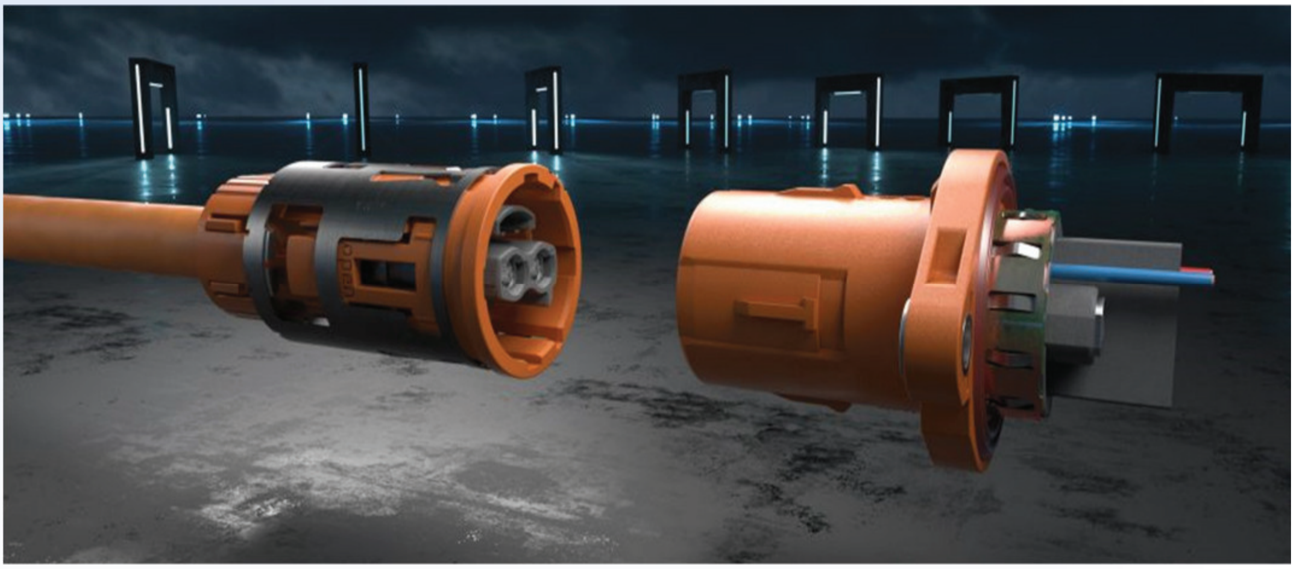
Analysis, optimization and verification of an HV connector



HV-Connector PowerStar HPS40-2, Hirschmann Automotive, www.hirschmann-automotive.com

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Overview

- Requirements for HV connectors
  - HV-connectors & EMC
- Test procedures for Screening effectiveness
  - Line injection procedure, Triaxial procedure
- Simulation und Analysis
  - Motivation & Method,
  - Triaxial cell with HV-connector,
  - Quantitative Analysis, Delta transfer impedance
  - Qualitative Analysis,
- Test adapter
- Comparison of Simulation & Measurement
- Conclusion & Outlook

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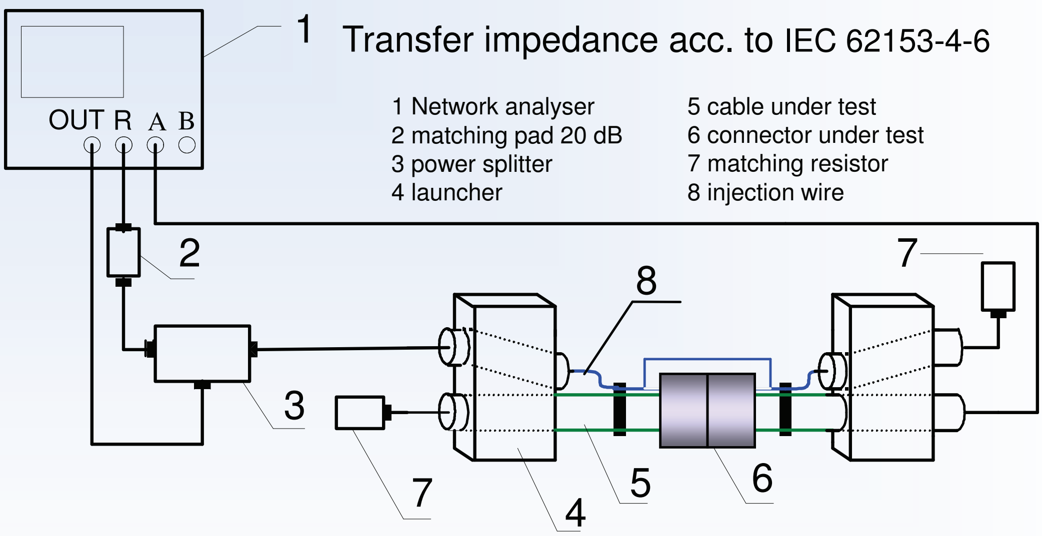
Requirements for HV connectors

