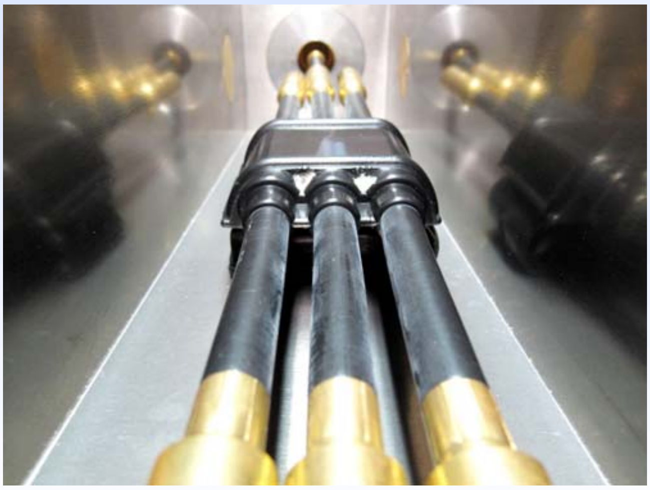
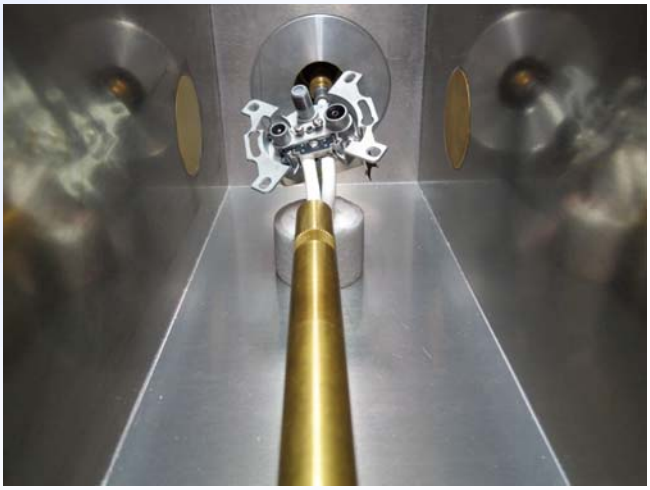
EMC of Cables & Connectors & test methods with Triaxial test procedure



CATV - Tap off in Triaxial Cell 1000/150



CATV - Wall outlet in Triaxial Cell 1000/150 with Tube in tube

Progress of International Standards for Triaxial Procedure,

TR 62153-4-1 Ed2	Introduction to electromagnetic (EMC) screening measurements	2007-11	**46/438/CD**
62153-4-3Ed2	Surface transfer impedance - Triaxial method	2006-03	**46/471/FDIS**
62153-4-4Ed2	Shielded screening attenuation, test method for measuring of the screening attenuation a_S up to and above 3 GHz	2006-05	**46/439/CDV**
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	2006-04	**46/459/CD**
62153-4-9Ed2	Electromagnetic Compatibility (EMC) – Coupling attenuation, triaxial method	2008-03	in preparation
62153-4-10Ed2	Shielded screening attenuation test method for measuring the Screening Effectiveness of Feedtroughs and Electromagnetic Gaskets	2009-05	**46/494/CD**
62153-4-15	Test method for measuring transfer impedance and screening attenuation - or coupling attenuation with Triaxial Cell		**46/454/CD**
62153-4-16	Relationship between surface transfer impedance and screening attenuation, Conversion a_S and Z_T		under consideration

Outline

- Physical Basics of Cable Screening
  - Definitions, electrical length
  - Coupling Transfer Function
- Revised and new Standards for Triaxial test procedures
  - IEC 62153-4-3Ed2, Transfer impedance
  - IEC 62153-4-4Ed2, Screening attenuation
  - IEC 62153-4-7Ed2, a_S & Z_T with Tube in tube
  - IEC 62153-4-9, Coupling Attenuation
  - IEC 62153-4-15, Triaxial Cell
  - IEC 62153-4-16, Conversion of a_S and Z_T
- Conclusion & Discussion

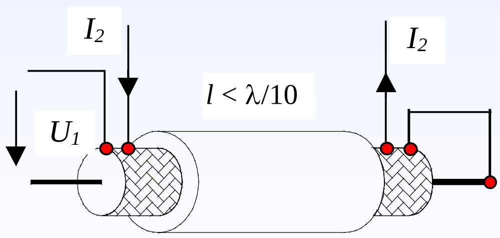
Definitions, electrical length

high frequencies: Screening attenuation

$$a_S = 10 \log (P_1/P_2) = 20\log_{10} (U_1/U_2) \text{ [dB]}$$

Ratio of two powers --> **length independent**

low frequencies: Transfer impedance



$$Z_T = \frac{U_1}{I_2} \quad [\text{m}\Omega/\text{m}]$$

Ratio of **U/I = R** --> **length dependent (Ohms law)**

Wave length λ

λ = (c_0 • v_k) / f

electrically long:

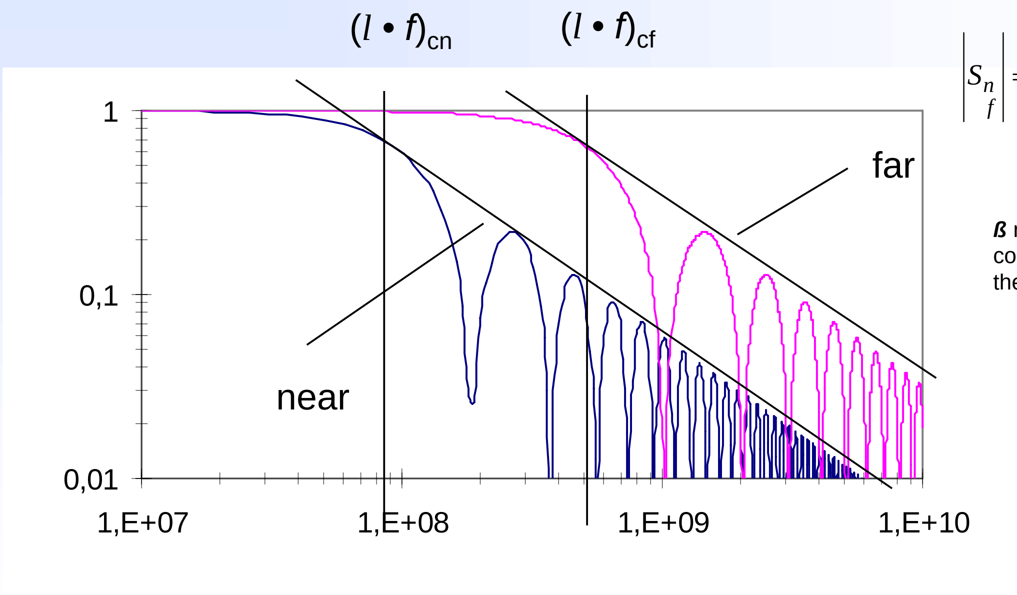
$$f > \frac{c_o}{2 \cdot l \cdot \left|\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}\right|}$$

electrically short:

$$f < \frac{c_o}{10 \cdot l \cdot \sqrt{\varepsilon_{r1}}}$$

(IEC 62153-4-3/-4-4)

