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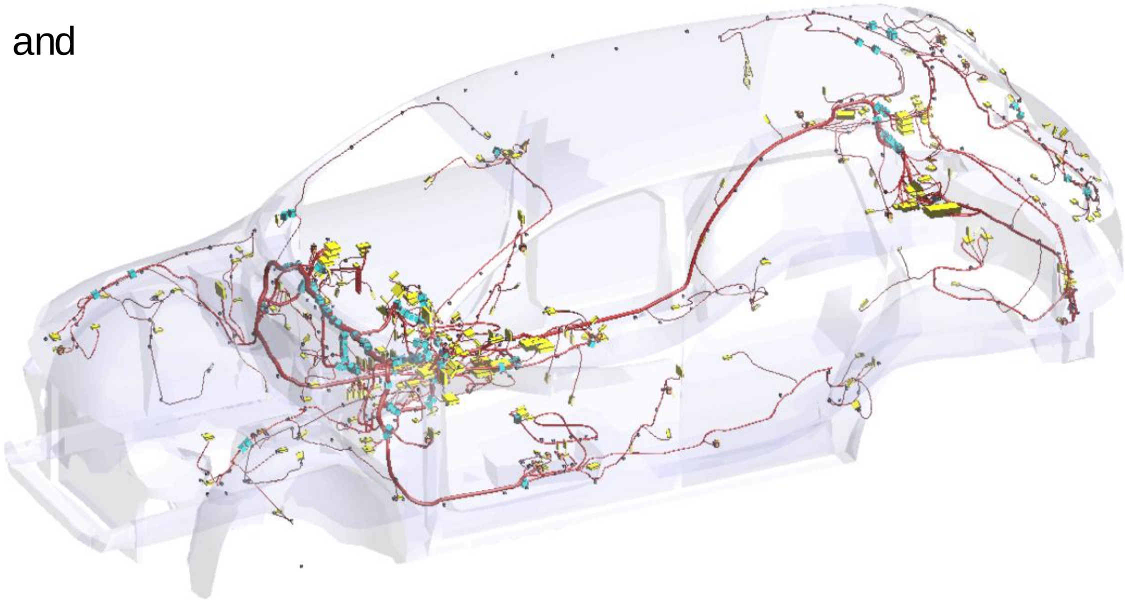

Comparative Study of Transfer Impedance (Z_T) Measurement Methods and Simulationmodels to Analyze Shielding Behaviour of High Voltage Cables in Electric Vehicles

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Bordsysteme

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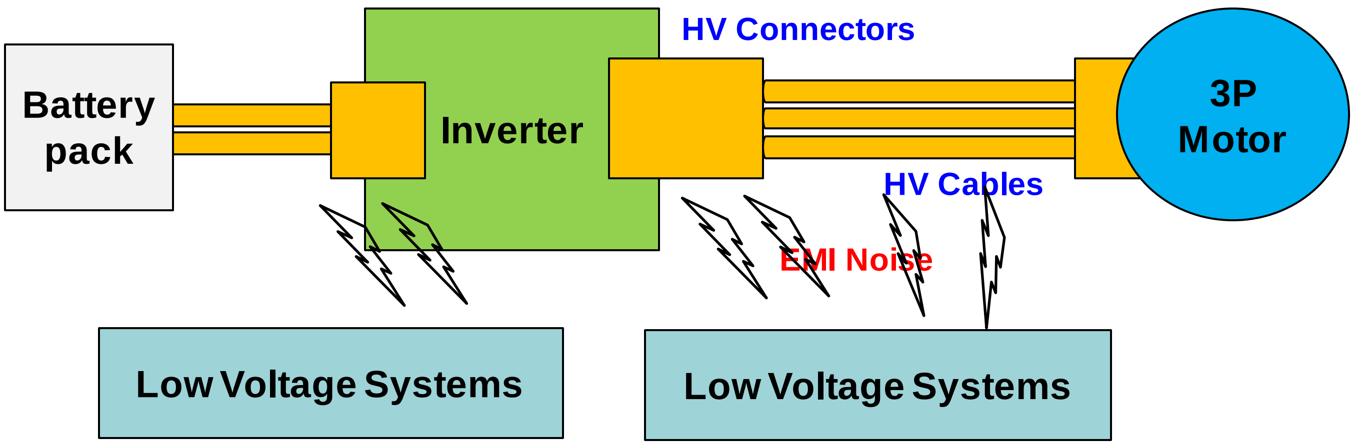
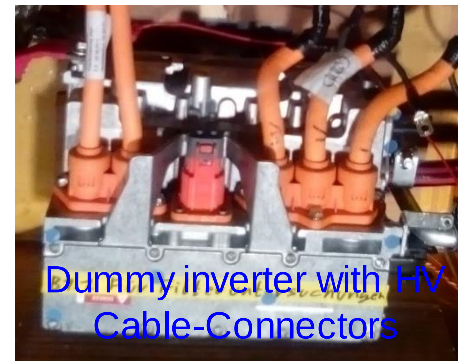
- Introduction
- Measurement methods
- Simulation methods
- Conclusions

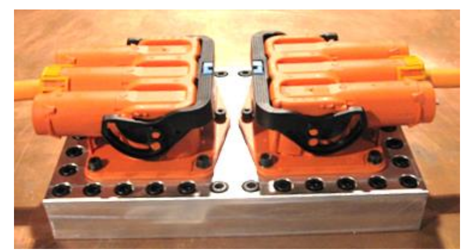
Content

Problem Overview

- In Electrical Vehicles (EV) and Hybrid-Electrical Vehicles (HEV)
  - Power drive systems, inverters convert and provide PWM signals at high voltage ($V_{peak\text{-}to\text{-}peak} \geq 300V$) to drive the E-motors via HV-cables (shielded power cables)
  - EMI noise signals from these HV-cables may cause malfunction of LV electronics devices, MCUs, vehicular communication networks (LIN, CAN, Flexrays, MOST, etc), AM Radio, etc




Dummy inverter with HV Cable-Connectors


HV Cable-Connectors

- **Optimum shielding of the HV-cables and HV-connectors**

Steps:

- How to evaluate shielding performance of HV-shielded cables?
  - Shielding Effectiveness vs. Transfer Impedance

- Shielding Effectiveness (SE)
  - Is a measure for the not just shielded cable, but also depends on external parameters
  - For the same shield, we can get different SE by varying the external parameters
  - Good for overall integrated system shielding analysis

- Transfer Impedance (Z_T)
  - Is an intrinsic property of the shield, and doesn't depend on external parameters
  - For the same shield, Z_T is independent of external parameters like termination load, external layouts, etc.
  - Good for component level shielding analysis

