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Prüfverfahren für metallische Kommunikationskabel und andere passive Bauteile –

Teil 4-16: Elektromagnetische Verträglichkeit (EMV) – Erweiterung des Frequenzbereiches zu höheren Frequenzen für den Kopplungswiderstand und zu niedrigeren Frequenzen für die Schirmdämpfung bei Messungen mit dem Triaxialverfahren (IEC 62153-4-16:2021); Deutsche Fassung EN IEC 62153-4-16:2021

Metallic cables and other passive components test methods –

Part 4-16: Electromagnetic compatibility (EMC) –

Extension of the frequency range to higher frequencies for transfer impedance and to lower frequencies for screening attenuation measurements using the triaxial set-up
(IEC 62153-4-16:2021);

German version EN IEC 62153-4-16:2021

Méthodes d'essai des câbles métalliques et autres composants passifs –

Partie 4-16: Compatibilité électromagnétique (CEM) –

Extension de la plage de fréquences à des fréquences supérieures pour l'impédance de transfert et à des fréquences inférieures pour mesurer l'affaiblissement d'écran à l'aide d'un montage triaxial
(IEC 62153-4-16:2021);

Version allemande EN IEC 62153-4-16:2021

Total number of pages 25 Pages

DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE

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Beginning of validity

The beginning of validity of this DIN standard approved as a European Standard by CENELEC on 2021-09-28 is 2023-12-01.

National foreword

Previous draft standard: E DIN EN IEC 62153-4-16 (VDE 0819-153-4-16):2023-10.

The German committee responsible for this document is DKE/K 412 "Kommunikationskabel (Kabel, Leitungen, Wellenleiter, Lichtwellenleiter, Komponenten, Zubehör und Anlagentechnik für die Nachrichten- und Informationsübertragung)" of the DKE German Commission for Electrical, Electronic & Information Technologies of DIN and VDE (www.dke.de).

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The original document contains colour figures that are displayed in grey scales in the paper version. The electronic version of the present document contains the figures in the original colour type.

National Annex NA (informative)

Relationship with European and international documents

In case of an undated reference in the normative text (reference to another document without indication of its date of publication, without indication of a specific clause, a table, a figure etc.) the reference is to the latest edition of the referenced document.

In case of a dated reference in the normative text the reference is always to the latest edition of the referenced document.

The following list contains information about the relationship between the referenced documents and the relevant German documents.

Table NA.1

| European document | International document | German document | Classification in the VDE Specifications Code of safety standards |
|--------------------------|-------------------------------|--|--|
| – | IEC 61156-1:2007 | – | – |
| – | IEC 62153-4-3:2013 | – | – |
| – | IEC 62153-4-4 | – | – |
| EN IEC 62153-4-15 | IEC 62153-4-15 | DIN EN IEC 62153-4-15 (VDE 0819-153-4-15) | VDE 0819-153-4-15 |
| – | IEC TR 62152:2009 | – | – |
| – | IEC TS 62153-4-1:2014 | – | – |

National Annex NB (informative)

Bibliography

DIN EN IEC 62153-4-15 (VDE 0819-153-4-15), *Metallic cables and other passive components test methods - Part 4-15: Electromagnetic compatibility (EMC) - Test method for measuring transfer impedance and screening attenuation- or coupling attenuation with triaxial cell*

– Leerseite –

English version

**Metallic cables and other passive components test methods – Part 4-16:
Electromagnetic compatibility (EMC) – Extension of the frequency range
to higher frequencies for transfer impedance and to lower frequencies
for screening attenuation measurements using the triaxial set-up
(IEC 62153-4-16:2021)**

Méthodes d'essai des câbles métalliques et autres
composants passifs – Partie 4-16: Compatibilité
électromagnétique (CEM) – Extension de la plage de
fréquences à des fréquences supérieures pour l'impédance
de transfert et à des fréquences inférieures pour mesurer
l'affaiblissement d'écran à l'aide d'un montage triaxial
(IEC 62153-4-16:2021)

Prüfverfahren für metallische Kommunikationskabel und
andere passive Bauteile – Teil 4-16: Elektromagnetische
Verträglichkeit (EMV) – Erweiterung des Frequenzbereiches
zu höheren Frequenzen für den Kopplungswiderstand
und zu niedrigeren Frequenzen für die Schirmdämpfung
bei Messungen mit dem Triaxialverfahren
(IEC 62153-4-16:2021)

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European Foreword

The text of document 46/817/FDIS, future edition 2 of IEC 62153-4-16, prepared by IEC/TC 46 “Cables, wires, waveguides, RF connectors, RF and microwave passive components and accessories” was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 62153-4-16:2021.

The following dates are fixed:

- latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement (dop): 2022-06-28
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The text of the International Standard IEC 62153-4-16:2021 was approved by CENELEC as a European Standard without any modification.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

| Publication | Year | Title | EN/HD | Year |
|----------------|------|--|-------------------|------|
| IEC 62153-4-3 | 2013 | Metallic communication cable test methods - - Part 4-3: Electromagnetic compatibility (EMC) - Surface transfer impedance - Triaxial method | - | - |
| IEC 62153-4-15 | - | Metallic cables and other passive components test methods - Part 4-15: Electromagnetic compatibility (EMC) - Test method for measuring transfer impedance and screening attenuation - or coupling attenuation with triaxial cell | EN IEC 62153-4-15 | - |

1 Scope

This part of IEC 62153 specifies a method to extrapolate the test results of transfer impedance to higher frequencies and the test results of screening attenuation to lower frequencies when measured with the triaxial set-up in accordance with IEC 62153-4-3, IEC 62153-4-4 [1]¹ and IEC 62153-4-15. This method is applicable for homogenous screens, i.e. screens having a transfer impedance directly proportional to length. The transfer impedance can have any frequency behaviour, i.e. it could have a behaviour where it does not increase with 20 dB per decade as observed for screens made of a foil and a braid.

¹ Numbers in square brackets refer to the bibliography.

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 62153-4-3:2013 *Metallic communication cable test methods – Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method*

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

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

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

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

3.2 Abbreviated terms

| | |
|-----|---------------------------|
| CUT | cable under test |
| DUT | device under test |
| TDR | time domain reflectometer |
| VNA | vector network analyser |

4 Overview

The triaxial set-up can be used to measure both the surface transfer impedance (IEC 62153-4-3, IEC 62153-4-15) and the screening attenuation (IEC 62153-4-4, IEC 62153-4-15). The transfer impedance is in general measured with a coupling length of maximum 0,5 m resulting in an upper frequency limit of around 100 MHz, whereas the screening attenuation is in general measured with a coupling length of 2 m to 3 m resulting in an upper frequency limit for the transfer impedance of around 10 MHz and a lower frequency limit for the screening attenuation of around 100 MHz (see also IEC TS 62153-4-1:2014, Clauses 8 and 9 [2]).

Figure 1 shows the grey zone between electrically short (measurement range for the transfer impedance) and electrically long (measurement range for the screening attenuation). The parameters used in the simulation are:

- forward transfer scattering parameter S_{21} in accordance with IEC 62153-4-3, Method B, where the value of the load resistor equals the characteristic impedance of the CUT;
- impedance of inner circuit is 50 Ω ;
- impedance of outer circuit is 150 Ω ;
- relative dielectric permittivity of inner circuit 2,3;
- relative dielectric permittivity of outer circuit 1,1;
- coupling length 50 cm and 200 cm;
- transfer impedance calculated according to T. KLEY [3] for a copper braid design of: diameter under braid 2,95 mm, number of spindles 16, number of wires per spindle 5, wire diameter 0,12 mm, lay length 15 mm.

