A Survey on the Extension of the UTD to the Analysis of Inhomogeneous Plane Wave Diffraction

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Abstract

An overview of the work performed to extend the Uniform Geometrical Theory of Diffraction (UTD) to the analysis of inhomogeneous plane wave diffraction by a wedge is presented in this paper. The work was done in collaboration between the staff of the Microwave and Radiation Laboratory, Department of Information Engineering, University of Pisa and Prof. Robert G. Kouyoumjian, ElectroScience Laboratory, Ohio State University. We introduce first the two-dimensional solution for the scattering of inhomogeneous plane waves by a perfectly conducting wedge in a lossless medium. The above solution is then extended to account for dissipative losses in the medium surrounding the wedge, when also the wedge faces may be characterized by different surface impedances. Suitable expressions for the fields are also found in the more general three-dimensional case, for arbitrary polarization. The final objective is to apply these UTD solutions for calculating electromagnetic scattering from polygonal cylinders buried in lossy media.

1. Introduction

As well known, high-frequency methods are based on the definition of a suitable set of diffraction coefficients, which are determined by analytically solving specific canonical scattering problems. Each canonical problem is characterized by simple geometries (as for instance wedges, tips, corners), which however well approximate the exterior surface of the scattering body in the vicinity of the pertinent scattering center. In this context, the first part of this paper is concerned with the analysis of the diffraction of an inhomogeneous plane wave by a perfectly conducting wedge. This situation may occur in practice when the incident wave is a surface wave, a lateral wave [1], [2], or a wave propagating in a lossy medium. In addition, it may occur locally in a Gaussian beam at points away from its axis or on the dark side of a caustic in the focal region of a reflector antenna. A solution is sought in the format of the Uniform Geometrical Theory of Diffraction (UTD) [3], that is, in terms of a reflected field and a diffracted field, so that it can be applied to calculate the scattering from more complex geometries with edges. In particular, an integral representation for the total field is obtained and then evaluated by a uniform asymptotic procedure [4]. The shadow and reflection boundaries of the geometrical optics field are found to be displaced from their conventional locations. The extent of the transition regions is also described. The solution is then extended to account for dissipative losses in the medium surrounding the wedge, including the case in which the wedge is not perfectly conducting [5]. To demonstrate the accuracy of the UTD solution, numerical results are presented and compared with those calculated from an eigenfunction solution.

The diffraction of an inhomogeneous electromagnetic plane wave obliquely incident on the edge of a perfectly conducting wedge was later on addressed [6], to extend the results for the normal incidence case. Uniform high-frequency expressions were obtained for the diffracted field. The generalized dyadic diffraction coefficient in the standard UTD ray-fixed coordinate system was represented by a 2 x 2 full matrix with the extradiagonal terms accounting for a coupling between the two components of the incident and diffracted electric field parallel and perpendicular to the edge-fixed incidence and diffraction plane, respectively. The latter characteristic of the diffraction matrix is due to both the vectorial properties of the evanescent incident electric field and the inclusion of higher-order terms in the asymptotic expression of the edge diffracted field. The introduction of higher-order terms in the asymptotic evaluation also guarantees an improved accuracy for smaller values of the large parameter, namely, for observation points closer to the diffracting edge, as compared with the ordinary UTD.

As an application, the extended UTD solution has been used to calculate the scattering from an object buried in a lossy medium [7]-[9]. First, the accuracy of the high frequency method is examined by comparing numerical results for the scattering by a polygonal cylinder in a lossy medium of infinite extent with reference data calculated by a Method of Moments (MoM) solution [7]. Next, the more difficult scattering problem of a polygonal cylinder in a lossy half space is treated. The UTD solution for the unbounded region is employed together with the fields of rays

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introduced by the interface between air and the lossy medium to obtain expressions for the scattered field in air and in the lossy medium.

2. Two-Dimensional Diffraction Coefficients

A uniform asymptotic solution for the scattering of an inhomogeneous plane wave by a perfectly conducting wedge has been obtained in [4]. This solution is uniform in the sense that it remains valid at the shadow and reflection boundaries. The solution was presented in the standard format of the UTD, and suitable expressions were given for the edge diffraction coefficients. Numerical comparisons with the eigenfunction solution have shown that the diffraction coefficients are accurate, even when the field point is only $\lambda/4$ away from the edge; furthermore, they are exact in the case of the half plane. The shadow (SB) and reflection (RB) boundaries result to be displaced from their classical locations for an incident homogeneous plane wave. The displacement is in the direction of decreasing field strength of the incident or reflected field, and the extent of the displacement depends on the inhomogeneity of the incident field. The transition regions adjacent to the shadow and reflection boundaries are bounded by an ellipse; hence at a sufficiently large distance from the edge, the classical Geometrical Theory of Diffraction (GTD) can be used. The presence of losses in the medium surrounding the wedge affects the diffraction coefficients and the locations of the SB and RB, but not the shape of the transition regions even though the incident field may have a rapid spatial variation at the edge a slope diffraction term is not required, because this effect is included in the asymptotic solution. The results have been generalized in [5] to account for dissipative losses in the medium surrounding the wedge, also extending the analysis to non perfectly conducting wedges.