- full functionality at voltages of up to 1000 V
- continuous current carrying capacity: 280 A at 23°C or 195 A at 83°C
- temperature range from - 40 °C to +170 °C
- low emission resp. high immunity, for both, new and aged connectors:
  - Transfer impedance: between 2 mΩ und 10 mΩ
  - Screening attenuation: up to 70 dB at 300 MHz – fresh and after aging
- low weight
- inexpensive design

Another aspect of the reduction of electrosmog in the electric car through appropriate shielding of the components is the protection of the occupants.

Line injection procedure



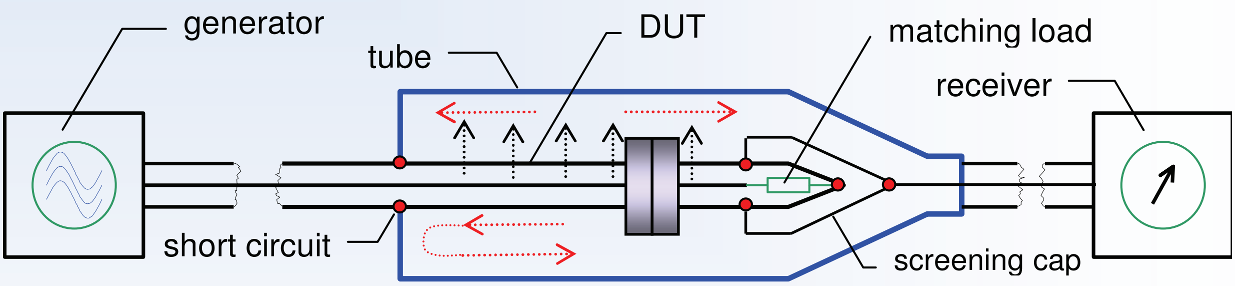
Transfer impedance acc. to IEC 62153-4-6

1 Network analyser
2 matching pad 20 dB
3 power splitter
4 launcher
5 cable under test
6 connector under test
7 matching resistor
8 injection wire

The Line injection procedure exhibits different drawbacks:
- Measurement at the near and far end required, - matching of the feed wire is critical, 20 dB required
- repeated turning of the test object and/or changing of the feed wire to cover all problem areas,
- with the feed wire method, only the transfer impedance can be measured, not the screening attenuation, Furthermore, simulation with triaxial test procedure becomes more easy