Theory: The Summing Function S_{nf}



$$\left|S_{\frac{n}{f}}\right| = \frac{\left|2\sin\left(\frac{(\beta_1 \pm \beta_2).L_c}{2}\right)\right|}{(\beta_1 \pm \beta_2).L_c}$$

≈ sin x/x

ß represents the phase constant of the inner resp. the outer circuit

low frequencies

$$\left|S_{\frac{n}{f}}\right| \rightarrow 1$$

high frequencies

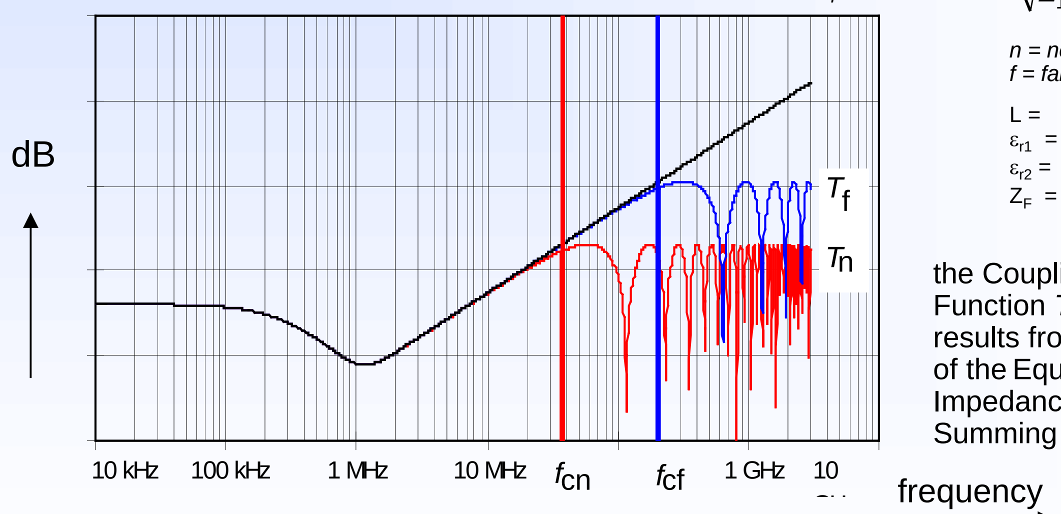
$$\left|S_{\frac{n}{f}}\right| \rightarrow \frac{2}{(\beta_1 \pm \beta_2)\cdot l}$$

(oscillating behaviour)

introduced by Halme/Szentkuti 1988, [8]

Calculated Coupling Transfer Function, T_{nf}

a_s and Z_T vs frequency



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

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 multiplication of the Equivalent Transfer Impedance Z_{TE} and the Summing Function S_{nf}

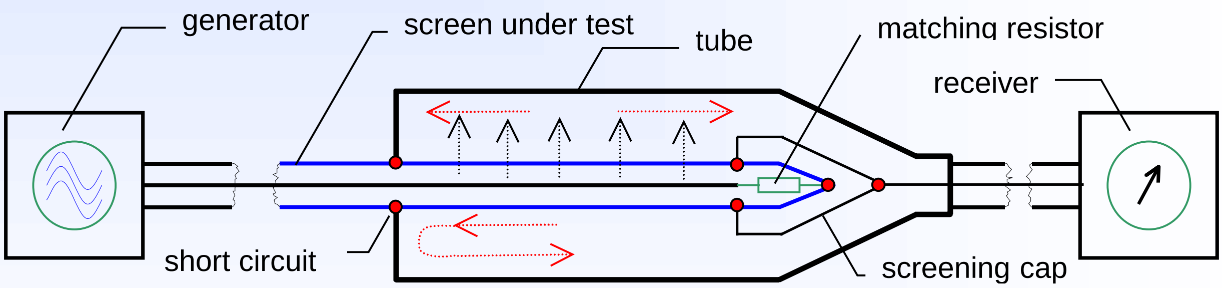
Transfer impedance ←

Screening attenuation →

Measuring with the Triaxial test set-up *CoMeT*

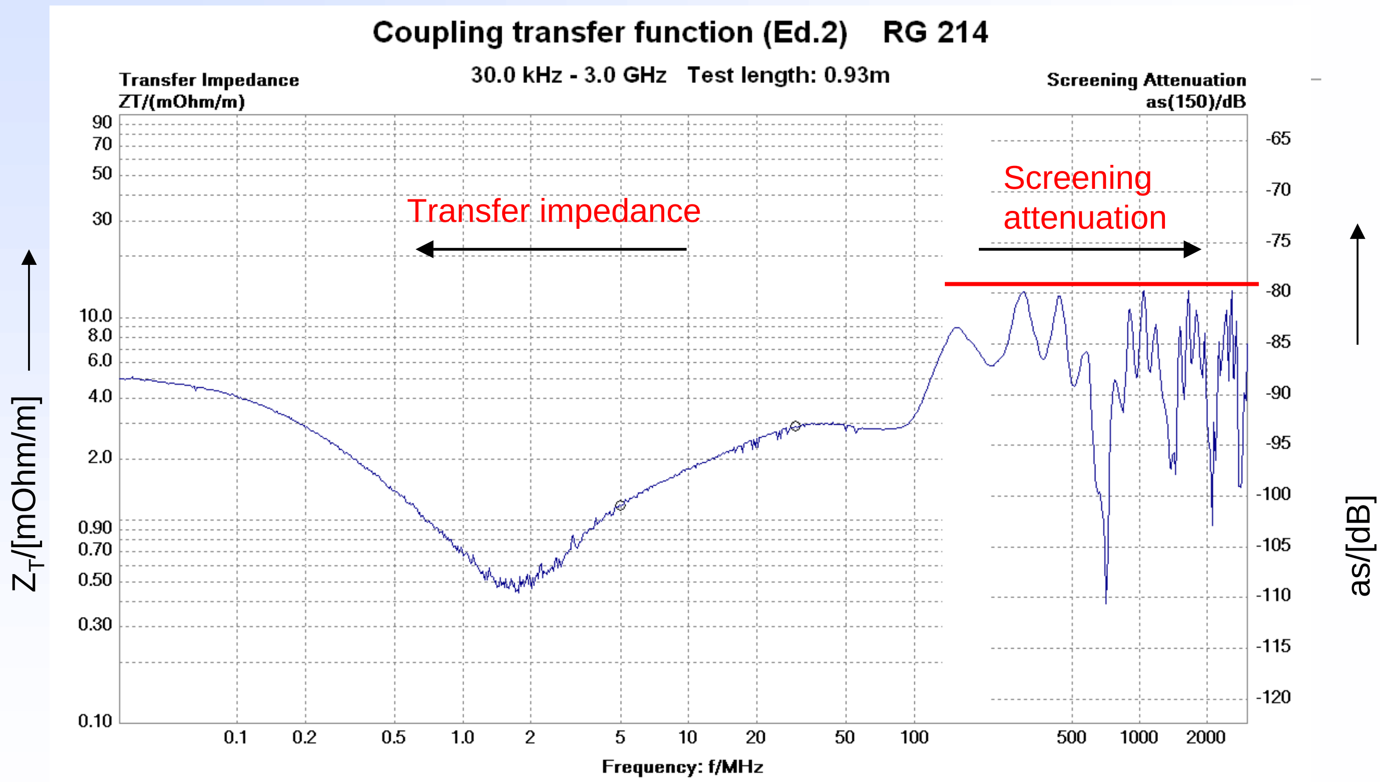
Transfer impedance & Screening attenuation

