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Edition 2.2 2024-06
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

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Metallic communication cable test methods –
Part 4-9: Electromagnetic compatibility (EMC) related test method for measuring coupling attenuation of screened balanced cables – Triaxial method

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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method

FOREWORD

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

IEC 62153-4-9 edition 2.2 contains the second edition (2018-05) [documents 46/681/FDIS and 46/685/RVD], its amendment 1 (2020-07) [documents 46/773/FDIS and 46/776/RVD] and its amendment 2 (2024-06) [documents 46/990/FDIS and 46/1002/RVD].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendments 1 and 2. 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 62153-4-9 has been prepared by IEC technical committee 46: Cables, wires, waveguides, RF connectors, RF 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:

– two test procedures, open head and standard head procedure;
– measuring with balun or with multiport respectively mixed mode VNA;
– extension of frequency range up to and above 2 GHz.

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

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

The committee has decided that the contents of this document and its amendments 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- withdrawn, or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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INTRODUCTION to Amendment 1

The goal of this amendment is to extent IEC 62153-4-9 such that also the coupling attenuation of unscreened single or multiple balanced pairs or unscreened quads can be measured with the triaxial test procedure.

Further complement is the extension of the usable frequency range down to frequencies below 9 kHz to measure the low frequency coupling attenuation of screened and unscreened balanced pairs or quads.

METALLIC COMMUNICATION CABLE TEST METHODS –

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

1 Scope

This part of IEC 62153 applies to metallic communication cables. It specifies a test method for determining the coupling attenuation a_C of screened balanced cables. Due to the concentric outer tube, measurements are independent of irregularities on the circumference and external electromagnetic fields.

A wide dynamic and frequency range can be applied to test even super screened cables with normal instrumentation from low frequencies up to the limit of defined transversal waves in the outer circuit at approximately 4 GHz. However, when using a balun, the upper frequency is limited by the properties of the balun.

Measurements can be performed with standard tube procedure (respectively with standard test head) according to IEC 62153-4-4 or with open tube (open test head) procedure.

The procedure described herein to measure the coupling attenuation a_C is based on the procedure to measure the screening attenuation a_S according to IEC 62153-4-4.

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 60050-726, *International Electrotechnical Vocabulary – Chapter 726: Transmission lines and waveguides*

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

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

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

IEC 62153-4-5, *Metallic communication cables test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing clamp method*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in IEC 60050-726, IEC TS 62153-4-1 and IEC 62153-4-4, as well as the following symbols apply.

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

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

a_s is the screening attenuation which is comparable to the results of the absorbing clamp method in dB;

a_c is the coupling attenuation related to the radiating impedance of 150 Ω in dB;

a_u is the unbalanced attenuation;

$a_{m,min}$ is the attenuation recorded as minimum envelope curve of the measured values in dB;

a_z is the additional attenuation of a possible inserted adapter, if not otherwise eliminated e.g. by the calibration, in dB;

C_T is the through capacitance of the outer conductor in F/m;

c_0 is the vacuum velocity in m/s;

dx is the differential length operator of integration;

λ_0 is the vacuum wavelength in m;

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

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

$\varepsilon_{r2,n}$ is a normalised value of the relative dielectric permittivity of the environment of the cable;

f is the frequency in Hz;

j is the imaginary operator (square root of minus one);

L is the transmission line parameter-inductance;

l is the effective coupling length in m;

φ is a phase factor in the ratio of the secondary to primary circuit end voltages (U_1/U_2);

P_1 is the feeding power of the primary circuit in W;

P_2 is the measured power received on the input impedance;
R of the receiver in the secondary circuit in W;

P_r is the radiated power in the environment of the cable, which is comparable to P_{2n} + P_{2f} of the absorbing clamp method in W;

$P_{r,max}$ is the periodic maximum value of the common mode radiated power in W;

P_s is the radiated power in the normalised environment of the cable under test,
(Z_s = 150 Ω and $|\Delta v / v_1|$ = 10 %) in W,

$$\varphi_1 = 2\pi \times \left(\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right) \times l / \lambda_0 \quad (1)$$

$$\varphi_2 = 2\pi \times \left(\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}\right) \times l / \lambda_0 \quad (2)$$

$$\varphi_3 = \varphi_2 - \varphi_1 = 4\pi \times \sqrt{\varepsilon_{r2}} \times l / \lambda_0 \quad (3)$$

R is the input impedance of the receiver in Ω;

R_{DM} is the differential mode termination, Ω;

S is the summing function;

T is the coupling transfer function;

U_1 is the input voltage of the primary circuit formed by the cable in V;

U_2 is the output voltage of the secondary circuit in V;

Ω is the radian frequency ω;

Z_1 is the (differential mode) characteristic impedance of the cable under test (primary circuit) in Ω;

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

Z_{com} is the common mode (unbalanced);

Z_{diff} is the nominal characteristic impedance of the differential mode (balanced);

Z_F is the capacitive coupling impedance of the cable under test in Ω/m,

$$Z_F = Z_1 \cdot Z_2 \cdot j \cdot 2 \cdot \pi \cdot f \cdot C_T \tag{4}$$

Z_S is the normalised value of the characteristic impedance of the environment of the cable;

Z_T is the transfer impedance of the cable under test in Ω/m;

4 Principle of the measuring method

4.1 General

Coupling attenuation of screened balanced cables describes the overall effect against electromagnetic interference (EMI) taking into account both the unbalance attenuation of the pair and the screening attenuation of the screen.

The disturbing circuit (the inner or primary circuit) consists of the test cable which is fed by a generator and is impedance-matched at the near and far ends. The disturbed circuit (the outer or secondary circuit) is formed by the solid metallic tube and the short section of the cable under test covered by the tube. The disturbed circuit (the outer or secondary circuit) is terminated at the near end in a short circuit and is terminated at the far end with a calibrated receiver or network analyser.

The voltage peaks at the far end of the secondary circuit are measured with a calibrated receiver or network analyser. For this measurement a matched receiver is not necessary. These voltage peaks are not dependant on the input impedance of the receiver, provided that the input impedance of the receiver is lower than the characteristic impedance of the secondary circuit. However, it is advantageous to have a low mismatch, for example by selecting a range of tube diameters for several cable sizes.

To measure the coupling attenuation as well as to measure the unbalance attenuation a differential signal is required. This can, for example, be generated using a balun which converts the unbalanced signal of a 50 Ω network analyser into a balanced signal.

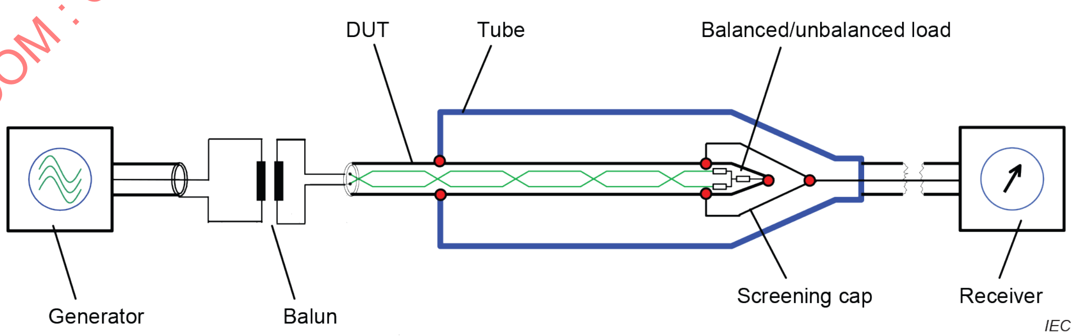


Figure 1 – Coupling attenuation, principle test set-up with balun and standard tube

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 Annex B.

The test set-up (see Figures 1, 2, 3 and 4) is a triaxial system consisting of an outer solid metallic tube in which the cable under test (CUT) is concentrically positioned.

At the near end, the screen of the screened cable under test is short circuited with the solid metallic tube.

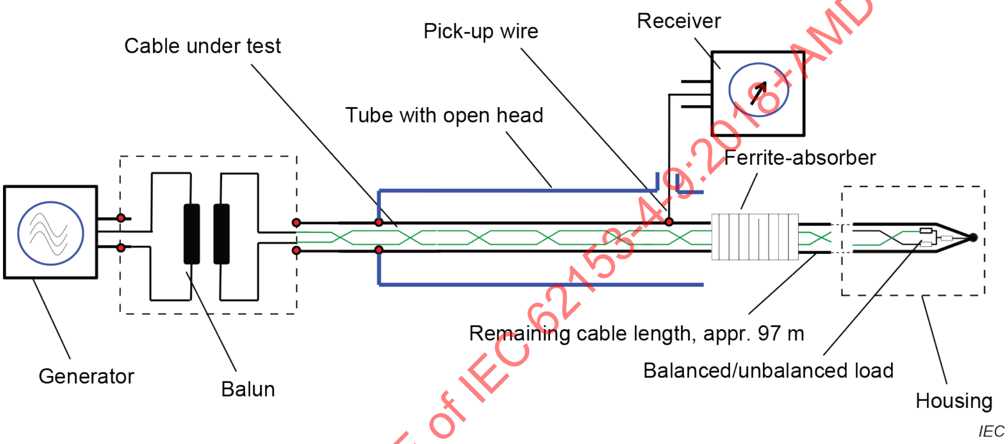


Figure 2 – Coupling attenuation, principle test set-up with balun and open head

At the far end, the tube can be equipped with a “test head” which can be removed from the tube for easier connecting of the CUT. The set-up according to IEC 62153-4-4 is designated as the standard procedure, respectively the procedure with standard head. The advantage is an overall closed and shielded set-up.

Alternatively, the tube can be equipped with an open head at the far end (see Figures 2 and 4).

4.2 Procedure A: measuring with standard tube (standard head)

The set-up detailed in Procedure A uses the standard test-head and is in principle the same as described in IEC 62153-4-4. The screened balanced DUT can be fed either in common mode or in differential mode. In this way, both, screening attenuation of the screen or coupling attenuation of the screened pair can be measured. In principle, with the same set-up, also the transfer impedance of the screen can be measured (taking into account the length of the DUT).

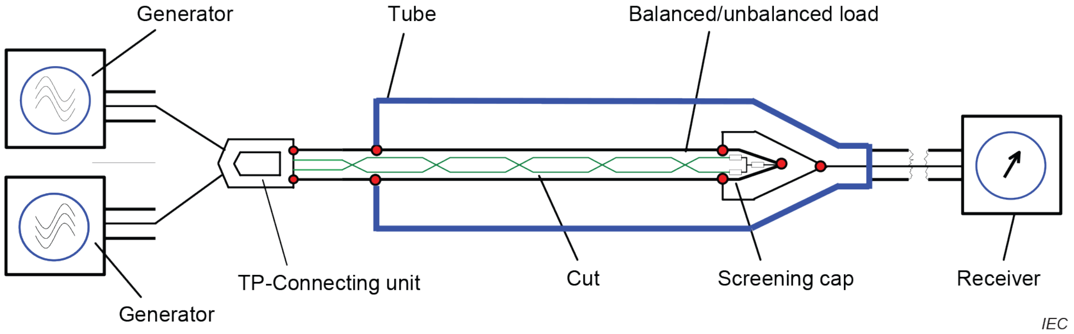


Figure 3 – Coupling attenuation, principle set-up with multiport VNA and standard head

The DUT shall be matched at the far end in common and differential mode. Return loss of the CUT in common and differential mode shall be measured. Values for return loss in common and differential mode shall be at least 10 dB.

4.3 Procedure B: measuring with open head

In case of measuring with open head the first several meters of a longer length of the cable to be tested are concentrically positioned in an outer solid metallic tube. The remaining length (usually of 100 m length) that extends past the tube is placed in a highly shielded box and terminated with common mode and differential mode terminations (see Figure 6). The cable screen shall be connected with low impedance to the screened box. The center point of the differential mode termination shall be connected via the resistor R_{CM} to the highly screened box or cable screen (see Figure 6).

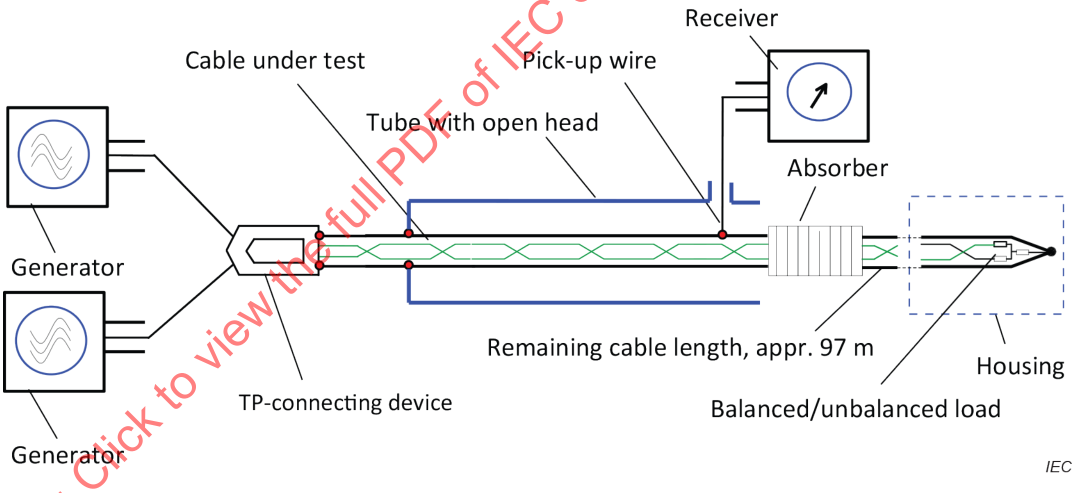


Figure 4 – Coupling attenuation, principle set-up with multiport VNA and open head

At the near end, the screen of the screened cable under test is short circuited with the solid metallic tube.

At the far end, the tube is let open and the signal is picked up by a “pick up wire”, which is connected to the screen of the cable under test (see Figure 4). The open tube system can also be equipped with a “test head” which can be removed from the tube for easier connecting of the CUT.

At the open end of the tube, absorbers shall be applied to match the system and to avoid back travelling waves into the system. The attenuation of the absorber shall be at least 20 dB. A combination of a ferrite absorber and/or nanocrystalline absorber may be used. A procedure to measure the attenuation of absorbers is given in Annex A.

