EMC of SPE Cables, Connectors and Assemblies – Simulation and Measurement

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Abstract

The design of screened and unscreened single-pair Ethernet cables (SPE cables) intended for a specific application (10Base-T1, 100Base-T1, 1000Base-T1) was investigated in terms of its shielding characteristics. The cable and the test setup, which was intended for later evaluation, were modelled as a digital twin in a 3D simulation program for electromagnetic waves.

By modelling the measurement setup in accordance with the IEC 62153-4-7 standard, it was possible to determine the required characteristics of radiation behaviour and balance in accordance with the relevant standards and to compare them with the required limits.

In addition to analysing the behaviour of the cable with nominal dimensions, a tolerance analysis was carried out based on the permissible electrical tolerances. By visualising the electrical fields, the causes of the measured behaviour could be identified.

Once a prototype had been made, the characteristics of the SPE cable were measured in the laboratory using the triaxial method. The result of the measurement was between the simulated values of the nominal and the worst case geometry. This confirmed the simulated screening behaviour.

Keywords: Single Pair Ethernet; SPE; EMC; Coupling Attenuation; Low frequency coupling attenuation; Screening attenuation; LFCA: Simulation; Triaxial Test Procedure

1. Introduction

Single Pair Ethernet (SPE) technology, based on transmission standards according to IEEE 802.3cg, is being implemented at various applications, e.g. in new generations of automobiles, where it can replace CAN and other bus systems. In the industrial sector, SPE offers an alternative to existing fieldbus systems.

In SPE applications, higher symmetries and coupling attenuations are required for SPE cabling systems compared to the classical Ethernet environment.

The coupling attenuation a_C of SPE cables, connectors and assemblies as measure of their EMC behaviour can be measured according to IEC 62153-4-7 and, if necessary, optimised step by step. However, this requires several complex sample designs. Instead of several sample designs, appropriate 3D electromagnetic simulations of the performance and EMC of SPE cables during the development process will save time and money.

Both the simulation and the verification/measurement of the EMC performance on the finished connector or cable should be carried out using the same method, in this case the triaxial method according to IEC 62153-4-7.

2. SPE Cables and Connectors

The following table gives an overview of SPE standards for cables and connectors describing the transmission characteristics and the requirements for unbalance attenuation (symmetry) and coupling attenuation.

Table 1. SPE cable and connector standards

IEC Standards	Description
	Multicore and symmetrical pair/quad cables for digital communications
61156-11	Part 11: Symmetrical single pair cables with transmission characteristics up to 1,25 GHz - Horizontal floor wiring - Sectional specification
61156-12	Part 12: Symmetrical single pair cables with transmission characteristics up to 1,25 GHz - Work area wiring - Sectional specification
61156-13	Part 13: Symmetrical single pair cables with transmission characteristics up to 20 MHz - Horizontal floor wiring - Sectional specification
61156-14	Part 14: Symmetrical single pair cables with transmission characteristics up to 20 MHz - Work area wiring - Sectional specification
63171 Series	Connectors for electrical and electronic equipment - Shielded or unshielded free and fixed connectors for balanced single-pair data transmission with current-carrying capacity - General requirements and tests

3. Simulation and Analysis

3.1 Motivation

a) The realistic presentation of quantitative results such as screening attenuation a_S, coupling attenuation a_C and transfer impedance Z_T, depending on whether shielded or unshielded systems are considered. It shall be assessed whether the design meets the requirements of the application with the existing limits for the above parameters.

b) Visualisation of interference points and areas where shielding is inadequate. This input is particularly important to the designer so that the screening characteristics can be improved to meet the required limits.

3.2 Procedure

A typical approach is to simulate the connector or the assembly and the measurement environment in a 3D electromagnetic simulation programme, see Figure 1.

The CAD data of the connector design form the basis for the simulation of the connector. These still have to be modified in order to achieve a realistic contact of the individual screening parts. As the performance of the simulation programs increases, they are also able to incorporate effects from complex surface coatings, surface roughness, etc. into the calculations.

