Measuring the EMC on RF-connectors and connecting hardware. Tube in tube test procedure

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Abstract

Although customers require the Screening attenuation as measure of the screening effectiveness, on short elements like connectors or short cable assemblies one can measure only the Transfer impedance up to the GHz range.

With the new "Tube in tube" test procedure the cut-off frequency between the Transfer impedance and the Screening attenuation can be moved to lower frequency ranges.

The new test procedure offers a wide frequency range from a few kHz up to and above 3 GHz with a high dynamic range down to 125 dB with high reproducibility. Sample preparing is fast and easy.

Due to the closed test set-up, the procedure is insensitive against outer EMC disturbances.

The test procedure is under consideration at IEC TC46/WG 5, Screening effectiveness, as IEC SC 46A/657/CD.

Keywords: Transfer impedance; Screening attenuation; Coupling attenuation; Tube in tube method; Triaxial method

1. Introduction

Due to the increasing use of all kind of electric or electronic equipment, the electromagnetic pollution increases. To reduce this electromagnetic pollution, all components of a system, especially the connecting cables and the connectors respectively the assemblies shall be screened.

Although customers require the Screening attenuation as measure of the screening effectiveness of cables and connectors, on short elements like connectors or short cable assemblies one can measure only the Transfer impedance up to the GHz range.

The following report gives the physical basics of EMC measurements on coaxial and balanced RF-connectors, a brief description of an enhanced test procedure as well as different comparable test results.

2. Physical basics

2.1 Surface Transfer Impedance Z_T

The surface transfer impedance Z_T [Ω] of an electrically short screen is defined as the quotient of the longitudinal voltage induced to the inner circuit by the current fed into the outer circuit or vice versa.

in case of cables, Z_T of an electrically short cable screen is expressed in Milli-ohms per length [mΩ/m] or in decibels in relation to 1Ω.

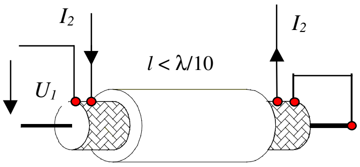

Figure 1- Definition of Z_T

$$Z_T = \frac{U_1}{I_2 \cdot l} \qquad \text{m}\Omega/\text{m} \tag{1a}$$

$$Z_T \ \text{dB}(\Omega) = +20 \cdot \log_{10}\left(\frac{|Z_T|}{1\Omega}\right) \tag{1b}$$

In case of single units like connectors or connecting hardware, the Transfer impedance is expressed as the Transfer impedance of the unit.

2.2 Screening attenuation a_S

At coaxial elements respectively in the common mode of screened balanced elements, 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 is termed screening attenuation a_S.

The screening attenuation a_S of electrically long elements, e.g. coaxial cables is defined as the logarithmic ratio of the power fed into the cable and the radiated maximum peak power:

$$a_S = 10 \cdot \log_{10}\left(Env\left| \frac{P_{feed}}{P_{rad,\max}} \right| \right) \tag{2}$$

2.3 Coupling attenuation a_C

At screened balanced cables or conductors, the coupling attenuation a_C is the sum of the unbalance attenuation a_U of the pair and the screening attenuation a_S of the screen.

For electrically long devices, i.e. above the cut-off frequency, the coupling attenuation a_C is defined as the logarithmic ratio of the feeding power P_1 and the periodic maximum values of the coupled power $P_{r,max}$ in the outer circuit.

$$a_C = 10 \cdot \log_{10}\left(Env\left| \frac{P_{feed}}{P_{r,\max}} \right| \right) \tag{3}$$

2.4 Coupling transfer function

The coupling transfer function $T_{n,f}$ gives the relation between the Screening attenuation a_S and the Transfer impedance Z_T of a screened element like a coaxial cable or a coaxial connector (n = near end, f = far end). In the lower frequency range, where the samples are electrically short, the Transfer impedance Z_T can be measured up to the cut-off frequencies $f_{cn,f}$. Above these cut off frequencies $f_{cn,f}$ in the range of wave propagation, the Screening attenuation a_S is the measure of screening effectiveness. In case of cables, the cut-off frequencies $f_{cn,f}$ may be moved towards higher or lower frequencies by variable length of the cable under test.

