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inside

**Metallic communication cable test methods –
Part 4-9: Electromagnetic compatibility (EMC) – 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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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 cancels and replaces the first edition published in 2008. This 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.

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

FDIS	Report on voting
46/681/FDIS	46/685/RVD

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

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 will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

• reconfirmed,

• withdrawn,

• replaced by a revised edition, or

• amended.

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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 baluns.

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 62153-4-5 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/TR TS 62153-4-1, *Metallic communication cable test methods – Part 4-1: Electromagnetic compatibility (EMC) – Introduction to electromagnetic (EMC) 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 62153-4-5 IEC 62153-4-4, as well as the following symbols apply.

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 ~~an eventually~~ 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~~s~~ 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,

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

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

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

R is the input impedance of the receiver in Ω;

~~R_1~~ 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;

~~under test (150 Ω secondary circuit impedance Z_2) in Ω;~~

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

Z_{diff} is the nominal characteristic ~~differential mode~~ 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

~~The test set up (see Figure 1) is a triaxial system consisting of an outer solid metallic tube in which are concentrically positioned the first several meters of a longer length of the cable to be tested. The length of the cable under test that extends past the tube is placed in a highly shielded box and terminated with common mode and differential mode terminations.~~

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 ~~it~~ 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.

Figure 1 – Principle test set-up

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.

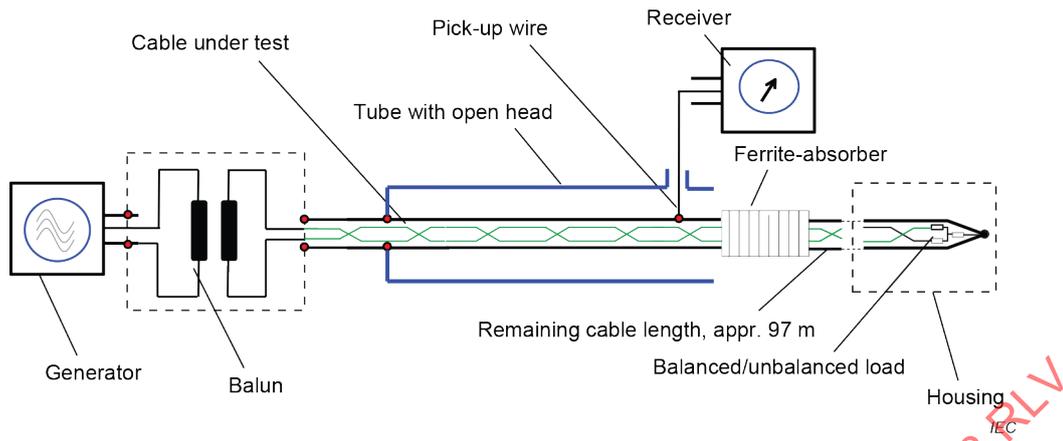At the far end, the tube is let open and the signal is picked up by a "pick up wire", which is connected to the screen of the cable under test (see Figure 4). The open tube system can also be equipped with a "test head" which can be removed from the tube for easier connecting of the CUT.

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 ~~Theoretical background~~ 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

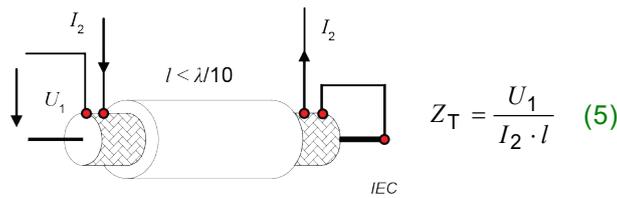The test procedure for transfer impedance is described in IEC 62153-4-3. According to the definition it can be measured on short cable samples.

5.3 Screening attenuation a_s

The screening attenuation a_s is given by

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

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

$$\sqrt{\left|\frac{P_{2max}}{P_1}\right|} \approx \frac{c_0}{\omega\sqrt{Z_1 \times Z_2}} \times \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}\right| \quad (11)$$

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:

$$\left|\frac{U_2}{U_1}\right| \approx \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} \times \left[1 - e^{-j\varphi_1}\right] + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} \times \left[1 - e^{-j\varphi_2}\right]\right| \times \left|\frac{1}{\omega \times Z_1}\right| \times$$
$$\left|\frac{c_0}{2 + (Z_2/R - 1) \times (1 - e^{-j\varphi_3})}\right| \quad (12)$$

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 $Z_S = 150\ \Omega$ (see IEC 62153-4-4) one gets:

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

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

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 $Z_S = 150\ \Omega$ one gets for screened balanced cables (in the common mode) the screening attenuation a_s:

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

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

5.4   Unbalanced attenuation a_u

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.

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 (transverse - unsymmetry) and the difference of the inductance and resistance between the two wires r (longitudinal - unsymmetry).

$$e = C_{10} - C_{20} \tag{5}$$

$$r = (R_2 + j\omega \times L_2) - (R_1 + j\omega \times L_1) \tag{6}$$

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

$$T_\text{u,n} = \frac{1}{4} \times \frac{1}{\sqrt{Z_\text{diff} \times Z_\text{com}}} \times \int_0^l (j\omega \times e(x) \times Z_\text{diff} \times Z_\text{com} + r(x)) \times e^{-(\gamma_\text{diff} + \gamma_\text{com}) \times x} dx \tag{7}$$

$$T_\text{u,f} = \frac{1}{4} \times \frac{1}{\sqrt{Z_\text{diff} \times Z_\text{com}}} \times \int_0^l (j\omega \times e(x) \times Z_\text{diff} \times Z_\text{com} - r(x)) \times e^{(\gamma_\text{diff} - \gamma_\text{com}) \times (l-x)} dx \tag{8}$$

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):

$$T_\text{u\,f}^\text{n} = (j\omega \times e \times Z_\text{diff} \times Z_\text{com} \pm r) \times \frac{1}{\sqrt{Z_\text{diff} \times Z_\text{com}}} \times \frac{l}{4} \times S_\text{f}^\text{n} \tag{9}$$

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_r = 1). In practice, there are small systematic couplings as well as statistical couplings. Thus $T_{u,n}$ increases by approximately 10 dB per decade and $T_{u,f}$ by less then 20 dB per decade.

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 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:

$$a_c = a_u + a_s \tag{13}$$

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

$$a_c = -10 \times \log_{10} \left(\text{Env} \left| \frac{P_{r,max}}{P_1} \right| \right) \tag{14}$$

---

[1]   Figures in square brackets refer to the Bibliography.

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

$$\frac{P_S}{P_2} = \frac{P_{Smax}}{P_{2max}} = \frac{R}{2 \times Z_S} \text{\hspace{2cm}} (15)$$

~~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.~~

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.

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 ~~2~~ 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 ~~, see 6.2~~; or

- a Twisted Pair (TP)-connecting unit when measuring with multiport respectively with mixed mode VNA;

- ~~ferrite~~ absorber rings (ferrite or nanocrystalline) with an attenuation ~~$a_{Ferrite} > 10$ Db~~ $a_{absorber} > 20$ 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.
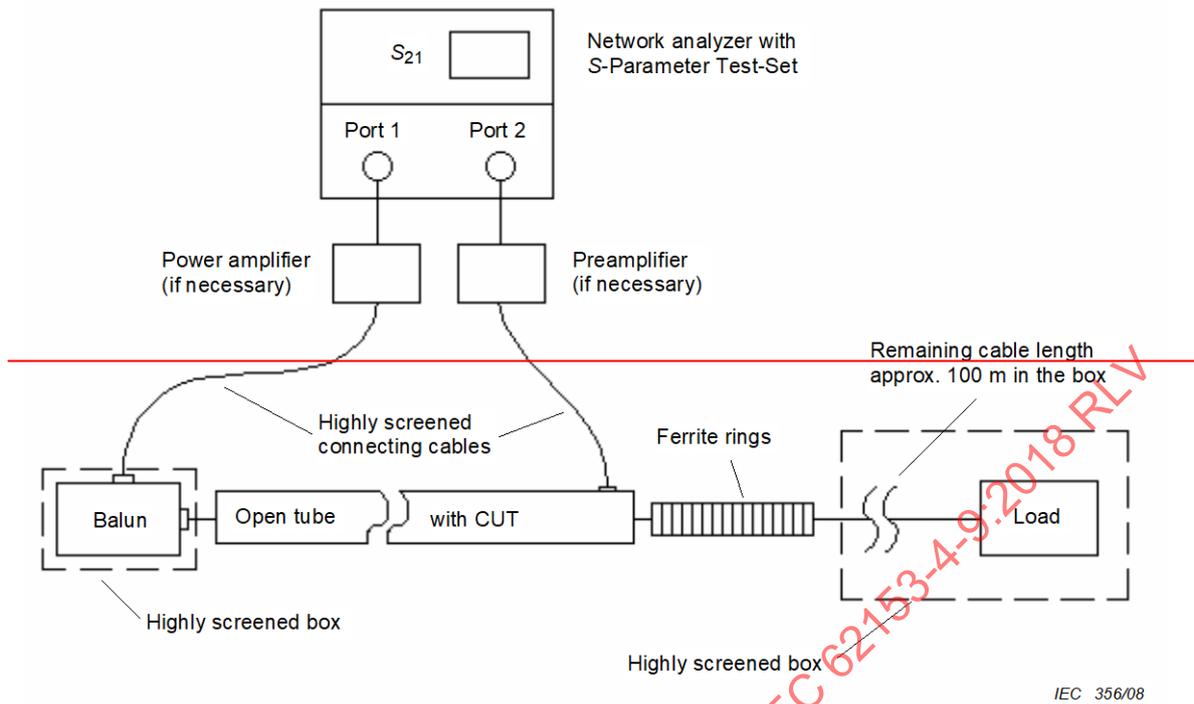
IEC   356/08

