Novel Embedded Passives Resistor Grid Network Based Wideband Radar Absorber

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Abstract— **A novel three-layer Jaumann absorber (JA) with a measured radar reflectivity of –10 dB (minimum) from 2 to 14 GHz. is reported in this paper. The panel JA is analyzed using transmission line model and design curves are drawn in matlab. The JA design is analyzed using HFSS v15 software. The three space cloths which form the resistive layers of JA are designed using innovative concept of embedded passives (EP) resistor grid networks on infinitesimally thin (thickness = 5 mils) dielectric substrates and are developed as PCBs using conventional photolithographic technology. The prototype JA is developed as panel of size 280 x 280 mm. The thickness of JA is 28.5 mm and the weight is 208 gm. Monostatic radar cross section (RCS) measurements are carried out on JA in microwave anechoic chamber. Experimental results match closely with predicted and simulation results.**

*Keywords— **Radar Cross Section; Spacecloth; Jaumann Absorber; Salisbury screen.***

I. INTRODUCTION

Infinitesimally thin resistive sheets also known as spacecloths with design specified surface resistivity in Ω/sq. are crucial for design and development of Salisbury screen and wide band Jaumann radar absorbers [1, 2]. A novel design of spacecloth in the form of square grid chip resistor network on electrically very thin (thickness = 5 mils) dielectric substrates is reported in our earlier paper [3] for practical implementation of spacecloths.

Jaumann Absorber (JA) comprises of multiple spacecloth layers each backed by quarter wavelength thick dielectric spacers finally backed by the conducting plane whose Radar Cross Section (RCS) needs to be reduced. Several wide band JA designs for both normal and off-normal Angle Of Incidence (AOI) [4-5] have been reported in literature. But it is noted that an accurate design of spacecloths for practical realization of JA is not available. In another form of wide band circuit analog radar absorber design, the spacecloths are replaced by lossy frequency selective surfaces (FSS) [6], wherein resistive losses in FSS layers are realized by printing the periodic pattern with resistive inks. In [7,8], lumped resistors have been used to realize wide band circuit analog radar absorbers with the inherent limitations of using lumped resistors such as parasitic effects, prohibitively high cost of microwave resistors and above all, reliability issues resulting from soldering related defects and assembly. We have addressed this issue successfully in our paper [9], wherein lumped passives such as resistors have been totally eliminated by designing embedded passives (EP) resistors based resistive fractal FSS layers for design and implementation of wide band circuit analog radar absorber.

In this paper, design and development of a 3- layer panel JA is presented, with radar reflectivity of –10 dBsm (minimum) from 2 to 14 GHz. The innovative concept of EP resistors is used for practical realization of spacecloths, for achieving the desired sheet resistance. The three spacecloths are modeled and designed as EP resistor square grid networks on infinitesimally thin (thickness = 5 mils) microwave substrates. From our earlier paper [3], the sheet resistance is shown to be equal to the value of the resistor at the center of each side of an electrically small, square grid. The three different space cloths are designed as EP resistor grid networks and fabricated using conventional photolithographic technology.

II. EM MODELING OF PANEL JA

The schematic of a 3-layer Jaumann absorber is shown in Fig. 1. The JA is modeled using space cloths as pure resistive shunt elements terminated in a short circuit. The spacecloths are infinitesimally thin (thickness = 5 mils) and hence are assumed to be purely resistive layers. The transmission line equivalent circuit is shown in Fig. 2. The three space cloths are modeled with taper of surface resistivities to aid in matching the impedance of the impinging EM wave to the conducting backplane. The spacecloths are labeled as R1, R2 and R3, where, R1 is the surface resistivity of the spacecloth immediate to the ground plane, R2 is the middle spacecloth and R3 is the surface resistivity in Ω/square of the spacecloth at the front face of JA. In general, R3>R2>R1.

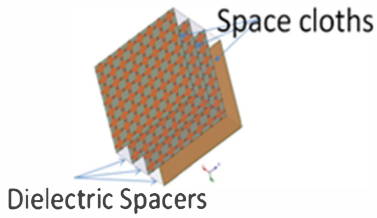

Fig. 1. Schematic of 3 layer JA.

