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

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Chambéry, France
18-21 june 2019
23RD IEEE WORKSHOP ON SIGNAL AND POWER INTEGRITY

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

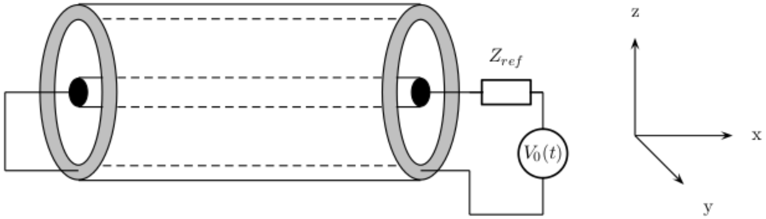
- Measured in Ohms per meter:

$$Z_t = \frac{\partial V_{tr}}{\partial x} \frac{1}{I_0} \quad \Omega/\mathrm{m}$$

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



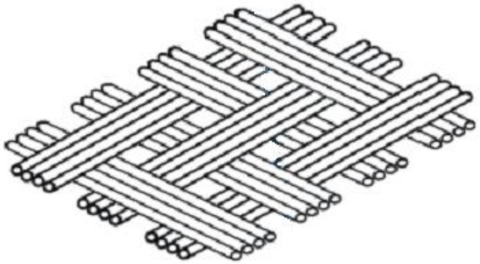
S.A. Schelkunoff, “The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields”, *The Bell System Technical Journal*, Volume 13, Issue 4, Oct. 1934

Characterization of cable shields

Characterization of transfer impedance of braided shields via terms of

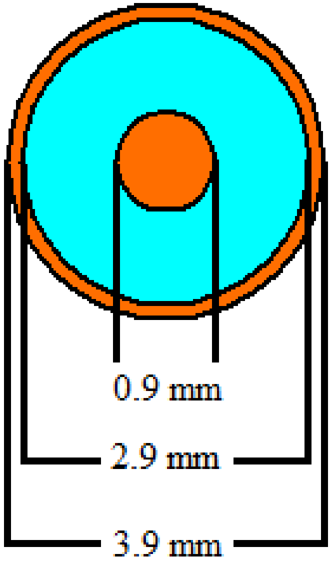
- Inner radius of the shield
- Shield thickness
- Conductivity of the shield
- Weave angle of the shield
- Coverage factor

- 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

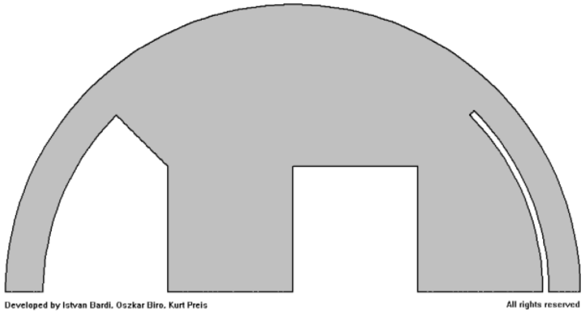
➢ ***Shield thickness of 0.30mm***

Materials:

