Near-Field Scattering by Physical Theory of Diffraction and Shooting and Bouncing Rays

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I. Introduction

The problem of electromagnetic wave scattering is very important in defense applications. The research on this topic was mostly centered on far-field analysis: Assume an incident plane wave, compute its scattered field due to the scatterer, and evaluate the radar cross section (RCS) of the scatterer. When the transmitting and receiving antennas are far from the scatterer, the incident wave can be approximated by a plane wave on every part of the target, the far-field analysis thus applies. However, in practical applications, there are many situations that the distance between the transmitting antenna 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, and a near-field analysis is necessary.

Most scattering papers on academic journals are related to the far-field analysis. I believe that much research on near-field analysis must have been done, but is difficult to find in academic journals because of its military value. The only near-field study that the author knows is the NcPTD code developed in DEMACO [1]. However, in [1] only the Physical Theory of Diffraction (PTD) is modified to deal with near-field scattering of convex scatterers. The Method of Shooting and Bouncing Rays (SBR), which is useful in evaluating the far-field RCS of concave targets, was not included. Also, the formulae in [1] are not explicit. The reader has to do more works to get usable expressions. This paper will present the PTD and SBR formulae for near-field scattering from a unified view.

Since the propagation speed of the electromagnetic wave is much larger than the speeds of the target and the missile, at any given instant we can determine the positions and orientations of the missile, target, and antennas. This scenario thus is "frozen" to let the electromagnetic wave be radiated from the transmitting antenna, scattered by the scatterer, and received by the receiving antenna. The received signal is expressed by the received complex amplitude b_4 [2]. Because the "frozen" scenario varies with time, the received b_4 is a function of time, we can also find the near-field RCS [1] at any moment.

II. Near-Field Scattering Formulae

A transmitting antenna Tx with input resistance R_T and vector effective antenna height (VEH) [3] $\bar{h}_T$ is located at $\bar{r}_T$. Meanwhile, a receiving antenna Rx with input resistance R_R and VEH $\bar{h}_R$ is located at $\bar{r}_R$. In addition to these two antennas, there is a scatterer composed of facets in free space. Let each facet be subdivided into small cells such that both distances from the target to Tx and to Rx are in the far-field zone of the induced currents on each cell.

Select a point on a cell, say, $\bar{r}_C$, the center of that cell. Then, the far-field approximation plus the assumption that the corresponding pattern of Tx does not change much for points on a cell enables us to approximate the incident field as a local plane wave to induce an electric current on the surface of the target. Approximate the surface current by physical optics (PO), the received field at $\bar{r}_R$ according to the PO current on a cell with a center $\bar{r}_c$ can be regarded as originating from an "image" electric current element. The received complex amplitude due to the cell is then derived as

$$b_4 = \frac{k^2}{16\pi^2}\left(\frac{\eta}{\sqrt{R_R R_T}}\right)\frac{e^{-jk(R_{CR}+R_{CT})}}{R_{CR}R_{CT}}\int_{cell} e^{jk(\hat{\zeta}_C+\hat{R}_{CR})\bullet\bar{R}'_C}ds' \\ [-(\hat{n}\bullet\bar{h}_{TC})(\hat{\zeta}_C\bullet\bar{h}_{RC})+(\hat{n}\bullet\hat{\zeta}_C)(\bar{h}_{TC}\bullet\bar{h}_{RC})] \tag{1}$$

where k is the wavenumber, η is the intrinsic impedance of the free space, R_{CT} and R_{CR} are the distances from $\bar{r}_C$ to $\bar{r}_T$ and $\bar{r}_R$, respecively. The unit vectors $\hat{\zeta}_C$ and $\hat{R}_{CR}$ point from $\bar{r}_C$ to $\bar{r}_T$ and $\bar{r}_R$, respectively. Besides, $\bar{h}_{TC}$ and $\bar{h}_{RC}$ are the VEH of Tx and Rx in the direction of $\bar{r}_C$, respectively. The integral over a cell can be calculated through [4]. Note that $\bar{R}'_C = \bar{r}' - \bar{r}_C$.

For PEC targets the diffraction is also important. The diffraction theory associated with the Physical Optics is the Physical Theory of Diffraction (PTD). By PTD a set of equivalent electric and magnetic line currents is attached on the edge of the PEC wedge. Assume that each edge can be decomposed or approximated by many linear segment. The received field at $\bar{r}_R$ according to the PTD edge currents on an illuminated linear segment of length d with a center $\bar{r}_C$ can also be treated as originating from an "image" electric current element. This current element contributes to the received complex amplitude as

$$b_4 = \frac{jk}{32\pi^2}\left(\frac{\eta}{\sqrt{R_R R_T}}\right)\frac{e^{-jk(R_{CR}+R_{CT})}}{R_{CR}R_{CT}} d\,\mathrm{sinc}[\frac{kd}{2}(\hat{\zeta}_C+\hat{R}_{CR})\bullet\hat{t}] \\ [-D_s(\bar{h}_{TC}\bullet\hat{t})(\hat{R}_{CR}\times\hat{t})+D_h(\hat{\zeta}_C\times\bar{h}_{TC})\bullet\hat{t}\,\hat{t}]\bullet(\bar{h}_{RC}\times\hat{R}_{CR}) \tag{2}$$

Here $\hat{t}$ is the unit vector along the edge segment. The notations D_s and D_h are Ufimtsev-Keller PTD diffraction coefficients [5].

