Modeling and Simulation of Chaff Cloud with Random Orientation and Distribution

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Abstract — **In this paper, modeling and simulation of chaff cloud using fullwave electromagnetic solver is presented. Scattering characteristics of chaff using a cloud of strip dipoles has been studied in presence or large target. The influence of mutual coupling between the dipoles is taken into account. Randomly oriented and distributed chaff cloud is generated using automated script. Both monostatic and bistatic RCS of chaff cloud in presence of 41 meter large aircraft is calculated using Finite Difference Time domain (FDTD) solver of EMPro simulation tool. It has been shown that complicated chaff cloud can be modeled and analyzed without any approximations or simplifications, in a relatively reasonable time, using the electromagnetic Finite Difference Time Domain (FDTD) solver.**

Index Terms — Chaff Cloud, RCS, Electromagnetic Simulation, FDTD solver

I. INTRODUCTION

Chaff finds are mainly used in electromagnetic countermeasures. A cloud of chaff is an artificial target made up of a bunch of small thin metallized glass fiber or wire. Chaff consists of thin dipole elements cut to resonate at radar frequencies. Chaff Clouds are dispensed in the air through the chaff cartridge on aircrafts. Chaff Cloud masks the real target return signal therefore, the detection of target become more complicated. The reflected signal from the chaff cloud disturbs the opponent's radar system and creates a false signature in the enemy radar. Because of high RCS signature, after launching a chaff cloud, the incoming missile tends to track on the chaff. The aircraft can then perform a fast, sharp maneuver, deviating from the missile path.

Radar Cross Section (RCS) is defined as the area a target would have to occupy to produce the amount of reflected power that is detected back at the radar, and is classified according to the types of mono-static or bi-static radars. Most RCS measurements of interest are of monostatic case, for which the radar transmitter and receiver are sensibly at the same point in space. For the bistatic case, the transmitter and receiver are separated. In RCS calculation the radar target scattering data is collected.

The calculation of electromagnetic scattering by a chaff cloud is complex and no exact theory is currently available for calculation of all the phenomena observed. Several technique has been proposed for chaff cloud modeling [1, 2]. In conventional method, usually the RCS of a unitary strip is computed and later the statistics of a chaff cloud are taken into consideration, in order to evaluate its global electromagnetic characteristics. One disadvantage of this computation approach is, it does not consider the coupling among adjacent strips and does not include the target in the scenario.

Mutual coupling is the most important problem in calculating the scattering of multiple scatterers. In particular, when scatterers are densely placed, mutual coupling between scatterers is strong and a tremendous amount of calculations is required to take this phenomenon into account. In Chaff cloud, several different lengths of chaffs increase the bandwidth over which the chaff is effective.

In this paper modeling of a chaff cloud using automated python script based code, with strips randomly distributed is presented. It is computed with large aircraft as a target. The simulation is done with EMPro that is 3D full wave electromagnetic simulator, using FDTD solver. The proposed chaff cloud generation script can be applied to any orientation and distribution of the cloud.

In Electromagnetic simulation, the difficulty of estimating the RCS of a chaff cloud arises due to huge dimension of the analysis region and extremely large number of chaff scatterers. Finite Difference Time Domain technique enables computation for RCS of a chaff cloud in sort time without taking any approximation into simulation. The FDTD conformal mesh method is applied to generate mesh grids due to the complex orientation distribution of chaff. .Chaff Clouds other applications have also been found in communications and weather monitoring [3] – [4].

II. DESIGN PARAMETERS OF CHAFF CLOUD

The operating frequency of chaff susceptible radar is chosen in the L band (1 GHz). Dipole orientation, Distribution density, Cloud shapes, Dipole resonant length, is some of important parameters that affect the RCS

1. Dipole Orientation and Distribution Density

The dipole orientations and distribution are important factors determining the RCS of a chaff cloud. Dipole orientations affect the RCS of a chaff cloud in terms of either a more vertical, more horizontal or a spatial average orientation,

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relative to the radar polarization [5-6]. If all the dipoles are within the radar resolution cell, the distribution of dipoles in the chaff cloud will not affect the RCS for a low dipole density due to negligible coupling , however, if there is coupling within the chaff cloud, the dipole distribution will have an effect on the RCS.

2. Chaff Cloud Shape

For low density clouds with low coupling between the dipoles the cloud shape does not play any significant role. For high density clouds with strong coupling between dipoles the shape does, however, affect the RCS.

