lines it is [9], [10]:

$$T_{\text{s,}\substack{\text{n}\\\text{f}}} = \left(Z_F \pm Z_T\right) \times \frac{1}{\sqrt{Z_1 \cdot Z_2}} \times \frac{l}{2} \times S_{\substack{\text{n}\\\text{f}}} \quad \text{(C.6)}$$

For low frequencies, when S = 1, the coupling transfer function corresponds to the frequency behaviour of the surface transfer impedance and capacitive coupling impedance. After a rise with 20 dB per decade, the coupling transfer function shows different cut-off frequencies $f_{cn,f}$ for the near and far end. Above these cut-off frequencies, the samples are considered as electrically long.

The calculated coupling transfer function of a coaxial cable is given in Figure C.3. The principle set-up of the triaxial test procedure is given in Figure C.4.

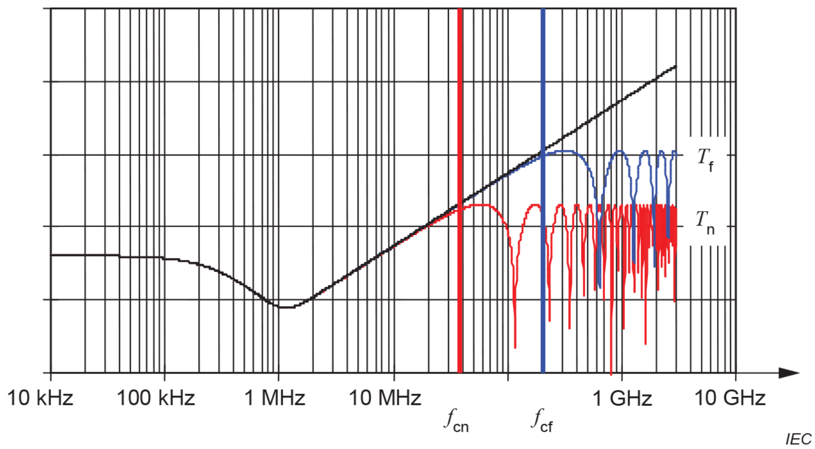


Figure C.3 – Calculated coupling transfer function (l = 1 m; e_{r1} = 2,3; e_{r2} = 1; Z_F = 0)

Below the cut-off frequencies, the surface transfer impedance Z_T is the measure of the screening effectiveness. The value of the transfer impedance Z_T increases with the sample length.

Above the cut-off frequencies in the range of wave propagation, respectively in the range where the samples are electrically long, the screening attenuation a_S is the parameter for the screening effectiveness. The screening attenuation is a length-independent quantity.

C.2.2.2 Cable assembly screens

Cable assemblies are composed by the cable itself and a connector at each end. In addition to the coupling of the components itself, the coupling of the transition between cable and connector also should be taken into account. Mounting a good connector to a good cable will not automatically lead to a good assembly because the connection between the cable and the connector may be worse.

Each part of it has a different coupling, thus one has to integrate in sections along the sample, i.e. one section for each component (connector A, transition, cable, transition, connector B). In a first approach, the velocity in each section could be assumed to be equal. The coupling transfer function for matched lines is then expressed by:

$$T_n = \frac{1}{\gamma_1 + \gamma_2} \times \sum_{i=1}^{n} \left[\frac{Z_{F,i} + Z_{T,i}}{2 \times \sqrt{Z_1 \times Z_2}} \times e^{-(\gamma_1+\gamma_2)\times \sum_{k=1}^{i-1} L_i} \times \left(1 - e^{-(\gamma_1+\gamma_2)\times L_i}\right) \right] \quad \text{(C.7)}$$

$$T_f = \frac{e^{-\gamma_2 L_c}}{\gamma_1 - \gamma_2} \times \sum_{i=1}^{n} \left[\frac{Z_{F,i} - Z_{T,i}}{2 \times \sqrt{Z_1 \times Z_2}} \times e^{-(\gamma_1-\gamma_2)\times \sum_{k=1}^{i-1} L_i} \times \left(1 - e^{-(\gamma_1-\gamma_2)\times L_i}\right) \right] \quad \text{(C.8)}$$

where

$\gamma_{1,2}$ is the complex wave propagation constant of inner, respectively outer circuit;

L_c is the whole coupling length (sum of the segment lengths);

L_i is the length of segment i;

n is the number of segments (for cable assemblies, 3);

$T_{n,f}$ is the coupling transfer function at the near respectively far end;

$Z_{1,2}$ is the characteristic impedance of inner, respectively outer circuit;

Z_F is the capacitive coupling impedance;

Z_T is the surface transfer impedance;

γ is the propagation constant
= (α + jβ), where α is the attenuation constant and β is the phase constant.

C.2.2.3 Coupling in the triaxial set-up

The above-mentioned coupling transfer functions are valid if the primary and secondary circuit are matched. However, in the triaxial set-up, the secondary system (outer circuit) is mismatched (see also Clause C.3). At the near end, one has the short circuit between the sample screen. At the far end, one has the mismatch between the impedance of the outer circuit and the receiver input impedance resulting in the reflection coefficient $r_{2,f}$. In this case, the resulting coupling transfer function (at the receiver end) is obtained by:

$$T^{*} = \left(T_{f} - T_{n} \times e^{-\gamma_2 \times L_C}\right) \times \frac{1 + r_{2,f}}{1 + r_{2,f} \times e^{-2 \times \gamma_2 \times L_C}} \qquad (C.9)$$

~~where~~

~~γ_2 is the complex wave propagation constant of outer circuit;~~

~~L_c is the whole coupling length (sum of the segment lengths);~~

~~$r_{2,f}$ is the reflection coefficient;~~

~~$T_{n,f}$ is the coupling transfer function at the near respectively far end.~~

C.3 Triaxial test set-up

C.3.1 General

The triaxial test set-up is one of the classical methods to measure the transfer impedance and has been recently extended for the measurement of the screening attenuation of cable screens [7]. The triaxial set-up is described in IEC 62153-4-3 and IEC 62153-4-4 and consists of a tube of brass or aluminium with an inner diameter of about 40 mm. Other diameters may be used depending on the frequency range to be measured.

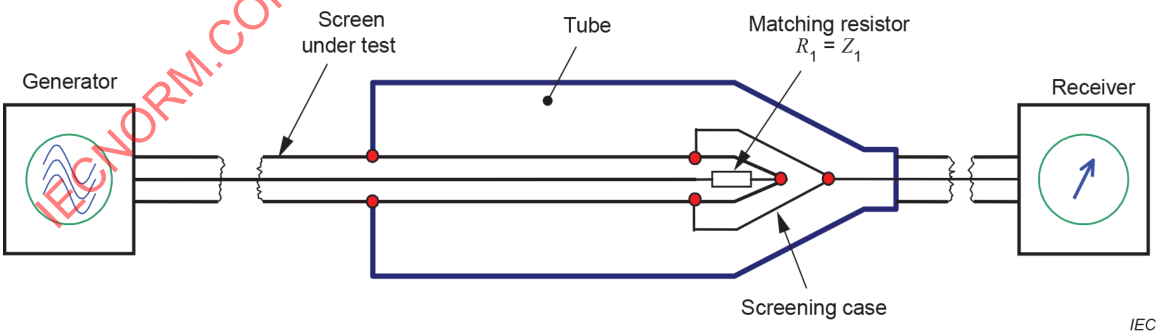


Figure C.4 – Triaxial set-up for the measurement of the screening attenuation a_S and the transfer impedance Z_T

For the measurement of the transfer impedance (electrically short coupling length), the tube length is 0,5 m to 1 m. For the measurement of the screening attenuation (electrically long coupling length), the measuring tube is extended to a length of 2 m to 3 m (see also the above theoretical explanation).

In the outer circuit, at the near end, the screen under test is short circuited with the measuring tube. The electrical waves, which are coupled over the whole cable length from the inner system into the outer system, propagate in both directions, to the near and to the far end. At the short circuited end, they are totally reflected, so that at the measuring receiver, the superposition of near and far end coupling can be measured as the disturbance voltage ratio U_2/U_1. The screening attenuation as a power ratio is then related to a standardised characteristic impedance of the outer system Z_S = 150 Ω.

$$a_S = 20 \times \log\left(\left|\frac{U_2}{U_1}\right|_{max}\right) + 10 \times \log\left(\frac{2 \times Z_S}{Z_1}\right) \quad (C.10)$$

where

Z_1 is the characteristic impedance of the sample under test and Z_S is 150 Ω.

C.3.2 Measurement of cable assemblies

C.3.2.1 General

When measuring cable assemblies in the triaxial test set-up, there is the problem in that their lengths differ widely and are either shorter or longer than the commonly used measuring tube of 2 m or 3 m. However, the investigations of the above-given coupling functions show that:

a) for assemblies longer than the measuring tube, it is sufficient to measure just both accessible assembly ends;

b) for assemblies shorter than the measuring tube, one can extend the assembly by a well-screened cable inside a closed copper tube. This is the so called tube in tube method.

C.3.2.2 Assembly longer than the measuring tube

In screening attenuation measurements of cable assemblies, it is evident that the result is characterised by the weakest part. Either the cable or the connector or the transition between cable and connector. Thus, for cable assemblies which are longer than the measuring tube, it is sufficient to measure the assembly from both ends (provided that the cable screen is homogenous). The worst case of both measurements is then the screening attenuation of the whole assembly. The simulated graphs given in Figure C.5 and Figure C.6 underline that evidence.

The simulation parameters are:

a) cable screen

length:	500 cm
DC resistance:	13 m Ω/m
magnetic coupling:	0,04 mH/m
capacitive coupling:	0,02 pF/m

b) connector screen including transition from cable to connector

length:	5 cm
DC resistance:	2 m Ω/m
magnetic coupling:	0,002 mH
capacitive coupling:	0 pF/m

c) outer circuit (secondary system)

impedance:	150 Ω
dielectric permittivity:	1,1

d) inner circuit (primary system)

impedance: 50 Ω

dielectric permittivity: 2,3

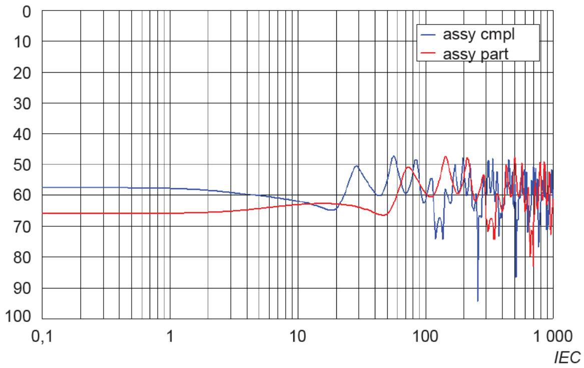


Figure C.5 – Simulation of a cable assembly (logarithmic scale)

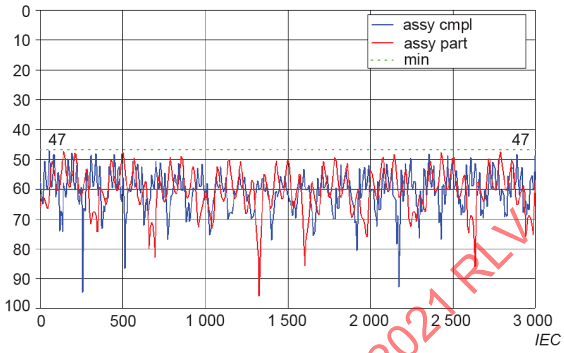


Figure C.6 – Simulation of a cable assembly (linear scale)

The blue line shows the result of the complete cable assembly, i.e. 500 cm cable and both connectors. The red line shows the result for just one part of the assembly, i.e. 195 cm of the cable and one connector. In the lower frequency range, where the samples are electrically short, one gets a length dependent result. However, in the higher frequency range, where the samples are electrically long, one gets the same minimum value, i.e. the same screening attenuation of 47 dB.

C.3.2.3 Assembly shorter than the measuring tube

When the assembly is shorter than the measuring tube, the assembly can be extended by a well screened connecting cable inside a closed copper tube. This is the so called tube in tube method (see also Figure C.7 and Figure C.8).

The extension tube then acts as a resonator. The same principle is also used for the measurement of connectors. Further details can be obtained from the following explanation of the measurement of connectors.

C.3.3 Measurement of connectors

C.3.3.1 General

Usual RF connectors have mechanical dimensions in the longitudinal axis in the range of 10 mm to 50 mm. With the definition of electrical long elements, we get cut-off frequencies of about 3 GHz or higher for standard RF-connectors. Above that frequency, they are considered to be electrically long.

The screening attenuation is by definition only valid in the frequency range above the cut-off frequency, where the elements are electrically long. Thus, the screening attenuation of a RF connector itself can only be measured at frequencies above 3 GHz.

However, by extending the RF-connector by a RF-tight closed metallic tube, a cable assembly which is electrically long is built. Thus, the cut-off frequency, respectively the lower frequency limit, to measure the screening attenuation is extended towards lower frequencies. If one connects this extension tube directly to the connector under test, one is measuring the screening attenuation of the connector (and its mated adapter). If one connects the extension tube to the connecting cable close to the connector, one measures the screening attenuation of the combination of the connector (and its mated adapter) and the transition between cable and connector (see also figures below).

NOTE Although the connector itself stays electrically short, the combination of the connector and the extension tube shows the behaviour (the screening attenuation) of the connector when connected to a well screened cable, which has a screening effectiveness better than the one of the connectors (or the transition between cable and connector). See also the explanation in C.3.3.2.

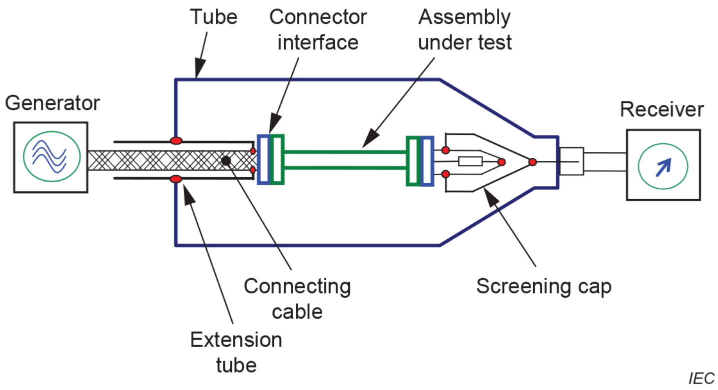


Figure C.7 – Triaxial set-up with extension tube for short cable assemblies

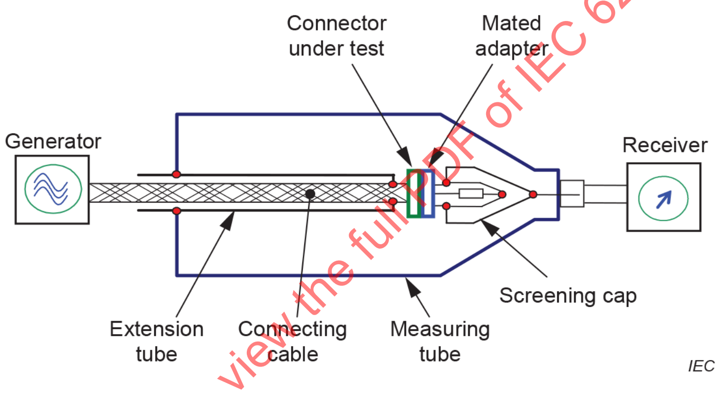


Figure C.8 – Triaxial set-up with extension tube for connectors

C.3.3.2 Measurement set-up

For the measurement of RF connectors, the triaxial set-up according to IEC 62153-4-3 respectively IEC 62153-4-4 has been extended by a RF-tight closed metallic tube (see Figure 8). The extension tube is either connected to the connector under test or to the screen of the connecting cable of the connector under test. At the far end, the connector under test is connected to the screening cap of the triaxial test set-up via its mated adapter.

The measurement of the screening attenuation itself is the same as the measurement of cable screens according to IEC 62153-4-4.

C.3.3.3 Measurement results and simulations

In a first approach, one has measured short cable pieces instead of a connector. The advantage is that the results are not influenced by a mating adapter or the transition between cable and connector. The cable is a coaxial cable with an impedance of 75 Ω, foam PE dielectric and a single braid screen (not optimised, i.e. under-braided). The simulations have been done with the equations (C.7), (C.8) and (C.9) where the number of sections is 2. The first section is the connecting cable with the RF-tight extension tube.

Thus, the transfer impedance and capacitive coupling impedance of that section is neglected. The second section is the cable under test with following parameter:

DC resistance:	8 m Ω/m
magnetic coupling:	0,6 mH/m
capacitive coupling:	0,02 pF/m
impedance:	75 Ω
dielectric permittivity:	1,35

The comparison of the simulation (Figure C.9, Figure C.11) with the measurement results (Figure C.10, Figure C.12) show a good correspondence. In the lower frequency range, when the samples are electrically short, one gets the same results. However, in the higher frequency range, one can see the influence of the extension tube. The 10 cm sample is electrically short over the whole frequency range, as the cut-off frequency is 5,9 GHz. Thus, the coupled power increases with increasing frequency. However, the quasi cable assembly composed of the connector and the extension tube is electrically long above 590 MHz, which results in a constant maximum coupled power. One characteristic of an electrically long object is also that the maximum coupled power is independent of the sample length (see C.2.1). This is underlined in Figure C.13 and Figure C.14, where the simulated results of a 4 cm sample in a 1 m respectively 2 m tube, i.e. with a 96 cm, respectively 196 cm extension tube, are shown. The envelope of both curves is identical.

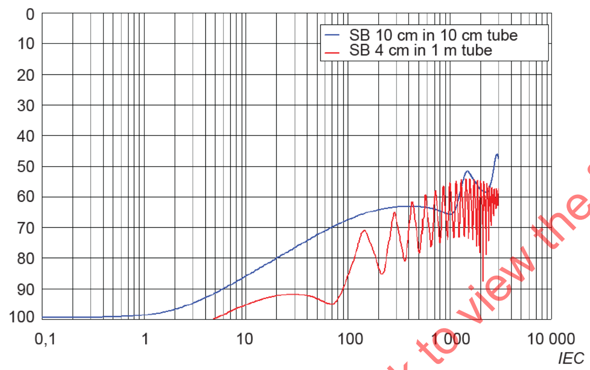


Figure C.9 – Simulation, logarithmic frequency scale

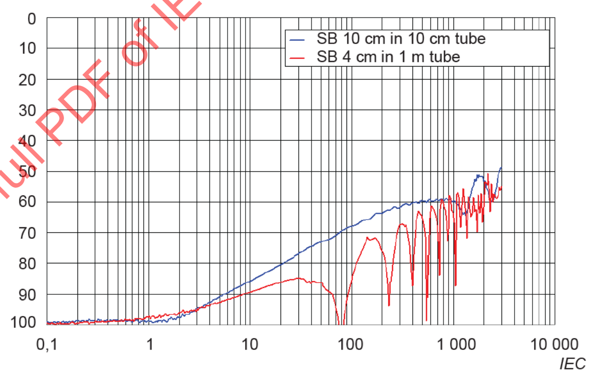


Figure C.10 – Measurement, logarithmic frequency scale

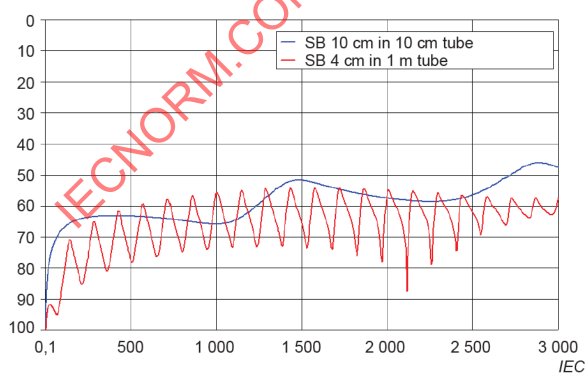


Figure C.11 – Simulation, linear frequency scale

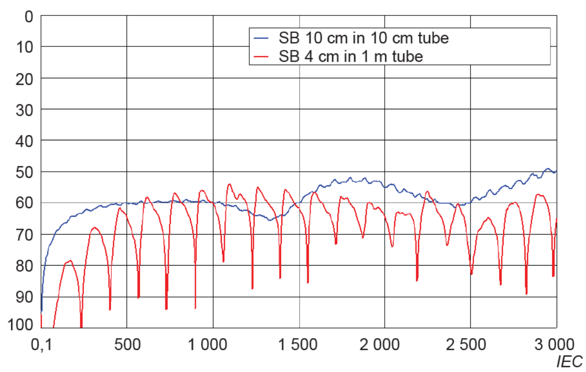


Figure C.12 – Measurement, linear frequency scale

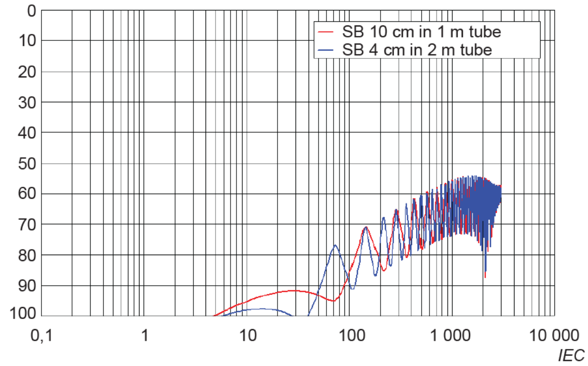


Figure C.13 – Simulation, logarithmic frequency scale

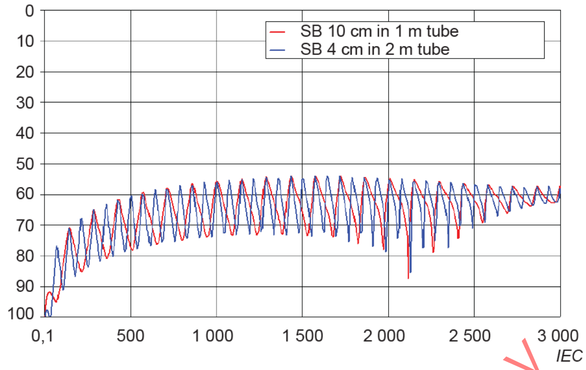


Figure C.14 – simulation, linear frequency scale

C.4 Conclusion

Customers and users of RF cables, cable assemblies and connectors ask more often for screening effectiveness values in decibels (dB) instead of transfer impedance values in ~~mW~~ mΩ respectively ~~mW~~ mΩ/m. The tube in tube method replies to that need since it offers a simple and reliable method to measure the screening attenuation in dB of connectors and cable assemblies. That method is an extension of the shielded screening attenuation (long triaxial) test set-up according to IEC 62153-4-4.

The comparison of the measured and the calculated curves show good concordance.

The advantages of the tube in tube method for connectors and assemblies are the same as for the measurement of the screening attenuation of cable screens in the tube:

- simple and easy test set-up;
- insensitive against electromagnetic disturbances from outside;
- high dynamic range >130 dB;
- good reproducibility.

Annex D
(informative)

Influence of contact resistances

Contact resistances between the feeding cable and the extension tube or the screening case in the test head may influence the test result. Contacts shall be prepared carefully with low resistance or with low impedance. Contacts shall be achieved over the complete circumference of the screen. Critical contacts are shown in Figure D.1.

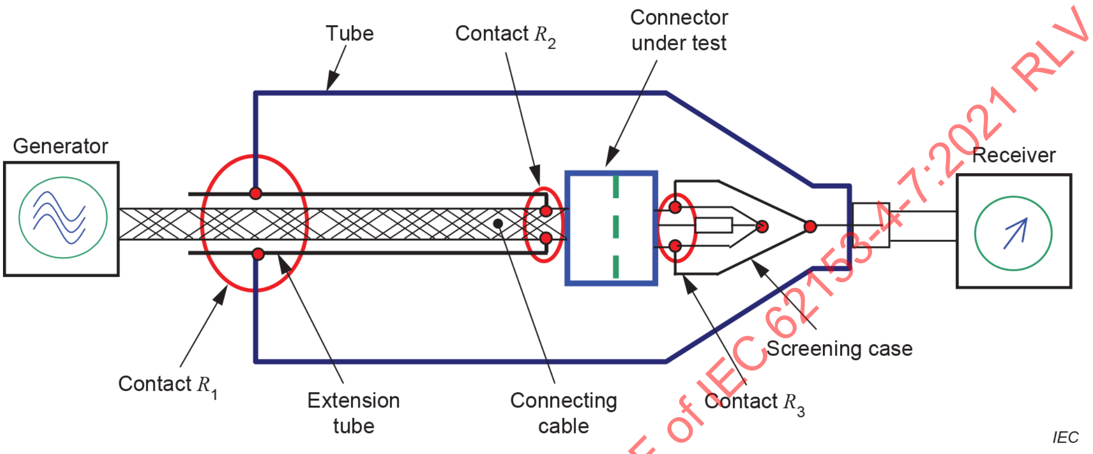
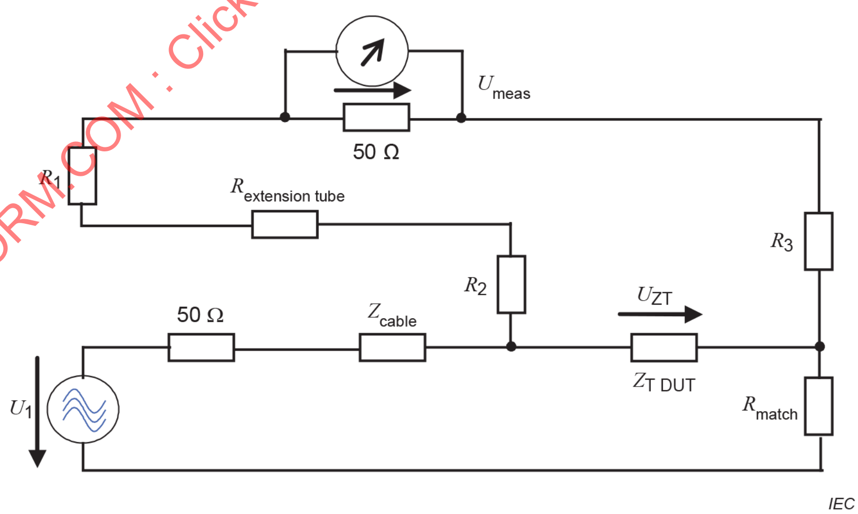


Figure D.1 – Contact resistances of the test set-up

The equivalent circuit of the complete test set-up including the contact resistances is given in Figure D.2. The test set-up shall be designed such that contact resistances of the extension tube are in series with the input impedance of the receiver and the contact resistance of the screening case including the matching load of the DUT is in series with the generator.



Key

R_1, R_2 and R_3	contact resistances depicted in Figure D.1.
Z_{cable}	characteristic impedance of the connecting cable (see Figure B.1)
Z_{DUT}	transfer impedance of the DUT

Figure D.2 – Equivalent circuit of the test set-up

In this case, contact resistances of a few mΩ in series with the 50 Ω input resistance of the generator or the receiver are negligible.

The test set-up should be designed such that contact resistances are not in series with the transfer impedance of the DUT. If contact resistances are in series with the transfer impedance of the DUT, they will influence the result considerably.

Annex E
(informative)

Direct measurement of screening effectiveness of connectors

E.1 ~~General~~ Scope

This document describes the measurement of transfer impedance and screening or coupling attenuation of connectors and cable assemblies with the tube in tube procedure. As shown in Figure 2, connectors usually are measured with a short piece of connecting cable.

In different cases, it may be required to measure the screening effectiveness direct on the connector or without connecting cable, e.g. to evaluate the EMC of the interface of the mated connectors. Clause E.2 describes the test set-up for direct connector measurement.

E.2 Test set-up

The test set-up and measurements are in principle the same as in Clause 8 to Clause 10 of this document.

Contrary to the set-ups in Clause 8 to Clause 10 of this document, the RF-tight tube in tube and the screening cap are directly connected to the connector under test (CUT), see Figure E.1; e.g. by a screwing joint of the connector under test to the extension tube and the screening cap. The torque of this screwing joint shall be specified by the connector manufacturer. In order to vary the test length and therefore the cut off frequencies, a moveable shorting plane can be used as an option, see also IEC 62153-4-15:2015, Annex F. Any contact solution providing a 360-degree contact with sufficiently low resistance to avoid resonances can be used for the sliding short.

