A Novel 6 to 14 GHz. Thin Radar Absorber Based on Circular Resistive Patch FSS

Chandrika Sudhendra, ACR Pillai
Ministry of Defence, DRDO
Bangalore, India
chansudhtumkur@gmail.com

Madhu AR
RV College of Engineering
Bangalore, India

KARK RAO
PES College of Engg.
Mandya, India

***Abstract* – Design and development of a novel, circularly polarized thin radar absorbing material (RAM) with 10 dB (minimum) Radar Cross Section Reduction (RCSR) from 6 to 14 GHz. and 15 dB from 8 to 12 GHz. using resistive circular patch frequency selective surfaces (FSS) is presented in this paper. The design is analyzed using the full-wave simulation software, HFSS v15. The size of the assembled prototype panel RAM is (280 mm x 280 mm). The total thickness of RAM is 6.2 mm. The weight of panel RAM is 92 gm. Monostatic radar cross section (RCS) measurements are carried out in microwave anechoic chamber to verify the performance. Simulation and experimental results agree closely.**

Keywords— Circuit analog radar absorber, RAM ,RAS, RCS, RCSR.

I. INTRODUCTION

Radar Absorbing Materials (RAM) design and practical implementation is crucial in enabling stealth design of air-vehicles. The airborne operational requirement demands wide absorption bandwidths with constraints in thickness. But these are conflicting requirements. Salisbury screen [1] and Jaumann radar absorber [2,3] are some of the preliminary dielectric radar absorber designs which have been continually improved, for better performance. Although simple in construction, the real design lacuna in Salisbury screen is lack of accurate design of spacecloth for realizing the desired performance. In an earlier paper [4], we have addressed this issue by proposing novel chip resistor grid networks on infinitesimally thin microwave substrate for realization of spacecloth. The homogenous resistive sheets in a conventional Salisbury screen are replaced by resistive frequency selective surfaces (FSS) in circuit analog RAM designs for wide band absorption bandwidths. Using surface mount discrete passives such as chip resistors, earlier papers [5,6] describe wide bandwidths from circuit analog RAM. The obvious limitation in these wide band circuit analog RAM designs is the large number of discrete resistors which need to be soldered on to FSS layer. We have addressed this problem successfully in our recent papers [7-8], wherein novel concept of integral or embedded passives (EP) resistors is used for realization of resistive FSS. Based on EP resistors concept, large numbers of resistors are realized integral to the FSS with no soldering at all, thus eliminating soldering related defects resulting in quantum leap in reliability.

Capacitive circuit radar absorbers described in [9] replace band-stop resistive FSS by low-pass resistive FSS such as square patches. Practical implementation of RAM and crucial experimental verification details are not described in the paper.

In this paper, a novel thin and wide band panel RAM based on *resistive* circular patch FSS is presented with experimental radar reflectivity of -10 dB (minimum) from 6 to 14 GHz. The circular patch is a capacitive type of FSS and has a low-pass spatial filter characteristic. The prototype RAM thickness is 6.2 mm and an experimental Radar Cross Section Reduction (RCSR) of greater than 10 dB has been realized from 6 to 14 GHz. and 14 dB from 7.5 to 12 GHz, for normal incidence. The size of the panel RAM is (280 x 280) mm and its weight is 92 gm.

In the following sections, the EM design and simulation of RAM using HFSS simulation software is described. Next, the PCB design and fabrication of resistive FSS layer is presented. This PCB layer is assembled with the Rohacel® foam spacer, backed by a conducting plane. The assembled panel RAM is tested for its RCSR performance in microwave anechoic chamber and the simulation and measurement results are compared and discussed.

II. EM DESIGN

For a dielectric RAM, which is broadband and non-magnetic, minimum thickness constraint is given by Rozanov [10] as

$$\lambda_{\max}\Gamma_0 \leq 172d \tag{1}$$

λ_{max} is the wavelength at the lowest frequency, Γ_0 is the reflection coefficient in dB and d is the total thickness of RAM. Hence, for desired RCSR and thickness, the lowest absorption frequency is constrained to a theoretical limit.