DC up to and above 12 GHz with one test set-up

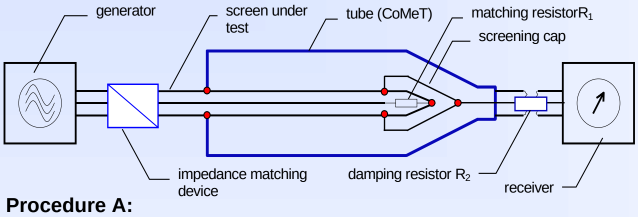


Generator and receiver are included in a modern network analyser

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



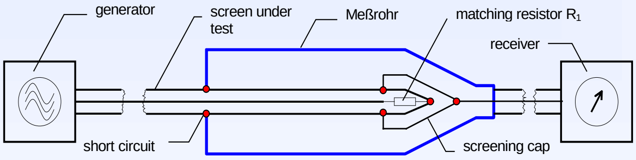
Changes of IEC 62153-4-3, Transfer impedance



Procedure A:
Matched inner circuit with damping resistor in outer circuit R_2

matched – matched – short

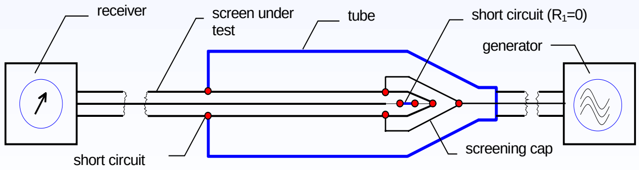
$$Z_T = \frac{R_1(Z_0+R_2)}{Z_0 L_c} 10^{-\left\{\frac{a_{meas} - a_{cal} - \left(a_{pad} + 10\log_{10}\left(\frac{Z_0}{Z_{CUT}}\right)\right)}{20}\right\}}$$



Procedure B:
Inner circuit with load resistor and outer circuit without damping resistor

mismatched –matc hed– short

$$Z_T = \frac{R_1 + Z_0}{2 \cdot L_c} \cdot 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}}$$



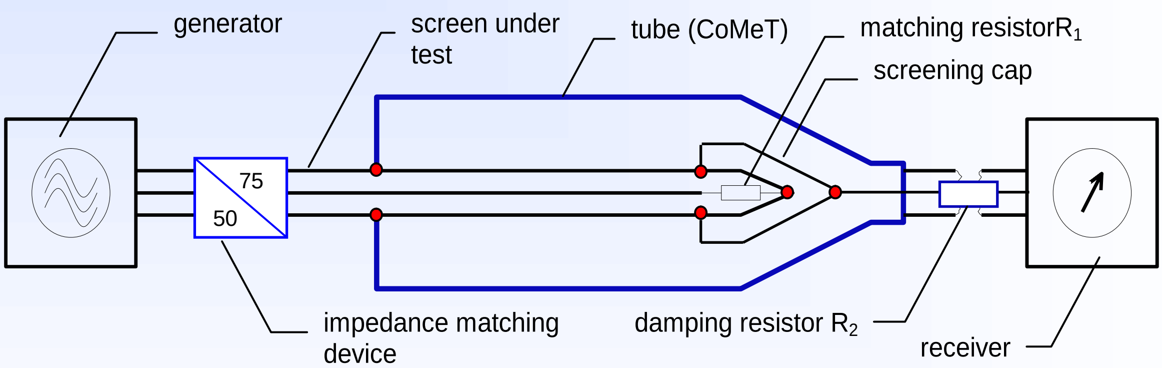
Procedure C:
(Mismatched)-Short-Short without damping resistor

mismatched – short – short

$$Z_T = \frac{Z_0}{2 \cdot L_c} \cdot 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}}$$

Procedure A: Matched inner circuit with damping resistor R_2

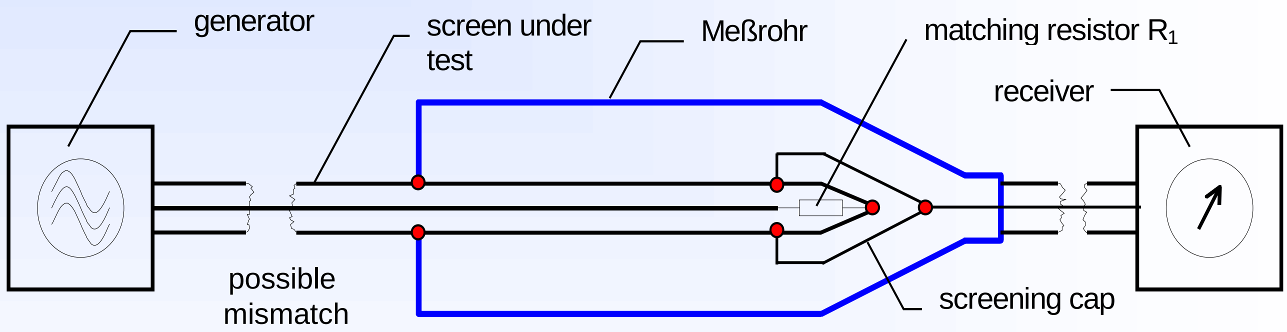
matched – matched – short with damping resistor R_2



$$Z_T = \frac{R_1(Z_0+R_2)}{Z_0 L_c} 10^{-\left\{\frac{a_{meas} - a_{cal} - \left(a_{pad} + 10\log_{10}\left(\frac{Z_0}{Z_{CUT}}\right)\right)}{20}\right\}}$$

Procedure B: Mismatched and inner circuit with load resistor

mismatched – matched – short

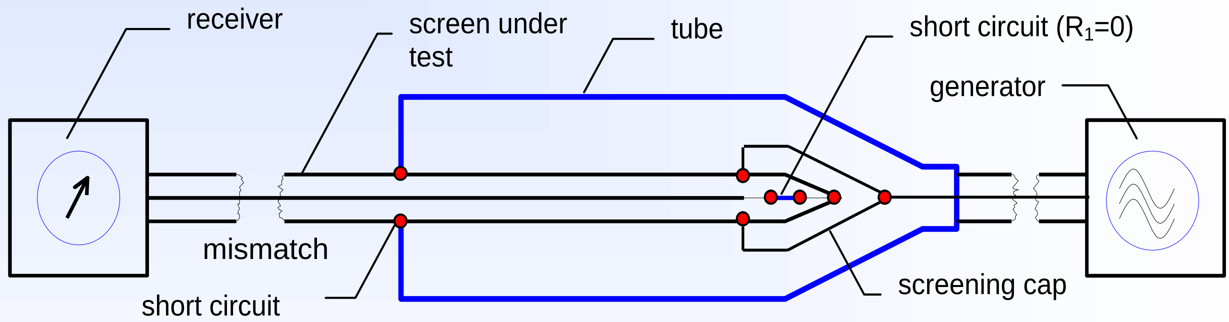


$$Z_T = \frac{R_1 + Z_0}{2 \cdot L_c} \cdot 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}}$$

