IEC 62153-4-15

Edition 2.1 2024-05
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

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inside

Metallic cables and other passive components test methods – Part 4-15: Electromagnetic compatibility (EMC) related test method for measuring transfer impedance and screening attenuation or coupling attenuation with triaxial cell

IEC 62153-4-15:2021-08+AMD1:2024-05 CSV(en)

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

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

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.10; 33.120.10 ISBN 978-2-8322-8869-6

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CONTENTS

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METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell

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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 62153-4-15 edition 2.1 contains the second edition (2021-08) [documents 46/814/FDIS and 46/822/RVD] and its amendment 1 (2024-05) [documents 46/992/FDIS and 46/1004/RVD].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 62153-4-15 has been prepared by IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This second edition constitutes a technical revision.

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

a) measurement of coupling attenuation of balanced connectors, assemblies and components with balun and balunless added;
b) application of a test adapter was added;
c) application of a moveable shorting plane;
d) application of the triaxial "absorber" cell;
e) correction of test results in the case that the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2.

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 the parts in the IEC 62153-4 series, published under the general title *Metallic communication cable test methods – Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document and its amendment 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

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- withdrawn, or
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METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell

1 Scope

This part of IEC 62153 specifies the procedures for measuring with triaxial cell the transfer impedance, screening attenuation or the coupling attenuation of connectors, cable assemblies and components, for example accessories for analogue and digital transmission systems, and equipment for communication networks and cabling.

Measurements can be achieved by applying the device under test directly to the triaxial cell or with the tube-in-tube method in accordance with IEC 62153-4-7.

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 61196-1, *Coaxial communication cables – Part 1: Generic specification – General, definitions and requirements*

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 62153-4-4:2015, *Metallic communication cable test methods – Part 4-4: Electromagnetic compatibility (EMC) – Test method for measuring of the screening attenuation* a_S *up to and above 3 GHz, triaxial method*

IEC 62153-4-7, *Metallic communication cable test methods – Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring the transfer impedance* Z_T *and the screening attenuation* a_s *or coupling attenuation* a_c *of connectors and assemblies up to and above 3 GHz – Triaxial Tube in tube 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 62153-4-16, *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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61196-1 and the following apply.

3.1

triaxial cell

rectangular housing in analogy to the principles of the triaxial test procedure, consisting of a non-ferromagnetic metallic material

Note 1 to entry: The triaxial test procedure is described in IEC 62153-4-3 and IEC 62153-4-4.

3.2

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 [Ω] (see Figure 1)

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

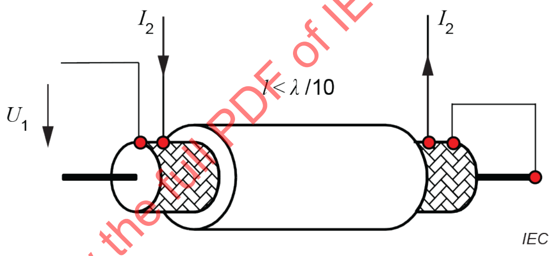


Figure 1 – Definition of Z_T

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

$$Z_T \ \text{dB}(\Omega) = 20 \cdot \lg\left(\frac{|Z_T|}{1\Omega}\right) \tag{2}$$

3.3

effective transfer impedance

Z_{TE}

impedance defined as:

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

where Z_F is the capacitive coupling impedance

3.4
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 $P_\mathrm{r,max}$ in the outer circuit

$$a_\mathrm{s} = 10 \cdot \lg\left(\mathrm{Env}\left|\frac{P_1}{P_\mathrm{r,max}}\right|\right) \tag{4}$$

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

$$a_\mathrm{s} = 20 \cdot \lg \frac{150\Omega}{Z_\mathrm{TE}} \tag{5}$$

where

150 Ω is the standardised impedance of the outer circuit.

3.5
coupling attenuation

a_c

for a screened balanced device, 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 $P_\mathrm{r,max}$ in the outer circuit.

3.6
coupling length

length of cable that is inside the test jig, i.e. the length of the screen under test

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

$$\lambda_\mathrm{o}/L > 10 \cdot \sqrt{\varepsilon_\mathrm{r1}} \quad \text{or} \quad f < \frac{c_\mathrm{o}}{10 \cdot L \cdot \sqrt{\varepsilon_\mathrm{r1}}} \tag{6}$$

or electrically long, if

$$\lambda_\mathrm{o}/L \leq 2 \cdot \left|\sqrt{\varepsilon_\mathrm{r1}} - \sqrt{\varepsilon_\mathrm{r2}}\right| \quad \text{or} \quad f > \frac{c_\mathrm{o}}{2 \cdot L \cdot \left|\sqrt{\varepsilon_\mathrm{r1}} - \sqrt{\varepsilon_\mathrm{r2}}\right|} \tag{7}$$

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_0 is the velocity of light in free space, in m/s.

3.7
device under test
DUT
connector with mating connector and attached connecting cables or cable assembly consisting of the assembly with their attached mated connectors and with connecting cables

4 Physical background

See IEC TS 62153-4-1, IEC 62153-4-3, IEC 62153-4-4, and Annex A to Annex F.

5 Principle of the test methods

5.1 General

The IEC 62153-4 series describes different test procedures to measure screening effectiveness on communication cables, connectors and components.

Table 1 gives an overview of the test procedures of the IEC 62153-4 series carried out with the triaxial test setup.

Table 1 – IEC 62153-4 series, Metallic communication cable test methods – Test procedures with triaxial test setup

IEC 62153-4 series	Metallic communication cable test methods – Electromagnetic compatibility (EMC)
IEC TS 62153-4-1	Introduction to electromagnetic 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 a_S up to and above 3 GHz
IEC 62153-4-7	Shielded screening attenuation test method for measuring the Transfer impedance Z_T and the screening attenuation a_S or the coupling attenuation a_C of RF-connectors and assemblies up to and above 3 GHz, 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
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 setup

Larger connectors, cable assemblies, and components do not fit into the commercially available test rigs (tubes) of the triaxial test procedures of IEC 62153-4-3, IEC 62153-4-4, and IEC 62153-4-7, respectively, which were designed originally to measure transfer impedance and screening attenuation on communication cables, connectors, and assemblies.

Since rectangular housings with RF-tight caps are easier to manufacture than tubes, the "triaxial cell" was designed to test larger devices, such as connectors, assemblies and components. The principles of the triaxial test procedures in accordance with IEC 62153-4-3, IEC 62153-4-4 and IEC 62153-4-7 can be transferred to rectangular housings. Tubes and rectangular housings may be operated in combination in one test setup (see Figure 2 and Figure 3).

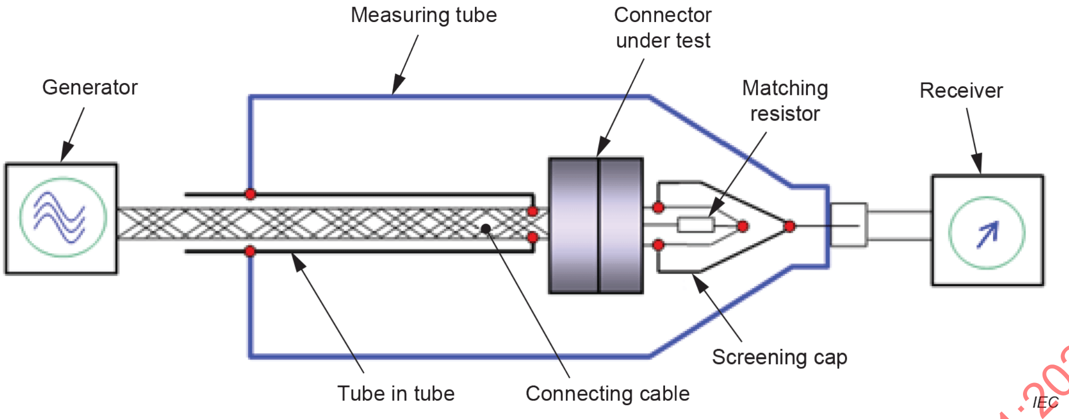


Figure 2 – Principle depiction of the triaxial test setup (tube) to measure transfer impedance and screening attenuation with tube in tube in accordance with IEC 62153-4-7

In principle, the triaxial cell can be used in accordance with all triaxial procedures of Table 1, where originally a cylindrical tube is used. The screening effectiveness of connectors, assemblies or other components can be measured, in principle, in the tube as well as in the triaxial cell. Test results of measurements with tubes and with triaxial cells correspond well.

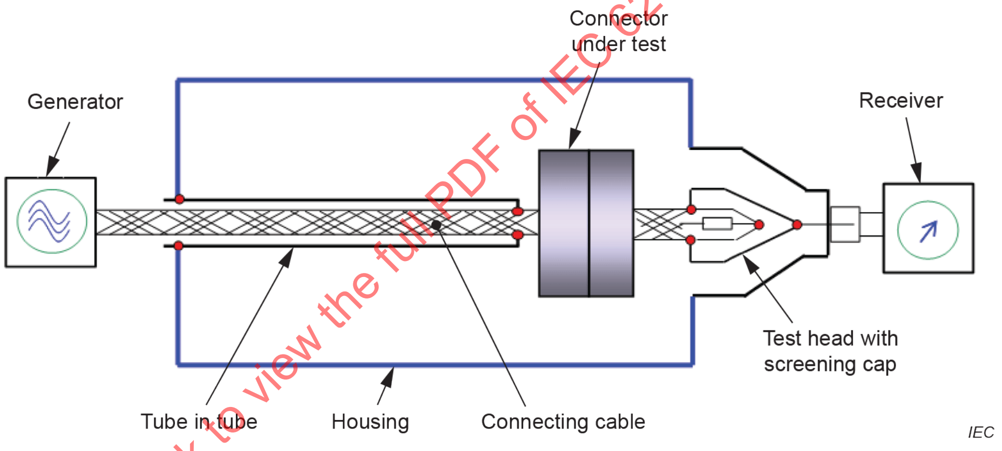


Figure 3 – Principle depiction of the triaxial cell to measure transfer impedance and screening attenuation of connectors or assemblies with tube in tube in accordance with IEC 62153-4-7

The triaxial cell test setup is based on the triaxial system in accordance with IEC 62153-4-3 and IEC 62153-4-4, consisting of the DUT, a solid metallic housing and an RF-tight extension tube (optional). The matched device under test (DUT), which is fed by a generator via a connecting cable, 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 connecting cable (or the tube in tube, if applicable) and a solid metallic housing or cell having the DUT in its axis.

5.2 Transfer impedance

The test determines the screening effectiveness of a shielded device 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 the secondary circuit in order to determine the surface transfer impedance. This test measures only the galvanic and magnetic components of the transfer impedance. To measure the electrostatic component (the capacitance coupling impedance), the method described in IEC 62153-4-8 shall be used.

The triaxial method for the measurement of the transfer impedance 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 can be 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 component 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 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 housings of an appropriate 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.

5.4 Coupling attenuation

The coupling attenuation of screened balanced pairs describes the global effect against electromagnetic interference (EMI) and takes into account the screening attenuation of the screen and the unbalance attenuation of the pair. A detailed description of coupling attenuation can be found in IEC 62153-4-9.

5.5 Tube-in-tube method

If required, measurements in accordance with IEC 62153-4-7 can also be achieved in the triaxial cell, using the triaxial cell instead of the tube fixture (see Figure 2 and Figure 3).

6 Test procedures

6.1 General

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

6.2 Triaxial cell

The triaxial cell consists of a rectangular housing in analogy to the principles of the triaxial test procedures in accordance with IEC 62153-4-3 and IEC 62153-4-4. The material of the housing shall be of non-ferromagnetic metallic material. The length of the housing should be preferably 1 m.

Reflections of the transmitted signal can occur (in the outer circuit) owing to the deviation of the characteristic impedances. The plane of the short circuit at the near end (generator side) should be therefore preferably directly on the wall of the housing.

At the receiver side, the transition of the housing to the coaxial system impedance (50 Ω-system) should be also directly on the wall of the housing.

6.3 Cut-off frequencies, higher-order modes

The triaxial test procedure uses the principle of transverse electromagnetic wave propagation (TEM – waves). At higher frequencies, the triaxial cell becomes in principle a cavity resonator, or a rectangular waveguide, which exhibits resonances depending on its dimensions; see Figure 4.

Above these resonance frequencies, propagation of TEM waves is disturbed and measurements of screening attenuation with triaxial test method are limited.

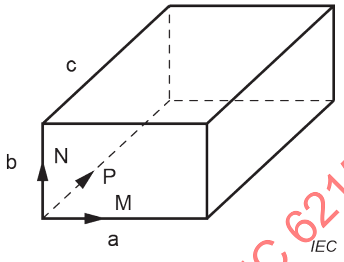


Figure 4 – Rectangular waveguide

The cut-off frequency f_c of a rectangular cavity resonator is given by:

$$f_c = \frac{c_0}{2a} \tag{8}$$

For a rectangular cavity resonator, the resonance frequencies can be calculated using Equation (9). For this calculation, one of the parameters M, N, P can be set to zero.

$$f_{MNP} = \frac{c_0}{2}\sqrt{\left(\frac{M}{a}\right)^2 + \left(\frac{N}{b}\right)^2 + \left(\frac{P}{c}\right)^2} \tag{9}$$

where

M, N are the number of modes (even, 2 of 3 > 0);
a,b,c are the dimensions of the cavity;
c_0 is the velocity of light in free space.

NOTE Conductive parts inside the cavity resonator or a poor centring of the DUT in the triaxial cell can lead to deviating resonance frequencies or to muting them.

Measurements of screening attenuation can be achieved up to the first cut-off frequency (M, N = 1).

The frequency range of the triaxial cell can be extended up to and above 3 GHz by using absorber material placed on the bottom of the cell, see Annex C.

6.4 Test equipment

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

The measuring equipment consists of the following:

a) a vector network analyser (with S-parameter test set), or
b) a signal generator with the same characteristic impedance as the coaxial system of the cable under test or with an impedance adapter and complemented with a power amplifier, if necessary, for very high screening attenuation, in combination with a receiver with optional low-noise amplifier for very high screening attenuation;
c) impedance-matching circuit if necessary:
   - primary side: nominal impedance of generator,
   - secondary side: nominal impedance of the inner circuit,
   - loss: > 10 dB.
d) balun for impedance matching of the unbalanced generator output signal to the characteristic impedance of balanced cables for measuring the coupling attenuation. Requirements for the balun are given in IEC 62153-4-9:2018, 6.3. Alternatively, a VNA with a mixed mode option may be used, see IEC TR 61156-1-2.

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;
- absorber material.

6.5 Calibration procedure

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

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

When using a (vector) network analyser without an S-parameter test-set, i.e. by using a power splitter, a THRU calibration shall be established that includes the test leads used to connect the test setup 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 can be corrected:

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

where

a_{cal} is the attenuation obtained at the calibration procedure, in dB;
P_1 is the power fed during calibration procedure, in W;
P_2 is the power at the receiver during calibration procedure, in W;
S_{21} is the measured S-parameter.

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 or balun is used, the attenuation shall be measured over the above-mentioned frequency range, and the data shall be saved.

6.6 Test leads and connecting cables to the DUT

Test leads and connecting cables to the DUT shall be well screened.

When measuring transfer impedance, the transfer impedance Z_{con} of the connecting cables inside the test setup can be measured separately, either in the triaxial tube or in the triaxial cell, expressed in mΩ/m, in accordance with IEC 62153-4-3. The length of the connecting cables in the set up shall be measured, the transfer impedance Z_{con} calculated and be subtracted from the measured transfer impedance of the DUT.

When measuring screening attenuation or coupling attenuation, the screening attenuation or the coupling attenuation of the connecting cables can be measured separately, either in the triaxial tube or in the triaxial cell, expressed in dB, in accordance with IEC 62153-4-4 or IEC 62153-4-9.

The measured screening attenuation or coupling attenuation of the connecting cables inside the setup shall be at least 10 dB better than the measured value of the DUT.

7 Sample preparation

7.1 Coaxial connector or assembly or quasi-coaxial component

The connector or the assembly or the component under test shall be connected to its mating part in accordance with the specifications of the manufacturer.

A well-screened coaxial connecting cable shall be mounted to the connector, the assembly or the component under test and/or its mating part(s). One end of the connecting cable shall be connected to the test head of the test setup and matched with the nominal characteristic impedance of the DUT.

The screen of the other end of the connecting cable shall be connected to the wall of the housing (the short circuit at the generator side).

In the case of a tube-in-tube procedure, the other end of the connecting cable shall be passed through the RF-tight tube in 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 a low contact resistance. On the generator side, the screen of the connecting cable shall not be connected to the extension tube. The extension tube shall be connected to the wall of the housing (the short circuit at the generator side).

7.2 Balanced or multipin connectors or components

The device under test shall be connected to its mating part in accordance with the specifications of the manufacturer.

A balanced or multi-conductor cable, which is usually used with the connector or the device under test, shall be mounted to the connector under test and its mating part or to the device under test in accordance with the specification of the manufacturer.

Screened balanced or multiconductor cables or multipin conductors or components are treated as a quasi-coaxial system when measuring transfer impedance or screening attenuation. Therefore, at the open ends of the feeding cable, all conductors of all pairs shall be connected together. All screens, also 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 6).

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.