Accordingly, the least thickness of a -10 dB wide-band dielectric RAM such as proposed in this paper cannot be less than 1/17 of the largest operating wavelength which is calculated to be 2.9 mm. The total thickness of RAM proposed in this paper is 6.2 mm and hence does not violate the fundamental design rules given in [10].

The basic FSS geometry of RAM comprises of a circular resistive patch etched on a 0.2 mm thick FR4 substrate. The dielectric profile of the proposed RAM is given in Fig. 1.

The transmission line equivalent circuit of RAM is given in Fig. 2(a). The equivalent circuit consists of a series RC circuit modelling the resistive circular patch FSS layer shunted across the short circuited transmission line. A low permittivity Rohacel foam dielectric spacer of thickness 6mm (thickness<< $\lambda/4$) is used as the spacer between the resistive FSS layer and the conducting backplane. The dielectric spacer is modelled as a transmission line of length ***d***, as shown. It is noted that dielectric profile of RAM is similar to a conventional Salisbury screen but with reduced thickness. A three dimensional schematic of RAM is shown in Fig. 2(b).

From Fig. 2(a) it is noted that the resistive circular patch FSS element based textured layer is a capacitive FSS and is a low-pass FSS. Two degrees of freedom of the FSS geometry namely the size of the circular patch and the pitch simplify the design of RAM for realizing wide band RCSR performance. The resistive FSS layer has surface impedance given by:

$$Z_{FSS} = R_S + \frac{1}{j\omega C_S} \tag{2}$$

Where, R_s is the surface resistance and C_s is the capacitance of the FSS layer. The free-space input impedance of RAM for normal incidence is given by:

$$Z_{in} = \frac{jZ_{FSS} Z\tan(\beta d)}{Z_{FSS} + jZ\tan(\beta d)} \tag{3}$$

Where, $\boldsymbol{Z}$ is the characteristic impedance of the PEC backed dielectric spacer, which behaves as an inductor (for sufficiently small thickness) and $\boldsymbol{\beta}$ is the propagation constant of the foam spacer material.

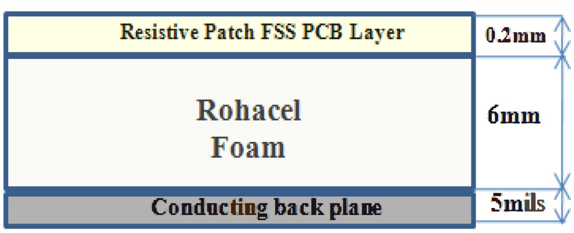

Fig. 1 Dielectric profile of the thin RAM.

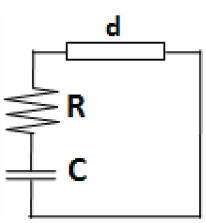

Fig. 2(a). Transmission line equivalent circuit of RAM.

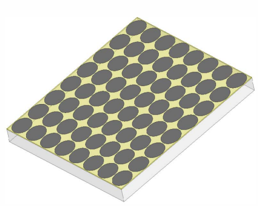

Fig. 2(b). A 3D schematic of proposed RAM.

The free-space reflection co-efficient, $\boldsymbol{\rho}$ of RAM at normal incidence is given by:

$$\rho = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{4}$$

and reflectivity $\boldsymbol{\Gamma}$, by

$$\Gamma = 20\log_{10}(\rho) \tag{5}$$

Where, $\boldsymbol{Z_0}$ is the free space impedance and is equal to **377** Ω.

III. EM SIMULATION, RESISTIVE FSS PCB DESIGN, FABRICATION AND RCS MEASUREMENTS

Using Floquet's theorem for periodic surfaces such as resistive FSS, a unit cell geometry model of resistive circular patch FSS based RAM is simulated for its performance in HFSS simulation software. The unit cell geometry model of RAM in HFSS is shown in Fig. 3. It comprises of circular patch FSS on a 250 Ohms/sq. thin film based resistive sheet on FR4 substrate of thickness 0.2 mm. Rohacel foam dielectric spacer with $\boldsymbol{\varepsilon_r}$ = 1.07 with $\boldsymbol{\tan\delta}$ = 0.0003 is used as the optimized thickness of foam is 6 mm.