5 Screening parameters

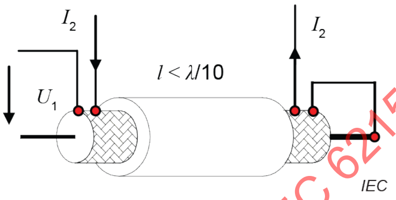
5.1 General

To protect a cable against external electromagnetic interference or to avoid radiation into the environment, the cable is surrounded with screens made of metal foils and/or braids. For cables used in harsh electromagnetic environments, elaborate shield structures, made of several layers or magnetic materials, are also used. In case of balanced cables, also the overall symmetry of the pair contributes to the screening effectiveness in addition to the screen.

The sole effect of the screen is described by the transfer impedance and the screening attenuation. The influence of the symmetry is grasped by the unbalance attenuation. The overall effect of the screen and the symmetry of the pair (for balanced cables) are described by the coupling attenuation.

5.2 Transfer impedance

For an electrically short screen, the transfer impedance Z_T is defined as the 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, related to length in Ω/m or in mΩ/m (see Figure 5).



$$Z_T = \frac{U_1}{I_2 \cdot l} \quad (5)$$

Figure 5 – Definition of transfer impedance

The test procedure for transfer impedance is described in IEC 62153-4-3. According to the definition it can be measured on short cable samples.

5.3 Screening attenuation

The screening attenuation a_S is the measure of the effectiveness of a cable screen. It is the logarithmic ratio of the feeding power P_1 to the maximum radiated power $P_{r,max}$.

With the arbitrary determined normalized value Z_S = 150 Ω (see IEC 62153-4-4) one gets:

$$a_S = 10 \cdot \lg\left|\frac{P_1}{P_{r,max}}\right| = 10 \cdot \lg\left|\frac{P_1}{P_{2,max}} \cdot \frac{2 \cdot Z_S}{R}\right| \text{ dB} \quad (6)$$

$$a_S = 20 \cdot \lg\left|\frac{U_1}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_1}\right] \text{ dB} \quad (7)$$

whereas R is the input impedance of the receiver. More details are given in IEC TS 62153-4-1 and in IEC 62153-4-4.

With the arbitrary determined normalized value Z_S = 150 Ω one gets for screened balanced cables (in the common mode) the screening attenuation a_S:

$$a_s = 10 \cdot \lg \left| \frac{P_{com}}{P_{r,max}} \right| \text{ dB} \quad (8)$$

$$a_s = 20 \cdot \lg \left| \frac{U_{com}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{com}} \right] \text{ dB} \quad (9)$$

5.4 Unbalance attenuation

Screened balanced pairs may be operated in two different modes: the differential mode (balanced) and the common mode (unbalanced). In the differential mode one conductor carries the current $+I$ and the other conductor carries the current $-I$; the screen is without current. In the common mode, both conductors of the pair carry half of the current $+I/2$, and the screen is the return path with the current $-I$, comparable to a coaxial cable.

Under ideal conditions respectively with ideal cables, both modes are independent from each other. However under real conditions, both modes influence each other.

The unbalance attenuation a_u of a pair describes in logarithmic scale how much power couples from the differential mode to the common mode and vice versa. It is the logarithmic ratio of the input power in the differential mode P_{diff} to the power which couples to the common mode P_{com} [8][1].

$$a_u = 10 \cdot \lg \left| \frac{P_{diff}}{P_{com}} \right| \text{ dB} \quad (10)$$

$$= 20 \cdot \lg \left| \frac{U_{diff}}{U_{com}} \right| + 10 \cdot \lg \left[\frac{Z_{com}}{Z_{diff}} \right] \text{ dB} \quad (11)$$

Differences in the resistance of the conductors, in the diameter of the core insulation, in the core capacitance, unequal twisting and different distances of the cores to the screen are some reasons for the unbalance of the pair.

At low frequencies, the unbalance attenuation decreases with increasing cable length. At higher frequencies and/or length, the unbalance attenuation approaches asymptotic to a maximum value – similar to the screening attenuation – depending on the type of cable and its distribution of the inhomogeneity along the cable length. Unbalance attenuation may be determined for the near end as well as for the far end of the cable [5].

5.5 Coupling attenuation

The coupling attenuation of screened balanced pairs describes the global effect against electromagnetic interference (EMI) and takes into account both the effect of the screen and the symmetry of the pair.

1 Figures in square brackets refer to the Bibliography.

6 Measurement

6.1 General

Measurements can be performed with a two-port VNA and balun (see Figures 1 and 2) or with multiport or mixed mode VNA and connecting unit (see Figures 3 and 4) both with standard tube, respectively with standard test head, or with open test head procedure.

6.2 Equipment

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.

The measurement set-ups are shown in Figures 1 to 4 and consist of:

- a metallic non ferromagnetic tube with a length sufficient to produce a superimposition of waves in narrow frequency bands which enable the envelope curve to be drawn; the test head of the tube may be standard head according to IEC 62153-4-4 (Figures 1 and 3) or open head (Figures 2 and 4)
- a two port network analyser when measuring with balun (a separate generator and receiver may also be used);
- a balun for impedance matching of an unbalanced generator output signal to the characteristic impedance of balanced cables; or
- a Twisted Pair (TP)-connecting unit when measuring with multiport respectively with mixed mode VNA;
- absorber rings (ferrite or nanocrystalline) with an attenuation a_{absorber} > 20 dB in the measured frequency range when using the open head method;
- metallic boxes to shield the balun and the remaining cable length including the matching resistors when using the open test head method.

6.3 Balun requirements

A balun may be required to match the output impedance of the generator (a balun is not required when a balanced output generator is used) to the nominal characteristic impedance of the cable under test. The balun performance requirements are specified in Table 1.

The attenuation of the balun shall be kept as low as possible because it will limit the dynamic range of the coupling attenuation measurements.

Table 1 – Balun performance characteristics (1 MHz to 1 GHz)

Parameter	Value
Impedance, primary[a]	50 Ω (unbalanced)
Impedance, secondary[b]	100 Ω or 150 Ω (balanced)
Insertion loss[c] (including matching pads if used)	≤ 10 dB
Return loss, bi-directional	≥ 6 dB
Power rating	To accommodate the power of the generator and amplifier (if applicable)
Output signal balance[d]	≥ 50 dB from 1 MHz to 30 MHz ≥ 50 dB from 30 MHz to 100 MHz ≥ 30 dB from 100 MHz to 1 GHz

[a] Primary impedance may differ if necessary to accommodate analyser outputs other than 50 Ω.

[b] Balanced outputs of the test baluns should be matched to the nominal impedance of the symmetrical cable pair. 100 Ω should be used for termination of 120 Ω cabling.

[c] The insertion loss of a balun shall be mathematically deduced from three insertion loss measurements with three baluns back-to-back (see also IEC 62153-4-5).

[d] Measured per ITU-T Recommendations G.117 [1] and O.9 [2].

6.4 TP-connecting unit requirements

When measuring with “virtual balun”, a TP connecting unit is required. See Table 2.

Table 2 – TP-connecting unit performance characteristics (1 MHz to 2 GHz)

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

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

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

[c] With the test set-up according to [b], the absolute dB value of the S-parameter S_{dd21} then represents the attenuation of the differential mode.

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

6.5 Sample preparation

A differential mode termination is required for each pair at the near and far end of the cable.

$$R_{\mathrm{DM}} = \frac{Z_{\mathrm{diff}}}{2} \tag{12}$$

The termination of the common mode ($R_{DM}//R_{DM} + R_{CM}$) is under consideration.

NOTE Since modern mixed mode VNAs use a 25 Ω generator and receiver impedance as default value for the common mode (see Clause C.2), a value of zero Ω for R_{CM}, respectively a short circuit, is used in general.

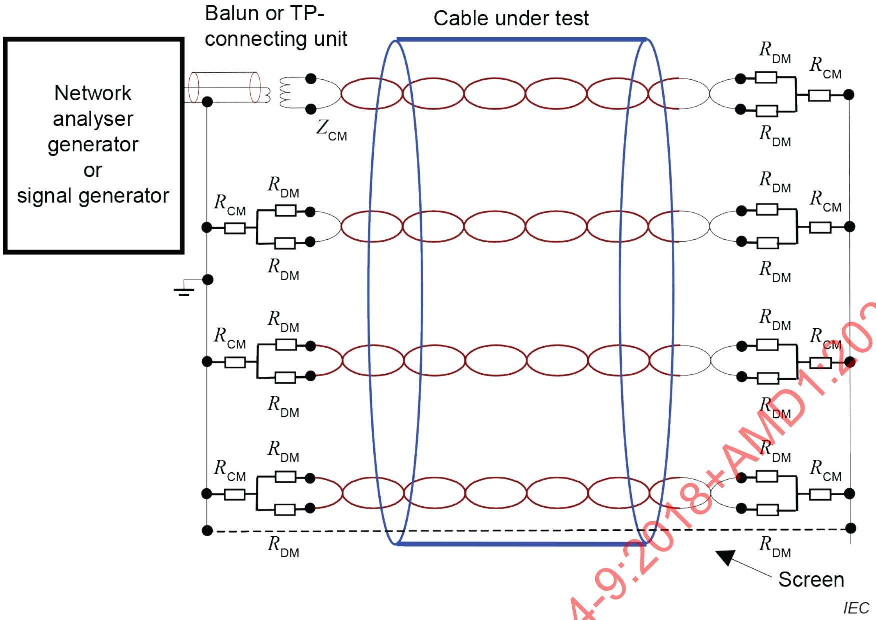


Figure 6 – Termination of the cable under test with balun feeding

6.6 Procedure

The pair under test is terminated at the far end by differential and common mode terminations according to Figure 3. The sample is then centered in the tube and fed by a generator in the differential mode via a balun or with multiport or mixed mode VNA.

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

Only the peak values of the maximum of the voltage ratio or the minimum of the attenuation shall be measured and recorded as a function of the frequency in order to determine the envelope curve.

Attenuation introduced by the inclusion of adapters, instead of direct connection, shall be taken into account when calibrating the triaxial apparatus.

When using multiport or mixed mode VNA, a complete calibration of all ports shall be performed according to the specification of the manufacturer, e.g. by using an electronic calibration kit.

The voltage ratio measured is not dependent on the diameter of the outer tube of the triaxial test set-up nor on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

6.7 Test length

The coupling length is electrically long, if

$$\lambda_o / l \le 2 \times \left| \sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}} \right| \quad \text{or} \quad f > \frac{c_o}{2 \times l \times \left| \sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}} \right|} \qquad (13), (14)$$

6.8 Measurement precautions

The cable under test shall be positioned concentric in the tube to obtain homogeneous wave propagation.

The balun (if applicable) and the remaining cable length including the matching resistors (in case of open head procedure), shall be positioned in a well-screened box to avoid disturbances from outside into the test set-up as well as to avoid radiation from the test set-up.

It is important to place the absorber rings as near as possible to the receiver side of the tube to absorb interfering, backward travelling waves.

7 Expression of results

7.1 Procedure A: measuring with a standard head

The attenuation of the balun or of the TP-connecting unit shall be subtracted from the measuring results.

The voltage ratio U_{diff}/U_{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.

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:

$$a_c = 10 \cdot \lg \left| \frac{P_{diff}}{P_{com}} \right| + 10 \cdot \lg \left| \frac{P_{com}}{P_{r,max}} \right| \text{ dB,} \qquad ((10) + (8))$$

$$a_c = 20 \cdot \lg \left| \frac{U_{diff}}{U_{com}} \right| + 10 \cdot \lg \left[\frac{Z_{com}}{Z_{diff}} \right] + 20 \cdot \lg \left| \frac{U_{com}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{com}} \right] \text{ dB,} \qquad ((11) + (9))$$

$$a_c = 20 \cdot \lg \left| \frac{U_{diff}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{diff}} \right] \qquad (15)$$

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

7.2 Procedure B: measuring with an open head

The attenuation of the balun or of the TP-connecting unit shall be subtracted from the measuring results.

The voltage ratio U_{diff}/U_{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. The operational attenuation a_{tube} = 20·lg(U_1/U_2) of the outer system of the test set-up shall be measured according to Figure 7 in case of open head procedure with the same absorber and DUT configuration as used during the coupling attenuation measurement:

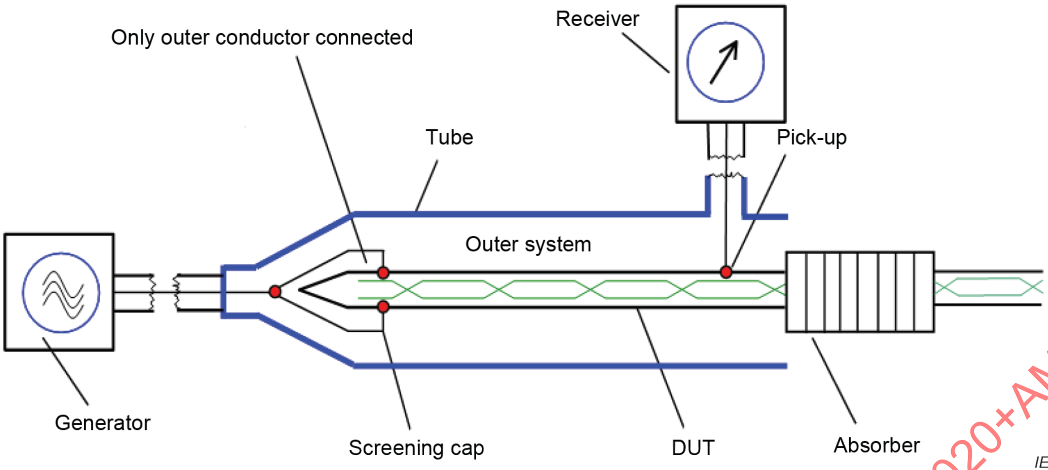


Figure 7 – Test set-up to measure a_{tube}

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:

$$a_c = 10 \cdot \lg\left|\frac{P_{diff}}{P_{com}}\right| + 10 \cdot \lg\left|\frac{P_{com}}{P_{r,max}}\right| \text{ dB,} \qquad ((10) + (8))$$

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{com}}\right| + 10 \cdot \lg\left[\frac{Z_{com}}{Z_{diff}}\right] + 20 \cdot \lg\left|\frac{U_{com}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{com}}\right] \text{ dB,} \qquad ((11) + (9))$$

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{diff}}\right] \text{ dB,} \qquad (16)$$

and with the correction of the operational attenuation a_{tube} of the outer system in case of open head procedure:

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{diff}}\right] - a_{tube} \text{ dB,} \qquad (17)$$

where $a_{tube} = 20 \cdot \lg[U_1 / U_2]\text{dB}$

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

8 Test report

The test report shall include:

a) a description of the tested cable and length;
b) the length of the tube;
c) the test procedure (standard or open head).

