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MEASUREMENTS OF THE SCREENING EFFECTIVENESS OF CONNECTORS AND CABLE ASSEMBLIES

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Abstract: This report describes a test method to determine the screening effectiveness of connectors and cable assemblies. The shielded screening attenuation (long triaxial) test set-up according to IEC 61196-1 clause 12.6 is used and has been extended to take into account the particularities of connectors and cable assemblies. This method is now under discussion in the international working group IEC TC 46 WG5.

Keywords: cable assembly, connector, screening effectiveness, triaxial set-up.

1. INTRODUCTION

Due to the increasing use of all kind of electric or electronic equipment, electromagnetic pollution increases. To reduce this electromagnetic pollution, all components of a system, especially the connecting cables (assemblies) shall be screened. It is obvious, that one needs standardised measuring procedures to compare the screening effectiveness of different screen designs. The basic screening parameters are the transfer impedance Z_T and the screening attenuation a_S or coupling attenuation a_C. One already has either the triaxial or the line injection method to obtain the transfer impedance Z_T of cables, connectors and cable assemblies. However for the measurement of the screening a_S or coupling a_C attenuation of connectors and cable assemblies an easy and cost effective method is missing.

Recently one has introduced the shielded screening attenuation (long triaxial) test method for the measurement of the screening or coupling attenuation of cables [1][2][3]. That method could also be used for the measurement of connectors and cable assemblies. In the following the principles are described.

2. PHYSICAL BASICS

2.1 General coupling equation

For the measurement of the coupling it is expedient to use the concept of operational attenuation with the square root of power waves, like in the definition of scattering parameters [4][5]. The general coupling transfer function is then defined as:

$$T_{n,f} = \frac{\underline{U}_{2n,f} / \sqrt{\underline{Z}_2}}{\underline{U}_1 / \sqrt{\underline{Z}_1}} = \frac{\sqrt{\underline{P}_{2n,f}}}{\sqrt{\underline{P}_0}} \qquad (1)$$

The electromagnetic influence between the sample under test and the surrounding is in principle the crosstalk between two lines and is caused by capacitive and magnetic coupling. At the near end the magnetic and capacitive coupling add where at the far end they subtract [5][6]. The coupling along the sample length is obtained by integrating the infinitesimal coupling distribution along the sample with the correct phase. The phase effect, when summing up the infinitesimal couplings along the line is expressed by the summing function S [5]. When the sample attenuation is neglected than *S* could be expressed by the following equation. Where $\beta_{1,2}$ are the phase velocities of the primary respectively secondary circuit and *l* the coupling length. The indices n and f denote the near respectively far end.

$$S_{n,f}(lf) = \frac{\sin\left[(\beta_2 \pm \beta_1) l/2\right]}{(\beta_2 \pm \beta_1) l/2} \exp\left(-j(\beta_2 + \beta_1) l/2\right) \qquad (2)$$

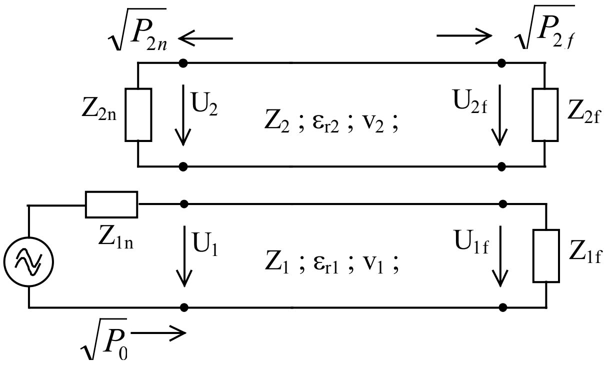


Fig. 1 : Equivalent circuit

For high frequencies the asymptotic value becomes:

$$\left|S_{\substack{n\\f}}\right| \rightarrow \frac{2}{(\beta_1 \pm \beta_2)\cdot l} \qquad (3)$$