The design problem of JA is to find the unknown spacecloth sheet resistivities that will minimize the reflection for desired bandwidth or vice versa. Three design variables are available to the designer namely:

i. **Spacecloths:** The number and type of taper given to spacecloths can be varied and this results in maximum control of the realizable RCS Reduction (RCSR). With accurate modeling, the number of spacecloths can be reduced which results in reduced thickness of JA. The various resistivities of spacecloths can be designed based on the following design criteria:

a. Exponential taper: $R_{k+1} = R_k \times k$, k=1, 2…N.

b. Quadratic taper: $R_{k+1} = R_k \times k^2$, with k =1, 2….N, where R1 is the surface resistivity of the first spacecloth layer and N is the total number of layers of JA.

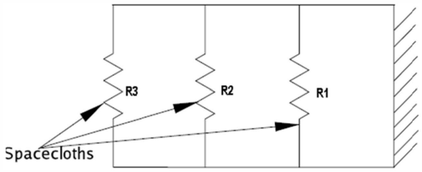

Fig. 2. Transmission line equivalent circuit of JA with spacecloths as resistive shunt elements.

ii. **Dielectric spacer:** Conventional JA designs are carried out using a low dielectric constant spacer, which results in maximum RCSR bandwidth**.**

iii. **Backplane:** the conducting backplane whose RCS needs to be reduced. This is taken as PEC for modeling and simulation. In a practical situation, the backplane has been effectively replaced by carbon reinforced plastic (CFRP) with absolutely no loss in performance, with structural rigidity.

iv. **Superstrate:** In a practical application, a low-loss superstrate needs to be applied. This superstrate has to satisfy the EM requirements of very low loss and thickness.

The reflection coefficient S_{11} of JA at normal incidence is given by [10]:

$$|S_{11}| = \sqrt{\frac{\left(1-\sqrt{\varepsilon_r}x_N\right)^2+\varepsilon_r Y_N^2}{\left(1+\sqrt{\varepsilon_r}x_N\right)^2+\varepsilon_r Y_N^2}} \qquad \text{…….. (1)}$$

where,

ε_r is the spacer relative dielectric constant.

x_i is given by :

$$\frac{x_{i-1}\left(1+\tan^2\theta\right)}{\left(1-Y_{i-1}\tan\theta\right)^2+\left(x_{i-1}\tan\theta\right)^2} \qquad \text{…….(2)}$$

$$(i = 2,3,....n))$$

$$Y_i = G_i + Y_0\,\frac{Y_{i-1}+Y_0\tanh(\theta)}{Y_0+Y_{i-1}\tanh(\theta)} \qquad \text{……. (3)}$$

and θ has the usual meaning.

III. DESIGN OF 3-LAYER PANEL JA

A 3-layer JA for RCSR of 10 dB from 2 to 14 GHz is designed based on the equations given above, and the design curve for realizing the desired performance is shown in Fig. 3. The spacer dielectric constant, ε_r = 1.03 is considered for the finalized design curve

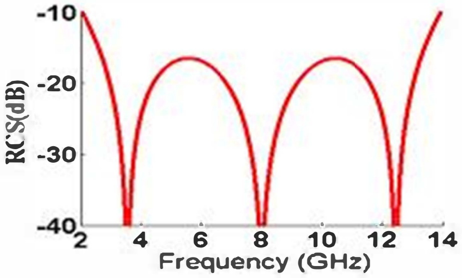

Fig. 3. Predicted RCSR performance of JA in Matlab

Parametric design studies are carried out by varying the spacer dielectric constants and the parametric design curves are shown in Fig. 4.

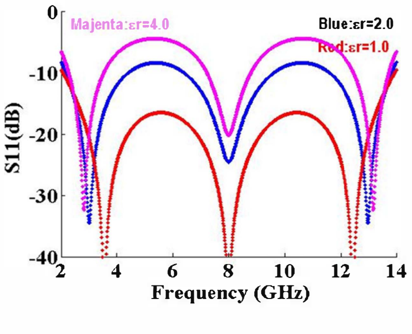

Fig. 4. Matlab design curves with varying ε_r. R_s of spacecloths fixed.

The thickness of 3 layer JA designed for center frequency of 8 GHz. is 28.4 mm. The weight of (280 x 280) mm prototype panel JA is equal to 208 gm. The three spacecloths are optimized to be 370Ω/sq, 750Ω/sq and 1.2 kΩ/sq., which are used in simulation and subsequent fabrication.

