ECOTERRA
Journal of Environmental Research and Protection

Attenuation characteristics of electromagnetic shielding materials

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Abstract. Electromagnetic field effects on life are important because people live in the fields of increasing intensities. The paper presents a method for the simulation of composite materials that can be used in electromagnetic shielding. The paper begins with the analysis of the importance of building materials that have electromagnetic shielding characteristics in design of new intelligent buildings. Then a model for simulate the shielding efficiency is introduced and three types of measurements to confirm the validity of the model. PSPICE and SIMULINK simulation results for shielding effectiveness evaluation applied to composite materials are presented. Three methods of measurement are presented, at 10GHz, at 1GHz and in the range 10 MHz to 1 GHz.
Key Words: electromagnetic compatibility, simulation, composite materials, building materials.

Introduction. Increasingly more people are looking for answers to questions about the effects of electromagnetic radiation on physical and mental health of the individual. Mobile and fixed service stations mounted on blocks concern among the population.

World Health Organization shows that there are a huge number of mobile and fixed stations serving mobile telephony (WHO 2014). Mobile phones emit powers between 0, 2W and 3W and fixed stations up to 100W in the range of 800-1800 MHz frequencies. Electromagnetic energy is absorbed in the human body and produce heat, but the self-system of regulating body keeps a constant temperature.

WHO carried out the research on the effects of electromagnetic waves and mentioned in the report that there was no connection between the exposure through the use of mobile phones and cancer (WHO 2011). Studies go further in this direction, but in others such as changes in brain activity, reaction times, etc. However, investigations are not finalized and it is premature to draw a conclusion, so that WHO recommends caution with mobile phones, especially for children, shortening the calls, the use of system calls “hands free” etc. For fixed stations, measures must be taken to limit the access of antenna in the vicinity of where the energy radiated is great. The paper of Al-Orainy (2003) and the report published in the Netherlands (Health Council of the Netherlands 2006) and taken over by WHO confirm the results of the WHO.

On the WHO website are punctual research results published on the effects of electromagnetic radiation emitted by mobile phones and the organization proposes new directions of research. In Al-Orainy (2003) was published a study on 550 thousand people in Denmark who carried out the incidence of cancer and did not register an incidence increased to mobile phone users. Generally, there was no increase in the number of cases of cancer in the world over the past decade, where the number of mobile and fixed stations has skyrocketed, what is already serious statistical evidence that electromagnetic radiation doesn’t cause cancer.

However, biological effects (other than warming) were highlighted in cell cultures (increases) or to invertebrates (increasing fertility) so that the studies can continue and it is recommended that samples of the population should grow for tests.

Electromagnetic shielding materials. Determination of electromagnetic shielding for building materials has a great importance in the context of designing intelligent buildings (house, industrial, administrative buildings, etc.). The introduction of materials that have the capacity of electromagnetic shielding has many motivations:

- the human exposure to the field decreases;

- t he more and more great number of electronic devices at home or office that use and radiate in radio frequency, and thus interfere (thus for instance wireless routers) can be partially isolated in an adequate space, such as an apartment, a house, a floor, etc.;

- the power equipment, as for instance transformers, telecommunication equipment, antennas placed on the building's roof, can be isolated inside special rooms or by using separation levels;

- electronic spying is made more difficult.

Studies on building materials with electromagnetic shielding capacity appear at the beginning in the military field research. Hereby Lasiter (1964) reports measurements of attenuation introduced by concrete, and variation of attenuation in time. The report of Garett (1966) presents a study of some techniques for measurement and prediction of the shielding effectiveness of building materials used for military facilities.

