Design Optimization of Conformal Radar Absorbing Structures using Soft Computing Techniques

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Abstract:
Modern military aviation always aims at low observable platforms to reduce the probability of being explored. These can be achieved by various means such as RCS reductions through shaping, radar absorbing structures, through null placement using phased arrays etc. This paper describes design optimization of a conformal radar absorbing structure that reduces RCS of curved surfaces over a wide band. A semi-cylindrical RAS with periodic square patterned layer made of fiber reinforced composites and conducting polymer was designed and simulated. Further the designed radar absorbing structure has been optimized using multi objective soft computing techniques for significant RCS reduction over the entire X band. The simulated results show that the RCS is reduced by more than -22 dBsm within the X-band.

***Key Words**: Radar absorbing structure, circuit analog absorber, radar cross section, conducting polymer, soft computing*

I. INTRODUCTION

Stealth technology also called low observable (LO) technology is the technique to make friendly aircrafts and warships less visible (ideally invisible) to the enemy's divers radar and detection capabilities in order to enhance its survivability and hence the capability to complete mission in the hostile terrain. Further, the main aspect of low observable technology is the radar cross-section reduction whereby the transmitted electromagnetic signals from detecting radar is absorbed and scattered by the target structure. As the larger RCS results increased probability of detection by the enemy, the stealth aircrafts required to have low radar cross-section.

Reduction in RCS can be obtained by low observable techniques such as Stealth shaping and absorbing structures or materials. The reflections from the curved surface such as airfoil, dihedral parts of the fuselage leads to increased RCS and hence probability of being explored[1].

In this paper the curved surface radar absorbing structure is designed and simulated. The proposed semi-cylindrical shaped load bearing radar absorbing structure is made of fiber-reinforced composites and conducting polymers. A real valued particle swarm optimization algorithm is implemented to optimize the design parameters for ensuring minimum reflectivity from the structure. These conformal shaped low observable structures are feasible to use in stealth platform military applications.

II. CIRCUIT ANALOG RAS

The radar absorbing materials consist of materials causing dielectric loss and magnetic loss, which dissipate the electromagnetic energy as heat. But this lossy material has adverse effect on the aircraft constraints such as weight and mechanical properties. So study of the radar absorbing structure became popular. The radar cross-section is the measure of a target's ability to reflect radar signal in the direction of radar receiver, i.e. it is the measure of backscatter power per steradian in the direction of the radar to the power density that is intercepted by the target. The RCS can be expressed [2] as

$$\sigma = \underset{a \to \infty}{lt}\, 4\pi a^2 \frac{\left|E^s\right|^2}{\left|E^i\right|^2} \tag{1}$$

where a is the distance from radar, Es indicates the scattered electric field and Ei is the incident electric field at the target.

It is possible to apply the principle of circuit analog absorber into RAS [3]. The circuit analog absorber consists of three layers, a resistive sheet with periodic patterns made of lossy material, a dielectric substrate and a bottom metallic ground plane. The resistive sheet is responsible for the EM energy absorption and its equivalent circuit is as shown in Figure 1. The equivalent circuit consist of a series R, L, and C combination with equivalent impedance of

$$Z = R + X_C + X_L \tag{2}$$

As the equivalent impedance become equal to the free space impedance (377 ohm) the minimum reflection condition occurs, and resulting maximum absorption. The resistance parameter is related to the electrical conductivity (σ) and thickness of the layer, whereas the capacitance and inductance depends on the periodic pattern size and shape. So by controlling the impedance of the structure, better radar absorption can be achieved.

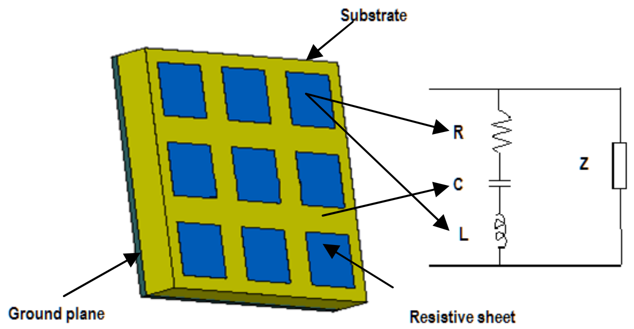

Fig. 1. Circuit analog absorber and Equivalent circuit

III. CONFORMAL RAS

In the study of conformal RAS, a semi-cylindrical structure with circuit analog layer consists of periodically repeating square shaped unit cells were designed. The performance of the radar absorbing structures simulated and compared with each other using FEM based electro-magnetic field analysis program and the RAS performance is evaluated using reflection parameter and far field RCS. The target frequency was set to 10GHz, because most of the military application radar systems operate in X band.

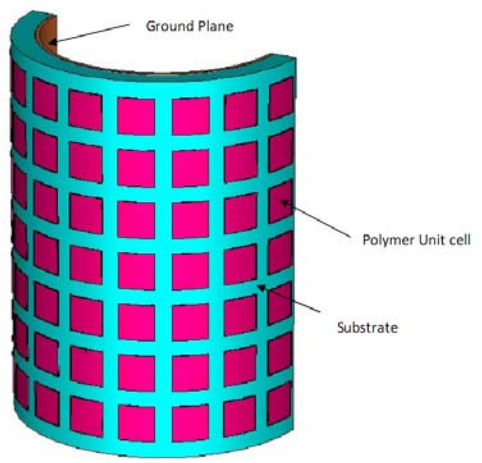

Fig. 2.Schematic diagram of conformal RAS.

