Near-Field Scattering Characters of the Ship

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***Abstract*— The near-field scattering of ships is a very useful characteristic parameter for theory analysis and measurement. With the MLFMM, the near-field scattering of a typical simplified ship have been simulated to analyze the near-field scattering characters of the ship in free space in different detecting distances and incident angles. And the results show that with reduction of range, the difference between results of near-field and far-field scattering become very prominent. In addition, the required distance between antennas and ships may be far less than traditional far-field distance by comparing mean of scattering results. Accordingly to the phenomena of dominant lobe division of near-field scattering patterns, we developed a new expression to estimate the width of dominant lobe division. Finally, the viability of this expression is also given.**

***Keywords*—MLFMM, near-field scattering, ship**

I. INTRODUCTION

The electromagnetic wave scattering is of great significance to the research of modern targets, such as ships. The research on this topic was mostly centered on far-field analysis: assume an incident plane wave, compute its scattered field due to the scatter, and evaluate the radar cross section (RCS) of the scatterer.

However, in practical applications, there are many situations that the distance between the radar and the scatterer is not large enough to treat the field arriving the scatterer as a plane wave. In these conditions the far-field analysis is not valid while the near-field analysis is necessary. Therefore, in some kind of scenario, it can be more appropriate to deal with the near field scattering characteristics of the targets. For example, most of the times, ships are observed in near field condition.

The few near-field scattering studies that the authors know are the NcPTD code and the Cpatch code developed in DEMACO [1]. Then, Shyh-Kang Jeng has investigated the near-field scattering by Physical Theory of Diffraction and Shooting and Bouncing Rays [2].

However, these studies mainly based on the high frequency methods instead of numerical method, such as MLFMM. It is well-known that the prediction precision based MLFMM is more than that based high frequency methods. Obviously, higher prediction precision can ensure that characteristic analysis is more effective. Also, to our eyes, the near-field scattering of ship by MLFMM have not be found in academic journals.

This paper presents some results of near-field scattering of the ship based MLFMM. In addition, the variation characteristic of near-field scattering versus detecting distance and different elevation angles has been investigated. Moreover, the comparison of means of near-field scattering of the ship in different distances is obtained. For the sake of analysis, some predicted results and discussions about typical construction of the ship will also be given.

II. STATEMENT OF PROBLEM

Let's consider the near-field scattering problem of a typical simplified ship in free space in Fig. 1. To calculate the EM fields scattered by the ship we have used the MLFMM [3]. Then we subdivide the ship surface in N sub-surfaces (triangular meshes), in such a way that all the elementary surfaces are in the far field of the detecting antenna and target. So, the electric and magnetic fields scattered by a perfectly conducting target are given by electric-field integral equation (EFIE).

$$\hat{t}\bullet\int_S\left[\bar{J}(r')+\frac{1}{k^2}\nabla\bullet\bar{J}(r')\nabla\right]\frac{e^{jkR}}{R}d's=\frac{4\pi j}{k\eta}t\bullet\bar{E}^i(r') \quad (1)$$

where $\bar{J}$ denotes the surface currents, $\hat{t}$ is the unit vector tangent to the surface of the PEC, $\bar{E}^i$ is the incident electric field, η represents the free space impedance and k refers to the wavenumber.

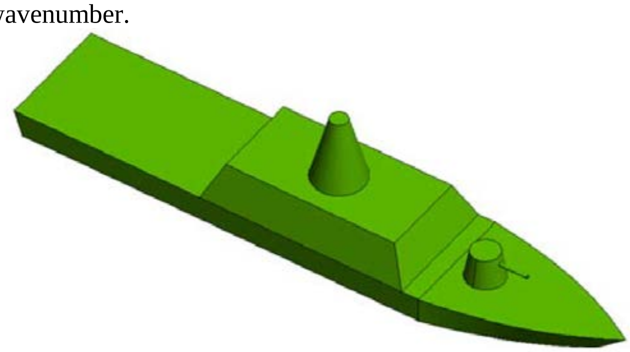

Figure. 1 A typical simplified ship (length 34m, width 7m, height 8m)

Then, the traditional far scattering (RCS) is followed.

$$\sigma_{FAR} = \lim_{r\to\infty} 4\pi r^2 \frac{\left|\vec{E}^s\right|^2}{\left|\vec{E}^i\right|^2} = \lim_{r\to\infty} 4\pi r^2 \frac{\left|\vec{H}^s\right|^2}{\left|\vec{H}^i\right|^2} \quad (2)$$

