History and recent trends of Triaxial test procedures

B. Démoulin

1934 Sergei Alexander Schelkunoff

1991 Thomas Kley

Paul Villien

1955 W. Klein

1976 M. Tyni

1988 Lauri Halme

1988 Bernhard Eicher

1990 Otto Breitenbach

1959 Heinrich Kaden

1968 Erich Homann

1961 R.F. Muehlberger

Eric Bech

Jürgen Spatz

1961 John Zorzy

1956 Heinz Jungfer

1969 Meyer de Stadelhofen

1956 L. Krügel

1974 E.F. Vance

1936 H. Ochem

Eric Guiol

Patrick Fowler

History and recent trends of Triaxial test proc., Overview

- History of EMC test procedures
  - First triaxial EMC concepts
  - Absorbing clamp procedure
  - Wire injection procedure
- Progress of triaxial test procedure
- Recent trends of triaxial procedure
  - Screening effectiveness of unscreened pairs
  - Test adapter & TP-Connecting unit
  - Low frequency coupling attenuation
  - Screening effectiveness at higher frequencies
- Outlook, Conclusion & Discussion

First triaxial EMC concepts

The Triaxial test procedure to has a long tradition and history.
Schelkunoff, (probably) first mention the concept of Transfer impedance Z_T for cable screens 1934

Further early description of Transfer impedance Z_T of different cable screen constructions including a triaxial test procedure is given 1936 by the German engineer Heinz Ochem.

A complete description of screening phenomena was given by Heinrich Kaden, in "The book of Kaden" 1950 respectively 1959 as 2nd edition.

There are numerous further articles describing the Triaxial procedure in the period from1950 to 1975

Vance (1974), Tyni (1976) & Kley (1991) among others described models for the calculation of coupling phenomena of braided screens. These models are still the basis for simulation software.

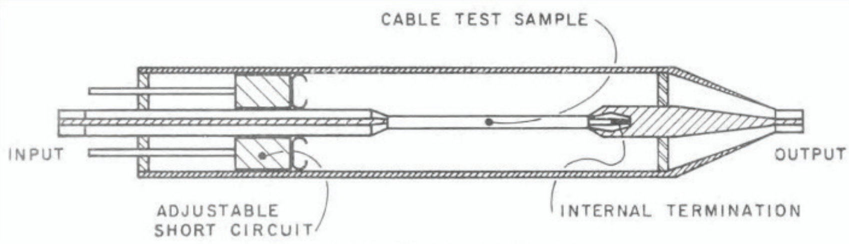


Figure 2—Tri-Axial Cable Leakage Test Unit.

Triaxial test set-up 1961 by John Zorzy & R.F. Mühlenberger

Although analytical models of Z_T are useful for shielding analysis,
measurements are still the most reliable method of determining the Z_T due to the complex structure of braided shields.

The "ready for cable TV" room antenna

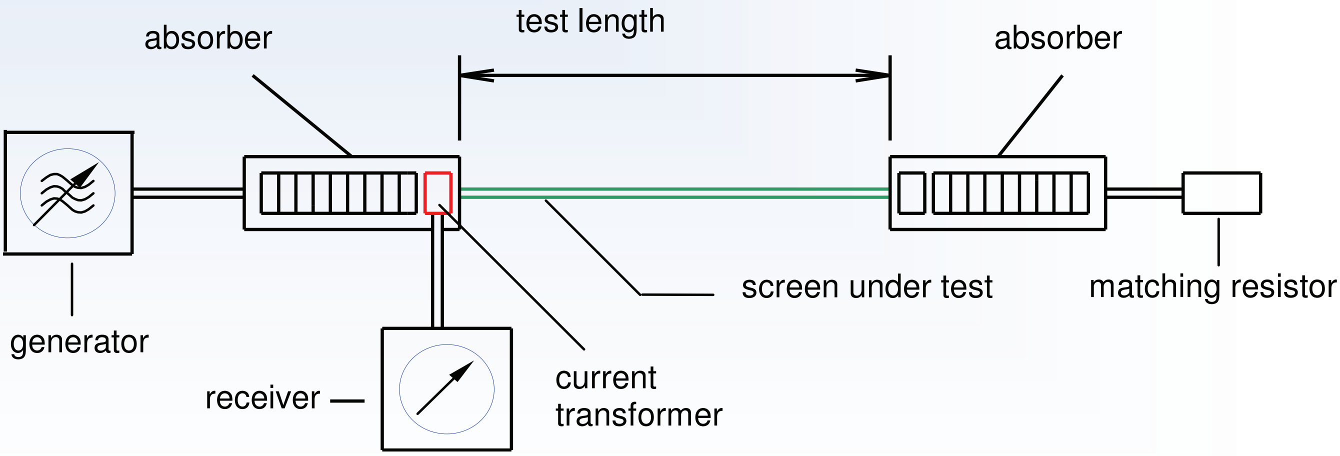
Due to **leaky** cable networks, Cable TV could be received with a room antenna.
The "ready for cable TV" room antenna causes the German Telecom (Deutsche Post)
to tighten their cable networks. At first 75 dB screening attenuation up to 1 GHz was required.
In 2000, screening classes acc. to EN 50117 were introduced, e.g. Class A with 85 dB up to 1 GHz

Screening- or Coupling attenuation with Absorbing clamps

With the first cable-TV networks in the nineteen-seventies, a procedure to measure screening of CATV cables towards higher frequencies was needed.

Meyer de Stadelhofen described the absorbing clamps first in 1969.

The clamp procedure was standardized as German standard (DIN 47250 Teil 6) in January 1983 and by IEC in June 1993 as amendment 2 to IEC 96-1



IEC 62153-4-5, Screening attenuation from 30 MHz to 1000 MHz with is currently under revision by IEC TC 46/WG5 as 2nd Edition including balunless measurements up to 2,4 GHz.

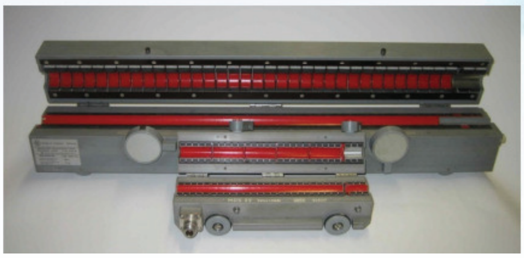
1985 – first computer controlled EMC-test station with VNA

my first task at bedea in **1985** was to establish a test station to measure screening attenuation (in dB)

It was realized with a Computer controlled Vector Network Analyser (VNA) ZVB from R&S and with absorbing clamps MDS 21