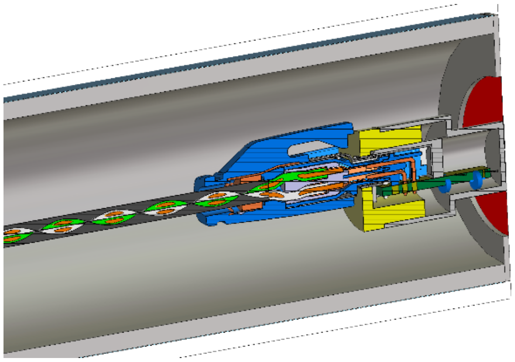

Figure 1. Principal model of an SPE Connector with Cable in Triaxial Test setup

The simulation environment realistically simulates the essential characteristics of the measurement environment to account for their influence on the results.

In the simulation environment, the essential properties of the measurement environment are realistically simulated in order to take into account their influence on the results.

In this case it is the length and internal diameter of the measurement tube. The connection of the test leads to the vector network analyser (VNA) etc. can then be simplified, e.g. the calibration plane of the VNA can be represented in a simplified way by coaxial waveguides. Figure 2 shows thetriaxial test setup using an SPE connector.

Depending on the method chosen, the simulation is performed in the time domain, e.g. by using the Finite Integration Technique (FIT) method with subsequent transformation into the frequency domain, or directly in the frequency domain by solving the linear system of Maxwell's equations using an iterative or direct solution algorithm for each frequency point considered [6].

3.3 Analyses

As a measurement using a vector network analyser (VNA), S-parameters are obtained with both approaches. Using the appropriate relationships S-parameters are incorporated into parameters such as screening attenuation a_S or coupling attenuation a_C

Figure 2. Triaxial test setup with an SPE Connector

The advantage of simulation is that it can be used to visualise processes within the objects being analysed, such as connectors, cables or even the entire test setup. This can be achieved by analysing the electric and magnetic field distributions in the time and frequency domain and can provide information about weak points in the shielding concept or in the symmetry of the components.

A further advantage of simulation is that, in a standardised arrangement, reliable values for the EMC criteria transfer impedance Z_T, screening attenuation a_S and coupling attenuation a_C can be determined for the components at a very early stage of development, thus enabling a fast, efficient and cost-optimised design.

3.4 Unbalance attenuation

The unbalance attenuation a_U of a balanced cable describes in a logarithmic ratio how much power is coupled over from the differential mode to the common mode system (or vice versa). It is the logarithmic ratio of the power fed in the differential mode P_{diff} to the power coupled over into common-mode P_{com}.

3.5 Coupling attenuation

The coupling attenuation a_C is a measure of the screening behaviour respectively the EMC of e.g. balanced cables connectors and assemblies and takes into account both the effect of the screening attenuation a_S of the screen (if present) and the effect of the unbalance attenuation a_U of the pair.

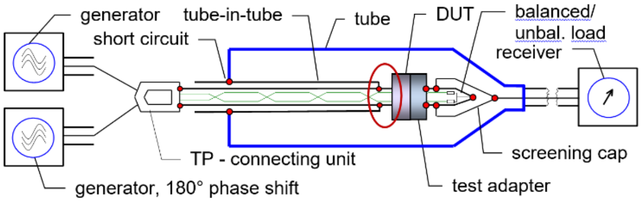

Figure 3. Coupling attenuation of a Connector according to IEC 62153-4-7

The amendment IEC 62153-4-9Amd1 describes the measurement of coupling attenuation at low frequencies, “Low Frequency Coupling Attenuation” (LFCA) on balanced cables from 100 kHz upwards. The test setup is the same as the setup for the measurement of coupling attenuation at higher frequencies.

This allows the coupling attenuation of SPE connectors and SPE connecting cables to be measured over a wide frequency range from 100 kHz up to and beyond 2 GHz.

At single screened balanced cables (SPE cables) and at low frequencies, the coupling attenuation a_C can be considered at first approach as the sum of the unbalance attenuation a_U of the pair and the screening attenuation a_S of the screen, [2], [3].

