# Analysis of Radar Cross Section of a Moving Ellipsoid Target

Yajing Li, Kuisong Zheng, and Mingyue Yang
School of Electronics and Information, Northwestern Polytechnical University, Xi'an 710072 Shaanxi, China
kszheng@nwpu.edu.cn

***Abstract*—The scattered properties in the far-field region of an ellipsoid target, moving at high speed, are presented by a three-dimensional Lorentz Finite-Difference Time-Domain (FDTD) method. When the target is rest, the results are in good agreement with those by the MoM method and the conventional FDTD method. Numerical results show that the radar cross section (RCS) in the far-field region from the moving target is modulated by the moving speed.**

***Keywords—Lorentz-FDTD; high-speed; far-field region; RCS;***

## I. INTRODUCTION

A Lorentz Finite-Difference Time-Domain (FDTD) method is presented to solve the problem of electromagnetic properties of a complex target moving at high speed in our previous work [1-3]. An incident plane wave with the Gaussian waveform was considered into the moving coordinate system in [1]. Reference [2] displayed how to analyze the electromagnetic scattered fields from a moving dielectric slab in the near-field region. A three-dimensional Lorentz-FDTD method has been presented to analyze the radiated fields of a high-speed moving dipole at an oblique incidence in [3]. Reference [4] descripted the radar cross section (RCS) properties of uniformly moving objects in the two-dimensional space. The RCS of high-speed moving target is calculated in this paper.

The remainder of this paper is organized as follows: Section II briefly introduces the transformation formulas of the proposed method. Section III illustrates the RCS of a moving ellipsoid shaped target. Finally, concluding remarks are drawn in Section IV

## II. TRANSFORMATION FORMULAS

Here, we present the process chart of implementing the proposed method, as shown in Fig. 1. In this chart, one key step is initialized to deduce the transformation formulas of the space and time increments between two systems. One is the moving system, and another is the laboratory system. In the following sections, we arrange the variables without the primed defined in the laboratory system of *K*. Similarly, the variables with the primed are defined in the moving system of *K*'.

According to Lorentz transformation, the relationships of the space and time increments are written by

$$\Delta x=\left[1+\frac{v_x^2}{v^2}(\gamma-1)\right]\Delta x'+\frac{v_xv_y}{v^2}(\gamma-1)\Delta y'+\frac{v_xv_z}{v^2}(\gamma-1)\Delta z' \quad (1)$$

$$\Delta y=\frac{v_xv_y}{v^2}(\gamma-1)\Delta x'+\left[1+\frac{v_y^2}{v^2}(\gamma-1)\right]\Delta y'+\frac{v_yv_z}{v^2}(\gamma-1)\Delta z' \quad (2)$$

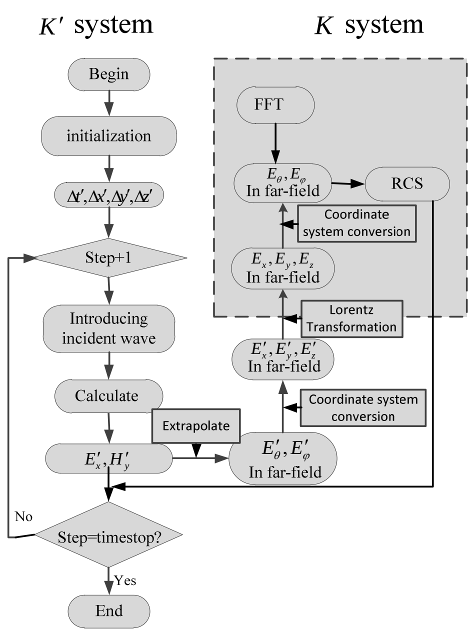



Fig.1 The process chart of the proposed method.

$$\Delta z=\frac{v_xv_z}{v^2}(\gamma-1)\Delta x'+\frac{v_yv_z}{v^2}(\gamma-1)\Delta y'+\left[1+\frac{v_z^2}{v^2}(\gamma-1)\right]\Delta z' \quad (3)$$

$$\Delta t=\gamma\Delta t'\left(1-\frac{v}{c}\hat{a}_s\cdot\hat{a}_v\right) \quad (4)$$

where $\gamma=1/\sqrt{1-(v/c)^2}$ with the speed $c$ of light in free space, and the $v$ is the moving speed of target with $\vec{v}=v_x\hat{a}_x+v_y\hat{a}_y+v_z\hat{a}_z$. The term of $\hat{a}_s\cdot\hat{a}_v$ in (4) represents the dot product of the unit vector of the scattered direction and that of the moving direction.

