Balunless measurement of coupling attenuation of screened balanced cables up to 2 GHz

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Abstract
Coupling attenuation of screened balanced cables describes the overall effect against electromagnetic interference (EMI) taking into account both the effect of the screening and the balance of the pair. The extension of the frequency range of balanced cables up to 2 GHz requires the revision of test procedures for coupling attenuation. Balunless measurements of coupling attenuation on balanced cables up to 2 GHz and above requires a 4-port network analyzer and a respective connection device. Mixed mode S-parameters for a 4-Port network analyzer as well as a connection device are described. The extension of the triaxial test procedure according to IEC 62153-4-9 is discussed. Test results are compared with absorbing clamp procedure according to IEC 62153-4-5.

Keywords: coupling attenuation, screening attenuation, triaxial test procedure, absorbing clamps, unbalance attenuation.

1 Introduction
By implementation of 40 Gbps digital data transmission for applications in data centers, the range in which symmetrical data cables are used in structured cabling now reaches 2 GHz.

The draft standards of IEC 61156-9 [1] and IEC 61156-10 [2], Cables for horizontal floor wiring and cables for work area wiring with transmission characteristics up to 2 GHz, describe data cables up to 2 GHz. They are related to ISO/IEC TR 11801-9901 [3], which specify requirements of cabling (channel) up 2 GHz.

The screening effectiveness of such cables is described among other parameters by the coupling attenuation which takes into account both, the unbalance attenuation of the pair and the screening attenuation of the screen. As test procedure to measure coupling attenuation the standard IEC 62153-4-9, coupling attenuation with the triaxial test procedure, [7] applies.

To measure the coupling attenuation as well as to measure the unbalance attenuation a differential signal is required. This can, for example, be generated using a balun which converts the unbalanced signal of a 50 Ω network analyzer into a balanced signal. Commercial baluns with high performance, however, are available up to about 1.2 GHz only.

Alternatively, a balanced signal may be obtained by using a vector network analyzer (VNA) having two generators with a phase shift of 180°. Another alternative is to measure with a multi-port VNA (virtual balun). The properties of balanced pairs are determined mathematically from the measured values of each single conductor of the pair against reference ground. The coverable frequency range for the determination of the reflection and transmissions characteristics of symmetrical pairs is no longer limited by the balun but by the VNA and the connection technique.

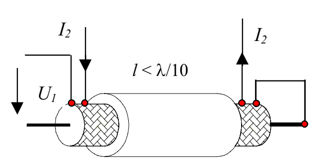
The applicability of this kind of signal generation with a multi-port VNA to measure the coupling attenuation according to IEC 62153-4-9 [7] is investigated in the following report. The goal is to measure the coupling attenuation up to at least 2 GHz.

The extension of the standard IEC 62153-4-9 to these frequencies will be discussed in particular with respect to the question of the necessary test length to be used as well as the test head (open head or standard test head). For this approach test results of the triaxial method according to IEC 62153-4-9 and IEC 62153-4-5 (clamp method), [6] are compared.

2 Screening-Parameters
2.1 General
To protect a cable against external electromagnetic interference or to avoid radiation into the environment, it is surrounded with screens made of metal foils and/or braids. For cables used in harsh electromagnetic environments elaborate shield structures, made of several layers or magnetic materials, are also used. In case of balanced cables, also the overall symmetry of the pair contributes to the screening effectiveness in addition to the screen.

The sole effect of the screen is described by the transfer impedance and the screening attenuation. The influence of the symmetry is grasped by the unbalance attenuation. The overall effect of the screen and the symmetry of the pair (for balanced cables) are described by the coupling attenuation.

2.2 Transfer impedance
For an electrically short screen, the transfer impedance Z_T is defined as the quotient of the longitudinal voltage U_1 induced to the inner circuit by the current I_2 fed into the outer circuit or vice versa, related to length in Ω/m or in mΩ/m, see figure. 1.



$$Z_T = \frac{U_1}{I_2 \cdot l} \quad (1)$$

Figure 1: Definition of transfer impedance

The test procedure is described in IEC 62153-4-3. According to the definition it can be measured on short cable samples.

2.3 Screening Attenuation
The screening attenuation a_S is the measure of the effectiveness of a cable screen. It is the logarithmic ratio of the feeding power P_1 to the maximum radiated power $P_{r,max}$.

With the arbitrary determined normalized value Z_S = 150 Ω [5] one gets:

$$a_S = 10 \cdot \lg \left| \frac{P_1}{P_{r,max}} \right| = 10 \cdot \lg \left| \frac{P_1}{P_{2,max}} \cdot \frac{2 \cdot Z_S}{R} \right| \text{ dB,} \qquad (2a)$$

$$a_S = 20 \cdot \lg \left| \frac{U_1}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_1} \right] \text{ dB,} \qquad (2b)$$

whereas R is the input impedance of the receiver. More details are given in IEC 62153-4-1 and in IEC 62153-4-4.

With the arbitrary determined normalized value Z_S = 150 Ω one gets for screened balanced cables (in the common mode) the screening attenuation a_S:

$$a_S = 10 \cdot \lg \left| \frac{P_{com}}{P_{r,max}} \right| \text{ dB,} \qquad (3a)$$

$$a_S = 20 \cdot \lg \left| \frac{U_{com}}{U_{2,max}} \right| + 10 \cdot \lg \left[\frac{2 \cdot Z_S}{Z_{com}} \right] \text{ dB,} \qquad (3b)$$

2.4 Unbalance Attenuation

Screened balanced pairs may be operated in two different modes: the differential mode (balanced) and the common mode (unbalanced). In the differential mode one conductor carries the current +*I* and the other conductor carries the current -*I*; the screen is without current. In the common mode both conductors of the pair carry half of the current +*I*/2; and the screen is the return path with the current -*I*, comparable to a coaxial cable [11, 12].

Under ideal conditions respectively with ideal cables both modes are independent from each other. However under real conditions, both modes influence each other.

