RCS studies of metallic fibers for their application in chaff

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Abstract: Chaff is an electronic countermeasure (ECM) device dispensed into the atmosphere to generate false targets, and to deny or disrupt radar tracking [1]. The return from chaff is due to its shape, blooming and radar wave scattering properties [2]. Currently, most of the chaff cartridges are made up of aluminum coated glass fibers (20-24µm) or aluminum foils [3]. Two types of electrically conducting fibers viz copper coated carbon fiber (9-10µm) and copper coated aluminum fiber (18-20µm) have been developed in DLJ for indigenization of chaff. These fibers have been studied by modeling and experimentation in terms of their RCS response to see its application as an alternative payload in chaff cartridge. RCS measurements for both DLJ developed fibers and aluminum coated glass fiber were carried out in anechoic chamber by making test coupons in array form. RCS versus frequency response as well as aspect angle pattern show the almost equal RCS and resonant behavior. The RCS measurements output of DLJ developed fibers were compared with the performance of aluminum coated glass fibers. Other than RCS response these fibers have very low manufacturing cost, fine and light weight. As the proposed metallic fibers have smaller diameter (light weight), the blooming and staying at the atmosphere are also better than the aluminum coated glass fiber. Based on the results, proposed two types of metallic fibers may be used as an alternative chaff material with improved performance.

1. Introduction

Chaff consists of a bunch of small, thin metalized glass fibers and is spread by aircrafts or warships to create a dynamic target[1]. The RCS of chaff clouds depends on number of elements, electromagnetic property, their relative distribution, shape and size of chaff cloud , mutual coupling and polarization of radar wave[2].

The maximum RCS achieved by a chaff cloud is given by

$$\sigma = 0.172 N \lambda^2 \quad \text{......................................(1)}$$

where N is no. of dipoles in cartridge and λ is wavelength . RCS is directly proportional to number of dipoles in chaff cartridge. Number of dipoles can be increased by taking very thin fiber so that the chaff cartridge can accommodate more number of fibers. The number of dipoles, ejection velocity, RCS response, packing density and terminal velocity depends strongly upon the fiber materials properties like equivalent density, high electrical conductivity, fiber diameter etc.

To get sufficient reflection from any metallic coated material its coating thickness must be atleast equal to skin depth [3].The skin depth is given as

$$\delta_s = \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{\rho}{\pi f \mu}} \quad \text{........................ (2)}$$

Where µ is permeability (4π* 10-7 H/m) for free space, δs is skin depth (m), ρ is resistivity (Ωm), ω is radian frequency, σ is conductivity (mho/m) and f is frequency.

At lowest frequency (2GHz) the skin depth of copper and Aluminum is 1.46micron and 1.89micron respectively. This skin depth will be sufficient for higher frequencies also and hence the coating thickness for copper has been optimized as 1.5micron. Based on the skin depth calculation copper coated carbon fiber (7micron carbon fiber coated with 1.5micron copper coating) and copper coated Aluminum fiber (18 micron Aluminum fiber coated with 1micron copper coating) has been synthesis as alternate chaff payload material.

In this paper, using different compositions of fiber the test coupon of dipole array were prepared and the mutual coupling and resonant effect of the fiber in the array distribution has been investigated. The study of mutual coupling between dipoles were carried out analyticaly and then validated by the RCS measurement. The RCS measurement of the test coupons were also carried out for all type of fiber in anechoic chamber using vector network analzer and based on the measurement results the functional properties of chaff fiber is compared . The measured results were used to validate the simulated pattern.

