A CAD tool for the electromagnetic modeling of braided wire shields

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Contents

1 A CAD tool for the electromagnetic modeling of braided wire shields 5
1.1 Geometric model 6
1.2 Numerical model 6
1.3 Results 9
1.4 Conclusion 13

Chapter 1

A CAD tool for the electromagnetic modeling of braided wire shields

In this report we present a computer aided design tool which can be useful for characterizing the shielding quality of braided wire shields. This numerical tool can be applied systematically to a wide variety of situations where complex geometries and materials may be present. Also, it can help in the validation and improvement of existent analytical models. These analytical models can be hard to compare directly against measurement because of uncertainties in the input data produced by manufacturing tolerances or changes in the properties caused by aging and handling. The work described in this report and the research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013, under grant agreement no. 205294, project HIRF-SE (High Intensity Radiated Fields Synthetic Environment).

Introduction

The shielding effectiveness of a braided wire shield can be characterized by a parameter called the surface transfer impedance (Z_t). This parameter was initially introduced by Schelkunoff [12] and is defined as:

$$Z_t = \frac{1}{I_0}\frac{\partial V}{\partial z} \tag{1.1}$$

where I_0 is the current flowing through the shield induced on its outer surface and $\partial V/\partial z$ is the voltage per unit length on the inside of the shield. The transfer impedance is an intrinsic parameter whose value depends only on the geometry and materials of the braid. It allows to estimate the effect produced by an external field in the wires inside the cable or, reciprocally, the radiation leaked from inside the cable to the environment. A low Z_t indicates a good shielding against interfering electromagnetic fields.

The objective of this report is to present a computer aided design (CAD) tool for computing the transfer impedance of braided wire shields. This numerical tool can be applied systematically to a wide variety of situations where complex geometries and materials may be present. Also, it can help in the validation and improvement of existing analytical models [16, 5, 11, 15, 13]. These analytical models can be hard to compare directly against measurement because of uncertainties in the input data produced by manufacturing tolerances [2] or changes in the properties caused by aging and handling [1]. On the other hand, we can easily compare analytical results against the CAD tool presented here because all the parameters involved in the comparative are exactly known.

1.1 Geometric model

The first step before starting with the numerical analysis is to generate a CAD geometry representing the braided wire shield. This task is performed with a plug-in integrated in the pre-processor software GiD [4, 3]. The data are introduced in a user-friendly window created with Tcl/Tk which generates automatically the geometry and imports it to GiD (see Fig. 1.1).

The parameters required to generate a braided wire geometry are: one-step or two-step wire mode (see Fig. 1.1 and Fig. 1.2, respectively), diameter of a single wire (d), inner diameter of the shield (D), number of carriers (i.e. belts of wires) in the braid (C), number of wires in a carrier (N), weave angle of the braid (α), distance between the braid and the integrations surfaces ($\lambda_{internal}$ and $\lambda_{external}$, see right picture of Fig. 1.3), distance between carriers (λ_{medium}), separation between wires inside the same carrier (κ), shape of the function describing a smoother or steeper ascent/descent of the wires (Γ, $\Omega \in [0,1]$), diameter of the central core (current density source, see left picture of Fig. 1.3) and, diameter of the external contour (radiation boundary condition surface, see left picture of Fig. 1.3).

The geometry generated with all the above parameters (see Fig. 1.3 or left picture of Fig. 1.2) is the unit cell from which a full braid geometry can be obtained. We only have to rotate the unit cell in the XY-plane and translate it along the Z-axis to create a complete braided wire shield (see Fig. 1.1 or right picture of Fig. 1.2).

