Design and Optimisation of Radar Absorbing Material with the Help of Resistor FSS

Ravinderjit Kaur* and Dr.Munish Ratan**
*Masters in Electronics and Communication Engineering
**Professor in Guru Nanak Dev Engineering College in department of ECE

Abstract: RADAR absorption materials (RAMs) and coatings have been widely used in stealth technology since World War II. Stealth refers to the ability to evade from the detection from any kind of radar detection. Radar absorbing materials have found a significant importance in today's stealthy Therefore, numerous research works have been done to pursue a high-performance absorber to solve the electromagnetic pollution problem. Thus with advancement it has been invented that the frequency selective surface embedded in the layers of radar absorbing material has better absorption than the normal ones. But till now the proposed different geometric structures or the use of lumped elements in the material so far has one or the other limitation. So this work has been proposed to find the best trade off between the maximum absorption bandwidth and minimum material thickness with the use of particle swarm optimization and also compares the results of with and without lumped elements. The proposed comparison and results of optimization are in good agreement.

Literature Review

Lee et al. (2010) presents microwave absorbers that contain three ultra-thin FSS on a solitary layer. The unique design imbibes tremendous features to the design. The most important feature being that the design offers flexibility in obtaining numerous various absorbing bandwidths just by changing the two retaining crests, which are created by two distinctive resonance impacts on the FSS. Dual band design has been prepared by manipulating the dimension parameters, 3-dB and 10-dB band absorbers.

Sudhendr et al. (2013) presents the research that develops four-layered Radar Absorbing Material (RAM) with hexagonal shaped resistive patches on Frequency Selective Surface (FSS). The absorption range of the prototype lies in the Ultra Wide Band (UWB) range i.e. from 1.7 GHz to 25GHz. The thickness and weight of the RAM prototype unit with dimensions of (280 mm *280 mm) measures 16.8 mm and 190 gm respectively. FSS layers are made up of FR4 substrate material with 0.2 mm etching thickness plane.

Mahule et al. (2014) presents designing and simulation of three layered Jaumann absorber (JA) was conducted in which JA panel was analysed using transmission line model and the results in form of design curves were obtained in matlab while the designing and analysis was done using HFSS Vis software. The radar reflectivity of -10dB (minimum) is found to be in the range of 2 to 14 GHz.

Yang et al. (2014) implemented electromagnetic (EM) parameters of a kid of RAM with occasional structure of thin aluminum circulars were making up by HFSS software. The RAM was developed from two layers: upper layer, an intermittent cluster of aluminum circular and lower layer, C/Al2O3 ceramic covering thermal sprayed on metallic substrates, were composed and arranged by the simulated results. The deliberate reflection coefficient was 40 dB at 11 GHz and the 5 dB transmission capacity was around 9 GHz. The RAM's width is 2.0 mm.

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Bie et al. (2015) presents the paper that focuses on two major factors for an ideal absorber being thin thickness and broadband absorption. So to realise these properties, a three layered structure is introduced in which A double looped resistive frequency selective surface is sandwiched between double layered MRA. FSS is made up of periodic array of 2 dimensional metallic elements to provide resistive patches and the combination forms the shape of spiral square shaped frequency selective surface. The proposed width of section is 1.7 mm. The reflectivity for -13 dB minimum is in the frequency scope of 7.9–18 GHz while for −10 dB is 11.4 GHz. The analysis of results shows that the novel design is quite effective in widening bandwidth and getting a thinner thickness.

Results And Discussions

The geometric model of RAM designed in HFSS software has been used for as the basic unit cell for the implementation of Particle Swarm Optimization technique. Then the PSO optimization provides the dimensions at which an optimum return loss and minimum thickness is obtained.