3. Dipole Resonant Length

The half-wave dipole is used for chaff cloud generation that resonate at a length a little shorter than 0.5λ and closer to 0.47λ - 0.48λ, This is due to the EM wave travelling more slowly in the dipole medium than it does in free space.

4. Chaff Material

Chaff consists of a glass or fiber filaments which are coated with a conducting material. The most common used chaff material [7] is aluminum coated glass

III. GENERATION OF CHAFF CLOUD

This design considers a pure monochromatic radar wave of 1 GHz (L-band), which is a frequency commonly used by the many tracking radars. The half wavelength metallic strips of length 150 mm are modeled. Since the number of individual strips is in the thousands, an automated modeling scheme is necessary. A python script is written to generate randomly oriented and distributed chaff clouds. Fig. 1 illustrates the Flow chart of chaff cloud modeling.

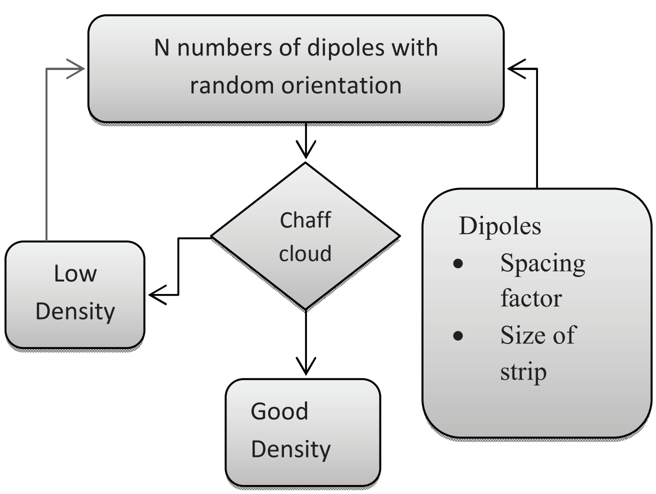

Fig. 1. Flow chart of chaff cloud modeling.

The main parameter variable used in chaff cloud scripts are:

- Number of Strips
- Size of resonating strip (length and width of Strip)
- Size of Cloud
- Distribution type

The number of dipoles (N) and size of cloud parameters are set by the user; the other parameters are randomly set for each dipole in python script. Python is a powerful programming language and it is imported in Agilent's 3D Electromagnetic simulation tool EMPro to generate chaff cloud. Fig. 2 show generated chaff cloud with 12000 metallic strips using below script.

```
# -----------------Defining Chaff Cloud Parameters---------------
NUMBER_OF_STRIPS = 100 #number of dipoles
STRIP_SPACING = 4000   # this parameter controls the chaff cloud size
WIDTHS = 5             #width of dipoles
LENGTHS = 300          #length of dipoles
SIZE_X=1.5             #cloud shape control
SIZE_Y=2
SIZE_Z=1
#-----Main function to generation chaff cloud in EMPro-------
def setupGeometry():
        pec = empro.activeProject.materials()["PEC"]
        for i in range(NUMBER_OF_STRIPS):
        # Modeling the strips using random function
                x=random.randrange(-
STRIP_SPACING*SIZE_X, STRIP_SPACING *SIZE_X,1)
                y=random.randrange(-
STRIP_SPACING*SIZE_Y, STRIP_SPACING*SIZE_Y,1)
                z=random.randrange(-
STRIP_SPACING*SIZE_Z, STRIP_SPACING*SIZE_Z,1)
                ang = random.randrange(0, 360,1)
```

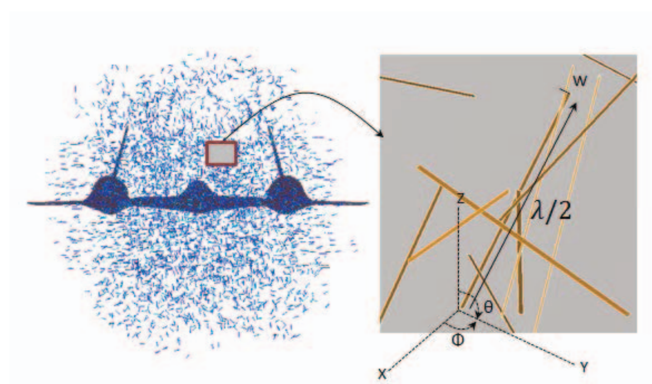

Fig. 2. Spherical Chaff cloud of randomly oriented and distributed dipoles

IV. RCS SIMULATION SETUP

Once the 3D model of chaff cloud is ready, real target (like air craft) CAD file is imported and placed behind the cloud. Here the models are excited by a plane wave with a certain frequency to model the incoming wave from a radar transmitter placed in the far field, so that the electromagnetic wave can be considered plane. Fig 3 shows all steps to perform RCS simulation.

