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INTERNATIONAL STANDARD

colour inside

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

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Part 4-4: Electromagnetic compatibility (EMC) – Test method for measuring of the screening attenuation a_s up to and above 3 GHz, triaxial method

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

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

This edition includes the following significant technical changes with respect to the previous edition. Impedance matching adapters are no longer required when measuring devices have a characteristic impedance different from the characteristic impedance of the test equipment. The reflection loss due to a mismatch is taken into account by a (calculated) correction factor.

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

FDIS	Report on voting
46/545/FDIS	46/554/RVD

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

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

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

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

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- withdrawn,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

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

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METALLIC COMMUNICATION CABLE TEST METHODS –

Part 4-4: Electromagnetic compatibility (EMC) – Test method for measuring of the screening attenuation a_s up to and above 3 GHz, triaxial method

1 Scope

This part of IEC 62153 describes a test method to determine the screening attenuation a_S of metallic communication cable screens. Due to the concentric outer tube, measurements are independent of irregularities on the circumference and outer electromagnetic field.

A wide dynamic 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.

2 Normative references

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

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

3 Symbols and theoretical background

3.1 Electrical symbols

Z_1	characteristic impedance of the primary circuit (cable under test)
Z_2	characteristic impedance of the secondary circuit
Z_S	normalized value of the characteristic impedance of the environment of a typical cable installation (150 Ω). It is in no relation to the impedance of the outer circuit of the test set-up Z_2 Z_S is always 150 Ω (arbitrary determined) whereas Z_2 is varying with the dimensions of the CUT and inner diameter of the tube
R	input impedance of the receiver
Z_T	transfer impedance of the cable under test in Ω/m
$Z_F = Z_1 \times Z_2 \times j\omega \times C_T$	capacitive coupling impedance of the cable under test in Ω/m
f	frequency in Hz
C_T	through capacitance of the outer conductor per unit length in F/m
ε_{r1}	relative dielectric permittivity of the cable under test
ε_{r2}	relative dielectric permittivity of the secondary circuit
$\varepsilon_{r2,n}$	normalized value of the relative dielectric permittivity of the environment of the cable
l	effective coupling length
λ_0	vacuum wavelength

c_0	vacuum velocity
a_s	screening attenuation which is comparable to the results of the absorbing clamp method
P_1	feeding power of the primary circuit
P_2	measured power received on the input impedance R of the receiver in the secondary circuit
P_r	radiated power in the environment of the cable, which is comparable to $P_{2,n} + P_{2,f}$ of the absorbing clamp method
S_{11}	scattering parameter S_{11} (complex quantity) of the set-up where the primary side of the two port is the DUT and the secondary side is the tube
S_{21}	scattering parameter S_{21} (complex quantity) of the set-up where the primary side of the two port is the DUT and the secondary side is the tube

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

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

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

3.2 Theoretical background

There will be a variation of the voltage U_2 on the far end, caused by the electromagnetic coupling through the screen and superimposition 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.

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

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

i.e. formally **|** $A + B$ **|** × C × D, where $A \times C$ is the far-end crosstalk, $B \times C$ is the reflected near-end crosstalk and D is the mismatch factor.

The total oscillations of D are

<2 dB, if	$1 < Z_2/R < 1{,}25$
3 dB, if	$Z_2/R = 1{,}4$
but	10 dB and more, if $Z_2/R > 3$.
Maximum values of $A \times C$ and $B \times C$ are given, if	$\varphi_{1,2} = (2N + 1) \times \pi$ and N is an integer.

The voltage ratio measured is not dependent on the diameter of the outer tube of the triaxial test set-up or on the characteristic impedance Z_2 of the outer system, provided that Z_2 is larger than the input impedance of the receiver.

A more detailed description of the subject is given in IEC 62153-4-1.

3.3 Screening attenuation

The logarithmic ratio of the feeding power P_1 and the periodic maximum values of the power $P_{\mathrm{r,max}}$ which may be radiated due to the peaks of voltage U_2 in the outer circuit is termed screening attenuation a_{s}.

$$a_{\mathrm{s}} = -10 \times \log_{10}\left(Env\left| \frac{P_{\mathrm{r,max}}}{P_1} \right| \right) \tag{2}$$

The relationship of the radiated power P_{r} to the measured power P_2 received on the input impedance R is

$$\frac{P_{\mathrm{r}}}{P_2} = \frac{P_{\mathrm{r,max}}}{P_{2,\mathrm{max}}} = \frac{R}{2 \times Z_{\mathrm{S}}} \tag{3}$$