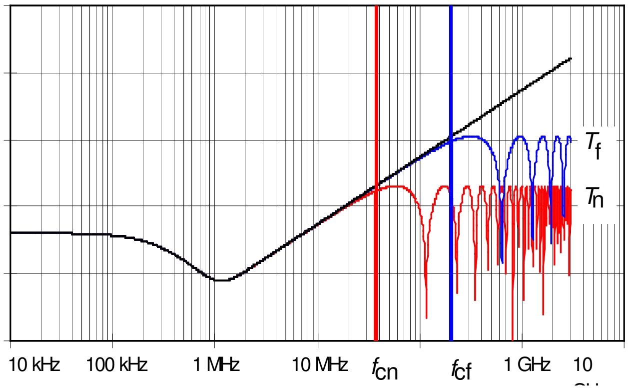

Figure 2 - Calculated Coupling transfer function

2.1 Relationship between length and Screening measurements

The relationship between the effective coupling length of the device under test and the electrical wave length is important for the characteristic curve of the screening measurements. In the frequency range of electrically short coupling lengths, the measured screening effectiveness decreases with increasing length. Therefore it is necessary to define the related length. In case of cables, the measured value is related to 1 m by dividing the measured value by the length under test and the value is given in Milli-Ohms per meter [mΩ/m]. In case of fixed elements like connectors or connecting hardware, the measured value is the value of the unit and will not be related to length. When measuring connectors or connecting hardware, care should be taken with connecting cables and contact resistance's, because they add to the test result.

With electrically long lengths respectively in the range of wave propagation, the Screening attenuation formed by the maximum envelope curve is the measure of the screening effectiveness. Therefore the Screening attenuation is defined only at high frequencies, above the cut-off frequencies.

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 samples:

$$f_c \cdot l \geq \frac{c_0}{\pi \cdot \left| \sqrt{\varepsilon_{r1}} \pm \sqrt{\varepsilon_{r2}} \right|} \qquad (4)$$

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

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

Above the cut-off frequency they are considered to be electrically long.

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

But customers and users of RF connectors and assemblies like to have the Screening attenuation also in the MHz range, because it is more illustrative than the Transfer impedance and can be used for direct calculation of emission and radiation.

3. Tube in tube procedure

The problem can be solved by using the Tube in tube procedure, based on the shielded screening attenuation test set-up according IEC 62153-4-4 (triaxial method). By extending the electrical short 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.

The Tube in tube procedure allows the measurement of the connector (and its mated adapter) together with its connecting cables. 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 the cable and the connector under test. This measurement reproduces the practical application of a connector, the measurement of the naked connector without connecting cable is worthless.

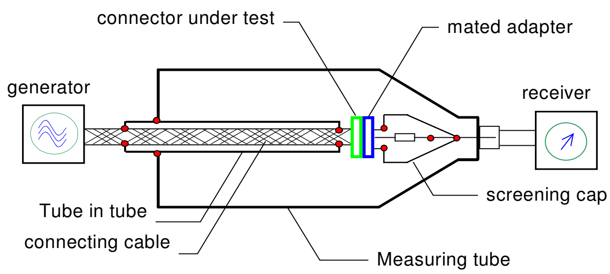

Figure 3 – Principle test set-up for measuring the Screening attenuation of a connector with the tube in tube procedure

3.1 Procedure

The connector respectively the assembly under test is connected to the connecting cable and mounted together with the RF-tight extension tube into the measuring tube. The connector under test is connected to its mating connector in the test head and is fed via the connecting cable with RF energy by the generator.

In case of coaxial connectors, the mating connector is matched with its characteristic impedance. In case of screened balanced or multiconductor cables, the pair under test is matched with a symmetrical/asymmetrical load (see figure 4b). In this way, the Transfer impedance as well as the Screening and the Coupling attenuation of the pair under test may be measured with one test set-up.

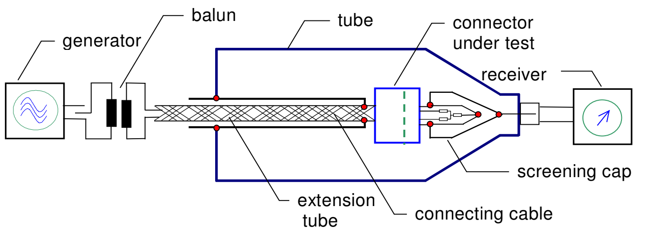

Figure 4a – Principle test set-up for measuring the coupling attenuation of screened balanced or multipin connectors

With the test set-up according to figure 4a, one can measure the Coupling attenuation a_C, when the device under test (DUT) is fed in the differential mode as well as the Screening attenuation a_S, when the DUT is fed in the common mode. The difference between the measurement of the Screening attenuation a_S and the measurement of the Coupling attenuation a_C is the Unbalance attenuation a_U.