usable for both,
Transfer impedance
and Screening attenuation

Procedure C: (Mismatched)-Short-Short without R_2

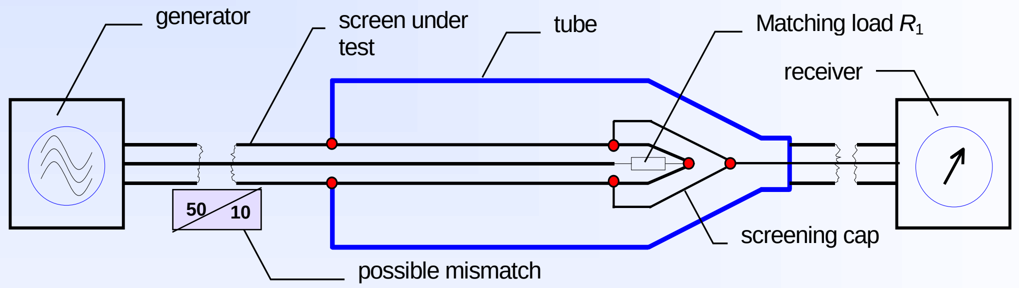
mismatched – short – short



$$Z_T = \frac{Z_0}{2 \cdot L_c} \cdot 10^{-\left\{\frac{a_{meas} - a_{cal}}{20}\right\}}$$

generator and receiver are interchanged
against Procedure A and Procedure B
highest sensitivity up to the µOhm range

Changes of IEC 62153-4-4, Screening attenuation



innerer circuit with matching load $R_1 = Z_1$

$$a_S = 10\cdot\log_{10}\left|\frac{P_1}{P_{r,max}}\right| = 10\cdot\log_{10}\left|\frac{P_1}{P_{2,max}}\cdot\frac{2\cdot Z_S}{Z_1}\right|$$

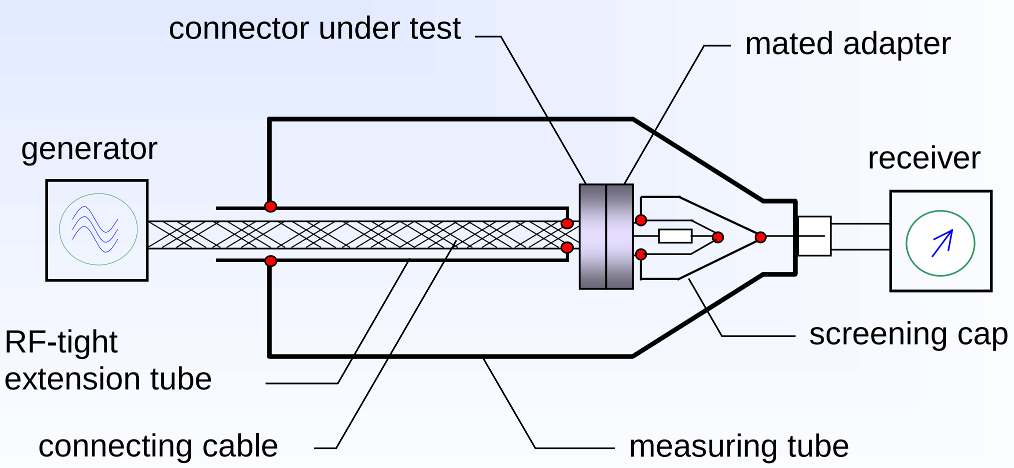
$$a_S = Env\left\{-20\cdot\log_{10}|S_{21}| + 10\cdot\log_{10}|1-r^2| + 10\cdot\log_{10}\left|\frac{300\Omega}{Z_1}\right|\right\}$$

The term $|1 - r^2|$ represents the reflexion attenuation due to the mismatch between generator and DUT
In case of mismatch of 50 Ohm output imedance of the generator to e.g. 10 Ohm impedance of the DUT, the correction value is about 2,5 dB !

Reflexion coefficient $r = \left|\left(\frac{Z_0 - Z_1}{Z_0 + Z_1}\right)\right|$

IEC 62153-4-7Ed2, Triaxial set-up with “Tube in tube“

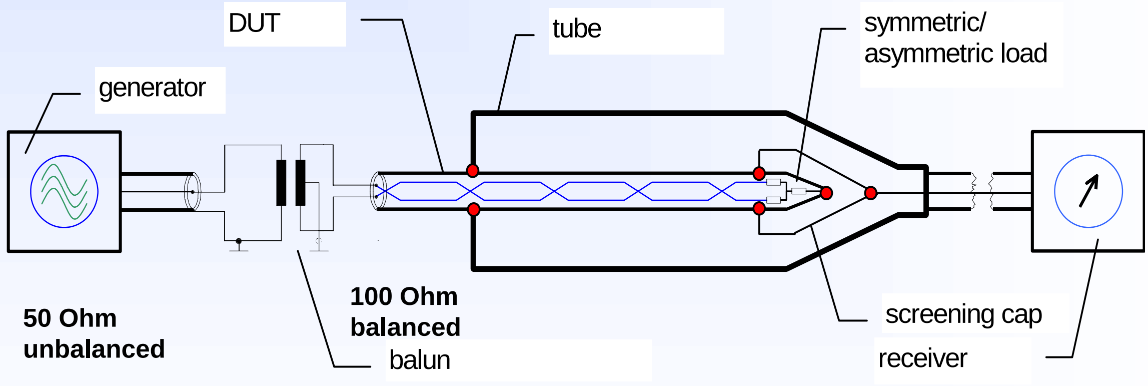
Edition 2 of IEC 62153-4-7, includes the changes of 62153-4-3, Transfer impedance and of 62153-4-4, Screening attenuation.



IEC 62153-4-7Ed2, Transfer impedance and Screening attenuation of connectors and assemblies, Tube in tube test procedure

Measuring of Coupling attenuation

Coupling attenuation is the sum of the Unbalance attenuation of the pair and the Screening attenuation of the screen



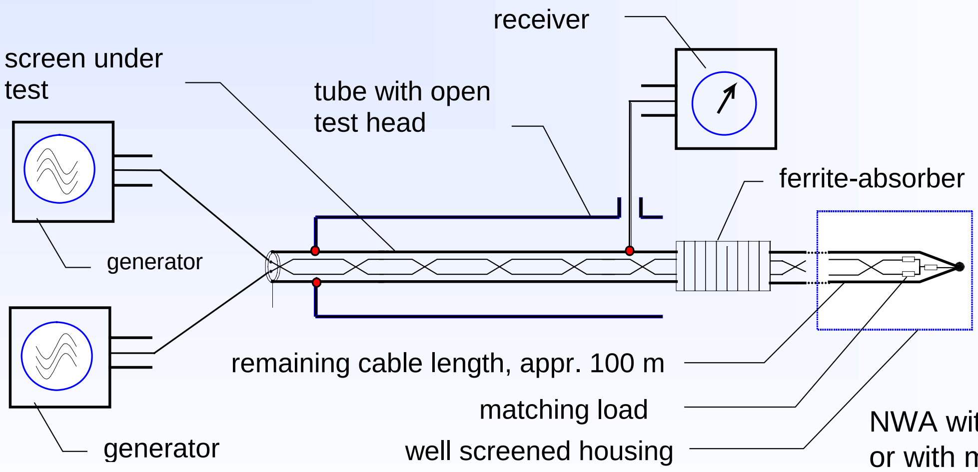
simplified method with standard test head

