The Near-Field Scattering of Chaff Cloud

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***Abstract*—The near field electromagnetic scattering of the chaff cloud is discussed in this paper. The cloud is illuminated by a horn antenna which is located in the near field region of the cloud. The scattered far field is calculated with method of moments which the coupling between chaff elements can be considered. Some simulations are done to analyze how the scattering results are affected by antenna pattern, the distance between the antenna and chaff cloud and the density of the chaff cloud.**

Keywords—chaff cloud; method of moments; near field scattering

I. INTRODUCTION

In recent years, some researches had been done to study the scattering characteristics of the chaff cloud. R. A. HESSEMER found an analytical expression for the RCS of chaff oriented randomly [1]. C. J. PALERMO calculated the average cross section using variational method, and some measurements is performed to ensure the calculation values [2]. Yanping Guo described the scattering characteristics of chaff using stokes vector and studied the polarization characteristic of the chaff [3]. Shao Xianhe investigated the polarization difference between Chaff cloud and ship [4,5]. Sherman W. Marcus established the chaff cloud model as medium for higher density clouds [6]. Ilkka Ellonen studied the chaff clutter filtering from radar data with discrete wavelet transform [7]. Although their results are valuable, the coupling between chaff dipoles are neglected in most of their works. The near field scattering is not mentioned in all the listed references. But to the best of the authors' knowledge, the research on near field scattering is more practical than far field scattering in some military scenes. So in this paper we mainly discuss the near field scattering characteristics of chaff cloud with the consideration of the coupling between elements in chaff. In most electromagnetic scattering calculation method, the Method of Moments (MOM) is acknowledged to be an excellent method which can consider the electromagnetic interaction between scatters.

II. SCATTEFUNG CROSS-SECTION MODEL

A. *Chaff cloud modeling*

The chaff cloud is always diffusing randomly in free space. So a statistical method can be used to describe the distributions of the dipoles in chaff. In most cases, the location of the dipole center and the zenith and azimuth angle of a dipole obey a given distribution function. In this paper, assuming the dipoles has a uniformly random orientation for all directions. The weight function in the PDF form given as follow [8]

$$f(\varphi) = f(\theta) = \frac{1}{2\pi} \tag{1}$$

where θ and φ denote the zenith and azimuth angle of a dipole. Similarly, the central position of each dipole can be generated respect the weight function in the PDF form as follow

$$f(x) = f(y) = f(z) = 1 \tag{2}$$

So the parameters can be created as follows

$$\begin{cases} \theta = \text{rand}() \cdot \pi \ , \ \varphi = \text{rand}() \cdot 2\pi \\ x = x_{\min} + (x_{\max} - x_{\min}) \cdot \text{rand}() \\ y = y_{\min} + (y_{\max} - y_{\min}) \cdot \text{rand}() \\ z = z_{\min} + (z_{\max} - z_{\min}) \cdot \text{rand}() \end{cases} \tag{3}$$

In formula(3), rand() denotes the uniform random number generator which can generate a random number between 0 and 1.

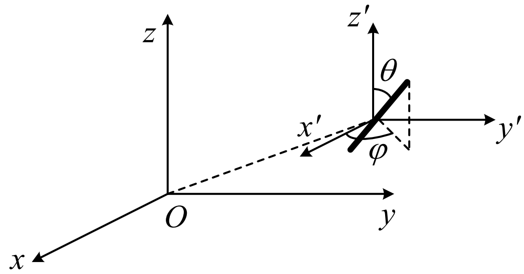

Fig.1 coordinates system of a single dipole

B. *The near field scattering of the chaff cloud*

The division rule of the near field and far field is originally defined in antenna measurements. The rule tells that if the distance between observation point and source point is less than $d_{\min}$, the observation point can be considered located in the near field region of the source point. $d_{\min}$ is defined as

$$d_{\min} = \max\left\{\frac{2D^2}{\lambda}, 10\lambda\right\} \tag{4}$$

Where D and λ denote the maximum dimension and the wavelength of the antenna.

