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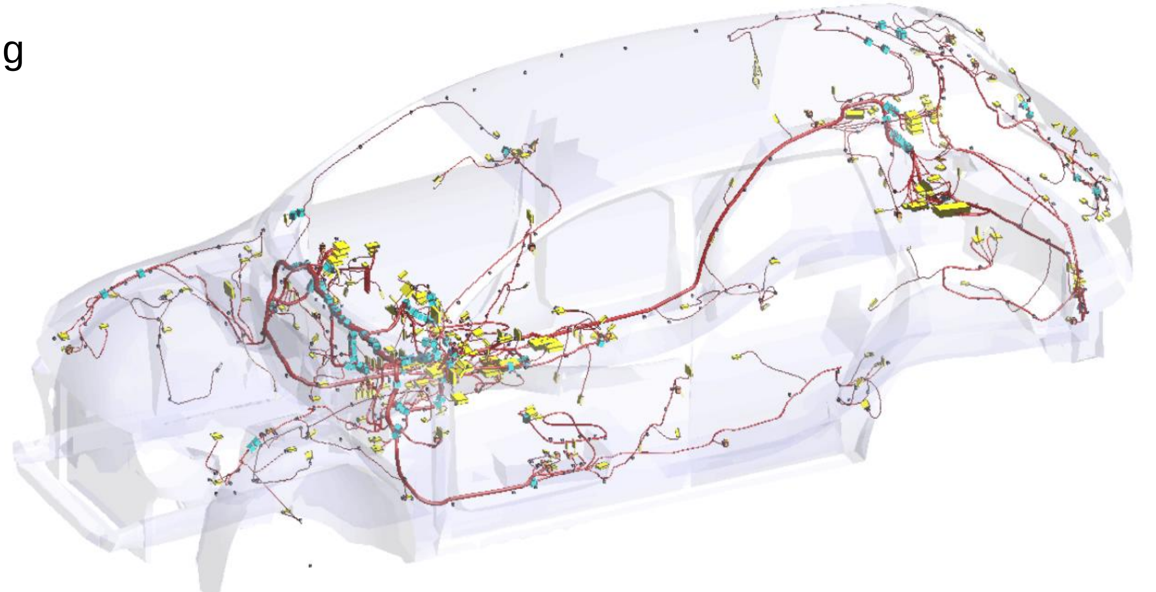

Analysis of the Shielding Properties of HV-Cable and HV-Cable-Connector Systems using Transfer Impedance Z_T and Antenna Measurements

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Technische Universität Dortmund

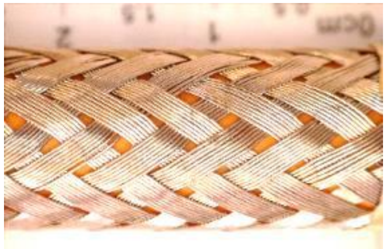
Bordsysteme

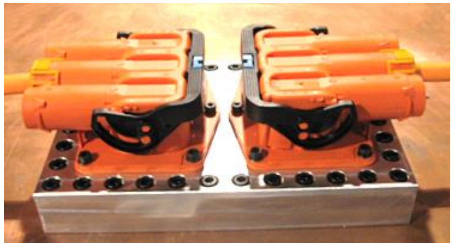
Contents

Motivation

- Goal
  - Electromagnetic shield analysis of HV-Cable and HV-Cable-Connectors systems used in EVs and HEVs
- Overview of research
  - Transfer Impedance Z_T analysis (mostly used by Cable and Connector companies)
  - Antenna Measurements (used in Automotive EMI tests)
  - Both used to analyze shielding performance of cables and connectors
  - Investigations to find correlation between Z_T and antenna measurements
  - HV-Connector analysis to find critical EMI points
- Benefit
  - Use of correlation between Z_T and Antenna measurements can simplify our measurements
  - Predict Antenna measurement results from Z_T measurements or vice versa
  - Improvements in the Connector shielding design

HV Cable
(braided shield)





HV Cable-Connectors

Contents

Transfer Impedance (Z_T)

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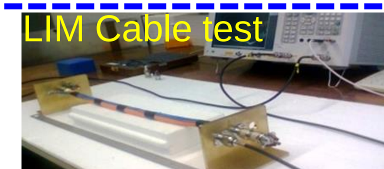
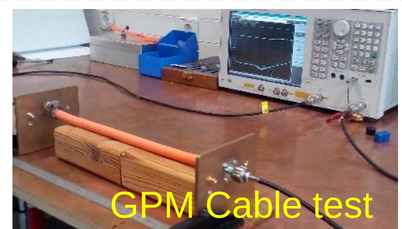
<u>Ground Plate Method (GPM)</u>

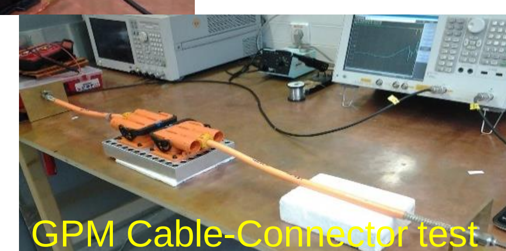
- Existing measurement methods
  - Triaxial Method:
    - Test setup has to be modified for different size of DUT
  - Line Injection Method:
    - Difficult to measure non-symmetrical DUTs
- Alternative Method “Ground Plate Method”
  - Overcomes the limitation of the existing methods
  - Flexible to measure Z_T of non-symmetrical samples and large connectors
  - Ability to correlate with Antenna measurements with least variation in test setup
- In previous investigations, it has been
  - Used for both HV-Cable and HV-Cable-Connector systems
  - Verified by comparing measurement results with both Triaxial Method and Line Injection Method

Triaxial Method



Line Injection Method (LIM)