3. Extension to the Three-Dimensional Case

A uniform high-frequency solution for the diffraction of an inhomogeneous electromagnetic plane wave by a perfectly conducting wedge at oblique incidence has been presented in the framework of UTD. Indeed, the solution in [4] is valid at normal incidence and when both the real and imaginary components of the incident wave vector lie in the plane transverse to the edge (two-dimensional problem). The analysis in [4] has been extended in [6] to treat the more general case of skew incidence and completely arbitrary orientation of the exponential decay direction of the evanescent incident field. First, a representation of the incident field in terms of a plane wave with complex incidence angles is provided for a completely arbitrary incident inhomogeneous plane wave. Then, an exact integral representation for the total field is obtained by analytically continuing the Sommerfeld solution to complex incidence angles. The exact integral representation of the field is asymptotically evaluated by deforming the original Sommerfeld integration contour onto the two steepest descent paths (SDPs) through the saddle points at π and $-\pi$. The residue contributions of the poles that are captured in the contour deformation process are associated with the geometrical optics (GO) field contributions. The diffracted field contribution is obtained by asymptotically evaluating the integrals along the SDPs. To obtain the total field continuity at both the shadow boundaries (SBs) of the incident and reflected fields, all terms of order $K^{-1/2}$ must be retained in the asymptotic approximation of the longitudinal field components, where K is the large parameter. Uniform asymptotic expressions are then derived for all the scattered field components, which are needed to construct a generalized dyadic diffraction coefficient. Numerical comparisons with the exact eigenfunction solution have shown that the asymptotic solution of the diffraction canonical problem remains accurate even at distances from the edge less than a wavelength. The exponential variation of the incident field close to the edge determines a rotation of the shadow boundaries with respect to the conventional GO shadow boundaries, as already discussed in [4], [5], as well as a variation of the semi-angle aperture of the generalized Keller diffraction cone. The diffracted field amplitude can be derived by resorting to a generalized dyadic diffraction coefficient which is not diagonal. The analytical solution of the canonical diffraction problem has been carried out through the introduction of complex angles, so requiring an accurate asymptotic evaluation of the diffraction integrals since the GO pole singularities result to be complex and cross the steepest descent paths away from the corresponding saddle points. The high-frequency solution contains the standard UTD transition function extended to complex arguments as in [4]. Finally, it has been shown that the uniform asymptotic approximation accurately describes the effects due to the rapid spatial variation of the incident field close to the diffracting edge.

4. Scattering from a Buried Object

The scattering from objects buried in lossy media represents a key problem for remote sensing applications. Indeed, the availability of efficient backscattering simulation techniques may allow us to test and optimize different detection and location procedures. In this context, several numerical techniques have been proposed to evaluate the field backscattered in air by objects buried in a dissipative half space. Although numerical techniques are surely more flexible to match the complexity of realistic remote sensing problems, the definition of a suitable ray optical procedure could let us gain a deeper physical insight into the problem, together with a higher numerical efficiency. The calculation of the field scattered from an object buried in a lossy half space can be performed by resorting to the solutions presented in [4]-[6]. Using uniform edge diffraction coefficients [4], [5], a UTD solution has been obtained for the field scattered by a perfectly electric conducting (PEC) polygonal cylinder in a lossy medium of infinite extent. Later on, the same scatterer located in a lossy half space was treated ray optically, and the presence of the interface was included in the solution [7]. In particular, within the lossy medium the total scattered field is the sum of the fields reflected and diffracted from the polygonal cylinder, the field scattered by the cylinder and then reflected from the interface between the two media, and a lateral wave field [1], [2], [8], [9]. We will focus our attention on the calculation of the field scattered in air. Since the main issue is represented by the calculation of the ray contributions that after diffracting by the scattering object cross the interface to provide the field scattered in air, we will make reference to a simple two-dimensional scatterer, namely a PEC strip buried in a lossy half space. When a plane wave impinges on a plane interface between air (region 2, $k_2 = k_0$) and a lossy dielectric (region 1, $k_1 = k = nk_0$), an inhomogeneous plane wave is excited in the lossy medium (Fig. 1). Let this be incident on a PEC strip parallel to the interface. The strip has a width *w* and is located at a distance *d* from the interface. This two-dimensional problem is uniform in the direction of the strip axis (*y*-direction), and the observation point is in region 2.

