Electromagnetic Shielding Effectiveness Evaluation For Materials

Petre Ogruţan*, Lia Elena Aciu**
*(Department of Electronics and Computers, Transilvania University of Brasov, Romania
** (Department of Electrical Engineering and Applied Physics, Transilvania University of Brasov, Romania

ABSTRACT

The theory of electromagnetic shielding is based on the waves equations describing the behavior of electromagnetic field in material. The proposed approach consist in a PSpice model using transmission line model to simulate the attenuation introduced by a material characterized by the macroscopic parameters ε, μ, σ. To verify the data obtained through PSpice simulation, a wave-guide-based measurement system at 10GHz was employed. The new measurement method presented in the paper consists in two high directivity antennae, tuned to the establish operation frequency, one for transmission and one for receiving signal, the material sample placed between them and a data acquisition system.

***Keywords* -** Electromagnetic shielding, Engineering education, Environment, Nanomaterials, PSpice model

I. INTRODUCTION

Electrical properties of materials are important for a wide range of applications [1, 2]. In the present context, in which wireless devices are spreading very rapidly, electromagnetic interference begins to appear increasingly more often. The advent of WiFi wireless routers in nearly every apartment, has led to a demand of the market for electromagnetic shielding materials for buildings [3]. Specifically, the basic material of constructions with a shielding effect must be taken into account [4]. To determine the shielding properties of materials have been used simulation methods and experimental determination. Paper [5] clarifies the principles of simulation and measurement since 1988. The paper proposes to measure attenuation in enclosure TEM (Transverse Electro-Magnetic) but whose applicability was invalidated by [6].

Currently, the simulation of electromagnetic screens and attenuation measurement in order to increase the accuracy of simulation and measurement are important [1,2,7, 8]. New ways of measuring and modeling are proposed for new materials appeared on the market, created by nanoprocesses and nanotechnologies.

The authors of this paper propose an original method of simulation that is distinguished by its simplicity and ease of use. The simulation is verified through several measuring methods to check the possibility of using them. Simulation method has been applied for the purpose of teaching at the Faculty of Electrical Engineering and Computer Science, the discipline of Electromagnetic Compatibility. Educational effects were positive, students have appreciated practical applications of simulation.

II. ATTENUATION OF THE ELECTROMAGNETIC FIELD IN MATERIALS

For EMC theory and practice is important to know as much as possible about the reflecting and the absorbing phenomena in the materials used as electromagnetic shields.

There are many analytical and computing models to solve the problem of electromagnetic shielding, meaning the determination of the influence of a shield (conductor /semiconductor, with/without magnetic properties) on electromagnetic radiation. Mainly have been used more often Kaden model for symmetrical structures and Schelkunoff - Schulz model for the infinite plane shield. According to that, the shielding effectiveness SE_{dB} equation express [9, 10] the global attenuation introduced by a shield, considering all phenomena that appears on both separation surfaces between shield and surrounding environment:

$$SE_{dB} = A_{dB} + R_{dB} + B_{dB} \qquad (1)$$

where A_{dB} is the absorption loss, R_{dB} is the reflection loss and B_{dB} is the correction describing the succession of re-reflection phenomena.

The theory of shielding was developed mostly on the basis of transmission lines model, using the Schelkunoff-Schulz isomorphism:

$$SE_{dB} \equiv IA_{dB} \qquad (2)$$

where IA_{dB} is the insertion attenuation corresponding to the washer-shaped material placed in coaxial Tem cell.

It has been already demonstrated that Schelkunoff – Schulz isomorphism is affected by a basic error that limits its applicability in the area of electrically thick samples. Limitations of this isomorphism mainly consist in:

1. Deficiencies of Schelkunoff – Schulz isomorphism **–** This model based on the assumption that there is propagation along the coaxial line. There are, however, cases when propagation is absent in the TEM cell/line, but it occurs within the material sample. These cases

were not approached. Although analyzed and subsequently extended by many specialists, Schelkunoff –Schulz model validity was not proved in the case when propagation is absent in the coaxial line but exists within the material sample. A 6 dB correction must be applied to the values calculated by Schelkunoff –Schulz theory when no propagation occurs in the line [11, 12].

2. Limitation in practical applications – Theoretical predictions with Shelkunoff – Schulz model are invalidated at higher frequencies. The failure of coaxial TEM cells ASTM standards methods [6] at high frequency was caused mainly by the occurrence of higher modes in the test sample.