1.2 Numerical model

Once the CAD geometry is ready, we apply the finite element method (FEM) to the unit cell (see figures 1.3 and 1.4). The boundary conditions employed are: periodic boundary conditions (PBC) on the transversal planes ($\mathbf{E}(\mathbf{r}) = \mathbf{E}(\mathbf{r}+\mathbf{p})$, being $\mathbf{p}$ a vector pointing in the Z-direction with a modulus equal to the longitudinal length of the unit cell), cyclic boundary conditions (CBC) on the longitudinal planes ($\mathbf{E}(\mathbf{r}) = \Re_z^{\varphi}\{\mathbf{E}(\Re_z^{\varphi}\{\mathbf{r}\})\}$, being $\Re_z^{\varphi}\{\cdot\}$ a rotation about the Z-axis with an angle of $\varphi = 4\pi/C$) and, first order absorbing boundary conditions (1st ABC) on the exterior surface. The problem is driven by a longitudinal current density $\mathbf{J}$ placed along the centered inner cylinder.

The above FEM model is the adaptation to braided wire geometries of the numerical model presented in [10]. We also use the same FEM software as in [10] to compute the electric fields in the unit cell. This software is called ERMES [7] and solves the time-harmonic Maxwell equations with the FEM formulation explained in [6, 8, 9]. ERMES has been implemented in C++ and has a graphical user interface integrated in GiD.

