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Applications of the Incremental Theory Diffraction to the scattering by planar configurations

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I. **INTRODUCTION.** The description of high-frequency electromagnetic scattering by complex structures is of interest in many practical applications, such as reflector antennas pattern and RCS prediction, analysis of radiating characteristics in a complex environment, etc.. As is well known, two leading high-frequency theories have provided very effective tools for most engineering purposes, namely the Geometrical Theory of Diffraction (GTD) [1], especially in its uniform extension (UTD) [2], and the Physical Theory of Diffraction (PTD)[3].

The GTD leads to a very attractive picture of the scattering from a complex object, in terms of rays emanating from isolated "flash points". However, still there are some difficulties in applying this ray method close and at caustics. Furthermore, there is an inherent limitation, at least from a conceptual point of view, due to the fact that in several cases GTD is able to predict a non-vanishing field in restricted angular regions. It should be noted, however, that this latter inconvenience, may be alleviated by introducing diffracted field contributions from vertices.

Within the framework of the original PTD pioneered by Ufimtsev [3], several formulations for a wedge [4][5][6] have been presented to asymptotically describe fringe current contributions, that may occur whenever an edge discontinuity introduces a relevant distortion of the Physical Optics (PO) currents. The major attempt of these techniques, besides eliminating caustic singularities, is that of providing an extension for observation angles which are not on the diffraction cone.

Recently, an Incremental Theory of Diffraction (ITD) [7] has been developed which provides a unified framework for describing high-frequency phenomena. The procedure essentially consists of a localization process, based on a rigorous Fourier transform analysis of canonical problems. The solution of a cylindrical canonical configuration is thought of as a superposition of an infinite uniform distribution of incremental field contributions, that are localized along a directrix of the cylinder. The pertinent element factor may be extracted by establishing a Fourier transform pair relationship between the incremental contribution and the solution of the cylindrical canonical problem. Next, these incremental field contributions are adiabatically distributed and integrated along the actual shadow boundary line (SBL). The total scattered field is represented as the sum of a generalized Geometrical Optics (GO) field plus incremental diffracted fields. This method is applicable to any local shape, where a uniform, cylindrical, local canonical configuration with arbitrary cross-section is appropriate. Also, its formulation is uniformly valid at any incidence and observation aspects, including caustic of the corresponding ray-field representation.

In this paper, the electromagnetic scattering from some planar structures is investigated, to demonstrate the validity of the ITD. First, the scattering from a disc illuminated by a scalar plane wave, is considered. Next, the bistatic echo area of a disc and a square plate are analyzed and compared

with either the exact solution or other techniques. Finally, the diffracted field by a perfectly conducting circular disc which is illuminated by a short electric dipole is calculated by different methods and discussed.

II. WEDGE SHAPED CONFIGURATION.

Let us consider first an edge discontinuity and its relevant infinite, local canonical wedge problem. Let us introduce at Q' a cylindrical coordinate system (ρ, ϕ, z) with the z axis at the edge of the wedge, and a spherical (r, β, ϕ) coordinate system, with its origin at Q' (Fig. 1). Also, let us denote by (β', ϕ') the local direction at Q' of an arbitrarily polarized incident plane wave, and by $n\pi$ the exterior wedge angle. The high-frequency incremental diffracted field contribution at any point P arising from Q' on the edge, is

$$\vec{F}^d(Q') = \vec{\vec{S}}^d(Q') \cdot \vec{E}^i(Q') \frac{e^{-jkr}}{2\pi r} \tag{1}$$

where $\underline{E}^i$ is the electric field of the incident plane wave, and

$$\vec{\vec{S}}^d(Q') = D_s(kr\sin^2\beta)\ \hat{\beta}\hat{\beta}' + D_h(kr\sin^2\beta)\ \hat{\phi}\hat{\phi}' \tag{2}$$

with

$$D_q(\rho) = \sum_{j,l=1}^{2} b_q \frac{1}{2n} \cot\left[\frac{\pi + (-1)^j\ \Phi_l}{2n}\right] \mathcal{F}\left[k\rho\ a_j\left(\Phi_l\right)\right] \tag{3}$$

where $b_s = (-1)^l$, $b_h = 1$, $\Phi_l = (\phi - (-1)^l\phi')$, $\mathcal{F}[Ka]$ is the UTD transition function, and $a_{1,2}(\Phi)$ is the same as $a^{-,+}(\Phi)$ in eq. (27) of [2].

Next, let us consider a finite surface with an edge. A first order approximation of the high-frequency scattered field may be obtained by resorting to the PO approximation. The PO integration process asymptotically contains information from both stationary phase contributions and end-point contributions at the SBL. These latter contributions are inaccurate because they do not contain the correct local information at the edge of the SBL. Thus, they should be taken out and replaced by proper incremental diffracted field contributions. An estimate of the above end-point contribution is deduced from a pertinent local canonical problems, which consists of a half-lit infinite (y=0) plane with an infinite straight SBL (z) locally tangent to the actual SBL at Q'.

