Modeling and Simulation of Electromagnetic Absorption Properties of the Different Nanostructured Composites

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Abstract – **The relatively recent development of the capability of computing systems and of electromagnetic numerical methods, that benefit from these capabilities, allows the use of the electromagnetic simulation as a accurately method to investigate low-loss materials. Successful determination of parameters by simulation and subsequent application of the NRW procedure (The working procedure originally proposed by Nicolson, Ross and Weir) has brought to the attention of researchers this procedure.**

Keywords – Simulation, Electromagnetic Absorption Properties, Nanostructured Composites

I. INTRODUCTION

Inserts with different dielectric materials have been used extensively in microwave absorber technology [1]. Various types of materials and their effect on electromagnetic energy are investigated in [2], [3], [4] especially in the field of nanotechnologies and the improvement of absorption technologies in the microwave frequency range.

Analytical methods were initially addressed to determine the parameters of a material with inserts from another material, Lord Rayleigh and Lewin, cited in [5], [6] being the first how investigate these issues. The interest for theoretical approaches has remained constant as new dielectric combinations/inserts have been found for achieve an adequate behavior at high frequencies [7], [8]. However, analytical approaches have been successful only for simple structures and and generally are ineffective in microwave frequencies where the wavelength begins to become comparable with the distances between particles and/or particle size.

The emergence and improvement of vector analyzers allowed the characterization of materials with inserts by measurements [9]. The working procedure initially proposed by Nicolson, Ross and Weir (NRW procedure) is frequently used [9], [10] and improved [11], [12], [13] to eliminate the instability of the NRW procedure for low-loss materials, in the situation which the errors of measure affect the accuracy of the results.

The relatively recent development of the capability of computing systems and of electromagnetic numerical methods that benefit from these capabilities allows the use of simulation electromagnetic as a method of accurately investigating low-loss materials. Successful determination of parameters by simulation and subsequent application of the NRW procedure brought to the attention of the researchers this procedure [14], [15].

II. THE NICOLSON, ROSS, WEIR PROCEDURE IN INFINITE ENVIRONMENTS

This procedure aims to replace a dielectric material with inserts with an equivalent material in terms of behavior in electromagnetic field. It compares the response of an infinite planar layer of height *d* from the material with inserts, with the response that would be obtained in case of a homogeneous material, in both cases the excitation being in the form of plane wave [10]. Thus, it is possible to substitute a structurally complex material with a simpler material to simulate more complex structures, where these materials represent a small portion of the overall complexity of the structure. If through measurements such a structure is difficult to implement, in the case of electromagnetic simulation the plane wave excitation and the infinite dimensions represent some of the simplest models. In [10] the necessary steps are described to obtain the complex electrical permitivity of a non-magnetic material from the reflection and transmission parameters determined by simulation (S11 and S21).

$$\varepsilon^* = \varepsilon' - j \cdot \varepsilon'' = \varepsilon' \cdot \left(1 - j \cdot \tan\delta\right), \qquad (1)$$

$$K = \frac{S_{11}^2 - S_{21}^2 + 1}{2 \cdot S_{11}}, \qquad (2)$$

$$\Gamma = K \pm \sqrt{K^2 - 1}. \qquad (3)$$

$$T = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21}) \cdot \Gamma}, \qquad (4)$$

$$\gamma = \frac{\ln(1/T)}{d}, \qquad (5)$$

$$\varepsilon^* = \frac{\gamma}{\gamma_0} \cdot \left(\frac{1-\Gamma}{1+\Gamma}\right). \qquad (6)$$

The procedure allows using the intermediate variable K (2) to calculate the transmission and reflection coefficients (3), (4). If the height of the layer is low from an electrical point of view (5) is obtained as the first solution of the complex logarithm (order n = 0) [10], and then (6) and (1) can be used to extracts the effective dielectric parameters (permittivity and tangent of the angle of loss), parameters that can be allocated to a homogeneous dielectric environment that successfully replaces the much more complex structure with microscopic inserts in macroscopic simulations. However, it is necessary to examine the fields in the insert structure to validate the homogeneous dielectric behavior.

