“Balunless” Measurement of Coupling Attenuation of Balanced Cables & Components

by:
Bernhard Mund
bedea Berkenhoff & Drebes GmbH
Asslar, Germany
www.bedea.com

and Thomas Hähner
Nexans
Lyon, France
www.nexans.com

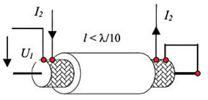
With implementation of 40 Gbps digital data transmission for data center applications, the range in which symmetrical data cables are used in structured cabling has reached the 2 GHz mark. Screening effectiveness of such cables is relative to the sum of the unbalance attenuation of the pair and the screening of the screen. This article describes measurement of coupling attenuation with a multi-port VNA and the corresponding four-port mixed mode S-parameters.

Screening Effectiveness Parameters

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 screen structures, made of several layers or magnetic materials, are also used. In addition to the screen also the overall symmetry of the pair contributes to the screening effectiveness.

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) is described by the coupling attenuation.

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, in Ω/m or in mΩ/m, (see **Figure 1**). The test procedure is decribed in *IEC 62153-4-3*.



$$Z_T = \frac{U_1}{I_2 \cdot l},$$

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

Fig. 1 — Definition of transfer impedance.

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_2. Details are given in *IEC 62153-4-4*.

$$a_S = 10 \cdot \log(P_1 / P_2) \qquad \mathrm{dB}$$

Unbalance Attenuation. Screened balanced pairs may be operated in 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[1].

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” 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_d, to the power which couples to the common mode P_c.

$$a_u = 10 \cdot \log(P_d / P_c)$$

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 minimum value in the range of 20 dB to 40 dB, depending of the type of cable and its distribution of the inhomogeneities over the cable length. Unbalance attenuation may be determined for the near end as well as for the far end of the cable[3] (**Figure 2**).

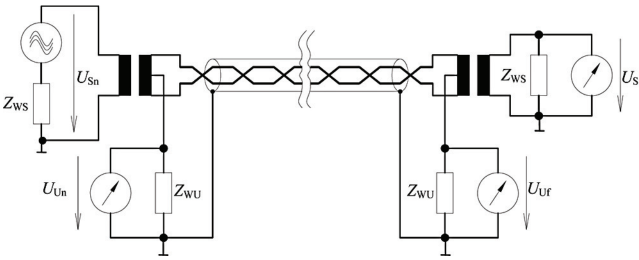


Fig. 2 — Near and far-end unbalance with baluns.

Coupling Attenuation. As discussed above, balanced cables, which are driven in the differential mode will radiate a part of the input power (or vice versa), due to irregularities in the cables’ symmetry.

The coupling attenuation describes the global effect against electromagnetic interference (EMI) and takes into account both the effect of the screen and the symmetry of the pair

In the case of unscreened balanced twisted pairs (UTP), only the symmetry of the cable acts and the coupling attenuation a_c is the unbalance attenuation a_u, which describes in this case the complete EMC behavior of the cable.

In the case of screened balanced twisted pairs (STP), the screening attenuation of the screen as well as the unbalance attenuation of the pair protects against EMI. Thus, as first approach, the coupling attenuation is the sum of the unbalance attenuation a_u of the pair the screening attenuation a_s of the screen. Since both quantities usually are given in a logarithmic ratio, they simply may be, in a first approach added into the coupling attenuation a_c.

$$a_c = a_u + a_s \ \mathrm{dB}$$

Principle to measure coupling attenuation is seen in **Figure 3**.

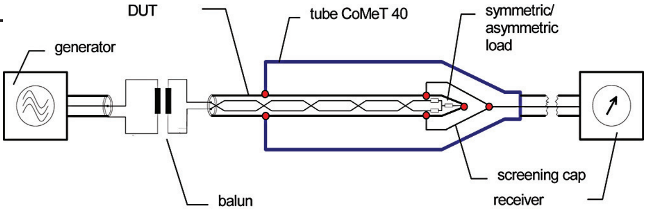


Fig. 3 — Measuring of coupling attenuation with a balun.

Differential Signal

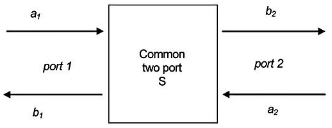
To measure the unbalance and coupling attenuation, a differential signal is required. It can for example be generated using a balun that converts the unbalanced signal of a 50 Ohm network analyzer into a balanced signal. But commercial baluns are available up to 1.2 GHz only.

Alternatively, a balanced signal may be achieved with a network analyzer having two generators—where one has a phase shift of 180° to the other generator. So the coupling attenuation can be measured up to and above 3 GHz. However, such devices are expensive and hardly available.

Another frequently used alternative is measurement with a multi-port VNA and application of the corresponding mixed mode S-parameters. This requires at least four ports for measuring. To fully test a four-pair data cable, 16 ports are required if one wants to avoid the reconnection of pairs. In this configuration, the coupling attenuation can be measured up to and above 3 GHz.