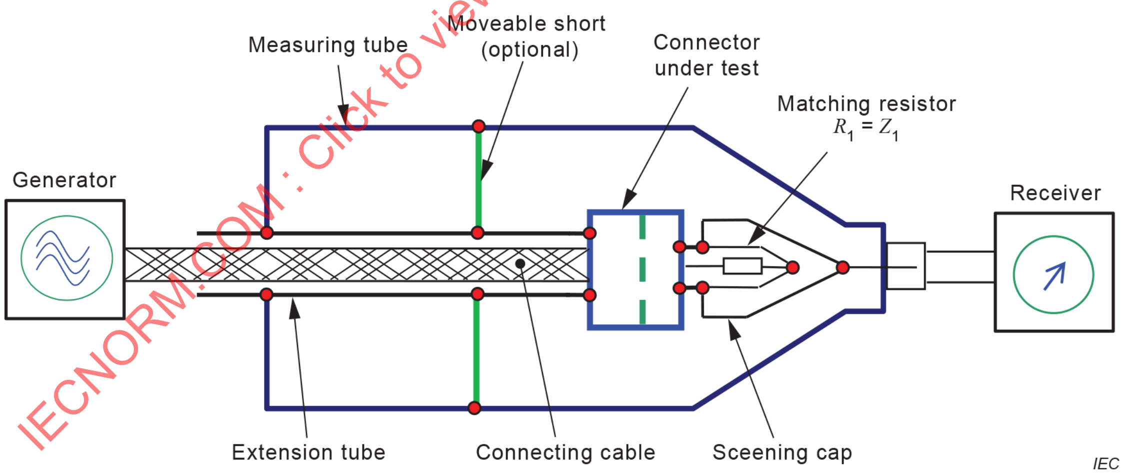


Figure E.1 – Principle of the test set-up to measure transfer impedance and screening attenuation of a connector

The same applies in principle to the set-up for measuring cable assemblies, see Figure E.2.

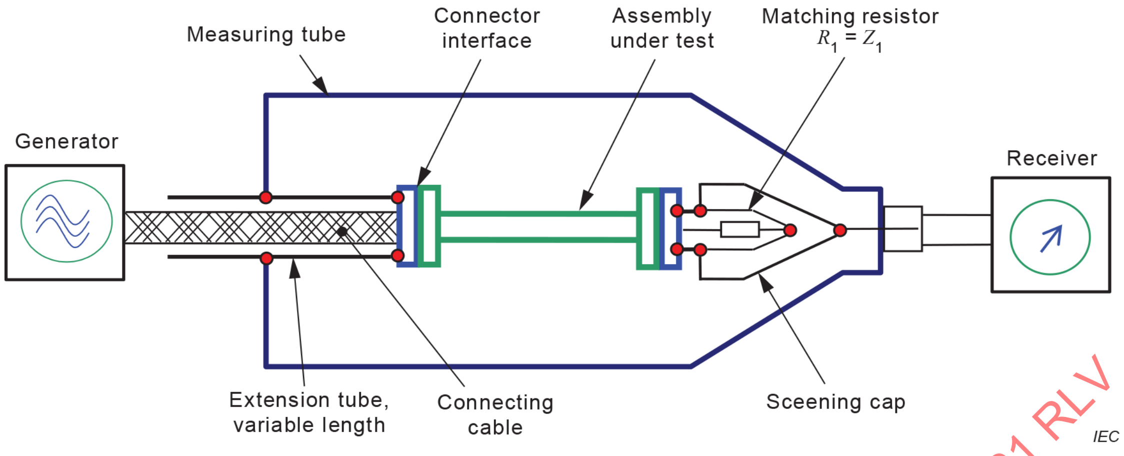
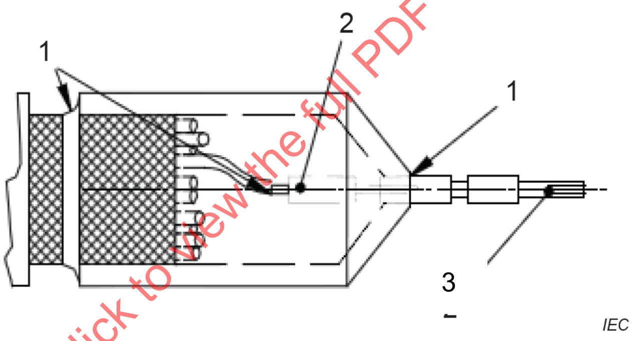


Figure E.2 – Principle of the test set-up to measure transfer impedance and screening attenuation of a cable assembly

If a multi conductor cable is tested instead of a single-conductor cable, a combination of inner conductors (cores) shall be selected such that their impedance to the screen is closest to the internal impedance of the test receiver, see Figure E.3 (e.g. determined by means of a reflectometer).



Key

1 connection

2 terminating impedance 50 Ω

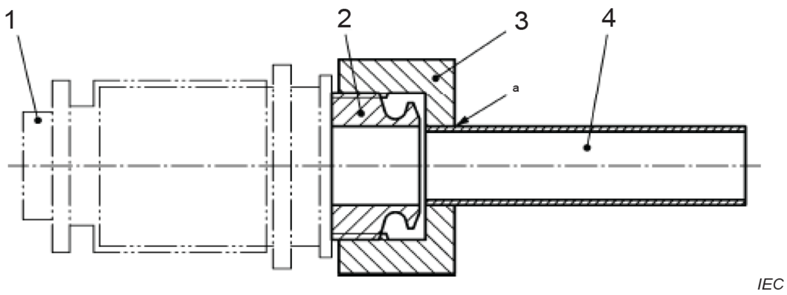
3 inner contact from RF connector connected to the shielded tube

Figure E.3 – Example of sample preparing

E.3 Construction details of test set-up

The connection of the RF-tight tube as well as the RF-tight connection of the screening cap may influence the test results considerably. Worse mounted connections may lead to leakages and to poor test results.

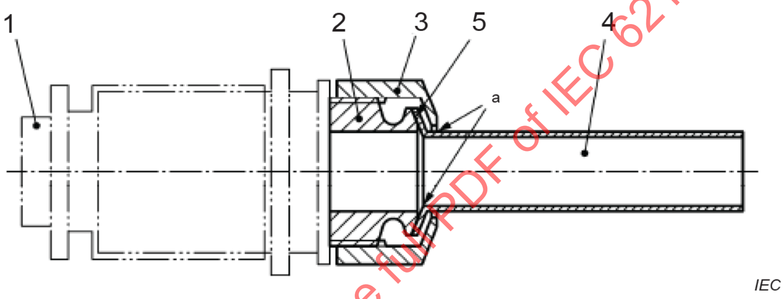
Figure E.4 and Figure E.5 give examples of how to connect the tube in tube and the screening cap to the CUT.



Key

1 mating connector
2 coupling
3 bush (Cu-material)
4 copper tube
a ~~RF-density~~ RF-tight connection (soldered for example)

Figure E.4 – Screening tube with separate nut



Key

1 mating connector
2 coupling
3 nut
4 copper tube
5 cone
a matching edge-raised or chamfered

Figure E.5 – Screening fixed with associated nut

Annex F
(normative)

Mixed mode S-parameters

F.1 General

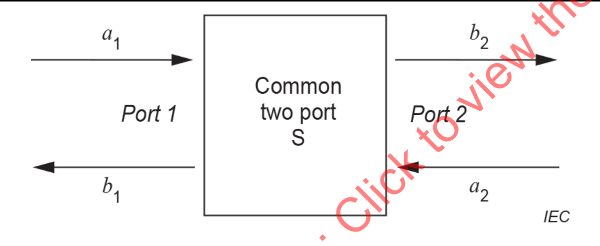
To measure parameters like unbalance attenuation, coupling attenuation, etc. of balanced cables, connectors and components, a differential signal is required. This can, for example, be generated by using a balun which converts the unbalanced signal of a 50 Ω network analyser into a balanced signal.

Alternatively, a balanced signal may be obtained by using a vector network analyser (VNA) having two generators with a phase shift of 180°. Another alternative is to measure with a multi-port VNA (virtual balun).

The properties of balanced pairs are determined mathematically from the measured values of each single conductor of the pair against reference ground. The coverable frequency range for the determination of the reflection and transmissions characteristics of symmetrical pairs is no longer limited by the balun but by the VNA and the connection technique.

F.2 Definition of mixed mode S-parameters

The transmission characteristics of four poles or two ports, such as coaxial cables, may be described by the scattering parameter or abbreviated "S-parameter". In matrix notation, it is written as illustrated in Figure F.1.

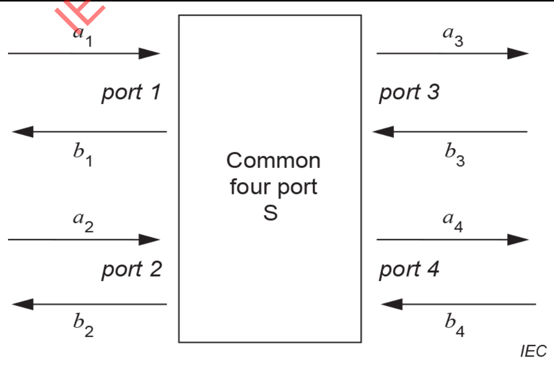


$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

where a and b are the normalized power waves of the input and output ports.

Figure F.1 – Common two-port network

The definition of the scattering matrix can be easily extended to arbitrary N gates. For a four-port, these result in the network illustrated in Figure F.2.



$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = \left(S^{\text{std}}\right) \cdot \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{43} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix}$$

Figure F.2 – Common four port network

For the measurement of symmetrical two-ports, the physical ports of the multi-port VNA are combined into logical ports, as illustrated in Figure F.3.

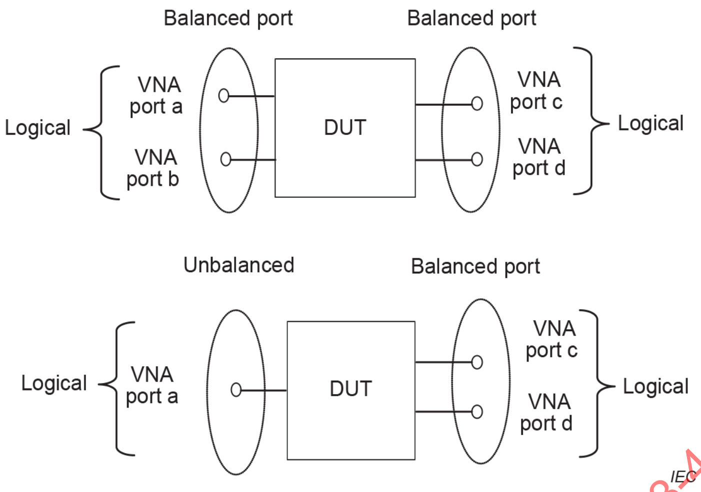
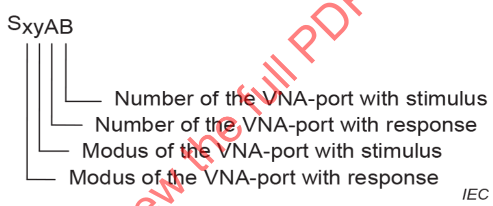


Figure F.3 – Physical and logical ports of a VNA

The nomenclature in Figure F.4 is used.



Modus	s: Single ended (unbalanced, coaxial)
	d: Differential mode (balanced)
	c: Common mode

Figure F.4 – Nomenclature of mixed mode S-parameters

Accordingly, the S-parameters can be understood as ratios of power waves.

$$S_{xyAB} = \frac{\text{input signal at VNA-port A at modus x}}{\text{input signal at VNA-port B at modus y}}$$

The conversion of the asymmetrical four-port scattering parameters S^{std} to mixed mode scattering parameters S^{mm} for a symmetrical two-port network is given by:

$$S^{mm} = M \cdot S^{std} \cdot M^{-1}$$

where

$$M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \quad \text{(C.2)}$$

$$S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd21} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix}$$

For the measurement of a two-port with an unbalanced port (single ended) and a balanced port, the following measurement configurations arise (see Figure F.5):

			Stimulus		
			Single ended	Differential mode	Common mode
			Logical port 1	Logical port 2	Logical port 2
Response	Single ended	Logical port 1	S_{ss11}	S_{sd12}	S_{sc12}
	Differential mode	Logical port 2	S_{ds21}	S_{dd22}	S_{dc22}
	Common mode	Logical port 2	S_{cs21}	S_{cd22}	S_{cc22}

IEC

Figure F.5 – Measurement configuration, single ended response

The measurement of the coupling attenuation corresponds to a stimulus in the differential mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sd12}. The measurement of the screening attenuation corresponds to a stimulus in common mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sc12}.

For the measurement of a four-port, the following test configurations are obtained (see Figure F.6):

			Stimulus			
			Differential mode		Common mode	
			Logical port 1	Logical port 2	Logical port 1	Logical port 2
Response	Differential mode	Logical port 1	S_{dd11}	S_{dd12}	S_{dc11}	S_{dc12}
		Logical port 2	S_{dd21}	S_{dd22}	S_{dc21}	S_{dc22}
	Common mode	Logical port 1	S_{cd11}	S_{cd12}	S_{cc11}	S_{cc12}
		Logical port 2	S_{cd21}	S_{cd22}	S_{cc21}	S_{cc22}

IEC

Figure F.6 – Measurement configuration, differential mode response

The measurement of the attenuation of a balanced pair corresponds to a stimulus and a response in differential mode, i.e. a measurement of the S-parameter S_{dd21}. The measurement of the unbalance attenuation with stimulus in differential mode and common mode response corresponds at the near end with the S-parameter S_{cd11} or S_{cd21} when measured at the far end.

F.3 Reference impedance of a VNA

When measuring with 4 port VNA with mixed mode parameters, a full 4-port calibration, e.g. with electronic calibration units, shall be applied. The VNA (Z_0 = 50 Ω physical analyser ports) sets the default values reference impedances for the differential mode Z_{0d} = 100 Ω (= 2 × Z_0) and for the common mode Z_{0c} = 25 Ω (= Z_0/2).

Annex G
(normative)

Accessories for measuring coupling attenuation

G.1 TP connecting unit

A balanced signal may be obtained with a vector network analyzer (VNA) having two generators with a phase shift of 180° or with a multi-port VNA using mixed mode S-parameters (balunless or virtual balun, respectively). To connect the unbalanced ports of the VNA with the balanced device under test (DUT), a TP-connection unit, also with high RF performance, is required. The TP connecting unit performance requirements are specified in Table G.1.

Table G.1 – TP-connecting unit performance characteristics (100 kHz to 2 GHz)

Parameter	Value
Characteristic impedance, primary side (single ended)[a]	50 Ω
Characteristic impedance, secondary side (differential)[a]	1 × 100 Ω (differential)
Return loss, differential mode[b]	> 20 dB
Attenuation, differential mode[c]	< 0,3 dB
Unbalance attenuation (TCTL)[d]	> 60 dB-10×log (f), 40 dB max.

[a] Two ports with single ended impedances of 50 Ω generates a common mode impedance of 25 Ω and a differential mode impedance of 100 Ω.

[b] To be measured e.g. with a 4 port mixed mode network analyser. One logical port is generated by the combination of two single ended ports. A second logical port is generated by the combination of two other single ended ports. The S-parameter S_{dd11} then represents the negative return loss of the differential mode.

[c] With the test set-up according to [b] the absolute dB value of the S-parameter, S_{dd11} then represents the return loss of the differential mode.

[d] With the test set-up according to [b] the S-parameter, S_{cd21} represents the negative unbalance attenuation (TCTL).

G.2 Termination of the DUT

A differential mode termination is required for each pair at the near and far end of the cable as shown in Figure G.1.

$$R_{DM} = \frac{Z_{diff}}{2} \quad (11)$$

The termination of the common mode ($R_{DM}//R_{DM}$) is 25 Ω.

NOTE Since modern mixed mode VNAs use a 50 Ω generator and receiver impedance as default value, the common mode value results in 25 Ω.

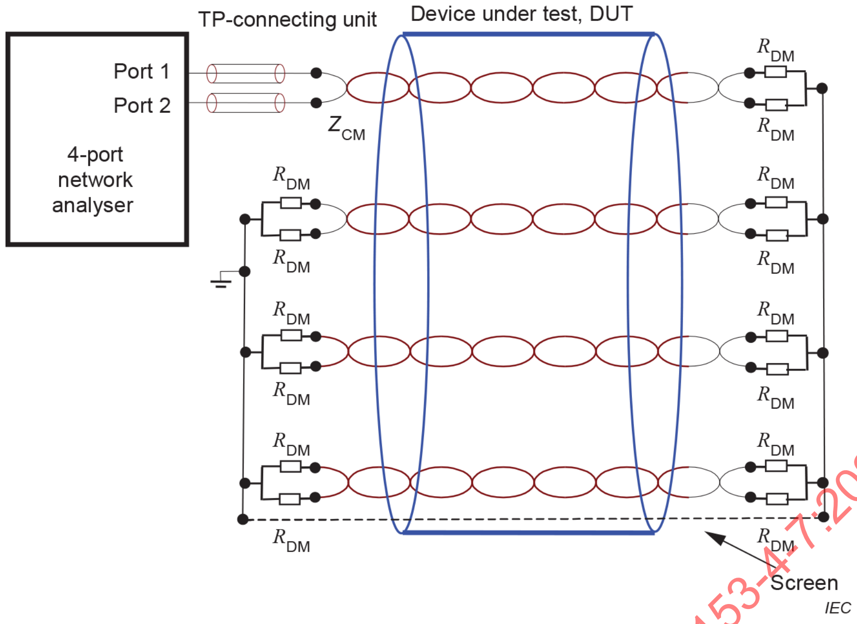


Figure G.1 – Termination of the device under test, principle

G.3 Test adapter

G.3.1 General

When measuring transfer impedance and screening- or coupling attenuation on connectors or cable assemblies, test adapters are required to connect the DUT with the test set-up. Test adapters may limit the sensitivity of the test set-up and possibly falsify the test results. Qualification tests of test adapters shall be performed to establish the noise floor, respectively the sensitivity of the entire test system. We can divide between two basic concepts when realizing differential adapters and suppling the adapters with test signals.

G.3.2 Direct feeding with coaxial cables

The first concept is called the direct feeding concept. It applies coaxial feeding cables reaching right to the adapter (Figure G.2). It is recommended to use connectors showing up metrology connector compatible interfaces. The advantage is then that the performance of the coaxial feeding cables can be very well verified and can be directly connected to the ports of the calibrated generator or the VNA. The generator/VNA calibration plane could be even located at the end of the coaxial feeder cables by including them into the calibrated part of the test port cables.

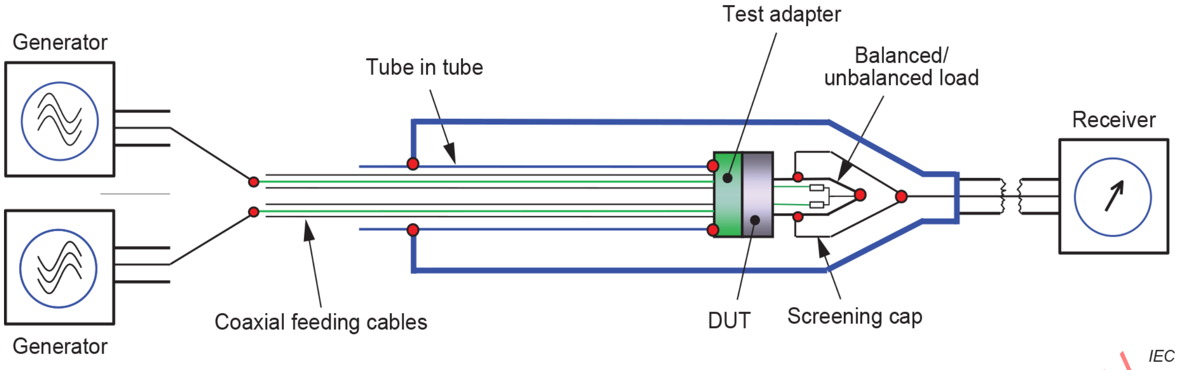


Figure G.2 – Balunless measurement of coupling attenuation of a balanced connector, direct feeding, principle

G.3.3 Balanced feeding cable

The second concept applies to balanced feeding cables (Figure G.3). Therefore, market available differential cable assemblies which are showing up the compatible connector interface could be reworked and finished with a suitable housing to build up the test adapter. The dis-advantage of the balanced feeding cable concept is the more difficult verification of the electrical performance.

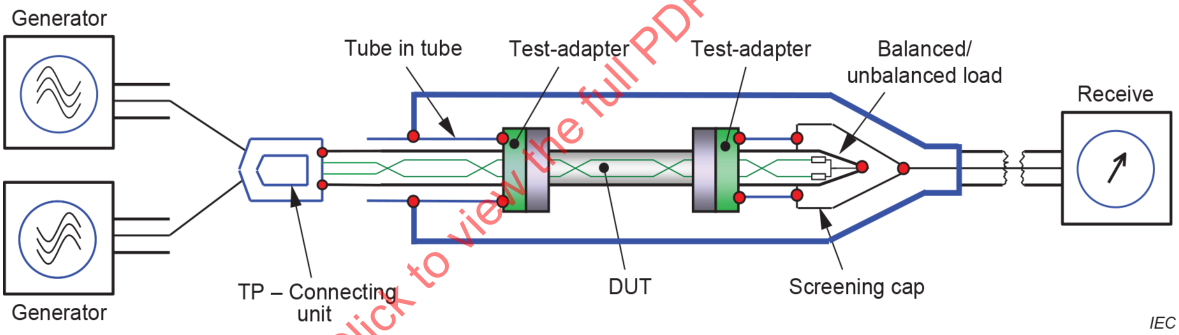


Figure G.3 – Balunless measurement of coupling attenuation of a cable assembly using balanced feeding cable, principle

G.3.4 Movable short circuit

Adapters including a higher number of balanced pairs may require bigger housing volumes. The relation of the diameter of the outer tube and the diameter of the adapter housing defines the impedance of the adapter section of the outer system. If this relation is below 2.3, an additional point of reflections is generated affecting additional measurement uncertainties. One way to overcome these additional uncertainties is to implement the near end shortage plane directly into the adapter as shown in Figure G.4. The quality of the hereby realised contact resistance shall be verified.

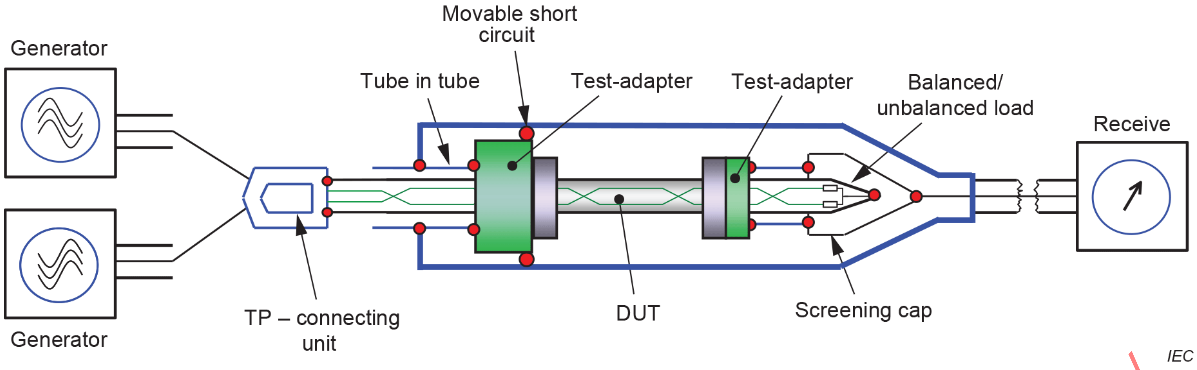


Figure G.4 – Balunless measurement of coupling attenuation of a cable assembly using adapters with implemented short circuit, principle

Annex H
(informative)

Low frequency screening attenuation

Screening attenuation for cables and cable assemblies is based on system requirements and regulations, often defined for frequencies above 30 MHz. To measure the screening attenuation, an electrically long DUT is required. For common CATV cables, this would require a test length of 20 m. However, for practical reasons the test length is in the range of 2 m to 3 m which would correspond to a minimum frequency of 300 MHz from which on screening attenuation could be measured. However, it is common practice to interpret the measured results between 30 MHz and 300 MHz as screening attenuation. The error introduced by this interpretation is neglectable provided the test length is at least 2 m. In case of doubt, the test length shall be increased.

Figure H.1 shows an example for a test result of a cable assembly when the test length is 2 m. In the diagram, the given cut-off frequency Fg(sd) is calculated according to IEC 62153-4-4:2015 which is located approximately at 300 MHz. The given limit lines are valid for the screening classes A and A+ according to the European Standard EN 50117-9-2:2019. The requirements for the low frequency screening attenuation from 30 MHz to 300 MHz can be clearly met.

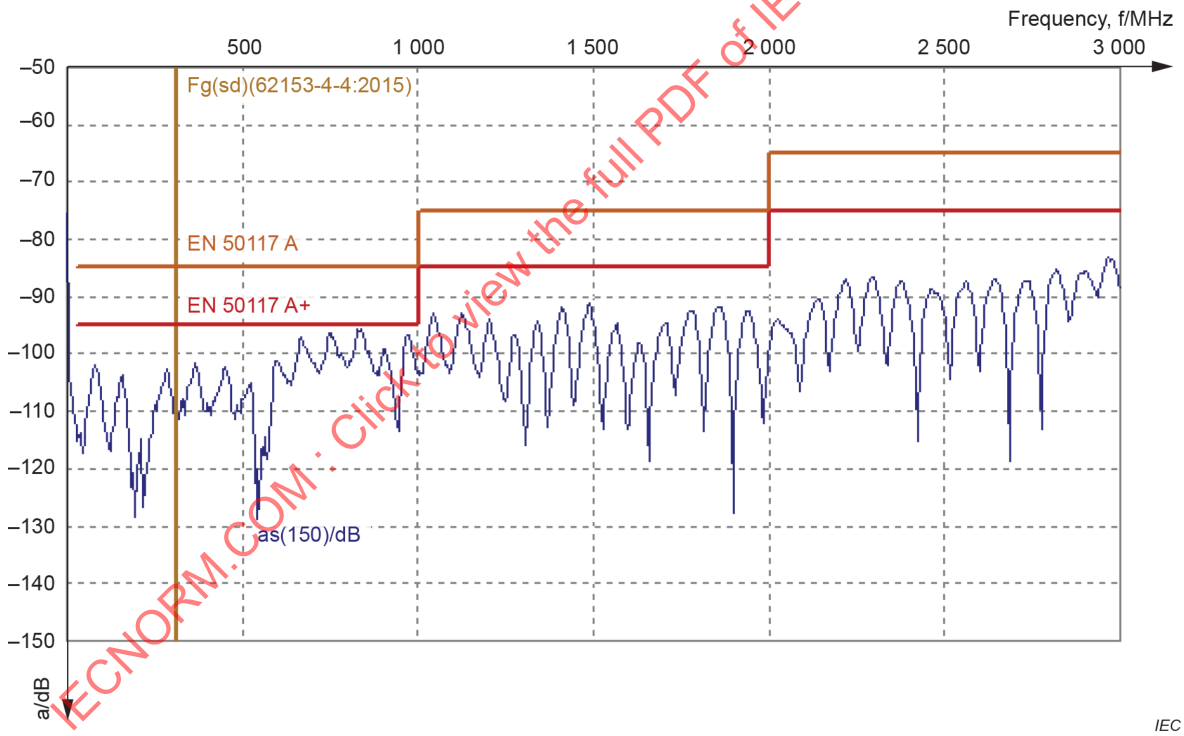


Figure H.1 – Example for a screening attenuation test result of a cable assembly with a test length of 2 meters

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[2] IEC ~~TR~~ 62153-4-16, *Metallic communication cable test methods – Part 4-16: ~~Technical report on the relationship between~~ Electromagnetic compatibility (EMC) – Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up*

[3] VG 95214-12, *Test of components – Part 12: Measuring methods for transfer impedance and screening attenuation, transfer impedance of screened components (triaxial method, KS 12 B) and conductive gaskets (triaxial method, KS 22 B)*

[4] VG 95214-13, *Test of components – Part 13: Measuring methods for transfer impedance and screening attenuation, screening attenuation of screened components (triaxial method, KS 13 B)*

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IEC 62153-4-7

Edition 3.0 2021-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Metallic cables and other passive components test methods –
Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies – Triaxial tube in tube method

Méthodes d’essai des câbles métalliques et autres composants passifs –
Partie 4-7: Compatibilité électromagnétique (CEM) – Méthode d’essai pour mesurer l’impédance de transfert, Z_T,et l’affaiblissement d’écrantage, a_S, ou l’affaiblissement de couplage, a_C, des connecteurs et des cordons – Méthode triaxiale en tubes concentriques

IEC 62153-4-7:2021-07(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies – Triaxial tube in tube method

FOREWORD

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This third edition cancels and replaces the second edition published in 2015 and its Amendment 1:2018. This edition constitutes a technical revision.

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

The document is revised and updated. It now includes IEC 62153-4-7:2015/COR1:2016 and IEC 62153-4-7:2015/AMD1:2018. Furthermore, the changes of the revised IEC 62153-4-9:2018 are included.

Measurements of the coupling attenuation can be achieved now by using a mixed mode network analyser (virtual balun). The following new annexes have been added:

– Annex E contains informative information about the direct measurement of screening effectiveness of connectors;
– Annex F gives normative information about mixed mode parameters;
– Annex G contains normative information about accessories for measuring coupling attenuation;
– Annex H discusses the low frequency screening attenuation.

