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A Simple Wideband Passive Scatterer Reducing a Corner Diffraction Loss

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Abstract

Diffraction describes propagation into a shadow region, showing increasing attenutation with frequency. This behaviour is relevant to 5G systems where the mmwave frequencies have reduced coverage in non-line-of-sight areas of an urban environment. Here we seek to improve around-the-corner coverge by changing the electromagnetic nature of the corner. The simplest approach is to use a passive dipole scatterer placed at the corner. The coverage improvement is shown to be tens of dB above that of diffraction, and wideband.

1 Introduction

Nearly all radio communications links rely on Non-Line-Of-Sight (NLOS) propagation. Powerful signal processing techniques in most receivers remove the effect of signal distortion caused by the dispersion of the multipath link. For mass produced wireless products, such as for cellular and wifi, this signal processing has become transparent and very low cost. The coverage of a radio system relates to the energy available at the receiver location. A dominant mechanism for NLOS propagation is diffraction, a well-established theory pioneered by Keller [1]. An interpretation is that it describes the difference between the fields predicted by geometric optics and the actual fields within and near to the shadow region. The Uniform Geometrical Theory of Diffraction (UTD) is formulated from the continuity of waves from the illuminated region to the shadow region [2], and can be visualized by some types of simulation, and verified by careful measurement, e.g., [3, 4, 5]. A traditional method to increase the signal level in a shadow region is by repeater, including passive repeaters, e.g., [6, 7, 8]. For wide angular coverage, the simplest solution is using a passive dipole scatterer. For example, switched parasitic elements have been used to create changes in antenna patterns for improving changing links [9].

This paper shows how a passive dipole scatterer or an array of dipole scatterers can enhance the energy in the shadow region. We use careful simulation which allows evaluation of the fields for a given configuration. This provides an effective design before undertaking physical measurements. For simplicity, the dipole scatterer is placed over a perfectly electric conducting (PEC) corner, allowing a canonical situation that fosters a check for both polarizations. For vertical polarization (the parallel polarization case with the electric field and the dipole parallel to the vertical building corner), there is significant enhancement of the available power in the shadow region. The length of the dipole is not a major factor so the scattering is wideband. The concept seems practical in that it is feasible to have corners of many buildings, etc., modified with such a low profile, simple (low cost), and unintrusive structure. Future work will establish the significance of the coverage improvement from a wireless communications metric such as network capacity.

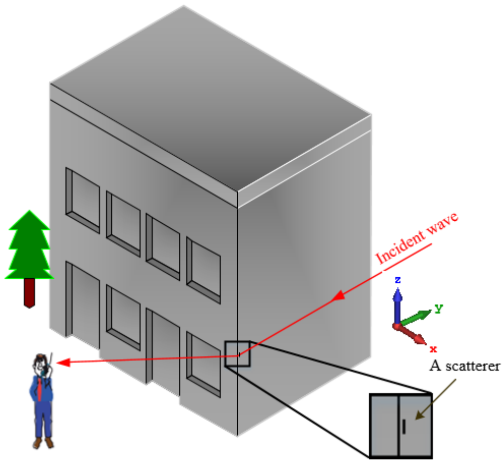


Figure 1. Propagation around a corner of a building with an affixed simple dipole scatter (after[5]).

2 Description of the Model

The propagation around a corner with an affixed parallel dipole scatterer is depicted in Fig.1. The corner which is used in the simulation model has a "height", width and length of 14λ, 6λ and 10λ, respectively (see Fig.2). A half-wavelength vertical (parallel) polarized dipole antenna is used as a transmitter. It is located at $X_{Tx} = Y_{Tx} = \lambda$. The receiver (observation point) is at Y_{Rx} varied along the shadow region parallel to the wall in the X direction. A passive parallel half-wavelength dipole is located over the corner with a spacing of h_s and $\theta = 45°$. The receiving dipole, scattering dipole, and the transmitter dipole are aligned in the plane of incidence. CST Microwave Studio [10] time domain solver is used for simulation. All the simulation