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

$$\sqrt{\left| \frac{P_{2,\mathrm{max}}}{P_1} \right|} \approx \frac{c_{\mathrm{o}}}{\omega \sqrt{Z_1 \times R}} \times \left| \frac{Z_{\mathrm{T}} - Z_{\mathrm{F}}}{\sqrt{\varepsilon_{\mathrm{r1}}} - \sqrt{\varepsilon_{\mathrm{r2}}}} + \frac{Z_{\mathrm{T}} + Z_{\mathrm{F}}}{\sqrt{\varepsilon_{\mathrm{r1}}} + \sqrt{\varepsilon_{\mathrm{r2}}}} \right| \tag{4}$$

3.4 Impact of coupling length and relationship between the screening attenuation and the surface transfer impedance Z_{T}

The relationship between the effective coupling length of the cable under test and the electrical wave length is important for the characteristic curve of the screening attenuation (see Figures 1 and 2). In the frequency range of electrically short coupling lengths, the measured attenuation decreases with increasing length. Therefore, it is necessary to define the related length.

With electrically long lengths, the screening attenuation formed by the maximum envelope curve to the coupling voltage ratio is constant for a 6 dB/octave (20 dB/decade) increasing transfer impedance. Therefore, the screening attenuation is defined only at high frequencies.

The coupling length is electrically short, if

$$\lambda_0 / l > 10 \times \sqrt{\varepsilon_{\mathrm{r1}}} \quad \text{or} \quad f < \frac{c_0}{10 \times l \times \sqrt{\varepsilon_{\mathrm{r1}}}} \tag{5}$$

or electrically long, if

$$\lambda_0 / l \le 2 \times \left| \sqrt{\varepsilon_{\mathrm{r1}}} - \sqrt{\varepsilon_{\mathrm{r2}}} \right| \quad \text{or} \quad f > \frac{c_0}{2 \times l \times \left| \sqrt{\varepsilon_{\mathrm{r1}}} - \sqrt{\varepsilon_{\mathrm{r2}}} \right|} \tag{6}$$

where

l	is the effective coupling length in metres (approximately 2 m in Figure 3);
λ_0	is the free space wavelength in metres;
$\varepsilon_{\mathrm{r1}}$	is the resulting relative permittivity of the dielectric of the cable;

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

f is the frequency in Hz.

The measured voltage ratio is related to the transfer impedance Z_T for electrically short coupling length by

$$Z_T \times l \approx Z_1 \times \left|\frac{U_2}{U_1}\right| \tag{7}$$

Also, at high frequencies, Z_T can be calculated if Z_F is negligible:

$$Z_T \approx \left|\frac{\omega \times \sqrt{Z_1 \times R} \times \left|\varepsilon_{r1} - \varepsilon_{r2}\right|}{2 \times c_o \times \sqrt{\varepsilon_{r1}}} \times \sqrt{\left|\frac{P_{2\max}}{P_1}\right|}\right| \tag{8}$$

therefore

$$\sqrt{\left|\frac{P_{2\max}}{P_1}\right|} \approx \left|\frac{Z_T \times 2 \times c_o \times \sqrt{\varepsilon_{r1}}}{\omega \times \sqrt{Z_1 \times R} \times \left|\varepsilon_{r1} - \varepsilon_{r2}\right|}\right| \tag{9}$$

A more detailed description of the subject is given in IEC 62153-4-1.