Figure 2 – Set-up to measure the coupling attenuation

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.

$$R_1 = \frac{Z_{diff}}{2}$$

~~The center taps of the terminations shall be connected together; and shall be connected to the screens.~~

~~The entire length of the cable shall be at least 100 m.~~

$$R_{DM} = \frac{Z_{diff}}{2} \qquad (12)$$

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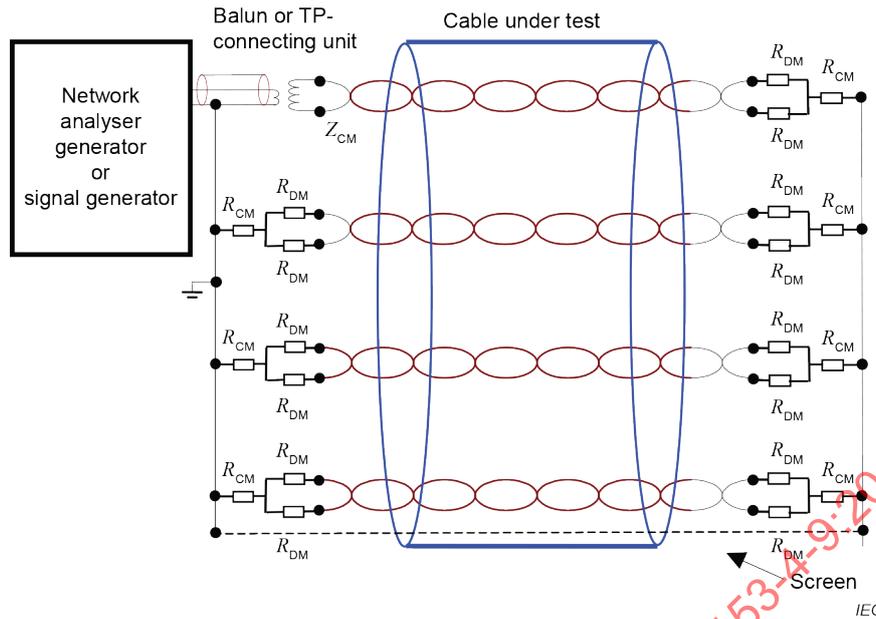
Figure 6 – Termination of the cable under test with balun feeding

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 must shall be measured and recorded as a function of the frequency in order to determine the envelope curve.

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

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

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

6.8   Measurement precautions

The cable under test shall be positioned ~~as~~ concentric ~~as possible~~ in the ~~outer~~ 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 ~~ferrite~~ 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 $U_{\mathrm{diff}}/U_{\mathrm{2max}}$ 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 $Z_{\mathrm{S}} = 150\ \Omega$:

$$a_{\mathrm{c}} = 10 \times \log_{10}\left|\frac{P_1}{P_{\mathrm{r,max}}}\right| = 10 \times \log_{10}\left|\frac{P_1}{P_{\mathrm{2,max}}} \times \frac{2 \times Z_{\mathrm{S}}}{R}\right| \tag{18}$$

$$= 20 \times \log_{10}\left|\frac{U_1}{U_{\mathrm{2max}}}\right| + 10 \times \log_{10}\left|\frac{300\ \Omega}{Z_1}\right| \tag{19}$$

$$= a_{\mathrm{m,min}} - a_{\mathrm{z}} + 10 \times \log_{10}\left|\frac{300\ \Omega}{Z_1}\right| \tag{20}$$

$$a_{\mathrm{c}} = 10 \cdot \lg\left|\frac{P_{\mathrm{diff}}}{P_{\mathrm{com}}}\right| + 10 \cdot \lg\left|\frac{P_{\mathrm{com}}}{P_{\mathrm{r,max}}}\right|\ \mathrm{dB}, \tag{(10) + (8)}$$

$$a_{\mathrm{c}} = 20 \cdot \lg\left|\frac{U_{\mathrm{diff}}}{U_{\mathrm{com}}}\right| + 10 \cdot \lg\left[\frac{Z_{\mathrm{com}}}{Z_{\mathrm{diff}}}\right] + 20 \cdot \lg\left|\frac{U_{\mathrm{com}}}{U_{\mathrm{2,max}}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_{\mathrm{S}}}{Z_{\mathrm{com}}}\right]\ \mathrm{dB}, \tag{(11) + (9)}$$

$$a_{\mathrm{c}} = 20 \cdot \lg\left|\frac{U_{\mathrm{diff}}}{U_{\mathrm{2,max}}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_{\mathrm{S}}}{Z_{\mathrm{diff}}}\right] \tag{15}$$

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 $a_{tube} = 20 \cdot \lg(U_1/U_2)$ 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:
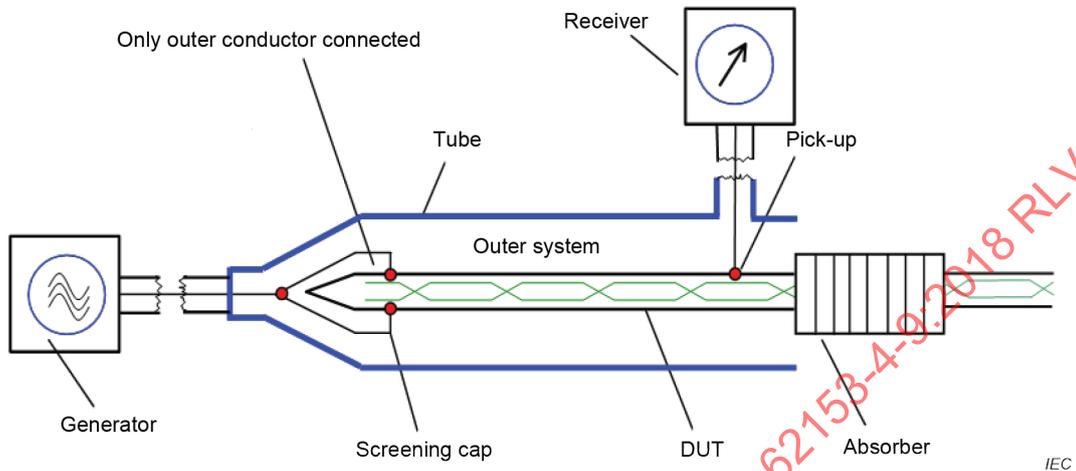

Figure 7 – Test set-up to measure a_{tube}

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 $Z_S = 150\ \Omega$:

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

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

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

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

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

where

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

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 105 Ω twinax cable is shown plotted versus frequency on logarithmic and linear scales respectively in Figures 4 and 5. The same parameter is plotted for FTP cable in Figures 6 and 7.
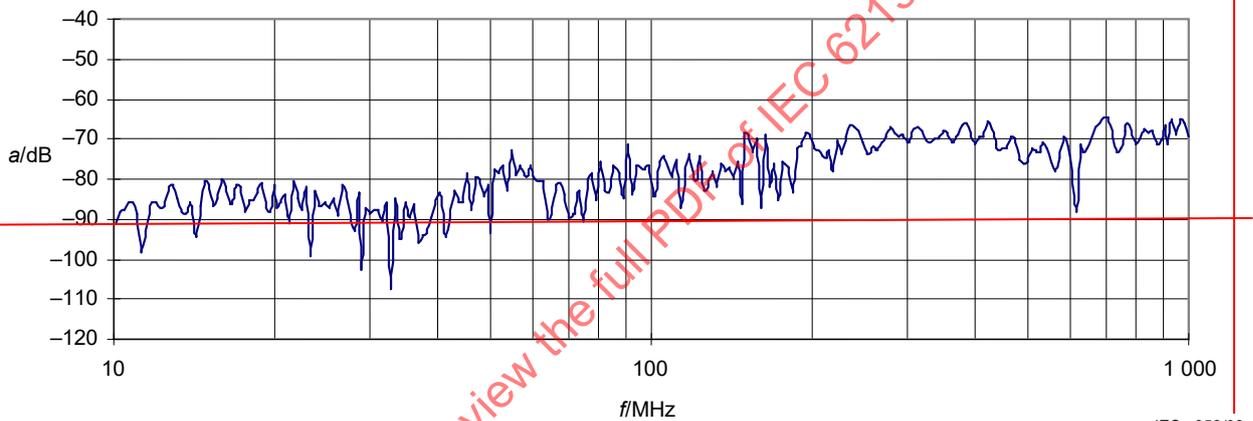

IEC   358/08

Figure 4 – Twinax 105 log

IEC   359/08
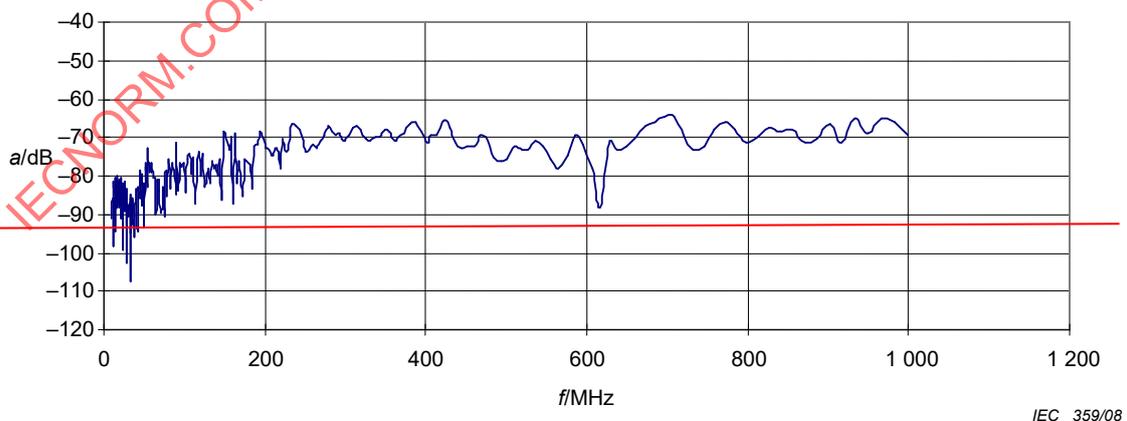
Figure 5 – Twinax 105 linear

