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# Novel Ultra Wide Band Polarisation Independent Capacitive Jaumann Radar Absorber

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**ABSTRACT**

An ultra wide band (UWB), reduced thickness four layers capacitive jaumann absorber (CJA) with measured reflectivity of -15 dB (minimum) from 2 GHz to 19 GHz is presented in this paper. The novel CJA is designed and implemented by modifying the jaumann absorber (JA) design. The crucial impedance matching layers of CJA are designed by conceptualizing hexagonal resistive grid on dielectric substrates. Reduced thickness of 24.8 mm is realised by capacitive loading of hexagonal resistive grids with hexagonal resistive patches. Absorption performance of CJA is verified by full wave analysis using high frequency structural simulator software. Polarisation independent absorption performance is realised. Absorption of 96.5 per cent (minimum) is achieved with variation in angles of incidence from 0° to 30°. Resistive capacitive layers of CJA are developed as electrically thin printed circuit boards and integrated with alternating low loss, low density foam dielectric spacers backed by metallic conducting plane. Size of panel CJA is 280 mm × 280 mm. Fabricated panel CJA is evaluated for radar cross section (RCS) performance in microwave anechoic chamber. Matching results are obtained in simulation and measurements. The reduced thickness, low weight, UWB CJA finds application in RCS reduction of air vehicles/unmanned air vehicle.

**Keywords:** Capacitive Jaumann absorber; Jaumann absorber; Radar cross section; Salisbury screen

## 1. INTRODUCTION

Radar absorbers (RA) are crucial for realising radar low observability in stealth air vehicles/unmanned air vehicles (UAV)s. RAs need to be designed for UWB absorption bandwidths with weight and thickness constraints, which are conflicting requirements. The RAs need to be developed with low weight and thickness and also as robust, flight worthy structures which can withstand both kinematic and aerodynamic loads.

Salisbury screen[1-3] is the oldest dielectric RA and simple in construction. Its dielectric profile comprises a thin resistive layer known as spacecloth, ideally with surface resistivity of 377 Ω/sq, spaced from the reflecting ground plane by a quarter wavelength ( $\lambda/4$, $\lambda$= wavelength) thick dielectric spacer. The large thickness and narrow 20 dB bandwidth of 25 per cent limit its applications. However, Salisbury screen serves as a baseline design which has been rigorously pursued for realising better performance[4-6]. Jaumann absorbers (JA), the multilayer Salisbury screens are reported for realising UWB absorption bandwidths. Multiple spacecloth layers alternating with $\lambda/4$ thick dielectric spacers backed by the conducting plane complete the dielectric profile of JA. Realising the desired surface resistivity taper of spacecloths in JA translates to realising UWB absorption. Design of JA is reported[1-9]. The crucial challenge in implementation of JA lies in realisation of spacecloths with accurate surface resistivity. Earlier studies on JA do not report design of spacecloths for implementation of either Salisbury screen or JA. This limitation in accurate design has been addressed and resolved in our earlier papers[10,11]. However, large thickness of JA limits its application. Circuit analog radar absorbers[12-14] based on frequency selective surfaces (FSS) are reported for realising reduced thickness RAs. Resistive loading of FSS, which is crucial for RA implementation, is realised by using lumped, discrete resistors. This leads to primary disadvantages such as prohibitive cost and soldering of very large number of lumped resistors, soldering related defects and assembly and undesired parasitic reactance. RA designs based on lumped resistor loading cannot be translated to air worthy hardware, limiting the designs to proof-of-concept studies. But resistive loading of FSS is crucial in realisation of desired absorption in RAs. The deleterious effect of lumped resistor loading of FSS in RA design is successfully addressed by the authors in their papers[10-11,15] by UWB RA implementation using planar/EP resistor technology. Thousands of resistors constituting the resistive FSS layers of RA were implemented without any soldering at all. Capacitive circuit RAs are reported in[16-18]. Compared to circuit analog RA design using band stop resistive FSS such as loops, the capacitive circuit RA design is based on resistive low pass FSS patches, which results in wider absorption bandwidth combined with reduced thickness.

