Study Regarding Knitting Parameters in 3D Textiles Shields Implementation

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Abstract *- The presence of disruptive EM fields in our environment represents the cause of many dysfunctions of the equipments that are assuring the precision and the security from different domains of activities. Nowadays the emphasis is on producing EM shields that besides good shielding properties they must have and good mechanical properties, low production cost and constructive diversity. This can be achieved with shields from textile materials, which we'll study in this paper.*

Keywords*: electromagnetic shielding, knitted shields, textile shields*

1. INTRODUCTION

Nowadays electromagnetic fields are present all around us, and their influence may disturb the functionality of electrical equipments that are sensible to these fields. Therefore there is a need of shielding these equipments against the electromagnetic fields. In addition, in the last decades members of public institutions and scientific society have tried to sensitize the mass-media on the necessity of protecting the vital civil equipments against terrorist possible EMP (electromagnetic pulse) attacks.

Classical shielding structures are made of metals (for which the attenuation is realized by reflexion) as copper, aluminum, stainless steel, silver, gold and so on, combined by welding or riveting. The metals are used under different forms as bulky (films, plates or meshes) or are inserted as particles in polymeric materials or as thin metallic coatings.

The materials for which the attenuation is realized by absorption, so called absorbers, have a restricted application area in comparison with the metals. This class of materials includes the ferrodielectrics, which are dielectrics with high dielectric constant (e.g. $BaTiO_3$) and the magnetics of high permeability known as ferrimagnetics (e.g. Fe_3O_4).

In the last decades the design of EM shields took account of some new variables as production cost, specific weight and, thus, following these requirements most part of scientific publications are focused on structural materials. Plastics with metallic coatings are being more and more frequently utilized, but also conducting polymers, textile materials with metallic insertion (metallic and conducting fibers) and nanoconducting materials (metallic powders, metallic nanoparticles, carbon and carbon nanotubes).

The biggest attenuation efficiency is presented by conductive elastomers and the metallic bulk, but they have a high production cost. The conductive textiles possess verry good elastic behavior and they can be manufactured in a large palette of constructive sections, at the lowest production cost, but with a lower shielding efficiency.

Manuscript received March 22, 2010.

2. TEXTILE SHIELDING

In figure 1 are presented the structures of layers and fibers that are presently used in electromagnetic shielding, from the point of view of the presence of the conductive and nonconductive materials. Thus we can specify the following structures: (a) homogeneus panels treated with hygroscopic agents which gives the material a conductive characteristic, (b) panels covered by a thin conductive layer, (c) panels with unidirectional conductive structure, (d) panels with bidirectional conductive or matrix structure.

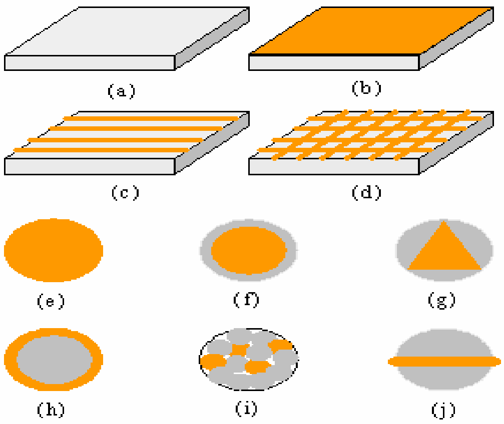

Fig. 1. Structures of conductive panels and fibres.

Depending on the technological typology of the production process of these panels, we can define the following: nonwoven panels (made from a mixture of natural or synthetic fiber with conductive filaments connected by a binder), woven panels (made by a perpendiculary crossing of the textile and conductive fibers in varied configurations) and knitted panels (made by chaining the knitted mesh using textile and conductiveafibers). The conductive structure of the panels is made by using composite fibers which represent a combination of natural textile wires/fibers (cotton, hemp, wool) or synthetic (viscose, relon, tergal, staple fibre) with conductive materials (Silver , Copper, Gold, Carbon, Stainless Steel). Thus we can specify the following structures of composite conductive fibers: (e) full conductive wire, (f) wire with conductive core, (g) wire with trilobal conductive core, (h) wire with conductive surface, (i) twisted wire from conductive and textile fibers or twisted wire from conductive filaments and textile fibers, (j) sandwich-type wire.

3. THE NOVELTY

The present study is aimed at the development of a new generation of electromagnetic (EM) shields, obtained by space knitting in 3 layers, orthogonally oriented, from composite conducting fibres. *The base structure* will consist of 3 layers, the top and the bottom layers being manufactured of coated fibres and the middle layer, which will assure the connection with the other two, will be realized using core conducting fibres. Starting from this imposed architecture new shielding structures will be developed by changing the knitting technology but also the fibres composition.

The shields performances, is evaluated using *3D ElectromagneticField Simulation software: CST Studio Suite 2009*. A tricot mesh cell was firstly simulated and afterwards the S-Parameters results were taken into consideration to see the shielding effectiveness.