Principle of the Triaxial test procedure

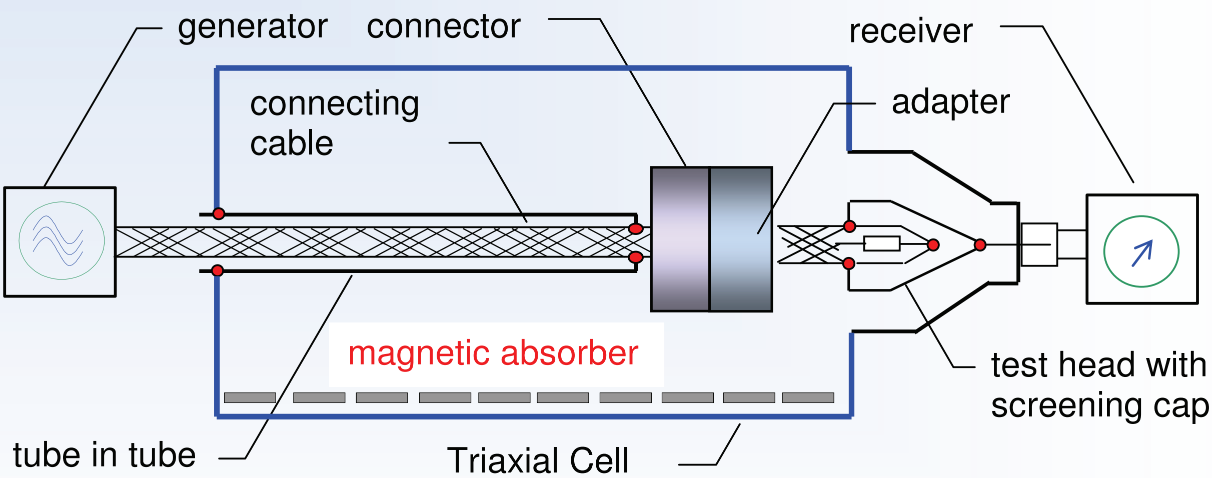
Transfer impedance & Screening attenuation from DC up to and above 9 GHz with one test set-up



The triaxial 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

Triaxial “absorber cell”

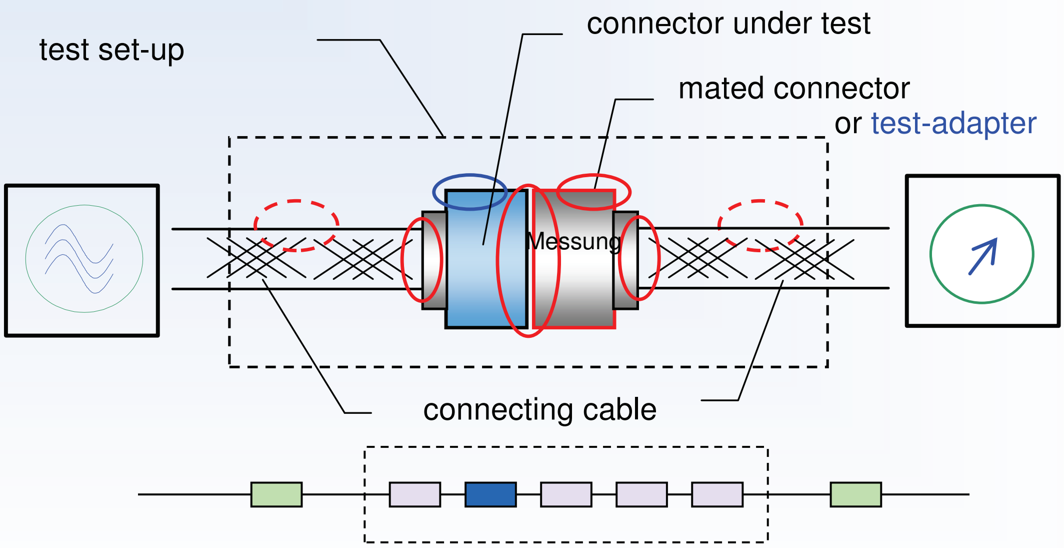


The triaxial "absorber cell" according to IEC 62153-4-15 is suitable for larger connectors

At certain frequencies, triaxial cells become waveguides.
Higher order modes can be easily suppressed by using absorbing materials like ferrite tiles or by nano crystalline or by magnetic absorbers placed in the cell.

Influencing variables when measuring the EMC of a connector

Connectors can only be measured when plugged in; If there is no mated connector, a test adapter is required



When measuring a connector, there are different transitions or transfer impedances to consider. Transfer impedances add up !

Connections should therefore be made with care and with impedance as low as possible.

