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Original research article

Analysis of 3D elliptical reflector antenna coated with chiral layer under normal incident electromagnetic wave

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ABSTRACT

In this paper, a 3D elliptical reflector coated with chiral medium has been analyzed to find the field in the vicinity of focal region using geometrical optics (GO) and Maslov's method. As the GO approximation does not work at the focal points due to unreal singularities occur at these points. Therefore, Maslov's theory has been applied to derive the expressions which are also valid at focal points. These focal points usually are of great importance in all practical applications. The effects of thickness (d) of the coated medium, chirality parameter (β) of the coated medium and permittivity (ε) of the medium on the focal region fields are illustrated. A special case of elliptical reflector coated with conventional medium has also been evaluated. The derived fields expressions are plotted using MATLAB software.

1. Introduction

The propagation of electromagnetic waves in artificial mediums in a prescribed fashion through varying the design parameters have been the prime focus of interest of many authors [1–4]. Among various other forms, chiral medium and its interaction with electromagnetic wave has been discussed extensively over the years due to its potential application in the field of antenna, radar, material design, optics and data storage. Within the context, reports have appeared highlighting the applications of such artificial material when these materials are coated with some other optical, microwave, radar, and antenna devices. In this stream, the focussing of waves by reflector and lenses having single or multi-layered coatings of different kinds of mediums have been reported in the literature implementing various analytical approaches [5–9]. These focusing systems are widely used over the years for satellite communication, laser systems, solar systems, radar technology, optical communication and microwave systems. Mostly metallic or dielectric materials are used in the design of these focussing devices. The metal based reflectors have the potential to operate over wide band of frequencies. However, at higher frequency band considerable part of the reflected wave is lost due to absorption. Therefore, to overcome these losses the reflectors are coated with some electromagnetic materials like chiral medium which exhibits the property of controlling the losses by adjusting the chirality parameter [10–14]. Moreover, these coatings can also be used as a stealth radome to protect the antenna from the environmental hazards, and reduce the radar cross section of the enclosed antenna system. Apart from these chiral medium exhibits many potential applications in the field of biomedicine, biochemistry and for obtaining data in the remote sensing of vegetation layers [15–17]. Chiral medium due to its the birefringence nature

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convert a lineally polarized wave to two eigen modes. These two eigen modes are left circularly polarized (LCP) and right circularly polarized (RCP) waves, exhibiting different values of refraction indices and phase velocities. For the last few decades chiral medium has been extensively analyzed by the electromagnetic community, such as scattering of wave, reflection and transmission through chiral interfaces and slabs, cross coupling of electric and magnetic fields and radiation characteristics of antennas embedded in the chiral medium. Chiral medium in association with many devices are studied by many analytical and computational method due to its interesting application in various scientific community [18–26]. Among them a ray based GO approximation method has been used in this paper. However, GO fails at the all important focal points due to the un-realistic singular points. Therefore, an asymptotic method based on theory proposed by Maslov is applied to derive the fields which are also valid at the focal points. For the last few decades Maslov's method is applied by many authors for different focusing systems. It uses the information obtained from GO approximation and hybrid coordinates system and avoids the singularities in GO method due to the shrinking of wave. The expressions are converted into space coordinates by Fourier transformation. The effects of parabolic, two dimensional elliptical, circular, paraboloidal and spherical reflector coated with chiral coating were analyzed in [7–11]. Apart from this other type of coating such as plasma coating, nihility coating and other artificial materials are analyzed to get some exotic characteristics [27–31]. In this paper, focal region fields of a 3D elliptical reflector coated with chiral medium are analyzed. This work is an extension of previous work from two dimensional case to three dimensional case [8]. In the next section the high frequency field expressions for the focal region fields are derived using GO and Maslov's method. The numerical results are illustrated in Section 3. Conclusions are drawn accordingly in Section 4.

2. Geometric optics and Maslov's high frequency field expressions for the elliptical reflector covered by chiral medium

The general form of GO field can be calculated using Gauss's theorem [25] and is given by

$$u(r) = E(r_0)J^{-1/2}\exp(-jk(s_0+t)) \tag{1}$$

In the above equation $E(r_0)$ is the initial magnitude of the electromagnetic field intensity. The Jacobian $J = D(t)/D(0)$, which transform the expression from ray coordinates (ξ, η, ζ) to Cartesian coordinate (x, y, z). The term $D(t) = \partial(x, y, z)/\partial(\xi, \eta, t)$ is the determinant. The amplitude of the GO equation can be derived using Transport equation and its phase can be derived using Eikonal equation. The derived GO solution become invalid around the focal points due to the unrealistic singularities. To derive expressions which are also valid around the focal region we use Maslov's method which exploits the simplicities of ray theory and Fourier transform. In the last few decades Maslov's method was applied to derive the focal region fields of various focusing systems [16–20]. Stationary phase method is applied to find the Fourier integral. The generalized form of focal region fields using Maslov's method is given in [11].

$$u(r) = \frac{k}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}E(r_0)\left[\frac{D(t)}{D(0)}\frac{\partial(p_x,p_y)}{\partial(x,y)}\right]^{-\frac{1}{2}}\exp(-jk(s_0+t-x(p_x,p_y,z)p_x-y(p_x,p_y,z)p_y+xp_x+yp_y))dp_xdp_y \tag{2}$$

The Jacobian term $\frac{D(t)}{D(0)}\frac{\partial(p_x,p_y)}{\partial(x,y)}$ in the above expression can be calculated by the formula,

$$\frac{D(t)}{D(0)}\frac{\partial(p_x,p_y)}{\partial(x,y)} = \frac{1}{D(0)}\frac{\partial(p_x,p_y,z)}{\partial(\xi,\eta,\zeta)}. \tag{3}$$

Consider the reflection of a plane wave traveling along positive z-axis is incident on the elliptical reflector covered by chiral medium as shown in Fig. 1.

$$\zeta = g(\xi,\eta) = \frac{a}{b}\sqrt{b^2-\xi^2-\eta^2} = \frac{a}{b}\sqrt{b^2-\rho^2} \tag{4}$$

In the above relationship a, b are the radii of the 3D PEC elliptical reflector along the major and minor axis respectively. Where (ξ, η, ζ) are the initial values of (x, y, z), $\rho^2 = \xi^2 + \eta^2$. Let the incident wave is traveling along z-axis and is given by

$$\mathbf{E}_i = \mathbf{a}_x\exp(-jk_oz) \tag{5}$$

and making an angle α with unit surface normal which is given by

$$\mathbf{a}_n = \sin\alpha\cos\gamma\mathbf{a}_x + \sin\alpha\sin\gamma\mathbf{a}_y + \cos\alpha\mathbf{a}_z \tag{6}$$

where α and γ are given as

$$\sin\alpha = \frac{-\acute{g}(\rho)}{\sqrt{1+(\acute{g}(\rho))^2}} = \frac{a\rho}{\sqrt{b^2(b^2-\rho^2)+a^2\rho^2}} \tag{7}$$

$$\cos\alpha = \frac{1}{\sqrt{1+(\acute{g}(\rho))^2}} = \frac{b\sqrt{b^2-\rho^2}}{\sqrt{b^2(b^2-\rho^2)+a^2\rho^2}} \tag{8}$$