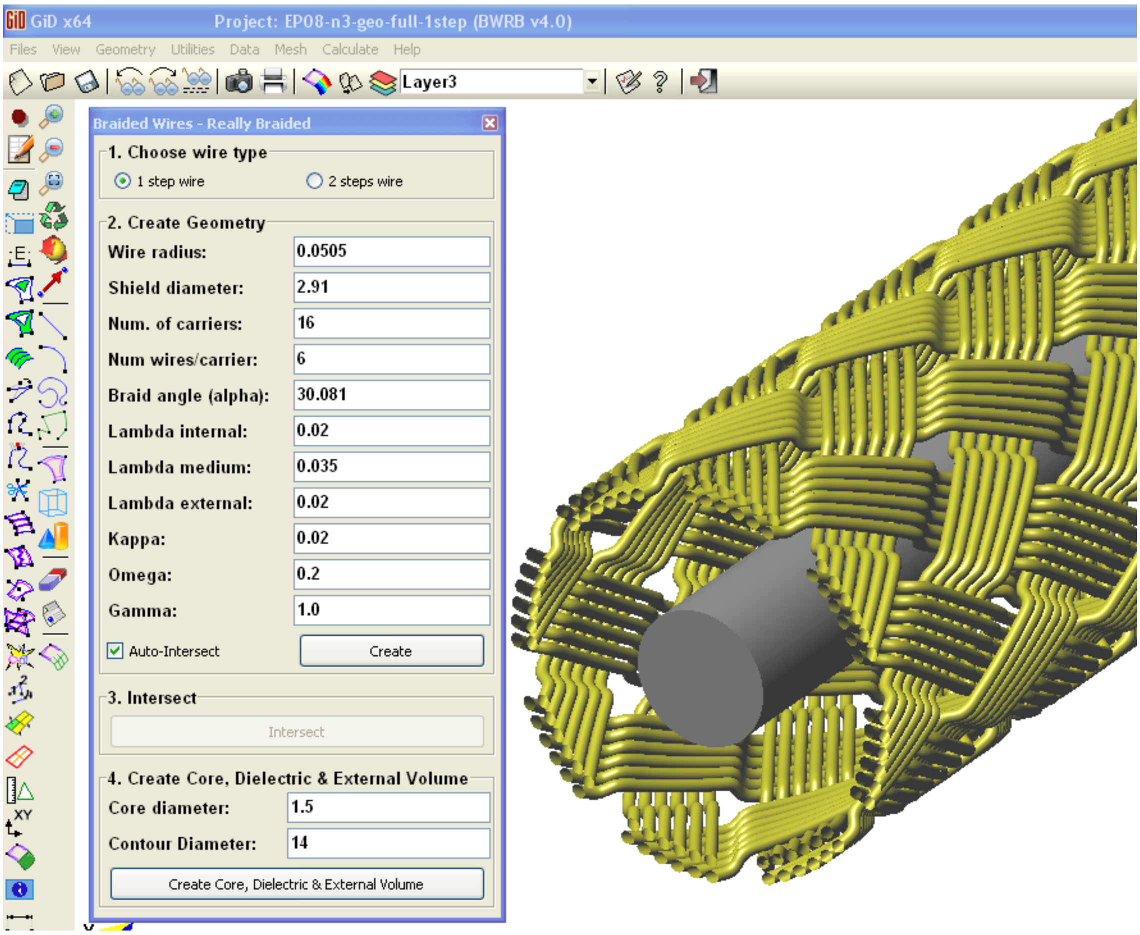

Figure 1.1: Graphical user interface integrated in the software GiD [4, 3]. Braided wire CAD geometry generated with the one-step wire mode activated.

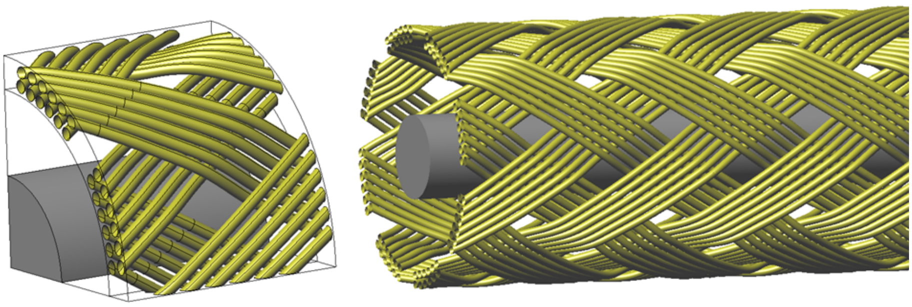

Figure 1.2: Two-step wire mode. Left: unit cell. Right: braided wire geometry generated from the unit cell on the left.