It is well-known that the classical definition of RCS is a far field parameter. It supposes that the wave front is plane on the entire ship surface. In near field we should deal with limitations due to the directivity of the antenna diagram and to the spherical shape of the wave front. In this study we only focus on the effect of the wave front shape. We suppose that the antenna radiation is isotropic, and then the exact expression of scattering in near field conditions is this expression.

$$\sigma_{NEAR} = 4\pi r^2 \frac{\left|\vec{E}^s\right|^2}{\left|\vec{E}^i\right|^2} = 4\pi r^2 \frac{\left|\vec{H}^s\right|^2}{\left|\vec{H}^i\right|^2} \quad (3)$$

Fig. 2 shows the monostatic scattering of this ship, versus azimuth angle, elevation angle, in near field at 150, 200, 500, 2000 meters (namely approximated far field range) respectively. For the sake of highlight, the scale in this picture is not well-proportioned.

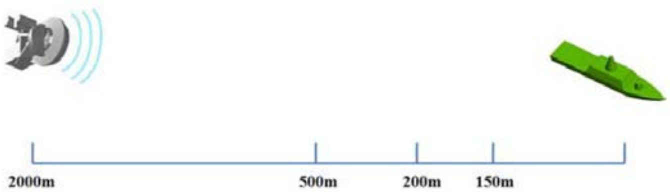

Figure. 2 The schematic drawing of detecting the ship with different distances.

III. Results and Analysis

A. Curves of near-field and far-field scattering

According to the geometrical configurations of Fig. 2, Fig. 3-6 plot the near-field scattering of the typical simplified ship in free space, at 300MHz and perpendicular polarization, at different elevation angles (90^o and 87^o) and azimuth angles (0^o-180^o) for several ranges R from near field to far field. Being confined to computer resource, here we only consider one frequency point.

From these pictures, we observe that the near field effects are mainly materialized by the shift and the spreading of some echoes. For example, the echo generated by the shipboard leading edge appears at 90^o in far field; whereas in near field, this echo appears shifted and spread in a certain angular domain. These results show that with reduction of range, the difference between results of near-field and far-field scattering become very prominent. In addition, when the elevation angle is changed, the trend of the difference is still pronounced. Moreover, it is noteworthy that peaks of curves of elevation angle 87^o are more than those of elevation angle 90^o. Obviously, this comparison result is attributed to the fact that at elevation angle 87^o, the incident rays are close to the normal direction of superstructure and cannon.

B. Comparison of mean of scattering results

For the sake of comparison of mean of scattering results, the statistical method of the typical means of scattering results of the ship is followed.

- Get ride of the results of four angle domains: $\pm 4.5^o$ of elevation angles of 0^o, 90^o, 180^o and 270^o.
- Transform the residual results from log space to linear space.
- Take the arithmetic mean of linear results.

Fig. 7-8 show the typical means of scattering results with different distances of the typical simplified ship. From these pictures, we can see that at the condition of error margin with 1dB, even rather nearer distance, such as 500m and the quarter of far-field distance, can satisfied with the traditional far-field requirement of measurement. So, it means that as for complex targets, such as ships, the required distance for RCS measurement between antennas and them may be far less than traditional far-field distance. Of course, it appears that the differences of typical means of scattering results grow as the distance shrinks further.

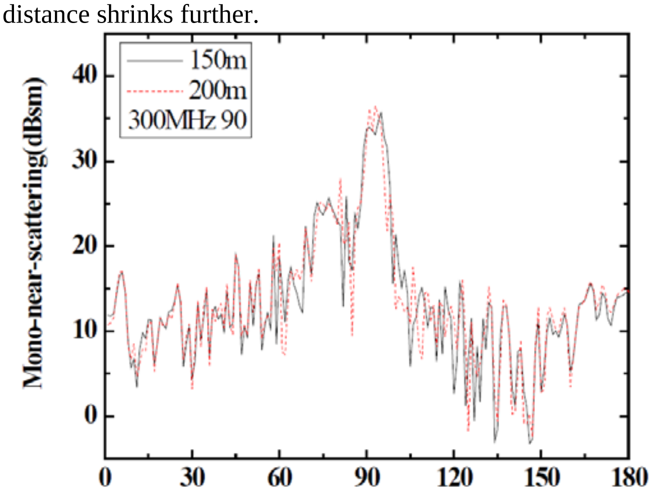

Figure. 3 Near-field scattering results of the typical simplified ship (150-200m, 300MHz, 90^o)