IEC 62153-4-9, Coupling attenuation, triaxial method, **(simplified)**

EMC of cables, connectors and components with Triaxial test procedure bedea

Balunless Coupling attenuation (open head)

Baluns are commercial available up to about 1.2 GHz,
new cable constructions according to IEC 61156-9 (46C/976/NP) and IEC 61156-10 (46C/976/NP) or to TIA specifications require to measure Coupling attenuation up to 1,6 resp. 2 GHz



NWA with two generators or with mixed mode option

IEC 62153-4-9, Coupling attenuation, Triaxial method, **(open test head)**
procedure with 2 generators and influence of unbalance attenuation is under consideration at IEC TC 46/WG 5

Balunless Coupling attenuation (simplified, standard head)

Baluns are commercial available up to about 1.2 GHz
new cable constructions according to IEC 61156-9 (46C/976/NP) and IEC 61156-10 (46C/976/NP)
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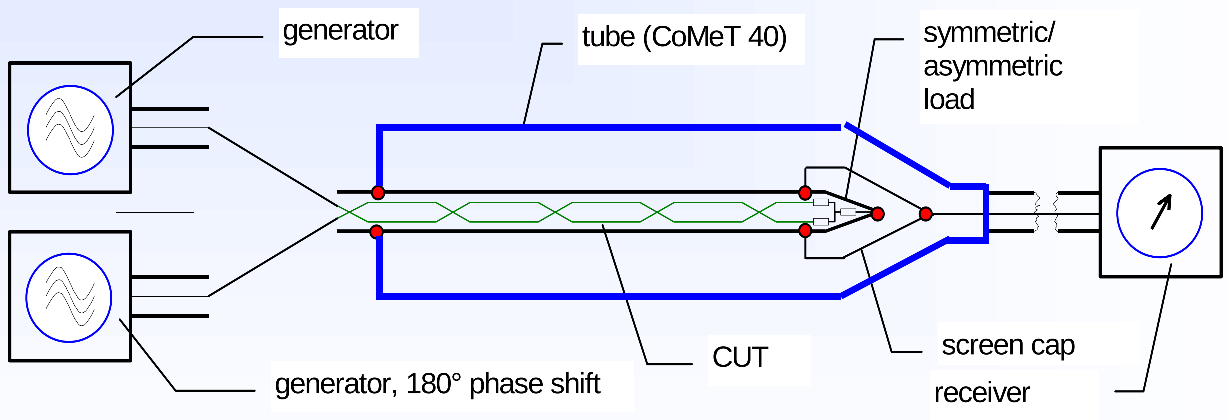
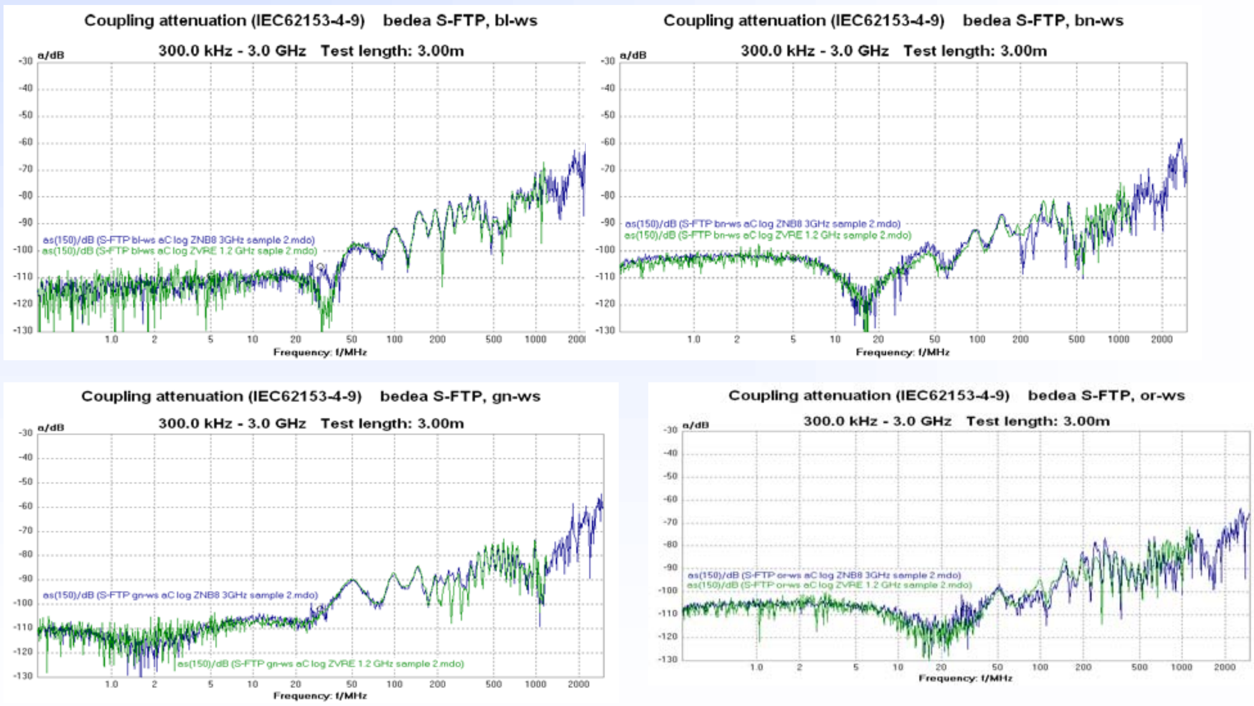


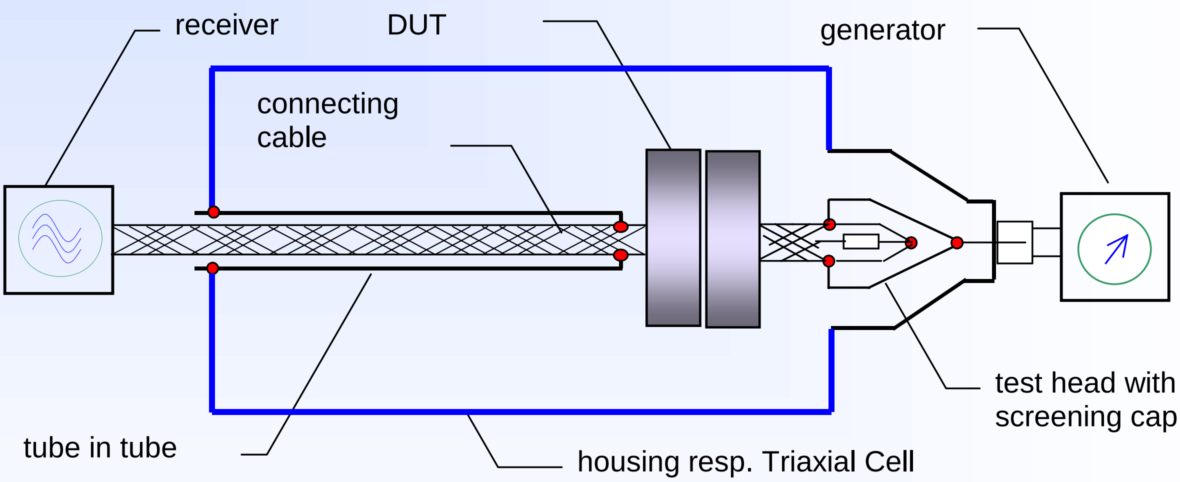
IEC 62153-4-9, Coupling attenuation, Triaxial method, (simplified)
procedure with 2 generators and influence of unbalance attenuation is under consideration at IEC TC 46/WG 5