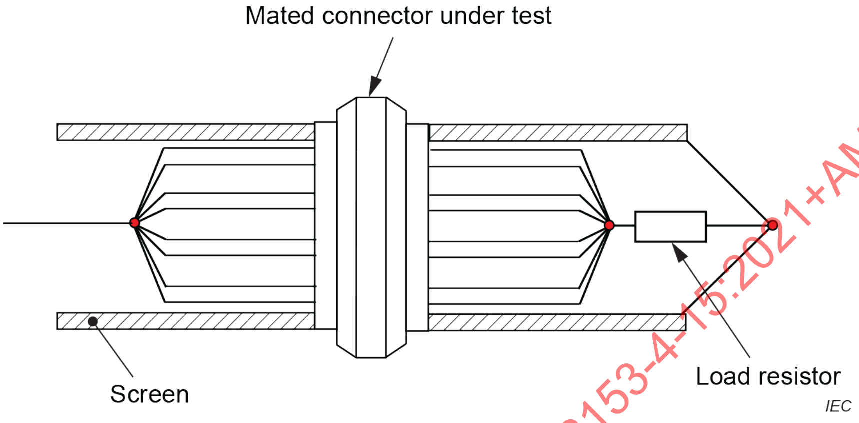


Figure 5 – Preparation of balanced or multipin connectors for transfer impedance and screening attenuation

When measuring the coupling attenuation, the connecting cable shall be fed by a balun or shall be balunless with a VNA with multimode option. The pair under test shall be matched by a symmetrical/asymmetrical load. The pairs that are not under test shall be matched.

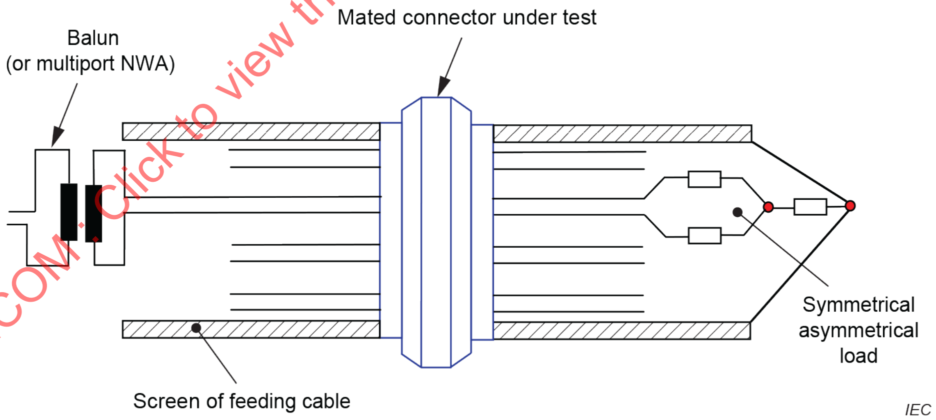


Figure 6 – Preparation of balanced or multipin connectors for coupling attenuation measurement

7.3 Cable assemblies

The connectors of the assembly under test shall be connected with their mating parts on both ends, on one end in the case of single-ended assemblies, in accordance with the specifications of the manufacturer.

The mating connectors shall be connected with well-screened coaxial feeding cables.

In the case of multi-pin conductor assemblies, all conductors of the assembly under test shall be short circuited on both ends in the mating connector. If the assembly under test is connected in its intended use directly to a specific unit and no mating connecter is available, the manufacturer of the assembly shall provide an appropriate mating connector or an appropriate adaptation. The mating connector or the adaption shall be well screened, at least 10 dB better than the device under test. Care shall be taken to ensure that the connection of the connecting cable to the mating connector or the adaption is well screened.

7.4 Other screened devices

The screening effectiveness of other shielded or screened devices, e.g. screened cable conduits, may also be measured with the triaxial cell. They shall be prepared and treated as quasi-coaxial systems.

8 Transfer impedance (short-matched)

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 of IEC 62153-4-3 (the tube being replaced by a cell): 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.

Other procedures in accordance with 62153-4-3 may be applied accordingly, if required.

8.2 Principle block diagram of transfer impedance

A block diagram of the test setup to measure transfer impedance in accordance with test method B of IEC 62153-4-3 is shown in Figure 7.

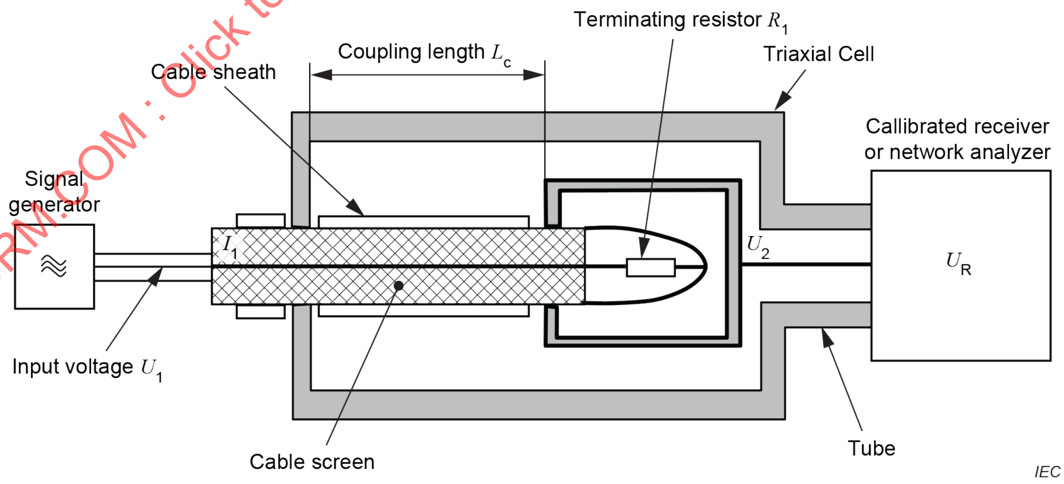


Figure 7 – Test setup (principle) for transfer impedance measurement in accordance with test method B of IEC 62153-4-3

8.3 Measuring procedure

The length of the connecting cables inside the cell to connect the DUT shall be measured.

The transfer impedance of the connecting cables, which connect the DUT, shall be measured in accordance with IEC 62153-4-3. The measured value shall be related to the length of the connecting cables inside the cell to connect the DUT, the result being the transfer impedance of the connecting cables, Z_{con}.

The DUT shall be connected to the generator and the outer circuit (cell) to the receiver.

The attenuation, a_{meas}, shall be 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:

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

where

a_{meas}	is the attenuation measured at measuring procedure, in dB;
P_1	is the power fed to inner circuit, in W;
P_2	is the power in the outer circuit, in W;
S_{21}	is the measured S-parameter.

8.4 Evaluation of test results

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

$$Z_{\text{T}} = \frac{R_1 + Z_0}{2} \cdot 10^{-\left(\frac{a_{\text{meas}} - a_{\text{cal}}}{20}\right)} - Z_{\text{con}} \tag{12}$$

where

Z_{T}	is the transfer impedance, in Ω;
Z_0	is the system impedance (in general 50 Ω);
a_{meas}	is the attenuation measured at measuring procedure, in dB;
a_{cal}	is the attenuation of the connection cables if not eliminated by the calibration procedure of the test equipment, in dB;
R_1	is the terminating resistor in inner circuit (either equal to the impedance of the inner circuit or the impedance of the generator), in Ω;
Z_{con}	is the transfer impedance of connecting cables, in Ω.

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

8.5 Test report

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

9 Screening attenuation

9.1 General

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

9.2 Impedance matching

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 a maximum 200 ps rise time or using the method described in Annex A of IEC 62153-4-4:2015.

An impedance matching adapter to match the impedance of the generator and the impedance of the quasi-coaxial system is not recommended because it reduces the dynamic range of the test setup and may have sufficient matching (return loss) only up to 100 MHz when using self-made adapters that are necessary for impedances other than 60 Ω or 75 Ω (see Annex B of IEC 62153-4-4:2015).

9.3 Measuring with matched conditions

9.3.1 Procedure

The DUT shall be connected to port 1 and the test head of the setup shall be connected to port 2 of the vector network analyser (Figure 7).

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.

9.3.2 Evaluation of test results

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

$$a_\text{S} = 10 \cdot \lg \left| \frac{P_1}{P_\text{r,max}} \right| = 10 \cdot \lg \left| \frac{P_1}{P_\text{2,max}} \cdot \frac{2 \cdot Z_\text{S}}{R} \right| \tag{13}$$

$$= Env \left\{ -20 \cdot \lg \left| S_{21} \right| + 10 \cdot \lg \left| \frac{300\ \Omega}{Z_1} \right| \right\} - \alpha_\text{att} \tag{14}$$

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 setup 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 device under test, in Ω;

R Is the input impedance of the receiver;

α_{att} is the attenuation of the impedance matching adapter – if used and if not taken into account otherwise, e.g. during the calibration procedure of the network analyzer.

This conversion – Equations (13) and (14) – from the measured forward transfer scattering parameter S_{21} to screening attenuation is only valid if the characteristic impedance of the outer circuit Z_2 is higher than the input impedance of the receiver R (see IEC TS 62153-4-1:2014, Clause 9). In the case where the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2, a correction factor may be applied (see Annex E).

Details of attenuation versus the forward transfer scattering parameter S_{21} are given in Annex G.

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

9.4 Measuring with mismatch

9.4.1 General

The DUT shall be connected to port 1 and the test head of the setup 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.

9.4.2 Evaluaton 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].

$$a_s = 10\cdot\lg\left|\frac{P_1}{P_{r,max}}\right| = 10\cdot\lg\left|\frac{P_1}{P_{2,max}}\cdot\frac{2\cdot Z_S}{R}\right| \qquad (15)$$

$$= Env\cdot\left\{-20\cdot\lg\left|S_{21}\right| + 10\cdot\lg\left|1-r^2\right| + 10\cdot\lg\left|\frac{300\ \Omega}{Z_1}\right|\right\} \qquad (16)$$

where

a_s is the screening attenuation related to the radiating impedance of 150 Ω, in dB;

R is the receiver input impedance, in Ω;

Env is the minimum envelope curve of the measured values, in dB;

S_{21} is the scattering parameter S_{21} (complex quantity) of the setup where the primary side of the two port is the DUT and the secondary side is the tube;

---

[1] Z_s is the normalised value of the characteristic impedance of the environment of a typical cable installation. It is in no relation to the impedance of the outer circuit of the test setup.

r is the reflection coefficient between the generator's impedance and the nominal characteristic impedance of the cable under test: $r = \left| \left(\frac{Z_0 - Z_1}{Z_0 + Z_1} \right) \right|$;

Z_0 is the characteristic impedance of system, in Ω, (usually 50 Ω);

Z_1 is the characteristic impedance of the device under test, in Ω.

This conversion – Equations (15) and (16) – from the measured forward transfer scattering parameter S_{21} to screening attenuation is only valid if the characteristic impedance of the outer circuit Z_2 is higher than the input impedance of the receiver R (see IEC TS 62153-4-1:2014, Clause 9). In the case where the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2, a correction factor may be applied (see Annex E).

9.5 Test report

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

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

10 Coupling attenuation

10.1 General

Measuring of coupling attenuation shall be in accordance with IEC 62153-4-9.

IEC 62153-4-9 describes both, measuring with balun and balunless measurements. 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 (usually 100 Ω) 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.

A detailed description of mixed mode parameters is given in Annex C of 62153-4-9:2018.

10.2 Procedure

10.2.1 Coupling attenuation with balun

The DUT is connected to the connecting cables in accordance with the instructions of the manufacturer and terminated at the far end by differential and common mode terminations in accordance with IEC 62153-4-9. The sample is then centred in the cell.

The DUT shall be connected via a balun to port 1 (i.e. it is exited in differential mode) and the test head of the setup shall be connected to port 2 of the vector network analyser. The forward transfer scattering parameter S_{21} shall be measured.

Only the maximum peak values of the measured forward transfer scattering parameter S_{21} shall be 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, and the attenuation of the balun shall be taken into account when calibrating the triaxial apparatus.

The maximum peak values of the measured forward transfer scattering parameter S_{21} are not dependent on the diameter of the outer tube of the triaxial test setup or on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

10.2.2 Balunless coupling attenuation

IEC 62153-4-9 describes the measurement with a standard test head as well as with an open test head. The method described herein is the method with a standard head. According to IEC 62153-4-9, measurements can be performed with balun or balunless. The balunless procedure with the standard test head is shown in Figure 8.

The DUT is connected to the connecting unit and terminated at the far end by differential and common mode terminations, in accordance with IEC 62153-4-9. The sample is then centred in the cell.

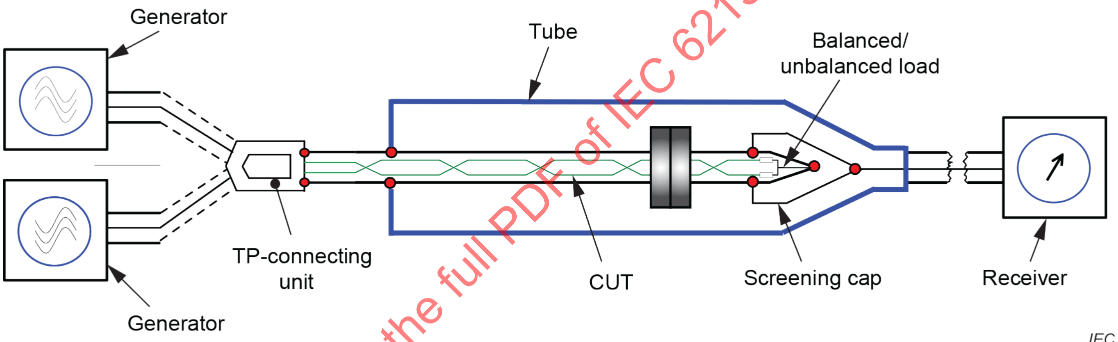


Figure 8 – Principle test setup for balunless coupling attenuation measurement according to IEC 62153-4-9

Connecting cables shall be connected to the TP connecting unit in accordance with IEC 62153-4-9.

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

10.3 Expression of results

The attenuation of the balun or the TP-connecting unit shall be subtracted from the measuring results. The coupling attenuation a_c shall be calculated with the normalised value Z_S = 150 Ω:

$$a_{\text{c}} = 10 \cdot \lg\left|\frac{P_{\text{diff}}}{P_{\text{r,max}}}\right| = 10 \cdot \lg\left|\frac{P_{\text{diff}}}{P_{\text{com}}}\right| + 10 \cdot \lg\left|\frac{P_{\text{com}}}{P_{\text{r, max}}}\right| \text{ dB,} \qquad (17)$$

$$a_{\text{c}} = 20 \cdot \lg\left|\frac{U_{\text{diff}}}{U_{\text{com}}}\right| + 10 \cdot \lg\left[\frac{Z_{\text{com}}}{Z_{\text{diff}}}\right] + 20 \cdot \lg\left|\frac{U_{\text{com}}}{U_{2,\text{max}}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_{\text{S}}}{Z_{\text{com}}}\right] \text{ dB,} \qquad (18)$$

$$a_\mathrm{c} = 20 \cdot \lg \left| \frac{U_\mathrm{diff}}{U_\mathrm{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_\mathrm{S}}{Z_\mathrm{diff}} \right] \mathrm{dB}, \qquad (19)$$

where

a_c	is the coupling attenuation related to the radiating impedance of 150 Ω, in dB;
P_diff	is the input power in the differential mode, in W;
P_com	is the output power which couples to the common mode, in W;
$P_\mathrm{r,max}$	is the periodic maximum value of the common mode radiated power, in W;
U_diff	is the input voltage in the differential mode, in V;
U_com	is the output voltage in the common mode, in V;
$U_\mathrm{2,max}$	is maximum output peak voltage in the common mode, in V;
Z_diff	is the nominal characteristic differential mode impedance of the differential mode (balanced), in Ω;
Z_com	the characteristic common mode impedance (unbalanced), in Ω;
Z_S	is the normalised value of the characteristic impedance of the environment of the cable, in Ω.

The coupling attenuation shall be described by an envelope line as described in Annex H, Clause H.3. In case the measurement is made with mixed mode scattering parameters, the coupling attenuation shall be obtained as described in Annex H, Clause H.2.

10.4 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.

Annex A
(informative)

Principle of the triaxial test procedure

A.1 General

With the triaxial test setup, one can measure the transfer impedance at the lower frequency range and the screening attenuation or the coupling attenuation at higher frequencies.

The test setup consists of a network analyser (or alternatively a discrete signal generator and a selective measuring receiver) and a tube with terminations to the cable screen and the network analyser or receiver. The material of the tube shall be well conductive and non-ferromagnetic, for example brass or aluminium.

The cable under test (CUT), which is centred in the middle of the tube, forms together with the tube a triaxial system (see Figure A.1). The inner system is the CUT itself and the outer system is formed by the screen under test and the tube.

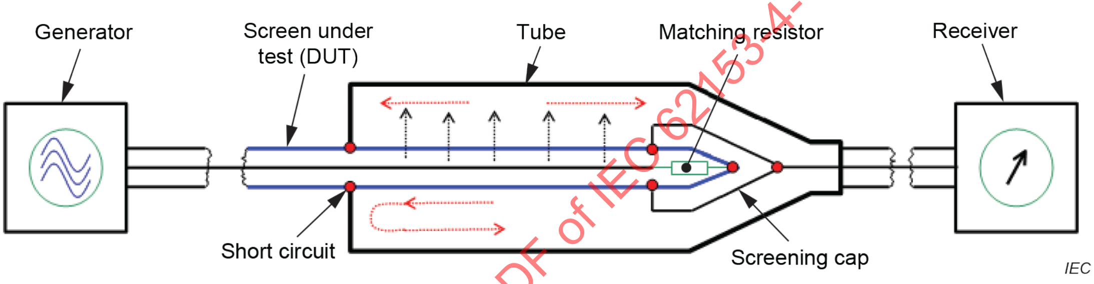


Figure A.1 – Principle test setup to measure transfer impedance and screening attenuation

The CUT is terminated with its characteristic impedance at the far end (see Figure A.1).