In this paper, a novel four layers JA is designed for UWB absorption of 15 dB (minimum) from 2.5 GHz to 17 GHz. Thickness of panel JA of size (280 mm × 280 mm) is 30.8 mm. Each spacecloth layer of JA is designed using

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hexagonal planar resistive grid on electrically thin dielectric substrates. The hexagon grid geometry enables realisation of polarisation independent absorption performance. The surface resistivity taper of spacecloths crucial for realising desired UWB absorption is achieved by changing the aspect ratio of the hexagonal resistive grid. The design is analysed using transmission line model (TLM) and verified using 3D electromagnetic (EM) simulation software, high frequency structural simulator (HFSS). To realise UWB absorption combined with reduced thickness, the hexagonal resistive grid is loaded with hexagonal resistive patches, which results in increased absorption bandwidth of 15 dB (minimum) from 2 GHz to 19 GHz accompanied by reduction in thickness from 30.8 mm to 24.8 mm. The constituent resistive-capacitive (RC) layers of capacitive jaumann absorber (CJA) are fabricated as electrically thin printed circuit boards (PCB) using standard print and etch process. The four RC layers are bonded to low loss foam spacers and finally backed by the conducting ground plane. The panel CJA is tested for its radar cross section (RCS) over entire frequency band in microwave anechoic chamber. Measured and simulated results agree well.

## 2. MULTILAYER JA

### 2.1 Transmission line Analysis of 4 layer Jaumann Absorber

Four layer JA is analysed using TLM and is shown in Fig. 1. The four resistive sheets with surface resistivity of $R_1$, $R_2$, $R_3$ and $R_4$ Ω/sq, are shunted across the terminating conducting back plane which is modelled as short circuit and the spacer layers are modelled as quarter wavelength transmission lines.

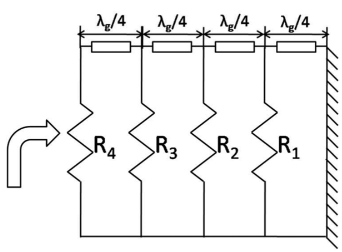



**Figure 1. Transmission line model of JA**

Based on TLM, the normal incidence reflection coefficient/ reflectivity[8] of four layers JA is given by:

$$|S_{11}| = \sqrt{\frac{\left(1-\sqrt{\varepsilon_r}X_4\right)^2+\varepsilon_r Y_4^2}{\left(1+\sqrt{\varepsilon_r}X_4\right)^2+\varepsilon_r Y_4^2}} \tag{1}$$

$$X_i = \frac{377}{\sqrt{\varepsilon_r}R_i} + \frac{X_{i-1}\left(1+\tan^2\theta\right)}{\left(1-Y_{i-1}\tan\theta\right)^2+\left(X_{i-1}\tan\theta\right)^2} \tag{2}$$

$$Y_i = \frac{Y_{i-1}+\tan\theta\left(1-Y_{i-1}^2-Y_{i-1}\tan\theta-X_{i-1}^2\right)}{\left(1-Y_{i-1}\tan\theta\right)^2+\left(X_{i-1}\tan\theta\right)^2} \tag{3}$$

where

$$\left(i=2,3,4\right),\ X_1=\frac{377}{\sqrt{\varepsilon_r}R_1},\ Y_1=-\cot\cot\theta,\ \theta=\left(\frac{\pi}{2}\right)\left(\frac{f}{f_0}\right)$$

and $\varepsilon_r$ is relative dielectric constant.

Optimised sheet resistivity of spacecloths[5] for deriving normal incidence reflection loss of four layers planar JA is given in Table 1. Spacer dielectric constant $\varepsilon_r$ is = 1.03+$j$0.0003 for center frequency of 10 GHz. The predicted normal incidence reflection coefficient of JA is plotted in Fig. 2. It is observed that 10 dB (minimum) absorption from 2 GHz to 18 GHz and 15 dB (minimum) from 2.5 GHz to 17GHz can be achieved.