In the example shown in Figure 1, the transfer impedance can be measured up to around 30 MHz using a coupling length of 50 cm and the screening attenuation can be measured starting from 150 MHz using a coupling length of 200 cm.

This document describes how to extrapolate the test results of transfer impedance to higher frequencies and the test results of screening attenuation to lower frequencies when measured with the triaxial set-up in accordance with IEC 62153-4-3, IEC 62153-4-4 and IEC 62153-4-15.

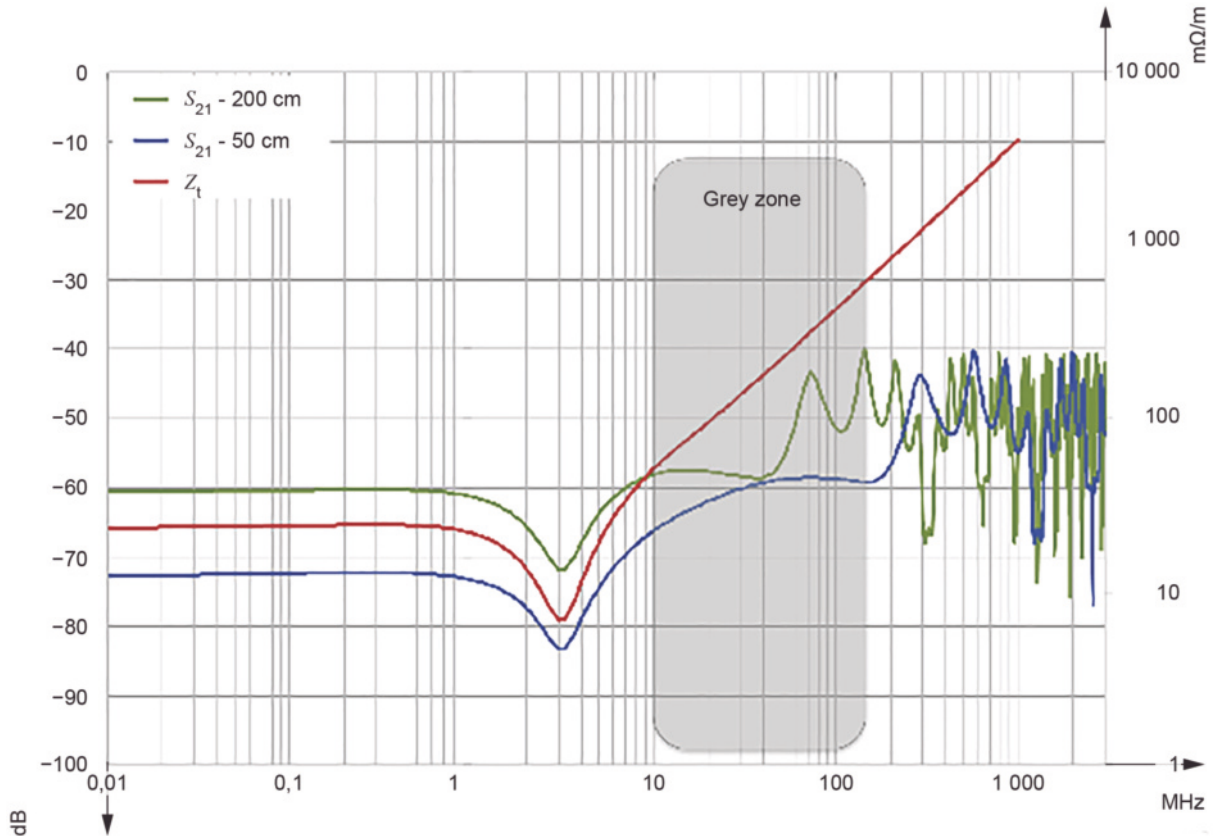


Figure 1 – Simulation of the scattering parameter S_{21} (left hand scale) and the transfer impedance (right hand scale) for a single braid screen

5 Frequency behaviour of the triaxial set-up

Knowing the frequency behaviour of the triaxial set-up one may convert a screening attenuation measurement to transfer impedance and vice versa. And on the other hand, one may extend the results of the measured transfer impedance to higher frequencies.

The general equations for the coupling between the inner and outer circuit for any load conditions are described in [3] and [4].

The relation between the measured forward transfer scattering parameter and the transfer impedance respective screening attenuation is described in [4].

In Formula (1) the capacitive coupling through the screen is neglected. In this case the transfer impedance Z_T is obtained from the measured forward transfer scattering parameter S_M by:

$$Z_T|_{Z_F=0} = S_M \frac{2\sqrt{Z_1 Z_2}}{\sqrt{1-r_{1n}^2} \sqrt{1-r_{2f}^2}} \times \frac{[1+r_{1n}r_{1f}e^{-2\gamma_1 L} + r_{2f}e^{-2\gamma_2 L} + r_{1n}r_{1f}r_{2f}e^{-2(\gamma_1+\gamma_2)L}]}{e^{-\gamma_2 L} \left[\frac{1-e^{-(\gamma_1-\gamma_2)L}}{\gamma_1-\gamma_2} (1-r_{1f}e^{-(\gamma_1+\gamma_2)L}) + \frac{1-e^{-(\gamma_1+\gamma_2)L}}{\gamma_1+\gamma_2} (1-r_{1f}e^{-(\gamma_1-\gamma_2)L}) \right]} \quad (1)$$

For low frequencies ($\gamma L \ll 1$) Formula (1) becomes

$$Z_T = S_M \frac{Z_{2f}(Z_{1n} + Z_{1f})}{2L\sqrt{Z_{1n}Z_{2f}}} \quad (2)$$

where

- Z_T is the transfer impedance;
- Z_F is the capacitive coupling impedance ($Z_F = 0$);
- S_M is the measured forward transfer scattering parameter;
- L is the coupling length;
- Z_1, Z_2 are the characteristic impedances of the inner circuit (cable) and outer circuit (tube), respectively;
- γ_1, γ_2 are the wave propagation factors in the inner circuit (cable) and outer circuit (tube), respectively;
- r_{1n}, r_{1f} are the reflection coefficients in the inner circuit (cable) at the near end and far end, respectively;
- r_{2f} is the reflection coefficient in the outer circuit (tube) at the far end.

Formula (2) is the basis for the conversion formulae given in IEC 62153-4-3 and IEC 62153-4-15.

