

Development of Double Layer Microwave Absorber Using Genetic Algorithm

Abhishek Kumar¹, Samarjit Singh¹ and Dharmendra Singh²

¹Department of Applied Mechanics, Motilal Nehru National Institute of technology Allahabad, Allahabad-211004, India

²Department of Electronics and Communication, Indian Institute of Technology Roorkee, Roorkee-247667, India

abhishek@mnnit.ac.in

Abstract. In this paper, an efficient two-layer microwave absorber at X-band is designed, optimized and implemented using the available materials with frequency dependent complex permittivity and complex permeability values as material database. The present work is focused on the design of a two-layer microwave absorber with good microwave absorption properties combined with broadband features at X-band. The optimization of various parameters such as materials, their sequence and thickness for obtaining better microwave absorption characteristics at X-band has been realized using Genetic Algorithm (GA). The optimized results were used to design a two-layer microwave absorber and experimentally tested using Attenuation Testing Device (ATD). Further verification of the experimentally obtained absorption results were simulated in High Frequency Structure Simulator (HFSS). The ATD result show that the maximum Reflection Loss (RL) for two-layer microwave absorber was -21.98 dB with 2.77 GHz bandwidth (corresponding to -10 dB) at 11.06 GHz for a total coating thickness of 1.5 mm.

1. Introduction

In recent years, the use of microwave signals has been very significant due to the mammoth increase in the use of electronic devices especially in areas such as communication systems, radar and stealth technology used in military spheres [1]. This technological advancement has led to the advent of microwave absorbing materials. Due to the rapid growth in the use of microwave absorbers, there is a continuous need to improve their performance in order to attain better microwave absorption properties. In response to the need, an effective microwave absorber requires more and more attention towards improving the performance of the already existing materials by tailoring them. Different types of materials have been used for microwave absorption, which include magnetic and dielectric (non-magnetic) absorbers. The microwave absorption characteristic of these materials is dependent on their complex permittivity and permeability values for the concerned frequency range. One of the major concerns in developing a microwave absorber is to obtain broadband characteristics. The need to design microwave absorbers with broadband characteristics has led to the concept of multi-layering. In multi-layering, thin microwave absorbing coatings are stacked one over another to gain broadband characteristics. For designing multi-layer microwave coatings, the number of layers contained in the coating, material choice for each layer and their thickness need to be optimized from a predefined set of available materials, over a specified frequency range [2]. The material choice for each layer is quite



critical due to impedance matching. An impedance match promotes the penetration of the incident microwave radiation into the material and thereafter absorption of the microwave energy takes place which attenuates the incident microwave radiations [3]. Understanding the various phenomena that act on multi-layer absorbers is complex. The complexity in understanding the mechanisms arises from the diverse impedances involved in the formation of multi-layered structures which results in various ways the incident microwave can interact with each layer. To take into consideration these complexities, computer simulation is necessary for the resolution of complex algorithms [4].

In this work, design and analysis of two-layer microwave absorber has been carried out. The synthesized materials with complex permittivity and complex permeability values were used as the material database for evaluation of the microwave absorption characteristics in the X-band. The optimization of various parameters such as materials, their sequence and thickness of each layer has been successfully carried out using Genetic Algorithm (GA). The optimized values were simulated using High Frequency Structure Simulator (HFSS) and the experimental measurements were done using Attenuation Testing Device (ATD).

2. Theoretical background of multi-layering

The multi-layering approach is very critical in enhancing the broadband characteristics of the microwave absorber. It is also an important tool to reduce the overall coating thickness of the absorber. The multi-layering technique increases the number of boundaries and interfaces [5]. These boundaries and interfaces act as sites for multiple internal reflections thereby increasing the probability of phase cancellation and hence improving the microwave absorption characteristics. Besides this, interfacial polarization occurs due to the entrapment of charge carriers at the interfaces of the heterogeneous media in multi-layering. The charge transfer between the various phases present in the multi-layered material may give rise to the interfacial polarization and the associated relaxations which contribute to the enhanced microwave absorption performance of the heterogeneous multi-layered system. The phenomenon of multi-layering has been clearly depicted in Figure 1.

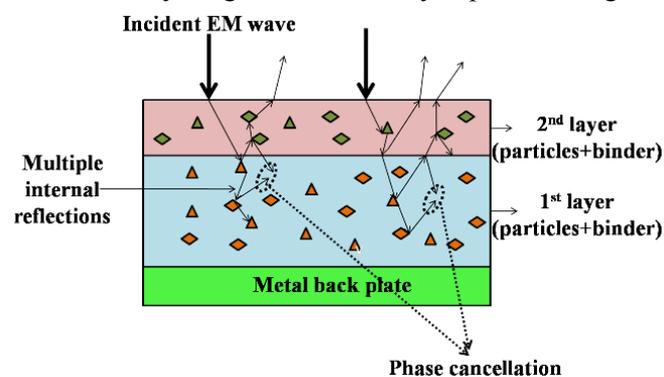


Figure 1. A cartoon depicting multi-layering phenomenon for a double layer microwave absorber.