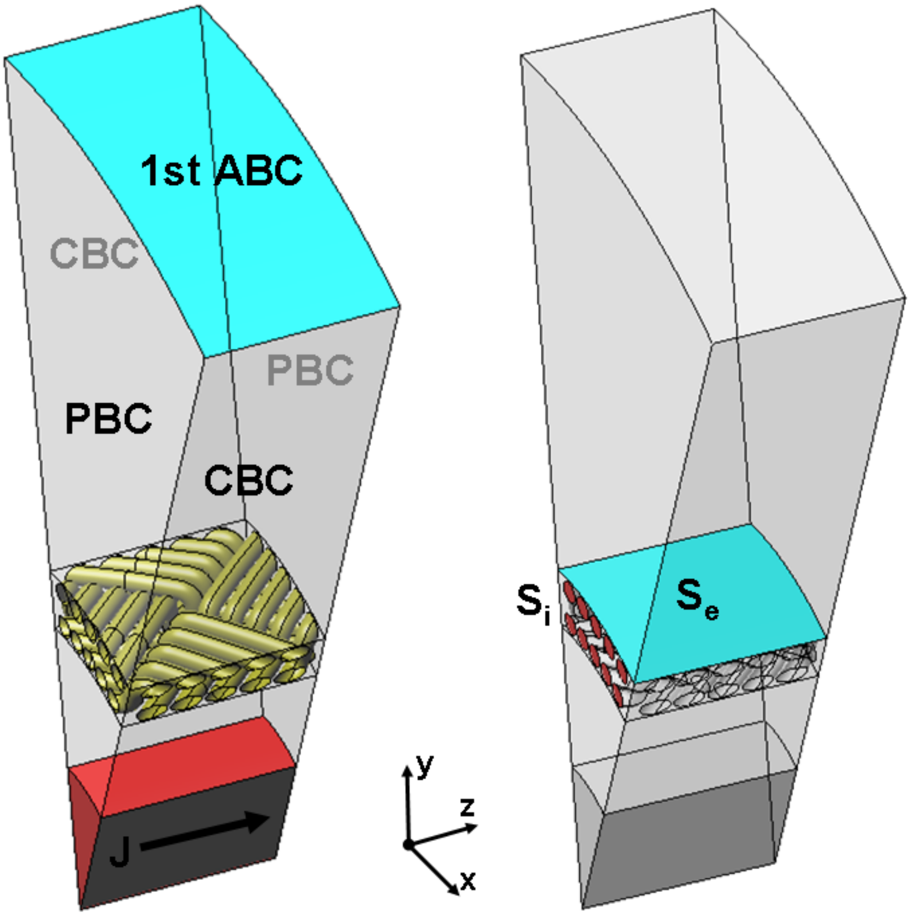

Figure 1.3: FEM model. Left: boundary conditions applied to the unit cell. Right: surfaces where the electric field $\mathbf{E}$ is integrated to obtain Z_t.

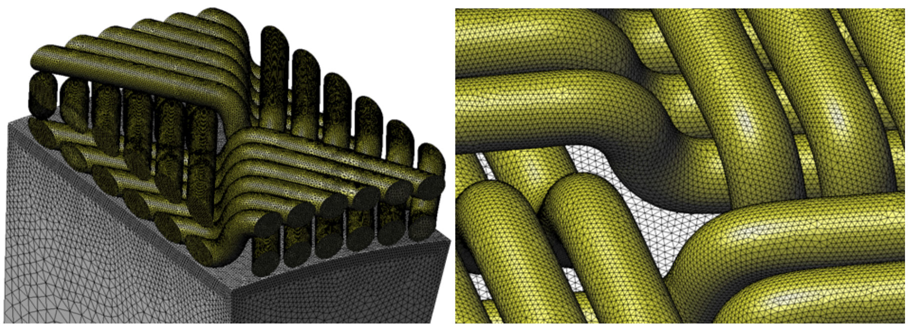

Figure 1.4: Details of the FEM mesh used to compute the electric field in the unit cell.

Table 1.1: Braided wire shield samples

Sample	D(mm)	d(mm)	C	N	$\alpha(^{o})$	σ(S/m)
1	1.50	0.100	16	3	21.44	4.12e7
2	2.95	0.101	16	6	30.08	4.12e7

As is in [10], we use the following equations to obtain Z_t from the calculated electric field **E** (see right picture of Fig. 1.3):

$$\frac{\partial V}{\partial z} = \frac{1}{A_e} \iint_{S_e} E_z \, dS_e \tag{1.2}$$

and

$$I_0 = \frac{C}{2} \iint_{S_i} \sigma E_z \, dS_i, \tag{1.3}$$

where E_z is the modulus of the longitudinal component of the electric field, S_e is a surface located just above the braid, C is the number of carriers, S_i is the transversal surface of the wires, A_e is the area of S_e and σ is the electrical conductivity of the wires. Equation (1.2) represents the transversal electric field averaged over S_e and equation (1.3) represents the induced current going through the shield. In the two-step wire mode we must multiply the integral of equation (1.3) by $C/4$ instead of by $C/2$.

Although Z_t was originally defined as the ratio between the voltage per unit length on the inner surface of the shield and the induced current flowing through its outer surface (see section 1), it can also be defined, by reciprocity, as the ratio between the voltage per unit length on the outer surface of the shield and the current flowing through the shield induced on its inner surface [1]. This last definition is the one adopted here. We induce a current in the braid from the inside of the shield with the fields generated by a longitudinal **J** and measure the voltage per unit length in a surface just above the outer side of the braid (see Fig. 1.3).