Figure 2 shows the comparison between the results of transfer impedance obtained from Formula (1) and the commonly used conversion formula between the measured forward transfer scattering parameter and transfer impedance as described in IEC 62153-4-3. The configuration is detailed in Table 1. The inner circuit is mismatched having a short circuit at the far end. (i.e. method C of IEC 62153-4-3)

Table 1 – Parameters for simulation of triaxial set-up

| Parameter | Values |
|---|--------------------|
| Reference impedance of VNA, Z_0 | 50 Ω |
| Coupling length, L | 0,5 m |
| Impedance of inner circuit (CUT), Z_1 | 75 Ω |
| Load at the near end of the inner circuit, Z_{1n} | 50 Ω |
| Load at the far end of the inner circuit, Z_{1f} | 0 Ω |
| Dielectric permittivity of the inner circuit, ϵ_{r1} | 2,25 |
| Attenuation of the inner circuit, α_1 | 0 dB/m |
| Impedance of outer circuit (tube), Z_2 | 150 Ω |
| Load at the near end of the outer circuit, Z_{2n} | 0 Ω |
| Load at the far end of the outer circuit, Z_{2f} | 50 Ω |
| Dielectric permittivity of the outer circuit, ϵ_{r2} | 1,0 |
| Attenuation of the outer circuit, α_2 | 0 dB/m |
| DC resistance of the screen, R_T | 13,6 m Ω /m |
| Coupling inductance of the screen, M_T | 0,93 nH/m |
| Coupling capacitance of the screen, C_T | 0 pF/m |

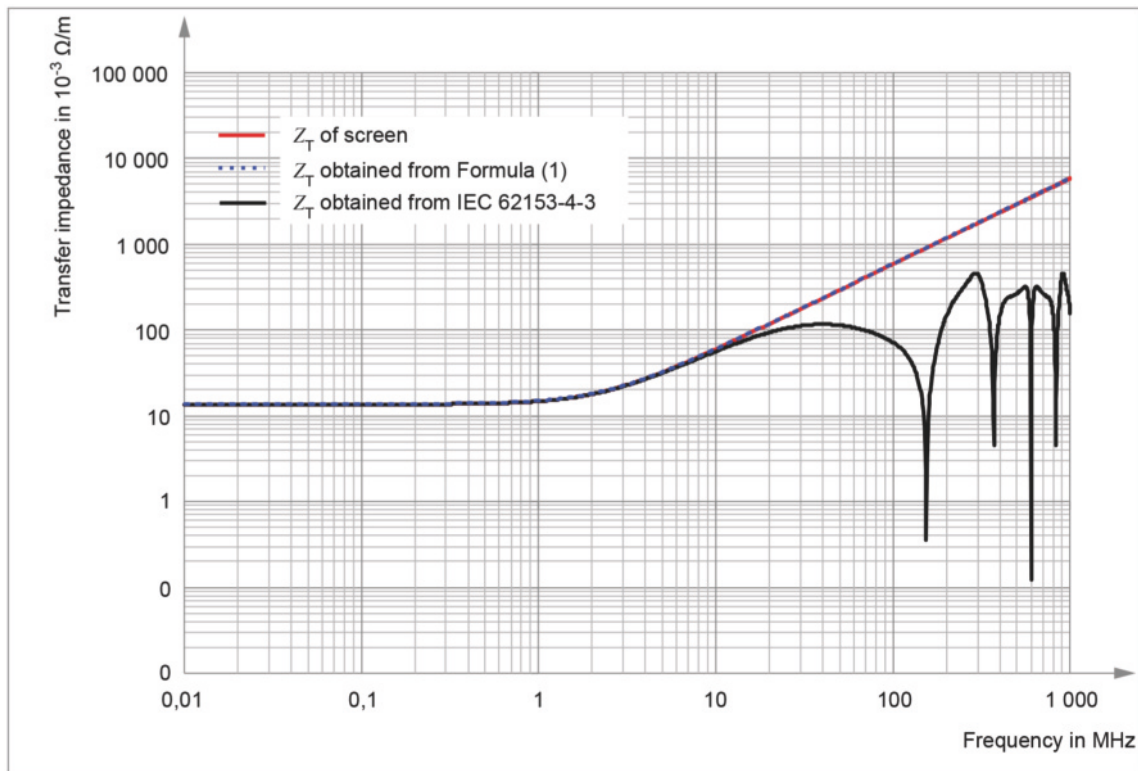


Figure 2 – Comparison of formulae for conversion between forward transfer scattering parameter and transfer impedance

The transfer impedance obtained from Formula (1) corresponds, as expected, to the transfer impedance obtained from the screen parameter (R_T , M_T , and C_T). But using Formula (12) described in IEC 62153-4-3:2013 to convert the measured forward transfer scattering parameter to transfer impedance limits the upper frequency for the transfer impedance to about 30 MHz.

6 Extrapolation of transfer impedance measurement results

6.1 General

The test results of the transfer impedance shall be extrapolated to higher frequencies by using Formula (1) instead of the formulae detailed in IEC 62153-4-3 and IEC 62153-4-15 to convert the measured forward transfer scattering parameter S_M to the transfer impedance.

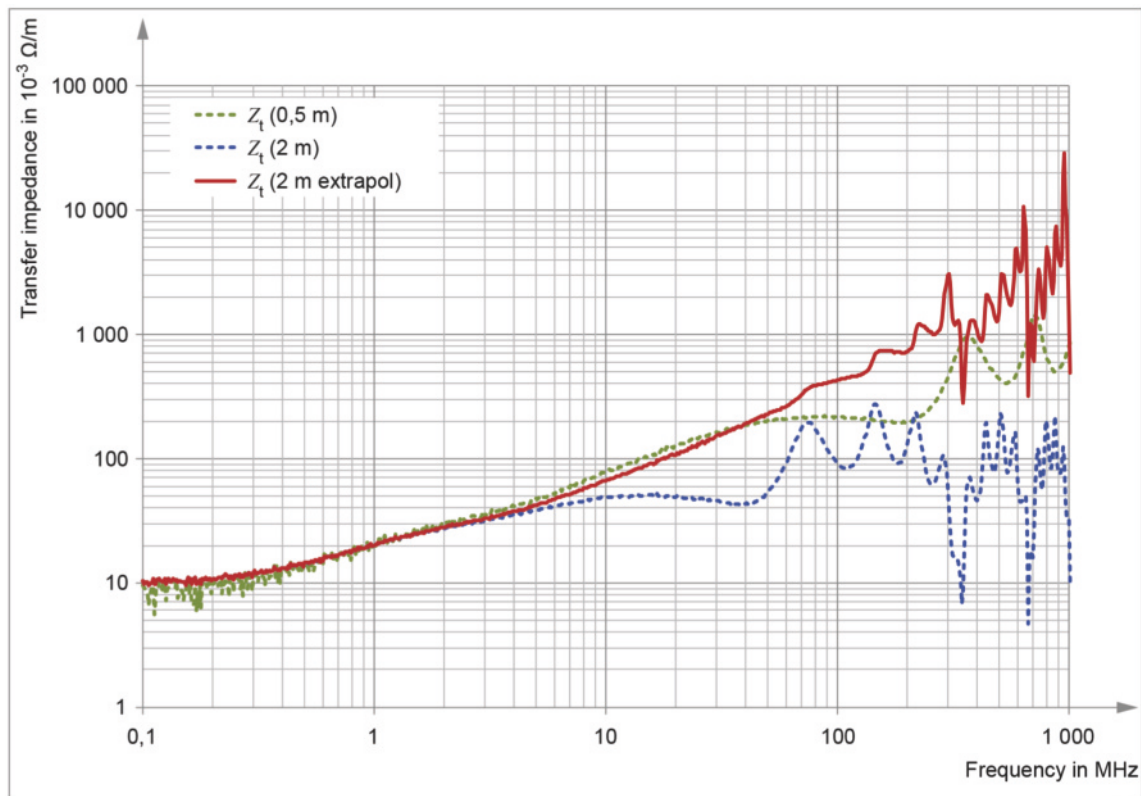
6.2 Example of a measurement according to IEC 62153-4-3, Method B

Figure 3 shows an example of the extrapolation of the measured transfer impedance of an RG59 type cable. The measurement was done in accordance with IEC 62153-4-3, Method B (matched inner circuit) with a coupling length of 2 m. For the extrapolation, a relative dielectric permittivity of 2,3 and 1,1 was assumed for the inner circuit and outer circuit, respectively. The blue dotted line is the measurement result obtained with a coupling length of 2 m. The green dotted line is the measurement result obtained with a coupling length of 0,5 m. The red solid line is the extrapolation of the measurement with a coupling length of 2 m.

