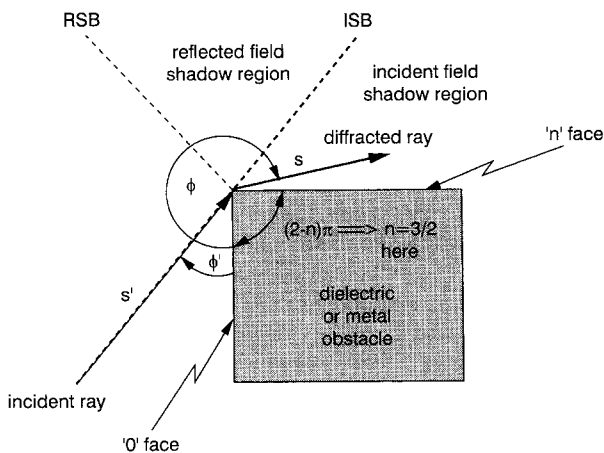


Improved diffraction coefficients for lossy dielectric wedges

K.A. Remley, A. Weisshaar and H.R. Anderson

Improved site-specific prediction of the diffracted fields from lossy dielectric obstacles is presented. A commonly used set of diffraction coefficients are redefined in a more physical way. The theoretical basis for the improvement is presented and validation is given by comparison to full-wave simulation results.

Introduction: Site-specific propagation modelling techniques, such as ray-tracing [1], enable the accurate determination of received signals for both line-of-sight and non-line-of-sight conditions. These site-specific techniques are typically based on the uniform theory of diffraction (UTD) [2] for the characterisation of diffracted fields arising from obstacles made of perfect electrical conductors. However, the development of a uniform diffraction model for obstacles with finite conductivity is the subject of continuing research. In 1984, Luebbers [3] introduced a computationally efficient, heuristic modification to the UTD equations which is currently used in many ray-tracing models, as, for example, in [4]. As discussed by Luebbers [3, 5], accurate use of these heuristic diffraction coefficients is restricted to applications involving obstacles (wedges) with large interior angles, configurations with observation points near shadow boundaries (as defined in Fig. 1), and configurations with observation angles greater than the angles of incidence. In cases where these conditions are not satisfied, a non-physical dip in the diffracted field may result for certain angles of observation [6]. In this Letter, the Luebbers formulation is modified by redefining the angular dependence of the diffraction coefficients in a more physical way. This new set of diffraction coefficients, described in detail in [7], enables more accurate prediction of the diffracted fields for a wide range of wedge interior angles and for any observation angle.



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Fig. 1 Geometry of diffraction problem

90° ($n = 3/2$) wedge problem is illustrated, with '0' face and 'n' face denoted. ISB and RSB refer to incident field and reflected field shadow boundaries, respectively

Development: The geometry of the problem is given in Fig. 1. A dielectric wedge with 90° interior angle is illuminated by a ray at an angle of incidence ϕ' . A diffracted ray is observed in the inci-

dent field shadow region at the angular position ϕ . In the original Luebbers formulation, Fresnel reflection coefficients R_0 and R_n are incorporated into the two UTD coefficients associated with the reflection shadow boundary (RSB in Fig. 1) [3]. R_0 is calculated at $\theta_0 = \phi'$, corresponding to the angular location of the transmitter relative to the incidence face ('0' face), and R_n is calculated at $\theta_n = n\pi - \phi$, corresponding to the angular location of the observation point relative to the diffraction face ('n' face). We will now demonstrate that the accuracy of the diffraction field calculation can be significantly increased by redefining the angles at which the Fresnel coefficients are calculated. In this new formulation, the angle θ_0 remains solely dependent on the transmitter location, ϕ' , because the location of the RSB is solely dependent on ϕ' . However, because the relationship between the observation point and the RSB depends on both the transmitter and observation point locations, the angle θ_n is calculated using both ϕ and ϕ' . Table 1 compares angles θ_0 and θ_n for the original and new diffraction coefficient formulations. Here we consider four different transmitter and observation point configurations, depending on whether the angle of incidence, ϕ' , is greater than or less than 180° , and whether the observation point, ϕ , is in the 'illuminated' region, where $|\phi - \phi'| < 180^\circ$, or in the 'shadowed' region.

Table 1: Comparison of angles involved in calculation of original Luebbers diffraction coefficients and new diffraction coefficients

Region	Luebbers		New	
	θ_0	θ_n	θ_0	θ_n
$\phi' < \pi$, illuminated	ϕ'	$n\pi - \phi$	$-\phi'$	$-(\phi + \phi')$
$\phi' < \pi$, shadow	ϕ'	$n\pi - \phi$	ϕ'	$n\pi - (\phi + \phi')$
$\phi' < \pi$, illuminated	ϕ'	$n\pi - \phi$	ϕ'	$n\pi - (\phi + \phi')$
$\phi' < \pi$, shadow	ϕ'	$n\pi - \phi$	$n\pi - \phi'$	ϕ