III. CHARACTERISTICS OF USED MATERIALS

The simulation was done with CST Microwave Studio simulation program. The border conditions used in simulations are presented in Fig. 1 and are aimed to investigate the interaction of a plane wave with the considered sample.
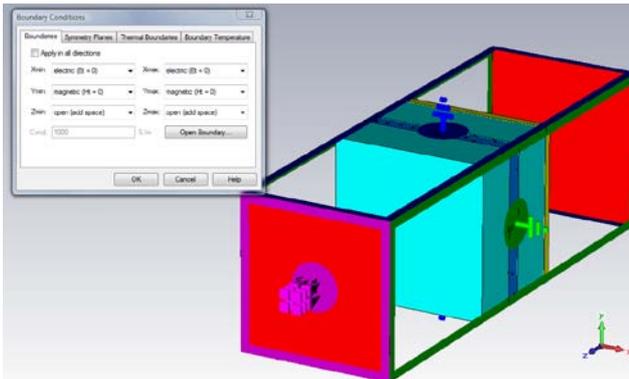

Fig. 1. Border conditions

The metal inserts are ferrite type (noted in text and graphs with the Fe symbol) dispersed in the polymer matrix based on polyethylene (LDPE and HDPE). The characteristics of structures used in simulations are presented in the table 1.

For the prediction of electromagnetic performances by correlating the electromagnetic absorption properties with the structure, architecture and composition of nano-structured composites, simulations were made for different combinations of substrate, inserts, mass density and particle size. The evolution of parameters such as: total specific absorption rate and evolution of the total absorbed power, was evaluated.

Table 1. Dimensions of structures with Fe particles dispersed in HDPE/LDPE matrix.

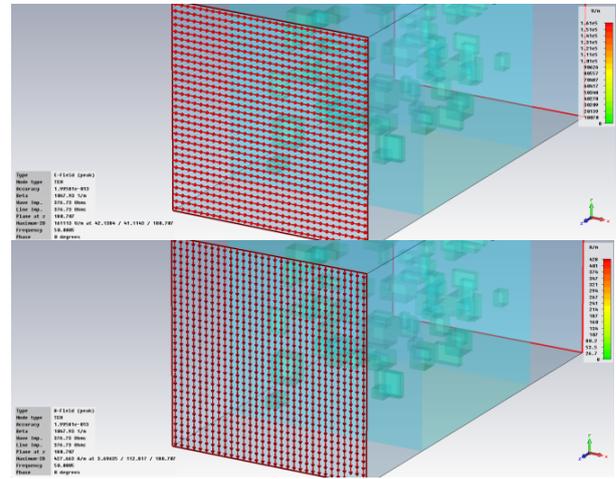| Substrate	Fe[%]	R_{Sf} [µm]	L=W=H [µm]		
			1	5	25
HDPE	10%		34.133	170.67	853.34
	7%		38.810	194.05	970.25
	3%		52.112	260.56	1302.8
LDPE	10%		34.411	172.06	860.28
	7%		39.127	195.64	978.18
	3%		52.540	262.70	1313.5

Fig. 2. Electrical and magnetic field at port level, plane waveform

The reflection and transmission parameters determined by simulation (S11 and S21) are shown below for Fe and HDPE and LDPE support matrix.
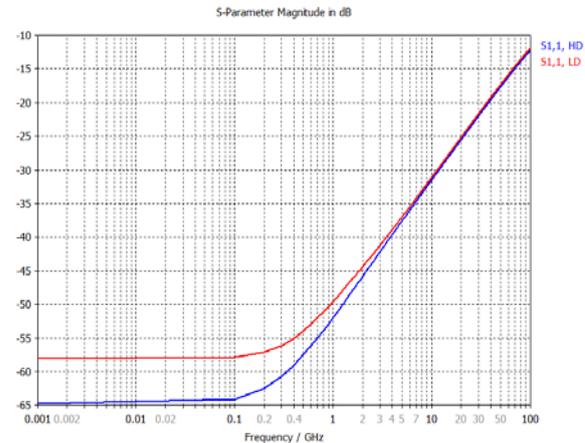