The condition of occurrence for superior modes inside a material sample of thickness *d* is:

$$f < \frac{1}{\pi d^2 \sigma \mu_0} \quad (3)$$

In the substantiation of Schulz's model, it was disregarded that, since the material is a conductor, the wavelength λ in the shielding material will decrease drastically in accord with the relation:

$$\lambda = \lambda_0 \sqrt{\frac{2\omega\varepsilon_0}{\sigma}} \quad (4)$$

where λ_0 is the wavelength of the incident wave, for which the expression can be derived from the definition of the velocity of an electromagnetic wave:

$$\lambda_0 = \frac{c}{f}, \quad \lambda = \frac{v}{f}, \text{ and } c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}. \quad (5)$$

The general expression of SE_{dB}, equation (1), was artificially split into terms/factors that should represent reflection, absorption and respectively re-reflections:

$$A_{dB} = 20 \lg e^{\alpha d} \quad (6)$$

$$R_{dB} = 20 \lg \frac{\left|(Z_0 + \underline{Z}_S)^2\right|}{4 Z_0 \left|\underline{Z}_S\right|} \quad (7)$$

$$B_{dB} = 20 \lg \left| 1 - \left(\frac{\underline{Z}_S - Z_0}{\underline{Z}_S + Z_0} \right)^2 e^{-2\underline{\Gamma} d} \right| \quad (8)$$

where Z_0 is free space wave impedance, $\underline{Z}_S$ is complex wave impedance of material, $\underline{\Gamma} = \alpha + j\beta$ is complex propagation constant and *d* is shield/material thickness.

According to Schelkunoff 's theory, the sum of these terms represents SE_{dB}:

$$SE_{dB} \cong 20 \lg \left(e^{\alpha d} \frac{Z_0}{4\left|\underline{Z}_S\right|} \left| 1 - e^{-2\underline{\Gamma} d} \right| \right. \quad (9)$$

For a general conductive material, the relation above becomes:

$$SE_{dB} \equiv IA_{dB} = 20 \lg \left(e^{d/\delta} \frac{Z_0 \sigma \delta}{4\sqrt{2}} \sqrt{1 - 2e^{-d/\delta} \cos 2d/\delta + e^{-4d/\delta}} \right) \quad (10)$$

and represents the main relation for disapproved ASTM standards [6].

Equations (3), (4), (5) were not experimentally validated for a conductive, even semiconductor non-magnetic material, so, up to present, based on the known theory, it is not possible to predict the reflected respectively absorbed waves by a shield characterized by ε, μ, σ, by a certain thickness d, at a certain frequency, when A_{dB}<4dB [10], or, in other words, when multiple re-reflections should be considered. Reference [10] shows the reflection losses, absorption losses and re-reflections losses.

Old ASTM ES7-83 or ASTM D 4935-89 standards based on Schelkunoff – Schulz isomorphism have been disapproved since some years ago, but not replaced with other standardized method for SE_{dB} determination for the most general case – conductive dielectrics shield. Due to all of these it was necessary to elaborate new methods to determine absorption as function of the macroscopic parameters of material, ε, μ, σ, material thickness and radiation frequency.

III. Shielding Effectiveness Evaluation with PSpice Model

The proposed approach consists in a PSpice model using transmission line model to simulate the attenuation introduced by a material characterized by the macroscopic parameters ε, μ, σ, Fig. 1 and Fig. 2. [13]. Fig. 1 shows the similarity of Electric Field Strength E– Voltage V and Magnetic Field Strength H- Current I and Fig. 2 the proposed PSpice model.

