Magnetic Shielding Effectiveness of Multilayer Wire Mesh Screen

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Abstract—***Recently the use of wire mesh screens for shielding structure especially for medical diagnostic applications as MRI, is a very active field of research and industrial development, due to their light-weight structures and capability which allow both light and air transmission. To improve a magnetic field shielding a simple physical model of multilayer shields containing both conductive brass wire mesh screen and magnetic steel SAE sheet, was made and described wiht a simple theoretical model. The effect of air-gap in the adjacent sheet of the multilayer screen, were analyzed with our model and compared with experimental shielding effectiveness measurements. Experimental data shown a quite agreement with the analytical model highlight as useful in shielding against magnetic field for is a wide range of frequencies, the combined effectiveness of magnetic screen, wire-mesh screen and air-gap thickness.***

Keywords: ***magnetic shielding, multilayer shieding, wire-mesh screen***

I. Introduction

The most useful way to solve the problem to shield electromagnetic field in a wide range of frequency is based on the analysis and realizations of multilayer medium. Generally the magnetic layer contributes to magnetic reflection at low frequency while the conductivity layer, provides reflection as the frequency rises, and each layer absorb energy depending on the skin-depth parameter.

Moreover in the last years, advanced composite materials have been used in many industrial and military applications as a good replacement of metals. Nevertheless the use of wire-mesh screens for magnetic shielding, is recently increasing due to their reduced weight per unit area compared to metallic sheets and for light and air transmission property, more useful especially for medical diagnostic applications as Magnetic Resonant Imaging (MRI).

Multilayer or laminated shields are obtained by a stratification of two or more sheets of different solid materials. In this paper nevertheless, we have considered a three layer sheet composed by a double grid of parallel conducting wires of brass and a single sheet of steel SAE each placed on x-y plane and separated by an air gap. For this 3-layer screen, we have proposed a simple full-wave analysis carry out initially considering the transmission coefficient of a normally incident electromagnetic plane wave through a screen made of periodic metal grids based on the work of Casey [1].

Using this work we have previously valuated the impedance of a single thin wire-mesh screen and then the entire screen studied considering it as a classical multilayer structure with a Schelkunoff line theory approach.

From the developed analytical model we have analyzed the air-gap dependence of the multilayer shielding effectiveness comparing these dependence with the experimental results. The quite agreement of the data allows to design an efficiency multilayer sheet in which is possible to obtain a positive contribute of multiple reflections choosing an appropriate thickness of air gap for a fixed frequency or vice versa, improve in this way the performance of the screen.

II. Analytical Model of Multilayer Shield

The first step to develop the analytical model of multilayer screen, is to modify, for our purposes, a planar wire-mesh screen with bounded junction as mentioned in Casey's work [1], using the same dimensions of our thin brass grid.

The brass screen geometry is shown in Fig. 1.

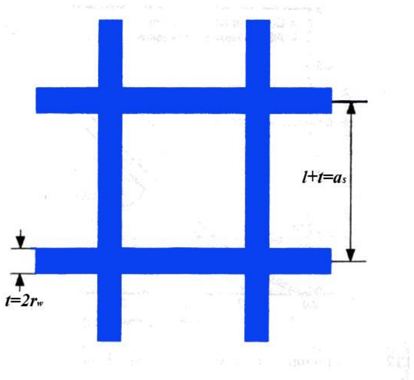

Figure 1. Geometry of an individual square wire-mesh. The wire junctions are assumed to be bonded.

These wires have circular section of radius r_w =0.4 mm and characterized by its conductivity σ_r =0.26 and its permeability parameter μ_r =1. We suppose that the distance a_s = 3 mm which divide two wires is very large compared to the radius r_w.