The "Unbalance Attenuation" a_U of a pair describes in logarithmic scale how much power couples from the differential mode to the common mode and vice versa. It is the logarithmic ratio of the input power in the differential mode P_{diff} to the power which couples to the common mode P_{com}, [prEN 50289-1-9Ed2].

$$a_u = 10 \cdot \lg \left| \frac{P_{diff}}{P_{com}} \right| \text{ dB,} \qquad (4a)$$

$$= 20 \cdot \lg \left| \frac{U_{diff}}{U_{com}} \right| + 10 \cdot \lg \left[\frac{Z_{com}}{Z_{diff}} \right] \text{ dB,} \qquad (4b)$$

Differences in the resistance of the conductors, in the diameter of the core insulation, in the core capacitance, unequal twisting and different distances of the cores to the screen are some reasons for the unbalance of the pair.

At low frequencies the unbalance attenuation is decreasing with increasing cable length. At higher frequencies and/or length the unbalance attenuation approaches asymptotic to a maximum value, - similar to the screening attenuation - depending of the type of cable and its distribution of the inhomogeneities along the cable length. Unbalance attenuation may be determined for the near end as well as for the far end of the cable [9, 10].

2.5 Coupling Attenuation

The coupling attenuation of screened balanced pairs describes the global effect against electromagnetic interference (EMI) and takes into account both the effect of the screen and the symmetry of the pair. As first approach, coupling attenuation a_C is considered as sum of the unbalance attenuation a_U of the twisted pair and the screening attenuation a_S of the screen [7].

$$a_c = a_u + a_s \qquad (5)$$

It is important to consider the screening attenuation to be defined as the maximum value of the measurement trace inside the relevant frequency range. Therefore, this equation should read = $a_U + a_{S,max}$ and it is valid only in the lower frequency range and with certain constraints. Coupling attenuation and screening attenuation are usually far-end measurements while the only unbalance parameter that can possibly be measured is the near-end unbalance. At higher frequencies, the phase relations respectively the different propagation velocities of differential and common mode lead to unavoidably differences.

A measurement is also possible on unshielded pairs (U/UTP). In this case only the symmetry of the pair acts. Equation (5) for the definition of the coupling attenuation is applicable accordingly.

3 Mixed mode (virtual balun)

3.1 General

To measure the unbalance and coupling attenuation a differential signal (differential mode) is required. It can for example be generated using a balun which converts the unbalanced signal of a 50 Ω network analyzer into a balanced signal. But commercial baluns are available up to 1.2 GHz only. Alternatively a balanced signal may be obtained with a network analyzer having two generators where one has a phase shift of 180° to the other generator. However, such devices are expensive and hardly available.

Another frequently used alternative is the measurement with a multi-port VNA and the application of the corresponding mixed mode S-parameters [8]. It requires at least 4 ports for measurements on a balanced pair. To fully test a four pair data cable, 16 ports are required if reconnection of pairs is to be avoided.

3.2 Definition of mixed mode S-Parameters

The transmission characteristics of four poles or two ports, such as coaxial cables may be described by the scattering parameter or abbreviated "S-parameter". In matrix notation it is written:

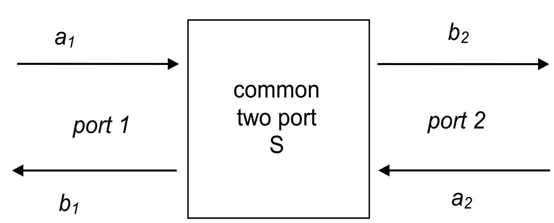


Figure 2 – Common two-port network

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \qquad (6)$$

where a and b are the normalized power waves of the input and output ports.

The definition of the scattering matrix can be easily extended to arbitrary N gates. For a four-port these results in:

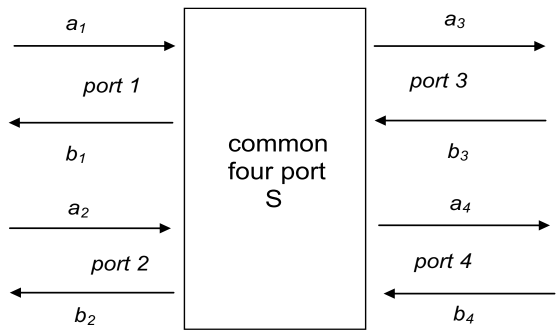


Figure 3 – Common four port network

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{pmatrix} = \left(S^{std}\right) \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{43} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} x \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{pmatrix} \quad (7)$$

For the measurement of symmetrical two-ports the physical ports of the multi-port VNA are combined into logical ports:

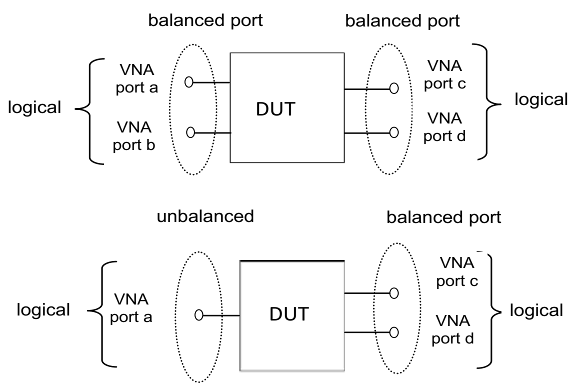
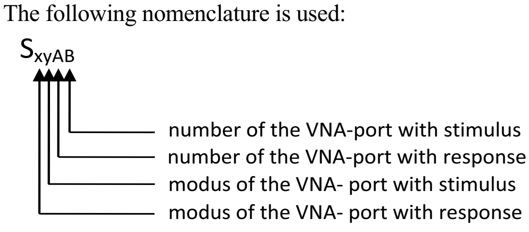


Figure 4 – Physical and logical ports of VNA

The following nomenclature is used:



Modus	s: Single ended (unbalanced, coaxial)
	d: Differential mode (balanced)
	c: Common mode

Figure 5: Nomenclature of mixed mode S-Parameters

Accordingly, the S-parameters can be understood as ratios of power waves.

$$S_{xyAB} = \frac{\text{input signal at VNA-port A at modus x}}{\text{input signal at VNA-port B at modus y}} \quad (8)$$

The conversion of the asymmetrical four-port scattering parameters S^{std} to mixed mode scattering parameters S^{mm} for a symmetrical two-port network is given by:

$$S^{mm} = M \cdot S^{std} \cdot M^{-1} \quad \text{where}$$

$$M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \quad (9a)$$

$$\text{and } S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd11} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix} \quad (9b)$$

For the measurement of a two-port with an unbalanced port (single ended) and a balanced port, the following measurement configurations arise:

			Stimulus		
			Single ended	Differential mode	Common mode
			Logical port 1	Logical port 2	Logical port 2
Response	Single ended	Logical port 1	S_{ss11}	S_{sd12}	S_{sc12}
	Differential mode	Logical port 2	S_{ds21}	S_{dd22}	S_{dc22}
	Common mode	Logical port 2	S_{cs21}	S_{cd22}	S_{cc22}

The measurement of the coupling attenuation corresponds to a stimulus in the differential mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sd12}. The measurement of the screening attenuation corresponds to a stimulus in common mode and to a response in the unbalanced (coaxial) mode (single ended), i.e. a measurement of the S-parameter S_{sc12}.