IEC   360/08

Figure 6 – FTP log

IEC   361/08
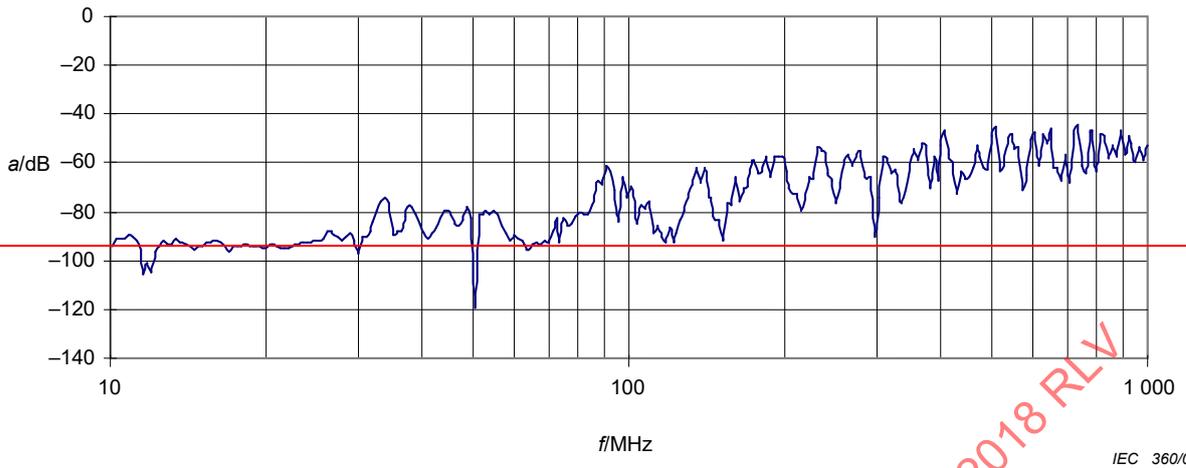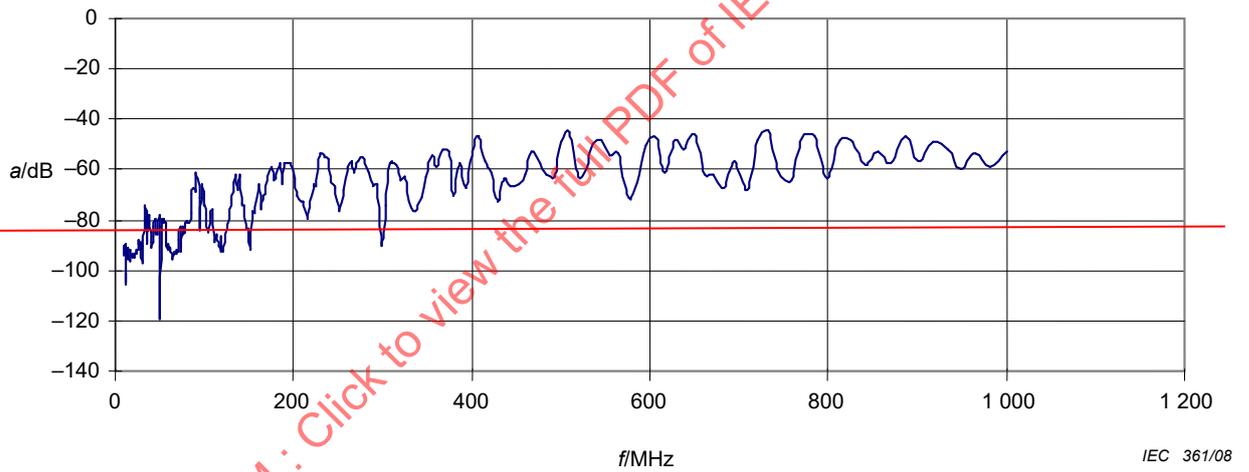
Figure 7 – FTP linear

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.
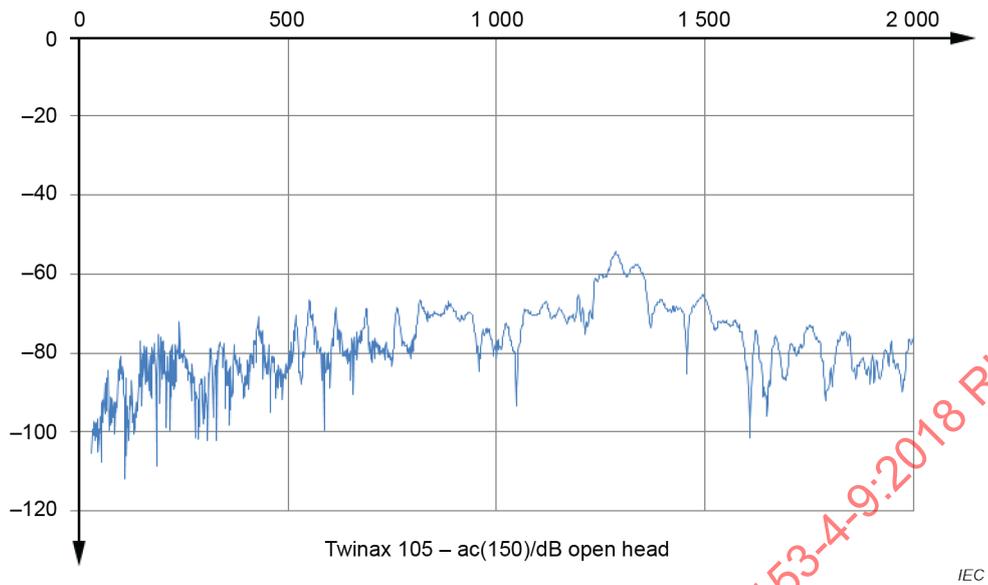
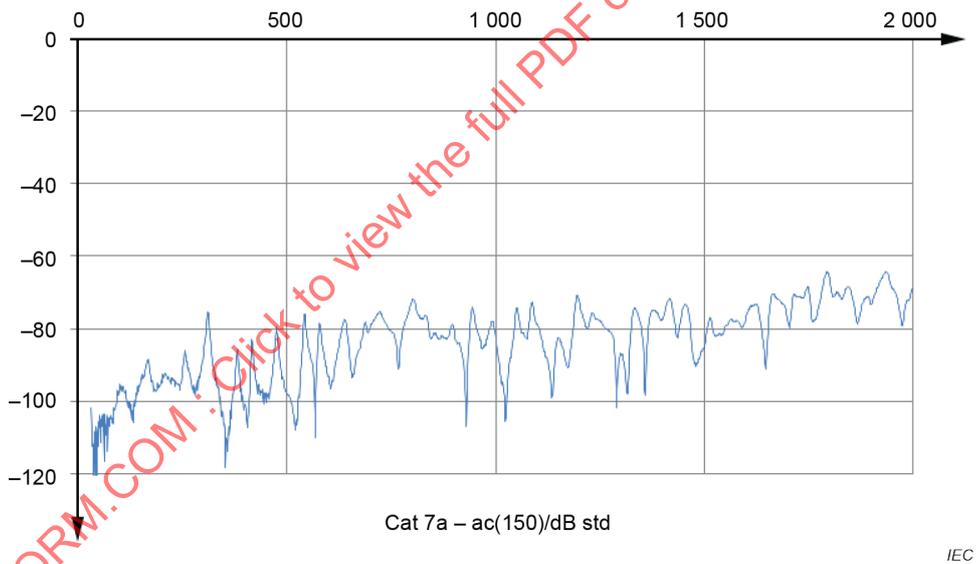Figure 8 – Coupling attenuation Twinax 105, open head procedure

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

Cat 8.2 – ac(150)/dB open head

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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:

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

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

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):

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

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 $T_{u,n}$ increases by approximately 10 dB per decade and $T_{u,f}$ by less then 20 dB per decade.

B.2 Screening attenuation a_s

The screening attenuation a_s is given by

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

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

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

$$\left|\frac{U_2}{U_1}\right| \approx \left|\frac{Z_T - Z_F}{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}} \cdot \left[1 - e^{-j\varphi_1}\right] + \frac{Z_T + Z_F}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} \times \left[1 - e^{-j\varphi_2}\right]\right| \cdot \left|\frac{1}{\omega \cdot Z_1}\right| \cdot$$

$$\left|\frac{c_0}{2 + (Z_2/R - 1) \cdot \left(1 - e^{-j\varphi_3}\right)}\right|$$ (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:

$$a_c = a_u + a_s$$ (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):

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

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

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

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.

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

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.