This laminated shield can be described electromagnetically by an equivalent sheet impedance operator Z_s, when the mesh dimensions are small compared to wavelength [2]. The operator Z_s relates the tangential electric field E_s to the surface current density on the screen as:

$$E_s = Z_s \times J_s. \tag{1}$$

The equivalent sheet impedance for a screen with square meshes of dimension $a_s \times a_s$ is:

$$Z_s = (Z_w * a_s + j\omega L_s)(I - n \cdot n) + \frac{j\omega L_s}{2K_0\varepsilon_r}\nabla_s \times \nabla_s, \tag{2}$$

where Z_w is the internal impedance per unit length of the mesh wire, K_0 is the free-space wave number, and ∇_s denotes the surface del operator.

I is the idem factor or identity dyadic, n is a unit vector normal to the surface occupied by the mesh, and L_s, the sheet inductance parameter is:

$$L_s = \frac{\mu_0 a_s}{2\pi}\ln\left(1 - e^{-2\pi r_w / a_s}\right)^{-1}, \tag{3}$$

where r_w is the radius of the mesh wires.

A multilayer structure can be studied as a wire-mesh sheet embedded in a dielectric matrix, however this approach neglects the interaction among different sheet.

In fact between adjacent sheets the air-gap can considerably affect the shielding effectiveness of the multilayer screen, due to the multiple-reflection mechanism which is exalted.

To develop a simple analytical model of shielding effectiveness for any number of multiple sheets, composed by different material each with own impedance (depending on the sheet geometry), we can be extended Schelkunoff line theory approach.

It is well known that the three contributions of the shielding effectiveness are the first reflection, absorption and multiple reflections [3]:

$$SE[dB] = A[dB] + R[dB] + B[dB]. \tag{4}$$

For the multilayer screen after simple passage we can obtain the three contribute of shielding effectiveness for any number of sheets (whether metals or air gaps) as follow:

$$A = 8.686 \times \sum_i \alpha_i t_i \tag{5}$$

where A is the absorption loss of the wave, t_i is the thickness of the screen, and for a wire-mesh screen α_i is equal to:

$$\alpha_i = \frac{2\pi}{\lambda_c}\sqrt{1 - \left(\frac{f}{f_c}\right)^2}. \tag{6}$$

Moreover, R is the reflection loss term and B represents the multiple-reflection loss term which according to [4], are respectively equal to:

$$R = 20\log_{10}\left|\frac{1}{4^{i+1}}\left(1 + \frac{\eta_1}{Z_0}\right)\left(1 + \frac{\eta_2}{\eta_1}\right)\ldots\left(1 + \frac{Z_0}{\eta_1}\right)\right|, \tag{7}$$

$$B = 20\log_{10}\left|(1 - q_1 e^{-2m_1 t_1})(1 - q_2 e^{-2m_2 t_2})\ldots(1 - q_n e^{-2m_n t_n})\right|, \tag{8}$$

in which η_i and m_i are the characteristic impedance and the propagation constant of the *i* sheet, ξ_{i-1} is the impedance looking to the right of each section, Z_0 is the characteristic impedance of the incident wave and q_i is:

$$q_i = \frac{(\eta_i - \eta_{i-1})(\eta_i - \xi_i)}{(\eta_i + \eta_{i-1})(\eta_i + \xi_i)}. \tag{9}$$

III. Simulation and Experimental results

In this section, we show the results of the our theoretical model shown in Fig. 2, and compared with the measurements made on its physical model. More specifically, the data have been obtained and measurements in the range of frequency of 1MHz – 20 MHz.

The physical model of our 3-layer sheet, have been carefully adapted to an aperture of a shielding room and measurements performed according to IEEE Standard 299-1997 [5].

First of the distance of the magnetic field source in the experimental measurement for our measurement frequency range, is such that we have considered the shield in the near field of the magnetic source.

It must be pointed out that near fields are much more complicated in structure than are far fields (which are simple and resemble uniform plane waves).