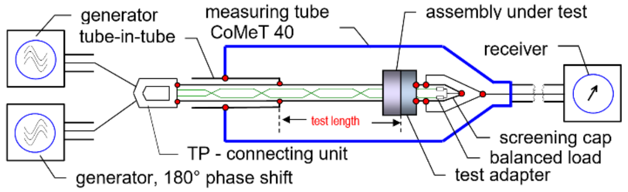

Figure 4. Coupling attenuation of a Cable assembly according to IEC 62153-4-7

3.6 Test adapter

The screening effectiveness of an individual connector or assembly can be measured with suitable test adapters only.

Test adapters may limit the sensitivity of the test setup. Therefore, test laboratories shall conduct qualification tests with their existing adapter hardware to establish the noise floor(s) for the entire test system. Should the qualification test require connecting cables, these shall have a tubular outer conductor. Measurements are considered as 'valid' as long as the measured value is at least 6 dB above the sensitivity established.

Test adapters shall be assembled in agreement between the manufacturer (or the supplier) of the device under test and the test laboratory.

4. Comparison between simulation and measurement,

4.1 Foil screened cable

A cable with the following structure was selected as the object for demonstrating the procedure.

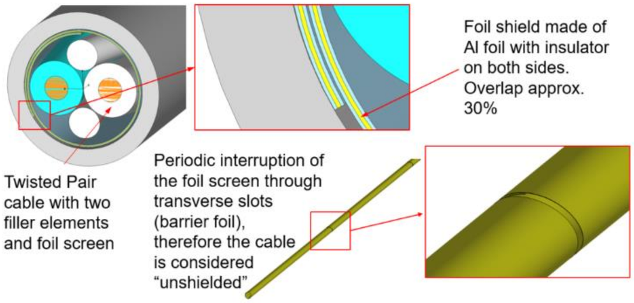

Figure 5. Cross-section of an SPE Cable with Foil screen

The special feature of this cable construction is that the screen is periodically interrupted by transverse slots. Cables equipped with such “barrier foils” can meet high requirements for cable-to-cable crosstalk (alien crosstalk) and at the same time ensure that no unwanted interference current can flow in this barrier foil. Nevertheless, such cables can be considered as unshielded.

In addition to simulating the ideal state of the cable, a worst-case consideration of tolerances should also be carried out to show how the electrical properties under consideration may be affected (electrical properties change).

The variation of the cable characteristics is represented by 2 parameters:

- The diameter of the cores D1, D2 varies by ±1.4%, derived from the permissible variation of the ohmic resistance (± 2%) of a copper core assuming that the resistivity of the copper is constant.
- The dielectric constant of the core insulation ε_{r1a}, ε_{r1b} varies by ± 0.05. This is an assumption due to variations, e.g. due to different colouring.

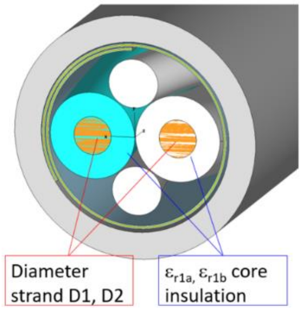

Figure 6. Depiction of variations in an SPE cable

The simulation environment simulates the measurement setup, a measurement tube with an inside diameter of 40mm.

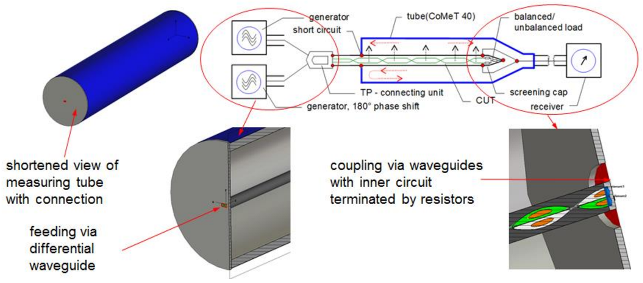

Figure 7. Model of Triaxial Test Set-up in Simulation environment

The results of the simulation and the measurement are shown in the following two diagrams.