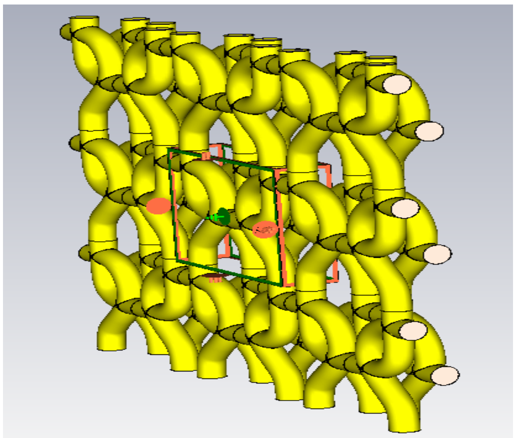

Fig. 2. 3D Knitted Shield.

4. SCATTERING PARAMETERS

Scattering parameters or S-parameters are properties used in electrical engineering, electronics engineering, and communication systems engineering describing the electrical behaviour of linear electrical networks when undergoing various steady state stimuli by small signals.

Although applicable at any frequency, S-parameters are mostly used for networks operating at radio frequency (RF) and microwave frequencies where signal power and energy considerations are more easily quantified than currents and voltages. S-parameters change with the measurement frequency so this must be included for any S-parameter measurements stated, in addition to the characteristic impedance or system impedance system impedance. S-parameters are readily represented in matrix form and obey the rules of matrix algebra.

4.1. The general S-parameter matrix

For a generic multi-port network, each of the ports is allocated an integer 'n' ranging from 1 to N, where N is the total number of ports. For port n, the associated S-parameter definition is in terms of incident and reflected 'power waves', a_n and b_n respectively.

Kurokawa defines the incident power wave for each port as:

$$a=\frac{1}{2}k(V+Z_p I) \quad (1)$$

and the reflected wave for each port is defined as:

$$Z_p^* I) \quad (2)$$

where Z_p is the diagonal matrix of the complex reference impedance for each port, Z_p^* is the elementwise complex conjugate of Z_p ,V and I are respectively the column vectors of the voltages and currents at each port and

$$k=\frac{1}{2}\left(\sqrt{|R\{Z_p\}|}\right)^{-1} \quad (3)$$

Sometimes it is useful to assume that the reference impedance is the same for all ports in which case the definitions of the incident and reflected waves may be simplified to:

$$\frac{I)}{|} \quad (4)$$

$$b=\frac{1}{2}\frac{(V+Z_p^* I)}{\sqrt{|R\{Z_0\}|}} \quad (5)$$

For all ports the reflected power waves may be defined in terms of the S-parameter matrix and the incident power waves by the following matrix equation:

$$b=S*a \quad (6)$$

where S is an N x N matrix the elements of which can be indexed using conventional matrix notation.

4.2. 2-Port S-Parameters

The S-parameter matrix for the 2-port network is probably the most commonly used and serves as the basic building block for generating the higher order matrices for larger networks. In this case the relationship between the reflected, incident power waves and the S-parameter matrix is given by:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix}=\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \quad (7)$$

Expanding matrices into equations gives:

$$b_1 = S_{11}a_1 + S_{12}a_2 \quad (8)$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \quad (9)$$

Each equation gives the relationship between the reflected and incident power waves at each of the network ports, 1 and 2, in terms of the network's individual S-parameters, S_{11}, S_{12}, S_{21}, S_{22}. If one considers an incident power wave at port 1 (a_1) there may result from it waves exiting from either port 1 itself (b_1) or port 2 (b_2).

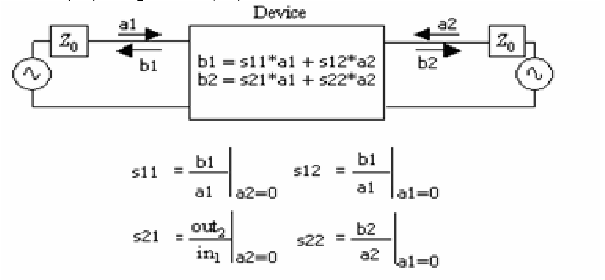

Fig. 3. A two-port S-parameter matrix records the reflection coefficients and transmission gain from both sides of the device.

However if, according to the definition of S-parameters, port 2 is terminated in a load identical to the system impedance (Z_0) then, by the maximum power transfer theorem, b_2 will be totally absorbed making a_2 equal to zero.

Therefore:

$$S_{11} = \frac{b_1}{a_1} \text{ and } S_{21} = \frac{b_2}{a_1} \quad \text{and} \quad S_{21} = \frac{b_2}{a_1} \quad (10)$$

Similarly, if port 1 is terminated in the system impedance then a_1 becomes zero, giving

$$S_{12} = \frac{b_1}{a_2} \text{ and } S_{22} = \frac{b_2}{a_2} \quad \text{and} \quad S_{22} = \frac{b_2}{a_2} \quad (11)$$

Each 2-port S-parameter has the following generic descriptions:

S_{11} is the input port voltage reflection coefficient
S_{12} is the reverse voltage gain
S_{21} is the forward voltage gain
S_{22} is the output port voltage reflection coefficient

5. EXPERIMENTAL

We accomplished and simulated in *CST Studio Suite* a tricot mesh (fig. 4) made by coating a fiber of Polyimide with a thin layer of Silver. The section of this fiber could be observed in figure 5.