The electromagnetic shielding of buildings can be obtained in a classically manner, using a copper foil placed between two wall material layers. This is a very expensive solution and asks for a lot of manual labor. Nowadays the great number of research papers and patents in the area prove the orientation of scientific communities towards finding new effective solutions, at lower costs. Thus, in the paper of Guckert (2007) is presented a method for obtain gypsum based building material with increased thermal conductivity and shielding capacity. The gypsum-based building plates can be used as interior room walls, in the case of, for example, the room contains computer technique, with the advantage of good dissipation of heat through the walls with thermal enhanced conductivity. In the gypsum-based building plates can be inserted carbon fibers (8-15% from the material weight) resulting relatively high costs, or according to the quoted patent, it is preferable to mould gypsum and black lead (25-75% from the material weight). Patent presented in Takamasa & Masatake (1995) describes special concrete that contains carbon fibers that have 4-30 mm length and 1-20 μm in diameter and that assure an 30 – 50 dB attenuation. In Murdoch (1999) it is presented a building material formed by blacklead, amorphous carbon (25-75% from the material weight), and sand, that has very good attenuation properties, especially in the range of hundreds of MHz. As binding material can be used, for example, concrete. The attenuation introduced by this material is minimum 30 dB. As application example is mentioned the NATO TEMPEST measurement standards (referring to non-intentional radiation phenomena resulting from communication and data treatment systems).

Papers of Guan et al (2003) and Architectural shielding (2014) present a synthesis of several methods for obtaining building materials that have the capacity of electromagnetic shielding and describe the link between conductivity and the shielding efficiency. The papers present building materials obtained by adding carbon powders, ferrite based powders or metallic particles: silver (with the disadvantage of the costs), copper (with the disadvantage of the metal oxidation), and nickel (with the disadvantage of reduced conductivity). It also was produced a concrete with insertions of amorphous carbon and SiO_2.

An interesting and original idea (Guan et al 2003; Singh & Badiger 2013) is to use the carbon smoke (the flying ash) composed of light particles that contain metals (iron, aluminum) and absorbent substances as SiO_2 and Fe_2O_3. The ash included in cement produce an increasing of shielding with approximate 4 dB. Other researches use a high-density metal (lead) in addition to cement.

Thus an effective electromagnetic shielding and a supplementary ionizing radiation shielding are obtained (Materials used in radiation shielding 2014; Singh & Badiger 2013). The experiments were conducted using a gamma radiation source. Other papers quote researches related to metallic layers disposed on the surface of window glass, which assure a 30 dB efficiency of shielding.

As for instance, a conclusive proof of the importance of the field is that at the 21st Exhibition on Solutions for Electromagnetic Interference an entire section is dedicated to electromagnetic shielding materials (EMC JAPAN 2014).

PSPICE® and SIMULINK® simulations for shielding effectiveness evaluation applied to composite materials. Late twentieth century is considered by many experts as age materials. These materials with properties superior to traditional materials are present in top technology fields such as microelectronics, aerospace technology, nuclear technology, medical implants construction technique, but also in the automotive industry, shipbuilding, chemicals, furniture, construction materials industry, sports.

Composite conductive structures can be used as electromagnetic shields, repeated reflections on structure planes providing a greater attenuation.

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 (Ogrutan et al 2007).

The method has been validated for copper (Aciu et al 2010), the results obtained being compared with theoretical results published by White (1980).

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.

The capability of a shield can be expressed using Shielding Effectiveness, that can be computed by the relation (1):

$$SE_{dB} = 20\lg\frac{U_i}{U_0} \qquad (1)$$

Simulation of electromagnetic shield through a transmission line is suggestive represented in Figure 1, (Schelkunoff 1943):

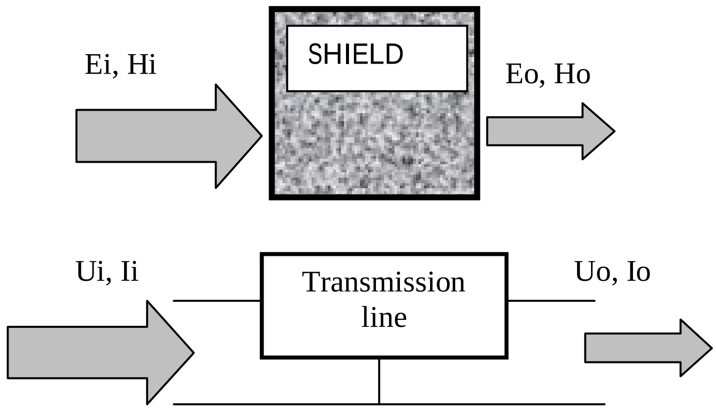


Figure 1. Lossless Transmission line model showing material properties.