And for low frequencies the summing function becomes:

$$\left|S_{\substack{n\\f}}\right| \rightarrow 1 \qquad (4)$$

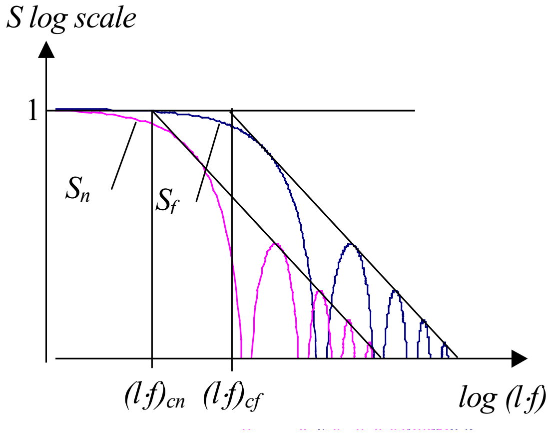


Fig. 2 : Summing function S

The point of intersection between the asymptotic values for low and high frequencies is the so called cut-off frequency f_c. This frequency gives the condition for electrical long sampels:

$$f_{c,\substack{n\\f}} \cdot l \geq \frac{c}{\pi \cdot \left|\sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}}\right|} \qquad (5)$$

where $\varepsilon_{r1,2}$ are the relative dielectric permittivity of the inner and the outer system and l is the cable length.

2.2 Coupling transfer function

2.2.1 Homogenous screens

The primary screening quantities of a screen are the surface transfer impedance Z_T and the capacitive coupling impedance Z_F or the effective transfer impedance Z_{TE}. For homogeneous screens like for connectors or cables they can be assumed to be constant along the length. The integration could then be easily solved. The coupling between the sample and the surrounding could be expressed by the following coupling transfer function. For matched lines it is [4][5]:

$$T_{s,\substack{n\\f}} = \left(Z_F \pm Z_T\right)\cdot\frac{1}{\sqrt{Z_1 \cdot Z_2}}\cdot\frac{l}{2}\cdot S_{\substack{n\\f}} \qquad (6)$$

For low frequencies, when S=1, the coupling transfer function corresponds to the frequency behaviour of the surface transfer impedance and capacitive coupling impedance. After a rise with 20 dB per decade the coupling transfer function shows different cut off frequencies $f_{cn,f}$ for the near and far end. Above these cut off frequencies the samples are considered as electrical long.

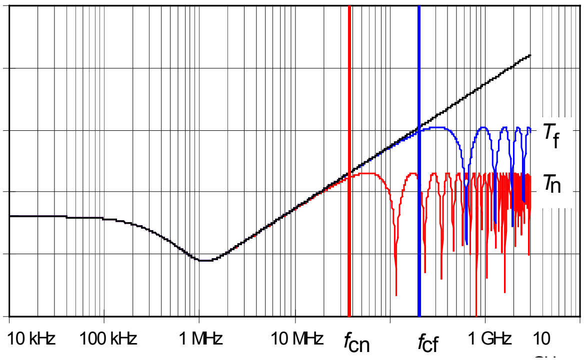


Fig. 3 : Calculated coupling transfer function
(l = 1 m; ε_{r1} = 2,3; ε_{r2} = 1; Z_F=0)

Below the cut off frequencies the surface transfer-impedance Z_T is the measure of the screening effectiveness. The value of the transferimpedance Z_T increases with the sample length.

Above the cut off frequencies in the range of wave propagation, respectively in the range where the samples are electrical long, the screening attenuation a_S is the parameter for the screening effectiveness. The screening attenuation is a length independent quantity.

2.2.2 Cable assembly screens

Cable assemblies are composed by the cable itself and a connector at each end. In addition to the coupling of the components itself also the coupling of the transition between cable and connector has to be taken into account. A good connector and a good cable screen doesn't mean - without any precautions - a good assembly.

Each part of it has a different coupling, thus one has to integrate in sections along the sample, i.e. one section for each component (connector A, transition, cable, transition, connector B). In a first approach the velocity in each section could be assumed to be equal. The coupling transfer function for matched lines is then expressed by:

$$T_n = \frac{1}{\gamma_1+\gamma_2}\sum_{i=1}^{n}\left[\frac{Z_{F,i}+Z_{T,i}}{2\sqrt{Z_1 \cdot Z_2}} \cdot e^{-(\gamma_1+\gamma_2)\cdot\sum_{k=1}^{i-1} L_i} \cdot \left(1-e^{-(\gamma_1+\gamma_2)\cdot L_i}\right)\right] \qquad (7)$$

$$T_f = \frac{e^{-\gamma_2 L_C}}{\gamma_1-\gamma_2}\sum_{i=1}^{n}\left[\frac{Z_{F,i}-Z_{T,i}}{2\sqrt{Z_1 \cdot Z_2}} \cdot e^{-(\gamma_1-\gamma_2)\cdot\sum_{k=1}^{i-1} L_i} \cdot \left(1-e^{-(\gamma_1-\gamma_2)\cdot L_i}\right)\right] \qquad (8)$$

where:

$\gamma_{1,2}$	complex wave propagation constant of inner respectively outer circuit
L_c	whole coupling length (sum of the segment lengths)
L_i	length of segment i
n	number of segments (for cable assemblies 3)
$T_{n,f}$	coupling transfer function at the near respectively far end
$Z_{1,2}$	Characteristic impedance of inner respectively outer circuit
Z_F	Capacitive coupling impedance
Z_T	Surface transfer impedance

2.2.3 Coupling in the triaxial set-up

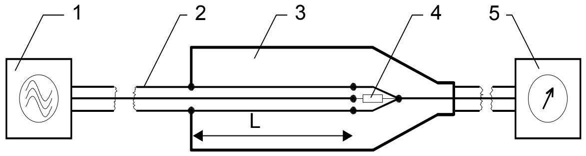
The above mentioned coupling transfer functions are valid if the primary and secondary circuit are matched. However in the triaxial set-up the secondary system (outer circuit) is mismatched (see also the following section). At the near end one has the short circuit between the sample screen. At the far end one has the mismatch between the impedance of the outer circuit and the receiver input impedance resulting in the reflection coefficient $r_{2,f}$. In that case the resulting coupling transfer function (at the receiver end) is obtained by:

$$T^{*}=\left(T_f-T_n\cdot e^{-\gamma_2 L_C}\right)\frac{1+r_{2,f}}{1+r_{2,f}\cdot e^{-2\gamma_2 L_C}} \qquad (9)$$

3. TRIAXIAL TEST SET-UP

3.1 General

The triaxial test set-up is one of the classical methods to measure the transferimpedance and has been recently extended for the measurement of the screening attenuation of cable screens [1][2]. The triaxial set-up is described in IEC 61196-1 and EN 50289-1-6, and consists of a tube of brass or aluminium with an inner diameter of about 40 mm.



1 generator
2 cable under test
3 measuring tube
4 termination load
5 measuring receiver
L coupling length

Fig. 4 : triaxial set-up for the measurement of the screening attenuation a_S and the transfer impedance Z_T

For the measurement of the transfer impedance (electrically short coupling length) the tube length is 0,5 m to 1 m. For the measurement of the screening attenuation (electrically long coupling length) the measuring tube is extended to a length of 2m to 3m. (See also above theoretical explanation).

In the outer circuit, at the near end the screen under test is short circuited with the measuring tube. The electrical waves, which are coupled over the whole cable length from the inner system into the outer system, are travelling in both directions, to the near and the far end. At the short circuited end they are totally reflected, so that at the measuring receiver the superposition of near and far end coupling can be measured as the disturbance voltage ratio U_2/U_1. The screening attenuation as a power ratio is then related to a standardised characteristic impedance of the outer system Z_s=150Ω.

$$a_s = 20\cdot\log\left(\left|\frac{U_2}{U_1}\right|_{\max}\right)+10\cdot\log\left(\frac{2\cdot Z_s}{Z_1}\right) \qquad (10)$$

where Z_1 is the characteristic impedance of the sample under test and Z_s is 150 Ω.

3.2 Measurement of cable assemblies

3.2.1 General

When measuring cable assemblies in the triaxial test set-up one has the problem, that their lengths are differing widely and are either shorter or longer than the commonly used measuring tube of 2 or 3m. However the investigations of the above given coupling functions show, that:

a) for assemblies longer than the measuring tube it is sufficient enough to measure just both accessible assembly ends.

b) for assemblies shorter than the measuring tube one can extend the assembly by a well screened cable inside a closed copper tube. The so called tube in tube method.

3.2.2 Assembly longer than the measuring tube

In screening attenuation measurements of cable assemblies it is evident, that the result is characterised by the weakest part. Either the cable or the connector respectively the transition between cable and connector. Thus for cable assemblies, which are longer than the measuring tube it is sufficient enough to measure just both accessible ends (provided that the cable screen is homogenous). The following simulated graphs underline that evidence. The simulation parameters are:

a) cable screen

length:	500 cm
DC resistance:	13 mΩ/m
magnetic coupling:	0,04 mH/m
capacitive coupling:	0,02 pF/m

b) connector screen including transition from cable to connector

length:	5 cm
DC resistance:	2 mΩ/m
magnetic coupling:	0,002 mH
capacitive coupling:	0 pF/m

c) outer circuit (secondary system)

