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Distribution characteristic of scattering field for an ellipsoidal target irradiated by an electromagnetic wave from an arbitrary direction*

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It is of great importance for engineering applications to obtain the expression of scattering field for an ellipsoidal target irradiated by an electromagnetic wave from an arbitrary direction. Literature relevant to this problem is seldom found. In this paper, the scattering field for an ellipsoidal target is presented by utilizing the scale transformation of electromagnetic field and the rotation of coordinate system, with an electromagnetic wave projecting on the target from an arbitrary direction. The obtained result is in good agreement with the solution available from the literature if we consider the scale factors to be unity. Taking a conducting ellipsoidal target for sample, we perform the partial simulations of the ellipsoidal model and a plant leaf model by choosing different scale factors. The obtained results show that the distribution characteristic of scattering field is sensitively affected by the polarization of the incident wave and varies not much with the incident wave angle but changes with the observation point. At some points the scattering energy arrives at its maximum.

Keywords: ellipsoidal target, scale analysis, arbitrary incidence and polarization, scattering characteristics

PACC: 5235H, 4110H, 9580D

1. Introduction

In recent years, there has been increasing interest of scholars and engineers in the research of complex electromagnetic scattering for plant leaves, chaffs, etc. In the literature,[1] the deciduous leaves are modelled as discs and needles to study electromagnetic wave from the randomly oriented dielectric scatters by utilizing the Helmholtz integration equation and numerical arithmetic. In Refs.[2, 3] the echo power of electromagnetic wave from a finite long fiberglass coated with aluminium is investigated by regarding it as a scattering model for chaffs. Actually, a more exact model for plant leaves should be an ellipsoidal disc, and a better model for chaffs should be a finite long elliptical cylinder. In a Cartesian coordinate system, when the three semi axes a, b and c for an elliptical sphere are given with different sizes, the so obtained elliptical spheres are different from each other in size and shape. For example, when $a \gg b \approx c$, the elliptical sphere is approximated as a leaf or a finite long cylinder located along the x-axis. Thus investigating the property of scattering wave from an elliptical sphere is of significance both in theory and in engineering, when the incident wave propagates and polarizes in arbitrary directions. References [4–6] have derived an expression of scattering field from a sphere for the incident wave propagating in the z-axis direction and polarizing along the x-axis direction. In Ref.[7] the scattering field from a sphere is presented when the sphere is irradiated by an electromagnetic wave from an arbitrary direction rather than a particular one. And in Refs.[8–11] the scale transformation of electromagnetic wave and a curved-face coordinate system are used respectively to investigate the scattering characteristics of an elliptical sphere under the particular condition of electro-

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magnetic wave propagating in the z-axis direction and polarizing in the x-axis direction. In Refs.[12–16] the electromagnetic interaction between a spherical target and rough surface and the scattering characteristics for a cluster spheres are researched in detail. Many other subjects of complex electromagnetic scattering are frequently published.[17−23]

The structure of this paper is as follows. The solution of scattering field from an ellipsoidal target is presented on the assumption that the incident wave propagates and polarizes in arbitrary directions. And then the agreement between the obtained solution and the solution available from the literature for the sphere target case is demonstrated. Finally, we take a conducting elliptical sphere model and perform the partial simulations based on the obtained results. The distribution characteristics of scattering field from an elliptical sphere are shown to depend on the target size, the azimuth angle, the operating frequency, etc and discussed in detail. The method used is valid for the research of a coated elliptical sphere and features briefness in calculation and clearness in physical significance.

2. Scattering for ellipsoid irradiated by an electromagnetic wave with polarization and propagation in arbitrary directions