C. Analysis for dominant lobe division.

As we known, far-field scattering curves of the flat always exhibit the acute character at the normal direction. Moreover, as for the near-field scattering of the flat, the curve character may be changed into the configuration of dominant lobe division [4], so does the shipboard. As illustrated in Fig 3-6, we can see that the dominant lobe division occurs in different distances around the shipboard, namely it is a frequent phenomena in near-field scattering. In addition, shorter distance the more remarkable it exhibits. The picture of detail with enlarged scale of these phenomena is shown in Fig. 9, while the double-arrow lines denote the width of dominant lobe division.

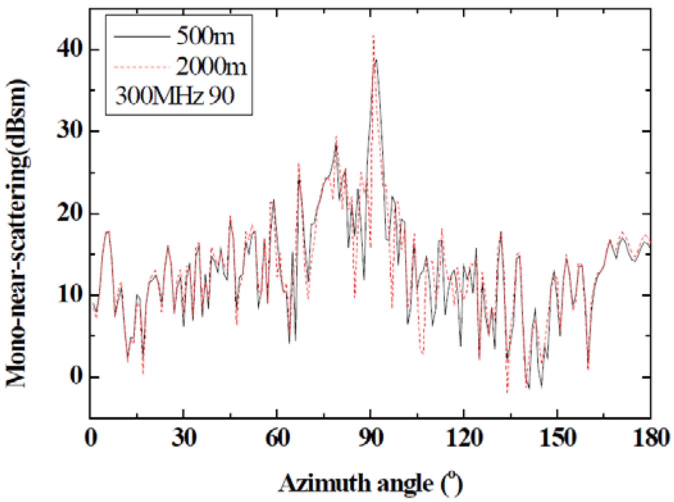

Figure. 4 Near-field scattering results of the typical simplified ship (500-2000m, 300MHz, 90°)

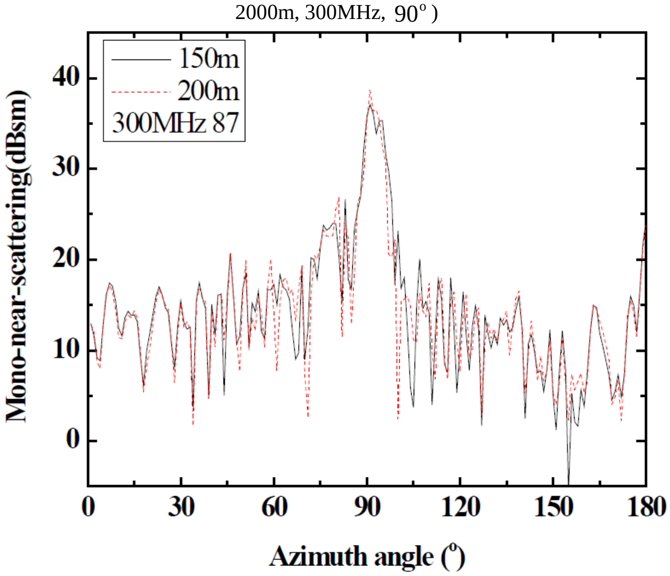

Figure. 5 Near-field scattering results of the typical simplified ship (150-200m, 300MHz, 87°)

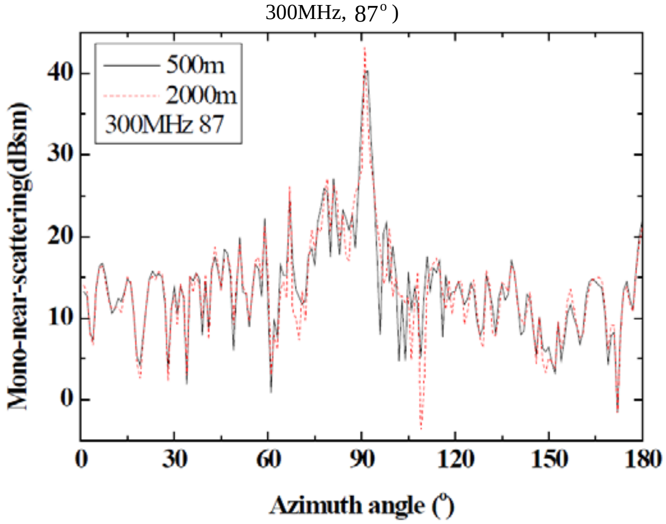

Figure. 6 Near-field scattering results of the typical simplified ship (500-2000m, 300MHz, 87°)