In the electromagnetic scattering, the near field region is defined by the maximum dimension of the target instead of maximum dimension of the antenna. In the ordinary cases, the size of the target is much greater than the antenna's. So we can consider that the target is located in the far field region of the antenna, and the antenna is located in the near field region of the target. Under this premise, the target can be considered illuminated by the inhomogeneous plane wave. Therefore, the incident wave can be given as follow

$$\vec{E}_{in} = f(\theta,\varphi)\cdot\vec{E}_0 \exp(-j\vec{k}\cdot\vec{r}) \tag{5}$$

Where $f(\theta,\varphi)$ is the antenna pattern function, $\vec{E}_0$ is the Polarization vector of the incident wave, $|\vec{k}|$ is the wavenumber, $\vec{r}$ is the position vector.

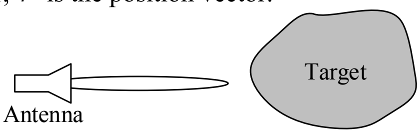

Fig.2 the scene of near field illumination

C. The rewrite of the MOM (neer field MOM)

The MOM is very useful in solving radiation and scattering problems. This paper focuses on the practical solution of boundary integral equations of radiation and scattering using this method. We can formalize this process by introducing a method of weighted residuals known as the Method of Moments (MOM). Considering the generalized problem

$$L(f) = g \tag{6}$$

where L is a linear operator, g is a known forcing function, and f is unknown which can be expanded into a sum of (weighted basis functions,

$$f = \sum_{n=1}^{N} a_n f_n \tag{7}$$

where a_n are unknown weighting coefficients, substitution of Equ. (7) into Equ. (6) yields

$$\sum_{n=1}^{N} a_n L(f_n) = g \tag{8}$$

With definition of inner product, Equ. (8) can be written in the form of matrix as

$$\mathbf{Za} = \mathbf{b} \tag{9}$$

The matrix elements of $\mathbf{Z}$ and $\mathbf{b}$ are

$$z_{mn} = \langle f_m, L(f_n)\rangle \tag{10}$$

$$b_m = \langle f_m, g\rangle \tag{11}$$

From the electromagnetic theory, the integral equations on the surface of the PEC can be written as

$$\left\langle \vec{E}^{\mathrm{inc}}(\vec{r}), \vec{f}_m \right\rangle = j\omega\left\langle \vec{A}(\vec{r}), \vec{f}_m \right\rangle + \left\langle \nabla\Phi(\vec{r}),, \vec{f}_m \right\rangle \tag{12}$$

Where

$$\vec{A}(\vec{r}) = \frac{\mu}{4\pi}\int_S \vec{J}(\vec{r}')\frac{e^{-jkR}}{R}\mathrm{d}s' \tag{13}$$

$$\Phi(\vec{r}) = \frac{-1}{4\pi j\omega\varepsilon}\int_S \nabla'_s\cdot\vec{J}(\vec{r}')\frac{e^{-jkR}}{R}\mathrm{d}s' \tag{14}$$

The Rao-Wilton-Glisson (RWG) triangular basis function is used to preform inner product. So the elements in Equ. (10) and (11) can be written as

$$Z_{mn} = l_m\left[j\omega\left(\vec{A}(\vec{r}_m^{c+})\cdot\frac{\vec{\rho}_m^{c+}}{2} + \vec{A}(\vec{r}_m^{c-})\cdot\frac{\vec{\rho}_m^{c+}}{2} \right) + \Phi(\vec{r}_m^{c-}) - \Phi(\vec{r}_m^{c+}) \right] \tag{15}$$

$$b_{mn} = l_m\left[\vec{E}^{\mathrm{inc}}(\vec{r}_m^{c+})\cdot\frac{\vec{\rho}_m^{c+}}{2} + \vec{E}^{\mathrm{inc}}(\vec{r}_m^{c-})\cdot\frac{\vec{\rho}_m^{c-}}{2} \right] \tag{16}$$

The near field MOM can be easily obtained just rewriting the Equ. (16) as follow

$$b_{mn} = l_m\left[f(\theta,\varphi)\cdot\vec{E}^{\mathrm{inc}}(\vec{r}_m^{c+})\cdot\frac{\vec{\rho}_m^{c+}}{2} + f(\theta,\varphi)\cdot\vec{E}^{\mathrm{inc}}(\vec{r}_m^{c-})\cdot\frac{\vec{\rho}_m^{c-}}{2} \right] \tag{17}$$

Using the near field MOM, a numerical solution of the scattering integral equations can be found with the target illuminated by a real antenna instead of the plane wave.