(the ZVB could work with narrow RF bandwith)

absorbing clamps
MDS 21, 30 MHz - 1 GHz
& MDS 22, 500 MHz - 2400 MHz

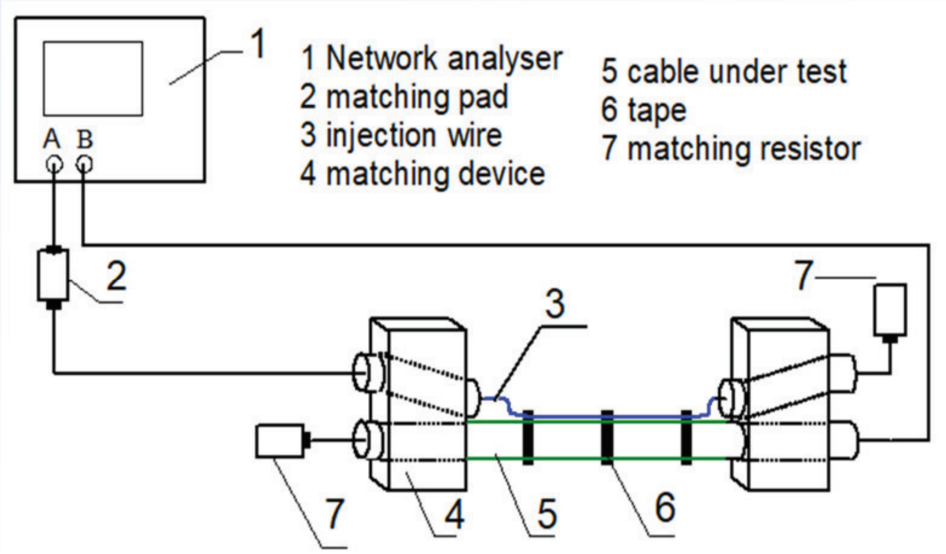


R&S ZPV
with GPIB Interface

up to this time, screening effectiveness was measured only with measuring receivers

Line injection method

The line injection method which was developed by experts of the Swiss Telecom was first mentioned by Bernhard Eicher at al – 1988. It was standardized 1993-03 in IEC 96-1Amd2,



With the dielectric constants ε_{r1}, ε_{r2} of outer and inner circuit respectively, the propagation velocities v_1, v_2 and the test length L_c, the cut off frequency f_c is given by:

$$f_c = \frac{c}{\pi \cdot L_c \cdot \left|\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right|}$$

$$= \frac{1}{\pi \cdot L_c \cdot \left|\frac{1}{v_1} - \frac{1}{v_2}\right|}$$

Depending on the propagation velocities of inner and outer circuit, Transfer impedance can be measured in the range of 50 MHz to about 1 GHz.

History and recent trends of Triaxial test procedure

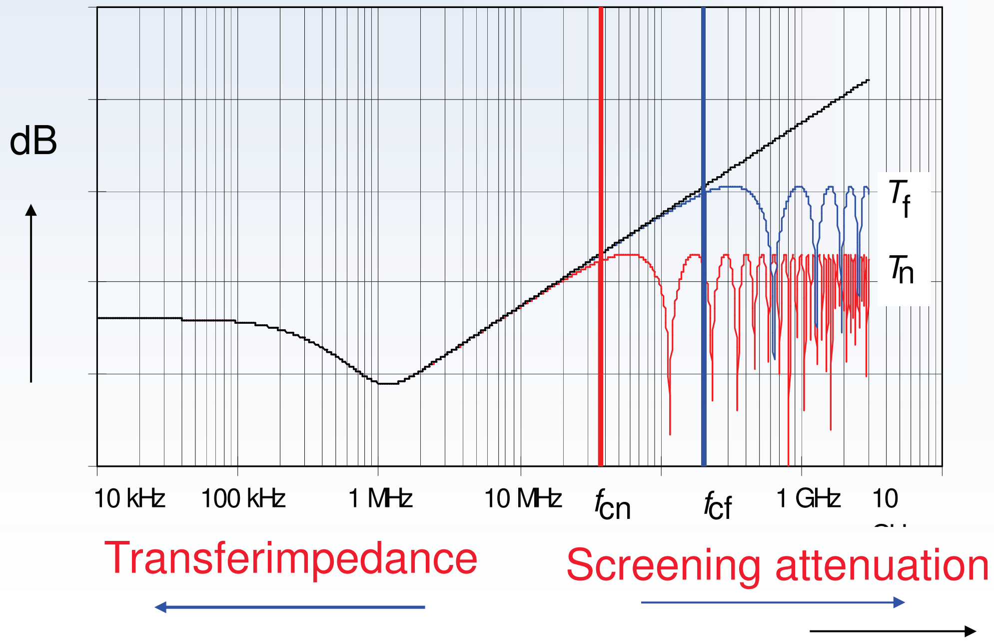
Calculated Coupling Transfer Function T_{nf} (RG 058)

The Coupling Transfer Function shows the behaviour of Z_T and a_s of a cable screen over the frequency

$$T_{s,\,n/f} = (Z_F \pm Z_T)\cdot\frac{1}{\sqrt{Z_1 \cdot Z_2}}\cdot\frac{l}{2}\cdot S_{n/f}$$

n = near end
f = far end

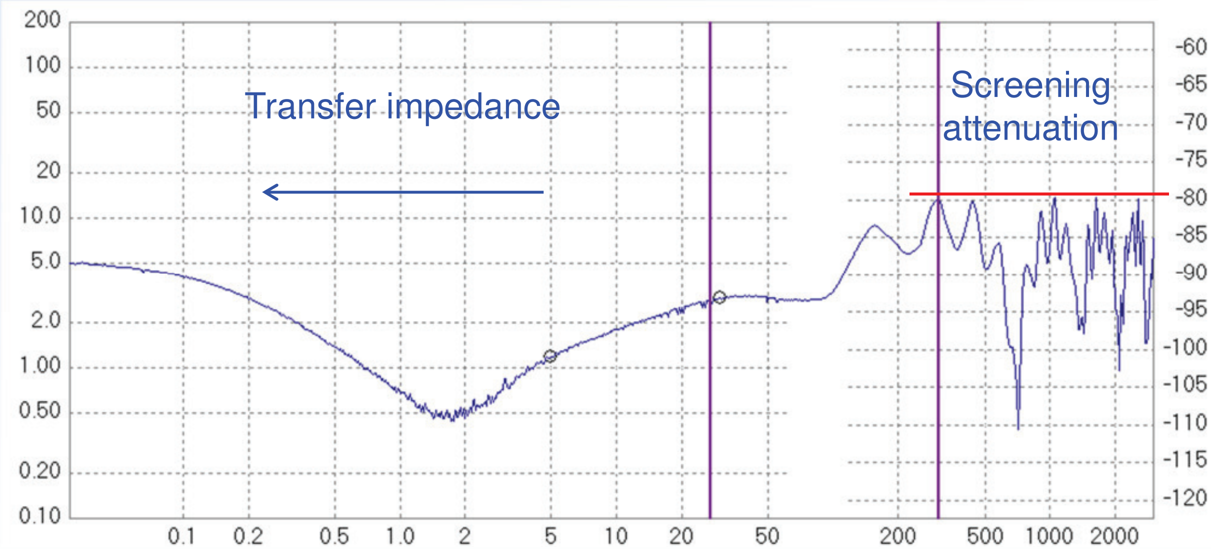
L = 1 m
ε_{r1} = 2,3
ε_{r2} = 1,0
Z_F = 0



The Coupling Transfer Function T_{nf} results from the multiplikation of the equivalent Transfer impedance Z_{TE} and the Summing function S_{nf}

Progress of triaxial test procedure

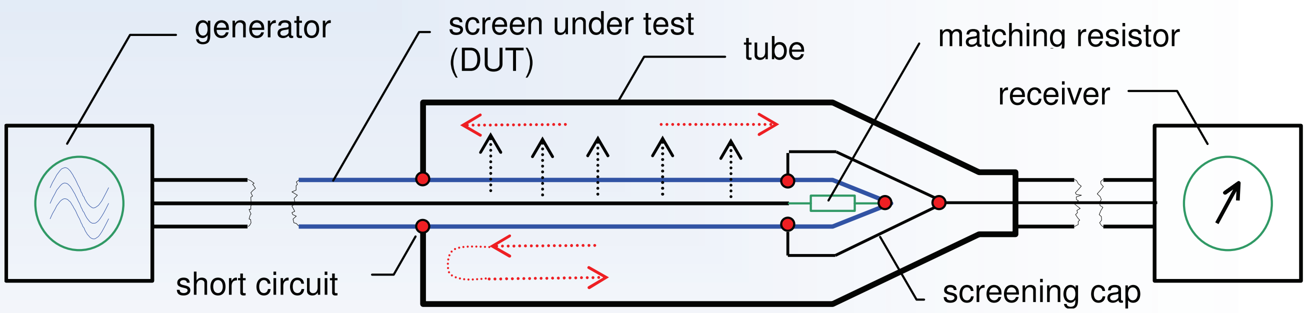
Until the end of the 1980ties only Transfer impedance was measured with the triaxial set-up. Based on the Coupling Transfer Function, Otto Breitenbach, Germany, started 1990 the research to measure screening effectiveness with the triaxial procedure also in the higher frequency range.