S_{xyAB}

number of the VNA-port with stimulus
number of the VNA-port with response
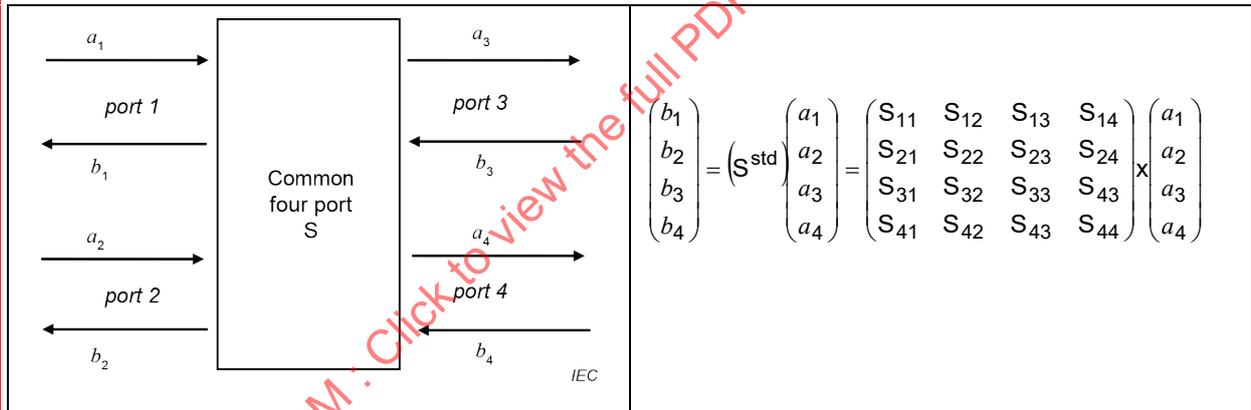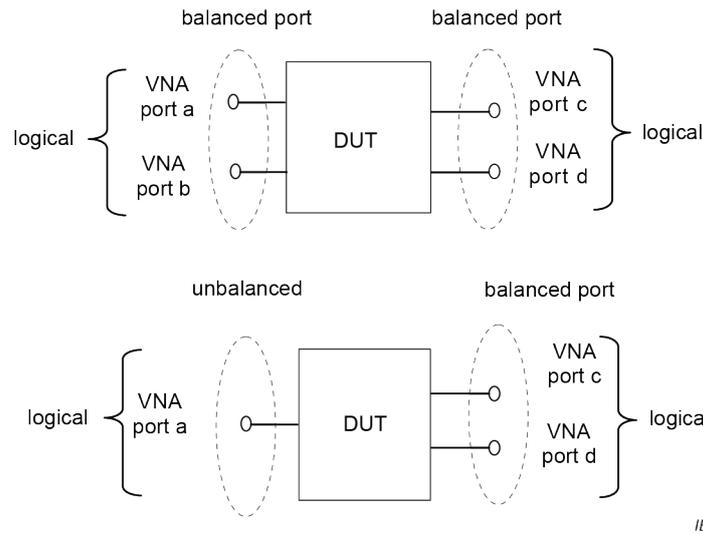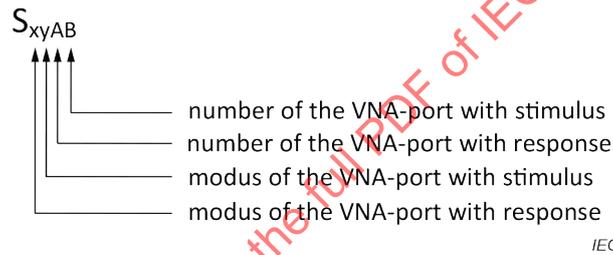modus of the VNA-port with stimulus
modus of the VNA-port with response

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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.

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

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:

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

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

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

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}

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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}

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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.

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

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

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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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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 cancels and replaces the first edition published in 2008. This 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.

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

FDIS	Report on voting
46/681/FDIS	46/685/RVD

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

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 will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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

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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,

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

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

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

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.
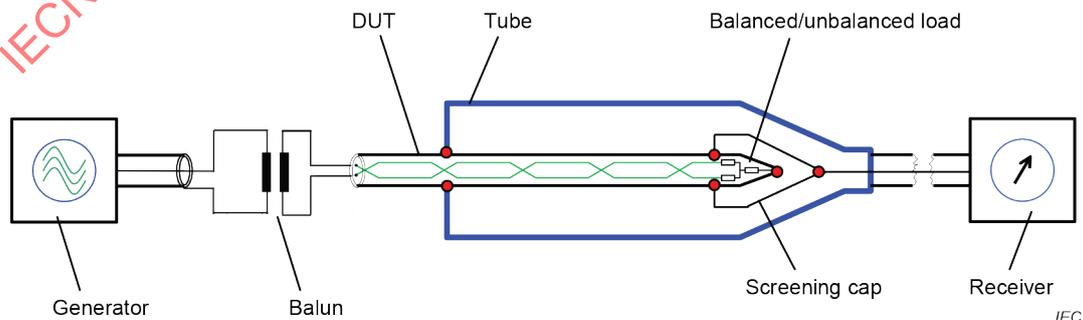

**Figure 1 – Coupling attenuation, principle test set-up
with balun and standard tube**

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.

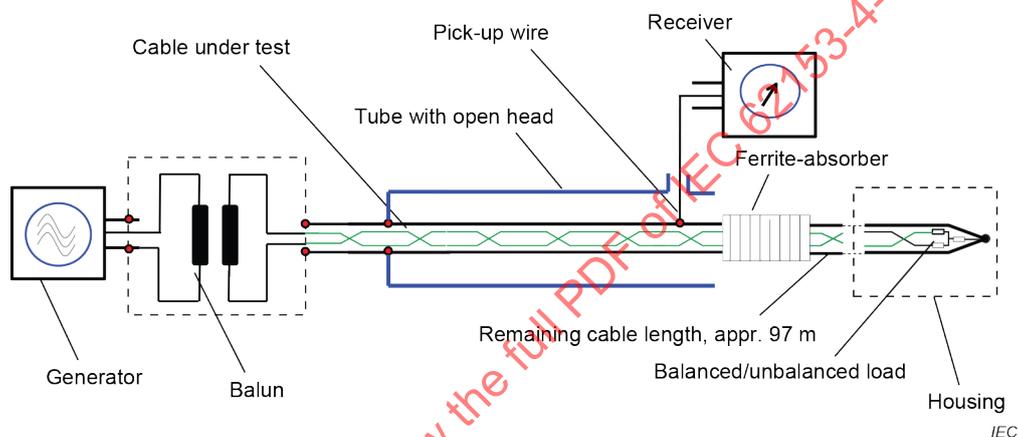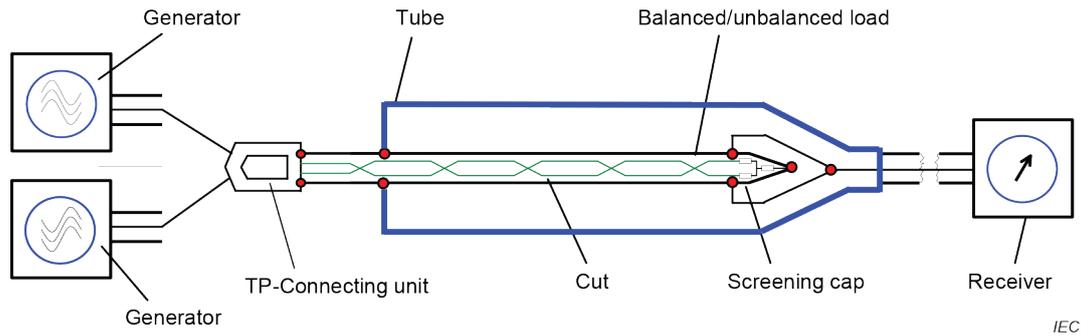At the far end, the tube is let open and the signal is picked up by a "pick up wire", which is connected to the screen of the cable under test (see Figure 4). The open tube system can also be equipped with a "test head" which can be removed from the tube for easier connecting of the CUT.

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 $m\Omega/m$ (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 $Z_S = 150\ \Omega$ (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 $Z_S = 150\ \Omega$ one gets for screened balanced cables (in the common mode) the screening attenuation a_s:

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

$$a_{\mathsf{s}} = 20 \cdot \lg \left| \frac{U_{\mathsf{com}}}{U_{2,\mathsf{max}}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_{\mathsf{S}}}{Z_{\mathsf{com}}} \right] \mathsf{dB} \tag{9}$$

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].

$$a_{\mathsf{u}} = 10 \cdot \lg \left| \frac{P_{\mathsf{diff}}}{P_{\mathsf{com}}} \right| \mathsf{dB} \tag{10}$$

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

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.

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[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.