2.1. The procedure of solving the problem

It is assumed that there is an ellipsoidal sphere located at the origin of a Cartesian coordinate system Σ as illustrated in Fig.1. We use a, b and c to denote its three semi axes. The ellipsoidal sphere can be changed into a round sphere and the incident wave can also be turned into another one[10,11] expressed by the new coordinates $\Sigma_{\rm m}$ as shown in Fig.2, by utilizing the scale transformation, thereby the measurement criterion changes with the direction correspondingly. From Refs.[7, 11] we can obtain the solution of scattering field from the sphere and then transform this solution into the initial coordinate system Σ, thus the solution of scattering field from an ellipsoid is obtained for the incident wave irradiating the target from an arbitrary direction. The concrete process of solving this problem is demonstrated in Figs.1–4. In the coordinate system Σ, there is an ellipsoidal target described with the semi axes of a, b, c. In Fig.3, θ_0 is the angle between the wave propagating direction and the z-axis direction, ϕ_0 is the angle between the polarization direction and the x-axis direction. These two parameters can entirely determine the incident wave propagation[7] in the coordinate system Σ. After scale transformation, the target in the coordinate system $\Sigma_{\rm m}$ can be changed into a round sphere with a radius of 1m, and the original parameters θ_0 and ϕ_0 are changed into $\theta_{0\rm m}$ and $\phi_{0\rm m}$ as shown in Fig.2. All the physical quantities in $\Sigma_{\rm m}$ are symbolized with subscript m. We have another coordinate system Σ' obtained by rotating $x_{\rm m}$ axis through an angle $\phi_{0\rm m}$ around the $z_{\rm m}$ axis and then rotating the $z_{\rm m}$ axis through an angle $\theta_{0\rm m}$ around the $x_{\rm m}$ axis as shown in Figs.3 and 4. Now the incident wave propagates along the z'-axis direction, polarizes along the x'-direction, and irradiates on a sphere. All the physical quantities in Σ' are marked with a superscript, i.e. a prime "$'$". Finally the solution of scattering field from the ellipsoidal target is obtained after a series of inverse transformations.

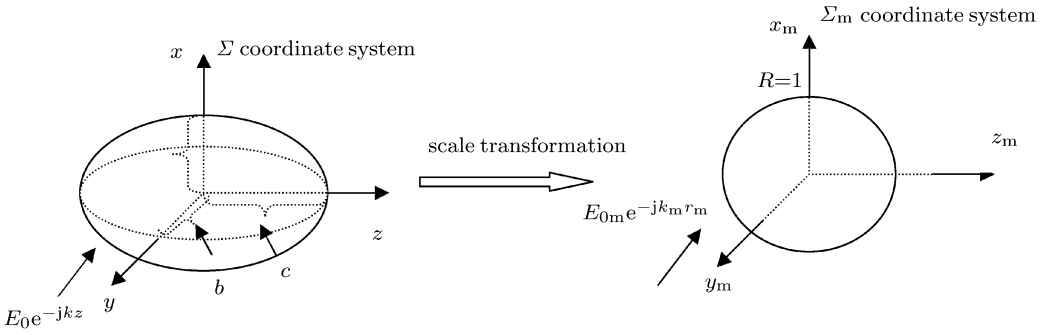


Fig.1. Incident wave irradiating on an ellipsoidal target. **Fig.2.** Incident wave irradiating on a spherical target.

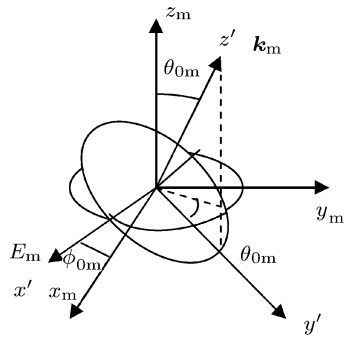


Fig.3. Relation between coordinate system $\Sigma_{\rm m}$ and coordinate system Σ'.

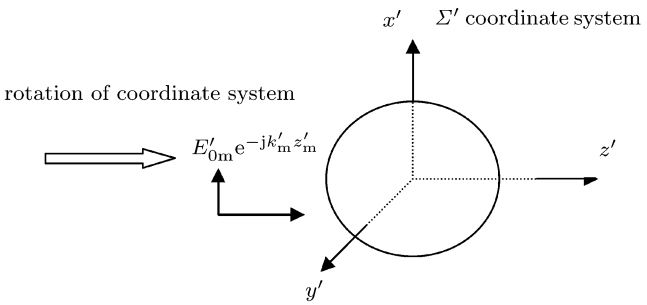


Fig.4. Incident wave irradiating on a sphere.

2.2. The scattering field from an elliptical sphere

A plane electromagnetic wave in the coordinate system Σ may be written as

$$E = E_0{\rm e}^{-{\rm j}k\cdot r}. \tag{1}$$

Its propagating direction crosses the z-axis at an angle θ_0 and its polarization direction crosses the x-axis at an angle ϕ_0. We know from the Refs.[10, 11] that the measurement standard for length is changed as the scale factors a, b, c are introduced. Accordingly the incident wave in the coordinate system $\Sigma_{\rm m}$ is changed into the following form:

$$E_{\rm m} = E_{0\rm m}{\rm e}^{-{\rm j}k_{\rm m}\cdot r_{\rm m}}, \tag{2}$$

where, $E_{0\rm m} = E_0/q_0$, and $k_{\rm m} = k/q_0$, with

$$q_0 = \left(\frac{\sin^2\theta_0\cos^2\varphi_0}{a^2} + \frac{\sin^2\theta_0\sin^2\varphi_0}{b^2} + \frac{\cos^2\theta_0}{c^2}\right)^{1/2}.$$