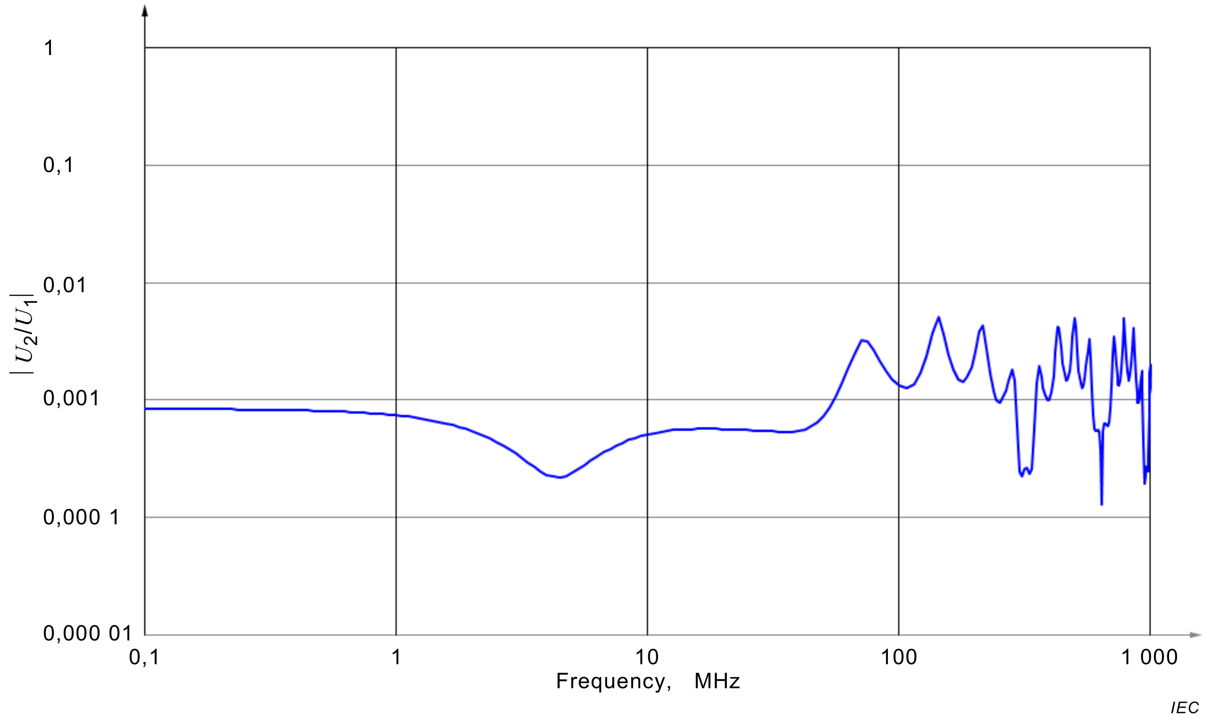

Figure 1 – Relationship of U_2/U_1 on a log (f) scale for a single braided cable

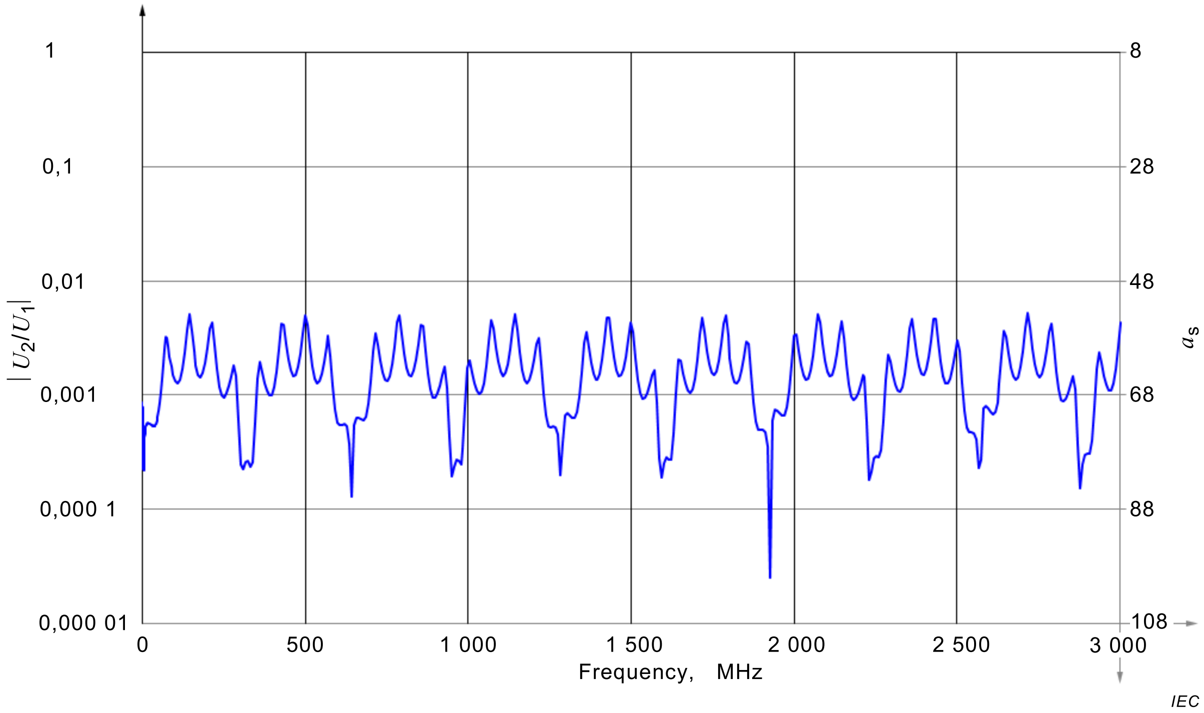

Figure 2 – Relationship of U_2/U_1 on a linear (f) scale and screening attenuation a_s on a linear (f) scale for a single braided cable

