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Stochastic algorithm for optimal layer arrangement in a multilayer material for magnetic shielding

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Abstract—This study presents a new method of combining the layers of magnetic materials and conductive materials for the elaboration of an optimal thin multilayer magnetic shielding for a given frequency range. The method consists in using genetic algorithms coupled with a finite element modeling tool for the choice of the thicknesses and the order of the layers within the multilayer allowing to obtain the optimal multilayer magnetic shield. This method allows to study the impact of the number of layers, the thickness, and the position of the layers on the shielding effectiveness of planar multilayer magnetic shields.

Keywords—Genetic algorithms, magnetic shielding, multilayers.

I. INTRODUCTION

The increasing integration of electronics in all sectors of activity generates problems of electromagnetic pollution and electromagnetic compatibility. One of the effective solutions to limit electromagnetic interference between various electronic systems within the same electromagnetic environment consists in using electromagnetic shielding. However, the need to develop very thin, very light, and less expensive magnetic shielding with high shielding effectiveness (SE) constitutes a real challenge. In [1], Hoburg *et al* have shown the benefit of combining magnetic materials and conductive materials to form effective magnetic shielding. They showed the impact of the number of pairs of layers of magnetic and conductive materials on the SE of the multilayer formed. Their work is limited to a single frequency with a random choice of layers thicknesses and layers order. The interest in multilayer structure for the magnetically shielded room has been investigated in [2]. This study is focused on a three-layer metal composite with a random choice of each layer thickness to form the desired shield total thickness. Clérico *et al* have highlighted the interest of combining magnetic and conductive materials to develop magnetic shielding over a wide frequency range [3]. However, their work is limited to a single three-layer

structure and the impact of the order of the layers has not been studied.

The purpose of this work is to show how genetic algorithms can be coupled with finite element modelling tools to determine each layer thickness, the number of layers, and the order of the layers for the optimal structure of a multilayer magnetic shield for a given total thickness, given materials, and frequency range.

II. METHOD

From Schulz *et al* [4] equations, the magnetic shielding effectiveness (SE) of planar multilayer shields at a given frequency is given by:

$$SE = 20 \log_{10} \left| \prod_{i=1}^{N+1} e^{\frac{(1+j)l_i}{\delta_i}} \right| + 20 \log_{10} \left| \prod_{i=1}^{N+1} \frac{1}{1 + \rho_i} \right| + 20 \log_{10} \left| \prod_{i=1}^N \left(1 + \rho_i \gamma_{i+1} e^{-\frac{2(1+j)l_i}{\delta_i}} \right) \right| \quad (1)$$

Where N is the number of layers, l_i is the thickness of i^{th} layer, δ_i is the skin depth of i^{th} layer, ρ_i is the i^{th} layer intrinsic impedance and γ_i the recursive relation of reflexion loss. All materials involved in the multilayer must be good conductive materials which means $\sigma_i \gg 2\pi f \epsilon_i$ where σ_i and ϵ_i are respectively the electrical conductivity and dielectric permittivity of the i^{th} layer.

The objective function used in the developed genetic algorithm is given by:

$$S = \Delta f * SE_{Max} - \int_{f_{Min}}^{f_{Max}} SE(f) df \quad (2)$$

Where f_{Min} and f_{Max} are respectively the minimum and the maximum frequency of the considered range of frequency and

$$\Delta f = f_{Max} - f_{Min} \quad (3)$$

The proposed method steps are as follow:

- 1) Input the electromagnetic properties of materials to be combined, total thickness of the multilayer and maximum number of layers. 2) Determination of all possible layer combinations. 3) Optimization of each possible combination based on genetic algorithm. 4) Sorting of all feasible combinations based on the value of $T = \sum_{i=f_{Min}}^{f_{Max}} SE_i$. 4) Send the multilayer parameters to a finite element modelling tool through a livelink for result validation. 5) Print the best combination structure and its SE over the frequency range.

III. APPLICATION

The proposed method is used to determine the optimal combination of aluminum ($\sigma = 36 * 10^6 S/m, \mu_r = 1$) and an iron alloy ($\sigma = 1.67 * 10^6 S/m, \mu_r = 1800$) to form a multilayer of 400 μm total thickness for magnetic shielding over a frequency range of 1Hz to 10 kHz. COMSOL Multiphysics is used as finite element modelling tool and is associated to MATLAB through livelink for MATLAB module.