Breitenbach realized, that the max. values of the resonances of the triaxial procedure at higher frequencies could be used as measure of the Screening attenuation up to and above 3 GHz. (supported by Thomas Hähner)

Principle of the Triaxial test set-up

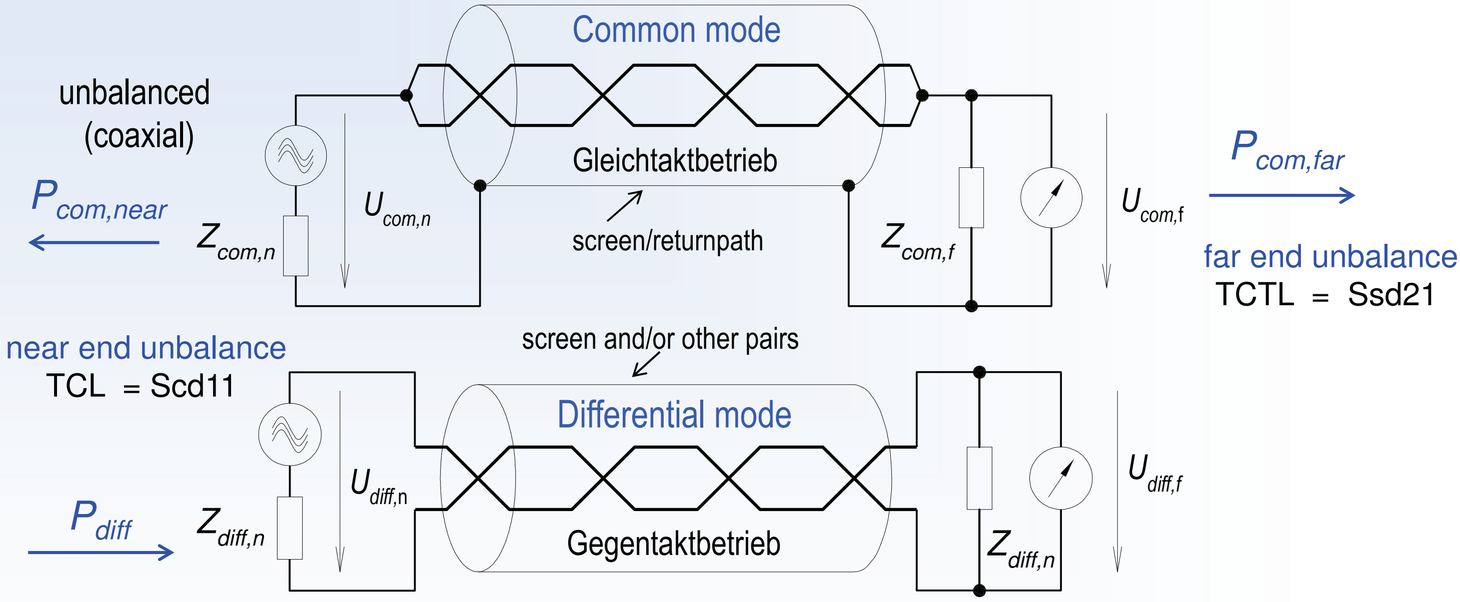
Transfer impedance & Screening attenuation from DC up to and above 9 GHz with one test set-up



The set-up consists of the DUT in the middle of the tube, the generator and the receiver included in a modern VNA, the matching resistor at far end and the short circuit at near end.
The DUT is fed by the generator. Due to the weak screen, energy is coupling into the outer system respectively in the tube and a wave is travelling in both directions first.
The short circuit at near end causes a total reflection; and the complete energy which couples into the outer system is travelling to the receiver and is measured there.
The logarithmic ratio of the received power to the input power is the Screening attenuation.

IEC 62153-4-3Ed2, Transfer impedance, IEC 62153-4-4Ed2, Screening attenuation

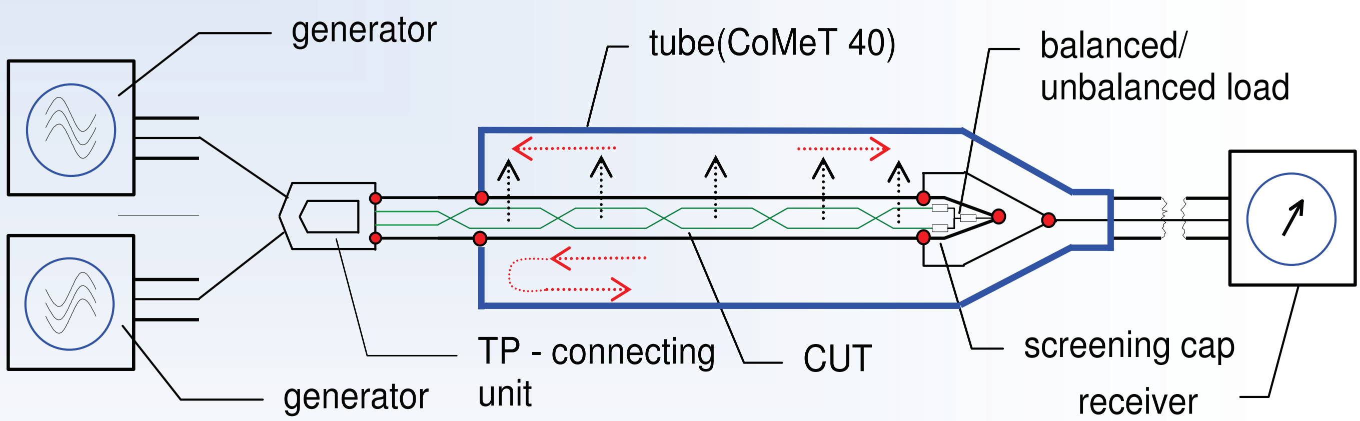
Common mode & differential mode



Balanced cables can be operated in the common mode as well as in the differential mode. 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_{diff} to the power which couples to the common mode P_{com}:

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

Screening & Coupling attenuation with Triaxial procedure

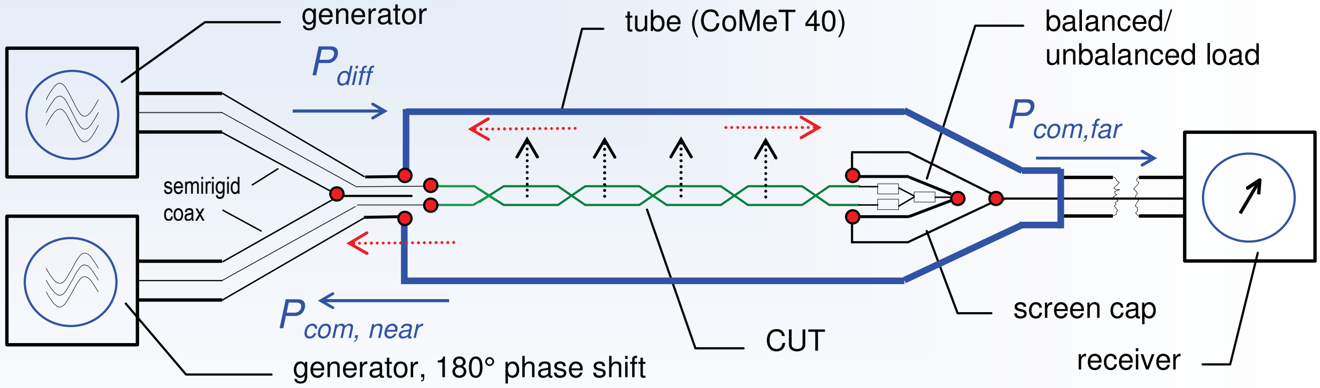


The principle for coupling attenuation measurement is the same than the basic triaxial procedure with generator and receiver and a short circuit at near end.
IEC 62153-4-9, Coupling attenuation on screened balanced cables was revised recently; Edition 2 was published in May 2018.
The revised version contains the balunless measurement of coupling attenuation with open test head as well as the measurement with standard test head up to 2 GHz.

IEC 62153-4-9Ed2, Coupling attenuation – Triaxial method

Unscreened pairs with Triaxial procedure - principle

In order to accept the triaxial procedure as reference procedure, some experts demand to measure also the screening effectiveness of unscreened balanced pairs with the triaxial test set-up.

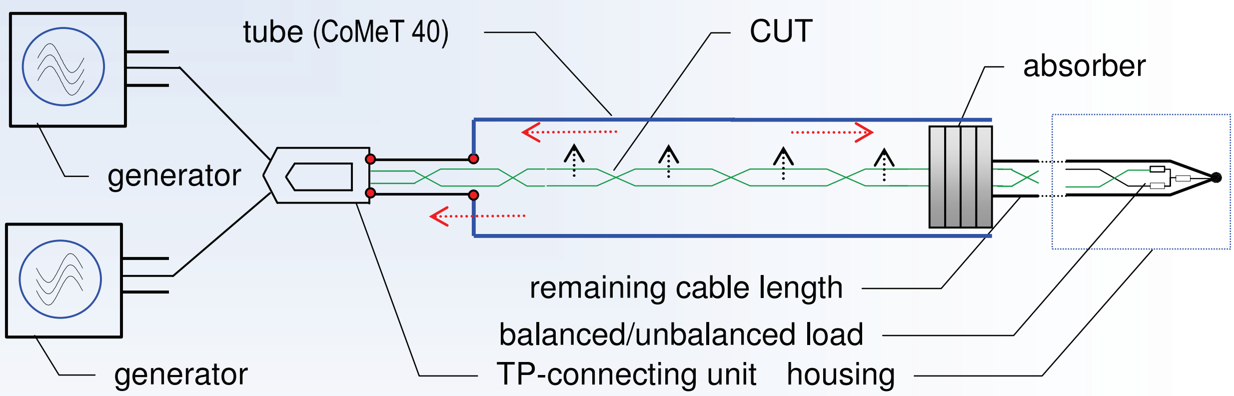


This figure shows the principle set-up for balanced unscreened pairs.
The principle is the same than the balunless procedure for screened balanced cables.

Since there is no screen on the unscreened pair,
there is no short circuit at the near end as in the basic triaxial set-up;

hence coupling measurements can be performed on both ends.

Near end Coupling attenuation with Triaxial procedure



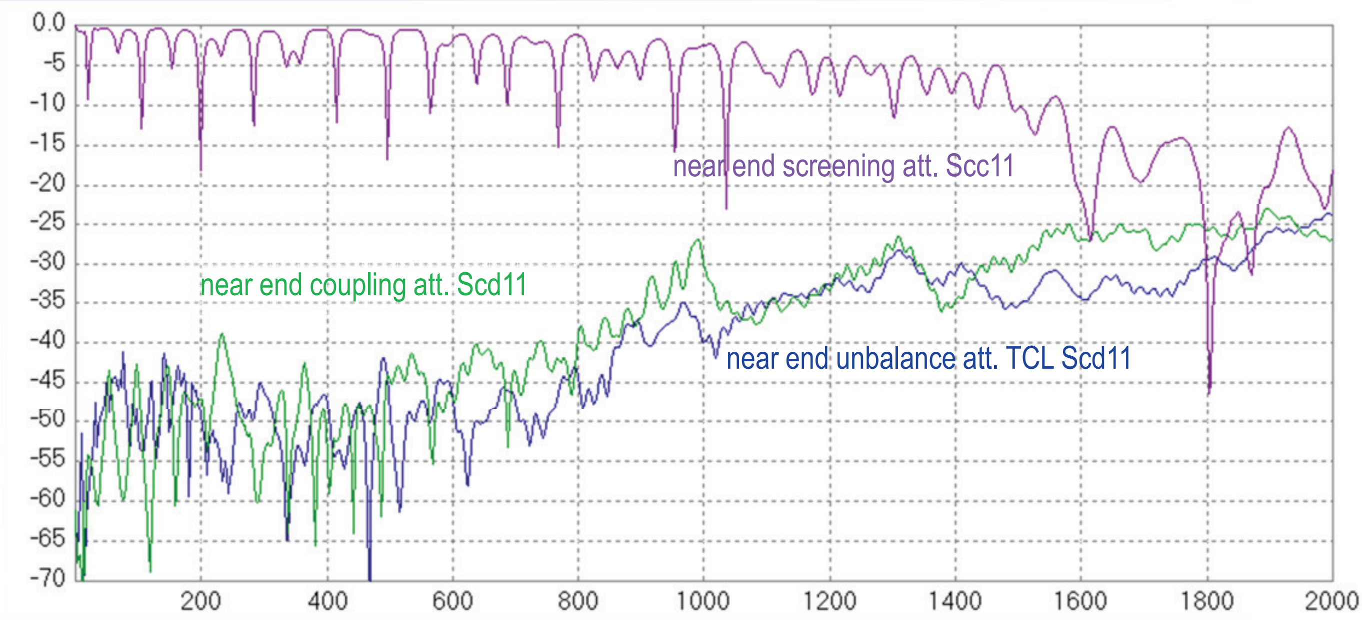
This figure shows the configuration for near end coupling attenuation measurement.
Absorber are used for proper matching at the far end.

The back travelling energy at the near end as shown above is considered as the near end coupling.
It can be measured as Scd11 where Scd11 is also the unbalance attenuation (TCL) of the unscreened cable under test (CUT) at near end !

near end coupling attenuation of a single unscreened balanced pair = TCL !