Good concordance is observed between the from 2 m extrapolated results and the 0,5 m measured results. The extrapolation works well up to 100 MHz. The spikes observed above 100 MHz are due to slight differences between the real and assumed dielectric permittivities.

This example shows that it is possible by the use of Formula (1) to measure the transfer impedance and screening attenuation with one and the same triaxial set-up with a coupling length of 2 m instead of doing two

measurements, one with a short coupling length for the transfer impedance and one with a long coupling length for the screening attenuation.



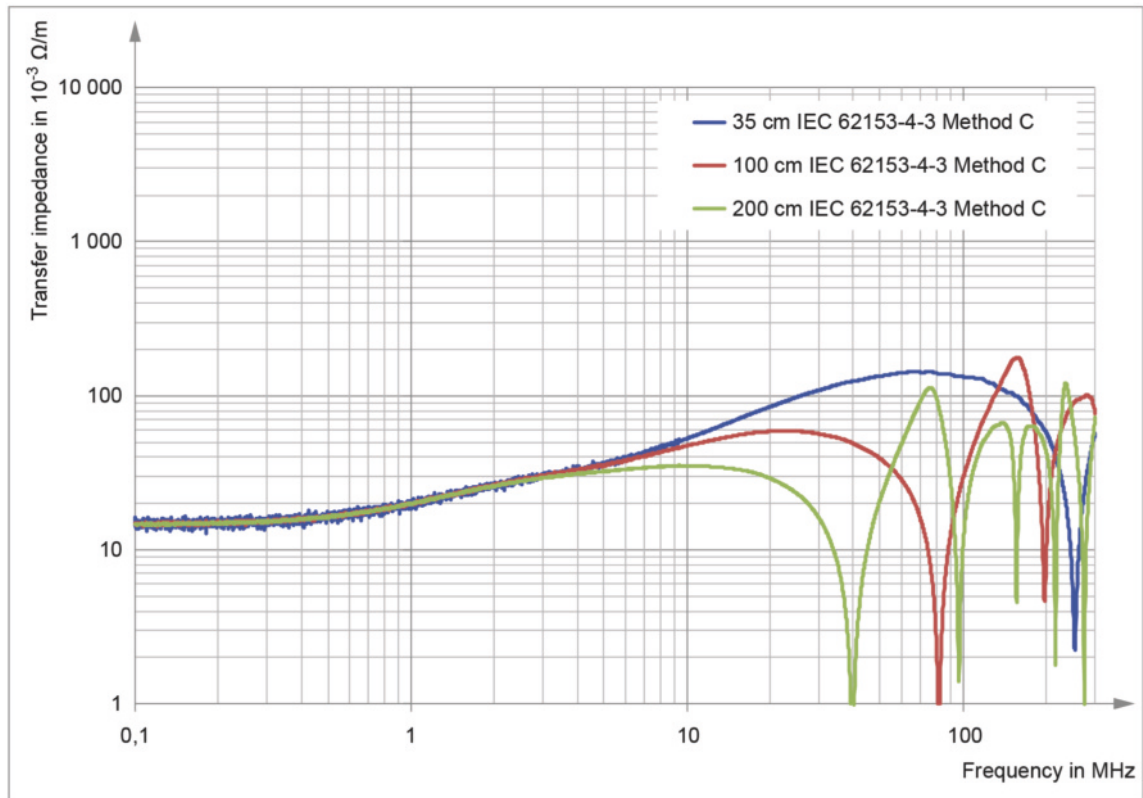
Cable measured with a coupling length of 2 m and assuming relative dielectric permittivity of 2,3 and 1,1 for the inner circuit and outer circuit, respectively.

Figure 3 – Example of the extrapolation of the transfer impedance of an RG59 type cable

6.3 Example of a measurement according to IEC 62153-4-3, Method C

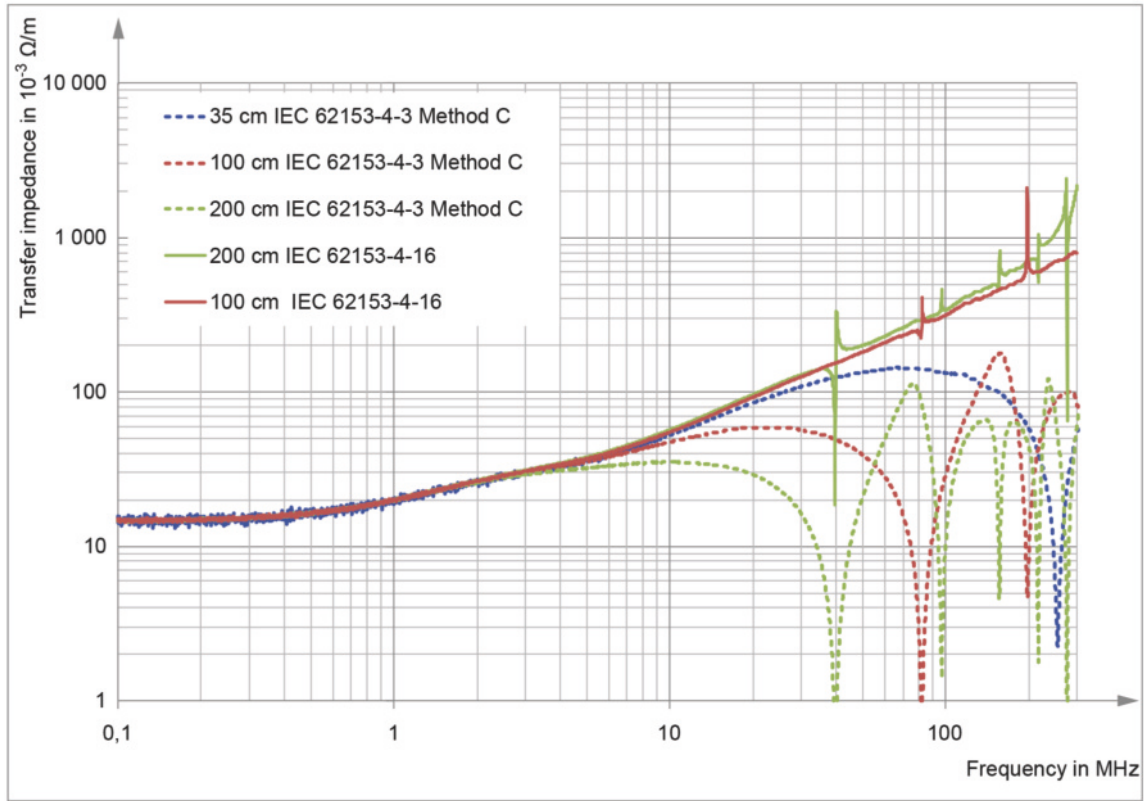
Figure 4 shows the test results of transfer impedance measurement (IEC 62153-4-3, Method C) for a single braided coaxial cable with a 50 Ω impedance. The DUT is short circuited at the far end ($Z_{1f} = 0$). The results are shown for three different coupling lengths 35 cm, 100 cm and 200 cm. The cut-off frequency for the transfer impedance measurement decreases as the length increases, from 60 MHz for 35 cm to 10 MHz for 200 cm.