The optimized simulation performance is given in Fig. 4. It is observed from Fig. 4, that a minimum RCSR of 10 dB is predicted from 6 to 14.5 GHz. and RCSR of 15 dB from 7.4 GHz. to 12.2 GHz., for both TE and TM modes. Hence, the RAM design can be used to realize circular polarization performance.

Extensive Parametric simulation studies are carried out in HFSS to assess the effect of all design parameters on RAM performance such as the thickness of dielectric spacer, size of the patch, spacing of the patch and off-normal angles of incidence. The optimized design parameters for the patch FSS are: diameter of the circular patch= 9.6 mm. and pitch or the spacing between patches = 0.4 mm and size of the unit cell = 10 mm.

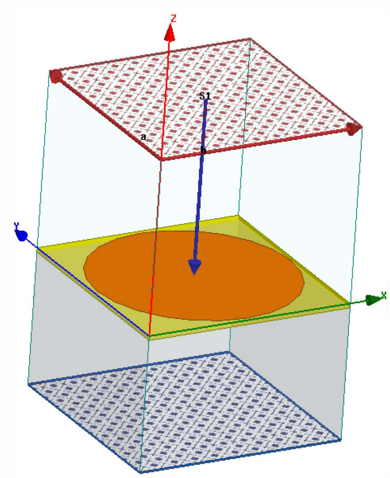

Fig. 3. Unit cell geometry model of RAM in HFSS.

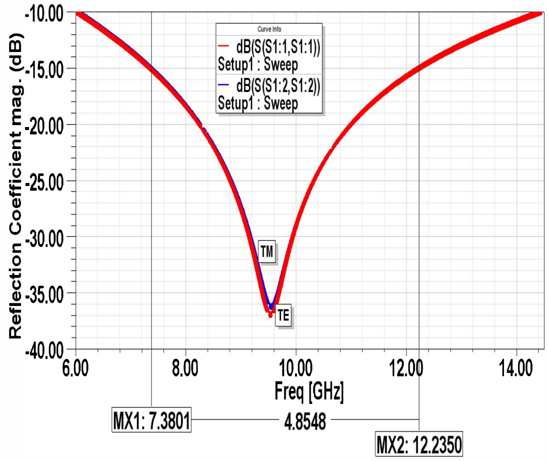

Fig.4.Optimized simulation performance of RAM for circular polarization.

A representative graph is shown in Fig. 5, which gives the simulation results of parametric studies on RAM for off-normal incidence, varying the angle of incidence from 0 to 30 degrees, for TE incidence.

The circular patch based resistive FSS layer is designed as an electrically thin (thickness = 0.2 mm) PCB using the PCB layout design software, *Visula v. 2.3.* The photo films generated are used for fabrication of the resistive FSS PCB. The FSS PCB is bonded to a *Rohacel* dielectric spacer of thickness 6 mm using a double sided *Fixon*® tape which is backed by a conducting plane. The conducting backplane of RAM comprises of tin plated copper foil of size 280 x 280 mm. A photograph of the panel RAM is shown in Fig. 6. Total thickness of RAM is 6.2 mm.

RCS experiments are carried out on panel RAM in microwave anechoic chamber to verify the design and simulation. A pseudo monostatic RCS measurement set up with a very small bistatic angle is used for characterizing RAM for its RCSR. The panel RAM is securely placed on a thermocol stand on a single axis positioner turn table and rotated continuously in azimuth. The conducting backplane serves as self calibrating reference with which the RCS readings from RAM side are compared. High directivity horn antennas are used for transmission and reception and are well isolated from each other. Continuously varying phase shifter and attenuator are used in the two sampled ports of directional couplers connected to the transmitting and

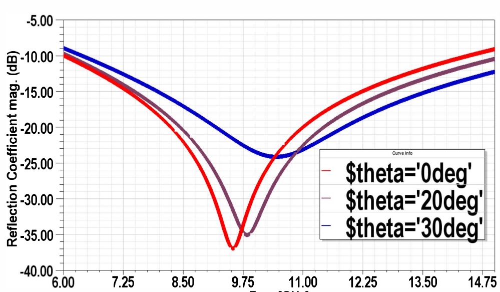

Fig.5.Off-normal incidence simulation performance of RAM.TE incidence.