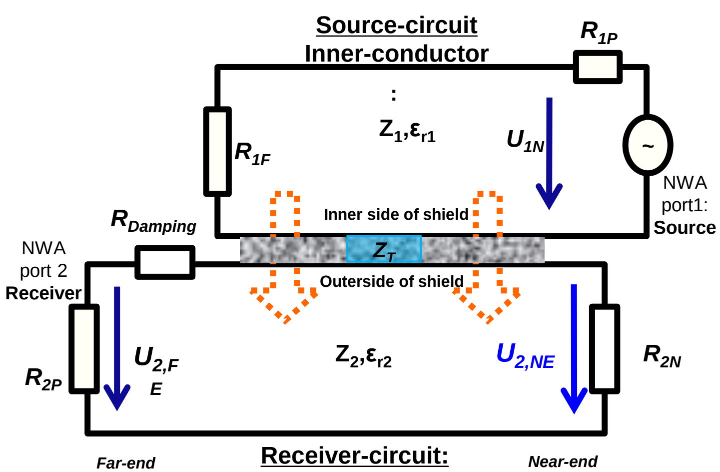




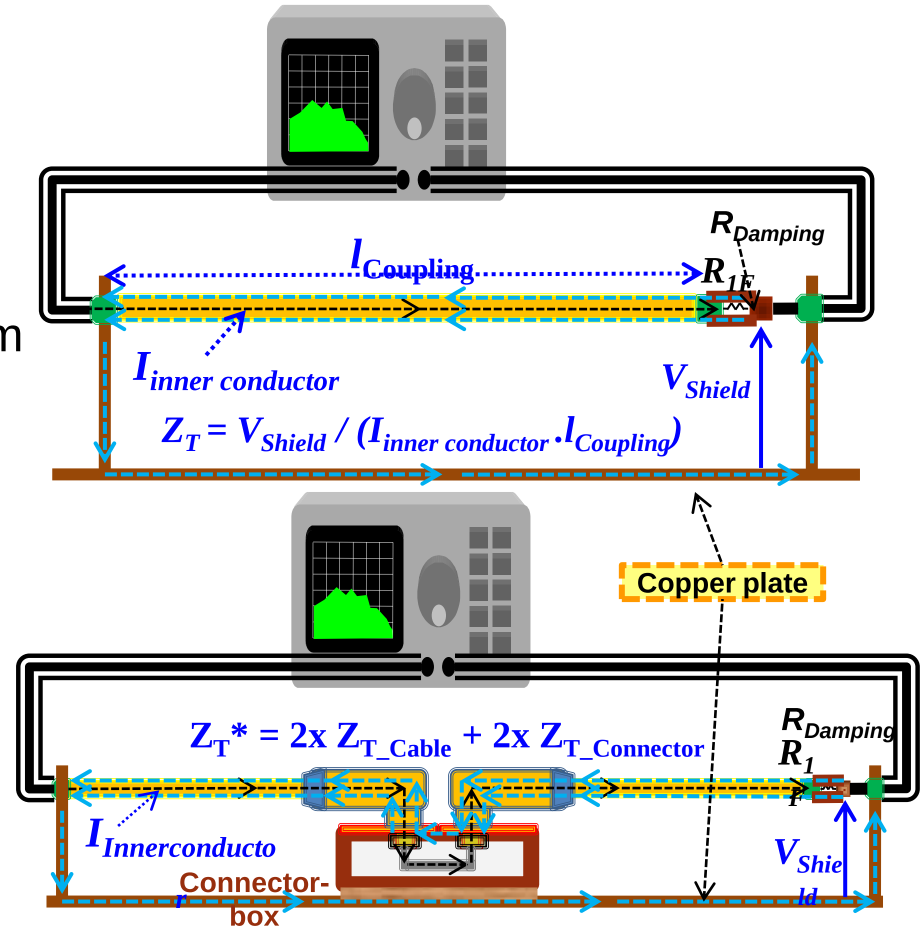
Ground Plate Method (GPM)

Ground Plate Method (GPM)

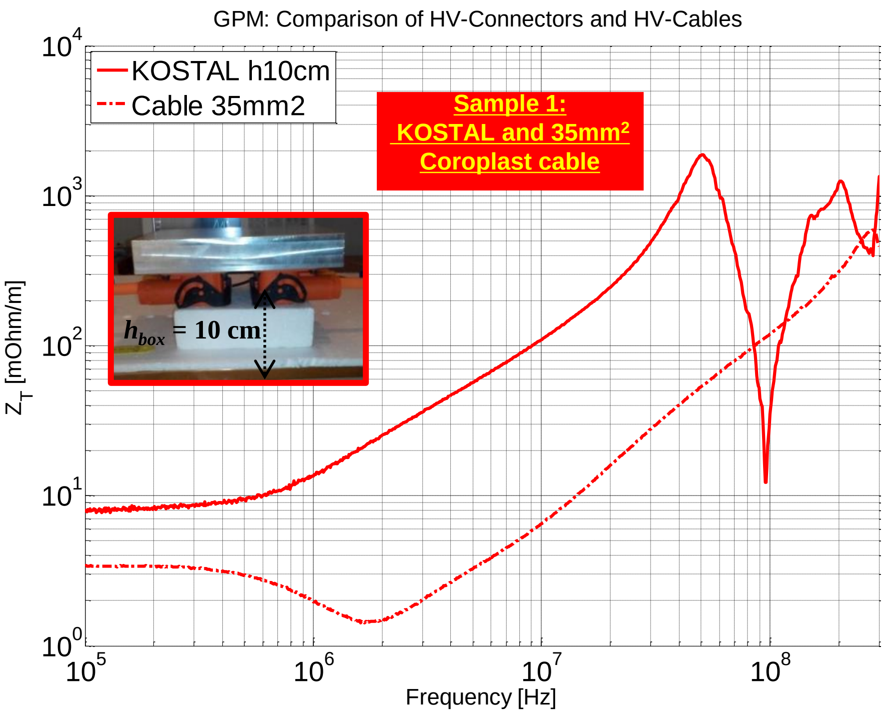
- Circuit schematics for all three measurement setups are similar
  - Source circuits are almost same
  - Receiver circuits are different (physically)
- Same GPM test setup for both HV-Cable and HV-Cable-Connector system