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

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.
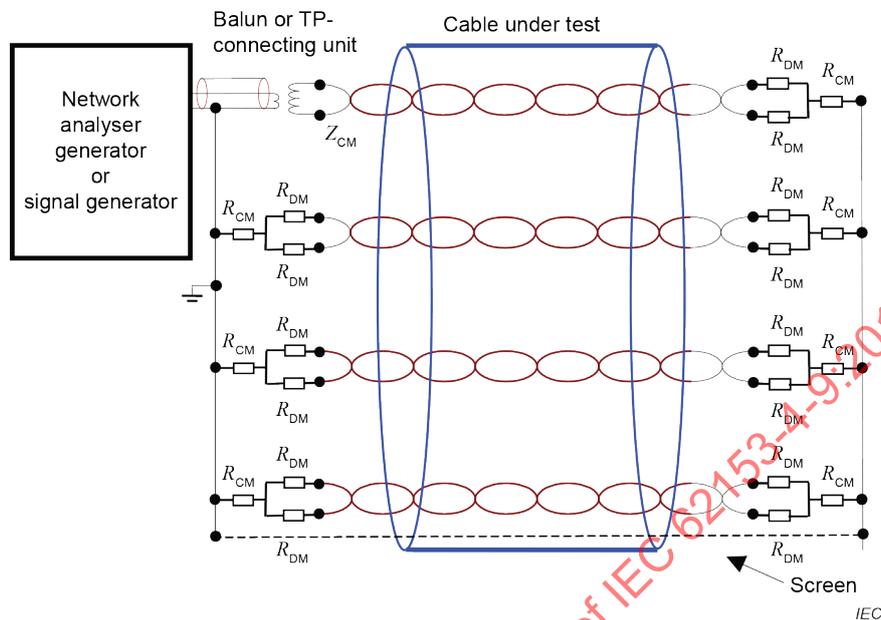

Figure 6 – Termination of the cable under test with balun feeding

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

$$\frac{\lambda_\text{o}}{l} \le 2 \times \left| \sqrt{\varepsilon_\text{r1}} - \sqrt{\varepsilon_\text{r2}} \right| \qquad \text{or} \qquad f > \frac{c_\text{o}}{2 \times l \times \left| \sqrt{\varepsilon_\text{r1}} - \sqrt{\varepsilon_\text{r2}} \right|} \qquad\qquad (13), (14)$$

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

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 $Z_\text{S} = 150\ \Omega$:

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

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

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

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 $U_\text{diff}/U_\text{2max}$ shall be measured with calibrated VNA (or calibrated generator and receiver) and corrected with regard to the influence of test leads and connecting units. The operational attenuation $a_\text{tube} = 20 \cdot \lg(U_1/U_2)$ 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:
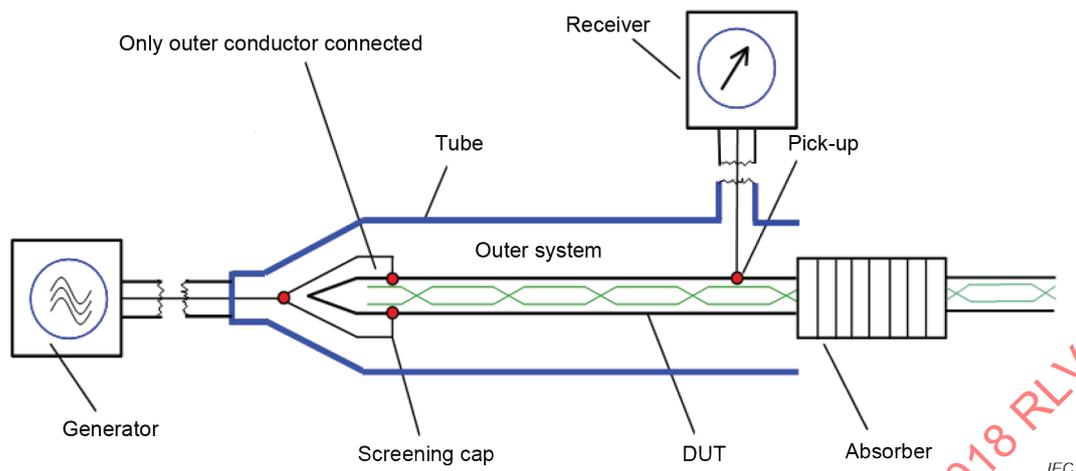
Figure 7 – Test set-up to measure a_{tube}

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 $Z_S = 150\ \Omega$:

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

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

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

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

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.
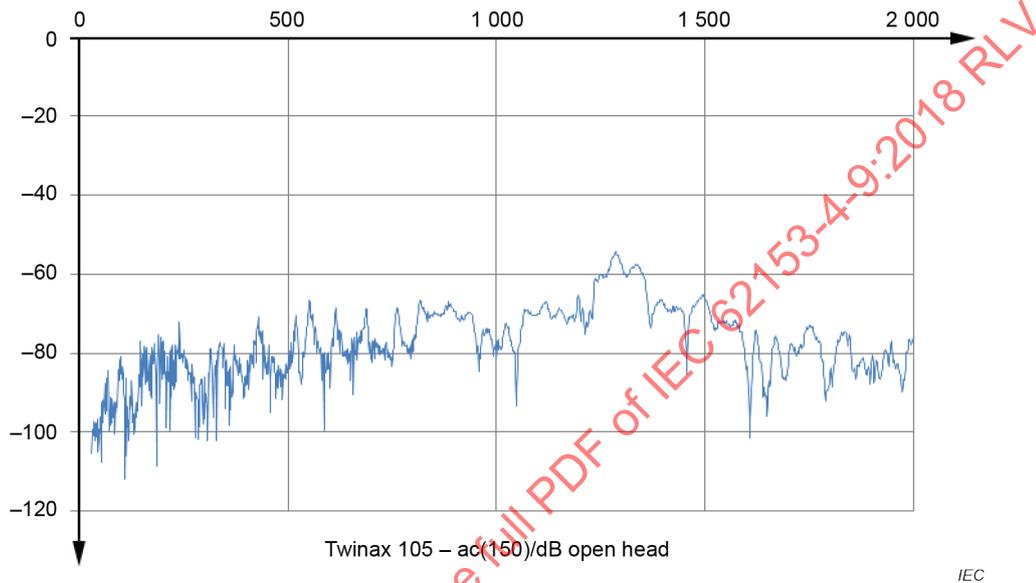

Figure 8 – Coupling attenuation Twinax 105, open head procedure
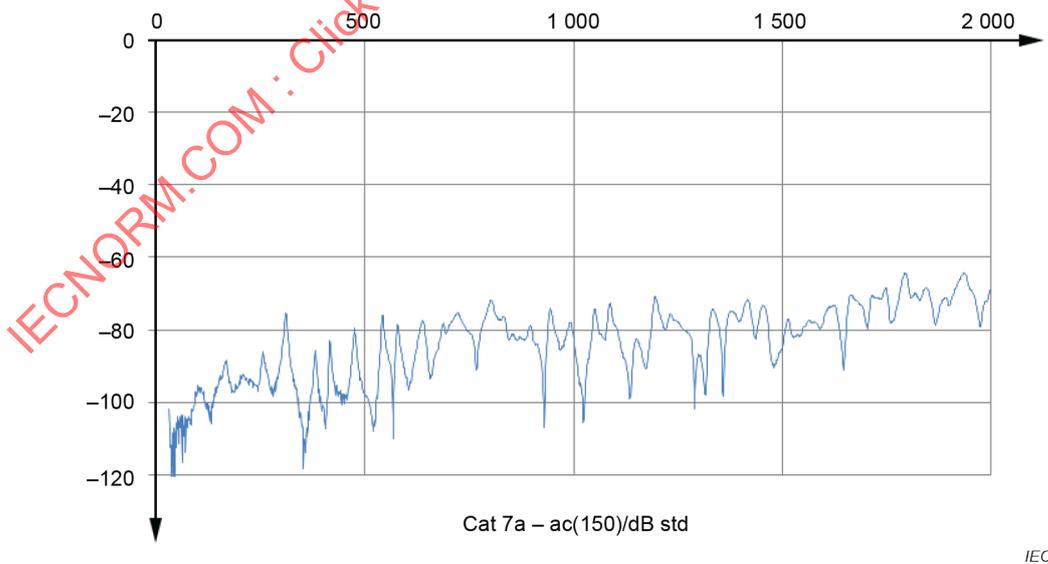

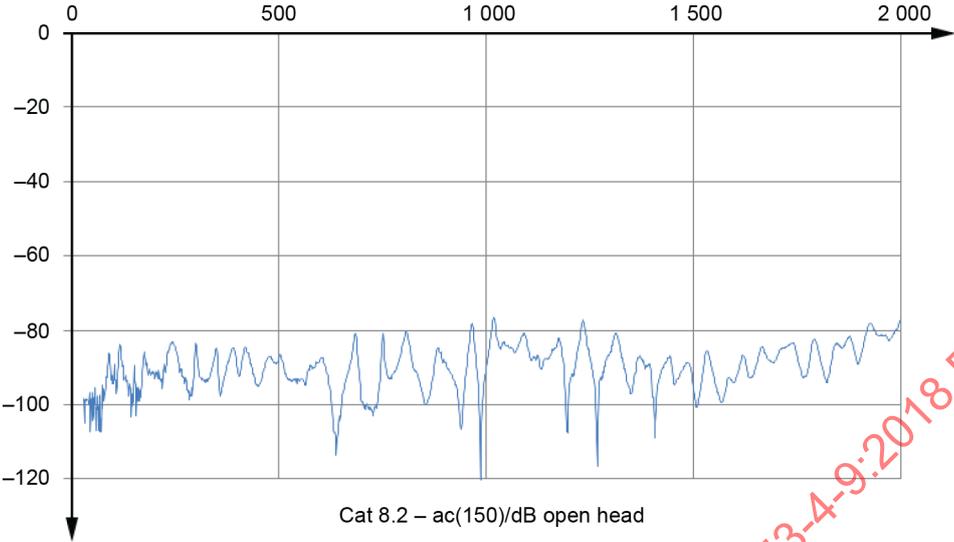Figure 9 – Coupling attenuation Cat 7a, standard head procedure

