Finite element analysis of cable shields to investigate the behavior of the transfer impedance with respect to fast transients

Susanne Bauer, Werner Renhart, Oszkár Bíró
IGTE, Institute of Fundamentals and Theory in Electrical Engineering
Graz University of Technology
Christian Türk
Ministry of Defence of Austria
General Overview

- Definition of transfer impedance
- Model description
- Simulation setup
- Results
- Outlook
Cable shields

Definition of transfer impedance: [1]

• Defined as: Ratio between the transferred voltage per unit length on the internal surface of the shield and the longitudinal current on the external side of the shield.

• Measured in Ohms per meter:

\[
Z_t = \frac{\partial V_{tr}}{\partial x} \frac{1}{I_0} \text{ } \Omega/m
\]

where \( x \) is the longitudinal space coordinate.

Used Setup:

• The electromagnetic interference current (EMI current) is applied to the inner circuit formed by the inner conductor and the shield.
• This EMI current produces a differential transfer voltage on the outer side of the shield.

Characterization of cable shields

Characterization of transfer impedance of braided shields via terms of

- Inner radius of the shield
- Shield thickness
- Conductivity of the shield
- Weave angle of the shield
- Coverage factor
- Number of carriers
- Number of filaments
- Filament diameter
Cable model

Coaxial cable: RG58/CU, basic geometry

Geometry:
- Diameter of inner conductor: 0.90mm
- Inner diameter of shield: 2.90mm
- Outer diameter of shield: 3.50mm

- **Shield thickness of 0.30mm**

Materials:
- Conductors: Copper, 56MS/m
- Dielectric: Polyethylene, $\varepsilon_r = 2.4$
FEM- Model

Model parameters

- Inner radius of the shield
- Shield thickness
- Conductivity of the shield
- Weave angle of the shield
- Coverage factor

- Number of carriers
- Number of filaments
- Filament diameter
Skin effect and discretization issues

Exponential decrease of current density from its value at the surface $J_S$:

$$J = J_S e^{-\frac{z}{\delta}}$$

Where $\delta$ is the skin depth:

$$\delta = \sqrt{\frac{2 \cdot \rho}{\omega \mu}}$$

- $\rho$ ... resistivity of the conductor
- $\omega$ ... angular frequency
- $\mu$ ... permeability $\mu = \mu_0 \cdot \mu_r$

<table>
<thead>
<tr>
<th>$\delta$</th>
<th>$f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$652 \mu m$</td>
<td>$10 kHz$</td>
</tr>
<tr>
<td>$206 \mu m$</td>
<td>$100 kHz$</td>
</tr>
<tr>
<td>$6.52 \mu m$</td>
<td>$100 MHz$</td>
</tr>
</tbody>
</table>

[Diagrams showing current density distributions at different frequencies]
Simulation

- For the numerical analysis, the $A, V - A$ - formulation is used [2]
- A magnetic vector potential $A$ and an electric scalar potential $V$ represented by a modified scalar potential $v$ are introduced
- The magnetic vector potential $A$ is used in the non-conducting region $\Omega_i$ and in the conducting region $\Omega_c$
- The scalar potential $v$ is used in the conducting region $\Omega_c$

$$B = \nabla \times A \text{ in } \Omega_c \text{ and } \Omega_i$$

$$E = -\frac{\partial A}{\partial t} - \nabla V = -\frac{\partial A}{\partial t} - \nabla \frac{\partial v}{\partial t} \text{ in } \Omega_c$$

Simulation (2)

For an eddy current problem with current excitation, the boundary conditions are

$$\nu_0 = 0 \text{ on } \Gamma_{E1} \text{ and } \nu_0 = \nu_x \text{ on } \Gamma_{E2}$$

$$\nu_x \ldots \text{ voltage between these two electrodes}$$

With a given current $I_0$ the following relationship has to be satisfied additionally:

$$\int_{\Gamma_{E2}} \sigma \left( \frac{\partial \mathbf{A}}{\partial t} + \nabla \frac{\partial \mathbf{V}}{\partial t} \right) \cdot \mathbf{n} d\Gamma = I_0$$

Applying Galerkin techniques leads to a system of first order differential equations

$$[A]\{a\} + [B]\{\dot{a}\} = \{b\}$$

This is solved by time-stepping applying the backward Euler scheme [3] resulting in a system of algebraic equations

$$[A]\{a_k\} + \frac{1}{\Delta t_k} [B]\{a_k\} = \frac{1}{\Delta t_k} [B]\{a_{k-1}\} + \{b_k\}$$
Results

Test results at 100kHz

Line diagram of current density evaluated over the cable diameter

Computed by E11.86/Postprocessed by E11.86
Results

Broadband investigation

As input function a gaussian pulse is applied

Transfer impedance vs frequency

Baseband spectrum of i(t) in dB

Solid shield, copper shield with aperture and braided shield
Results

Transient simulation

As input function the standardized EFT/BURST pulse was applied via a 50 Ω resistance (IEC 61000-4-4:2012)

Set Voltage: \( U_s \)  
1000 V

Rise-time: \( t_r \)  
(5±1.5)ns

Pulse Width: \( t_d \)  
(50±15)ns

The testing signal is modelled as a double exponential pulse [4]:

\[
V_0(t) = V_s \cdot k \left( e^{-\alpha t} - e^{-\beta t} \right)
\]

applied current vs normalized induced voltage

Cable deformities such as pinched cables and their influence on signal integrity and crosstalk:

- Impedance mismatch, since the characteristic impedance is geometry dependent.
- Apertures in the shield create an additional path for the electromagnetic coupling between the inside and the outside of the shield.

Outlook:

- Refining the geometry
- Parameterized model for sensitivity analysis
- Extraction of manageable model for further simulation (SPICE)
References


Thank you for your attention

Susanne.bauer@tugraz.at