A Novel Thin and Wide Band Circularly Polarized Radar Absorber for Aircraft Stealth Applications

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Abstract:

A novel design, full wave analysis, development and microwave testing of frequency selective surface based thin and wide band panel radar absorber (RA) is reported. The thickness of RA is 0.2 λ_0, and weight is 86 gm. Monostatic Radar Cross Section measurements are carried out on the RA to verify the design. 10 dB (minimum) measured RCSR is realized over a band of 6.8 GHz to 18.3 GHz.

Key Words: Embedded passives, FSS, RCS, RCSR.

I INTRODUCTION

Application of Radar absorbers (RA) stems from the crucial need of realizing radar low observability in stealthy air vehicles. External aerodynamic configuration design including RA, integrated as load bearing radar absorbing structures (RAS) is the primary step in a stealthy air vehicle design. RAS design poses unique challenges as wide band width requirements conflict with low thickness specifications of an air worthy structure. A wide band RA reported in open literature is the Jaumann RA [1-3]. An accurate electromagnetic design and implementation of multiple *spacecloths* with desired surface resistivity taper for synthesis of the desired impedance profile in Jaumann RA, is reported in [4]. However, the multiple quarter wavelength thickness of JA limits its application to radar cross section reduction (RCSR) of wing leading edges of a stealthy air vehicle. Circuit analog RAs based on frequency selective surfaces (FSS) enable design of RA for realizing wide band RCSR. Realizing resistive FSS for implementation of RA is a challenge as pure FSS do not absorb EM energy and open literature is flooded with designs reporting use of lumped resistors[5,6]. Soldering of thousands of discrete resistors has its own disadvantages such the restrictive cost of high frequency resistors, cross talk and undesired parasitic effects. These limitations which preclude the design of air worthy RAS have been addressed in earlier papers by an innovative conceptualization and integration of resistors as *'embedded passives'* (EP) resistors. Thousands of resistors are integrated into the dielectric RA without any soldering thus resulting in a significant improvement in reliability, which has been reported by the authors in their earlier papers for the design and development of thin and wide band radar absorbing structures, which was a first time development reported in open literature.

In this paper, a ***novel*** thin and wide band panel circuit analog dielectric RA is reported. The dielectric profile of RA comprises a resistive FSS layer atop a low dielectric constant, RF transparent, low density foam spacer backed by the conducting ground plane that needs to be shielded. The total thickness of panel dielectric RA is 5.2 mm and its dielectric profile is similar to Salisbury screen with much reduced thickness and is designed for wide band width. 10 dB (minimum) measured RCSR is realized from 6.8 GHz to 18.3 GHz. and the thickness of RA is 0.2λ_0, where λ_0 is the free space wavelength, at the design centre frequency of 12.5 GHz. A 10 dB RCSR is realized over a band of 8 GHz to 18 GHz, for angles of incidence varying from 0 to 30 degrees.

II ELECTROMAGNETIC DESIGN

The dielectric profile of panel RA is shown in Fig. 1 and comprises the resistive FSS top layer atop a low density Rohacell foam dielectric spacer, backed by the conducting ground plane that needs to be shielded. The unit cell of the resistive FSS layer is conceptualized using a combination of resistive patches and resistors. The novelty of the RA lies in implementation of thousands of resistors as embedded passives resistors. The resistive FSS layer is designed and developed as 0.2 mm thick PCB using standard ECAD tools and photolithographic technology. The RA is modeled using transmission line equivalent circuit model and is given in Fig. 2. The resistive FSS layer is modeled as a series RLC circuit in shunt with the dielectric spacer backed conducting ground plane, acting as a short circuited transmission with length <λ/4, which is modeled as an equivalent inductance.

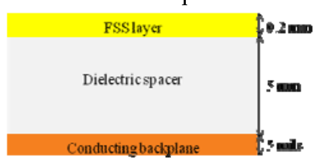

Fig.1 Dielectric profile of thin and wide band RA.

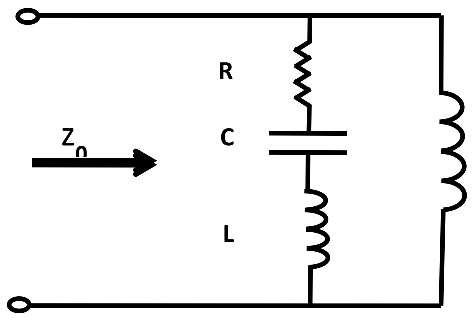

Fig.2 Transmission line equivalent circuit of RA.