For the measurement of a two-port with two balanced ports, the following test configurations are obtained:

			Stimulus			
			Differential mode		Common mode	
			Logical port 1	Logical port 2	Logical port 1	Logical port 2
Response	Differential mode	Logical port 1	S_{dd11}	S_{dd12}	S_{dc11}	S_{dc12}
		Logical port 2	S_{dd21}	S_{dd22}	S_{dc21}	S_{dc22}
	Common mode	Logical port 1	S_{cd11}	S_{cd12}	S_{cc11}	S_{cc12}
		Logical port 2	S_{cd21}	S_{cd22}	S_{cc21}	S_{cc22}

The measurement of the attenuation of a balanced pair corresponds to a stimulus and a response in differential mode, i.e. a measurement of the S-parameter S_{dd21}. The measurement of the unbalance attenuation with stimulus in differential mode and common mode response corresponds at the near end with the S-parameter S_{cd11} or S_{cd21} when measured at the far end.

3.3 Reference impedance of VNA

When measuring with 4 port VNA with mixed mode parameters, a full calibration, e.g. with electronic calibration units shall be achieved. The VNA (Z_0 = 50 Ω physical analyzer ports) sets the default values reference impedances for the differential mode Z_{0d} = 100 Ω (= 2 * Z_0) and for the common mode Z_{0c} = 25 Ω (= Z_0/2). By renormalisation, the reference impedances can be set to the values of the DUT, e.g. to 50 Ω common mode.

3.4 Feeding of the device under test (DUT)

To feed the test signal into the balanced DUT, the two 50 Ω ports of the multi-port network analyzer must be connected to the two wires of the balanced cable. The symmetry and geometry of the test specimen should be affected as less as possible. Matching and symmetry of the connecting device should be superior to the cables under test [14].

For appropriate connecting devices there are different - usually expensive - commercial solutions available, but so far only for four pairs. To measure the coupling attenuation a connecting device for a single pair is required. For the measurements listed below a newly designed connecting device for one symmetrical pair with the following properties is used:

Characteristic impedance, primary side	2 x 50 Ω (25 Ω Common mode)
Characteristic impedance, secondary side, (25 Ω common mode when matched with 50 Ω)	1 x 100 Ω differential
Unbalance attenuation, secondary side (open)	> 40 dB
Unbalance attenuation, secondary side (matched)	> 40 dB
Attenuation, primary side (short circuit)	< 0,2 dB
Attenuation, secondary side (back to back)	< 0,8 dB

Figure 5 - TP- Connecting unit for balanced cables

Transfer impedance and Screening attenuation of balanced cables are parameters of the screen and independent of the characteristics of the pair. Usually they are measured with two port VNAs as S21 where the two wires of the pair are short circuited. When using multiport VNAs and a TP-connection unit, they shall be measured in the common mode, single ended, e.g. S_{cs21}. Matching of the common mode can be achieved acc. to fig. 12.

4 Coupling attenuation

4.1 General

Up to now, measurement of coupling attenuation of balanced cables can be achieved either with clamp method according to IEC 62153-4-5, [6] or with the triaxial test set up according to IEC 62153-4-9, [7]. Measuring with absorbing clamps shows different drawbacks against the measurement with the triaxial test set-up. Calibration of composite loss and reflexion loss of the clamps is complicated and depends on the characteristics of the DUT. Furthermore, the measurement with absorbing clamps shall be performed in a screened room if necessary for higher screening values to avoid environmental influences.

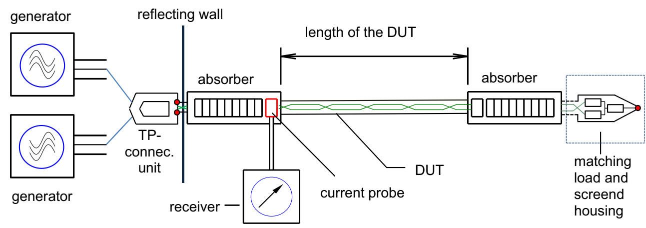


Figure 6: Principle of absorbing clamp procedure

Especially in the frequency range up to 100 MHz, the composite loss of the clamps is considerable, possible disturbances from radio stations are also considerable, so that different weaknesses of the clamp method are superimposing. With the triaxial test set-up with standard test head environmental influences are excluded by the set-up itself.

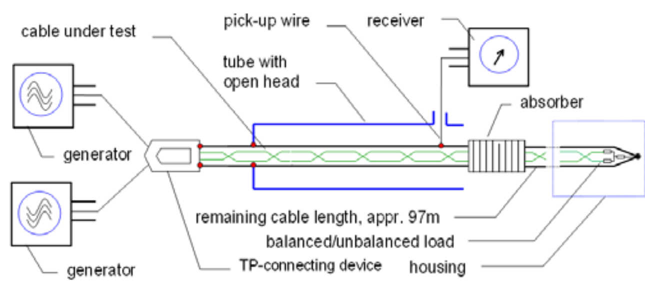


Figure 7: Coupling attenuation according to IEC 62153-4-9 with open head and multiport VNA

Absorbing clamps are available for the frequency range from 30 MHz to 1 GHz (MDS 21) and from 500 MHz to 2,5 GHz (MDS 22). That means, that two test set-ups are required for measurements up to 2 GHz. Measurements above 2,5 GHz are not possible with clamps. Due to the limited availability of high performance baluns at frequencies above 1,2 GHz, the use of the triaxial set-up according to IEC 62153-4-9 [7] in combination with a multiport VNA (see Figure 7 to 9) is preferred.