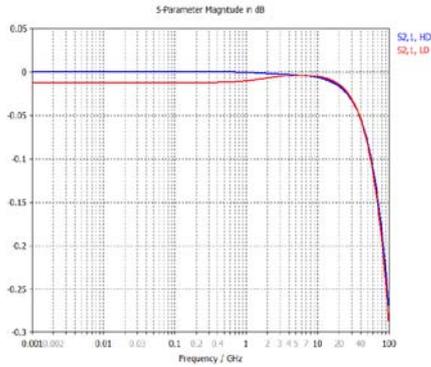*Fig. 3. S_{11}, Inserts Fe, HDPE and LDPE matrix*

Fig. 4. S_{21} , Inserts Fe, HDPE and LDPE matrix

IV.   RESULTS AND DISCUSSIONS

For each substrate combination, inserts, mass density, particle size, two analyzes were performed, one of these analyzes represent the reference in which the particles were missing.
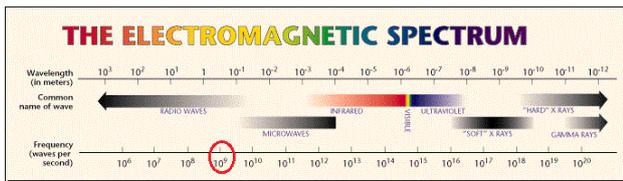

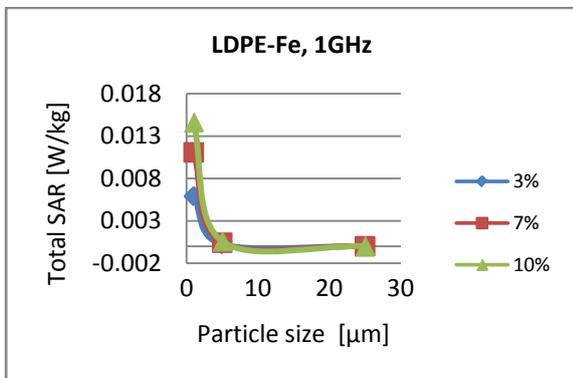Fig. 5. Selecting the interest frequency in the RF/MW domain

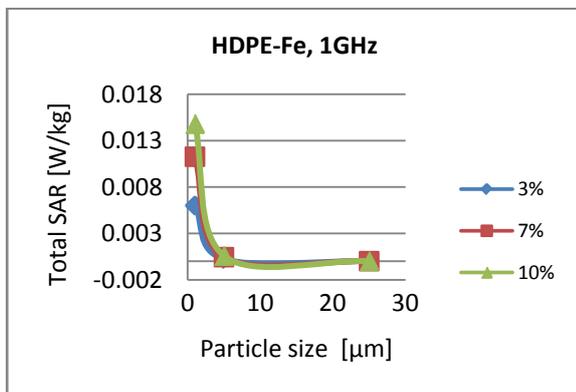Fig. 6. Total SAR for LDPE matrix and Fe inserts

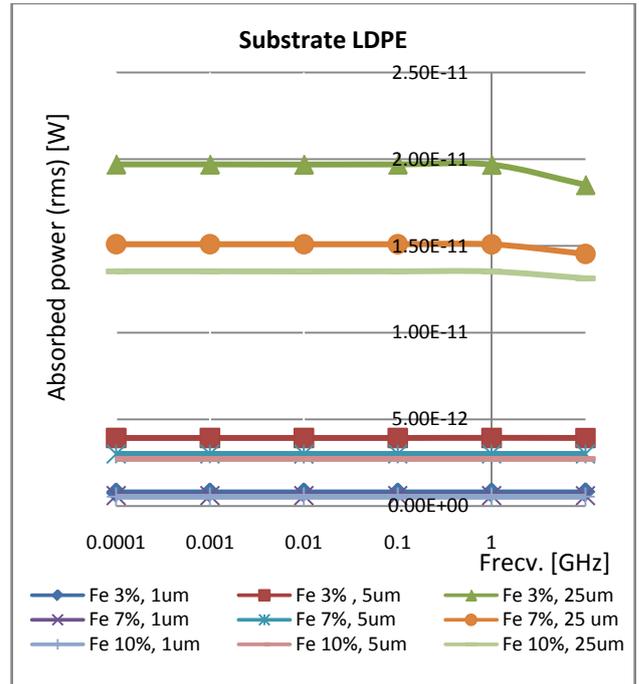Fig. 7. Total SAR for HDPE matrix and Fe inserts