Layered composite materials have the main advantage the economic one and qualitative reasons, because their use is by saving important quantities of expensive materials or deficient, improving at the same time, the qualities of products and increasing the duration of their operation in conditions of high performance.

Composite material structure, reveals itself in the fabrication, electrical characteristics of layers containing components, i.e. electric conductivity σ, the electric permittivity ε and the magnetic permeability μ is represented in Figure 2.

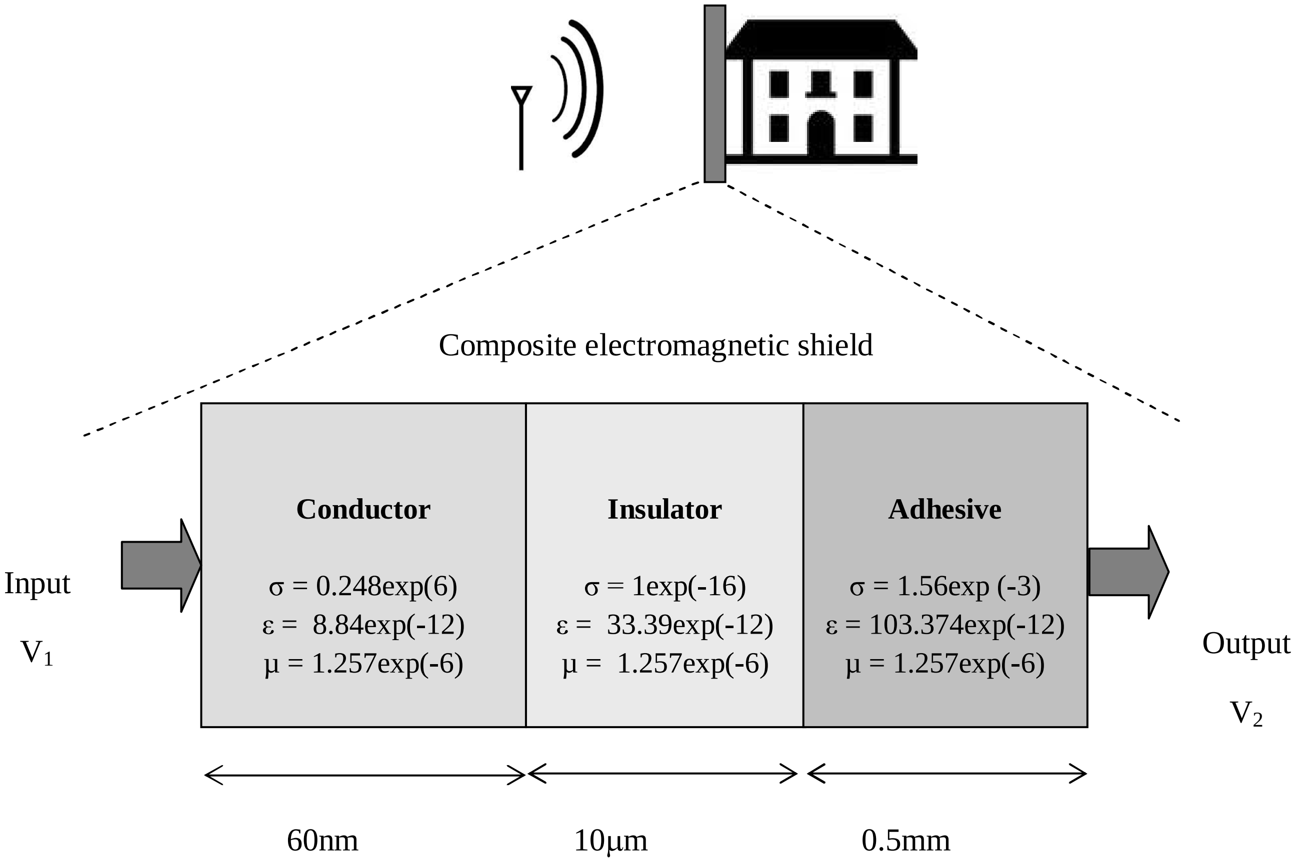


Figure 2. About the composite material structure.

