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ITD FORMULATION FOR
THE CURRENTS ON A PLANE ANGULAR SECTOR

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1. INTRODUCTION
The electromagnetic scattering of a corner at the interconnection of two straight edges joined by a plane angular sector is important in the framework of Geometrical Theory of Diffraction (GTD) and of its uniform extension (UTD) [1]. The same canonical problem is also useful in order to obtain fringe currents, namely the currents that are induced on the face by the total diffraction mechanism; their radiation provides the improvement of the Physical Optics (PO) field in the framework of the Physical Theory of Diffraction (PTD) [2]. The exact electromagnetic solution of the plane angular sector is due to Satterwhite and Kouyoumjian [3], but the series expansion of this solution is very slowly convergent for increasing distance from the tip and not well-suited for practical asymptotic evaluation. The solution in [3] has been used in [4] for obtaining the currents close to the tip.

Recently, vertex diffraction coefficients have been derived in the plane-wave far-field regime by using the induction theorem [5]. These coefficients account for second order interactions between the two edges and provide the physical property to satisfy reciprocity. The same formulation has been used in [6] for deriving a uniform solution to apply at finite distance from the tip.

In this paper, asymptotic, closed form expressions of the fringe currents of the plane angular sector are derived by using the Incremental Theory of Diffraction (ITD) [7][8]. The application of this theory in deriving currents has been found particularly attractive, as demonstrated in [9] for the case of a circular ground plane illuminated by a vertical dipole. This is due to the fact that the ITD diffraction coefficients satisfy the boundary conditions (BC) of their relevant canonical problem, so that they warrant a reasonably accurate prediction of the currents.

2. FORMULATION
The geometry at a vertex interconnecting the two edges (denoted by 1 and 2) of a plane angular sector is shown in Fig. 1a, in which \( \Omega \) denotes the angle between the two edges. Both a spherical coordinate systems \((r, \beta, \phi)\) with the relevant unitary vectors \((\hat{r}, \hat{\beta}, \hat{\phi})\), and a cylindrical coordinate system \((p_i, \phi_i, z_i)\) are defined at each edge \(i=1,2\) with their origin at the tip (Fig.1a). A plane wave illumination is assumed; the direction of incidence is denoted by \((\beta', \phi')\) and its polarisation by the unit vector \(\hat{p}_{\parallel}\).

In our description the total current \( J \) is represented as

\[
J = J^{PO} + J_1 + J_2
\]

where \( J^{PO} \) denotes PO current, and \( J_1, J_2 \) are fringe current contributions relevant to edge 1, 2 respectively. The latter are represented as the sum of those induced by the ray contributions represented in Fig. 1b. Singly diffracted rays from edges 1 and 2 arise at \(Q_1\) and \(Q_2\), respectively. A vertex contribution arises from the tip and a double diffraction (DD) contribution.

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from a point $Q_1$ on edge 2 after diffracting at the point $Q_1'$ on edge 1 (the other DD term $2\rightarrow1$ is not depicted in the same figure). In the following, we will discuss only the contributions in which the first diffraction occurs at the edge 1; indeed $\mathcal{J}_2'$ can be easily obtained from $\mathcal{J}_1'$ by changing 1 with 2.

We denote by $\mathcal{J}_1'$ and $\mathcal{J}_1''$ the currents induced by the singly and doubly diffracted rays, respectively; these contributions are discontinuous when, the observation is such that $Q_1$ or $Q_n$ ($n=1,2$) disappears from the vertex, respectively, i.e. at the shadow boundary lines (SBLs) defined by $\beta_1=\beta'_1$ and $\beta_2=\beta'_2-\Omega$, respectively. These discontinuities are compensated by the vertex contribution, that is conveniently subdivided into two different contributions $\mathcal{J}_1^v$ and $\mathcal{J}_1''^v$, providing the continuity of the total current.

Thus our representation of the fringe current $\mathcal{J}_1'$ is

$$\mathcal{J}_1' = \mathcal{J}_1' + \mathcal{J}_1''$$

where

$$\mathcal{J}_1' = \mathcal{J}_1' + \mathcal{J}_1^v \quad \text{and} \quad \mathcal{J}_1'' = \mathcal{J}_1'' + \mathcal{J}_1''^v$$

In the following subsections, the two contributions $\mathcal{J}_1'$ and $\mathcal{J}_1''$ are discussed separately.