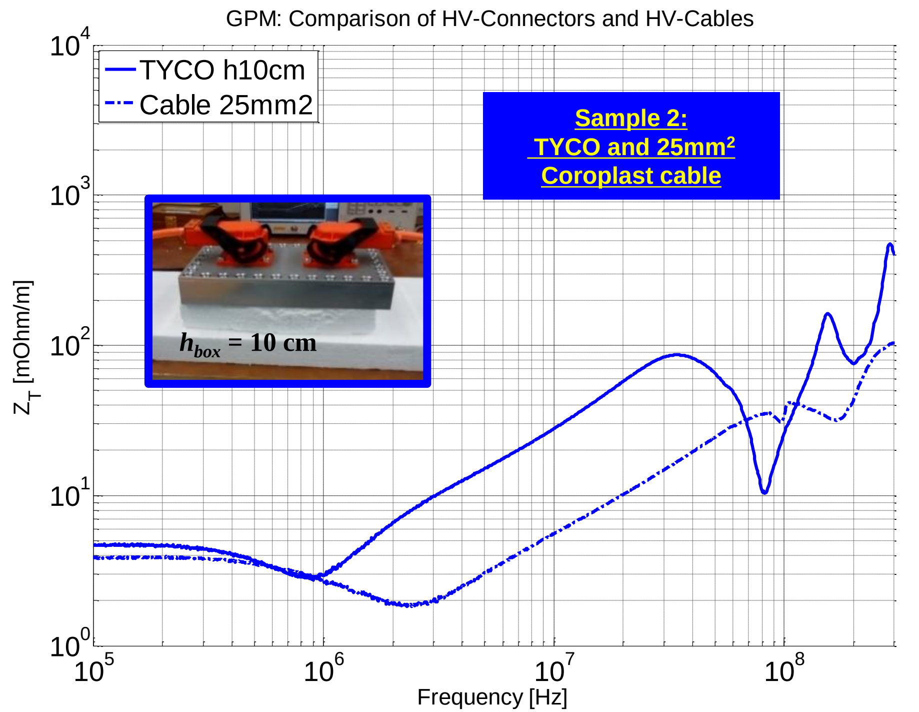


Cylinder (Triaxial-Method)/
Injection (Parallel) lines (Line Injection Method)/
Copper-plate (Ground-Plate Method)



Z_T measurements using GPM (for two types of connectors)





- Z_T measurements for HV-Cable-Connector sample 1(left) and 2(right)
  - Reference Z_T measurements for corresponding cables are shown
  - Connector has higher $R_{contact}$ and adds extra Inductance
  - Compared to sample 1, sample 2 has lower Z_T, thus better shielding performance

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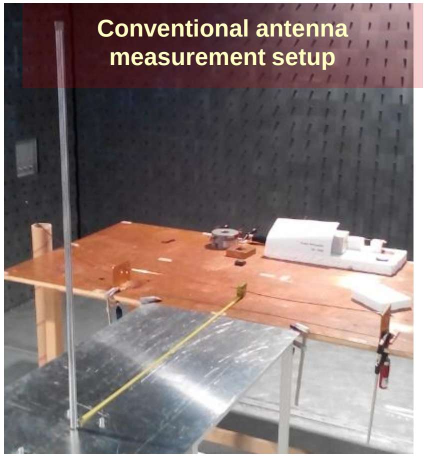
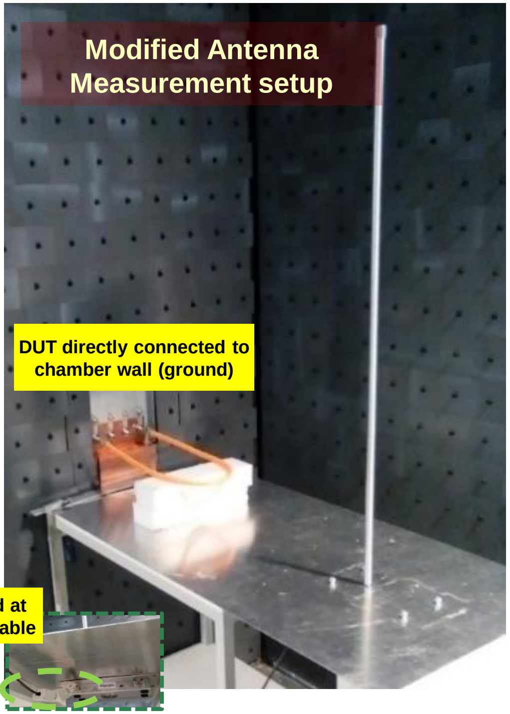
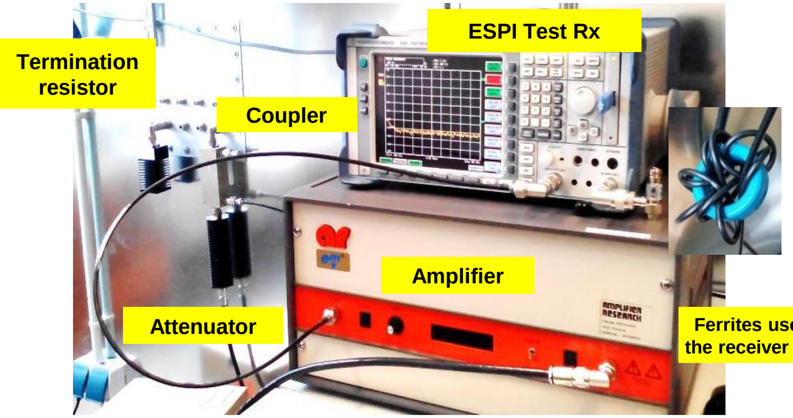
Field measurements

- Initial investigations
  - Conventional antenna measurement method and different approaches were used for field measurements
- Problems faced were
  - Variable influence of the connecting cables
  - Strong coupling was required for correlating with $\boldsymbol{Z_T}$
- Modification in the setup as per requirements to correlate with $\boldsymbol{Z_T}$