- Conductors: Copper, 56MS/m
- Dielectric: Polyethylene, $\epsilon_r = 2.4$

FEM- Model

ELEctromagnetic Field ANalysis Tool 3D


Developed by Istvan Bardi, Oszkar Biro, Kurt Preis

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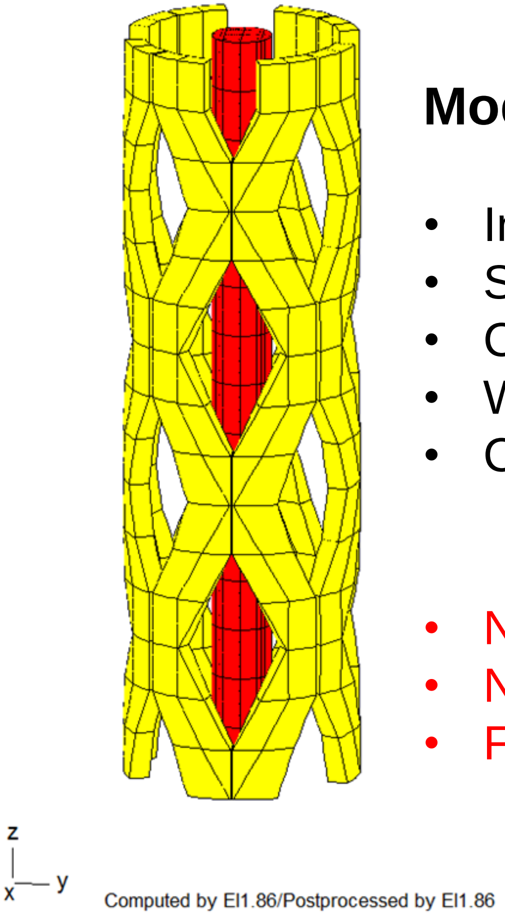


Computed by EI1.86/Postprocessed by EI1.86

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 δ is the skin depth:

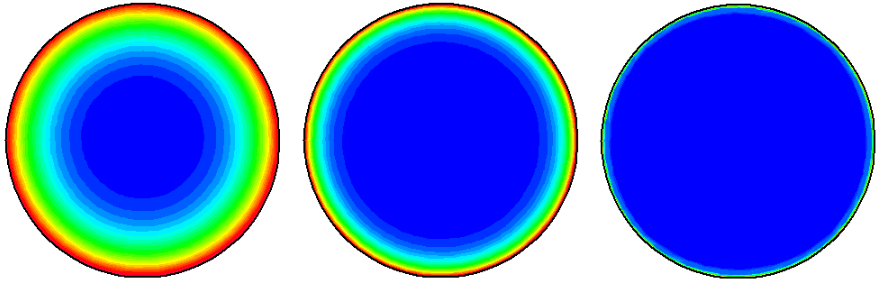
$$\delta = \sqrt{\frac{2 \cdot \rho}{\omega\mu}}$$

ρ … resistivity of the conductor

ω … angular frequency

μ … permeability $\mu = \mu_0 \cdot \mu_r$

$\delta = 652 \mu m$ $\delta = 206 \mu m$ $\delta = 6.52 \mu m$



$f = 10 kHz$ $f = 100 kHz$ $f = 100 MHz$

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 Ω_i and in the conducting region Ω_c
- The scalar potential v is used in the conducting region Ω_c

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

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

O.Bíró, K. Preis, "On the use of the magnetic vector potential in the finite-element analysis of three-dimensional eddy currents", *IEEE Transactions on Magnetics*, Vol. 25, No. 4, July 1989

Simulation (2)

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

Γ_{E1}, Γ_{E2} ... surfaces of the electrodes

$$v_0 = 0 \; on \, \Gamma_{E1} \; and \; v_0 = v_x \; on \, \Gamma_{E2}$$

v_x ... voltage between these two electrodes

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

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

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

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

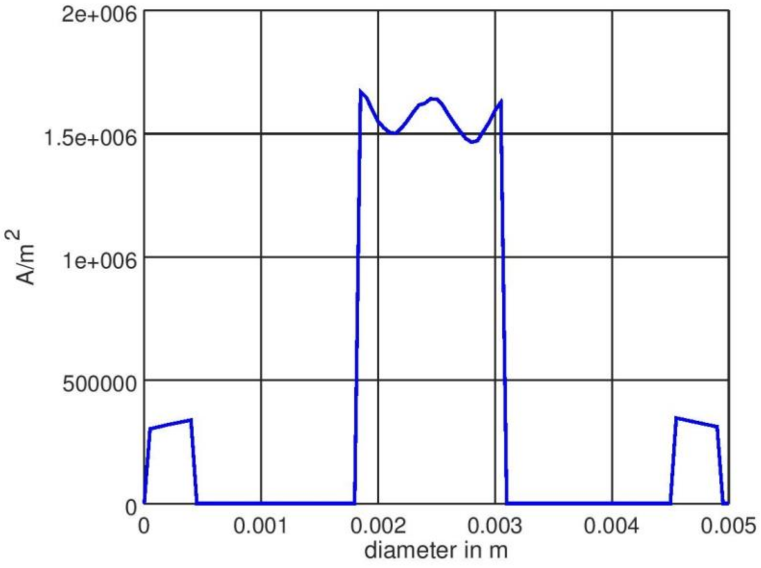
This is solved by time-stepping applying the backward Euler scheme [3] resulting in a system of algebraic equations