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

FDIS	Report on voting
46/812/FDIS	46/820/RVD

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

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

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

A list of all parts of the IEC 62153 series, under the general title *Metallic cables and other passive components test methods* can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this 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

The shielded screening attenuation test set-up according to IEC 62153-4-3 and IEC 62153-4-4 have been extended to take into account the particularities of electrically short elements like connectors and cable assemblies. Due to the concentric outer tube of the triaxial set-up, measurements are independent of irregularities on the circumference and outer electromagnetic fields.

With the use of an additional resonator tube (inner tube respectively tube in tube), a system is created where the screening effectiveness of an electrically short device is measured in realistic and controlled conditions. Also, a lower cut off frequency for the transition between electrically short (transfer impedance Z_T) and electrically long (screening attenuation a_S) can be achieved.

A wide dynamic and frequency range can be applied to test even super screened connectors and assemblies with normal instrumentation from low frequencies up to the limit of defined transversal waves in the outer circuit at approximately 4 GHz.

METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies – Triaxial tube in tube method

1 Scope

This part of IEC 62153 deals with the triaxial tube in tube method. This triaxial method is suitable to determine the surface transfer impedance and/or screening attenuation and coupling attenuation of mated screened connectors (including the connection between cable and connector) and cable assemblies. This method could also be extended to determine the transfer impedance, coupling or screening attenuation of balanced or multipin connectors and multicore cable assemblies. For the measurement of transfer impedance and screening- or coupling attenuation, only one test set-up is needed.

2 Normative references

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

IEC TS 62153-4-1:2014, *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic screening measurements*

IEC 62153-4-3, *Metallic communication cable test methods – Part 4-3: Electromagnetic Compatibility (EMC) − Surface transfer impedance − Triaxial method*

IEC 62153-4-4, *Metallic communication cable test methods – Part 4-4: Electromagnetic compatibility (EMC) –Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method*

IEC 62153-4-8, *Metallic cables and other passive components – Test methods – Part 4-8: Electromagnetic compatibility (EMC) – Capacitive coupling admittance*

IEC 62153-4-9:2018, *Metallic communication cable test methods – Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method*

IEC 62153-4-10, *Metallic communication cable test methods – Part 4-10: Electromagnetic compatibility (EMC) – Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets - Double coaxial test method*

IEC 62153-4-15:2015, *Metallic communication cable test methods – Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell*

IEC 62153-4-16, *Metallic communication cable test methods – Part 4-16: Electromagnetic compatibility (EMC) – Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up*

EN 50117-9-2:2019, *Coaxial cables – Part 9-2: Sectional specification for coaxial cables for analogue and digital transmission – Indoor droop cables for systems operating at 5 MHz – 3 000 MHz*

3 Terms and definitions

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

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

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

3.1
surface transfer impedance
Z_T
for an electrically short screen, quotient of the longitudinal voltage U_1 induced to the inner circuit by the current I_2 fed into the outer circuit or vice versa

Note 1 to entry: The surface transfer impedance is expressed in ohms.

Note 2 to entry: The value Z_T of an electrically short screen is expressed in ohms [Ω] or decibels in relation to 1 Ω.

Note 3 to entry: See Figure 1.

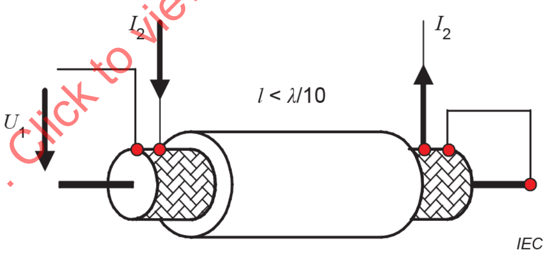


Figure 1 – Definition of Z_T

$$Z_T = \frac{U_1}{I_2} \tag{1}$$

$$Z_T \text{ dB}(\Omega) = +20 \times \log_{10}\left(\frac{|Z_T|}{1\Omega}\right) \tag{2}$$

3.2
effective transfer impedance
Z_{TE}
maximum absolute value of the sum or difference of the capacitive coupling impedance Z_F and the transfer impedance Z_T at every frequency:

$$Z_{TE} = \max\left|Z_F \pm Z_T\right| \quad (3)$$

3.3
screening attenuation

a_S

for electrically long devices, i.e. above the cut-off frequency, logarithmic ratio of the feeding power P_1 and the periodic maximum values of the coupled power $P_{r,max}$ in the outer circuit

$$a_S = -10 \times \log_{10}\left(\text{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \quad (4)$$

Note 1 to entry: The screening attenuation of an electrically short device is defined as:

$$a_S = 20 \times \log_{10}\frac{150\,\Omega}{Z_{TE}} \quad (5)$$

where

150 Ω is the standardized impedance of the outer circuit.

3.4
coupling attenuation

a_C

for a screened balanced device, the sum of the unbalance attenuation a_U of the symmetric pair and the screening attenuation a_S of the screen of the device under test

Note 1 to entry: For electrically long devices, i.e. above the cut-off frequency, the coupling attenuation a_C is defined as the logarithmic ratio of the feeding power P_1 and the periodic maximum values of the coupled power $P_{r,max}$ in the outer circuit.

3.5
coupling length

length of device under test

Note 1 to entry: The coupling length is electrically short, if

$$\frac{\lambda_o}{l} > 10 \times \sqrt{\varepsilon_{r1}} \quad \text{or} \quad f < \frac{c_o}{10 \times l \times \sqrt{\varepsilon_{r1}}} \quad (6)$$

or electrically long, if

$$\frac{\lambda_o}{l} \leq \pi \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right| \quad \text{or} \quad f \geq \frac{c_o}{\pi \times l \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right|} \quad (7)$$

where

l is the effective coupling length, in m;

λ_0 is the free space wavelength, in m;

ε_{r1} is the resulting relative permittivity of the dielectric of the cable;

ε_{r2} is the resulting relative permittivity of the dielectric of the secondary circuit;

f is the frequency, in Hz;

c_o is the velocity of light in free space.

3.6
device under test
DUT
device consisting of the mated connectors with their attached cables

4 Physical background

See respective clauses of IEC TS 62153-4-1, IEC 62153-4-3, IEC 62153-4-4, IEC 62153-4-9 and Annex C and Annex D.

5 Principle of the test methods

5.1 General

IEC 62153-4 (all parts) describes different test procedures to measure screening effectiveness on communication cables, connectors and components with triaxial test set-up.

Table 1 gives an overview about IEC 62153-4 (all parts) test procedures with triaxial test set-up.

Table 1 – IEC 62153, Metallic communication cable test methods – Test procedures with triaxial test set-up

	Metallic communication cable test methods – Electromagnetic compatibility (EMC)
IEC TS 62153-4-1	Introduction to electromagnetic (EMC) screening measurements
IEC 62153-4-3	Surface transfer impedance – Triaxial method
IEC 62153-4-4	Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method
IEC 62153-4-7	Test method for measuring the transfer impedance Z_T and the screening attenuation a_s or coupling attenuation a_C of RF-connectors and assemblies up to and above 3 GHz – Triaxial tube in tube method
IEC 62153-4-9	Coupling attenuation of screened balanced cables, triaxial method
IEC 62153-4-10	Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets – Double coaxial test method
IEC 62153-4-15	Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell
IEC 62153-4-16	Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up

Usually, RF connectors have mechanical dimensions in the longitudinal axis in the range of 20 mm to maximum 50 mm. With the definition of electrical short elements, we get cut off or corner frequencies for the transition between electrically short and long elements of about 1 GHz or higher for usual RF-connectors.

To measure the screening attenuation instead of transfer impedance also in the lower frequency range, the tube in tube procedure was designed. The electrically length of the RF-connector is extended by a RF-tightly closed metallic extension tube (tube in tube). See Figure 2.

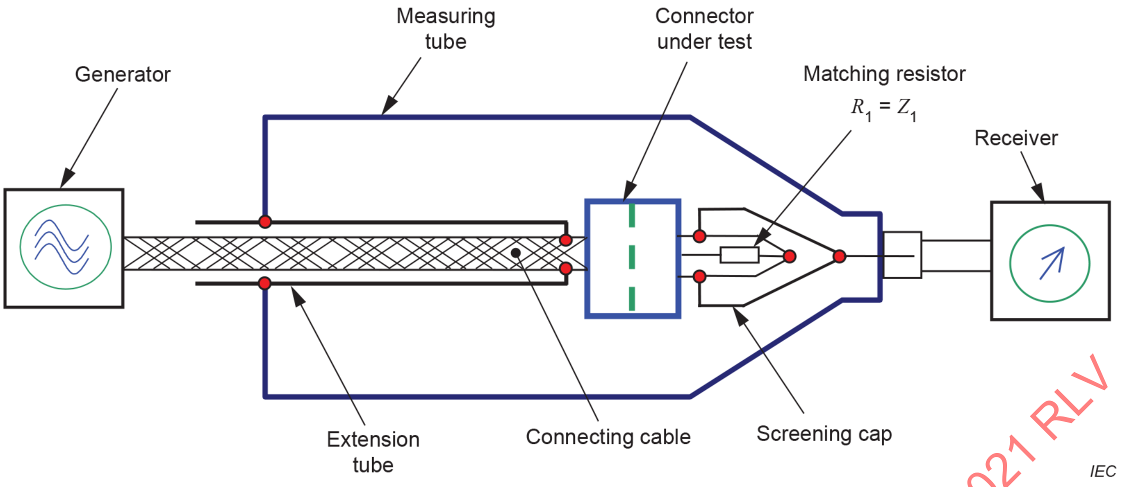


Figure 2 – Principle of the test set-up to measure transfer impedance and screening or coupling attenuation of connectors with tube in tube

The tube in tube test set up is based on the triaxial system according to IEC 62153-4-3 and IEC 62153-4-4 consisting of the DUT, a solid metallic tube and (optional) a RF-tight extension tube. The matched device under test, DUT, which is fed by a generator, forms the disturbing circuit which may also be designated as the inner or the primary circuit. The connecting cables to the DUT are additionally screened by the tube in tube.

The disturbed circuit, which may also be designated as the outer or the second circuit, is formed by the outer conductor of the device under test (and the extension tube), connected to the connecting cable and a solid metallic tube, having the DUT under test in its axis.

5.2 Transfer impedance

The test determines the screening effectiveness of a shielded cable by applying a well-defined current and voltage to the screen of the cable, the assembly or the device under test and measuring the induced voltage in secondary circuit in order to determine the surface transfer impedance. This test measures only the magnetic component of the transfer impedance. To measure the electrostatic component (the capacitance coupling impedance), the method described in IEC 62153-4-8 should be used.

The triaxial method of the measurement is in general suitable in the frequency range up to 30 MHz for a 1 m sample length and 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 is found in Clause 9 of IEC TS 62153-4-1:2014 as well as in IEC 62153-4-3.

5.3 Screening attenuation

The disturbing or primary circuit is the matched cable, assembly or device under test. The disturbed or secondary circuit consists of the outer conductor (or the outermost layer in the case of multiscreen cables or devices) of the cable or the assembly or the device under test and a solid metallic housing, having the device under test in its axis (see Figure 3).

The voltage peaks at the far end of the secondary circuit shall be measured. The near end of the secondary circuit is short-circuited. For this measurement, a matched receiver is not necessary. The expected voltage peaks at the far end are not dependent on the input impedance of the receiver, provided that it is lower than the characteristic impedance of the secondary circuit. However, it is an advantage to have a low mismatch, for example, by selecting of housings of sufficient size. A detailed description can be found in Clause 10 of IEC TS 62153-4-1:2014 as well as in IEC 62153-4-4. Additional Information on the interpretation of screening attenuation test results at frequencies below the cut-off frequency can be found in Annex H.

5.4 Coupling attenuation

Balanced cables, connectors, assemblies or devices which are driven in the differential mode may radiate a small part of the input power, due to irregularities in the symmetry. For unscreened balanced cables, connectors, assemblies or devices, this radiation is related to the unbalance attenuation a_u. For screened balanced cables, connectors or assemblies, the unbalance causes a current in the screen which is then coupled by the transfer impedance and capacitive coupling impedance into the outer circuit. The radiation is attenuated by the screen of the component and is related to the screening attenuation a_S.

Consequently, the effectiveness against electromagnetic disturbances of shielded balanced cables, connectors or assemblies is the sum of the unbalance attenuation a_U of the pair and the screening attenuation a_S of the screen. Since both quantities usually are given in a logarithmic ratio, they may simply be added to form the coupling attenuation a_C:

$$a_C = a_U + a_S \tag{8}$$

Coupling attenuation a_C is determined from the logarithmic ratio of the feeding power P_1 and the periodic maximum values of the power $P_{r,max}$ (which may be radiated due to the peaks of voltage U_2 in the outer circuit):

$$a_C = -10 \times \log_{10}\left(\mathrm{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \tag{9}$$

The relationship of the radiated power P_r to the measured power P_2 received on the input impedance R is:

$$\frac{P_R}{P_2} = \frac{P_{Rmax}}{P_{2max}} = \frac{R}{2 \times Z_S} \tag{10}$$

There will be a variation of the voltage U_2 on the far end, caused by the electromagnetic coupling through the screen and superposition of the partial waves caused by the surface transfer impedance Z_T, the capacitive coupling impedance Z_F (travelling to the far and near end) and the totally reflected waves from the near end.

To feed the balanced device under test, a differential mode signal is necessary. This can be achieved with a two-port network analyser (generator and receiver) and a balun or a multiport network analyser. The procedures to measure coupling attenuation are described in Clause 10. Annex G gives normative information on accessories for coupling attenuation measurements.

6 Test procedure

6.1 General

The measurements shall be carried out at the temperature of (23 ± 3) °C. The test method determines the transfer impedance or the screening attenuation or the coupling attenuation of a DUT by measuring in a triaxial test set-up according to IEC 62153-4-3, IEC 62153-4-4 and IEC 62153-4-9.

6.2 Tube in tube procedure

Usually, RF connectors have mechanical dimensions in the longitudinal axis in the range of 20 mm to maximum 50 mm. With the definition of electrically short elements, we get cut off or corner frequencies or corner for the transition between electrically short and long elements of about 1 GHz or higher for usual RF-connectors.

In the frequency range up to the cut off frequency, where the device under test (DUT) is electrically short, the transfer impedance of the DUT can be measured. For frequencies above the cut-off frequency, where the DUT is electrically long, the screening attenuation can be measured.

By extending the electrically length of the RF-connector by a RF-tightly closed metallic extension tube (tube in tube), the tested combination becomes electrically long and the cut-off frequency is moved towards the lower frequency range. In this way, also in the lower frequency range, the screening attenuation may be measured and the effective transfer impedance of electrical short devices calculated.

The test set up is a triaxial system consisting of the DUT, a solid metallic tube and a RF-tight extension tube. The matched device under test, DUT, which is fed by a generator forms the disturbing circuit which may also be designated as the inner or the primary circuit.

The disturbed circuit, which may also be designated as the outer or the second circuit, is formed by the outer conductor of the device under test, connected to the extension tube and a solid metallic tube having the DUT under test in its axis.

The principle of the test set-up is shown in Figure 2 and Figure 3. The set-up is the same for measuring the transfer impedance and the screening- or the coupling attenuation, whereas the length of the inner and the outer tube may vary.

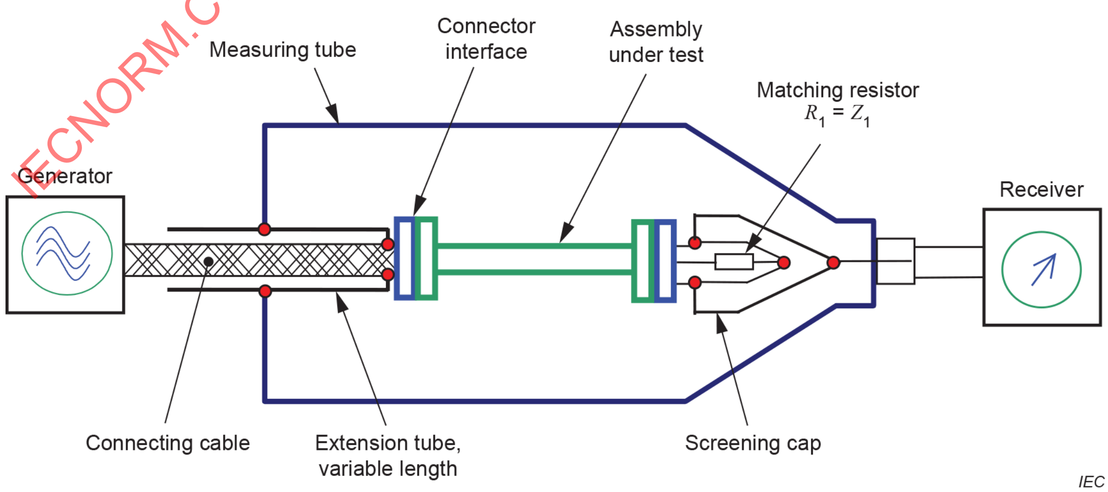


Figure 3 – Principle of the test set-up to measure transfer impedance and screening attenuation of a cable assembly

The voltage ratio of the voltage at the near end (U_1) of the inner circuit (generator) and the voltage at the far end (U_2) of the secondary circuit (receiver) shall be measured (U_1/U_2). The near end of the secondary circuit is short-circuited.

Depending on the electrical length of the tested combination, the DUT and the extension tube, the result may be expressed either by the transfer impedance, the effective transfer impedance or the screening attenuation (or the coupling attenuation).

For this measurement, a matched receiver is not necessary. The likely voltage peaks at the far end are not dependent on the input impedance of the receiver, provided that it is lower than the characteristic impedance of the secondary circuit. However, it is an advantage to have a low mismatch, for example by selecting a range of tube diameters for various sizes of DUTs.

6.3 Test equipment

The principle of the test set-up is shown in Figure 2 and Figure 3 and consists of:

– an apparatus of a triple coaxial form with a length sufficient to produce a superimposition of waves in narrow frequency bands which enable the envelope curve to be drawn,

– tubes with variable lengths, e.g. by different parts of the tubes and/or by a movable tube in tube. In case of larger connectors or components, the triaxial tubes may be replaced by a triaxial cell according to IEC 62153-4-15.

– a RF-tight extension tube (tube in tube), variable in length, which should preferably have a diameter such that the characteristic impedance to the outer tube is 50 Ω or equal to the nominal characteristic wave impedance of the network analyser or the generator and receiver. The material of the extension tube shall be non-ferromagnetic and well conductive (copper or brass) and shall have a thickness ≥1 mm such that the transfer impedance is negligible compared to the transfer impedance of the device under test,

– a signal generator and a receiver with a calibrated step attenuator and a power amplifier if necessary for very high screening attenuation. The generator and the receiver may be included in a network analyser,

– a balun for impedance matching of the unbalanced generator output signal to the characteristic wave impedance of balanced cables for measuring the coupling attenuation. Requirements for the balun are given in IEC 62153-4-9:2018, 6.3. Alternatively, instead of a balun, a Vector Network analyser (VNA) with mixed mode option and a twisted-pair (TP) connecting unit may be used. The requirements for the TP connecting unit are given in IEC 62153-4-9:2018, 6.4.

Optional equipment is:

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

6.4 Calibration procedure

The calibration shall be established at the same frequency points at which the measurement 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 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 S-parameter test-set, i.e. by using a power splitter, a THRU calibration shall be established including the test leads used to connect the test set-up to the test equipment.

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

$$a_{\text{cal}} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \qquad (11)$$

where

P_1 is the power fed during calibration procedure;

P_2 is the power at the receiver during 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. This can be achieved e.g. by connecting two impedance matching adapters of the same type and the same manufacturer "back to back" together and measure:

$$2 \times a_{\text{imd}} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \qquad (12)$$

Further information on impedance matching adapters is given in IEC 62153-4-3, Annex B.

6.5 Connection between extension tube and device under test

The connection between the extension tube and the attached cables of the device under test shall be such that the contact resistance is negligible. A possible connection technique as well as a description of the influence of contact resistances is given in Annex D. Annex E gives information about the direct connection of the extension tube to connectors under test.

6.6 Dynamic range respectively noise floor

With the verification test, the residual transfer impedance respectively the noise floor due to the connection of the feeding cable to the extension tube shall be determined.

The feeding cable is matched with its characteristic impedance and connected to the test head. The extension tube shall then be connected to the feeding cable (without DUT), using the same connection technique as during the test. The piece of cable between the connection points shall be as short as possible (see Figure 4).

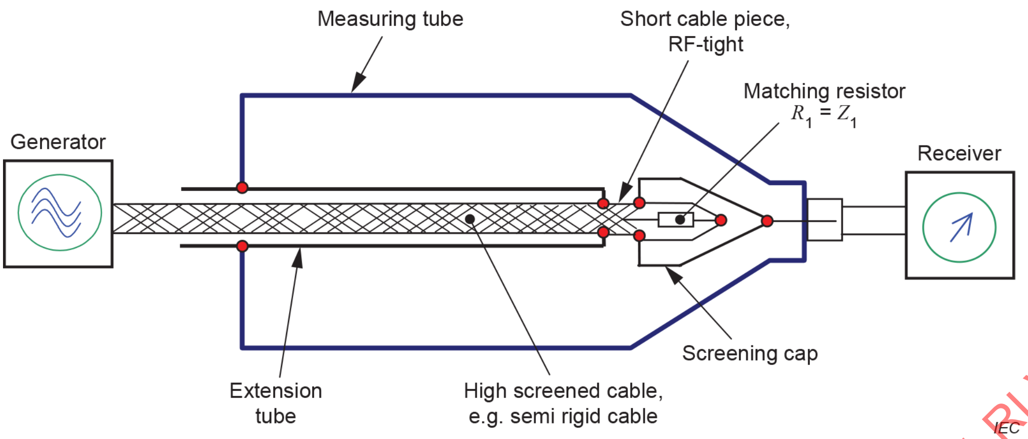


Figure 4 – Principle set-up for verification test

The voltage ratio U_1/U_2 shall be measured with the NWA.

The noise floor a_n of the connection of the extension tube to the feeding cable is then given by:

$$a_n = 20 \times \log_{10}(U_1/U_2) \quad (12)$$

The noise floor shall be at least 10 dB better than the measured value.

The residual transfer impedance of the connection of the extension tube to the feeding cable is given by:

$$Z_{Tr} = Z_1 \times \left| \frac{U_2}{U_1} \right| \quad (13)$$

6.7 Impedance matching

If unknown, the nominal characteristic impedance of the (quasi-)coaxial system can either be measured by using a TDR with maximum 200 ps rise time or using the method described in Annex A. An impedance matching adapter to match the impedance of the generator and the impedance of the (quasi-)coaxial system is not recommended as it reduces the dynamic range of the test set-up and may have sufficient matching (return loss) only up to 100 MHz (see Annex B).

6.8 Influence of adapters

When measuring transfer impedance and screening attenuation or coupling attenuation on connectors or cable assemblies, test adapters are required if no mating connectors to the connectors of the DUT are available.

Test adapters and/or mating connectors may limit the sensitivity of the test set up and may influence the measurement.

The type and/or the design of the test adapter shall be stated in the test report.

A more detailed description on the design and the influence of test adapters is under consideration.

7 Sample preparation

7.1 Coaxial connector or device

A feeding cable shall be mounted to the connector under test and it's mating part according to the specification of the manufacturer. One end shall be connected to the test head where the feeding cable is matched with the nominal characteristic impedance of the device under test. It may be short circuited, when measuring the transfer impedance with (mismatched)-short-short without damping resistor according to IEC 62153-4-3.

The other end of the connecting cable shall be passed through the extension tube and connected to the generator. On the side of the device under test, the screen of the feeding cable shall be connected to the extension tube with low contact resistance (see 6.2 and Annex B). On the generator side, the screen of the feeding cable shall not be connected to the extension tube.

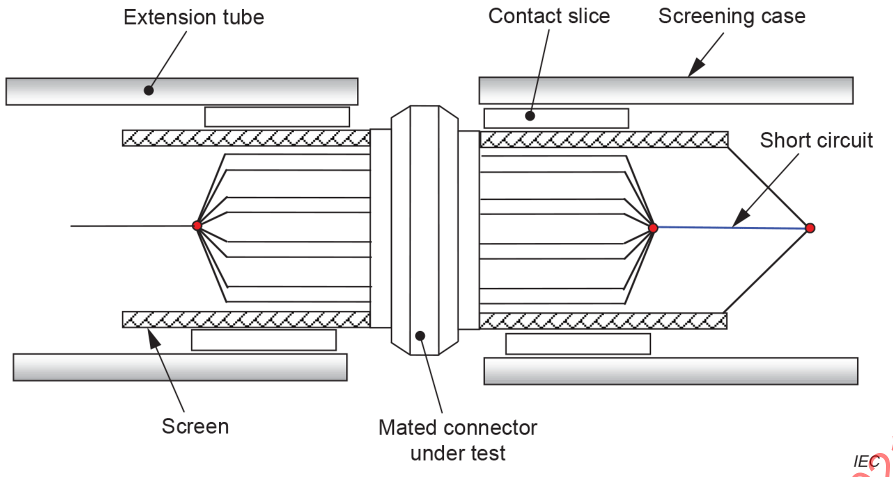
7.2 Balanced or multiconductor device

A balanced or multiconductor cable which is usually used with the connector under test shall be mounted each to the connector under test and it's mating part according to the specification of the manufacturer.

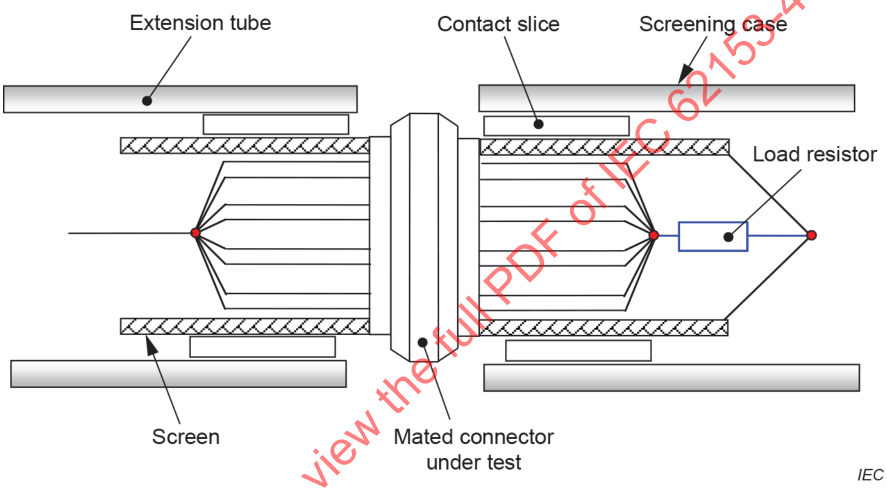
When measuring transfer impedance or screening attenuation, screened balanced or multiconductor cables are treated as a quasi-coaxial system. Therefore, at the open ends of the feeding cable, all conductors of all pairs shall be connected together. All screens, including those of individually screened pairs or quads, shall be connected together at both ends. All screens shall be connected over the whole circumference (see Figure 5 and Figure 5b).

One end shall then be connected to the test head where the feeding cable is matched with the characteristic impedance (screening attenuation and transfer impedance with short/matched procedure) or with a short circuit (transfer impedance with short/short procedure).