Simulation & Analysis

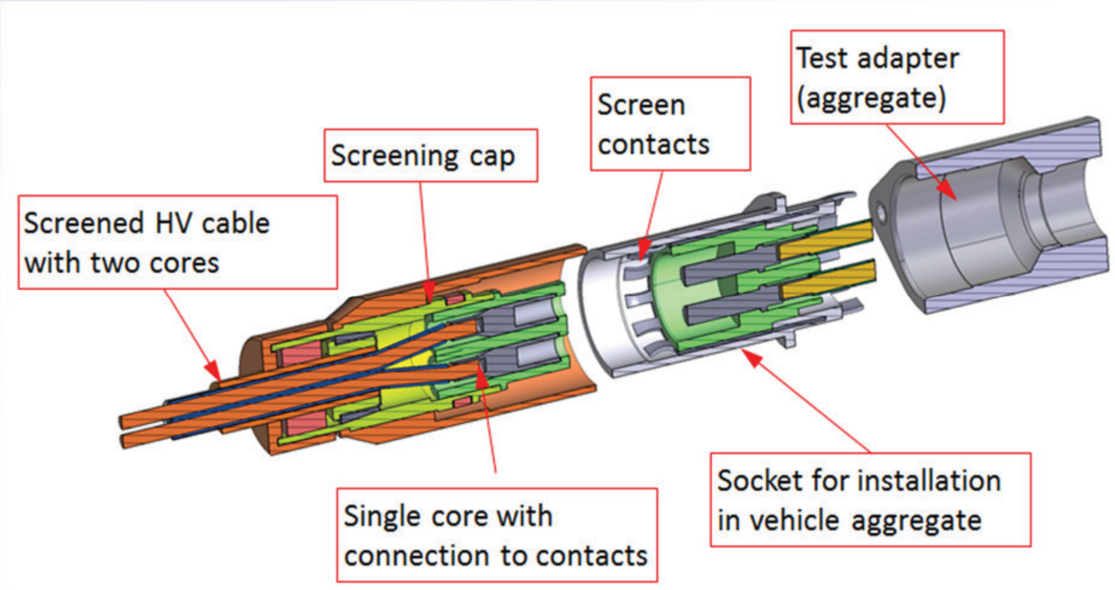
Motivation:

- realistic presentation of quantitative results such as transfer impedance and screening attenuation.
- Visualization of imperfections and regions in which the shielding is insufficient.
- targeted improvement of the shielding properties by developers.

Method:

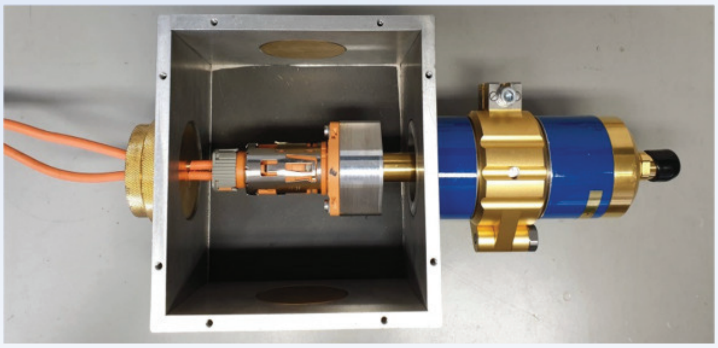
- Simulation in an electromagnetic 3D simulation program based on the modified CAD data,
- Realistically reproduction of surface coatings, surface roughness, etc.

Basic replication of an HV connector



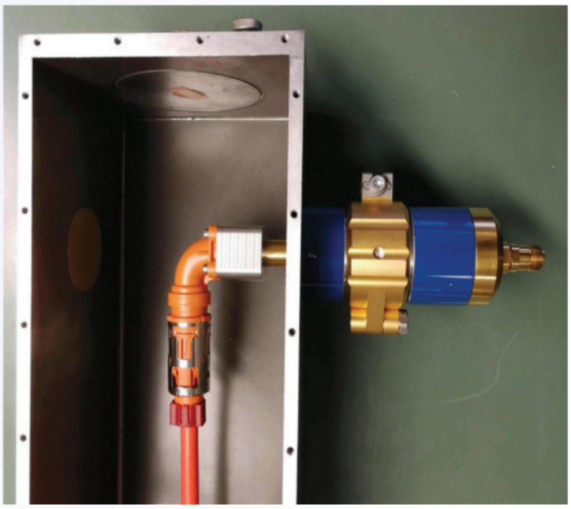
When simulating the connector, the CAD data of the construction form the basis, more complex material properties, such as complex surface coatings, surface roughness, etc. can be realistically reproduced.
The structure of the simulation depends on the selected measurement method (triaxial method).

