2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Multiple-Bounce Scattering from Electrically Large Objects: Is Ray Optics Sufficient?

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Abstract

Application of Geometrical Optics (GO) to calculation of multiple-bounce contributions to electromagnetic scattering from electrically large objects represented by polygon meshes is examined. It is shown that ray-based approaches may lead to significant errors in describing the interaction between distant polygons and the use of Physical Optics (PO) might be necessary to reliably predict the multiple-bounce contributions to the scattered field.

1. Introduction

Simulation of electromagnetic fields in applications involving electrically large objects, e.g. prediction of scattering cross sections of electrically large bodies, positioning of antennas on large platforms, or modeling propagation in urban areas, requires the use of asymptotic approximations, either ray-based (GO/GTD/UTD) or current-based (PO/PTD), e.g. [1,2].

A common approach implemented in many commercial software packages combines the GO method with rapid algorithms for ray tracing to describe the interaction of the rays with reflecting surfaces. For example, the method of shooting and bouncing rays (SBR) is widely used for prediction of scattering cross sections of very large objects [3]. However, every ray-based method has a number of limitations, such as caustics and the necessity of tracing massive numbers of rays through multiple bounces. The PO method overcomes these limitations but is more time-consuming as integration over the reflecting surface is required at every bounce. A realization of the iterative Physical Optics (IPO), which combines PO with iterative solution of MFIE, has been proposed in [4]. Alternative realizations of IPO are also possible.

This paper shows that for geometries represented by superposition of flat panels or facets (polygon meshes), which is a standard representation in CAD, there exist further limitations which even more necessitate the use of PO for calculation of interactions between the facets. The specific limitations of ray-based techniques in this class of geometries are due to the following GO assumptions: (a) a ray reflected by a facet propagates in free space without decay as a plane wave in the direction of specular reflection; (b) shadow boundaries are perfectly sharp; (c) a ray missing (even infinitesimally) a facet does not produce any reflected ray. On the other hand, far from the facet, where $D^2/\lambda > 1$ with D being the size of the facet and λ the wavelength, the physical picture is fully different from that assumed by GO: the scattered field is similar to a spherical wave, which propagates in all directions and decays as the inverse power of the distance from the facet, and there are no sharp shadow boundaries. Ray optics is inapplicable in the far field of every facet and therefore incorrectly describes the interaction between distant panels of a faceted object. As applied to the double-bounce scattering, these failures of GO and the need for application of PO have been identified in [5].

In this paper the deficiency of ray optics is demonstrated by considering simple configurations involving several PEC plates oriented in such a way as to allow multiple reflections between them. It will be shown that GO leads to significant errors in describing the interaction between the plates, whereas the PO approximation correctly describes the fields in such configurations.

The paper is organized as follows. In section 2 the test geometries are introduced. In section 3 the GO and PO solutions for the scattered field are compared and instructive diagrams are presented.

2. Test Configurations

The aforementioned aspects of the calculation of bounces at panels with either GO or PO can be nicely studied with the help of two test configurations shown in Figs. 1 and 2. The configuration in Fig. 1, which will be referred to as configuration 1, consists of two square PEC plates with the side length a at a right angle to each other so as to form a dihedral reflector for the rays propagating in the x-y plane. Each plate is shifted by a distance d from the z axis. With $d = 0$ the configuration reduces to a conventional dihedral corner reflector.

The second configuration (Fig. 2) is obtained from configuration 1 upon an additional shift of one plate by the distance a along the z axis to exclude the double bounce of the GO rays with the incidence direction in the x-y plane.

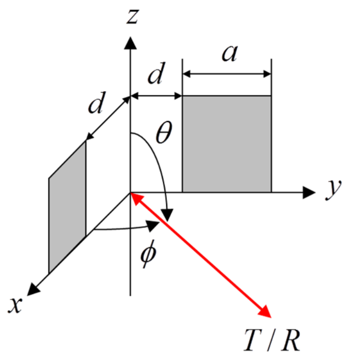

Figure 1. Configuration 1: two PEC square plates at 90° to each other.

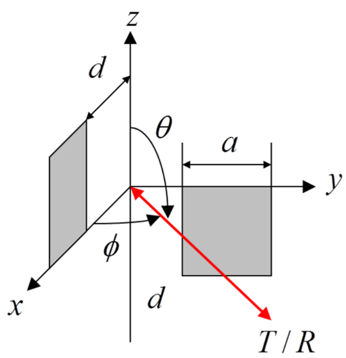

Figure 2. Configuration 2: as configuration 1 but the plates are shifted along the *z* axis by the distance equal to the side length a.

3. Numerical Comparisons

Backscattering cross sections of the configurations have been calculated by using either GO or PO to describe the interaction between the plates, followed by a PO integration of the surface currents determined by either method. The approach, in which the induced currents are determined with GO, corresponds to the SBR method (GO+PO). The use of PO for calculation of the currents corresponds to the IPO method (PO+PO).