9 Requirements

The results of the minimum coupling attenuation shall 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.

10 Plots of coupling attenuation versus frequency (typical results)

Coupling attenuation for a 105 Ω twinax cable versus frequency on linear scale is shown in Figure 8. The same parameter is shown in Figures 9 and 10 for Cat 7a and Cat 8.2 cable.

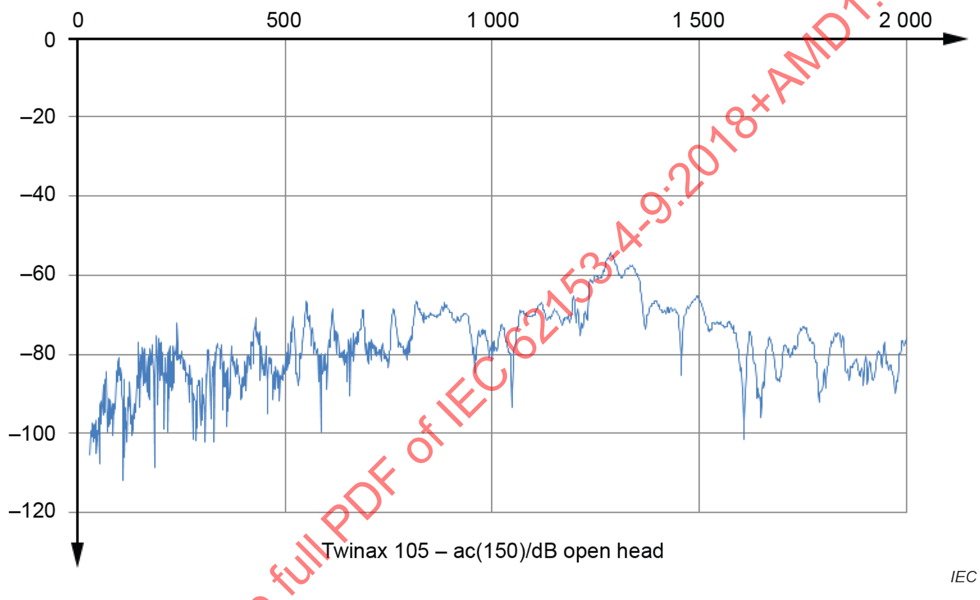


Figure 8 – Coupling attenuation Twinax 105, open head procedure

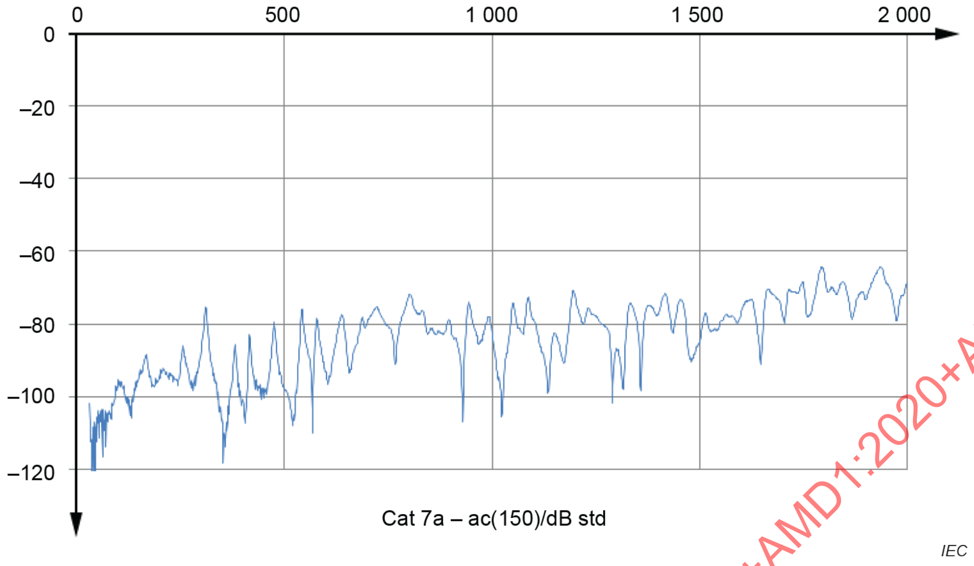


Figure 9 – Coupling attenuation Cat 7a, standard head procedure

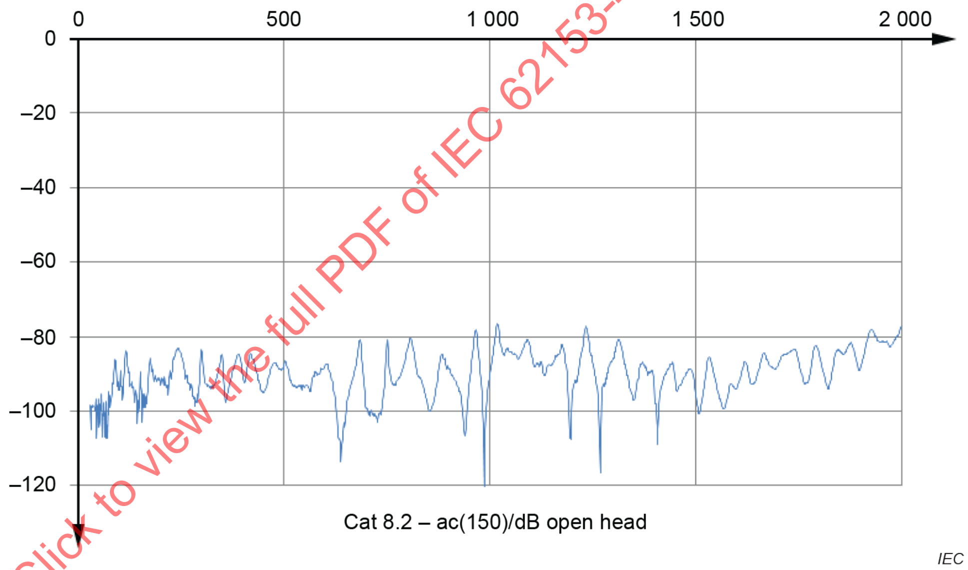


Figure 10 – Coupling attenuation Cat 8.2, open head procedure

Annex A
(normative)

Insertion loss of absorber with triaxial set-up

For the qualification of absorbers for the triaxial method, a coaxial system can be used. The test set-up as shown in Figure A.1 consists of a measuring tube with two test heads and an inner conductor, designed in a way that the measuring tube with the inner conductor forms a 50 Ω system. The absorbers to be tested are pushed onto the inner conductor. The transmission parameter (S_{21}) is measured with and without absorber. The difference between the two measurements results in the insertion loss of the absorber.

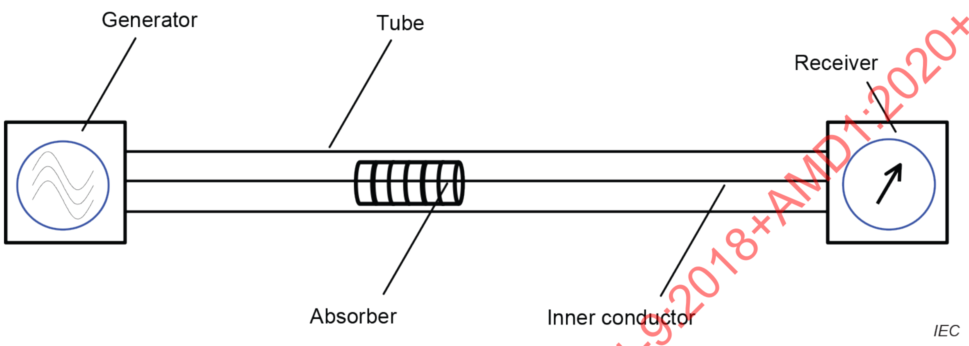
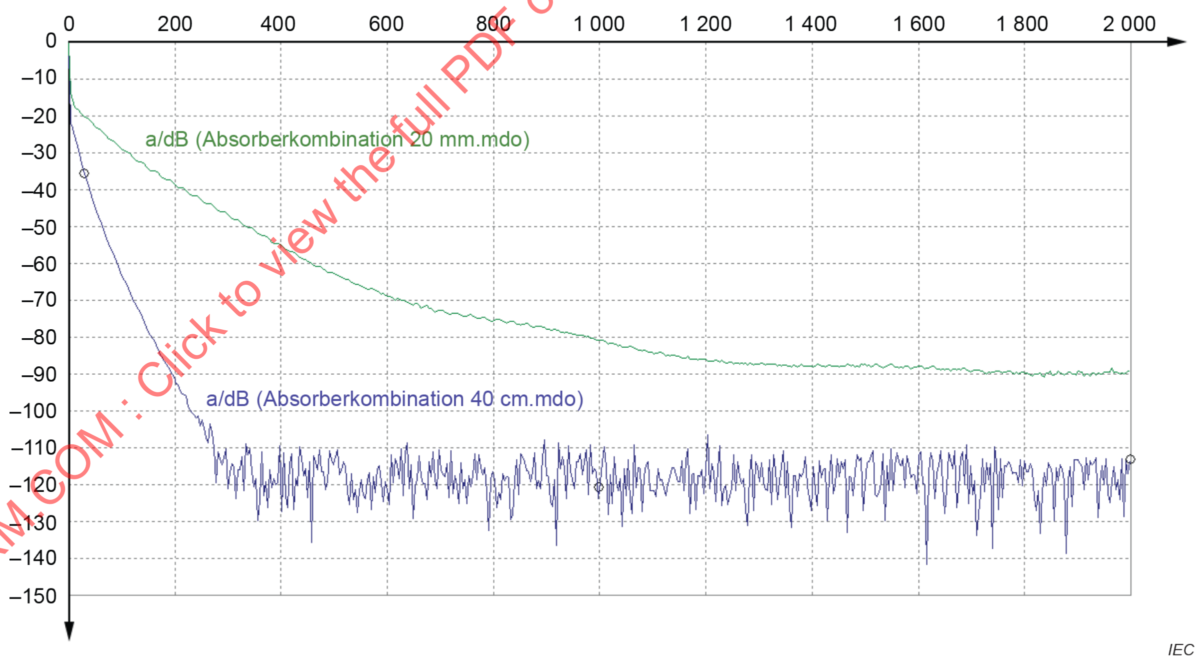


Figure A.1 – Insertion loss of absorber with triaxial set-up

Examined are both the nanocrystalline absorber as well as the ferrite absorber. The best effect over the entire frequency range from 30 MHz up to 2 GHz was achieved with a combination of nanocrystalline absorbers and a ferrite absorber.



key

Absorberkombination combination of absorbers

Figure A.2 – Insertion loss of absorber with triaxial set-up

Figure A.2 shows the insertion loss of a combination of nanocrystalline absorbers and ferrite absorber at a length of 20 cm and 40 cm.

NOTE Attenuation of absorbers depends on the sourrunding. It is higher in a metallic enclosure.

Annex B
(informative)

Physical background

B.1 Unbalance attenuation a_u

Screened balanced pairs may be operated in the differential mode (balanced) or the common mode (unbalanced). In the differential mode, one conductor carries the current $+I$ and the other conductor carries the current $-I$; the screen is without current. In the common mode, both conductors of the pair carry half of the current $+I/2$; and the screen is the return path with the current $-I$.

Under ideal conditions with ideal cables, both modes are independent of one another. Actually both modes influence each other due to differences in the diameter of the core insulation, unequal twisting and different distances of the pair. The unsymmetry is caused by the capacitive unbalance to earth e (transversal unsymmetry) and the difference of the inductance and resistance between the two wires r (longitudinal unsymmetry).

$$e = C_{10} - C_{20} \tag{B.1}$$

$$r = \left(R_2 + j\omega \cdot L_2\right) - \left(R_1 + j\omega \cdot L_1\right) \tag{B.2}$$

The coupling transfer functions between the two modes at the near and far ends is then expressed by:

$$T_{\text{u,n}} = \frac{1}{4} \cdot \frac{1}{\sqrt{Z_{\text{diff}} \cdot Z_{\text{com}}}} \cdot \int_0^1 \left(j\omega \cdot e(x) \cdot Z_{\text{diff}} \cdot Z_{\text{com}} + r(x)\right) \cdot e^{-\left(\gamma_{\text{diff}} + \gamma_{\text{com}}\right) \cdot x} dx \tag{B.3}$$

$$T_{\text{u,f}} = \frac{1}{4} \cdot \frac{1}{\sqrt{Z_{\text{diff}} \cdot Z_{\text{com}}}} \cdot \int_0^1 \left(j\omega \cdot e(x) \cdot Z_{\text{diff}} \cdot Z_{\text{com}} - r(x)\right) \cdot e^{\left(\gamma_{\text{diff}} - \gamma_{\text{com}}\right) \cdot (l-x)} dx \tag{B.4}$$

Z_{diff} and Z_{com} are in principle the same coupling transfer functions compared to the coupling through the screen. The integral may be solved if the distribution of the unsymmetry functions along the cable length is known.

For a constant unsymmetry along the cable length, the coupling function is expressed by (similar to the form of the coupling function for cable screens):

$$T_{\text{uf}}^{\text{n}} = \left(j\omega \cdot e \cdot Z_{\text{diff}} \cdot Z_{\text{com}} \pm r\right) \cdot \frac{1}{\sqrt{Z_{\text{diff}} \cdot Z_{\text{com}}}} \cdot \frac{1}{4} \cdot S_{\text{f}}^{\text{n}} \tag{B.5}$$

If the cable is electrically long, there is the same phenomenon as for the coupling through the screen. Depending on the velocity difference between the differential and the common mode circuit, the envelope of the transfer function approaches a constant value which is frequency and length independent. However, if the velocity difference is zero, then the transfer function at the far end increases by 20 dB per decade over the whole frequency range (S_{f} = 1). In practice, there are small systematic couplings as well as statistical couplings. Thus $T_{\text{u,n}}$ increases by approximately 10 dB per decade and $T_{\text{u,f}}$ by less then 20 dB per decade.