HV-connector in triaxial cell



Straight HV connector (180°) in triaxial cell

In principle, only the screening effectiveness of the connector is measured. The transfer impedances of the short piece of connection cable as well as the transfer impedances of the test adapter and connecting sleeve to the test head are regarded as zero.

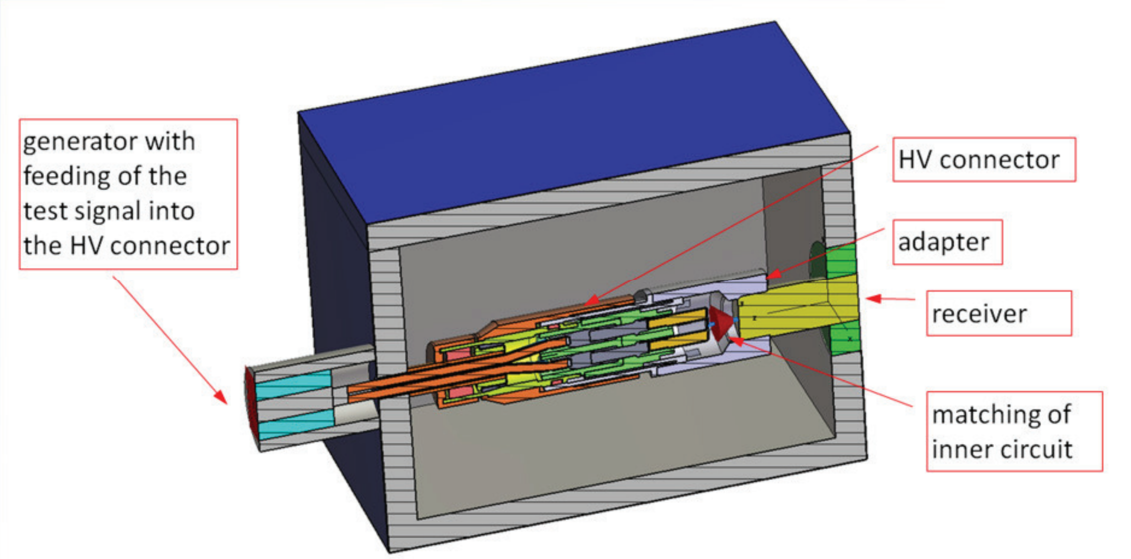


Angled (90°) HV-conector in 1000 mm cell

First only the cable is measured and then the cable with the connector. The transfer impedance of the connector is then obtained by subtracting both measurements or by calculating the delta transfer impedance

3D EM analysis of an HV connector

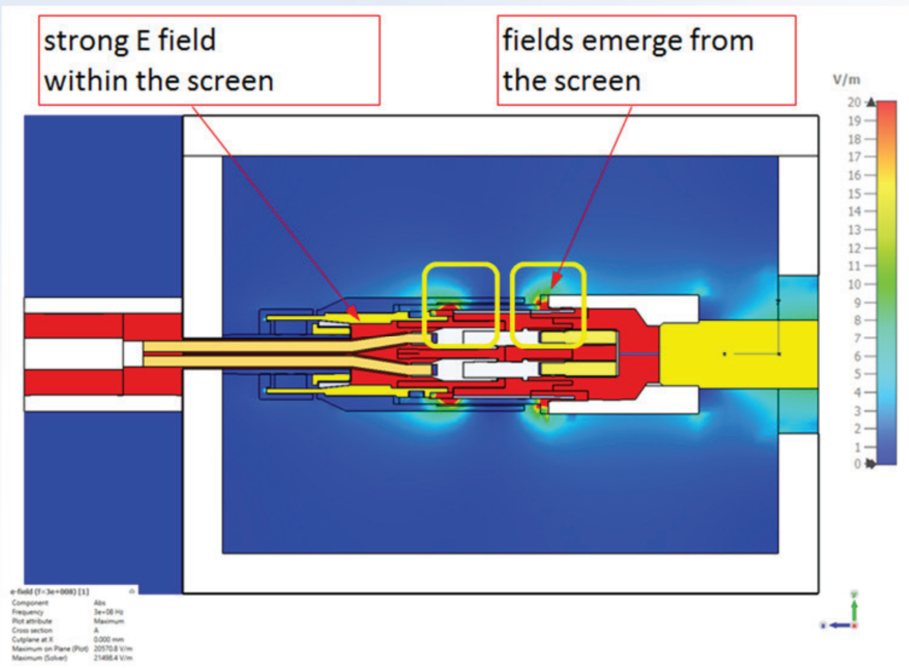
3D EM analysis of HV connector through the simulation of the triaxial measurement method



Depending on the chosen method, the simulation takes place in the time domain, e.g. with the Finite Integration Technique (FIT) method with subsequent transformation into the frequency domain. Another common method is to solve the linear system of Maxwell's equations using an iterative or direct solution algorithm for each frequency point considered [6].