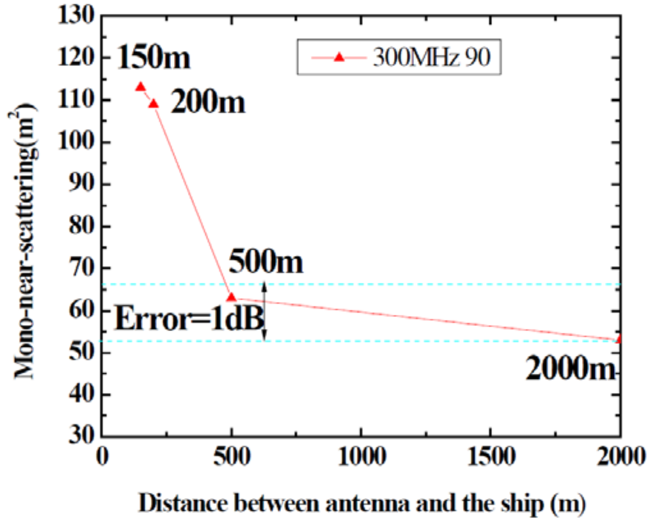

Figure. 7 The typical means with different distance of the typical simplified ship. (300MHz, 90°)

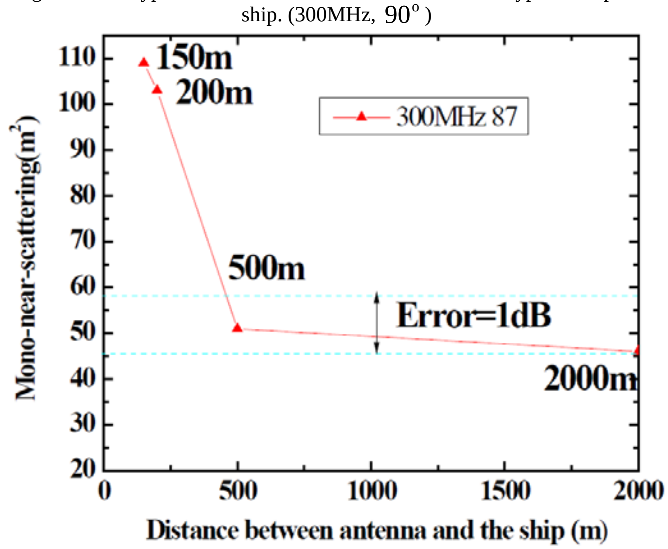

Figure. 8 The typical means with different distance of the typical simplified ship. (300MHz, 87°)

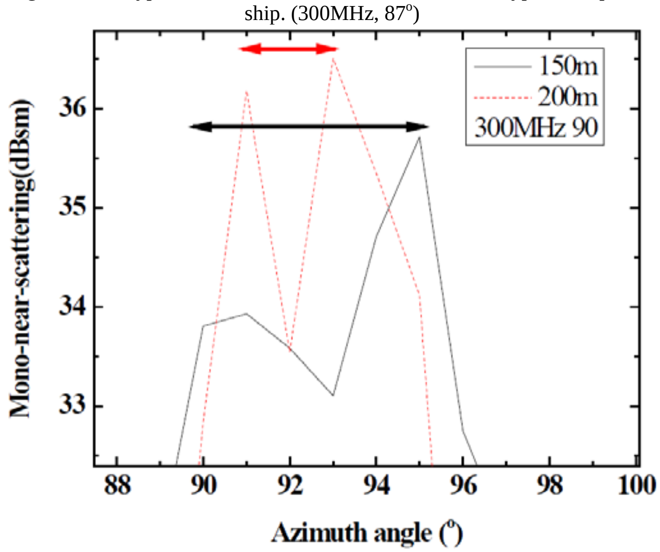

Figure. 9 The phenomena of dominant lobe division of near-field scattering patterns (detail with enlarged scale).