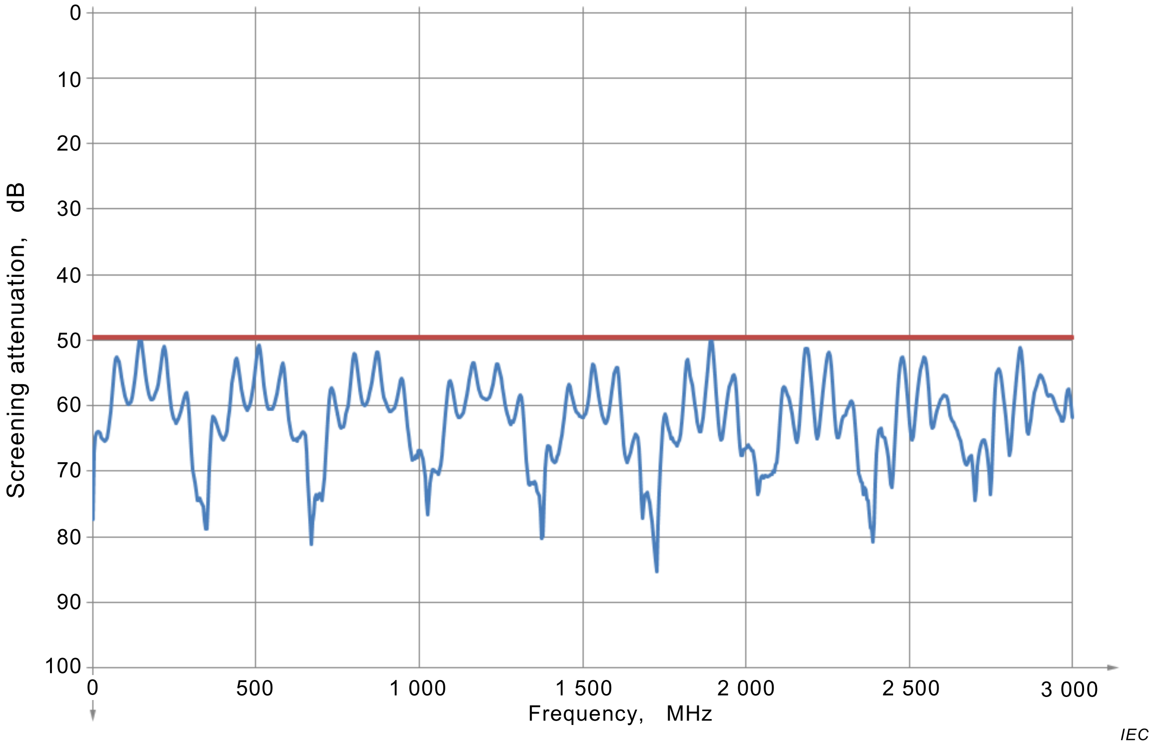

Figure 3 – Measured screening attenuation a_s formed by the maximum envelope curve to the measured coupling voltage ratio U_2/U_1 of a single braided cable

4 Principles of the measuring method

The disturbing or primary circuit is the matched cable under test. The disturbed or secondary circuit consists of the outer conductor (or the outermost layer in the case of multiscreen cables) of the cable under test and a solid metallic tube having the cable under test in its axis (see Figures 4 and 5).