IV. HFSS SIMULATION AND FABRICATION

The predicted design of 3 layer JA is verified using ANSYS HFSS simulation software. Using Floquet's theorem for periodic FSS structures such as planar JA described in this paper, a unit cell geometry model of JA is simulated in HFSS.The optimized ***S11***/RCS simulation performance is given in Fig. 5, for both TE and TM incidence. The grid size is taken to be λ/10 at the design center frequency of 8 GHz. The three spacecloth layers are all designed as square grid networks, as the desired sheet resistance values can be realized using this geometrical resistor grid network.

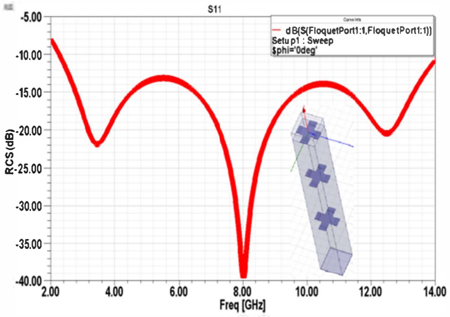

Fig. 5. Three layer EP resistors based JA simulation performance for TE and TM incidence in HFSS. *Inset: unit cell JA geometry model in HFSS.*

The space cloth with 370Ω/sq. sheet resistance is the closest to the conducting backplane. The EP resistor at the center of each side of the electrically small square grid is designed for 370 Ω. Similar design rules are followed for design of the 750 and 1200 Ω/sq. spacecloth layers. In the inset of Fig. 5, the geometry model of the JA used for simulation with the EP resistor square grid network is shown.

It is observed that a 10 dB RCSR (minimum) performance is obtained from 2 to 14 GHz, for normal incidence. Next, the AOI is varied from 0 to 30 degrees and the HFSS simulation performance is shown in Fig. 6, for TE incidence.

The most crucial step in the fabrication of EP resistors based JA is in the spacecloth PCB design and processing. 'Selective etching' has to be followed and accurate translation of the PCB design to hardware is vital for achieving the desired performance from RAM.

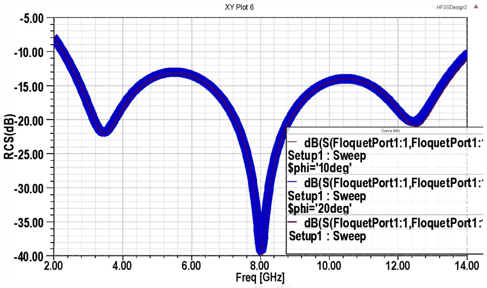

Fig. 6. HFSS simulation performance with variation in AOI from 0 to 30 degrees. *TE incidence.*

The three spacecloths are developed as PCBs on FR4 substrate of thickness 5 mils. The grid size of the EP resistor square grid network is 3.75 mm. A commercially available resistive sheet of 250 Ω/sq. is used for fabrication of EP resistors. The resistive sheet is available only with some finite values of sheet resistance. With this innovative design, it is possible to convert a single resistive sheet with fixed sheet resistance to *any* desired sheet resistance, which is crucial for design and implementation of broadband Jaumann radar absorber.

The spacecloths layers are bonded to *Rohacel* foam dielectric spacers of thickness 9.3 mm using a two sided *Fixon* tape. Thus bonded three spacecloth layers with spacers are finally bonded to a tin plated 3M copper foil of size 280 x 280 mm, which serves as the conducting backplane. The total thickness of the assembled three layers panel JA is 28.4 mm and the weight of prototype panel JA is 208 gm. A photograph of the three-layer prototype panel JA is given in Fig. 7 with a zoomed unit cell in the inset, for clarity.

V. RCS MEASUREMENTS

Monostatic RCS measurements are carried out on the prototype JA shown in Fig. 7, in microwave anechoic chamber. Representative RCS plots of the prototype three layer JA is shown in Figs. 8a and 8b. RCS measurements are carried out in S, C and X-bands and results are available.