II. The Modelling Of The Chaff Fibre Array Scattering

For modeling RCS behavior of dipoles, the arrangement of dipoles in array form is preferred over random distribution as it accounts for the conceptualization of the various factors such as mutual coupling, resonance and ease of measurement. The chaff fiber array test coupons have been prepared for each type of fiber for the measurement and simulation purpose. It is well known fact that the radiation field of an array arrangement can be represented as [4]

$$\vec{E}(\theta,\varphi) = \vec{E}_e(\theta,\varphi).E_a(\theta,\varphi) \quad .... (3)$$

where $\vec{E}_e(\theta,\varphi)$ and $E_a(\theta,\varphi)$ are element the radiating fields of fibre element and array respectively in spherical coordinate system. In the same manner the RCS of the chaff fibre array model can be represented as the product of element RCS factor (σ_e) and array RCS factor (σ_A)[5]. These factors are represented as shown by (4)

$$\sigma_e = 4\pi r^2 . \left| \frac{\vec{E}^s_\theta(\vec{k})}{\vec{E}^i_\theta(\vec{k})} \right|^2 \quad .... (4)$$

where $\vec{E}^s_\theta$ is the scattered field from the target towards the radar receiver and $\vec{E}^i_\theta$ is the incident field on the target. $\vec{k}$ is the propagation vector of the field. The σ_A can be defined as shown in (5)

$$\sigma_A = \left| \sum_{m=0}^{M_x} \sum_{n=0}^{N_y} e^{j2k_0[\sin(\theta)\cos(\varphi)mdx + \sin(\theta)\sin(\varphi)ndy]} \right|^2 \quad .... (5)$$

where M_x & N_y represent the number of rows and columns of the array respectively, *dx* and *dy* represent the separation between the dipoles in horizontal and vertical direction.

According to the above explanation, the total RCS of the array can be written as shown in equation (6)

$$\sigma(\theta, \varphi) = \sigma_e(\theta, \varphi). \sigma_A(\theta, \varphi) \quad .... (6)$$

where θ and φ represents the orientation of fibre in spherical coordinate system. Here, a 10x7 array is simulated and then compared with the RCS v/s aspect angle measurement of Aluminum coated glass fiber .

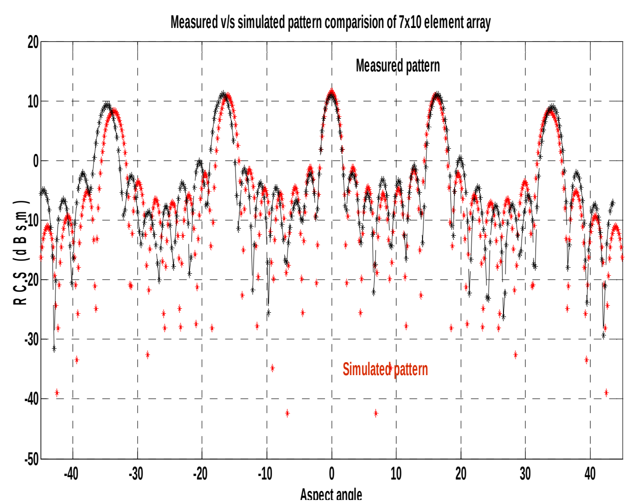

Figure 1. RCS versus aspect angle comparison of simulation and measurement of fiber array (7 x 10) at 3 GHz

Results in figure1 indicate good corelation between measured and simulated RCS pattern with aspect angle.

III. Experimental Work:

A. *Preparation of Fibers*

Copper coated carbon fibers and Copper coated aluminium fibers were prepared at DLJ. First type of chaff fiber is prepared by electroless plating process. It consists of three steps i.e. pretreatment by acid wash, sensitization and activation. After pretreatment electroless copper coating of 1-1.5 micron were carried out using $CuSO_4.H_2O$ as metal ion source and formaldehyde as a reducing agent .

The another fiber i.e. 22±3µm copper coated aluminum fiber was prepared by mechanical working through trade.

B. *Test Coupons Preparation*

The test coupons were prepared in linear array form so as to study the factors governing RCS behavior of dipole. In preparation of linear array model, thermocol sheet (low dielectric constant~1.2) were used as a base material and the different array configurations were made with each type of chaff fiber . The thermocol sheets are transparent to microwave and show very low RCS. Array size was decoded considering constraint of quite zone size. Number of test coupons were prepared with 2λ, λ and λ/2 separation. The details are given in table 1.