B.2 Screening attenuation a_s

The screening attenuation a_s is given by

$$a_s = -10 \times \log_{10}\left(\text{Env}\left|\frac{P_{r,\max}}{P_1}\right|\right) \tag{B.6}$$

At high frequencies and when the cable under test is electrically long:

$$\sqrt{\left|\frac{P_{2\max}}{P_1}\right|} \approx \frac{c_0}{\omega\sqrt{Z_1 \cdot Z_2}} \cdot \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}\right| \tag{B.7}$$

For exact calculation, if feedback from the secondary to the primary circuit is negligible, the ratio of the far end voltages U_1 and U_2 are given by:

$$\left|\frac{U_2}{U_1}\right| \approx \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} \cdot \left[1 - e^{-j\varphi_1}\right] + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} \times \left[1 - e^{-j\varphi_2}\right]\right| \cdot \left|\frac{1}{\omega \cdot Z_1}\right| \cdot \left|\frac{c_0}{2 + (Z_2 / R - 1) \cdot \left(1 - e^{-j\varphi_3}\right)}\right| \tag{B.8}$$

B.3 Coupling attenuation a_c

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

Consequently, the effectiveness against electromagnetic disturbances of shielded balanced cables is the sum of the unbalanced attenuation a_u of the pair and the screening attenuation a_s of the screen. Since both quantities are usually given in a logarithmic ratio, they may simply be added to form the coupling attenuation a_c:

$$a_c = a_u + a_s \tag{B.9}$$

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

$$a_c = -10 \cdot \log_{10}\left(\text{Env}\left|\frac{P_{r,\max}}{P_1}\right|\right) \tag{B.10}$$

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

$$\frac{P_S}{P_2} = \frac{P_{Smax}}{P_{2max}} = \frac{R}{2 \cdot Z_S} \qquad (B.11)$$

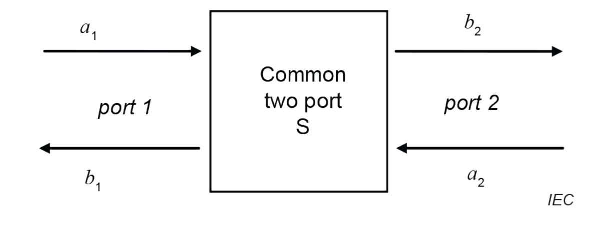
There will be a variation of the voltage U_2 on the far end, caused by the electromagnetic coupling through the screen and superposition of the partial waves caused by the surface transfer impedance Z_T ,the capacitive coupling impedance Z_F (travelling to the far and near end) and the totally reflected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

Annex C
(informative)

Mixed mode parameters

C.1 Definition of mixed mode S-Parameters

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

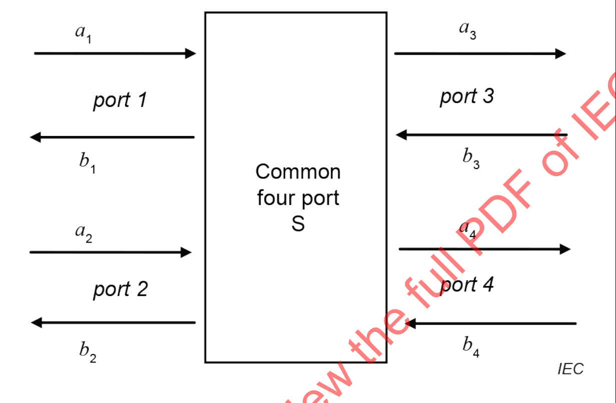


$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

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

Figure C.1 – Common two-port network

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



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

Figure C.2 – Common four port network

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

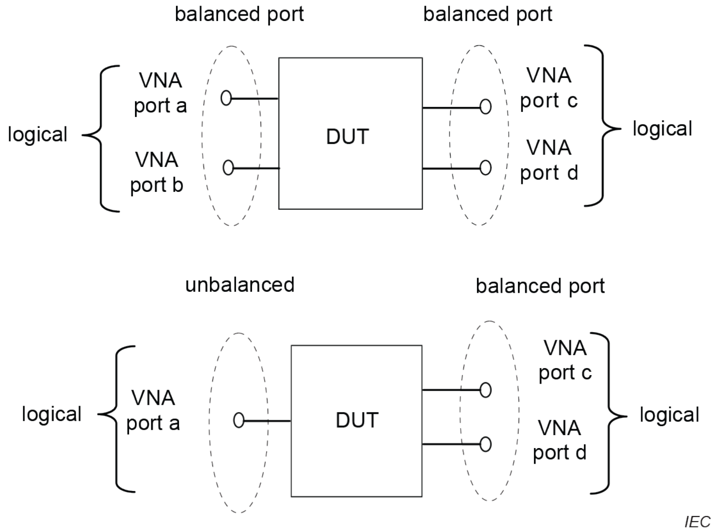
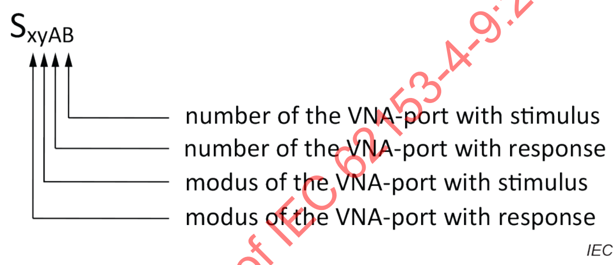


Figure C.3 – Physical and logical ports of VNA

The nomenclature in Figure C.4 is used.



Modus	s: single ended (unbalanced, coaxial)
	d: differential mode (balanced)
	c: common mode

Figure C.4 – Nomenclature of mixed mode S-Parameters

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

$$S_{xyAB} = \frac{\text{input signal at VNA-port A at modus x}}{\text{input signal at VNA-port B at modus y}} \quad \text{(C.1)}$$

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

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

$M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$ (C.2)	$S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd11} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix}$ (C.3)

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

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

IEC

Figure C.5 – Measurement configuration, single ended response

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

For the measurement of a two-port with two balanced ports, the following test configurations are obtained (see Figure C.6):

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

IEC

Figure C.6 – Measurement configuration, differential mode response

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

C.2 Reference impedance of VNA

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

Annex D
(normative)

Measuring the screening effectiveness of unscreened single or multiple balanced pairs

D.1 General

IEC 62153-4-9 describes the measurement of coupling attenuation of balanced pairs with the triaxial test set-up. Due to the short circuit between the screen of the cable under test (CUT) and the triaxial tube at the near end, the method described in IEC 62153-4-9 applies only to screened balanced cables.

This annex describes the procedures for measuring coupling attenuation of unscreened single or multiple balanced pairs. Furthermore, the screening effectiveness of screened and unscreened balanced pairs at frequencies down to 9 kHz is described.

D.2 Background

Figure D.1 shows the basic triaxial test set-up with a short circuit between the screen of the cable under test (CUT) and the tube at the near end.

Due to the energy which couples through the screen from the inner system (the CUT) into the outer system (the tube), a wave is travelling in both directions in the outer system. The short circuit at the near end causes a total reflection so that the complete energy that couples from the CUT into the outer system is travelling to the receiver and is measured as superimposed curve. The measured maximum values, respectively the envelope curve, is the screening attenuation according to IEC 62153-4-4, see also IEC TS 62153-4-1.

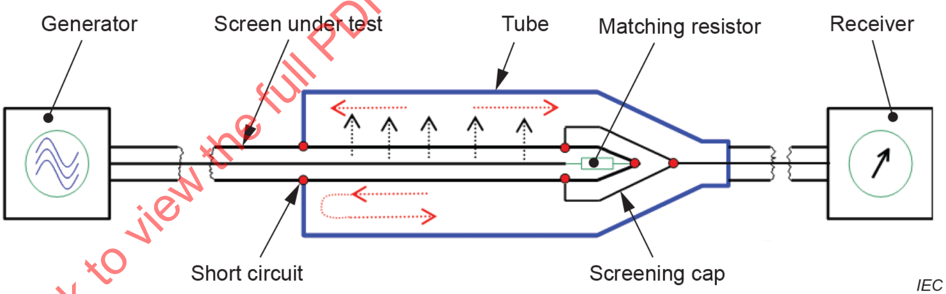


Figure D.1 – Basic triaxial tube procedure according to IEC 62153-4-3 / IEC 62153-4-4

The same principle applies to screened balanced cables, where also the interaction between differential mode and common mode shall be considered (see Figures 1 and 3).

D.3 Triaxial set-up for unscreened balanced pairs

D.3.1 Principle

Basically, it should be distinguished between single unscreened pairs and multiple unscreened pairs. In case of multiple unscreened pairs, the EMC behavior, respectively test results, depends on the treatment of the remaining pairs, e.g. grounded or not.

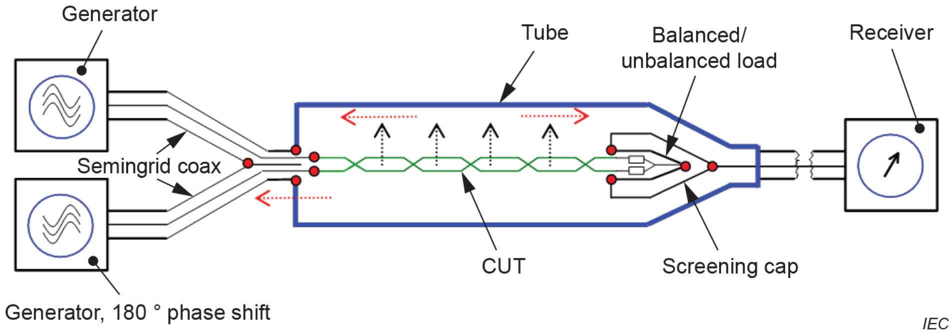


Figure D.2 – Screening effectiveness of unscreened balanced pairs, principle set-up

Figure D.2 shows the principle triaxial set-up for balanced unscreened single or multiple balanced pairs. The signal is fed into the tube in the differential mode via two parallel semi rigid coaxial cables of equal length with the screens connected to the tube. Due to the conversion from the differential mode into the common mode (into the tube), a wave is travelling in both directions in the test section.

D.3.2 Inner and outer system

In the basic triaxial system according to Figure D.1, the inner system is formed by the cable under test (CUT) and the outer system is formed by the tube and the outer conductor of the CUT (the inner conductor of the outer system is the outer conductor of the inner system). At the near end, the screen is connected to the tube by a short circuit. This principle is valid for both coaxial and screened balanced cables.

In case of unscreened balanced cables, the inner system is the CUT (the differential mode) and the outer system is formed by the tube and the common mode of the CUT.

Since there is no screen on the unscreened pair, there is no short circuit at the near end as in the basic triaxial set-up according to Figure D.1; hence coupling measurements can be performed on both ends.

D.4 Unscreened single pairs

D.4.1 Near-end coupling attenuation of a single unscreened balanced pair

The back-travelling energy at the near end in Figure D.2 is considered as the near end coupling. It can be measured as S_{cd11}, where S_{cd11} is also the unbalance attenuation (TCL) of the unscreened cable under test (CUT) at the near end.

Figure D.3 shows the configuration for near-end coupling measurement of unscreened single pairs.

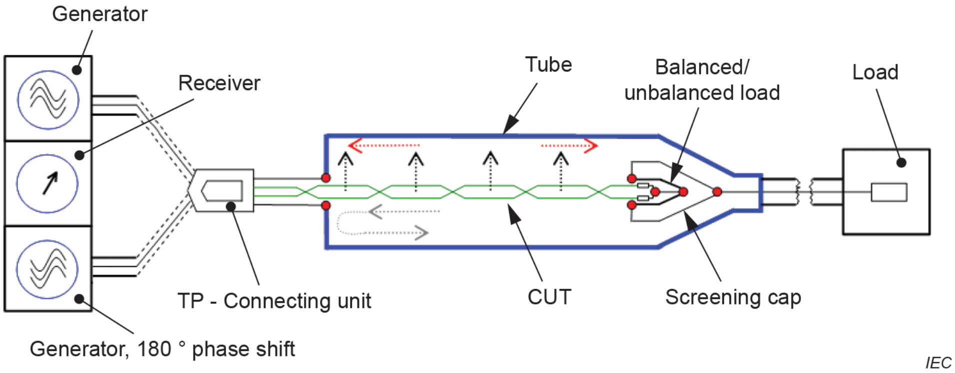


Figure D.3 – Configuration for near end coupling measurement of an unscreened single pair, principle set-up

A differential and common mode termination is required for each pair at the far end of the cable. For cables with 100 Ω characteristic impedance, two 50 Ω resistors are used.

D.4.2 Far end screening attenuation and coupling attenuation of single unscreened balanced pairs

Figure D.4 shows the set-up for the far end screening attenuation (S_{sc21}) and the far end coupling attenuation (S_{sd21}) measurement of an unscreened pair.

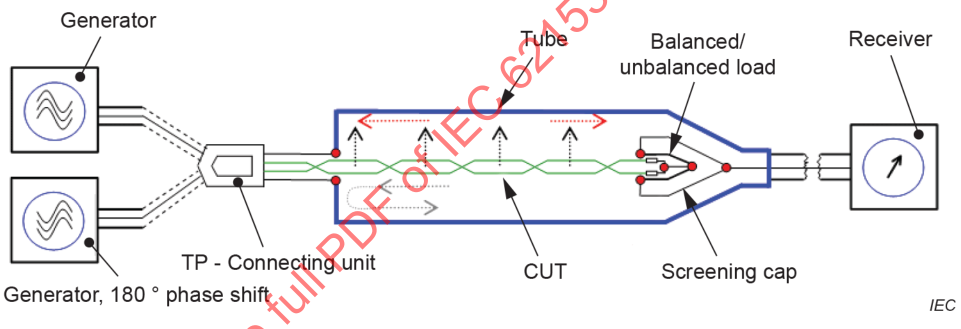


Figure D.4 – Far end screening attenuation and coupling attenuation (S_{sc21} and S_{sd21}) of an unscreened balanced pair, principle set-up

The CUT shall be matched with 50/50/0 Ω; that means 100 Ω for the differential mode and 25 Ω for the common mode. The 25 Ω common mode load is in series to the receiver of the network analyser.