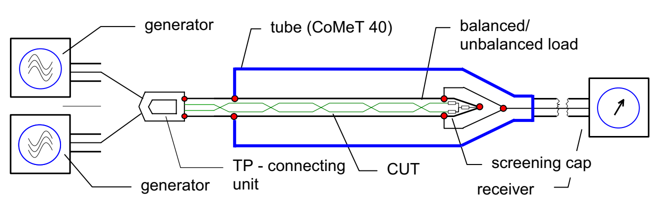


Figure 8: Coupling attenuation with standard head and multiport VNA

4.2 Coupling attenuation with triaxial test set-up, open head procedure

The current edition of IEC 62153-4-9, [7] describes the measurement of coupling attenuation with the triaxial test set-up with open test head, see Figure 7. Whereas the screening attenuation of homogeny cable screens is length independent coupling attenuation takes into account both, the screening attenuation of the screen and the balance of the pair.

When developing IEC 62153-9 it was assumed, that unbalance attenuation decreases with increasing cable length and a length of about 100 m would be required for the coupling attenuation measurement. This assumption was the main reason for developing the open head procedure. In this procedure at least 3 m of the DUT are placed in the tube and the remaining length of about 97 m is placed in a screened box, see figure 7.

To avoid reflected waves travelling into the set-up, absorbers shall be attached in front of the open head. Absorbers should have at least an insertion loss of > 20 dB. A combination of ferrite absorbers and nano-crystalline absorbers show good performance over the complete frequency range from 30 MHz to 2 GHz.

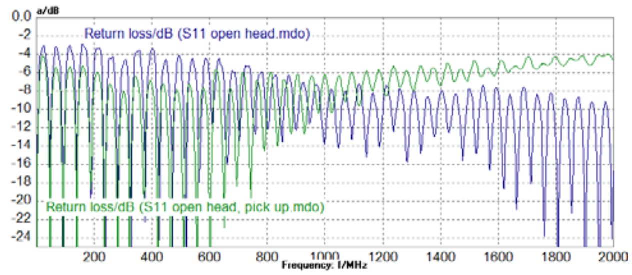


Figure 9a – Return loss S11 open head set-up, 3m and pick up, with absorbers and clamp MDS 22

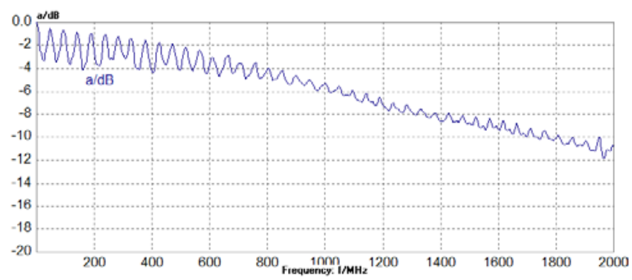


Figure 9b – Operational attenuation a_{tube} of the open head set-up, 3m

To pick up the signal, a pick up wire shall be applied to the screen of the DUT at the open end of the test head (see figure 7). This pick-up causes certain attenuation in the outer system of about 11 dB at 2 GHz and 3 m tube due to low return loss, see figures 9a and 10. Return loss of pick up and the outer system and the operational attenuation a_{tube} are measured according to figure 20.

4.3 Coupling attenuation with triaxial test set-up, standard head

An alternative to the open test head procedure is the measurement of coupling attenuation with standard head according to figure 8.

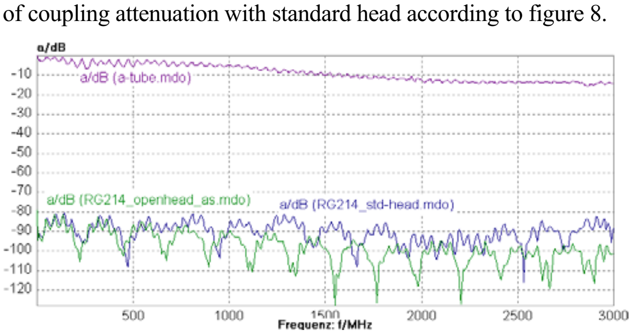


Figure 10 – Screening attenuation of RG 214 with open and with standard head 3m.

It is therefore reasonable to consider whether the triaxial procedure to measure coupling attenuation must be used with open test head or whether at appropriately high frequencies it can also be carried out with the standard head. Standard head means the procedure according to IEC 62153-4-4, [5] where the DUT can be connected in a screened case at the test head at far end, see fig. 8.

Figure 10 shows the measurement of the screening attenuation with open and with standard head and operational attenuation a_{tube} of the outer system of the open head set-up. If the trace of the open head is corrected with the operational attenuation, both traces open and standard head are nearly identical.

IEC 62153-4-4 describes the measurement of screening attenuation of coaxial cables with standard head. The cable under test is matched at the far end with its characteristic impedance. With the same principle also the coupling attenuation of screened twisted pairs can be measured. To match the screened pair under test at the far end in both, common and differential mode, a small printed circuit board (PCB) was designed, (see figure 11).

Figure 11: Screening case with PCB

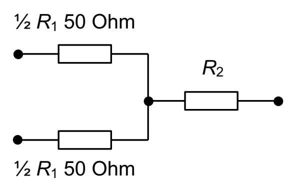


Figure 12: balanced/unbalanced termination network

Usual balanced/unbalanced loads for twisted pair cables are given in below:

	Char. impedance (Zcom)	½ R_1	length resistor R_2
S/FTP	appr. 33 Ohm	50 Ohm	8 Ohm
F/UTP	appr. 50 Ohm	50 Ohm	25 Ohm
U/UTP	appr. 75 Ohm	50 Ohm	50 Ohm

The inductance of the load resistors is intended to be as small as possible. This is particularly problematic for the common mode signal due to typically long distance from center point of the two differential mode resistors R_1 to the screen.

Generally, the triaxial procedure with open test head shows good comparability to the procedure with standard head. Figure 10 shows the comparison of the measurement of screening attenuation of double braid screen of a RG 214 (see also figure 16). At screening attenuation measurements it is usual to evaluate the maximum peak values only. These values are nearly identical when correct the open head trace with the operational attenuation.

For evidence that coupling attenuation measurements with balun are equivalent to measurements with multiport VNA with virtual balun, references are given on [12, 13].

4.4 Calculation of unbalance attenuation of balanced pairs

To check the suitability of the standard head procedure for balanced cables, first the behavior of the unbalance attenuation of balanced pairs is to investigate at various lengths.