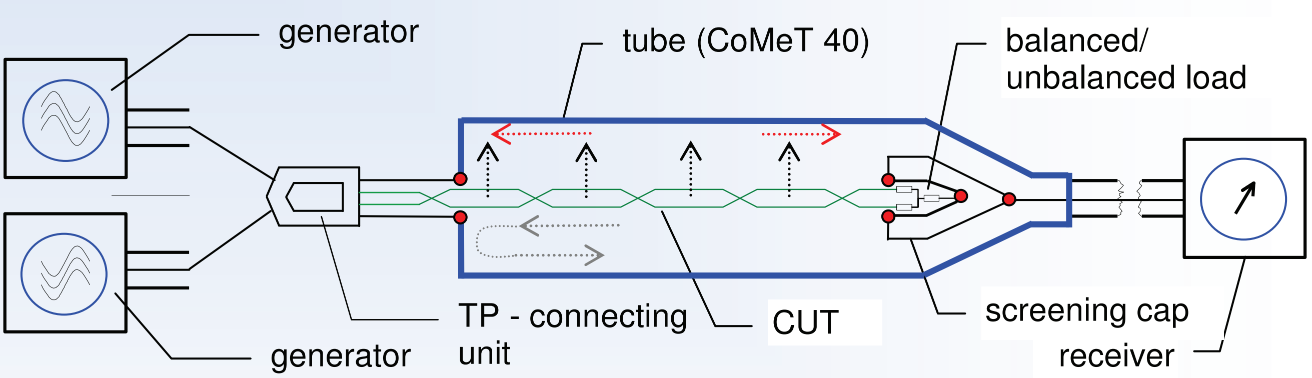
Near end coupling att. & TCL of an unscreened balanced pair

near end unbalance attenuation (TCL) of a 5m single unscreened balanced pair, laid on a wooden table and the near end coupling attenuation measurement (Scd11) in the triaxial set-up



near end coupling attenuation of a single unscreened balanced pair = TCL !

Far end Screening- & Coupling att. with Triaxial procedure

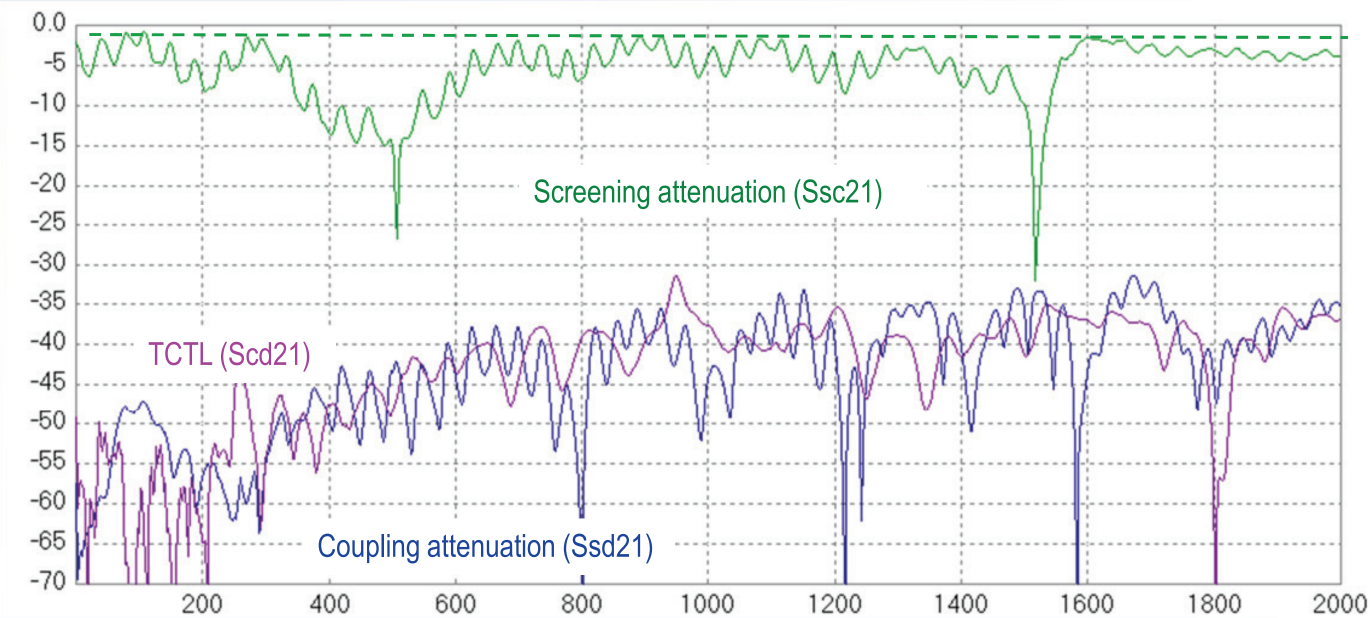


set-up for the far end screening attenuation (Ssc21) and the far end coupling attenuation (Ssd21) measurement of an unscreened pair.
The CUT is matched with 50/50/25 Ohm; that means 100 Ohm for the differential mode and 50 Ohm for the common mode.
The 50 Ohm common mode resistor is in series to the receiver of the network analyser.

The Ssd21 measurement (far end coupling attenuation) is in principle the same than a Scd21 measurement (far end unbalance attenuation).

far end coupling attenuation of a single unscreened pair ≈ far end unbalance attenuation

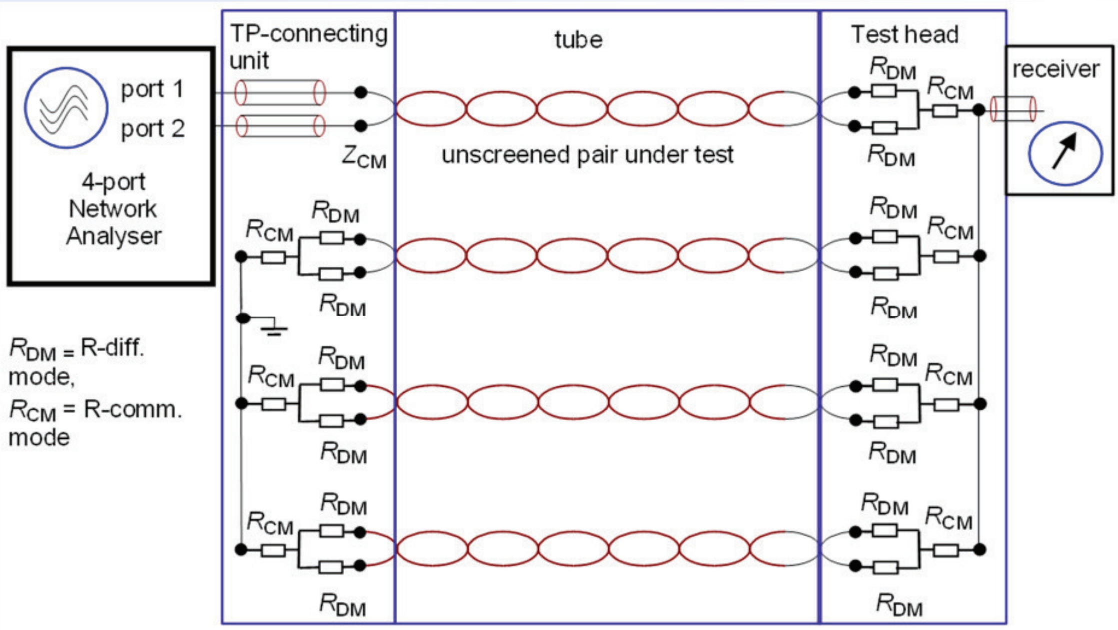
Far end Screening & Coupling attenuation of an unscreened balanced pair



far end screening attenuation of a single unscreened balanced pair = nearly zero !
far end coupling attenuation is nearly the far end unbalance attenuation (TCTL)