The trigonometric functions of azimuthal angle are

$$\sin\theta_{0\rm m} = \frac{\sin\theta_0 g_0}{q_0},$$
$$g_0 = \left(\frac{\cos^2\varphi_0}{a^2} + \frac{\sin^2\varphi_0}{b^2}\right)^{1/2},$$
$$\cos\theta_{0\rm m} = \frac{\cos\theta_0/c}{q_0},$$
$$\sin\varphi_{0\rm m} = \frac{\sin\varphi_0/b}{g_0},$$

and

$$\cos\varphi_{0\rm m} = \frac{\cos\varphi_0/a}{g_0}. \tag{3}$$

Another coordinate system Σ' is constructed by rotating the $x_{\rm m}$ axis through an angle $\phi_{0\rm m}$ around the $z_{\rm m}$ axis and then rotating the $z_{\rm m}$ axis through an angle $\theta_{0\rm m}$ around the $x_{\rm m}$ axis as shown in Fig.3. The incident wave in the coordinate system Σ' propagates along the z'-axis and polarizes along the x'-direction, which projects on a sphere, namely

$$E'_{\rm i} = E'_0{\rm e}^{-{\rm j}k'z'}, \tag{4}$$

where $E'_0 = E_{0\rm m} = E_0/q_0$, and $k' = k_{\rm m} = k/q_0$. The scattering field from the target in the new coordinate system can be written as [4,6,11]

$$E_{\theta' s} = \frac{{\rm j}E'_0{\rm e}^{-{\rm j}k'r'}}{k'r'}\cos\varphi' s_2(\theta'),$$
$$E_{\varphi' s} = \frac{-{\rm j}E'_0{\rm e}^{-{\rm j}k'r'}}{k'r'}\sin\varphi' s_1(\theta'), \tag{5}$$

where

$$s_2(\theta') = \sum_{n=1}^{\infty} a_n[c_n\tau_n + d_n\pi_n],$$
$$s_1(\theta') = \sum_{n=1}^{\infty} a_n[\pi_n c_n + d_n\tau_n],$$
$$\tau_n = \frac{{\rm d}P_n^1(\cos\theta')}{{\rm d}\theta'},$$
$$\pi_n = \frac{P_n^1(\cos\theta')}{\sin\theta'},$$
$$c_n = -\frac{\hat{J}'_n(k')}{\hat{H}'_n(k')},$$
$$d_n = -\frac{\hat{J}_n(k')}{\hat{H}_n(k')},$$

and

$$a_n = \frac{2n+1}{n(n+1)}.$$

We know from the Refs.[7, 11] that the trigonometric functions for the above may be expressed as

$$\sin\theta' = \sqrt{A^2+B^2}, \quad \cos\varphi' = A/\sqrt{A^2+B^2}, \quad \sin\varphi' = B/\sqrt{A^2+B^2},$$
$$\cos\theta' = \sin\theta_{0\mathrm{m}}\sin\theta_{\mathrm{m}}\sin(\varphi_{0\mathrm{m}}+\varphi_{\mathrm{m}}) + \cos\theta_{0\mathrm{m}}\cos\theta_{\mathrm{m}}, \tag{6}$$

$$\mathrm{d}\theta' = \frac{[\sin\theta_{0\mathrm{m}}\cos\theta_{\mathrm{m}}\sin(\phi_{0\mathrm{m}}+\phi_{\mathrm{m}}) - \cos\theta_{0\mathrm{m}}\sin\theta_{\mathrm{m}}]\mathrm{d}\theta_{\mathrm{m}} + \sin\theta_{0\mathrm{m}}\sin\theta_{\mathrm{m}}\cos(\phi_{0\mathrm{m}}+\phi_{\mathrm{m}})\,\mathrm{d}\phi_{\mathrm{m}}}{-\sqrt{A^2+B^2}},$$
$$A = \cos\varphi_{0\mathrm{m}}\sin\theta_{\mathrm{m}}\cos\varphi_{\mathrm{m}} - \sin\varphi_{0\mathrm{m}}\sin\theta_{\mathrm{m}}\sin\varphi_{\mathrm{m}},$$

and

$$B = \cos\theta_{0\mathrm{m}}\sin\varphi_{0\mathrm{m}}\sin\theta_{\mathrm{m}}\cos\varphi_{\mathrm{m}} - \sin\theta_{0\mathrm{m}}\cos\theta_{\mathrm{m}} + \cos\theta_{0\mathrm{m}}\cos\varphi_{0\mathrm{m}}\sin\theta_{\mathrm{m}}\sin\varphi_{\mathrm{m}}.$$

