Coupling attenuation & Burst test on balanced cables and cabling systems

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Abstract

The term SPE describes the new Single Pair Ethernet technology based on transmission standards according to IEEE 802.3cg. In addition to good transmission properties, high electromagnetic compatibility (EMC) from 100 kHz upwards is required for SPE cables, SPE connectors and SPE cabling systems.

Evidence of a correspondingly high EMC (emission and ingress) of balanced cables and components can be provided by measuring the coupling attenuation (CA) and the low frequency coupling attenuation (LFCA) according to IEC 62153-4-7 or IEC 62153-4-9. Alternatively, the interference immunity of SPE components can be determined by using the burst test according to IEC 61000-4-4 and evaluated according to IEC 61000-4-6.

The following report describes the measurement of coupling attenuation and burst test on SPE cables, components and systems. Measurement results and the correlation between both procedures are considered and discussed.

A mathematical description of the relationship between both test procedures is given.

Keywords: EMC, Coupling attenuation, Single pair ethernet, SPE, Burst test, Unbalance attenuation, Cable assembly, SPE connector, Correlation, Mode conversion, MICE table

1. Screening Parameters

1.1 General

The physical principles for measuring transfer impedance and screening or coupling attenuation on cables, connectors and other components using the triaxial method are described in detail in the literature, see [1, 2, 3, 4, 21] among others.

For coaxial cables, connectors and components, the transfer impedance Z_T applies at frequencies up to approx. 30 MHz. From 30 MHz the screening attenuation a_S is the measure of the shielding effect.

For screened balanced cables, connectors and components, the coupling attenuation a_C is the measure of their shielding effectiveness and is largely responsible for the EMC of the systems implemented with it. The coupling attenuation of balanced pairs is proportional to the unbalance attenuation of the balanced pair and the screening attenuation of the screen.

1.2 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}. [1, 2, 3, 4].

$$a_u = 10 \cdot \log\left(P_{diff}/P_{com}\right) \qquad (1)$$

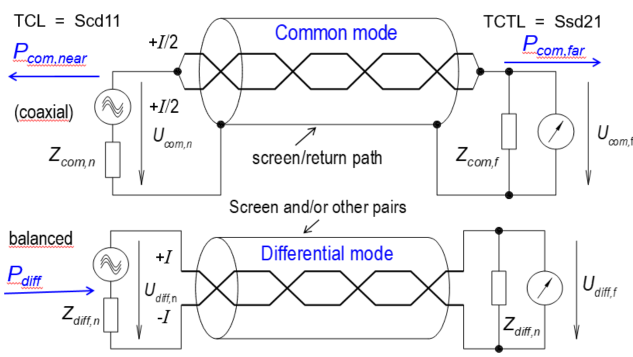


Figure 1 - Common and differential mode of a screened twisted pair (STP)

For low frequencies, the unbalance attenuation decreases with increasing length. With increasing frequency and/or length, the unbalance attenuation - similar to the screening attenuation - asymptotically approaches a limit value (assuming systematic coupling). The unbalance can be determined for both the near end and the far end of a cable, see Figures 2a and 2b [5, 6, 8]

Different conductor resistances, insulation diameters, core capacities, uneven stranding and changing distances between the inner conductor and the shield e.g. can be causes of the asymmetry.

The unbalance attenuation can be measured according to IEC 61156-1 with a multi-port VNA and "virtual balun" function. The unbalance attenuation at the near end is described as Scd11 (TCL) and the unbalance attenuation at the far end is described as Scd21 (TCTL), [3].

The transfer function of the unbalance attenuation of balanced (symmetrical) pairs and the coupling transfer function of screened balanced pairs is described more detailed in [6].

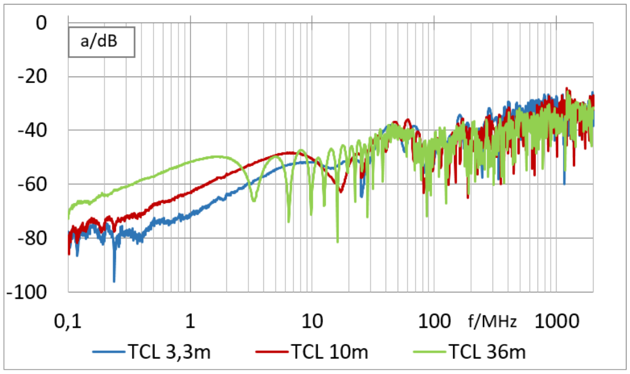


Figure 2a: Unbalance attenuation of a shielded SPE cable at the near end (TCL), different lengths