On the other hand, we need to transform the related parameters of the incident wave in system *K* to those in system *K*'. Those parameters are listed as the amplitude, the wave vector, and the incident angles of $\theta_i$ and $\varphi_i$, as shown in the following equation in (5).

$$\vec{E}_i=E_0\sin\left(\omega_i t-xk_i\sin\theta_i\cos\varphi_i-yk_i\sin\theta_i\sin\varphi_i-zk_i\cos\theta_i\right) \quad (5)$$

To obtain the RCS properties of moving target, we use the Huygens principle to derive the formulas of fields from the near-field region to the far-field region. The observation angles $\theta_s$ and $\varphi_s$ are defined in this progress.

Finally, we consider the transformation formulas of the electromagnetic fields between these two systems. According to the Lorentz transformation, the fields in system $K'$ are transformed into those in system $K$ given by

$$\vec{E} = \vec{E}'_{\parallel} + \gamma\left(\vec{E}'_{\perp} - \vec{v} \times \vec{B}'\right) \tag{6}$$

In (6), the subscript is defined according to the movement direction.

## III. Numerical Results and Analysis

In this section, a metallic ellipsoid-shaped target is illustrated by referring to the reference [5]. The shape of an ellipsoid is shown in Fig.2. The diameter in the long axis of the ellipsoid is 2m, and the short axis is 1m. The space increments are defined as $\Delta x' = \Delta y' = \Delta z'$=0.05m and the time increment is designed as $\Delta t' = \Delta x' / 2c$. The incident propagation direction of a Gaussian pulse is set to the angles of $(\theta_i, \varphi_i) = (0°, 0°)$. The target moves along with the angles of $(\theta_v, \varphi_v) = (0°, 0°)$ with the speed $v$ along the $+z$ axis. The back-scattered fields in far-field region are shown in Fig. 3 and Fig. 4.

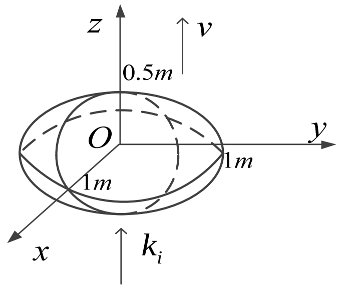



Fig.2 The sketch graph of a metallic ellipsoid.

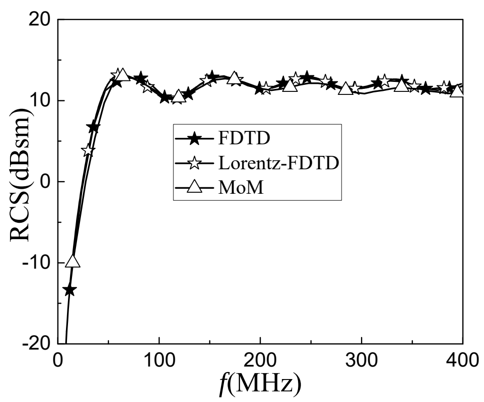
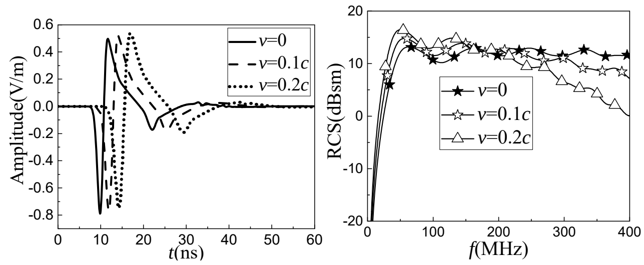



Fig.3 Comparisons of scattered fields with the conventional FDTD and MoM.

According to the proposed method, when the target is at rest, the back-scattered fields of the ellipsoid are calculated and plotted in Fig. 3. By comparing the curves in Fig.3, the accuracy of the proposed method is verified. Then, the presented method is solved to the moving target at high speed in the far-field region. The scattered waves and the RCS results of the ellipsoid in the far-field region is plotted in Fig. 4 at different speeds of $v$=0, 0.1$c$ and 0.2$c$. The comparisons of the scattered waves versus speed are displayed in Fig.4 (a). From Fig.4 (b), it is noted that the movement of the target modulates the RCS fields. In special, the faster the movement speed, the stronger the modulation effect.




(a) (b)

Fig.4 The back-scattered fields from the moving target at different speeds. (a) Scattered waves in time domain; (b) RCS results in frequency domain.

## IV. Conclusion

In this paper, an ellipsoid-shaped target, moving at high speed, has been considered by using the Lorentz-FDTD method. Certainly, the proposed method can also deal with the radiated fields when the target moves at low speed. The RCS results of the target in the far-field region have been presented for different movement speeds. In our further research work, the scattered properties of more complex targets at different speeds and different frequency bands in the far-field region will be considered.

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