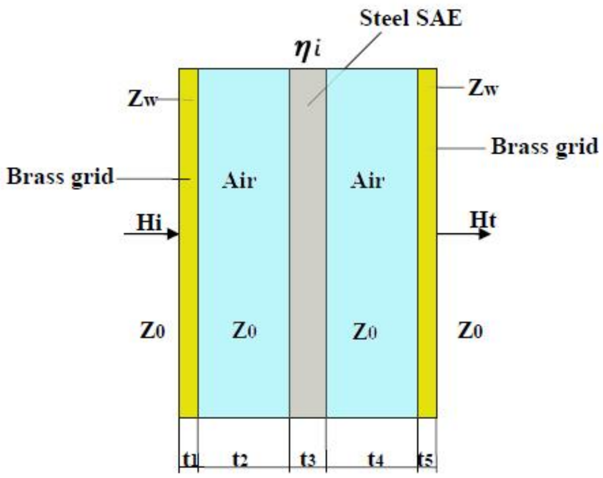

Figure 2. Layout of 3-layer screen. where Z_w is the internal impedance per unit length of the mesh wire and Z_0 is the characteristic impedance of the incident wave.

Hence, analysis of the effects of plane, conducting barriers on near fields is a very complicated process.

It is unreasonable to expect that simple and highly accurate formulas can be obtained for near-field shielding as we can obtain (exactly) for far-field shielding.

The following results are approximations to the exact results (which are very complicated). The heart of this approximate method is to replace the intrinsic impedance of free space, with the wave impedance for magnetic field source (which distance r from the screen):

$$Z_H = 2\pi f \mu_0 r \, . \tag{10}$$

Identify the kind of field source, we can realize the physical screen model with geometrical property which was the same of the theoretical model.

It was created by covering the wooden support with a brass double wire-mesh grid with an inner sheet of Steel (SAE 1045)of 1 mm of thickness.

Moreover the air-gaps thickness between adjacent wire-mesh screens and the steel SAE sheet, were the same and of 1 cm of thickness.

The wooden support (30x30x2cm) was covered by a double wire-mesh grid with a_s and r_w respectively of 3 mm and 0.4 mm (see Fig. 3) [6].

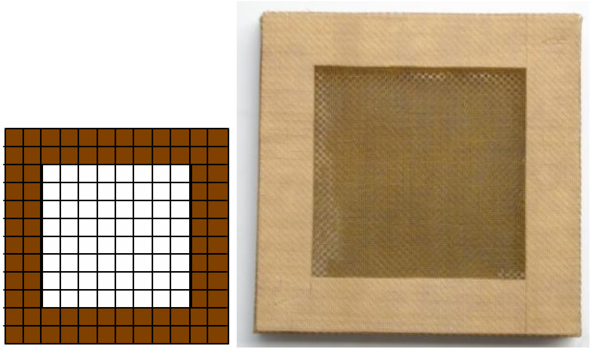

Figure 3. Physical implementation of the our model.

In Fig. 4, the frequency-dependences of the Shielding Effectiveness *SE*, reflection loss term *R*, multiple-reflection loss term *B* and the absorption loss term *A* are reported using our theoretical 3-layer screen model.

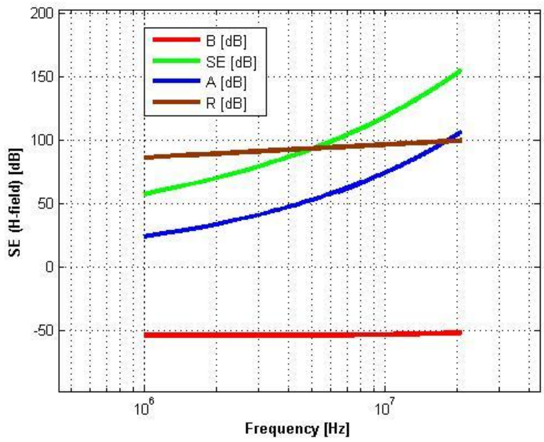

Figure 4. Shielding Effectiveness and its contributions for 3-layer sheet.