1.3 Results

ERMES was used to compute the transfer impedance of the two samples of braided wire shields described in table 1.1. The distance between carriers (λ_{medium}) was calculated with the formula given in [13]:

$$\lambda_{medium} = h = \frac{2d^2}{b+d} \tag{1.4}$$

$$b = \frac{2\pi D_m}{C} cos\,(\alpha) - Nd \tag{1.5}$$

where $D_m = D + 2d$ is the average diameter of the shield and d, C, N and, α were yet defined in section 1.1. The core diameter was 0.75 mm for sample 1 and 1.50 mm for sample 2. The contour diameter was 8.0 mm for sample 1 and 14.0 mm for sample 2. The rest of the parameters described in section 1.1 were set at the same value for both samples: One-step wire mode, $\lambda_{external} = 0.02$ mm, $\lambda_{internal} = 0.02$ mm, $\kappa = 0.02$ mm, $\Omega = 0.2$ and, $\Gamma = 1.0$.

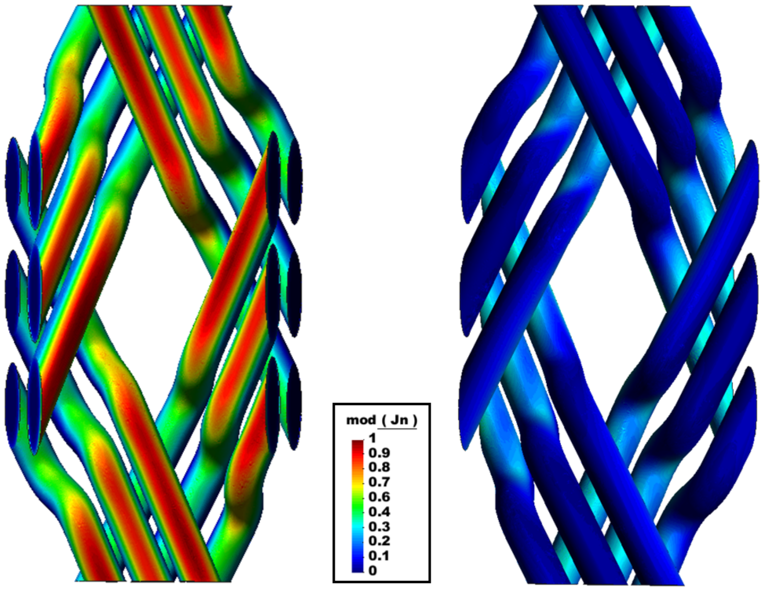

Figure 1.5: Modulus of the current density **J** (normalized to its maximum value) at $f = 100\,\mathrm{MHz}$ for sample 1. Left: inside view of the braid. Right: outer view of the braid.

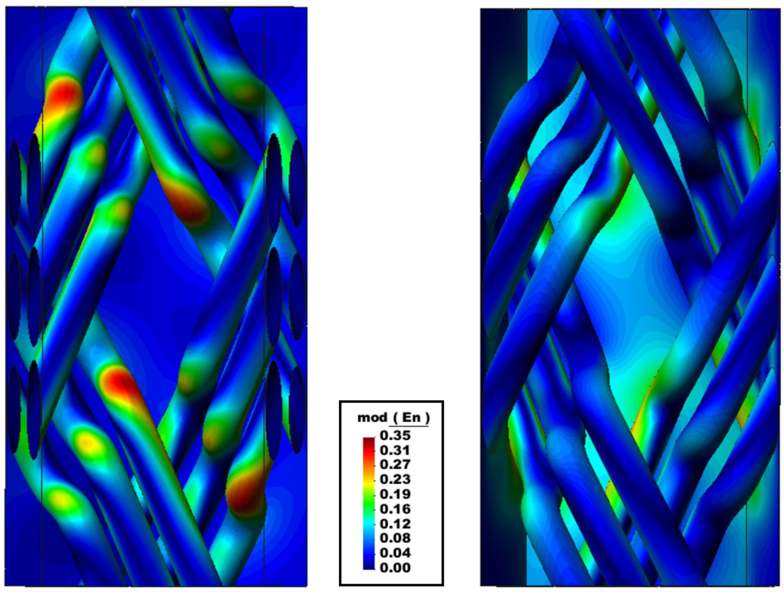

Figure 1.6: Modulus of the electric field **E** (normalized to its maximum value) at $f = 100\,\mathrm{MHz}$ for sample 1. Left: inside view of the braid. Right: outer view of the braid.

