A Simple Wideband Passive Scatterer Reducing a Corner Diffraction Loss

Roshanak Zabihi* Christopher G. Hynes Rodney G. Vaughan

Sierra Wireless Communications Lab
Simon Fraser University, Canada

URSI GASS 2020

Rome, Italy
August 2020

Outline

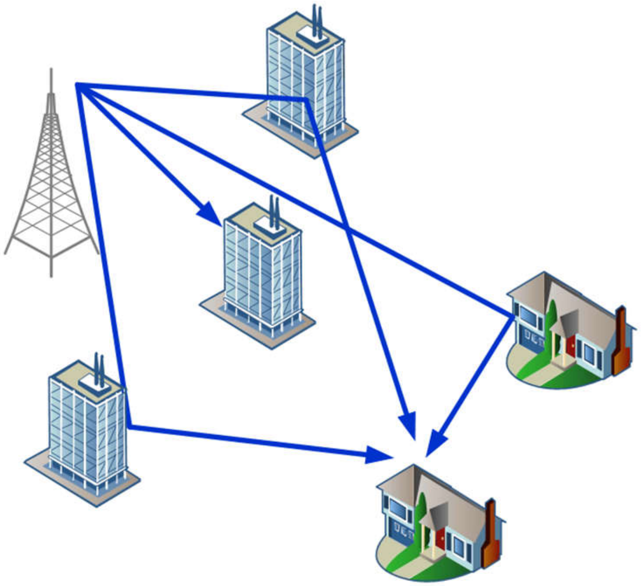
- Introduction
- Description of the Model used for Demonstration
- Simulation Approach
- Diffraction by a Corner – Uniform Theory of Diffraction
- Results
- Conclusions

Introduction

- ☐ Increasing carrier frequencies for communication capacity brings greater shadowing compromising the radio coverage.

- ☐ mmWave signals are severely attenuated in the simplest of non-line-of-sight (NLOS) scenarios - around the corner of a building.

Diffraction is a dominant propagation mechanism.



Introduction

- A traditional method to increase signal coverage in diffraction situations is the use of passive repeaters.
- Passive repeaters are a very low cost way to *“fill in” a shadow region* compared to active repeaters* having an amplifier stage or fully regenerate the signal.
- Examples of passive repeaters include Yang’s double flat reflectors from 1957*, Norton’s large passive reflectors from 1962**,and more recently, using Yagi-Uda antennas*** and four-element patch antenna arrays****.
- There is ongoing interest within the communications community in the concept of adaptive, active scattering surfaces to improve NLOS link gains**.

---

* R. Yang. Passive repeater using double flat reflectors. In *1958 IRE International Convention Record*, volume 5, pages 36–41, March 1957.

** M. Norton. Microwave system engineering using large passive reflectors. *IRE Transactions on Communications Systems*, 10(3):304–311, Sep. 1962.

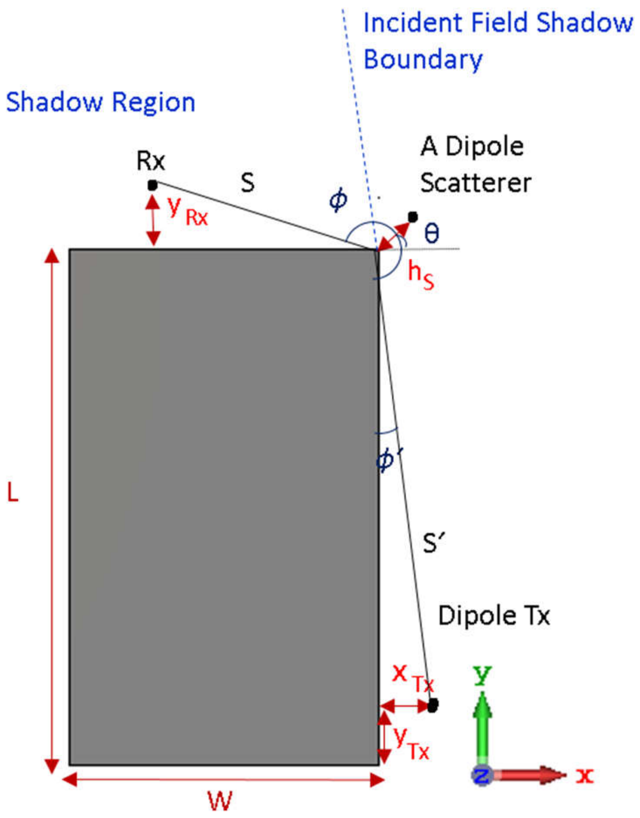
*** J. I. Chaves, A. G. Junior, and J. R. Desccardeci. Design of passive retransmitting system for cellular communication. volume 2, pages 76–83, Dec. 2001.

**** T. Tang, T. Hong, C. Liu, W. Zhao, and M. Kadoch. Design of 5G dual-antenna passive repeater based on machine learning. In *2019 15th International Wireless Communications Mobile Computing Conference (IWCMC)*, pages 1907–1912, June 2019.

