On the characterization of electromagnetic shielding effectiveness of materials

Valeriu David[1], Emil Vremera [1], Alexandru Salceanu [1], Ionut Nica[1], Octavian Baltag[2]

[1] Technical University of Iasi, Faculty of Electrical Engineering, Bd. D. Mangeron, 53, Iasi, Romania, phone +40 232 278680, fax+40 232 237627, e-mail valdavid@ee.tuiasi.ro
[2] University of Medicine and Pharmacology Iasi, Faculty of Bioengineering, Str. Universitatii, 16, Iasi, Romania, phone +40 232 213573

Abstract-In this paper we present different techniques for measuring the electromagnetic shielding effectiveness of the materials. A comparative study regarding the advantages and the limits of these methods in electromagnetic characterization of advanced materials for shielding purpose is considered. Additionally, the possibility to separate the contribution of absorption and reflection properties of these materials to the total shielding effectiveness was investigated.

I. Introduction

The development of new materials for electromagnetic shielding and their shielding properties characterization is of great interest [1], [2], [3]. These materials for innovative shielding have good mechanical properties but little weight and can even substitute the metallic ones in many applications. Because of their complexity, described by chemical composition and sample size, the measurement of their shielding effectiveness is quite difficult. In this paper we present several methods for the materials shielding characterization in a broadband frequency range, focusing the free space techniques. Also, it is considered the determination of the absorption and reflection properties of these materials which are very important in the case of the electromagnetic absorbers like Salisbury screens, Jaumann layers and resistive thin film [4].

II. Measurement set-up for shielding effectiveness characterization

The shielding effectiveness, *SE*, describes the performance of the shield and it is defined as [5]:

$$SE_P = 10 \cdot \log_{10} \frac{incident\ \ power\ density}{transmitted\ \ power\ density} \tag{1}$$

The two power densities in this ratio are the measured powers before respectively after the shield is placed.
Also, the expressions of the shielding effectiveness function of electric field, respectively magnetic field are:

$$SE_E = 20 \cdot \log_{10} \frac{E_{\mathrm{R,0}}}{E_{\mathrm{R,S}}} \tag{2}$$

$$SE_H = 20 \cdot \log_{10} \frac{H_{\mathrm{R,0}}}{H_{\mathrm{R,S}}} \tag{3}$$

where: $E_{\mathrm{R,0}}$ and $H_{\mathrm{R,0}}$ are the root mean square, rms, of the electric field strength, respectively of the magnetic field received without the shield; $E_{\mathrm{R,S}}$ and $H_{\mathrm{R,S}}$ are the rms electric field strength, respectively the magnetic field received in the same point, when the shield is placed between the transmitting antenna and the receiving antenna.

In the far field conditions or the plane wave case, $\frac{E}{H} = \xi = 377\ \Omega$, the shielding effectiveness are equaly:

$$SE_E = SE_H \tag{4}$$

Generally, the shielding is achieved both by reflection losses and absorption losses. The knowledge and the control of each type of loss, reflection and absorption, are necessary in the electromagnetic absorbers study and in their applications design (e.g., invisibility properties).
The basic test methods for the shielding effectiveness measurement of a material sample are [6]: the

coaxial holder method, the dual-TEM cell method, nested reverberation chamber method [7], anechoic chamber with aperture method and time domain method [8].
Referring to the measurement sites, the shielding properties measurements for materials can be made in controlled test sites or in free space.

A. Measurement in controlled test sites

The main measuring method in the controlled medium is the coaxial holder method [9]**.** This method uses a holder transmission line and a vector network analyzer, as is shown in Fig. 1. The sample material is placed and fixed in the flanged circular coaxial transmission line holder. By measuring the S-parameters, S_{11} and S_{21} – reflection and transmission coefficients, it is possible to determine the contribution of the absorption and the reflection at the total shielding effectiveness.
Generally, the maximum operating frequency is around 2 GHz. The increasing of the maximum operating frequency determines the decreasing of the flanged coaxial line dimensions and, of course, the sample dimensions [1], [10].

This measuring system is compact and allows automation and data proceeding by computer control. The difficulty of this measurement method arises from the sample preparation. Thus, the dimensions of the sample must be small, especially for higher frequency measurements and the influence of the contact resistance between the sample and the coaxial holder is necessary to be considered.