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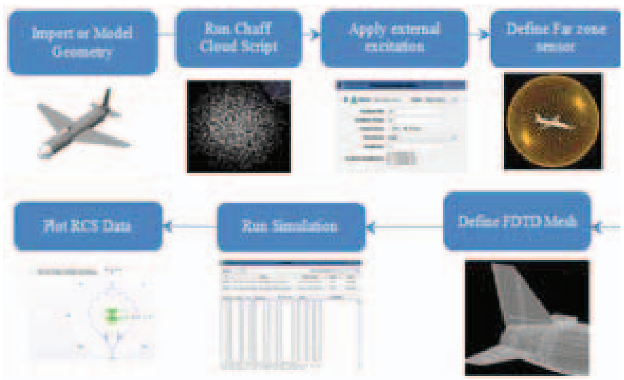


Fig. 3. Chaff Cloud RCS Calculation Flow in EMPro

V. SIMULATION AND RESULTS

To model a chaff cloud as a whole, one first needs to understand the RCS behavior of a single dipole element. After modeling and optimization of single dipole, the next step is modeling and simulation the RCS of chaff cloud along with real-life target.

1. Single Chaff Dipole

To model a chaff cloud as a whole, one first needs to understand the RCS behavior of a single dipole element. First a simulation was run with FDTD solver to investigate the dipole resonant length at 1 GHz as a function of the width. The dipole with were simulated from 1 mm to 5 mm in 0.5mm increments Fig. 4 shows that the dipole resonant frequency variation w.r.t different dipole width with dipole length of half wavelength. Also it can be seen that dipole resonance length is not exactly half wavelength, there is frequency shift at lower side. To shit dipole resonance frequency at 1 GHz, dipole length is selected 0.46 * wavelength.

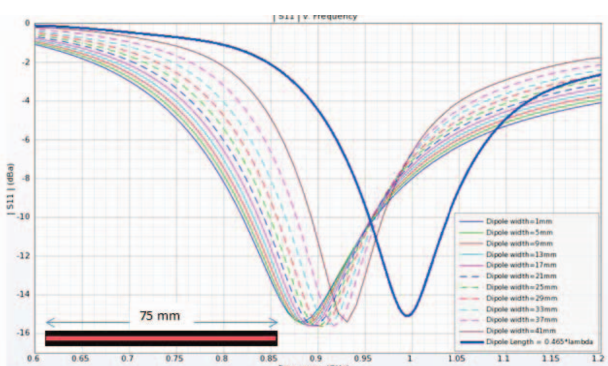
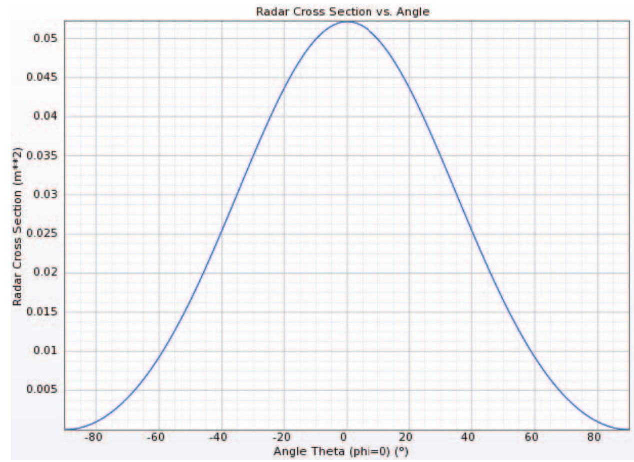
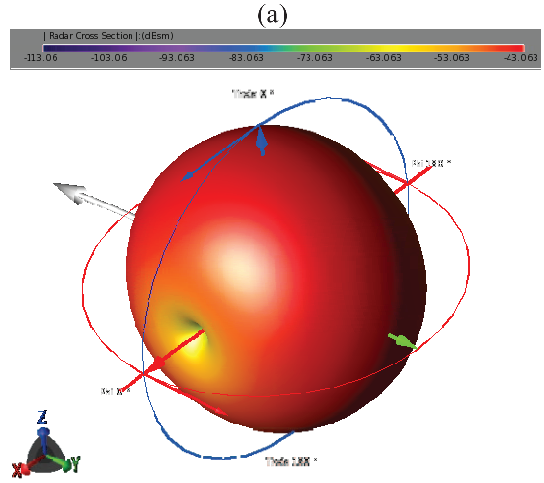


