# Building Corner Diffraction Measurements and Predictions Using UTD

Harry R. Anderson

*Abstract*— **Measurements of the electric field in the vicinity of the corner of a stone building are presented. The experimental results are compared to theoretical predictions using the uniform theory of diffraction (UTD) for dielectric wedges and simple specular ground reflections. The comparison of the two results show close agreement indicating that UTD is a viable approach for predicting the diffracted field around building corners in applications such as propagation modeling for communications systems operating in urban environments.**

## I. INTRODUCTION

The deployment of high-speed digital communication systems in urban environments has placed new demands on propagation models for designing such systems. The objective of most propagation models is to predict the median path loss from the transmitter to the receiver. For signal transmission bandwidths that are sufficiently narrow, this approach is adequate because multipath reflections from elements of the propagation environment can be treated as variations or fading in the received signal envelope. However, for high-speed digital or other signals where the bandwidth of the signal is sufficiently wide, multipath propagation results in a frequency-selective channel response corresponding to multipath echoes at the receiver that can be resolved into separate signal pulses. Depending on the receiver design, these delayed signal pulses lead to intersymbol interference (ISI) when the detector in the receiver attempts to decode a transmitted data pulse. Consequently, there is strong motivation to develop propagation models that can accurately predict the amplitude and delay of multipath echoes in real propagation environments.

The technique that has emerged as being well suited to this task is ray-tracing based on geometric optics. In addition to predicting signal levels, ray-tracing inherently provides pulse-delay information as a function of total ray path length. A number of papers have appeared in the literature that discussed the use of ray-tracing for predicting signal levels and time dispersion in communication channels operating in urban environments [1]–[4]. These models generally employ a combination of "propagation primitives," including smooth-surface specular reflection, uniform theory of diffraction (UTD), through-wall transmission, and scattering.

As with any model, it is important to obtain experimental verification. The experimental work published thus far has focused on those "macroscopic" effects which are of most interest to communication systems designers—the mean signal level and the "root mean square (RMS) delay spread" of the channel. However, relatively little work has been done to experimentally verify the elemental propagation constructs that are used in the ray-tracing models, especially UTD. Measurements of diffraction fields have been done under laboratory conditions achieving satisfactory agreement with wedge diffraction predictions [5]. No measurements of diffraction around a single isolated corner of a real building have appeared in the literature.

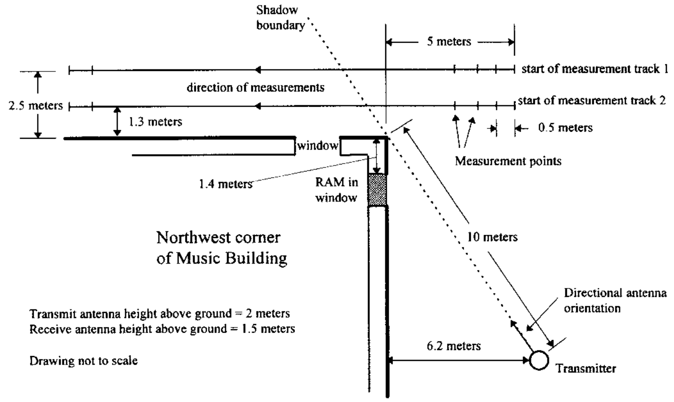

Fig. 1. Plan view of measurement site for corner diffraction measurements.

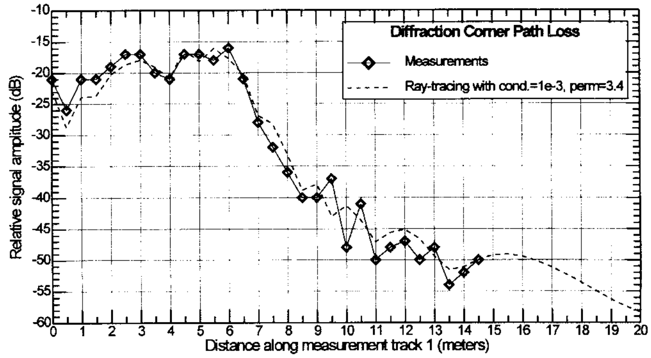

Fig. 2. Corner diffraction total fields measurements and ray-tracing predictions for track one.

