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Design of a Multilayer Electromagnetic Wave Absorber using Numerical Optimization

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Abstract – **Military as well as commercial applications of electromagnetic wave absorbers are discussed. The basic problem required to be solved in designing an absorber is presented before briefly discussing multi- layered absorbers. A method for optimization of Layered absorber performance is given. Results are tallied with published ones and the design process is illustrated by an example.**

I. INTRODUCTION

When an electromagnetic wave absorber (EMW) is applied on a target its radar cross section reduces and its detection by radar becomes difficult. Therefore, absorbers are used in camouflaging military aircrafts and missiles against radar detection. An EMW absorber, therefore, is also called as Radar Absorbing Material (RAM). Besides this important and crucial military application, EMW absorbers also have many commercial applications, which are acquiring increasing importance due to the present phenomenal growth of wireless communication and broadcasting [1].

An ideal absorbing material would be a paint like material (very thin and extremely light in weight) – also called 'stealth paint' – effective for any target geometry, over a very broad range of frequencies and all angles of incidence and polarizations. Such a material when applied on an aircraft, missile, or army tank, which have geometrically complex shapes, will make them invisible to the radar. These materials and technologies play a major role in deciding losers or winners in modern wars.

II. STATEMENT OF THE PROBLEM

When an EMW absorber is illuminated with a unit amplitude plane, one part, *R*, of the incident wave is reflected, another part *A* is absorbed, and the remaining, *T*, is transmitted through the absorber. That is,

$$R + A + T = 1 \qquad (1)$$

Normally absorbers are backed by metallic sheets making $T = 0$. For an ideal absorber, R should also be equal to zero and thus A=1. The above condition should be met for all frequencies, polarizations and angles of incidence of the incoming wave. The above condition should also be fulfilled for all geometries of the absorber, because in many applications such as camouflaging of army targets such as aircrafts and missiles, the absorbers may be placed on non-planar complex geometrical bodies. It is also desired that the above condition should be achieved for a very thin layer of absorber meaning that the absorber material should be extremely lossy.

III. MULTILAYERED ABSORBERS

The problem of a multilayered absorber (Fig. 1) can be seen as that of impedance matching between impedance at the input to the absorber and the conducting termination at the end of the absorber. The theory for the determination of parallel and perpendicular reflection coefficients from such a multilayered absorber is well developed and is given in [2].

IV. OPTIMIZATION

Until the decade of 1980s, layered absorbers were designed by hit and trial method. Lately theoretical techniques to synthesize broadband layered absorber for a given performance have been developed [3]. In designing a multilayered absorber our objective is to minimize the reflection coefficient by finding out the optimized values of RAM array parameters, namely; h, ε, μ, σ which mean; the thickness, permittivity, permeability and effective conductivity of various layers respectively for a given M layered RAM. Although we can optimize μ we generally do not do so because most commercially available RAMs are made of nonmagnetic materials (this means μ is held fixed at $\mu=\mu_0$). For the purpose of optimization we construct a Cost function defined as:

$$\chi = \sum_{i=1}^{NF} \sum_{j=1}^{NA} \{ |R^{\parallel}_{oi}(\theta_j)|^N + |R^{\perp}_{oi}(\theta_j)|^N \} \qquad (2)$$

Where NF is the number of frequencies in the optimization bandwidth and NA is the number of angles for which the optimization is to be performed. N is an index. Since the reflection coefficient is always less than one, the higher the value of N, lesser is the weight which the terms with small reflection coefficients have in the

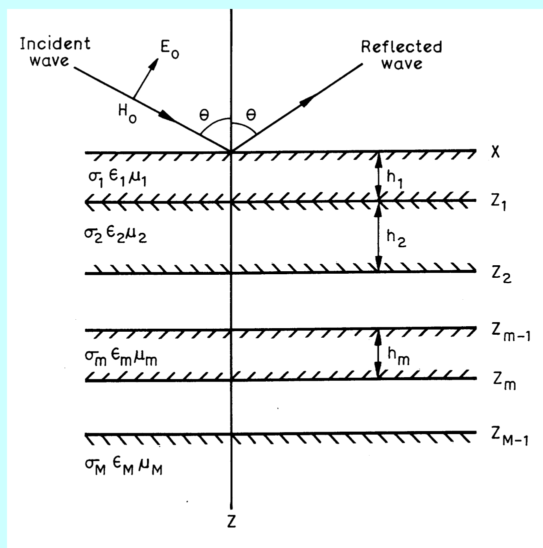

Fig. 1. ***Schematic of a multilayered absorber with an incident plane em wave at angle θ***

overall value of the cost function. This rightly focusses the attention on terms with larger values of reflection coefficient. This index usually lies between 2 and 3.