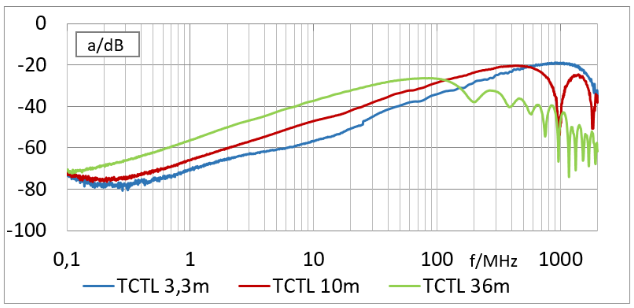


Figure 2b: Unbalance attenuation of a shielded SPE cable at the far end, (TCTL), different lengths

1.3 Screening Attenuation

The screening attenuation a_S of a cable screen is defined as the logarithmic ratio of the power P_1 fed into the matched cable and the maximum peak power $P_{2,max}$ in the matched outer circuit, in a frequency range where the cable is electrical long.

$$a_s = 10\log_{10}\left|\frac{P_1}{P_{2,\max}}\right| \qquad (2)$$

Details of the screening attenuation measurement of cable screens are described in IEC 62153-4-4 [1, 2, 3, 21]. Below the cut off frequency according to IEC 62153-4-4, where the cables are electrical short, length dependence of a_S shall be considered.

2. Measuring the Coupling Attenuation with the Triaxial Method

2.1 General

The coupling attenuation a_C of shielded balanced pairs describes the overall effect against electromagnetic interference (EMI) and takes into account both, the screening effect of the screen and the mode conversion or the unbalance attenuation a_U of the pair.

At a first approach (and at low frequencies) the coupling attenuation a_C of a single screened balanced pair (SPE) can be considered as the addition of the near end unbalance attenuation of the balanced pair and the screening effectiveness of the screen.

The coupling attenuation of screened balanced SPE cables can be measured according to IEC 62153-4-9 using the triaxial method, see Figure 3.

The balanced cable to be tested forms a three-wire system together with the measuring tube, consisting of the balanced pair, the cable shield and the measuring tube.

The balanced pair of the cable under test is fed with a differential 100 Ω signal via two 180° phase-shifted generators. Energy first couples from the differential-mode into the common-mode circuit and then from the common-mode circuit into the measuring tube (the outer circuit). Due to the total reflection at the short circuit at the end close to the generator (the near end), all of the energy coupled into the outer circuit runs to the receiver, [5]. Measurement results of a SPE cable are shown in Figure 4, (raw values).

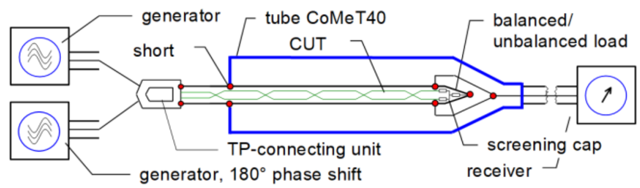


Figure 3: Measurement of the coupling attenuation a_C of a screened balanced SPE cable with multi-port VNA and with virtual balun according to IEC 62153-4-9

The measurement results of balanced cables changes at low frequencies depending on the measurement length. In order to achieve comparable results, a measuring length of 3m for LFCA is required in the IEC standards for SPE cables [25].

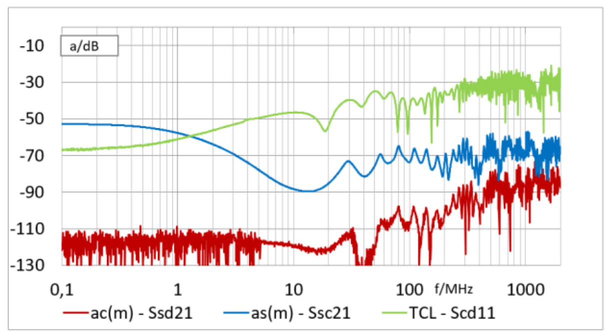


Figure 4: Unbalance attenuation a_U (Scd11, TCL), screening attenuation a_S(m) (Ssc21) and coupling attenuation a_C(m) CA/LFCA (Ssd21) 5m SPE cable, raw values

2.2 Coupling Attenuation at Low Frequencies, LFCA

The lower cut-off frequency to measure coupling attenuation according to IEC 62153-4-9Ed2 is given by:

$$f > \frac{c_0}{2*l*\left|\sqrt{\varepsilon_{r1}}-\sqrt{\varepsilon_{r2}}\right|} \qquad (3)$$

where:

c_0 = velocity of light, l = test length
ε_{r1}, ε_{r2} = dielectric constant of inner and outer circuit

That means, coupling attenuation on screened balanced pairs with manageable length can be measured only from about 30 MHz upwards. A test procedure for the EMC behavior of screened balanced cables at lower frequencies is needed.