- **Main focus of this talk is on Z_T:**
  - Predicting **Transfer Impedance** using simulation and measurement methods

Basic Terminology

- Transfer Impedance (Z_T)
  - It is defined as:

$$Z_T = \frac{dV_{SHIELD}}{I_{SHIELD} \cdot l_{SHIELD}}$$

Measurement method

Based on above formula, various test setup have been proposed (Triaxial Method and Line Injection Method)

Simulation methods

Based on braid parameters, dimensions, Z_T can be predicted

Based on circuit models

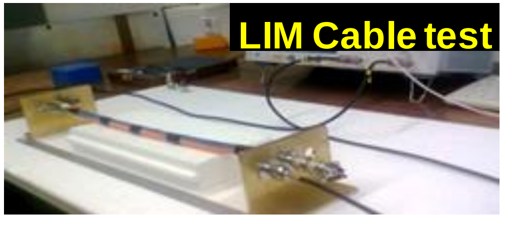
Content

- Introduction
- Measurement methods
  - Existing methods
  - Ground Plate Method (GPM)
  - Capacitive Voltage Probe (CVP) Method
- Simulation methods
- Conclusions

Existing methods

- Z_T measurement methods
  - Triaxial Method (IEC 62153-4-3)
    - Complex structure for variable sizes and connectors
    - Variable size of tubes require for different sizes and shapes, specially for connectors

  - Line Injection Method (LIM) (IEC 62153-4-6)
    - For non-symmetrical cables and connector assemblies, different positioning of the injection wires can cause inaccuracy in measured results



Use of alternative methods to measure Z_T

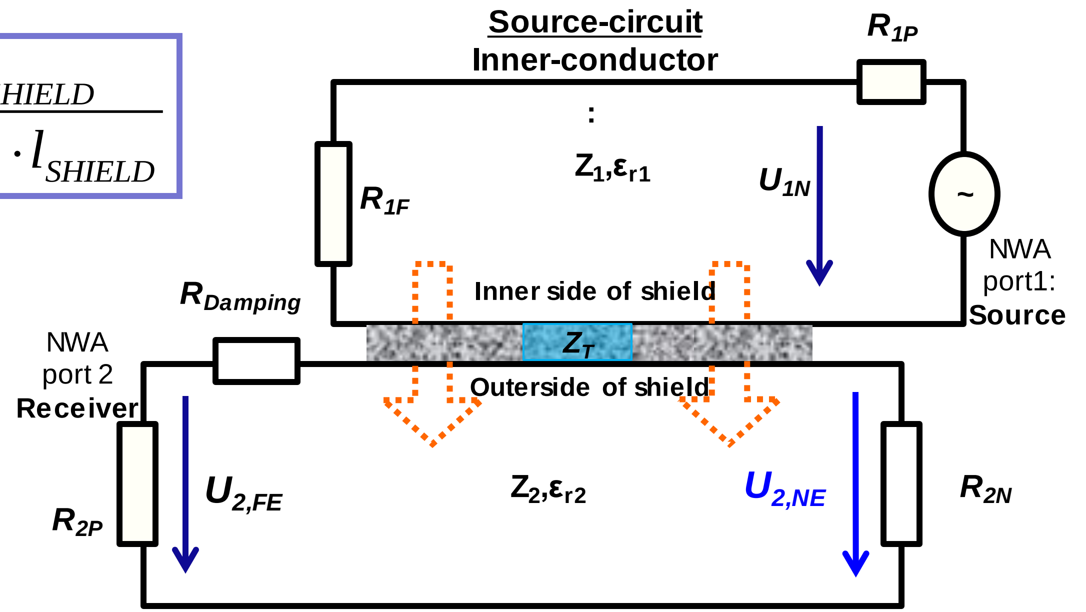
- For shielding analysis of HV-cable-connector systems, it should be
  - Flexible to measure Z_T of non-symmetrical samples and large connectors
  - With maximum accuracy and better repeatability/reproducibility

- To overcome these issues in HV-cable-connector analysis, following methods are used:
- Ground Plate Method (GPM)
  - 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*
- Capacitive Voltage Probe (CVP) measurement
  - Direct measurement of Voltage over the shield
  - Transfer Impedance can be approximated using both voltage and input current
  - *Ability to correlate with Antenna measurements with least variation in test setup*

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

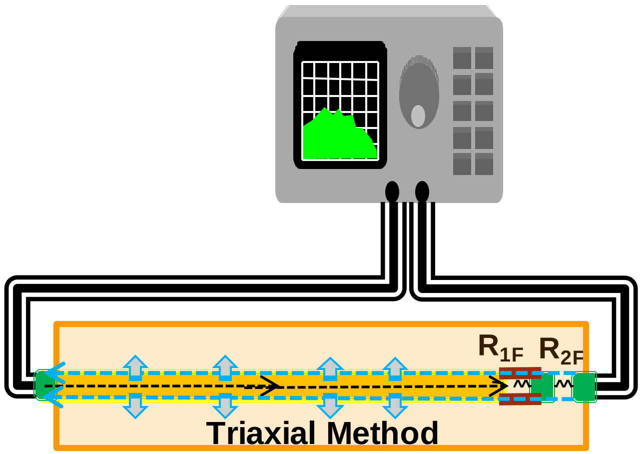
$$Z_T = \frac{dV_{SHIELD}}{I_{SHIELD} \cdot l_{SHIELD}}$$

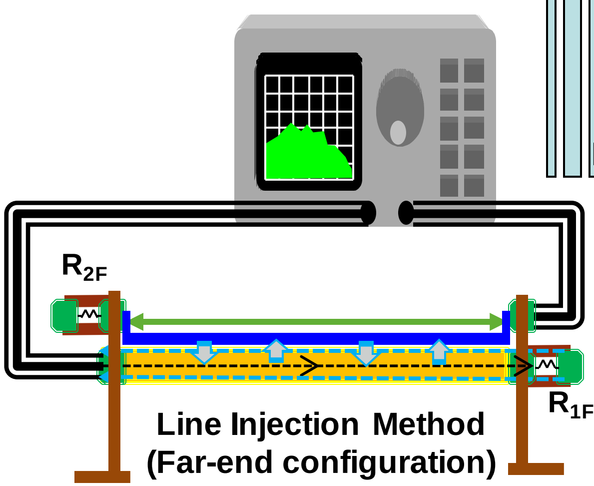


Receiver-circuit:
Cylinder (Triaxial-Method)/
Injection (Parallel) lines (Line Injection Method)/
Copper-plate (Ground-Plate Method)