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

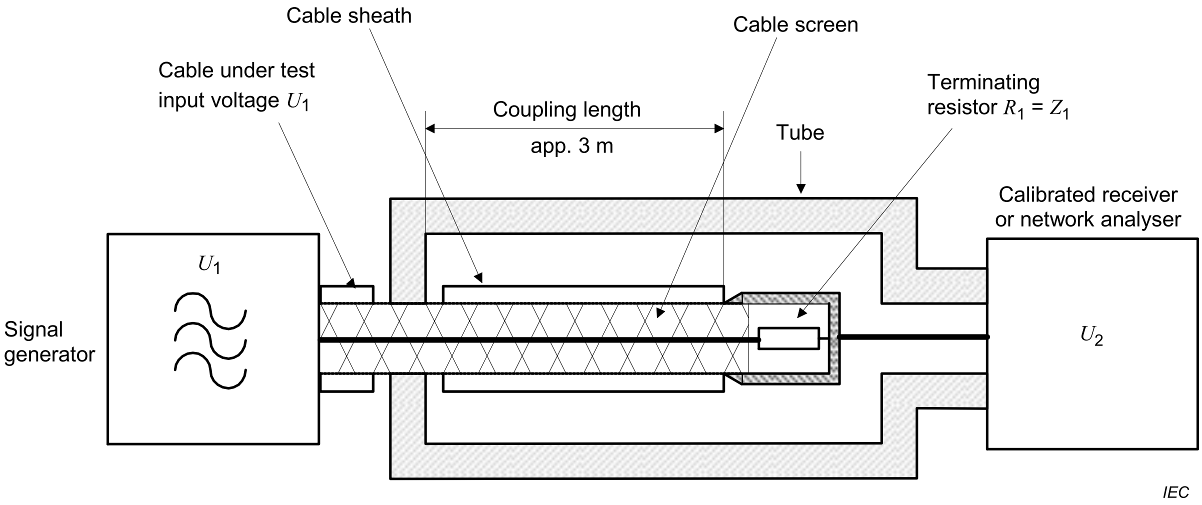

Figure 4 – Triaxial measuring set-up

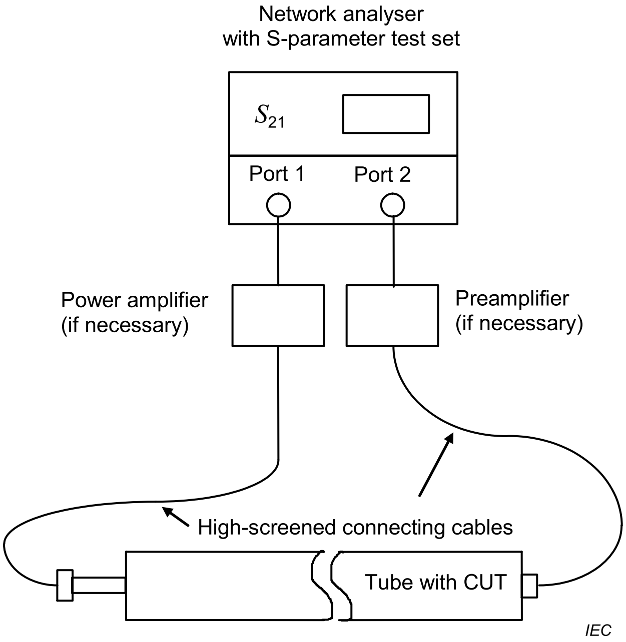

Figure 5 – Triaxial measuring set-up connected to the network analyser

5 Measurement

5.1 Equipment

The measuring set-up is shown in Figures 4 and 5 and consists of

- an apparatus of a triple coaxial form with a length sufficient to produce a superimposition of waves in narrow frequency bands which enable the envelope curve to be drawn,
- commonly (for dielectrics with low permittivity), a coupling length of minimum 2 m is preferable to determine the screening attenuation from less than 200 MHz upwards (see also 3.4). The cylindrical cable screen forms both the outer conductor of the energized coaxial system and the inner conductor of the outer system. The outer conductor of the outer system is a tube of about 50 mm inner diameter with a short-circuit to the screen on the fed side of the cable. The ratio of the inner diameter of the tube to the outer diameter of the screen shall be sufficient to ensure that the characteristic impedance is larger than the input resistance of the receiver. The value of the relative dielectric permittivity of the outer circuit shall be approximately one, irrespective of the enclosing cable sheath,
- it is recommended to use a vector network analyser allowing the measurement of all scattering parameters of a quadripole (two port). In the case where the generator impedance and the DUT have the same impedance, a discrete generator and receiver may be used,
- high sensitive or power amplifier if necessary for very high screening attenuation.

5.2 Cable under test

5.2.1 Coaxial cables

On the far end side, the sample under test shall be terminated by a very well screened resistance (better screened than the screen under test) equal to the nominal value of the characteristic impedance of the sample under test. See Annex A for details on how to determine the nominal characteristic impedance. The termination may be done using several resistors in parallel. The connections between the terminating resistance(s), the screening cap and the cable screen(s) shall be made with care so that the contact resistance can be neglected when interpreting the results. Special care shall be taken in preparing foil screens in order to avoid cracks in the foil which may introduce errors in the test results.

The cable under test shall be positioned as nearly concentric as possible in the outer tube to obtain homogeneous wave propagation. To achieve the centering, one may use distance pieces made of a material having a dielectric permittivity of less than 1,10 (e.g. Styrofoam).

On the fed side, the cable screen is connected to the short-circuit disc of the outer tube, and care shall be taken so that the contact resistance is small and does not influence the results.

5.2.2 Symmetrical and multiconductor cables

Screened symmetrical and multiconductor cables are treated as a quasi-coaxial system – i.e. in addition to the below, the requirements of 5.2.1 for coaxial cables shall be applied. The conductors of all pairs shall be connected together at both ends. All screens, also those of individually screened pairs or quads, shall be connected together at both ends. The screens shall be connected over the whole circumference (see Figure 6).