To give a quantitative analysis for it, we regard the conduct flat as the research subject and use the theory derivation to get the analysis expression. And then with this analysis, we shall give a coarse explanation for the ship. From the Fig. 9, we will find that the width of dominant lobe division can be regarded as the function of distance, size of flat, etc. Besides, since the distances do not satisfy with far field condition, the incident wave should be spherical wave. In our study, we assume that the size of flat is D in the direction of analysis and distances are R. As for the normal incidence, there will be strong reflection, just like far-field scattering. As for the oblique incidence, since the spherical wave effect, when the incident ray inclines to the normal direction, the dominant lobe division will exist in certain angle. With incident angle increase, while the incident ray is perpendicular to edge of flat, it will be in the end. Therefore, it is the critical condition now. If we assume incline angle to the normal indirection to be θ, we can obtain the new formula as followed:

$$\theta = \arcsin\left(D/2R\right) \quad (4)$$

Here θ is also the width of dominant lobe division of near-field scattering curve.

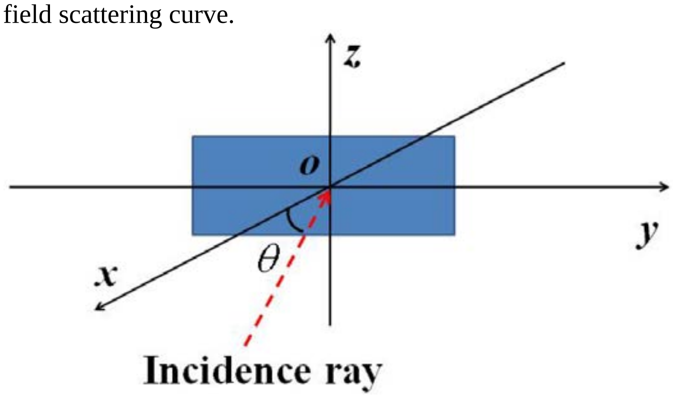

Figure. 10 The incident sketch of a conductor flat.

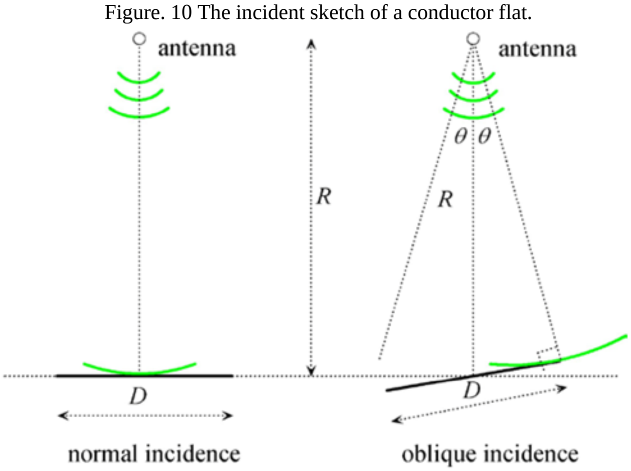

Figure. 11 The incident sketch of analysis of dominant lobe division.

According to the (4), we can obtain the width of dominant lobe division with different distances (150m and 200m at elevation angle 90°). It is very clear that they agree well with the results from MLFMM from Table I. Therefore, our new formula has been verified. In addition, obviously, our formula is much faster than that of MLFMM.

TABLE I
THE DOMINANT LOBE DIVISION WIDTH WITH DISTANCES

Case	Comparison	
	MLFMM	**The new formula**
150m, 90°	1.25°	1.3°
200m, 90°	2.5°	2.6°

Using this theory analysis, we may find that due to the facet construction of the ships, when incident ray is close to the normal direction of that, the phenomena of dominant lobe division may be exhibited.

IV. CONCLUSIONS

We proposed a simulation of near-field scattering characters of a typical simplified ship based on MLFMM. The simulation results shown that the near-field scattering characters, such as the dominant lobe division, become very prominent as the detecting distances reduce from 2000m to 150m. And we observed that for the ships, the required distance for RCS measurement between antennas and them may be far less than traditional far-field distance by comparing mean of scattering results. Moreover, we compared the predicted widths of dominant lobe division with MLFMM and the proposed new expression, and verified the validation the new expression.

Our study show the need to study near-field scattering of the ship that would exhibit more complicated characters in space and would possibly reduce significantly the distance between detecting antennas and ships. Considering the influence of sea surface is the other major direction of future research.

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