Another limitation of the measurements in controlled test sites is given by the difficulties to characterize the angular reflectivity.

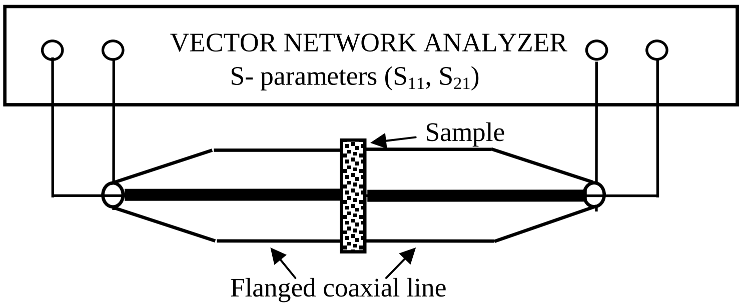

Fig. 1. Measurement in controlled test sites: coaxial holder method

B. Free-space measurement techniques in the frequency domain

A method which allows wide frequency range measurements with the upper frequency limit around of tens of GHz is the free-space technique. Moreover, this method allows the shielding effectiveness measurement for the large samples size. Thus, this electrical contact-free method is suitable for a large class of shielding and in-situ measurements become possible.
Fig. 2 shows the transmission measurement method.

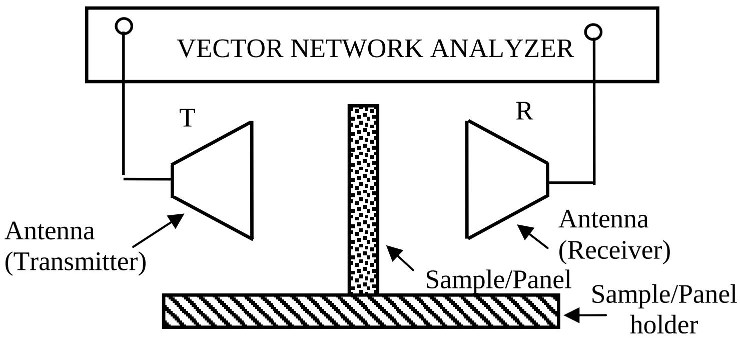

Fig. 2**.** Free-space transmission measurement method

By determining the field received by the antenna R in two situations: without and respectively with the sample/panel, we can obtain the shielding effectiveness for each frequency using (2) and it is possible to plot frequency characteristic of *SE*.
Fig. 3 shows the reflection measurement method.

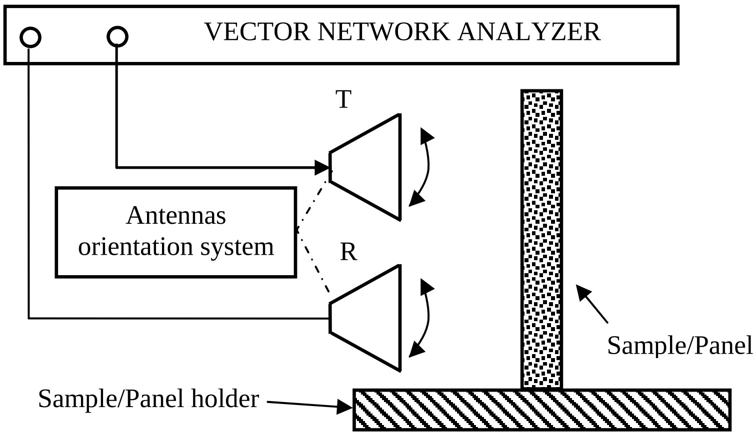

Fig. 3**.** Free-space reflection measurement method

Reflection coefficient (*RC*) is:

$$RC = 20 \cdot \log_{10} \frac{E^r}{E^i} \tag{5}$$

where E^r is the electric field reflected by the sample/panel and E^i is the incident electric field.
An indication of the sample reflectivity is given also by the backscattering coefficient (*BC*), which is expressed as:

$$BC = 20 \cdot \log_{10} \frac{E_{\mathrm{S}}}{E_{\mathrm{MP}}} \tag{6}$$

where, E_S is the electric field received by antenna R in the case of the sample/panel (field scattered by testing material), and E_{MP} is the electric field received by R antenna in case of a metallic plate reference situated in same place as sample/panel (field scattered by reference structure).
The instrumentation set-up shown in Fig. 3 allows, due to the suitable orientation of the transmitting and receiving antennas system, the obtaining of the wanted angle of the incidence and the angular reflexivity of the sample/panel.
For the reflection measurement in the normal incidence of the wave case, a single antenna together with a broadband high-directivity directional coupler can be used.
The main difficulties of the free space measured techniques are those related to control the electromagnetic environment, consisting in the separation of the desired electric field from perturbing fields (e.g. unwanted reflections in measurement places).

C. Free-space measurement techniques in the time domain

The time domain method allows the measurement of *SE* in a wide frequency band and decreases the measurement time.
Comparatively with the continuous wave (CW) free space techniques, the time domain method allows separation of the desired signal from the unwanted reflections in the laboratory by using differences in their time arrival at the receiving antenna (time winding method).
Fig. 4 shows the shielding effectiveness measurement by time domain technique.
The shielding effectiveness of the materials to pulsed electromagnetic field may be calculated with an expression of the same type as (2):

$$SE_E = 20 \cdot \log_{10} \frac{E_{\mathrm{R,0}}^{peak}}{E_{\mathrm{R,S}}^{peak}} \tag{7}$$

where $E_{\mathrm{R,0}}^{peak}$ and $E_{\mathrm{R,S}}^{peak}$ are the peak values of the pulsed electric fields displayed on oscilloscope before, respectively after the sample shield is placed between the transmitting and receiving antennas.
Because of the shielding effectiveness of the materials depends on the frequency (*SE* is different, depending on frequency component of the field) the shapes of these two pulses, without and with the

shield, may be different.
The recorded data, namely the pulsed electric fields captured by oscilloscope, may be converted from time domain into the frequency domain using FFT algorithms; after this, we can obtain the shielding effectiveness for each frequency component (2) and plot the frequency characteristic of *SE*. In this mode, it is possible to compare the results of the time domain method with the frequency domain method.
In the case of the time domain method, the dynamic range is about 50-60 dB, much more less than the ones obtained using the frequency domain method for measurement of shielding effectiveness (about 100 dB).

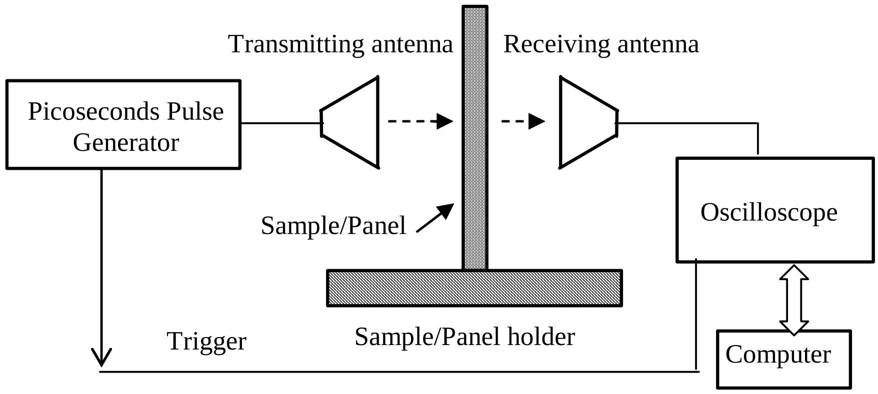

Fig. 4. Time domain measurement technique

By placing the receiving antenna in front of the sample, as is shown in Fig. 3, the reflection properties of the material could be determined.

III. Experimental results

We determined the backscatter characteristics of the flexible foam sheet broadband microwave absorber – ECCOSORB AN-79. This absorber has 61 cm x 61 cm dimensions and 11 cm thickness.
The reflectivity of the ECCOSORB AN-79 absorber, in accordance with the catalog data [11], is shown in Fig. 5.