Analysis of the weak points of a HV connector due to leaked E-fields

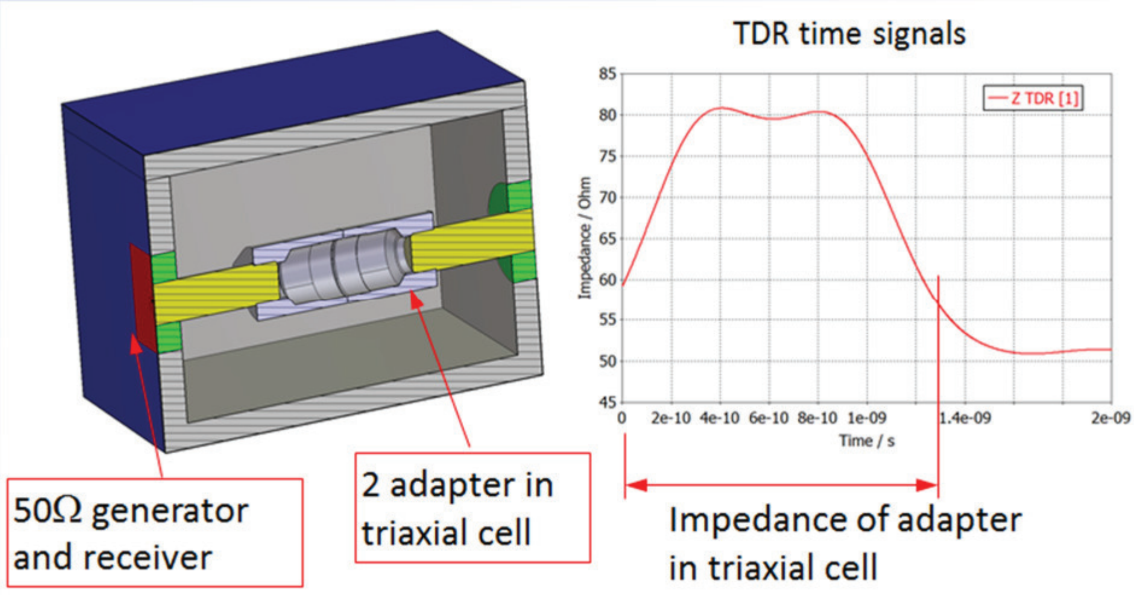
Maximum value of the amount of the E-field in a time domain simulation



The maximum field strength is approx. 20kV/m.
To visualize the screening effects in the range of approx. 80 dB,
the maximum field strength to be displayed was limited by a factor of 80 dB to 20V/m.

Only in this representation the places where the fields emerge from the connector are clearly visible

Test adapter



Instead of complex measurements, the EMC of the test adapter can be optimized through simulation; The TDR simulation of the impedance of the outer circuit results in approx. 80Ω. The test adapter shows ideal EMC behavior, since all components are made of solid metal.

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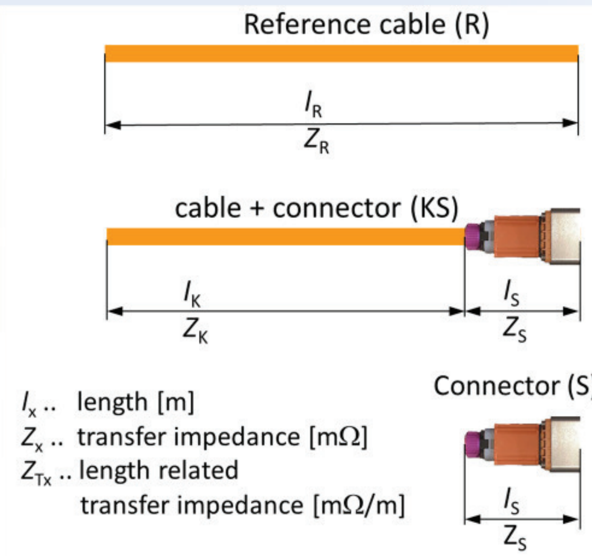
Delta transfer impedance