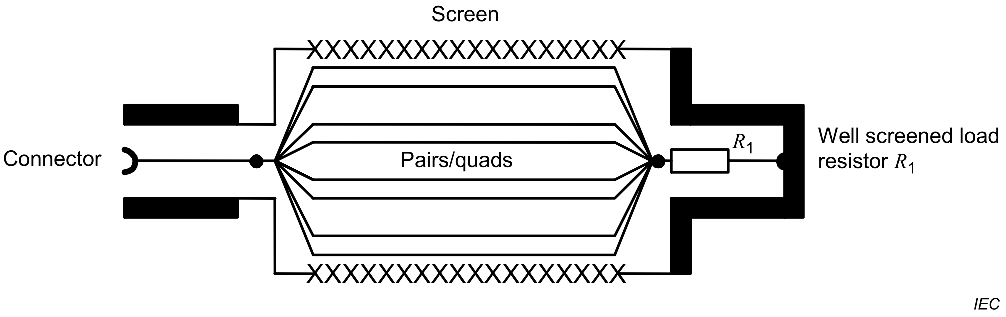

Figure 6 – Preparation of test sample (symmetrical and multi-conductor cables)

5.2.3 Impedance matching

If unknown, the nominal characteristic impedance of the (quasi-)coaxial system can either be measured by using a TDR with maximum 200 ps rise time or using the method described in Annex A. An impedance matching adapter to match the impedance of the generator and the impedance of the (quasi-)coaxial system is not recommended as it reduces the dynamic range of the test set-up and may have sufficient matching (return loss) only up to 100 MHz when using self-made adapters which are necessary for impedances other than 60 Ω or 75 Ω (see Annex B). One may use an attenuator at the generator output to avoid reflected waves which could harm the generator. The attenuation of such attenuator shall be taken into account in the test results.

5.3 Procedure

The DUT shall be connected to port 1 and the tube to port 2 of the vector network analyser (see Figure 5).

The (complex) scattering parameter S_{21} shall be measured. The reflection loss[1] (see Annex C) caused by the mismatch between the generator and DUT has to be taken into account. To do this in principle one should measure the (complex) scattering parameter S_{11} of the DUT. However, it has been shown that this measurement is prone to error due to the “poor” load resistance of the DUT. Thus S_{11} is calculated as described in 5.4.

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

5.4 Expression of results

The screening attenuation a_S which is comparable to the results of the absorbing clamp method shall be calculated with the arbitrary determined normalised value Z_S = 150 Ω[2].

$$\begin{aligned} a_\mathrm{S} &= 10 \times \log_{10}\left|\frac{P_1}{P_\mathrm{r,max}}\right| = 10 \times \log_{10}\left|\frac{P_1}{P_\mathrm{2,max}} \times \frac{2 \times Z_\mathrm{S}}{R}\right| \\ &= Env\left\{-20 \times \log_{10}\left|S_{21}\right| + 10 \times \log_{10}\left|1 - r^2\right| + 10 \times \log_{10}\left|\frac{300\Omega}{Z_1}\right|\right\} - a_\mathrm{att} \end{aligned} \qquad (10)$$

---

[1] Reflection loss should not be confused with return loss or mismatch loss.

[2] Z_s is the normalized value of the characteristic impedance of the environment of a typical cable installation. It is in no relation to the impedance of the outer circuit of the test set-up.

$$r = S_{11} = \frac{Z_1 - Z_0}{Z_1 + Z_0} \tag{11}$$

where

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

a_att is the attenuation of the attenuator or impedance matching adapter – if used and if not taken into account otherwise, e.g. during the calibration procedure of the network analyzer;

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

r is the reflection coefficient between the generator impedance and the nominal characteristic impedance of the cable under test;

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

Z_1 is the nominal characteristic impedance of the cable under test in Ω (see 5.2.3);

Z_0 is the output impedance of the generator, i.e. system impedance of the network analyser, in Ω.

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

6 Requirement

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

Annex A
(normative)

Determination of the impedance of the inner circuit

If the impedance Z_1 of the inner circuit is not known, it may be determined using a TDR with maximum 200 ps rise time or using the following method with a (vector) network analyser (VNA).

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

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

where

f_{test} is the test frequency;

c is the speed of light 3×10^8 m/s;

L_{sample} is the length of sample.