Fig. 1 presents the best structure for each number of layers varying from 2 to 8. The bottommost layer is the closest to the magnetic field source.

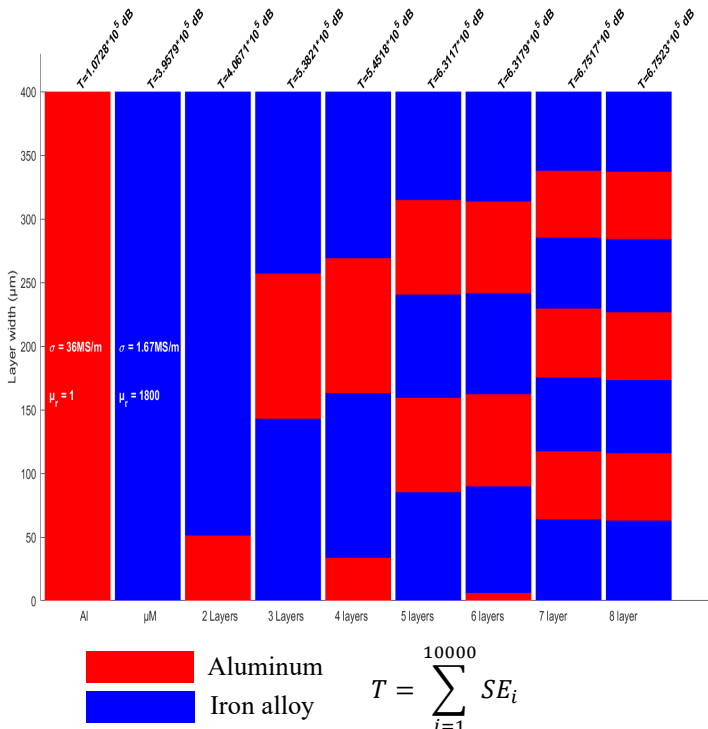


Fig. 1: Best structure for each number of layers

The results suggest that for the considered materials, for odd number of layers, the best structure is the one enclosed by the magnetic material. This can be explained by the fact that this structure maximizes the shorted turn effect. For even number of

layers, as the total number of layers increases, the first layer thickness, made of conductive material, decreases, and tends to zero as shown by 8 layers structure. There is then no interest to go beyond 7 layers for the chosen example. The shielding effectiveness for the presented structures is shown in fig. 2.

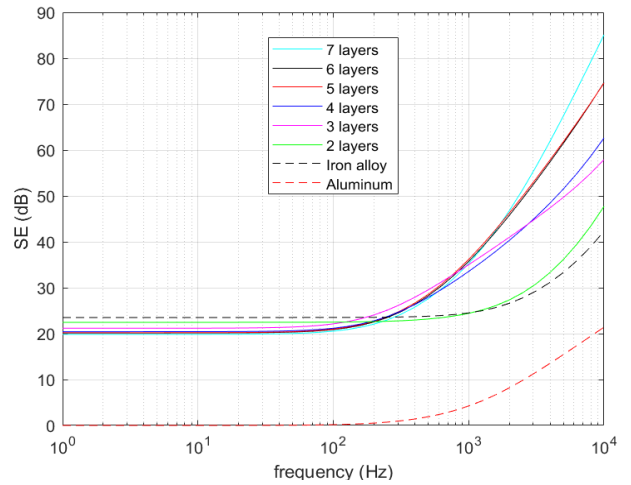


Fig. 2. Shielding effectiveness versus frequency for different structures

For a total thickness of 400 μm , there is up to 70.59% increase in shielding effectiveness of 7 layers shield over the iron alloy shield. A mean gain of 27.94 dB/Hz over the frequency range of 1Hz to 10 kHz is noted. This gain is due to the best choice of optimal layers thicknesses and arrangement by the algorithm. For the six layers structure, the same structure as the one chosen by the algorithm but with equal thickness of all layers would have introduced a mean loss of 2.1 dB/Hz over the frequency range compared to the structure with layer thickness chosen by the algorithm. This result shows the importance of layer thickness choice on the shielding effectiveness of a multilayer. For five layers structure, the loss induced by choosing a structure surrounded by aluminum instead of the structure chosen by the algorithm is 8.04 dB/Hz over the considered frequency range. This result highlights the importance of layer order in a multilayer magnetic shield.

A table summarizing the optimal combination of several well-known materials into multilayer magnetic shield and physical phenomenon explaining these results will be proposed in the extended version of the paper.

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