The high-frequency incremental end-point PO contribution $\underline{F}_e^{po}(Q')$ at any point P from Q' on the edge, is

$$\vec{F}_e^{po}(Q') = \vec{\vec{S}}^{po}(Q') \cdot \vec{E}^i(Q') \frac{e^{-jkr}}{2\pi r} \tag{4}$$

in which $\underline{E}^i$ is the electric field of the incident plane wave, and

$$\vec{\vec{S}}^{po} = S_{\beta\beta'}^{po}\ \hat{\beta}\hat{\beta}' - \cos\beta\ \hat{\beta}\hat{\phi}' + S_{\phi\phi'}^{po}\ \hat{\phi}\hat{\phi}' \tag{5}$$

with

$$S_{\beta\beta'}^{po}\Big/_{\phi\phi'} = \frac{1}{2}\left(\mp \cot\left(\frac{\pi - \Phi^+}{2}\right)\mathcal{F}[2K\cos^2(\frac{\Phi^+}{2})] + \cot\left(\frac{\pi - \Phi^-}{2}\right)\mathcal{F}[2K\cos^2(\frac{\Phi^-}{2})]\right) \tag{6}$$

where $\Phi^{\pm} = (\phi \pm \phi')$, and $\mathcal{F}$ is the UTD transition function. Both the incremental fields in (1) and (4) are adiabatically distributed and then integrated along the actual SBL. In subtracting the latter contribution from that of the PO surface integration, a field is obtained which is referred to as a generalized GO field. This is expressed as

$$\vec{E}_g^{go}(P) = \int\int_S \vec{F}^{po}(Q') \, dS - \int_{SBL} \vec{F}_e^{po}(Q') \, dl \qquad (7)$$

Then, the total scattered field is represented as

$$\vec{E} = \vec{E}_g^{go} + \vec{E}^d \qquad (8)$$

in which $\vec{E}^d$ is the generalized diffracted field

$$\vec{E}^d(P) = \int_{SBL} \vec{F}^d(Q') \qquad (9)$$

V. NUMERICAL RESULTS. Only the numerical example of the bistatic echo area of a perfectly conducting $6\lambda \times 6\lambda$ square plate is presented hereinafter. Further numerical results will be shown and discussed during the oral presentation. Fig. 2b-e shows the four component of the scattering matrix for the direction of incidence and the range of observation which are depicted in Fig. 2a. In this range, the PO field is zero at all directions of observation. The results calculated by the method of moments (MoM - continuous line. [8]) and by first order PTD (dashed line, [8]) are compared with those obtained by the first order ITD coefficients in eq.s (1). It is found that both asymptotic methods are in the same very good agreement with MoM near and at the caustic. This is expected since the two theories provide the same prediction at the first order diffraction cones. At other aspects the two asymptotic methods predict different results. Close and at grazing aspects, both first order asymptotic results deviates from MoM. This is a consequence of neglecting higher order interactions mechanisms. A PTD estimate of second order mechanisms is available in [8]. However, as will also be shown during the oral presentation, simple first order descriptions of scattering phenomena are in general much more satisfactory, for most practical purpose, than in this specific example. This was indeed selected in [8] in order to emphasize the importance of including high order scattering mechanisms.

VI. REFERENCES

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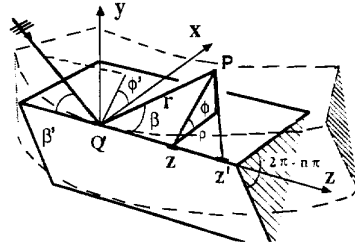
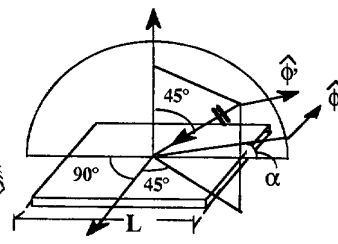Fig. 1: Geometry at a locally wedge shaped configuration
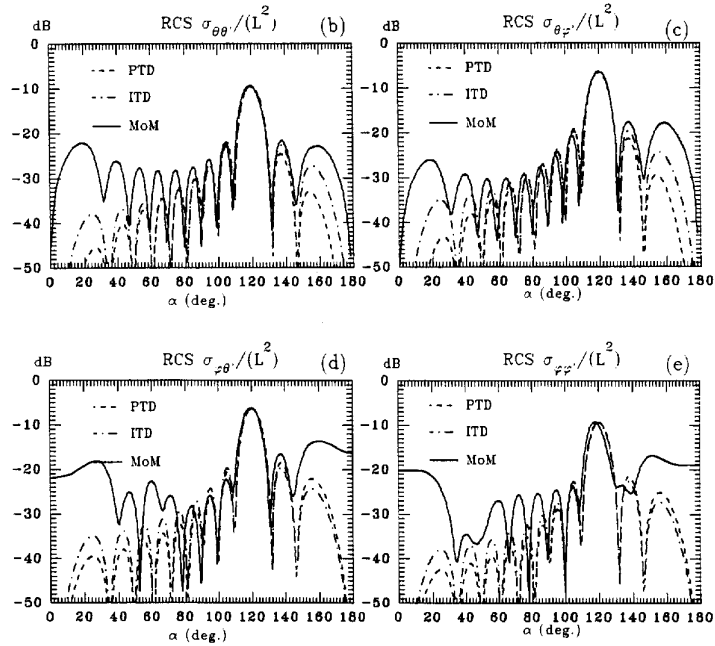
Fig. 2a: Direction of incidence and range of observation

Fig. 2b-e: Bistatic echo area of a square plate