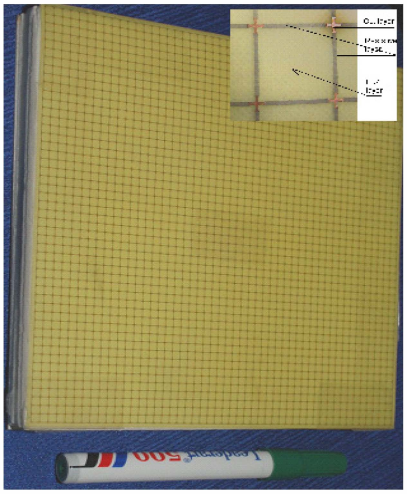

Fig. 7. Photograph of the prototype three layer JA *Inset: A single cell.*

Best RCSR performance of 25 dB is obtained at 8 GHz. In Figs. 8a and 8b, RCS returns from the conducting backplane is plotted at 0° of the polar chart which serves as a self calibrating reference with which the RCS return from the absorber side is compared. The RCS return from the absorber side is plotted at 180° of the chart. From Fig. 8b, it is seen that measured RCSR is 18 dB at 5.6 GHz. RCS measurement results are carried out up to 14 GHz. The experimental RCSR of the JA lies between 15 to 25 dB. These results are highly satisfactory.

VI. DISCUSSION OF RESULTS

A wide band 3 layer panel JA is presented in this paper. The three spacecloths are designed and fabricated based on innovative EP resistor grid networks as electrically very thin PCBs. This has several advantages such as: thousands of discrete resistors are practically implemented on the electrically thin substrate as an integral part of the substrate *without* any soldering at all. This leads to a quantum increase in reliability due to elimination of soldering related defects and assembly. Any desired sheet resistance of space cloth can be achieved, which translates to the capability to design and practical implementation of Salisbury screen or JA for any desired broadband and polarization performance.

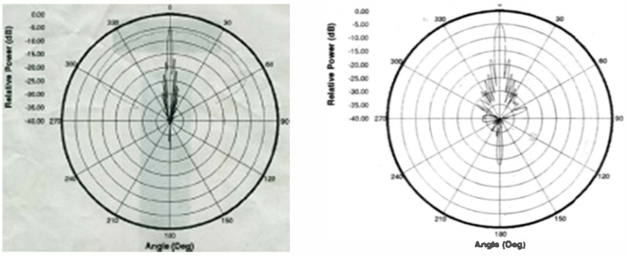

Fig. 8(a) Fig. 8(b)

Fig. 8(a) and 8(b) Experimental RCS plot s of JA

Fig 8(a) Frequency: 9 GHz. Polarization: VP

Fig 8(b) Frequency: 5.6 GHz. Polarization: VP.

The parametric design curves shown in Fig. 4 with the variation in spacer relative dielectric constant reveal that with the increase in spacer ε_r, bandwidth of JA decreases, with a corresponding reduction in thickness.

From Figs. 3 and 5, it is observed that there is a shift in frequency, in prediction and simulation. The grid size chosen for simulation and subsequent fabrication is λ/10, at 8 GHz. With further reduction in grid size, the frequency shift tends to zero. But, the grid size cannot be made arbitrarily small since limitations arise in fabrication. It is noted that the desired 10 dB (minimum) experimental RCSR is realized in the desired frequency bands. Hence, it may be concluded that the design can be used for development of wide band JA from 2 to 14 GHz. with assured satisfactory RCSR results. The experimental results can be further improved by following a wet lay-up process for assembly of panel JA. Also, with the two dimensional symmetry of the structure, it is observed from Fig. 5 that the design can be used for circular polarization and also up to AOI varying from 0 to 30°.

VII. CONCLUSION

An innovative approach of design of EP resistors based spacecloths is used effectively to design a wide band prototype panel Jaumann radar absorber with RCSR of 10 dB(minimum) from 2 to 14 GHz. An average RCSR of approximately 15 dB has been realized over the frequency bands. The design can be used to meet circular polarization requirements and also for AOI varying from 0 to 30 degrees. The JA design with reduced weight is suitable for applications in aircraft stealth technology especially for RCS reduction of wing leading edges. Further, the JA can be realized as a flight worthy structure by using Carbon Fiber Reinforced Plastic (CFRP) as the conducting backplane with enhanced structural rigidity without compromising RCSR.

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