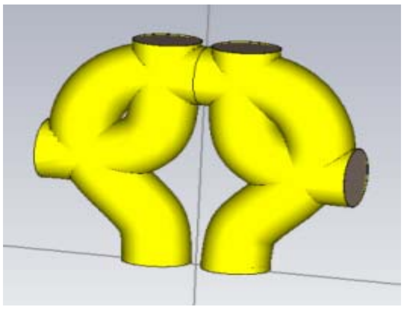

Fig. 4. Knitted mesh cell.

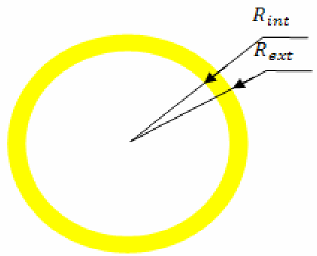

Fig. 5. Section through a fiber.

$$R_{int} = R_{ext} * r \text{, r=ratio between } R_{int} \text{ and } R_{ext} \quad (12)$$

The simulations were realized with the *Transient Solver* provided by *CST Studio Suite*. To see how structural values influence the shielding effectiveness we swept the values of the structural parameters of the mesh cell as follows:

1. R_{ext} between 10 and 30 microns with a step of 10 microns, r = 0.98:
   a. Single tricot mesh cell (figure 6);
   b. Two tricot mesh cell, overlapped one over the other (figure 7);

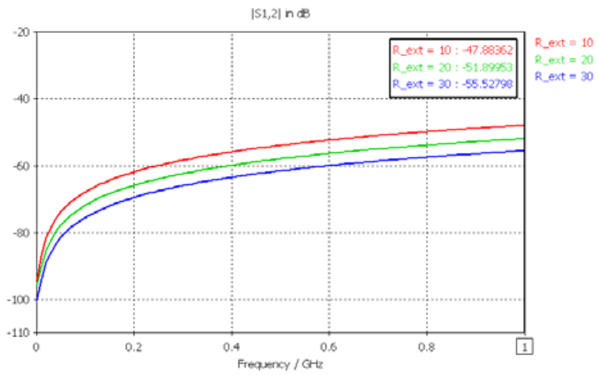

Fig. 6. Parameter Sweep R_{ext} between 10 and 30 microns for single mesh cell.

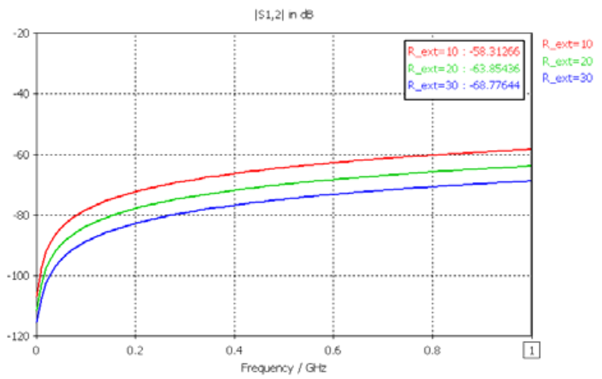

Fig. 7. Parameter Sweep R_{ext} between 10 and 30 microns for 2 overlapped mesh cells.

2. r between 0.74 and 0.98 with a step of 4, R_{ext} microns (figure 8).

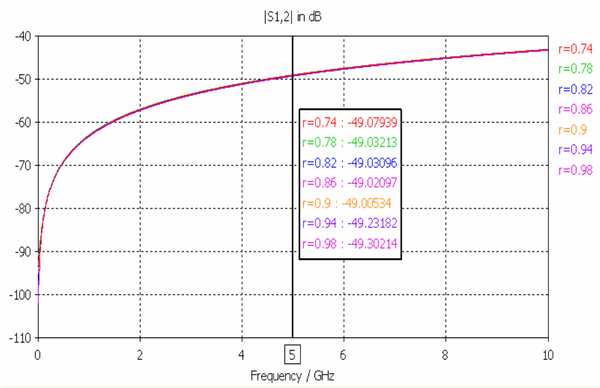

Fig. 8. Parameter Sweep r between 0.74 and 0.98.

6. CONCLUSIONS

As we can see in the graphic from figure 8, the variation of the ratio between R_{ext} and R_{int} (thickness of the Silver layer) doesn't produce any noticeable variation of the attenuation.

Based on the results shown in the graphic from figure 6 the attenuation for a single tricot mesh cell with R_{ext}=10 microns is approximately 223 (47.88dB) while for the structure with two overlapped mesh cells, figure 7, the attenuation is approximately 794 (58.31 dB). Therefore our improved shield structure is 3.56 times better than the single mesh cell structure.

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