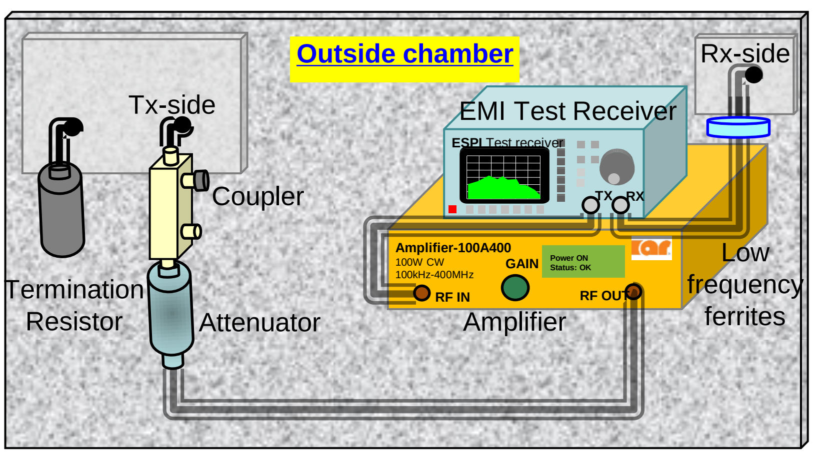


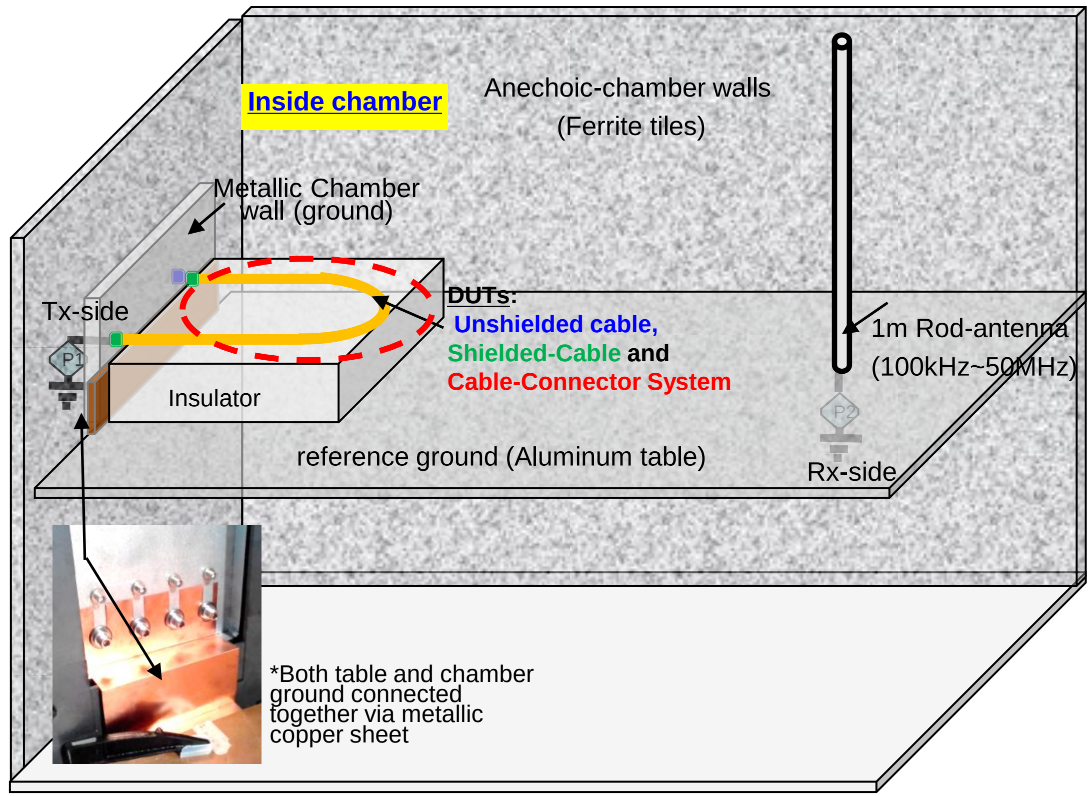




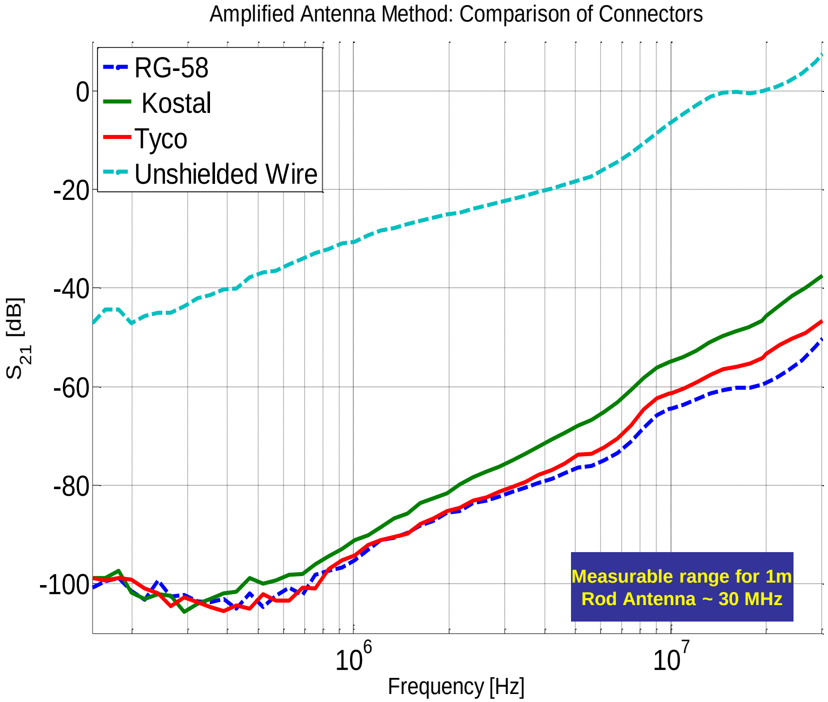
Measurement setup

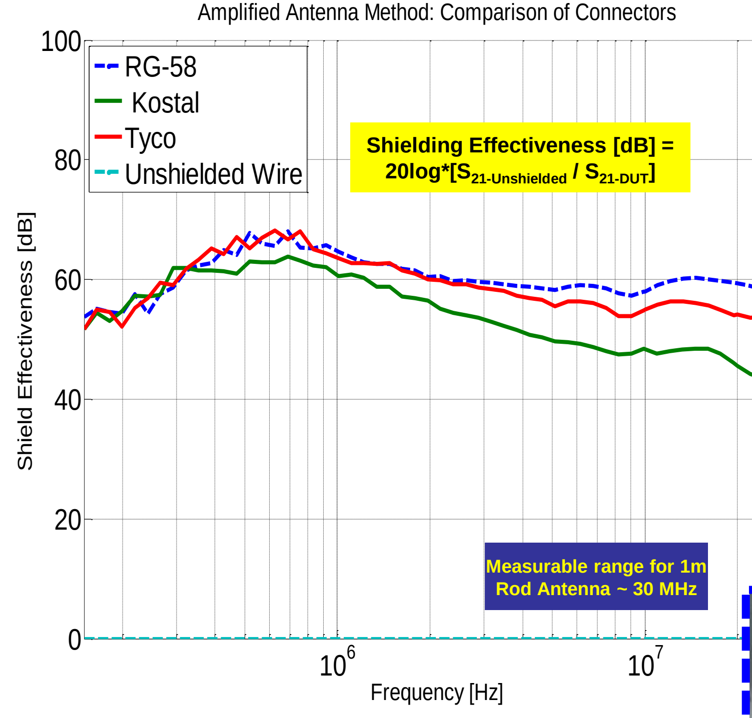
- Modifications in test setup were made for development of better correlation
  - Amplifier may be used for increasing the dynamic range and sensitivity of the setup to measure coupling
  - Low frequency ferrites help to limit common-mode currents