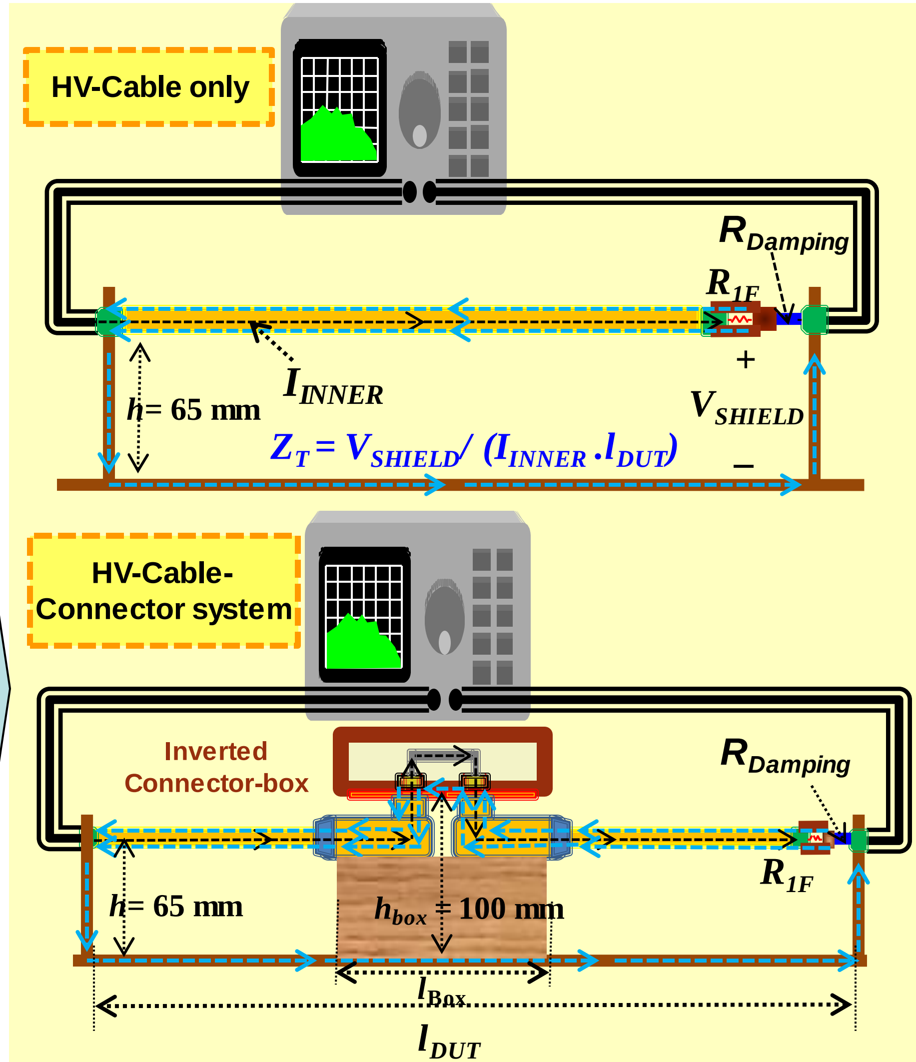
Ground Plate Method (GPM)

- Test setup





Alternative method for measuring Transfer Impedance Z_T



Ground Plate Method (GPM)