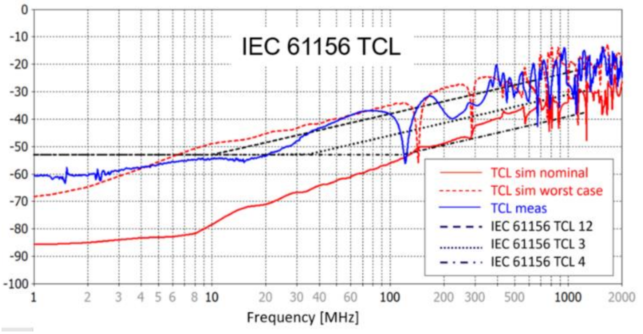

Figure 8. Transfer Conversion Loss (TCL) from Simulation and Measurement

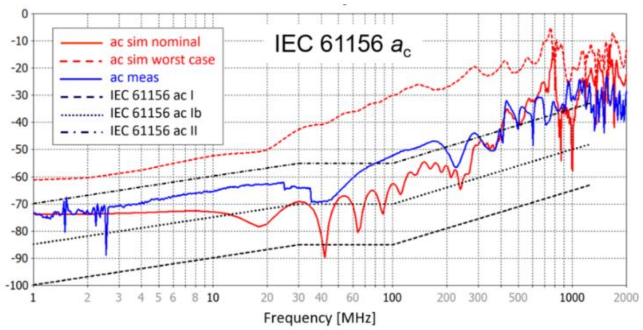

Figure 9. Coupling attenuation a_C from Simulation and Measurement

Simulated and measured:

Transverse Conversion Loss (TCL) measure of the balance of the cable structure. TCL can also be referred to as Scd11.

The coupling attenuation a_C, which is calculated by converting the S-parameters Ssd21:

$$a_C = -S_{sd21} + 10log_{10}\left|\frac{2 \cdot Z_S}{Z_0}\right|$$

$$a_C = -S_{sd21} + 7{,}78\ dB$$

where

S_{sd21}	logarithmic value (in dB) of the forward scattering parameter for the transmission. The device under test was excited in differential mode, the transmitted power is received in single-ended mode,
Z_S	normalised value of a characteristic impedance of the cable environment, , $Z_S = 150\ \Omega$,
Z_0	System impedance, $Z_0 = 50\ \Omega$

Both variables were measured on a cable sample and calculated using simulations with nominal and worst case parameters. In addition, the IEC 61156 limits are shown in the graphs to help categorise the results. Depending on the class, these apply in a frequency range from 1 MHz to 20 MHz, 600 MHz or 1250 MHz.

The plots show that the measured values for both TCL and a_C are only below the limits of the first cable class in the range up to 20 MHz. Both measured curves lie between the simulated values with the ideal nominal parameters and the worst-case parameters.

In order to better understand the reason for this behaviour, the distribution of the electric field is considered. In the associated simulation, a step signal with a rise time of 0.7 ns, corresponding to the maximum frequency of 1250 MHz, is fed into the differential port of the assembly and travels through the cable to the matching resistor. Observation of the E-field over time shows particularly clearly the points at which fields emerge from the cable.

The focus here is on the overlapping foil and the cross slots. In order to analyse the behaviour, it is necessary to zoom in very sharply on the field strength display. Here the field strength inside the cable, where the useful signal flows, is around 10000 V/m, very high compared to the maximum of 10 V/m on the display, and therefore this area is constantly coloured red.

Figure 10. Amount of Electric field transverse to cable and Emerge from Screening foil

The analysis of the overlapping screen shows only a very small leakage of the electric field.

The second analysis shows the representation of the electric fields at a specific point in time during signal propagation in a longitudinal section through the cable and measuring tube.

It is easy to see that the fields emerge at the points where the transverse slots are in the shield.