Figure 5 shows the conversion of the measured scattering parameter S_M to the transfer impedance using Formula (1) instead of Formula (12) given in IEC 62153-4-3:2013. The conversion was done using a relative dielectric permittivity of the inner circuit (DUT) of 2,3 (PE dielectric) and 1,0 of the outer circuit (cable jacket was removed). The cut-off frequency was increased from 10 MHz for 200 cm and from 20 MHz for 100 cm respectively to 200 MHz. The observed residual peaks at higher frequencies are due to the capacitive coupling impedance Z_F which is not exactly zero and due to uncertainties in the dielectric permittivity used in the conversion formula.



Cable with a 50 Ω impedance; inner circuit short circuit; coupling length 35 cm, 100 cm, 200 cm.

Figure 4 – Measurement of transfer impedance of a single braided cable



Cable with a 50 Ω impedance; Formula (1); inner circuit short circuit; assuming relative dielectric permittivity of 2,3 and 1,0 for the inner circuit and outer circuit, respectively.

Figure 5 – Conversion of measured scattering parameter S_M to the transfer impedance of a single braided cable

7 Extrapolation of screening attenuation measurement results

The test results of the screening attenuation and the measured forward transmission scattering parameter S_M shall be extrapolated to lower frequencies, or in other words extrapolated from a short to a long length by first converting S_M to the transfer impedance using Formula (1). In a second step the so obtained transfer impedance is converted to the extrapolated forward transmission scattering parameter S_E by:

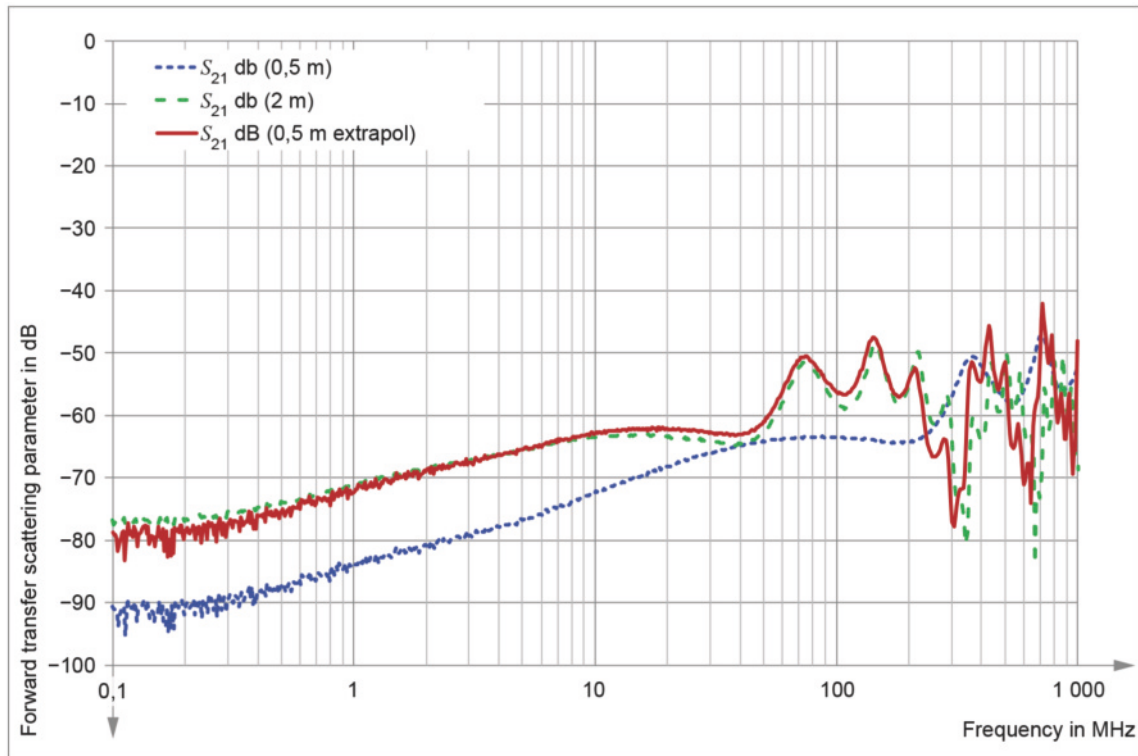
$$S_E|_{L_2} = \frac{1}{Z_T} \frac{2\sqrt{Z_1 Z_2}}{\sqrt{1-r_{1n}^2} \sqrt{1-r_{2f}^2}} \times \frac{[1+r_{1n}r_{1f}e^{-2\gamma_1 L_2} + r_{2f}e^{-2\gamma_2 L_2} + r_{1n}r_{1f}r_{2f}e^{-2(\gamma_1+\gamma_2)L_2}]}{e^{-\gamma_2 L_2} \left[\frac{1-e^{-(\gamma_1-\gamma_2)L_2}}{\gamma_1-\gamma_2} (1-r_{1f}e^{-(\gamma_1+\gamma_2)L_2}) + \frac{1-e^{-(\gamma_1+\gamma_2)L_2}}{\gamma_1+\gamma_2} (1-r_{1f}e^{-(\gamma_1-\gamma_2)L_2}) \right]} \quad (3)$$

where

- S_E is the forward transfer scattering parameter extrapolated to length L_2 ;
- Z_T is the transfer impedance obtained from the measured forward transfer scattering parameter S_M ;
- L_2 is the extrapolated coupling length;
- Z_1, Z_2 are the characteristic impedances of the inner circuit (cable) and outer circuit (tube), respectively;
- γ_1, γ_2 are the wave propagation factors in the inner circuit (cable) and outer circuit (tube), respectively;