The extension of IEC 62153-4-9Amd1 describes the measurement of the coupling attenuation at low frequencies (LFCA) on symmetrical cables from 100 kHz upwards. The measurement set-up is the same as the set-up for measuring the coupling attenuation at higher frequencies, [5]. The LFCA can also be measured analogously for SPE connectors and SPE cable assemblies.

LFCA varies with length. In order to get comparable test results between different test laboratories respectively between different test samples, the same test length shall be applied. For LFCA measurements on balanced cables and connectors, a test length of 3m is recommended.

2.3 SPE connectors

The IEC 62153-4-7Ed3 standard, describes various methods for measuring the coupling attenuation of connectors and ready-made cable asemblies, based on IEC 62153-4-9.

Figures 5a and 5b shows the basic measurement set-up for measuring the coupling attenuation of a screened balanced connector using the tube-in-tube method. An RF-tight tube is inserted into the measuring tube. The inner tube forms a 50 Ω system with the outer tube.

The shielded balanced connection cable is located in the inner tube. For mechanical reasons, the contact between the shield of the connection cable and the inner tube is approx. 3 cm in front of the connector to be tested.

This measures both the connector to be tested and the quality of the connection between the connector and the connection cable. The selected distance between tube-in-tube and the test object should be documented in the test report for comparison measurements.

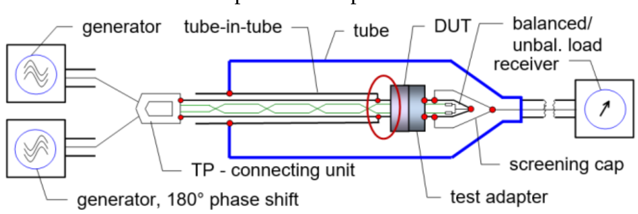


Figure 5a: Measuring CA/LFCA of a connector with tube-in-tube with short piece of connecting cable

Figure 5a shows the measurement CA/LFCA with tube-in-tube and a short piece of connecting cable. In this way the influence of assembling of cable and connector is measured

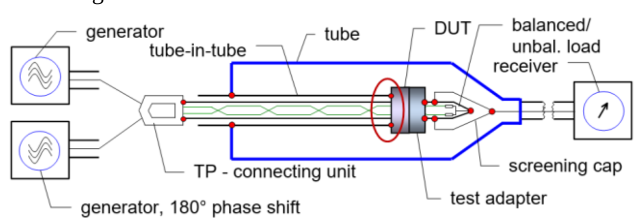


Figure 5b: Measuring CA/LFCA of a connector with tube-in-tube with direct connection

Appropriate test adapters are required for both procedures. As they will influence the test result, they shall be as good as possible.

2.4 Coupling Attenuation of Cable Assemblies

Measuring of coupling attenuation of cable assemblies with tube in tube procedure is shown in Figure 6.

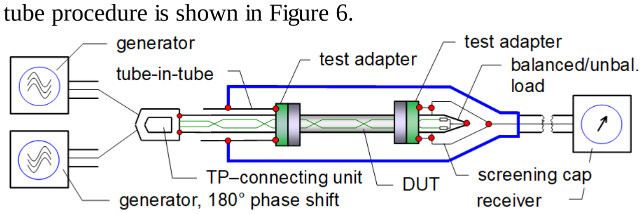


Figure 6: Measuring the coupling attenuation a_C of a balanced assembly with tube-in-tube method according to IEC 62153-4-7 with test adapter

Another option for measuring of paired connectors arrangement is shown in Figure 7. The pair of connectors is placed in the middle of the measuring tube. In contrast to the measurement set-up shown in Figure 6, the contribution of the feed and termination lines is not eliminated by the tube-in-tube application, but is superimposed on the coupling through the connectors.