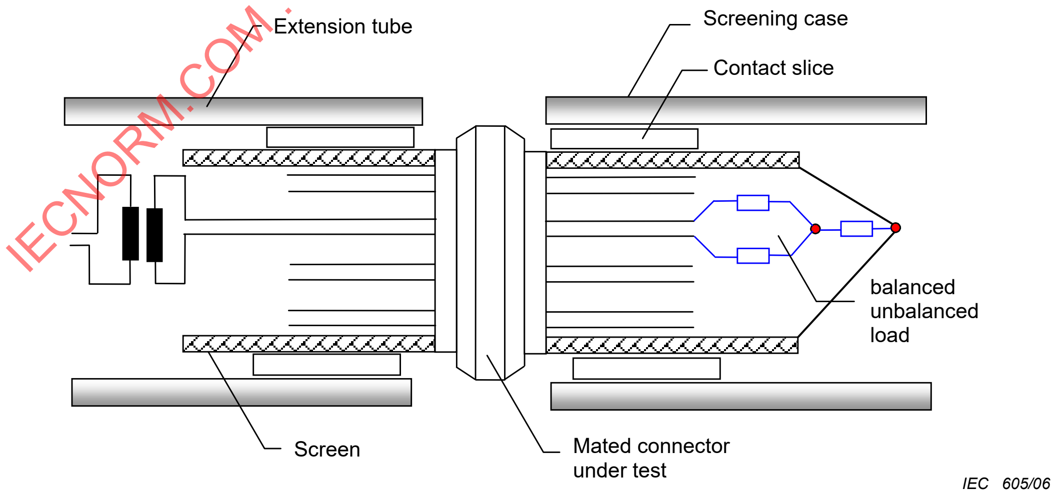
The other end shall be led through the extension tube and shall be connected to the feeding port (VNA or generator) by the use of an appropriate adapter.



a) **Principle preparation of balanced or multiconductor connectors for transfer impedance (short/short)**

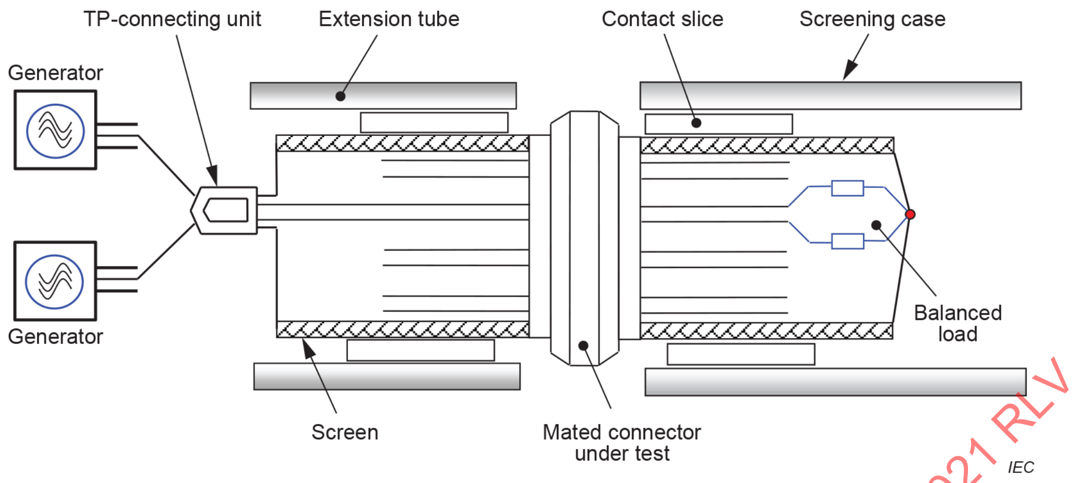


b) **Principle preparation of balanced or multiconductor connectors for transfer impedance (short/matched) and screening attenuation**



c) **Principle preparation of balanced or multiconductor connectors for coupling attenuation using a balun**

NOTE 1 Add terminations for all pairs if the cable is not pair screened. If a pair screen is added, the termination of all pairs is not mandatory but preferred.



d) Principle preparation of balanced or multiconductor connectors for coupling attenuation using a virtual balun

NOTE 2 Add terminations for all pairs if the cable is not pair screened. If a pair screen is added, the termination of all pairs is not mandatory but preferred.

Figure 5 – Preparation of balanced or multiconductor connectors

7.3 Cable assembly

If the cable assembly fits into the tube, it shall be measured according to Figure 3. Longer cable assemblies can be cut, and each side measured separately.

8 Measurement of transfer impedance

8.1 General

IEC 62153-4-3 describes three different triaxial test procedures:

– matched inner circuit with damping resistor in outer circuit,
– inner circuit with load resistor and outer circuit without damping resistor,
– (mismatched)-short-short without damping resistor.

The procedure described herein is in principle the same as in IEC 62153-4-3 with matched inner circuit without the use of the impedance matching adapter and without the damping resistor R_2. It has a higher dynamic range than testing with damping resistor in outer circuit.

The load resistor R_1 could 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.

NOTE Other procedures of 62153-4-3 can be applied accordingly if required.

8.2 Principle block diagram of transfer impedance

A block diagram of the test set-up to measure transfer impedance according to test method of IEC 62153-4-3 with load resistor in inner circuit and without damping resistor in outer circuit is shown in Figure 6.

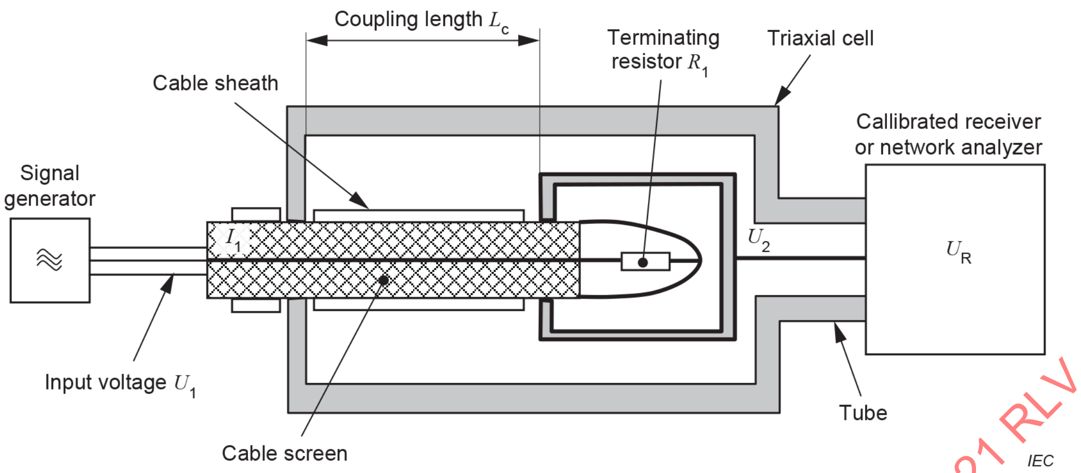


Figure 6 – Test set-up (principle) for transfer impedance measurement according to test of IEC 62153-4-3 with load resistor in inner circuit and without damping resistor in outer circuit

8.3 Measuring procedure – Influence of connecting cables

When measuring a connector or a component without tube in tube, the transfer impedance of the connecting cables inside the tube to connect the DUT shall be measured.

The transfer impedance of the connecting cables which connects the DUT shall be measured according to IEC 62153-4-3. The measured value shall be related to the length of the connecting cables inside the test set-up to connect the DUT, the result is the transfer impedance of the connecting cables, Z_{con}.

8.4 Measuring

The DUT 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:

$$a_{meas} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \tag{15}$$

where

P_1 is the power fed to inner circuit;

P_2 is the power received in the outer circuit.

8.5 Evaluation of test results

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

$$Z_T = \frac{R_1 + Z_0}{2} \times 10^{-\left(\frac{a_{meas} - a_{cal}}{20}\right)} - Z_{con} \tag{16}$$

or

$$Z_{\mathrm{T}} = \frac{R_1 + Z_0}{2} \times 10^{-(\frac{a_{\mathrm{meas}} - a_{\mathrm{cal}}}{20})} - Z_{\mathrm{Tr}} \qquad (17)$$

when using the tube in tube method.

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;
R_1	is the terminating resistor in inner circuit (either equal to the impedance of the inner circuit or the impedance of the generator);
Z_{con}	is the transfer impedance of connecting cables;
Z_{Tr}	is the residual transfer impedance, see 6.6.

NOTE Contrary to the measurement of the transfer impedance of cable screens, the transfer impedance of connectors or assemblies is not related to length.

8.6 Test report

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

The use and the design of test adapters (if any) shall be described.

9 Screening attenuation

9.1 General

This method is in principle the same as described in IEC 62153-4-4.

9.2 Impedance matching

9.2.1 General

Measuring of screening attenuation can be achieved with or without impedance matching.

If the characteristic impedance of the DUT is unknown, the nominal characteristic impedance of the quasi-coaxial system can either be measured by using a TDR with maximum 200 ps rise time or using the method described in Annex A.

An impedance matching adapter to match the impedance of the generator and the impedance of the system device under test (see Figure 7) is not recommended as it reduces the dynamic range of the test set-up and may have sufficient matching (return loss) only up to 100 MHz when using self-made adapters which are necessary for impedances other than 60 Ω or 75 Ω (see Annex B).

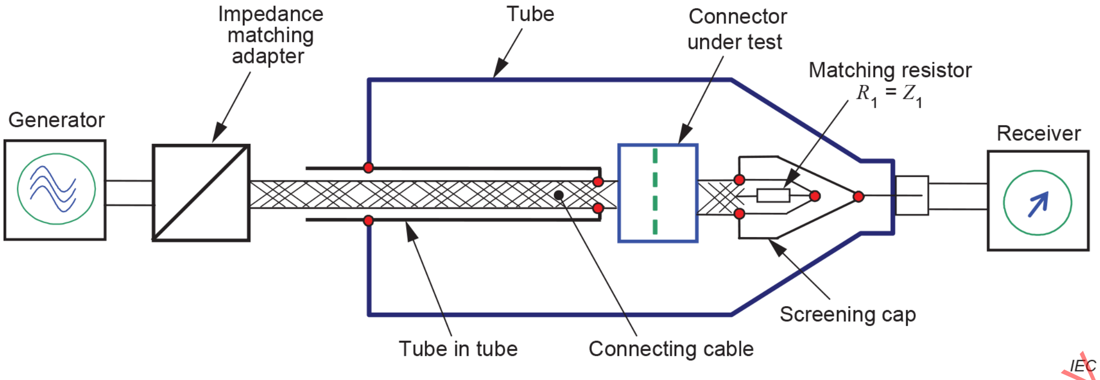


Figure 7 – Measuring the screening attenuation with tube in tube with impedance matching device

The DUT with the connected extension tube shall be installed in the measuring tube. The extension tube shall be short circuited to the measuring tube at the near end of the generator. The feeding cable shall be connected to the generator (via an impedance matching device if necessary) and the output of the measuring tube shall be connected to the receiver.

The scattering parameter S_{21} shall be measured.

Only the peak values of the obtained screening attenuation graph are used to determine the envelope curve.

9.2.2 Evaluation of test results with matched conditions

The screening attenuation a_S shall be calculated with the arbitrary determined normalised value Z_S = 150 Ω[1].

$$a_S = 10 \times \log_{10} \left| \frac{P_1}{P_{r,max}} \right| = 10 \times \log_{10} \left| \frac{P_1}{P_{2,max}} \times \frac{2 \times Z_S}{R} \right| - a_{imd} \tag{18}$$

$$= \text{Env} \left\{ -20 \times \log_{10} \left| S_{21} \right| + 10 \times \log_{10} \left| \frac{300\,\Omega}{Z_1} \right| - a_{imd} \right\} \tag{19}$$

where

a_S	is the screening attenuation related to the radiating impedance of 150 Ω, in dB;
a_{imd}	is the attenuation of the impedance matching device (if appropriate);
Env	is the minimum envelope curve of the measured values, in dB;
S_{21}	is the scattering parameter S_{21} (complex quantity) of the set-up where the primary side of the two port is the DUT and the secondary side is the tube;
Z_1	is the characteristic impedance of the cable under test, in Ω.

1 Z_S is the normalized value of the characteristic impedance of the environment of a typical cable installation. It is not in relation to the impedance of the outer circuit of the test set-up.

At frequencies lower than the limit of the electrically long coupling length, the measurement will be similar to that for surface transfer impedance.

9.2.3 Measuring with mismatch

The DUT shall be connected to port 1 and the test head of the set-up shall be connected to port 2 of the vector network analyser.

If not known, the characteristic impedance Z_1 of the DUT shall be measured (see 9.2).

The scattering parameter S_{21} shall be measured.

Only the peak values of the obtained screening attenuation graph are used to determine the envelope curve.

9.2.4 Evaluation of test results

The screening attenuation a_S which is comparable to the results of the absorbing clamp method shall be calculated with the arbitrary determined normalised value Z_S = 150 Ω[1].

$$a_S = 10 \times \log_{10}\left|\frac{P_1}{P_{r,max}}\right| = 10 \times \log_{10}\left|\frac{P_1}{P_{2,max}} \cdot \frac{2 \times Z_S}{R}\right| \tag{20}$$

$$= \text{Env}\left\{-20 \times \log_{10}\left|S_{21}\right| + 10 \times \log_{10}\left|1 - r^2\right| + 10 \times \log_{10}\left|\frac{300\,\Omega}{Z_1}\right|\right\} \tag{21}$$

where

a_S	is the screening attenuation related to the radiating impedance of 150 Ω, in dB;
Env	is the minimum envelope curve of the measured values, in dB;
S_{21}	is the scattering parameter S_{21} (complex quantity) of the set-up where the primary side of the two port is the DUT and the secondary side is the tube;
r	is the reflection coefficient $= \left|\left(\frac{Z_0 - Z_1}{Z_0 + Z_1}\right)\right|$;
Z_0	is the characteristic impedance of system, in Ω (usually 50 Ω);
Z_1	is the characteristic impedance (in complex form) of the device under test, in Ω.

9.3 Test report

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

The use and the design of test adapters (if any) shall be described.

10 Coupling attenuation

10.1 General

Coupling attenuation of balanced transmission devices including differential pairs describes the overall effect against electromagnetic interference (EMI) considering both the unbalance attenuation of the pair and the screening attenuation of the screen. Subclause 5.4 of this document gives additional information on coupling attenuation. The principles of measuring the coupling attenuation of balanced cables are described in IEC 62153-4-9. Parts of the information given therein as well as the specific information needed for measuring connectors and cable assemblies is given in the following subclauses.

10.2 Procedure for testing connectors

The coupling attenuation measurements of connectors can be performed with either a two-port VNA (or a generator and a receiver) and a balun (see Figure 8) or with a multiport (or mixed mode) VNA and a TP-connecting unit (see Figure 9) in both cases with the use of the tube-in tube procedure.

The DUT is connected to the connecting cables at the near end according to the instructions of the manufacturer and terminated at the far end by differential and common mode terminations according to Figure 5c. The sample is then centred in the tube and fed by either a generator (or port 1 of a 2-port VNA with the balun to provide the differential mode (Figure 8) or it is fed by 2 ports building up a differential pair of a multiport VNA with the TP-connecting unit (Figure 9).

The quotient of the voltages at the output of the outer circuit and the input of the cable is measured, either directly by a network analyser or with a calibrated step attenuator [assuming that the receiver has the same input impedance as the output impedance of the signal generator ($R = Z_1$)] which is inserted as an alternative to the triaxial apparatus.

Only the peak values of the maximum of the voltage ratio or the minimum of the attenuation shall be measured and recorded as a function of the frequency in order to determine the envelope curve. Attenuation introduced by the inclusion of adapters, instead of direct connection, shall be taken into account when calibrating the triaxial apparatus. The voltage ratio measured is not dependent on the diameter of the outer tube of the triaxial test set-up or on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

The evaluation of the test result is given in 10.4.

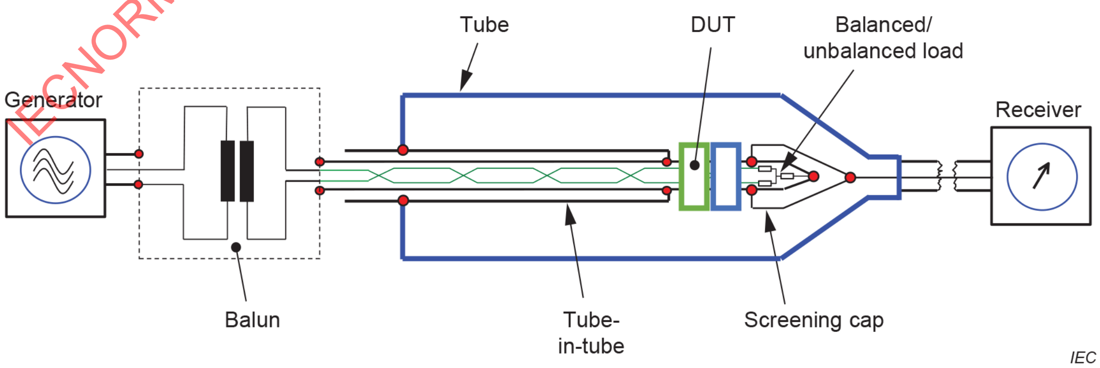


Figure 8 – Coupling attenuation, principle test set-up with 2-port VNA and balun

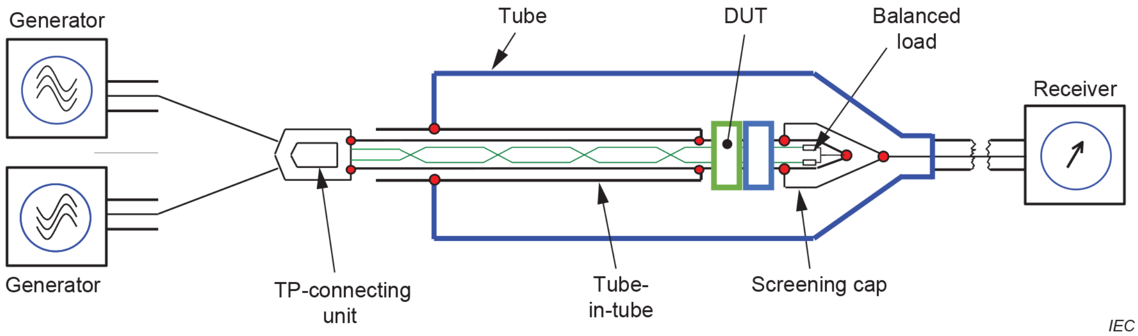


Figure 9 – Coupling attenuation, principle set-up with multiport VNA and TP-connecting unit

10.3 Procedure for testing cable assemblies

Most of the basics of the procedure for testing cable assemblies are comparable to the test of connectors which are described in 10.2. The following additional precautions shall be taken. The measurement of cable assemblies can be divided in two different problems depending on the length of the test objects. If the assembly is shorter than the length of the outer tube, the complete cable assembly can be tested at once as shown in Figure 10. The near end of the cable assembly is connected to an adapter that contains the mating counterpart of the cable assemblies near end. This adapter provides the test signals (near end or feeding adapter). At the far end, the cable assembly is connected to a second adapter (far end or matching adapter) that contains the mating counterpart of the cable assemblies far end connector. The far end adapter includes the matching resistors of the differential pairs according to Figure 5c.

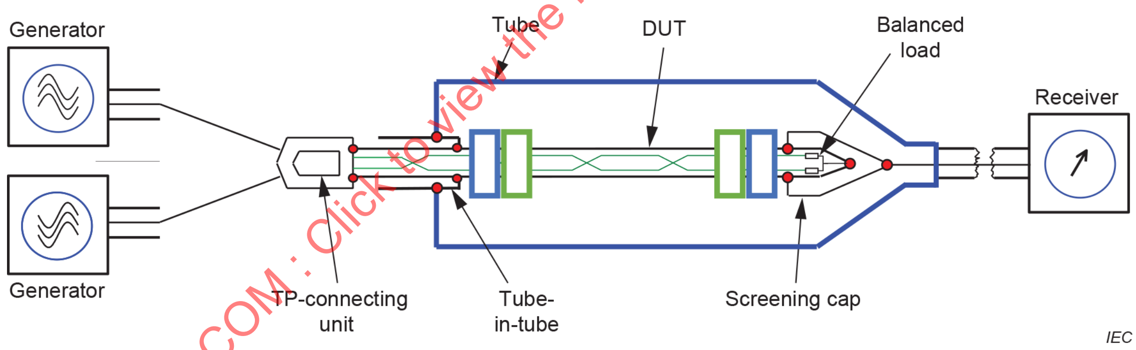


Figure 10 – Coupling attenuation, principle test set-up with multiport VNA and TP-connecting unit for measuring complete cable assemblies

If the cable assembly which is to be tested is longer than the outer tube, it shall be cut into two halves which shall be measured separately without the use of the tub-in-tube process. This situation is depicted in Figure 11. The near end of the measured halve is connected via the TP-connection unit to the generators (2-ports of the multiport VNA) building the differential pair. The screen of the halved cable assembly at the near end is connected to the tube by removing the cable sheath. The far end of the measured cable assembly halve is containing the connector. It is connected to the far end adapter containing the matching resistors of the differential signal pairs according to Figure 5c.

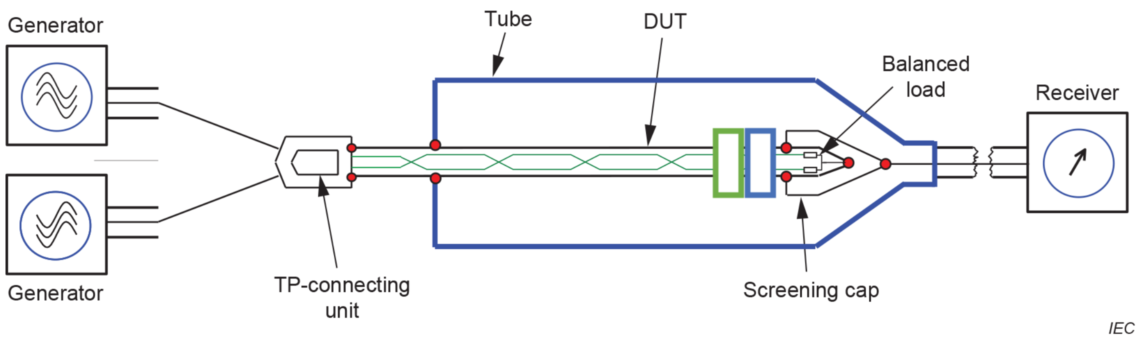


Figure 11 – Coupling attenuation, principle test set-up with multiport VNA and TP-connecting unit for measuring halved cable assemblies

10.4 Evaluation of test results when using a balun

The attenuation of the balun shall be subtracted from the measuring results. The coupling attenuation a_C shall be calculated with the normalised value Z_S = 150 Ω:

$$a_C = 10 \times \log_{10} \left| \frac{P_1}{P_{r,max}} \right| = 10 \times \log_{10} \left| \frac{P_1}{P_{2,max}} \times \frac{2 \times Z_S}{R} \right| \tag{22}$$

$$a_C = 20 \times \log_{10} \left| \frac{U_1}{U_{2max}} \right| + 10 \times \log_{10} \left| \frac{2 \times Z_S}{Z_1} \right| \tag{23}$$

$$a_C = a_{m,min} - a_z + 10 \times \log_{10} \left| \frac{2 \times Z_S}{Z_1} \right| \tag{24}$$

where

a_C	is the coupling attenuation related to the normalised radiating impedance of 150 Ω, in dB;
$a_{m,min}$	is the attenuation recorded as minimum envelope curve of the measured values, in dB;
a_z	is the additional attenuation of an inserted balun, if not otherwise eliminated e.g. by the calibration, in dB;
U_1	is the input voltage of the primary circuit formed by the cable, in V;
U_2	is the output voltage of the secondary circuit, in V;
Z_1	is the (differential mode) characteristic impedance of the cable under test, in Ω.

10.5 Evaluation of test results when using a multiport VNA

The voltage ratio U_{diff}/U_{2max} shall be measured with a calibrated multiport VNA (or calibrated generator and receiver) and corrected with regard to the influence of test leads and connecting units.

NOTE The voltage ratio U_{diff}/U_{2max} corresponds to the invers of the mixed mode S-parameters S_{sd21} and S_{ds12}, respectively according to the conventions shown in Annex F.

The coupling attenuation a_C which is comparable to the results of the absorbing clamp method shall be calculated with the arbitrary determined normalized value Z_S = 150 Ω:

$$a_C = 20 \times \log_{10} \left| \frac{U_{diff}}{U_{2max}} \right| + 10 \times \log_{10} \left| \frac{2 \times Z_S}{Z_{diff}} \right| \qquad (25)$$

where

a_C	is the coupling attenuation related to the normalised radiating impedance of 150 Ω, in dB;
U_{diff}	is the differential voltage at the calibrated generator ports;
U_{2max}	is the output voltage of the secondary circuit, in V;
Z_S	is the arbitrary determined normalised impedance (150 Ω);
Z_{diff}	is the (differential mode) characteristic impedance of the cable under test, in Ω.

The envelope curve over the minimum values shall be used as result.

10.6 Test report

The test report shall indicate whether the results of minimum coupling attenuation comply with the value indicated in the relevant cable specification.

If a limiting value of the radiating power is specified for a cable system operating with a defined power level, the difference between the power level and the limit of radiating power shall not be greater than the coupling attenuation of the cable provided for the system.

The use and the design of test adapters (if any) shall be described.

A typical measurement graph of a connector is given in Figure 12.

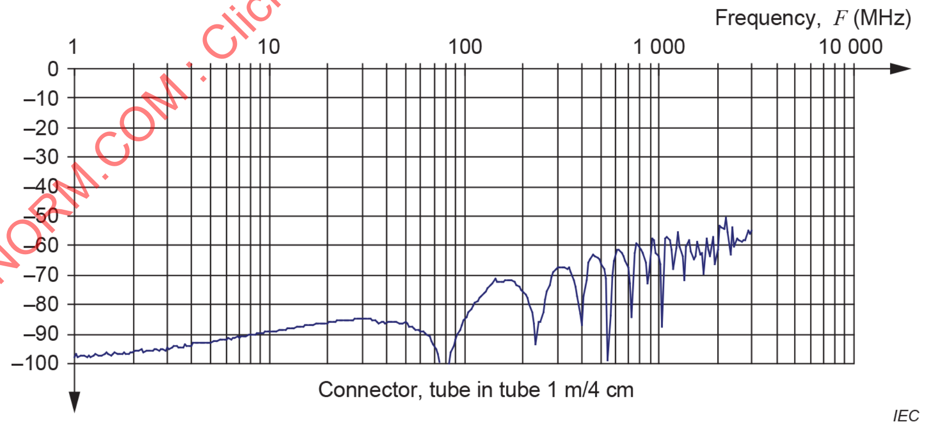


Figure 12 – Typical measurement of a connector of 0,04 m length with 1 m extension tube

Annex A
(normative)

Determination of the impedance of the inner circuit

If the impedance Z_1 of the inner circuit is not known, it may be determined using a TDR with maximum 200 ps rise time 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 approximately the frequency for which the length of the sample is 1/8 λ, where λ is the wavelength.

$$f_{\text{test}} \approx \frac{c_0}{8 \times L_{\text{sample}} \times \sqrt{\varepsilon_{\text{r1}}}} \tag{A.1}$$

where

f_{test}	is the test frequency;
c_0	is the speed of light (3 × 10^8 m/s);
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
(informative)

Example of a self-made impedance matching adapter

The graphs in Figure B.1 and Figure B.2 show the attenuation and return loss of a 50 Ω to 5 Ω impedance matching adapter. A DUT impedance of 5 Ω is typical when measuring multipair cables with individually screened pairs or when measuring high voltage cables for electrical vehicles.

The attenuation and return loss were obtained from an open/short measurement. One can obtain that the matching adapter only works up to 10 MHz.

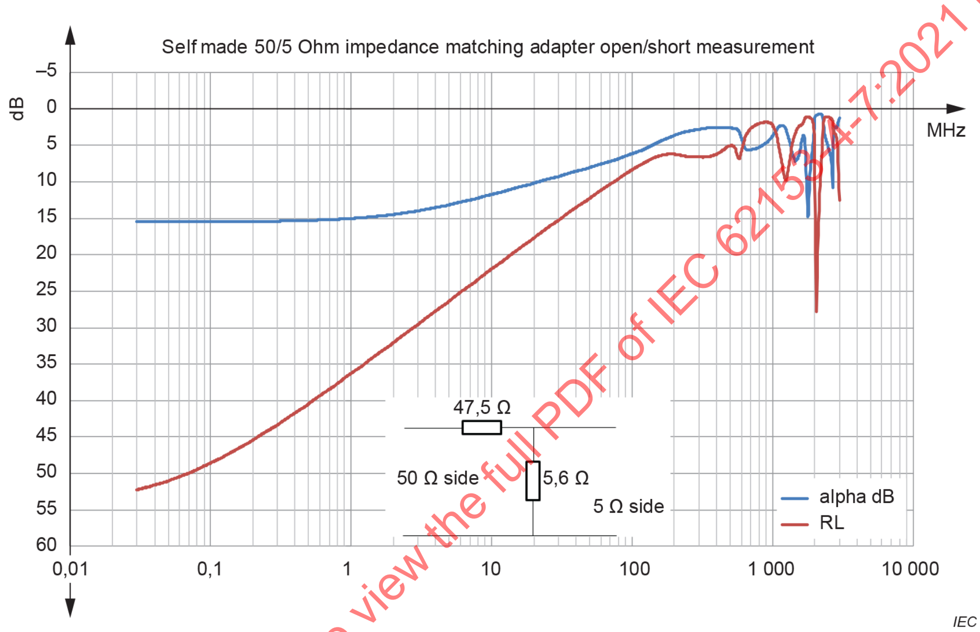


Figure B.1 – Attenuation and return loss of a 50 Ω to 5 Ω impedance matching adapter, log scale

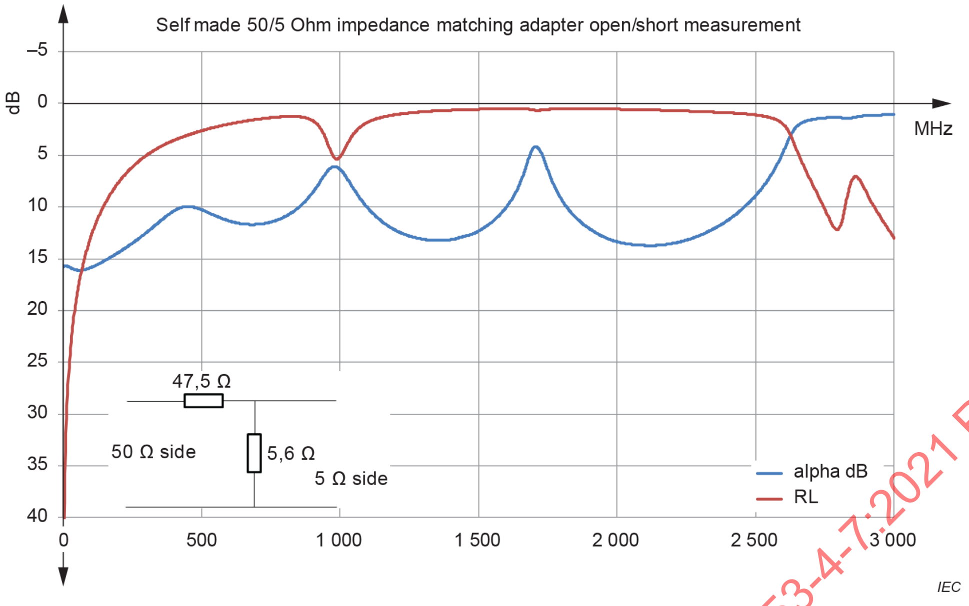


Figure B.2 – Attenuation and return loss of a 50 Ω to 5 Ω impedance matching adapter, lin scale

Annex C
(informative)

Measurements of the screening effectiveness of connectors and cable assemblies

C.1 General

Due to the increasing use of all kinds of electric or electronic equipment, electromagnetic pollution is on the increase. To reduce this electromagnetic pollution, all components of a system, especially the connecting cables (assemblies) shall be screened. It is obvious that one needs standardised measuring procedures to compare the screening effectiveness of different screen designs. The basic screening parameters are the transfer impedance Z_T and the screening attenuation a_S or coupling attenuation a_C. Either the triaxial or the line injection method can be used to obtain the transfer impedance Z_T of cables, connectors and cable assemblies. However, for the measurement of the screening a_S or coupling a_C attenuation of connectors and cable assemblies, an easy and cost effective method does not exist.

