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ITD APPROACH FOR PREDICTING NEAR FIELD RADIATION BY A CIRCULAR HORN

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1. INTRODUCTION

Radiation and diffraction problems from open ended waveguide and circular horns (CH) are often encountered in electromagnetic compatibility (EMC) applications. A high-frequency description of these phenomena may provide an efficient alternative to other numerically intensive methods, as well as a basic tool for constructing hybrid techniques. EMC couplings are often established through directions that are quite different from those typically considered in the design of horn antennas (e.g. grazing and/or backside directions). Thus, the Kirchoff approximation for the aperture integration (AI), which is in general satisfactory for the horn design, may not be adequate for EMC purpose. Indeed, this approximation fails at observation aspects close to and beyond the plane of the aperture. At those aspects, better accuracy may be obtained by using GTD [1], including second order diffraction mechanisms. On the other hand axial caustic singularities occur in the GTD description; furthermore, the accuracy of a GTD approach decreases when rapid spatial variation of higher order modes occur along the aperture rim. To overcome these difficulties, fringe field corrections may be introduced for improving the AI estimate. Based on the Physical Theory of Diffraction (PTD) [2] non uniform currents may be introduced at the rim on the metallic walls of the horn to correct those predicted by PO on the same walls. Similarly by referring to aperture fields [3], non uniform equivalent currents may be directly introduced to correct the estimate of the aperture distribution. In both cases incremental field contributions are obtained to be distributed along the rim.

In this paper, incremental diffraction coefficients at the edge of a CH are derived on the basis of the Incremental Theory of Diffraction (ITD) [4]-[6]. These distributed diffracted field contributions are used to predict mode radiation in the near zone, as well as to the reciprocal problem of EM coupling of a spherical wave into the CH. To preserve accuracy at aspects below the aperture plane, second order, incremental diffraction contributions are also included. For the sake of simplicity, the analysis presented here is restricted to the scalar case, with hard boundary conditions on the walls. This provides guidelines for the more general EM case.

2. FORMULATION

Let us consider the CH depicted in Fig.1 with a flare angle θ_f and an aperture radius a; let us assume an almost uniform phase distribution on the aperture so that the aperture field is essentially a projected hard (TM) circular waveguide mode; i.e.,

$$\Phi_{mn}(\rho', \psi') = \cos n\psi' \, J_n(k\rho' \sin\theta_t) \qquad (1)$$

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where (ρ', ψ') are the cylindrical coordinates of the aperture, $ksin\theta_t = k_{t_{mn}}$ is the transverse modal wavenumber of the circular waveguide, and J_n is the *n-th* order Bessel function. A spherical coordinate system (r, θ, ψ) is introduced with its z axis perpendicular to the aperture and its origin at the center of the aperture.

Furthermore, let us denote by ψ' the angular position of the edge element at Q' and introduce there a local spherical coordinate system

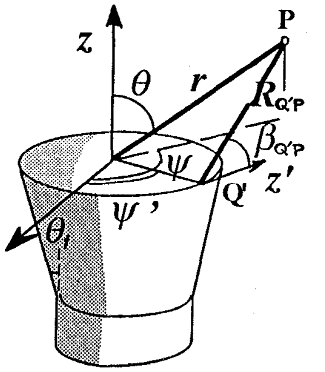

Fig. 1 Geometry of the circular horn

$$(R_{Q'P}, \beta_{Q'P}, \phi_{Q'P})$$

with its origin at Q', its z' axis tangent to the edge, and its $\phi=0$ reference at the internal wall. Useful relationships between absolute and local coordinates are

$$R_{Q'P} = |Q' - P| \qquad (2)$$

$$\beta_{Q'P} = cos^{-1}(\hat{R}_{Q'P} \cdot \hat{\psi}') \qquad (3)$$

$$\phi_{Q'P} = cos^{-1}\left(\frac{-\hat{\psi}' \cdot (\hat{z}cos\theta_f + \hat{\rho}'sin\theta_f)}{sin\beta_{Q'P}}\right) \qquad (4)$$

By invoking the locality principle at high frequency, each element of the rim is illuminated by a field whose local wavefront has the same curvature as that of the rim and a direction of propagation perpendicular to the rim itself. An appropriate local canonical problem is that of a half-plane locally tangent at Q' along the rim, wich is illuminated by a pependicularly incident plane wave from a direction $\phi' = \theta_t - \theta_f$.

The incremental plane wave response from Q' is directly deduced from the ITD localization process [4]. This procedure leads to the incremental diffraction contribution

$$f_{mn}^{itd}(\psi') = \Phi_{mn}(a, \psi')\ F(Q', P, K_{Q'P}) \qquad (5)$$

from each point Q' along the edge to any point $P \equiv (r, \theta, \psi)$ in the near zone, where

$$F(Q', P, K_{Q'P}) = \frac{exp(-jkR_{Q'P})}{4\pi R_{Q'P}}\Big(D(K_{Q'P}, \phi_{Q'P} - \theta_t + \theta_f) + D(K_{Q'P}, \phi_{Q'P} + \theta_t - \theta_f)\Big) \qquad (6)$$

$$D(K, x) = \frac{1}{2}\, sec\left(\frac{x}{2}\right)\, \mathcal{F}\left(2Kcos^2\left(\frac{x}{2}\right)\right) \qquad (7)$$

$$K_{Q'P} = k\ R_{Q'P}\ sin^2\beta_{Q'P} \qquad (8)$$

in which $\mathcal{F}(x)$ is the UTD transition function. The same procedure is applied to find the PO end point contribution [4], [5] $f_{mn}^{epo}(\psi')$; its expression is the same as that in (5) after replacing $D(K, x)$ in (7) by

$$D^{po}(K,\ x)= \frac{1}{2}\ tan(\frac{x}{2})\ \mathcal{F}\Big(2K\ cos^2(\frac{x}{2})\Big). \tag{9}$$