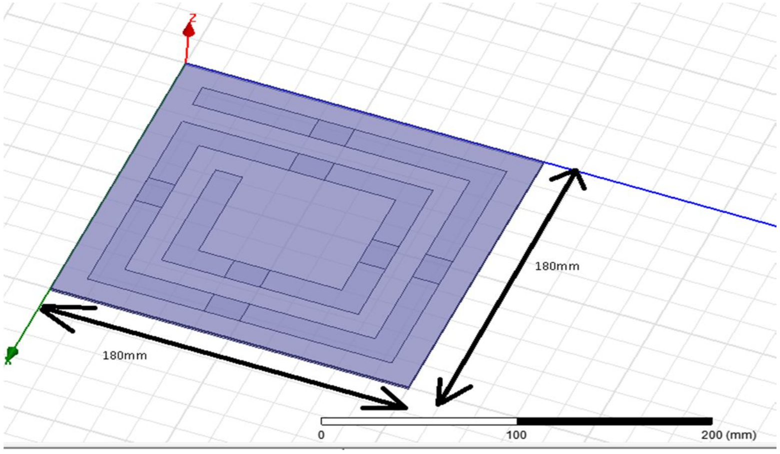

Fig.5.1 Unit cell of RAM of dimensions 180X180mm.

The patches visible in the figure 5.1 are lumped elements. The combined impedance value of these lumped elements is 377Ω.

The thickness of the unit cell is 1.8 mm. The characteristics of three layers is as given below:

Layer 1 is a magnetic radar absorbing material made up of Al_2O_3 material. The thickness of this layer is 0.8mm.

Layer 2 is embedded RAM, which is Frequency Selective Surface made up of lumped elements. Its substrate is made up of FR4. The thickness of this layer is 0.6mm. The Impedance value of the lumped elements so used in the Frequency selective surface is 377Ω. This value of impedance is equal to the impedance of the air. So this facilitates in achieving maximum reflectivity coefficient.

Layer 3 is the topmost layer of the unit cell. This material used is magnetic RAM made up of Al_2O_3 material. The thickness of this layer is 0.4mm.

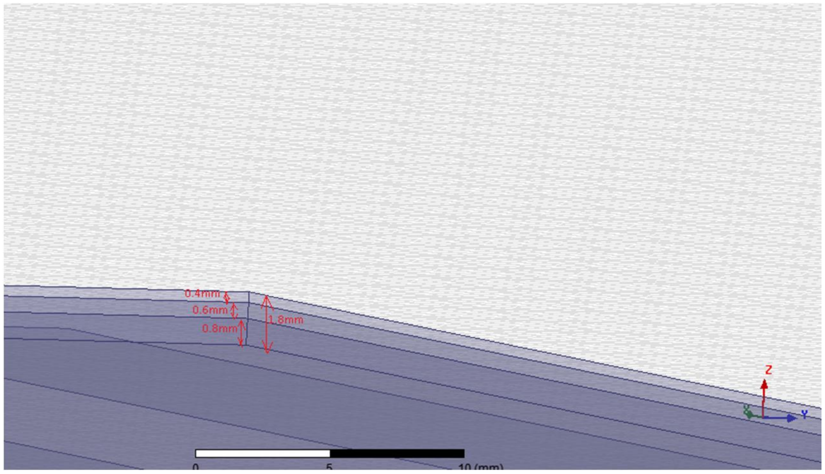

Fig 5.2 The thickness of unit cell is 1.8mm

Simulation Setup

During optimization, the behavior of variable/ particle is governed by few conditions. The objective function for PSO algorithm implementation is as given below:

$$V_i^{i+1} = w * V_i^t + c_1 * Rand1() * (pb_i^t - X_i^t) + c_2 * Rand2() * (pg^t - x_i^t),$$

Fig 5.3 Objective function of PSO (Robati et al., 2012)

where *i* indicates number of particle of the swarm, while *t* denotes iteration number. *pb* signifies local best position of variable *Xi*, while *pg* represents global best position. The functions *Rand 1(), Rand2()* are of stochastic nature functions which are responsible for making particle move in the global best direction. This iterative equation is repeatedly implemented until the stopping or the limiting conditions set at the beginning are met. In this case, the limiting conditions are set as listed below:
Particle 1: Thickness
Particle 2: Bandwidth
No. of iterations/cycles: 100
Swarm size : 100
Velocity scaling factor: 0.5
The least step size of swarm's best location prior to finding finishes: 1e-8
While some of the benchmark values set proposed by various studies for different values of these parameters is as given below:

Table 5.1 PSO Simulation Parameters

Sr. No.	Name of Parameter	Value
1.	C1	*2*
2.	C2	2
3.	Winit	0.9
4.	Wfinal	0.4

Simulation Results
So after simulation when no FSS is embedded in the structure nor the optimization is applied the two variable parameters ratings counts to thickness being at 3mm and bandwidth being in the range of 4-7.5GHz as shown in Fig. 5.4.