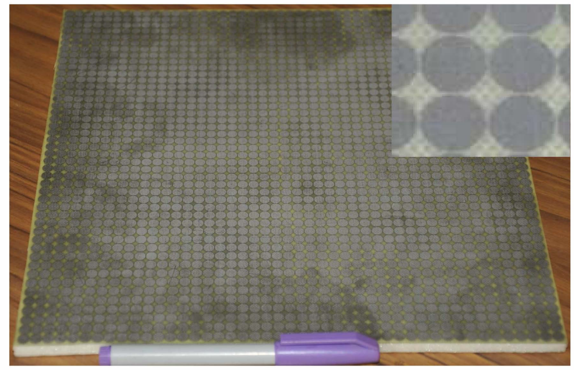

Fig. 6. Photograph of prototype panel RAM. Size: 280 x 280 mm. Thickness = 6.2 mm. *Inset:* Zoomed cells for clarity.

receiving antenna for performing vectorial cancellation of the background at each measurement frequency. RCSR readings are taken with a frequency step size of 500 MHz.

A representative RCS plot of RAM is given in Fig. 7, for 8 GHz. for vertical polarization. It is noted that the experimental RCSR is 15 dB. Measurement results are available at all other frequencies from 6 to 14 GHz.

IV. DISCUSSION OF RESULTS

i. A thin and wide band circuit analog RAM based on resistive circular patch FSS from 6 to 14 GHz., for normal incidence is described in this paper. The simulation results shown in Fig. 4 and measured results agree very well. Experimental RCSR of ≥ 15 dB has been recorded in ***X***-band and ≥ 10 dB has been recorded 6 to 14.5 GHz. At the band edge frequencies, the experimental RCS values are slightly lesser than simulated values. This is due to the limitations in experimental set up. It is observed that simulated and measured results agree well.

ii. The thickness of wide band RAM is 6.2 mm. While meeting the minimum thickness criterion given in[10], the thickness of RAM is 0.8 λ(λ=50 mm, at 6 GHz.) and can be categorized as thin RAM.

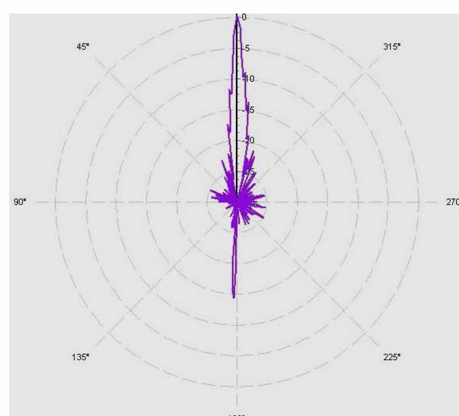

Fig. 7. RCSR plot of panel RAM. Frequency 8 GHz. Polarization: VP . RCSR = 15 dB.

iii. The weight of panel RAM is 92 gm. This reduced weight is realized with the use of light weight, Rohacel foam, which is an airworthy material with low dielectric constant. The crucial resistive FSS layer is realized as thin PCB with a thickness of 0.2 mm. Hence with the reduced weight and thickness, the RAM is suitable for airborne stealth applications.

iv. It is noted from Fig. 5, that with variation in angle of incidence, the RCSR response shifts to the right for both TE and TM incidence of the wave. This response is expected and can be easily addressed by either using a superstrate [3] or by iterating the design. But it is noted that this design can be used in ***X***-band with 15 dB RCSR even for off-normal incidence up to 30 degrees, without any degradation in performance. This may be attributed to the reduced thickness of RAM [12] which has resulted in angular stability up to 30 degrees.

v. The prototype design can be easily upgraded by replacing the conducting copper foil by a carbon fiber reinforced plastic (CFRP) ground plane, which is a structural material with good conductivity. From earlier RCS experiments on a CFRP panel and same size aluminium panel it was found that the RCS values agreed to within 0.2 dB at all aspect angles. This substantiates the use of CFRP as the structural material with good conductivity.

vi. The crucial resistive FSS layer is designed and developed as microwave PCB using conventional and accurate PCB design and fabrication technology. The experimental and simulation results agree very closely to an order of 0.8 to 1 dB and are encouraging. Rohacel foam with low dielectric constant is a potential candidate as a light weight structural material and can be used in an airborne application.

vii. The interelement spacing is kept << than $\lambda g/2$, which results in the suppression of free space grating lobes.

viii. For realizing ultra-wide band RCSR performance, a four layer RAM has been designed which is based on circular resistive patch FSS with RCSR of 10 dB from 2 to 25 GHz. Fabrication and RAM assembly and construction are complete and experimental work is under progress.