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

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

Z_1 is calculated as:

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

Annex B
(informative)

Example of a self-made impedance matching adapter

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

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

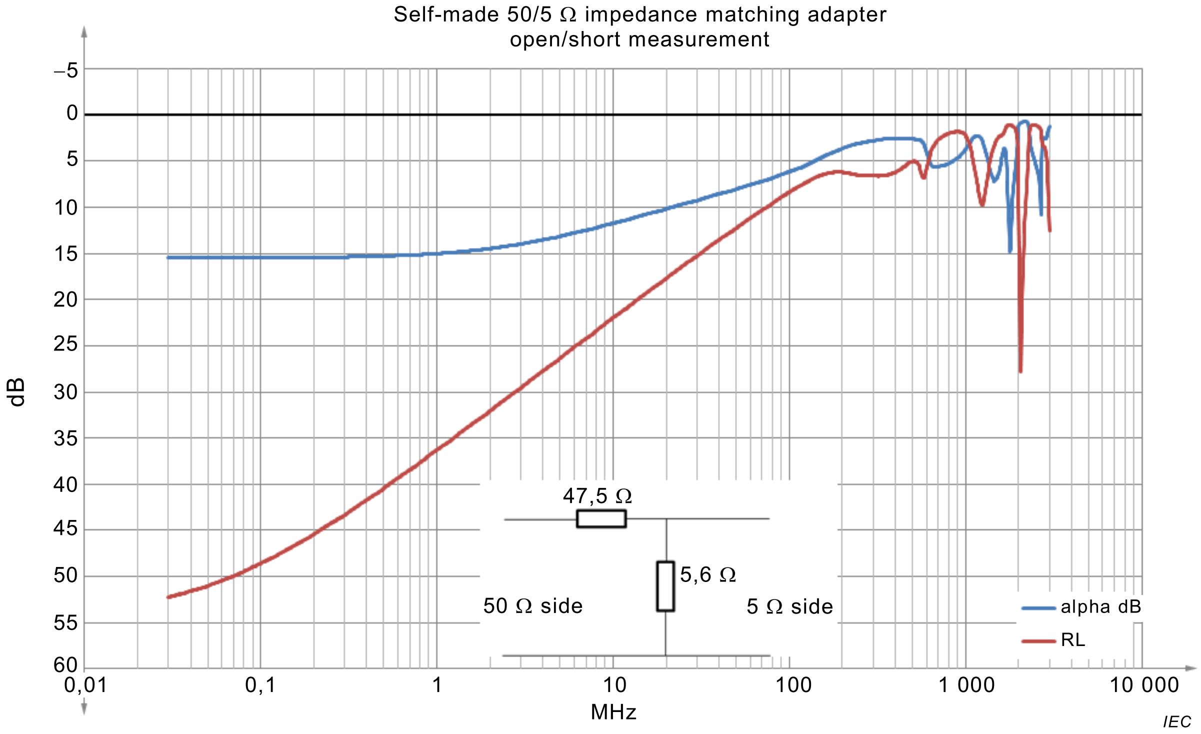

Figure B.1 – Attenuation and return loss of an 50 Ω to 5 Ω impedance matching adapter; logarithmic frequency scale