Mixed-Mode S-Parameters (balunless measurement)

The transmission characteristics of quadripole or two-ports, such as coaxial cables may be described by the scattering parameter or abbreviated "S-parameter". In matrix notation we have that which is seen in **Figure 4**.

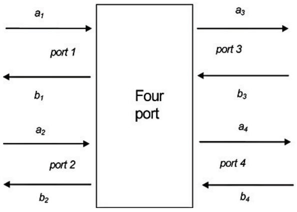


$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = (S) \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

where a,b are the square root of the power waves entering respectively leaving the two-port

Fig. 4 — Common two-port.

The definition of the scattering matrix can be easily extended to arbitrary N ports. Four-port results are seen in **Figure 5**.



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

Fig. 5 — Four-port network.

For measuring symmetrical two-ports, the physical ports of the multi-port VNA are combined into logical ports (**Figure 6**).

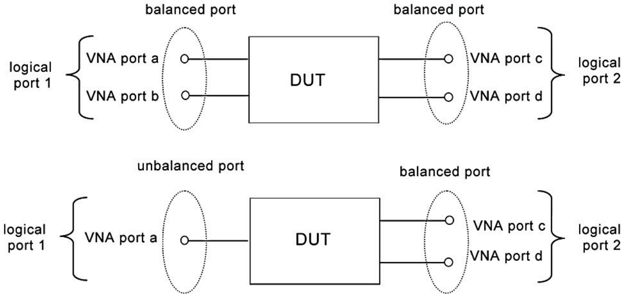
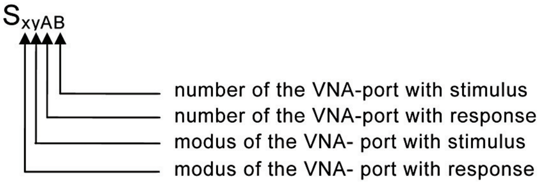


Fig. 6 — Physical and logical ports of VNA.

The following nomenclature is used:



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

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

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:

$$S^{mm} = M \cdot S^{std} \cdot M^{-1} \quad M = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix} \quad S^{mm} = \begin{bmatrix} \begin{bmatrix} S_{dd11} & S_{dd12} \\ S_{dd21} & S_{dd22} \end{bmatrix} & \begin{bmatrix} S_{dc11} & S_{dc12} \\ S_{dc21} & S_{dc22} \end{bmatrix} \\ \begin{bmatrix} S_{cd11} & S_{cd12} \\ S_{cd21} & S_{cd22} \end{bmatrix} & \begin{bmatrix} S_{cc11} & S_{cc12} \\ S_{cc21} & S_{cc22} \end{bmatrix} \end{bmatrix}$$

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

			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 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.

Measuring of Coupling Attenuation with Multiport VNA

The measuring of coupling attenuation of balanced cables is specified in the following standards:

- *IEC 62153-4-5*, Coupling or screening attenuation—absorbing clamp method.

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- *IEC 62153-4-9*, Coupling attenuation of screened balanced cables, triaxial method.

The measuring of coupling attenuation can be achieved with absorbing clamps or with the triaxial test procedure. Measuring with absorbing clamps shows some drawbacks against the measurement with the triaxial test procedure.

Absorbing clamp measurements should be done in a screened room to avoid environmental disturbances. Whereas with the triaxial set-up, environmental influences are excluded by the triaxial test set-up itself.

Another drawback of the clamps is the limited frequency range. With the clamp MDS 21 one can measure from 30 MHz up to 1 GHz, and with the MDS 22 one can measure from 500 MHz to 2.5 GHz. Measurements above 2.5 GHz are not possible with clamps.

Therefore, the triaxial test procedure is preferred. The *IEC 62153-4-9* standard describes the triaxial test procedure with open test head (**Figure 7**).

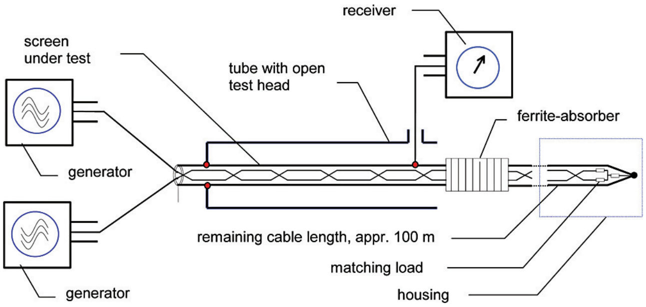

Fig. 7 — Measuring of coupling attenuation according to *IEC 62153-4-9* with open test head.

The tube length in this case is at least 2 m (to correctly determine the influence of the screening attenuation) and the length of the specimen is 100 m (to correctly determine the influence of the unbalance attenuation). Since the unbalance attenuation increases with length, the measuring tube is equipped with an open test head.