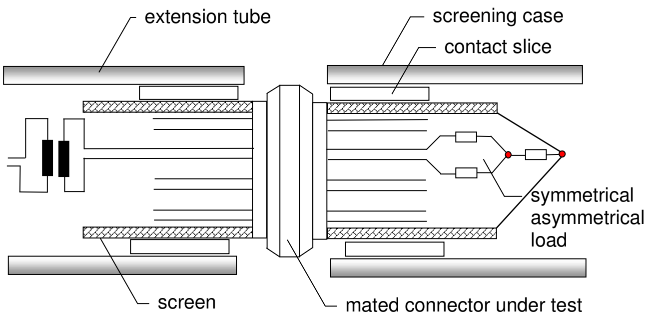

Figure 4b – Principle preparation of balanced or multiconductor connectors for coupling attenuation

The connector under test forms together with the connecting cable and the Tube in tube the inner system, where the electrical short connector is enlarged by the RF-tight Tube in tube. The outer system is formed by the outer conductor of the connector under test, enlarged by the Tube in tube and the measuring tube.

The energy, which couples from the inner system into the outer system travels in both directions. At the short circuit at the near end it will be reflected, so that at the far end the superimposition of both waves can be measured. The logarithmic ratio of the feeding voltage to the measured voltage at the far end is the measure of the Screening attenuation respectively the Coupling attenuation.

With the same test set-up also the Transfer impedance may be measured with only one sample preparing.

During the measurement, the connector under test is connected to is mating part. It is not possible to separate the influence of the device under test from its mating part or to make a calibration of the mating part alone.

Therefore the type of the mating connector should be reported in the test report. Different mating parts or mating parts from different manufacturers may lead to different test results.

The sensitivity of the system depends on the RF-tightness of the Tube in tube and the connection technique. The sensitivity respectively the ground floor of the system may be determined while measuring a semi rigid cable instead of a connector. With the CoMeT system a sensitivity of >125 dB up to 3 GHz was measured.

4. Measurements 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).

For the calculation, the sample under test has been divided into two parts, the extension tube and the cable piece. Thus the transfer impedance and capacitive coupling impedance of extension tube is neglected. The second section is the cable piece under test with the parameters of table 1.

The comparison of the simulation (Fig. 5a, 6a) with the measurement results (Fig. 5b, 6b) 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.

DC resistance	8 mΩ/m
magnetic coupling	0.6 mH/m
capacitive coupling	0.02 pF/m
impedance:	75 Ω
dielectric permittivity	1.35

Table 1- Parameters of the cable under test

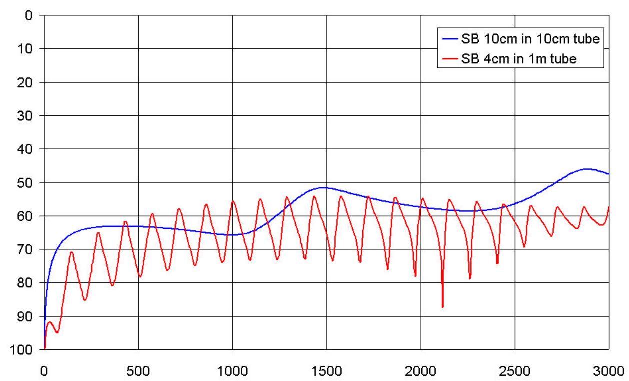

Figure 5a - Simulation, lin. frequency scale

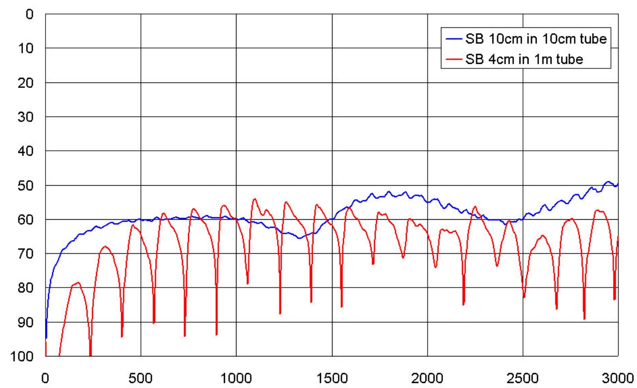

Figure 5b - Measurement, lin. frequency scale

The 10 cm 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.