The objective of the work described here is to investigate the viability of the UTD corner model primitive when it is applied to real building corners. An experiment was designed to measure the electric field in the vicinity of the corner of a stone building. Comparison of the resulting measurements with predictions based on the UTD are presented.

## II. UTD FIELD PREDICTIONS

The UTD was presented in the now classic work by Kouyoumjian and Pathak [6] as an improvement on Keller's original geometric theory of diffraction (GTD) formulation [7], which contains singularities at the reflection and shadow boundaries resulting in infinite diffracted fields at those boundaries. The UTD equations were later modified by Luebbers [8] to include reflection coefficients which modify the face reflection terms in the UTD equations as a heuristic approach to calculating fields around finite conductivity or dielectric wedges. These equations for the diffracted field around corners are straightforward to implement in computer programs and thus have become commonly used in current ray-tracing propagation models.

The diffraction and specular reflection coefficients were incorporated in a ray-tracing propagation model [3], which was used to make the theoretical predictions of the field around the building corner. Both the diffracted rays and ground reflection rays were included.

Manuscript received January 13, 1997.
The author is with EDX Engineering, Inc., Eugene, OR 97440 USA.
Publisher Item Identifier S 0018-926X(98)01499-9.

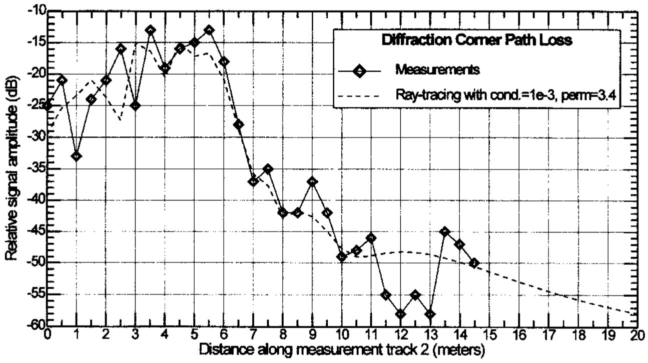

Fig. 3. Corner diffraction total fields measurements and ray-tracing priedictions for track two.

## III. CORNER DIFFRACTION MEASUREMENTS

Fig. 1 is a plan view of the measurement location at the northwest corner of the Music Building on the campus of the University of Bristol in Great Britain. This location was chosen because it is elevated with no nearby buildings or automobile traffic to cause backscattered energy and the stone surface is similar to the stone surface of many urban buildings in Bristol and other cities. The area immediately adjacent to the building is also flat and mostly paved, making measurement track layout convenient. The building itself has two large glass windows on the stone faces joining at the corner. In order to reduce the possibility of through-window energy distorting the measurements, radar absorbing material (RAM) was placed in the window nearer the transmitting antenna, as shown in Fig. 1.

Measurements were taken every 0.5 m along tracks one and two starting in the line-of-sight (LOS) region where both direct and diffracted fields are present, crossing the shadow boundary, and continuing well into the shadow region where only the diffracted field should be present. The operating frequency for these experiments was set at 1823 MHz with an unmodulated sine-wave carrier. This frequency was chosen because it is close to the 1850–1990 MHz band where many of the new high-speed digital communication systems will be operating.

The output power from the transmitter was set at 0 dBmW and feed into a Jaybeam type 7360-1800 directional antenna with a 3-dB beamwidth of about 26°. Using a directional transmitting antenna pointed at the corner reduces the illumination of other structures and thereby reduces extraneous reflections at the receiver.

The receive antenna was omnidirectional in the horizontal plane with 0-dBd gain. A linear pre-amplifier followed by a spectrum analyzer were used to measure the amplitude of the received signal. Vertical polarization was used for all measurements.