Optimization Technique:

The cost function, ξ**,** defined above is optimized with respect to a multi-dimensional vector, *V*, given below:

$$\overline{V} = (\overline{h}, \overline{m}, \overline{s}, \overline{e}) \qquad (3)$$

Where $\overline{h}$, etc., are themselves vectors. For example, h_i is the thickness of the i^{th} layer The multidimensionality of *V* together with the complexity of the cost function complicates the optimization. Considering the nature of the cost function, we have chosen the Modified Powell Method [4] for optimization. This method does not involve the computation of the numerical derivatives of x. The process of finding numerical derivative besides being computationally expensive for functions like x, can turn out to be unstable in many cases and therefore has been avoided. Modified Powell Method is a direction set method in which successive line minimizations are done along non-interfering directions.

To implement Powell's method initialize the set of directions $\boldsymbol{u}_i$ to the basis vectors of Equation (3) such that

$$\boldsymbol{u}_i = \boldsymbol{e}_i \qquad i = 1,2,3 \text{ ----- } N \qquad (4)$$

here *N* is the number of variables being optimized, e.g., consider a two layered RAM in which we have decided to optimize all the parameters except m, then the initial direction set will be an identity matrix of order 8 and in a particular column various values will be associated with (h_1, h_2, $|e_1|$, $|e_2|$, $\angle e_1$, $\angle e_2$, s_1, s_2). We proceed as in [4] and complete the optimization.

V. RESULTS AND DISCUSSION

A computer program for Design and Analysis of a layered absorber as discussed above was tested with the following results:

(1) Example 4.13, Problem 4-7-6 and 4-7-9 of Kraus[5] were checked against our program and there was no discrepancy.

(2) The results given by Perini and Cohen [3] in their figures matched with those computed by our program. Fig. 2 is shown as verification against Figs. 12 of [3].

Now we discuss the problem of designing an absorber in X band, with low reflection coefficients in the whole angular range of incidence (0 to 90 degrees) and for both kinds of polarizations (parallel and perpendicular). For this we start with a four layered RAM with the following configuration (electro2.str), which already has a good performance in the 30 to 60 degrees range at 6 GHz esp. for parallel polarization, borrowed from [3] and whose performance is depicted in Fig.2:

Layer 1:

h = 1.8403 cm s = 0.0 e_r = 1.3290 $\angle 0.0$

$\mu_r = 1.0 \angle 0.0$

Layer 2:

h = 1.2560 cm $\sigma = 0.0$ $\epsilon_r = 2.4725 \angle 0.0$

$\mu_r = 1.0 \angle 0.0$

Layer 3:

h = 0.9028 cm $\sigma = 0.0$ $\epsilon_r = 3.2935 \angle 0.0$

$\mu_r = 1.0 \angle 0.0$

Layer 4:

h = 6cm $\sigma = 0.0$ $\epsilon_r = 4.743 \angle -0.3218$

$\mu_r = 1.0 \angle 0.0$

These layers are placed on a conductor.

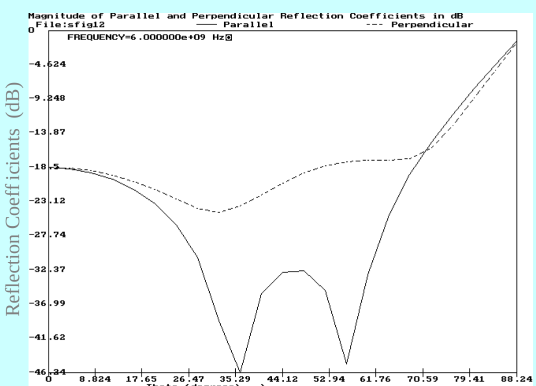

Fig. 2. ***Reflection Coefficients for the RAM configuration of Fig.12 of [3].***