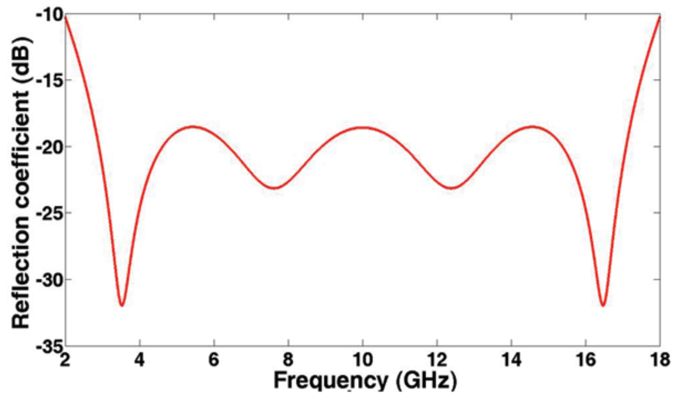



**Figure 2. Predicted reflection coefficient of JA.**

### 2.2 Design and Simulation of Four Layers Planar JA

The crucial challenge in implementation of JA lies in realisation of spacecloths with accurate surface resistivity for each spacecloth layer. Spacecloths are designed using hexagonal resistive grid network[19]. Hexagonal resistive grid network is shown in Fig. 3(a). The spacecloth surface resistivity R is given by

$$R = R_s\left(l/w\right) \tag{4}$$

where

$R_s$ is sheet resistance, Ω/sq, $l/w$ is aspect ratio of the grid = $h/\sqrt{3}w$, $h$ is apothem of the grid, and $w$ is width of resistive grid.

The four spacecloths of JA are realised using hexagonal resistive grid network on 0.2 mm thick FR4 dielectric

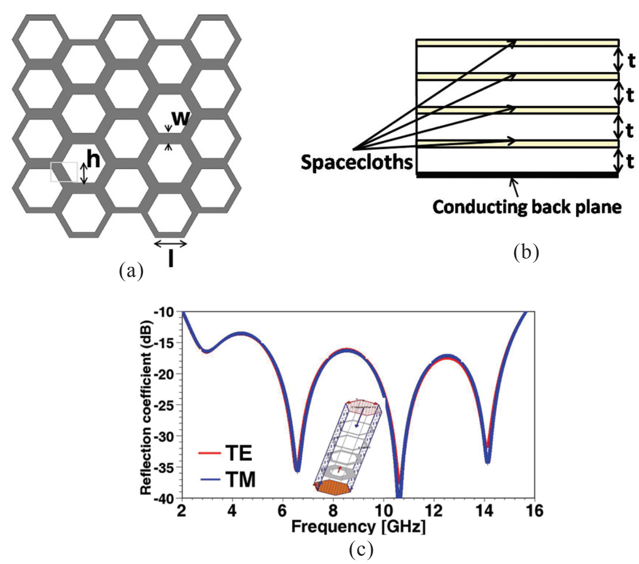



**Figure 3. Design and Simulation of JA: (a) Hexagonal resistive grid network, (b) Dielectric profile of four layers JA, and (c) Simulated reflection coefficient of planar JA. Inset: Simulation geometry model.**

substrate. Sheet resistance $R_s$ = 250 Ω/sq is used for realising all spacecloths. Using Eqn. (4), sheet resistance of four spacecloths of JA is realised by changing the aspect ratio of hexagonal resistive grid. Dielectric profile of four layers JA is given in Fig. 3(b). Four spacecloth layers alternate with four quarter wavelength thick Rohacel foam dielectric spacers with $\varepsilon_r$ = 1.03+$j$0.0003 and are terminated by conducting ground plane. HFSS simulation geometry model comprises four spacecloths modeled as hexagonal resistive grid networks and surface resistance of 250 Ω/sq is assigned, to achieve desired sheet resistances from the spacecloths. Design details of four spacecloths numbered with ascending order from the conducting back plane are given in Table 1. In HFSS, periodic boundary conditions are imposed on the unit cell and excited using the Floquet port. Simulated normal incidence reflection coefficient of four layers planar JA is given in Fig. 3(c) and simulation geometry model is shown in the inset. It is observed that a minimum 15 dB absorption from 2.5 GHz to 15 GHz can be realised. The thickness of four layers JA with 15dB absorption from 2.5 GHz to 15.5. GHz is 30.8 mm.