In many specifications of the limit values of the transfer impedance of connectors, the term delta transfer impedance is used (e.g. by the automotive industry).



$$Z_{TR} = \frac{Z_R}{l_R} \quad (3)$$

$$Z_{TKS} = \frac{Z_K + Z_S}{l_K + l_S} \quad (4)$$

$$Z_{TS} = \frac{Z_S}{l_S} \quad (5)$$

The delta transfer impedance Z_{TDiff} can be derived from the measurement of the transfer impedance of the pure cable and the measurement of the cable with connector, using the equations on the left.

The delta transfer impedance Z_{TDiff} can become negative, when the transfer impedance of the connector Z_S is significantly smaller than transfer impedance of the reference cable.

$$Z_{TDiff} = Z_{TKS} - Z_{TR} \quad (6)$$

$$Z_{TDiff} = \left(\frac{l_K}{l_K + l_S} - 1\right) \cdot Z_{TR} + \frac{Z_S}{l_K + l_S} \quad (7)$$

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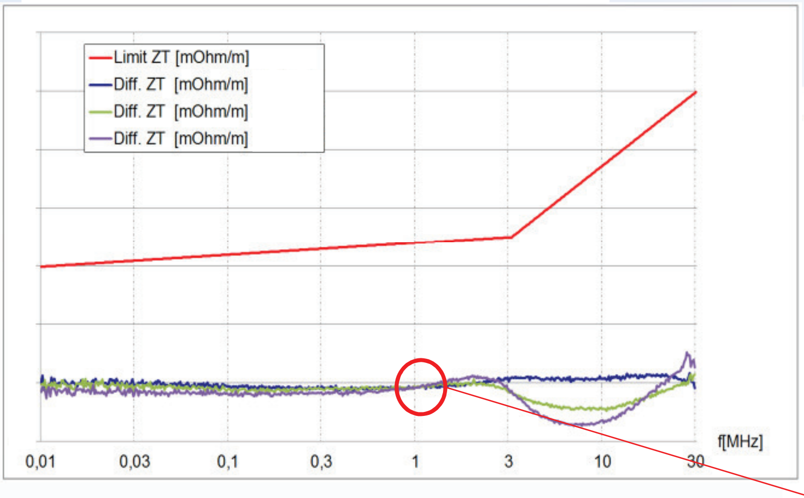
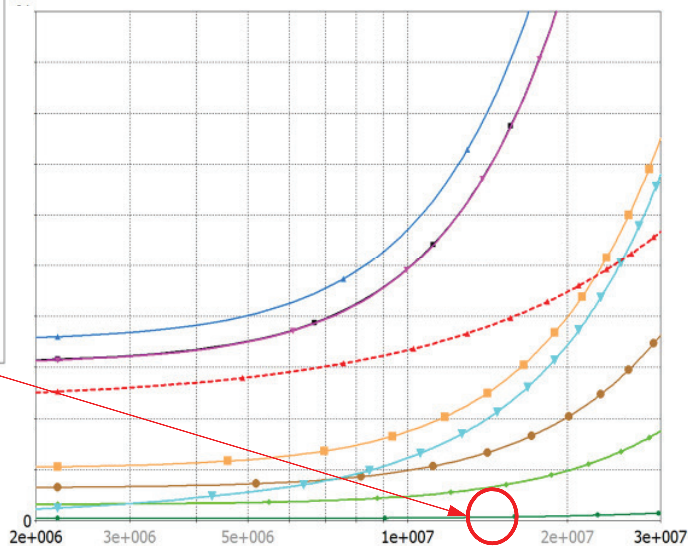
Transfer impedance, comparison simulation - measurement

Delta-Transfer impedance [mΩ/m]