D.5 Screening- and coupling attenuation measurement of multiple unscreened balanced pairs

Figure D.5 shows the configuration for measuring the coupling attenuation of multiple unscreened pairs.

All pairs of the CUT shall be matched at the far end with a PCB 50/50/0 Ω and connected at the near end with an appropriate TP-connecting unit according to Table 2. The TP-connecting unit shall be connected to ground potential.

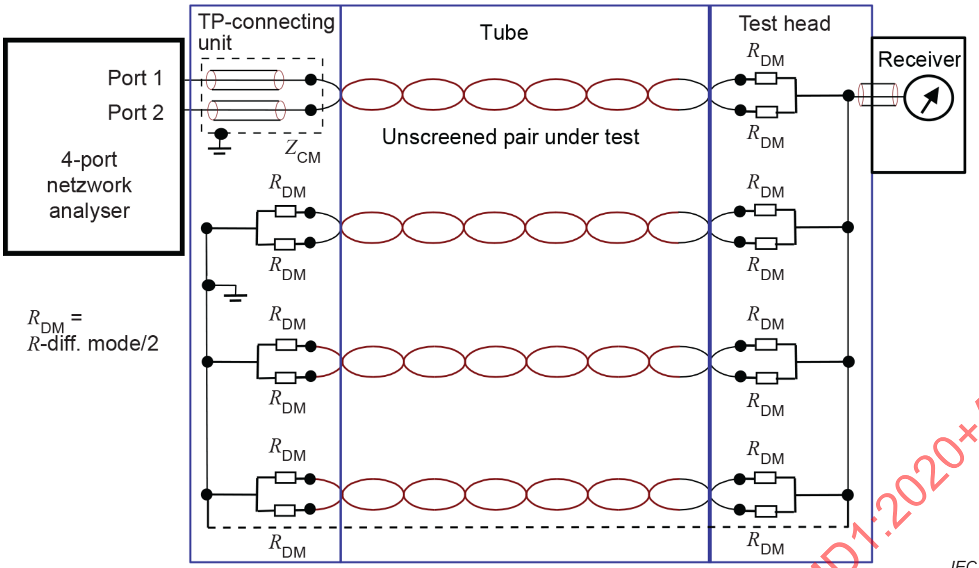


Figure D.5 – Basic configuration of screening attenuation and coupling attenuation test of multiple unscreened balanced pairs

D.6 Measurement

Balunless procedures of Clause 6 in accordance with Figures D.3 and D.4 apply for the measurement.

D.7 Expression of test results

Subclause 7.1 applies for the expression of test results.

D.8 Low frequency coupling attenuation

The lower cut off frequency to measure the coupling attenuation is given by equation (13), see Subclause 6.7. That means, coupling attenuation of screened and unscreened balanced pairs with manageable length can be measured only from about 30 MHz upwards. A test procedure for the EMC behaviour of screened balanced cables at lower frequencies is needed for applications like 10 Mbit/s (IEEE 802.3cg) and 100 Mbit/s (IEEE 802.3bw).

Since unscreened pairs have no screen, measuring of transfer impedance as specified for coaxial and for screened balanced cables is not possible.

Alternatively, the "low frequency coupling attenuation" $a_{C,lf}$ is introduced. The test set-up is the same as the set-up for coupling attenuation according to Figure 8, but starting in principle from DC. Low frequency coupling attenuation $a_{C,lf}$ can be measured on both screened and unscreened balanced pairs.

Low frequency coupling attenuation $a_{C,lf}$ includes the unbalance attenuation of the pair over the whole frequency range, the transfer impedance of the screen (if any) at lower frequencies and the screening attenuation at higher frequencies.

Since the results of the low frequency coupling attenuation are depending on the length of the CUT and cannot (readily) be extrapolated to other lengths, a test length of 3 m is specified to get comparable test results. Results of a suitable test length of 3 m are shown in Figure D.6.

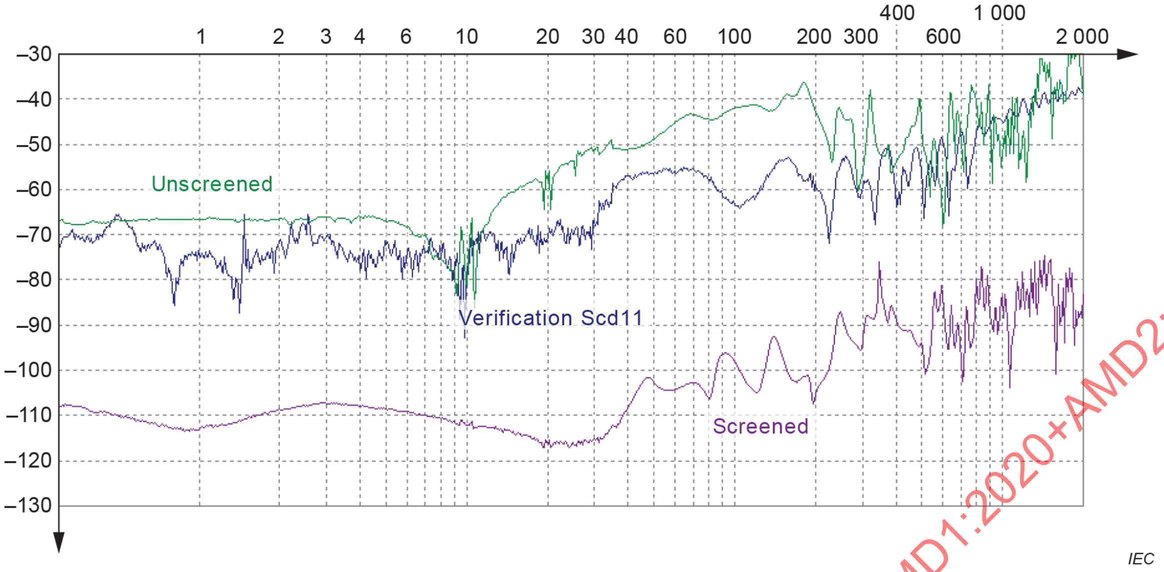


Figure D.6 – Low frequency coupling attenuation $a_{C,lf}$ of a single screened and unscreened balanced pair, 3 m

Test set-up verification shall be performed according to Clause D.9.

D.9 Set-up verification and measurement uncertainties

Optimally calibrated and phase-stabilized measuring devices (VNA, test leads and connecting units) show a specific frequency-dependent course of a system-mode conversion.

This is at low frequencies between –80 dB and –70 dB and increases with increasing frequencies at about –60 dB to –40 dB. Depending on the phase position, this system-mode conversion superimposes the mode conversion of the test object constructively or destructively. The result of the measurement is thereby falsified and, in particular, very strong if the amount of the mode conversion of the test object approaches or even undershoots the amount of the system mode conversion.

All low frequency coupling attenuation ($a_{C,lf}$) measurements and measurements of high coupling attenuation values may be victims of such overlays. The system values shall therefore be recorded and included in the measurement uncertainty analysis.

An estimation of the system mode conversion can be done by e.g. recording the reflected mode conversion parameter S_{cd11} with a TP-connecting unit having an open loop.

Figure D.7 shows an example of the reflected mode conversion parameter S_{cd11} with a TP-connecting unit having an open loop.

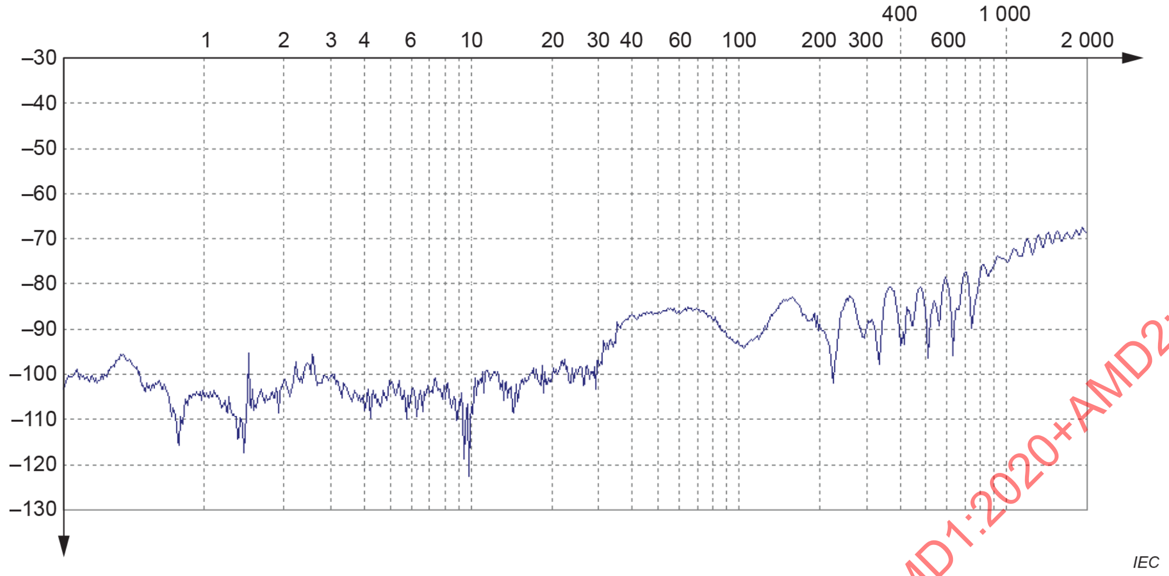


Figure D.7 – Reflected mode conversion parameter S_{cd11} with a TP-connecting unit having an open loop

Annex E
(normative)

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

E.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.

E.2 Coupling attenuation expressed by mixed mode scattering parameter

Formulae (15) and (16) are rearranged and expressed by a mixed mode scattering parameter, see Formula (E.1).

$$a_c = -S_{sd21} + 10\log_{10}\left|\frac{Z_{diff}}{Z_0}\right| + 10\log_{10}\left|\frac{2Z_s}{Z_{diff}}\right| = -S_{sd21} + 10\log_{10}\left|\frac{2Z_s}{Z_0}\right| = -S_{sd21} + 7{,}78\ \text{dB} \qquad \text{(E.1)}$$

where

a_c is the coupling attenuation;

S_{sd21} is the logarithmic magnitude (in dB) of the forward transmission scattering parameter; DUT stimulated in differential mode; received power in single ended mode;

Z_{diff} is the differential mode impedance; Z_{diff} = 2 × Z_0 = 100 Ω;

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.

E.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 (E.2):

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

where

f is the frequency in MHz;

E_c is the envelope 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 E.1.

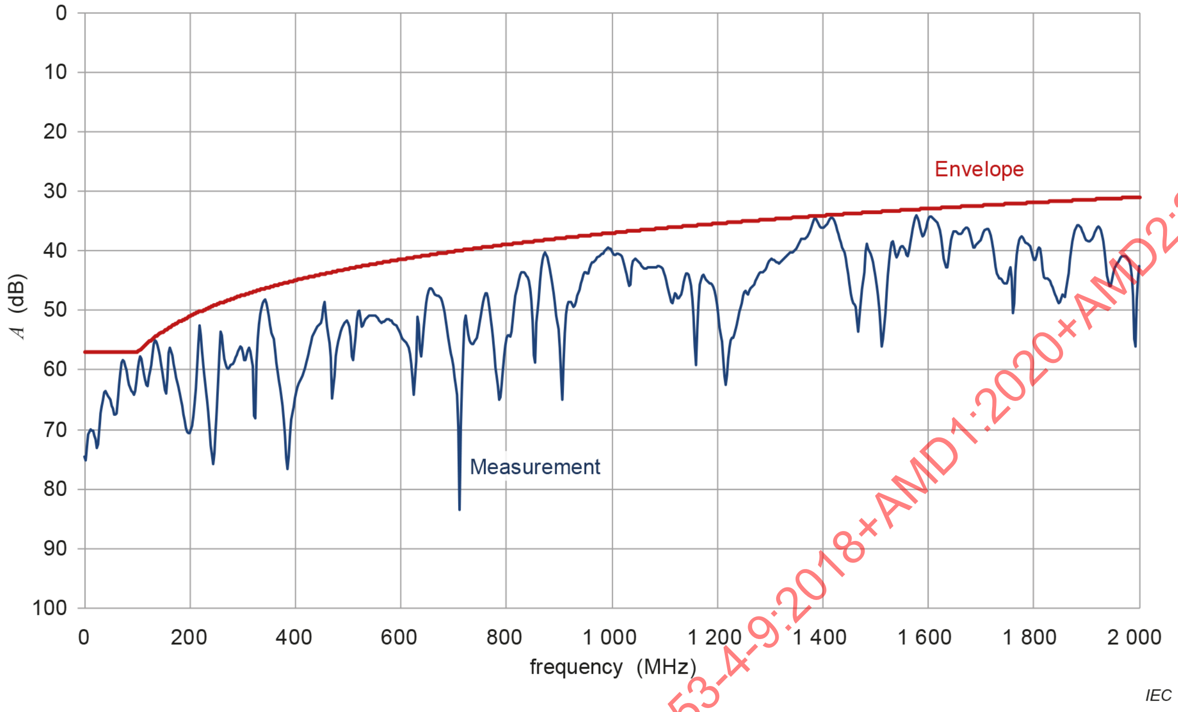


Figure E.1 – Example of coupling attenuation with envelope line

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method

FOREWORD

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

IEC 62153-4-9 edition 2.2 contains the second edition (2018-05) [documents 46/681/FDIS and 46/685/RVD], its amendment 1 (2020-07) [documents 46/773/FDIS and 46/776/RVD] and its amendment 2 (2024-06) [documents 46/990/FDIS and 46/1002/RVD].

This Final version does not show where the technical content is modified by amendments 1 and 2. A separate Redline version with all changes highlighted is available in this publication.