Thus, a modal fringe field

$$\Psi^{f}_{mn} = \int_{0}^{2\pi} (f^{itd}_{mn}(\psi') - f^{epo}_{mn}(\psi'))\ a\ d\psi' \tag{10}$$

is obtained, that is intended to provide a correction to the field from the Kirchoff approximation of AI.

3. DOUBLE DIFFRACTION INCREMENTAL CONTRIBUTION.

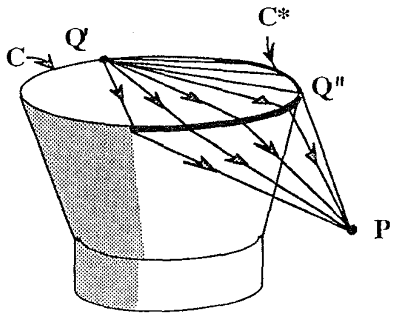

Fig. 2. Incremental double diffraction

It was found that the field predicted by (9) is not accurate as desired for observation aspects below the aperture plane ($\theta > \pi/2$). Indeed, at those aspects, the incremental field contributions, emanating from that part C of the rim which is not directly seen from the observation point P, are shadowed by the wall corresponding to the remainder C* of the rim which is directly seen from P (Fig. 2). These incremental contributions may reach the observation point only via a double diffraction mechanisms through the edge C*.

A double diffraction incremental contribution may be obtained by illuminating the second edge C* by the incremental field of a first order contribution from C. To this end, for each spherical incremental contribution from Q' on C, a second order incremental contribution F"(Q', Q", P) is found at any point Q" on C*. It can be conveniently expressed [6] as

$$F''(Q',\ Q'',\ P)= F(Q',\ Q'',\ K_{Q'Q''})F(Q'',\ P,\ \overline{K}) \tag{11}$$

where

$$\overline{K}= \frac{R_{Q'Q''}\ sin^2\beta_{Q'Q''}\ R_{Q''P}\ sin^2\beta_{Q''P}}{R_{Q'Q''}\ sin^2\beta_{Q'Q''}\ +\ R_{Q''P}\ sin^2\beta_{Q''P}} \tag{12}$$

The simple product of the incremental coefficients is used in (11) becouse the point Q" is outside the transition region of the illuminating incremental fields. The integration of F'' on C* provides the second order diffraction contribution. The complete solution is obtained by replacing $F(Q',\ P,\ K_{Q'P})$ in (5) by

$$\hat{F}(Q',\ P,\ K_{Q'P})=F(Q',\ P,\ K_{Q'P})U(\frac{\pi}{2}-\theta)+\int_{C^*} F''(Q',\ Q'',\ P)a\ d\psi'' \tag{13}$$

where $U(x)$ is the Heavyside unit step function. It is worth noting that the integral in (12) can be approximated by its stationary phase contribution to avoid double integration. This leads to a standard UTD diffraction coefficients for the double diffracted field from C^* for each incremental point Q' on C.

4. PRELIMINARY RESULTS

Preliminary, encouraging calculations have been obtained in the far-field limit for an open ended circular waveguide. Electromagnetic calculations will be shown during the oral presentation.

REFERENCES

[1] H. Y. Yee, L.B. Felsen, J.B. Keller, "Ray theory of reflection from the open end of a waveguide, " *SIAM J. Appl. Math.* 16, 268-300, 1968

[2] P. Ya. Ufimtsev,"Elementary edge waves and the physical theory of diffraction," *Electromagnetics*, Vol.11, no. 2, pp. 125-159, April-June 1991.

[3] A. Altintas, P. H. Pathak, M. C. Liang, " A selective modal scheme for the analysis of the EM coupling into or radiation from large open ended waveguide", *IEEE Trans. Antennas Propagat.* , Vol. 36, no. 1, Jan. 1988.

[4] R. Tiberio, S. Maci, "An Incremental Theory of Diffraction: scalar formulation," *IEEE Trans. Antennas Propagat.* , Vol. 42, no. 5, May 1994.

[5] R. Tiberio, S. Maci, A. Toccafondi "An Incremental Theory of Diffraction: Electromagnetic formulation," *IEEE Trans. Antennas Propagat.* , Vol. 43, no. 1, Jan. 1995.

[6] S. Maci, R. Tiberio, A. Toccafondi "Incremental Diffraction coefficient for source/observation at finite distance from an edge" submitted to *IEEE Trans. Antennas Propagat.*

[7] L. A. Wainstain, "The theory of sound waves in open tubes" Zh. Tekh. Fiz., 19, 911-930, 1949.