Measurement of 3 series parts

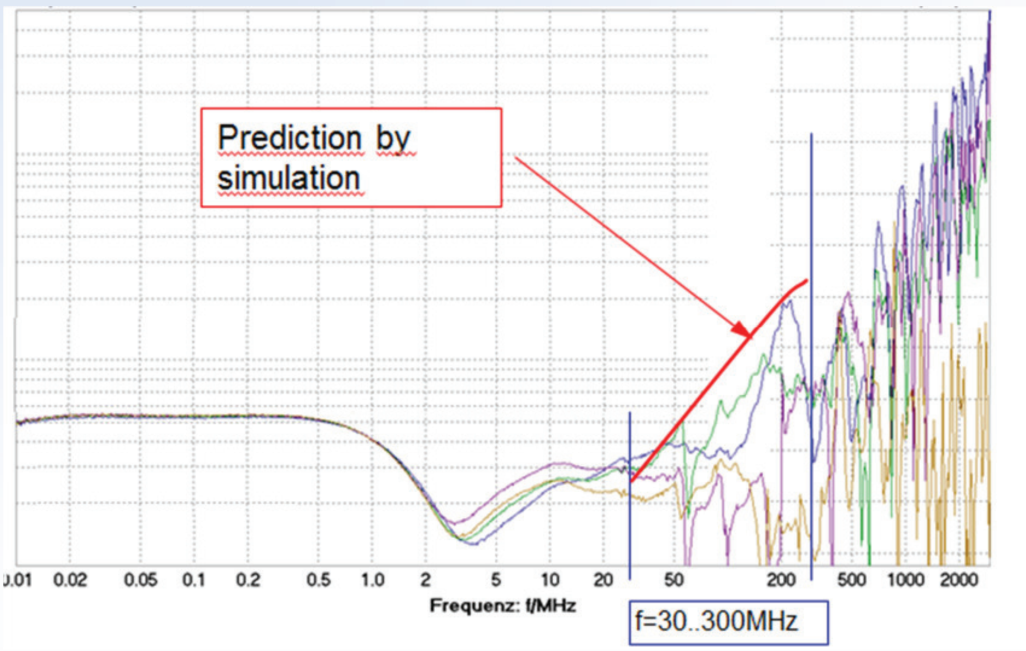


Simulation, design iterations



Measured transfer impedance with several design iterations as well as limit value curve. Simulation and measurement are far below the required limit values

Comparison, simulation - measurement



Prediction and measurement show good correlation

The prediction shows the screening effectiveness in the area from 30 MHz to 300 MHz for a test length of 1m with good correlation to the measured curves.

acc. to IEC 62153-4-3 and IEC 62153-4-4 this frequency range is the area of transition between transfer impedance and screening attenuation.

Measured and predicted values can be extrapolated to other frequencies resp. other lengths

Conclusion

- High EMC requirements are placed on HV connectors, e.g. a transfer impedance of 2 mΩ to 10 mΩ and a screening attenuation of approx. 70 dB.
- EMC-compliant design of HV plugs must be integrated right from the start of development.
- This is done quickly and cost effective by means of suitable 3D electromagnetic simulations instead of the time-consuming construction of samples.
- The simulation and the verification/measurement of the EMC behavior on the finished connector should be carried out using the same method, i.e. preferably using the triaxial method.
- The triaxial cell is suitable for measuring larger HV connectors.
- Test adapters can be optimized by suitable 3D simulation.
- Prediction by simulation and verification with the triaxial method show a good
- Correlation.
- Due to the increased demand for HV connectors we expect this method to be used more widely in future applications.

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Standards & Literature

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[2] IEC 62153-4-4, Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method

[3] IEC 62153-4-6, Surface transfer impedance, line injection method

[4] IEC 62153-4-7, Test method for measuring the transfer impedance Z_T and the screening attenuation a_S or the coupling attenuation ac of RF-connectors and assemblies up to and above 3 GHz, Triaxial tube in tube method

[5] IEC 62153-4-15, Test method for measuring transfer impedance and screening attenuation or coupling attenuation with triaxial cell

[6] Lauri Halme & Bernhard Mund, Messen der Schirmwirkung elektrischer Kabel, Anwenderforum Elektrische Kabel, Technische Akademie Esslingen [TAE], 15. Oktober 2013

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