This arrangement enables the measurement of long SPE cable assemblies (> 3m), splitting them in the middle and plugging them in at the ends.

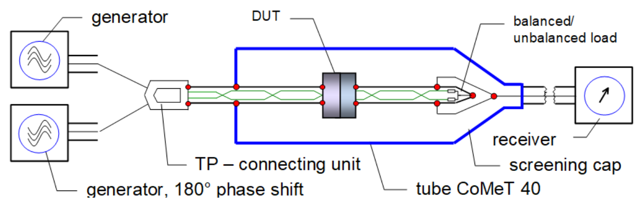


Figure 7: Measuring of CA/LFCA (Scd21) of a pair of SPE connectors in the middle of the tube

2.5 Unscreened Balanced Cables & Connectors

In case of unshielded balanced pairs, the inner system consists of the unshielded DUT fed in differential mode. The outer system is formed by the the common mode of the test object and the measuring tube. Because there is no shield at the unshielded pair, there is no near-end short circuit. The wave towards the near end is not reflected in the tube and travels back to the generators.

Therefore, coupling attenuation of unshielded pairs can be measured at both ends as near end and far end coupling attenuation.

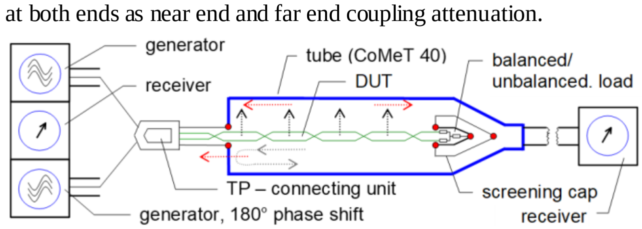


Figure 8: Coupling attenuation of unscreened balanced cables

The wave running back towards the near end in Figure 8 can be measured as S-parameter Scd11; it can be viewed as the near-end coupling attenuation. In the field of cable standardization, the parameter Scd11 is also defined as the near end unbalance attenuation (TCL) of the unshielded pair, [3, 4, 5]. That means, in case of unshielded balanced pairs, the near end coupling attenuation is in principle the same as the near end unbalance attenuation TCL.

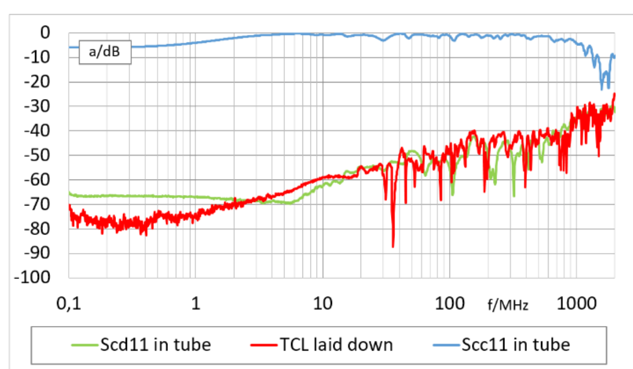


Figure 9: LFCA/CA of an unscreened balanced cable

3. Burst test

3.1 General

Alternatively to the measurement of coupling attenuation, the interference immunity of SPE cables, connectors and components can be measured using the burst test according to IEC 61000-4-4 and evaluated according to IEC 61000-6-1 or /-6-2. IEC 61000-6-2 describes requirements for SPE applications in harsh environments.

Electrical Fast Transient/Burst (EFT/B) are short, repeated pulses of high voltage that typically occur e.g. when motors start or equipment changes state. The pulses can interfere in the frequency range used by Ethernet, which is 1 MHz to 500 MHz. Ethernet cables usually have well-balanced twisted pairs and high levels of screening attenuation to protect from this sort of interference.

3.2 Test Procedure

The repetitive fast transient test according to IEC 61000-4-4 is a test with bursts consisting of a number of fast transients which are coupled into power, control, signal and earth ports of the DUT, see Figure 10. Significant for the test are the high amplitude, the short rise time, the high repetition frequency, and the low energy of the transients [27].

The test is intended to demonstrate the immunity of electrical and electronic equipment when subjected to types of transient disturbances such as those originating from switching transients (interruption of inductive loads, relay contact bounce, etc.) [27].