In expression (6), the quantities with subscript 0m are the relative azimuthal angles θ_0 and ϕ_0; the quantities with subscript m refer to the variables corresponding to angles θ and ϕ. We refer to the transformations from (1) to (5) as the positive transformations. The scattering field from an ellipsoidal target irradiated by the incident wave with polarization and propagation in arbitrary directions will be derived through an inverse transformation in the following. We know [7] the following relations of electromagnetic field between coordinate systems Σ' and Σ_{m}

$$\boldsymbol{E}_{\mathrm{sm}} = \boldsymbol{P}_{\mathrm{s}}\boldsymbol{E}'_{\mathrm{s}}, \quad \text{and} \quad \boldsymbol{P}_{\mathrm{s}} = \boldsymbol{P}_{\mathrm{m}}^{-1}\boldsymbol{A}_0^{-1}\boldsymbol{P}_1. \tag{7}$$

We also acquire the following relation of electromagnetic field between[10,11] coordinates Σ and Σ_{m}

$$\boldsymbol{E}_{\mathrm{s}} = \boldsymbol{Q}^{-1}\boldsymbol{E}_{\mathrm{sm}}. \tag{8}$$

The relation of scattering electromagnetic field between in coordinate system Σ and in coordinate system Σ' is derived by substituting expression (7) into relation (8)

$$\boldsymbol{E}_{\mathrm{s}} = \boldsymbol{T}\boldsymbol{E}'_{\mathrm{s}}, \tag{9}$$

where $\boldsymbol{T} = \boldsymbol{Q}^{-1}\boldsymbol{P}_{\mathrm{m}}^{-1}\boldsymbol{A}_0^{-1}\boldsymbol{P}_1$. The elements in matrix (9) can be found from the literature. The scattering field in the Σ coordinate system is presented by inserting expression (5) into expression (9), namely

$$E_{\theta\mathrm{s}} = T_{22}E_{\theta'\mathrm{s}} + T_{23}E_{\phi'\mathrm{s}},$$

and

$$E_{\varphi\mathrm{s}} = T_{32}E_{\theta'\mathrm{s}} + T_{33}E_{\phi'\mathrm{s}}, \tag{10}$$

which are the expression of the scattering field from an ellipsoidal target irradiated by the incident wave in an arbitrary direction. For convenience, all the physical quantities above are expressed with Σ coordinates. The following are the concrete expressions:

$$r' = rq, \quad k'r' = kr,$$

$$T_{22} = q_{21}p_{12} + q_{22}p_{22},$$
$$T_{23} = q_{21}p_{13} + q_{22}p_{23},$$
$$T_{32} = q_{31}p_{12} + q_{32}p_{22} + q_{33}p_{32},$$

and

$$T_{33} = q_{31}p_{13} + q_{32}p_{23} + q_{33}p_{33},$$

where

$$q_{21} = \frac{\sin(2\theta)}{2q}\left[g^2 - \frac{1}{c^2}\right], \quad q_{22} = \frac{g}{cq},$$
$$q_{31} = \frac{\sin\theta\sin(2\varphi)}{2q}\left[\frac{1}{b^2} - \frac{1}{a^2}\right], \quad q_{32} = \frac{\cos\theta\sin(2\varphi)}{2cqg}\left[\frac{1}{b^2} - \frac{1}{a^2}\right], \quad q_{33} = \frac{1}{abg},$$

$$\begin{aligned} p_{12} = &-\cos\theta\sin\theta_{\mathrm{m}}\cos\theta_0 - \sin\theta_0\cos\theta\cos\theta_{\mathrm{m}}\sin\varphi_{\mathrm{m}} + \cos\varphi_0\sin\theta\cos\theta_{\mathrm{m}}\cos\varphi_{\mathrm{m}}\cos\varphi \\ &- \sin\theta_0\cos\varphi_0\sin\theta_{\mathrm{m}}\sin\theta\sin\varphi - \sin\theta_0\sin\theta_{\mathrm{m}}\sin\theta\cos\varphi\sin\varphi_0 - \sin\theta\cos\theta_{\mathrm{m}}\cos\varphi_{\mathrm{m}}\sin\varphi\sin\varphi_0 \\ &+ \cos\theta_0\sin\varphi_0\cos\theta_{\mathrm{m}}\sin\varphi_{\mathrm{m}}\sin\theta\cos\varphi + \cos\varphi_0\cos\theta_{\mathrm{m}}\sin\varphi_{\mathrm{m}}\sin\theta\sin\varphi\cos\theta_0, \end{aligned}$$