International Standard IEC 62153-4-9 has been prepared by IEC technical committee 46: Cables, wires, waveguides, RF connectors, RF 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:

– two test procedures, open head and standard head procedure;
– measuring with balun or with multiport respectively mixed mode VNA;
– extension of frequency range up to and above 2 GHz.

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

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

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

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

INTRODUCTION to Amendment 1

The goal of this amendment is to extent IEC 62153-4-9 such that also the coupling attenuation of unscreened single or multiple balanced pairs or unscreened quads can be measured with the triaxial test procedure.

Further complement is the extension of the usable frequency range down to frequencies below 9 kHz to measure the low frequency coupling attenuation of screened and unscreened balanced pairs or quads.

METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-9: Electromagnetic compatibility (EMC) – Coupling attenuation of screened balanced cables, triaxial method

1 Scope

This part of IEC 62153 applies to metallic communication cables. It specifies a test method for determining the coupling attenuation a_C of screened balanced cables. Due to the concentric outer tube, measurements are independent of irregularities on the circumference and external electromagnetic fields.

A wide dynamic and frequency range can be applied to test even super screened cables with normal instrumentation from low frequencies up to the limit of defined transversal waves in the outer circuit at approximately 4 GHz. However, when using a balun, the upper frequency is limited by the properties of the balun.

Measurements can be performed with standard tube procedure (respectively with standard test head) according to IEC 62153-4-4 or with open tube (open test head) procedure.

The procedure described herein to measure the coupling attenuation a_C is based on the procedure to measure the screening attenuation a_S according to IEC 62153-4-4.

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 60050-726, *International Electrotechnical Vocabulary – Chapter 726: Transmission lines and waveguides*

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

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

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

IEC 62153-4-5, *Metallic communication cables test methods – Part 4-5: Electromagnetic compatibility (EMC) – Coupling or screening attenuation – Absorbing clamp method*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in IEC 60050-726, IEC TS 62153-4-1 and IEC 62153-4-4, as well as the following symbols apply.

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

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

a_s is the screening attenuation which is comparable to the results of the absorbing clamp method in dB;

a_c is the coupling attenuation related to the radiating impedance of 150 Ω in dB;

a_u is the unbalanced attenuation;

$a_{m,min}$ is the attenuation recorded as minimum envelope curve of the measured values in dB;

a_z is the additional attenuation of a possible inserted adapter, if not otherwise eliminated e.g. by the calibration, in dB;

C_T is the through capacitance of the outer conductor in F/m;

c_0 is the vacuum velocity in m/s;

dx is the differential length operator of integration;

λ_0 is the vacuum wavelength in m;

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

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

$\varepsilon_{r2,n}$ is a normalised value of the relative dielectric permittivity of the environment of the cable;

f is the frequency in Hz;

j is the imaginary operator (square root of minus one);

L is the transmission line parameter-inductance;

l is the effective coupling length in m;

φ is a phase factor in the ratio of the secondary to primary circuit end voltages (U_1/U_2);

P_1 is the feeding power of the primary circuit in W;

P_2 is the measured power received on the input impedance;

R of the receiver in the secondary circuit in W;

P_r is the radiated power in the environment of the cable, which is comparable to $P_{2n} + P_{2f}$ of the absorbing clamp method in W;

$P_{r,max}$ is the periodic maximum value of the common mode radiated power in W;

P_s is the radiated power in the normalised environment of the cable under test,

(Z_s = 150 Ω and $|\Delta v / v_1|$ = 10 %) in W,

$$\varphi_1 = 2\pi \times \left(\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right) \times l / \lambda_0 \qquad (1)$$

$$\varphi_2 = 2\pi \times \left(\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}\right) \times l / \lambda_0 \qquad (2)$$

$$\varphi_3 = \varphi_2 - \varphi_1 = 4\pi \times \sqrt{\varepsilon_{r2}} \times l / \lambda_0 \qquad (3)$$

R is the input impedance of the receiver in Ω;

R_{DM} is the differential mode termination, Ω;

S is the summing function;

T is the coupling transfer function;

U_1 is the input voltage of the primary circuit formed by the cable in V;

U_2 is the output voltage of the secondary circuit in V;

Ω is the radian frequency ω;

Z_1 is the (differential mode) characteristic impedance of the cable under test (primary circuit) in Ω;

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

Z_{com} is the common mode (unbalanced);

Z_{diff} is the nominal characteristic impedance of the differential mode (balanced);

Z_F is the capacitive coupling impedance of the cable under test in Ω/m,

$$Z_F = Z_1 \cdot Z_2 \cdot j \cdot 2 \cdot \pi \cdot f \cdot C_T \quad (4)$$

Z_S is the normalised value of the characteristic impedance of the environment of the cable;

Z_T is the transfer impedance of the cable under test in Ω/m;

4 Principle of the measuring method

4.1 General

Coupling attenuation of screened balanced cables describes the overall effect against electromagnetic interference (EMI) taking into account both the unbalance attenuation of the pair and the screening attenuation of the screen.

The disturbing circuit (the inner or primary circuit) consists of the test cable which is fed by a generator and is impedance-matched at the near and far ends. The disturbed circuit (the outer or secondary circuit) is formed by the solid metallic tube and the short section of the cable under test covered by the tube. The disturbed circuit (the outer or secondary circuit) is terminated at the near end in a short circuit and is terminated at the far end with a calibrated receiver or network analyser.

The voltage peaks at the far end of the secondary circuit are measured with a calibrated receiver or network analyser. For this measurement a matched receiver is not necessary. These voltage peaks are not dependant on the input impedance of the receiver, provided that the input impedance of the receiver is lower than the characteristic impedance of the secondary circuit. However, it is advantageous to have a low mismatch, for example by selecting a range of tube diameters for several cable sizes.

To measure the coupling attenuation as well as to measure the unbalance attenuation a differential signal is required. This can, for example, be generated using a balun which converts the unbalanced signal of a 50 Ω network analyser into a balanced signal.

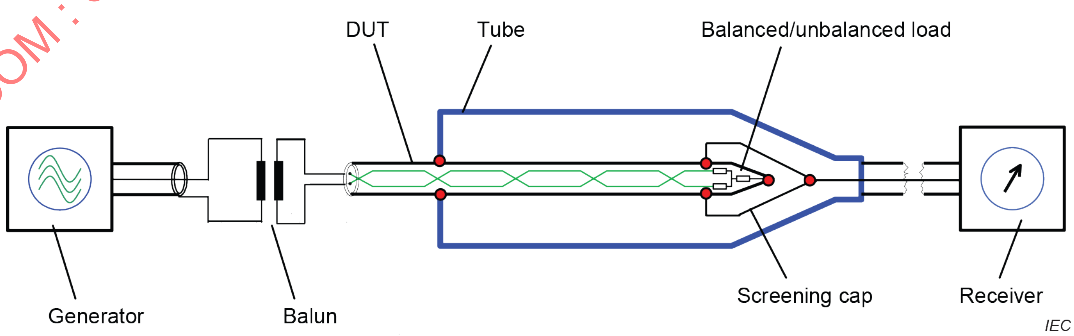


Figure 1 – Coupling attenuation, principle test set-up with balun and standard tube

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 Annex B.

The test set-up (see Figures 1, 2, 3 and 4) is a triaxial system consisting of an outer solid metallic tube in which the cable under test (CUT) is concentrically positioned.

At the near end, the screen of the screened cable under test is short circuited with the solid metallic tube.

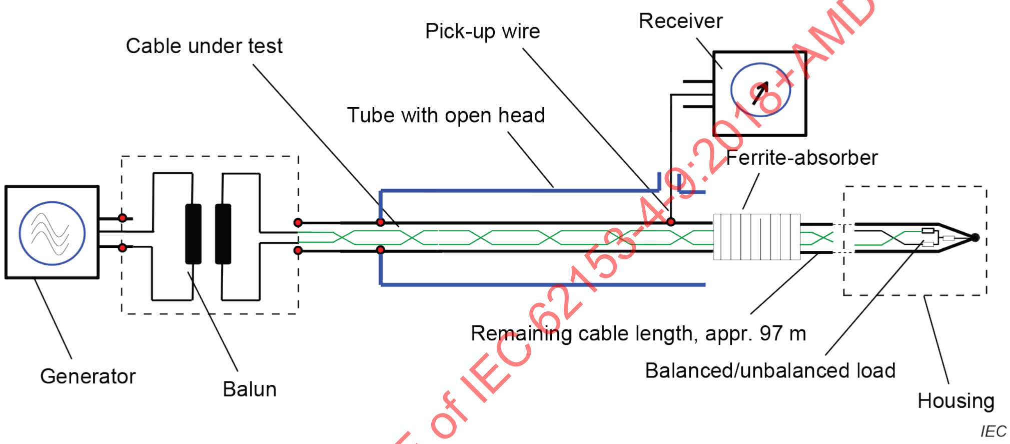


Figure 2 – Coupling attenuation, principle test set-up with balun and open head

At the far end, the tube can be equipped with a "test head" which can be removed from the tube for easier connecting of the CUT. The set-up according to IEC 62153-4-4 is designated as the standard procedure, respectively the procedure with standard head. The advantage is an overall closed and shielded set-up.

Alternatively, the tube can be equipped with an open head at the far end (see Figures 2 and 4).

4.2 Procedure A: measuring with standard tube (standard head)

The set-up detailed in Procedure A uses the standard test-head and is in principle the same as described in IEC 62153-4-4. The screened balanced DUT can be fed either in common mode or in differential mode. In this way, both, screening attenuation of the screen or coupling attenuation of the screened pair can be measured. In principle, with the same set-up, also the transfer impedance of the screen can be measured (taking into account the length of the DUT).

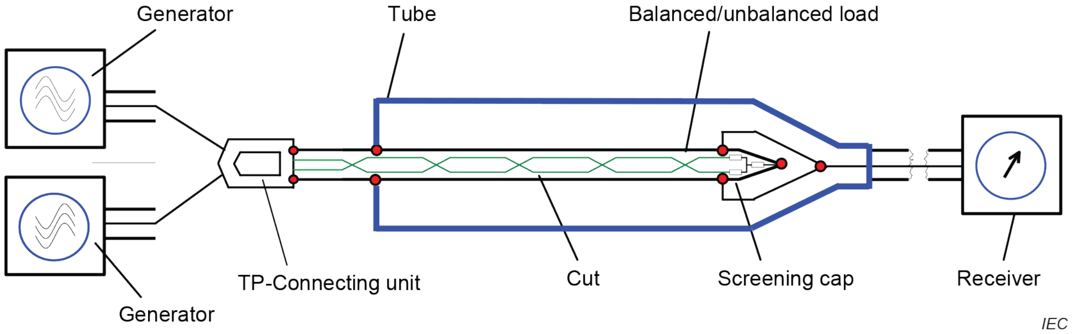


Figure 3 – Coupling attenuation, principle set-up with multiport VNA and standard head

The DUT shall be matched at the far end in common and differential mode. Return loss of the CUT in common and differential mode shall be measured. Values for return loss in common and differential mode shall be at least 10 dB.

4.3 Procedure B: measuring with open head

In case of measuring with open head the first several meters of a longer length of the cable to be tested are concentrically positioned in an outer solid metallic tube. The remaining length (usually of 100 m length) that extends past the tube is placed in a highly shielded box and terminated with common mode and differential mode terminations (see Figure 6). The cable screen shall be connected with low impedance to the screened box. The center point of the differential mode termination shall be connected via the resistor R_{CM} to the highly screened box or cable screen (see Figure 6).

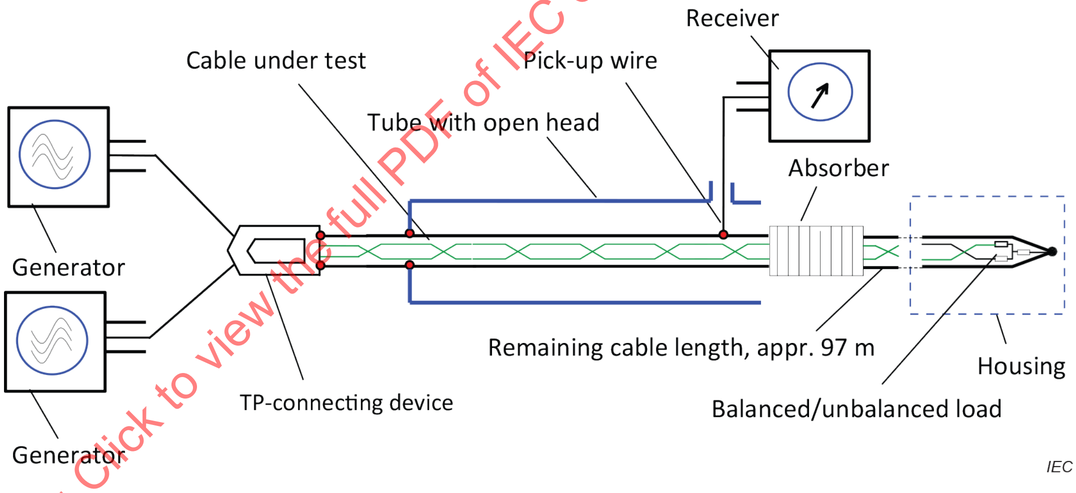


Figure 4 – Coupling attenuation, principle set-up with multiport VNA and open head

At the near end, the screen of the screened cable under test is short circuited with the solid metallic tube.

At the far end, the tube is let open and the signal is picked up by a “pick up wire”, which is connected to the screen of the cable under test (see Figure 4). The open tube system can also be equipped with a “test head” which can be removed from the tube for easier connecting of the CUT.

At the open end of the tube, absorbers shall be applied to match the system and to avoid back travelling waves into the system. The attenuation of the absorber shall be at least 20 dB. A combination of a ferrite absorber and/or nanocrystalline absorber may be used. A procedure to measure the attenuation of absorbers is given in Annex A.

5 Screening parameters

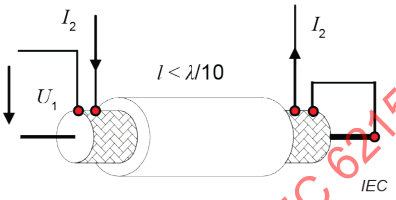
5.1 General

To protect a cable against external electromagnetic interference or to avoid radiation into the environment, the cable is surrounded with screens made of metal foils and/or braids. For cables used in harsh electromagnetic environments, elaborate shield structures, made of several layers or magnetic materials, are also used. In case of balanced cables, also the overall symmetry of the pair contributes to the screening effectiveness in addition to the screen.