V. CONCLUSION

A thin and wide band prototype panel RAM based on resistive circular patch FSS is described in this paper. The RAM design is weight and thickness efficient and meets all the required specifications. The RAM is suited for applications in airborne stealth.

ACKNOWLEDGMENT

The authors convey their grateful thanks to Shri. PS Krishnan, Distinguished Scientist and Director, ADE for his continued guidance, encouragement, support and according permission to present this paper in the conference. We place on record our hearty thanks to Shri. S. Gurudev, Scientist G, Group Director, for his unstinted support and guidance. We also thank Dr. V. Ramachandra, Sc. G, Head, FTTT division and Mr. Diptiman Biswas, Sc. E, ADE for RCS measurements.

REFERENCES

[1] R. .L. Fante, M.T. McCormack, T.D. Syst and M.A. Wilmington. "Reflection properties of the Salisbury screen", *IEEE Trans. Antennas Propag.,* vol. 36, pp.1443-1454, 1988.

[2] L. J. Du Toit, "The design of Jaumann absorbers", *IEEE Trans. Antennas Propag. Mag.,* vol.36, no.6, pp.17-25, 1994.

[3] B. . Munk, P. Munk, and J. Prior, "On designing Jaumann and circuit analog absorbers (CA Absorbers) for oblique angle of incidence," *IEEE Trans. Antennas Propag.,* vol. 55, no. 1, 2007.

[4] Chandrika Sudhendra, V.Mahule, AK Mohanty and ACR Pillai, "A Novel Space Cloth Using Resistor Grid Network for Radar Absorbers in Stealth Applications", pp. 83-86, *Proc. ICCSP 2011.*

[5] Juan Yang and Zhong xiang Shen, "A Thin and Broadband Absorber Using Double-Square Loops", pp. 388-391, *IEEE Antennas and Wireless Propagation Letter,* vol. 6, 2007.

[6] Yang Luo, Yuan Zhuang, Shouzheng Zhu, "Thin and broadband Salisbury screen absorber using Minkowski fractal structure", *IEEE* pp.2573-2574, 978-1-4244-2802-1/2009.

[7] Chandrika Sudhendra, P.Jose, ACR Pillai and KARK Rao, "A Resistive Fractal FSS Based Broadband Radar Absorber", Chapter 3, V. Sridhar et al. (eds.), Emerging Research in Elect., Comp. Science and Technology, *Lecture Notes in Electrical Engineering* 248, DOI: 10.1007/978-81-322-1157-0_3, ©Springer India 2014.

[8] Chandrika Sudhendra, AK Mohanty, V.Mahule, ACR Pillai and KARK Rao, "Embedded Passives Resistor Grid Networks Based Novel Wideband Radar Absorber", communicated to IEEE Intnl. Conf. on Elect. Computin and Commn. Technologies – CONECCT 2014.

[9] Alireza Kazem Zadeh and Anders Karlsson, "Capacitive circuit Method for Fast and Efficient Design of Wideband Radar Absorbers", *IEEE Trans. Antennas Propag.,* vol. 57, no. 8, pp. 2307–2314, Aug. 2009.

[10] K. N. Rozanov, "Ultimate thickness to bandwidth ratio of radar absorbers," *IEEE Trans. Antennas Propag.,* vol. 48, no. 8, pp. 1230–1234, Aug. 2000.

[11] Filippo Costa, Agostino Monorchio and Giuliano Manara, "Analysis and Design of Ultra Thin Electromagnetic Absorbers Comprising Resistively Loaded High Impedance Surfaces", vol.58,no.5, pp.1551-1558, *IEEE Trans. Antennas and Propag,,* May 2010.

[12] Filippo Costa,and A. Monorchio,"Electromagnetic Absorbers based on High-Impedance Surfaces:From ultra-narrowband to utlra-wideband absorption", Advanced Electromaegntics, Vol. 1, No.3, October 2012.