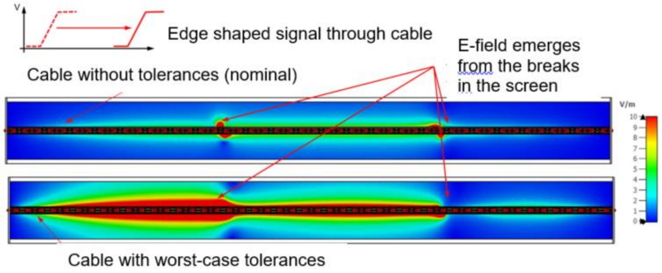

Figure 11. Amount of Electric field (longitudinal) and Emerge from transverse Slots

The same scaling of the representation also makes it clear that this is the main cause of the limited shielding effect, in contrast to the overlapped shield. It is also clear that the lower unbalance attenuation a_U of the cable means that in the worst case the field that emerges is significantly larger.

4.2 Application to double shielded SPE cable

To demonstrate that this method can also be applied to cables with the lowest coupling attenuation (well screened), a double-shielded SPE cable was analysed and simulated.

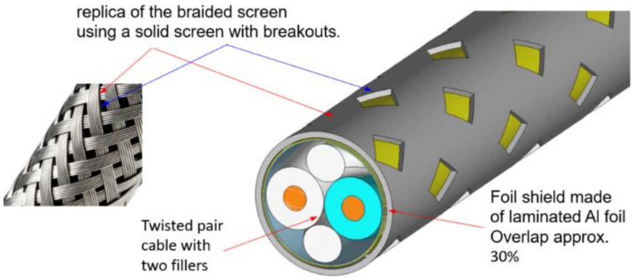

Figure 12. Cross-section of an SPE cable with Foil and Braid screen

The results of simulation and measurement of the coupling attenuation are shown in the following diagram:

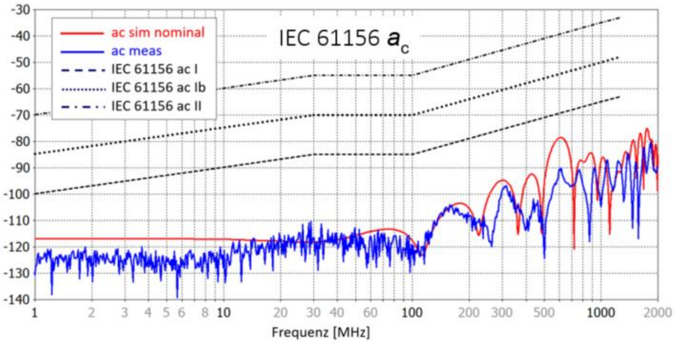

Figure 13. Coupling attenuation a_C from Simulation and Measurement

The diagram shows that the measured values for a_C are below the limits of the best cable class throughout the frequency range. The measured curve agrees surprisingly well with the simulated behaviour of the cable.

Again, the electric field should be analysed using the same method. As the radiation is much weaker, the fields must be scaled to a maximum of 1V/m.

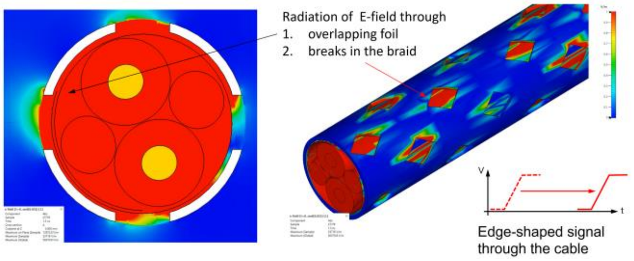

Figure 14. Amount of the electric field

The analysis shows very clearly how the E-field first exits through the overlapping foil (left) and then through the free areas of the braided screen. It should be noted that these results were generated by a complete 3D simulation and not by adapted behaviour models to replicate shield properties.

5. Summary and conclusion

In the previous sections, the analysis of balance (symmetry) and screening behaviour of SPE cables and connectors was carried out using simulation methods, followed by verification by measurement.

For both methods, simulation and measurement, the triaxial method was chosen as the identical procedure for both methods to ensure comparability of results.

A further advantage lies in the fact that, with the aid of simulation in a standardised arrangement, reliable values for the analysed EMC criteria can be determined at a very early stage of development, thus enabling a fast, efficient and cost-optimised design.

The additional visualisation of interference points and areas where screening is not sufficient is the most important input for a design team to make targeted modifications to a design.

