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Modified theory of physical optics and the correction terms of the physical theory of diffraction

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ABSTRACT

The methods of physical optics and physical theory of diffraction are reviewed for electromagnetic waves. The Fermat principle and its' modified version are investigated and the necessity of the introduction of a variable unit vector is put forth. The scattering integrals of modified theory of physical optics are reviewed in this context. Recent comments on the modified theory of physical optics are discussed and refuted clearly. A proof is given on the nature of the physical theory of diffraction's correction terms. The proof is visualized with some numerical simulations.

1. Introduction

The method of physical optics (PO) is based on the integration of a surface current along the illuminated part of a scatterer. The physical optics current is evaluated by taking into consideration of the incident magnetic field. Although this technique leads to the exact geometric optics (GO) fields, the edge contribution of the PO scattering integral yields incorrect edge diffracted waves [1]. A patching approach, named as the physical theory of diffraction (PTD), was suggested by Ufimtsev in 1950s [2]. The defects of PTD were outlined in [3,4] and also will be mentioned in this paper. Its main problem is that PTD does not fix the defect of PO in its main algorithm. Only proposes additional correction currents (?!!) in order to obtain the exact diffracted field expressions. With this approach, PTD only offers a temporary solution for PO. In 2004, I introduced a new method that fixes the defect of PO in its own integrand [5]. This technique is named as the modified theory of physical optics (MTPO). In [5], I showed that it was possible to evaluate the correct diffracted field expressions by taking into account three axioms for the construction of the scattering integral. Later the method was extended for the perfectly conducting wedge [6], impedance half-plane [7] and impedance wedge [8]. The comparisons of the MTPO solution for these cases are in exact harmony with the exact solutions [9–12]. However, Ufimtsev and co-workers attacked MTPO by stating that the method was incorrect [13]. They attributed their objection on two proposals, both of which were wrong. The first one was that MTPO was violating the laws of GO. This point was completely incorrect, because the reason of PO's problem was the construction of its' current by only considering the Fermat's principle. The second objection was stating that the Green's function of MTPO did not satisfy the Helmholtz equation. Their comments were entirely refuted in [14]. Ufimtsev and his friends reply [15] was only showing their ability in distorting the facts as will be shown in detail in this paper. This group of authors also attacked the work of Basdemir [16,17]. However, their weak proposals were solidly rebutted [18]. An interesting point is that Ufimtsev et al. tried to calumniate MTPO in [17] although Basdemir did not use this method in his paper. As a result, the related group was desperately trying to refute a method that was giving the exact solution of the scattered fields by a perfectly conducting half-screen [19–23]. Recently they also wrote a comment [24], which was full of incorrect statements and distortions, on a paper, published in this journal [25]. Although the previous comments of this author and Basdemir clearly proved that the proposals of this group were wrong, their overall claims may deceive some readers. For this reason a comparative review of

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MTPO became a necessity in order to fix this problem. We will also put forward the overall misleading arguments of Ufimtsev and co-workers by giving a detailed analysis of their past and recent comments on MTPO in order to prevent any possible deception. In the last section of this paper, a proof, related with the structure of the correction terms of PTD, will be given in order to refute exactly the approach of Ufimtsev et al.

A time factor of $\exp(j\omega t)$ is assumed and suppressed throughout the paper. ω is the angular frequency.

2. Methods of PO and PTD

The total electric field can be expressed by

$$\vec{E_T} = \vec{E_i} + \vec{E_S} \tag{1}$$

when an incident field interacts with an obstacle on its path of propagation [3]. Here, $\vec{E_i}$ is the incident wave and $\vec{E_S}$ represents the scattered field, which can be defined by

$$\vec{E_S} = -\frac{j\omega\mu_0}{4\pi}\iint_{S_I}\vec{J}_{PO}(Q)G(P,Q)dS' \tag{2}$$

according to PO. μ_0 is the permeability and S_I illuminated part of the scatterer. $\vec{J}_{PO}$ and G can be introduced as

$$\vec{J}_{PO}(Q) = 2\vec{n}\times\vec{H_i}\,|_{S_I} \tag{3}$$

and

$$G(P,Q) = \frac{e^{-jkR}}{R} \tag{4}$$

that show the PO current and Green's function respectively. $\vec{n}$ is the unit normal vector of the surface and k wave-number. $\vec{H_i}$ shows the incident magnetic field. P and Q are the observation and integration points respectively. R is the distance between these two points. The total field will be written as

$$\vec{E_T} = \vec{E}_{GO} + \vec{E}_{dPO} \tag{5}$$

if the scattering integral of PO is evaluated exactly or asymptotically [1]. $\vec{E}_{GO}$ and $\vec{E}_{dPO}$ are the GO field and PO's diffracted wave respectively. The PO integral leads to the exact GO fields. However its edge point contribution, which gives the diffracted waves, is incorrect. PTD offers the addition of a correction term as

$$\vec{E_T} = \vec{E}_{GO} + \vec{E}_{dPO} + \vec{E_C} \tag{6}$$

to Eq. (5). The correction term $\vec{E_C}$ is obtained by the equation of

$$\vec{E_C} = \vec{E_d} - \vec{E}_{dPO} \tag{7}$$

where $\vec{E_d}$ is the correct diffracted field. Although Ufimtsev mentioned the existence of fictitious fringe currents, which are only mathematical correction terms, he could not evaluate their explicit expressions [4]. In the literature, only the correction fields exist. As can be seen from Eq. (7), the PTD offers a temporary solution to the defect of PO. This method is not able to fix the main problem of the scattering integral, given in Eq. (2). Thus PTD became trivial after the introduction of MTPO. A second important point that I want to stress is that the Green's function, used in the scattering integrals, does not satisfy the boundary conditions on the surface of the scatterer. This is not a requirement, because the total field, which is the summation of the incident and scattered waves, must satisfy the boundary conditions. The scattered field does not obey the boundary condition on the scatterer by this means. Only, the surface current, in Eq. (3), is obtained by using a boundary condition.

3. The modified Fermat's principle and variable unit normal vector

A whole perfect electric conducting (PEC) layer, which lays at $z = 0$ plane, is taken into account. It is well known that a plane electromagnetic wave that hits on the surface reflects by the same angle with the angle of incidence according to the Fermat's principle. Thus the unit normal vector of the surface divides the angle between the incident and reflected rays into two equal parts. The PO current, in Eq. (3), is defined according to this principle. However, the actual Fermat's principle is not valid at the edge point where there exists more than one ray, all of which diverge with different angles. Also the unit normal vector of the surface divides the angle between the incident and diffracted waves into two equal parts only for one ray. For these reasons, Keller introduced a modified form of the Fermat's principle for edge diffraction [26]. When these points are considered in terms of the concept of scattering integral, the problem is the integration of the modified Fermat's principle into the integrand mathematically. The PO integral leads to the incorrect diffracted field expressions, since the PO integral does not satisfy the modified Fermat's principle at the edge point. In 2004, I solved this problem by defining a scattering angle, which had a different value from the angle of incidence [5] and introducing the concept of variable unit vector [27,28]. The related geometry is given in Fig. 1. Thus the boundary conditions becomes