The following new method, which fills this gap, is described hereafter. It is based on the recently introduced shielded screening attenuation (long triaxial) test method for the measurement of the screening or coupling attenuation of cables [7], [8][2].

C.2 Physical basics

C.2.1 General coupling equation

For the measurement of the coupling, it is expedient to use the concept of operational attenuation with the square root of power waves, as in the definition of scattering parameters [9], [10]. The general coupling transfer function is then defined as:

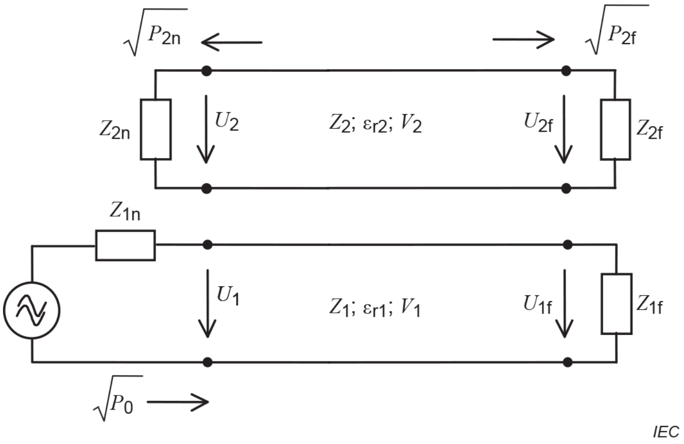
$$T_{n,f} = \frac{\underline{U}_{2n,f} \big/ \sqrt{Z_2}}{\underline{U}_1 \big/ \sqrt{Z_1}} = \frac{\sqrt{\underline{P}_{2n,f}}}{\sqrt{\underline{P}_0}} \tag{C.1}$$

The electromagnetic influence between the sample under test and the surrounding is in principle the crosstalk between two lines and is caused by capacitive and magnetic coupling. At the near end, the magnetic and capacitive coupling adds whereas at the far end they subtract [10], [11]. The coupling along the sample length is obtained by integrating the infinitesimal coupling distribution along the sample with the correct phase. The phase effect, when summing up the infinitesimal couplings along the line is expressed by the summing function S [10]. When the sample attenuation is neglected, then S could be expressed by the following equation, where $\beta_{1,2}$ are the phase velocities of the primary respectively the secondary circuit and l the coupling length. The indices n and f denote the near respectively the far end.

The equivalent circuit for two coupled lines is given in Figure C.1.

$$S_{n,f}(lf) = \frac{\sin\left[(\beta_2 \pm \beta_1)\cdot l/2\right]}{(\beta_2 \pm \beta_1)\cdot l/2} \exp\left(-j(\beta_2 + \beta_1)\cdot l/2\right) \tag{C.2}$$

2 Figures in square brackets refer to the Bibliography.



Key

$\sqrt{P_0}$ square root of the feeding power

$\sqrt{P_{2n}}$ square root of the coupled power, near end

$\sqrt{P_{2f}}$ square root of the coupled power, far end

Z_{nm} matching resistors, 1 = primary circuit, 2 = secondary circuit, n = near end, f = far end

Z_n characteristic impedance, 1 = primary circuit, 2 = secondary circuit

ε_{rn} dielectric constant, 1 = primary circuit, 2 = secondary circuit

V_n velocity of propagation, 1 = primary circuit, 2 = secondary circuit

Figure C.1 – Equivalent circuit of coupled transmission lines

Figure C.2 shows the summing function which is in principle a sin (x)/x function. For high frequencies, the asymptotic value becomes:

$$\left|S_{\substack{n\\f}}\right| \rightarrow \frac{2}{(\beta_1 \pm \beta_2) \times l} \tag{C.3}$$

And for low frequencies, the summing function becomes:

$$\left|S_{\substack{n\\f}}\right| \rightarrow 1 \tag{C.4}$$

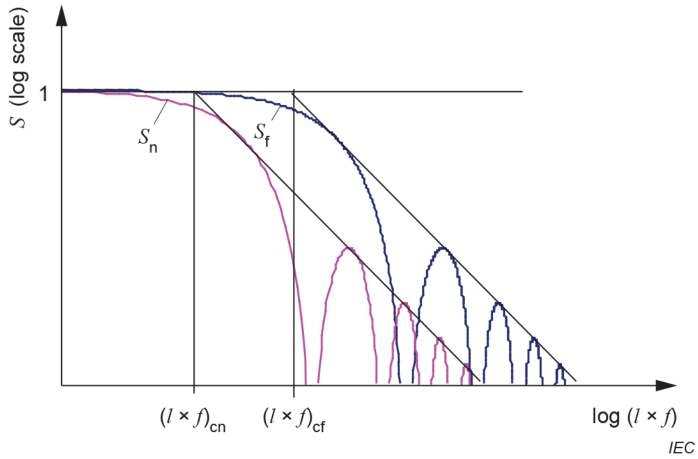


Figure C.2 – Summing function S

The point of intersection between the asymptotic values for low and high frequencies is the so called cut-off frequency f_c. This frequency gives the condition for electrical long samples:

$$f_{\substack{c,n\\f}} \times l \geq \frac{c_0}{\pi \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right|} \tag{C.5}$$

where

ε_{r1} is the relative dielectric permittivity of the inner system;

ε_{r2} is the relative dielectric permittivity of the outer system;

l is the cable length.

C.2.2 Coupling transfer function

C.2.2.1 Homogenous screens

The primary screening quantities of a screen are the surface transfer impedance Z_T and the capacitive coupling impedance Z_F or the effective transfer impedance Z_{TE}. For homogeneous screens such as for connectors or cables, they can be assumed to be constant along the length. The integration could then be easily solved. The coupling between the sample and the surrounding could be expressed by the following coupling transfer function. For matched lines it is [9], [10]:

$$T_{\substack{s,n\\f}} = \left(Z_F \pm Z_T\right) \times \frac{1}{\sqrt{Z_1 \cdot Z_2}} \times \frac{l}{2} \times S_{\substack{n\\f}} \tag{C.6}$$

For low frequencies, when S = 1, the coupling transfer function corresponds to the frequency behaviour of the surface transfer impedance and capacitive coupling impedance. After a rise with 20 dB per decade, the coupling transfer function shows different cut-off frequencies $f_{cn,f}$ for the near and far end. Above these cut-off frequencies, the samples are considered as electrically long.

The calculated coupling transfer function of a coaxial cable is given in Figure C.3. The principle set-up of the triaxial test procedure is given in Figure C.4.

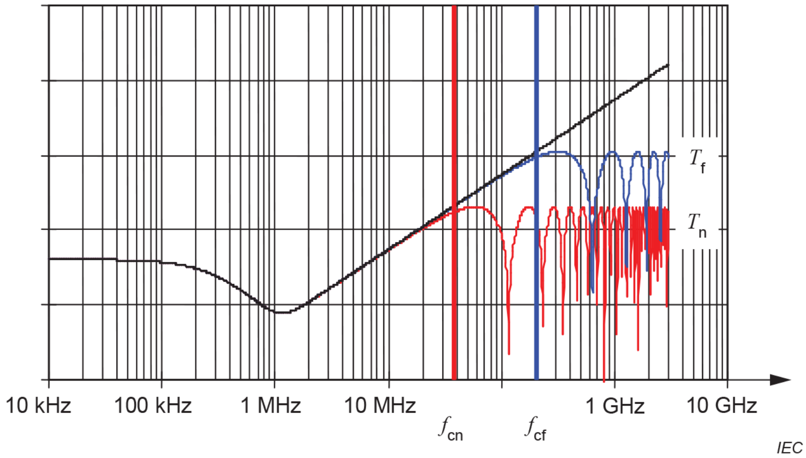


Figure C.3 – Calculated coupling transfer function (l = 1 m; e_{r1} = 2,3; e_{r2} = 1; Z_F = 0)

Below the cut-off frequencies, the surface transfer impedance Z_T is the measure of the screening effectiveness. The value of the transfer impedance Z_T increases with the sample length.

Above the cut-off frequencies in the range of wave propagation, respectively in the range where the samples are electrically long, the screening attenuation a_S is the parameter for the screening effectiveness. The screening attenuation is a length-independent quantity.

C.2.2.2 Cable assembly screens

Cable assemblies are composed by the cable itself and a connector at each end. In addition to the coupling of the components itself, the coupling of the transition between cable and connector also should be taken into account. Mounting a good connector to a good cable will not automatically lead to a good assembly because the connection between the cable and the connector may be worse.

Each part of it has a different coupling, thus one has to integrate in sections along the sample, i.e. one section for each component (connector A, transition, cable, transition, connector B). In a first approach, the velocity in each section could be assumed to be equal. The coupling transfer function for matched lines is then expressed by:

$$T_n = \frac{1}{\gamma_1 + \gamma_2} \times \sum_{i=1}^{n} \left[\frac{Z_{F,i} + Z_{T,i}}{2 \times \sqrt{Z_1 \times Z_2}} \times e^{-(\gamma_1+\gamma_2)\times \sum_{k=1}^{i-1} L_i} \times \left(1 - e^{-(\gamma_1+\gamma_2)\times L_i}\right) \right] \quad \text{(C.7)}$$

$$T_f = \frac{e^{-\gamma_2 L_c}}{\gamma_1 - \gamma_2} \times \sum_{i=1}^{n} \left[\frac{Z_{F,i} - Z_{T,i}}{2 \times \sqrt{Z_1 \times Z_2}} \times e^{-(\gamma_1-\gamma_2)\times \sum_{k=1}^{i-1} L_i} \times \left(1 - e^{-(\gamma_1-\gamma_2)\times L_i}\right) \right] \quad \text{(C.8)}$$

where

$\gamma_{1,2}$ is the complex wave propagation constant of inner, respectively outer circuit;

L_c is the whole coupling length (sum of the segment lengths);

L_i is the length of segment i;

n is the number of segments (for cable assemblies, 3);

$T_{n,f}$ is the coupling transfer function at the near respectively far end;

$Z_{1,2}$ is the characteristic impedance of inner, respectively outer circuit;

Z_F is the capacitive coupling impedance;

Z_T is the surface transfer impedance;

γ is the propagation constant
= (α + jβ), where α is the attenuation constant and β is the phase constant.

C.2.2.3 Coupling in the triaxial set-up

The above-mentioned coupling transfer functions are valid if the primary and secondary circuit are matched. However, in the triaxial set-up, the secondary system (outer circuit) is mismatched (see also Clause C.3). At the near end, one has the short circuit between the sample screen. At the far end, one has the mismatch between the impedance of the outer circuit and the receiver input impedance resulting in the reflection coefficient $r_{2,f}$. In this case, the resulting coupling transfer function (at the receiver end) is obtained by:

$$T^* = \left(T_f - T_n \times e^{-\gamma_2 \times L_C}\right) \times \frac{1 + r_{2,f}}{1 + r_{2,f} \times e^{-2 \times \gamma_2 \times L_C}} \qquad \text{(C.9)}$$

C.3 Triaxial test set-up

C.3.1 General

The triaxial test set-up is one of the classical methods to measure the transfer impedance and has been recently extended for the measurement of the screening attenuation of cable screens [7]. The triaxial set-up is described in IEC 62153-4-3 and IEC 62153-4-4 and consists of a tube of brass or aluminium with an inner diameter of about 40 mm. Other diameters may be used depending on the frequency range to be measured.

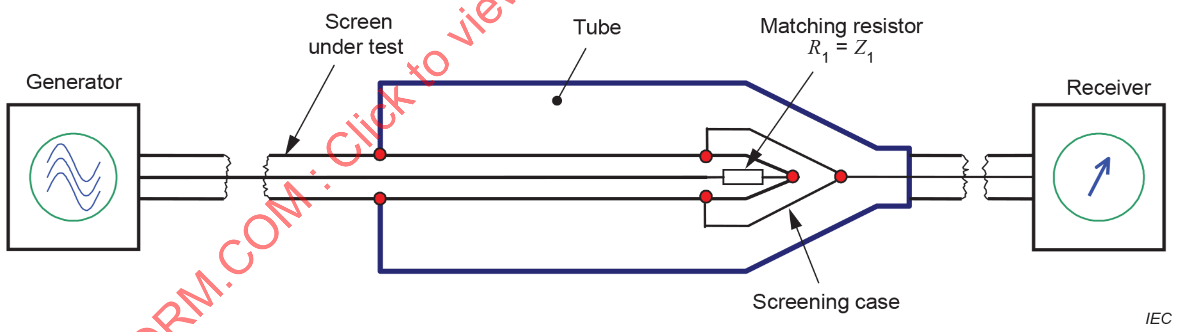


Figure C.4 – Triaxial set-up for the measurement of the screening attenuation a_S and the transfer impedance Z_T

For the measurement of the transfer impedance (electrically short coupling length), the tube length is 0,5 m to 1 m. For the measurement of the screening attenuation (electrically long coupling length), the measuring tube is extended to a length of 2 m to 3 m (see also the above theoretical explanation).

In the outer circuit, at the near end, the screen under test is short circuited with the measuring tube. The electrical waves, which are coupled over the whole cable length from the inner system into the outer system, propagate in both directions, to the near and to the far end. At the short circuited end, they are totally reflected, so that at the measuring receiver, the superposition of near and far end coupling can be measured as the disturbance voltage ratio U_2/U_1. The screening attenuation as a power ratio is then related to a standardised characteristic impedance of the outer system Z_S = 150 Ω.

$$a_S = 20 \times \log\left(\left|\frac{U_2}{U_1}\right|_{max}\right) + 10 \times \log\left(\frac{2 \times Z_S}{Z_1}\right) \quad (C.10)$$

where

Z_1 is the characteristic impedance of the sample under test and Z_S is 150 Ω.

C.3.2 Measurement of cable assemblies

C.3.2.1 General

When measuring cable assemblies in the triaxial test set-up, there is the problem in that their lengths differ widely and are either shorter or longer than the commonly used measuring tube of 2 m or 3 m. However, the investigations of the above-given coupling functions show that:

a) for assemblies longer than the measuring tube, it is sufficient to measure just both accessible assembly ends;
b) for assemblies shorter than the measuring tube, one can extend the assembly by a well-screened cable inside a closed copper tube. This is the so called tube in tube method.

C.3.2.2 Assembly longer than the measuring tube

In screening attenuation measurements of cable assemblies, it is evident that the result is characterised by the weakest part. Either the cable or the connector or the transition between cable and connector. Thus, for cable assemblies which are longer than the measuring tube, it is sufficient to measure the assembly from both ends (provided that the cable screen is homogenous). The worst case of both measurements is then the screening attenuation of the whole assembly. The simulated graphs given in Figure C.5 and Figure C.6 underline that evidence.

The simulation parameters are:

a) cable screen

length:	500 cm
DC resistance:	13 m Ω/m
magnetic coupling:	0,04 mH/m
capacitive coupling:	0,02 pF/m

b) connector screen including transition from cable to connector

length:	5 cm
DC resistance:	2 m Ω/m
magnetic coupling:	0,002 mH
capacitive coupling:	0 pF/m

c) outer circuit (secondary system)

impedance:	150 Ω
dielectric permittivity:	1,1

d) inner circuit (primary system)

impedance:	50 Ω
dielectric permittivity:	2,3

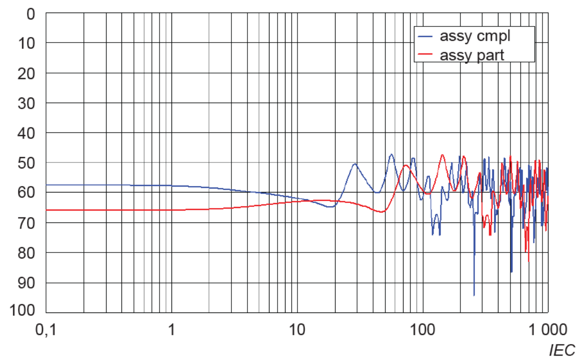


Figure C.5 – Simulation of a cable assembly (logarithmic scale)

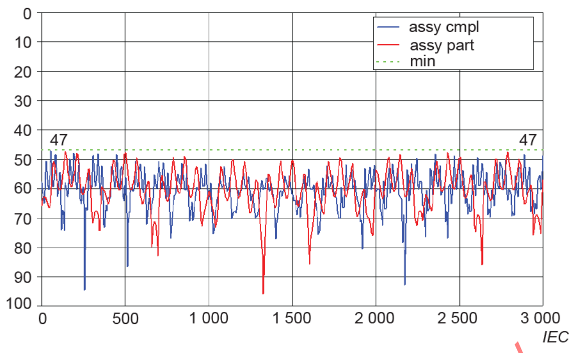


Figure C.6 – Simulation of a cable assembly (linear scale)

The blue line shows the result of the complete cable assembly, i.e. 500 cm cable and both connectors. The red line shows the result for just one part of the assembly, i.e. 195 cm of the cable and one connector. In the lower frequency range, where the samples are electrically short, one gets a length dependent result. However, in the higher frequency range, where the samples are electrically long, one gets the same minimum value, i.e. the same screening attenuation of 47 dB.

C.3.2.3 Assembly shorter than the measuring tube

When the assembly is shorter than the measuring tube, the assembly can be extended by a well screened connecting cable inside a closed copper tube. This is the so called tube in tube method (see also Figure C.7 and Figure C.8).

The extension tube then acts as a resonator. The same principle is also used for the measurement of connectors. Further details can be obtained from the following explanation of the measurement of connectors.

C.3.3 Measurement of connectors

C.3.3.1 General

Usual RF connectors have mechanical dimensions in the longitudinal axis in the range of 10 mm to 50 mm. With the definition of electrical long elements, we get cut-off frequencies of about 3 GHz or higher for standard RF-connectors. Above that frequency, they are considered to be electrically long.

The screening attenuation is by definition only valid in the frequency range above the cut-off frequency, where the elements are electrically long. Thus, the screening attenuation of a RF connector itself can only be measured at frequencies above 3 GHz.

However, by extending the RF-connector by a RF-tight closed metallic tube, a cable assembly which is electrically long is built. Thus, the cut-off frequency, respectively the lower frequency limit, to measure the screening attenuation is extended towards lower frequencies. If one connects this extension tube directly to the connector under test, one is measuring the screening attenuation of the connector (and its mated adapter). If one connects the extension tube to the connecting cable close to the connector, one measures the screening attenuation of the combination of the connector (and its mated adapter) and the transition between cable and connector (see also figures below).

NOTE Although the connector itself stays electrically short, the combination of the connector and the extension tube shows the behaviour (the screening attenuation) of the connector when connected to a well screened cable, which has a screening effectiveness better than the one of the connectors (or the transition between cable and connector). See also the explanation in C.3.3.2.

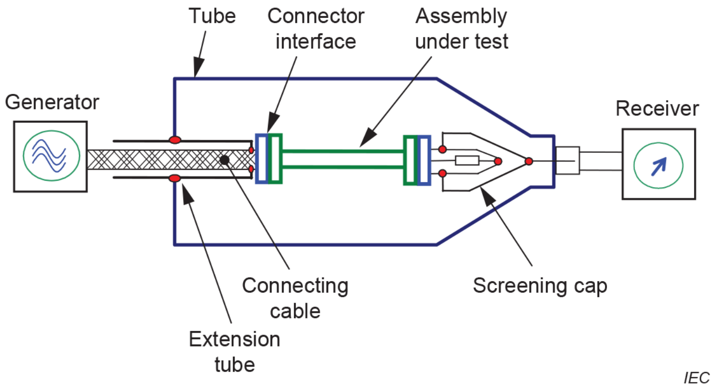


Figure C.7 – Triaxial set-up with extension tube for short cable assemblies

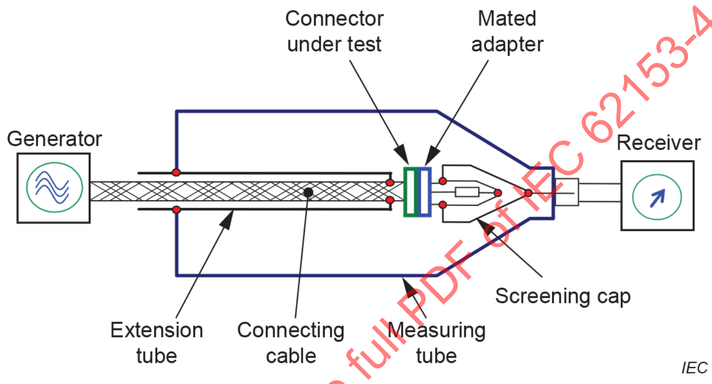


Figure C.8 – Triaxial set-up with extension tube for connectors

C.3.3.2 Measurement set-up

For the measurement of RF connectors, the triaxial set-up according to IEC 62153-4-3 respectively IEC 62153-4-4 has been extended by a RF-tight closed metallic tube (see Figure 8). The extension tube is either connected to the connector under test or to the screen of the connecting cable of the connector under test. At the far end, the connector under test is connected to the screening cap of the triaxial test set-up via its mated adapter.

The measurement of the screening attenuation itself is the same as the measurement of cable screens according to IEC 62153-4-4.

C.3.3.3 Measurement results and simulations

In a first approach, one has measured short cable pieces instead of a connector. The advantage is that the results are not influenced by a mating adapter or the transition between cable and connector. The cable is a coaxial cable with an impedance of 75 Ω, foam PE dielectric and a single braid screen (not optimised, i.e. under-braided). The simulations have been done with the equations (C.7), (C.8) and (C.9) where the number of sections is 2. The first section is the connecting cable with the RF-tight extension tube.

Thus, the transfer impedance and capacitive coupling impedance of that section is neglected. The second section is the cable under test with following parameter:

DC resistance:	8 m Ω/m
magnetic coupling:	0,6 mH/m
capacitive coupling:	0,02 pF/m
impedance:	75 Ω
dielectric permittivity:	1,35

The comparison of the simulation (Figure C.9, Figure C.11) with the measurement results (Figure C.10, Figure C.12) show a good correspondence. In the lower frequency range, when the samples are electrically short, one gets the same results. However, in the higher frequency range, one can see the influence of the extension tube. The 10 cm sample is electrically short over the whole frequency range, as the cut-off frequency is 5,9 GHz. Thus, the coupled power increases with increasing frequency. However, the quasi cable assembly composed of the connector and the extension tube is electrically long above 590 MHz, which results in a constant maximum coupled power. One characteristic of an electrically long object is also that the maximum coupled power is independent of the sample length (see C.2.1). This is underlined in Figure C.13 and Figure C.14, where the simulated results of a 4 cm sample in a 1 m respectively 2 m tube, i.e. with a 96 cm, respectively 196 cm extension tube, are shown. The envelope of both curves is identical.

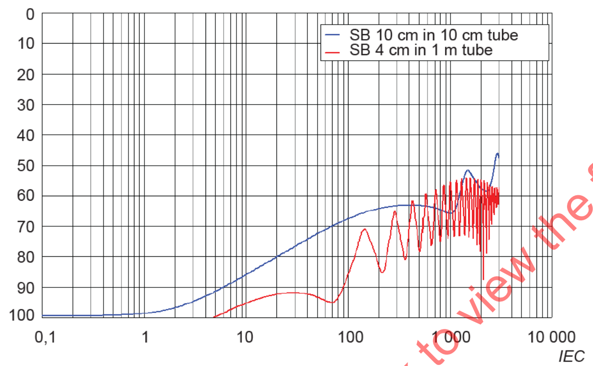


Figure C.9 – Simulation, logarithmic frequency scale

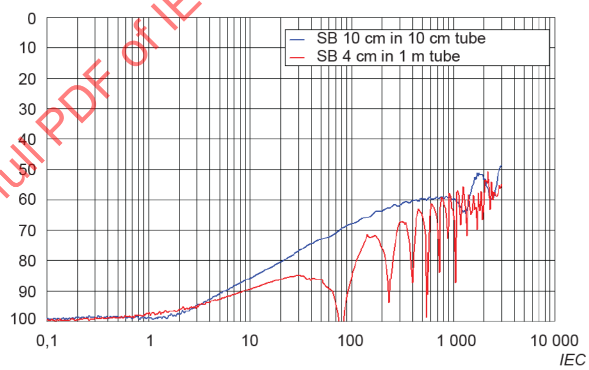


Figure C.10 – Measurement, logarithmic frequency scale

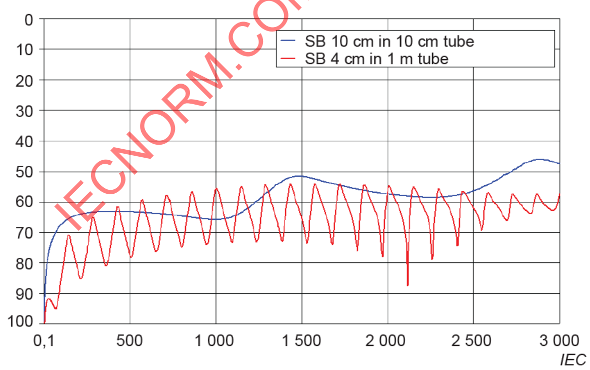


Figure C.11 – Simulation, linear frequency scale

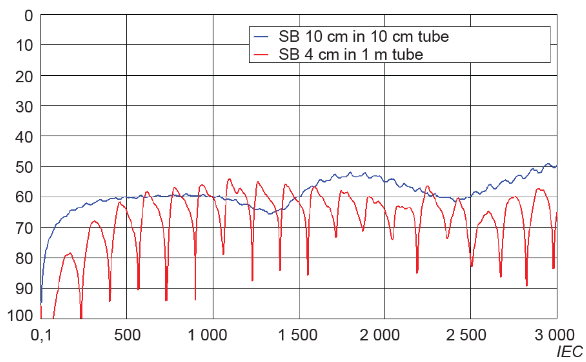


Figure C.12 – Measurement, linear frequency scale

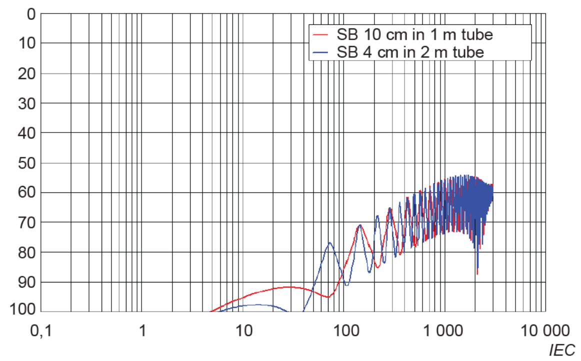


Figure C.13 – Simulation, logarithmic frequency scale

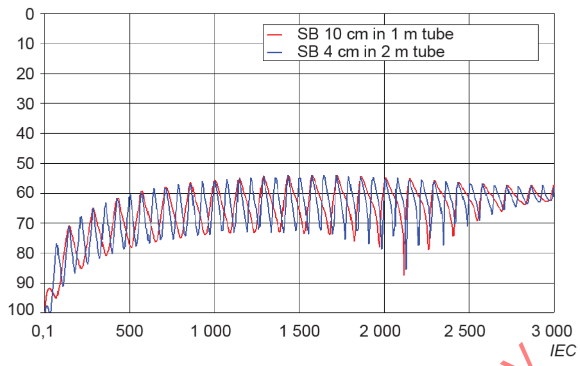


Figure C.14 – simulation, linear frequency scale

C.4 Conclusion

Customers and users of RF cables, cable assemblies and connectors ask more often for screening effectiveness values in decibels (dB) instead of transfer impedance values in mΩ respectively mΩ/m. The tube in tube method replies to that need since it offers a simple and reliable method to measure the screening attenuation in dB of connectors and cable assemblies. That method is an extension of the shielded screening attenuation (long triaxial) test set-up according to IEC 62153-4-4.