A fundamental minimum thickness limitation [7] for the purely dielectric, wide band RA reported in this paper is given by :

$$\lambda_{\max}\Gamma_0 \leq 172d \quad \text{... (1)}$$

Where, Γ_0 is the reflection coefficient in dB

λ_{max} is the free space wavelength at the lowest frequency of operation of RA and d is the thickness of non-magnetic RA. This thickness limitation is for the lowest absorption frequency. Using equation 1, the minimum thickness for the lowest operating frequency of 6.8 GHz for the RA is calculated to be 2.56 mm and hence does not violate the fundamental design rule.

III EM SIMULATION

Using Floquet's theorem for analyzing the periodic surfaces such as FSS, a unit cell geometry of RA is analyzed using the EM simulation software, HFSS. The optimized unit cell geometry model of RA in HFSS is shown in Fig. 3. The unit cell with 90° rotational symmetry is used to derive circular polarization performance from RA. The unit cell dimension, pitch, resistive patches and the EP resistors are all optimized in HFSS to derive the desired RCSR performance from RA. The resistive FSS top layer is developed as a 0.2 mm thick FR4 PCB. 'Selective etching' is carried out for etching the EP resistors. The EP resistors are designed to realize 95 Ω. Complete details of PCB layout design and fabrication of EP resistors is given in [8,9]. Rohacell foam spacer of thickness 5 mm is used as the dielectric spacer and is modeled with ε_r = 1.04 and tanδ = 0.0007. A commercially available resistive sheet of 50Ω/sq. is used for etching the resistors. The surface resistivity of the resistive patches at the centre of the unit cell and also at the corners is 50 Ω/sq. A 3D schematic of the panel RA is shown in Fig. 4.

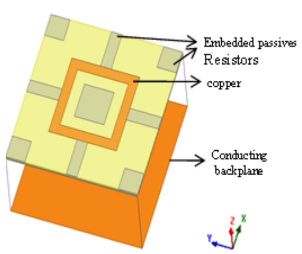

Fig.3 Unit cell geometry model of RA in HFSS.

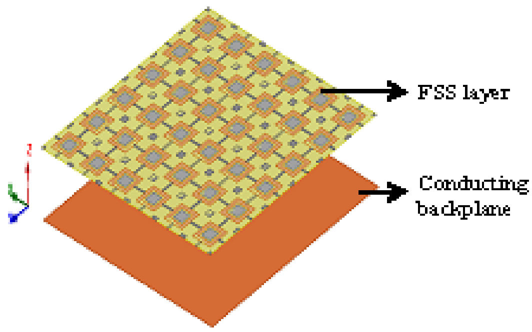

Fig.4 3D schematic of the RA.

The simulated RCSR/reflection coefficient performance of RA for both TE and TM incidence is shown in Fig. 5, for normal incidence. The plots coincide exactly and indicate good circular polarization performance of RA, at normal incidence. However, the RA is subjected to non normal angles of incidence (AOI) in the operating environment which necessitates design of RA for realizing the desired RCSR performance for various angles of incidence. The design caters to non degraded RCSR performance from 8 GHz. to 18 GHz. It is observed that the desired RCSR performance of RA is preserved from 8 GHz to 18 GHz with respect to AOI variation from 0° to 30° for both TE and TM modes and is shown in Fig.6 and Fig.7 respectively. Exhaustive parametric simulation studies such as superstrate effects, moisture absorption and variation in spacer thickness are carried out to assess the RCSR performance of RA.