impedance: 150 Ω
dielectric permittivity: 1,1

d) inner circuit (primary system)

impedance: 50 Ω
dielectric permittivity: 2,3

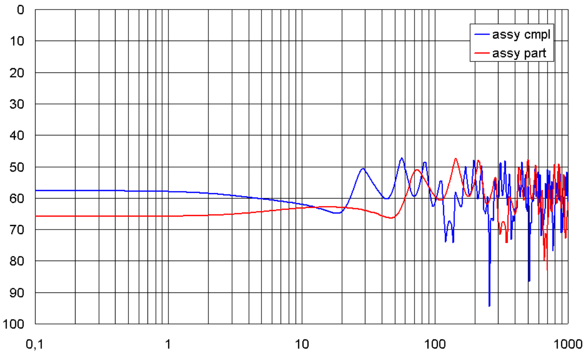


Fig. 5 : simulation of a cable assembly (log scale)

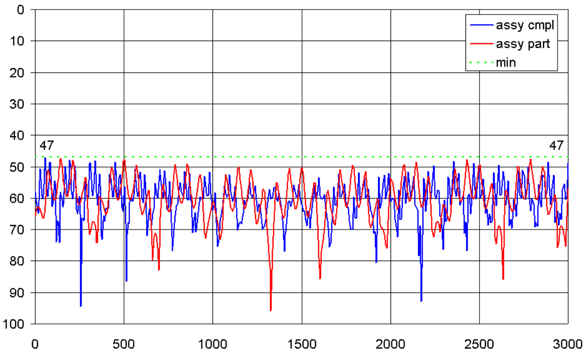


Fig. 6 : simulation of a cable assembly (lin scale)

The blue line shows the result of the complete cable assembly, i.e. 500 cm cable and both connectors. The red line shows the result for just one part of the assembly, i.e. 195 cm of the cable and one connector. In the lower frequency range, where the samples are electrically short one gets a length dependent result. However in the higher frequency range, where the samples are electrically long, one gets the same minimum value, i.e. the same screening attenuation of 47 dB.

3.2.3 Assembly shorter than the measuring tube

When the assembly is shorter than the measuring tube, than one can extend the assembly by a well screened connecting cable inside a closed copper tube. The so called tube in tube method (see also Fig. 7).

The extension tube is than acting as a resonator. The same principle is also used for the measurement of connectors. Further details can be obtained from the following explanation of the measurement of connectors.

3.3 Measurement of connectors

3.3.1 General

Usual RF connectors have mechanical dimensions in the longitudinal axis in the range of 10mm to 50mm. With equation (5), i.e. the definition of electrical long elements, we get cut off frequencies of about 3 GHz or higher for standard RF-connectors. Above that frequency they are considered to be electrically long.

The screening attenuation is by definition only valid in the frequency range above the cut off frequency, where the elements are electrically long. Thus the screening attenuation of a RF connector itself can only be measured at frequencies above 3 GHz.

However by extending the RF-connector by a RF-tight closed metallic tube, one is building a cable assembly which is electrically long. Thus the cut off frequency respectively the lower frequency limit to measure the screening attenuation is extended towards lower frequencies. If one connects this extension tube directly to the connector under test, one is measuring the screening attenuation of the connector (and its mated adapter). If one connects the extension tube to the connecting cable close to the connector, one is measuring the screening attenuation of the combination of the connector (and its mated adapter) and the transition between cable and connector (see also Fig. 8).

Note: Although the connector itself stays electrically short, the combination of the connector and the extension tube shows the behaviour (the screening attenuation) of the connector when connected to a well screened cable, which has a screening effectiveness better than the one of the connector (or the transition between cable and connector). See also the explanation in the following section.

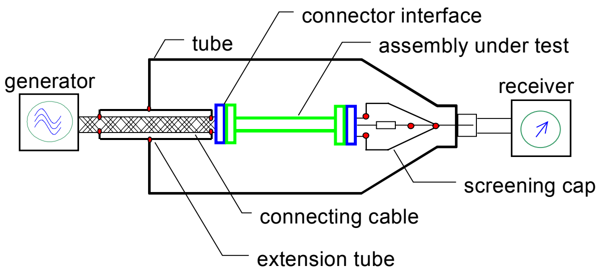


Fig. 7 : triaxial set-up with extension tube for short cable assemblies

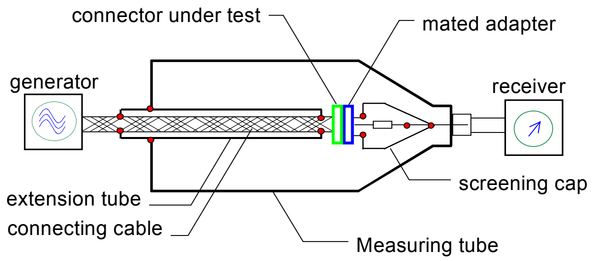


Fig. 8 : triaxial set-up with extension tube for connectors.