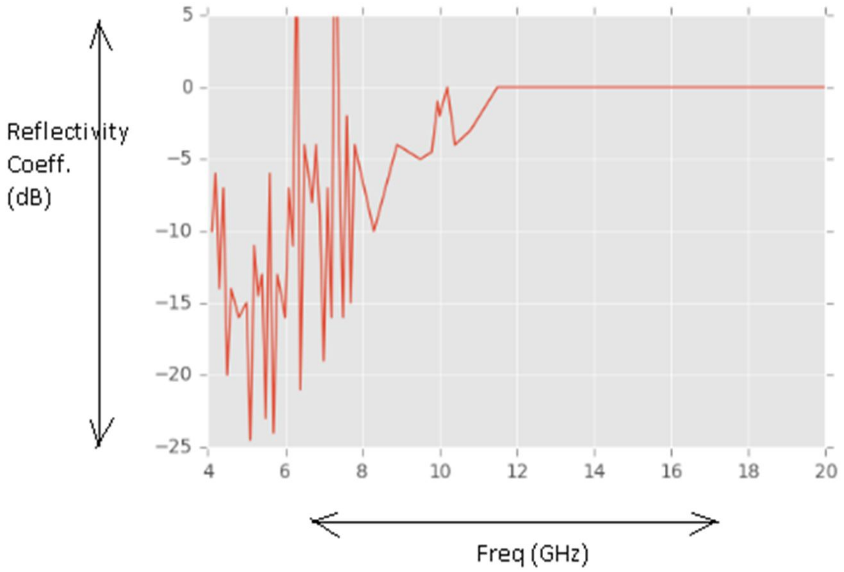

Fig.5.4 Simulation results for without embedded FSS

After embedding the frequency selective surface into the structure the bandwidth improves from the previous case and now ranges from 4 to 11 GHz as shown in Fig. 5.5.

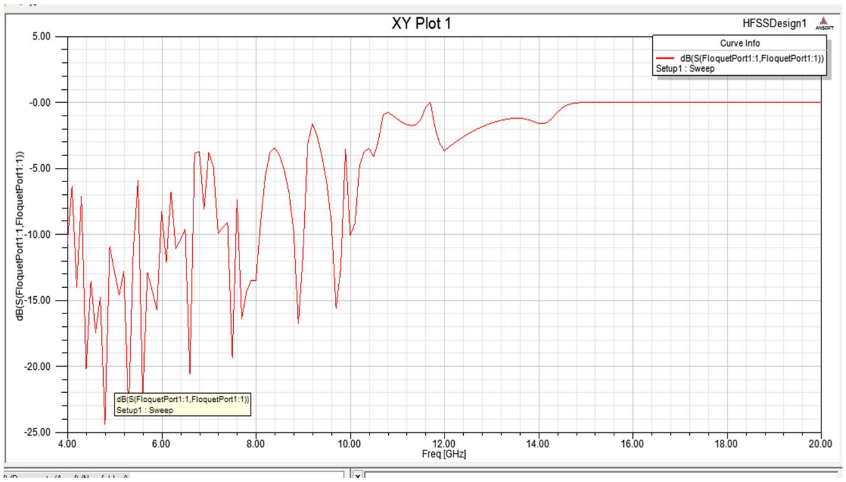

Fig.5.5 Reflectivity of the unit cell with embedded FSS and before applying PSO optimization

XY Plot:
X-Axis: Frequency (GHz)
Y-Axis: Reflectivity (dB)
Then after applying PSO algorithm to the FSS embedded structure, both the parameters show improved performance. thickness of the unit cell and the absorption bandwidth, it is observed that highly optimized results were obtained wherein the thickness of unit cell is obtained after optimization is 1.8mm, while the bandwidth ranges from 4 to 10 GHz for the minimum reflectivity coefficient of -10 dB, 5 to 7 GHz for the minimum reflectivity coefficient of -20dB and 12 to 20 GHz for the minimum reflectivity coefficient of -15dB as shown in Fig. 5.6.