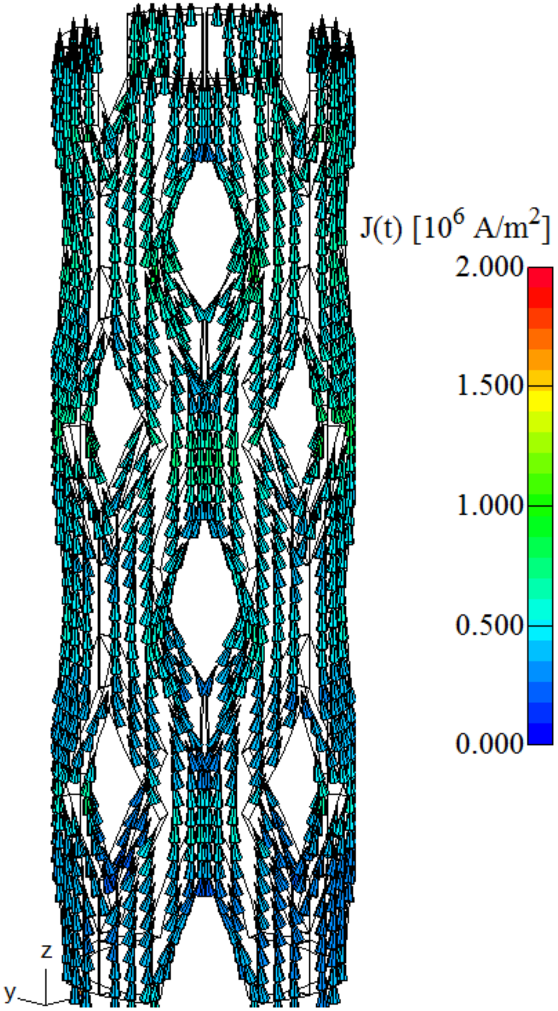
$$[\mathrm{A}]\{a_k\} + \frac{1}{\Delta t_k}[B]\{a_k\} = \frac{1}{\Delta t_k}[B]\{a_{k-1}\} + \{b_k\}$$

B.Weiss, O.Bíró, "On the Convergence of Transient Eddy-Current Problems",

Test results at 100kHz

Line diagram of current density evaluated over the cable diameter





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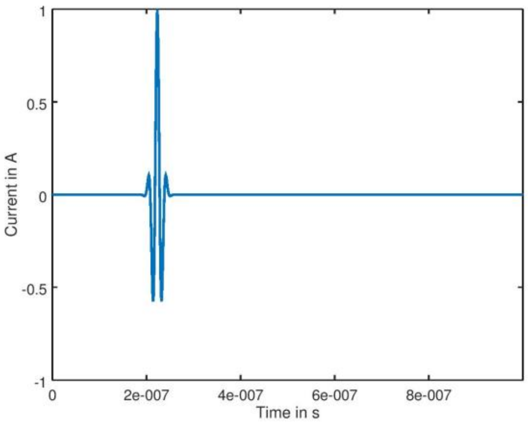
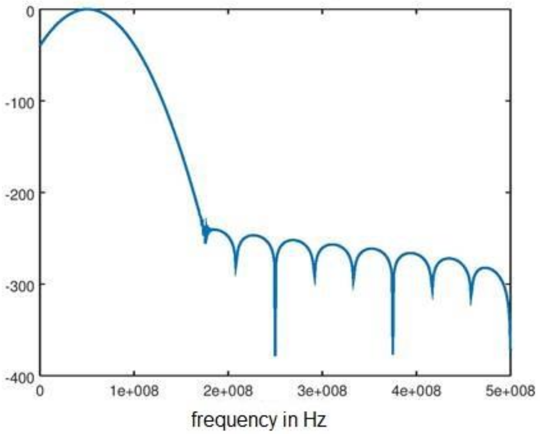
Broadband investigation