For simulation have been used the following model, where T1 is the line transmission model for Adhesive material, T2 is the line transmission model for Insulator and T3 is the line transmission model for the conductive layer in the analyzed composite material (Figure 3).

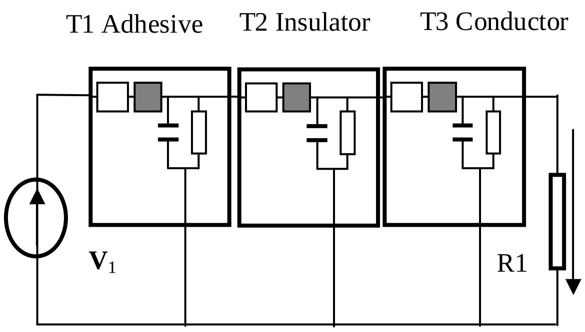


Figure 3. Layered composite material transmission line model.

After the simulation made in the frequency range of 1GHz - 500GHz, it can be seen that till 3GHz the electromagnetic waves attenuation is low, for all frequencies (Figure 4).

The results obtained by simulations have compared with experimental determinations at 10GHz. The composite material capability to attenuate the electromagnetic waves, expressed by the shielding effectiveness, is around 2dB and was computed by relation (1) after simulations.

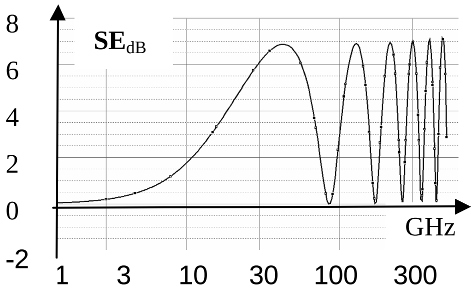


Figure 4. The material attenuation in the frequency range of 1GHz - 500GHz.

Based on the transmission line mode SIMULINK simulations have been made for the composite material (Figure 5).

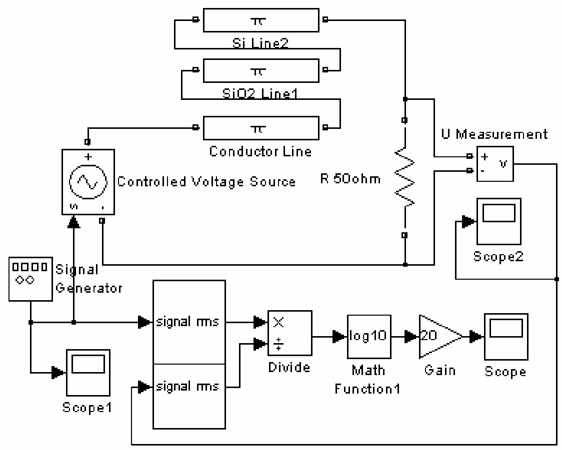


Figure 5. SIMULINK simulation model for composite material.

The shielding effectiveness (simulated at 10GHz) is shown in Figure 6, calculated with relation (1). Comparing the simulation results obtained with different programs it can be seen that the attenuation introduced by the composite material at a frequency of 10GHz are in the range of (1.5dB-3dB).

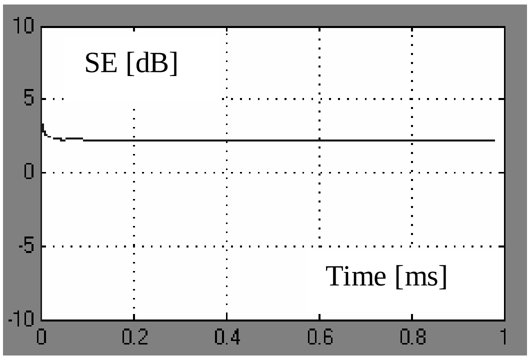


Figure 6. The shielding effectiveness simulated at 10 GHz.