The screen under test is short circuited with the tube at the near end of the generator. Owing to this short circuit, the influence of capacitive parts is excluded.

A generator with the voltage U_1 feeds the inner system. The voltage U_2 is measured with a measuring receiver with an input impedance larger or equal to the characteristic impedance of the outer circuit, see Figure A.2.

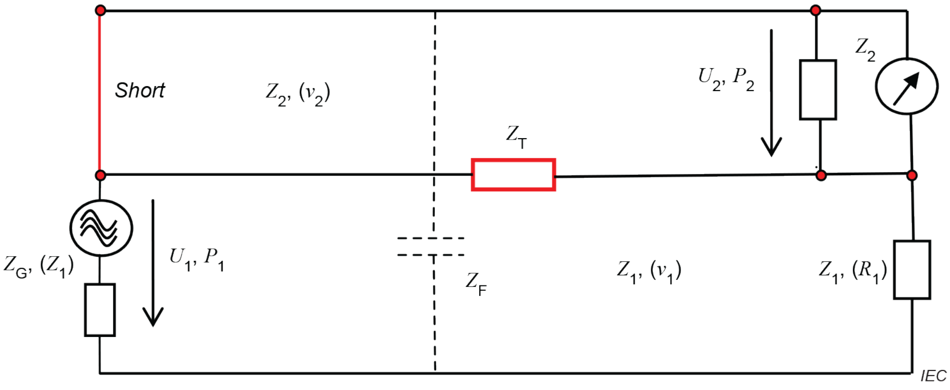


Figure A.2 – Equivalent circuit of the principle of the test setup in Figure A.1

The energy, which couples through the weak screen, travels into both directions of the tube, respectively the outer system. At the short circuit at the near end side of the generator, the wave is totally reflected, so that the receiver measures the complete energy that couples through the screen.

A.2 Transfer impedance

At the low frequency range, the transfer impedance Z_T may be calculated from the voltage ratio U_2/U_1:

$$Z_T \cdot l \approx Z_1 \cdot \left|\frac{U_2}{U_1}\right| \qquad \text{if } Z_T << Z_1 \tag{A.1}$$

A detailed description of the transfer impedance is given in IEC 62153-4-1 and in IEC 62153-4-3.

A.3 Screening attenuation

At high frequencies, the logarithmic ratio of the input power P_1 to the measured power P_2 in the outer circuit gives the screening attenuation a_S.

$$a_S = 10 \cdot lg\left(\left|\frac{P_1}{P_2}\right|_{max}\right) = 20 \cdot \text{lg}\left(\left|\frac{U_1}{U_2}\right|_{max}\right) + 10 \cdot \text{lg}\left|\frac{Z_2}{Z_1}\right| \tag{A.2}$$

In order to compare the screening attenuation with other test procedures in accordance with IEC 62153-4-4, the measured ratio of power P_1 to P_2 is related to the standardized characteristic impedance of the outer system of Z_s = 150 Ω (for further details see IEC TS 62153-4-1:2014, Clause 9):

$$a_S = 10 \cdot \text{lg}\left(\left|\frac{P_1}{P_{r,max}}\right|\right) = 10 \cdot \text{lg}\left(\left|\frac{P_1}{P_{2,max}} \cdot \frac{2 \cdot Z_s}{Z_R}\right|\right) = 10 \cdot \text{lg}\left(\left|\left(\frac{U_1}{U_{2,max}}\right)^2 \cdot \frac{Z_R}{Z_1} \cdot \frac{2 \cdot Z_s}{Z_R}\right|\right) \tag{A.3}$$

$$a_S = 10 \cdot \lg\left(\left|\frac{P_1}{P_r}\right|_{\max}\right) = 20 \cdot \lg\left(\left|\frac{U_1}{U_2}\right|_{\max}\right) + 10 \cdot \lg\left|\frac{2 \cdot Z_s}{Z_1}\right| \qquad (A.4)$$

where

P_1	is the power fed to the DUT (inner system), in W;
P_2	is the power measured at the receiver (outer system), in W;
P_r	is radiated power related to the normalised impedance of the environment
Z_S	= 150 Ω;
U_1	is the input voltage of the DUT, in V;
U_2	is the voltage measured at the receiver, in V;
Z_R	is the input impedance of the receiver, in Ω;
Z_G	is the output impedance of the generator, in Ω;
Z_S	is the arbitrary determined normalized impedance of the environment of a typical cable installation Z_S = 150 Ω.

A detailed description of the screening attenuation is given in IEC 62153-4-1 and in IEC 62153-4-4.

A.4 Coupling attenuation

Balanced cables, connectors, assemblies or devices that are driven in the differential mode may radiate a small part of the input power, due to irregularities in the symmetry of the pair. 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 that 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 interaction of the unbalance attenuation a_u of the pair and the screening attenuation a_S of the screen.

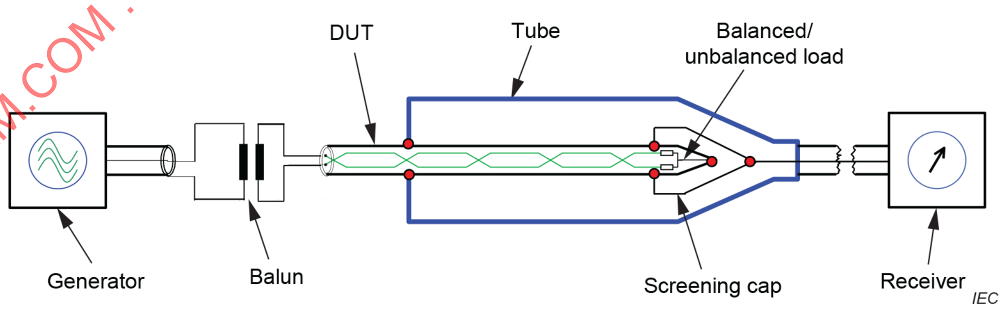


Figure A.3 – Coupling attenuation, principle of test setup with balun and standard tube

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

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 that 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.

A detailed definition of mixed mode S-parameters for measurements with virtual balun is given in IEC 62153-4-9:2018, Annex C.

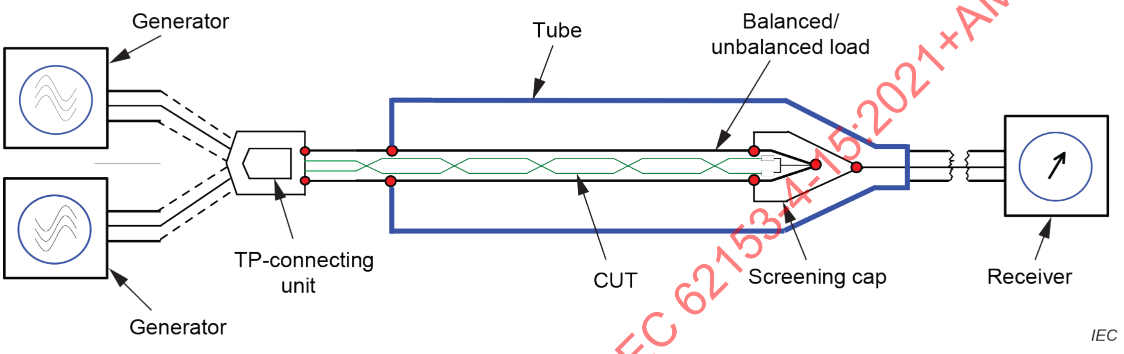


Figure A.4 – Coupling attenuation, principle of setup with multiport VNA and standard head

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:

$$a_C = 10 \cdot \lg\left|\frac{P_{diff}}{P_{com}}\right| + 10 \cdot \lg\left|\frac{P_{com}}{P_{r,\,max}}\right| \text{ dB,} \tag{A.5}$$

$$a_C = 20 \cdot \lg\left|\frac{U_{diff}}{U_{com}}\right| + 10 \cdot \lg\left[\frac{Z_{com}}{Z_{diff}}\right] + 20 \cdot \lg\left|\frac{U_{com}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{com}}\right] \text{ dB,} \tag{A.6}$$

$$a_C = 20 \cdot \lg\left|\frac{U_{diff}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{diff}}\right] \tag{A.7}$$

A detailed description of the coupling attenuation is given in IEC 62153-4-1 and in IEC 62153-4-9.

Annex B
(informative)

Triaxial cell

Larger connectors and cable assemblies do not fit into the commercially available test rigs of the triaxial test procedure, which were designed originally to measure transfer impedance and screening attenuation on communication cables, connectors, and assemblies.

The "triaxial cell" was designed to test larger devices and assemblies, especially for the HV cables and components for electromotive vehicles. The principles of the triaxial test procedures can be transferred to rectangular housings.

Tubes and rectangular housings can be operated in combination in one test rig. The screening effectiveness of larger connectors or devices can be measured in the tube as well as in the triaxial cell. Test results of tube and cell measurements correspond well.

The triaxial cell consists of a rectangular housing in analogy to the principles of the triaxial test procedure, in accordance with IEC 62153-4-3 and IEC 62153-4-4. The material of the housing shall be of non-ferromagnetic metallic material; see Figure B.1 and Figure B.2.

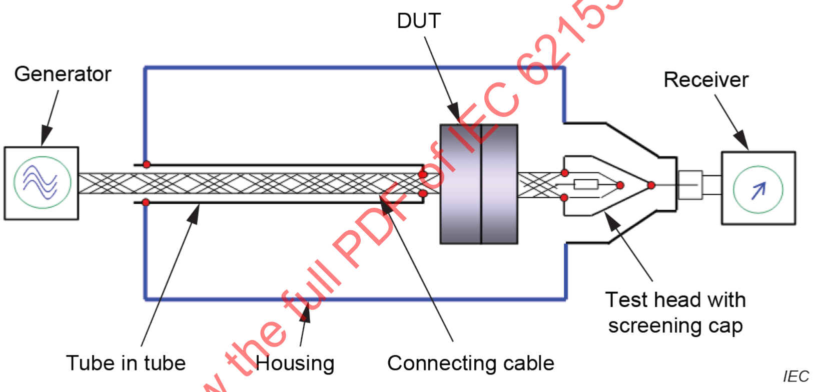


Figure B.1 – Principle depiction of the triaxial cell to measure transfer impedance and screening attenuation on a connector with tube-in-tube according to IEC 62153-4-7

Reflexions of the transmitted signal may occur (in the outer circuit), owing to the deviation of the characteristic impedances. The plane of the short circuit at the near end (generator side) should be therefore preferably directly on the wall of the housing of the cavity without any additional tube.

At the receiver side, the transition of the housing to the coaxial 50 Ω system should be also directly on the wall of the housing.

Figure B.2 – Examples of different designs of triaxial cells

Annex C
(normative)

Triaxial absorber cell

C.1 Cut-off frequencies, higher order modes

The triaxial test procedure uses the principle of transverse electromagnetic wave propagation (TEM waves). At higher frequencies, the triaxial cell becomes in principle a cavity resonator, or a rectangular waveguide, which exhibits resonances depending on its dimensions; see Figure C.1.

Above these resonance frequencies, propagation of TEM waves is disturbed and measurements of screening attenuation with the triaxial test method are limited.

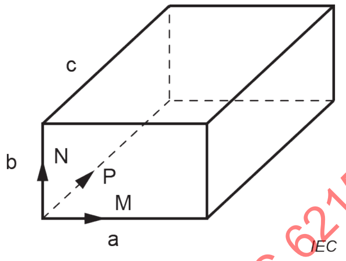


Figure C.1 – Cavity or rectangular waveguide

The cut-off frequency f_c of a cavity is given by:

$$f_c = \frac{c_0}{2a} \tag{C.1}$$

The resonance frequencies can be calculated with Equation (C.2). For this calculation, one of the parameters M, N, P may be set to zero. Conductive parts inside the cavity resonator can lead to deviating resonance frequencies or to mute them.

$$f_{MNP} = \frac{c_0}{2}\sqrt{\left(\frac{M}{a}\right)^2 + \left(\frac{N}{b}\right)^2 + \left(\frac{P}{c}\right)^2} \tag{C.2}$$

where

M, N, P	are the number of modes are the numbers of modes, where M, N stands for the transverse and P for the longitudinal integral multiple of the half of a wavelength (M, N, P = 1, 2, 3 where M or N can be set to zero);
a, b, c	are the dimensions of cavity where a, b are coupled to the transverse and c to the longitudinal dimension;
c_0	is the velocity of light in free space.

According to Equation (C.2), the cut off frequency for a triaxial cell with dimensions of, for example, 1 000 mm by 300 mm by 300 mm is about 500 MHz; for a triaxial cell with dimensions of 1 000 mm by 150 mm by 150 mm, it is about 1 GHz. Above the cut-off frequencies, different resonance peaks can be observed; see Figure C.2.

Figure C.2 shows comparable measurements screening attenuation of a cable RG 214 with a single-braid construction between a standard tube with a 40 mm inner diameter and different triaxial cells.

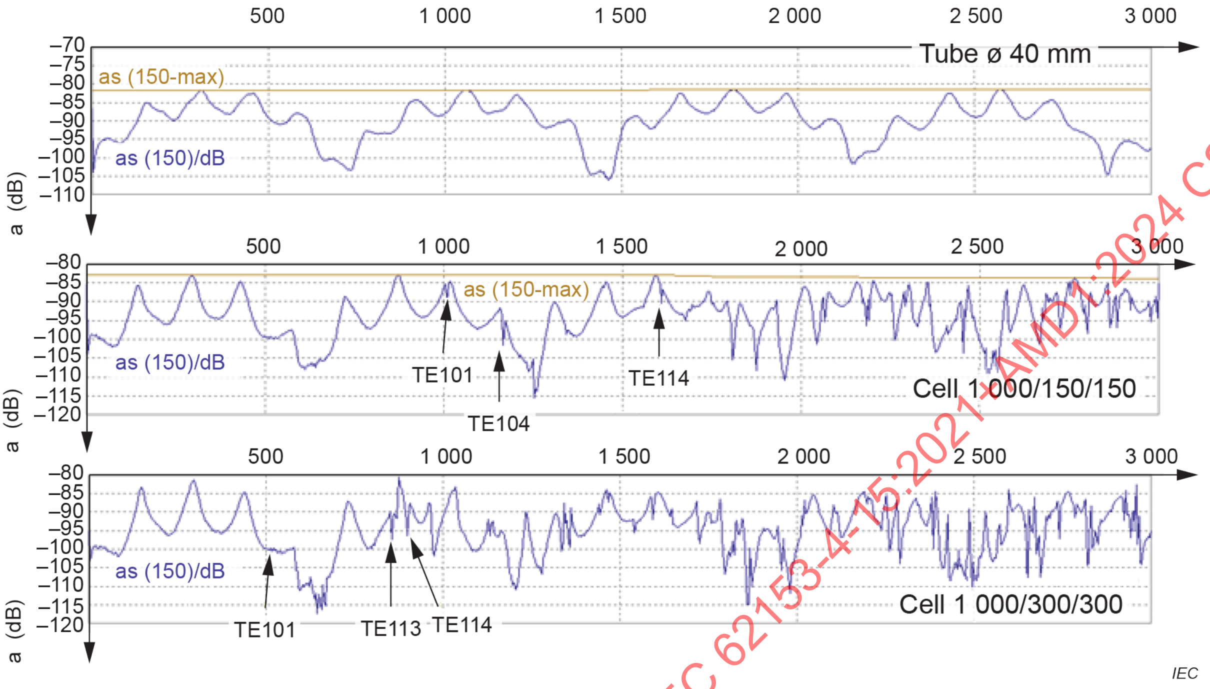


Figure C.2 – Comparison of the measurements of a RG 214 cable with 40 mm tube and triaxial cells

Compared to a measurement in the tube, different resonance peaks can be observed in the measurements with a triaxial cell of 1 000 mm by 150 mm by 150 mm, and of 1 000 mm by 300 mm by 300 mm, from about 500 MHz upwards and 1 GHz upwards, respectively. Above these frequencies, measurements with triaxial cells are unreliable.

C.2 Absorber

The problem of resonances and/or higher-order modes in the cell can be solved easily by using absorber material, placed on the bottom of the cell. The absorbers may be ferrites, nanocrystalline material or magnetic flat absorbers, see Figure C.3.