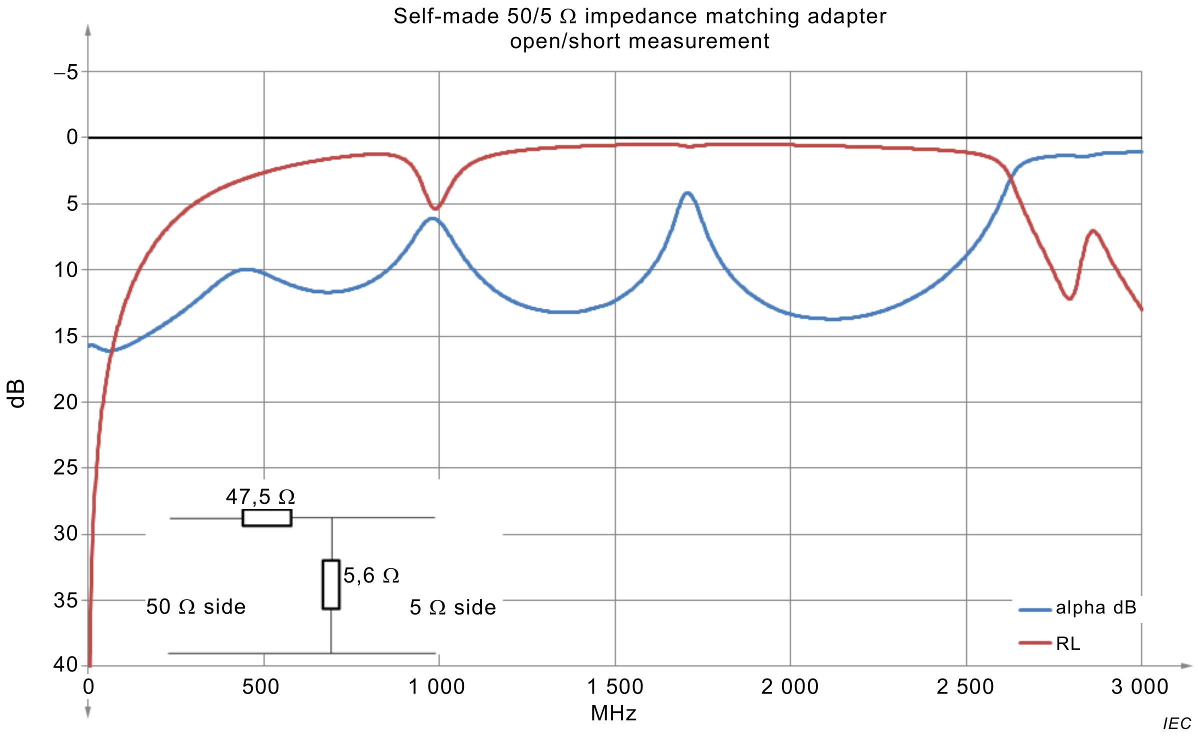

Figure B.2 – Attenuation and return loss of an 50 Ω to 5 Ω impedance matching adapter; linear frequency scale

Annex C
(informative)

Reflection loss of a junction

In case a source with an inner resistance R_i feeds a load with a different resistance R_L power is lost compared to the matched case due to the mismatch. If the source is connected to the junction by a transmission line with a characteristic impedance $Z_1 = R_\mathrm{i}$ and the load is connected to the junction by a transmission line with a characteristic impedance $Z_2 = R_\mathrm{l}$ the equivalent circuit is the following:

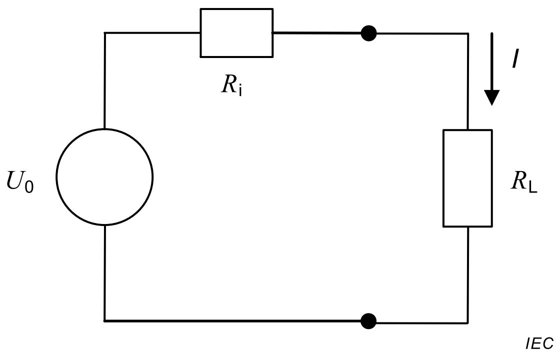

Figure C.1 – Equivalent circuit of generator with load

The power in the load resistance R_L is given by:

$$P = I^2 R_\mathrm{L} = \left(\frac{U_0}{R_\mathrm{i} + R_\mathrm{L}}\right)^2 R_\mathrm{L} = U_0^2 \frac{R_\mathrm{L}}{(R_\mathrm{i} + R_\mathrm{L})^2} \tag{C.1}$$

In case of impedance matching ($R_\mathrm{L} = R_\mathrm{i}$) the maximum power P_0 is fed:

$$P_0 = U_0^2 \frac{R_\mathrm{i}}{4R_\mathrm{i}^2} = \frac{1}{4} U_0^2 \frac{1}{R_\mathrm{i}} \tag{C.2}$$

The ratio of Equations (C.1) and (C.2) describes the loss:

$$\frac{P}{P_0} = \frac{U_0^2 R_\mathrm{L}}{(R_\mathrm{i} + R_\mathrm{L})^2} \frac{4R_\mathrm{i}}{U_0^2} = \frac{4R_\mathrm{L} R_\mathrm{i}}{(R_\mathrm{i} + R_\mathrm{L})^2} \tag{C.3}$$

The following auxiliary calculation introduces the reflection coefficient r:

$$\begin{gathered} 1 - r^2 = 1 - \left(\frac{R_\mathrm{L} - R_\mathrm{i}}{R_\mathrm{L} + R_\mathrm{i}}\right)^2 = \frac{(R_\mathrm{L} + R_\mathrm{i})^2}{(R_\mathrm{L} + R_\mathrm{i})^2} - \frac{(R_\mathrm{L} - R_\mathrm{i})^2}{(R_\mathrm{L} + R_\mathrm{i})^2} = \\ \frac{R_\mathrm{L}^2 + 2R_\mathrm{L} R_\mathrm{i} + R_\mathrm{i}^2 - R_\mathrm{L}^2 + 2R_\mathrm{L} R_\mathrm{i} - R_\mathrm{i}^2}{(R_\mathrm{L} + R_\mathrm{i})^2} = \frac{4R_\mathrm{L} R_\mathrm{i}}{(R_\mathrm{L} + R_\mathrm{i})^2} \end{gathered} \tag{C.4}$$

Using Equation (C.4), the power ratio (Equation (C.3) becomes:

$$\frac{P}{P_0} = 1 - r^2 \tag{C.5}$$

The magnitude in dB therefore is (see also IEC/TR 62152:2009 Equation. A.12):

$$\Gamma_s = -10\log_{10}\left|1 - r^2\right| \qquad \text{(C.6)}$$

Bibliography

IEC TR 62152:2009, *Transmission properties of cascaded two-ports or quadripols – Background of terms and definitions*

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