Table.1 Specification of test coupons

sample	Horizontal separation	Vertical separation	Test Coupon dimensions (cm)
Aluminum coated glass Fiber (28mm)	2λ	λ	44.8*42
Aluminum coated glass Fiber (28mm)	λ	λ	22.4*42
Aluminum coated glass Fiber (28mm)	λ/2	λ	11.2*42
Copper coated carbon fiber (28mm)	2λ	λ	44.8*42
Copper coated carbon fiber (28mm)	λ	λ	22.4*42
Copper coated carbon fiber (28mm)	λ/2	λ	11.2*42
Copper coated Aluminum fiber(28mm)	2λ	λ	44.8*42
Copper coated Aluminum fiber (28mm)	λ	λ	22.4*42
Copper coated Aluminum fiber (28mm)	λ/2	λ	11.2*42

The schematic of test coupon is shown in Figure 2 below to represent the arrangement along with the prepared sample with horizontal and vertical separation.

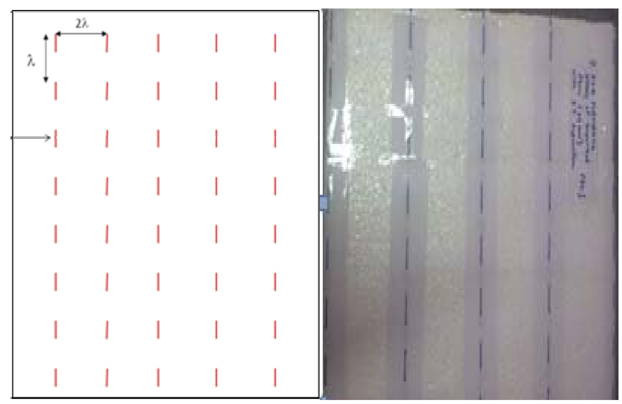

Figure 2. Linear distribution with 2λ separation line by line and λ separation collinear (Schematic and prepared sample).

The different dipole distribution models were created to study the mutual coupling effect, polarization dependency on RCS and resonance effect of dipoles. RCS measurements with vertical polarization were carried out for these samples for 3-8GHz in anechoic chamber and measurement data were compared with the simulation of different distributions of dipole array.

C. *RCS Measurement in Anechoic Chamber*

The RCS measurements of the prepared test coupons were carried out in anechoic chamber at Defence Laboratory, Jodhpur. Vector network analyzer along with broadband illumination horns covering the frequency range 3-8 GHz with low side lobes for reduced coupling are used for RCS measurement. A target stand made of low-density foam is used for placement of the target. The instrumentation interfaces to a PC based controller over GPIB bus. Figure 3 shows the RCS measurement setup in anechoic chamber at DL, Jodhpur.

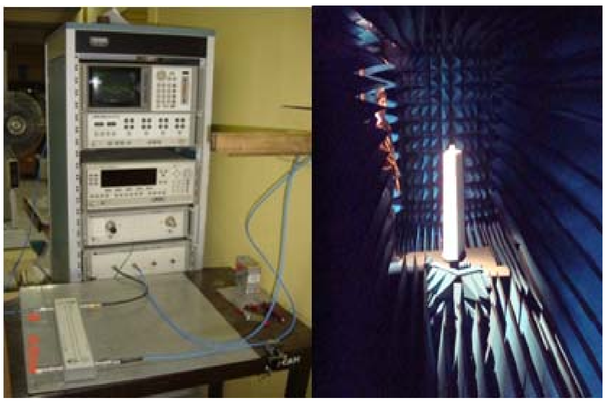

Figure 3 VNA Instrumentation and Anechoic Chamber for RCS Measurements

Data is processed by background subtraction and calibration with respect to a known standard. In background subtraction, the frequency trace data of the chamber with the test target not present is subtracted from the corresponding frequency trace data with the test target present. This removes key clutter contributions including leakage between transmit and receive antennas, as well as chamber reflections from the walls and absorbers. This data is then normalized to the data obtained by measuring a known calibration target i.e. standard sphere. The normalization process removes any frequency response error of the instrumentation, and also permits the measurement result to be expressed directly in absolute dBsm.

RCS versus frequency and RCS versus aspect angle measurement of all the coupons were carried out to see the effect of mutual coupling and the resonance effect of fiber on the RCS response of the prepared array coupons. RCS versus frequency response and the RCS versus aspect angle pattern were generated and the various effects were determined. The performance of the Aluminum coated glass fiber were measured and then compared with copper coated carbon fiber and copper coated Aluminum fiber .