Figure 2 shows the semi-cylindrical shaped RAS. The diameter and radius of the designed structure was 34 mm and 44 mm respectively. The unit cell has a size of 4mm and thickness of 0.008mm. The unit cells are made of conducting polymer with a conductance of 1300 s/m and are periodically repeating at a distance 2mm. The substrate below the conducting layer is made of glass fabric/epoxy with ε_r=4.3 and thickness of 2.7 mm. The ground plane is responsible for transmission of EM wave from structure, so its thickness must be greater than the skin depth. The skin depth is a function of frequency and corresponding to 10 GHz target frequency a 0.5 mm thick ground plane made of conducting carbon fabric/epoxy with conductivity 60000 s/m is used. The absorbance is calculated as

$$A=1-|s_{11}|^2-|s_{21}|^2 \qquad (3)$$

Due to conducting back plate s_{21} become zero and absorbance can be maximized by minimization of reflection from top surface of the proposed structure.

IV. OPTIMIZATION OF CONFORMAL RAS

The designed conformal RAS structure has been optimized for the required performance parameters. The design parameters to be optimized are the thickness of substrate layer, dimension of the unit cell, separation between unit cells and their periodicity to achieve the desired performance, which is a time consuming task. So soft computing has been used as the optimization tool along with FEM solver. Soft computing techniques become more popular due to its properties such as global optimization, quick convergence and accuracy. Real valued particle swarm optimization technique is used for optimization with fitness function as minimum reflection [4]. The visual basic for applications (VBA) scripting language is used for interfacing the optimization code in MATLAB with FEM solver. The optimized results are discussed in the following section.

V. RESULTS AND DISCUSSION

The simulated RCS of the optimized conformal RAS is shown in Figure 3 and RCS performance at various frequencies in X band are given in table 1. It can be observed that minimum RCS of -32.47dBsm is obtained at the target frequency of 10 GHz wheras for flat-plate the minimum RCS reduction is -27 dBsm. The structure without RAS has maximum reduction in RCS of -15 dBsm. Figure 4 shows the return loss curve. The designed RAS had a minimum reflection loss of -30.54 dB at 10 GHz , that is more than 99.9% of the incident EM energy is absorbed. Also more than 90% absorption is achieved in the entire X band. So this conformal RAS design can be applied to the applications where RCS reduction of curved surfaces are required

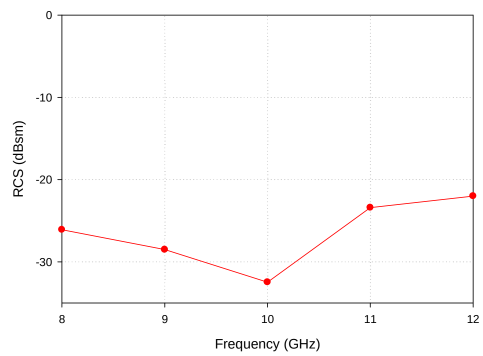

Fig. 3. RCS simulation of conformal RAS.

Table 1. RCS of conformal RAS in X band

Frequency (GHz)	RCS (dBsm)
8	-26.09
9	-28.51
10	-32.47
11	-23.4
12	-22.0

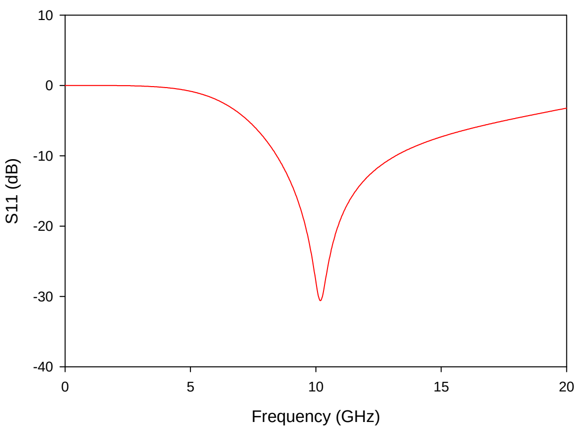

Fig. 4. Return loss characteristic of conformal RAS.

VI. Conclusion

A conformal radar absorbing structure is designed using conducting polymer layer. The designed RAS has been optimized using soft computing techniques to achieve minimum RCS. The soft computing algorithm in conjunction with FEM based electromagnetic simulation tool is used to design and simulate the RAS. It is observed that the RCS is reduced as compared to the planar structure and has better absorption in the entire X band. The results show suitability of these structures in the stealth applications.

References

[1] F. Neri, "Introduction to Electronic Defense Systems," 2nd edition, pp. 554-558, SciTeECH, Raeigh, NC,USA,2004

[2] E. F. Knott, J. F. Shaeffer and M. T. Tuley, Radar Cross-section, 2nd edn, pp. 64–68. SciTECH, Raleigh, NC, USA (2004)..

[3] K. J. Vinoy, and R. M. Jha, Radar Absorbing Materials from Theory to Design and Characterization. Kluwer Academic Publishers, Boston, ISBN 0-7923-9753-3, 1996.

[4] B. Choudhury and R M Jha, *Soft computing in Electromagnetics: Methods and Applications*, Cambridge University Press, UK, ISBN: 978-1-107-12248-2, 215p., 2015

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