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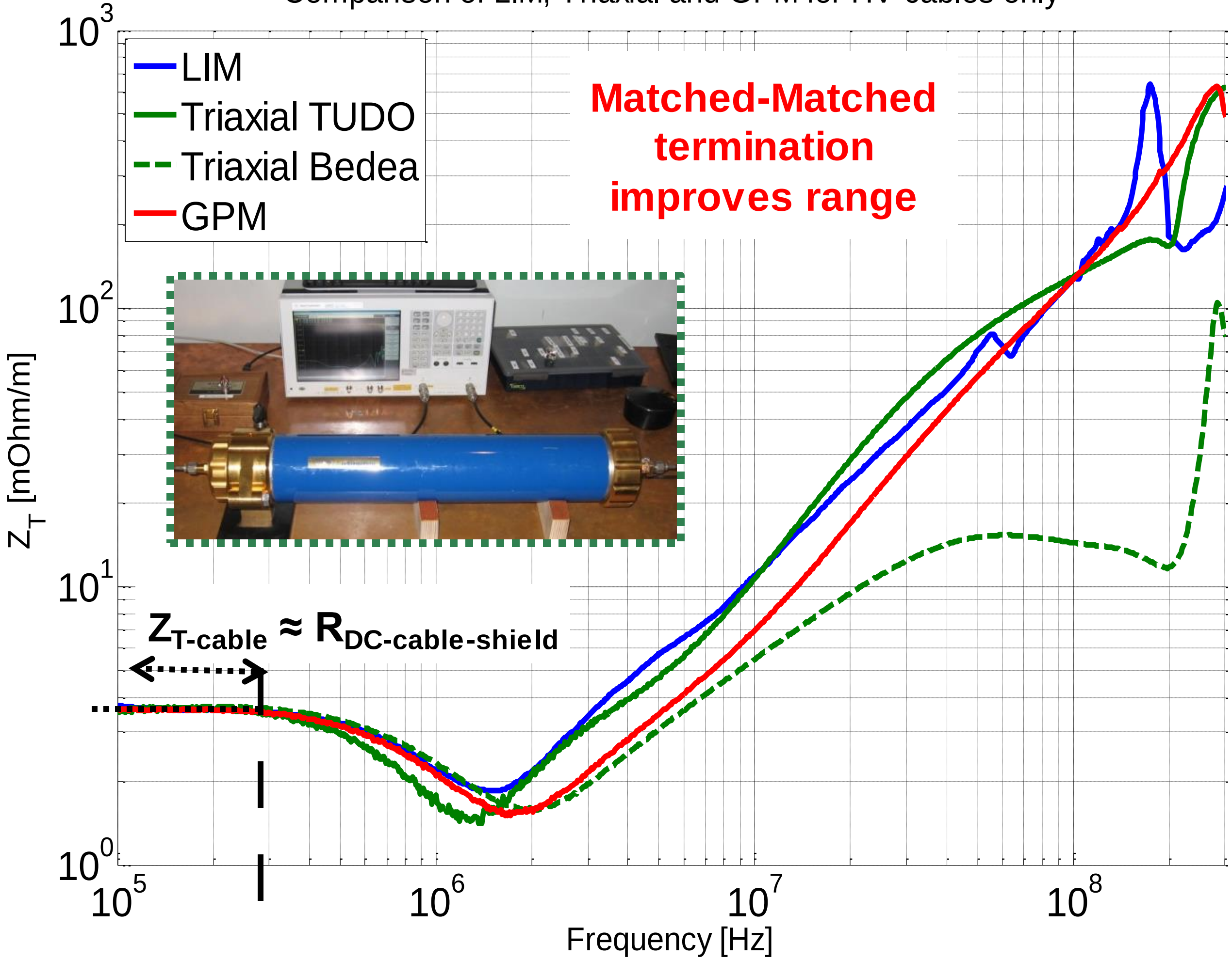
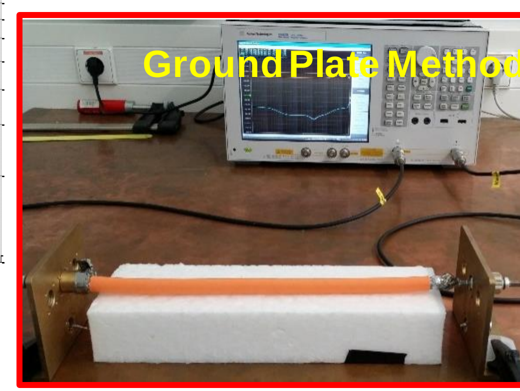
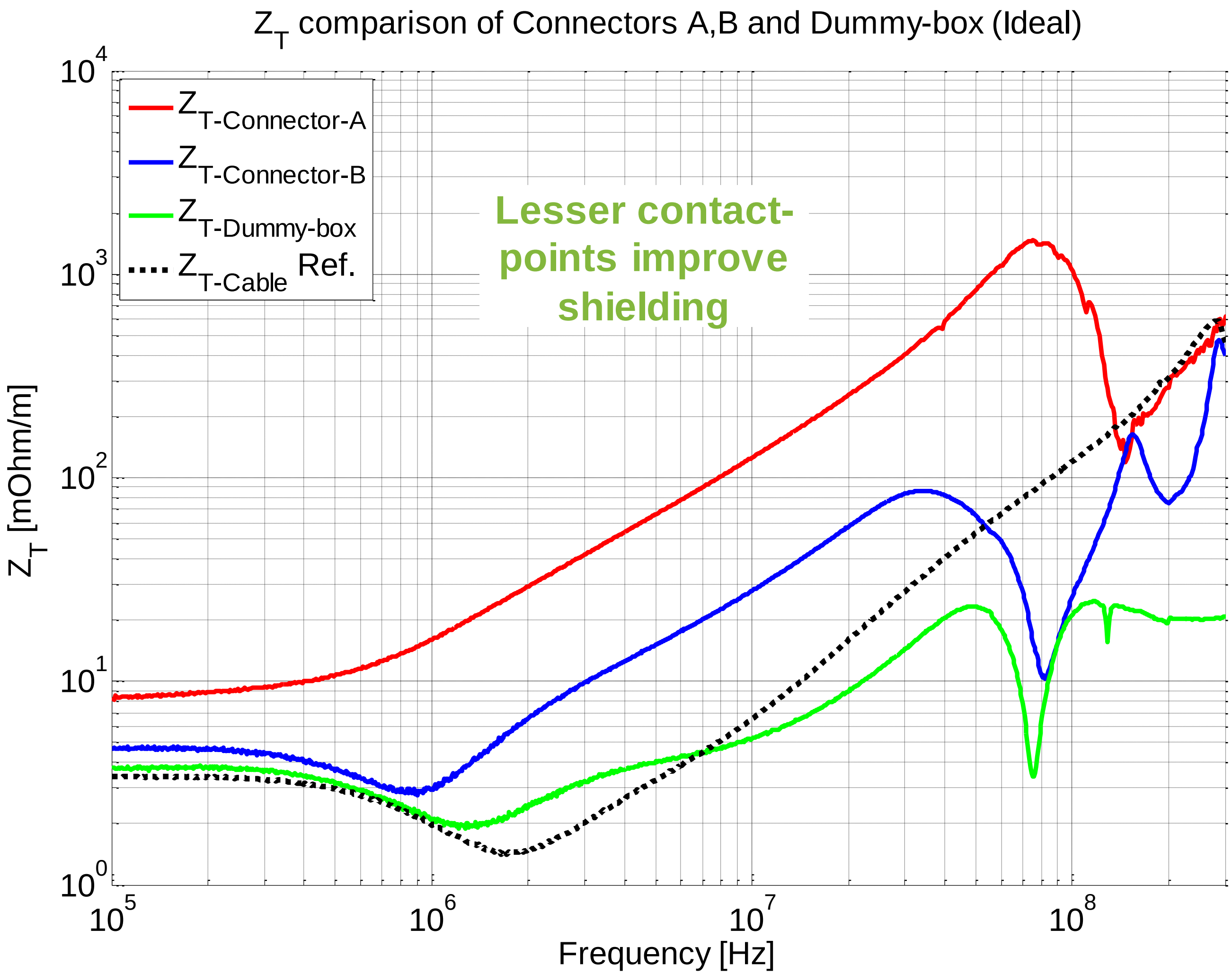
Ground Plate Method (GPM)

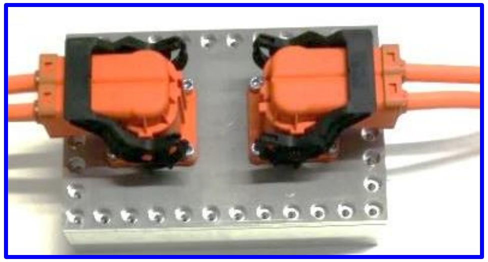
Comparison of LIM, Triaxial and GPM for HV-cables only

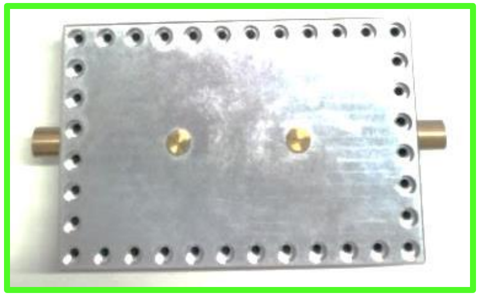




Ground Plate Method (GPM)