The comparison of the measured and the calculated curves show good concordance.

The advantages of the tube in tube method for connectors and assemblies are the same as for the measurement of the screening attenuation of cable screens in the tube:

- simple and easy test set-up;
- insensitive against electromagnetic disturbances from outside;
- high dynamic range >130 dB;
- good reproducibility.

Annex D
(informative)

Influence of contact resistances

Contact resistances between the feeding cable and the extension tube or the screening case in the test head may influence the test result. Contacts shall be prepared carefully with low resistance or with low impedance. Contacts shall be achieved over the complete circumference of the screen. Critical contacts are shown in Figure D.1.

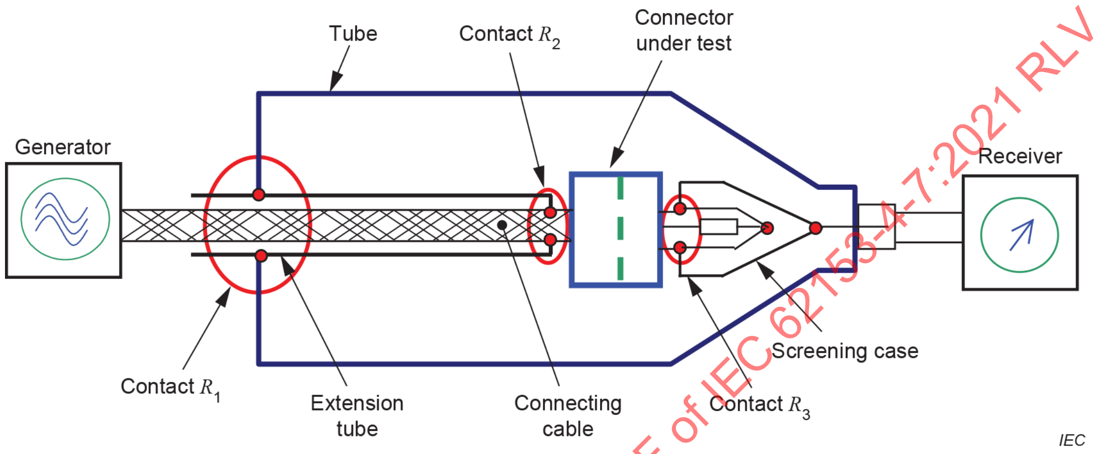
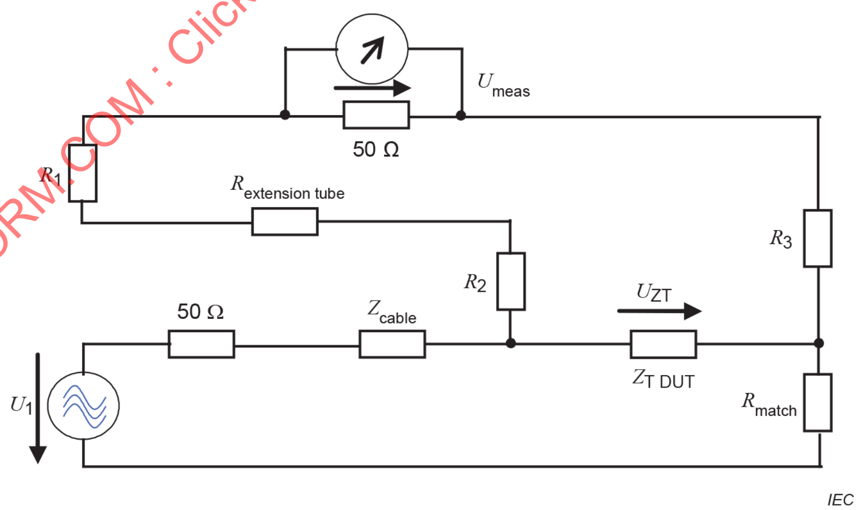


Figure D.1 – Contact resistances of the test set-up

The equivalent circuit of the complete test set-up including the contact resistances is given in Figure D.2. The test set-up shall be designed such that contact resistances of the extension tube are in series with the input impedance of the receiver and the contact resistance of the screening case including the matching load of the DUT is in series with the generator.



Key

R_1, R_2 and R_3	contact resistances depicted in Figure D.1.
Z_{cable}	characteristic impedance of the connecting cable (see Figure B.1)
Z_{DUT}	transfer impedance of the DUT

Figure D.2 – Equivalent circuit of the test set-up

In this case, contact resistances of a few mΩ in series with the 50 Ω input resistance of the generator or the receiver are negligible.

The test set-up should be designed such that contact resistances are not in series with the transfer impedance of the DUT. If contact resistances are in series with the transfer impedance of the DUT, they will influence the result considerably.

Annex E
(informative)

Direct measurement of screening effectiveness of connectors

E.1 Scope

This document describes the measurement of transfer impedance and screening or coupling attenuation of connectors and cable assemblies with the tube in tube procedure. As shown in Figure 2, connectors usually are measured with a short piece of connecting cable.

In different cases, it may be required to measure the screening effectiveness direct on the connector or without connecting cable, e.g. to evaluate the EMC of the interface of the mated connectors. Clause E.2 describes the test set-up for direct connector measurement.

E.2 Test set-up

The test set-up and measurements are in principle the same as in Clause 8 to Clause 10 of this document.

Contrary to the set-ups in Clause 8 to Clause 10 of this document, the RF-tight tube in tube and the screening cap are directly connected to the connector under test (CUT), see Figure E.1; e.g. by a screwing joint of the connector under test to the extension tube and the screening cap. The torque of this screwing joint shall be specified by the connector manufacturer. In order to vary the test length and therefore the cut off frequencies, a moveable shorting plane can be used as an option, see also IEC 62153-4-15:2015, Annex F. Any contact solution providing a 360-degree contact with sufficiently low resistance to avoid resonances can be used for the sliding short.

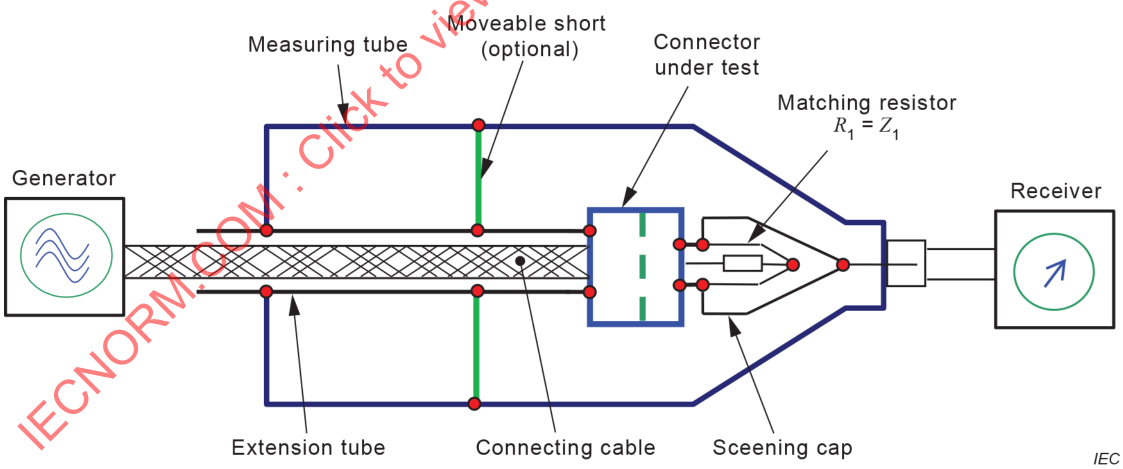


Figure E.1 – Principle of the test set-up to measure transfer impedance and screening attenuation of a connector

The same applies in principle to the set-up for measuring cable assemblies, see Figure E.2.

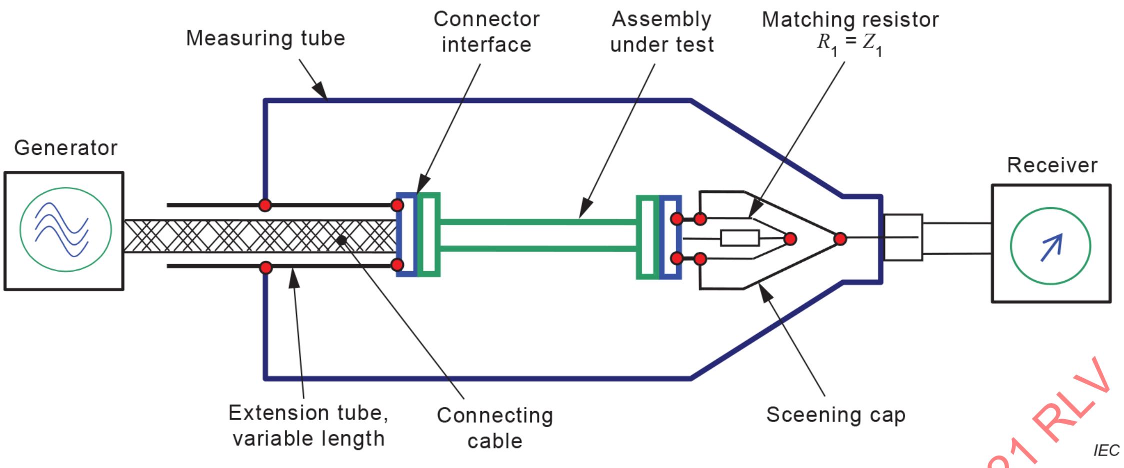
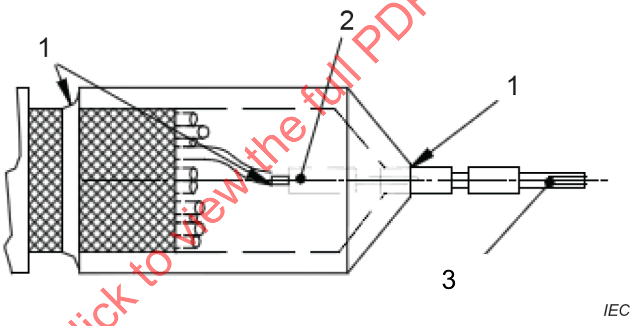


Figure E.2 – Principle of the test set-up to measure transfer impedance and screening attenuation of a cable assembly

If a multi conductor cable is tested instead of a single-conductor cable, a combination of inner conductors (cores) shall be selected such that their impedance to the screen is closest to the internal impedance of the test receiver, see Figure E.3 (e.g. determined by means of a reflectometer).



Key

1 connection

2 terminating impedance 50 Ω

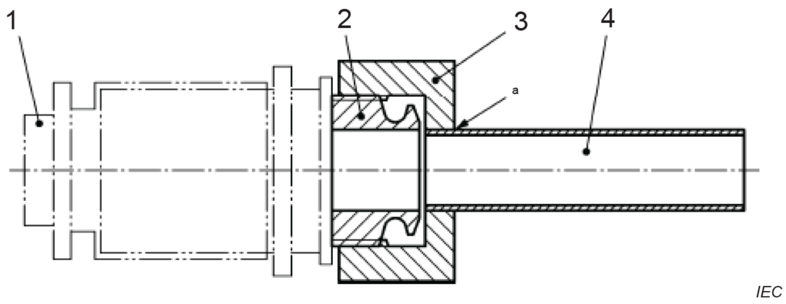
3 inner contact from RF connector connected to the shielded tube

Figure E.3 – Example of sample preparing

E.3 Construction details of test set-up

The connection of the RF-tight tube as well as the RF-tight connection of the screening cap may influence the test results considerably. Worse mounted connections may lead to leakages and to poor test results.

Figure E.4 and Figure E.5 give examples of how to connect the tube in tube and the screening cap to the CUT.



Key

1 mating connector

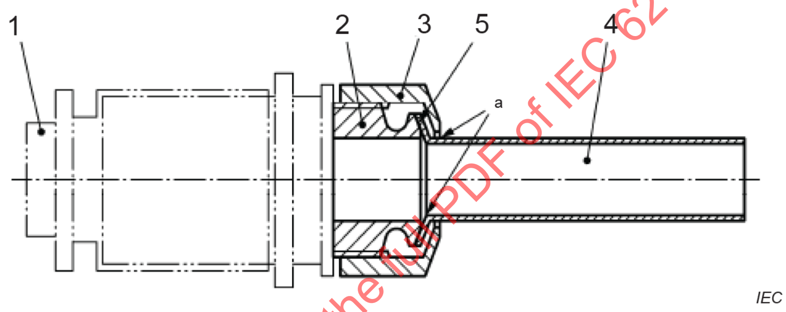
2 coupling

3 bush (Cu-material)

4 copper tube

a RF-tight connection (soldered for example)

Figure E.4 – Screening tube with separate nut



Key

1 mating connector

2 coupling

3 nut

4 copper tube

5 cone

a matching edge-raised or chamfered

Figure E.5 – Screening fixed with associated nut

Annex F
(normative)

Mixed mode S-parameters

F.1 General

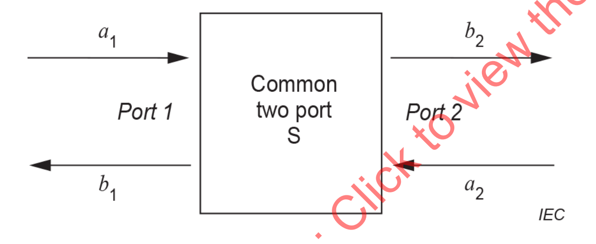
To measure parameters like unbalance attenuation, coupling attenuation, etc. of balanced cables, connectors and components, a differential signal is required. This can, for example, be generated by using a balun which converts the unbalanced signal of a 50 Ω network analyser into a balanced signal.

Alternatively, a balanced signal may be obtained by using a vector network analyser (VNA) having two generators with a phase shift of 180°. Another alternative is to measure with a multi-port VNA (virtual balun).

The properties of balanced pairs are determined mathematically from the measured values of each single conductor of the pair against reference ground. The coverable frequency range for the determination of the reflection and transmissions characteristics of symmetrical pairs is no longer limited by the balun but by the VNA and the connection technique.

F.2 Definition of mixed mode S-parameters

The transmission characteristics of four poles or two ports, such as coaxial cables, may be described by the scattering parameter or abbreviated “S-parameter”. In matrix notation, it is written as illustrated in Figure F.1.

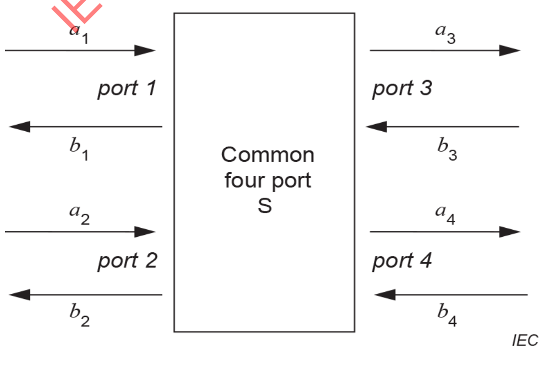


$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

where a and b are the normalized power waves of the input and output ports.

Figure F.1 – Common two-port network

The definition of the scattering matrix can be easily extended to arbitrary N gates. For a four-port, these result in the network illustrated in Figure F.2.



$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = \left(S^{\text{std}}\right) \cdot \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{43} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix}$$

Figure F.2 – Common four port network

For the measurement of symmetrical two-ports, the physical ports of the multi-port VNA are combined into logical ports, as illustrated in Figure F.3.

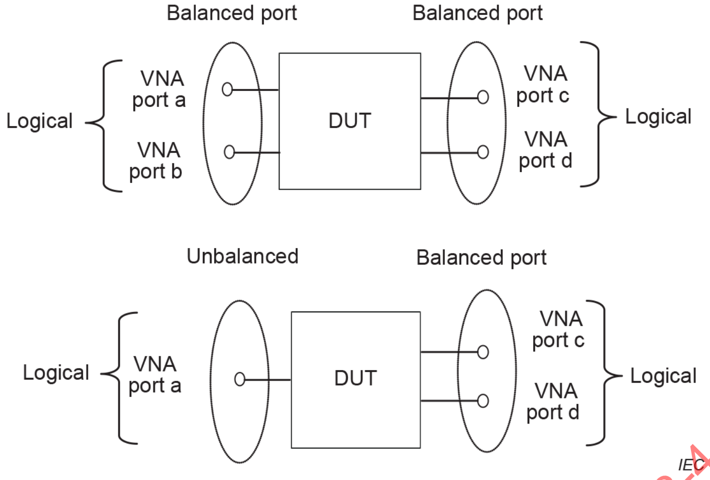
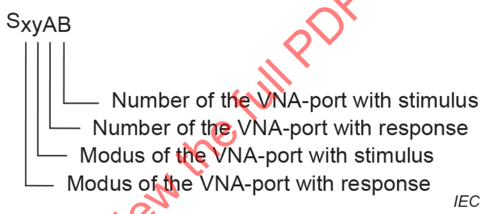


Figure F.3 – Physical and logical ports of a VNA

The nomenclature in Figure F.4 is used.



Modus	s: Single ended (unbalanced, coaxial)
	d: Differential mode (balanced)
	c: Common mode

Figure F.4 – Nomenclature of mixed mode S-parameters

Accordingly, the S-parameters can be understood as ratios of power waves.

$$S_{\mathrm{xyAB}} = \frac{\text{input signal at VNA-port A at modus x}}{\text{input signal at VNA-port B at modus y}}$$

The conversion of the asymmetrical four-port scattering parameters S^{std} to mixed mode scattering parameters S^{mm} for a symmetrical two-port network is given by:

$$S^{\mathrm{mm}} = M \cdot S^{\mathrm{std}} \cdot M^{-1}$$

where

$$M = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \quad (C.2)$$

$$S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd21} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix}$$

For the measurement of a two-port with an unbalanced port (single ended) and a balanced port, the following measurement configurations arise (see Figure F.5):

			Stimulus		
			Single ended	Differential mode	Common mode
			Logical port 1	Logical port 2	Logical port 2
Response	Single ended	Logical port 1	S_{ss11}	S_{sd12}	S_{sc12}
	Differential mode	Logical port 2	S_{ds21}	S_{dd22}	S_{dc22}
	Common mode	Logical port 2	S_{cs21}	S_{cd22}	S_{cc22}

IEC

Figure F.5 – Measurement configuration, single ended response

The measurement of the coupling attenuation corresponds to a stimulus in the differential mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sd12}. The measurement of the screening attenuation corresponds to a stimulus in common mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sc12}.

For the measurement of a four-port, the following test configurations are obtained (see Figure F.6):

			Stimulus			
			Differential mode		Common mode	
			Logical port 1	Logical port 2	Logical port 1	Logical port 2
Response	Differential mode	Logical port 1	S_{dd11}	S_{dd12}	S_{dc11}	S_{dc12}
		Logical port 2	S_{dd21}	S_{dd22}	S_{dc21}	S_{dc22}
	Common mode	Logical port 1	S_{cd11}	S_{cd12}	S_{cc11}	S_{cc12}
		Logical port 2	S_{cd21}	S_{cd22}	S_{cc21}	S_{cc22}

IEC

Figure F.6 – Measurement configuration, differential mode response

The measurement of the attenuation of a balanced pair corresponds to a stimulus and a response in differential mode, i.e. a measurement of the S-parameter S_{dd21}. The measurement of the unbalance attenuation with stimulus in differential mode and common mode response corresponds at the near end with the S-parameter S_{cd11} or S_{cd21} when measured at the far end.

F.3 Reference impedance of a VNA

When measuring with 4 port VNA with mixed mode parameters, a full 4-port calibration, e.g. with electronic calibration units, shall be applied. The VNA (Z_0 = 50 Ω physical analyser ports) sets the default values reference impedances for the differential mode Z_{0d} = 100 Ω (= 2 × Z_0) and for the common mode Z_{0c} = 25 Ω (= Z_0/2).

Annex G
(normative)

Accessories for measuring coupling attenuation

G.1 TP connecting unit

A balanced signal may be obtained with a vector network analyzer (VNA) having two generators with a phase shift of 180° or with a multi-port VNA using mixed mode S-parameters (balunless or virtual balun, respectively). To connect the unbalanced ports of the VNA with the balanced device under test (DUT), a TP-connection unit, also with high RF performance, is required. The TP connecting unit performance requirements are specified in Table G.1.

Table G.1 – TP-connecting unit performance characteristics (100 kHz to 2 GHz)

Parameter	Value
Characteristic impedance, primary side (single ended)[a]	50 Ω
Characteristic impedance, secondary side (differential)[a]	1 × 100 Ω (differential)
Return loss, differential mode[b]	> 20 dB
Attenuation, differential mode[c]	< 0,3 dB
Unbalance attenuation (TCTL)[d]	> 60 dB-10×log (f), 40 dB max.

[a] Two ports with single ended impedances of 50 Ω generates a common mode impedance of 25 Ω and a differential mode impedance of 100 Ω.

[b] To be measured e.g. with a 4 port mixed mode network analyser. One logical port is generated by the combination of two single ended ports. A second logical port is generated by the combination of two other single ended ports. The S-parameter S_{dd11} then represents the negative return loss of the differential mode.

[c] With the test set-up according to [b] the absolute dB value of the S-parameter, S_{dd11} then represents the return loss of the differential mode.

[d] With the test set-up according to [b] the S-parameter, S_{cd21} represents the negative unbalance attenuation (TCTL).

G.2 Termination of the DUT

A differential mode termination is required for each pair at the near and far end of the cable as shown in Figure G.1.

$$R_{DM} = \frac{Z_{diff}}{2} \qquad (11)$$

The termination of the common mode ($R_{DM}//R_{DM}$) is 25 Ω.

NOTE Since modern mixed mode VNAs use a 50 Ω generator and receiver impedance as default value, the common mode value results in 25 Ω.

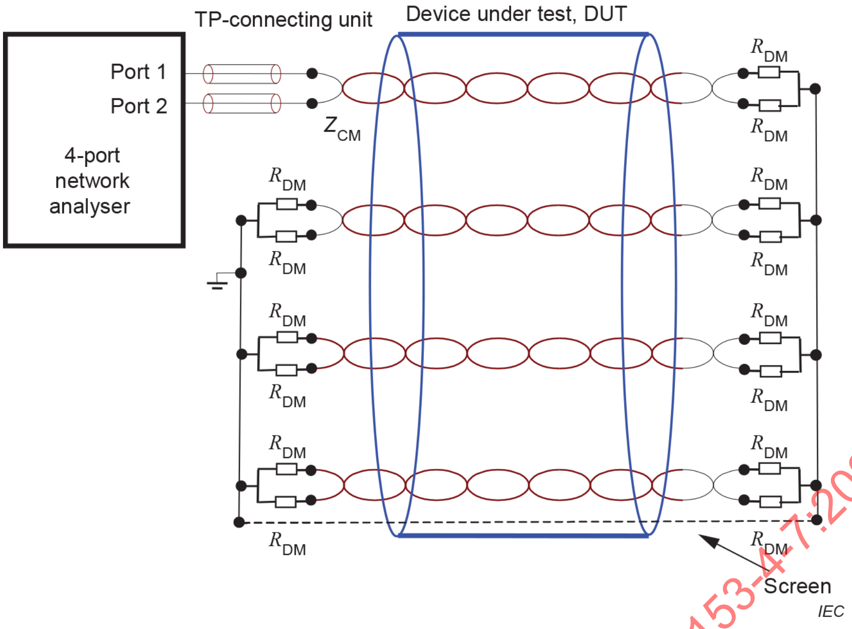


Figure G.1 – Termination of the device under test, principle

G.3 Test adapter

G.3.1 General

When measuring transfer impedance and screening- or coupling attenuation on connectors or cable assemblies, test adapters are required to connect the DUT with the test set-up. Test adapters may limit the sensitivity of the test set-up and possibly falsify the test results. Qualification tests of test adapters shall be performed to establish the noise floor, respectively the sensitivity of the entire test system. We can divide between two basic concepts when realizing differential adapters and suppling the adapters with test signals.

G.3.2 Direct feeding with coaxial cables

The first concept is called the direct feeding concept. It applies coaxial feeding cables reaching right to the adapter (Figure G.2). It is recommended to use connectors showing up metrology connector compatible interfaces. The advantage is then that the performance of the coaxial feeding cables can be very well verified and can be directly connected to the ports of the calibrated generator or the VNA. The generator/VNA calibration plane could be even located at the end of the coaxial feeder cables by including them into the calibrated part of the test port cables.

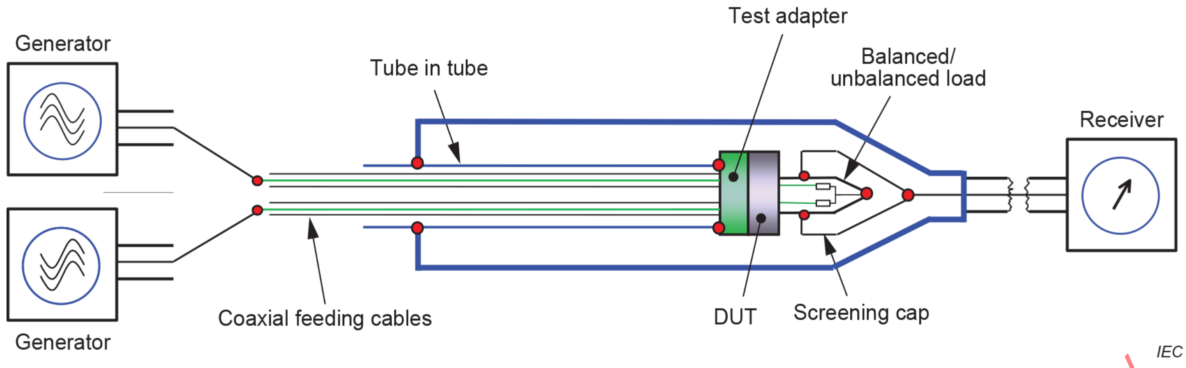


Figure G.2 – Balunless measurement of coupling attenuation of a balanced connector, direct feeding, principle

G.3.3 Balanced feeding cable

The second concept applies to balanced feeding cables (Figure G.3). Therefore, market available differential cable assemblies which are showing up the compatible connector interface could be reworked and finished with a suitable housing to build up the test adapter. The dis-advantage of the balanced feeding cable concept is the more difficult verification of the electrical performance.

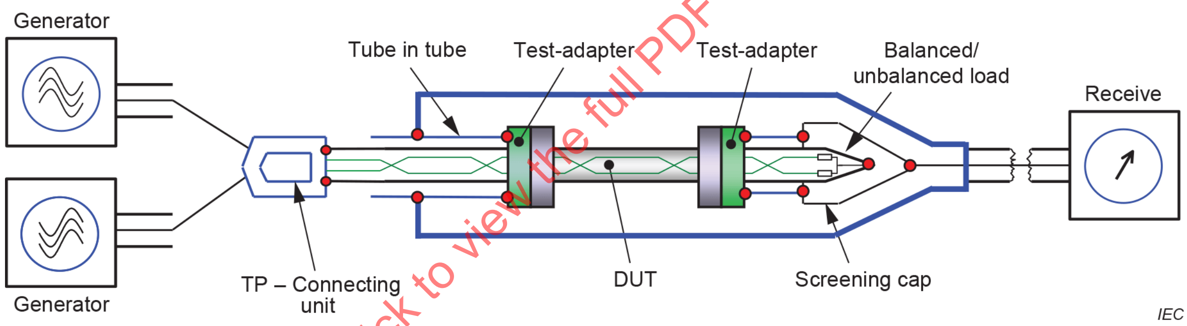


Figure G.3 – Balunless measurement of coupling attenuation of a cable assembly using balanced feeding cable, principle

G.3.4 Movable short circuit

Adapters including a higher number of balanced pairs may require bigger housing volumes. The relation of the diameter of the outer tube and the diameter of the adapter housing defines the impedance of the adapter section of the outer system. If this relation is below 2.3, an additional point of reflections is generated affecting additional measurement uncertainties. One way to overcome these additional uncertainties is to implement the near end shortage plane directly into the adapter as shown in Figure G.4. The quality of the hereby realised contact resistance shall be verified.