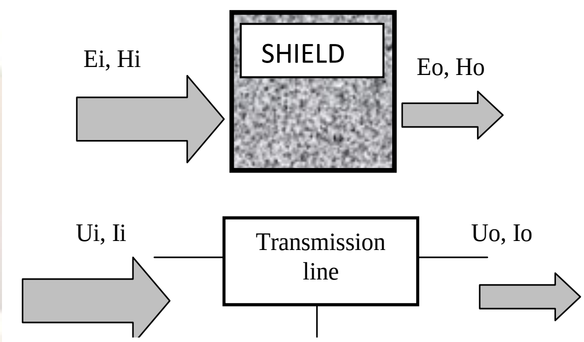

Fig.1: Loss less Transmission line model showing material properties

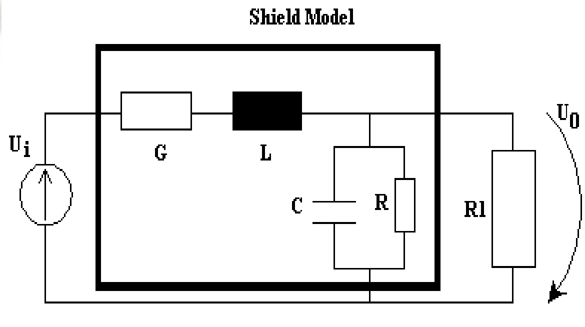

Fig. 2: PSpice Model using the Transmission line model for the studied material

$$SE_{dB} = 20\lg\frac{Ui}{U_O} \qquad (11)$$

The method has been validated for copper; the results obtained being compared with theoretical results published by White [10]. A good likeness between the graphs obtained by simulation and those obtained by White can be seen in [14]. Simulation conditions require that the electromagnetic radiation source be placed at a certain distance from the shield.

This simple method enables to obtain a quick shielding effectiveness evaluation for new materials only by knowing their macroscopic properties ε, μ, σ.

To verify the data obtained through PSpice simulation, a waveguide-based measurement system was employed. The measurements were aimed at a wide selection of materials with known electromagnetic characteristics, including materials obtained by nanoengineering or nanomaterials that can be used in intelligent buildings in form of sandwich structures in combination with classical construction materials. The employed measuring set-up is shown in Fig. 3.

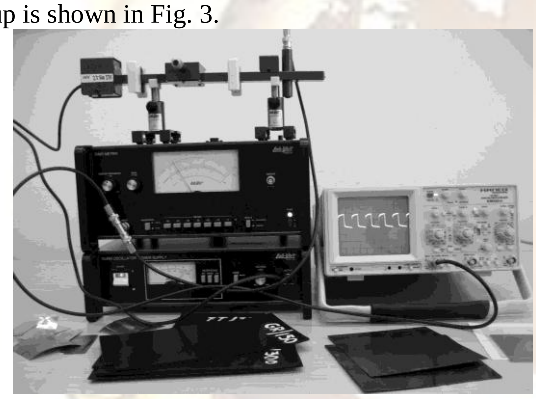

Fig. 3. The wave-guide-based measurement set-up for experimental determinations

The system has electromagnetic shielding and assures isolation against external electromagnetic fields that can disturb the measurements. The material samples are placed inside the rectangular wave-guide

IV. New Direct Method for Shielding Effectiveness Determination

The new measurement method presented in the paper has some similarities with the standard MIL-STD-285 and EN 50147 and consists in two high directivity antennae, tuned to the establish operation frequency, one for transmission and one for receiving signal, the material sample is placed between them, absorber for reflection and re-reflection waves and a data acquisition system [13]. The principle of the method is given in Fig. 4.

Shielding effectiveness is calculated as the difference between the visualized peaks (in dB) lobes from the receiving antenna in the absence and subsequently in the presence of the screen made from the tested material. The antenna position drives the reception antennae and the received field strength values are recorded on a circular diagram (2D) or in a Cartesian system.

The experiments were conducted using a system consisting of a set of transmission antennae fed at a frequency ranging between 50 MHz and 10 GHz and a second set of reception antennae capable of effecting a complete rotation in order to scan all possible directions to determine the main beam. The latter must be as narrow as possible to ensure total incidence on the shield surface at a distance corresponding with the Fraunhoffer zone ($d >> \delta$).