III. SIMULATION AND RESULTS

In the above section, the calculation method of near field scattering is presented. In this part, some simulations and analysis is done. At first, the chaff cloud is generated which respects the PDF form stated in Equ.(1) and Equ.(2). Then, a horn antenna is simulated which can be used to illuminate the target. At last, a comparison is performed which the target is illuminated by plane wave and antenna.

A. The chaff cloud model

This paper generates two types of chaff cloud with the conditions shown in table Ⅰ. One possible element center distribution of the two cases is plotted in Fig.3.

TABLE I. SIMULATION CONDITION

	The number of elements in chaff	***The type of the elements***	***The boundary of the chaff***
Case 1	$N_c = 100$	0.5λ dipole	$x_{max}=y_{max}=z_{max}=1$
Case 2	$N_c = 200$	0.5λ dipole	$x_{max}=y_{max}=z_{max}=1$

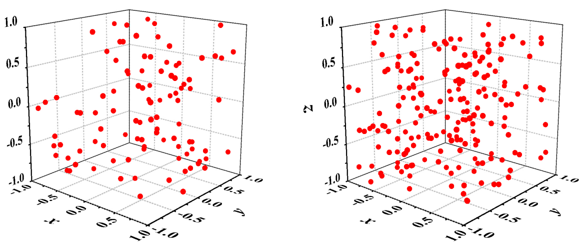

Fig.3 one possible canter distribution of the chaff

B. The antenna model

To illuminate the target, a horn antenna is simulated with FEKO software. The model of the antenna is shown in Fig.4. the parameters of the antenna is listed in tableⅡ. The antenna is working at the frequency of 1.645 GHz. The E-plane and H-plane are calculated with FEKO software and shown in Fig.5.

TABLE II. PARAMETERS OF THE ANTENNA

Parameters	***a***	***b***	***c***	***d***	***e***
Values(cm)	12.96	6.48	55.00	42.80	46.00

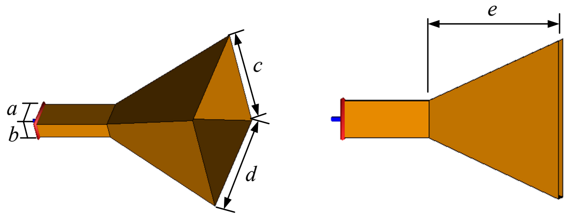

Fig.4 the model of a horn antenna

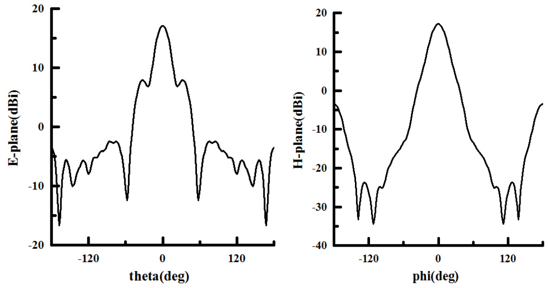

Fig.5 the E (left) and H (right) plane of the horn antenna

C. the calculation of the near field scattering

In the previous sections, the model of chaff cloud and antenna is created. In this part, a model contains these two models is established which is shown in Fig.6.

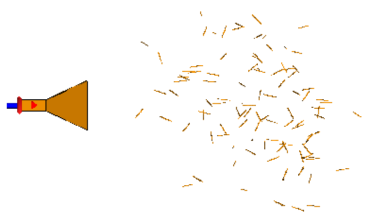

Fig.6 the image of the chaff cloud with antenna

Using the near field MOM mentioned in the second part, RCS is calculated. The comparison is shown in Fig.7. From the figure we can see that when the scale of chaff cloud is small, the distance between the chaff cloud and antenna has a great influence on the RCS values. This mainly because when the scale is small, the fields change per unit area with the increasing distance between chaff cloud and antenna on the chaff surface is greater than that of the big cloud.