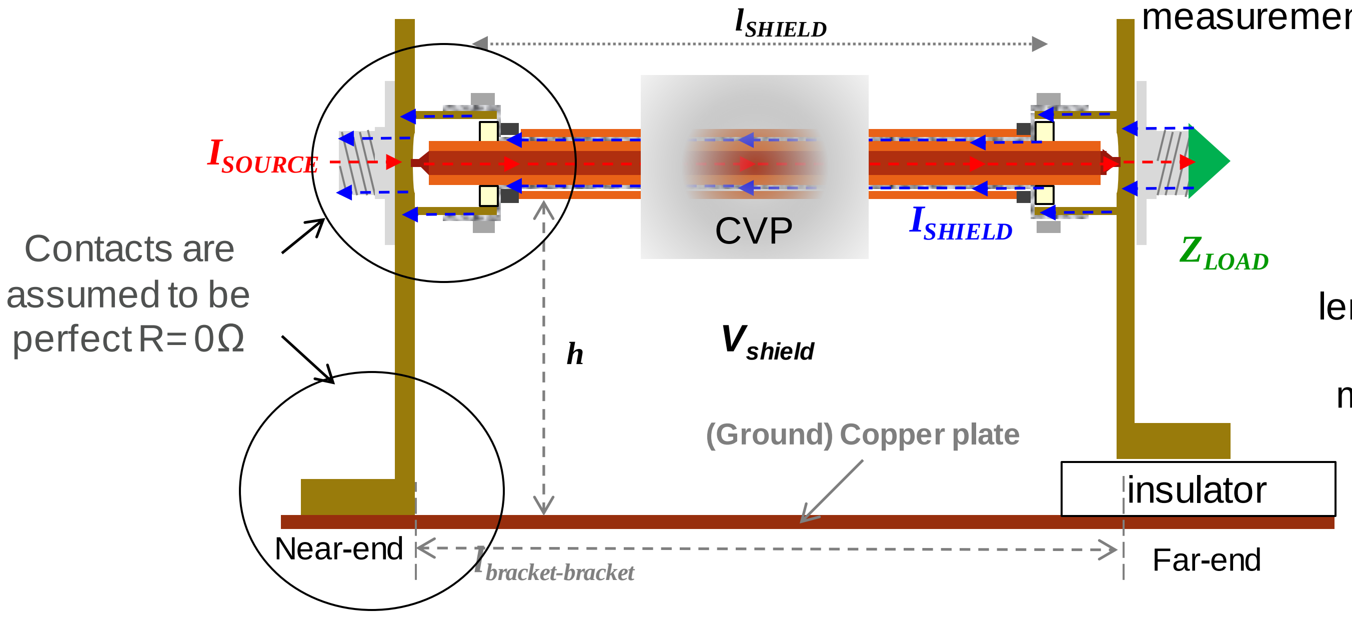
Capacitive Voltage Probe (CVP) test

- Using basic definition of Z_T

$$Z_T = \frac{dV_{SHIELD}}{I_{SHIELD} \cdot l_{SHIELD}}$$

$$\begin{cases} V_{CVP} \rightarrow V_{SHIELD} \\ I_{SOURCE} = \dfrac{V_{SOURCE}}{Z_{IN-50\Omega}} \end{cases}$$

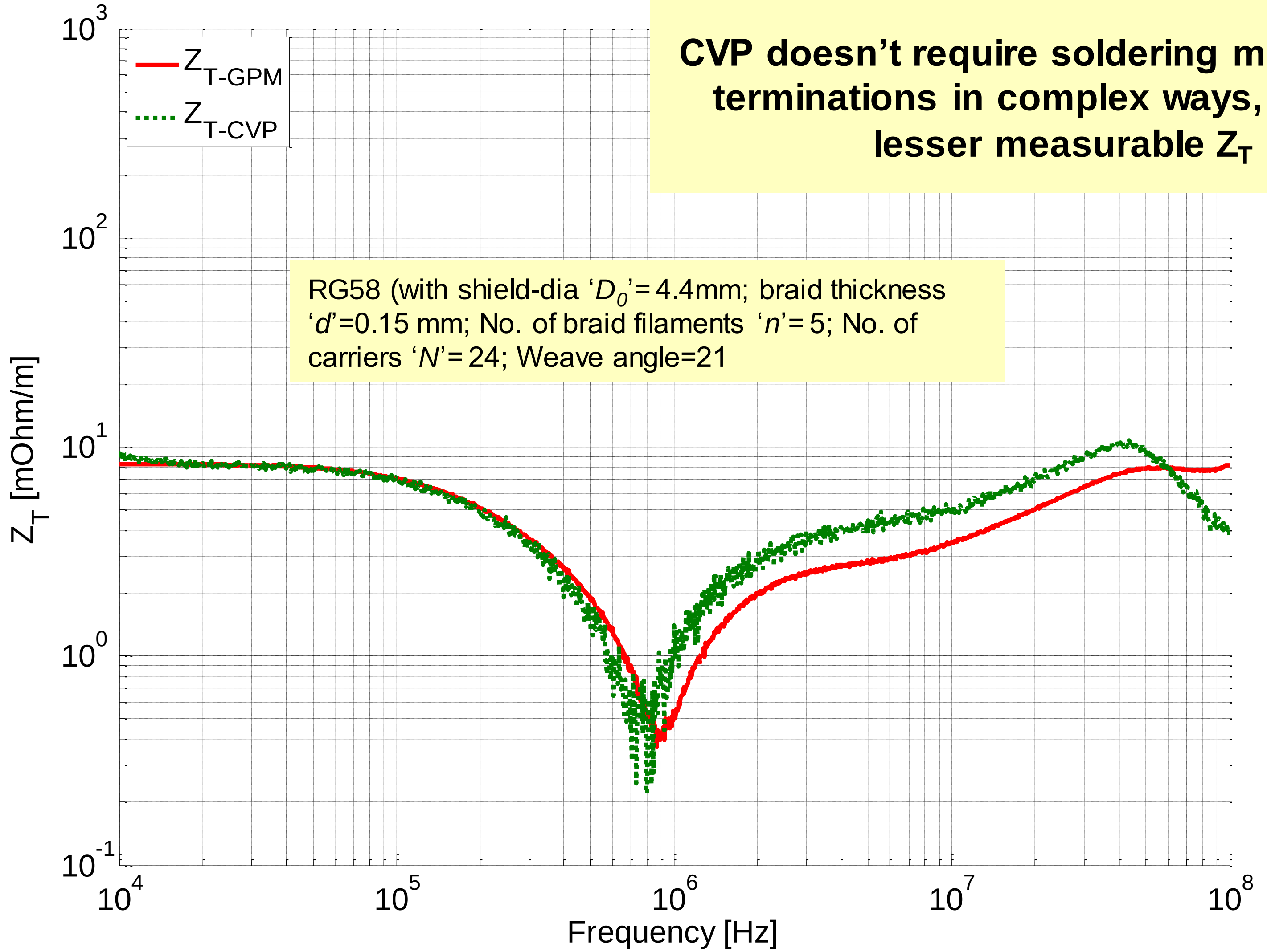
For unknown input impedance/mismatched system, it can be measured using reflection measurements using NWA