**Table 1. Design of spacecloths of four layers JA.**

| Spacecloth layers | Spacecloths numbered from back plane | Surface resistivity in Ω/sq. | Hexagon grid width, W, mm |
|---|---|---|---|
| 1 | $R_1$ | 276 | 3.622 |
| 2 | $R_2$ | 628 | 1.592 |
| 3 | $R_3$ | 1222 | 0.818 |
| 4 | $R_4$ | 1357 | 0.736 |

Hexagon grid side length l = 4 mm for all spacecloth layers.

### 2.3 Input Impedance of Resistive and RC Layer

Real and imaginary parts of input impedance of hexagonal resistive grid layer designed for 377 Ω (l = 2.176 mm and w = 1 mm) and hexagonal patch loaded RC layer (p = 2.5 mm) are shown in Fig. 4. From the figure, it is observed that for the resistive layer, the input impedance is purely resistive whereas for the RC layer, the reactive part of input impedance is capacitive. Hence, RC layers can be realised by loading hexagonal patch to the resistive layer[16].

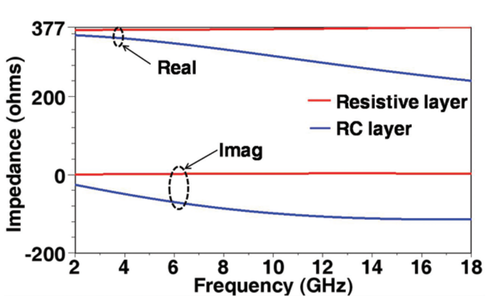



**Figure 4. Plot of real and imaginary parts of input impedance.**

## 3. FOUR LAYERS CAPACITIVE JAUMANN ABSORBER

### 3.1 Design and EM Simulation

To realise UWB absorption performance with reduced thickness and increased bandwidth, the four layers JA design is modified based on capacitive patch loading on each layer of spacecloths. 3D schematic of four layers CJA is shown in Fig. 5(a) and RC layer design is shown in Fig. 5 (b). Each spacecloth layer consists of hexagonal resistive grid networks loaded with hexagonal resistive patches at the center of the grid on 0.2 mm thick FR4 dielectric substrate with $\varepsilon_r$ = 2.4+$j$0.02 alternating with Rohacel foam dielectric spacers with $\varepsilon_r$ = 1.03+$j$0.0003, complete the dielectric profile of planar CJA and is shown in Fig. 5(c). The proposed four layers UWB RA is constituted by four RC layers alternating with low loss dielectric spacer layers, backed by the conducting plane. The equivalent circuit diagram based on TLM is given in Fig. 5(d). Each RC layer is modeled as a series RC circuit, in shunt with the short circuited transmission line. The dielectric spacers are each modeled as transmission lines of lengths $t_1$, $t_2$, $t_3$ and $t_4$. Design is optimised in HFSS to realise reduced thickness CJA. Optimised thickness of CJA is 24.8 mm, resulting in thickness reduction of 19.4 per cent accompanied by increased absorption bandwidth with minimum 15 dB absorption realised from 2 GHz to 19 GHz. Design of CJA is given in Table 2. Hexagon grid side length, l = 5.2 mm for all RC layers and surface resistance of 250 Ω/sq is assigned to each hexagonal grids and hexagonal patches of all layers.

**Table 2. Design of CJA.**

| Layers | W (mm) | P (mm) | Dielectric spacer layer thickness (mm) |
|---|---|---|---|
| 1 | 4.49 | 0.28 | $t_1$=9 |
| 2 | 1.92 | 0.61 | $t_2$=5 |
| 3 | 1.01 | 1.75 | $t_3$=5 |
| 4 | 0.91 | 2.53 | $t_4$=5 |