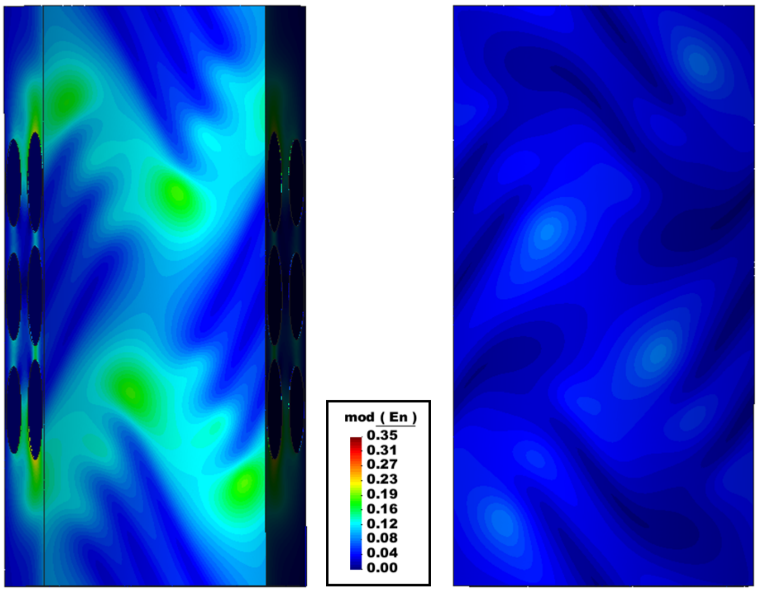

Figure 1.7: Modulus of the electric field **E** (normalized to its maximum value) at $f = 100\,\mathrm{MHz}$ for sample 1. Left: surface located 0.02 mm under the inside side of the braid. Right: surface located 0.02 mm above the outer side of the braid.

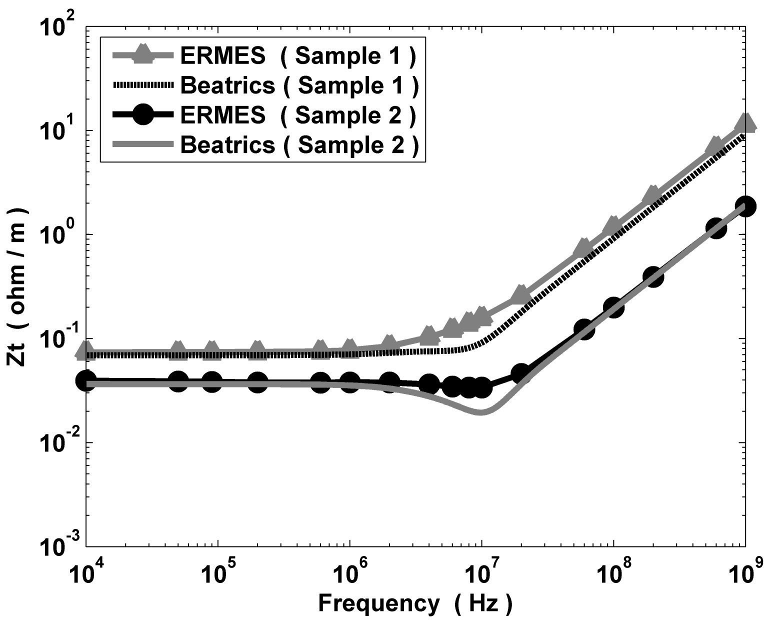

Figure 1.8: Modulus of the transfer impedance for sample 1 and 2 calculated with ERMES and Beatrics [13].

