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NUMERICAL MODELLING OF NON-CONVENTIONAL SHIELDING

A. Razicheanu, V. Ionita[*], H. Gavrila

MAGNAT Research Center, University “Politehnica” of Bucharest,
Spl. Independentei-313, 060042 - Bucharest, Romania

A non-conventional shielding solution, with useful applications in civil engineering, is presented. The composite based on ferrimagnetic garnets from chemical plant residuals is analysed in a room-shaped geometry and the influence of some parameters (frequency, thickness of the shield layer, applied magnetic field, configuration of the room walls) is studied. The experimental and numerical data show the effectiveness of this ecological and low-cost shielding solution.

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1. Introduction

The modern electromagnetic pollution imposes new solutions for shielding in domestic appliances [1]. The ecological and economical criteria allow the use of the non-conventional shielding materials, like the composites based on magnetic garnets. Microwave ferrites, such as yttrium-iron garnet, are used as waveguides for electromagnetic radiation and in nonreciprocal microwave devices such as phase shifters, circulators, gyrators or isolators [2,3,4]. A new domain is civil engineering, where the chemical plant residuals (e.g. pyrite ashes containing over 50% magnetic garnets) can be used for a new building material with shielding properties. Because ferrimagnetic garnets have lower magnetic properties than ferrites, the shielding effectiveness is influenced not only by the frequency, the thickness of the shield layer and the applied magnetic field, but also by the configuration of the building walls (the position of doors and windows).

2. Non-conventional shields

The ferrimagnetic garnet structure is $3M_2O_3{\cdot}5Fe_2O_3$, where M is usually yttrium or another rare-earth metal. Derivatives based on YIG (yttrium-iron garnet) are used in magnetic bubble memory and assorted microwave devices (e.g. phase shifters and waveguides). Recent simulations of such devices are done including thermal analysis [4] or hysteretic effect [5].

A new application of magnetic garnets is the shielding of buildings. The composite material, based on magnetic garnet, has lower saturation magnetisation than ferrite (0.2 T) and a low Curie temperature (hundred of Celsius degrees), but these values are acceptable in civil engineering. Unfortunately, the low relative magnetic permeability and the low electrical conductivity don't recommend it as a conventional shielding material. But, the ecological aspects and the very low price impose a new thinking. Also, garnet-type ferrites exhibit a gyromagnetic resonance and a Faraday rotation – polarization plane rotation of a plane electromagnetic wave as it travels through a ferrite in

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[*] Corresponding author: vali@mag.pub.ro

the direction of an applied magnetic field. These properties can be very useful to design a complex electromagnetic shield [6]. Unfortunately, the microscopic phenomena can't be included in a numerical modelling and simulation by usual CAD software packages.

The magnetic shielding effectiveness is measured by the shielding factor $S=H_a/H_p$, where H_a and H_p are the values of the magnetic field for a given point in the absence, respectively in the presence of the shield. For a cubic box of side a, S can be calculated [2] by:

$$S = \frac{4}{5}\frac{\mu_r d}{a} \tag{1}$$

where d is the shield thickness. In a more complex geometry, a numerical computation is necessary. For time-dependent magnetic fields, S increases with the frequency f: $S(f)=K\cdot S(0)$, where K is a correction factor, depending on the ratio of the shield thickness d to the penetration depth δ.

3. Problem formulation and modelling

The electromagnetic interference may correspond to a radiated near field or to a radiated far field. Usually, it can be considered a radiated near field, modeled by a quasi-stationary state, for frequencies up to 1 MHz. This hyphotesis can be also extended for a radiated far field, at higher frequencies, but the results are only qualitative, being necessary a time-variable formulation for the electromagnetic waves.

The evaluation of shielding effectiveness was done considering a sinusoidal steady-state regime. The applied magnetic field is imposed by boundary conditions, simulating both near field and far field. For frequencies up to 100 MHz, the magnetic properties of ferrimagnetic garnets don't vary, so the problem may be linear. The 3-D computation is performed with Flux3D$^{\copyright}$ software, based on Finite Element Method, using a formulation in vector electric potential **T** (for conductors) and scalar magnetic potential Φ (in all the domain). The final equations, in complex, are:

$$\begin{aligned}&\operatorname{curl}\left(\frac{1}{\sigma}\operatorname{curl}\mathbf{T}\right)-\operatorname{grad}\left(\frac{1}{\sigma}\operatorname{div}\mathbf{T}\right)+j\omega\mu(\mathbf{T}-\operatorname{grad}\Phi)=0\\&\operatorname{div}\left(\mu(\mathbf{T}-\operatorname{grad}\Phi)\right)=0\end{aligned} \tag{2}$$

for conductors, and

$$\operatorname{div}\left(\mu(-\operatorname{grad}\Phi)\right)=0 \tag{3}$$

for isolators.