For this range of frequency (1-20 MHz), from Fig. 4 can be observe that *B*, which represents the additional effects of multiple reflections and transmissions, is a negative number and in general, reduce the shielding effectiveness (since *R* and *A* will be positive). It is also possible to note as the reflection loss is the primary contributor to the shielding effectiveness at low frequencies while at the higher frequencies the presence of inner steel SAE material, increase the absorption loss and the total shielding effectiveness. To improve the shielding property it is well known that the effectiveness raises by increasing the number of layers without increasing the amount of metal employed and without use air-gap between adjacent sheets.

Conductors sheet and highly magnetic layers can be cascaded to increase the *SE* in order to realized EM shields for wide frequency range.

But from the analysis of the air gap between adjacent wire-mesh screens and the steel SAE sheet a dielectric air-gap may considerably affect the overall performance of the shield as we can see from Fig. 5.

Increasing the air gap between the shields we can observe from Fig. 5 that the shielding effectiveness increases for frequency up 10 MHz.

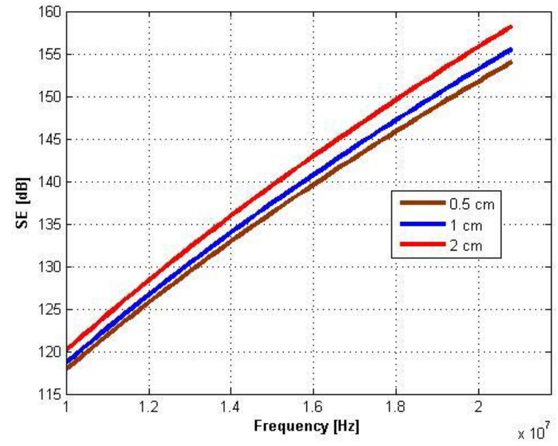

Figure 5. Shielding effectiveness trend with air gap thickness.

This increases depends on the multiple-reflection loss term *B* of the SE, which is exalted in the interior air-gaps.

In fact *B* generally is negative and for example for a double shield with air gap, the total shielding effectiveness of the shied is considerably less effective than the sum of two single shields over a considerable portion of the frequency spectrum due to the negative contribute of *B* term in the SE. The dependence of *B* for our 3-layer model is shown in Fig. 6, where as the air-gap between adjacent screens decreases B term increases lead to an increases of the *SE*.

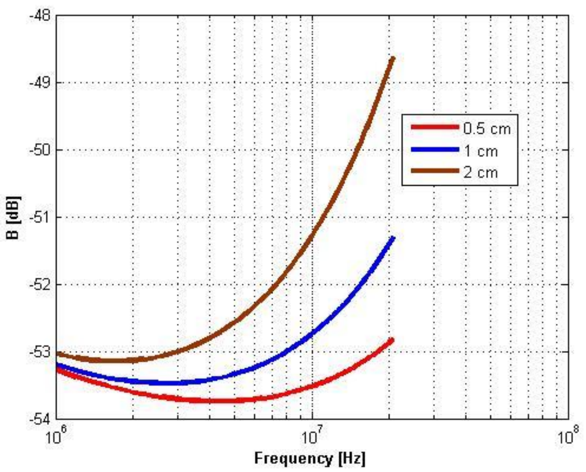

Figure 6. B term versus frequency for different thickness of air-gap.

Nevertheless, at frequencies high enough such that:

$$t=(2k-1)\frac{\lambda_0}{4} \quad k=1,2,3\ldots.. \tag{11}$$

we can obtain a shielding interspace resonances and the *B* term became a positive term lead to an improvement of the performance of the screen.

For example in the double shield whit air gap, *SE* can be much better than the sum of two separate single shields having the same total metal thickness.

First to compare the theoretical and experimental results is important to highlight that we have computed theoretical values of shielding effectiveness obtained for most values of shielding effectiveness, values of the order of hundreds of dB.