$$\begin{aligned} p_{13} = &\sin\theta_{\mathrm{m}}\sin\theta\sin\varphi\sin\varphi_0 - \cos\varphi_0\sin\varphi_{\mathrm{m}}\sin\theta\cos\varphi - \sin\theta_0\cos\theta\cos\varphi_{\mathrm{m}} \\ &+ \cos\varphi_0\cos\varphi_{\mathrm{m}}\sin\theta\sin\varphi\cos\theta_0 + \cos\varphi_{\mathrm{m}}\sin\theta\cos\varphi\cos\theta_0\sin\varphi_0, \end{aligned}$$

$$\begin{aligned}p_{22} =& \sin\theta_{\rm m}\sin\theta\cos\theta_0 - \sin\theta_0\cos\varphi_0\cos\theta\sin\theta_{\rm m}\sin\varphi + \cos\varphi_0\cos\theta\cos\theta_{\rm m}\sin\varphi_{\rm m}\sin\varphi\cos\theta_0\\ &+ \cos\theta\cos\theta_{\rm m}\sin\varphi_{\rm m}\cos\varphi\cos\theta_0\sin\varphi_0 - \sin\theta_0\cos\theta\sin\theta_{\rm m}\cos\varphi\sin\varphi_0 + \cos\varphi_0\cos\theta\cos\theta_{\rm m}\cos\varphi_{\rm m}\cos\varphi\\ &+ \sin\theta_0\cos\theta_{\rm m}\sin\varphi_{\rm m}\sin\theta - \cos\theta\cos\theta_{\rm m}\cos\varphi_{\rm m}\sin\varphi\sin\varphi_0,\end{aligned}$$

$$\begin{aligned}p_{23} =& \cos\theta\sin\varphi_{\rm m}\sin\varphi\sin\varphi_0 - \cos\varphi_0\cos\theta\sin\varphi_{\rm m}\cos\varphi + \sin\theta_0\cos\varphi_{\rm m}\sin\theta\\ &+ \cos\varphi_0\cos\theta\cos\varphi_{\rm m}\sin\varphi\cos\theta_0 + \cos\theta\cos\varphi_{\rm m}\cos\varphi\cos\theta_0\sin\varphi_0,\end{aligned}$$

$$\begin{aligned}p_{32} =& \cos\varphi_0\cos\theta_0\cos\theta_{\rm m}\sin\varphi_{\rm m}\cos\varphi - \cos\varphi_0\sin\theta_0\sin\theta_{\rm m}\cos\varphi - \cos\varphi_0\cos\theta_{\rm m}\cos\varphi_{\rm m}\sin\varphi\\ &+ \sin\theta_0\sin\theta_{\rm m}\sin\varphi\sin\varphi_0 - \cos\theta_{\rm m}\cos\varphi_{\rm m}\cos\varphi\sin\varphi_0 - \cos\theta_0\cos\theta_{\rm m}\sin\varphi_{\rm m}\sin\varphi\sin\varphi_0,\end{aligned}$$

$$p_{33} = \cos\varphi_0\cos\varphi_{\rm m}\cos\theta_0\cos\varphi + \cos\varphi_0\sin\varphi_{\rm m}\sin\varphi + \sin\varphi_{\rm m}\cos\varphi\sin\varphi_0 - \cos\varphi_{\rm m}\cos\theta_0\sin\varphi\sin\varphi_0,$$

with

$$q = \left(\frac{\sin^2\theta\cos^2\varphi}{a^2} + \frac{\sin^2\theta\sin^2\varphi}{b^2} + \frac{\cos^2\theta}{c^2}\right)^{1/2}, \quad g = \left(\frac{\cos^2\varphi}{a^2} + \frac{\sin^2\varphi}{b^2}\right)^{1/2},$$

$$\sin\theta_{\rm m} = \frac{\sin\theta g}{q}, \quad g = \left(\frac{\cos^2\varphi}{a^2} + \frac{\sin^2\varphi}{b^2}\right)^{1/2}, \quad \cos\theta_{\rm m} = \frac{\cos\theta/c}{q},$$
$$\sin\varphi_{\rm m} = \frac{\sin\varphi/b}{g}, \quad \text{and} \quad \cos\varphi_{\rm m} = \frac{\cos\varphi/a}{g}.$$