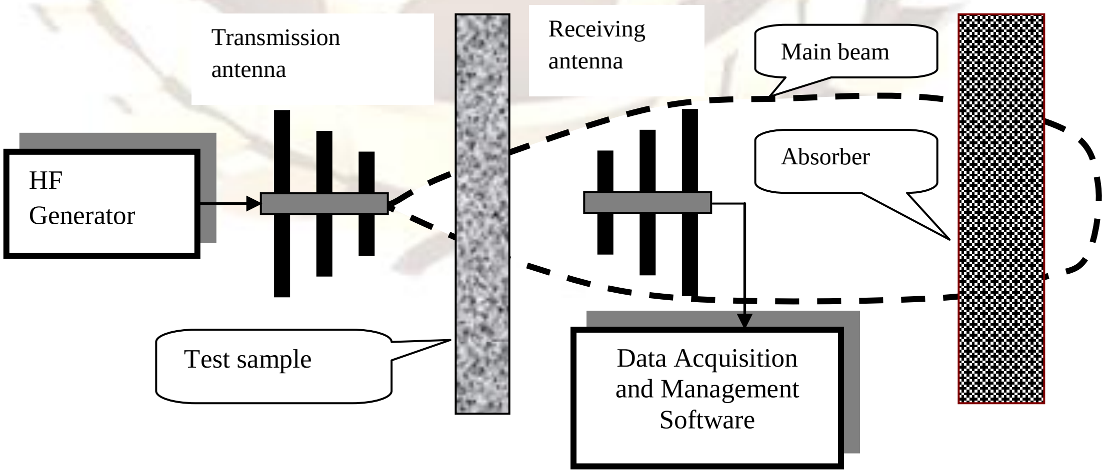

Fig. 4. The principle of the new method

V. Results and Discussion

In the measurements system with the new proposed method have been used tuned (helical, microstrip rectangular patch, pyramidal horn and Yagi) antennae.

The new measurement method having the setup in Fig. 5 has been validated both theoretically as well as experimentally, in Fresnel zone as well as in Fraunhoffer zone. For the first time an experimental verification of the theoretical predictions have been obtained for SE_{dB} in the area of the electrically thick samples ($d>\delta$)

Tested materials were: a Bismuth film on glass support, thin layers of 0.5 µm, 1 µm and 1.5 µm, respectively, to verify the method, synthetic graphite, 3 mm and 5 mm thickness and ferrite with absorbing properties. In the case of Bismuth thin film the errors occurring at both 1 GHz as well as at 10 GHz were smaller than 5% that is acceptable for this kind of measurements. The most relevant case is the measurement data obtained for Synthetic Graphite between 50 MHz and 1 GHz, that is in the area of the interest. A very good concordance of the increasing values can be observed in Fig. 6 and for the first time, the correct profile of the $F(f)=SE_{dB}$ function was obtained, namely the monotonously increasing behavior corresponding with the Fraunhoffer's area ($d>\delta$).

Fig. 7 presents the results of simulations and measured values obtained for various material samples inside the waveguide at 10 GHz, the plot being completed by using the waveguide method.

Fig. 8 presents a comparative synopsis of the employed methods on testing a FE300 nanomaterial [15] (Butadiene styrene rubber matrix filled with iron, 3mm thickness) sample. A good correspondence can be noticed between the simulated graph using our model and the experimental data obtained on employing the two testing systems.