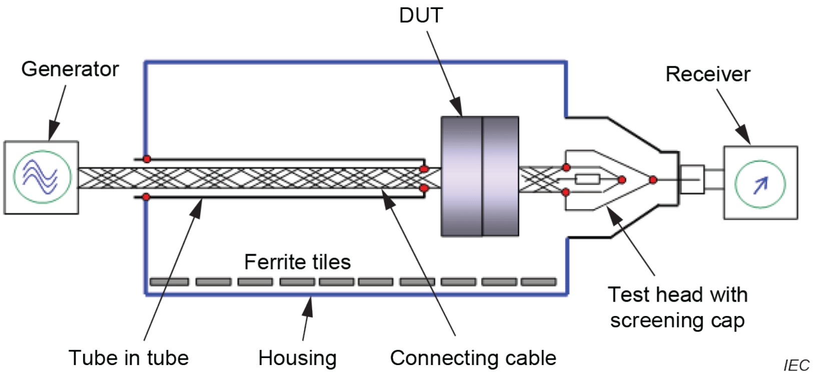


Figure C.3 – Principle of the triaxial cell with tube in tube and ferrite tiles as absorber

Figure C.4 shows measurements in triaxial cells with magnetic flat absorbers. Resonances and/or higher-order modes are suppressed. With absorber material in the cell, the usable frequency range can be extended up to and above 3 GHz. The maximum peak values of the measurements with absorber in the cell show a difference respectively an additional attenuation of about 3 dB at 3 GHz.

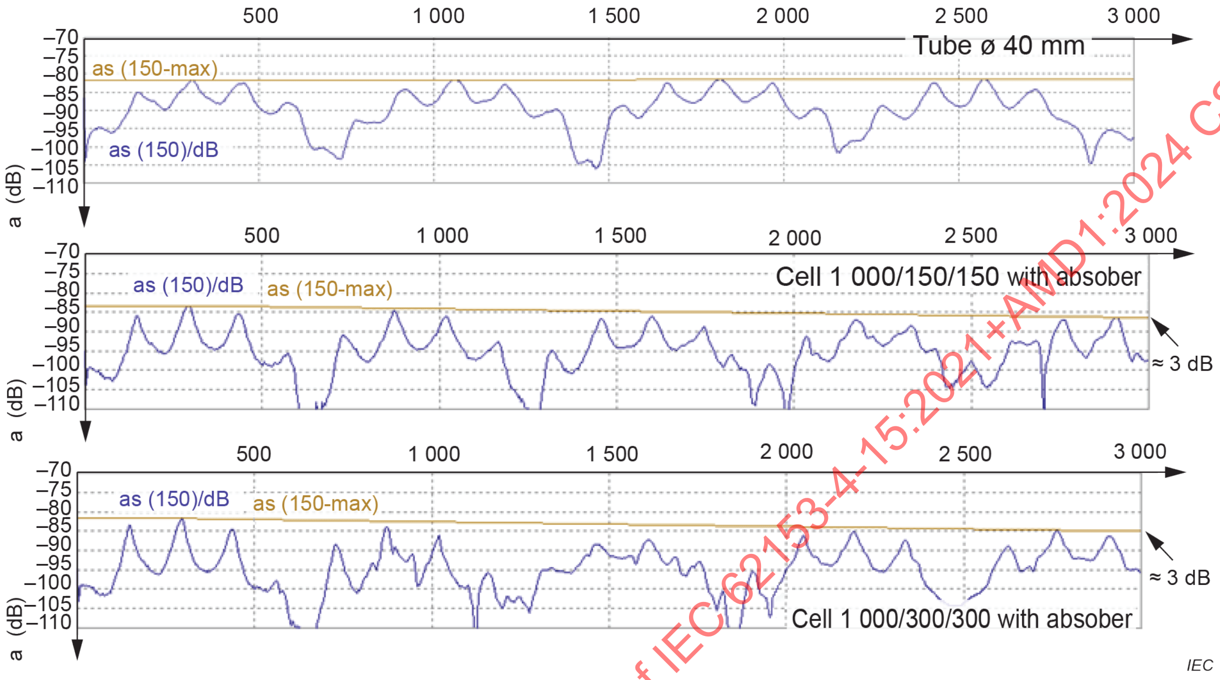


Figure C.4 – Comparison of the measurements of an RG 214 with 40 mm tube and triaxial cells with magnetic absorber

Although other absorber materials, such as ferrites or nanocrystalline absorbers, could be useful, magnetic flat absorbers are recommended because of their good mechanical characteristics and easy handling; see Figure C.5.

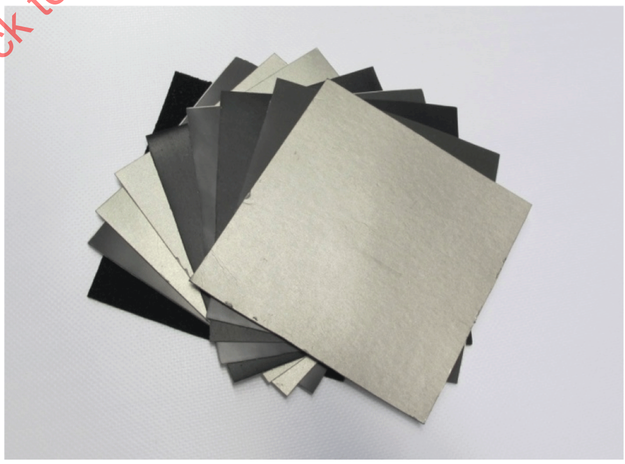


Figure C.5 – Examples of magnetic flat absorber

C.3 Influence of absorber

Measurements of Figure C.4 with absorber in the cell show an additional attenuation of about 3 dB at 3 GHz owing to the influence of the absorber.

The influence of the absorber in the cell can be measured by an S11 measurement, in accordance with Figure C.6. The test head of the cell is connected with a tube of copper or brass with the same diameter as the connecting case of the test head. The copper or brass tube is short circuited at the generator side (near end).

Perform a measurement without absorber and a measurement with absorber in the cell, in accordance with Figure C.6.

The difference of both measurements is the influence of the absorber and shall be used for the correction of the test results.

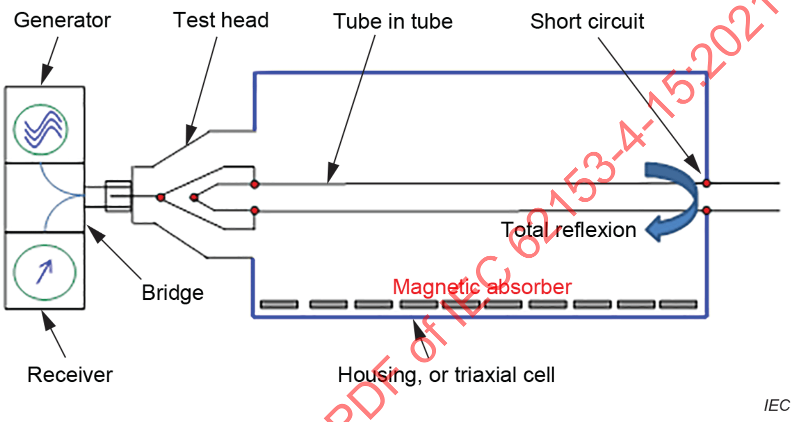
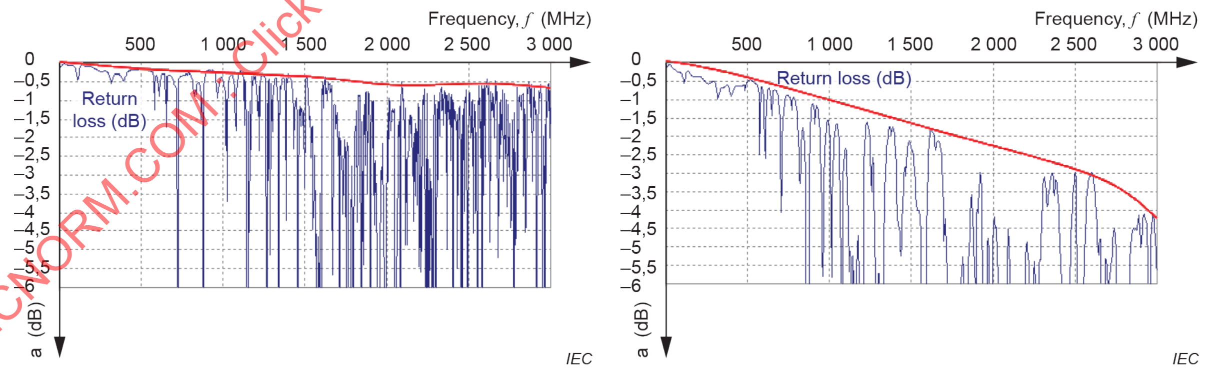


Figure C.6 – Setup for correction measurement

Figure C.7a and Figure C.7b show examples of S11 measurements in the cell without and with absorber.



a) **S11 measurement without absorber**

b) **S11 measurement with absorber**

Figure C.7 – Correction measurement

Annex D
(informative)

Application of a moveable shorting plane

D.1 Coupling transfer function

Depending on the length of the device under test and the frequency, the screening effectiveness is divided into the transfer impedance and the screening attenuation. The coupling transfer function in Figure D.1 shows the transfer impedance Z_T and the screening attenuation a_S of a cable screen versus frequency.

With the triaxial procedure, the transfer impedance Z_T and the screening attenuation a_S can be measured in one test setup.

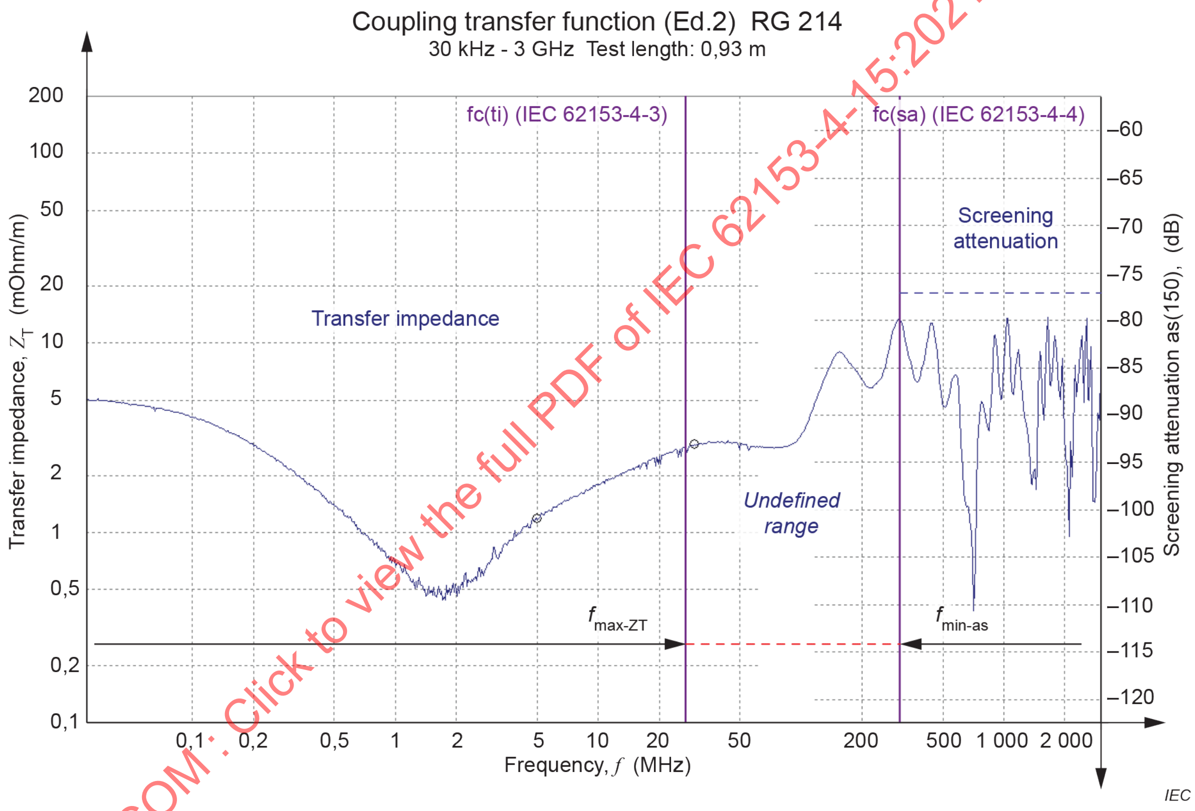


Figure D.1 – Measured coupling transfer function of a braided screen versus frequency with the triaxial cell

In the DC range, at very low frequencies, the transfer impedance of a braided screen is equal to the DC resistance. In the range of about 1 MHz to 10 MHz, the value of the transfer impedance drops down to lower values (at optimized braids) and increases then by about 20 dB per decade towards higher frequencies.

The coupling transfer function $T_{\mathrm{n,f}}$ gives the relation between the screening attenuation a_{S} and the transfer impedance Z_{T} of a cable screen. In the lower frequency range, where the cable samples are electrically short, the transfer impedance Z_{T} can be measured up to the cut-off frequencies $f_{\mathrm{cn,f}}$. Above these cut-off frequencies $f_{\mathrm{cn,f}}$ in the range of wave propagation, the screening attenuation a_{S} is the measure of screening effectiveness. The cut-off frequencies $f_{\mathrm{cn,f}}$ may be moved towards higher or lower frequencies by varying the length of the cable under test.

The upper cut off frequency $f_{\text{max-ZT}}$ for measuring the transfer impedance depends on the test method used (see IEC 62153-4-3) and may be approximated by:

$$f_{\text{max}-\text{ZT}} \leq \frac{c_0}{6 \cdot \sqrt{\varepsilon_{r1}} \cdot L_{\mathrm{c}}} \tag{D.1}$$

The lower cut off frequency $f_{\text{min-as}}$ for measuring the screening attenuation in accordance with IEC 62153-4-4 is given by:

$$f_{\text{min}-\text{as}} \geq \frac{c_0}{2 \cdot \left| \sqrt{\varepsilon_{\mathrm{r1}}} - \sqrt{\varepsilon_{\mathrm{r2}}} \right| \cdot L_{\mathrm{c}}} \tag{D.2}$$

Where

f is the frequency, in Hz;

c_0 is the velocity of light in free space, in m/s;

$\varepsilon_{\mathrm{r1}}$ is the relative dielectric constant of the inner system;

$\varepsilon_{\mathrm{r2}}$ is the relative dielectric constant of the outer system;

L_{c} is the coupling length, in m.

Figure D.1 shows the cut-off frequencies of the transfer impedance Z_{T} and of the screening attenuation a_{s}. For a cable of 1 m in length and a relative dielectric permittivity of the inner system ε_{r} of 2,28, one obtains an undefined range or a "grey zone" in the frequency range from about 30 MHz to about 300 MHz.

D.2 Effect of the measurement length on the measurement cut-off frequency

The distance of the shorting plane of the outer system of the triaxial test setup and the screening cap of the test head ("measurement length") defines the cut-off frequency for the measurement bandwidth of the transfer impedance Z_{T}. If a higher cut-off frequency for Z_{T} is required, a shorter distance between shorting plane and test head is needed. A detailed description of this context can be found in Clause 9 of IEC TS 62153-4-1:2014 as well as in IEC 62153-4-3.

D.3 Details of the movable shorting plane

The introduction of a movable shorting plane to the triaxial setup in combination with the tub-in-tube method is shown in Figure F.1. It gives full flexibility in choosing the shorting plane distance and therefore the cut-off frequency of the screening measurement.

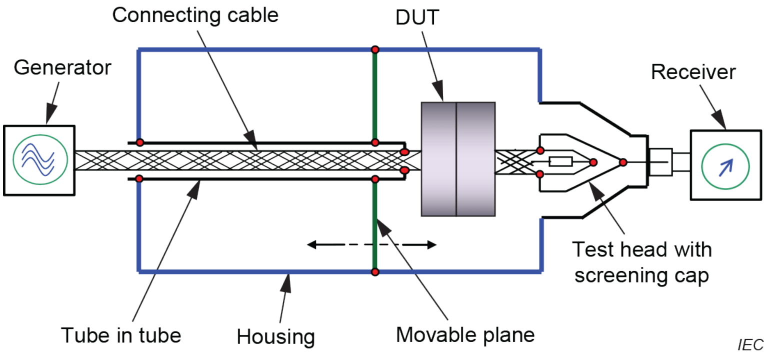


Figure D.2 – Cross-section of triaxial cell with movable shorting plane

The main requirements for such a plane are a sufficient conductivity of the plane material, as well as a sufficiently low contact resistance between the tube-in-tube and the plane, as well as the contact resistance between the plane and the outer housing of the triaxial cell. The application of suitable spring contacts, which are also used in other EMC applications, helps to ensure these contact requirements. Figure D.2, Figure D.3 and Figure D.4 give design examples of such a plane-to-housing contact solution, and a plane-to-tube contact solution.

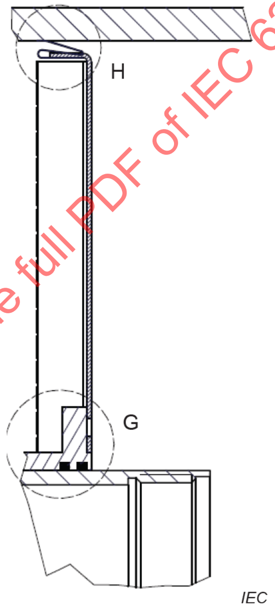


Figure D.3 – Crosscut of plane shortening housing and tube-in-tube

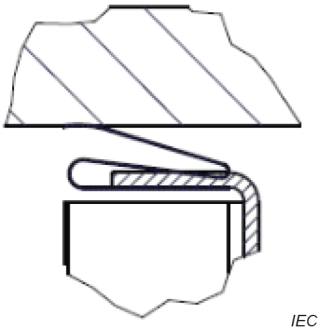


Figure D.4 – Detail H of Figure D.3: contact between plane and housing

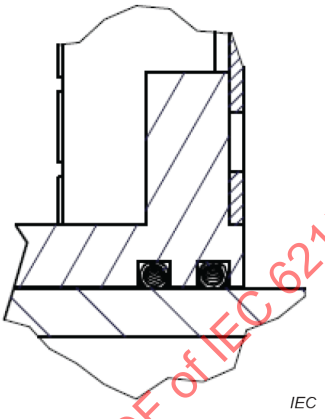


Figure D.5 – Detail G of Figure D.3: contact between plane and tube-in-tube

D.4 Measurement results

Figure D.6 shows a compilation of transfer impedance measurements made on one test sample with different shorting plane distances applied. The closer the plane gets to the test sample, the higher the cut-off frequency is located in the diagram.