Balunless vs balun, S-FTP cable



Different designs of Triaxial Cells

Triaxial Cell with Tube in tube, principle



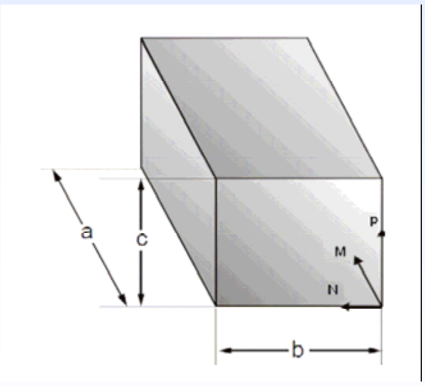
IEC 62153-4-15, Transfer impedance and screening attenuation with Triaxial cell and with Tube in tube procedure

IEC 62153-4-15, includes the changes of 62153-4-3, Transfer impedance and of of 62153-4-4, Screening attenuation.

Higher order modes of cavity

Resonance frequencies:

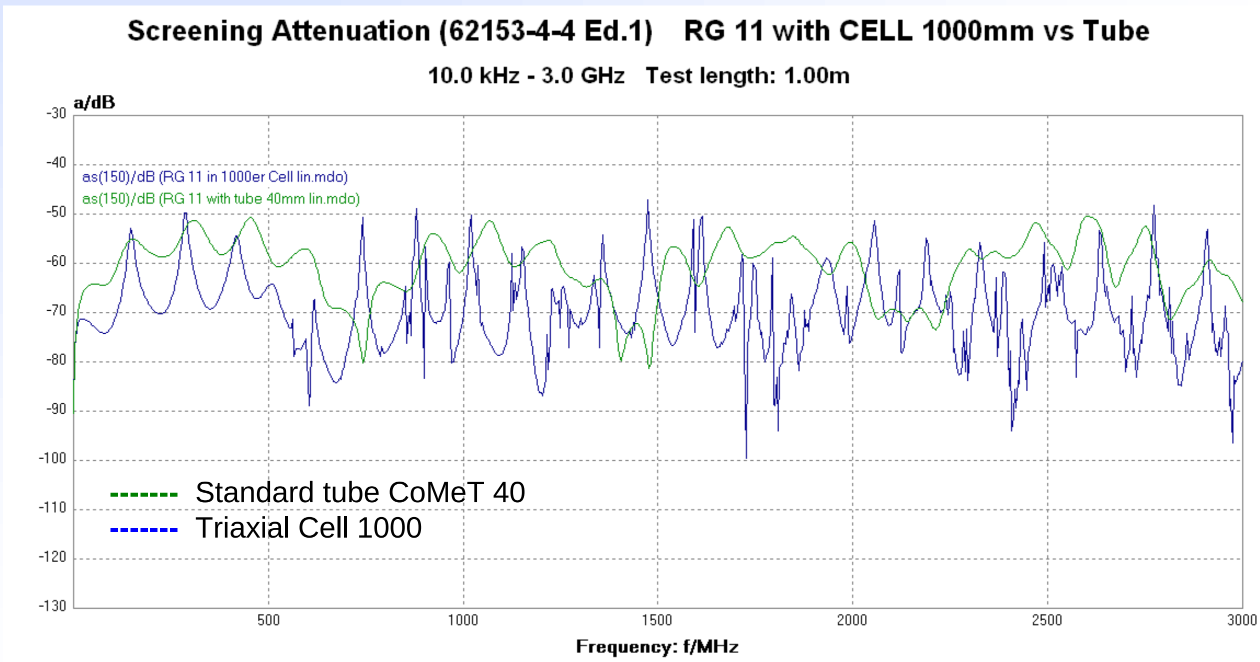
$$f_{mnp} = \frac{c_0}{2}\sqrt{\left(\frac{M}{a}\right)^2 + \left(\frac{N}{b}\right)^2 + \left(\frac{P}{c}\right)^2}$$



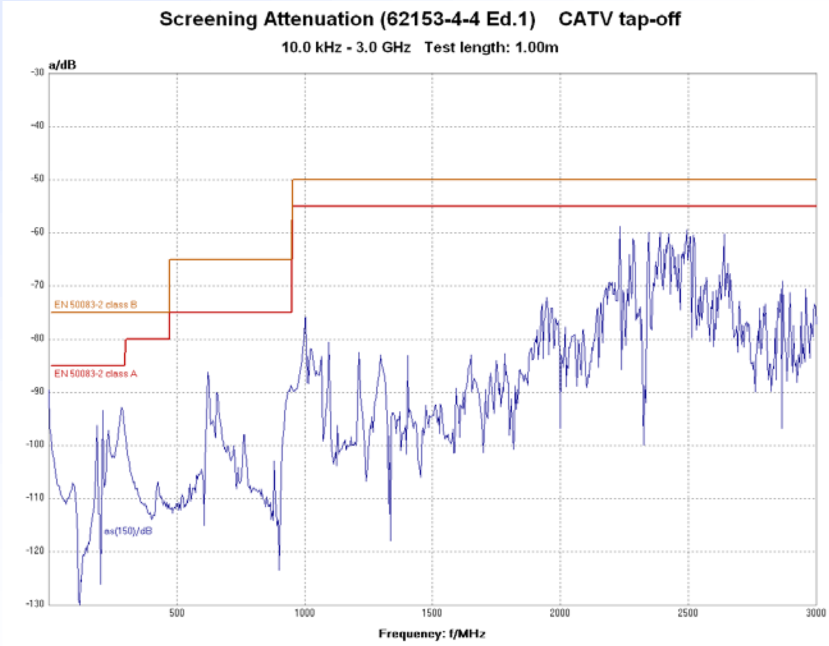
m, n, p: numbers of higher order modes
(whole numbered, 2 of 3 >0), a, b, c: size of cavity

750-er Cell				1000/300-er Cell				1000/150-er Cell			
a	b	c		a	b	c		a	b	c	
750	250	250		1000	300	300		1000	150	150	
m	n	p	f/GHz	m	n	p	f/GHz	m	n	p	f/GHz
1	**1**	**1**	**0,87**	**1**	**1**	**1**	**0,72**	**1**	**1**	**1**	**1,41**
1	2	0	1,22	1	2	0	1,01	1	2	0	2,00
0	2	1	1,34	0	2	1	1,12	0	2	1	2,24
1	2	1	1,36	1	2	1	1,13	1	2	1	2,24
2	2	0	1,26	2	2	0	1,04	2	2	0	2,00
0	1	2	1,34	0	1	2	1,12	0	1	2	2,24
1	1	2	1,36	1	1	2	1,13	1	1	2	2,24
2	2	1	1,40	2	2	1	1,16	2	2	1	2,24
0	2	2	1,70	0	2	2	1,41	0	2	2	2,83
1	2	2	1,71	1	2	2	1,42	1	2	2	2,83
2	3	0	1,84	2	3	0	1,53	2	3	0	3,00