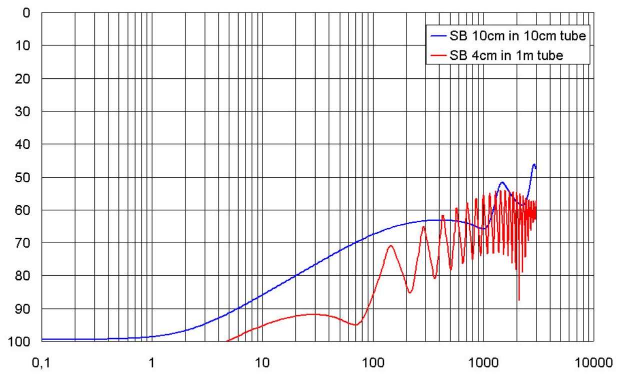

Figure 6a - Simulation, log. frequency scale

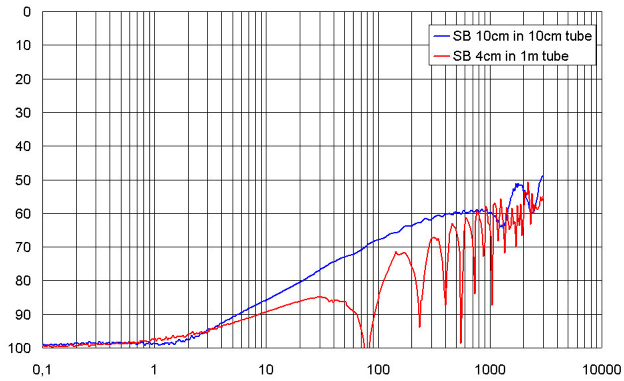

Figure 6b - Measurement, log. frequency scale

One characteristic of an electrically long object is also, that the maximum coupled power is independent of the sample length, (see envelope curve of figure 5a and b, single braid 4cm in 1m tube above 590 MHz).

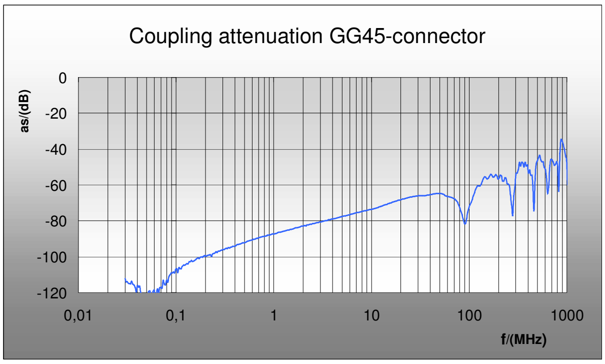

Figure 7 – Measurement of the coupling attenuation of a GG45 connector

Figure 7 shows the measurement of the coupling attenuation of a GG45 connector with the tube in tube procedure with 1m extension tube.

5. Influence of contact resistances

Contact resistances between the feeding cable and the extension tube respectively the screening case in the test head may influence the test result. Contacs in the test set-up shall be prepared carefully with low resistance respectively with low impedance. Contacts shall be achieved over the complete circumference of the screen. Critical contacs are shown in figure B2.

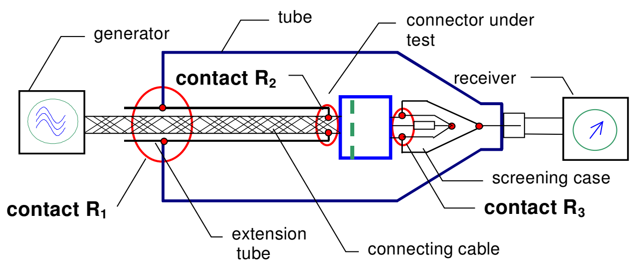

Figure 8 – Contact resistances of the test set-up

The equivalent circuit of the complete test set-up including the contact resistances is given in figure 9. The test set-up shall be designed such, that contact resistances of the extension tube are in series with the input impedance of the receiver and the contact resistance of the screening case including the matching load of the DUT is in series with the generator.