Longer DUT length will ensure better R_{DC} measurements

Capacitive Voltage Probe (CVP) test

CVP doesn't require soldering matched terminations in complex ways, but has lesser measurable Z_T



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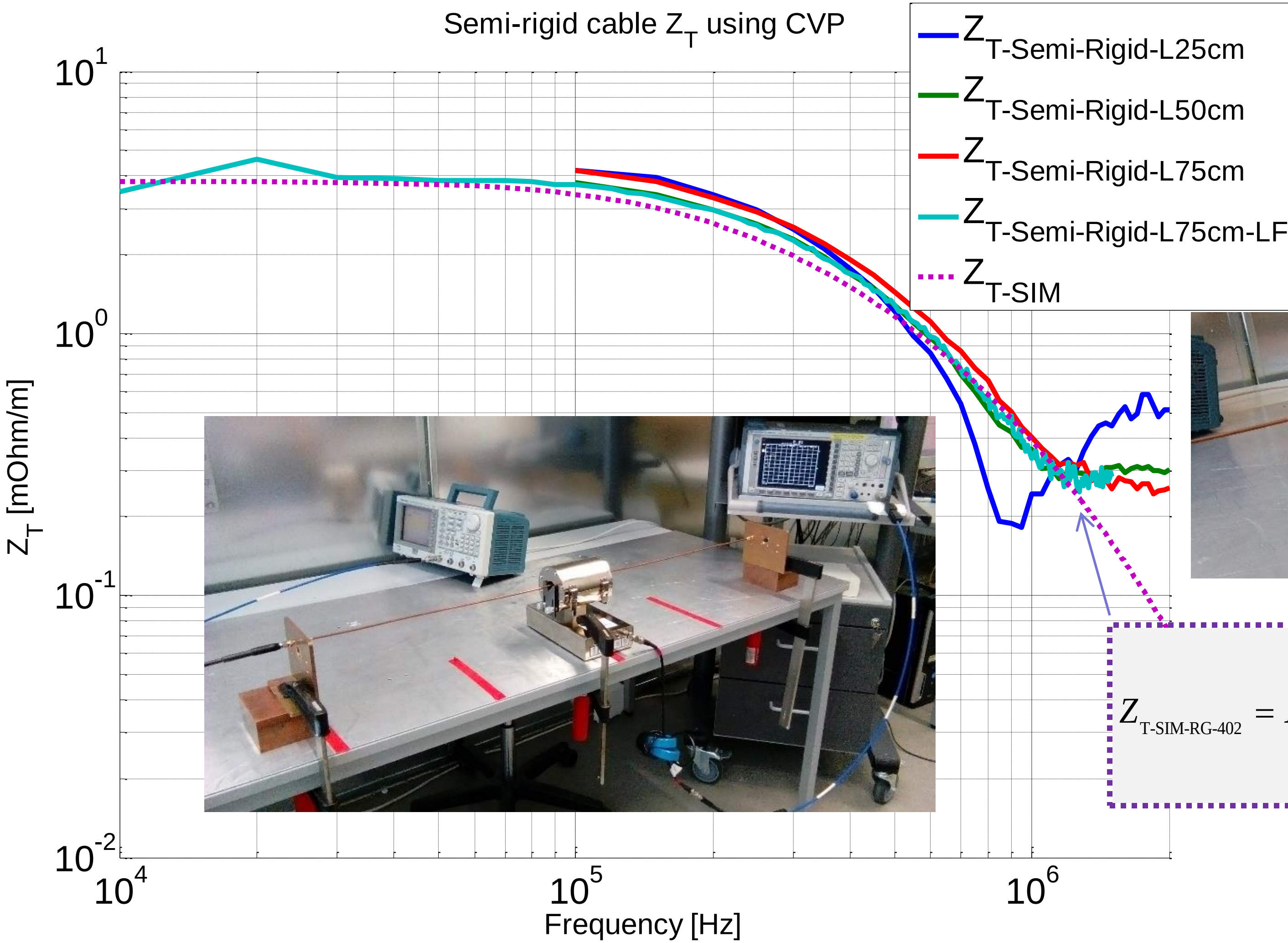
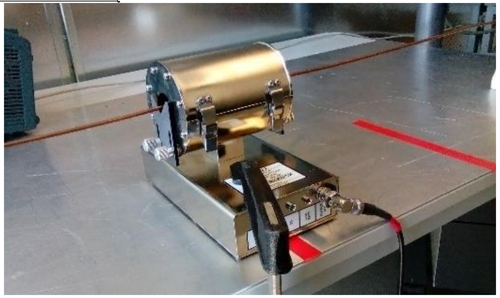
Capacitive Voltage Probe (CVP) test



Benefit:

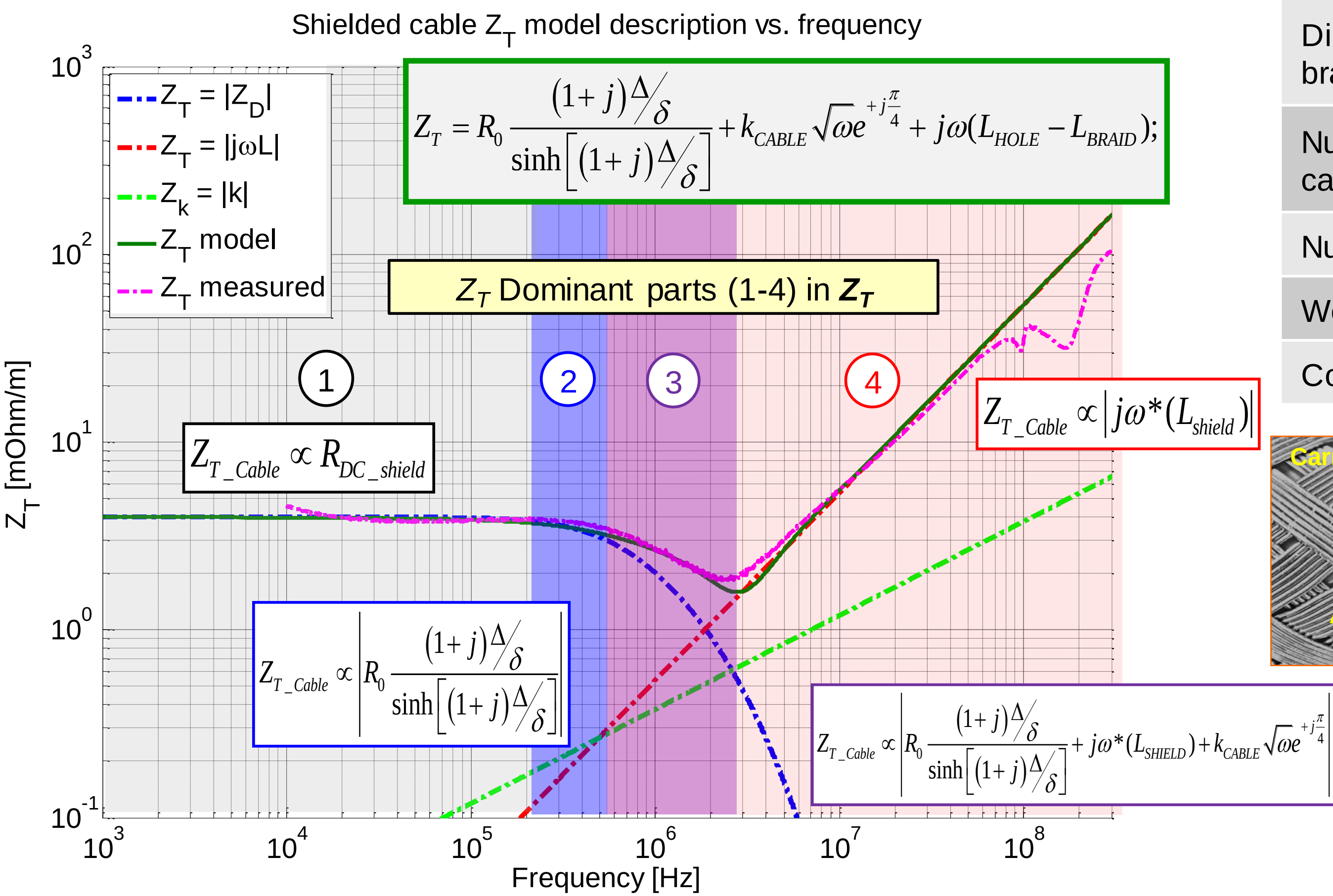
For semi-rigid cables, very good shielded cables CVP measures directly



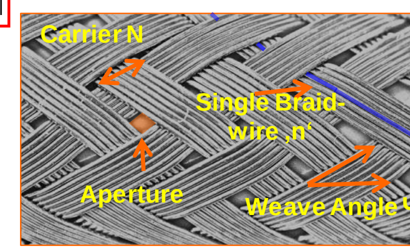
$$Z_{T\text{-SIM-RG-402}} = R_{DC} \frac{(1+j)\Delta/\delta}{\sinh\left((1+j)\Delta/\delta\right)};$$

Analytical Model

- Using analytical model (Demoulin model) for Z_T

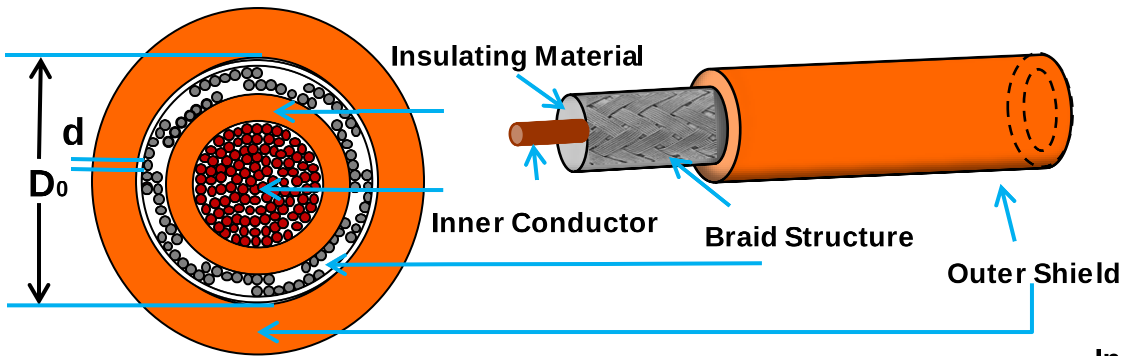


Braid parameters	
Diameter of the braid	D_0
Diameter of single braid wire	d
Number of wires in carrier	n
Number of carriers	N
Weave angle	Ψ
Conductivity	σ

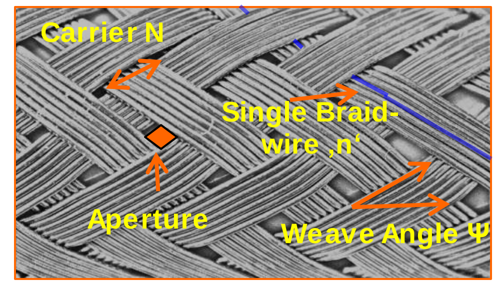


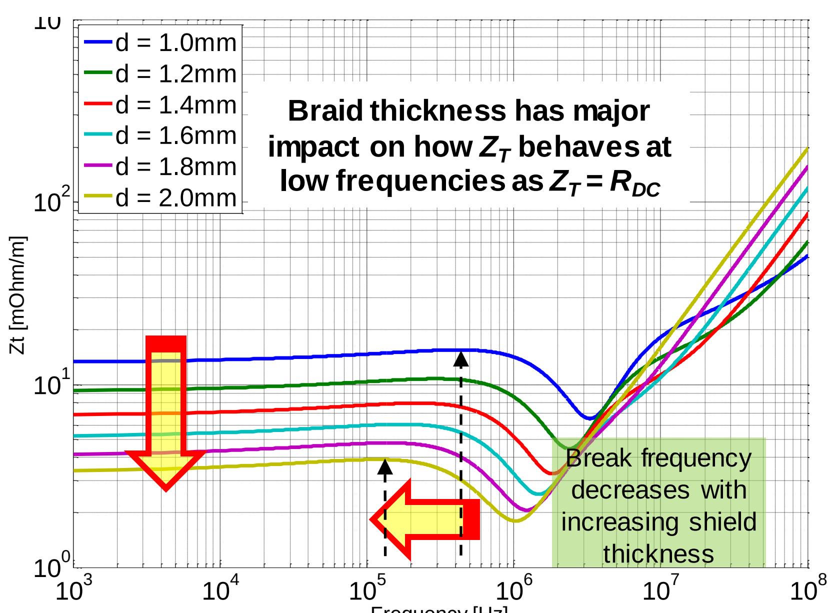
Analytical Model

- How Z_T can be improved based on geometrical parameters of the shield?