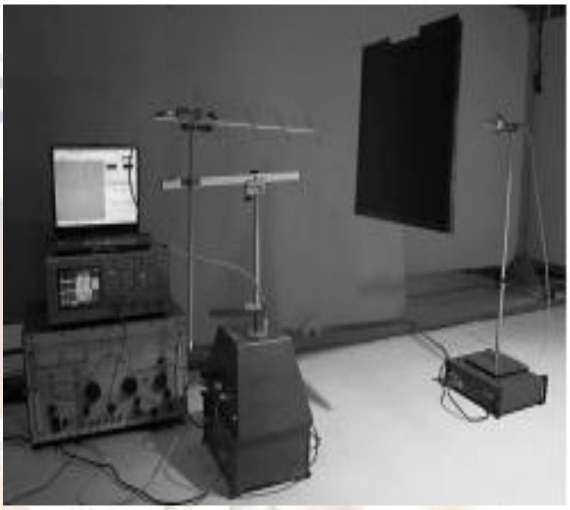

Fig. 5. Setup of the measurement system

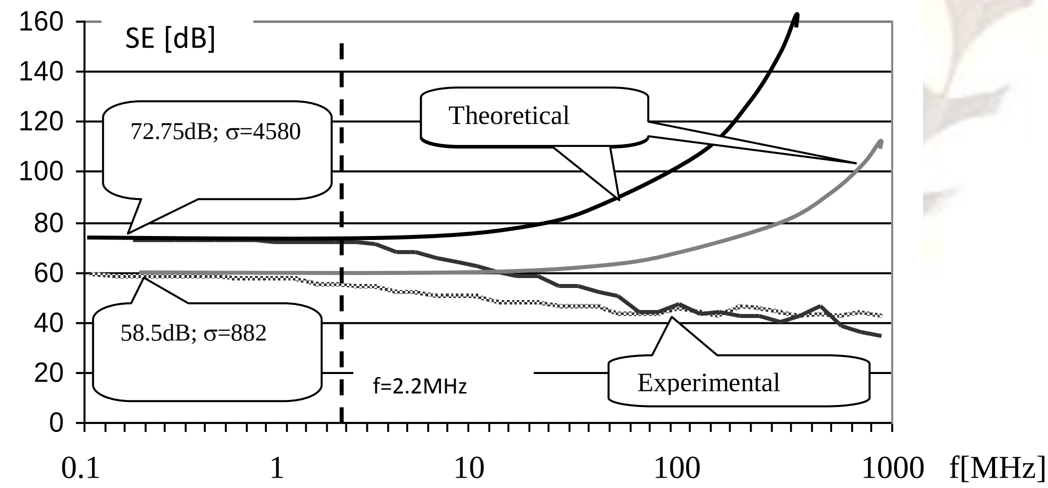

Fig. 6: Shielding effectiveness obtained with the new method for Synthetic Graphite

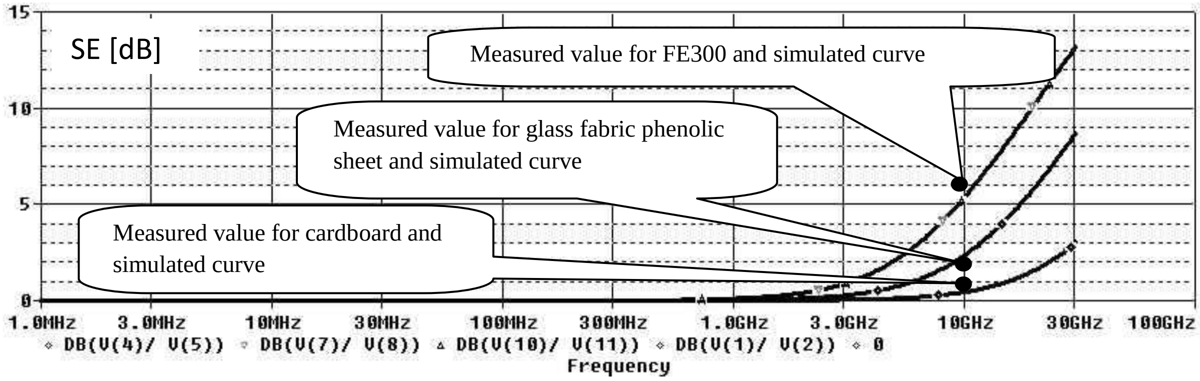

Fig. 7. Simulations and measured values for cardboard, glass fabric phenolic sheet and nanomaterials

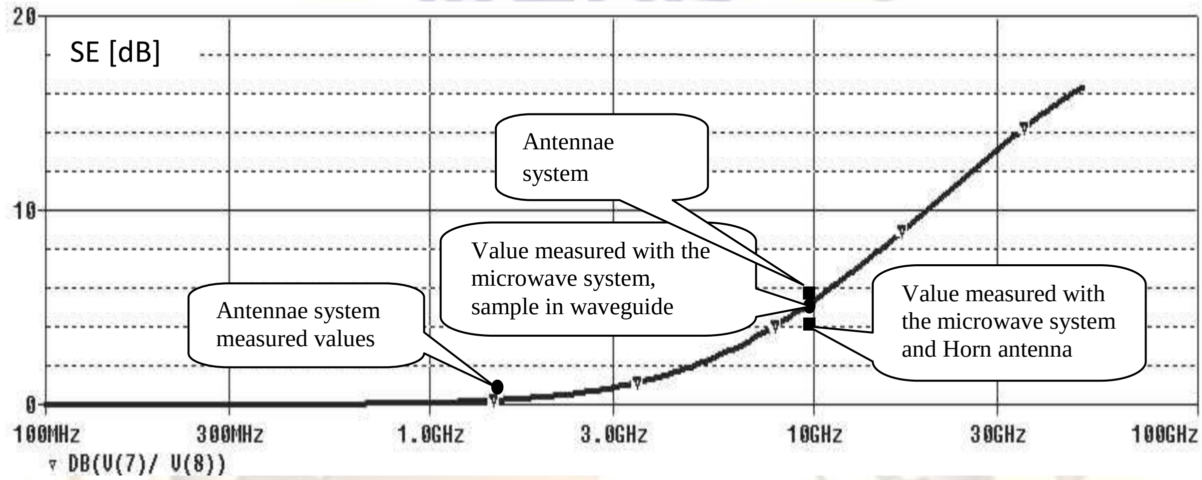

Fig 8. Simulated plot and points obtained by experimental determinations on the FE300 nanomaterial

VI. Conclusions

With respect to MIL-STD-285 and EN 50147 standards, the new measurement method proposed in this paper has a great theoretical and practical importance since it emphasizes the monotonously increasing function vs. frequency, in fact SE_{dB} in the area of the electrically thick samples (d>δ). The new method is more accurate compared to the coaxial TEM cells method where the measurement results are affected particularly in the area of interest (material absorption zone) by the perturbing higher oscillation modes.