4. Numerical simulations

Our study was focused on the following cases:

Case 1: A cubic box with a=400 mm and d=7 mm; the carbon-filled epoxy resin shielding composite has μ_r=5 and σ=0.2 S/m, according to the experimental measurements. The obtained shielding factor values are presented in Table 1. The analytical relation (1) can't be used in this case, due to the low magnetic permeability of the shield.

Table 1. Minimal and maximal shielding factor S inside a cubic box (d = 7 mm, a = 400 mm).

Frequency	Penetration depth	S_{min}	S_{max}
1 Hz	507 m	8.15	680
1 kHz	16.05 m	10.12	697
1 MHz	0.507 m	9.21	685
1GHz	16 mm	9.85	724

Case 2: A cubic box made with aluminium (*a*=400 mm, *d*=7 mm, $\sigma=3\cdot10^8$ S/m) with an (100 × 100 mm^2) aperture, covered by the composite shield (7 mm thickness). This configuration corresponds to the experimental device used for measuring the material parameters (μ_r, σ, atenuation factor etc.). The values of the shielding factor have the same large dispersion inside the box, due to the weak material characteristics and the reduced thickness of the shield; the frequency influence is weak.

These two cases were treated modeling a radiated near field by non-homogeneous Dirichlet boundary conditions imposed to a (50 × 50 mm^2) area at 300 mm distance from the box aperture.

Case 3: A real cubic room (*a*=4 m, *d*=30 cm) made with ordinary bricks, with an iron door (2 × 2 m^2) and a window (2 × 1 m^2) on opposite walls; the building is shielded with our ferrimagnetic garnet composite (μ_r=5, σ=0.2 S/m, 7 mm thickness). The geometric model use the problem symetry (see Fig. 1) and the radiated field is simulated by a non-homogeneous Dirichlet boundary conditions imposed to a (6x6 m^2) area at 9 m distance from the door. The simulations, involving 127191 first order finite elements, imply 37 minutes on a Pentium 4 processor (2.4 GHz) with 256 MB SyncroRAM.

For various frequencies, similar magnetic field distribution inside the room (see Fig. 2 for 1 MHz) is obtained. It can be observed that magnetic field enters the room mostly through the window, which is not protected. The most protected areas are behind the door, because the shielding effect of the garnet composite is improved by the iron of the door. For higher frequencies (GHz) the simulations are not accurate, because a wave formulation of the problem is necessary; in this case, also the garnet behaviour becomes nonlinear.

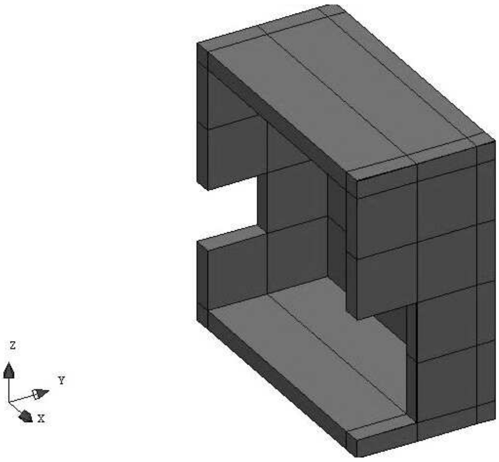

Fig. 1. Geometrical model of the cubic room.

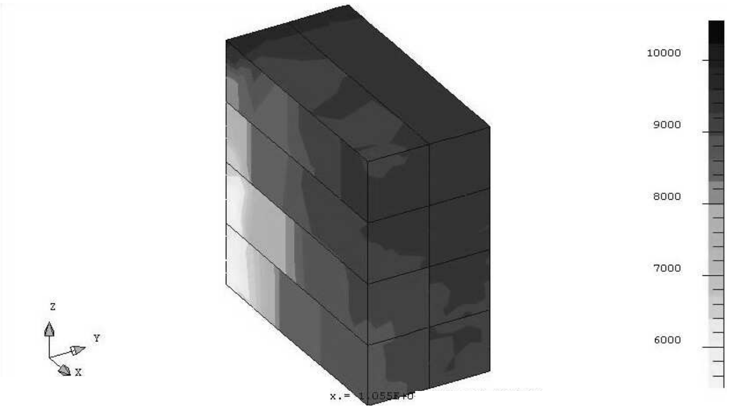

Fig. 2. Magnetic field distribution (in A/m) inside the room, at 1 MHz.

5. Conclusions

The use of the industrial magnetic residuals, like the ferrimagnetic garnets obtained from the pyrite ashes, seems to be satisfactory in the civil engineering domain, for shielding the electromagnetic interferences. The solution is low-cost and with positive ecological implications, but the shielding effectiveness is not so good as for the traditional shielding materials. The simulations show that the composite material must be combined with other materials in structured shields, according to the particular geometry and bandwidth of operation of the shielded device. The research still continues by preparing new composites and extending the frequency domain. The future modeling for higher frequencies must be a wave formulation with a nonlinear magnetic characteristic of the garnet shield.

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