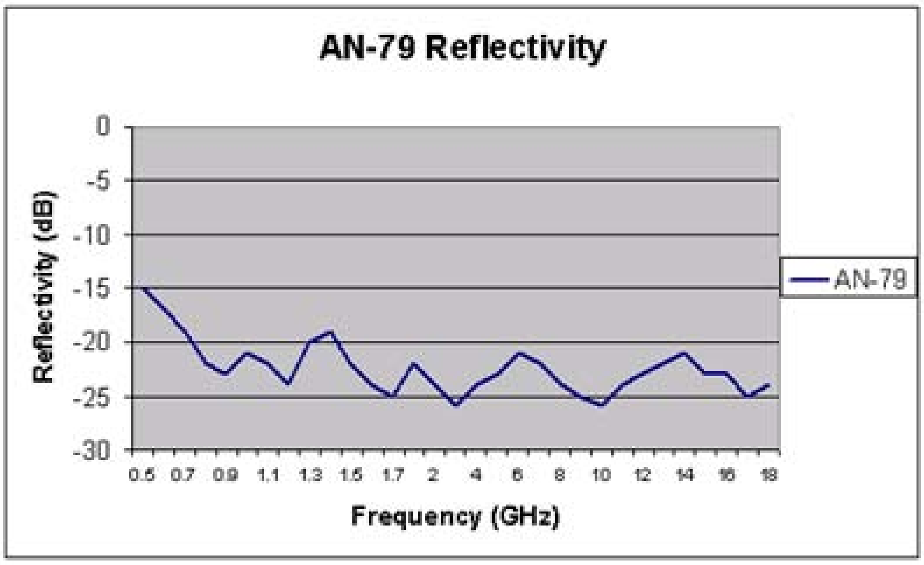

Fig. 5. Reflectivity of the "ECOSORB AN-79" absorber

Essentially, it is designed to reflect less than -20 dB of normal incident wave at frequencies above

600 MHz relative to a metal plate.
Fig. 6 shows our measurement system used to determine the backscattering coefficient of the absorber. The measurements have been performed in an ordinary laboratory environment. In these conditions we used an amplitude modulation signal.
The carrier frequency was 8,7 GHz and the modulating frequency was 1500 Hz. The modulate continuous wave emitted by a horn antenna T is reflected by absorber and, in a next measurement, by a reference structure (metallic plate with the same dimensions like the absorber – 61 cm x 61 cm).

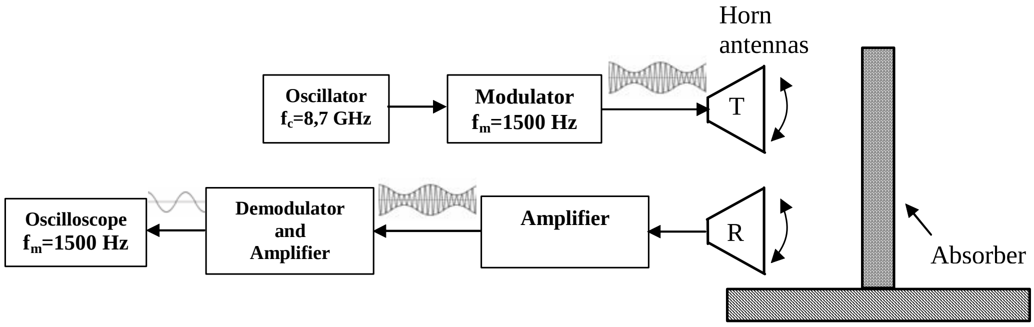

Fig.6. Measurement set-up for backscattering coefficient determination

The reflected signal is received by R horn antenna, amplified, demodulated and then the modulating signal (frequency of 1500 Hz) is displayed on the oscilloscope.
The backscattering coefficient (*BC*) is expressed function of reference structure (metal plate):

$$BC = 20 \cdot \log_{10} \frac{U_{\mathrm{A}}}{U_{\mathrm{MP}}} \tag{8}$$

where, U_{A} is the rms value of the displayed signal (frequency 1500 Hz) in the case of the absorber laid in front of the antennas, and U_{MP} is the rms value of the displayed signal in the case of the metal plate laid at the same distance in front of the antennas.
We made measurement for two incidence angle of the wave; normal incidence ($\phi \cong 0°$) and an oblique incidence ($\phi \cong 45°$).
The measurements were made for different distances between the antennas and the sample or metallic plate: the minimum distance is limited by the far field condition and the maximum distance is limited by the sensibility of the measurement system (the voltage response U_{A} may be under the noise floor).
In these condition, the values obtained for backscattering coefficient (*BC*) of the "ECOSORB AN-79" absorber were situated in the interval -25 ÷ -32 dB.