The procedure described in this article shows the ideal interplay between simulation and EMC measurement techniques at various stages of the product design process for SPE connectors, cables and assemblies.

The final verification of the simulation results with the triaxial method then allows important conclusions to be drawn, in addition to confirming compliance with the limits, providing important conclusions about the quality of the simulation and increasing confidence in the methodology presented.

It has also been shown that even cables with very good screening properties can be modelled with a high degree of accuracy in a full 3D simulation.

We are pleased, but not surprised, that comparison between simulation and mesasurement shows excellent agreement.

6. References

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7. Authors

After having successfully completed his apprenticeship as Radio- and TV Technician in 1979, **Ralf Damm** received his diploma in Telecommu-nications and Microprocessor-Technologies at FH Giessen-Friedberg. In 1987 he joined bda connectivity GmbH (former Berkenhoff & Drebes GmbH), working with electronic development of fibre optic components. In 2018 the bedea cable division has changed to bda connectivity GmbH.Later he was responsible for sales and supports for data communication networks and structured cabling. He is now member of the bda cable R&D department and responsible for sales & technical support of the CoMeT product line.

Dr. Thomas Gneiting is the founder and managing director of AdMOS, a company that focuses on modeling, simulation and design support. He studied at the Esslingen University of Applied Sciences and worked as a development engineer for digital controls at FESTO in Esslingen. After gaining practical experience in industry, he worked for 4 years in a joint research project at the Esslingen University of Applied Sciences and the Brunel University of West London, where he received his doctorate in 1997.

In the same year Thomas Gneiting founded the company AdMOS in Frickenhausen near Stuttgart. The focus of Dr. Gneiting lies in supporting customers in the design of connectors by means of electromagnetic simulation with subsequent verification.

Dave Hess, dba CORD DATA, currently works as a subject matter expert facilitating international standards development for connectivity technology, particularly in the area of shielded pair differential cabling.

He has worked for more than 40 years in both fields of electronic and photonic wired data communication connectivity and participates on the standards committees for physical interface and cabling standards: ISO, IEC, IEEE, INCITS, EIA, TIA, CTA, and ANSI.

Dave has been project leader for over 20 international standards. He received IEC 1906 awards for technical contributions in 2011 and 2014. He holds a B.S. degree in Mathematics from Pennsylvania State University and is a life member of IEEE.

Among other standadisation activities, he has served as Secretary of IEC TC 46; Communication cables and as Convenor of IEC TC 46/WG9, Cable assemblies.

Bernhard Mund received his apprenticeship diploma as Broadcast- and TV Technician in 1971 in Marburg, Germany and his diploma in Telecommuni-cations- and Micro processor-Technologies 1984 from FH Giessen-Friedberg, Germany.

Bernhard Mund has been in the cable business since 1985 when he joined the cable manufacturer bda connectivity GmbH, (former bedea Berkenhoff & Drebes GmbH) in Asslar, Germany. Formerly being R&D Manager of communication cables, he is now member of the RF- and EMC test engineering department responsible for R&D of the CoMeT test system. Besides his work for bda, Bernhard Mund has been contributing for more than 38 years in national and international standardization organizations.

He has served as Chairman of the German committee UK 412.3, Koaxialkabel as well as of Secretary of IEC SC 46A, Coaxial cables and of CLC SC 46XA, Coaxial cables. Among further standardization activities in different committees and working groups he is member of IEC TC 46/WG5, Test methods for electromagnetic compatibility (EMC) and of IEC TC 46/WG9, Cable assemblies.

Dipl.-Ing. (TH) **Ralf Tillmanns** studied communication technology at the Technical University of Duisburg.

He has more than 20 years of experience in network technology. Since 2000, his focus has been on the areas of development and measurement technology for data connectors and IT cabling infrastructure.

In addition, Ralf Tillmanns is active in various national and international standardization committees. Among others in the following committees: German speaker IEC TC46; IEC TC 46/ WG9; IEC TC 46/SC46C WG7; IEC SC48B WG3; WG5; SC65C.