This configuration is now optimized in the 8-12 GHz range (in steps of 1Ghz) and from 0 to 90 degrees in steps of 4.01 degrees. The index is chosen to be 2.3 . Since, it may not be possible to get materials with arbitrary values of μ all the parameters in all the layers except μ are optimized (16 real variables). The optimized configuration (electro2.opt) is found as:

Layer 1:

h = 1.064084 cm $\sigma = 0.0$ $\epsilon_r = 1.041534 \angle 0.0$ $\mu_r = 1.0 \angle 0.0$

Layer 2:

h = 6 cm $\sigma = 0.01399472$ $\epsilon_r = 1.0 \angle 0.0$

$\mu_r = 1.0 \angle 0.0$

Layer 3:

$h = 2.284871 \times 10^{-3}$ cm $\sigma = 0$ $\epsilon_r = 30.61913 \angle 0.0$ $\mu_r = 1.0 \angle 0.0$

Layer 4:

h = 6cm $\sigma = 0.1392010$ $\epsilon_r = 1.0 \angle 0.0$

$\mu_r = 1.0 \angle 0.0$

The cost of the starting configuration is 27.83426 whereas that of the optimized configuration is 2.521815. Due to limitations of space we will not show the performance of the optimized configuration; instead the performance of an absorber with the following configuration (electro3, obtained from the optimized configuration above) is shown in Figs. 3a-3e:

Layer 1:

h = 1.064084 cm $\sigma = 0.0$ $\epsilon_r = 1.041534 \angle 0.0$ $\mu_r = 1.0 \angle 0.0$

Layer 2:

h = 3 cm $\sigma = 0.01399472$ $\epsilon_r = 1.0 \angle 0.0$

$\mu_r = 1.0 \angle 0.0$

Layer 3:

h = 3cm $\sigma = 0.1392010$ $\epsilon_r = 1.0 \angle 0.0$

$\mu_r = 1.0 \angle 0.0$

The cost of this configuration turns out to be 6.319882 . Now suppose that waves with incident angles greater than 75 degrees do not concern us. In this case we start with a base plate of 1cm of $\varepsilon_r^* = \mu_r^* = 10\angle{-0.5}$ and $\sigma = 0.0$ Over this base plate layers 2 and 3 of the preceding absorber are placed and h, ε, σ of these two layers is optimized (8 real variables). In this case we end up with the following configuration (electro4.opt):

Layer 1:

h = 3cm σ = 0.01916077 ε_r = 1.003161$\angle$0.0 μ_r = 1.0$\angle$0.0

Layer 2:

h = 3cm σ = 0.06668725 ε_r = 1.0$\angle$0.0

μ_r = 1.0$\angle$0.0

Layer 3:

h = 1cm σ = 0.0 $\varepsilon_r = \mu_r$ = 10.0$\angle$-0.5

The performance of this configuration is shown in Figs. 4a-4e and its cost is 8.125681. Although this configuration is not as good as electro2.opt if the whole angular range from 0 to 90 is concerned, it is preferable if the angular range of concern is from 0 to 75 degrees i.e. if we can dispense with grazing incidence.