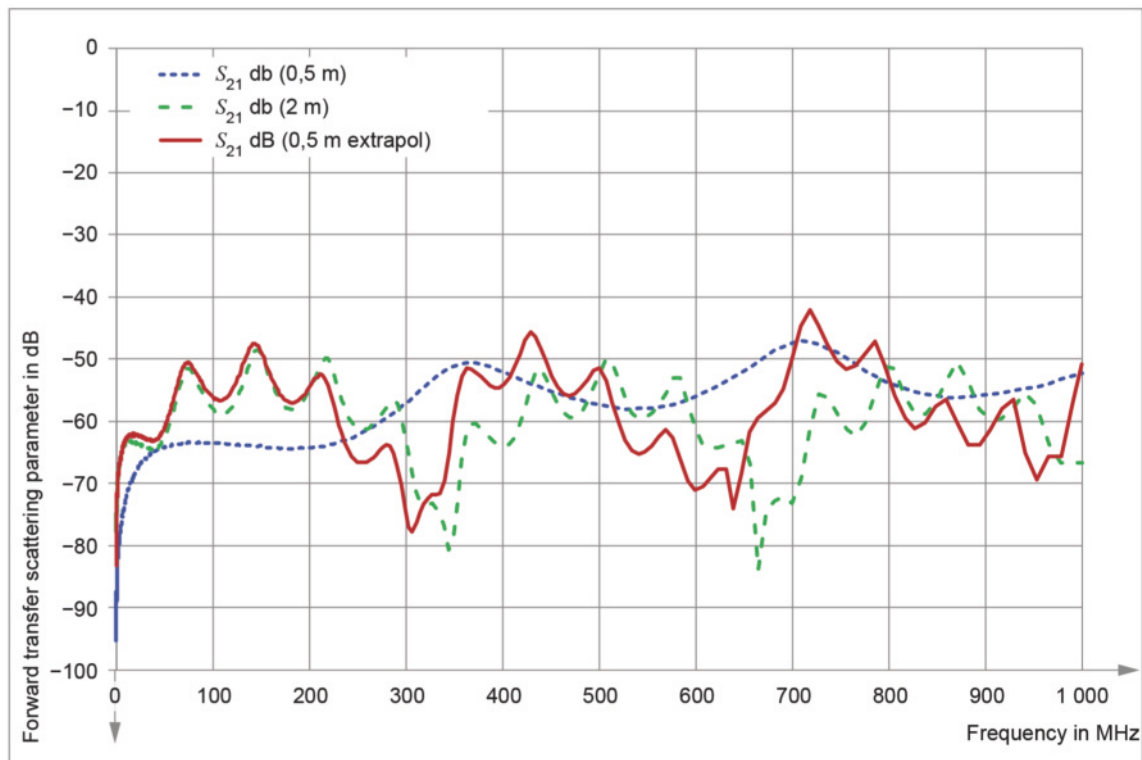
r_{1n}, r_{1f} are the reflection coefficients in the inner circuit (cable) at the near end and far end, respectively;
 r_{2f} is the reflection coefficient in the outer circuit (tube) at the far end.

Figure 6 and Figure 7 show examples of the extrapolation of the measured scattering parameter S_{21} of an RG59 type cable.



Cable measured with a coupling length of 0,5 m and assuming dielectric permittivities of 2,3 and 1,1 for the inner circuit and outer circuit, respectively

Figure 6 – Example of the extrapolation of the scattering parameter S_{21} in logarithmic frequency scale of an RG59 type cable



Cable measured with a coupling length of 0,5 m and assuming dielectric permittivities of 2,3 and 1,1 for the inner circuit and outer circuit, respectively.

Figure 7 – Example of the extrapolation of the scattering parameter S_{21} in linear frequency scale of an RG59 type cable

The measurement was done with a coupling length of 0,5 m. For the extrapolation, a dielectric permittivity of 2,3 and 1,1 was assumed for the inner circuit and outer circuit, respectively. The blue dotted line is the measurement result obtained with a coupling length of 0,5 m. The green dashed line is the measurement result obtained with a coupling length of 2 m. The red solid line is the extrapolation of the measurement with a coupling length of 0,5 m.

A good concordance is observed between the from 0,5 m extrapolated results and the 2 m measured results. The extrapolation works well up to 300 MHz. The deviations observed above 300 MHz are due to slight differences between the real and assumed dielectric permittivities.

8 Determination of the relative dielectric permittivity and impedance of the inner and outer circuits

8.1 General

In the conversion formulae, the exact dielectric permittivity and impedance of the inner and outer circuit are needed. The relative dielectric permittivity and impedance of the inner circuit (CUT) is in general known or may be obtained from an open/short measurement (see IEC 61156-1:2007/AMD1:2009, 6.3.10 [5], IEC TR 62152:2009, Clause A.6 [6]) or a TDR measurement.

For the determination of the impedance and relative dielectric permittivity of the outer circuit (tube), one can use a TDR measurement (rise-time maximum 200 ps) or use the theory of the transformation characteristics of a line. The input impedance of a line is expressed by the following equation (neglecting the attenuation):

$$Z_{in} = Z_c \frac{\frac{Z_{load}}{Z_c} + j \tan(2\pi \frac{L}{\lambda})}{1 + \frac{Z_{load}}{Z_c} j \tan(2\pi \frac{L}{\lambda})} \quad (4)$$

where

Z_{in} is the input impedance of the transmission line;
 Z_{load} is the load impedance of the transmission line;
 Z_c is the characteristic impedance of the transmission line;
 λ is the wave length of the transmission line;
 L is the length of the transmission line.

For even multiples of the half wavelength ($\lambda/2$), the input impedance is equal to the load impedance and for odd multiples of the quarter wavelength ($\lambda/4$), the transmission line acts as a dual transformer.

With the short circuit in the outer circuit of the triaxial set-up, one gets:

$$\begin{array}{llll} Z_{in} = 0 & \text{or} & S_{11} = -1 & \text{when} & L = n \lambda/2 \\ Z_{in} = \infty & \text{or} & S_{11} = +1 & \text{when} & L = (2n+1) \lambda/4 \end{array}$$

So by measuring the scattering parameter S_{11} and observing two successive resonances where the real part $\text{Re}(S_{11}) = -1$ (and the imaginary part $\text{Im}(S_{11}) = 0$), or two successive resonances where the real part $\text{Re}(S_{11}) = +1$ (and the imaginary part $\text{Im}(S_{11}) = 0$), one can obtain the relative dielectric permittivity:

When $\text{Re}(S_{11}) = -1$ or $\text{Re}(S_{11}) = +1$

$$\epsilon_r = \left[\frac{c_0}{2L \Delta f} \right]^2 \quad (5)$$

where

ϵ_r is the relative dielectric permittivity;
 c_0 is the speed of light in free space;
 L is the length of the transmission line;
 Δf is the frequency spacing between two successive resonances where the real part $\text{Re}(S_{11}) = -1$ (and $\text{Im}(S_{11}) = 0$), or two successive resonances where the real part $\text{Re}(S_{11}) = +1$ (and $\text{Im}(S_{11}) = 0$).

The observation of two successive resonances also allows for the determination of the characteristic impedance in the outer circuit. From Formula (4), the input impedance for a short circuited transmission line is obtained:

$$Z_{in}|_{Z_{load}=0} = Z_c j \tan(\beta L) \quad (6)$$

Hence:

$$Z_{in} = jZ_c \text{ for } \tan \beta L = 1, \beta L = (n\pi + \pi/4), f = (4n+1)/4 \Delta f$$