Since the test sample is of a very short elongation, it therefore provides a locally concentrated coupling area. This results in measurement curves with steadily increasing maximum values with a rippled character. The ripples are generated by a quarter wave cancellation of the reflected wave at the shorting plane. The envelope curve in red indicates the theoretical transfer impedance character of a single coupling area (as of the connector under test).

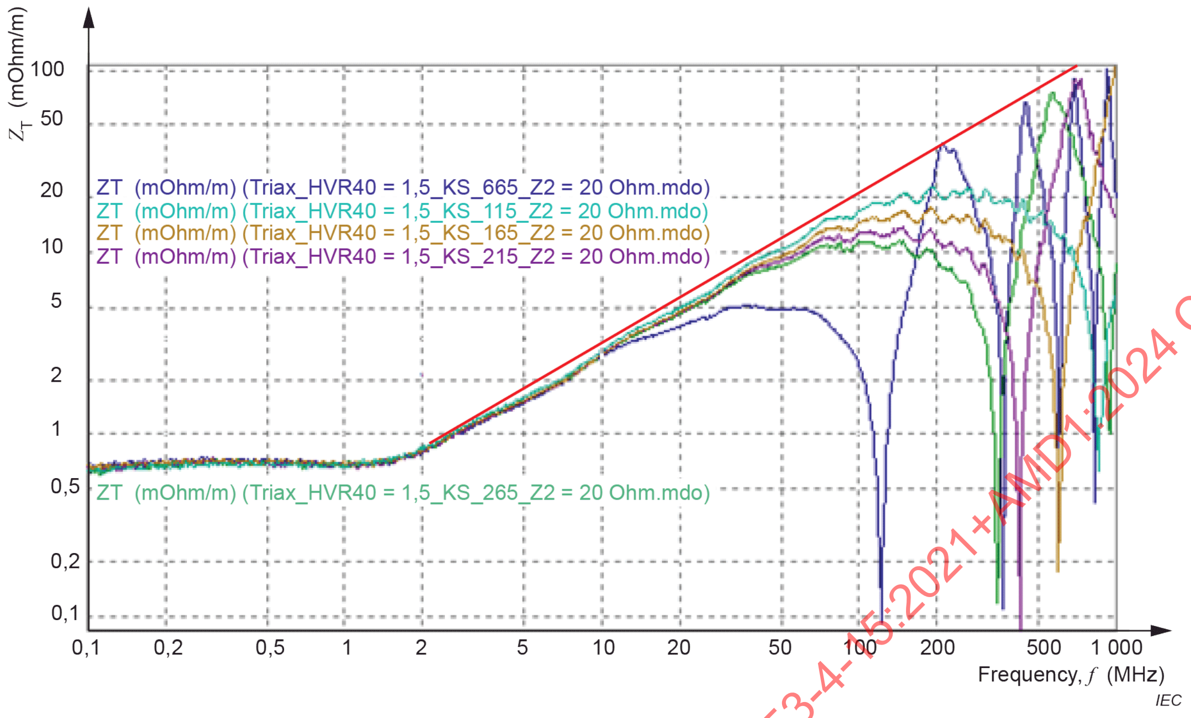


Figure D.6 – Compilation of transfer impedance test results with different shorting plane distances

In principle, the undefined range could be covered by varying the length of the device under test. But varying the length of the device under test is not always desired or possible in the case of DUTs with fixed length, for example, cable assemblies.

Hence, it should be discussed how the coupling transfer function could be the measure for the screening effectiveness, including transfer impedance and screening attenuation.

IEC 62153-4-7 is being revised. During this revision, it should be discussed how to introduce the coupling transfer function as shown in Figure D.1. The length of the test setup could be fixed to 1 m. The value of the minimum of the screening attenuation at $f_{\text{min-as}}$ could be extended to $f_{\text{max-ZT}}$ and be the measure of the screening attenuation. With this extension, the screening effectiveness, consisting of transfer impedance and screening attenuation, is explicitly described over the complete frequency range.

Furthermore, with the new procedure of IEC 62153-4-3, the cut off frequency $f_{\text{max-ZT}}$ of the transfer impedance can be moved towards higher frequencies and the undefined range can be reduced.

To compare different devices and for qualification purposes, the proposed application of the coupling transfer function is useful in any case.

Annex E
(informative)

Correction in the case that the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2

E.1 Impedance Z_2 lower than the input impedance of the receiver

If the characteristic impedance of the outer circuit Z is lower than the input impedance of the receiver, then the envelope curve (maximum values) of the measured forward transfer scattering parameter S_{21} will depend on the input impedance of the receiver (see IEC TS 62153-4-1:2014, Clause 9 and Figure E.1). In this case, a correction factor shall be used to correct the test results.

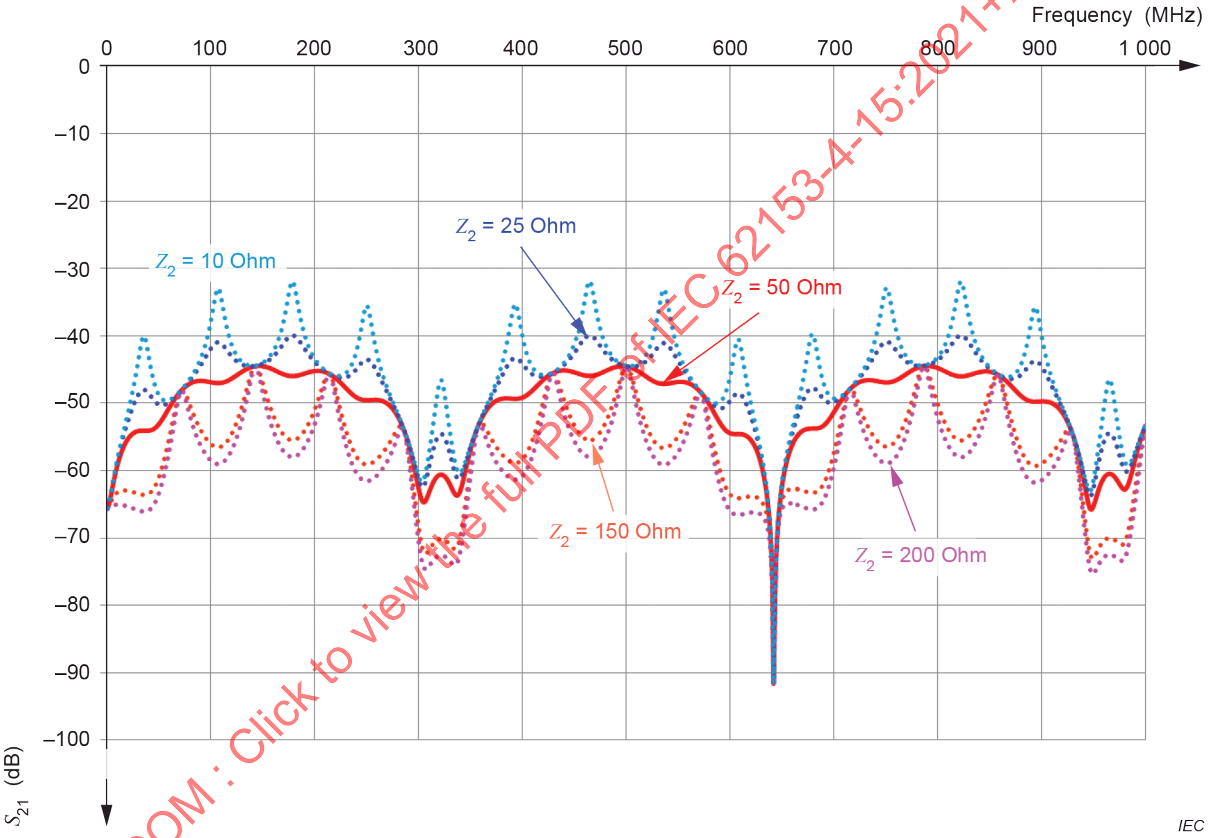


Figure E.1 – Example of forward transfer scattering parameter S_{21} for different impedances in the outer circuit where the receiver input impedance is 50 Ω

The characteristic impedance of Z_2 of the outer circuit can either be measured with a time domain reflectometer TDR or – if the DUT has a uniform cylindrical shape – be calculated in accordance with Equation (E.1).

$$Z_2 = \frac{60\ \Omega}{\sqrt{\varepsilon_\mathrm{r}}} \cdot \ln\left(1{,}27 \cdot \frac{D}{d}\right) \qquad \text{(E.1)}$$

where

ε_r is the dielectric permittivity in the outer circuit;

d is the diameter of the device under test, in mm;

D is the width of the cell, in mm.

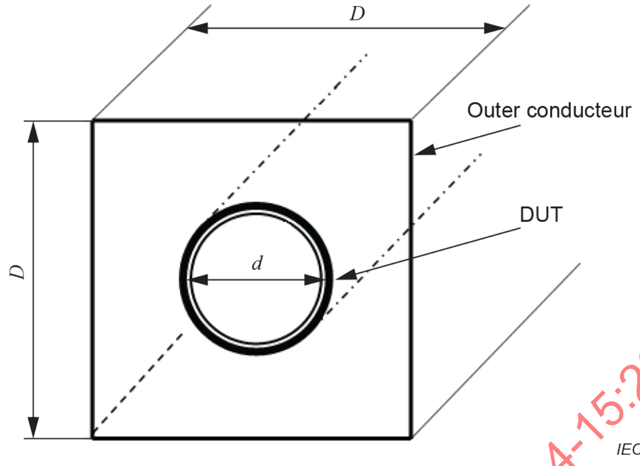


Figure E.2 – DUT with uniform cylindrical shape in the centre of the cell

E.2 Correction

For a DUT with uniform cylindrical shape resulting in an impedance of the outer circuit lower than the receiver input impedance, a correction factor is obtained with Equation (E.2). This correction factor shall be added to the measured forward transfer scattering parameter S_{21} (for a negative dB value, see Annex G).

$$a_{\text{corr}} = -20 \cdot \lg\left(\frac{R}{Z_2}\right) \tag{E.2}$$

Where

a_{corr} is the correction factor;

R is the input impedance of the receiver, in Ω;

Z_2 is the characteristic impedance of the outer circuit, in Ω.

For nonuniform DUTs, the correction is not straightforward because additional reflections superpose the results. This case is under further study.

Annex F
(informative)

Test adapter

When measuring transfer impedance or screening attenuation on connectors or cable assemblies, test adapters are required, see Figure F.1 and Figure F.2.

Test adapters may limit the sensitivity of the test setup. Therefore, test laboratories shall conduct qualification tests with their existing adapter hardware to establish the noise floor(s) for the entire test system. Should the qualification test require connecting cables, these shall have a tubular outer conductor. Measurements are considered as 'valid' as long as the measured value is at least 6 dB above the sensitivity established.

Test adapters shall be assembled in agreement between the manufacturer (or the supplier) of the device under test and the test laboratory.

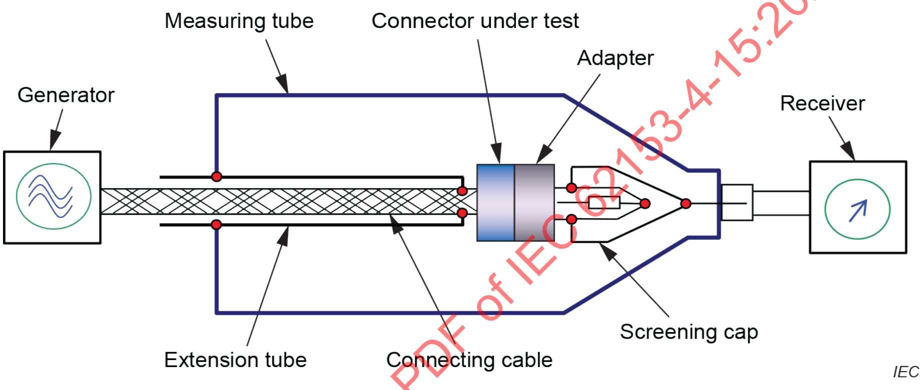


Figure F.1 – Principle of the test setup to measure transfer impedance and screening or coupling attenuation of connectors

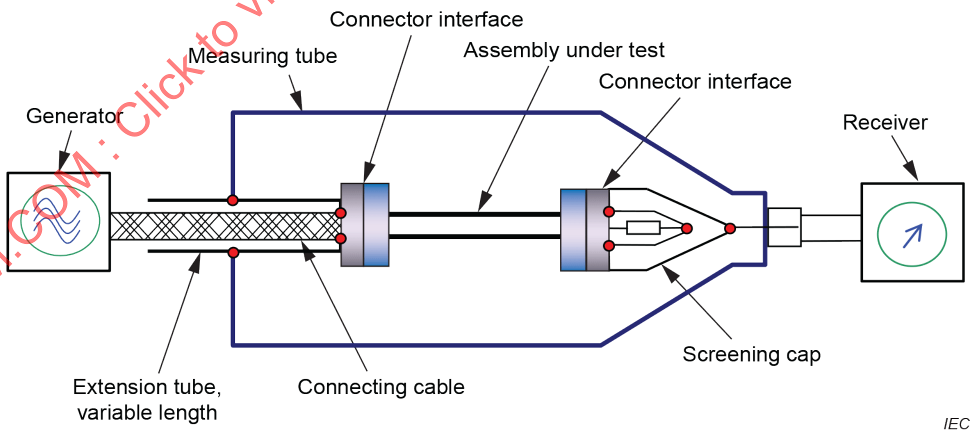


Figure F.2 – Principle of the test setup to measure transfer impedance and screening attenuation on a cable assembly

Annex G
(informative)

Attenuation versus scattering parameter S_{21}

Sometimes, confusion arises between attenuation and the forward transfer scattering parameter S_{21}. By definition, attenuation is the logarithmic ratio of the power at the input of a DUT to the power at the output of the DUT. The forward transfer scattering parameter S_{21} relates the output signal to the input signal.

For passive components, the image attenuation [depending on the device also named "wave attenuation" or "two-port attenuation" or "operational (Betriebs) attenuation" under matched conditions] is positive (as the output signal is smaller than the input signal), whereas the scattering parameter S_{21} is negative. Therefore, in the equations to convert the measured scattering parameter S_{21} to the screening or coupling attenuation, a minus sign is used in front of the S_{21} term (see 9.3.2 and 9.4.2).

Further details are described in IEC TR 62152.

Figure G.1 and Figure G.2 show the S_{21} measurement of a 3 dB attenuator. The measurements have been done with two different network analyzers and the results show negative values, as expected.

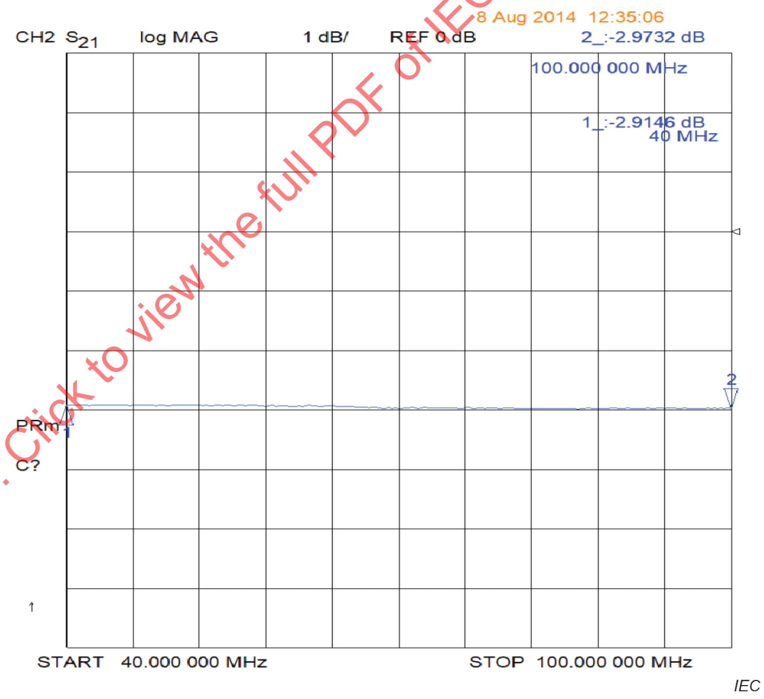


Figure G.1 – Measurement with HP8753D of S_{21} of a 3 dB attenuator

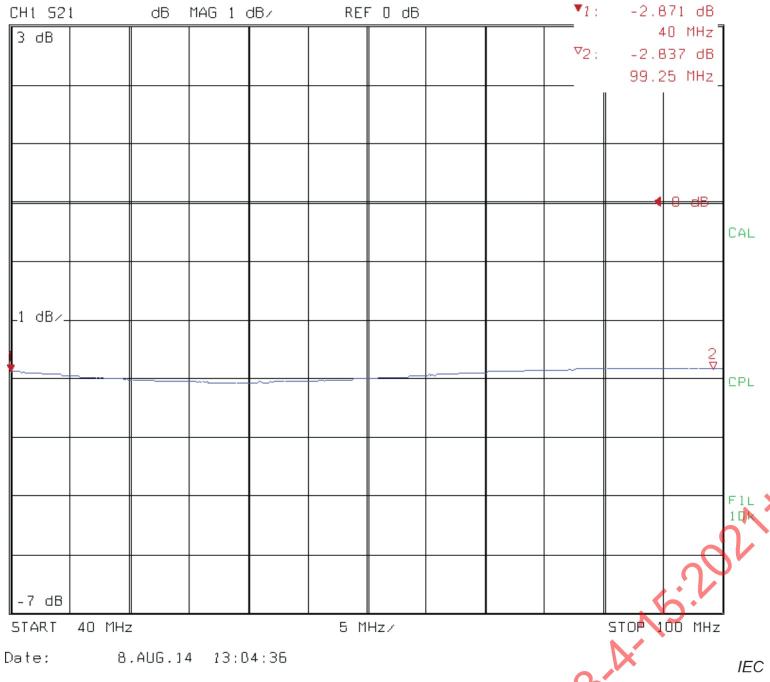


Figure G.2 – Measurement with ZVRE of S_{21} of a 3 dB attenuator

Annex H
(normative)

Coupling attenuation expressed by mixed mode scattering parameter and an envelope line

H.1 General

Coupling attenuation is often measured with a multiport network analyser with mixed mode scattering parameters. In this case, the formulae for the conversion from voltage ratio to the coupling attenuation shall be rearranged.