2.1. Mathematical formulation for multi-layering approach

An infinite conducting plate coated with multilayer microwave absorber having layers of different coating thickness with different complex permittivity and complex permeability is shown in Figure 2. Let an electromagnetic (EM) wave is incident perpendicular to the multi-layer absorber and propagates in the material. Coating parameters t_i , ϵ_i , μ_i and z_i represents the thickness, complex permittivity, complex permeability and intrinsic impedance, respectively of the i^{th} layer for multi-layer absorber. The first layer is in contact with a perfectly conducting metal plate and the m^{th} layer is terminated to free space. Let ϵ_0 , μ_0 and z_0 are the permittivity, permeability and impedance of free space respectively.

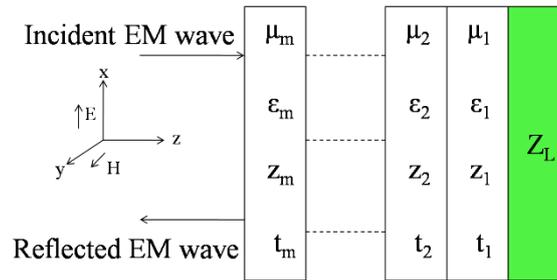


Figure 2. Schematic diagram of multi-layer microwave absorber.

The RL for multi-layering is calculated using the transmission line theory and is mathematically formulated as [6]:

$$\Gamma = \frac{Z_{in,m} - Z_0}{Z_{in,m} + Z_0} \quad (1)$$

The reflection coefficient for two-layer absorber, where layer 1 is backed with perfect conductor and layer 2 is in contact with free space, is written as:

$$\Gamma = \frac{Z_{in,2} - Z_0}{Z_{in,2} + Z_0} = \frac{\frac{\sqrt{\mu_1/\epsilon_1} \tanh(\gamma_1 t_1) + \sqrt{\mu_2/\epsilon_2} \tanh(\gamma_2 t_2)}{1 + \sqrt{\mu_1 \epsilon_2 / \mu_2 \epsilon_1} \tanh(\gamma_1 t_1) \tanh(\gamma_2 t_2)} - 1}{\frac{\sqrt{\mu_1/\epsilon_1} \tanh(\gamma_1 t_1) + \sqrt{\mu_2/\epsilon_2} \tanh(\gamma_2 t_2)}{1 + \sqrt{\mu_1 \epsilon_2 / \mu_2 \epsilon_1} \tanh(\gamma_1 t_1) \tanh(\gamma_2 t_2)} + 1} \quad (2)$$

$$Z_{in,2} = (Z_{in,1} + Z_2 \tanh(\gamma_2 t_2)) / ((Z_{in,1} / Z_2) \tanh(\gamma_2 t_2) + 1) \quad (3)$$

$$Z_2 = Z_0 \sqrt{\frac{\mu_2}{\epsilon_2}} \quad (4)$$

where, $Z_{in,2}$ input impedance for two-layer absorber at air/absorber interface and Z_2 impedance of second layer for two-layer absorber and

$$\gamma = j \frac{2\pi f}{c} \sqrt{\mu\epsilon} \quad (5)$$

The reflection loss (RL) of the incident EM wave normal to the multilayer absorber in dB is expressed as [7]:

$$\text{Reflection Loss (dB)} = -20 \log_{10} |\Gamma| \quad (6)$$

2.2. Parameter optimization using GA

The theoretical background and mathematical formulations gives us an indication that multi-layering is a very complex process which involves selection of suitable materials, their sequence and thickness of each layer for better microwave absorption characteristics. These parameters can be easily optimized with the help of Genetic Algorithm (GA). GA is a powerful optimization tool for problems having a large number of variables and has been extensively used by researchers for solving multi-layering problems. In the present work, ‘gamultiobj - multiobjective optimization using Genetic Algorithm’ has been used to optimize different variables for designing a two-layer microwave absorber, as it implements the genetic algorithm at the command line to minimize a multi-component objective function. The flowchart for GA optimization is shown in Figure 3(a) and the material database used has been shown in Table 1. The parameters used in ‘gatool’ for optimization is given in

Table 2. The following fitness function (F) has been maximized to optimize the different parameters i.e., to get maximum reflection loss (RL) values using GA

$$F = |\text{RL}_{\text{computed}} - \text{RL}_{\text{observed}}|^2 \quad (7)$$

where, $\text{RL}_{\text{observed}}$ is the required value fixed by the user and $\text{RL}_{\text{computed}}$ is calculated from the material database (Table 1) using Eqs. 2 to 6.