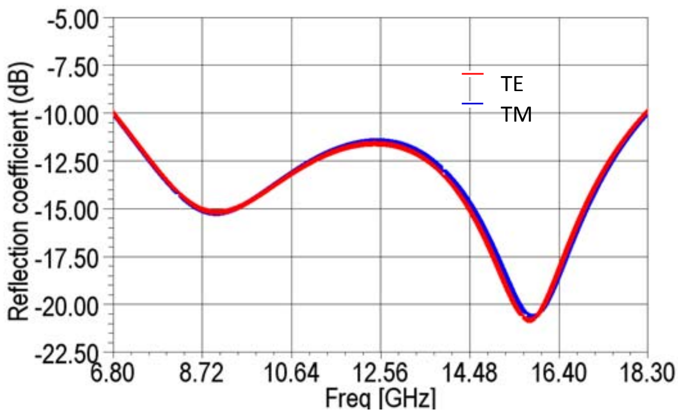

Fig.5 Simulated normal incidence RCSR performance of RA from 6.8 GHz. to 18.3 GHz., for TE and TM polarization

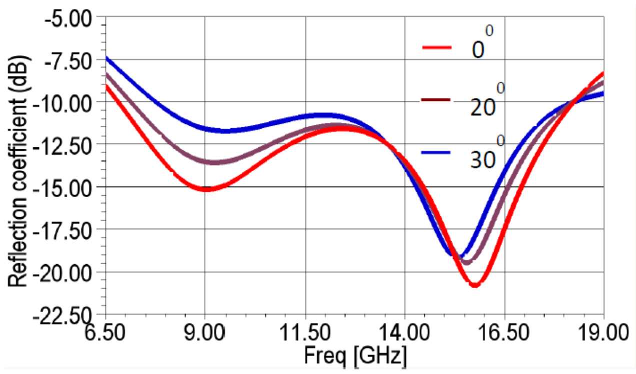

Fig.6 RCSR performance for non-normal AOI; TE incidence.

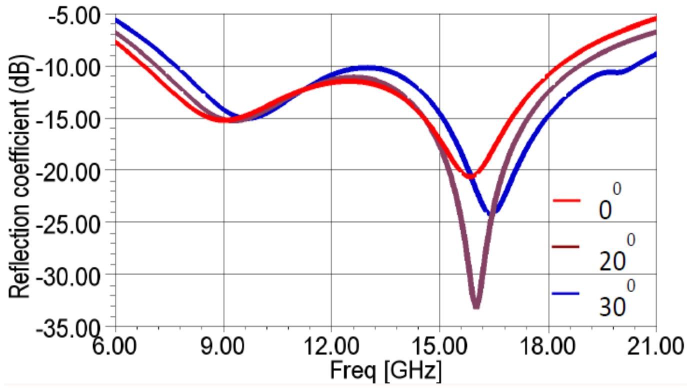

Fig.7 RCSR performance for various AOI; TM incidence.

IV PROTOTYPE RA AND RCS MEASUREMENTS

The 0.2 mm thick resistive FSS PCB layer developed using FR4 substrate is bonded to Rohacel foam spacer of thickness 5 mm. An EM conducting tin plated copper foil is used as the conducting back plane of RA. A double sided very thin tape is used for bonding the three layers of RA. The size of panel RA is (280 × 280) mm and the weight of panel RA is 86 gm. A photograph of the fabricated resistive FSS PCB top layer is shown Fig. 8.

Monostatic RCS measurements are carried out on the panel RA in microwave anechoic chamber. The pseudo monostatic RCS measurement set up comprises two high directivity horn antennas placed very close to each other ensuring high isolation between them. Continuously variable phase shifter and attenuator in the two sampled ports of directional couplers connected to the antennas enable 'Vectorial cancellation' of the background, at each measurement frequency. The panel RA is firmly secured on a one axis, RF transparent positioner table and a laser pointing mechanism ensures accurate alignment of RA. The conducting back plane of RA serves as a self calibrating reference with which the reflections from the radar absorber side are compared.

A representative RCS plot of RA is given in Fig. 9, for a frequency of 9 GHz. for vertical polarization. It is observed from the plot that that the measured RCSR is 15 dB. A comparison plot is drawn with measured and simulated RCSR in Fig.10. A measured RCSR of 10 dB(minimum) is realized over the frequency bands of operation. It is observed that the maximum difference between simulated and measured RCSR is 1 dB and the results agree fairly well over the bands of operation.