  - Direct connection of the DUT into the metallic chamber wall helps to avoid influence of brackets and connecting cables
  - Some effects due to bending and shape variation

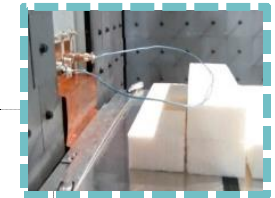




Measurement results



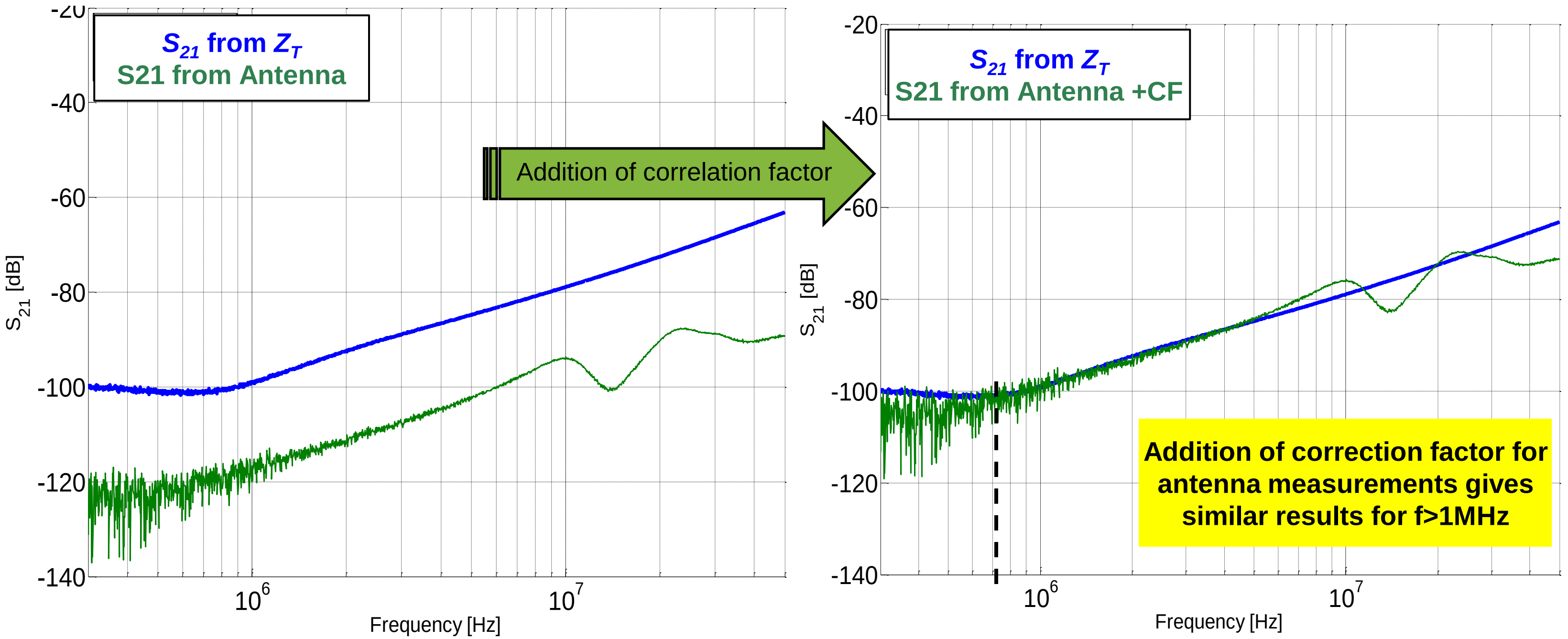




- Measurements were done for different samples
  - Unshielded cable was also measured as reference for finding Shielding effectiveness
  - Similar to ZT measurement results, difference between both samples can be seen (Sample 1 has lower shielding than sample 2)