The sole effect of the screen is described by the transfer impedance and the screening attenuation. The influence of the symmetry is grasped by the unbalance attenuation. The overall effect of the screen and the symmetry of the pair (for balanced cables) are described by the coupling attenuation.

5.2 Transfer impedance

For an electrically short screen, the transfer impedance Z_T is defined as the 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, related to length in Ω/m or in mΩ/m (see Figure 5).



$$Z_T = \frac{U_1}{I_2 \cdot l} \quad (5)$$

Figure 5 – Definition of transfer impedance

The test procedure for transfer impedance is described in IEC 62153-4-3. According to the definition it can be measured on short cable samples.

5.3 Screening attenuation

The screening attenuation a_S is the measure of the effectiveness of a cable screen. It is the logarithmic ratio of the feeding power P_1 to the maximum radiated power $P_{r,max}$.

With the arbitrary determined normalized value Z_S = 150 Ω (see IEC 62153-4-4) one gets:

$$a_S = 10 \cdot \lg\left|\frac{P_1}{P_{r,max}}\right| = 10 \cdot \lg\left|\frac{P_1}{P_{2,max}} \cdot \frac{2 \cdot Z_S}{R}\right| \text{ dB} \quad (6)$$

$$a_S = 20 \cdot \lg\left|\frac{U_1}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_1}\right] \text{ dB} \quad (7)$$

whereas R is the input impedance of the receiver. More details are given in IEC TS 62153-4-1 and in IEC 62153-4-4.

With the arbitrary determined normalized value Z_S = 150 Ω one gets for screened balanced cables (in the common mode) the screening attenuation a_S:

$$a_s = 10 \cdot \lg \left| \frac{P_{com}}{P_{r,max}} \right| \text{ dB} \tag{8}$$

$$a_s = 20 \cdot \lg \left| \frac{U_{com}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{com}} \right] \text{ dB} \tag{9}$$

5.4 Unbalance attenuation

Screened balanced pairs may be operated in two different modes: the differential mode (balanced) and the common mode (unbalanced). In the differential mode one conductor carries the current $+I$ and the other conductor carries the current $-I$; the screen is without current. In the common mode, both conductors of the pair carry half of the current $+I/2$, and the screen is the return path with the current $-I$, comparable to a coaxial cable.

Under ideal conditions respectively with ideal cables, both modes are independent from each other. However under real conditions, both modes influence each other.

The unbalance attenuation a_u of a pair describes in logarithmic scale how much power couples from the differential mode to the common mode and vice versa. It is the logarithmic ratio of the input power in the differential mode P_{diff} to the power which couples to the common mode P_{com} [8][1].

$$a_u = 10 \cdot \lg \left| \frac{P_{diff}}{P_{com}} \right| \text{ dB} \tag{10}$$

$$= 20 \cdot \lg \left| \frac{U_{diff}}{U_{com}} \right| + 10 \cdot \lg \left[\frac{Z_{com}}{Z_{diff}} \right] \text{ dB} \tag{11}$$

Differences in the resistance of the conductors, in the diameter of the core insulation, in the core capacitance, unequal twisting and different distances of the cores to the screen are some reasons for the unbalance of the pair.

At low frequencies, the unbalance attenuation decreases with increasing cable length. At higher frequencies and/or length, the unbalance attenuation approaches asymptotic to a maximum value – similar to the screening attenuation – depending on the type of cable and its distribution of the inhomogeneity along the cable length. Unbalance attenuation may be determined for the near end as well as for the far end of the cable [5].

5.5 Coupling attenuation

The coupling attenuation of screened balanced pairs describes the global effect against electromagnetic interference (EMI) and takes into account both the effect of the screen and the symmetry of the pair.

1 Figures in square brackets refer to the Bibliography.

6 Measurement

6.1 General

Measurements can be performed with a two-port VNA and balun (see Figures 1 and 2) or with multiport or mixed mode VNA and connecting unit (see Figures 3 and 4) both with standard tube, respectively with standard test head, or with open test head procedure.

6.2 Equipment

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.

The measurement set-ups are shown in Figures 1 to 4 and consist of:

- a metallic non ferromagnetic tube with a length sufficient to produce a superimposition of waves in narrow frequency bands which enable the envelope curve to be drawn; the test head of the tube may be standard head according to IEC 62153-4-4 (Figures 1 and 3) or open head (Figures 2 and 4)
- a two port network analyser when measuring with balun (a separate generator and receiver may also be used);
- a balun for impedance matching of an unbalanced generator output signal to the characteristic impedance of balanced cables; or
- a Twisted Pair (TP)-connecting unit when measuring with multiport respectively with mixed mode VNA;
- absorber rings (ferrite or nanocrystalline) with an attenuation a_{absorber} > 20 dB in the measured frequency range when using the open head method;
- metallic boxes to shield the balun and the remaining cable length including the matching resistors when using the open test head method.

6.3 Balun requirements

A balun may be required to match the output impedance of the generator (a balun is not required when a balanced output generator is used) to the nominal characteristic impedance of the cable under test. The balun performance requirements are specified in Table 1.

The attenuation of the balun shall be kept as low as possible because it will limit the dynamic range of the coupling attenuation measurements.

Table 1 – Balun performance characteristics (1 MHz to 1 GHz)

Parameter	Value
Impedance, primary[a]	50 Ω (unbalanced)
Impedance, secondary[b]	100 Ω or 150 Ω (balanced)
Insertion loss[c] (including matching pads if used)	≤ 10 dB
Return loss, bi-directional	≥ 6 dB
Power rating	To accommodate the power of the generator and amplifier (if applicable)
Output signal balance[d]	≥ 50 dB from 1 MHz to 30 MHz ≥ 50 dB from 30 MHz to 100 MHz ≥ 30 dB from 100 MHz to 1 GHz

[a] Primary impedance may differ if necessary to accommodate analyser outputs other than 50 Ω.

[b] Balanced outputs of the test baluns should be matched to the nominal impedance of the symmetrical cable pair. 100 Ω should be used for termination of 120 Ω cabling.

[c] The insertion loss of a balun shall be mathematically deduced from three insertion loss measurements with three baluns back-to-back (see also IEC 62153-4-5).

[d] Measured per ITU-T Recommendations G.117 [1] and O.9 [2].

6.4 TP-connecting unit requirements

When measuring with "virtual balun", a TP connecting unit is required. See Table 2.

Table 2 – TP-connecting unit performance characteristics (1 MHz to 2 GHz)

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

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

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

[c] With the test set-up according to [b], the absolute dB value of the S-parameter S_{dd21} then represents the attenuation of the differential mode.

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

6.5 Sample preparation

A differential mode termination is required for each pair at the near and far end of the cable.

$$R_{\text{DM}} = \frac{Z_{\text{diff}}}{2} \tag{12}$$

The termination of the common mode ($R_{DM}//R_{DM}$ + R_{CM}) is under consideration.

NOTE Since modern mixed mode VNAs use a 25 Ω generator and receiver impedance as default value for the common mode (see Clause C.2), a value of zero Ω for R_{CM}, respectively a short circuit, is used in general.

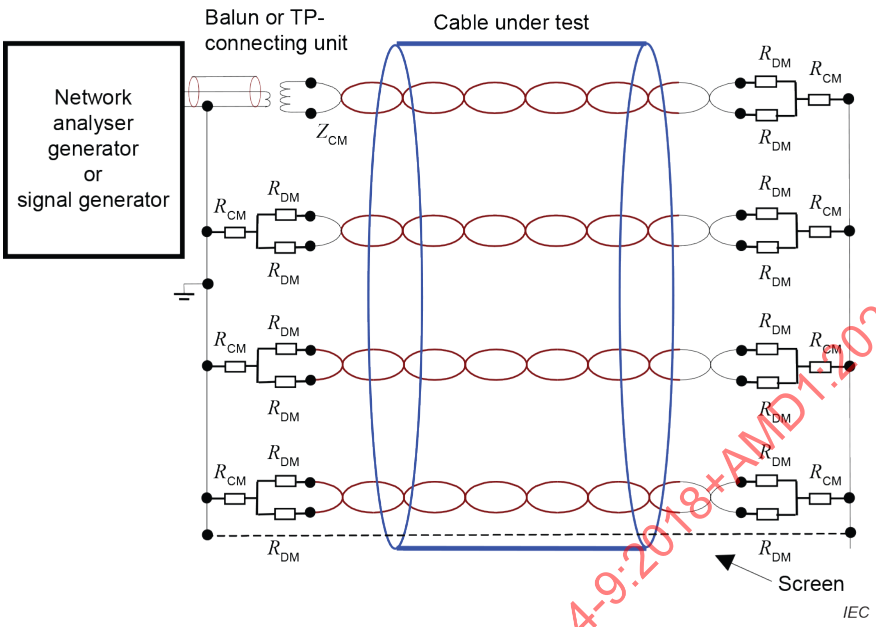


Figure 6 – Termination of the cable under test with balun feeding

6.6 Procedure

The pair under test is terminated at the far end by differential and common mode terminations according to Figure 3. The sample is then centered in the tube and fed by a generator in the differential mode via a balun or with multiport or mixed mode VNA.

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

Only the peak values of the maximum of the voltage ratio or the minimum of the attenuation shall be measured and recorded as a function of the frequency in order to determine the envelope curve.

Attenuation introduced by the inclusion of adapters, instead of direct connection, shall be taken into account when calibrating the triaxial apparatus.

When using multiport or mixed mode VNA, a complete calibration of all ports shall be performed according to the specification of the manufacturer, e.g. by using an electronic calibration kit.

The voltage ratio measured is not dependent on the diameter of the outer tube of the triaxial test set-up nor on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

6.7 Test length

The coupling length is electrically long, if

$$\lambda_o / l \leq 2 \times \left| \sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}} \right| \quad \text{or} \quad f > \frac{c_o}{2 \times l \times \left| \sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}} \right|} \qquad (13), (14)$$

6.8 Measurement precautions

The cable under test shall be positioned concentric in the tube to obtain homogeneous wave propagation.

The balun (if applicable) and the remaining cable length including the matching resistors (in case of open head procedure), shall be positioned in a well-screened box to avoid disturbances from outside into the test set-up as well as to avoid radiation from the test set-up.

It is important to place the absorber rings as near as possible to the receiver side of the tube to absorb interfering, backward travelling waves.

7 Expression of results

7.1 Procedure A: measuring with a standard head

The attenuation of the balun or of the TP-connecting unit shall be subtracted from the measuring results.

The voltage ratio U_{diff}/U_{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.

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:

$$a_c = 10 \cdot \lg \left| \frac{P_{diff}}{P_{com}} \right| + 10 \cdot \lg \left| \frac{P_{com}}{P_{r,max}} \right| \text{ dB,} \qquad ((10) + (8))$$

$$a_c = 20 \cdot \lg \left| \frac{U_{diff}}{U_{com}} \right| + 10 \cdot \lg \left[\frac{Z_{com}}{Z_{diff}} \right] + 20 \cdot \lg \left| \frac{U_{com}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{com}} \right] \text{ dB,} \qquad ((11) + (9))$$

$$a_c = 20 \cdot \lg \left| \frac{U_{diff}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{diff}} \right] \qquad (15)$$

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

7.2 Procedure B: measuring with an open head

The attenuation of the balun or of the TP-connecting unit shall be subtracted from the measuring results.

The voltage ratio U_{diff}/U_{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. The operational attenuation a_{tube} = 20·lg(U_1/U_2) of the outer system of the test set-up shall be measured according to Figure 7 in case of open head procedure with the same absorber and DUT configuration as used during the coupling attenuation measurement:

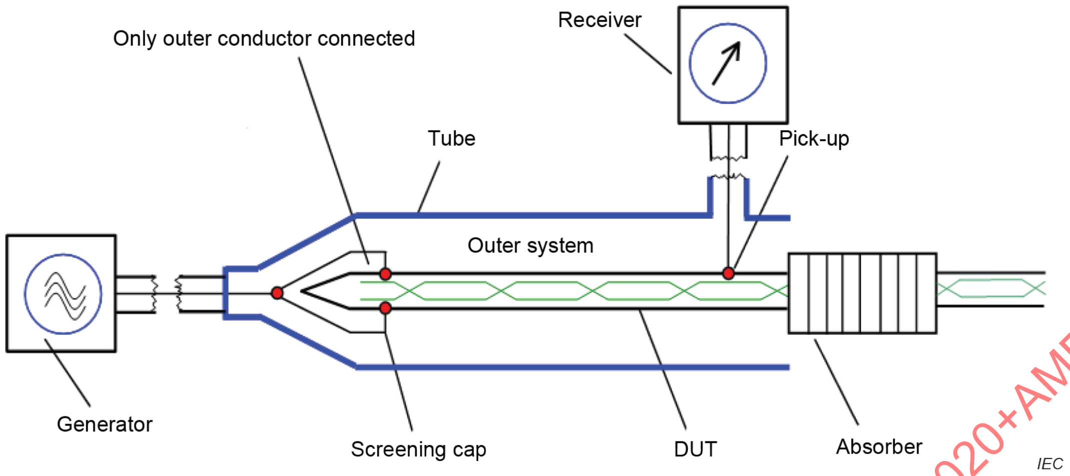


Figure 7 – Test set-up to measure a_{tube}

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:

$$a_c = 10 \cdot \lg\left|\frac{P_{diff}}{P_{com}}\right| + 10 \cdot \lg\left|\frac{P_{com}}{P_{r,max}}\right| \text{ dB,} \qquad ((10) + (8))$$

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{com}}\right| + 10 \cdot \lg\left[\frac{Z_{com}}{Z_{diff}}\right] + 20 \cdot \lg\left|\frac{U_{com}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{com}}\right] \text{ dB,} \qquad ((11) + (9))$$

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{diff}}\right] \text{dB,} \qquad (16)$$

and with the correction of the operational attenuation a_{tube} of the outer system in case of open head procedure:

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{diff}}\right] - a_{tube} \text{ dB,} \qquad (17)$$

where

$$a_{tube} = 20 \cdot \lg[U_1 / U_2] \text{dB}$$

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

8 Test report

The test report shall include:

a) a description of the tested cable and length;

b) the length of the tube;

c) the test procedure (standard or open head).