In this case, contact resistances of a few milli-Ohms in series with the 50 Ohms input resistance of the generator respectively the output impedance receiver are negligible.

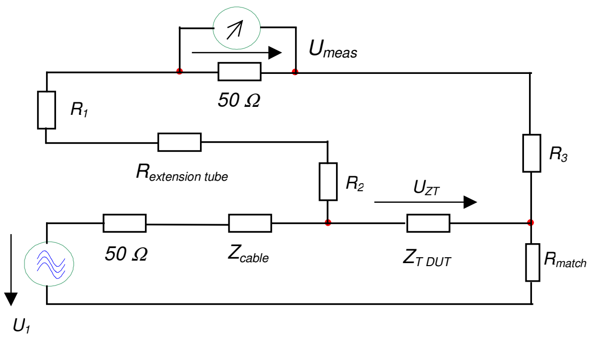

Figure 9 – Equivalent circuit of the test set-up with contact resistances

If contact resistances are in series with the Transfer impedance of the DUT, they will influence the result considerably.

6. Measuring of connecting hardware

A further development of the triaxial test set-up respectively the CoMeT-system is the measuring of multipin connectors and connecting hardware, e.g. for CATV applications and Data transmission networks.

The triaxial test set-up, combined with the tube in tube system is enlarged by a housing or a chamber which is able to take up the sample under test.

First measurements have been achieved and show encouraging results. One problem of the enlarged housing may be, that the cut off frequency of TEM waves will be moved towards lower frequencies. The procedure is under study at IEC TC 46/WG5.

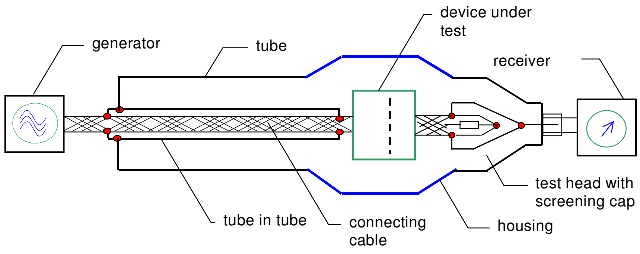

Figure 10 – Principle test set-up for measuring the Screening attenuation of connecting hardware with the Tube in tube procedure

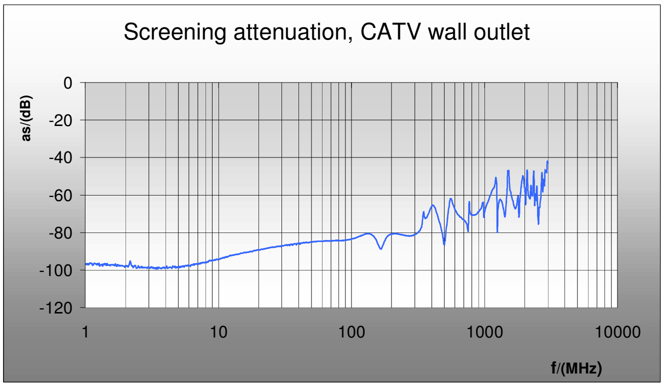

Figure 11 – Screening attenuation of a CATV-wall outlet with 0,5m Tube in tube and housing

7. Conclusions

Customers and users of RF cables, cable assemblies and connectors ask more often for Screening effectiveness values in decibels (dB) instead of Transfer impedance values in mΩ respectively mΩ/m.

The new Tube in tube method reply to that need since it offers a simple and reliable method to measure the Screening attenuation or the Coupling attenuation in dB of connectors and cable assemblies instead of the Transfer impedance also in the lower frequency range.

The method is an extension of the Shielded screening attenuation test set-up according IEC 62153-4-4 (triaxial method) and is under consideration at IEC TC46/WG 5, Screening effectiveness, as IEC SC 46A/657/CD.

With one test set-up one can measure both, the Transfer impedance at the lower frequency range as well as Screening attenuation or the Coupling attenuation in the higher frequency range with only one sample preparing.

A sensitivity respectively a noise floor of >125 dB up to 3 GHz was measured with the Tube in tube system.

A further development is the measuring of multipin connectors and connecting hardware with the Tube in tube procedure and an additional housing.

8. References

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9. Author

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He joined the manufacturer of communication cables *bedea* Berkenhoff & Drebes GmbH in 1985, where he is responsible for the research and the development of communication cables and the RF- and EMC laboratories.

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