NEW METHODS DEVELOPED FOR SHIELDING MATERIAL CHARACTERIZATION

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Abstract **– The theory of electromagnetic shielding is based on the waves equations describing the behavior of electromagnetic field in substance and also boundary phenomena by means of Fresnel's reflection and transmission coefficients. The interaction between electromagnetic radiation and infinite plane shield having finite thickness d, placed in free space in plane waves region depends of material/shield macroscopic parameters (ε, μ, σ), its thickness, radiation's frequency and incidence angle. Many models have been issued but lately Schelkunoff model was accepted. Even if it is formally accurate, it has not been experimentally validated up to present, in the area of electrically thick samples, according to numerous works in the field. The paper deals with original methods for visualization, measurement and simulation of shielding effectiveness.**

Keywords: *shielding effectiveness, TEM cell, antennas, line transmission, modeling.*

1. INTRODUCTION

For EMC theory and practice is important to know as much as possible about reflecting and absorbing materials used in electromagnetic shielding [1].

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 [2] 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 [3], [4], [5].

Limitations of this isomorphism mainly consist in:

- Limitation in practical applications at high frequency caused mainly by the occurrence of higher modes in the test sample;
- Deficiencies in the case when propagation is absent in the coaxial line but exists within the material sample;
- Basic Incongruities, due to the fact that general expression of SE_{dB}, equation (1) was artificially split into terms/factors that should represent reflection, absorption and respectively re-reflections.

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.

2. SHIELDING EFFECTIVENESS DETERMINATION WITH LINE TRANSMISSION SPICE MODEL

Shielding effectiveness *SE* is defined as the ratio between intensities of electric / magnetic/ electromagnetic fields without shield, *Ei*, *Hi*

respectively with shield *Eo*, *Ho* at normal incidence [6].
The proposed approach consist in a Spice model using transmission line model to simulate the attenuation introduced by a material characterized by the macroscopic parameters ε, μ, σ.
The model starts from the signal attenuation due to the shield, effect which occurs when an e.m.f. is induced in the electro-conductive shield depending on material conductivity (induce eddy currents) and its magnetic permeability. The proposed shield model after SPICE simulation is represented in Fig. 1 and 2.

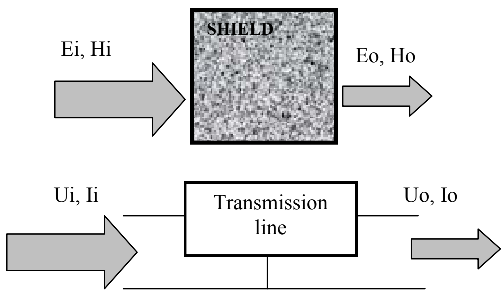

Figure 1: Loss less Transmission line model showing material properties

The shielding effectiveness in Schelkunoff's isomorphism is given by:

$$SE_{dB} = 20\log\frac{U_I}{U_O} \tag{3}$$

where, U_0 is the voltage without shield and U_I is the voltage after shielding.
The method has been validated for copper, the results obtained being compared with theoretical results published by White [7].

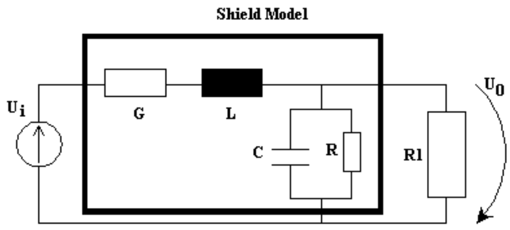

Figure 2: SPICE Model using the Transmission line model for the studied material

A good likeness between the graphs obtained by simulation and those obtained by White can be seen in Fig. 3 for two thickness of copper: 76 μm and 762 μm. 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.

3. NEW DIRECT METHOD FOR SE_{dB} SHIELDING EFFECTIVENESS DETERMINATION

The new 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. The principal of the method is given in Fig. 4 [8].