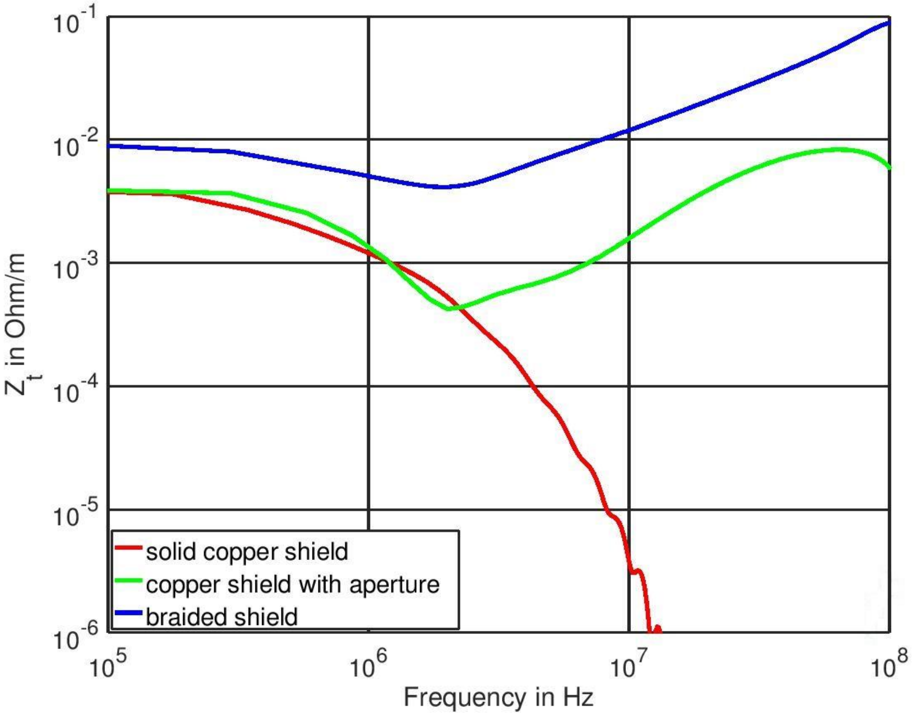
As input function
a gaussian pulse is applied