9 Requirements

The results of the minimum coupling attenuation shall 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.

10 Plots of coupling attenuation versus frequency (typical results)

Coupling attenuation for a 105 Ω twinax cable versus frequency on linear scale is shown in Figure 8. The same parameter is shown in Figures 9 and 10 for Cat 7a and Cat 8.2 cable.

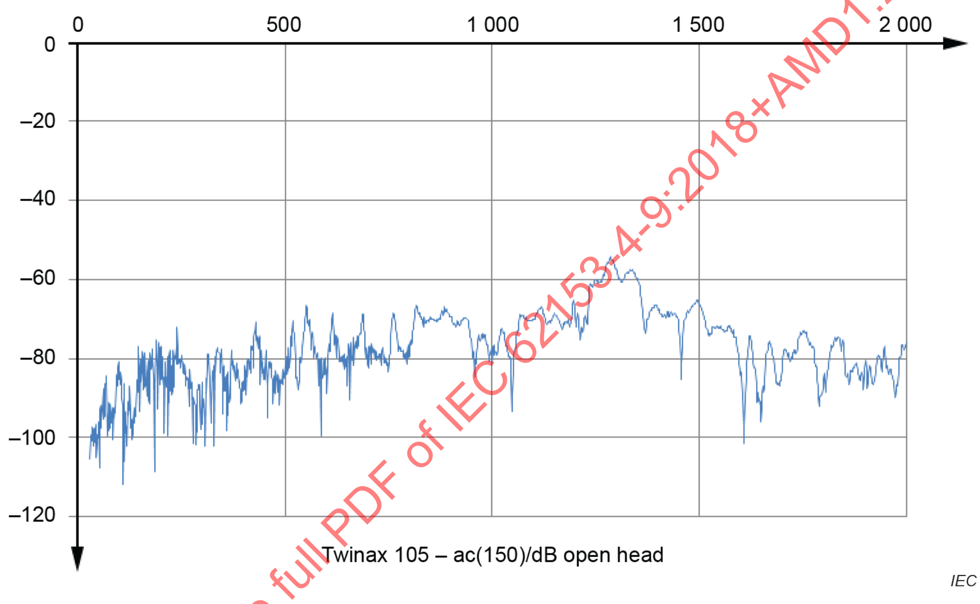


Figure 8 – Coupling attenuation Twinax 105, open head procedure

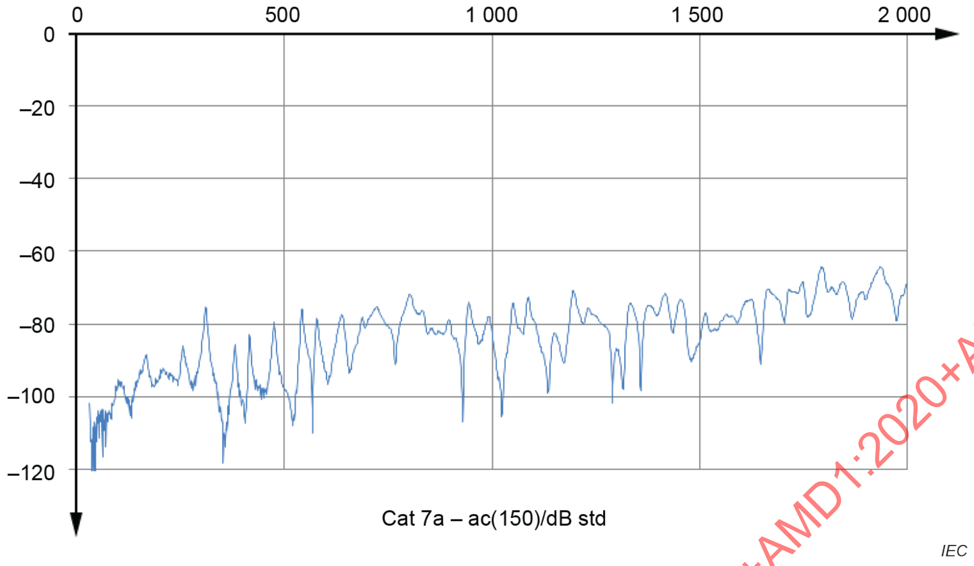


Figure 9 – Coupling attenuation Cat 7a, standard head procedure

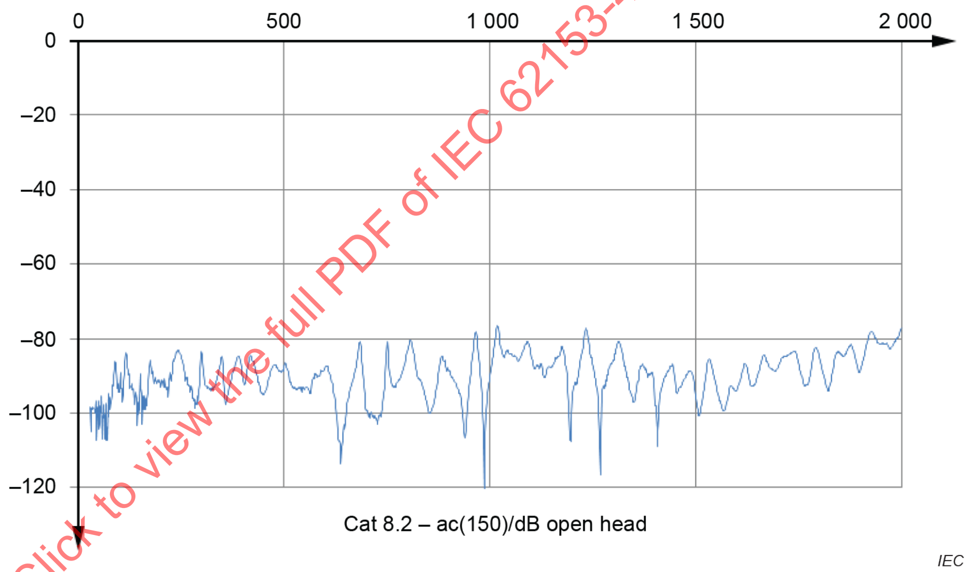


Figure 10 – Coupling attenuation Cat 8.2, open head procedure

Annex A
(normative)

Insertion loss of absorber with triaxial set-up

For the qualification of absorbers for the triaxial method, a coaxial system can be used. The test set-up as shown in Figure A.1 consists of a measuring tube with two test heads and an inner conductor, designed in a way that the measuring tube with the inner conductor forms a 50 Ω system. The absorbers to be tested are pushed onto the inner conductor. The transmission parameter (S_{21}) is measured with and without absorber. The difference between the two measurements results in the insertion loss of the absorber.

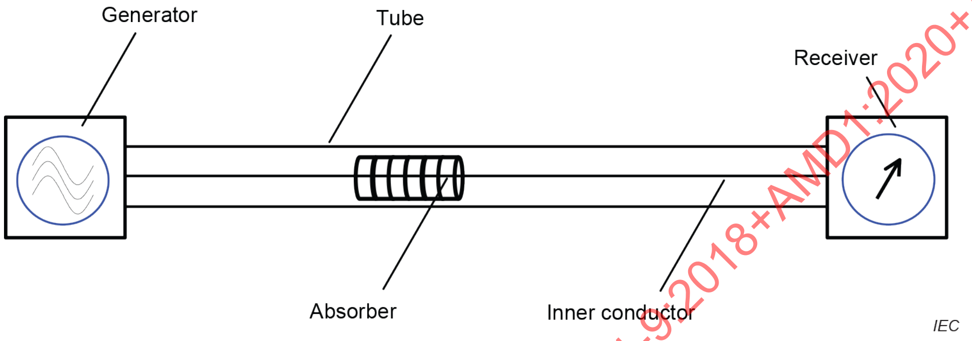
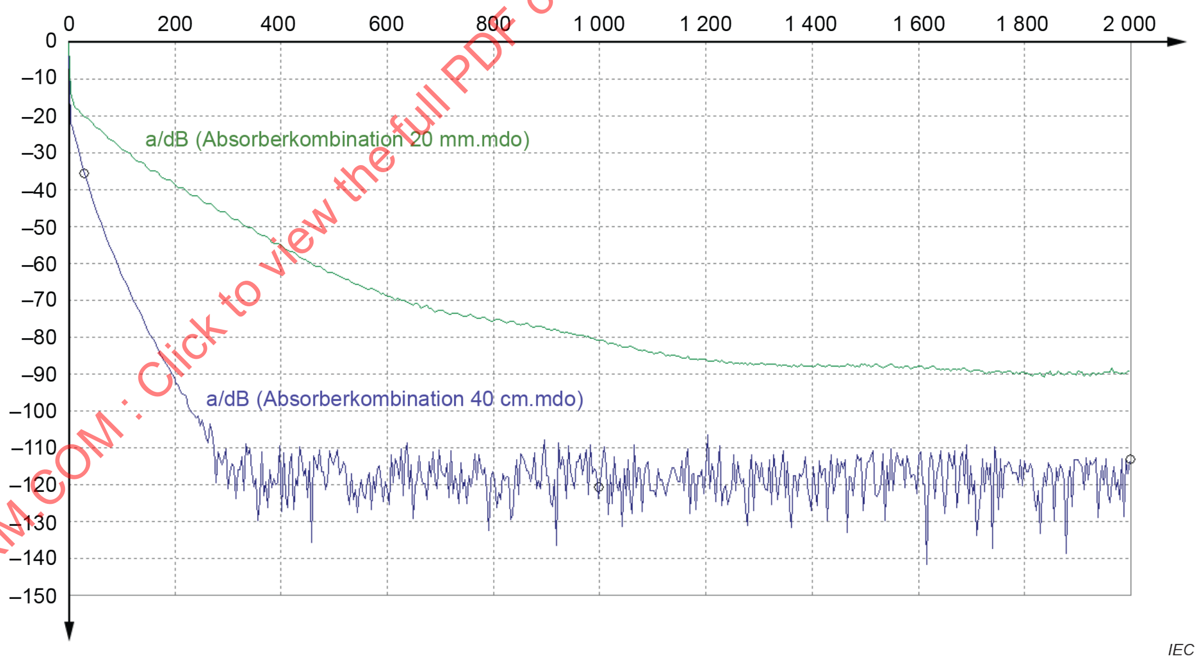


Figure A.1 – Insertion loss of absorber with triaxial set-up

Examined are both the nanocrystalline absorber as well as the ferrite absorber. The best effect over the entire frequency range from 30 MHz up to 2 GHz was achieved with a combination of nanocrystalline absorbers and a ferrite absorber.



key

Absorberkombination combination of absorbers

Figure A.2 – Insertion loss of absorber with triaxial set-up

Figure A.2 shows the insertion loss of a combination of nanocrystalline absorbers and ferrite absorber at a length of 20 cm and 40 cm.

NOTE Attenuation of absorbers depends on the sourrunding. It is higher in a metallic enclosure.

Annex B
(informative)

Physical background

B.1 Unbalance attenuation a_u

Screened balanced pairs may be operated in the differential mode (balanced) or the common mode (unbalanced). In the differential mode, one conductor carries the current $+I$ and the other conductor carries the current $-I$; the screen is without current. In the common mode, both conductors of the pair carry half of the current $+I/2$; and the screen is the return path with the current $-I$.

Under ideal conditions with ideal cables, both modes are independent of one another. Actually both modes influence each other due to differences in the diameter of the core insulation, unequal twisting and different distances of the pair. The unsymmetry is caused by the capacitive unbalance to earth e (transversal unsymmetry) and the difference of the inductance and resistance between the two wires r (longitudinal unsymmetry).

$$e = C_{10} - C_{20} \tag{B.1}$$

$$r = (R_2 + j\omega \cdot L_2) - (R_1 + j\omega \cdot L_1) \tag{B.2}$$

The coupling transfer functions between the two modes at the near and far ends is then expressed by:

$$T_{\mathrm{u,n}} = \frac{1}{4} \cdot \frac{1}{\sqrt{Z_{\mathrm{diff}} \cdot Z_{\mathrm{com}}}} \cdot \int_0^1 \left(j\omega \cdot e(x) \cdot Z_{\mathrm{diff}} \cdot Z_{\mathrm{com}} + r(x) \right) \cdot e^{-(\gamma_{\mathrm{diff}} + \gamma_{\mathrm{com}}) \cdot x} dx \tag{B.3}$$

$$T_{\mathrm{u,f}} = \frac{1}{4} \cdot \frac{1}{\sqrt{Z_{\mathrm{diff}} \cdot Z_{\mathrm{com}}}} \cdot \int_0^1 \left(j\omega \cdot e(x) \cdot Z_{\mathrm{diff}} \cdot Z_{\mathrm{com}} - r(x) \right) \cdot e^{(\gamma_{\mathrm{diff}} - \gamma_{\mathrm{com}}) \cdot (l-x)} dx \tag{B.4}$$

Z_{diff} and Z_{com} are in principle the same coupling transfer functions compared to the coupling through the screen. The integral may be solved if the distribution of the unsymmetry functions along the cable length is known.

For a constant unsymmetry along the cable length, the coupling function is expressed by (similar to the form of the coupling function for cable screens):

$$T_{\mathrm{uf}}^{\mathrm{n}} = (j\omega \cdot e \cdot Z_{\mathrm{diff}} \cdot Z_{\mathrm{com}} \pm r) \cdot \frac{1}{\sqrt{Z_{\mathrm{diff}} \cdot Z_{\mathrm{com}}}} \cdot \frac{1}{4} \cdot S_{\mathrm{f}}^{\mathrm{n}} \tag{B.5}$$

If the cable is electrically long, there is the same phenomenon as for the coupling through the screen. Depending on the velocity difference between the differential and the common mode circuit, the envelope of the transfer function approaches a constant value which is frequency and length independent. However, if the velocity difference is zero, then the transfer function at the far end increases by 20 dB per decade over the whole frequency range (S_{f} = 1). In practice, there are small systematic couplings as well as statistical couplings. Thus $T_{\mathrm{u,n}}$ increases by approximately 10 dB per decade and $T_{\mathrm{u,f}}$ by less then 20 dB per decade.