IV. Conclusions

The coaxial transmission line holder method allows the determination of the reflection and the absorption contributions in the overall shielding effectiveness of the material, but it is adequately only for small samples and generally, for normal incidence of the wave.
The free-space measurement methods allow measurements of the shielding effectiveness for large size samples or panels in a broadband frequency range. Moreover, by possibility to made "in situ" measurements it was obtained an unfailingly characterization for the shielding effectiveness.
For the free space measurement methods we are studying the possibility to control the electromagnetic interference and to measure both reflection and transmission in view of characterizing the electromagnetic properties for shields and absorbers as Salisbury screen and Jaumann layers. Also, both frequency domain and time domain shielding measurements were considered.
Using a simple measurement system we determined, in a normal laboratory environment, the backscattering coefficient of the flexible foam sheet broadband microwave absorber.
Further work needs to be done on the decrease of the electromagnetic interferences' effects in measurement of the materials' shielding proprieties.

Acknowledgements

This paper has been supported by the Romanian Ministry of Education and Research under the Project CEEX-M1-C2-312 (MATNANTECH 46/26.07.2006) "Shields for special buildings based on chiralhoneycomb structures”, the Project CEEX- M1 “CANCERDET” (20/2005) in the frame of the CEEX Program and FP6 STRP 013064 “CHISMACOMB” project.

References

[1] Maria Sabrina Sarto, Alessio Tamburrano, “Innovative Test Method for the Shielding Effectiveness Measurement of Conductive Thin Films in a Wide Frequency Range”, *IEEE Transactions on Electromagnetic Compatibility*, vol. 48, pp. 331-340, 2006.

[2] Mihai Badic, Mihai-jo Marinescu, Maria Stefan and Lia-Elena Aciu D. Williams, “An Iterative Method to Calculate Absorption Loss in Conductive Dielectrics”, *2006 IEEE International Symposium on Electromagnetic Compatibility*, Portland, Oregon, USA, 2006.

[3] J. A. Catrysse, M. de Goeije, W. Steenbakkers, L. Anaf, “Corelation Between Shielding Effectiveness Measurements and Alternative Methods for the Characterization of Shielding Materials”, *IEEE Transactions on Electromagnetic Compatibility*, vol.35, pp. 440-444, 1993.

[4] K. Takizawa, O. Hashimoto, “Transparent Wave Absorber Using Resistive Thin Film at V-Band Frequency”, *IEEE Transactions on Microwave Theory and Techniques*, vol.47, pp. 1137-1141, 1999.

[5] D. R. J. White, *Electromagnetic Shielding Materials and Performance*, Don White Consultants, Inc, 1980.

[6] P. F. Wilson, M. T. Ma, J. W. Adams, “Techniques for Measuring the Electromagnetic Shielding Effectiveness of Materials”, *IEEE Transactions on Electromagnetic Compatibility*, vol.30, pp. 239-259, 1988.

[7] C. L. Holloway, D. A. Hill, J. Ladbury, G. Koepke, R. Garzia, “Shielding Effectiveness Measurements of Materials Using Nested Reverberation Chambers”, *IEEE Transactions on Electromagnetic Compatibility*, vol.45, pp. 350-356, 2003.

[8] R. T. Johnk, A. Ondrejka, S. Tofani, M. Kanda, “Time Domain Measurements of the Electromagnetic Backscatter of Pyramidal Absorber and Metallic Plates”, *IEEE Transactions on Electromagnetic Compatibility*, vol.35, pp. 429-433, 1993.

[9] Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials, ASTM D-4935-99.

[10] I. K. Hong, C. Y. Lee, C. K. Jeong, D. E. Lee, K. Kim, and J. Joo, “Method and apparatus to measure electromagnetic interference shielding efficiency and its shielding characteristics in broadband frequency ranges”, *Rev. Sci. Instrum.*, vol.74, pp. 1098-1102, 2003.

[11] www.eccosorb.com.