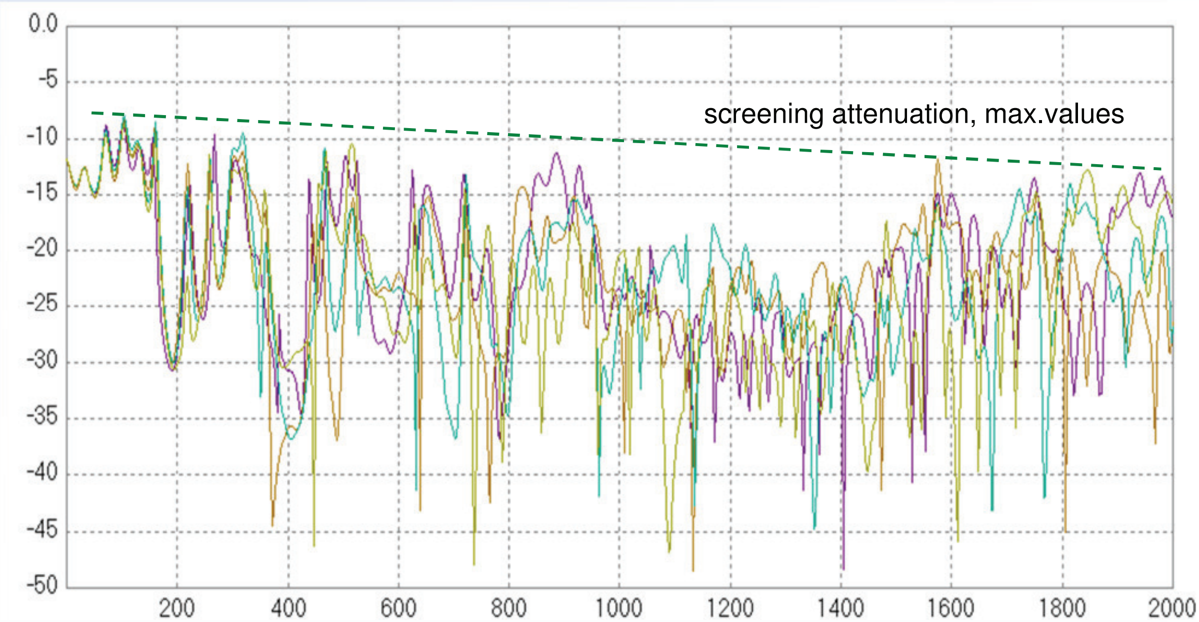
Screening- & Coupling att. of multiple balanced pairs

Basic configuration for coupling attenuation of multiple unscreened pairs



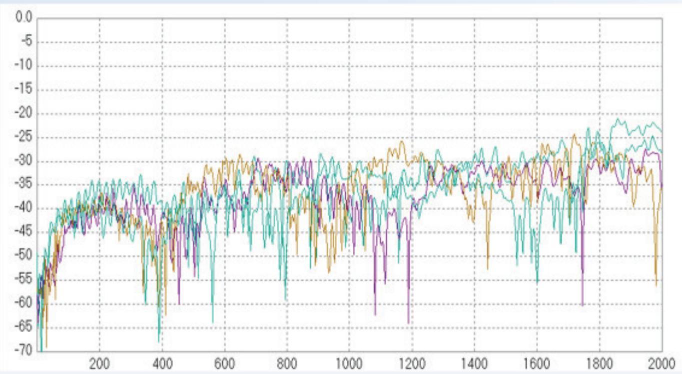
The pairs not under test are grounded by a resistor network 50/50/0. They act as an inner screen

Far end screening attenuation of an unscreened Cat5e

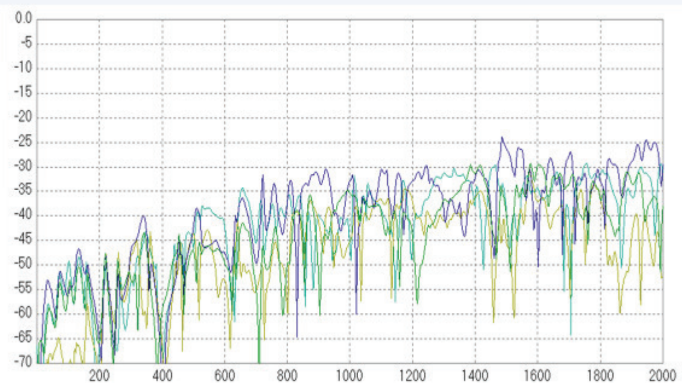


The measured screening attenuation (Ssc21) of about 8 to 12 dB of the unscreened pairs can be explained by the remaining pairs which acts as **"inner screen"**.

Far end unbalance- & coupling attenuation of a Cat5e



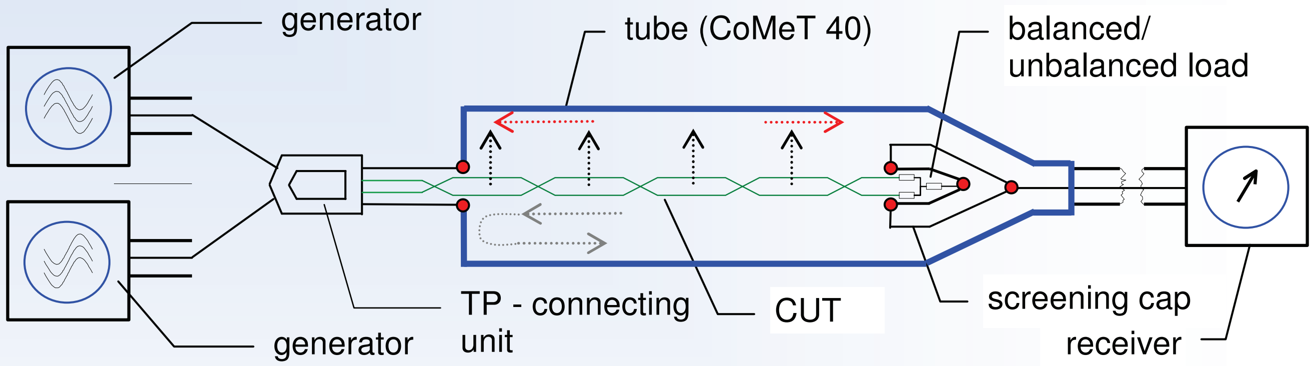
far end unbalance attenuation
of an unscreened Cat5e (Scd21)

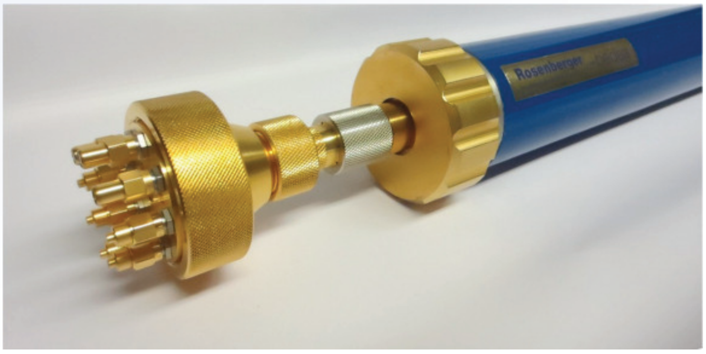


far end coupling attenuation
of an unscreened Cat5e (Ssd21)

The far end coupling attenuation (Ssd21) is about 5 to 10 dB better than the far end unbalance attenuation (Scd21), probably due to the screening effect of the remaining pairs with a trend to get equal values at higher frequencies.