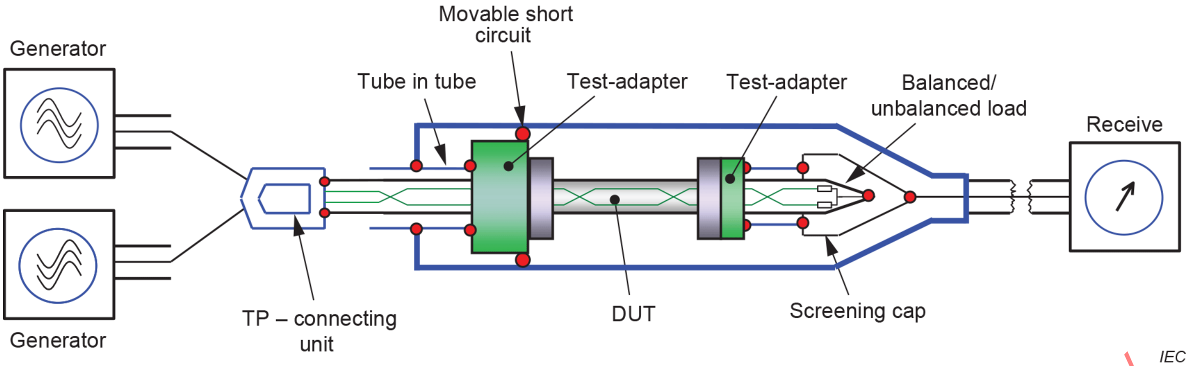


Figure G.4 – Balunless measurement of coupling attenuation of a cable assembly using adapters with implemented short circuit, principle

Annex H
(informative)

Low frequency screening attenuation

Screening attenuation for cables and cable assemblies is based on system requirements and regulations, often defined for frequencies above 30 MHz. To measure the screening attenuation, an electrically long DUT is required. For common CATV cables, this would require a test length of 20 m. However, for practical reasons the test length is in the range of 2 m to 3 m which would correspond to a minimum frequency of 300 MHz from which on screening attenuation could be measured. However, it is common practice to interpret the measured results between 30 MHz and 300 MHz as screening attenuation. The error introduced by this interpretation is neglectable provided the test length is at least 2 m. In case of doubt, the test length shall be increased.

Figure H.1 shows an example for a test result of a cable assembly when the test length is 2 m. In the diagram, the given cut-off frequency Fg(sd) is calculated according to IEC 62153-4-4:2015 which is located approximately at 300 MHz. The given limit lines are valid for the screening classes A and A+ according to the European Standard EN 50117-9-2:2019. The requirements for the low frequency screening attenuation from 30 MHz to 300 MHz can be clearly met.

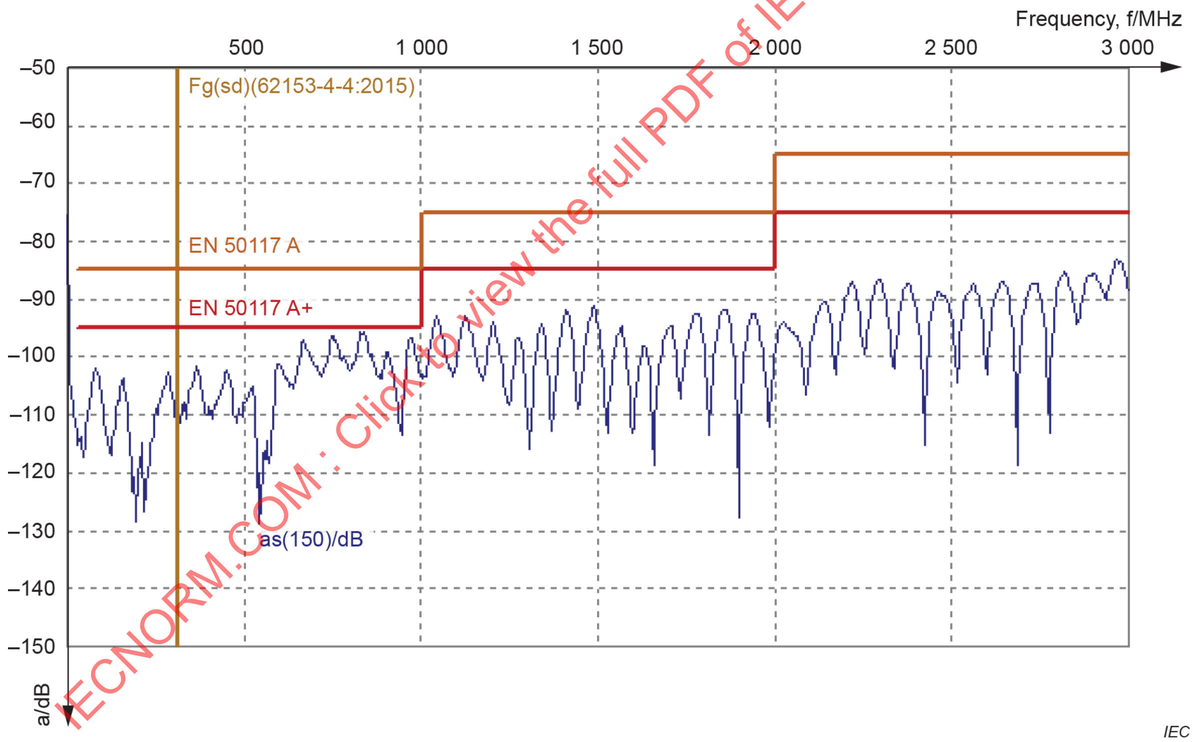


Figure H.1 – Example for a screening attenuation test result of a cable assembly with a test length of 2 meters

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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MÉTHODES D'ESSAI DES CÂBLES MÉTALLIQUES ET AUTRES COMPOSANTS PASSIFS –

Partie 4-7: Compatibilité électromagnétique (CEM) – Méthode d'essai pour mesurer l'impédance de transfert, Z_T,et l'affaiblissement d'écrantage, a_S, ou l'affaiblissement de couplage, a_C, des connecteurs et des cordons – Méthode triaxiale en tubes concentriques

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Cette troisième édition annule et remplace la deuxième édition parue en 2015, et son Amendement 1:2018. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

Le document a été révisé et mis à jour. Il inclut désormais l'IEC 62153-4-7:2015/COR1:2016 et l'IEC 62153-4-7:2015/AMD1:2018. En outre, les modifications relatives à la révision de l'IEC 62153-4-9:2018 sont incluses.

Les mesures de l'affaiblissement de couplage peuvent désormais être effectuées à l'aide d'un analyseur de réseau avec option de mode mixte (symétriseur virtuel). Les nouvelles annexes suivantes ont été ajoutées:

– l'Annexe E contient des informations relatives au mesurage direct de l'efficacité d'écrantage des connecteurs;
– l'Annexe F donne des informations normatives sur les paramètres du mode mixte;
– l'Annexe G contient des informations normatives concernant les accessoires permettant de mesurer l'affaiblissement de couplage;
– l'Annexe H traite de l'affaiblissement d'écrantage à basse fréquence.

Le texte de la présente Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
46/812/FDIS	46/820/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Le présent document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/standardsdev/publications.

Une liste de toutes les parties de la série IEC 62153, publiées sous le titre général *Méthodes d'essai des câbles métalliques et autres composants passifs*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu du présent document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

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INTRODUCTION

Le montage d'essai de l'affaiblissement d'écrantage blindé selon l'IEC 62153-4-3 et l'IEC 62153-4-4 a été étendu pour prendre en compte les particularités des éléments électriquement courts, comme les connecteurs et les cordons. En raison du tube concentrique externe du montage triaxial, les mesures sont indépendantes des irrégularités de la circonférence et des champs électromagnétiques externes.

Avec un tube résonnant supplémentaire (le tube interne des tubes concentriques), un système est créé, dans lequel l'efficacité d'écrantage d'un dispositif électriquement court est mesurée dans des conditions proches de la réalité et contrôlées. En outre, une fréquence de coupure inférieure pour la transition entre la faible longueur électrique (impédance de transfert, Z_T) et la grande longueur électrique (affaiblissement d'écrantage, a_S) peut être obtenue.

Une plage de fréquences large et dynamique peut être appliquée pour soumettre à essai même des cordons et des connecteurs fortement écrantés avec des instruments normaux, depuis les basses fréquences jusqu'à la limite des ondes transversales définies dans le circuit externe à environ 4 GHz.

MÉTHODES D'ESSAI DES CÂBLES MÉTALLIQUES ET AUTRES COMPOSANTS PASSIFS –

Partie 4-7: Compatibilité électromagnétique (CEM) – Méthode d'essai pour mesurer l'impédance de transfert, Z_T,et l'affaiblissement d'écrantage, a_S, ou l'affaiblissement de couplage, a_C, des connecteurs et des cordons – Méthode triaxiale en tubes concentriques

1 Domaine d'application

La présente partie de l'IEC 62153 traite de la méthode triaxiale en tubes concentriques. Cette méthode triaxiale convient pour déterminer l'impédance surfacique de transfert et/ou l'affaiblissement d'écrantage et l'affaiblissement de couplage de connecteurs écrantés et accouplés (y compris la connexion entre le câble et le connecteur) et de cordons. Cette méthode pourrait également être étendue pour déterminer l'impédance de transfert, l'affaiblissement de couplage ou l'affaiblissement d'écrantage de connecteurs symétriques ou à plusieurs broches et de cordons multiconducteurs. Pour le mesurage de l'impédance de transfert et de l'affaiblissement d'écrantage ou l'affaiblissement de couplage, un seul montage d'essai est nécessaire.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC TS 62153-4-1:2014, *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic screening measurements* (disponible en anglais seulement)

IEC 62153-4-3, *Metallic communication cable test methods – Part 4-3: Electromagnetic Compatibility (EMC) − Surface transfer impedance − Triaxial method* (disponible en anglais seulement)

IEC 62153-4-4, *Metallic communication cable test methods – Part 4-4: Electromagnetic compatibility (EMC) – Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method* (disponible en anglais seulement)

IEC 62153-4-8, *Câbles métalliques et autres composants passifs – Méthodes d'essai – Partie 4-8: Compatibilité électromagnétique (CEM) – Admittance de couplage capacitif*

IEC 62153-4-9:2018, *Méthodes d'essais des câbles métalliques de communication – Partie 4-9: Compatibilité électromagnétique (CEM) – Affaiblissement de couplage des câbles symétriques écrantés, méthode triaxiale*

IEC 62153-4-10, *Méthodes d'essai des câbles métalliques de communication – Partie 4-10: Compatibilité électromagnétique (CEM) – Impédance de transfert et affaiblissement d'écran des traversées et des joints d'étanchéité électromagnétiques – Méthode d'essai coaxiale double*

IEC 62153-4-15:2015, *Metallic communication cable test methods – Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell* (disponible en anglais seulement)

IEC 62153-4-16, *Metallic communication cable test methods – Part 4-16: Electromagnetic compatibility (EMC) – Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up* (disponible en anglais seulement)

EN 50117-9-2:2019, *Coaxial cables – Part 9-2: Sectional specification for coaxial cables for analogue and digital transmission – Indoor droop cables for systems operating at 5 MHz – 3 000 MHz* (disponible en anglais seulement)

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
impédance surfacique de transfert
Z_T
pour un écran électriquement court, quotient de la tension longitudinale, U_1, induite dans le circuit interne par le courant, I_2, délivré au circuit externe ou vice versa

Note 1 à l'article: L'impédance surfacique de transfert est exprimée en ohms.

Note 2 à l'article: L'impédance, Z_T, d'un écran électriquement court est exprimée en ohms [Ω] ou en décibels par rapport à 1 Ω.

Note 3 à l'article: Voir Figure 1.

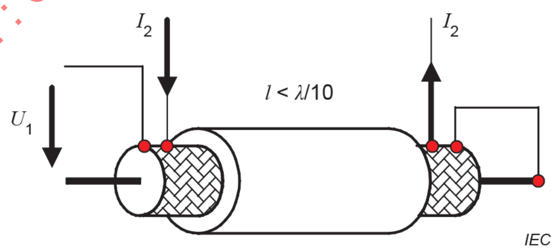


Figure 1 – Définition de Z_T

$$Z_T = \frac{U_1}{I_2} \tag{1}$$

$$Z_T \text{ dB}(\Omega) = +20 \times \log_{10}\left(\frac{|Z_T|}{1\Omega}\right) \tag{2}$$

3.2
impédance de transfert effective
Z_{TE}
valeur absolue maximale de la somme ou de la différence de l'impédance de couplage capacitif, Z_F, et de l'impédance de transfert, Z_T, à chaque fréquence

$$Z_{TE} = \max\left|Z_F \pm Z_T\right| \tag{3}$$

3.3
affaiblissement d'écrantage
a_S
pour les dispositifs électriquement longs, c'est-à-dire au-delà de la fréquence de coupure, le rapport logarithmique de la puissance d'alimentation, P_1, et des valeurs maximales périodiques de la puissance couplée, $P_{r,max}$, dans le circuit externe

$$a_S = -10 \times \log_{10}\left(\mathrm{Env}\left|\frac{P_{r,max}}{P_1}\right|\right) \tag{4}$$

Note 1 à l'article: L'affaiblissement d'écrantage d'un dispositif électriquement court est défini par:

$$a_S = 20 \times \log_{10}\frac{150\,\Omega}{Z_{TE}} \tag{5}$$

où

150 Ω est l'impédance normalisée du circuit externe.

3.4
affaiblissement de couplage
a_C
pour un dispositif symétrique écranté, somme de l'affaiblissement de dissymétrie, a_U, de la paire symétrique et de l'affaiblissement d'écrantage, a_S, de l'écran du dispositif soumis à essai

Note 1 à l'article: Pour les dispositifs électriquement longs, c'est-à-dire au-delà de la fréquence de coupure, l'affaiblissement de couplage, a_C, est défini comme le rapport logarithmique de la puissance d'alimentation, P_1, et des valeurs maximales périodiques de la puissance couplée, $P_{r,max}$, dans le circuit externe.

3.5
longueur de couplage
longueur du dispositif soumis à essai

Note 1 à l'article: La longueur de couplage est électriquement courte si

$$\frac{\lambda_o}{l} > 10 \times \sqrt{\varepsilon_{r1}} \quad \text{ou} \quad f < \frac{c_o}{10 \times l \times \sqrt{\varepsilon_{r1}}} \tag{6}$$

ou électriquement longue si

$$\frac{\lambda_o}{l} \leq \pi \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right| \quad \text{ou} \quad f \geq \frac{c_o}{\pi \times l \times \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right|} \tag{7}$$

où

l est la longueur de couplage effective, en m;

λ_0 est la longueur d'onde de l'espace libre, en m;

ε_{r1} est la permittivité relative résultante du diélectrique du câble;

ε_{r2} est la permittivité relative résultante du diélectrique du circuit secondaire;

f est la fréquence en Hz;

c_0 est la vitesse de la lumière dans l'espace libre.

3.6
dispositif soumis à essai
DUT
dispositif constitué de connecteurs accouplés avec leurs câbles attachés

Note 1 à l'article: L'abréviation "DUT" est dérivée du terme anglais développé correspondant "Device Under Test"

4 Contexte physique

Voir les articles correspondants de l'IEC TS 62153-4-1, de l'IEC 62153-4-3, de l'IEC 62153-4-4, de l'IEC 62153-4-9, ainsi que l'Annexe C et l'Annexe D.

5 Principe de la méthode d'essai

5.1 Généralités

L'IEC 62153-4 (toutes les parties) décrit différentes procédures d'essai permettant de mesurer l'efficacité de l'écrantage sur les câbles de communication, les connecteurs et les composants au moyen du montage d'essai triaxial.

Le Tableau 1 donne une vue d'ensemble des procédures d'essai de l'IEC 62153-4 (toutes les parties) réalisées avec le montage d'essai triaxial.

Tableau 1 – IEC 62153, Méthodes d'essai des câbles métalliques de communication – Procédures d'essai avec montage d'essai triaxial

	Méthodes d'essai des câbles métalliques de communication – Compatibilité électromagnétique (CEM)
IEC TS 62153-4-1	Introduction to electromagnetic (EMC) screening measurements
IEC 62153-4-3	Surface transfer impedance – Triaxial method
IEC 62153-4-4	Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method
IEC 62153-4-7	Méthode d'essai pour mesurer l'impédance de transfert, Z_T, et l'affaiblissement d'écrantage, a_s, ou l'affaiblissement de couplage, a_C, des connecteurs et des cordons jusqu'à 3 GHz et au-dessus – Méthode triaxiale en tubes concentriques
IEC 62153-4-9	Affaiblissement de couplage des câbles symétriques écrantés, méthode triaxiale
IEC 62153-4-10	Impédance de transfert et affaiblissement d'écran des traversées et des joints d'étanchéité électromagnétiques – Méthode d'essai coaxiale double
IEC 62153-4-15	Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell
IEC 62153-4-16	Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up

En règle générale, les dimensions mécaniques des connecteurs RF dans l'axe longitudinal sont comprises entre 20 mm et 50 mm au maximum. La définition des éléments électriquement courts donne des fréquences de coupure ou de cassure pour la transition entre éléments électriquement courts et électriquement longs d'environ 1 GHz ou plus pour des connecteurs RF usuels.

Pour mesurer l'affaiblissement d'écrantage plutôt que l'impédance de transfert, également dans la plage des basses fréquences, la procédure en tubes concentriques a été conçue. La longueur électrique du connecteur RF est prolongée par un tube d'extension métallique ne laissant pas passer les radiofréquences (tubes concentriques). Voir Figure 2.

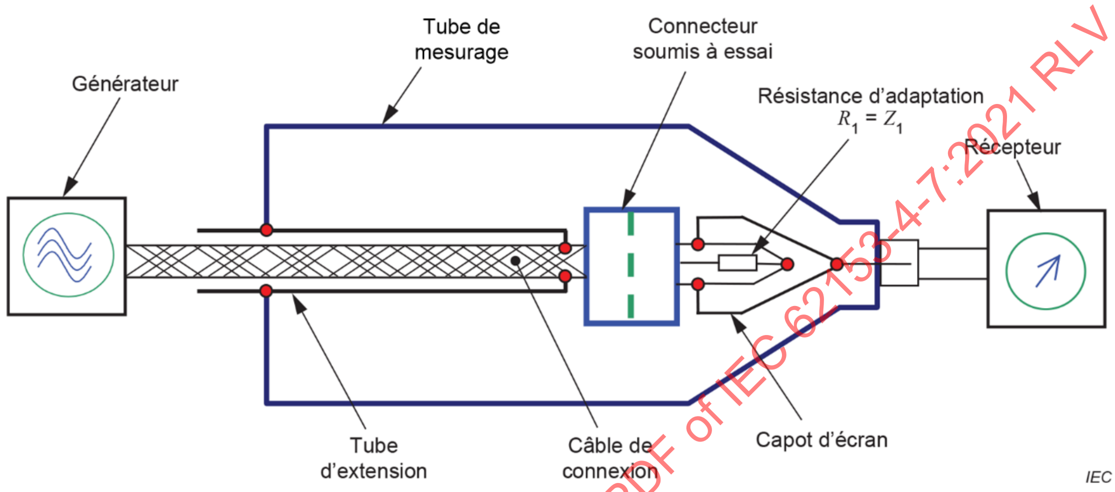


Figure 2 – Principe du montage d'essai pour mesurer l'impédance de transfert et l'affaiblissement d'écrantage ou l'affaiblissement de couplage de connecteurs en tubes concentriques

Le montage d'essai en tubes concentriques repose sur le système triaxial de l'IEC 62153-4-3 et de l'IEC 62153-4-4, comprenant le dispositif soumis à essai (DUT), un tube métallique massif et (en option) un tube d'extension ne laissant pas passer les radiofréquences. Le DUT adapté, qui est alimenté par un générateur, forme le circuit perturbant, qui peut également être appelé circuit primaire ou interne. Les câbles de connexion du DUT sont de plus protégés par les tubes concentriques.

Le circuit perturbé, qui peut également être appelé circuit secondaire ou externe, est formé par le conducteur externe du dispositif soumis à essai (et du tube d'extension), relié au câble de connexion et à un tube métallique massif dans l'axe duquel se trouve le DUT.

5.2 Impédance de transfert

L'essai détermine l'efficacité d'écrantage d'un câble blindé en appliquant un courant et une tension bien définis à l'écran du câble, du cordon ou du dispositif soumis à essai, et en mesurant la tension induite dans le circuit secondaire afin de déterminer l'impédance surfacique de transfert. Cet essai mesure uniquement la composante magnétique de l'impédance de transfert. Pour mesurer la composante électrostatique (l'impédance de couplage capacitif), il convient d'utiliser la méthode décrite dans l'IEC 62153-4-8.

La méthode triaxiale de mesurage est en général appropriée dans la plage de fréquences allant jusqu'à 30 MHz pour un échantillon de 1 m de longueur et jusqu'à 100 MHz pour un échantillon de 0,3 m de longueur, ce qui correspond à une longueur électrique inférieure à 1/6 de la longueur d'onde dans l'échantillon. Une description détaillée est présentée à l'Article 9 de l'IEC TS 62153-4-1:2014, ainsi que dans l'IEC 62153-4-3.

5.3 Affaiblissement d'écrantage

Le circuit perturbant ou primaire est le câble, cordon ou dispositif soumis à essai adapté. Le circuit perturbé ou secondaire comprend le conducteur externe (ou la couche la plus extérieure dans le cas de câbles ou de dispositifs à plusieurs écrans) du câble, du cordon ou du dispositif soumis à essai, et un boîtier métallique massif dans l'axe duquel se trouve le dispositif soumis à essai (voir Figure 3).

Les crêtes de tension à l'extrémité éloignée du circuit secondaire doivent être mesurées. L'extrémité proche du circuit secondaire est placée en court-circuit. Pour ce mesurage, un récepteur adapté n'est pas nécessaire. Les crêtes de tension attendues au niveau de l'extrémité éloignée ne sont pas dépendantes de l'impédance d'entrée du récepteur, à condition que cette dernière soit inférieure à l'impédance caractéristique du circuit secondaire. Toutefois, il est préférable d'avoir un faible défaut d'adaptation, par exemple en choisissant des boîtiers de taille suffisante. Une description détaillée peut être consultée à l'Article 10 de l'IEC TS 62153-4-1:2014, ainsi que dans l'IEC 62153-4-4. Des informations supplémentaires concernant l'interprétation des résultats d'essai de l'affaiblissement d'écrantage aux fréquences inférieures à la fréquence de coupure figurent à l'Annexe H.

5.4 Affaiblissement de couplage

Les câbles, connecteurs, cordons ou dispositifs symétriques qui sont alimentés en mode différentiel peuvent rayonner une faible partie de la puissance d'entrée, du fait des irrégularités dans la symétrie. Pour les câbles, connecteurs, cordons ou dispositifs symétriques non écrantés, ce rayonnement est lié à l'affaiblissement de dissymétrie, a_{U}. Pour les câbles, connecteurs ou cordons symétriques écrantés, la dissymétrie produit un courant dans l'écran, qui est ensuite couplé par l'impédance de transfert et l'impédance de couplage capacitif dans le circuit externe. Le rayonnement est atténué par l'écran du composant et est lié à l'affaiblissement d'écrantage, a_{S}.

Par conséquent, l'efficacité contre les perturbations électromagnétiques des câbles, connecteurs ou cordons symétriques blindés est la somme de l'affaiblissement de dissymétrie, a_{U}, de la paire et de l'affaiblissement d'écrantage, a_{S}. Les deux grandeurs étant en général données sous la forme d'un rapport logarithmique, elles peuvent être simplement additionnées afin d'obtenir l'affaiblissement de couplage a_{C}:

$$a_{\mathrm{C}} = a_{\mathrm{U}} + a_{\mathrm{S}} \quad (8)$$

L'affaiblissement de couplage, a_{C}, est déterminé par le rapport logarithmique de la puissance d'alimentation, P_1, et des valeurs maximales périodiques de la puissance, $P_{\mathrm{r,max}}$ (qui peuvent être rayonnées du fait des crêtes de tension, U_2, dans le circuit externe):

$$a_{\mathrm{C}} = -10 \times \log_{10}\left(\mathrm{Env}\left|\frac{P_{\mathrm{r,max}}}{P_1}\right|\right) \quad (9)$$

La relation entre la puissance rayonnée, P_{r}, et la puissance mesurée, P_2, reçue sur l'impédance d'entrée, R, est:

$$\frac{P_{\mathrm{R}}}{P_2} = \frac{P_{\mathrm{Rmax}}}{P_{\mathrm{2max}}} = \frac{R}{2 \times Z_{\mathrm{S}}} \quad (10)$$

Il y a une variation de la tension, U_2, sur l'extrémité éloignée, due au couplage électromagnétique à travers l'écran et à la superposition des ondes partielles dues à l'impédance surfacique de transfert, Z_T, à l'impédance de couplage capacitif, Z_F (allant vers l'extrémité éloignée et l'extrémité proche) et aux ondes totalement réfléchies provenant de l'extrémité proche.

Pour alimenter le dispositif soumis à essai symétrique, un signal en mode différentiel est nécessaire. Pour ce faire, un analyseur de réseau à deux ports (générateur et récepteur) et un symétriseur ou un analyseur de réseau à plusieurs ports peuvent être utilisés. Les procédures permettant de mesurer l'affaiblissement de couplage sont décrites à l'Article 10. L'Annexe G donne des informations normatives concernant les accessoires permettant de mesurer l'affaiblissement de couplage.

6 Procédure d'essai

6.1 Généralités

Les mesurages doivent être réalisés à une température de (23 ± 3) °C. La méthode d'essai détermine l'impédance de transfert, l'affaiblissement d'écrantage ou l'affaiblissement de couplage d'un DUT en les mesurant dans un montage d'essai triaxial selon l'IEC 62153-4-3, l'IEC 62153-4-4 et l'IEC 62153-4-9.

6.2 Procédure en tubes concentriques

En règle générale, les dimensions mécaniques des connecteurs RF dans l'axe longitudinal sont comprises entre 20 mm et 50 mm au maximum. La définition des éléments électriquement courts donne des fréquences de coupure ou des fréquences de cassure pour la transition entre éléments électriquement courts et électriquement longs d'environ 1 GHz ou plus pour des connecteurs RF usuels.

Dans la plage de fréquences allant jusqu'à la fréquence de coupure, auxquelles le DUT est électriquement court, l'impédance de transfert du DUT peut être mesurée. Pour les fréquences supérieures à la fréquence de coupure, auxquelles le DUT est électriquement long, l'affaiblissement d'écrantage peut être mesuré.

Si la longueur électrique du connecteur RF est augmentée au moyen d'un tube d'extension métallique ne laissant pas passer les radiofréquences (tubes concentriques), la combinaison soumise à essai devient électriquement longue et la fréquence de coupure se déplace vers une plage de fréquences inférieure. De cette manière, même dans la plage de fréquences inférieure, l'affaiblissement d'écrantage peut être mesuré, et l'impédance de transfert effective sur les dispositifs électriquement courts peut être calculée.

Le montage d'essai est un système triaxial constitué du DUT, d'un tube métallique massif et d'un tube d'extension ne laissant pas passer les radiofréquences. Le dispositif soumis à essai (DUT) adapté, alimenté par un générateur, forme le circuit perturbant, qui peut également être appelé circuit primaire ou circuit interne.

Le circuit perturbé, pouvant également être appelé circuit secondaire ou circuit externe, est formé par le conducteur externe du dispositif soumis à essai, relié au tube d'extension et à un tube métallique massif dans l'axe duquel se trouve le DUT.

Le principe du montage d'essai est représenté à la Figure 2 et à la Figure 3. Le montage d'essai est le même, qu'il s'agisse de mesurer l'impédance de transfert, l'affaiblissement d'écrantage ou l'affaiblissement de couplage, mais la longueur du tube interne et du tube externe peut varier.

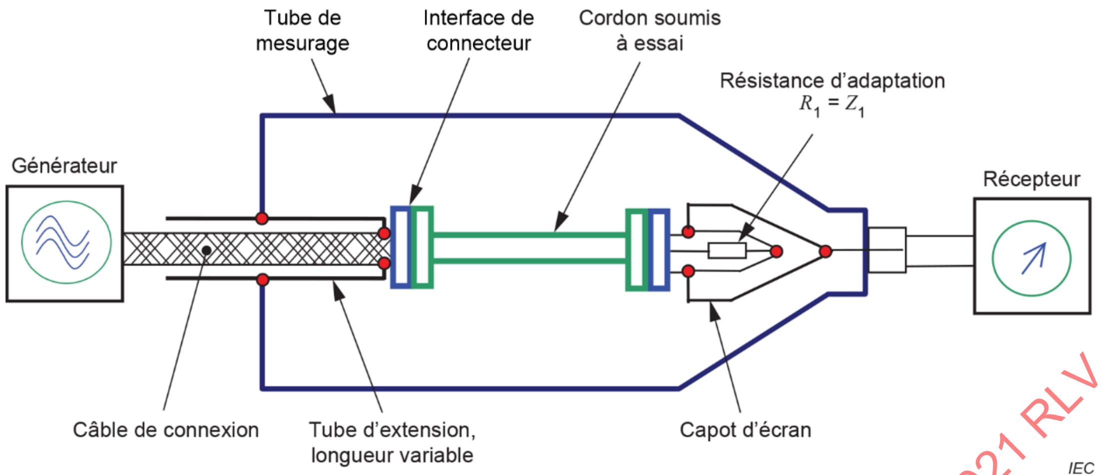


Figure 3 – Principe du montage d'essai pour mesurer l'impédance de transfert et l'affaiblissement d'écrantage d'un cordon

Le rapport de tensions entre la tension à l'extrémité proche (U_1) du circuit interne (générateur) et la tension à l'extrémité éloignée (U_2) du circuit secondaire (récepteur) doit être mesuré (U_1/U_2). L'extrémité proche du circuit secondaire est placée en court-circuit.