or

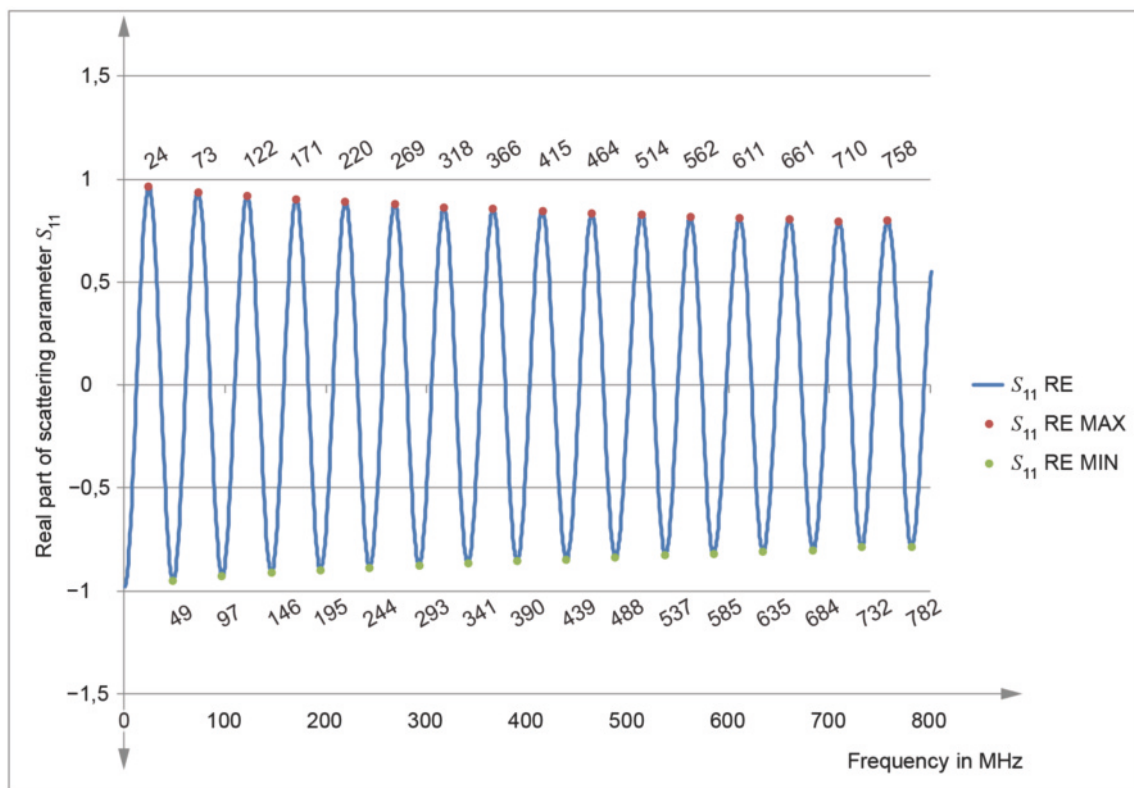
$$Z_{in} = -jZ_c \text{ for } \tan \beta L = -1, \beta L = (n\pi - \pi/4), f = (4n-1)/4 \Delta f$$

where

Z_{in} is the input impedance of the transmission line;
 Z_c is the characteristic impedance of the transmission line;
 L is the length of the transmission line;
 β is the phase constant of transmission line.

The principle of this method is shown in Figure 8, which shows the test results of a short circuited RG58 cable having a length of 203 cm. Subclause 8.2 describes how to apply this method to determine the relative dielectric permittivity and impedance of the outer circuit.

It is recommended to take the average frequency spacing of at least five successive resonances as shown in Figure 8. The average frequency spacing of two successive resonances is 48,90 MHz. Formulae (5) and (6) result in a relative dielectric permittivity of 2,28 and a characteristic impedance of 49,5 Ω which correspond to the typical values for this type of cable.



Test results of the real part of the scattering parameter S_{11} of an RG58 type cable (with solid PE insulation) having a length of 203 cm and a short circuit at the far end, where the average distance between two successive maxima is 48,93 MHz and between two successive minima is 48,87 MHz, i.e. the global average distance is 48,90 MHz.

Figure 8 – Measurement of S_{11} of the outer circuit (tube) having a length of 203cm

The characteristic impedance in the outer circuit can also be obtained if the dimensions of the cable and the tube and the relative dielectric permittivity in the outer circuit are known:

$$Z_2 = \frac{60}{\sqrt{\epsilon_{r2}}} \ln\left(\frac{D}{d}\right) \quad (7)$$

where

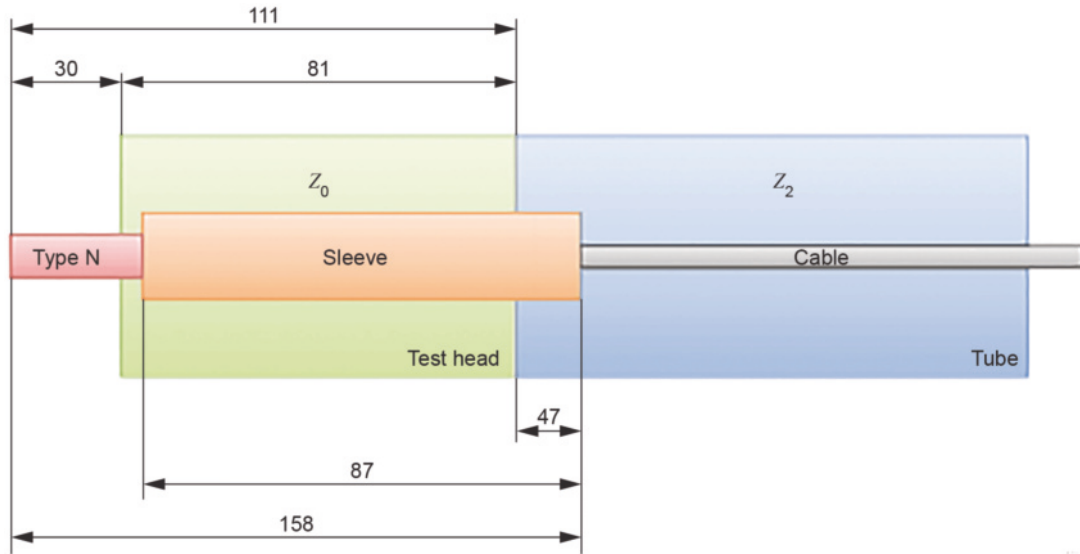
Z_2 is the characteristic impedance of the outer circuit in Ω ;

- ϵ_{r2} is the relative dielectric permittivity of the outer circuit;
 D is the inner diameter of the tube in mm;
 d is the outer diameter of the cable screen in mm.

8.2 Influence of the test head

To obtain the relative dielectric permittivity and impedance in the outer circuit from the measurement of the scattering parameter S_{11} , the configuration of the triaxial tube shall be taken into account. The well-known COMET set-up has a test head which is attached to the measuring tube, see Figure 9.

Dimensions in millimetres



Key

- Z_2 characteristic impedance in the outer circuit (tube)
 Z_0 characteristic impedance of the test head

Figure 9 – Example of test head (COMET set-up)

This test head is built to have a characteristic impedance of 50Ω to match with the test receiver. As the characteristic impedance in the outer circuit, Z_2 is different from the impedance of the test head, the test head will act as a line transformer and the S_{11} measurement shall be corrected.

$$S_{11}^{cor} = S_{11}^{meas} \times e^{j2\beta_H L_H^{mech}} = S_{11}^{meas} \times e^{j4\pi \cdot L_H^{elec} \cdot f / c_0} \quad (8)$$

$$L_H^{elec} = L_H^{mech} \sqrt{\epsilon_{r,H}} \quad (9)$$

where

- S_{11}^{cor} is the corrected scattering parameter S_{11} ;
 S_{11}^{meas} is the measured scattering parameter S_{11} ;
 L_H^{mech} is the mechanical length of the test head;
 L_H^{elec} is the electrical length of the test head;
 β_H is the phase constant of the test head;
 f is the frequency;

$\epsilon_{r,H}$ is the relative dielectric permittivity of the test head.

The electrical length of the test head can be obtained when replacing the cable in Figure 9 by a bare copper wire. Using such a DUT, the relative dielectric permittivity in the tube is equal to the one of air (1,00). The exact mechanical length of the tube is 948 mm, which is the 1 000 mm overall length minus 47 mm for the exceeding length of the screening cap (sleeve) minus 5 mm for the thickness of the short circuit disc.