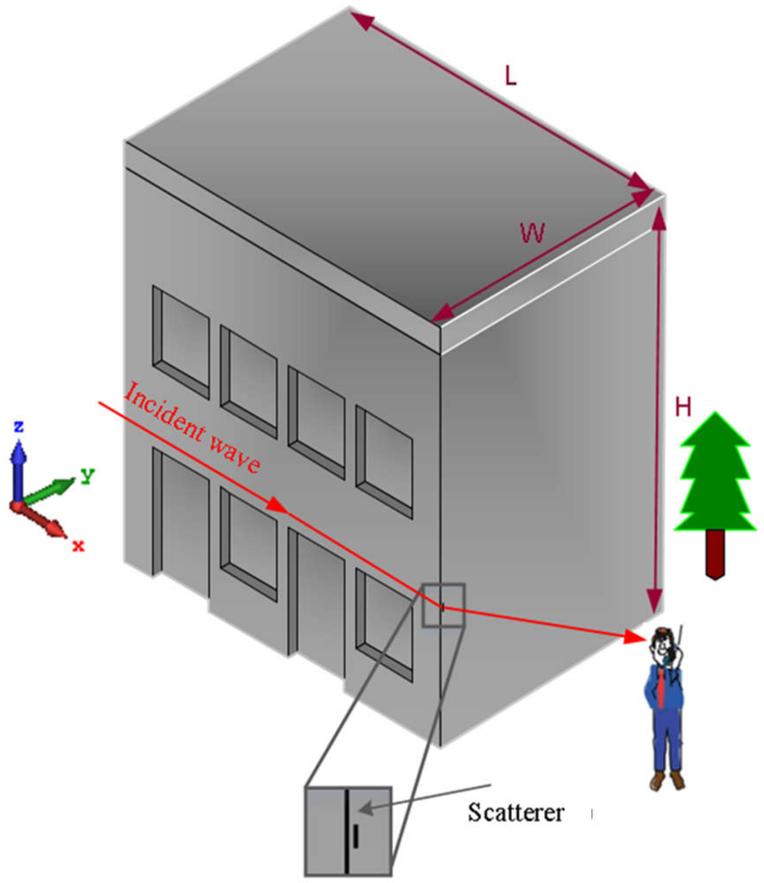
* J. Oh, M. Thiel, and K. Sarabandi. Wave-propagation management in indoor environments using micro-radio-repeater systems. *IEEE Antennas and Propagation Magazine*, 56(2):76–88, April 2014.

** E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M. Alouini, and R. Zhang. Wireless communications through reconfigurable intelligent surfaces. *IEEE Access*, 7:116753–116773, 2019.

Description of the Model used for Demonstration



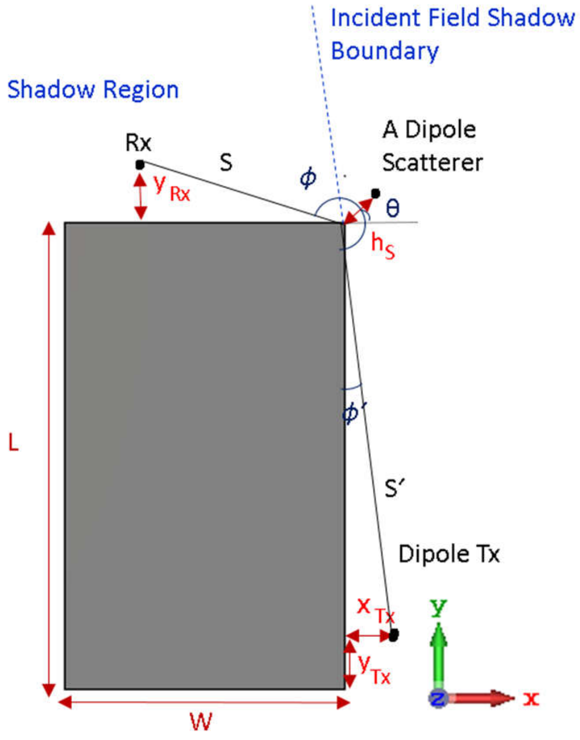
The geometry of the model (top view) used for simulation and measurement.



Propagation path around a corner.

Description of the Model used for Demonstration

- A simple dipole scatterer placed on the corner.
- The polarization is vertical (parallel case).
- The receiver is at $\mathrm{Y_{Rx}} = 2\lambda$ from the wall moved along the x-axis.
- The spacing between the dipole and the corner is $\mathrm{h_s} = 0.8\lambda$ with $\theta = 45^o$.
- The receiver, scattering dipole, and the transmitter are aligned in the plane of incidence.
- The transmit dipole is located $\mathrm{Y_{Tx}} = \mathrm{X_{Tx}} = \lambda$.



Dimension of the model	
W	6λ
L	10λ
H	14λ

Simulation Approach*

- ☐ The CST Microwave Studio time domain solver is used for simulation.
- ☐ The simulation boundaries are defined as open boundaries with perfectly matched layer (PML).
- ☐ We use a dipole source because of the energy leakage problem from using an open boundary with plane wave illumination.
- ☐ There is also leakage through any dielectric material with dipole illumination, so we use perfectly electrical conductor (PEC) for the building, which is a limitation in our results.