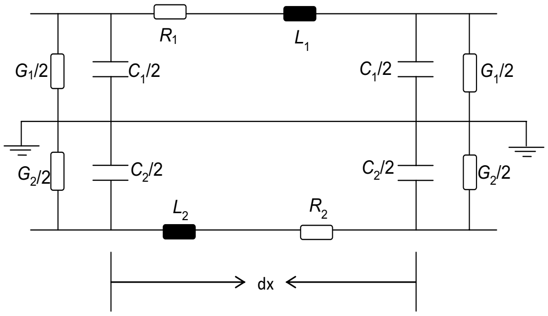


Figure 13: Equivalent circuit of a homogenous balanced cable with regular distribution of the primary transmission-line constants

Models for the analysis of the unbalance attenuation of pairs can be found for example, in [11] and [12]. Based on an equivalent circuit as shown in Figure 13, the longitudinal unbalance TA and the lateral unbalance L_A can be defined as follows:

$$T_A = (G_2 + j\omega C_2) - (G_1 + j\omega C_1) \quad (10a)$$

and $L_A = (R_2 + j\omega L_2) - (R_1 + j\omega L_1)$ (10b)

The terms of the unbalance coupling function can be formally written in the same way as for the crosstalk coupling function:

$$T_{u,n} = \frac{1}{4Z_{unbal.}} \int_{x=0}^{x=1} \left[T_A(x) \cdot Z_{unbal.}^2 + L_A(x)\right] \cdot e^{-(\gamma_{diff}+\gamma_{com})\cdot x} \cdot dx \quad (11)$$

$$T_{\substack{u,n\\u,f}} = \left(T_A \cdot Z_{unbal.}^2 \pm L_A\right) \cdot \frac{1}{Z_{unbal.}} \cdot \frac{1}{4} \cdot S_{\substack{n\\f}} \quad (12)$$

The phase effect by summing the infinitesimal couplings along the transmission line is expressed by the summing function S. Neglecting the cable attenuation S can be expressed by the following equation:

$$S_{\substack{n\\f}} = \frac{\sin(\beta_{diff} \pm \beta_{com}) \cdot \frac{l}{2}}{(\beta_{diff} \pm \beta_{com}) \cdot \frac{l}{2}} \cdot e^{-\left(j \cdot (\beta_{diff} \pm \beta_{com}) \cdot \frac{l}{2}\right)} \quad (13)$$

Here, the length of the equations cancels out, i.e. evenly distributed and at high frequencies, the unbalance attenuation is independent of length. At high frequencies the asymptotic value approaches to:

$$S_{\substack{n\\f}} = \frac{2}{(\beta_{diff} \pm \beta_{com}) \cdot l} \quad (14)$$

and at low frequencies the summing function becomes:

$$\left|S_{\substack{n\\f}}\right| \rightarrow 1 \quad (15)$$

Measurements of the behavior of the unbalance attenuation at different lengths and random disturbances are shown by way of example in Figure 14. It can be seen that no significant differences occur at frequencies above a few 10 MHz. So it seems possible to waive the 100 m sample length in the coupling attenuation measurement when the minimum test frequency is chosen high enough.

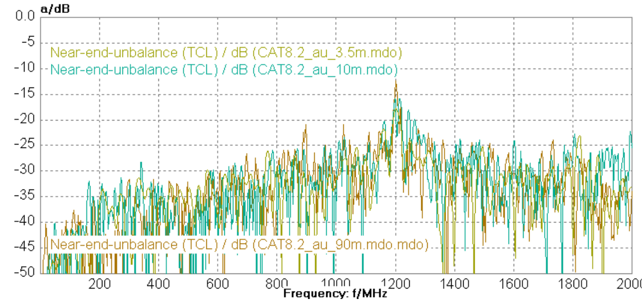


Figure 14: Unbalance attenuation at near end of Cat8.2 cable with different length with PCB

4.5 Return loss

Another criterion for qualification of a procedure is the return loss of the DUT. The requirement for return loss in both, common mode (Scc11) and differential mode (Sdd11) should be a value better than 10 dB. An example of measurements at different lengths is shown in figure 15a and 15b. The return loss of the longer sample shows better values as the attenuation of the sample adds to the inevitable mismatch at the far end.

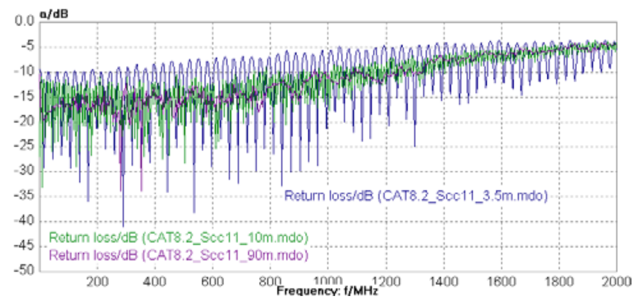


Figure 15a: Return loss common mode Cat8.2 cable with PCB 50/50/25, near end

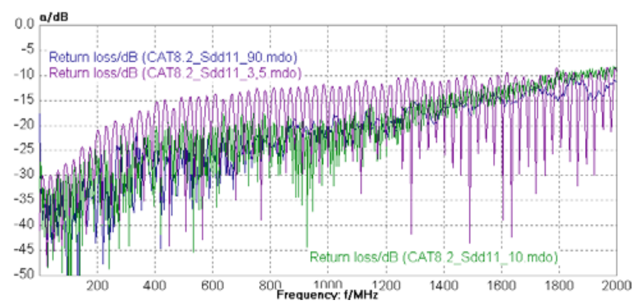


Figure 15b: Return loss differential mode of Cat8.2 cable with PCB, 50/50/25, near end

Especially for the common mode a good termination is difficult because the exact value of the common mode impedance usually is unknown and needs to be determined by measurement. Matching the DUT with standard values 50/50/0 (100 Ω diff. and 25 Ω com.) or with 50/50/25 (100 Ω diff. and 50 Ω com.) leads to max. 17 dB resp. 14 dB common mode return loss if a typical S/FTP value of 33 Ohm is assumed for the common mode impedance.

5 Measurements

Several measurements of screening and coupling attenuation with clamp method and with triaxial method using open and standard head were carried out with RG 058, RG 214, Twinax 105, Cat7a and Cat8.2 cables. Measurements were performed at the bedea test lab with R&S ZNB 8 4-port VNA, with triaxial CoMeT system and with Lüthi MDS 21 and MDS 22 absorbing clamps. PCBs were 50/50/25. Triaxial measurements are raw measurements without correction except figures 16, 17d, 17e, 18d and 19d, (as(m) respectively ac(m) are measured values without correction, as(150) is related to 150 ohm outer circuit).