Cat 8.2 – ac(150)/dB open head

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.
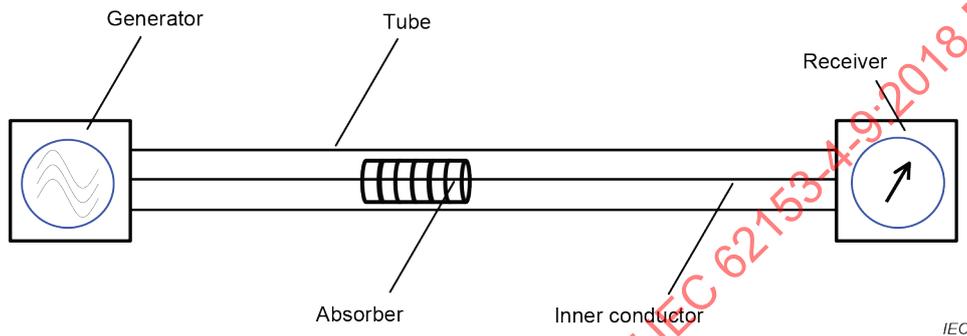

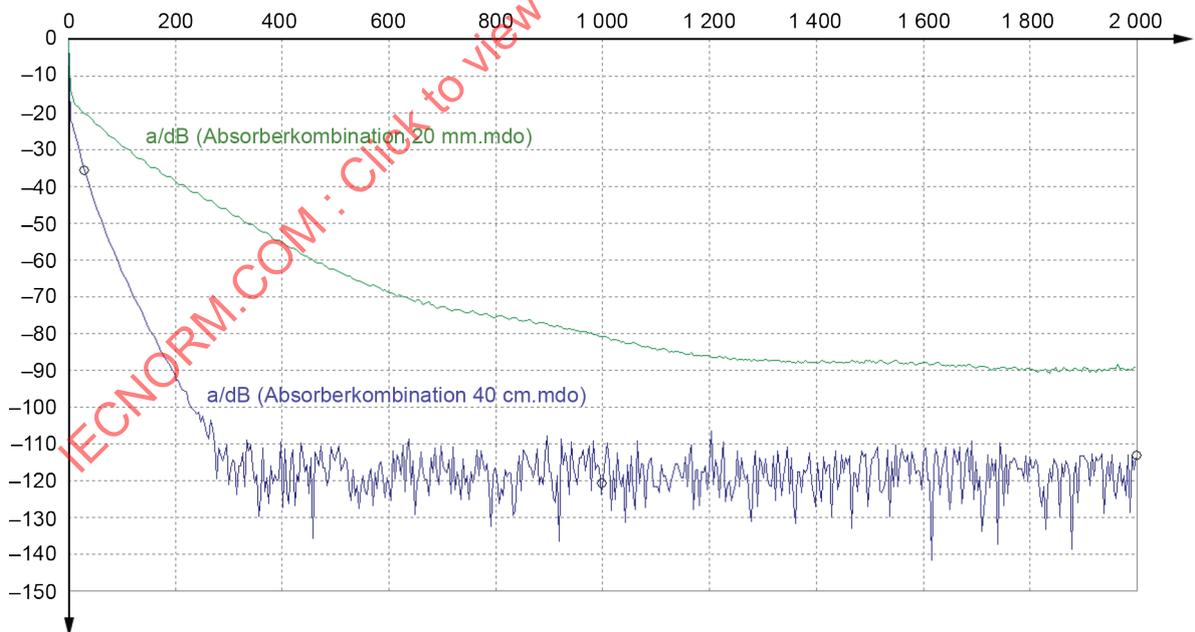**Figure A.1 – Insertion loss of absorber with triaxial set-up**

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:

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

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

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):

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

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 $T_{u,n}$ increases by approximately 10 dB per decade and $T_{u,f}$ by less then 20 dB per decade.

B.2 Screening attenuation a_s

The screening attenuation a_s is given by

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

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

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

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):

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

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

$$\frac{P_\mathrm{S}}{P_2} = \frac{P_\mathrm{Smax}}{P_{2\,\mathrm{max}}} = \frac{R}{2 \cdot Z_\mathrm{S}} \tag{B.11}$$

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.
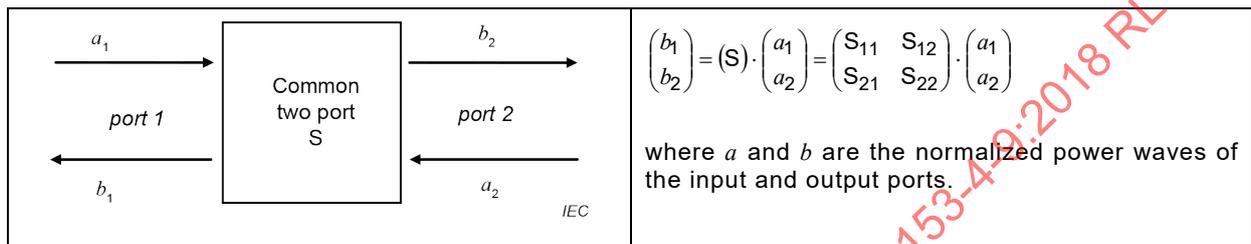

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

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.
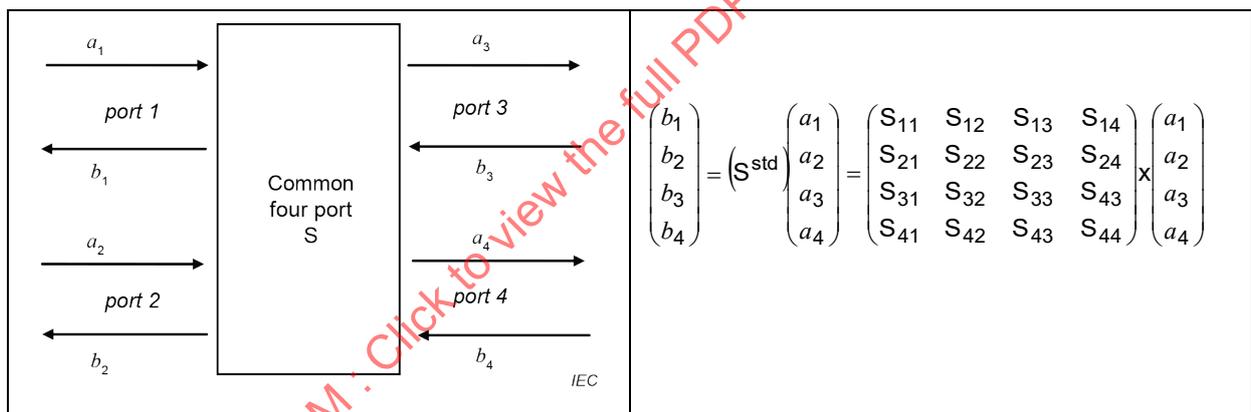

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = \left(S^{std} \right) \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{43} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix}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

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.
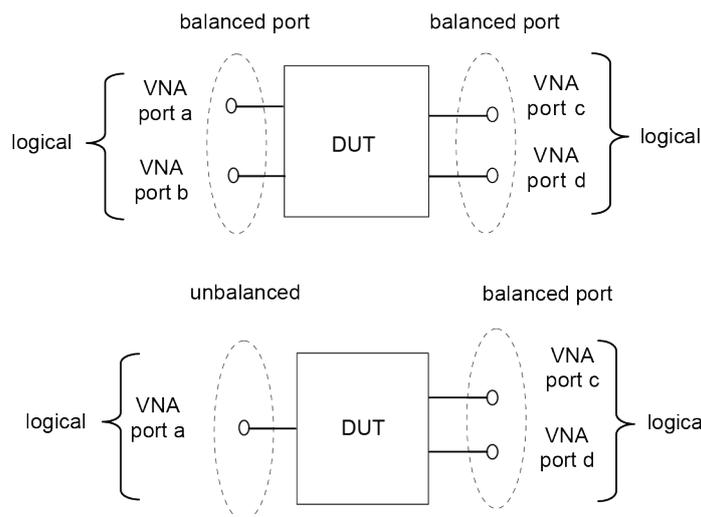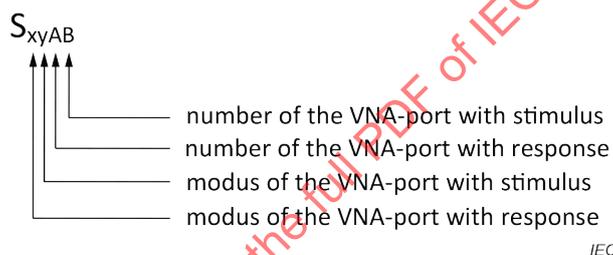
Figure C.3 – Physical and logical ports of VNA

The nomenclature in Figure C.4 is used.

S_{xyAB}

——— number of the VNA-port with stimulus
——— number of the VNA-port with response
——— modus of the VNA-port with stimulus
——— modus of the VNA-port with response

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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.

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

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:

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

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

$$S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd11} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix} \tag{C.3}$$

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}

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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}

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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.

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[5]   HÄHNER T./ MUND B., *Test methods for Screening and Balance of Communication* Cables, emc Zurich 1999

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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MÉTHODES D'ESSAIS DES CÂBLES MÉTALLIQUES DE COMMUNICATION –

Partie 4-9: Compatibilité électromagnétique (CEM) – Affaiblissement de couplage des câbles symétriques écrantés, méthode triaxiale

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1) La Commission Electrotechnique Internationale (IEC) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de l'IEC). L'IEC a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. A cet effet, l'IEC – entre autres activités – publie des Normes internationales, des Spécifications techniques, des Rapports techniques, des Spécifications accessibles au public (PAS) et des Guides (ci-après dénommés "Publication(s) de l'IEC"). Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec l'IEC, participent également aux travaux. L'IEC collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.

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La Norme internationale IEC 62153-4-9 a été établie par le comité d'études 46 de l'IEC: Câbles, fils, guides d'ondes, connecteurs, composants passifs pour micro-onde et accessoires.

Cette deuxième édition annule et remplace la première édition, parue en 2008. Cette édition constitue une révision technique.