Figure 3 and 4 show RCS as a function of the distance between the plates for configurations 1 and 2, respectively. The incoming plane wave is incident in the *x*-*y* plane at 45° to the *x* and *y* axes. The IPO results have been obtained with a proprietary simulation tool BISTRO.

The black line in Fig. 3 suggests that RCS is strongly underrated when the double bounce is neglected. Accounting for the double bounce makes the RCS level much greater. When the interaction between the plates is calculated according to GO, the result is independent of the distance between the plates (blue line), which is explained by the fact that according to GO the rays reflected from a flat surface propagate without attenuation in free space. When, however, PO is used to calculate the interaction (red line), the reflected field decays with growing distance between the plates, which accounts for the weakening of the interaction with the increasing distance.

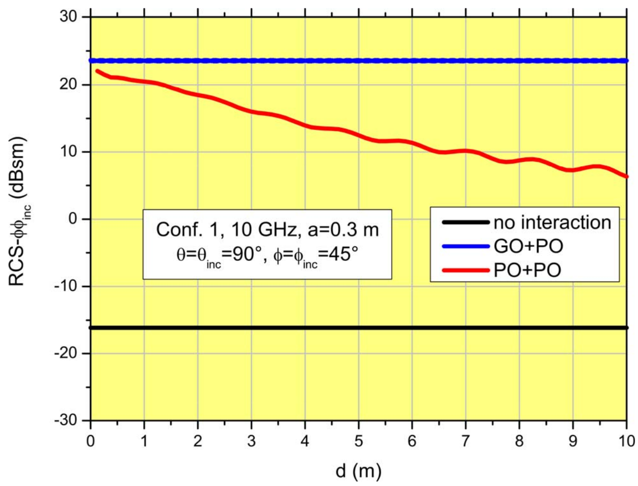

Figure 3. Backscattering cross section of configuration 1 as a function of the distance between the plates, with interaction between the plates neglected (black) or included and calculated by either GO (blue) or PO (red). The electric field vector is in the x-y plane.

The corresponding results for configuration 2 are presented in Fig. 4. According to GO, there is no interaction between the plates since all rays reflected at the one plate miss the other plate; so, RCS is low (blue line) and coincides with the black line in Fig. 3. When PO is used to calculate the interaction, one obtains finite values for the interaction and RCS takes much greater values (red line).

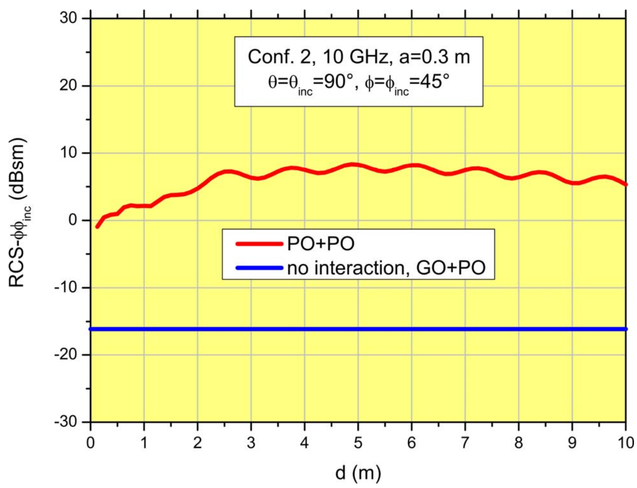

Figure 4. The same as in Fig. 3 but for Configuration 2.

4. Conclusions

Significant errors of ray-based methods in prediction of multiple scattering between distant facets of electrically large objects have been demonstrated. The results suggest the need for using the PO method for calculation of the multiple-bounce contributions.

5. References

1. F. Saez de Adana, O. Gutierrez, I. Gonzalez, M.F. Catedra, and L. Lozano, *Practical Applications of Asymptotic Techniques in Electromagnetics,* Artech House, 2011.

2. A.V. Osipov and S.A. Tretyakov, *Modern Electromagnetic Scattering Theory with Applications*, Wiley, 2017.

3. H. Ling, R.C. Chou, and S.W. Lee, "Shooting and Bouncing Rays: Calculating the RCS of an Arbitrarily Shaped Cavity," *IEEE Trans. Antennas Propag.,* **37**, Feb. 1989, pp. 194–205.

4. F. Obelleiro-Basteiro, J.L. Rodriguez, and R.J. Burkholder, "An Iterative Physical Optics Approach for Analyzing the Electromagnetic Scattering by Large Open-Ended Cavities," *IEEE Trans. Antennas Propag*., **43**, Apr. 1995, pp. 356–361.

5. A.V. Osipov, “PO-based Analysis of Double-bounce Scattering,” *Progress In Electromagnetics Research Symposium (PIERS 2009)*, March 23 – 27, 2009, Beijing, China.