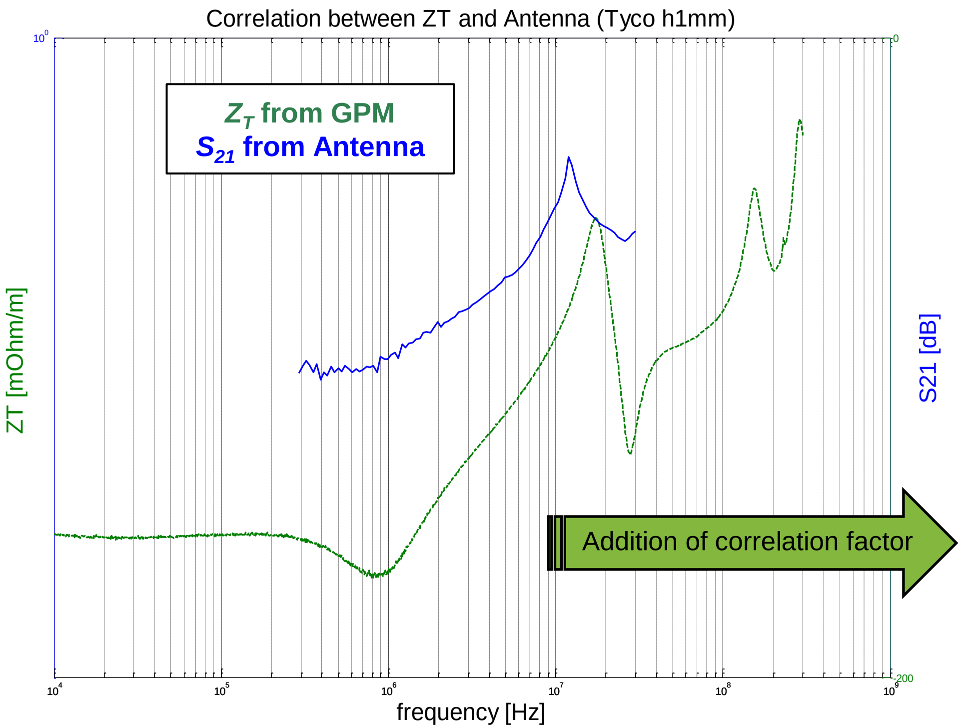
Contents

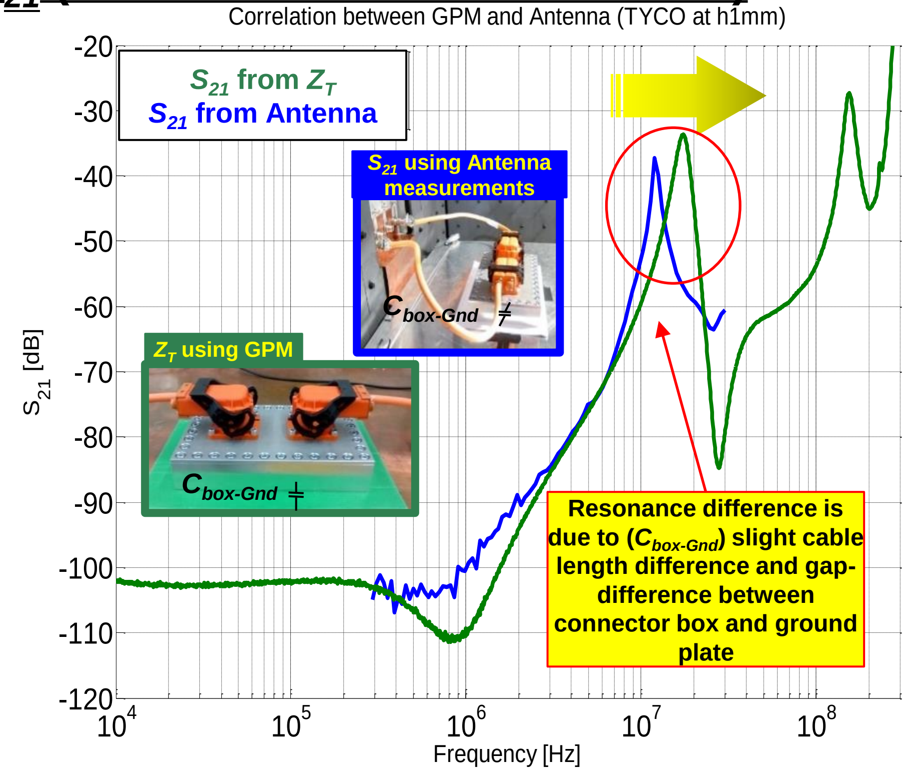
Correlating using S_{21} (from ZT) and S_{21} (from Antenna measurements)



- Correlation for HV-Cable only
  - For similar test conditions and addition of correct correlation factor, we see good correlation between both measurement results
  - Correlation factor depends on the DUT conditions (shape and height, etc), type of antenna and distance, etc

Correlating using S_{21} (from ZT) and S_{21} (from Antenna measurements)





- Correlation for HV-Cable-Connector system (TYCO)
  - For similar test conditions and addition of correct correlation factor, we see good correlation between both measurement results
  - Correlation factor depends on the DUT conditions (shape and height, etc), antenna factors and distance, etc