2.a. Contribution $\mathcal{J}_1'$

Let us consider an infinite half-plane with its edge aligned with edge 1 of the plane angular sector. The sum $\mathcal{I}_1^v(\beta'_1)$ of the fringe currents on the two faces of this infinite structure, is exactly expressed in terms of Fresnel integral. By means of the ITD localisation process, incremental diffraction contribution $i^v_1(z_1')$ associated to the incremental diffracted current distribution may be derived. These contributions exhibits a spherical spreading outgoing from the point $z_1'$. The fringe current contribution $\mathcal{J}_1'$ relevant to the semi-infinite edge may be constructed by superimposing the incremental contributions relevant to all the points on the semi-infinite extent $z_1' \geq 0$ of the edge, that are properly weighted by the incident wave phase factor; i.e.,

$$\mathcal{J}_1' = \int_{z_1'}^{\infty} i^v_1(z_1') e^{-j k z_1' \cos \beta'_1} \, dz_1'$$

The asymptotic evaluation of this integral provides two ray contributions. The first one is relevant to the stationary phase point of the integrand, which occurs at the point $Q_1$. This contribution may be recognize as that produced by the singly diffracted rays. The second contribution ($\mathcal{J}_1''$) is relevant to the end-point and provides the desired continuity of the currents $\mathcal{J}_1'$ when the point $Q_1'$ disappears from the vertex.

In order to asymptotically evaluate $\mathcal{J}_1'$ for $kr$ large, the spectral representation $i^v_1(z_1')$ is introduced in (4) yielding

$$\mathcal{J}_1' = \frac{1}{2\pi j} \int_{C} \mathcal{I}_1^v(\beta_1') \frac{\sin \theta_i}{(\cos \beta_1' - \cos \theta_i)} \, d\theta_i$$

where $C \equiv (-j\infty, +j\infty)$ with a counterclockwise indentation around the pole $\theta_i=\beta_1'$. $\mathcal{I}_1^v(\beta_1')$ exhibits a saddle point at $\theta_i=\beta_1$. By deforming $C$ onto a pertinent steepest descent path (SDP) through the saddle point $\theta_i=\beta_1$, the pole residue is captured when $\beta_1<\beta'_1$; thus, leading to the contributions

1765
Applying the modified Pauli-Clemmow method [1] to the SDP integral, leads to an asymptotic, closed form expression for the vertex contribution \( \tilde{J}_1 \).

2.2 Contribution \( \tilde{J}_1' \)

In order to define the wave that impinges on the second edge, only the field contribution relevant to the current \( \tilde{J}_1' \) is considered. At each point \( z_j' \) of the second edge, these currents are related to the magnetic field component \( \tilde{H}_1(z_j') \) along the direction \( s_1 = s_1 \times \hat{n} \) (\( \hat{n} \) normal to the top face) transverse to the grazing ray direction \( s_1 \). This magnetic field can be interpreted as a local H-polarized plane wave impinging on the second edge, so that a new set of incremental current distribution \( \tilde{I}_2''(z_j') \) can be associated to each point \( z_j' \) of the second edge; thus, obtaining

\[
\tilde{J}_1'' = \int_0^\infty \tilde{H}_1(z_j') \tilde{I}_2''(z_j') dz_j
\]  

The asymptotic evaluation of this integral provides two contributions. The first is associated to the stationary phase point, that occurs at \( Q_2'' \) (Fig. 1b), thus providing the term \( \tilde{J}_1'' \) corresponding to the doubly diffracted rays. The second contribution is an end-point from the vertex \( \tilde{J}_1'' \), that provides the desired continuity of the currents \( \tilde{J}_1'' \) at the SBL \( \beta_2 = \beta_1 - \Omega \), namely when both the points \( Q_1'' \) and \( Q_2'' \) disappear from the vertex.

3. NUMERICAL RESULTS

Numerical results have been carried out in order to test the solution presented above. Figure 2a shows radial currents on a plane angular sector with \( \Omega = 90^\circ \), illuminated by a plane wave as depicted in the inset. The polarization of the incident electric field is parallel to the incidence plane. The scan is performed versus \( \beta_1 \) coordinate from 0' to \( \Omega \) at a distance \( r = 0.5 \lambda \) from the tip. Our solution (continuous line) is compared with the exact solution (dashed line, from [4]) and the UTD solution (dotted line). This latter exhibits discontinuities at the two SBLs (\( \beta_2 \approx 38^\circ \) and \( \beta_1 \approx 52^\circ \)), that are well compensated by the vertex contributions. In Fig. 2b radial currents are
plotted for the case of a plane angular sector with $\Omega = 90^\circ$, illuminated by a plane wave as shown in the inset. The polarization of the $E$ field is parallel to the incidence plane. The scan is performed versus $\beta_1$ coordinate from $0^\circ$ to $\Omega$ at a distance $r=1.2a$ from the tip. Even in this case our solution improves the UTD. At the singly diffracted field $SBL$ ($\beta_1 \approx 38^\circ$) the compensation mechanism of $J'$ behaves as in Fig.2. Nevertheless, in the last part of the scan, the second order contributions play an important role in closer recovering the exact solution. Indeed a doubly diffracted field $SBL$ occurs at $\beta_1 \approx 52^\circ$; at this aspect a doubly diffracted current contribution $J''$ appears smoothly compensated by the relevant $J''$ term.

Fig. 2. Currents on a plane angular sector

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