IV. Results And Discussion:

A. *RCS Versus Frequency Response Comparison*

The figures 4-7 show the RCS versus frequency response comparison of the different compositions of the samples to study the mutual coupling and resonance effect.

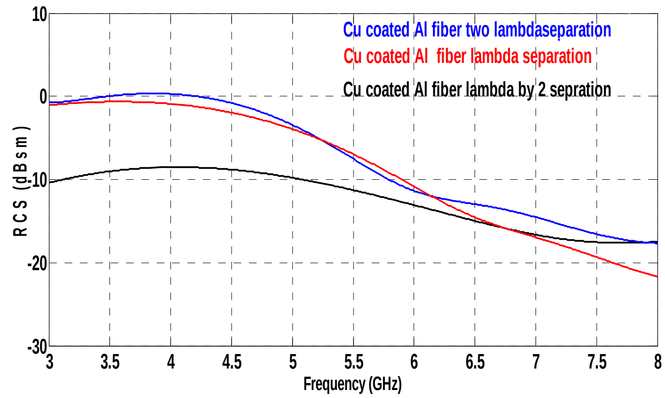

Figure4. RCS versus frequency comparison of copper coated Aluminum fiber array (8x5) with 2λ , λ and λ/2 separation

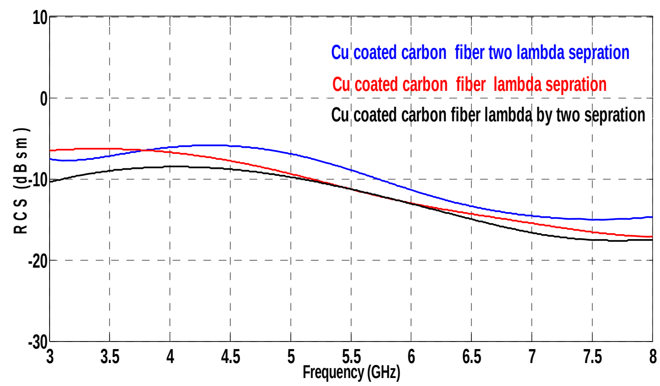

Figure 5. RCS versus frequency comparison of copper coated carbon fiber array with 2λ , λ and λ/2 separation

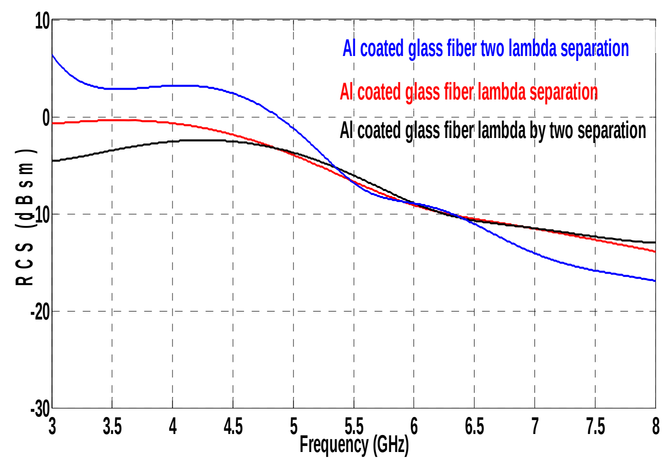

Figure 6. RCS versus frequency comparison Aluminum coated glass fiber array (8x5) with 2λ , λ and λ/2 separation