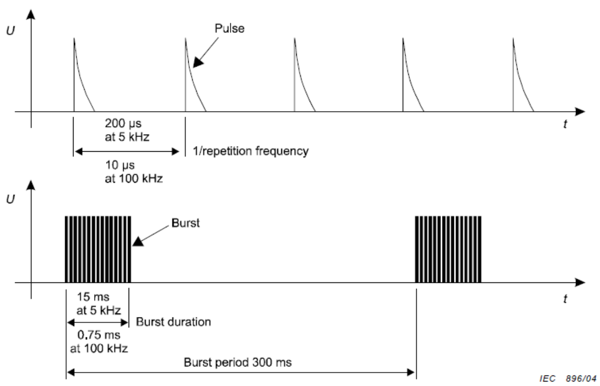


Figure 10 – Burst signal (source: IEC 61000-4-4)

The shape of the burst signal is generated using a burst generator and capacitively coupled into the cabling system with a coupling clamp. At the same time, data packets are transmitted via the cabling system. The IEC 61000-6-2 standard entitled "Electromagnetic compatibility (EMC) Part 6-2: Generic Standards for Immunity for Industrial Areas" describes various performance criteria with defined limit values.

For the fast transient (burst), the limit value for data signal transmission is ± 1 kV with test criterion B. This means that the amplitude of the burst signal is ± 1 kV and data packets may have errors, but operation of the data transmission is still functional, [7].

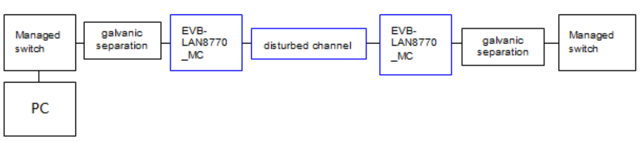


Figure 11: Cabling system for burst test

The test is intended to simulate the effect of a nearby disturbance (e.g., inverter, brush fire, etc.).

The test setup required for the burst test is shown schematically in Figure 11. First, a communication-capable Ethernet network is required for the test. This consists of three network devices, a PC and two Ethernet switches. Data transmission is initiated between these network devices so that data packets pass through the disturbed cabling system.

Since a single-pair Ethernet 100Base-T1 application is being tested, a conversion to the SPE system is required first. This conversion from 100Base-Tx to 100Base-T1 is performed by two evaluation boards.

3.3 Modified Burst Procedure

IEC 61000-4-4, Electrical fast transient/burst immunity test describe the burst test with fixed voltages, depending on the level of tests.

During the modified burst tests in this paper, the burst voltage was increased gradually. The level of the interference signal amplitude, at which the first errors occur in the transmitted data packets, was recorded. The test was carried out in the same setup with shielded and unshielded SPE components.

Figure 12a: Test set-up for burst test

Figure 12b: Test set-up for burst test

4. MICE table

The MICE table according to ISO/IEC 11801-1, subclause 6.2.2 classifies the environment for generic cabling, see Table 1.

The letters in MICE each represent one type of environmental impact – Mechanical, Ingress, Climatic/Chemical and Electromagnetic.

Table 1 – Channel environments

	1	2	3
Mechanical rating	M_1	M_2	M_3
Ingress rating	I_1	I_2	I_3
Climatic rating	C_1	C_2	C_3
Electromagnetic rating	E_1	E_2	E_3

For each of these environmental impacts, there are three classes – 1, 2, and 3 – that represent levels of severity. Class 1 stands for lower impact as for office applications, class 2 for light industry and class 3 for heavy industry environments.

In this paper the electromagnetic rating respectively the MICE requirements for burst test are of interest.

Table 2 – MICE requirements for burst test

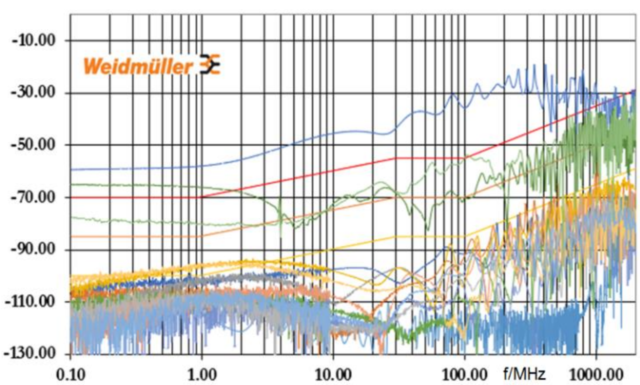
Electromagnetic rating	E_1	E_2	E_3
EFT/B (comms)	500V	500V	1000
	IEC 61000-6-1		IEC 61000-6-2

Table 2 (extract of table 2 of ISO/IEC 11801-1 and of table 6 of ISO/IEC TR 29106) describes the respective electro-magnetic environment and burst test requirements. (EFT = electromagnetic fast transient).