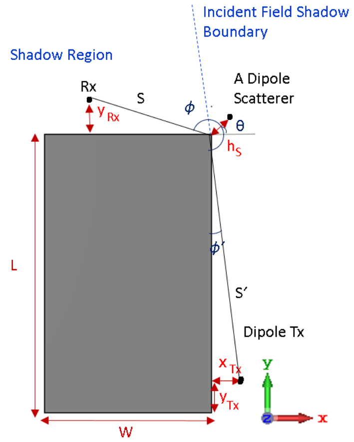


Figure 2. Simulation geometry of a parallel passive dipole over a corner, with a parallel-polarized dipole as a transmitter (after[5]). The dimensions of the corner are $H = 14\lambda$, $W = 6\lambda$ and $L = 10\lambda$. (H is in the Z direction, not shown here). The spacing between the dipole and the corner is h_s. The "height" of receiver (observation point) is Y_{Rx}. Only the forward direction is considered.

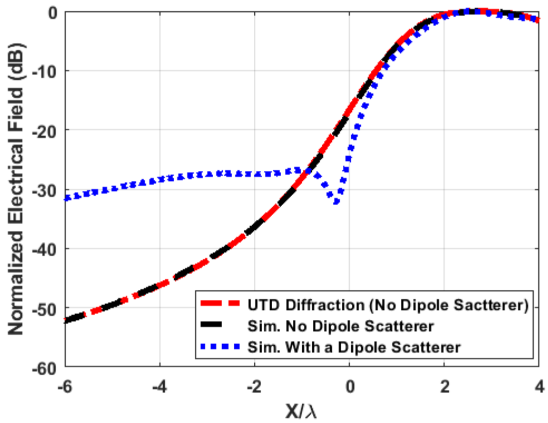


Figure 3. The normalized electric field over corner in (XY-plane at $Y_{Rx} = 2\lambda$), given by UTD in [2], compared to the simulated fields for the corner with/without a parallel half-wavelength dipole scatterer with $h_s = \lambda$. The transmitter is a dipole also with vertical (parallel) polarization (corner surface reflection coefficient is $R = -1$).

boundaries are defined as open boundaries with Perfectly Matched Layer (PML). Spherical or conical wave sources are not available in CST, and there is energy leakage from open boundary with plane wave illumination [11]. Because of these limitations, we use dipoles, and the corner walls must be PEC otherwise the fields will leak through the corner. With a PEC corner, the reflection coefficients simplify to $R = -1$ for parallel polarization and $R = 1$ for perpendicular polarization. This canonical structure allows checks of the simulation results against theoretical results. Most buildings do not have metallic, let alone PEC walls, of course, but because the incident angles of interest are at grazing, the building material and smoothness may not be critical in practice.

3 Results and Discussion

3.1 Parallel dipole scatterer over the corner

The simulated results from the corner diffraction (without any scatterer) is plotted in Fig. 3, and compared to the UTD formulation [2, 12] (bottom overlapping curves in the figure). The match is excellent. The simulated result with a parallel half-wavelength dipole over the corner is also plotted in Fig. 3. The spacing between the dipole and the corner for this example is $h_s = \lambda$, and the "height" of the receiver is $h_{RX} = 2\lambda$. These plots illustrate a significant enhancement of ∼20dB in the shadow region. The results are normalized to the maximum power in the lit region for both cases; i.e., with and without the dipole scatterer. For the same configuration, the simulated electrical fields on the XY-plane are shown in Fig.4a and 4b for corner without, and with, the parallel dipole. (The other plane cut, YZ-plane, is not shown here). This enhancement is essentially everywhere in the shadow region, and is the result of having two sources i.e., the dipole and its optical image, supplementing the diffraction-only contribution.

3.2 Effect of dipole length

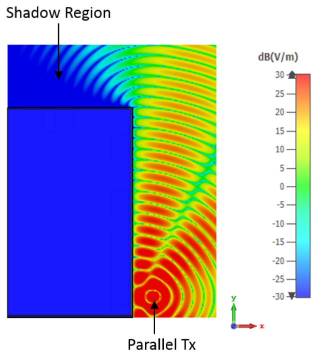
Fig. 5 shows that a very small dipole, here with length of 0.08λ, does not enhance the coverge. The figure shows how the field in the shadow iregion increases with increasing dipole length L_s. In short, a large gain is available in the immediate shadow over a wide range of frequencies.