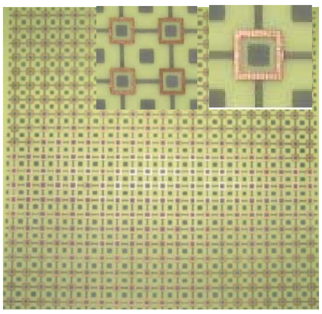

Fig.8 Photograph of the fabricated resistive FSS top layer of RA. *Inset: Zoomed cells for clarity.*

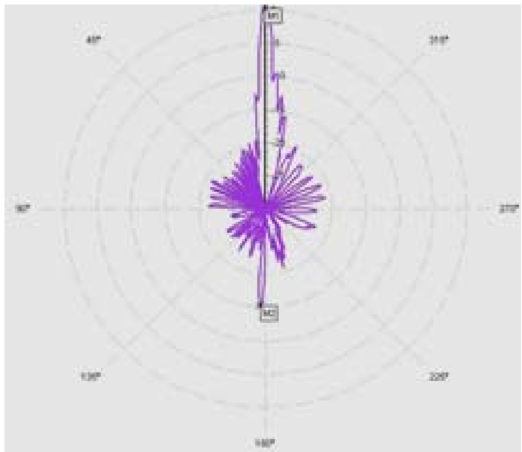

Fig.9 A representative RCS plot of RA.
Frequency: 9 GHz. Polarization: VP.15 dB RCSR measured

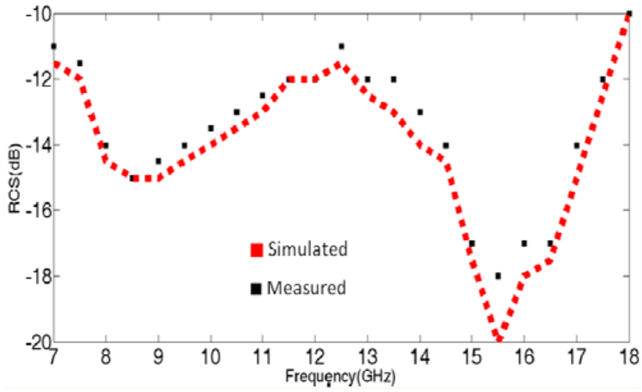

Fig.10 Comparison of simulated and measured results of RCSR vs. frequency.

V. DISCUSSION OF RESULTS

i. From Fig. 5, it is observed that a minimum RCSR of 10 dB is predicted from 6.8 GHz to 18.3 GHz., for normal incidence, for both TE and TM incidence and indicate perfect circular polarization. This has been realized experimentally and is attributed to the optimized unit cell design with square resistive patches with 90° rotational symmetry.

ii. The total thickness of panel RA is 5.2 mm (0.2 λ) and qualifies as thin RA with wide band RCSR.

iii. The crucial RCSR realization from 8 GHz to 18 GHz. has been realized for non-normal angles of incidence, with AOI varying from 0° to 30°. The design goals for realizing the wide band RCSR performance from 8 GHz to 18 GHz is realized.

iv. The weight of RA is 86 gm. The low weight is achieved by sandwich construction. This weight can be further reduced by use of lower density Rohacel foam.

v. The conducting back plane can be effectively replaced by using carbon fiber reinforced plastic (CFRP). From RCS measurements on a similar sized aluminium and CFRP panels in a compact RCS measurement chamber, it is found experimentally that the RCS returns match both in amplitude and angle. Hence, the design of RA can be seamlessly up scaled for application on a stealthy air vehicle with the constituent RA layers functioning primarily to derive the required RCSR and also as an air worthy structure. The necessary bonding between layers of the air worthy RA structure can be improved by using conventional composite fabrication technology.

VI. CONCLUSION

A thin and wide band RA with RCSR of 10 dB (minimum) from 8 GHz. to 18 GHz. is reported in this paper. The total thickness of RA is 5.2 mm (0.2λ) and qualifies as thin RA. Simulation and experimental RCS results agree very closely. The RA can be integrated as a radar absorbing structure and is suited for application in aircraft/UAV stealth.

The parametric studies carried out using HFSS to account for variation of design parameters, fabrication tolerances has shown that the design is robust and the RCSR performance does not degrade with either minor design parameter variations or with fabrication tolerances. The design goals of RA have been met and required performance has been realized.

ACKNOWLEDGMENT

The authors express their grateful thanks to Shri. MVKV Prasad, Outstanding Scientist and Director, ADE for his encouragement and according permission to present the paper in the symposium. We place on record our hearty thanks to Sri. Y. Dilip, Scientist G and Group Director, ADE, for his encouragement.

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