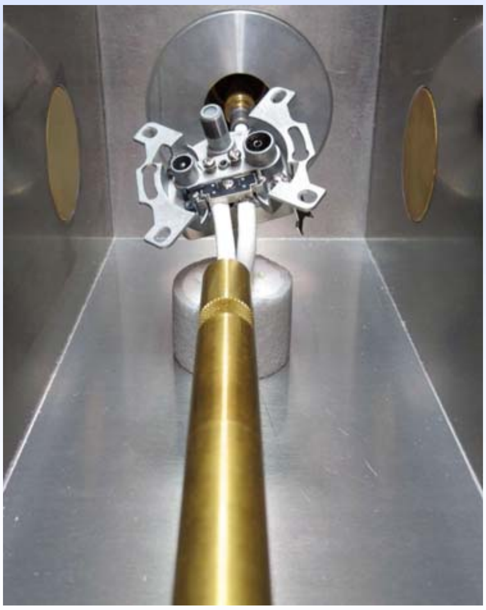
Comparison of RG 11 with Triaxial Cell and with Tube

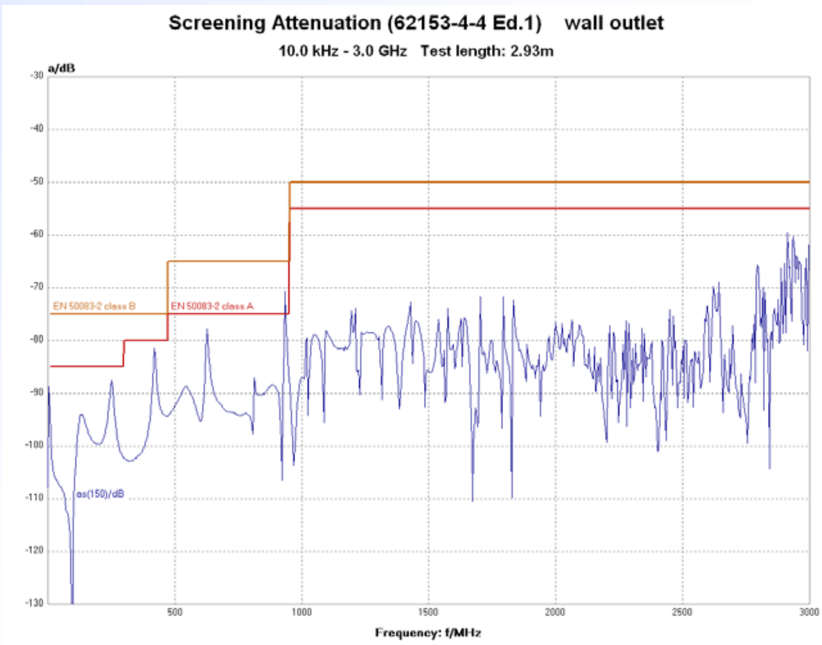


CATV-Tap-off with Triaxial Cell



CATV-wall outlet with Triaxial Cell





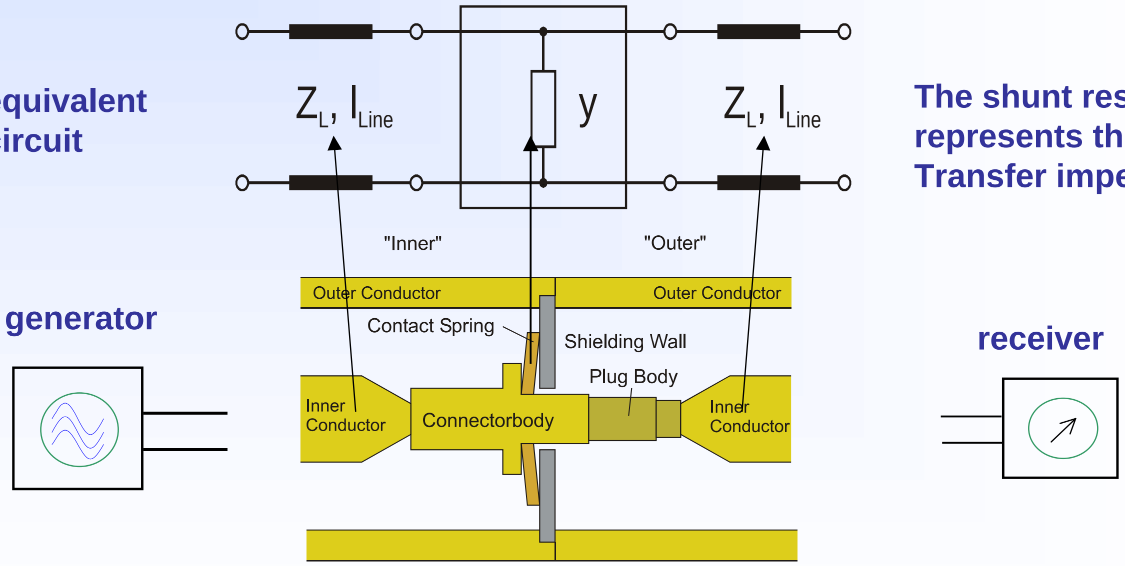
EMC of Feed-throughs & EMC Gaskets

equivalent circuit

The shunt resistor Y represents the Transfer impedance

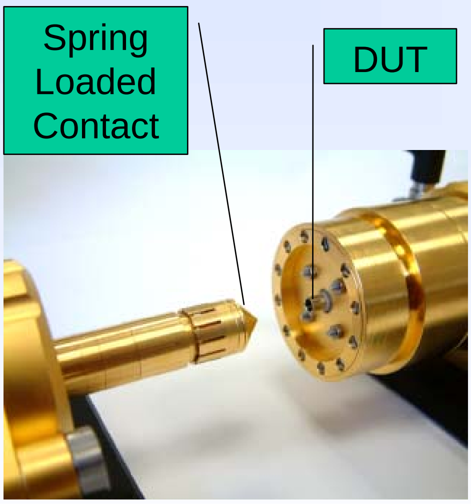
generator

receiver



Generator & receiver are included in the NWA

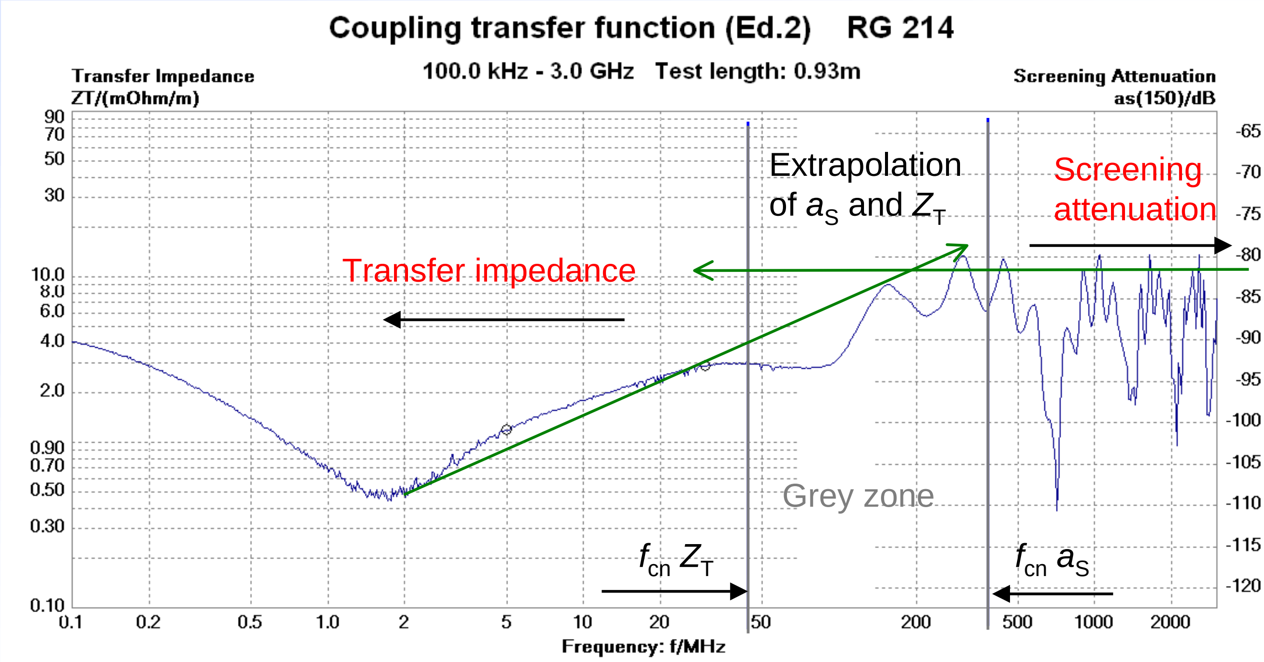
Test set-up for Feed-throughs & Gaskets



Practical design of the test-set-up

IEC 62153-4-10Ed2, Edition 2 is under consideration, 46/494/CD

Draft IEC 62153-4-16, Conversion of a_S and Z_T

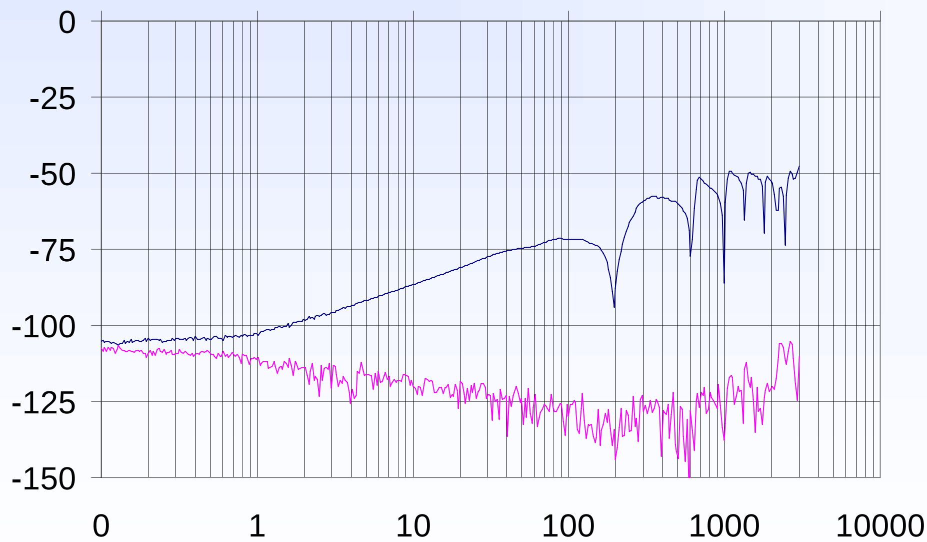


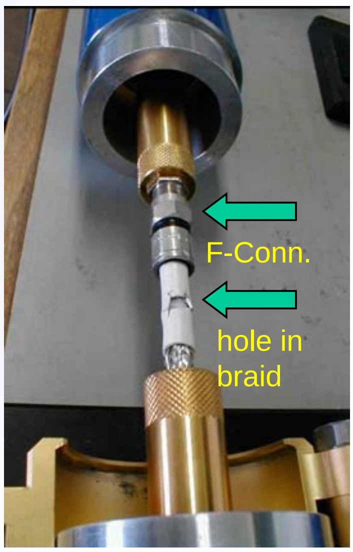
draft standard by Thomas Hähner

Cable with small hole, tube in tube, 0,5 m

Well screened CATV-Cable
with F-Connector

Same cable with one small hole, 3 mm





Conclusion 1

- The Screening effectiveness of Communication cables and connectors is described in the lower frequency range by the **Transfer impedance Z_T** and in the upper frequency range by the **Screening attenuation a_S**.
- With the **Triaxial Test set-up** one can measure **Transfer impedance Z_T** as well as the **Screening attenuation** a_S from DC up to 8 (12) GHz
  - with **one test set-up !**
- Furthermore, the **Coupling attenuation a_C** of screened balanced pairs can be measured balunless up to 3 GHz.
- With the revised standards of the triaxial test procedures according to the **IEC 62153-4-n** series, one can measure now with mismatch,
  - impedance matching devices are no longer needed.
- With multi port NWAs one can measure Coupling attenuation of balanced cables and components „“balunless“ up to 3 GHz.
- **Triaxial Cells** allow the measurement of larger connectors & components.

Conclusion 2

- **Advantages of the triaxial test-set-up**:
  - simple and easy sample preparation,
  - only one test set up for Z_T, a_S & $a_{C,}$
  - high sensitivity up to and above 125 dB (only limited by the NWA),
  - no radiation of electromagnetic energy,
  - covers the whole frequency range from DC up to 12 GHz,
  - high reproducibility.

- Further development is the **Conversion of a_S and Z_T**, IEC 62153-4-16
- Standards of the 62153-4-n series are maintained by IEC TC 46/WG 5

- This presentation & further information: *www.bedea.com*
- Contact person & further questions *bmund@bedea.com*

Literature

[1] Thomas Hähner, Bernhard Mund, “Balunless” Measurement of Coupling Attenuation of Balanced Cables & Components, Wire & Cable Technology international 07-2013.

[2] Bernhard Mund, Thomas Schmid: EMC of HV cables and components with Triaxial Cell, Wire & Cable Technology International/January & March 2012

[3] Bernhard Mund: EMC of Cables & Connectors & Test methods, EMC Zurich 2007

[4] Lauri Halme, Bernhard Mund et. al, Measurement of the Shielding or Screening Effectiveness of Feed-throughs and Electromagnetic Gaskets up to and above 4 GHz, IWCS (International wire and cable symposium) 2007.

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

[6] Thomas Hähner und Bernhard Mund: Measurement of the screening effectiveness of connectors & cable assemblies: International Wroclaw Symposium on Electromagnetic Compatibility, EMC 2002

[7] O. Breitenbach, T. Hähner, B. Mund, "Screening of cables in the MHz to GHz frequency range extended application of a simple measuring method", Colloquium on screening effectiveness measurements, Savoy Place London, 6 May 1998, Reference No:1998/452.

[8] Lauri Halme, Balint Szentkuti, The background for electromagnetic screening measurements of cylindrical screens. Tech. Rep. PTT(1988) No. 3.

CoMeT
Coupling Measuring Tube

Thank you for your attention

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