Baseband spectrum of i(t) in dB



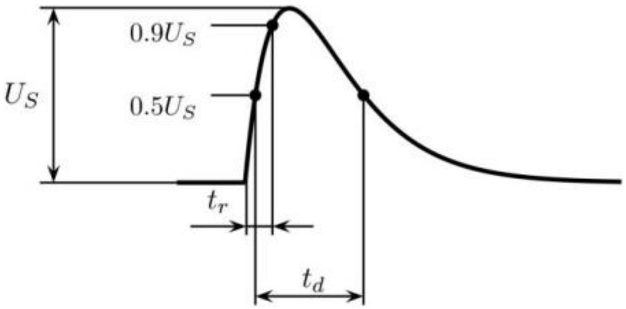
Transfer impedance vs frequency



Solid shield, copper shield with aperture and braided shield

Transient simulation

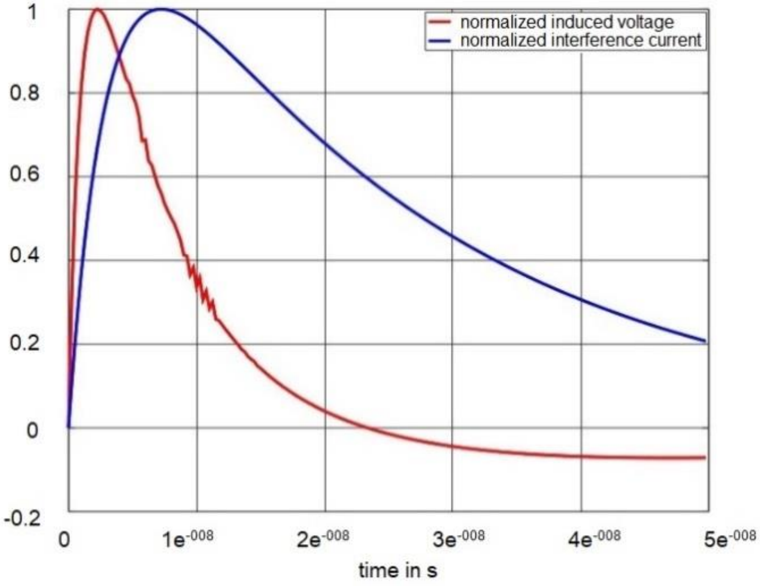
As input function the standardized EFT/BURST pulse was applied via a 50 Ω resistance (IEC 61000-4-4:2012)



Set Voltage: U_S	Rise-time: t_r	Pulse Width: t_d
1000 V	(5±1.5)ns	(50±15)ns

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

$$V_0(t)=V_S\cdot k\left(e^{-\alpha t}-e^{-\beta t}\right)$$

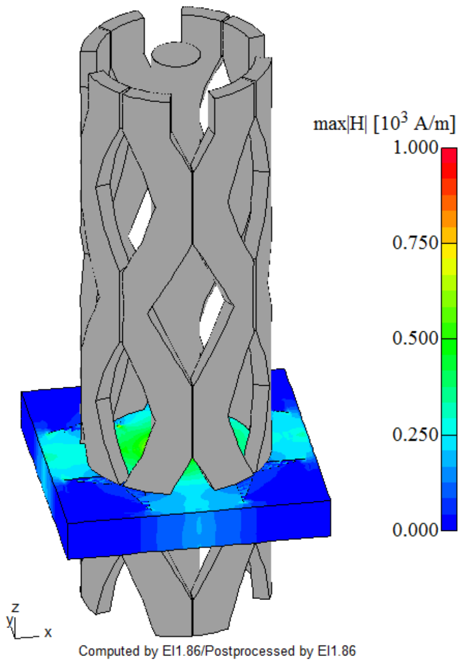


applied current vs normalized induced voltage

M. Magdowski, R. Vick, “Estimation of the Mathematical Parameters of Double-Exponential Pulses Using the Nelder-Mead Algorithm”, *IEEE Transactions on Electromagnetic Compatibility*, pp1060-1062, Nov. 2010

Outlook

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



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

References

(1) S.A. Schelkunoff, “The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields”,
The Bell System Technical Journal, Volume 13, Issue 4, Oct. 1934

(2) O. Bíró, K. Preis, “On the use of the magnetic vector potential in the finite-element analysis of three-dimensional eddy currents”,
IEEE Transactions on Magnetics, Vol. 25, No. 4, July 1989

(3) B. Weiss, O. Bíró, ”On the Convergence of Transient Eddy-Current Problems”,
IEEE Transactions on Magnetics,Vol. 40, No. 2, March 2004

(4) M. Magdowski, R. Vick, “Estimation of the Mathematical Parameters of Double-Exponential Pulses Using the Nelder-Mead Algorithm”, *IEEE Transactions on Electromagnetic Compatibility*, pp1060-1062, Nov. 2010

Thank you for your attention

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