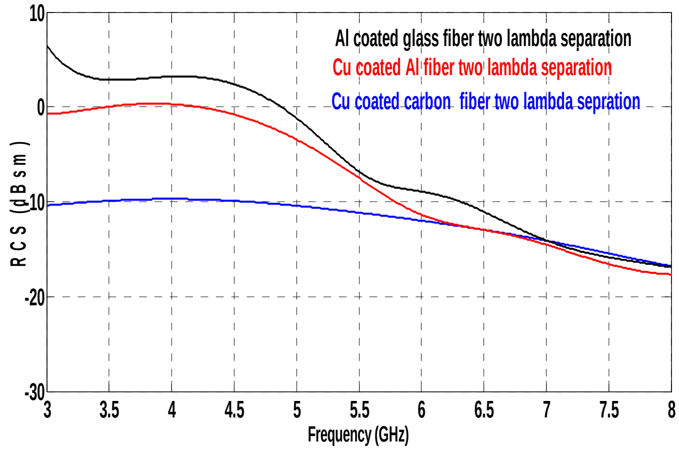

Figure 7. RCS v/s frequency comparison Aluminum coated glass fiber , copper coated carbon fiber and copper coated Aluminum fiber (8x5).

From figures 4-7 it is evident that all types of fibers are showing resonant effect with peak response at around 4.5 GHz.

The RCS reduction is obtained due to mutual coupling effect . It is well stated in literature that to avoid mutual coupling the separation between the fibers should be at least greater than 2λ. All the different types of fibers are showing almost same trend. The RCS v/s frequency response shown in Figure 8 is showing the comparison of these fibers and it is observed that all are showing almost comparable response.

B. RCS Versus Aspect Angle Comparison

The figures 8-11 show the RCS versus aspect angel response comparison of the different compositions of the samples to see the mutual coupling and resonance effect

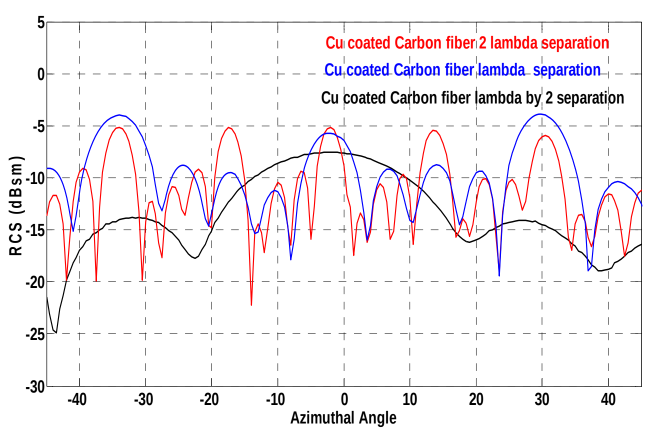

Figure 8. RCS versus azimuth angle comparison of Aluminum coated glass fiber array (8x5) with 2λ, λ and λ/2 separation at 4GHz

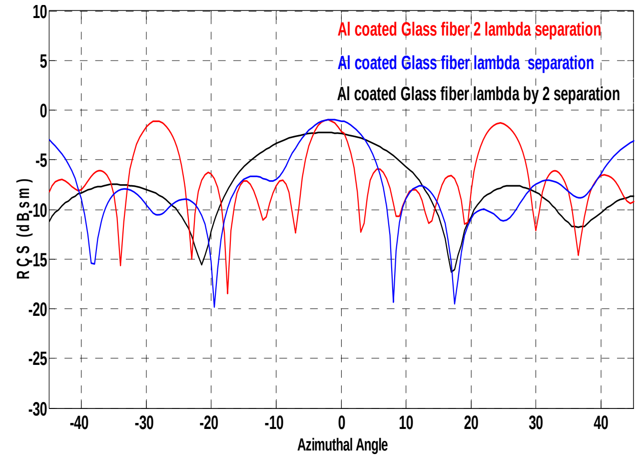

Figure 9. RCS versus azimuth angle comparison of Aluminum coated glass fiber array with 2λ , λ and λ/2 separation at 5GHz

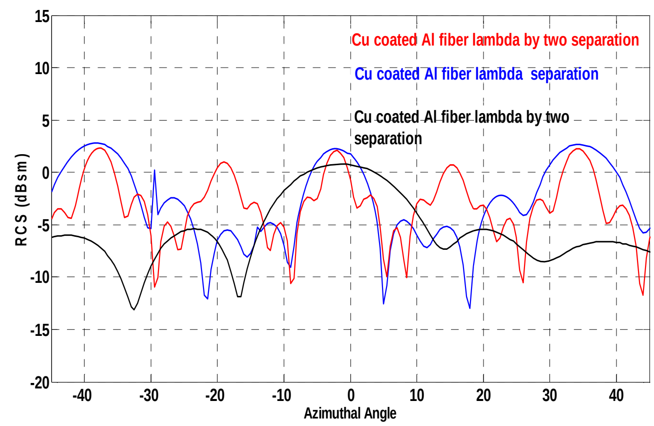

Figure 10. RCS versus azimuth angle comparison of Aluminum coated glass fiber array with 2λ , λ and λ/2 separation at 4 GHz