In this configuration, the expected frequency spacing is 158 MHz in the measurement of the scattering parameter S_{11} measured at the test head, see Formula (5). In Figure 10, one can observe that the results are distorted (red line) due to the line transformation of the test head. The expected frequency spacing of 158 MHz is obtained by taking an electrical length of 175 mm for the test head. This is shown in the blue line which represents the corrected scattering parameter S_{11} , see Formula (8).

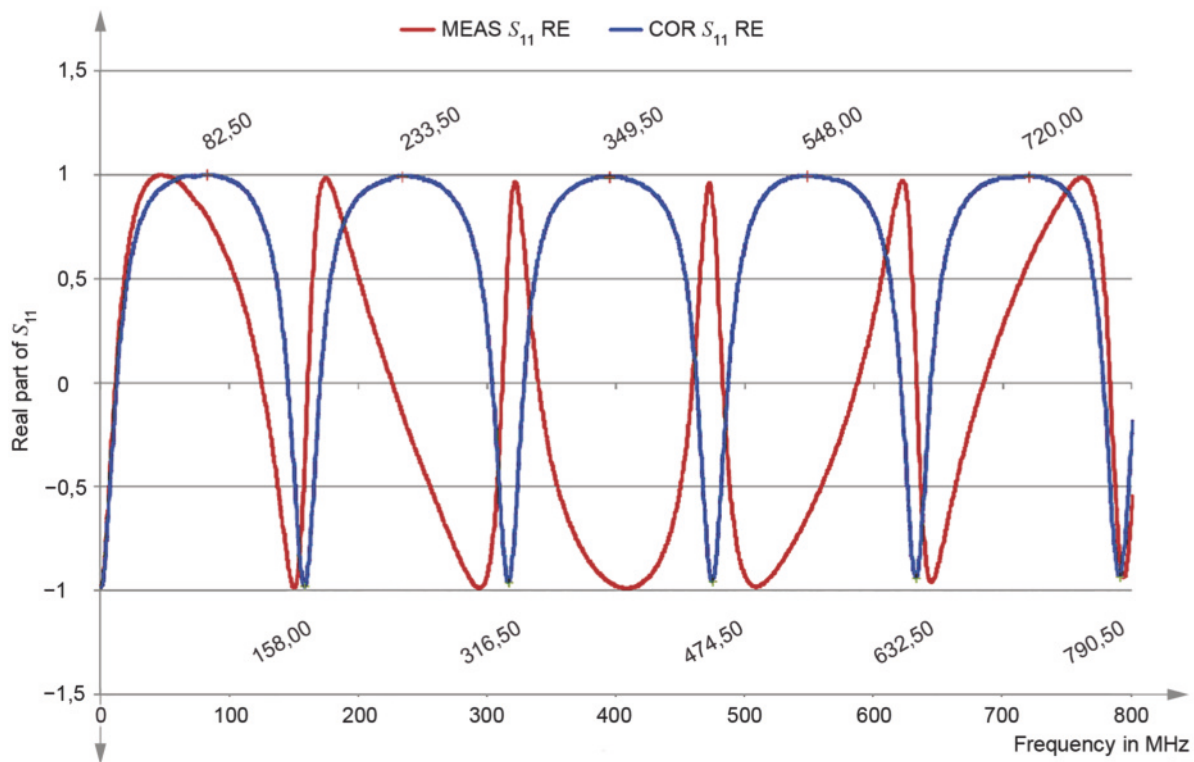


Figure 10 – Example how to obtain the electrical length of the test head from the S_{11} measurement using a bare copper wire as DUT (COMET set-up)

The so determined electrical length of the test head is used to correct the results in the case of a real CUT.

Figure 11 shows the test results of the scattering parameter S_{11} measured from the test head with an RG58 type cable as a CUT in the 2 m tube. The results are distorted (red line) due to the line transformation of the test head. The blue line shows the corrected results using Formula (8) and an electrical length for the test head of 175 mm.

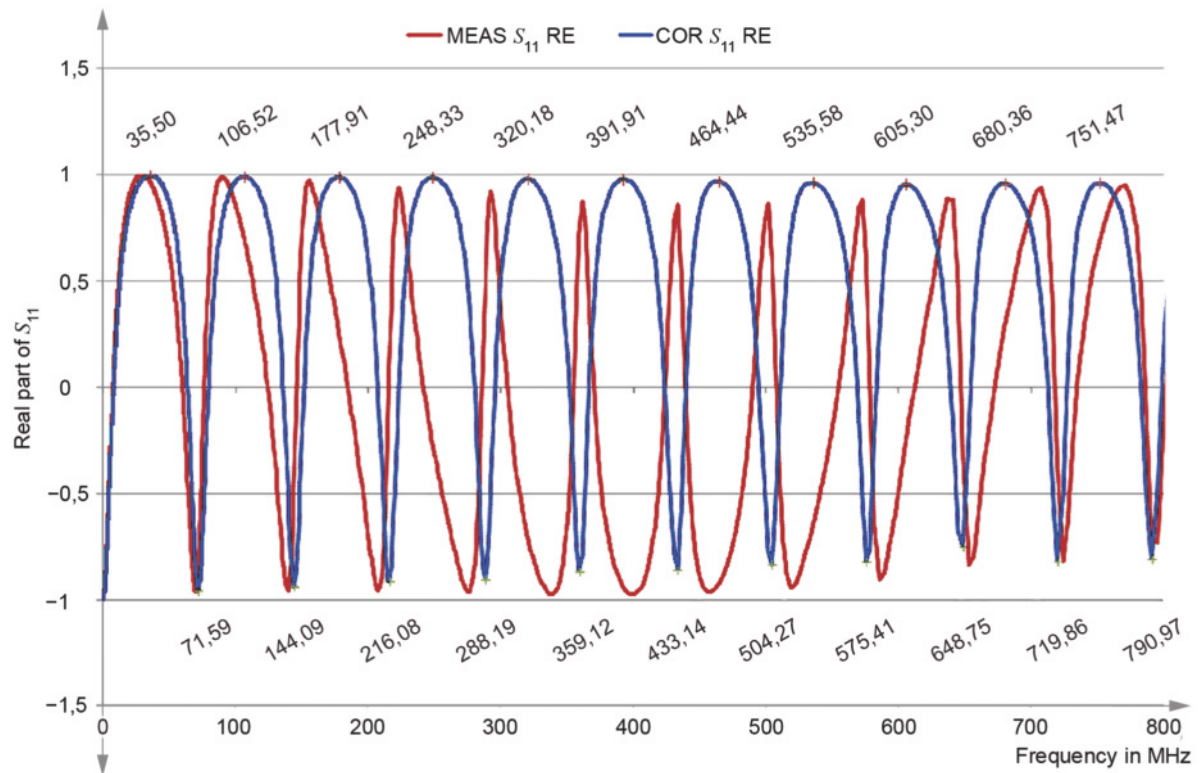


Figure 11 – Example of an RG58 type cable in 2 m triaxial set-up (COMET)

The exact mechanical length of the tube is 1 948 mm which is the 2 000 mm overall length minus 47 mm for the exceeding length of the screening cap (sleeve) minus 5 mm for the thickness of the short circuit disc. The average frequency spacing is 71,8 MHz which results in a relative dielectric permittivity in the outer circuit of 1,15 and a characteristic impedance in the outer circuit of 137 Ω , see Formulae (5) and (6).

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