3.3.2 Measurement set-up

For the measurement of RF connectors the triaxial set-up according to IEC 61196-1 has been extended by a RF-tight closed metallic tube (see Fig. 8). The extension tube is either connected to the connector under test or to the screen of the connecting cable of the connector under test. At the far end the connector under test is connected to the screening cap of the triaxial test set-up via its mated adapter.

The measurement of the screening attenuation itself is the same as the measurement of cable screens according to IEC 61196-1 Amendment 2 clause 12.6.

3.3.3 Measurement results and simulations

In a first approach one has measured short cable pieces instead of a connector. The advantage is, that the results are not influenced by a mating adapter or the transition between cable and connector. The cable has been a coaxial cable with an impedance of 75Ω, foam PE dielectric and a single braid screen (not optimised, i.e. under-braided). The simulations have been done with the equations (7), (8) and (9) where the number of sections is 2. The first section is the connecting cable with the RF-tight extension tube.

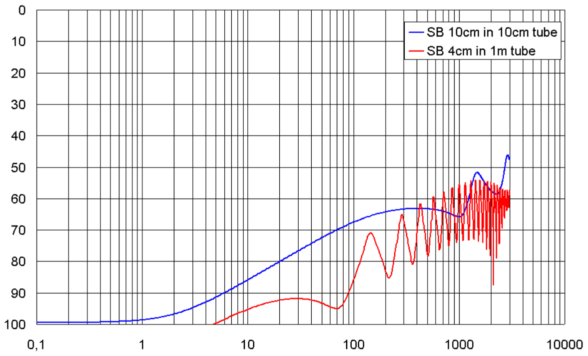


Fig. 9 : simulation, log. frequency scale

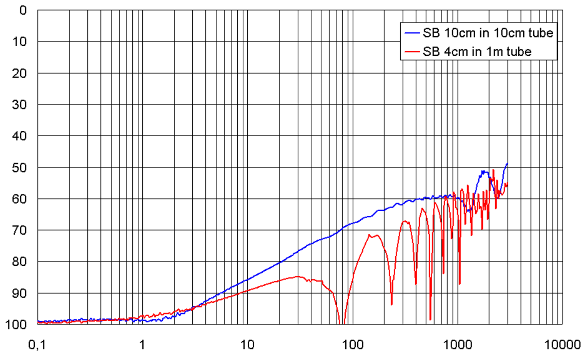


Fig. 10 : measurement, log. frequency scale

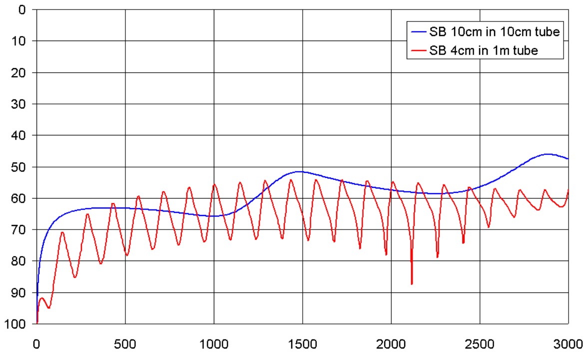


Fig. 11 : simulation, lin. frequency scale

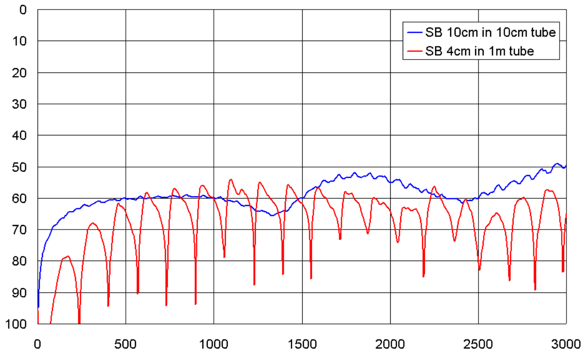


Fig. 12 : measurement, lin. frequency scale

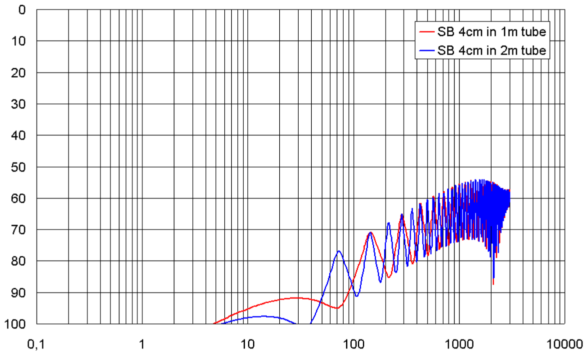


Fig. 13 : simulation, log. frequency scale

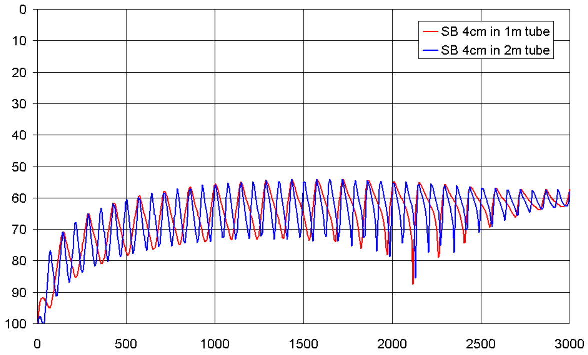


Fig. 14 : simulation, lin. frequency scale

Thus the transfer impedance and capacitive coupling impedance of that section is neglected. The second section is the cable under test with following parameter:

DC resistance:	8 mΩ/m
magnetic coupling:	0,6 mH/m
capacitive coupling:	0,02 pF/m
impedance:	75 Ω
dielectric permittivity:	1,35

The comparison of the simulation (Fig. 9, 11) with the measurement results (Fig. 10, 12) show a good correspondence. In the lower frequency range, when the samples are electrically short one gets the same results. However in the higher frequency range one can see the influence of the extension tube. The 10cm sample is electrically short over the whole frequency range, as the cut-off frequency is 5,9 GHz. Thus the coupled power is increasing with increasing frequency. However the quasi cable assembly composed of the connector and the extension tube is electrically long above 590 MHz, which results in a constant maximum coupled power. One characteristic of an electrically long object is also, that the maximum coupled power is independent of the sample length (see clause “General coupling equation”). This is underlined in figure 13 and 14, where the simulated results of a 4cm sample in a 1m respectively 2m tube, i.e. with a 96cm respectively 196cm extension tube, are shown. The envelope of both curves is identical.