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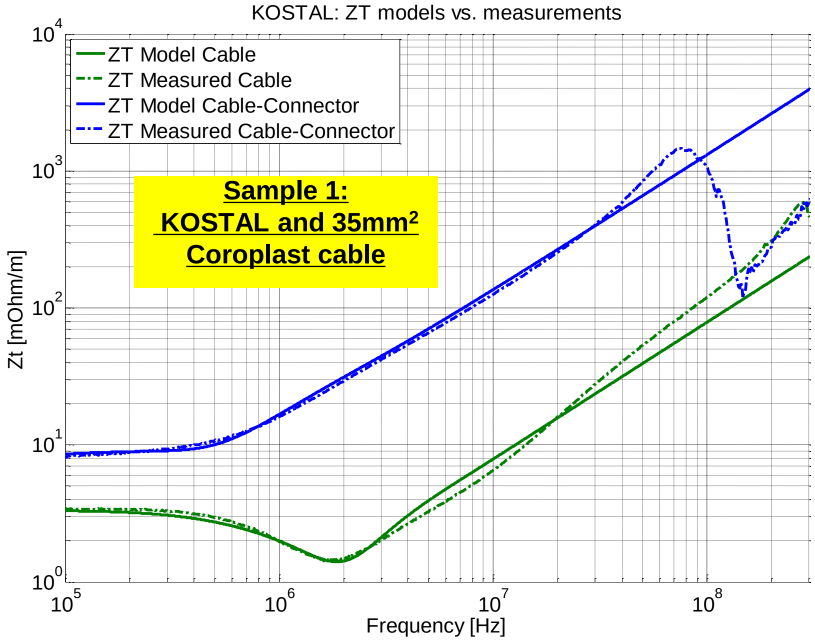
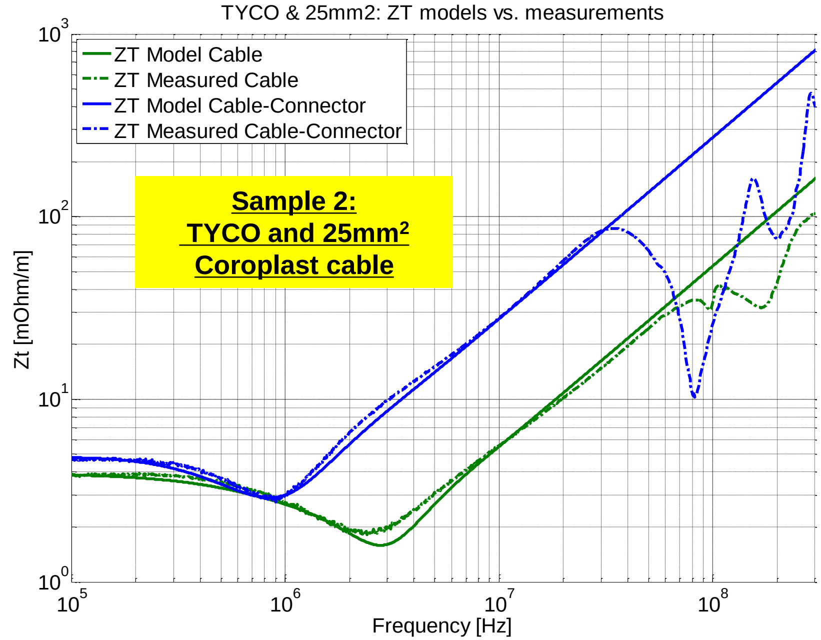
Finding the critical EMI points using Z_T model





- Explanation of the Z_T for both HV cable and cable-connector system
  - Connector has higher $R_{contact}$ and extra Inductance causes no lowest Z_T point (No-dip)
  - To make connector Z_T model: $R_{CONTACT}$ and $L_{CONNECTOR}$ in Z_{T_Cable} are added

Z_T Cable model:

$$Z_{T\_Kabel\_modell} = R_0 \frac{(1+j)d/\delta}{\sinh[(1+j)d/\delta]} + k_{CABLE}\sqrt{\omega}e^{+j\frac{\pi}{4}} + j\omega(L_{HOLE} - L_{BRAID});$$

Z_T Cable-Connector Model:

$$Z_{T\_Cable\_Connector} = \left[R_0 \frac{(1+j)d/\delta}{\sinh[(1+j)d/\delta]} + k_{CONNECTOR}\sqrt{\omega}e^{+j\frac{\pi}{4}} + j\omega(L_{HOLE} - L_{BRAID})\right] + R_{CONTACT} + j\omega L_{CONNECTOR};$$

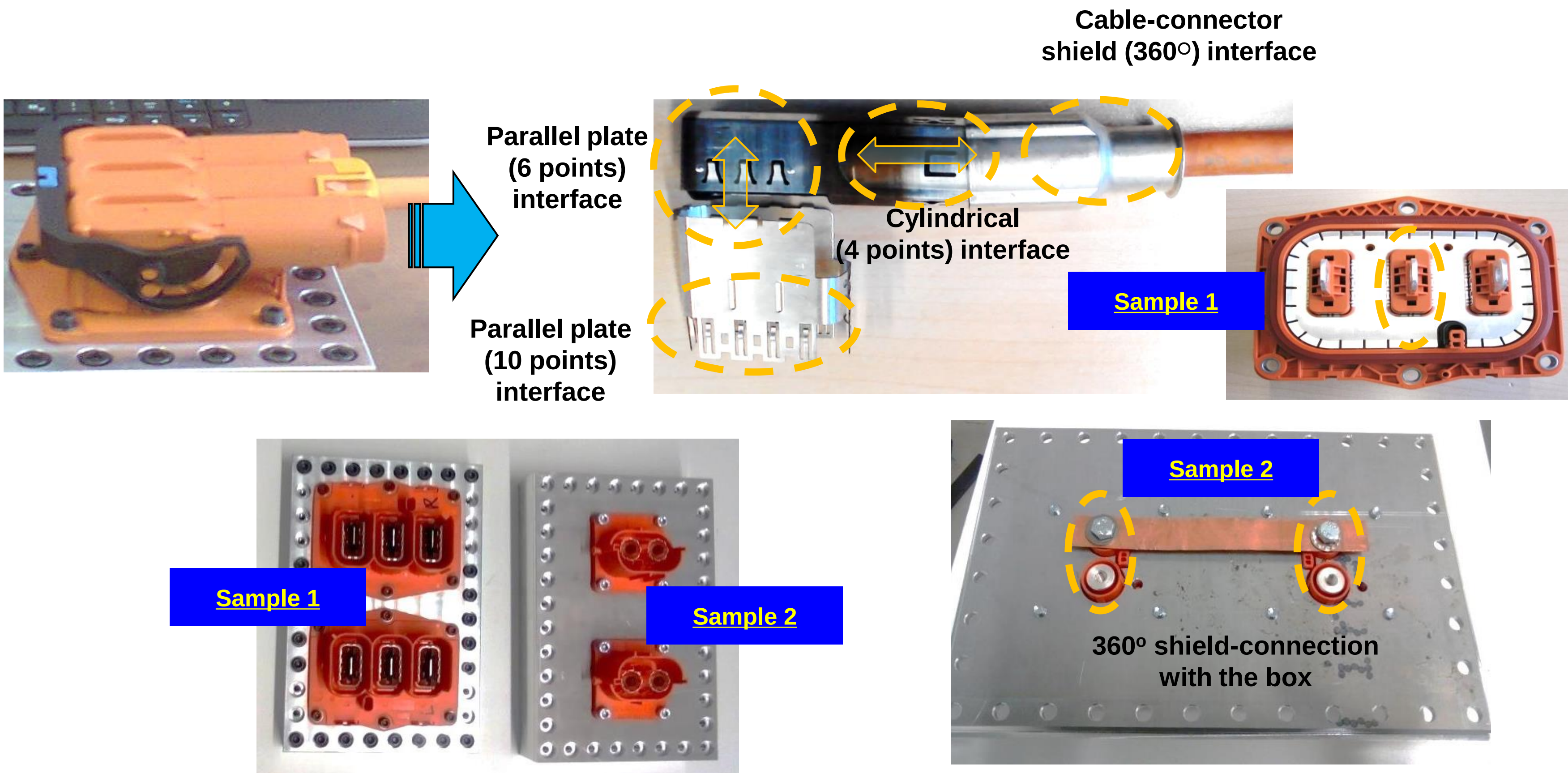
For example for sample 1 KOSTAL and 35 mm² Coroplast:

L_{HOLE} =3.65nH ; L_{BRAID} = 3.78nH; k_{CABLE} = 0.5e-7 ; R_0 = 3.3mOhm

$L_{CONNECTOR}$ =2.2nH ;$R_{CONTACT}$ = 3.5 mOhm ;$k_{CONNECTOR}$ = 50*k_{CABLE}

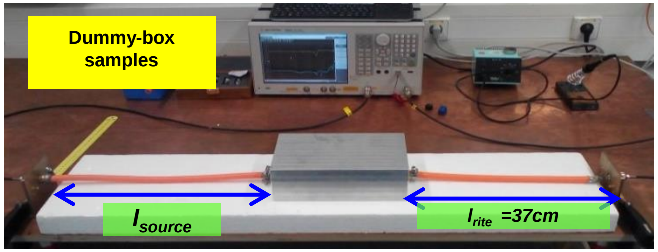
Comparison of different HV-Connectors

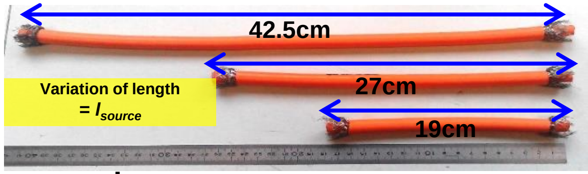
- Difference is at low-ffrequency
  - Sample 1 has higher DC-resistance compared to Sample 2 connectors
  - As there are more contact interfaces

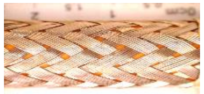


Comparison of HV-Connector box with an Ideal (dummy) box

- To experimentally compare the shield performance of the HV-Cable-Connector system, we used
  - a dummy box (connecting cables)





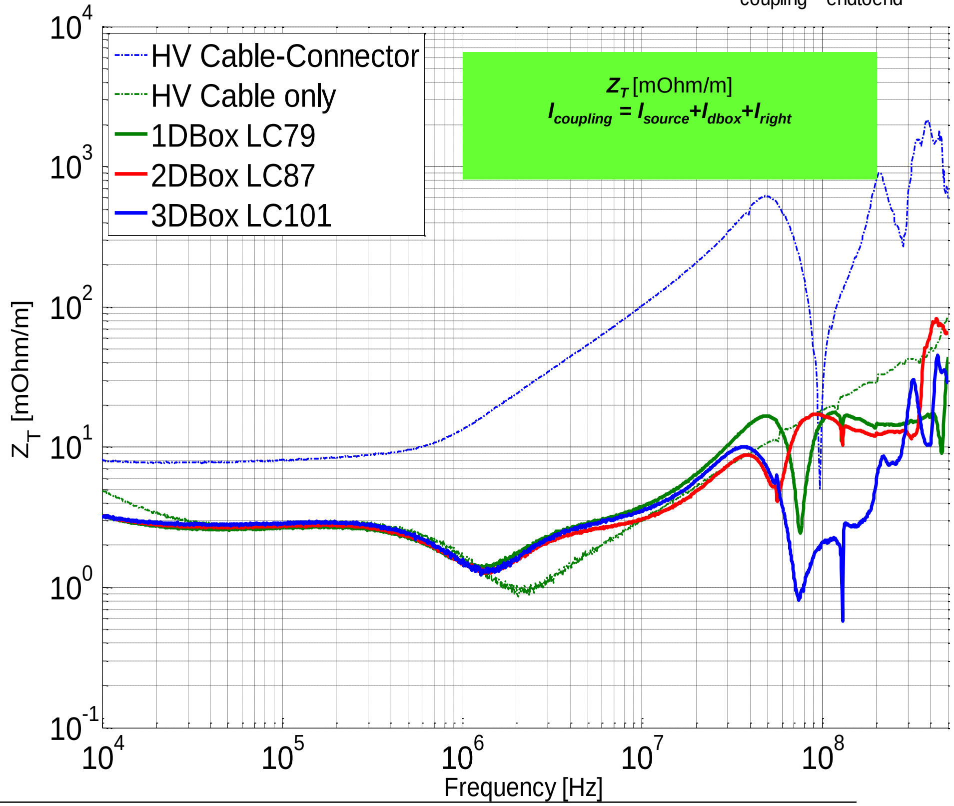


HV-Cable, braided shield (Coroplast 35mm²)

HV-Cable-Connector system

Ideal connector-box (Dummy-box)

Comparison of HV-Cable-Connector, HV-Cable & Dbox ($l_{coupling}=l_{endtoend}$)



- Observations
  - At low frequency, ideal connector has similar Z_T as that of cable
  - After ~1 MHz, additional inductances differentiates the connector-box from cable

Contents

Summary

- Investigations to do electromagnetic shield analysis of HV-Cable and HV-Cable-Connector systems has been presented
  - Transfer Impedance measurements have been presented using Ground Plate Method (GPM)
  - Antenna measurements have also been performed which were further used to find the shield effectiveness
  - Comparison of Ideal (dummy) Connector-box with conventional HV-Connector System has been made to suggest connector design improvements
- Benefits:
  - The presented work serves as start-up for correlating the Z_T and Antenna measurements
  - Correlation helps to simplify the measurements
  - Identification of the critical EMI points suggests improvements in connector shield designs

Future tasks

- Correlation between Z_T and Antenna (EMI) measurements
  - Using intermediate measurement setup
  - Using Current and Voltage measurements

Acknowledgments

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Danke für Ihre Aufmerksamkeit!

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