From the above equations, it is easy to find that the elements of the transformation matrix are completely determined by the parameters θ_0, φ_0 and θ, φ in Σ coordinates. There exists such a difficulty in trying to turn these elements into simple ones that the investigation of the scattering wave from an ellipsoidal target irradiated by a wave in an arbitrary direction becomes very complicated. In fact, the complicated expressions above must be solved by computer. If the incident azimuthal angles θ_0 and φ_0 are given, then the middle azimuthal angles $\theta_{0\rm m}$ and $\varphi_{0\rm m}$ can be determined; and if the observation azimuthal angles θ and φ and the distance r are given, these parameters $\theta_{\rm m}$, $\varphi_{\rm m}r'$ and θ', φ' are also known entirely.

2.3. Discussion and simulations

When the incident azimuthal angles θ_0 and φ_0 are zero, i.e. $\theta_0 = \varphi_0 = 0$, it follows from expression (3) that $\theta_{0\rm m} = 0$, and $\varphi_{0\rm m} = 0$, so that the elements of the matrix are written as

$$\begin{aligned}p_{12} =& -\cos\theta\sin\theta_{\rm m} + \sin\theta\cos\theta_{\rm m}\cos\varphi_{\rm m}\cos\varphi\\ &+ \cos\theta_{\rm m}\sin\varphi_{\rm m}\sin\theta\sin\varphi,\\ p_{13} =& -\sin\varphi_{\rm m}\sin\theta\cos\varphi + \cos\varphi_{\rm m}\sin\theta\sin\varphi,\\ p_{22} =& \sin\theta_{\rm m}\sin\theta + \cos\theta\cos\theta_{\rm m}\sin\varphi_{\rm m}\sin\varphi\\ &+ \cos\theta\cos\theta_{\rm m}\cos\varphi_{\rm m}\cos\varphi,\\ p_{23} =& -\cos\theta\sin\varphi_{\rm m}\cos\varphi + \cos\theta\cos\varphi_{\rm m}\sin\varphi,\\ p_{32} =& \cos\theta_{\rm m}\sin\varphi_{\rm m}\cos\varphi - \cos\theta_{\rm m}\cos\varphi_{\rm m}\sin\varphi,\end{aligned}$$

and

$$p_{33} = \cos\varphi_{\rm m}\cos\varphi + \sin\varphi_{\rm m}\sin\varphi.$$

When the scale factors satisfy that $a = 1$, $b = 1$, and $c = 1$, we obtain $\theta_{\rm m} = \theta$, $\phi_{\rm m} = \phi$, $q = 1$, $g = 1$, $q_{21} = 0$, $q_{22} = 1$, $q_{31} = 0$, $q_{32} = 0$, and $q_{33} = 1$, further $r' = r$, $k' = k$, $p_{12} = 0$, $p_{13} = 0$, $p_{22} = 1$, $p_{23} = 0$, $p_{32} = 0$, $p_{33} = 1$, $T_{22} = 1$, $T_{23} = 0$, $T_{32} = 0$, and $T_{33} = 1$. Thus we acquire from expression (6) that $\phi' = \phi$ and $\theta' = \theta$. Substituting the above results into expression (10), we can easily obtain

$$E_{\theta s} = E_{\theta' s}, \quad \text{and} \quad E_{\varphi s} = E_{\phi' s}. \tag{11}$$

The ellipsoidal target is reshaped into a spherical one with a radius of 1m when all the scale factors are taken to be 1. Expression (11) is an inevitable result that demonstrates the correctness of this algorithm used in this paper. The obtained result (10) is valid to investigate the scattering characteristics for a dielectric ellipsoidal target, conducting ellipsoidal target and multilayered dielectric ellipsoidal target if

we substitute the expressions of scattering field available from the literature relevant to those targets into expression (10). This result has established a theoretical base for studying the scattering wave from an elliptical disc, chaff and plant leaves. For the sake of briefness, we take a conducting ellipsoidal target model. The parameters used in the partial simulations are f=0.6 GHz, a=1.1 m, b=1.3 m, and c=1.5 m. The following are the results, in which E^2 in the y-axis denotes the scattering field power.