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

- deux procédures d'essai: à tête ouverte et à tête normalisée;
- mesure avec un symétriseur ou avec un analyseur de réseau vectoriel en mode mixte ou multiport;
- extension de la plage de fréquences jusqu'à 2 GHz et au-delà.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
46/681/FDIS	46/685/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

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

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

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**MÉTHODES D'ESSAIS DES CÂBLES
MÉTALLIQUES DE COMMUNICATION –**

**Partie 4-9: Compatibilité électromagnétique (CEM) – Affaiblissement
de couplage des câbles symétriques écrantés, méthode triaxiale**

1 Domaine d'application

La présente partie de l'IEC 62153 s'applique aux câbles métalliques de communication. Elle spécifie une méthode d'essai pour la détermination de l'affaiblissement de couplage, a_C, de câbles symétriques écrantés. Grâce au tube concentrique extérieur, les mesures sont indépendantes des irrégularités de la circonférence et des champs électromagnétiques externes.

Une large plage dynamique de fréquences peut être appliquée pour soumettre aux essais des câbles même fortement écrantés avec des instruments normaux depuis les basses fréquences jusqu'à la limite des ondes transversales définies dans le circuit externe à environ 4 GHz. Toutefois, lorsque des symétriseurs sont utilisés, la fréquence supérieure est limitée par les propriétés des symétriseurs.

Des mesures peuvent être réalisées en suivant la procédure à tube normalisé (tête normalisée) selon l'IEC 62153-4-4 ou la procédure à tube ouvert (tête ouverte).

La procédure de mesure de l'affaiblissement de couplage, a_C, décrite ici est fondée sur la procédure de mesure de l'affaiblissement d'écran, a_S, de IEC 62153-4-4.

2 Références normatives

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, *Vocabulaire Electrotechnique International (VEI) – Chapitre 726: Lignes de transmission et guides d'ondes*

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

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

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

IEC 62153-4-5, *Méthodes d'essai des câbles de métalliques de communication – Partie 4-5: Compatibilité électromagnétique (CEM) – Affaiblissement d'écran ou de couplage – Méthode de la pince absorbante*

3   Termes, définitions et symboles

Pour les besoins du présent document, les termes et définitions de l'IEC 60050-726, l'IEC TS 62153-4-1 et l'IEC 62153-4-4 ainsi que les symboles suivants s'appliquent.

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

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

a_s est l'affaiblissement d'écran, comparable aux résultats de la méthode par pince absorbante en dB;

a_c est l'affaiblissement de couplage lié à une impédance de rayonnement de 150 Ω en dB;

a_u est l'affaiblissement dû à la dissymétrie;

$a_{m,min}$ est l'affaiblissement enregistré comme la courbe d'enveloppe minimale des valeurs mesurées en dB;

a_z est l'affaiblissement supplémentaire d'un éventuel adaptateur inséré, s'il n'a pas été éliminé par exemple par l'étalonnage, en dB,

C_T est la capacité de traversée du conducteur extérieur en F/m;

c_0 est la vitesse dans le vide en m/s;

dx est l'opérateur d'intégration de longueur différentielle;

λ_0 est la longueur d'onde dans le vide en m;

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

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

$\varepsilon_{r2,n}$ est une valeur normalisée de la permittivité diélectrique relative de l'environnement du câble;

f est la fréquence en Hz;

j est l'opérateur imaginaire (racine carrée de moins 1);

L est l'inductance d'une ligne de transmission;

l est la longueur de couplage effective en m;

φ est un facteur de phase dans le rapport entre la tension de sortie du circuit secondaire et la tension de sortie du circuit primaire (U_1/U_2);

P_1 est la puissance d'alimentation du circuit primaire en W;

P_2 est la puissance mesurée reçue sur l'impédance d'entrée;
R du récepteur dans le circuit secondaire en W;

P_r est la puissance rayonnée dans l'environnement du câble, comparable à P_{2n} + P_{2f} de la méthode par pince absorbante in W;

$P_{r,max}$ est la valeur maximale périodique de la puissance rayonnée en mode commun en W;

P_s est la puissance rayonnée dans l'environnement normalisé du câble en essai,

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

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

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

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

R est l'impédance d'entrée du récepteur en Ω;

R_{DM} est la résistance de terminaison du mode différentiel en Ω;

S est la fonction somme;

T est la fonction transfert de couplage;

U_1 est la tension d'entrée du circuit primaire formé par le câble en V;

U_2 est la tension de sortie du circuit secondaire en V;

Ω est la fréquence angulaire ω;

Z_1 est l'impédance caractéristique (en mode différentiel) du câble en essai (circuit primaire) en Ω;

Z_2 est l'impédance caractéristique du circuit secondaire en Ω;

Z_{com} est le mode commun (dissymétrique);

Z_{diff} est l'impédance caractéristique nominale du mode différentiel (symétrique);

Z_{F} est l'impédance de couplage capacitive du câble en essai en Ω/m,

$$Z_{\mathrm{F}} = Z_1 \cdot Z_2 \cdot j \cdot 2 \cdot \pi \cdot f \cdot C_{\mathrm{T}} \tag{4}$$

Z_{S} est la valeur normalisée de l'impédance caractéristique de l'environnement du câble;

Z_{T} est l'impédance de transfert du câble en essai en Ω/m.

4 Principe de la méthode de mesure

4.1 Généralités

L'affaiblissement de couplage de câbles symétriques écrantés décrit l'effet global contre les perturbations électromagnétiques (EMI)[1] tenant compte à la fois de l'affaiblissement dû à la dissymétrie de la paire et de l'affaiblissement d'écran.

Le circuit perturbateur (circuit interne ou primaire) est constitué du câble d'essai qui est alimenté par un générateur et dont l'impédance est adaptée à l'extrémité proche et à l'extrémité éloignée. Le circuit perturbé (circuit externe ou secondaire) est formé du tube métallique solide et de la section courte du câble en essai recouverte par le tube. Le circuit perturbé (circuit externe ou secondaire) est terminé à l'extrémité proche par un court-circuit et à l'extrémité éloignée par un récepteur étalonné ou un analyseur de réseau.

Les crêtes de tension au niveau de l'extrémité éloignée du circuit secondaire sont mesurées à l'aide d'un récepteur étalonné ou d'un analyseur de réseau. Pour cette mesure, un récepteur adapté n'est pas nécessaire. Ces crêtes de tension ne sont pas dépendantes de l'impédance d'entrée du récepteur, à condition que cette dernière soit inférieure à l'impédance caractéristique du circuit secondaire. Toutefois, il est avantageux d'avoir un faible défaut d'adaptation, par exemple en choisissant une plage de diamètres de tubes pour plusieurs tailles de câbles.

Pour mesurer l'affaiblissement de couplage, mais aussi pour mesurer l'affaiblissement dû à la dissymétrie, un signal différentiel est exigé. Cela peut, par exemple, être généré en utilisant un symétriseur qui convertit le signal dissymétrique d'un analyseur de réseau de 50 Ω en un signal symétrique.

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[1] En anglais, EMI = electromagnetic interference.

Générateur — Symétriseur — Dispositif en essai — Tube — Charge symétrique/dissymétrique — Couvercle d'écran — Récepteur
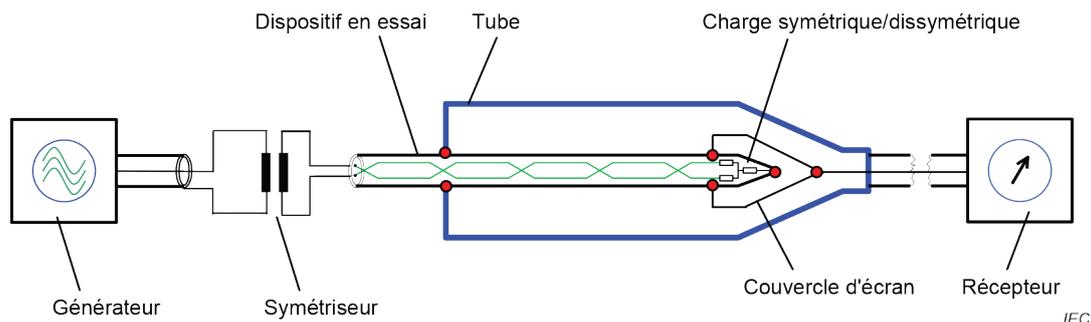
**Figure 1 – Affaiblissement de couplage, principe de montage d'essai
avec symétriseur et tube normalisé**

En variante, un signal symétrique peut être obtenu en utilisant un analyseur de réseau vectoriel (VNA)[2] ayant deux générateurs avec déphasage de 180°. Une autre alternative consiste à effectuer la mesure avec un analyseur de réseau vectoriel multiport (symétriseur virtuel). Les propriétés des paires symétriques sont déterminées mathématiquement à partir des valeurs mesurées de chaque conducteur de la paire par rapport à la terre de référence. La plage de fréquences pouvant être couverte pour la détermination des caractéristiques de réflexion et de transmission des paires symétriques n'est plus limitée par le symétriseur, mais par l'analyseur de réseau vectoriel et la technique de connexion.

Une définition détaillée des paramètres S en mode mixte pour des mesures avec un symétriseur virtuel est donnée à l'Annexe B.

Le montage d'essai (voir les Figures 1, 2, 3 et 4) est un système triaxial constitué d'un tube métallique solide externe dans lequel le câble en essai (CUT)[3] est placé de manière concentrique.

A l'extrémité proche, l'écran du câble en essai écranté est court-circuité avec le tube métallique solide.