Table 1. Material database used for optimization of two-layer absorber [8]

S No	Material	Code	S No	Material	Code	S No	Material	Code
1	BaFe ₁₂ O ₁₉ (2 h)	P ₁	11	SiC (1 h milled)	S ₃	21	Al ₂ O ₃	M ₁₀
2	BaFe ₁₂ O ₁₉ (4 h)	P ₂	12	SiC (2 h milled)	S ₄	22	Al ₂ O ₃ + 10 wt.% Al	M ₁₁
3	BaFe ₁₂ O ₁₉ (8 h)	P ₃	13	SiC (3 h milled)	S ₅	23	Al ₂ O ₃ + 10 wt.% Ni	M ₁₂
4	BaCo _{0.2} Fe _{11.8} O ₁₉	Q ₂	14	SiC (6 h milled)	S ₆	24	SiC + 10 wt.% Al	M ₂
5	BaCo _{0.4} Fe _{11.6} O ₁₉	Q ₃	15	SiC (10 h milled)	S ₇	25	SiC + 10 wt.% Co	M ₃
6	BaCo _{0.6} Fe _{11.4} O ₁₉	Q ₄	16	SiC (20 h milled)	S ₈	26	SiC + 10 wt.% Cr	M ₄
7	BaCo _{0.8} Fe _{11.2} O ₁₉	Q ₅	17	SiC (micro wire)	R ₃	27	SiC + 10 wt.% Mn	M ₅
8	BaCo _{1.0} Fe _{11.0} O ₁₉	Q ₆	18	TiO ₂	M ₄₀	28	SiC + 10 wt.% Ni	M ₆
9	SiC (200-325 mesh)	S ₁	19	TiO ₂ + 10 wt.% Al	M ₄₁	29	SiC + 10 wt.% Ti	M ₇
10	SiC (325-400 mesh)	S ₂	20	TiO ₂ + 10 wt.% Ni	M ₄₂	30	SiC + 10 wt.% Zn	M ₈

Table 2. Parameters used for optimization of a double layer absorber in gatool.

Entity	Selected parameters
Solver	Gamultiobj
Fitness function	@objfun
Number of variables	4
Lower bound	[0.5 0.5 0 0]
Upper bound	[2 2 29 29]
Population type	Double vector
Selection function	Tournament
Mutation function	Adaptive feasible
Cross over function	Two point
Direction	Both
Hybrid function	Fgoalattain

2.3. Modeling using High Frequency Structure Simulator (HFSS)

HFSS is a commercial finite element based solver for EM structures. In order to validate and analyze the GA optimized results, Ansys 'High Frequency Structure Simulator' (HFSS) tool has been used to compare the absorption with the experimental results in X-band (8.2-12.4 GHz). After optimization of various parameters for two-layer absorber, these GA optimized were used to design two-layer model backed with Al-metal in HFSS. The flowchart shown in Figure 3(b) depicts the various steps involved in the modeling of two-layer structure in HFSS.

2.4. Measurement of microwave absorption using Attenuation Testing Device (ATD)

The experimental measurements of the reflection loss of incident EM waves on the surface of the developed two-layer microwave absorber has been carried out using an ingeniously developed Attenuation Testing Device (ATD) for X-band similar to IEEE standard 1128-1998. This ATD setup consists of a pyramidal horn antenna with its aperture fitted with an extended wave guide terminated with a metallic variable short [9].

The reflected power (P_1) is noted without coating on reference conducting plate of size (72.4 x 96.4 mm²). After that reflected power (P_2) with absorber coated reference conducting plate is calculated.

The difference in the two readings of power ($P_1 - P_2$) gives power absorbed by the absorber. Thus, the absorption in dB can be written as:

$$\text{Absorption (dB)} = P_1 - P_2$$

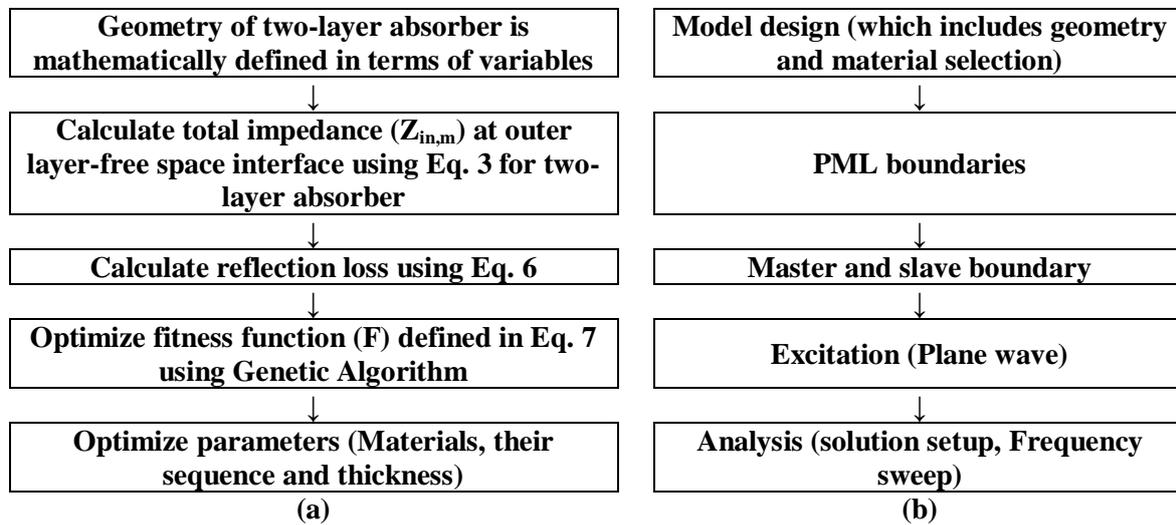


Figure 3. Flowchart depicting the steps involved in (a) optimization of parameters for a two-layer microwave absorber and (b) HFSS modelling.

3. Results and discussions

Two-layer absorber sheet has been fabricated as per the optimized results Table 3 and tested using ATD. The RL curve for two-layer microwave absorber is shown in Figure 4 and the corresponding RL data is listed in Table 4. The curve shows that the GA optimized materials M_{41} and M_6 have maximum RL of -13.67 dB and -24.93 dB with absorption bandwidth of 1.01 and 2.10 GHz, respectively. However, when these materials are stacked to become a two-layer absorber with first layer of M_{41} (thickness 0.7 mm) and second layer of material M_6 (thickness 0.8 mm), the value of RL as well as its bandwidth increases (Table 4). The simulation RL results of HFSS model are represented by RL_{HFSS} . The experimental results represented by RL_{ATD} also verify the optimized RL values. A small variation in HFSS and ATD results has been observed which is due to fabrication error in coating of materials.

Table 3. GA optimized results for two layer absorber.

S No	Two layer absorber	GA optimized result	Sample ID	Frequency Max. RL (GHz)	Thickness Max. RL (mm)	Max. RL (dB)	-10 dB absorption bandwidth (GHz)
1	I st layer material	M_{41}	M_{41}	10.13	1.3	-13.67	1.01
2	I st layer thickness	0.7 mm	M_6	11.81	1.5	-24.93	2.10
3	II nd layer material	M_6	RL_{HFSS}	10.72	0.7 + 0.8	-23.37	2.27
4	II nd layer thickness	0.8 mm	RL_{ATD}	11.06	0.7 + 0.8	-21.98	2.77

Table 4. Reflection loss results for two layer absorber.

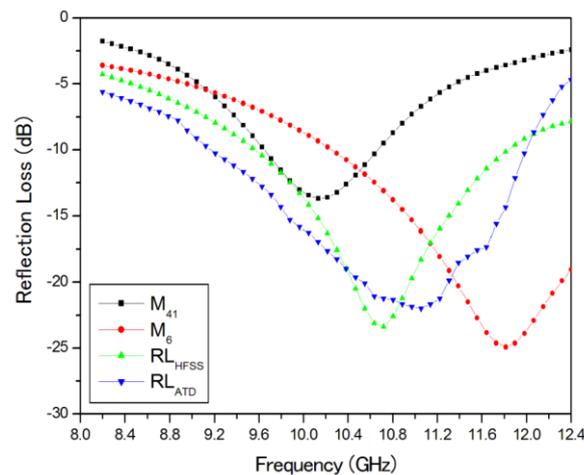


Figure 4. Reflection loss characteristic of two layer microwave absorber.

4. Conclusions

In the present work, a two-layer microwave absorber is designed using the materials from the material database and optimized using GA. The optimized GA result gives the materials, their sequence and thickness. The optimized results were used to develop a two layer microwave absorber and then experimentally tested using ATD in the X-band. Further verification of the tested results was simulated using HFSS tool. The results show that good RL characteristic with increase in broadband characteristic is observed for the two-layer microwave absorber. The attainment of coating thickness below 2 mm and RL values above -20 dB with increased bandwidth at X-band reveals excellent microwave absorption characteristic of the two-layer absorber.

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