Experimental results. During the experimental investigation, several methods were verified for determining the microwave field attenuation produced by the tested material samples. Following methods were applied:

- the method of microwave field power measurement, using a thermistor bridge;
- the radiofrequency substitution method;
- the RF detection method of microwave field power measurement;

- the microwave radiation method, using a horn antenna;
- the microwave field power measurement method using the spectrum analyzer;
- the measurement method using the TEM (Transversal ElectroMagnetic) cell.

By comparing the measurement results from identical material samples using various techniques, the most appropriate method of determining material effects on electromagnetic field transmission could be selected. Thus, the method known as “Measurement of microwave field power by radiofrequency detection” is considered to be the most appropriate technique for determining the attenuation of electromagnetic microwave field produced in nanomaterials. The above-mentioned method should be adopted in correlation with both the investigated microwave signal parameter and the considered frequency range so as to ensure high measuring accuracy while eliminating both the influence of perturbing electromagnetic fields and the errors produced by the power consumption inherent to the measuring process. Also, the results obtained by using the selected measurement method should be in concordance with the results obtained by employing alternative measurement methods and even with computer simulations.

Measurements at 10GHz. The measurement of microwave field power by radiofrequency detection involves amplitude modulation of the microwave signal using a 10 kHz rectangular wave signal. This will result in amplitude - modulated rectangular radiofrequency signal with a 50% duty cycle. A point-contact diode detector ensures radiofrequency energy detection and applies a voltage signal to the power meter:

$$U = \sqrt{P \cdot R_s} \quad (2)$$

where: U – is the detector output voltage;P – is the power of the detected signal; Rs – is the detector load resistance.

The utilized power meter displays the input signal power in dBmW, according to the relation:

$$P[dBm] = 10\lg\frac{P[mW]}{1mW} \quad (3)$$

Considering the methodology employed in the measuring procedure, the first step includes the measurement of microwave field power *P1*, in the absence of the studied material sample. Next, the examined nanomaterial sample is placed in the cross–sectional area of the waveguide and the power *P2* of the attenuated microwave signal is measured. The difference of powers *P1* and *P2* represents the attenuation introduced by sample under test and can be expressed as *dBm* or *dB* according to the instrument scale (Figure 1). Different types and categories of materials were used during the experimental investigations. These samples were of different thickness and formed of two or more layers of identical or different types of materials. For the composite material attenuation measuring in the field of radiofrequencies, was used the substitution method, known to be of high precision. Measuring scheme is given in Figure 7.

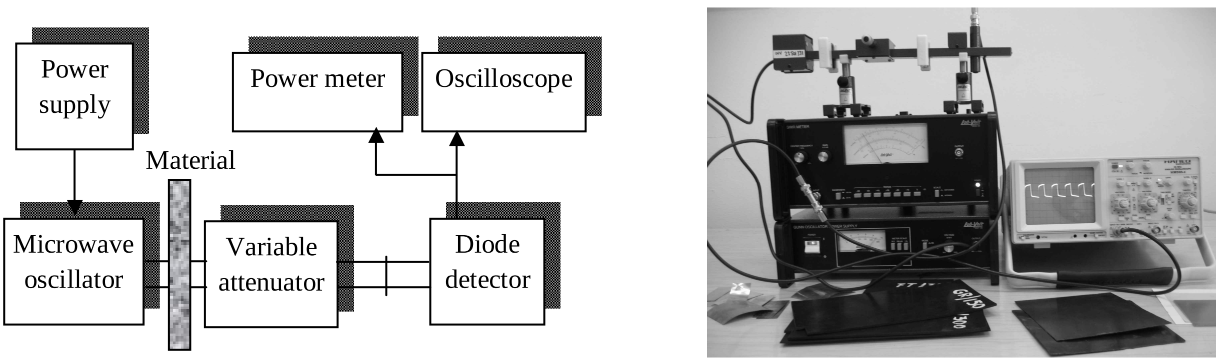


Figure 7. Block diagram for experimental determinations.