## IV. COMPARISION OF THEORETICAL AND EXPERIMENTAL RESULTS

Figs. 2 and 3 show plots of the predicted and measured results for the total field (diffracted plus direct) along measurement tracks one and two, respectively. For the predictions, the diffraction coefficients from Section II were used. The wall material was modeled with a conductivity of $1 \times 10^{-3}$ S/m and relative permittivity of 3.4. These material values are for dry sandy soil which, of the material types for which published values are available, most closely match the sandstone corner material of the Music Building. The ground is assumed to have a conductivity of $1.0 \times 10^{-2}$ S/m and a relative permittivity of ten.

As expected, the predicted fields in both Figs. 2 and 3 show an oscillatory pattern in the LOS region due to the direct and diffracted waves adding in and out of phase. There is also an additional single reflection ray from the wall that is a greater contributor to the field at the first several points on each measurement track than the diffracted ray. The predicted field also decreases away from the corner toward the track starting point as a result of the directional properties of the Jaybeam antenna, which were included in the ray-tracing model predictions. The peak in the predicted field occurs at the point where the diffracted and direct fields add in phase just before the direct field is obstructed by the corner. At the shadow boundary the predicted field has fallen by about 6 dB from its average LOS value. In the shadow region, the field continues to decrease as the bending angle around the corner gets increasingly acute.

## V. CONCLUSION

The ray-tracing predictions plotted in Figs. 2 and 3 for tracks one and two, respectively, show good agreement with the measurements. The peak just before the shadow boundary and the steep 20-dB drop in field strength after crossing the shadow boundary match the measurements quite closely. The oscillatory behavior in the LOS region is not well represented because the spacing of the measurement points (every 0.5 m or about three wavelengths) is too wide to discern the details of the oscillating pattern. Also, the measurements were done by visually averaging the signal amplitude displayed on a spectrum analyzer. A more uniform method for recording and averaging out time-dependent signal variations due to passing pedestrians would improve the consistency of the results. These measurements also show that signal transmission through the corner of the building is negligible, at least to the extent that it did not appear to alter the field significantly away from that found using the diffracted field only in the shadow region (along with the ground reflection from the diffracting corner). This result supports the assumption that for many circumstances through-building transmission for outdoor urban ray-tracing studies can be ignored without significantly affecting the prediction.

## ACKNOWLEDGMENT

The author would like to thank M. Beach and A. Nix of the University of Bristol, U.K., for their assistance in setting up and carrying out the measurements described here.

## REFERENCES

[1] J. W. McKown and R. L. Hamilton, "Ray-tracing as a design tool for radio networks," *IEEE Network Mag.*, vol. 5, pp. 27–30, Nov. 1991.

[2] K. S. Schaubach, N. J. Davis, and T. S. Rappaport, "A ray-tracing method for predicting path loss and delay spread in microcell environments," in *Proc. Veh. Technol. Soc. Conf.*, Denver, CO, May 1992, pp. 932–935.

[3] H. R. Anderson, "A ray-tracing propagation model for digital broadcast systems in urban areas," *IEEE Trans. Broadcasting*, vol. 39, pp. 309–317, Sept. 1993.

[4] S. Y. Tan and H. S. Tan, "UTD propagation model in an urban street scene for microcell communications," *IEEE Trans. Electromagn. Compat.*, vol. 35, no. 4, pp. 423–428, Nov. 1993.

[5] W. D. Burnside and K. W. Burgener, "High frequency scattering by a thin dielectric slab," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 104–110, Jan. 1983.

[6] R. G. Kouyoumjian and P. H. Pathak, "A uniform theory of geometric diffraction for an edge in a perfectly conducting surface," in *Proc. IEEE*, vol. 62, pp. 1448–1461, Nov. 1974.

[7] J. B. Keller, "Gometric theory of diffraction," *J. Opt. Soc. Amer.*, vol. 52, pp. 116–130, 1962.

[8] R. J. Luebbers, "Finite conductivity uniform GTD versus knife-edge diffraction on predicting propagation path loss," *IEEE Trans. Antennas Propagat.*, vol. AP-32, pp. 70–76, Jan. 1984.