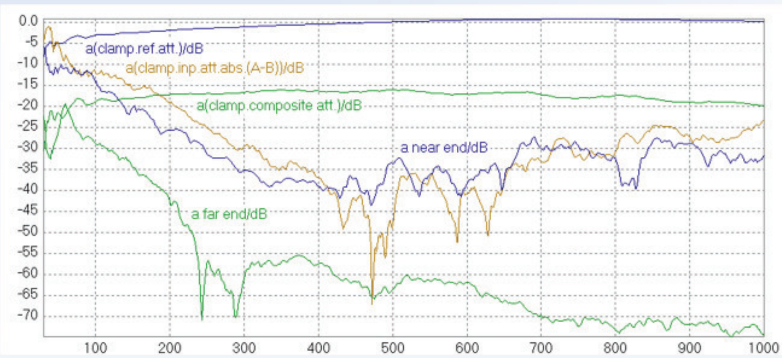
TP-connecting unit for balunless meassurement





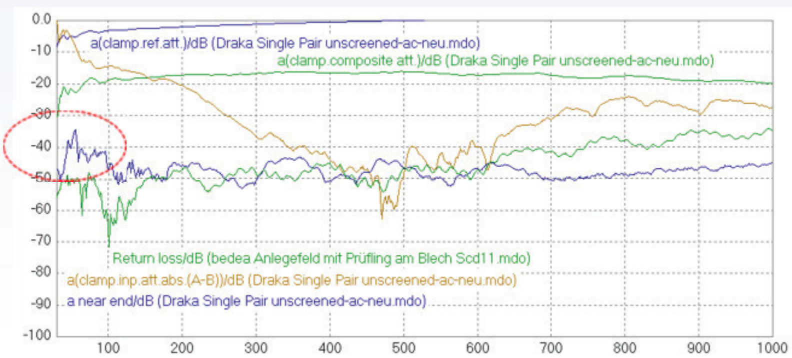
The TP-connecting unit is connected to the triaxial tube with consistently ground connection

Screening- and Coupling attenuation with MDS 21



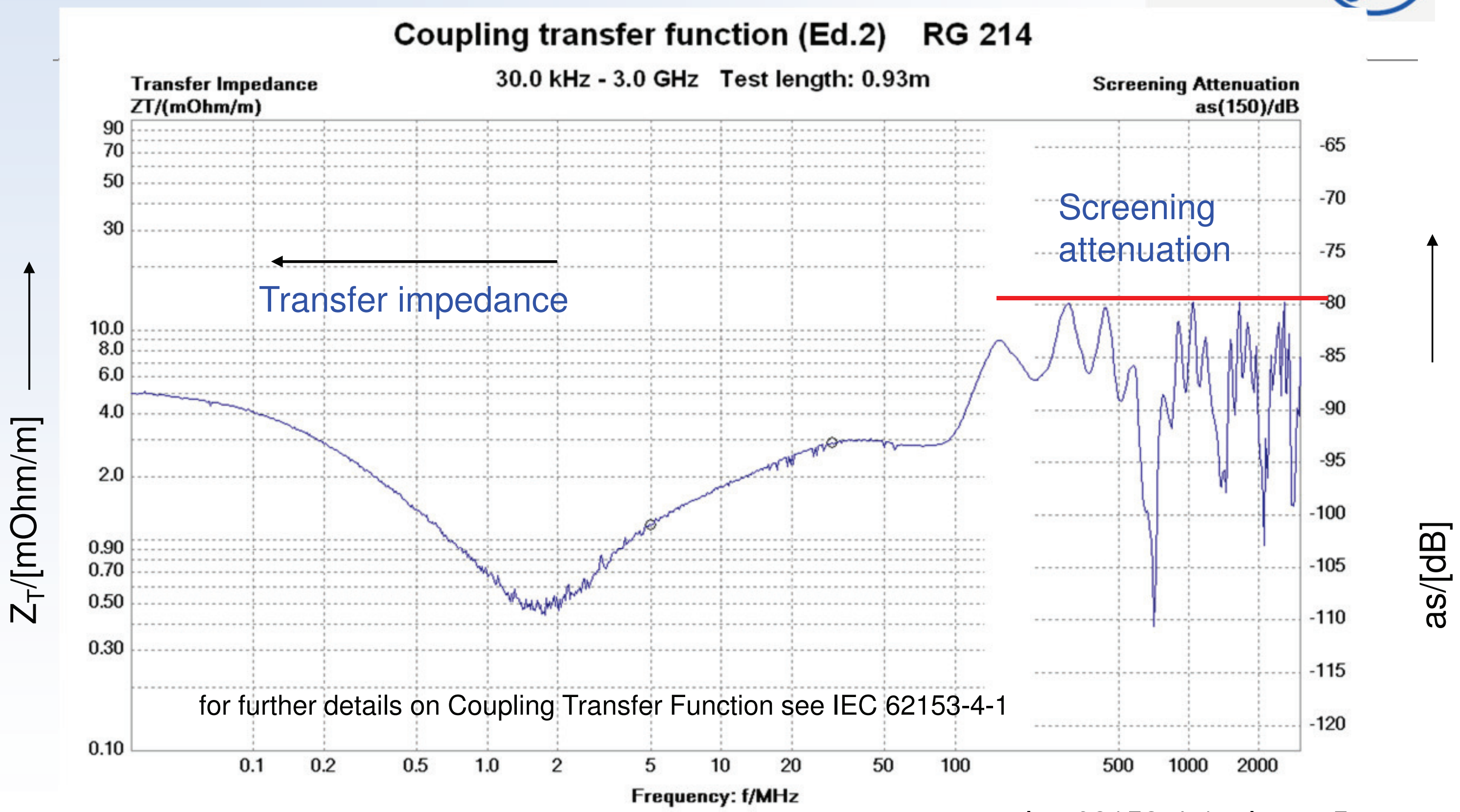
Screening attenuation of an unscreened balanced pair with absorbing clamp MDS 21

The absorber of the clamp suppresses the common mode currents.
At near end screening att. measurement, the attenuation of the absorber is actually measured;
hence Screening attenuation measurement of an unscreened balanced pair with clamps does not make any sense.