An envelope curve shall be drawn for the coupling attenuation. This simplifies the comparison of test results.

H.2 Coupling attenuation expressed by mixed mode scattering parameter

Formula (19) is rearranged and expressed by a mixed mode scattering parameter:

$$a_\text{c} = -20\log_{10}\left|S_\text{sd21}\right| + 10\log_{10}\left|\frac{Z_\text{diff}}{Z_0}\right| + 10\log_{10}\left|\frac{2Z_\text{s}}{Z_\text{diff}}\right| = -20\log_{10}\left|S_\text{sd21}\right| + 10\log_{10}\left|\frac{2Z_\text{s}}{Z_0}\right| \qquad \text{(H.1)}$$

where

a_c is the coupling attenuation;

S_sd21 is the forward transmission scattering parameter; DUT exited in differential mode; received power in single ended mode;

Z_diff is the differential mode impedance;

Z_s is the normalised value of the characteristic impedance of the environment of the cable; Z_s = 150 Ω;

Z_0 is the system impedance; Z_0 = 50 Ω.

H.3 Envelope line of coupling attenuation

The coupling attenuation is expressed by a value A of an envelope line. The value A shall be deduced by drawing a curve derived from the following Formula (H.2):

$$E_\text{c} = \begin{cases} A \text{ if } 30\text{ MHz} \leq f < 100\text{ MHz} \\ A - 20\log_{10}\left(\dfrac{f}{100}\right) \end{cases} \qquad \text{(H.2)}$$

where

f is the frequency in MHz;

E_c is the envelop line of coupling attenuation in dB;

A is the starting value of the envelope in dB.

This curve shall be raised until the first peak of the measurement trace is intersected. The value A (in dB) is read where the curve intersects the Y axis, see Figure H.1.

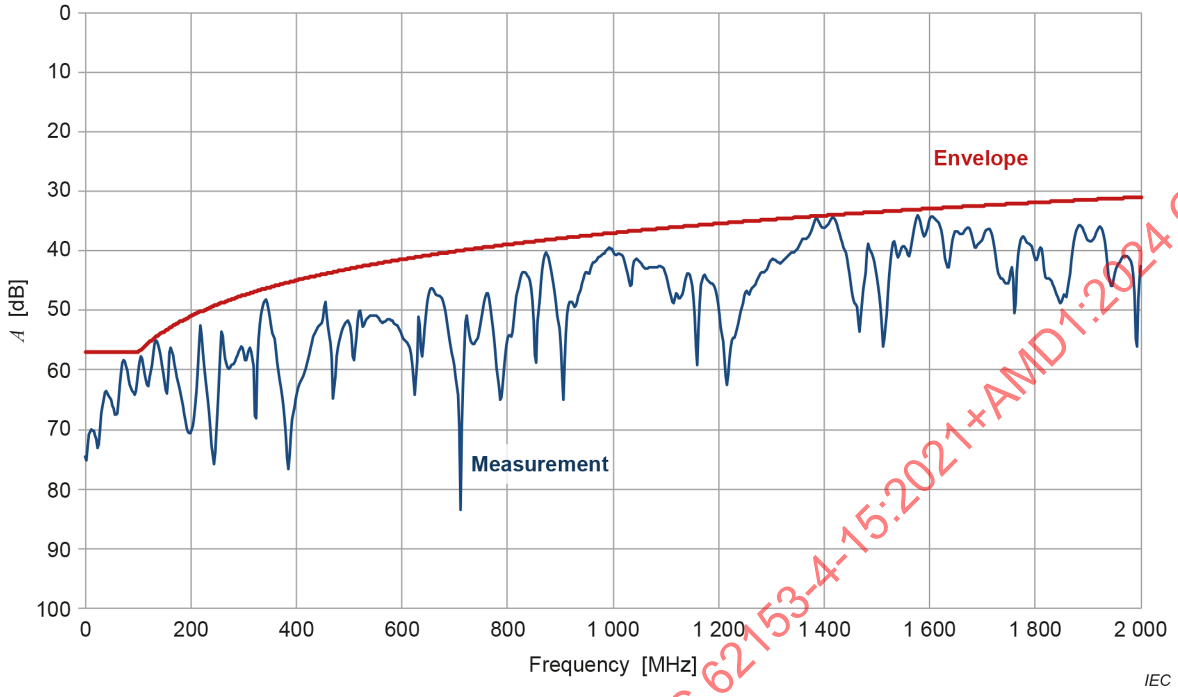


Figure H.1 – Example of coupling attenuation with envelope line

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LUCICANIN Ismar, POUHÈ David et al, *Higher Order Mode Suppression in Triaxial Cells, Proceedings of the 65th IWCS Conference, Providence,RI, USA, pp 133 – 139, Oct. 2016*

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 62153-4-15 edition 2.1 contains the second edition (2021-08) [documents 46/814/FDIS and 46/822/RVD] and its amendment 1 (2024-05) [documents 46/992/FDIS and 46/1004/RVD].

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

International Standard IEC 62153-4-15 has been prepared by IEC technical committee 46: Cables, wires, waveguides, R.F. connectors, R.F. and microwave passive components and accessories.

This second edition constitutes a technical revision.

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

a) measurement of coupling attenuation of balanced connectors, assemblies and components with balun and balunless added;
b) application of a test adapter was added;
c) application of a moveable shorting plane;
d) application of the triaxial "absorber" cell;
e) correction of test results in the case that the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2.

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 the parts in the IEC 62153-4 series, published under the general title *Metallic communication cable test methods – Electromagnetic compatibility (EMC)*, can be found on the IEC website.

The committee has decided that the contents of this document and its amendment 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, or
- revised.

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METALLIC CABLES AND OTHER PASSIVE COMPONENTS TEST METHODS –

Part 4-15: Electromagnetic compatibility (EMC) – Test method for measuring transfer impedance and screening attenuation – or coupling attenuation with triaxial cell

1 Scope

This part of IEC 62153 specifies the procedures for measuring with triaxial cell the transfer impedance, screening attenuation or the coupling attenuation of connectors, cable assemblies and components, for example accessories for analogue and digital transmission systems, and equipment for communication networks and cabling.

Measurements can be achieved by applying the device under test directly to the triaxial cell or with the tube-in-tube method in accordance with IEC 62153-4-7.

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 61196-1, *Coaxial communication cables – Part 1: Generic specification – General, definitions and requirements*

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 62153-4-4:2015, *Metallic communication cable test methods – Part 4-4: Electromagnetic compatibility (EMC) – Test method for measuring of the screening attenuation a_S up to and above 3 GHz, triaxial method*

IEC 62153-4-7, *Metallic communication cable test methods – Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring the transfer impedance Z_T and the screening attenuation a_s or coupling attenuation a_c of connectors and assemblies up to and above 3 GHz – Triaxial Tube in tube 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 62153-4-16, *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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61196-1 and the following apply.

3.1

triaxial cell

rectangular housing in analogy to the principles of the triaxial test procedure, consisting of a non-ferromagnetic metallic material

Note 1 to entry: The triaxial test procedure is described in IEC 62153-4-3 and IEC 62153-4-4.

3.2

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 [Ω] (see Figure 1)

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

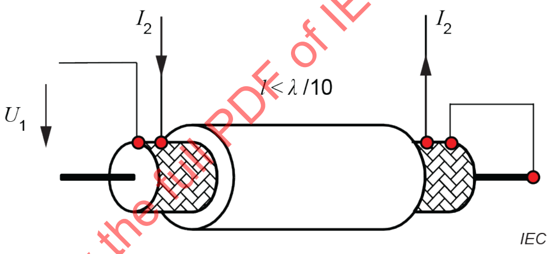

Figure 1 – Definition of Z_T

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

$$Z_T \text{ dB}(\Omega) = 20 \cdot \lg\left(\frac{|Z_T|}{1\,\Omega}\right) \tag{2}$$

3.3

effective transfer impedance

Z_{TE}

impedance defined as:

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

where Z_F is the capacitive coupling impedance

3.4
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 $P_\mathrm{r,max}$ in the outer circuit

$$a_\mathrm{s} = 10 \cdot \lg\left(\mathrm{Env}\left|\frac{P_1}{P_\mathrm{r,max}}\right|\right) \tag{4}$$

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

$$a_\mathrm{s} = 20 \cdot \lg\frac{150\Omega}{Z_\mathrm{TE}} \tag{5}$$

where

150 Ω	is the standardised impedance of the outer circuit.

3.5
coupling attenuation

a_c

for a screened balanced device, 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 $P_\mathrm{r,max}$ in the outer circuit.

3.6
coupling length

length of cable that is inside the test jig, i.e. the length of the screen under test

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

$$\lambda_\mathrm{o}/L > 10 \cdot \sqrt{\varepsilon_\mathrm{r1}} \quad \text{or} \quad f < \frac{c_\mathrm{o}}{10 \cdot L \cdot \sqrt{\varepsilon_\mathrm{r1}}} \tag{6}$$

or electrically long, if

$$\lambda_\mathrm{o}/L \leq 2 \cdot \left|\sqrt{\varepsilon_\mathrm{r1}} - \sqrt{\varepsilon_\mathrm{r2}}\right| \quad \text{or} \quad f > \frac{c_\mathrm{o}}{2 \cdot L \cdot \left|\sqrt{\varepsilon_\mathrm{r1}} - \sqrt{\varepsilon_\mathrm{r2}}\right|} \tag{7}$$

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_0	is the velocity of light in free space, in m/s.

3.7
device under test
DUT
connector with mating connector and attached connecting cables or cable assembly consisting of the assembly with their attached mated connectors and with connecting cables

4 Physical background

See IEC TS 62153-4-1, IEC 62153-4-3, IEC 62153-4-4, and Annex A to Annex F.

5 Principle of the test methods

5.1 General

The IEC 62153-4 series describes different test procedures to measure screening effectiveness on communication cables, connectors and components.

Table 1 gives an overview of the test procedures of the IEC 62153-4 series carried out with the triaxial test setup.

Table 1 – IEC 62153-4 series, Metallic communication cable test methods – Test procedures with triaxial test setup

IEC 62153-4 series	Metallic communication cable test methods – Electromagnetic compatibility (EMC)
IEC TS 62153-4-1	Introduction to electromagnetic 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 a_S up to and above 3 GHz
IEC 62153-4-7	Shielded screening attenuation test method for measuring the Transfer impedance Z_T and the screening attenuation a_S or the coupling attenuation a_C of RF-connectors and assemblies up to and above 3 GHz, 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
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 setup

Larger connectors, cable assemblies, and components do not fit into the commercially available test rigs (tubes) of the triaxial test procedures of IEC 62153-4-3, IEC 62153-4-4, and IEC 62153-4-7, respectively, which were designed originally to measure transfer impedance and screening attenuation on communication cables, connectors, and assemblies.

Since rectangular housings with RF-tight caps are easier to manufacture than tubes, the "triaxial cell" was designed to test larger devices, such as connectors, assemblies and components. The principles of the triaxial test procedures in accordance with IEC 62153-4-3, IEC 62153-4-4 and IEC 62153-4-7 can be transferred to rectangular housings. Tubes and rectangular housings may be operated in combination in one test setup (see Figure 2 and Figure 3).

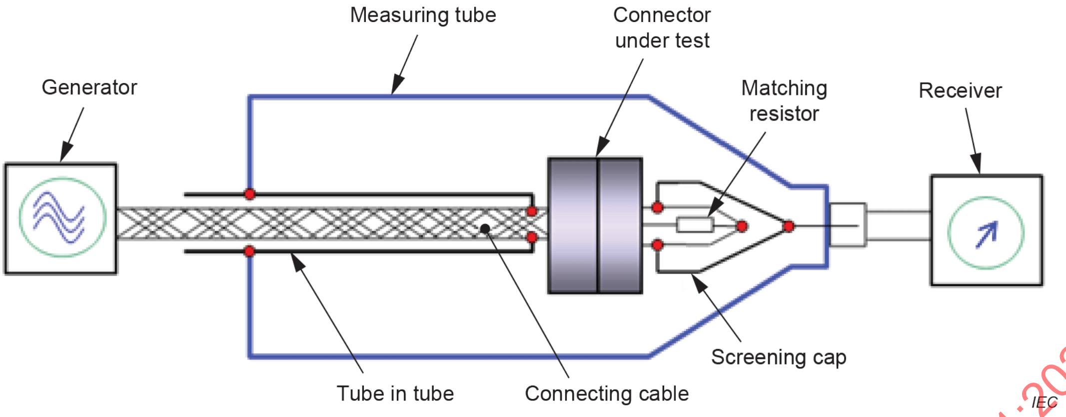

Figure 2 – Principle depiction of the triaxial test setup (tube) to measure transfer impedance and screening attenuation with tube in tube in accordance with IEC 62153-4-7

In principle, the triaxial cell can be used in accordance with all triaxial procedures of Table 1, where originally a cylindrical tube is used. The screening effectiveness of connectors, assemblies or other components can be measured, in principle, in the tube as well as in the triaxial cell. Test results of measurements with tubes and with triaxial cells correspond well.

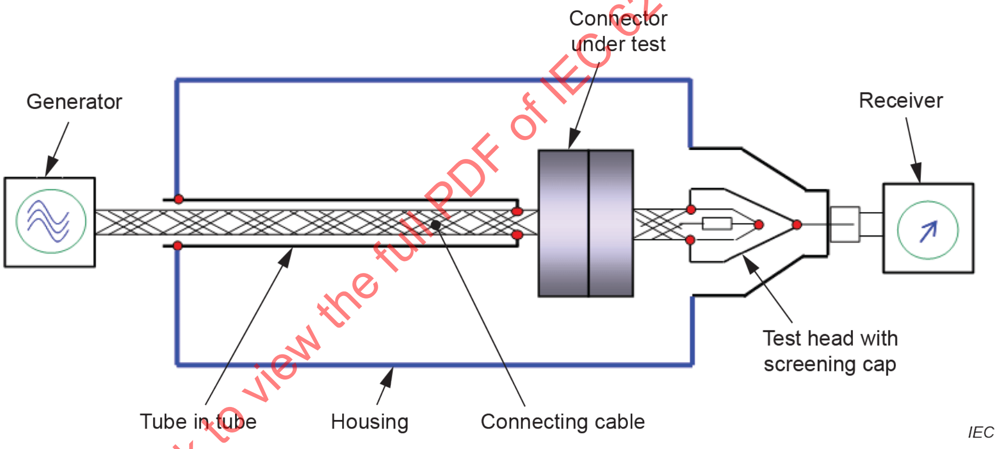

Figure 3 – Principle depiction of the triaxial cell to measure transfer impedance and screening attenuation of connectors or assemblies with tube in tube in accordance with IEC 62153-4-7

The triaxial cell test setup is based on the triaxial system in accordance with IEC 62153-4-3 and IEC 62153-4-4, consisting of the DUT, a solid metallic housing and an RF-tight extension tube (optional). The matched device under test (DUT), which is fed by a generator via a connecting cable, 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 connecting cable (or the tube in tube, if applicable) and a solid metallic housing or cell having the DUT in its axis.

5.2 Transfer impedance

The test determines the screening effectiveness of a shielded device 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 the secondary circuit in order to determine the surface transfer impedance. This test measures only the galvanic and magnetic components of the transfer impedance. To measure the electrostatic component (the capacitance coupling impedance), the method described in IEC 62153-4-8 shall be used.

The triaxial method for the measurement of the transfer impedance 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 can be 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 component 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 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 housings of an appropriate 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.

5.4 Coupling attenuation

The coupling attenuation of screened balanced pairs describes the global effect against electromagnetic interference (EMI) and takes into account the screening attenuation of the screen and the unbalance attenuation of the pair. A detailed description of coupling attenuation can be found in IEC 62153-4-9.