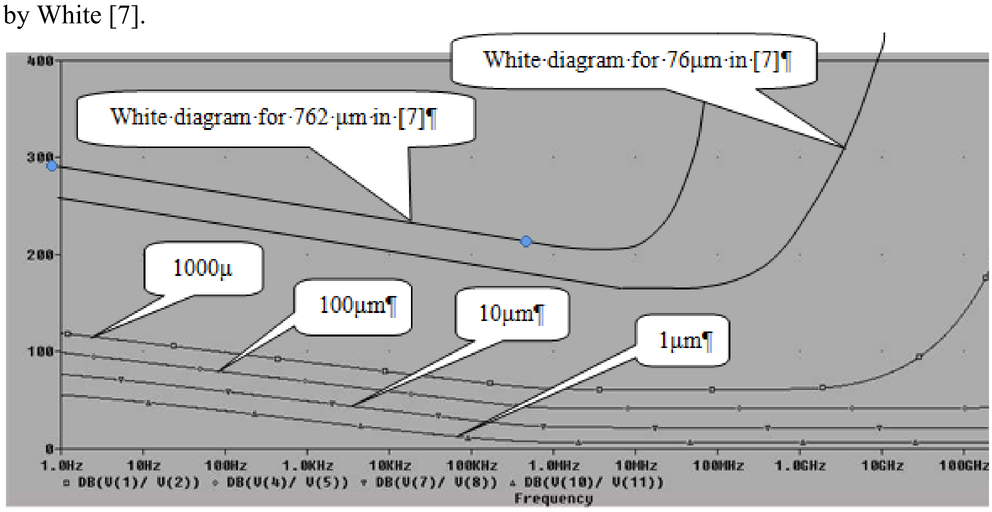

Figure 3: Shielding effectiveness of a copper shield, the highest effectiveness corresponds to the thickest shield

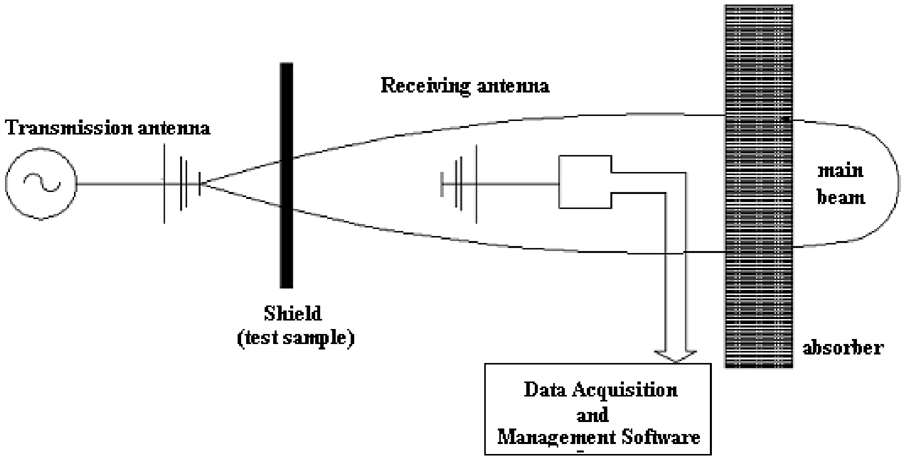

Figure 4: The principle of the new method

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 presented in Fig. 5 or from the Cartesian diagram.

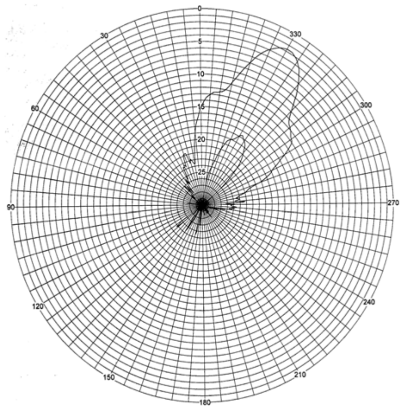

Figure 5: 2D diagram for 3m distances between antennas

The antenna drives the reception antennae positional 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 ($d >> \delta$).
In the measurements system with the new proposed method have been used tuned (helical, microstrip rectangular patch, pyramidal horn and Yagi) antennae. 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, ferrite slab 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) = $\boldsymbol{SE}_{dB}$ function was obtained, namely the monotonously increasing behavior corresponding with the Fraunhoffer's area.

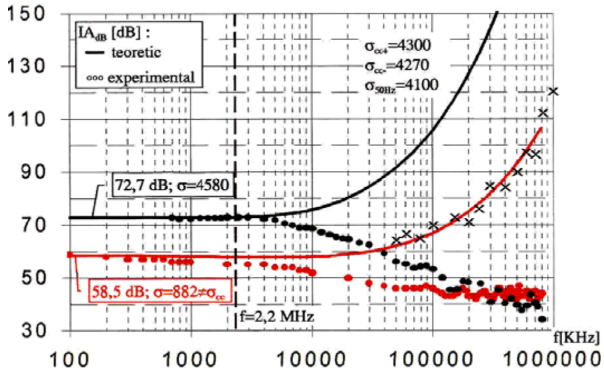

Figure 6: Shielding effectiveness obtained with the new method for Synthetic Graphite

The new measurement method having the setup in Fig. 7 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>δ).

Figure 7: Set up of the method

4. CONCLUSIONS

The results obtained with SPICE model were compared with the results obtained with a program developed by EDSA [10], the example being the effectiveness calculated for an iron shield of 1,7mm. For iron σ_R=0,17, μ_R=1000.

The EDSA program calculates a shielding effectiveness of 260dB, which is higher than the 200dB effectiveness obtained with the shield model.

Shielding effectiveness measurements on various materials inside the TEM cell show values close to the values obtained by simulations in the low-frequency range (below 1MHz). Due to the already mentioned differences, the proposed model can be used, in this stage, only for shielding efficiency evaluation. In order to obtain results that can be used in practice, the model needs to be improved.

With respect to MIL-STD-285 and EN 50147 standards, the first 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 ($d>\delta$). 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.

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