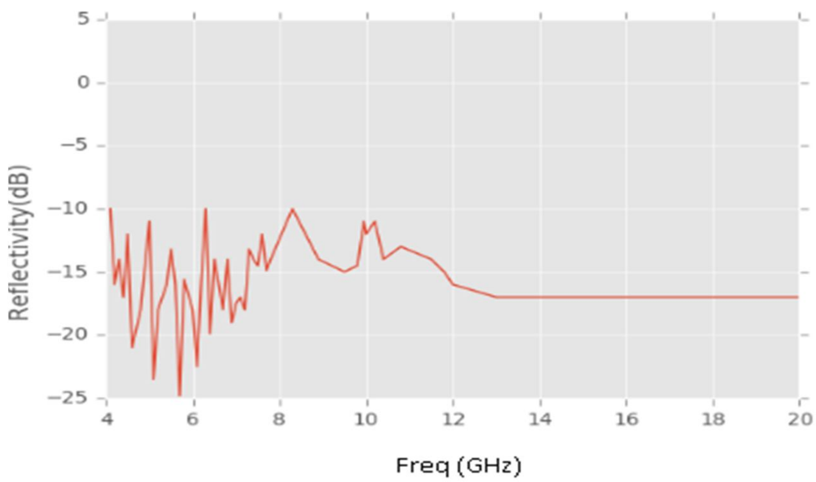

Fig 5.6 Reflectivity of unit cell after applying PSO Optimization

From the results, it is clear that the objectives of this research paper has been met to a great extent. The reflectivity bandwidth ranges from 4 to 20 GHz and the thickness is measured to be at 1.8mm.

Comparative Study

Table 5.2 Comparative Study

PARAMETER	THICKNESS	BANDWIDTH
previous work without fss	3.00mm	4-7.5GHz
previous work with fss (rao et al., 2015)	3.00mm	4-11 GHz
present work with fss after optimization	1.8mm	• 4 to 10 GHz for the minimum reflectivity coefficient of -10 dB. • 5 to 7 GHz for the minimum reflectivity coefficient of -20dB. • 2 to 20 GHz for the minimum reflectivity coefficient of -15dB.

The Table 5.2 comparison of present work with the previous work

Conclusion

The following inferences can be made from the results so obtained from the work:
In case 1, it is seen that in the unit cell without embedded FSS layer the bandwidth only ranges from 4-7.5GHz for the minimum reflectivity coefficient of -10dB.
In case 2, on embedding the Frequency selective surface between the two surfaces the bandwidth range increases from the previous case i.e. now from 4-11 GHz for the minimum reflectivity coefficient of -10dB.
In case 3, when PSO Optimization is applied on two parameters, namely thickness of the unit cell and the absorption bandwidth, it is observed that highly optimized results were obtained wherein the thickness of unit cell is obtained after optimization is 1.8mm, while the bandwidth ranges from 4 to 10 GHz for the minimum reflectivity coefficient of -10 dB, 5 to 7 GHz for the minimum reflectivity coefficient of -20dB and 12 to 20 GHz for the minimum reflectivity coefficient of -15dB.

Future Scope

The performance of Radar Absorbing material can be improved by using different shape, size and position of the lumped elements used in the proposed design.
The dimensions and weight can be optimized using different optimization techniques and results can be compared.
The absorption bandwidth can be optimized to the wider range.
The analysis range can be widened by including the analysis such as angular stability of the model at different incident angles to have a detailed insight to the feasibility of the model in practical use.

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