3.3 Impact of inline array of dipole scatterers

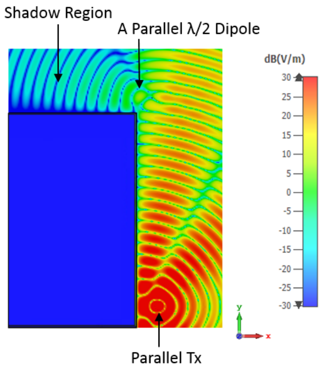
A larger scattering aperture is of obvious interest, and with an eye to array gain and beamforming possibiities using array techniques. Fig. 6 shows the simulated field strength for an inline passive array, and the improvement is ∼10dB compared to the single dipole scatterer ($L_s = \lambda/2$) case, and a long single wire scatterer of length $L_s = H = 14\lambda$.

3.4 Perpendicular dipole over the corner

In this section, the dipole orientations are all perpendicular to the wall. The UTD diffraction with the surface reflection, $R = 1$, is compared with the simulated corner without a dipole scatterer with horizontal (perpendicular) polarization (see Fig. 7). The simulation agrees well the UTD. The presence of a parallel dipole scatterer does not change the field, as intuitively expected. A perpendicular half-wavelength dipole at the corner can be expected to have some effect. The simulation results in Fig.7 illustrate that for this case (with $h_s = \lambda$ and $\theta = 45°$), the field is increased by only a few dB in the shadow region for a receiver "height" of $Y_{Rx} = 2\lambda$. So the improvement is not very significant for this case (although for communications aspects,



(a) Without a passive dipole scatterer.



(b) With a parallel passive $\lambda/2$ dipole ($h_s = \lambda$ and $\theta = 45°$).

Figure 4. The simulated electric field on XY-plane for corner (a) without and (b) with a parallel passive dipole scatterer. The transmitter is a dipole antenna with vertical (parallel) polarization (after [12]). The scattering dipole is shown to has a strong effect in the deep shadow region, and little effect in the lit region.

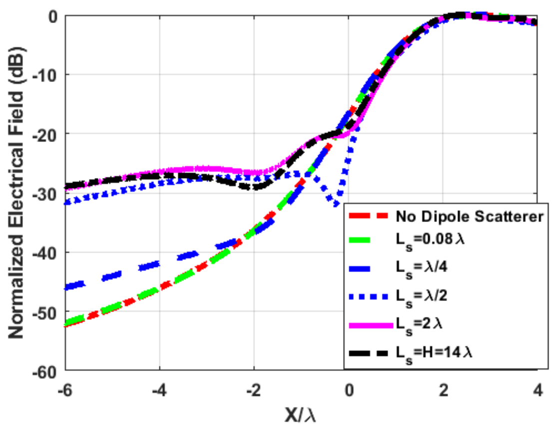


Figure 5. Comparison of the normalized simulated electrical field over the corner (XY-plane at $Y_{Rx} = 2\lambda$), with a parallel passive dipole over the corner ($h_S = \lambda$) with various lengths, L_s. The transmitter is a dipole with vertical (parallel) polarization.

such as coding and moduation, a couple of dB is a large improvement). The reasons for this configuration not being

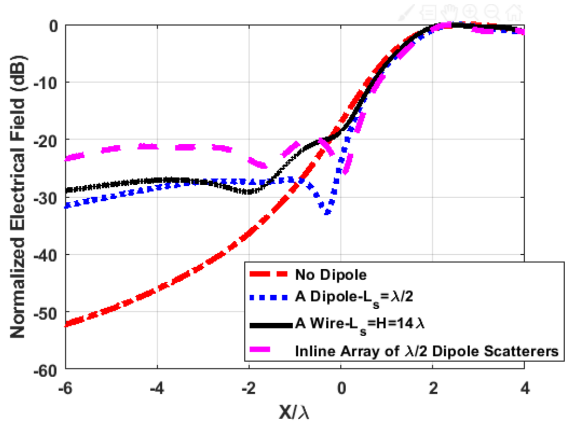


Figure 6. The normalized simulated electrical field over the corner (XY-plane at $h_{Rx} = 2\lambda$), with inline array of half-wavelength dipole scatterers over the corner as compared to the dipole scatterer with the length of $L_s = \lambda/2$ and the longer dipole scatterer (long wire) with the length of $L_s = H = 14\lambda$. The spacing h_s is λ.The transmitter is a dipole with vertical (parallel) polarization.