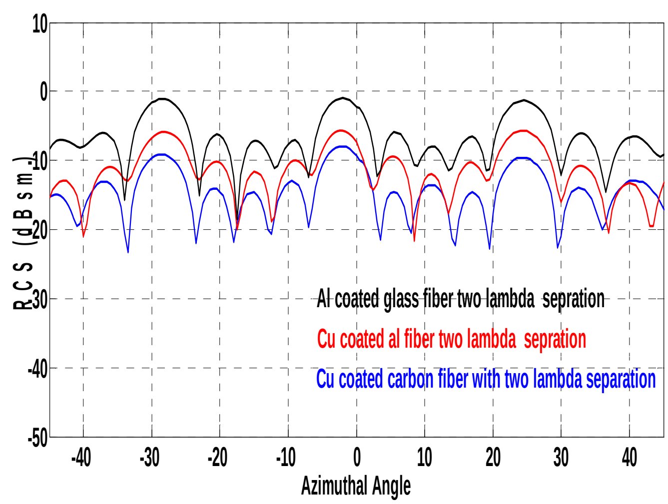

Figure 11. RCS versus azimuth angle comparison of Aluminum coated glass fiber, copper coated carbon fiber and copper coated Aluminum fiber at 5GHz

From the RCS v/s azimuth figure 8-11, it was observed that besides main peaks other peaks are also present. These are called as grating lobes and occur only when the separation is greater than λ. The grating lobes may be useful in the specular reflection from other directions. The positions and number of grating lobes and number of side lobes in between grating lobes have been validated by simulation. The number of minima in between two dominating lobe is given by N-2 where N is the number of column in the array. The figure 12 is showing the comparison of these fiber compositions. Similar RCS v/s azimuth behaviour is obtained for all kind of fibers.

V. CONCLUSIONS

The fibers were prepared by taking the thickness of skin depth. RCS versus frequency response as well as aspect angle pattern show the RCS dependency on mutual coupling between the dipoles and resonant behaviour. All the fibers are showing almost same mutual coupling and resonant behaviour. The simulated model has been validated based on RCS measurements with varying inter element spacing of the dipole. From the RCS v/s frequency and RCS v/s aspect angle figures it can be concluded that these fibers are showing similar RCS response The slight discrepancy in the comparison may be accounted for due to preparation of test coupons as the 100% equality of the samples cannot be guaranteed. The response can be enhanced by good surface finish. The RCS response of copper coated carbon fiber is less but it can be further enhanced by increasing the coating up-to 1.5-2 micron. By these modifications the DLJ developed chaff fiber will give at par scattering response. Additional significant advantage of copper coated carbon fiber is having less diameter (10micron) as compared to Aluminum coated Glass fiber (25micron), so that more no of dipole can be accommodated in same volume which will increase almost 6 times RCS response of chaff cloud.

VI. REFERENCES

[1] ACC TRSS, "Chapter 13. Chaff Employment" of Electronic Warfare Fundamentals, Nov. 2000.

[2] P. Pouliguien "Complete Modelling of Electromagnetic Scattering from Chaff Cloud", ANN Telecommun. Vol. 48, 1993.

[3] Brian C.F. Buters, "Chaff", IEEE Proc. Electronic countermeasure, Vol 129, pp197-201, 1982.

[4] Shuai Zhang, Shu-Xi Gong, 'Optimized Element Positions for Prescribed Radar Cross Section Pattern of Linear Dipole Arrays', Wiley Periodicals, Inc., 2011, pp 622-628.

[5] Yi Huang, Kevin Boyle, 'Antenna from Theory to Practice', Wiley publications, 2008, pp 191-200.