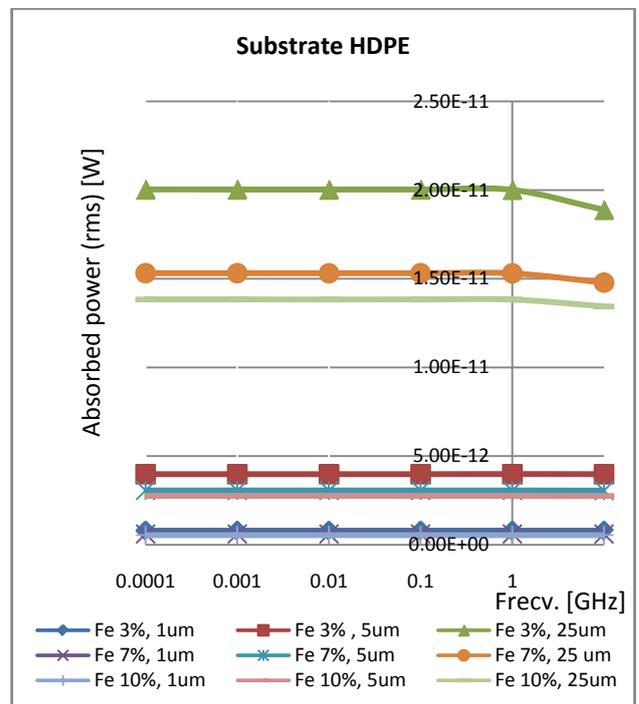
Fig. 8. Absorbed power for LDPE matrix and Fe inserts

Fig. 9. Absorbed power for HDPE matrix and Fe inserts

We calculated from the obtained data an increase in the specific absorption rate (SAR total) and the average absorbed power density of the reference to this analysis. These values will be able to make comparisons between different types of inserts / substrates.
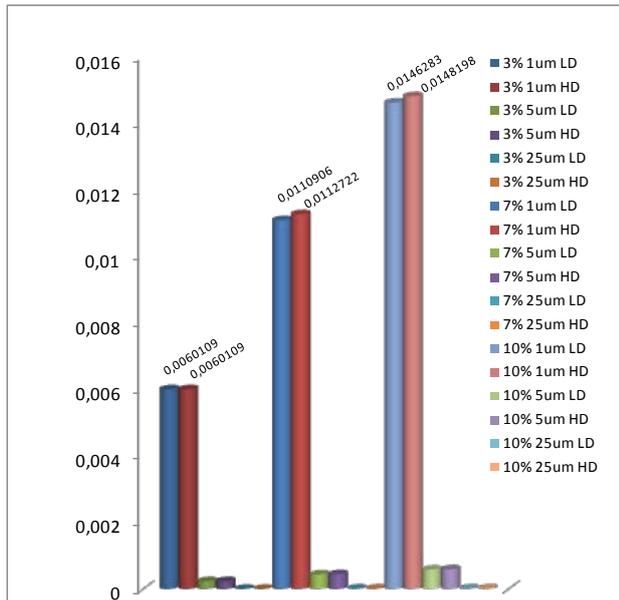
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Fig. 10. Comparison of total SAR values for LDPE/HDPE matrix and Fe insert

The simulations were made for 2 types of substrate combination and Fe inserts. For these inserts were considered 3 concentrations (3%, 7%, and 10%) and 3 dimensions for particle size (1µm, 5µm and 25µm). A good value of total SAR was obtained for combination with HDPE substrate, with 10% of Fe with 1µm size of the particle. The results of the LDPE substrates are roughly the same as those for the HDPE substrate. The simulations will be used as a start point for development of different nanostructured composites material with good electromagnetic absorption properties in RF/MW domain.

V.   ACKNOWLEDGMENT

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