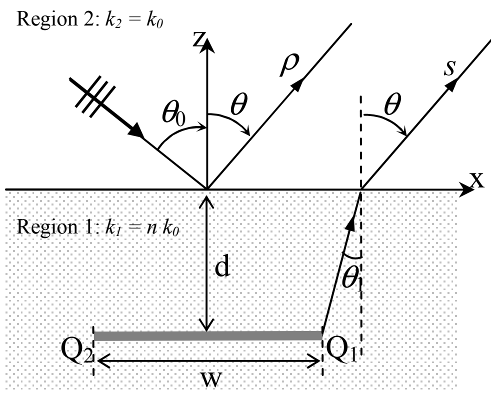

Fig. 1 – Geometry for the scattering by a buried strip.

A numerical example is shown here the demonstrate the accuracy of the UTD solution in the case of a lossy medium. The reference MoM solution was obtained in [7]-[9]. In particular, the analysis results in an impedance matrix consisting of two terms: $[Z]=[Z_0]+[Z_s]$. The first term $[Z_o]$ is just the impedance matrix for the scatterer in the corresponding unbounded lossy medium. The second term $[Z_s]$ accounts for the presence of the interface. The currents induced on the strip together with a special Green's function are employed to calculate the scattered field in air. Let us refer to the simple problem in which the interface is illuminated at normal incidence ($\vartheta_o = 0$ in Fig.1) by a plane wave exhibiting a unit amplitude at the interface ($z = 0$). The incident plane wave is TM polarized, at a frequency $f = 300MHz$. The lower medium is lossy ($n = 2 - j0.2$). The strip is parallel to the interface, has a width $w = 2\lambda_o$, and is located at a distance $d = 2\lambda_o$ from the interface. This example has the objective of assessing the accuracy of the UTD solution in calculating the field scattered in air in the case of a strip buried in a lossy half space. Curves for the scattered field in air are shown as functions of the observation angle ϑ. The field is calculated at a distance $\rho = 1000\lambda_o$. Starting from the surface current distribution evaluated with the MoM, we calculate the reference curves (continuous and dashed lines in Fig. 2). We note that the continuous line does not account for multiple interactions between the strip and the interface, while the dashed line does, since in the latter case the MoM impedance matrix includes the term $[Z_s]$. It is apparent that the UTD curve (continuous line with circles) is in very good agreement with both MoM curves. The latter are overlapped since the effect of multiple interactions between the strip and the interface has been chosen to be negligible. We point out that the PO data become less accurate at the increasing of the observation angle ϑ and also fail to predict the level of the nulls in the scattered pattern. The accuracy provided by the

UTD solution is actually very good. However, it is worth noting that in conditions where *d* is small the interaction between the scatterer and the interface must be taken into account.

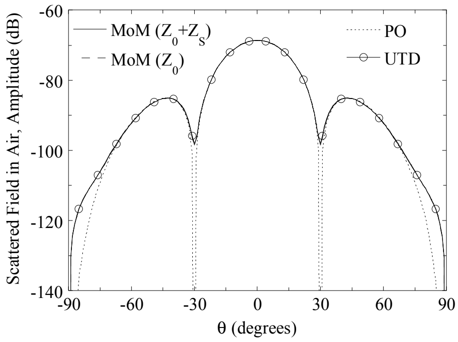

Fig. 2. Amplitude of the field scattered in air in the case of TM polarization. Continuous line: MoM (interactions with the interface neglected); dashed line: MoM (interactions with the interface accounted for); dotted line: PO; continuous line with circles: UTD.

5. Conclusions

The research activity which led to the definition of a UTD two-dimensional solution for the scattering of inhomogeneous plane waves by a perfectly conducting wedge in a lossless medium has been reviewed. The proposed solution has been later extended to account for dissipative losses in the medium surrounding the wedge, also in the presence of impedance boundary conditions on the two faces of the wedge. Suitable expressions for the fields were also found in the more general three-dimensional case, for arbitrary polarization. Finally, it has been shown that the above UTD solutions can be usefully applied for calculating electromagnetic scattering from metallic objects with edges buried in lossy media.

6. References

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