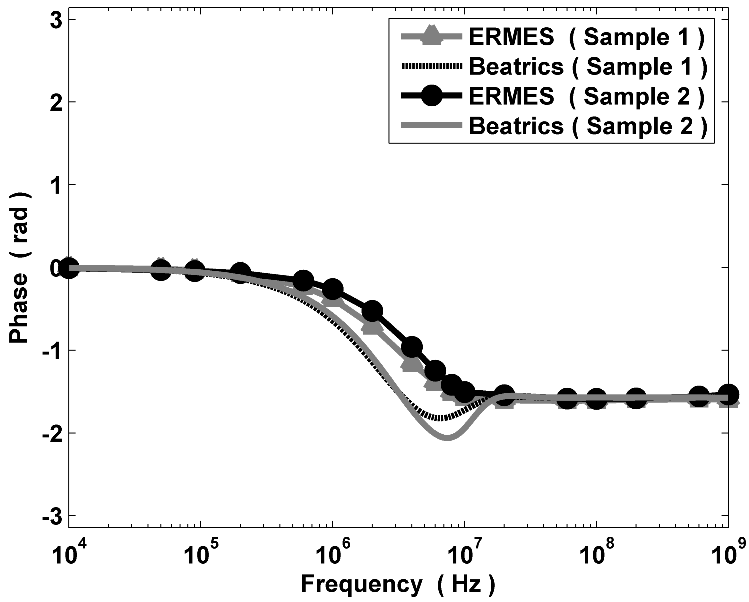

Figure 1.9: Phase of the transfer impedance for sample 1 and 2 calculated with ERMES and Beatrics [13].

In [14], it is shown experimentally that a braided shield has the same behavior as a shield consisting of insulated wires. Moreover, corrosion in aged cables also tent to accentuate this behavior. Therefore, we consider that all the wires of the braid are separated from each other by a finite distance (κ for wires inside the same carrier and λ_{medium} for wires in different carriers). The minimum separation between wires determines the minimum size of the mesh elements and, consequently, the size of FEM matrix and the hardware resources required for a simulation. The shorter is the separation, the smaller must be the size of the elements meshing the interspaces between wires. We meshed the unit cells of the braids taking special care of the surface of the wires and its interspaces (see Fig. 1.4). We used around 2.5×10^6 isoparametric 2nd order elements. The symmetric FEM matrix generated by ERMES occupied around $20\,\mathrm{GB}$ of RAM memory. ERMES needed between 2-3 hours (depending on the frequency range) to solve a single frequency in a computer with a CPU at 2.5 GHz and the operative system Microsoft Windows XP x64.

In Fig. 1.5 is shown the current density distribution at $f = 100\,\mathrm{MHz}$ in a unit cell of the braid of sample 1. In figures 1.6 and 1.7 is shown the electric field distribution around the braid of sample 1 at $f = 100\,\mathrm{MHz}$. The transfer impedance Z_t is obtained from the fields calculated with ERMES and the equations (1.2), (1.3) and (1.1). In Fig. 1.8 is shown the modulus of Z_t for sample 1 and 2. In Fig. 1.9 is shown the phase of Z_t also for both samples. As a reference, Z_t was also calculated with the analytical model Beatrics described in [13].

In figures 1.8 and 1.9 can be seen that Beatrics and ERMES provide equivalent values of Z_t. The differences in the medium frequency range are due to the fact that Beatrics does not model properly fine geometric details like the curvature of the wires or the gaps between wires in the same carrier. As it is shown in the last example of [10], it is precisely at this frequency range were the fine geometric details produce a more noticeable effect on the value of the Z_t. The differences at higher frequencies can be explained by the change in the dimensions of the shield holes caused by considering in ERMES a finite separation between the wires inside the same carrier ($\kappa = 0.02\,\mathrm{mm}$).

1.4 Conclusion

In this report we have presented a numerical tool which can be useful for computing Z_t on complex cable geometries and materials. Also, it can be helpful for the validation and improvement of existent analytical models which can be hard to validate directly against measurements. The results provided by ERMES are in good agreement with the analytical model of reference [13] for the samples simulated here. A more exhaustive validation (comparing ERMES against measurements and other analytical methods) it is been carried out and will be presented in a future work.

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