Coupling attenuation of an unscreened balanced pair with absorbing clamp MDS 21

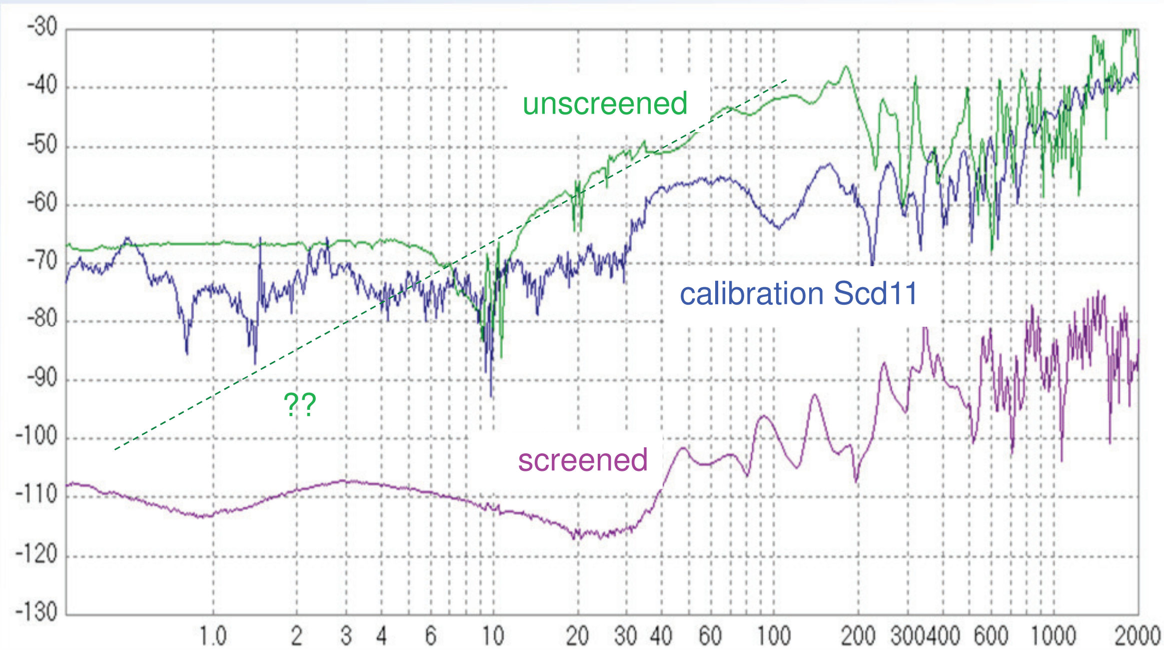
Coupling attenuation measurements of an unscreened balanced pair shows poor values below 100 MHz;
due to the poor attenuation of the absorber below 100 MHz.
(should be discussed with IEC TC 46/WG5)



see also 62153-4-1, clause 5

Low frequency Coupling attenuation

Low frequency Coupling attenuation of single balanced pairs can be measured with the same set-up as for Coupling attenuation but starting at 9 kHz



The unbalance of the TP-connecting unit shall be considered; test length 3m, **Ssd21**

Measurement uncertainties

When measuring unbalance or coupling, unbalance of test set-up shall be considered

Optimally calibrated and phase-stabilized measuring devices (VNA, test leads and connecting units) show a specific frequency-dependent course of a system-mode conversion.

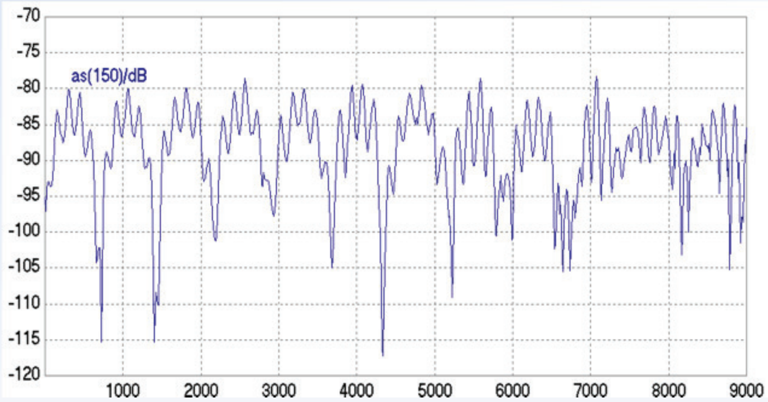
This is at low frequencies between -80dB and -70dB and increases with increasing frequencies at about -60 to -40dB. Depending on the phase position, this system-mode conversion superimposes the mode conversion of the test object constructively or destructively.

The result of the measurement is thereby falsified and, in particular, very strong if the amount of the mode conversion of the test object approaches or even undershoots the amount of the system mode conversion.

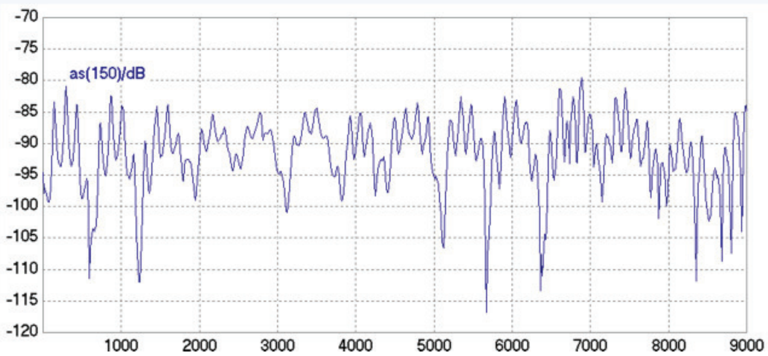
All Low frequency Coupling attenuation ($a_{C,lf}$) measurements (slide 18) may be victims of such overlays. The system values should therefore be recorded and included in the measurement uncertainty analysis.

An estimation of the system mode conversion can be done by measuring the reflected mode conversion parameter Scd11 with a TP-connecting unit having an open loop;

Measurements at higher frequencies



Screening attenuation of a RG 214 up to 9 GHz in Triaxial tube CoMeT 40



Screening attenuation of a RG 214 up to 9 GHz in Triaxial cell with magnetic absorber

Conclusion

- The Triaxial test procedure is well established to measure Transfer impedance Z_T and Screening attenuation a_S – or Coupling attenuation a_C on communication cables, connectors and components since more than 80 years.
- EMC of screened & unscreened balanced cables below 30 MHz can be measured as “Low frequency Coupling attenuation” $a_{C,lf}$ from less than 9 kHz (DC) upwards.
- It could be shown, that (Screening-) and Coupling attenuation of unscreened balanced pairs can be measured easily with the triaxial test procedure, (Coupling attenuation a_C of single unscreened pairs = unbalance attenuation a_U)
- Hence the triaxial test procedure should be the preferred procedure respectively the reference procedure to measure the coupling attenuation of screened and unscreened balanced cables as already established for coaxial cables.
- Advantages of the triaxial procedure: Continiously screened test set-up also for unscreend pairs with well defined ground connections and a broad frequency range from DC up to and above 3 GHz !
- Further measurements from different test laboratories should be performed
- Calibration of clamp procedure for unscreened pairs shall be discussed.
- Further questions: *bernhard.mund@bda-c.com*

Progress of International Standards for Triaxial Procedure

TS 62153-4-1	Introduction to electromagnetic (EMC) screening measurements	2014-01	**published**
62153-4-3Ed2	Surface transfer impedance - Triaxial method	2013-10	**published**
62153-4-4Ed2	Shielded screening attenuation, test method for measuring of the screening attenuation a_S up to and above 3 GHz	2015-04	**published**
62153-4-7Ed2	Shielded screening attenuation test method for measuring the Transfer impedance Z_T and the screening attenuation a_S or the coupling attenuation a_C of RF-Connectors and assemblies up to and above 3 GHz, Tube in tube method	2015-12	**published**
62153-4-9Ed2	Electromagnetic Compatibility (EMC) – Coupling attenuation, triaxial method	2018-04	**published**
62153-4-10Ed2	Shielded screening attenuation test method for measuring the Screening Effectiveness of Feedtroughs and Electromagnetic Gaskets	2015-11	**published**
62153-4-15	Test method for measuring transfer impedance and screening attenuation - or coupling attenuation with Triaxial Cell	2015-12	Revision in preparation
62153-4-16	Relationship between surface transfer impedance and screening attenuation, Conversion a_S and Z_T	2016-10	**published**

Literature

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[02] Thomas Hähner, Bernhard Mund: EMV-Verhalten symmetrischer Kabel – EMC Journal 4/1997

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Standardization – 1985

Standardization - today