Fig. 4. Dipole resonance frequency variation w.r.t to dipole width

For a single dipole, the monostatic RCS is at a maximum when the polarization of the incident E-field, radiated by the transmitting antenna, is parallel to the dipole axis as well as to the polarization of the receiving antenna. Monostatic and bistatic results of single dipole are shown in Fig. 5.



(a)



(b)

Fig. 5 Single Dipole (a) monostatic RCS (b) Bi-static RCS

2. Chaff Cloud simulation along with Target Aircraft

A 3053m³ spherical chaff cloud containing more than 12000 metallic strips was simulated using FDTD (Finite difference time domain) solver to calculate monochromatic and bistatic RCS as shown in Fig. 6. FDTD is a method which directly discretizes the partial differential form of Maxwell's equations based on Yee Grid that makes it appropriate solver for large and complex structures. The most challenging part is simulation setup is accurately meshing tiny structures of chaff clouds. FDTD conformal mesh technique has been used that exactly confine the structures in grids.

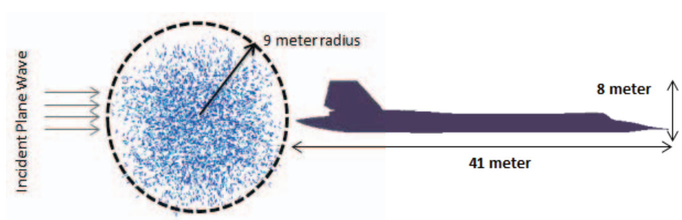


Fig. 6 Chaff cloud in front of an aircraft (41 m x 20 m x 8 m)

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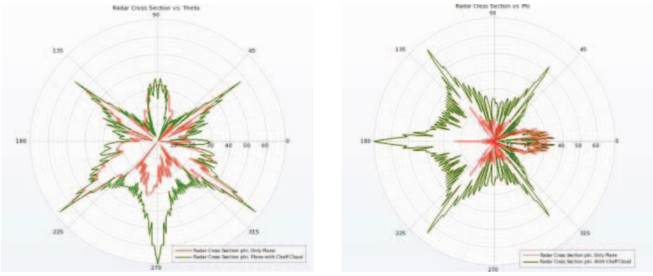
The incoming wave strikes the plane after it goes through the chaff cloud, which means that the total scattering by a wave incident from a single direction is considered.



Phi=0 Degree cut (a)   Theta=90 Degree cut (b)

Fig. 7. Monostatic RCS (a) Phi=0 degree (b) Theta=90 degree

Chaff cloud RCS simulation is performed in presence of real world aircraft with 41 m long and wingspan of 20 m with height of 8 m. complete simulation took 11 hours in a Windows-7 64-bit machines with 8 (intel) 2.8 GHz processors and a total RAM memory of 16.3 GB.

In monostatic RCS simulation, target is being hit by a plane wave incident from different directions and signal reflected back into the transmitter is collected. The monostatic (360° in steps of 1°) RCS polar plot is shown in Fig. 7 Chaff creates several peaks where the RCS exceeds the normal target signature. Because of several peak values in RCS data, the chaff cloud makes target detection very complicated.

VI. Conclusion

The chaff cloud is generated with random orientation and distribution using python script and full wave 3D time-domain based electromagnetic solver is used to simulate chaff cloud along with large aircraft. Chaff cloud strips were modeled as thin resonant metallic strips using automated script. The results show that a complicated real world chaff cloud along with large aircraft kind of simulation can be analyzed without any approximation or simplifications, in a reasonable time, using the FDTD solver. Using chaff cloud script, much more realistic cloud can be generated and conclusive results can be derived to address issues such as large number of dipoles and frequency response of the strips

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