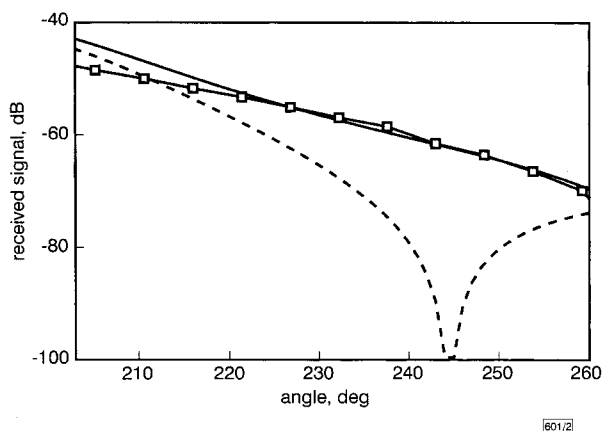


Fig. 2 Comparison of original Luebbers diffraction coefficients, new diffraction coefficients, and diffracted field found by combined FDTD/Kirchhoff method

Angle of incidence is $\phi' = 248^\circ$, and dielectric wedge has $\sigma = 0.1\text{S/m}$ and $\epsilon_r = 15.0$

--- original
 — new
 —□— FDTD

Validation: To validate the new set of diffraction coefficients, full-wave electromagnetic simulation results were used as a standard against which the ray-tracing results are compared [8]. The full-wave simulation was provided by the finite difference time domain (FDTD) method combined with the Kirchhoff surface integral formulation, a spatial transformation technique. We have considered diffraction from an infinite 90° wedge. The wedge was made of a dielectric material with $\sigma = 0.1\text{S/m}$ and $\epsilon_r = 15.0$. Observation points were located 270° along a ring centred around the diffracting corner. To approximate an infinite wedge in the full-wave model, the transmitter and observation points were placed close enough to prevent diffraction around the back of the wedge for the duration of the simulation. For the case shown, the transmitter and observation point locations were $s' = 0.8\text{m}$ and $s = 0.75\text{m}$

from the diffracting corner, respectively, corresponding to 2.4λ and 2.25λ at a frequency of 900MHz . Transmission through the dielectric material was not significant, as determined by examination of the mesh field plots from the FDTD simulations. The FDTD grid cell dimensions were $\Delta x = \Delta y = 0.025\text{m}$ ($\sim\lambda/13$), with $\Delta z = 3\Delta x$ to prevent diffraction over the top. The overall grid size was $79 \times 91 \times 50$, terminated under PML absorbing boundary conditions.

Fig. 2 compares the FDTD/Kirchhoff method results to ray-tracing results in the incident field shadow region for a perpendicularly polarised ideal dipole with $\phi' = 248^\circ$. Comparison is made with the new set of diffraction coefficients ('new') and the original set of Luebbers diffraction coefficients ('original'). The curve corresponding to the original formulation was calculated at ten times the FDTD simulation distances ($s' = 8.0\text{m}$ and $s = 7.5\text{m}$). The amplitude of this curve was scaled accordingly to better illustrate the dip effect, which becomes more pronounced at larger distances. The improvement in the ray-tracing simulation is readily apparent, since the dip in the diffraction region has been eliminated. Further simulation results are presented in [7].

Conclusion: An improved set of UTD diffraction coefficients for calculations involving dielectric wedges has been demonstrated. These improved coefficients enabled a more accurate prediction of the diffracted fields for a wide range of wedge interior angles and for any observation angle. The implementation required only a simple modification of the original formulation and, therefore, was nearly as computationally efficient as the original implementation.

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References

- ANDERSON, H.R.: 'A ray-tracing propagation model for digital broadcast systems in urban areas', *IEEE Trans. Broadcast.*, 1993, **39**, pp. 309–317
- KOUYOUMJIAN, R.G., and PATHAK, P.H.: 'A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface', *Proc. IEEE*, 1974, **62**, pp. 1448–1461
- LUEBBERS, R.J.: 'Finite conductivity uniform UTD versus knife diffraction prediction of propagation path loss', *IEEE Trans. Antennas Propag.*, 1984, **AP-32**, pp. 70–76
- ANDERSON, H.R. (EDX Engineering): 'Microcell 3D ray-tracing module'. Microcell Communication Simulator Software, 1997
- LUEBBERS, R.J.: 'A heuristic UTD slope diffraction coefficient for rough lossy wedges', *IEEE Trans. Antennas Propag.*, 1989, **37**, pp. 206–211
- DEMETRESCU, C., CONSTANTINOU, C.C., and MEHLER, M.J.: 'Scattering by a right-angled lossy dielectric wedge', *IEE Proc., Microw. Antennas Propag.*, 1997, **144**, pp. 392–396
- REMLEY, C.A.: 'Time domain modeling of electromagnetic radiation with application to ultrafast electronic and wireless communication systems'. PhD thesis, Oregon State University, Department of Electrical and Computer Engineering, March 1999
- REMLEY, C.A., WEISSHAAR, A., and ANDERSON, H.R.: 'A comparative study of ray tracing and ftdt for indoor propagation modeling'. Proc. Vehicular Technology Conf., Ottawa, Canada, May 1998, pp. 865–869