A shielding effectiveness of 100 dB means that the incident field has been reduced by a factor of 100.000.

So it is obvious that shielding effectiveness levels in excess of 120 dB are generally not achievable and also not measurable without extraordinary efforts. This allows to consider the following Fig. 7 and Fig. 8 opportunely.

Fig. 7 shows the SE values comparing the theoretical model with the experimental measurements made on our physical model.

We can deduce that this value are quite in agreement considering that above certain frequencies such quantities exceed any reasonable threshold of shielding level.

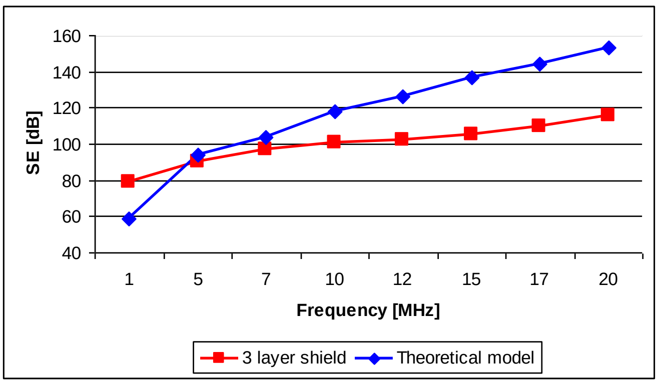

Figure 7. SE data of theoretical model and experimental data measured on our physical model.

To evaluate the good performance of our 3-layer screen to shield magnetic field, Fig. 8 shows the experimental and theoretical values, compared with a single sheet of steel SAE.

We can see the better performance of our physical model compared with the steel SAE sheet highlighting as useful in shielding against magnetic fields in wide range of frequencies combining its good properties of light-weight structures and the capability to allows both light and air transmission.

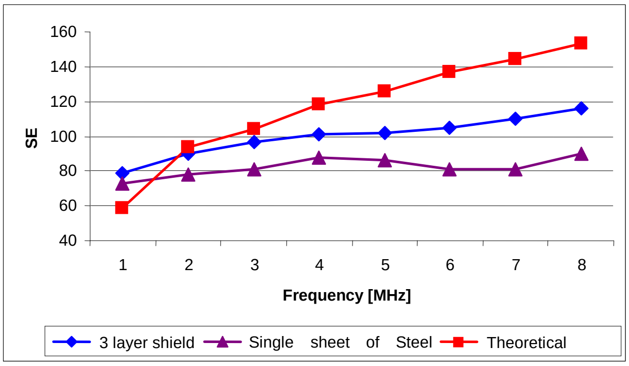

Figure 8. SE data of theoretical model compared with single steel SAE and with the experimental data measured on our physical model.

IV. Conclusion

To improve a magnetic field shielding a simple physical model of 3-layer shields containing both conductive brass wire mesh screen and steel SAE magnetic sheet, was made and described in this paper compared whit a simple theoretical model developed and shows in the paper.

The effect of air-gap in the adjacent sheets were analyzed and compared with experimental shielding effectiveness measurements.

The theoretical model was carry out considering initially the transmission coefficient of a normally incident electromagnetic plane wave through a screen made of periodic metal grids based on the work of Casey and then studying the entire multilayer screen, considering it as a classical multilayer structure with a Schelkunoff line theory approach.

The air-gap dependence of the multilayer shielding effectiveness was analyzed comparing the SE values with the experimental results allows us to design an efficiency multilayer sheet with a positive contribute of multiple reflections.

The experimental and theoretical data are quite in agreement, considering that some value of SE exceed any reasonable threshold of shielding level. These results lead us to use this 3-layer as useful in shielding against magnetic fields in wide range of frequencies.

In addition the analytical model of multilayer shield shown in this paper can be used with simple improvement, to analyze the shielding effectiveness of an arbitrary multilayer.

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