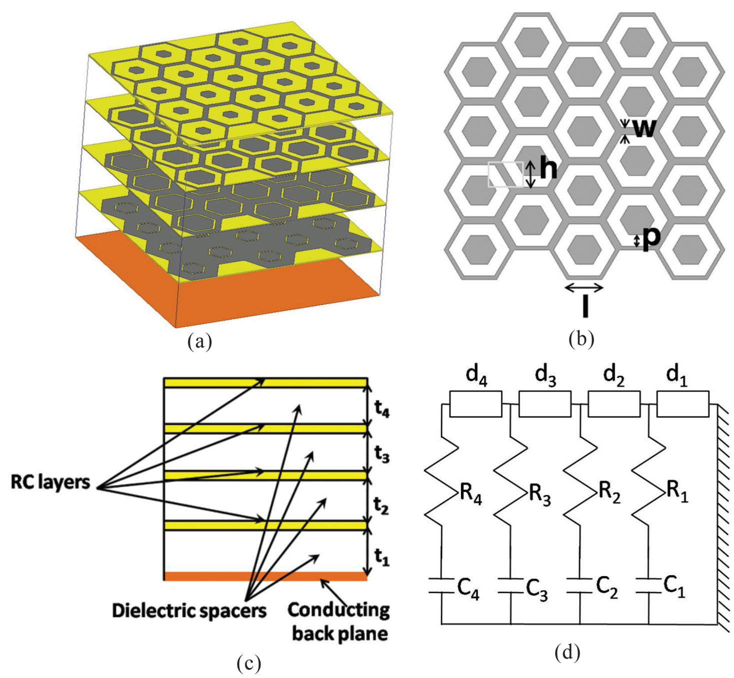
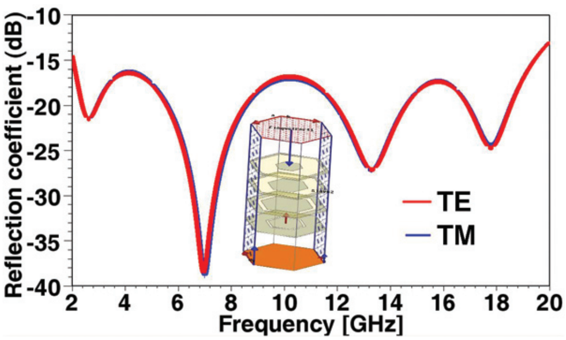



**Figure 5. Capacitive JA design: (a) 3D schematic of CJA, (b) RC layer geometry of CJA, (c) Dielectric profile of CJA, and (d) Transmission line model of CJA.**

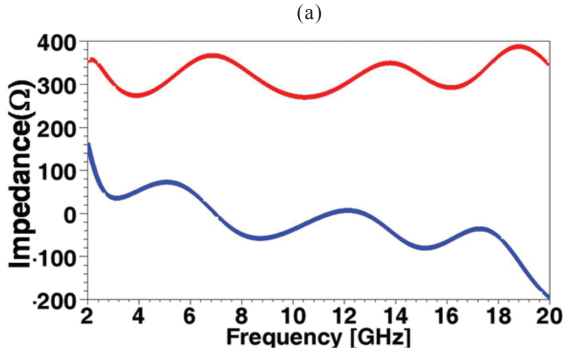
The planar CJA is simulated in HFSS using Floquet's port excitation with periodic master and slave boundaries. Normal incidence simulation performance is shown in Fig. 6(a), for TE and TM incidence and the simulation geometry model is shown in the inset. It is observed that reflectivity of -15 dB (minimum) is realised from 2 GHz to 19 GHz for normal incidence. Input impedance of four layers UWB capacitive JA is plotted in Fig. 6(b). As the absorber is backed by the conducting plane, transmission is zero and absorption is given in Eqn. (5). Accordingly, the 15 dB reflectivity translates to 96.5 per cent (minimum) absorption from 2 GHz to 19 GHz.

$$A(\omega) = 1 - \left(\left|S_{11}(\omega)\right|^2 + \left|S_{21}(\omega)\right|^2\right) \quad (5)$$

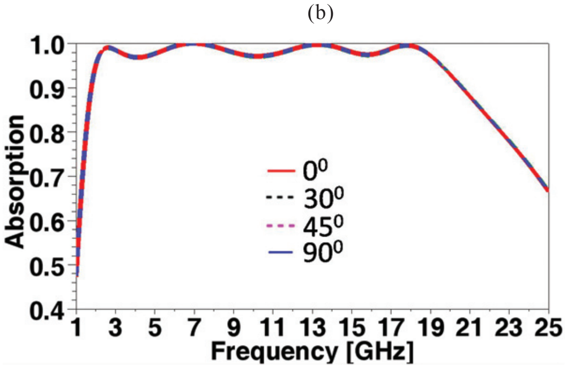
Six-fold symmetry of the hexagonal grid enables realisation of polarisation independent performance and simulated absorption is plotted in Fig. 6(c). The performance of CJA for various angles of incidence (AOI) from 0° to 45°, for both TE and TM incidences are plotted in Figs. 7(a) and 7 (b) respectively. It is observed that AOI performance of CJA is preserved with very minor variations.