Channel environments may be classified by using any combination of the MICE scheme, e.g. $M_1I_2C_3E_1$.

5. Test Results

Compilation of coupling attenuation of different SPE cables are shown in Figure 13.



------- Coupling attenuation Type I ------- Coupling attenuation Type Ib
-------- Coupling attenuation Type II (IEC 61156)

Figure 13: Coupling attenuation of different SPE cables

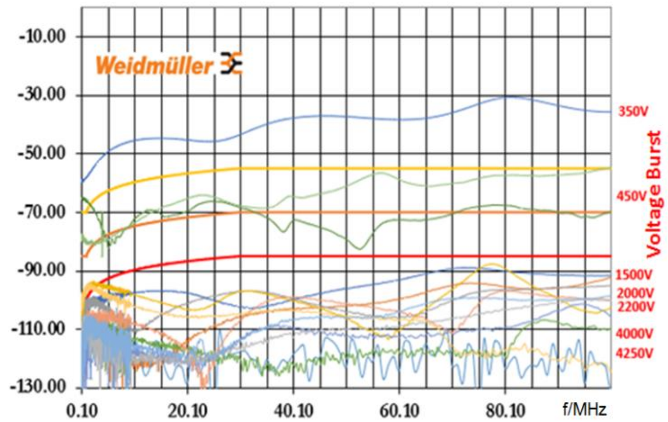
Coupling Attenuation CA and Low Frequency Coupling Attenuation LFCA of different SPE cables was measured with the triaxial test procedure according to IEC 62153-4-9, see Figure 13.

Cables with foil/braid constructions and good unbalance attenuation fulfills Coupling attenuation Type I requirements,

Cables with foil only or with poor unbalance attenuation are in the range of coupling attenuation Type Ib

Unscreened single pairs did not fulfill Coupling attenuation Type II reqiurements of IEC 61156 series.

Correlation between coupling attenuation measurement and Burst test is shown in Figure 14.



------- Coupling attenuation Type II ------- Coupling attenuation Type Ib
-------- Coupling attenuation Type I (IEC 61156)

Figure 14: Correlation between Coupling attenuation and Burst test

Figure 14 shows the coupling attenuation of different SPE cables according to IEC 62153-4-9 up to 100 MHz versus burst test.

The Y-axis on the right shows the burst voltages above which transmission according to IEC 61000-6-2 is no longer possible. The maximum burst voltage is correspondingly higher for cables with high coupling attenuation.

6. Conclusion and Outlook

The coupling attenuation of balanced cables can be measured according to IEC 62153-4-9, connectors, assemblies and components can be measured according to IEC 62153-4-7 using the tube-in-tube method. Based on the supplement to IEC 62153-4-9 Amd1, the coupling attenuation of balanced connectors and assemblies can also be measured at low frequencies from 100 kHz upwards as low frequency coupling attenuation, LFCA.

Alternatively to the measurement of coupling attenuation, the interference immunity of SPE cables, connectors and components can be determined by using the burst test according to IEC 61000-4-4 and evaluated according to IEC 61000-6-1 or /-6-2. This is e.g. a requirement for SPE applications in harsh environments according to the MICE table of ISO/IEC 11801-1.

Although there is no linear relationship between coupling attenuation and burst test, it is shown, that systems with SPE cables with high coupling attenuation can also withstand higher burst voltages.

- only shielded SPE cables meet E_3 requirements,
- unscreened or poor screened SPE cables meet E_1 & E_2 requirements,
- further measurements are necessary,
- a mathematical description of the relationships between coupling attenuation and burst test is in preparation,
- repeated tests with 10 Base-T1 application are in progress.

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9. Authors

After having successfully completed his apprenticeship as Radio- and TV Technician in 1979, **Ralf Damm** received his diploma in Telecommunications 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.

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,. He 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.

Bernhard Mund received his apprenticeship diploma as Broadcast- and TV Technician in 1971 in Marburg, Germany and his diploma in Telecommunications- 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 system. Besides his work for bda, Bernhard Mund has been contributing for more than 38 years in national and international standardi-zation organizations.

He has srved as Chairman of the German committee UK 412.3, Koaxialkbel 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).

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.