Comparative measurements between feeding through a balun and feeding by a multi-port VNA with mixed mode S-parameters show good agreement, and confirm that the coupling attenuation can be measured to at least 3 GHz when using a multi-port VNA.

For the sake of simplicity, in the comparative measurements presented in **Figure 8**, the length of the sample was restricted to 3 m and the measuring tube operated with a standard test head.

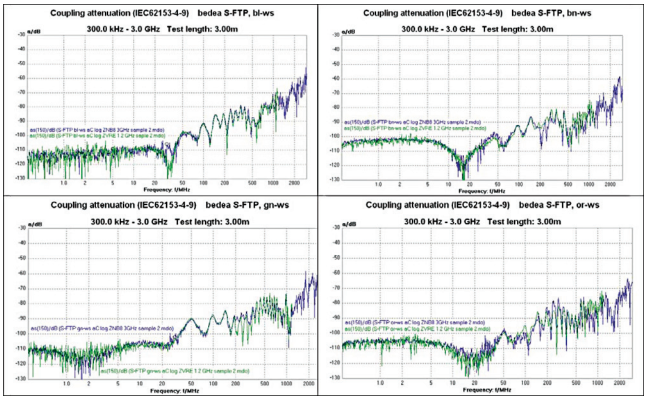

Fig. 8 — Comparable measurements with balun and with mixed-mode VNA.

The measurements with a multi-port VNA as described in **Figure 9** can be analogously applied for balanced cables, connectors and components with the "tube-in-tube" procedure according to *IEC 62153-4-7* as well as with the Triaxial cell according to *IEC 62153-4-15*.

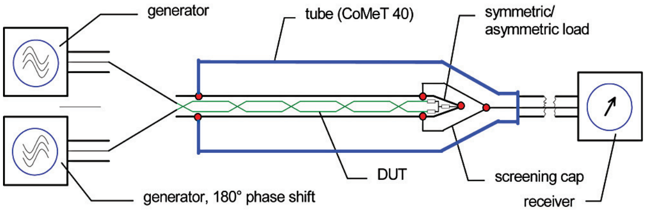

Fig. 9 — Measuring of coupling attenuation with multi-port VNA.

For further discussion or additional technical information, visit the websites listed below.
www.bedea.com / www.nexans.com

Literature:

[1] *Thomas Hähner, Bernhard Mund – EMC-performance of balanced (symmetrical cables)—IEE Colloquium on screening effectiveness measurements, Savoy Place London, 1998.*

[2] *Otto Breitenbach, Thomas Hähner und Bernhard Mund: Screening of Cables in the MHz to GHz Frequency Range; extended application of a simple measuring method; IEE Colloquium on screening effectiveness measurements, Savoy Place London, 1998.*

[3] *Thomas Hähner, Bernhard Mund—Test methods for screening and balance of communication cables—EMC Zürich 1999.*

[4] *Bernhard Mund: Measuring the EMC on RF-connectors and connecting hardware, Tube in tube test procedure, IWCS (International wire and cable symposium) 2004.*

[5] *Bernhard Mund, Thomas Schmid: Measuring EMC of HV cables and components with Triaxial Cell, Wire & Cable Technology international 01/03-2012.*

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Author Profiles:

__Bernhard Mund__ was born in 1953 in Marburg, Germany, After training as a Radio and TV Technician, Bernhard Mund studied Communication and Microprocessor Technologies at __FH Giessen-Friedberg__. In 1985, he joined the cable manufacturer __bedea Berkenhoff &Drebes GmbH__, Asslar, Germany. Beside his work for bedea, Mund is active in national and international standardization. He is Chairmen of the German NC UK 412.3 Koaxialkabel as well as Secretary of IEC SC 46A and of CENELEC SC 46XA, Coaxial cables. Further standardization activities among others are the membership of IEC TC 46/WG 5, Screening effectiveness.

__Thomas Hähner__ was born in 1965 in Berlin, Germany; in 1989 he received his Diploma in Electrical Engineering (Dipl.-Ing. (FH)) from the __Georg Simon Ohm University of Applied Science__ and in 2000, his Diploma in Business Administration (Dipl. Wirt.-Ing. (FH)) from the __University in Wildau, Germany__. Hähner has been in the cable business since 1990 when he joined __Nexans__ as R&D Engineer of radio frequency and data transmission cables and Manager of the RF test laboratory. Since 2011, he has been the Manager of the __Nexans Research Center__ in Lyon, France. He has been active for almost 20 years in national and international standardization. In 2010, Hähner was granted the 1906 IEC Award in recognition of his outstanding technical contribution in developing, writing and finalizing TC 46's IEC 62153-4 series on EMC test methods. Among other activities, he is Secretary of IEC TC 46/WG 5, Screening effectiveness. Since 2011, he has also been a member of __ACEC (Advisory Committee on Electromagnetic Compatibility)__.