For experimental determinations was used a wave guide system with a Gunn oscillator at a frequency of 10 GHz, as stated above. The result obtained through the mediation of several determinations is around SE_{dB} = 3dB. Comparing the value obtained with the simulations at the same frequency SE_{dB} = (1.5dB-3dB), it reveals a good precision, which means that the simulations made for the composite material are correctly made.

Measurements at 1GHz. The experimental measurements were performed at the High Voltage and Electromagnetic Compatibility Laboratory of the ICPE Bucharest, using a Labvolt system with antennas (Badic et al 2008). The antennas system is show in Figure 8.

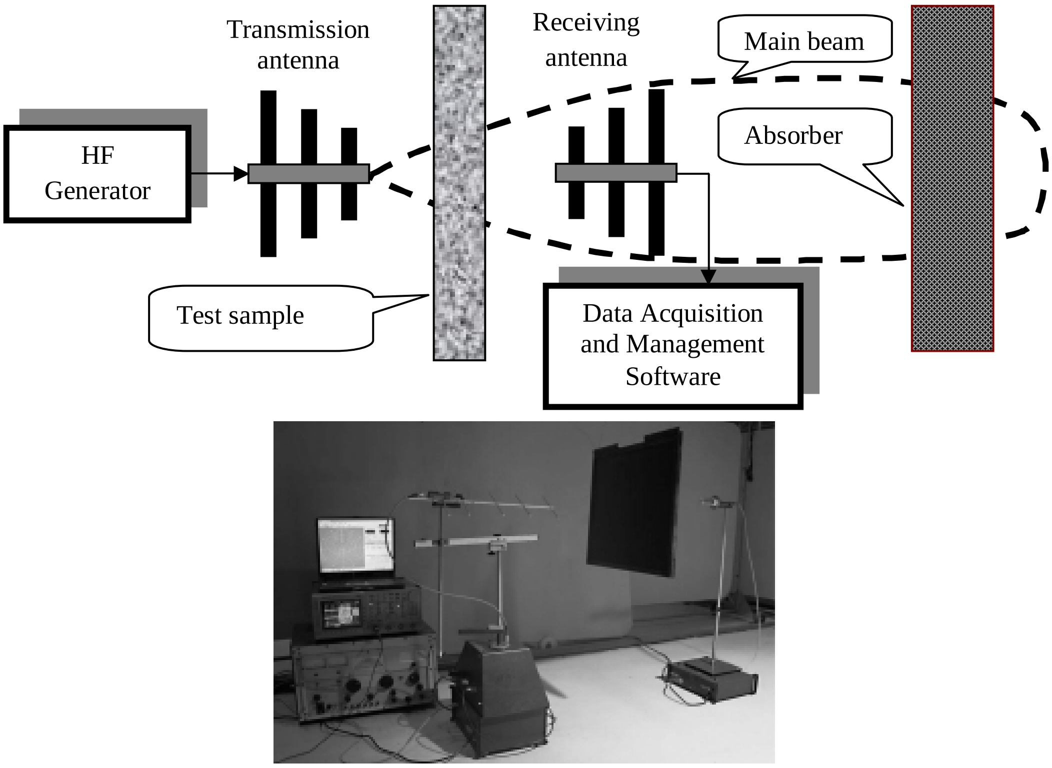


Figure 8. The composite material sample positioned between the transmitter and reception antennas.

The method 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. The principle of the method is given in Figure 8.

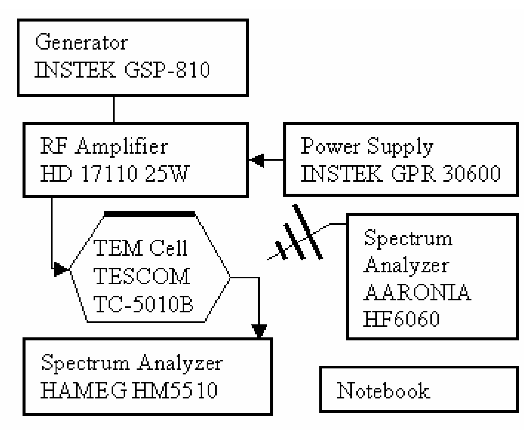
Shielding effectiveness is calculated as the difference between the visualized peaks (in dB) lobes from the receiving antenna in the absence and subsequently in the presence of the screen made from the tested material. This value can also be read directly from the 2D diagram or from the Cartesian diagram.