5.5 Tube-in-tube method

If required, measurements in accordance with IEC 62153-4-7 can also be achieved in the triaxial cell, using the triaxial cell instead of the tube fixture (see Figure 2 and Figure 3).

6 Test procedures

6.1 General

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

6.2 Triaxial cell

The triaxial cell consists of a rectangular housing in analogy to the principles of the triaxial test procedures in accordance with IEC 62153-4-3 and IEC 62153-4-4. The material of the housing shall be of non-ferromagnetic metallic material. The length of the housing should be preferably 1 m.

Reflections of the transmitted signal can occur (in the outer circuit) owing to the deviation of the characteristic impedances. The plane of the short circuit at the near end (generator side) should be therefore preferably directly on the wall of the housing.

At the receiver side, the transition of the housing to the coaxial system impedance (50 Ω-system) should be also directly on the wall of the housing.

6.3 Cut-off frequencies, higher-order modes

The triaxial test procedure uses the principle of transverse electromagnetic wave propagation (TEM – waves). At higher frequencies, the triaxial cell becomes in principle a cavity resonator, or a rectangular waveguide, which exhibits resonances depending on its dimensions; see Figure 4.

Above these resonance frequencies, propagation of TEM waves is disturbed and measurements of screening attenuation with triaxial test method are limited.

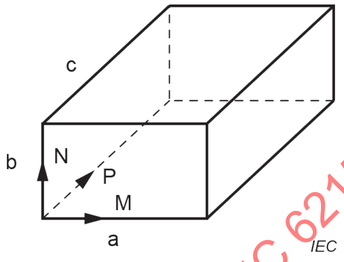

Figure 4 – Rectangular waveguide

The cut-off frequency f_c of a rectangular cavity resonator is given by:

$$f_c = \frac{c_0}{2a} \tag{8}$$

For a rectangular cavity resonator, the resonance frequencies can be calculated using Equation (9). For this calculation, one of the parameters M, N, P can be set to zero.

$$f_{MNP} = \frac{c_0}{2}\sqrt{\left(\frac{M}{a}\right)^2 + \left(\frac{N}{b}\right)^2 + \left(\frac{P}{c}\right)^2} \tag{9}$$

where

M, N are the number of modes (even, 2 of 3 > 0);

a,b,c are the dimensions of the cavity;

c_0 is the velocity of light in free space.

NOTE Conductive parts inside the cavity resonator or a poor centring of the DUT in the triaxial cell can lead to deviating resonance frequencies or to muting them.

Measurements of screening attenuation can be achieved up to the first cut-off frequency (M, N = 1).

The frequency range of the triaxial cell can be extended up to and above 3 GHz by using absorber material placed on the bottom of the cell, see Annex C.

6.4 Test equipment

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

The measuring equipment consists of the following:

a) a vector network analyser (with S-parameter test set), or

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

c) impedance-matching circuit if necessary:
   - primary side: nominal impedance of generator,
   - secondary side: nominal impedance of the inner circuit,
   - loss: > 10 dB.

d) balun for impedance matching of the unbalanced generator output signal to the characteristic impedance of balanced cables for measuring the coupling attenuation. Requirements for the balun are given in IEC 62153-4-9:2018, 6.3. Alternatively, a VNA with a mixed mode option may be used, see IEC TR 61156-1-2.

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;
- absorber material.

6.5 Calibration procedure

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

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

When using a (vector) network analyser without an S-parameter test-set, i.e. by using a power splitter, a THRU calibration shall be established that includes the test leads used to connect the test setup 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 can be corrected:

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

where

a_{cal} is the attenuation obtained at the calibration procedure, in dB;

P_1 is the power fed during calibration procedure, in W;

P_2 is the power at the receiver during calibration procedure, in W;

S_{21} is the measured S-parameter.

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 or balun is used, the attenuation shall be measured over the above-mentioned frequency range, and the data shall be saved.

6.6 Test leads and connecting cables to the DUT

Test leads and connecting cables to the DUT shall be well screened.

When measuring transfer impedance, the transfer impedance Z_{con} of the connecting cables inside the test setup can be measured separately, either in the triaxial tube or in the triaxial cell, expressed in mΩ/m, in accordance with IEC 62153-4-3. The length of the connecting cables in the set up shall be measured, the transfer impedance Z_{con} calculated and be subtracted from the measured transfer impedance of the DUT.

When measuring screening attenuation or coupling attenuation, the screening attenuation or the coupling attenuation of the connecting cables can be measured separately, either in the triaxial tube or in the triaxial cell, expressed in dB, in accordance with IEC 62153-4-4 or IEC 62153-4-9.

The measured screening attenuation or coupling attenuation of the connecting cables inside the setup shall be at least 10 dB better than the measured value of the DUT.

7 Sample preparation

7.1 Coaxial connector or assembly or quasi-coaxial component

The connector or the assembly or the component under test shall be connected to its mating part in accordance with the specifications of the manufacturer.

A well-screened coaxial connecting cable shall be mounted to the connector, the assembly or the component under test and/or its mating part(s). One end of the connecting cable shall be connected to the test head of the test setup and matched with the nominal characteristic impedance of the DUT.

The screen of the other end of the connecting cable shall be connected to the wall of the housing (the short circuit at the generator side).

In the case of a tube-in-tube procedure, the other end of the connecting cable shall be passed through the RF-tight tube in 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 a low contact resistance. On the generator side, the screen of the connecting cable shall not be connected to the extension tube. The extension tube shall be connected to the wall of the housing (the short circuit at the generator side).

7.2 Balanced or multipin connectors or components

The device under test shall be connected to its mating part in accordance with the specifications of the manufacturer.

A balanced or multi-conductor cable, which is usually used with the connector or the device under test, shall be mounted to the connector under test and its mating part or to the device under test in accordance with the specification of the manufacturer.

Screened balanced or multiconductor cables or multipin conductors or components are treated as a quasi-coaxial system when measuring transfer impedance or screening attenuation. Therefore, at the open ends of the feeding cable, all conductors of all pairs shall be connected together. All screens, also 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 6).

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.

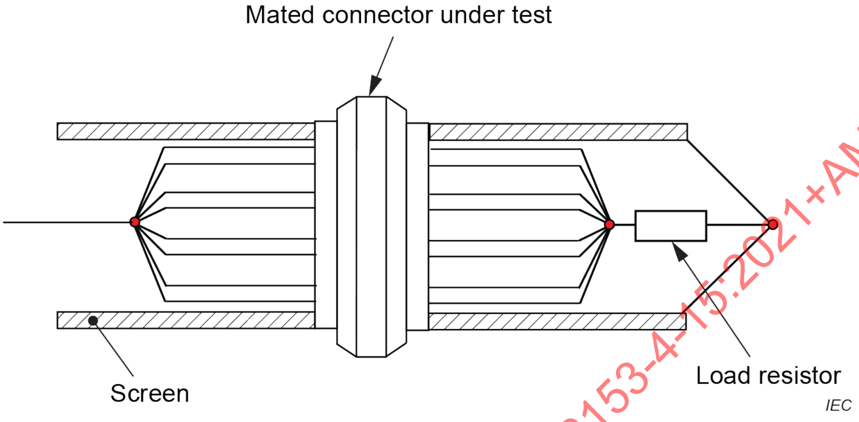

Figure 5 – Preparation of balanced or multipin connectors for transfer impedance and screening attenuation

When measuring the coupling attenuation, the connecting cable shall be fed by a balun or shall be balunless with a VNA with multimode option. The pair under test shall be matched by a symmetrical/asymmetrical load. The pairs that are not under test shall be matched.

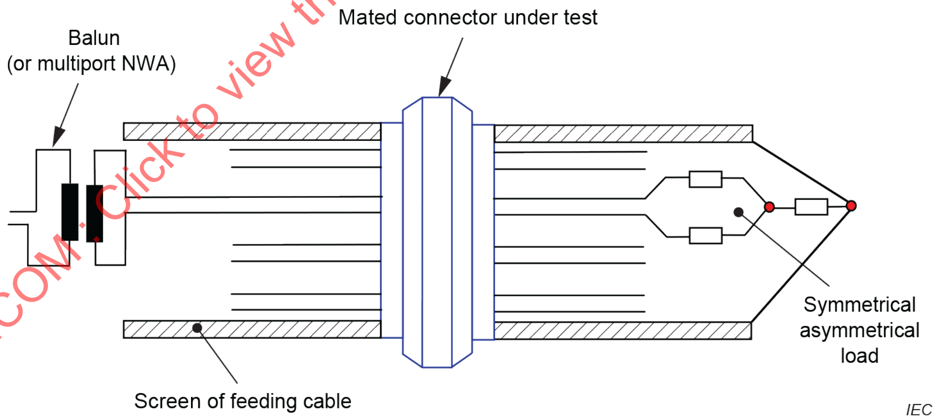

Figure 6 – Preparation of balanced or multipin connectors for coupling attenuation measurement

7.3 Cable assemblies

The connectors of the assembly under test shall be connected with their mating parts on both ends, on one end in the case of single-ended assemblies, in accordance with the specifications of the manufacturer.

The mating connectors shall be connected with well-screened coaxial feeding cables.

In the case of multi-pin conductor assemblies, all conductors of the assembly under test shall be short circuited on both ends in the mating connector. If the assembly under test is connected in its intended use directly to a specific unit and no mating connecter is available, the manufacturer of the assembly shall provide an appropriate mating connector or an appropriate adaptation. The mating connector or the adaption shall be well screened, at least 10 dB better than the device under test. Care shall be taken to ensure that the connection of the connecting cable to the mating connector or the adaption is well screened.

7.4 Other screened devices

The screening effectiveness of other shielded or screened devices, e.g. screened cable conduits, may also be measured with the triaxial cell. They shall be prepared and treated as quasi-coaxial systems.

8 Transfer impedance (short-matched)

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 of IEC 62153-4-3 (the tube being replaced by a cell): 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.

Other procedures in accordance with 62153-4-3 may be applied accordingly, if required.

8.2 Principle block diagram of transfer impedance

A block diagram of the test setup to measure transfer impedance in accordance with test method B of IEC 62153-4-3 is shown in Figure 7.

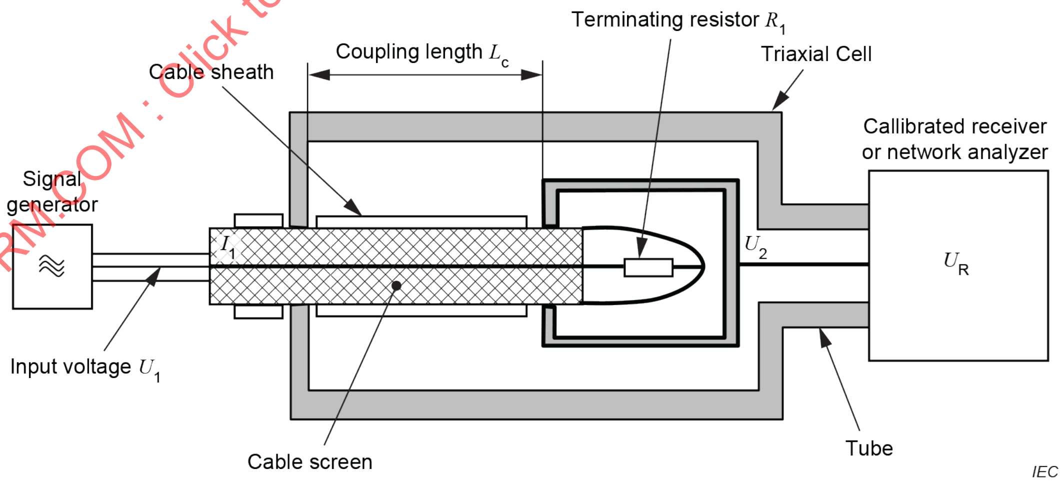

Figure 7 – Test setup (principle) for transfer impedance measurement in accordance with test method B of IEC 62153-4-3

8.3 Measuring procedure

The length of the connecting cables inside the cell to connect the DUT shall be measured.

The transfer impedance of the connecting cables, which connect the DUT, shall be measured in accordance with IEC 62153-4-3. The measured value shall be related to the length of the connecting cables inside the cell to connect the DUT, the result being the transfer impedance of the connecting cables, Z_{con}.

The DUT shall be connected to the generator and the outer circuit (cell) to the receiver.

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

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

where

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

P_1 is the power fed to inner circuit, in W;

P_2 is the power in the outer circuit, in W;

S_{21} is the measured S-parameter.

8.4 Evaluation of test results

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

$$Z_{\mathrm{T}} = \frac{R_1 + Z_0}{2} \cdot 10^{-\left(\frac{a_{\mathrm{meas}} - a_{\mathrm{cal}}}{20}\right)} - Z_{\mathrm{con}} \tag{12}$$

where

Z_{T} is the transfer impedance, in Ω;

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

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

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

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

Z_{con} is the transfer impedance of connecting cables, in Ω.

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

8.5 Test report

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

9 Screening attenuation

9.1 General

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

9.2 Impedance matching

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 a maximum 200 ps rise time or using the method described in Annex A of IEC 62153-4-4:2015.

An impedance matching adapter to match the impedance of the generator and the impedance of the quasi-coaxial system is not recommended because it reduces the dynamic range of the test setup and may have sufficient matching (return loss) only up to 100 MHz when using self-made adapters that are necessary for impedances other than 60 Ω or 75 Ω (see Annex B of IEC 62153-4-4:2015).

9.3 Measuring with matched conditions

9.3.1 Procedure

The DUT shall be connected to port 1 and the test head of the setup shall be connected to port 2 of the vector network analyser (Figure 7).

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.

9.3.2 Evaluation of test results

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

$$a_S = 10 \cdot \lg\left|\frac{P_1}{P_{r,\max}}\right| = 10 \cdot \lg\left|\frac{P_1}{P_{2,\max}} \cdot \frac{2 \cdot Z_S}{R}\right| \qquad (13)$$

$$= Env\left\{-20 \cdot \lg\left|S_{21}\right| + 10 \cdot \lg\left|\frac{300\ \Omega}{Z_1}\right|\right\} - \alpha_{att} \qquad (14)$$

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 setup 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 device under test, in Ω;
R	Is the input impedance of the receiver;

α_{att} is the attenuation of the impedance matching adapter – if used and if not taken into account otherwise, e.g. during the calibration procedure of the network analyzer.

This conversion – Equations (13) and (14) – from the measured forward transfer scattering parameter S_{21} to screening attenuation is only valid if the characteristic impedance of the outer circuit Z_2 is higher than the input impedance of the receiver R (see IEC TS 62153-4-1:2014, Clause 9). In the case where the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2, a correction factor may be applied (see Annex E).

Details of attenuation versus the forward transfer scattering parameter S_{21} are given in Annex G.

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

9.4 Measuring with mismatch

9.4.1 General

The DUT shall be connected to port 1 and the test head of the setup 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.

9.4.2 Evaluaton 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].

$$a_s = 10 \cdot \lg\left|\frac{P_1}{P_{r,max}}\right| = 10 \cdot \lg\left|\frac{P_1}{P_{2,max}} \cdot \frac{2 \cdot Z_S}{R}\right| \tag{15}$$

$$= Env \cdot \left\{-20 \cdot \lg\left|S_{21}\right| + 10 \cdot \lg\left|1 - r^2\right| + 10 \cdot \lg\left|\frac{300\ \Omega}{Z_1}\right|\right\} \tag{16}$$

where

a_s is the screening attenuation related to the radiating impedance of 150 Ω, in dB;

R is the receiver input impedance, in Ω;

Env is the minimum envelope curve of the measured values, in dB;

S_{21} is the scattering parameter S_{21} (complex quantity) of the setup where the primary side of the two port is the DUT and the secondary side is the tube;

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[1] Z_s is the normalised value of the characteristic impedance of the environment of a typical cable installation. It is in no relation to the impedance of the outer circuit of the test setup.

r is the reflection coefficient between the generator's impedance and the nominal characteristic impedance of the cable under test: $r = \left| \left(\frac{Z_0 - Z_1}{Z_0 + Z_1} \right) \right|$;

Z_0 is the characteristic impedance of system, in Ω, (usually 50 Ω);

Z_1 is the characteristic impedance of the device under test, in Ω.

This conversion – Equations (15) and (16) – from the measured forward transfer scattering parameter S_{21} to screening attenuation is only valid if the characteristic impedance of the outer circuit Z_2 is higher than the input impedance of the receiver R (see IEC TS 62153-4-1:2014, Clause 9). In the case where the receiver input impedance R is higher than the characteristic impedance of the outer circuit Z_2, a correction factor may be applied (see Annex E).

9.5 Test report

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

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

10 Coupling attenuation

10.1 General

Measuring of coupling attenuation shall be in accordance with IEC 62153-4-9.

IEC 62153-4-9 describes both, measuring with balun and balunless measurements. 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 (usually 100 Ω) 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.

A detailed description of mixed mode parameters is given in Annex C of 62153-4-9:2018.

10.2 Procedure

10.2.1 Coupling attenuation with balun

The DUT is connected to the connecting cables in accordance with the instructions of the manufacturer and terminated at the far end by differential and common mode terminations in accordance with IEC 62153-4-9. The sample is then centred in the cell.

The DUT shall be connected via a balun to port 1 (i.e. it is exited in differential mode) and the test head of the setup shall be connected to port 2 of the vector network analyser. The forward transfer scattering parameter S_{21} shall be measured.