(a)

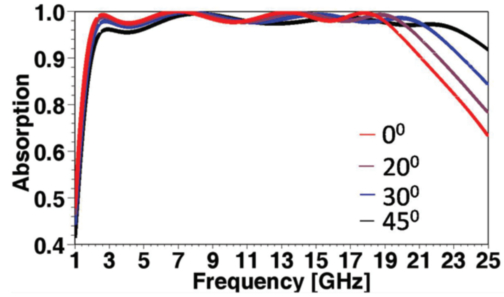



(b)

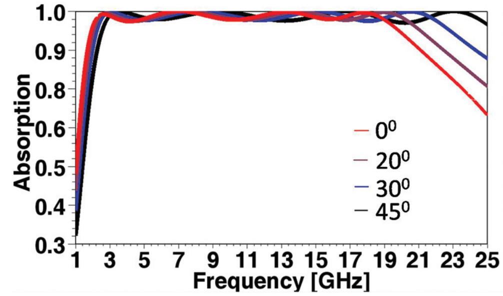



(c)

**Figure 6. Simulation results of capacitive JA: (a) Normal incidence simulation plot of reflection coefficient, (b) Input impedance of UWB capacitive JA, and (c) Polarisation performance**




(a)

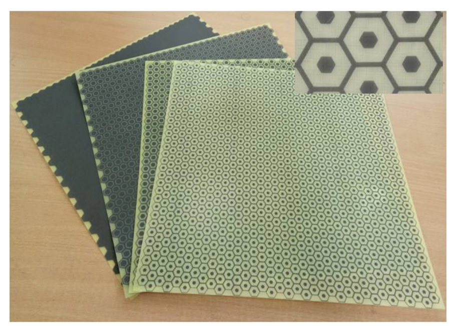



(b)

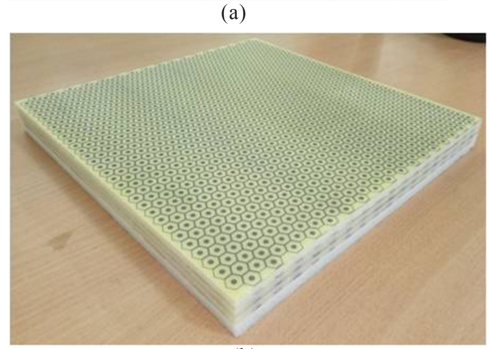
**Figure 7. AOI performance of capacitive JA: (a) TE incidence. and (b) TM incidence.**

## 3.2 CJA Implementation and RCS Measurements

Four RC layers of capacitive JA are developed using 0.2 mm thick FR4 substrate on which Ohmegaply™ 250 Ω/sq. resistive sheets are laminated. The hexagonal resistive grid with hexagonal resistive patch is developed using print and etch process in PCB fabrication facility. The fabricated RC layer PCBs of size 280 mm × 280 mm are shown in Fig. 8 (a). The PCBs are bonded to Rohacel foam dielectric spacers of different thicknesses (Table 2) and finally bonded to copper back plane, which serves as the conducting back plane of CJA. Photograph of the assembled planar CJA is shown in Fig. 8 (b).