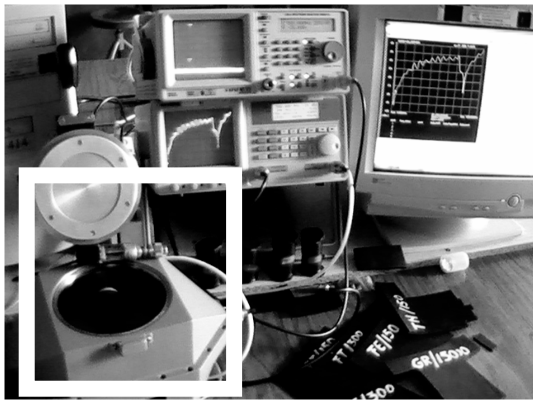
The experiments were conducted using a system consisting of a set of transmission antennae fed at a frequency ranging between 50 MHz and 10 GHz and a second set of reception antennae capable of effecting a complete rotation in order to scan all possible directions to determine the main beam. The latter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

Measurements in the range 10MHz to 1GHz frequency band. Based on the frequency – wavelength conversion:

$$\lambda_{[m]} = \frac{300}{f_{[MHz]}} \qquad (4)$$

The wavelength interval corresponding with the measurement frequency range is determined between 30 m and 0.3 m (30 cm). For this case, the measurements are performed especially on the metric band. This allows for the use of TEM cells, where the test samples are placed and of coaxial cable to interconnect the elements of the measurement system (Figure 9).





TEM CELL

Figure 9. Measurement setup for the 10MHz - 1GHz frequency interval.

The measuring system for the 10MHz - 1GHz frequency band includes the following equipments:

- RF signal generator, in the 10MHz – 1GHz band;
- spectrum analyzer in the 10MHz – 1.1GHz band;
- TEM cell;
- digital storage oscilloscope (DSO);
- connecting elements for the metric and decimetric band (coaxial cables, signal distributor, connectors).

The measurement methodology of the attenuation levels produced by each nanomaterials sample at different frequencies on the 10MHz - 1GHz range includes the following steps:

- instrument calibration and interconnecting of the system components in accordance with Figure 1;
- successive adjustment of the selected frequencies using the RF generator;
- for each selected frequency value, two values of electromagnetic field power, P1 - are determined in the absence of the material sample inside the TEM cell and another two values P2 – are determined with the material sample placed inside the TEM cell;
- the attenuation for each frequency value and sample type is calculated using the relation:

$$a_{[dB]} = 10 \cdot \lg \frac{P_2}{P_1} \quad (5)$$

- the attenuation versus frequency characteristic is drawn for each material type, between 10MHz and 1GHz.

The test sample is placed inside the TEM cell between the central conductors, perpendicularly to these, so as to completely cover cross-sectional area of the cell.

Conclusions. For determination of shielding efficiency some materials with known features and behaviors were tested. The experiments used a microwave test system (Labvolt) beginning with material samples positioned in the system waveguide and then positioning the samples in the field created by a Horn antenna. A second set of measurements were conducted using Labvolt and 2D/3D antennas and the third set were conducted with the TEM cell.

For a composite material the efficiency of shielding based on model parameters was calculated, and the results validate the correctness of the proposed model. The simulated curves obtained with PSPICE and SIMULINK and the experimental values obtained with 2D/3D antenna system, with the microwave system using wave guide and the TEM cell are consistent.

The future can bring big surprises on the border areas where composite materials will be used. In addition, the simple method of simulation presented in this paper offers to the manufacturer the possibility to pre-choose the dimensions and the combination of materials in order to get superior performance of the composite material.

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Received: 01 February 2014. Accepted: 28 February 2014. Published online: 31 March 2014.
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How to cite this article:
Ogruţan P. L., Aciu L. E., Stanca C., 2014 Attenuation characteristics of electromagnetic shielding materials. Ecoterra 11(1):66-75.