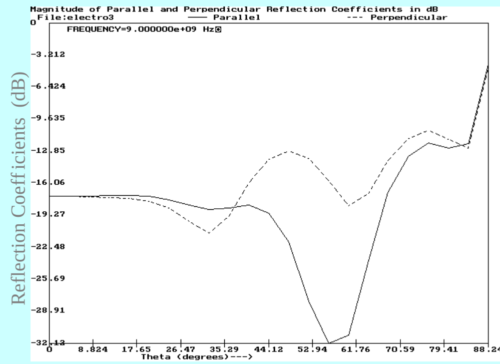

Fig. 3b. ***Reflection Coefficients for configuration electro3***

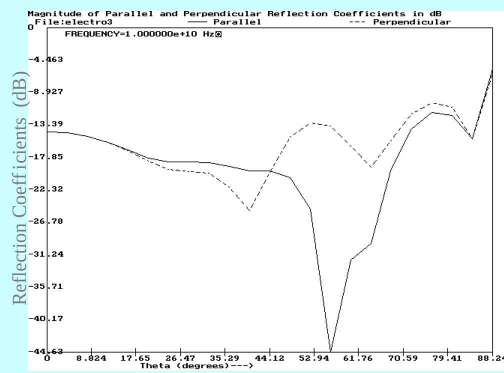

Fig. 3c. ***Reflection Coefficients for configuration electro3***

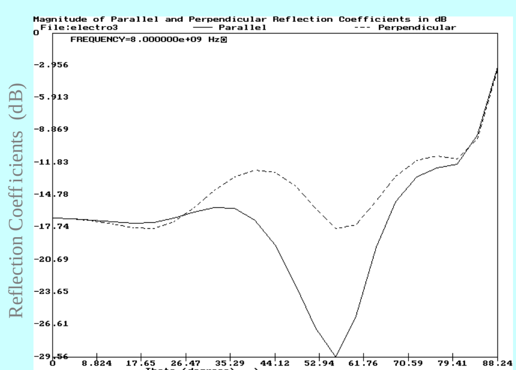

Fig. 3a. ***Reflection Coefficients for configuration electro3***

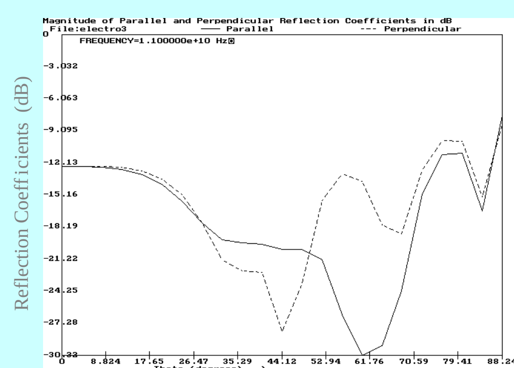

Fig. 3d. ***Reflection Coefficients for configuration electro3***

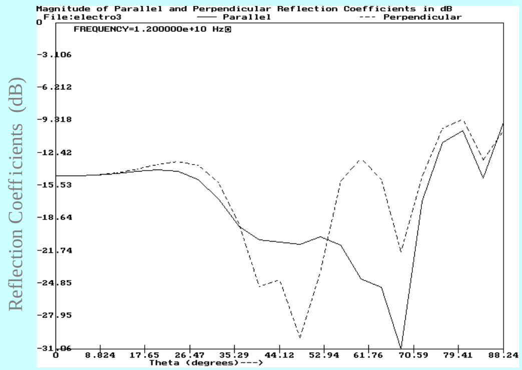

Fig. 3e. ***Reflection Coefficients for configuration electro3***

The above discussion briefly illustrates how we can design an absorber in the X band over entire angular range using this technique. Practical fabrication and experimental verification of our own results could not be done due to non-availability of experimental facilities at present.

VI. CONCLUSION

Electromagnetic wave absorber technology has been a very important electronic countermeasure technology after the invention of RADAR. Lately, there has arised a need to conduct research in this area for commercial applications such as to improve the performance of television receivers and other wireless receiving systems in congested cities. It is expected that absorbers would be used as a building material to reduce the RFI due to wireless local area network (LAN) service. Among broadband absorbers,