Générateur — Symétriseur — Câble en essai — Fil de détection — Tube à tête ouverte — Récepteur — Absorbeur en ferrite — long. de câble restante, env. 97 m — Charge symétrique/dissymétrique — Boîtier
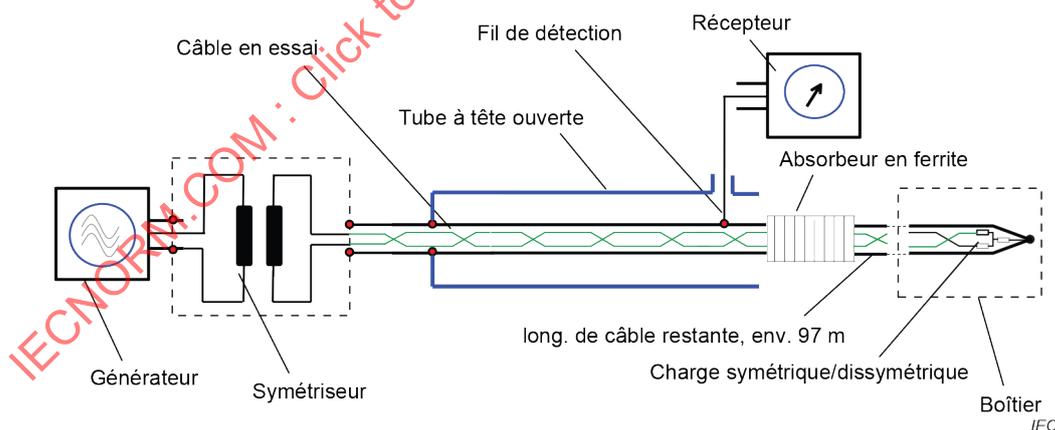
**Figure 2 – Affaiblissement de couplage, principe de montage d'essai
avec symétriseur et tête ouverte**

A l'extrémité éloignée, le tube peut être équipé d'une "tête d'essai" qui peut être retirée du tube pour faciliter la connexion du câble en essai. Le montage décrit dans l'IEC 62153-4-4 est désigné comme étant le montage de la procédure normalisée (procédure à tête normalisée). Il présente l'avantage de constituer un montage écranté et entièrement fermé.

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2 En anglais, VNA = vector network analyser.

3 En anglais, CUT = cable under test.

En variante, le tube peut être équipé d'une tête ouverte à l'extrémité éloignée (voir les Figures 2 et 4).

4.2 Procédure A: mesure avec un tube normalisé (tête normalisée)

Le montage détaillé dans la procédure A utilise une tête d'essai normalisée et est en principe le même que celui décrit dans l'IEC 62153-4-4. Le dispositif en essai (DUT)[4] symétrique écranté peut être alimenté en mode commun ou en mode différentiel. De cette façon, l'affaiblissement d'écran de l'écran ou l'affaiblissement de couplage de la paire écrantée peuvent être mesurés. En principe, l'impédance de transfert de l'écran peut être mesurée avec le même montage (en tenant compte de la longueur du dispositif en essai).
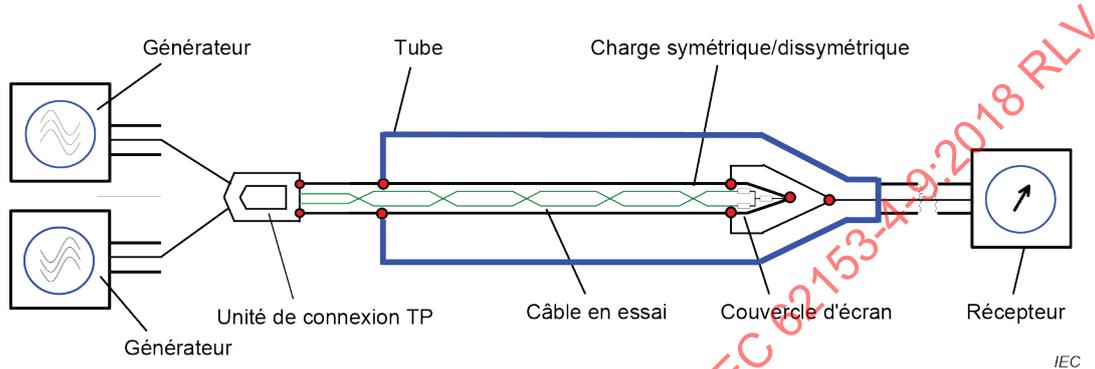
Générateur   Tube   Charge symétrique/dissymétrique
Unité de connexion TP   Câble en essai   Couvercle d'écran   Récepteur
Générateur

IEC

Figure 3 – Affaiblissement de couplage, principe de montage d'essai avec un analyseur de réseau vectoriel multiport et une tête normalisée

Le dispositif en essai doit être adapté à l'extrémité éloignée en mode commun et en mode différentiel. L'affaiblissement de réflexion du câble en essai en mode commun et l'affaiblissement de réflexion du câble en essai en mode différentiel doivent être mesurés. Les valeurs de l'affaiblissement de réflexion en mode commun et en mode différentiel doivent être 10 dB au minimum.

4.3 Procédure B: mesure avec une tête ouverte

En cas de mesure avec une tête ouverte, les premiers mètres d'une plus grande longueur du câble à soumettre à un essai sont placés de manière concentrique dans un tube métallique solide externe. La longueur restante (généralement 100 m de long) qui s'étend au-delà du tube est placée dans un boîtier fortement écranté et terminée par des sorties en mode commun et en mode différentiel (voir la Figure 6). L'écran du câble doit être connecté au boîtier écranté par une faible impédance. Le point central de la sortie en mode différentiel doit être connecté par l'intermédiaire de la résistance R_{CM} au boîtier fortement écranté ou à l'écran du câble (voir la Figure 6).

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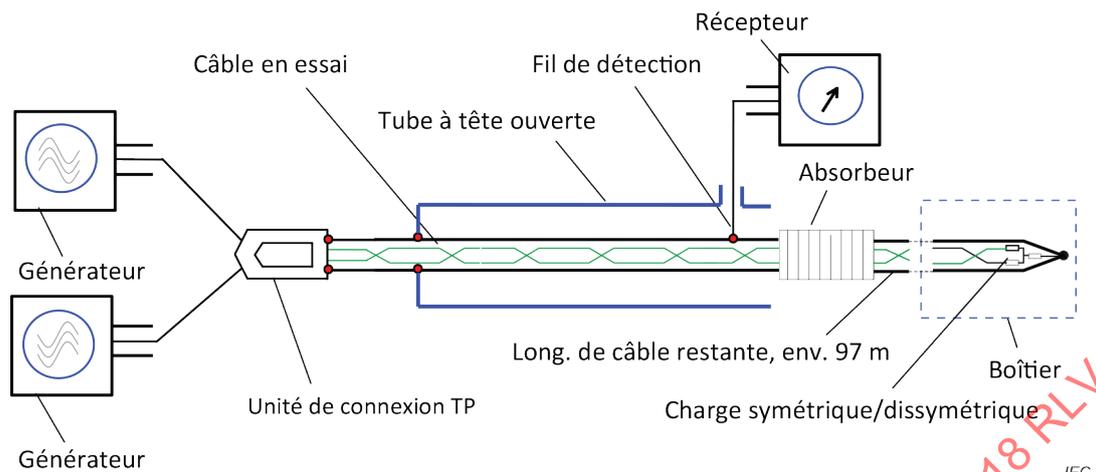4 En anglais, DUT = device under test.

Figure 4 – Affaiblissement de couplage, principe de montage d'essai avec un analyseur de réseau vectoriel multiport et une tête ouverte

A l'extrémité proche, l'écran du câble en essai écranté est court-circuité avec le tube métallique solide.

A l'extrémité éloignée, le tube est laissé ouvert, le signal est prélevé par un "fil de détection" qui est connecté à l'écran du câble en essai (voir la Figure 4). Le système à tube ouvert peut également être équipé d'une "tête d'essai" qui peut être retirée du tube pour faciliter la connexion du câble en essai.

A l'extrémité ouverte du tube, des absorbeurs doivent être appliqués pour adapter le système et pour éviter que des ondes ne reviennent dans le système. L'affaiblissement de l'absorbeur doit être d'au moins 20 dB. Une combinaison d'absorbeur à ferrite et/ou d'absorbeur nanocristallin peut être utilisée. Une procédure pour mesurer l'affaiblissement des absorbeurs est donnée à l'Annexe A.

5 Paramètres d'écrantage

5.1 Généralités

Pour protéger un câble contre les perturbations électromagnétiques externes ou pour éviter le rayonnement dans l'environnement, le câble est entouré d'écrans faits de feuilles et/ou de tresses métalliques. Pour les câbles utilisés dans des environnements électromagnétiques contraignants, des structures d'écran élaborées, faites de plusieurs couches ou de matériaux magnétiques, sont également utilisées. Dans le cas de câbles symétriques, l'efficacité de l'écran est améliorée par la symétrie globale de la paire en plus de l'écran.

L'effet de l'écran seul est décrit par l'impédance de transfert et par l'affaiblissement d'écran. L'influence de la symétrie est captée par l'affaiblissement dû à la dissymétrie. L'effet global de l'écran et de la symétrie de la paire (pour les câbles symétriques) sont décrits par l'affaiblissement de couplage.

5.2 Impédance de transfert

Pour un écran électriquement court, l'impédance de transfert Z_T est définie comme le quotient de la tension longitudinale U_1 induite dans le circuit interne par le courant I_2 délivré au circuit externe ou vice versa, par rapport à la longueur en Ω/m ou en mΩ/m (voir Figure 5).