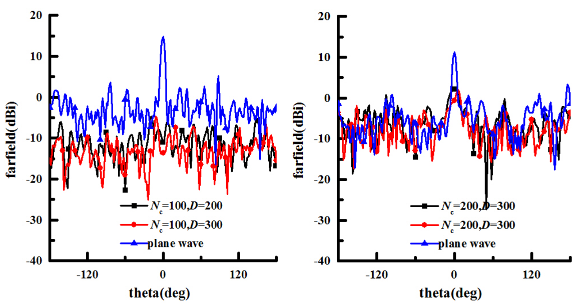

Fig.7 the comparison of near field and field scattering

The statistical characteristics of the chaff cloud in different conditions are calculated and listed in table Ⅲ. In this paper, only the mean and the variance of the RCS is considered. From the table we can see that the mean values of RCS are decrease with the increasing distance between chaff cloud and antenna. When the density of the chaff cloud is small, the variance of the RCS changes slightly comparing with the dense chaff cloud.

TABLE III. STATISTICAL CHARACTERISTICS OF THE CHAFF CLOUD RCS

Parameters	$D=200$	$D=300$	***Plane wave***
$N_c=100$	$\mu=-11.6719$ $\sigma^2=3.4657$	$\mu=-13.2707$ $\sigma^2=3.5544$	$\mu=-3.0981$ $\sigma^2=4.1157$
$N_c=200$	$\mu=-6.5235$ $\sigma^2=4.2013$	$\mu=-7.8811$ $\sigma^2=3.7159$	$\mu=-5.5622$ $\sigma^2=4.4480$

This paper also plots the probability density histograms of RCS in different conditions. It is shown in Fig.8. It can be found that the distributions of the probability density of the RCS are similar to the probability density of the normal distribution. We also can found that the mean values of the RCS with the plane wave illumination is greater than that of the antenna illumination. It is mainly because the plane wave can provide more energy to the chaff cloud than antenna. The variance values of the RCS when plane wave illuminates is greater than values of the antenna illuminates. This is because the energy is equally disperse on the surface of the chaff cloud.

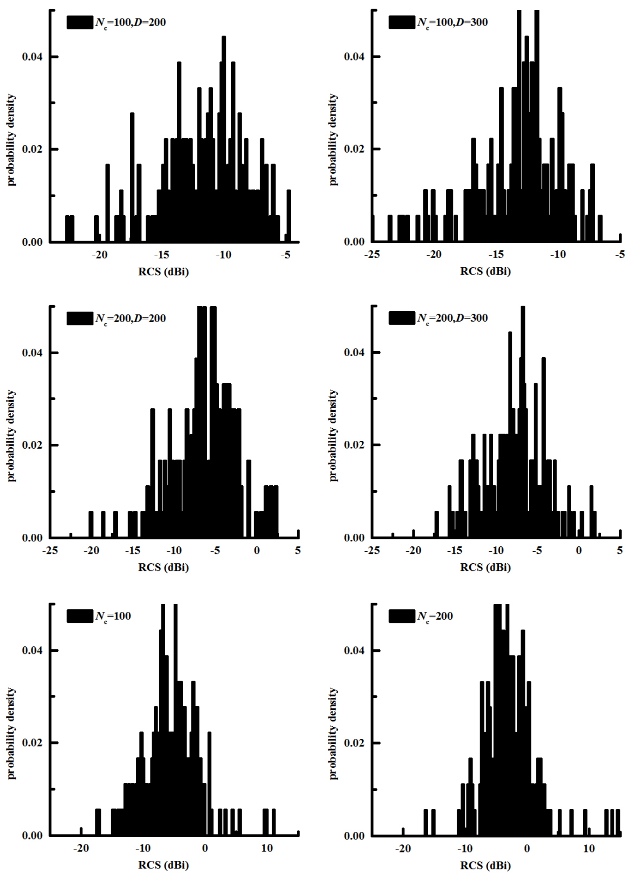

Fig.8 the probability density histogram of RCS in different conditions

IV. CONCLUSION

The near field scattering is discussed in this paper. To consider the electromagnetic coupling between chaff elements, the method of moments is used. A horn antenna is designed as the source of the electromagnetic scattering. Simulations show that the near field scattering has a lower reflection level and a smaller variance than plane wave illumination. At the same time, the variance of the RCS values changes slightly at Small chaff elements density. Whether the probability density of the RCS values obeys the normal distribution needs a further research.

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