Sample and set-up preparation shall be carried out very carefully. Samples shall be centered well in the tube, e.g. with foam support. Improper sample preparation and improper test set-up leads to false test results.

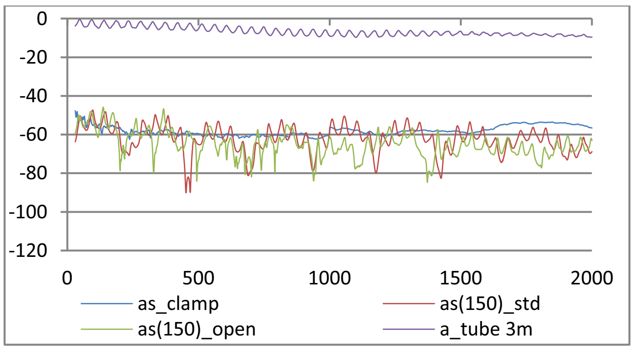


Figure 16: RG 058 triax std & open, vs. clamp

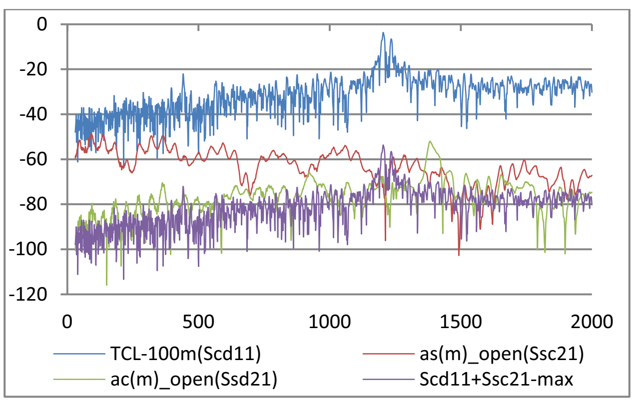


Figure 17a: Twinax - open head, 3m/100m

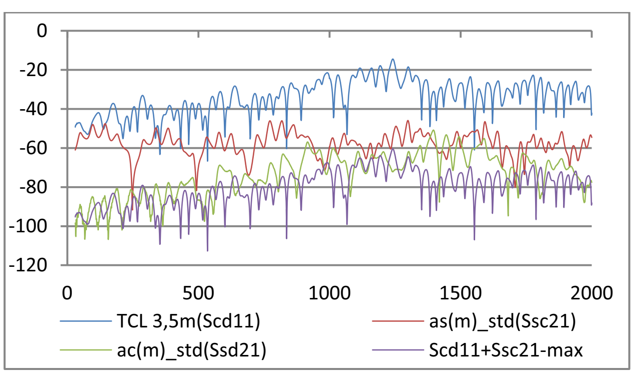


Figure 17b: Twinax - standard head, 3m

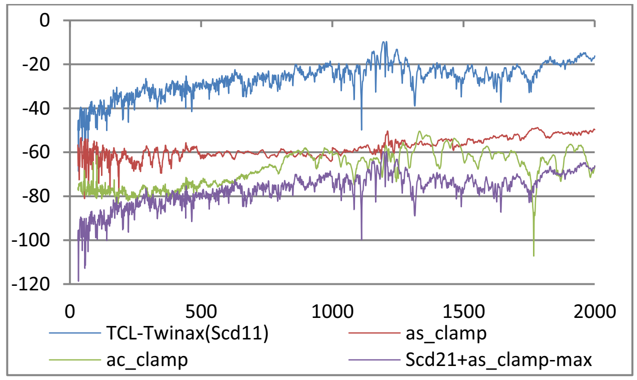


Figure 17c: Twinax 105 – absorbing clamps

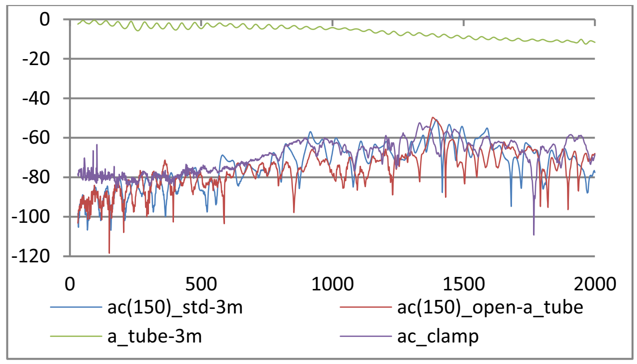


Figure 17d: Twinax 105 –compilation a_C, 3m

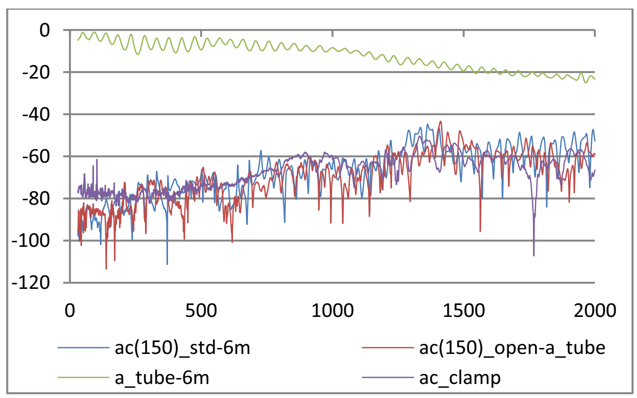


Figure 17e: Twinax 105 –compilation a_C, 6m

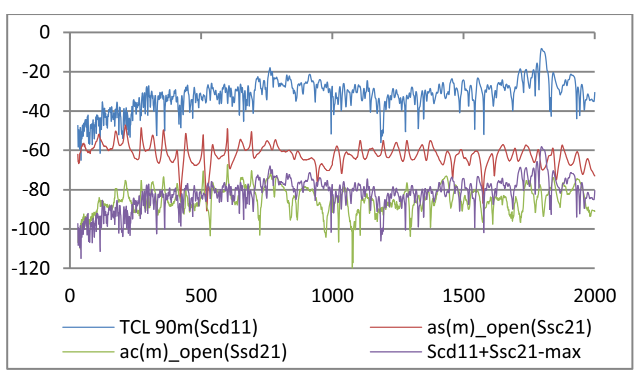