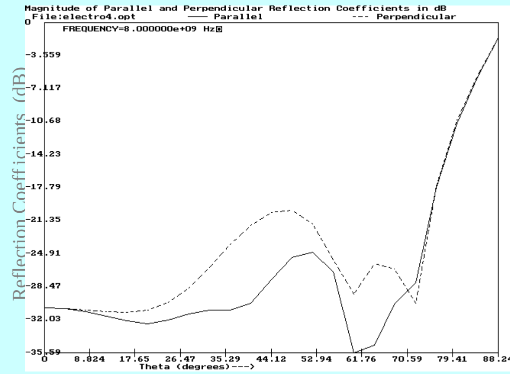

Fig. 4a. ***Reflection Coefficients for configuration electro4.opt***

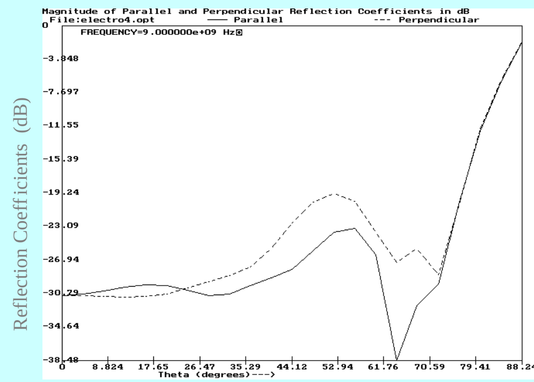

Fig. 4b. ***Reflection Coefficients for configuration electro4.opt***

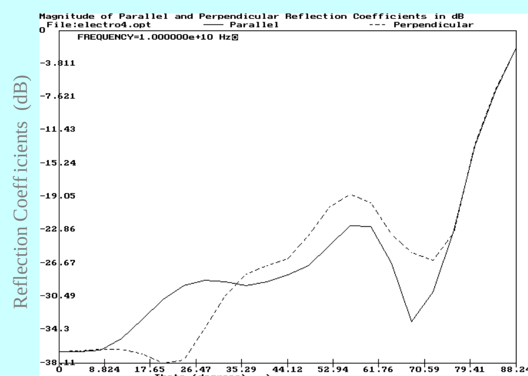

Fig. 4c. ***Reflection Coefficients for configuration electro4.opt***

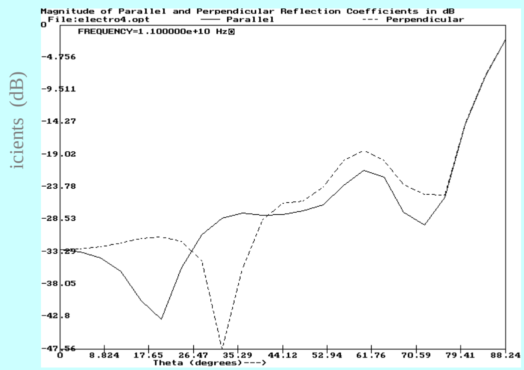

Fig. 4d. ***Reflection Coefficients for configuration electro4.opt***

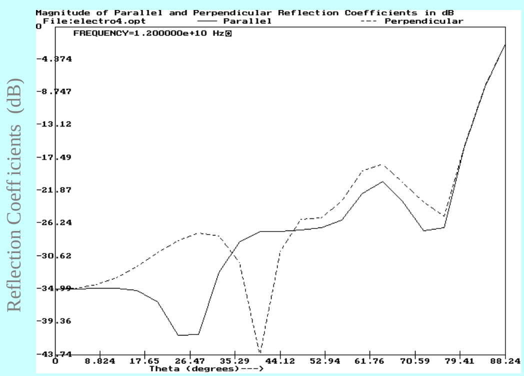

Fig. 4e. ***Reflection Coefficients for configuration electro4.opt***

geometric transition absorbers have more volume and are mostly used in RF anechoic chambers. Multilayered absorbers consisting of a stratified cascade of dielectric spacers occupy lesser space as compared to geometric transition absorbers and thus are more suitable in many applications. An optimization method to minimize the reflection coefficient of a layered absorber is discussed. The results obtained are compared with those given in the literature and the design process is briefly illustrated for a given problem. Other issues such as the structural integrity of the absorbers under aerodynamic forces have not been considered.

REFERENCES

[1] R. C. Jain, Understanding Electromagnetic Wave Absorbers, IETE Journal of Education, , Vol 41, No.1, pp. 1-8, Jan – March, 2000.

[2] J.R. Wait, Lectures on Wave Propagation Theory , Pergamon Press, pp. 7-14, 1981.

[3] J. Perini and L.S. Cohen, " Design of Broadband Radar Absorbing Materials for Large Angles of Incidence", IEEE Trans on EMC, Vol. 35, No. 2, pp. 223-230, May, 1993.

[4] W.H. Press et al., Numerical Recipes, Cambridge University Press , Chapter 10 pp. 412-417, 1986.

[5] J.D. Krauss and D. Fleisch, Electromagnetics with Applications, Mc Graw Hill International. Chapter 4, 5th edition, 1999.