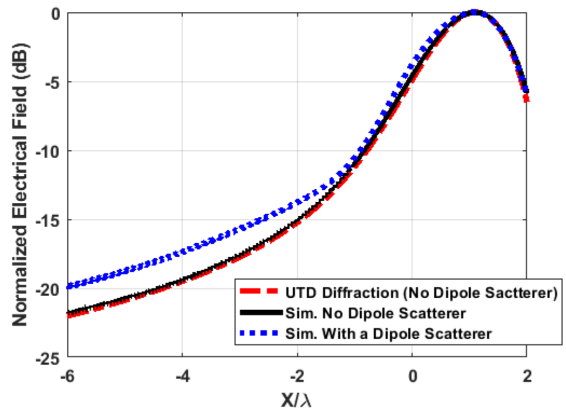
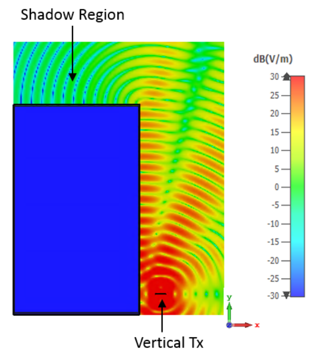
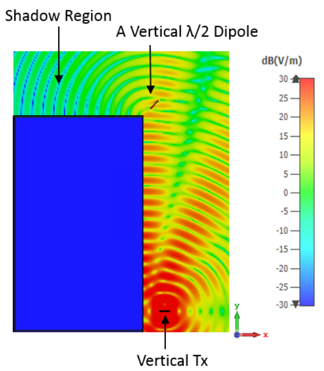


Figure 7. Comparison of the normalized simulated electrical field over the corner (XY-plane at $h_{Rx} = 2\lambda$), without and with a "vertical" half-wavelength dipole with a spacing of $h_s = \lambda$ and $\theta = 45°$. The transmitter is a dipole antenna with horizontal (perpendicular) polarization (surface reflection coefficient is $R = 1$). The simulated result is also compared to the UTD for validating the simulation model.

so effective are as follows. Firstly, the dipole scatterer is no longer parallel to the source or receiving polarization. Also, the corner diffraction attenuation for horizontal (perpendicular) polarization is less than that of the vertical (parallel) polarization. In this sense, the diffraction attenuation problem is not as important as for the vertical polarzation case. The simulated electrical field intensities on XY-plane are depicted in Fig. 8, illustrating, in comparison to Fig. 4, the reduced improvement.



(a) Without a passive dipole scatterer.



(b) With a "vertical" passive $\lambda/2$ dipole ($h_s = \lambda$ and $\theta = 45°$).

Figure 8. The simulated horizontal electric field on the XY-plane for a corner (a) without and (b) with a "vertical" half-wavelength dipole scatterer. The transmitter is a dipole antenna with horizontal (perpendicular) polarization (corner reflection coefficient is $R = 1$). The corner diffraction attenuation for horizontal polarization is less than that of the vertical polarization. The field is increased by only a few dB in the shadow region with the "vertical" dipole.

4 Conclusion

A passive scatterer can enhance the field strength in the optical shadow region of a corner, and this enhancement is quantified in this paper. The UTD wedge diffraction formulation offers a benchmark for the shadowing, but this is complicated to simulate using CST Microwave Studio. We describe our simulation approach and demonstrate a match between the simulation and diffraction results, despite using a dipole excitation instead of a plane wave. The scattering dipole is shown to has a strong effect in the deep shadow region, and little effect in the lit region, for vertical (parallel) polarization. Smaller signal enhancements are shown for horizontal (perpendicular) polarization. Arrays of dipole scatterers can further improve the energy enhancement. Physical measurements will be presented orally.

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