Selon la longueur électrique de la combinaison soumise à essai, du DUT et du tube d'extension, le résultat peut être exprimé par l'impédance de transfert, l'impédance de transfert effective ou l'affaiblissement d'écrantage (ou l'affaiblissement de couplage).

Pour ce mesurage, un récepteur adapté n'est pas nécessaire. Les éventuelles crêtes de tension à l'extrémité éloignée ne dépendent pas de l'impédance d'entrée du récepteur, à condition que cette dernière soit inférieure à l'impédance caractéristique du circuit secondaire. Toutefois, il est préférable d'avoir un faible défaut d'adaptation, par exemple en choisissant une plage de diamètres de tube pour plusieurs tailles de DUT.

6.3 Equipement d'essai

Le principe du montage d'essai est représenté à la Figure 2 et à la Figure 3, ce montage comprenant:

– un appareillage de forme coaxiale triple de longueur suffisante pour produire une superposition des ondes dans des bandes de fréquences étroites, ce qui permet de dessiner la courbe de l'enveloppe;
– des tubes de longueurs variables, par exemple différentes parties de tube et/ou des tubes concentriques mobiles. Dans le cas de connecteurs ou de composants plus gros, les tubes triaxiaux peuvent être remplacés par une cellule triaxiale selon l'IEC 62153-4-15;
– un tube d'extension (concentrique) ne laissant pas passer les radiofréquences, de longueur variable. Il convient, de préférence, que le diamètre de ce tube soit tel que l'impédance caractéristique par rapport au tube externe soit égale à 50 Ω ou à l'impédance d'onde caractéristique nominale de l'analyseur de réseau ou du générateur et du récepteur. Le matériau du tube d'extension ne doit pas être ferromagnétique, doit être très conducteur (cuivre ou laiton) et doit avoir une épaisseur≥ 1 mm, de sorte que l'impédance de transfert soit négligeable comparée à l'impédance de transfert du dispositif soumis à essai;
– un générateur de signal et un récepteur équipé d'un affaiblisseur à paliers étalonné et d'un amplificateur de puissance, le cas échéant, pour un affaiblissement d'écrantage très élevé. Le générateur et le récepteur peuvent être installés dans un analyseur de réseau;
– un symétriseur pour adapter l'impédance du signal de sortie de générateur dissymétrique sur l'impédance d'onde caractéristique de câbles symétriques, pour le mesurage de l'affaiblissement de couplage. Les exigences relatives au symétriseur sont données dans

l'IEC 62153-4-9:2018, Paragraphe 6.3. En variante, un analyseur de réseau vectoriel (VNA) avec option de mode mixte et une unité de connexion à paires torsadées (TP, Twisted-Pair) peuvent être utilisés à la place d'un symétriseur. Les exigences relatives à l'unité de connexion TP sont données dans l'IEC 62153-4-9:2018, Paragraphe 6.4.

L'équipement facultatif est le suivant:

– réflectomètre dans le domaine temporel (TDR, Time Domain Reflectometer) présentant un temps de montée inférieur à 200 ps ou un analyseur de réseau de fréquence maximale allant jusqu'à 5 GHz et capable de fonctionner dans le domaine temporel.

6.4 Procédure d'étalonnage

L'étalonnage doit être établi aux mêmes points de fréquence que ceux auxquels le mesurage est réalisé, c'est-à-dire selon un balayage en fréquence logarithmique sur l'ensemble de la plage de fréquences, spécifiée pour l'impédance de transfert.

Si un analyseur de réseau vectoriel est utilisé avec l'appareil d'essai de paramètres S, un étalonnage complet doit être établi sur deux ports, en y incluant les câbles de connexion utilisés pour raccorder le montage d'essai à l'équipement d'essai. Les plans de référence pour l'étalonnage sont les interfaces de connecteur des câbles de connexion.

Si un analyseur de réseau (vectoriel) est utilisé sans appareil d'essai de paramètres S, c'est-à-dire un répartiteur de puissance, un étalonnage de connexion directe (THRU) doit être établi, en y incluant les câbles d'essai utilisés pour raccorder le montage d'essai à l'équipement d'essai.

Si un générateur de signal et un récepteur séparés sont utilisés, l'affaiblissement composite des câbles d'essai doit être mesuré et les données d'étalonnage doivent être enregistrées, de façon à pouvoir corriger les résultats.

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

où

P_1 est la puissance introduite lors la procédure d'étalonnage;

P_2 est la puissance au niveau du récepteur lors la procédure d'étalonnage.

Si des amplificateurs sont utilisés, leur gain doit être mesuré sur la plage de fréquences mentionnée ci-dessus, et les données doivent être enregistrées.

Si un adaptateur d'impédance est utilisé, l'affaiblissement doit être mesuré sur la plage de fréquences mentionnée ci-dessus, et les données doivent être enregistrées. Pour ce faire, deux adaptateurs d'impédance du même type et du même fabricant peuvent être raccordés l'un à l'autre "dos à dos" et en mesurant:

$$2 \times a_{\text{imd}} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \tag{12}$$

Des informations complémentaires sur les adaptateurs d'impédance sont données dans l'IEC 62153-4-3, Annexe B.

6.5 Raccordement entre le tube d'extension et le dispositif soumis à essai

Le raccordement entre le tube d'extension et les câbles attachés du dispositif soumis à essai doit être tel que la résistance de contact soit négligeable. Une technique de connexion possible ainsi qu'une description de l'influence des résistances de contact sont données à l'Annexe D. L'Annexe E donne des informations sur la connexion directe du tube d'extension aux connecteurs soumis à essai.

6.6 Plage dynamique ou bruit de fond

Dans l'essai de vérification, l'impédance de transfert résiduelle et le bruit de fond généré par le raccordement du câble d'alimentation au tube d'extension doivent être déterminés.

Le câble d'alimentation est adapté sur son impédance caractéristique et relié à la tête d'essai. Le tube d'extension doit ensuite être relié au câble d'alimentation (sans le DUT) en utilisant la même technique de raccordement que pendant l'essai. Le câble entre les points de connexion doit être le plus court possible (voir Figure 4).

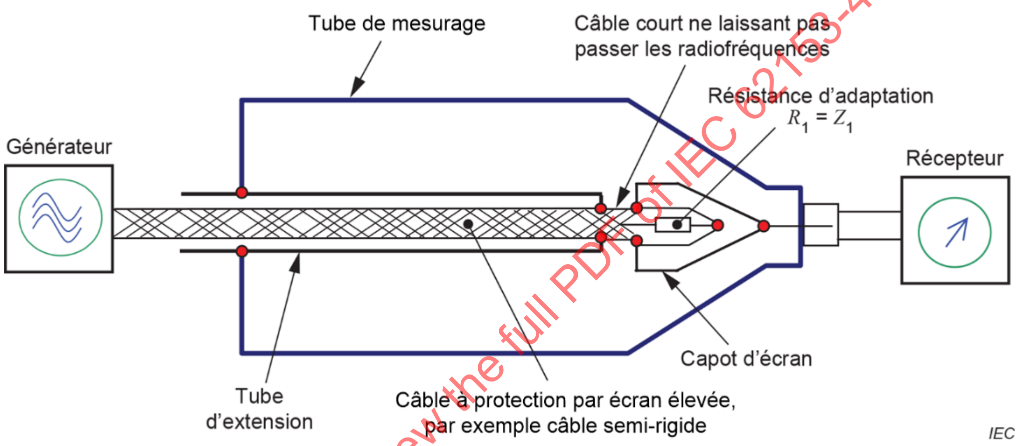


Figure 4 – Principe de montage pour l'essai de vérification

Le rapport de tension, U_1/U_2, doit être mesuré avec l'analyseur de réseau.

Le bruit de fond, a_n, du raccordement du tube d'extension au câble d'alimentation est alors donné par:

$$a_n = 20 \times \log_{10}(U_1 / U_2) \tag{12}$$

Le bruit de fond doit être meilleur que la valeur mesurée d'au moins 10 dB.

L'impédance de transfert résiduelle du raccordement du tube d'extension au câble d'alimentation est donnée par:

$$Z_{Tr} = Z_1 \times \left| \frac{U_2}{U_1} \right| \tag{13}$$

6.7 Adaptation d'impédance

Si l'impédance caractéristique nominale du système (quasi) coaxial est inconnue, elle peut être mesurée soit en utilisant un TDR présentant un temps de montée maximal de 200 ps, soit en utilisant la méthode décrite à l'Annexe A. Il n'est pas recommandé d'utiliser un adaptateur d'impédance pour adapter l'impédance du générateur et celle du système (quasi) coaxial, car cela réduit la plage dynamique du montage d'essai et peut offrir une adaptation suffisante (affaiblissement de réflexion) seulement jusqu'à 100 MHz (voir Annexe B).

6.8 Influence des adaptateurs

Lors du mesurage de l'impédance de transfert, de l'affaiblissement d'écrantage ou de l'affaiblissement de couplage sur des connecteurs ou des cordons, des adaptateurs d'essai sont exigés si aucun connecteur d'accouplement du DUT n'est disponible.

Les adaptateurs d'essai et/ou les connecteurs d'accouplement peuvent limiter la sensibilité du montage d'essai et peuvent avoir un impact sur le mesurage.

Le type et/ou la conception de l'adaptateur d'essai doivent être précisés dans le rapport d'essai.

Une description plus détaillée de la conception et de l'impact des adaptateurs d'essai est à l'étude.

7 Préparation d'échantillon

7.1 Connecteur ou dispositif coaxial

Un câble d'alimentation doit être monté sur le connecteur soumis à essai et sa partie accouplement conformément aux spécifications du fabricant. Une extrémité doit être reliée à la tête d'essai si le câble d'alimentation est adapté à l'impédance caractéristique nominale du dispositif soumis à essai. Il peut être court-circuité, si l'impédance de transfert est mesurée avec un court-circuit/court-circuit (sans adaptation) sans résistance d'amortissement, conformément à l'IEC 62153-4-3.

L'autre extrémité du câble de connexion doit passer à travers le tube d'extension et être reliée au générateur. Du côté du dispositif soumis à essai, l'écran du câble d'alimentation doit être relié au tube d'extension avec une faible résistance de contact (voir 6.2 et Annexe B). Du côté du générateur, l'écran du câble d'alimentation ne doit pas être relié au tube d'extension.

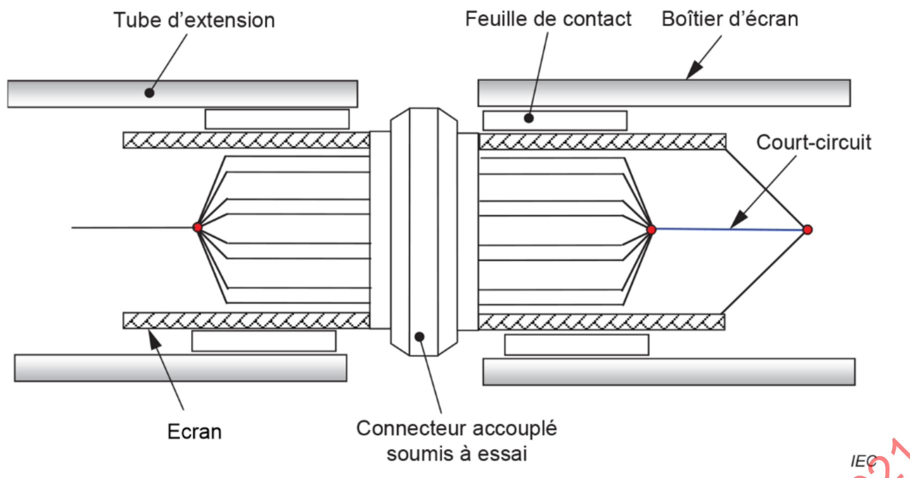
7.2 Dispositif symétrique ou multiconducteur

Un câble symétrique ou multiconducteur utilisé habituellement avec le connecteur soumis à essai doit être monté sur le connecteur soumis à essai et sa partie accouplement conformément aux spécifications du fabricant.

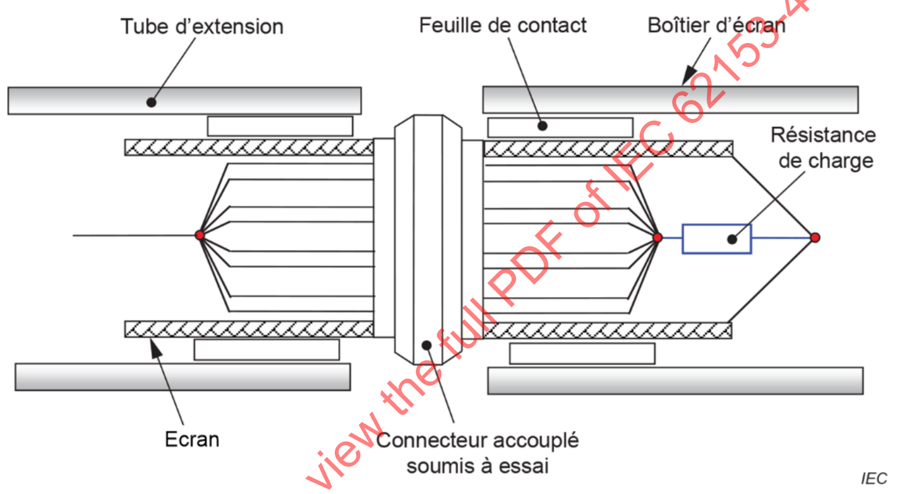
Lors du mesurage de l'impédance de transfert ou de l'affaiblissement d'écrantage, les câbles symétriques ou multiconducteurs équipés d'un écran sont traités comme un système quasi coaxial. Ainsi, au niveau des extrémités ouvertes du câble d'alimentation, tous les conducteurs de toutes les paires doivent être reliés les uns aux autres. Tous les écrans, y compris ceux des paires ou des quartes comportant un écran individuel, doivent être reliés les uns aux autres aux deux extrémités. Tous les écrans doivent être reliés sur toute la circonférence [voir Figure 5 a) et Figure 5 b)].

Une extrémité doit alors être reliée à la tête d'essai si le câble d'alimentation est adapté à l'impédance caractéristique (affaiblissement d'écrantage et impédance de transfert avec procédure court-circuit/avec adaptation) ou avec un court-circuit (impédance de transfert avec procédure court-circuit/court-circuit).

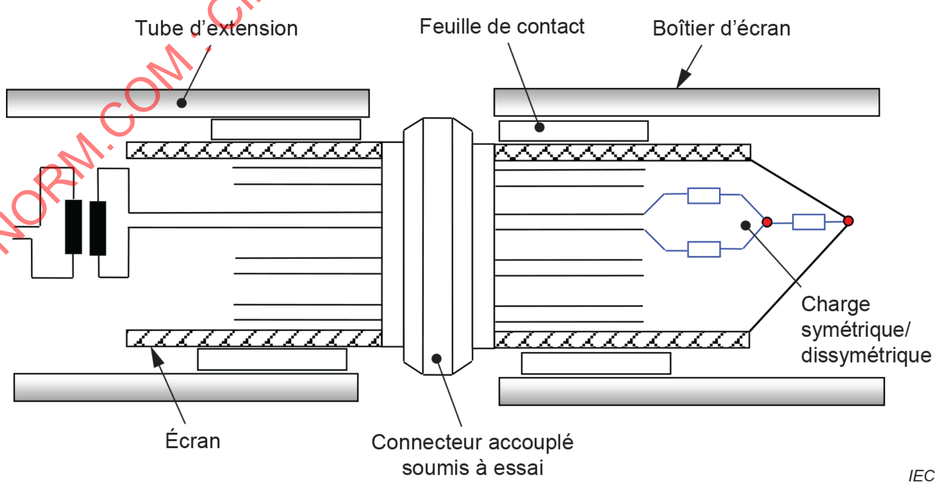
L'autre extrémité doit passer par le tube d'extension et doit être reliée au port d'alimentation [analyseur de réseau vectoriel (VNA, Vector Network Analyzer) ou générateur] à l'aide d'un adaptateur approprié.



a) Principe de préparation de connecteurs symétriques ou multiconducteurs pour l'impédance de transfert (court-circuit/court-circuit)

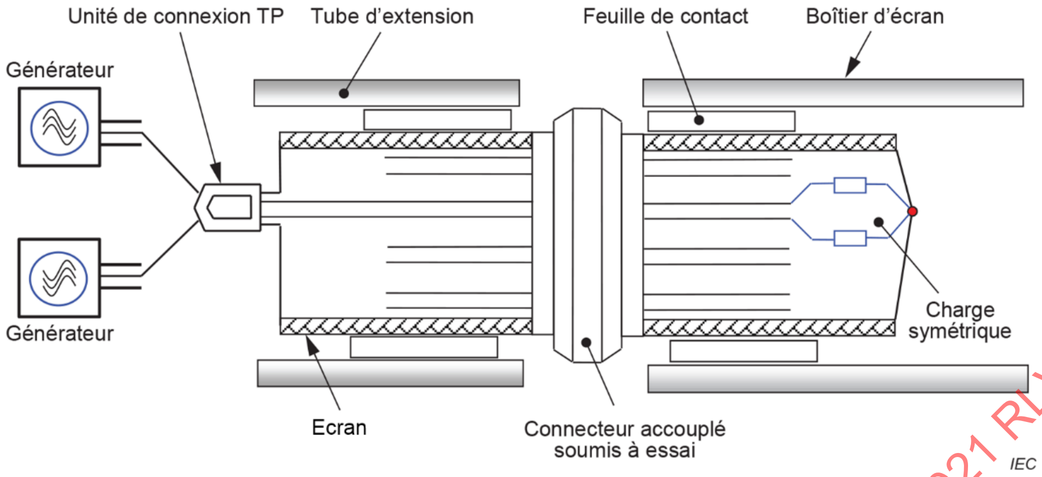


b) Principe de préparation de connecteurs symétriques ou multiconducteurs pour l'impédance de transfert (court-circuit/avec adaptation) et l'affaiblissement d'écrantage



c) Principe de préparation de connecteurs symétriques ou multiconducteurs pour l'affaiblissement de couplage en utilisant un symétriseur

NOTE 1 Ajouter des sorties pour toutes les paires si le câble n'est pas écranté par paires. Si un écran de paire est ajouté, la sortie de toutes les paires n'est pas obligatoire, mais recommandée.



d) Principe de préparation de connecteurs symétriques ou multiconducteurs pour l'affaiblissement de couplage en utilisant un symétriseur virtuel

NOTE 2 Ajouter des sorties pour toutes les paires si le câble n'est pas écranté par paires. Si un écran de paire est ajouté, la sortie de toutes les paires n'est pas obligatoire, mais recommandée.

Figure 5 – Préparation de connecteurs symétriques ou multiconducteurs

7.3 Cordon

Si le cordon tient dans le tube, il doit être mesuré conformément à la Figure 3. Les cordons plus longs peuvent être coupés et chaque section mesurée séparément.

8 Mesurage de l'impédance de transfert

8.1 Généralités

L'IEC 62153-4-3 décrit trois procédures d'essai triaxiales différentes:

– circuit interne adapté avec résistance d'amortissement dans le circuit externe;
– circuit interne avec résistance de charge et circuit externe sans résistance d'amortissement;
– court-circuit/court-circuit (sans adaptation) sans résistance d'amortissement.

La procédure décrite ici est en principe la même que celle de l'IEC 62153-4-3 avec circuit interne avec adaptation n'utilisant pas l'adaptateur d'impédance et ne présentant pas de résistance d'amortissement, R_2. Sa plage dynamique est plus élevée que celle des essais avec résistance d'amortissement dans le circuit externe.

La résistance de charge, R_1, pourrait soit être égale à l'impédance du circuit interne, soit être égale à l'impédance du générateur. Le deuxième cas est intéressant lorsqu'un analyseur de réseau est utilisé avec répartiteur de puissance plutôt qu'un appareil d'essai de paramètres S.

NOTE D'autres procédures de l'IEC 62153-4-3 peuvent par conséquent être appliquées si cela est exigé.

8.2 Diagramme de principe de l'impédance de transfert

Un diagramme du montage d'essai utilisé pour mesurer l'impédance de transfert selon la méthode d'essai de l'IEC 62153-4-3 avec résistance de charge dans le circuit interne et avec résistance d'amortissement dans le circuit externe est représenté à la Figure 6.

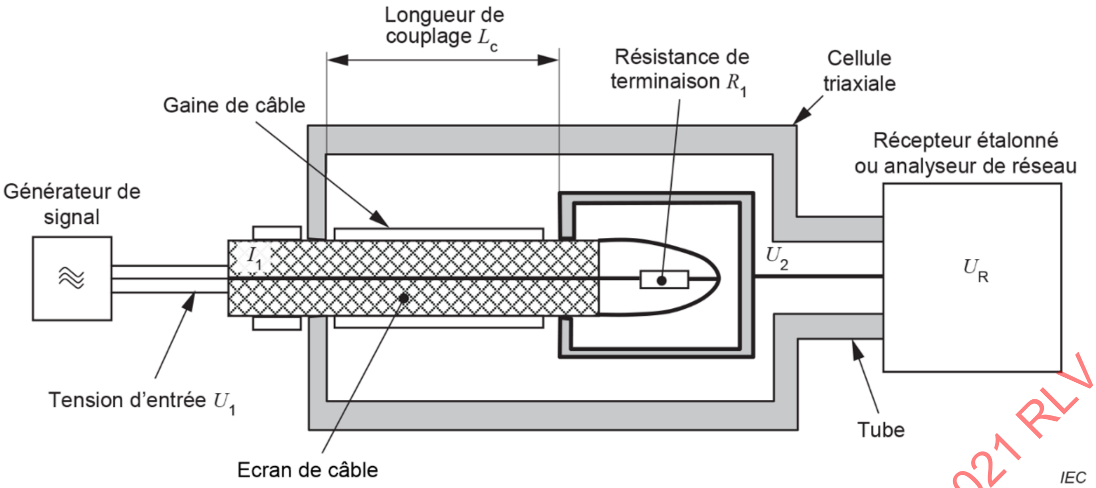


Figure 6 – Montage d'essai (principe) pour le mesurage de l'impédance de transfert selon l'essai de l'IEC 62153-4-3 avec résistance de charge dans le circuit interne et avec résistance d'amortissement dans le circuit externe

8.3 Procédure de mesurage – Influence des câbles de connexion

Lors du mesurage d'un connecteur ou d'un composant sans tube concentrique, l'impédance de transfert des câbles de connexion à l'intérieur du tube et servant à brancher le DUT doit être mesurée.

L'impédance de transfert des câbles de connexion qui permettent de brancher le DUT doit être mesurée conformément à l'IEC 62153-4-3. La valeur mesurée doit être rapportée à la longueur des câbles de connexion situés à l'intérieur du montage d'essai et servant à brancher le DUT, le résultat étant l'impédance de transfert des câbles de connexion, Z_{con}.

8.4 Mesurage

Le DUT doit être raccordé au générateur et le circuit externe (le tube) au récepteur.

L'affaiblissement, a_{meas}, doit de préférence être mesuré selon un balayage en fréquence logarithmique sur l'ensemble de la plage de fréquences, qui est spécifiée pour l'impédance de transfert et aux mêmes points de fréquence que pour la procédure d'étalonnage:

$$a_{meas} = 10 \times \log_{10}\left(\frac{P_1}{P_2}\right) = -20 \times \log_{10}(S_{21}) \qquad (15)$$

où

P_1 est la puissance entrant dans le circuit interne;

P_2 est la puissance reçue dans le circuit externe.

8.5 Interprétation des résultats d'essai

La conversion entre l'affaiblissement mesuré et l'impédance de transfert est donnée par la formule suivante:

$$Z_T = \frac{R_1 + Z_0}{2} \times 10^{-\left(\frac{a_{meas} - a_{cal}}{20}\right)} - Z_{con} \qquad (16)$$

ou

$$Z_T = \frac{R_1 + Z_0}{2} \times 10^{-\left(\frac{a_{meas} - a_{cal}}{20}\right)} - Z_{Tr} \qquad (17)$$

si la méthode en tubes concentriques est utilisée.

où

Z_T	est l'impédance de transfert;
Z_0	est l'impédance du système (en général 50 Ω);
a_{meas}	est l'affaiblissement mesuré par la procédure de mesurage;
a_{cal}	est l'affaiblissement des câbles de connexion s'il n'a pas été éliminé par la procédure d'étalonnage de l'équipement d'essai;
R_1	est la résistance de terminaison dans le circuit interne (qui est soit égale à l'impédance du circuit interne, soit égale à l'impédance du générateur);
Z_{con}	est l'impédance de transfert des câbles de connexion;
Z_{Tr}	est l'impédance de transfert résiduelle, voir 6.6.

NOTE Contrairement au mesurage de l'impédance de transfert des écrans de câble, l'impédance de transfert des connecteurs ou des cordons n'est pas liée à la longueur.

8.6 Rapport d'essai

Le rapport d'essai doit consigner les résultats d'essai et doit indiquer si les exigences de la spécification particulière correspondante sont satisfaites.

L'utilisation et la conception des adaptateurs d'essai (le cas échéant) doivent être décrites.

9 Affaiblissement d'écrantage

9.1 Généralités

Cette méthode est en principe la même que celle décrite dans l'IEC 62153-4-4.

9.2 Adaptation d'impédance

9.2.1 Généralités

L'affaiblissement d'écrantage peut être mesuré avec ou sans adaptation d'impédance.

Si l'impédance caractéristique du DUT est inconnue, l'impédance caractéristique nominale du système quasi coaxial peut être mesurée soit en utilisant un TDR présentant un temps de montée maximal de 200 ps, soit en utilisant la méthode décrite à l'Annexe A.

Il n'est pas recommandé d'utiliser un adaptateur d'impédance pour adapter l'impédance du générateur et celle du système soumis à essai (voir Figure 7), car cela réduit la plage dynamique du montage d'essai et peut offrir une adaptation suffisante (affaiblissement de réflexion) seulement jusqu'à 100 MHz, si des adaptateurs maison nécessaires pour les impédances autres que 60 Ω ou 75 Ω sont utilisés (voir Annexe B).

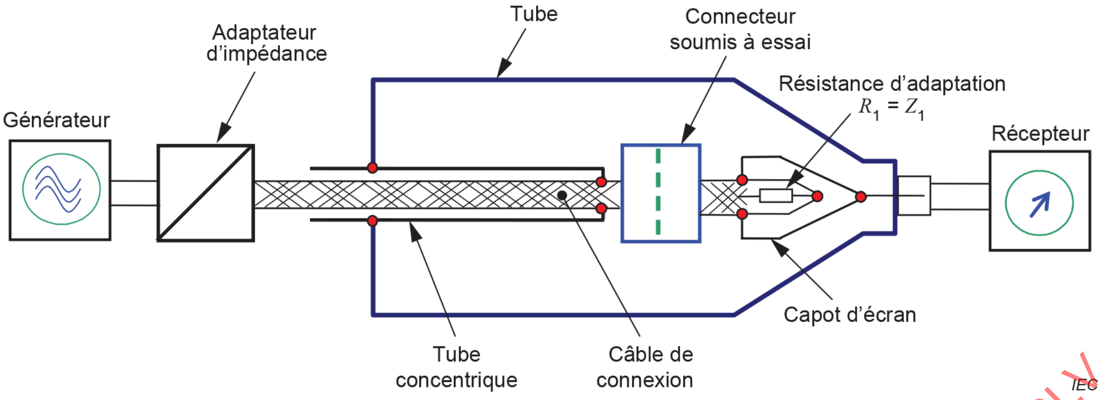


Figure 7 – Mesurage de l'affaiblissement d'écrantage en tubes concentriques et avec un dispositif d'adaptation d'impédance

Le DUT avec le tube d'extension connecté doit être installé dans le tube de mesure. Le tube d'extension doit être placé en court-circuit avec le tube de mesure à l'extrémité la plus proche du générateur. Le câble d'alimentation doit être relié au générateur (au moyen d'un dispositif d'adaptation d'impédance, le cas échéant) et la sortie du tube de mesure doit être reliée au récepteur.

Le paramètre de diffusion, S_{21}, doit être mesuré.

Seules les valeurs de crête du graphique d'affaiblissement d'écrantage obtenu sont utilisées pour déterminer la courbe de l'enveloppe.

9.2.2 Evaluation des résultats d'essai avec les conditions adaptées

L'affaiblissement d'écrantage, a_S, doit être calculé avec la valeur normalisée déterminée arbitrairement, Z_S = 150 Ω [1].

$$a_S = 10 \times \log_{10} \left| \frac{P_1}{P_{r,max}} \right| = 10 \times \log_{10} \left| \frac{P_1}{P_{2,max}} \times \frac{2 \times Z_S}{R} \right| - a_{imd} \qquad (18)$$

$$= \text{Env}\left\{ -20 \times \log_{10} \left| S_{21} \right| + 10 \times \log_{10} \left| \frac{300\,\Omega}{Z_1} \right| - a_{imd} \right\} \qquad (19)$$

1 Z_S est la valeur normalisée de l'impédance caractéristique de l'environnement d'une installation de câbles classique. Elle n'a aucun rapport avec l'impédance du circuit externe du montage d'essai.