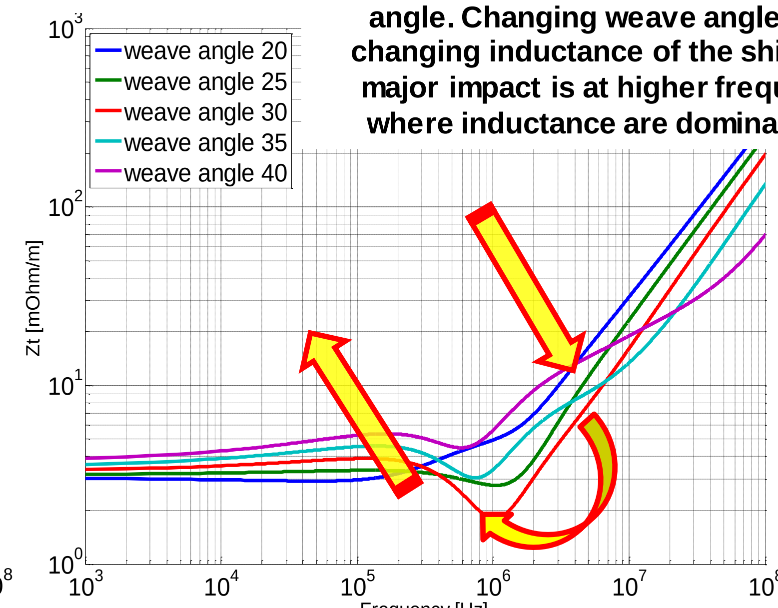


Geometrical parameters of shield



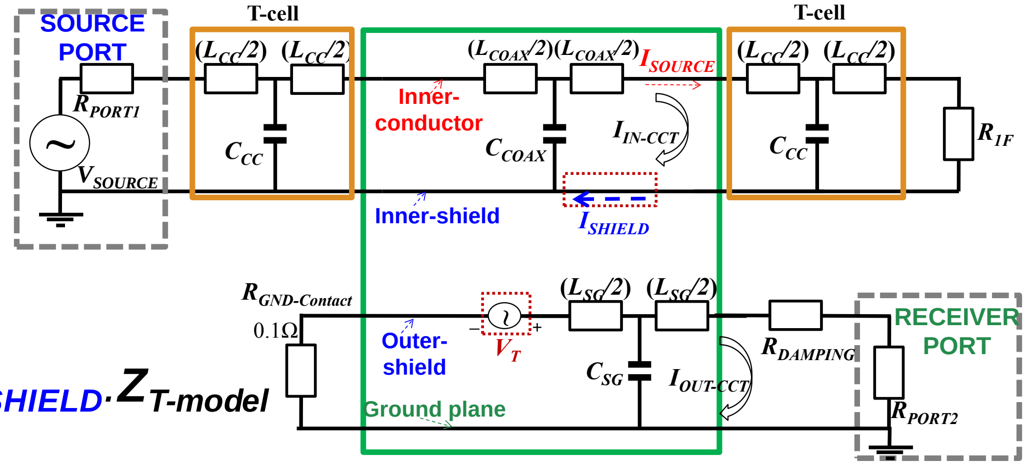


Inductance is directly dependent on weave angle. Changing weave angle means changing inductance of the shield thus major impact is at higher frequencies where inductance are dominant in Z_T

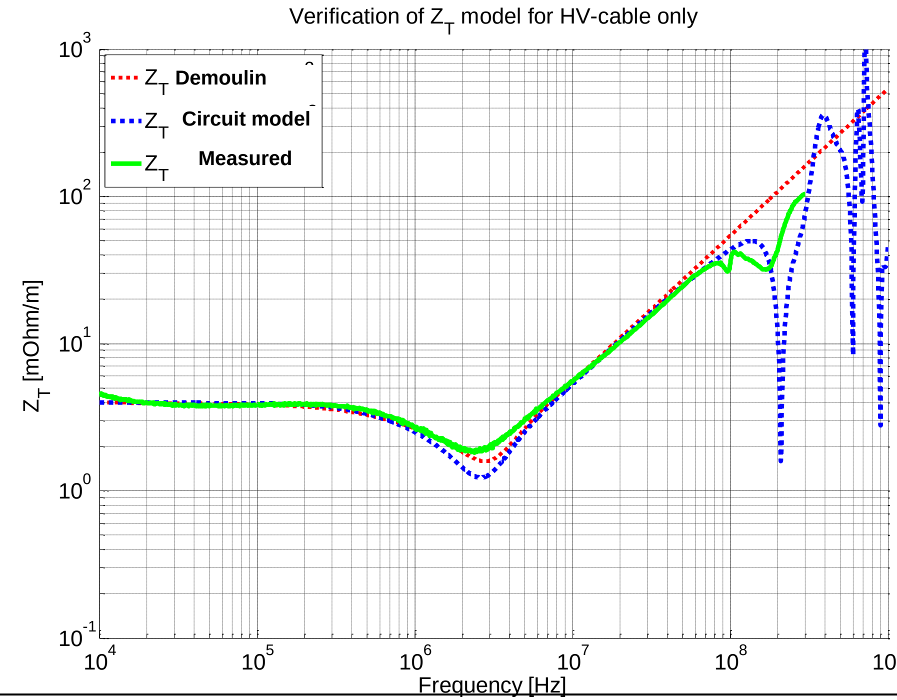


Circuit models

- Combination of analytical and circuit models
  - give more realistic prediction of shielding behavior



$$V_T = I_{SHIELD} \cdot Z_{T\text{-}model}$$



- Advantages: Possible to..
  - Add TL models for connecting cables, to predict realistic measurement results
  - Add to other modules, for complex system analysis

Content

Summary

- Overview
  - Comparative study of ZT measurement methods and Simulation methods for shielding analysis of HV cables used in EVs

- Measurement methods
  - Existing methods like Triaxial and Line Injection Methods
  - Ground Plate Method (GPM)
  - Capacitive Voltage Probe (CVP) Method

- Simulation methods
  - Analytical models
  - Circuit models

- Applications:
  - Component level shielding analysis of shielded cables and connectors
  - Further integration of proposed simulation methods into complex system simulations
  - Correlation with Antenna measurements

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Thanks for your attention!

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