4. CONCLUSION

Customers and users of RF cables, cable assemblies and connectors ask more often for screening effectiveness values in decibels (dB) instead of transferimpedance values in mΩ respectively mΩ/m. The explained tube in tube method reply to that need since it offers a simple and reliable method to measure the screening attenuation in dB on connectors and cable assemblies. That method is an extension of the shielded screening attenuation (long triaxial) test set-up according to IEC 61196-1 clause 12.6

The comparison of the measured and the calculated curves show good concordance.

The advantages of the tube in tube method for connectors and assemblies are the same as for the measurement of the screening attenuation of cable screens in the tube:

- simple and easy test set-up
- insensitive against electro magnetic disturbances from outside
- high dynamic range > 130 dB
- good reproducibility

A future investigation is the measurement of the screening attenuation of connectors for balanced cables and for multipin connectors.

5. REFERENCES

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BIOGRAPHICAL NOTES

Thomas Hähner was born 1965 in Germany. He received his Dipl.-Ing. degree for information and communication techniques from the Georg-Simon-Ohm Fachhochschule Nürnberg in 1989. He joined Nexans Germany in 1990, where he was responsible for the development and design of communication cables and the RF-laboratory. In 2000 he received his Dipl. Wirt.-Ing. degree from Technische Fachhochschule Wildau and moved to the mother company in France, where he is now responsible for the technical support. Thomas is a member of several national and international standardisation committees, e.g. in IEC TC46/WG5, screening effectiveness.

Bernhard Mund was born 1953 in Germany. He received his Dipl.-Ing. degree for communication- and microprocessor-techniques from the Fachhochschule Gießen-Friedberg in 1984. He joined the bedea Berkenhoff & Drebes GmbH in 1985, where he is responsible for the development and design communication cables and the RF-laboratory. Bernhard is a member of several national and international standardisation committees, e.g. in IEC TC46/WG5, screening effectiveness.