Figure 18a: Cat7a – open head, 3m/90m

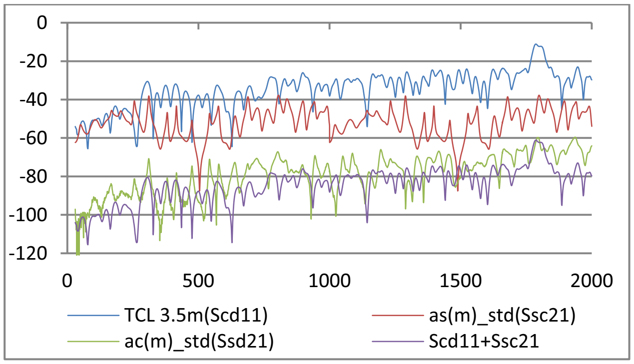


Figure 18b: Cat7a – standard head, 3m

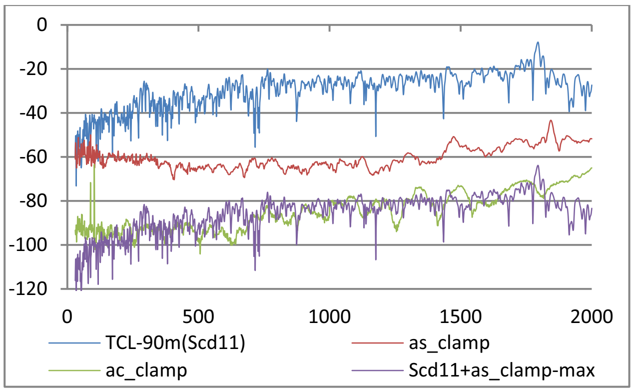


Figure 18c: Cat7a – absorbing clamps

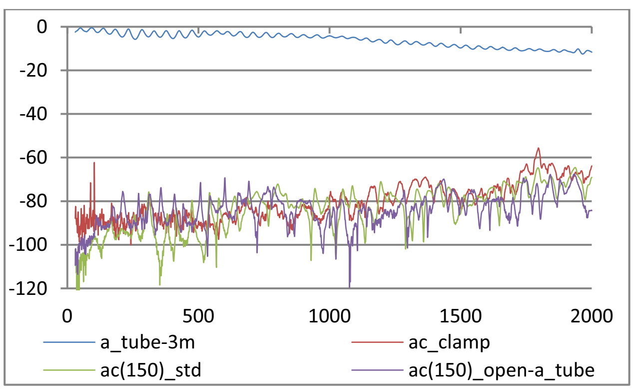


Figure 18d: Cat7a, compilation a_C

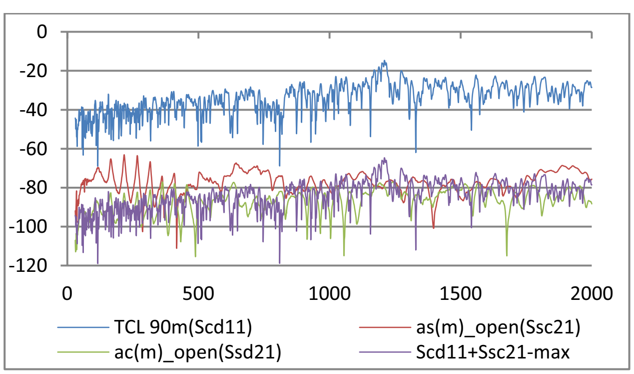


Figure 19a: Cat8.2 - open head, 3m/90m

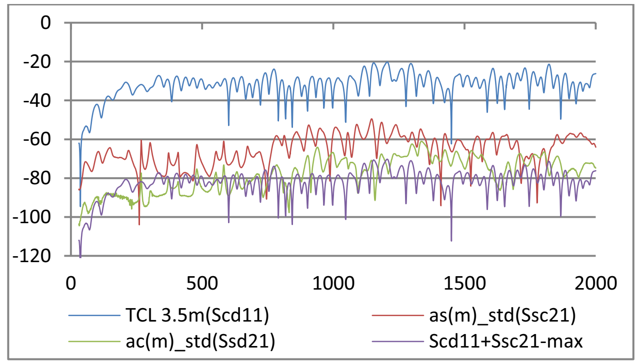


Figure 19b: Cat8.2– standard head, 3m

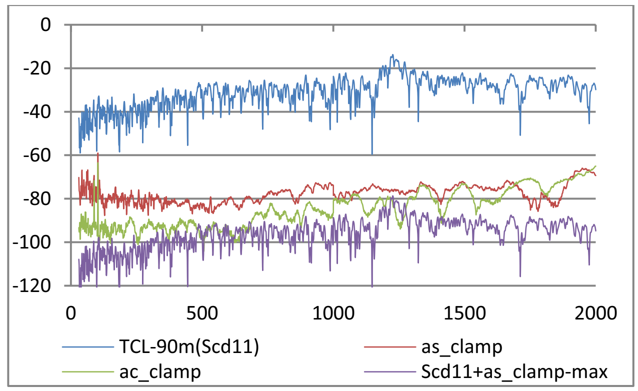


Figure 19c: Cat8.2 - absorbing clamps

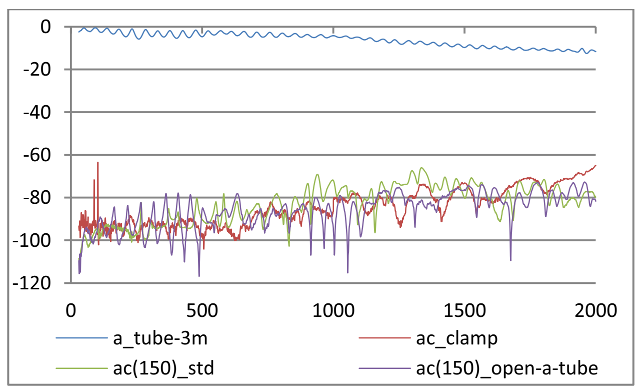


Figure 19d: Cat8.2, compilation a_C

When comparing clamp measurements with triaxial measurements, only the max. values of the traces shall be considered, that means, traces cannot be compared direct along all points of the trace.