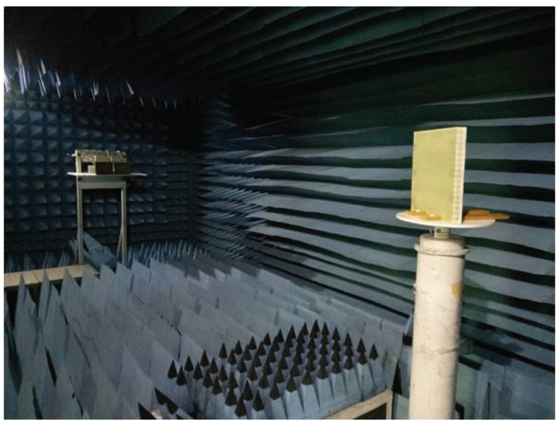
(a)



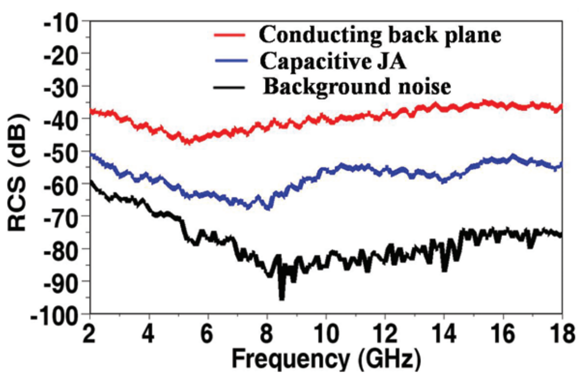
(b)

**Figure 8. Fabricated Capacitive JA (a) RC layers of CJA and (b) Assembled CJA.**

RCS measurements are carried out on fabricated CJA in shielded microwave anechoic chamber over the entire frequency bands of operation. Monostatic RCS measurement set up in microwave anechoic chamber is shown in Fig. 9(a). High directivity horn antennas are used for transmission and reception are placed next to each other. Analog phase shifter and attenuator in the sampled ports of directional couplers connected to the antennas enable vectorial cancellation of the background, at each measurement frequency. RCS measurements are carried out at L, S, C, X and Ku bands. The conducting backplane of CJA serves as a self-calibrating reference with which the reflection returns of the absorber side are compared. Measured RCS results of CJA are plotted in Fig. 9(b) and comparison plot of simulation and measurement results are plotted Fig. 9(c). It is observed that simulation and measurement results agree very closely.



(a)

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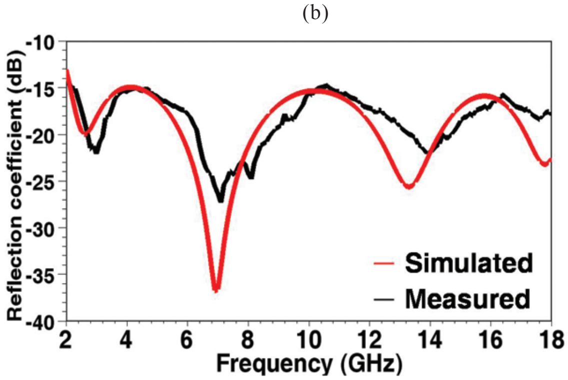


(c)

**Figure 9. RCS measurements of capacitive JA: (a) RCS measurement setup, (b) Measured RCS results, and (c) Comparison of simulated and measured results.**

## 4. CONCLUSION

Four layers JA and capacitive JA are presented in this paper. The crucial spacecloths of JA are realised as hexagonal resistive grid networks on electrically thin substrates. The novelty of the design comprises design of spacecloths for realising desired surface resistivity, using a single 250 Ω/sq resistive sheet, totally eliminating lumped discretes and associated soldering related defects, assembly and undesired parasitic reactances. Using capacitive loading of the hexagonal resistive grid network of spacecloths, a capacitive JA with reduced thickness and extended absorption bandwidth is realised. A thickness reduction of 19.4 per cent as compared to a conventional JA and bandwidth increase of 19.1 per cent (142.8 per cent to 161.9 per cent) with 15 dB (minimum) absorption is realised in capacitive JA. Accurate RC layer design and implementation sans lumped discretes has enabled translation of design to airworthy hardware. Also, polarisation insensitive, UWB absorption of 15 dB combined with wide angle TE and TM performance is realised. The CJA is suited for air vehicle stealth applications especially for RCS reduction of wing leading edges.

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In the current study, he is involved in design, analysis, simulation and RCS testing of radar absorber.

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In the current study, she is involved in design, analysis, RCS testing of radar absorber and conclusion through results.