Only the maximum peak values of the measured forward transfer scattering parameter S_{21} shall be 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, and the attenuation of the balun shall be taken into account when calibrating the triaxial apparatus.

The maximum peak values of the measured forward transfer scattering parameter S_{21} are not dependent on the diameter of the outer tube of the triaxial test setup or on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

10.2.2 Balunless coupling attenuation

IEC 62153-4-9 describes the measurement with a standard test head as well as with an open test head. The method described herein is the method with a standard head. According to IEC 62153-4-9, measurements can be performed with balun or balunless. The balunless procedure with the standard test head is shown in Figure 8.

The DUT is connected to the connecting unit and terminated at the far end by differential and common mode terminations, in accordance with IEC 62153-4-9. The sample is then centred in the cell.

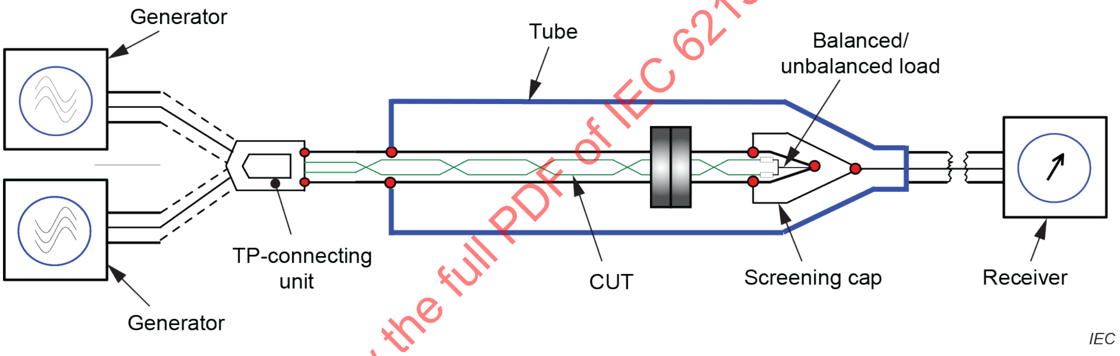

Figure 8 – Principle test setup for balunless coupling attenuation measurement according to IEC 62153-4-9

Connecting cables shall be connected to the TP connecting unit in accordance with IEC 62153-4-9.

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

10.3 Expression of results

The attenuation of the balun or the TP-connecting unit shall be subtracted from the measuring results. The coupling attenuation a_{c} shall be calculated with the normalised value Z_{S} = 150 Ω:

$$a_{\text{c}} = 10 \cdot \lg\left|\frac{P_{\text{diff}}}{P_{\text{r,max}}}\right| = 10 \cdot \lg\left|\frac{P_{\text{diff}}}{P_{\text{com}}}\right| + 10 \cdot \lg\left|\frac{P_{\text{com}}}{P_{\text{r, max}}}\right| \text{ dB,} \tag{17}$$

$$a_{\text{c}} = 20 \cdot \lg\left|\frac{U_{\text{diff}}}{U_{\text{com}}}\right| + 10 \cdot \lg\left[\frac{Z_{\text{com}}}{Z_{\text{diff}}}\right] + 20 \cdot \lg\left|\frac{U_{\text{com}}}{U_{\text{2,max}}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_{\text{S}}}{Z_{\text{com}}}\right] \text{ dB,} \tag{18}$$

$$a_{\mathrm{c}} = 20 \cdot \lg \left| \frac{U_{\mathrm{diff}}}{U_{2,\max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_{\mathrm{S}}}{Z_{\mathrm{diff}}} \right] \text{ dB,} \tag{19}$$

where

a_{c}	is the coupling attenuation related to the radiating impedance of 150 Ω, in dB;
P_{diff}	is the input power in the differential mode, in W;
P_{com}	is the output power which couples to the common mode, in W;
$P_{\mathrm{r,max}}$	is the periodic maximum value of the common mode radiated power, in W;
U_{diff}	is the input voltage in the differential mode, in V;
U_{com}	is the output voltage in the common mode, in V;
$U_{2,\max}$	is maximum output peak voltage in the common mode, in V;
Z_{diff}	is the nominal characteristic differential mode impedance of the differential mode (balanced), in Ω;
Z_{com}	the characteristic common mode impedance (unbalanced), in Ω;
Z_{S}	is the normalised value of the characteristic impedance of the environment of the cable, in Ω.

The coupling attenuation shall be described by an envelope line as described in Annex H, Clause H.3. In case the measurement is made with mixed mode scattering parameters, the coupling attenuation shall be obtained as described in Annex H, Clause H.2.

10.4 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.

Annex A
(informative)

Principle of the triaxial test procedure

A.1 General

With the triaxial test setup, one can measure the transfer impedance at the lower frequency range and the screening attenuation or the coupling attenuation at higher frequencies.

The test setup consists of a network analyser (or alternatively a discrete signal generator and a selective measuring receiver) and a tube with terminations to the cable screen and the network analyser or receiver. The material of the tube shall be well conductive and non-ferromagnetic, for example brass or aluminium.

The cable under test (CUT), which is centred in the middle of the tube, forms together with the tube a triaxial system (see Figure A.1). The inner system is the CUT itself and the outer system is formed by the screen under test and the tube.

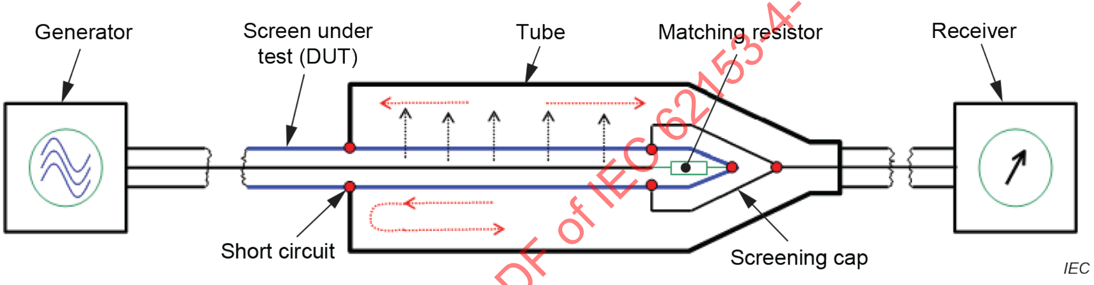

Figure A.1 – Principle test setup to measure transfer impedance and screening attenuation

The CUT is terminated with its characteristic impedance at the far end (see Figure A.1).

The screen under test is short circuited with the tube at the near end of the generator. Owing to this short circuit, the influence of capacitive parts is excluded.

A generator with the voltage U_1 feeds the inner system. The voltage U_2 is measured with a measuring receiver with an input impedance larger or equal to the characteristic impedance of the outer circuit, see Figure A.2.

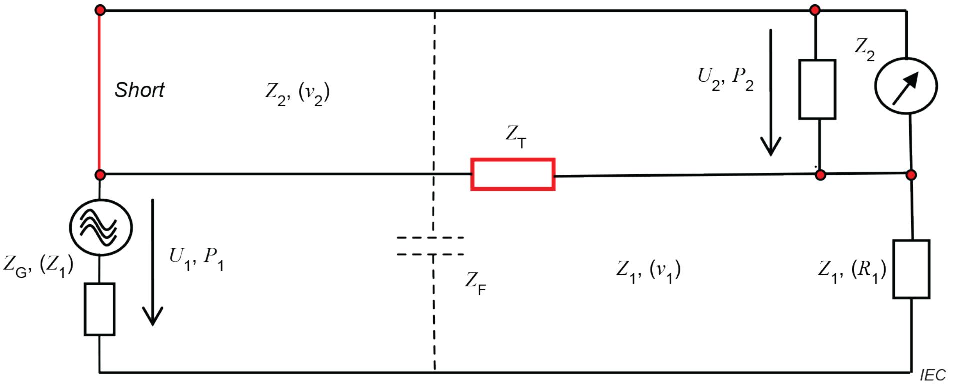

Figure A.2 – Equivalent circuit of the principle of the test setup in Figure A.1

The energy, which couples through the weak screen, travels into both directions of the tube, respectively the outer system. At the short circuit at the near end side of the generator, the wave is totally reflected, so that the receiver measures the complete energy that couples through the screen.

A.2 Transfer impedance

At the low frequency range, the transfer impedance Z_T may be calculated from the voltage ratio U_2/U_1:

$$Z_T \cdot l \approx Z_1 \cdot \left|\frac{U_2}{U_1}\right| \qquad \text{if } Z_T << Z_1 \tag{A.1}$$

A detailed description of the transfer impedance is given in IEC 62153-4-1 and in IEC 62153-4-3.

A.3 Screening attenuation

At high frequencies, the logarithmic ratio of the input power P_1 to the measured power P_2 in the outer circuit gives the screening attenuation a_S.

$$a_S = 10 \cdot lg\left(\left|\frac{P_1}{P_2}\right|_{\text{max}}\right) = 20 \cdot \text{lg}\left(\left|\frac{U_1}{U_2}\right|_{\text{max}}\right) + 10 \cdot \text{lg}\left|\frac{Z_2}{Z_1}\right| \tag{A.2}$$

In order to compare the screening attenuation with other test procedures in accordance with IEC 62153-4-4, the measured ratio of power P_1 to P_2 is related to the standardized characteristic impedance of the outer system of Z_s = 150 Ω (for further details see IEC TS 62153-4-1:2014, Clause 9):

$$a_S = 10 \cdot \text{lg}\left(\left|\frac{P_1}{P_{\text{r,max}}}\right|\right) = 10 \cdot \text{lg}\left(\left|\frac{P_1}{P_{\text{2,max}}} \cdot \frac{2 \cdot Z_s}{Z_R}\right|\right) = 10 \cdot \text{lg}\left(\left|\left(\frac{U_1}{U_{\text{2,max}}}\right)^2 \cdot \frac{Z_R}{Z_1} \cdot \frac{2 \cdot Z_s}{Z_R}\right|\right) \tag{A.3}$$

$$a_\text{S} = 10 \cdot \lg\left(\left|\frac{P_1}{P_\text{r}}\right|_\text{max}\right) = 20 \cdot \lg\left(\left|\frac{U_1}{U_2}\right|_\text{max}\right) + 10 \cdot \lg\left|\frac{2 \cdot Z_\text{S}}{Z_1}\right| \qquad \text{(A.4)}$$

where

P_1 is the power fed to the DUT (inner system), in W;

P_2 is the power measured at the receiver (outer system), in W;

P_r is radiated power related to the normalised impedance of the environment

Z_S = 150 Ω;

U_1 is the input voltage of the DUT, in V;

U_2 is the voltage measured at the receiver, in V;

Z_R is the input impedance of the receiver, in Ω;

Z_G is the output impedance of the generator, in Ω;

Z_S is the arbitrary determined normalized impedance of the environment of a typical cable installation Z_S = 150 Ω.

A detailed description of the screening attenuation is given in IEC 62153-4-1 and in IEC 62153-4-4.

A.4 Coupling attenuation

Balanced cables, connectors, assemblies or devices that are driven in the differential mode may radiate a small part of the input power, due to irregularities in the symmetry of the pair. 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 that 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 interaction of the unbalance attenuation a_u of the pair and the screening attenuation a_S of the screen.

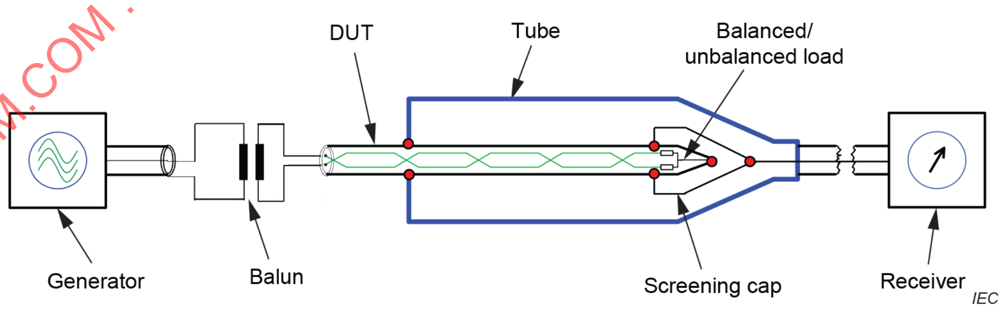

Figure A.3 – Coupling attenuation, principle of test setup with balun and standard tube

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

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 that 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.

A detailed definition of mixed mode S-parameters for measurements with virtual balun is given in IEC 62153-4-9:2018, Annex C.

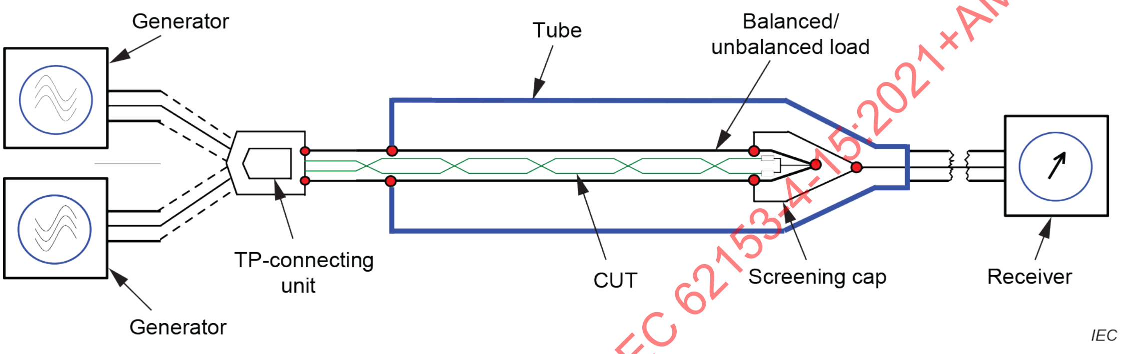

Figure A.4 – Coupling attenuation, principle of setup with multiport VNA and standard head

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:

$$a_\mathrm{C} = 10 \cdot \lg\left|\frac{P_\mathrm{diff}}{P_\mathrm{com}}\right| + 10 \cdot \lg\left|\frac{P_\mathrm{com}}{P_{\mathrm{r,\,max}}}\right| \ \mathrm{dB}, \tag{A.5}$$

$$a_\mathrm{C} = 20 \cdot \lg\left|\frac{U_\mathrm{diff}}{U_\mathrm{com}}\right| + 10 \cdot \lg\left[\frac{Z_\mathrm{com}}{Z_\mathrm{diff}}\right] + 20 \cdot \lg\left|\frac{U_\mathrm{com}}{U_{2,\mathrm{max}}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_\mathrm{S}}{Z_\mathrm{com}}\right] \ \mathrm{dB}, \tag{A.6}$$

$$a_\mathrm{C} = 20 \cdot \lg\left|\frac{U_\mathrm{diff}}{U_{2,\mathrm{max}}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_\mathrm{S}}{Z_\mathrm{diff}}\right] \tag{A.7}$$

A detailed description of the coupling attenuation is given in IEC 62153-4-1 and in IEC 62153-4-9.

Annex B
(informative)

Triaxial cell

Larger connectors and cable assemblies do not fit into the commercially available test rigs of the triaxial test procedure, which were designed originally to measure transfer impedance and screening attenuation on communication cables, connectors, and assemblies.

The "triaxial cell" was designed to test larger devices and assemblies, especially for the HV cables and components for electromotive vehicles. The principles of the triaxial test procedures can be transferred to rectangular housings.

Tubes and rectangular housings can be operated in combination in one test rig. The screening effectiveness of larger connectors or devices can be measured in the tube as well as in the triaxial cell. Test results of tube and cell measurements correspond well.

The triaxial cell consists of a rectangular housing in analogy to the principles of the triaxial test procedure, in accordance with IEC 62153-4-3 and IEC 62153-4-4. The material of the housing shall be of non-ferromagnetic metallic material; see Figure B.1 and Figure B.2.

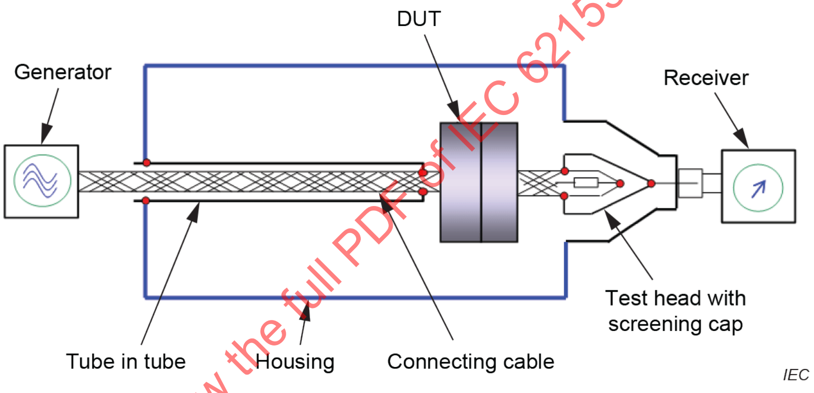

Figure B.1 – Principle depiction of the triaxial cell to measure transfer impedance and screening attenuation on a connector with tube-in-tube according to IEC 62153-4-7

Reflexions of the transmitted signal may occur (in the outer circuit), owing to the deviation of the characteristic impedances. The plane of the short circuit at the near end (generator side) should be therefore preferably directly on the wall of the housing of the cavity without any additional tube.

At the receiver side, the transition of the housing to the coaxial 50 Ω system should be also directly on the wall of the housing.