If multiple reflections become significant, we have to use the Shooting and Bouncing Rays (SBR) technique. The original SBR technique deals with only far-field scattering problem [6], thus we have to modify it to handle near-field scattering problems. First of all, the surface of the target is divided into many small cells. By connecting the transmitting antenna Tx and every small cells, we check if each connected line is blocked. If a connected line is not blocked, we can obtain a corresponding ray tube of triangular cross section.

These ray tubes will reflect over the scatterer surface. The propagation of the ray tubes can be determined by tracing the center rays. Repeat tracing the center ray until that no more reflection occurs. Let there be N reflections, $\bar{r}_N$ is the last reflection poine, $\hat{\zeta}_N$ is the reflected direction at the last bounce, l_N is the total ray path length, and each reflection can be attributed to an image electric current element. Let the VEH of the last image is $\bar{h}_N$, and the intersection area of the ray tube and the target around the last reflection point $\bar{r}_N$ is S_N with a normal $\hat{n}_N$. The field received at $\bar{r}_R$ then can be regarded as produced by an "image" electric current element. The received complex amplitude due to a ray tube

$$b_4 = -\frac{k^2}{32\pi^2}\left(\frac{\eta}{\sqrt{R_R R_T}}\right)\frac{e^{-jk(R_N+l_N)}}{R_N l_N}\int_{S_N} e^{jk(\hat{R}_N-\hat{\zeta}_N)\bullet\bar{R}_N'}ds' \quad (3)$$

$$[(\bar{h}_R \times \hat{R}_N)\bullet(\bar{h}_N \times \hat{n}_N)+(\hat{n}_N \times \bar{h}_R)\bullet(\hat{\zeta}_N \times \bar{h}_N)]$$

Note that in (3) $R_N = |\bar{r}_R - \bar{r}_N|$, $\hat{R}_N = (\bar{r}_R - \bar{r}_N)/R_N$. If only single bounce occurs, (3) can be reduced to the PO result (1).

The total received complex amplitude b_4 due to the scatterer then is the superposition of the contributions from all PO cells, PTD edge segments, and SBR ray tubes. Note, however, remember to exclude the single-bounce contribution in the SBR computation, when PO contribution has been included.

III. Numerical Results

Our formulae is applied to compute the near-field RCS of the second kind [1] for an aircraft model showing in Fig. 1. There are inlet and outlet in the head and tail of the model, respectively. Also, there are wings and vertical and horizontal tails made of plates. Hence for this model, all PTD and SBR formulas are required. The computed far-field and near-field RCS obtained by moving an H-polarized isotropic antenna on the xy plane are depicted in Fig. 2. The distances between the antenna and the origin are 50000 cm (far field case) and 500 cm (near-field case), respectively. From the results, we can observe that the near-field scattering is rather different from the far-field one. Numerical results for other interesting cases have also been carried out and will be presented in the conference.

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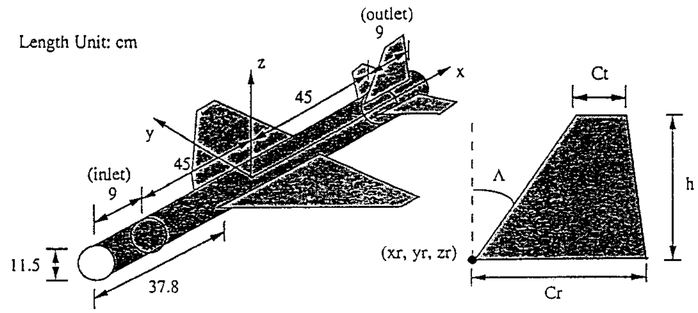

	xr	yr	zr	Cr	Ct	h	Λ
Right Wing	-16.2	5.75	0.0	43.7	2.7	27.0	56.6°
Right H-Tail	37.5	5.75	0.0	16.5	3.5	11.73	60.6°
V-Tail	37.5	0.0	5.75	16.5	3.5	11.73	60.6°

Fig. 1. Simplified Aircraft Model

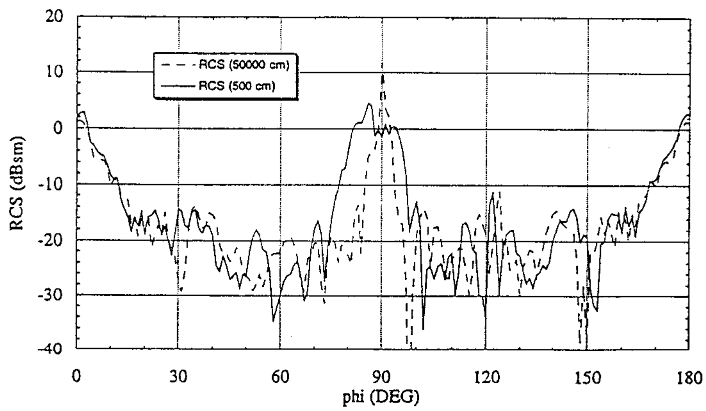

Fig. 2. Near-field and Far-field RCS of the simplified aircraft model