In Fig.5 the polarization angle φ_0 is $\pi/3$, and in Fig.6, the incident wave propagates along the z-axis direction. It is concluded that the scattering field generally varies not much with the incident wave, but at a particular observation point the scattering field changes greatly.

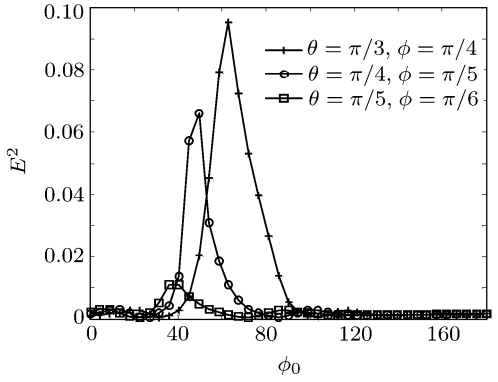


Fig.5. Scattering field power versus incident angle.

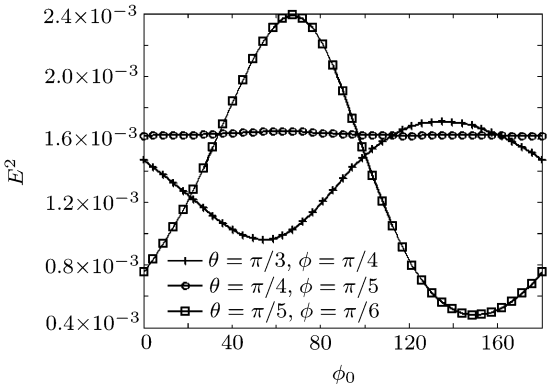


Fig.6. Scattering field power versus polarization angle.

The scattering field changes obviously with the polarizing angle, when the incident angle is fixed, Figures 7 and 8 imply that, when the polarization state of incident wave is fixed, the energy of scattering wave is very large in an observation area, but trivial in the remaining areas, which provides a theory for hiding targets and identifying targets.

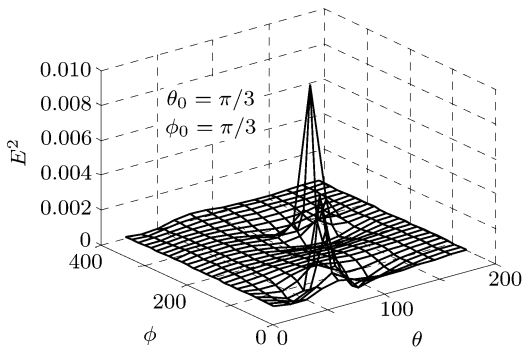


Fig.7. Scattering field power versus observation point.

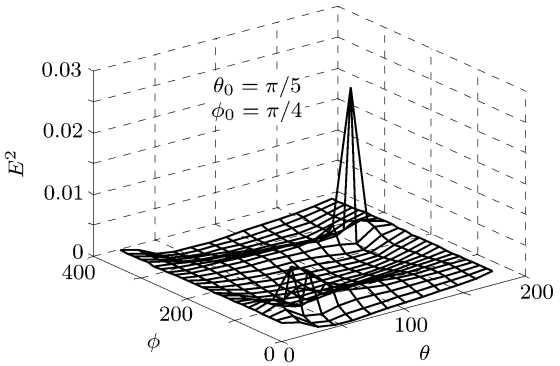


Fig.8. Scattering field power versus observation point.

Although the leaves of plant are various in shape and in size, they are elliptical discs in shape approximately and their size generally is on the order of several centimetres. So it is assumed in the following that $2c$=7 cm, $2b$=3 cm, $2a$=1 mm, and f=60 GHz. This kind of target is a very good scattering model for the leaf situated in the $y-z$ plane. The following are the partial simulations. The observation points in Figs.9 and 10 are the same which indicate that the polarization of incident wave has a great influence on the scattering field and the scattering effect arrives at its large value when the incident wave irradiates the target vertically. The size of scattering field is about several centimetres, on the same order as those in Figs.11 and 12. Figure 12 shows the scattering field varying with the angle ϕ sensitively and at an angle (ϕ) of 0 or π, the scattering field arrives at its maximum. It is understandable that the scattering is caused by the Faradic current on the leaf. In fact, if we use the parameters of $a \approx b \gg c$, this will be a good scattering model for a chaff and a finite long cylinder. Here, we no longer investigate it in detail.