The accomplished experimental determinations and the obtained measurement results demonstrate the validity of the proposed investigation methods in successfully testing different materials.

The methods are currently being perfected in order to provide greater accuracy in determining material electromagnetic shielding effectiveness.

References

[1] Al-Shabib W., Lachowicz, S. W., Modelling of polyaniline for Wi-Fi Electromagnetic Interference shielding, *Modeling, Simulation and Applied Optimization (ICMSAO), 2013 5th International Conference on,* DOI: 10.1109/ICMSAO.2013.6552654, 1-3

[2] Jianbao W., Bihua Z., Lihua S., Cheng G., Bin C., Analyzing the *Electromagnetic* Performances of Composite *Materials* With the FDTD Method, *Antennas and Propagation, IEEE Transactions on, Volume: 61 , Issue: 5,* DOI: 10.1109/TAP.2013.2242824, 2646 - 2654

[3] Romanca, M.; Ogrutan, P. ; Aciu, L.-E. ; Nicolae, G. ,Methods of investigating construction materials used for intelligent building shielding, *Optimization of Electrical and Electronic Equipment, OPTIM 2008. 11th International Conference on,* DOI: 10.1109/OPTIM.2008.4602520, 2008 , 191 – 196

[4] Ogunsola, A.; Reggiani, U. ; Sandrolini, L., Modelling shielding properties of concrete, *Electromagnetic Compatibility, EMC-Zurich 2006. 17th International Zurich Symposium on* DOI: 10.1109/EMCZUR.2006.214862, 2006, 34 – 37

[5] Wilson, P.F.; Ma, M.T., Techniques for measuring the electromagnetic shielding effectiveness of materials. II. Near-field source simulation, *Electromagnetic Compatibility, IEEE Transactions on, Volume: 30 , Issue: 3 , Part: 2,* DOI: 10.1109/15.3303, 1988 , 251 – 259

[6] Badic, M., Marinesc M.J., The failure of coaxial TEM cell ASTM standards methods in H.F. range, *Electromagnetic Compatibility, EMC 2002, IEEE International Symposium on*, vol. 1, 29 – 34.

[7] Sevgi, L., Electromagnetic Screening and Shielding-Effectiveness (SE) Modeling, *Antennas and Propagation Magazine, IEEE, Volume: 51, Issue: 1* DOI: 10.1109/MAP.2009.4939074 2009 , 211 – 216

[8] Xiaofeng Hu; Long Zhang, Simulation analysis of time domain and frequency domain test methods of electromagnetic shielding effectiveness of materials, *Mechanic Automation and Control Engineering (MACE), 2011 Second International Conference on*, DOI: 10.1109/MACE.2011.5987974, 2011 , 4378 - 4380

[9] A. Schelkunoff, *Electromagnetic Waves* (D. Van Nostrand Company, Inc., 1943).

[10] D.R.J. White, *Electromagnetic Shielding Materials and Properties* (Don White Consultants, Inc., 1980).

[11] M. Badic and M. J. Marinescu, Reflection loss in the case of plane waves impact on infinite absorbing slab, *Proceedings of IEEE Symposium on EMC, Boston, MA, USA 2003*, 626-629.

[12] M. Badic and M.-J. Marinescu, SE_{dB} determination for non-conductive electromagnetic absorbers, *Proceedings of IEEE International Symposium on EMC, Santa Clara, California, USA, 2004*, 557 - 561.

[13] M. Badic, L. Aciu, P. Ogrutan, A New Direct Method for SE_{dB} Determination, *International Symposium for Electromagnetic Compatibility, Detroit, 2008,* IEEE Catalog Number: CFP08EMC-CDR, ISBN: 978-1-4244-1699-8

[14] P. Ogrutan, L.E. Aciu, G. Nicolae, A SPICE Model to Evaluate Shielding Effectiveness of Conductive Materials, *The XVII International Conference on Electromagnetic Disturbances 2007, Poland*, ISBN 978-83-60200-37-7, 10.6-1, 10.6-4

[15] http://www.nipne.ro/activa-n_lab/Romanian_materials_of_the_future/presentations/W._Kappel-M_Lucaci.pdf