Clamp measurements show different peaks, e.g. in the range of 100 MHz. These peaks are disturbing signals from different radio stations as well as from GSM and LTE networks. To avoid those peaks, clamp measurements shall be performed in a screened room.

Measurements show, that the coupling attenuation a_C is in the range of $a_{S,max} + a_U$ in the lower frequency range. At higher frequencies at about 1000 MHz values of coupling attenuation tend to become similar to the values of the screening attenuation at Twinax 105 and at Cat 8.2.

At first glance, measurements of screening attenuation with triaxial standard head and absorbing clamps (Figures 18b/18c and 19b/19c) show large differences. But if one corrects the triaxial values according to [5] respectively formula (3b) with 33 ohm characteristic impedance common mode and with 150 ohm outer circuit, traces become similar.

Figure 16 shows that the clamp method and the triaxial method provide in principle equivalent maximum values. If one corrects the open tube curve with the operational attenuation a_{tube}, triaxial measurements with open head and standard head show nearly identical results of screening attenuation of a RG 058.

With correction of the operational attenuation a_{tube}, and with normalized value Z_S (see equation 16), maximum values of a Twinax 105 cable with standard and with open head as well as with clamps, show a good consistency, see figure 17d (3m length in triaxial set-up) and figure 17e (6m length in triaxial set-up). The same applies in principle for the Cat 8.2 cable, see figure 19d.

Figures 17d and 17e show also the behavior at lower frequencies with different length of the tubes (3m and 6m). Below 100 MHz, traces of the triaxial procedures increase at 6m length at about 3 dB to 6 dB. Clamp measurements below 100 MHz are not trustworthy and more reason for discussion.

6 Expression of test results

IEC 62153-4-9, coupling attenuation, open head procedure shall be revised and extended to 2 GHz. Expression of test results for the revised standard should be as follows:

The voltage ratio U_{diff}/U_{2max} shall be measured and corrected with regard to the influence of test leads and connecting units. The operational attenuation $a_{tube} = 20 \cdot \lg(U_1/U_2)$ of the outer system of the test set-up shall be measured according to figure 20 in case of open head procedure with the same absorber configuration as used during the coupling attenuation measurement:

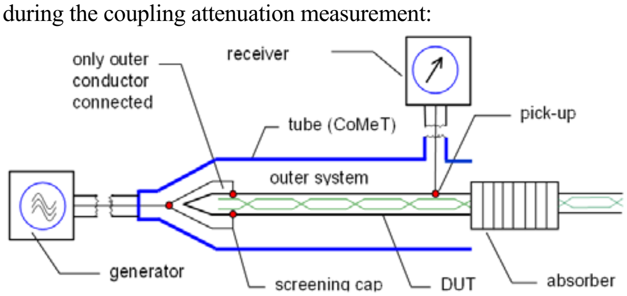


Figure 20: Test set-up to measure a_{tube}

The coupling attenuation a_C which is comparable to the results of the absorbing clamp method shall be calculated with the arbitrary determined normalized value $Z_S = 150\ \Omega$:

$$a_c = 10 \cdot \lg\left|\frac{P_{diff}}{P_{com}}\right| + 10 \cdot \lg\left|\frac{P_{com}}{P_{r,max}}\right| \text{ dB,} \qquad (4a + 3a)$$

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{com}}\right| + 10 \cdot \lg\left[\frac{Z_{com}}{Z_{diff}}\right] + 20 \cdot \lg\left|\frac{U_{com}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{com}}\right] \text{ dB,} \qquad (4b + 3b)$$

and with the correction of the operational attenuation a_{tube} of the outer system in case of open head procedure:

$$a_c = 20 \cdot \lg\left|\frac{U_{diff}}{U_{2,max}}\right| + 10 \cdot \lg\left[\frac{2 \cdot Z_S}{Z_{diff}}\right] - a_{tube} \text{ dB,} \qquad (16)$$

where $a_{tube} = 20 \cdot \lg[U_1/U_2]$

7 Conclusion

With regard to ensure a reliable coupling attenuation measurement at high frequencies several technical constraints are to be considered and problems to be solved. For the considered frequency range of several hundred MHz to 2 GHz, feeding and detection of the test signal by the method of mixed-mode parameters can be used. Modern network analyzers have appropriate features. Various connection devices for contacting balanced cables are available commercially.

The length dependency of the unbalance attenuation is so small at the considered frequencies that basically the same results can be expected using the open test head with a test length of 100 m and the standard test head of the triaxial tube with a length of 3 m.

However, the impact of the return loss is to be taken into account when measuring short lengths. An insufficient matching network at the end of the cable under test - particularly concerning both differential and common mode - increases the radiation of power by the CUT considerably. This problem is negligible in case of a 100 m long test specimen due to its attenuation.

According to experience, the return loss of the CUT should be better than about 10 dB also for a test length of 3 m. An improved version of a balanced/unbalanced matching network is in preparation.

The measurements presented show, that taking into account the boundary conditions described similar results can be expected from the triaxial method with open test head and with the standard head, as well as from the clamp method. Especially for frequencies above 1 GHz this indicates the triaxial method to be a good alternative to the clamp method since the required clamp for frequencies above 1 GHz is available only in a few test laboratories.

The triaxial procedure is much easier to handle and requires only one test set-up instead of two set-ups with the clamp procedure. Furthermore the transfer impedance can be measured with the same triaxial test set-up respectively with the same components. Due to the RF-tight triaxial set-up, screening measurements can be achieved up to about 130 dB. A screened room to suppress unwanted disturbing signals like radio, GSM, LTE etc. is not required.

8 Outlook

Beside the further development of connecting devices to connect the balanced pair to the unbalanced ports of the VNA, the characteristics of the open test head is the subject of further investigations. These will serve the revision of the standard series IEC 62153.

The observation, that the values of coupling attenuation tend to be in same range as the values of the screening attenuation at higher frequencies at about 1000 MHz needs to be analyzed and explained by further studies.

An improved PCB (see figure 11) to match the CUT at the screening case for the standard head procedure is in progress.

The use of standard values 25 ohm or 50 ohm and possibly 32 ohm to match the common mode should be considered by IEC TC 46/WG5.

Instability of screening and coupling attenuation of cable samples under test after physical treatment like bending and stretching shall be examined; a bending test before screening measurements as required for coaxial cables according to IEC 61196 series should be considered.

9 Acknowledgments

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Both Authors are members of IEC TC46/WG 5, screening effectiveness.