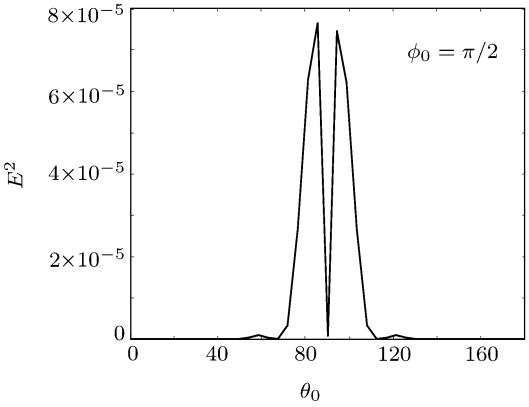


Fig.9. Scattering field power versus incident angle.

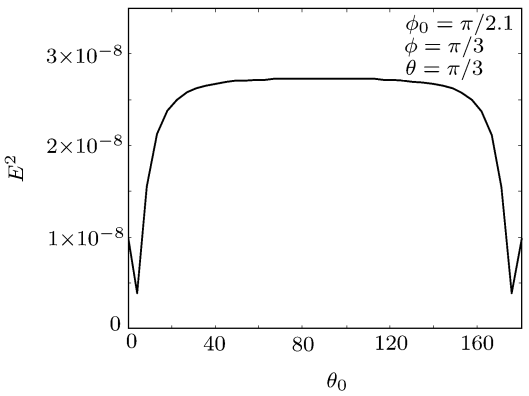


Fig.10. Scattering field power versus incident angle.

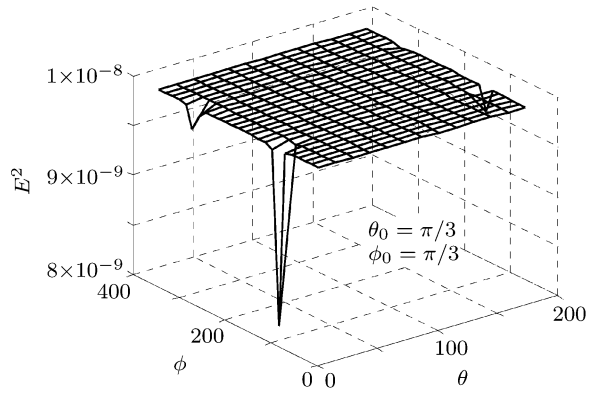


Fig.11. Scattering field power versus observation point.

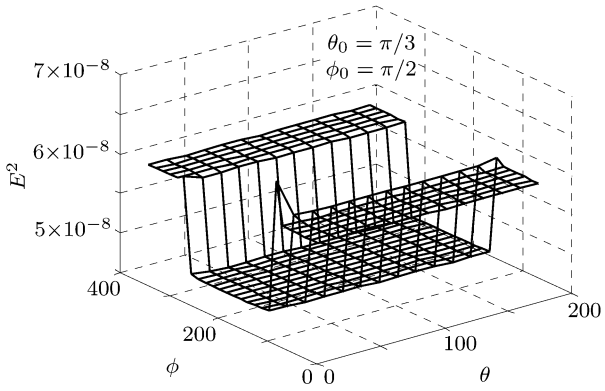


Fig.12. Scattering field power versus observation point.

3. Conclusion

The analytic solution of scattering wave from an ellipsoidal target irradiated by an electromagnetic wave in an arbitrary direction is a Gordian knot. Although it has received much attention of scientists and engineers, few relevant papers have been published. In this paper, the ellipsoidal target is first reshaped into a spherical target by utilizing the scale transformation of electromagnetic wave. Then we use the coordinate system rotation and some expressions available from the published literature to obtain the solution of scattering wave from the reshaped target. Finally the solution of scattering field from an elliptical target irradiated by an incident wave in an arbitrary direction is presented by performing an inverse transformation, inverse rotation transformation and inverse scales transformation. The results show that the solution of scattering wave of an elliptical target turns into that of a spherical target when all the scales are taken to be unity. The obtained result is consistent with that in the literature. We take a conducting ellipsoidal target as an example to establish a model both for elliptical target and plant leaf by using the different scale factors. Simulations for the two models are carried out separately. Results indicate that the scattering field is sensitively affected by the polarization of the incident wave and varies not much with the incident wave but changes with the observation point. At some points the energy of scattering wave arrives at its maximum. The method used here features the briefness in calculation and perspicuity in physical significance. The result obtained is convenient to computer simulation and has a broad application in the fields such as complex scatterings of chaff, plant leaves and target identification, etc.

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