---

* C. G. Hynes, R. Zabihi, and R. G. Vaughan. 3D simulation of infinite baffle diffraction. *Accepted in 14th European Conference on Antennas and Propagation, EuCAP*, March 2020.

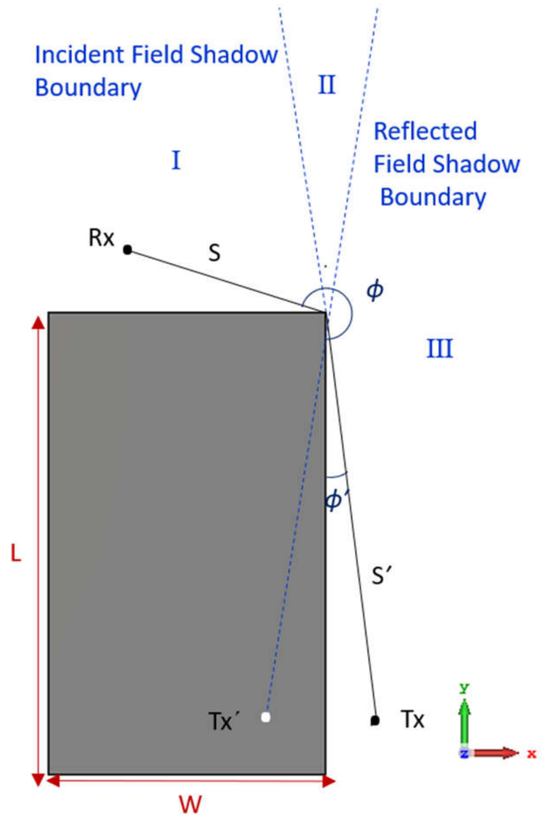
Diffraction by a Corner - UTD

The critical and complex 2D uniform theory of diffraction (UTD) equations*

$$\boxed{E_{UTD} = E_i D\left(\phi', \phi\right) A\left(s\right) e^{-jks}}$$

$$\begin{aligned} D\left(\phi', \phi\right) = & -\frac{e^{-j\pi/4}}{2n\sqrt{2\pi k}} \\ & \times \left[\cot\left(\frac{\pi + (\phi - \phi')}{2n}\right) F\left(k\mathcal{L}a^{+}(\phi - \phi')\right)\right. \\ & + \cot\left(\frac{\pi - (\phi - \phi')}{2n}\right) F\left(k\mathcal{L}a^{-}(\phi - \phi')\right) \\ & + R_1 \cot\left(\frac{\pi - (\phi + \phi')}{2n}\right) F\left(k\mathcal{L}a^{-}(\phi + \phi')\right) \\ & \left. + R_2 \cot\left(\frac{\pi + (\phi + \phi')}{2n}\right) F\left(k\mathcal{L}a^{+}(\phi + \phi')\right)\right] \end{aligned}$$

$$\boxed{\begin{aligned} & a^{\pm} = 2\cos^2\left(\frac{2\pi n N^{\pm} - \beta}{2}\right), \\ & \beta = \phi \pm \phi', \\ & N^{\pm} = \frac{\pm\pi + \beta}{2\pi n}. \end{aligned}}$$



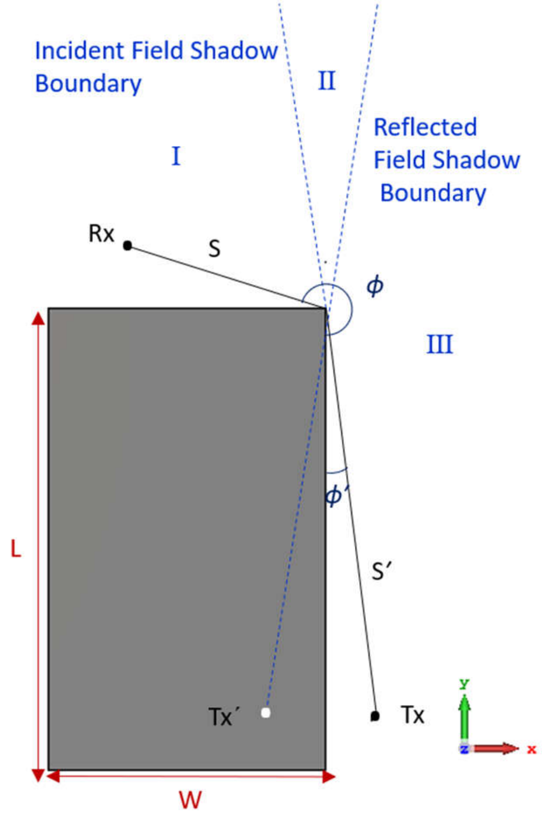
---

*R. G. Kouyoumjian and P. H. Pathak, “A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface,” *Proceedings of the IEEE*, vol. 62, no. 11, pp. 1448–1461, Nov 1974.

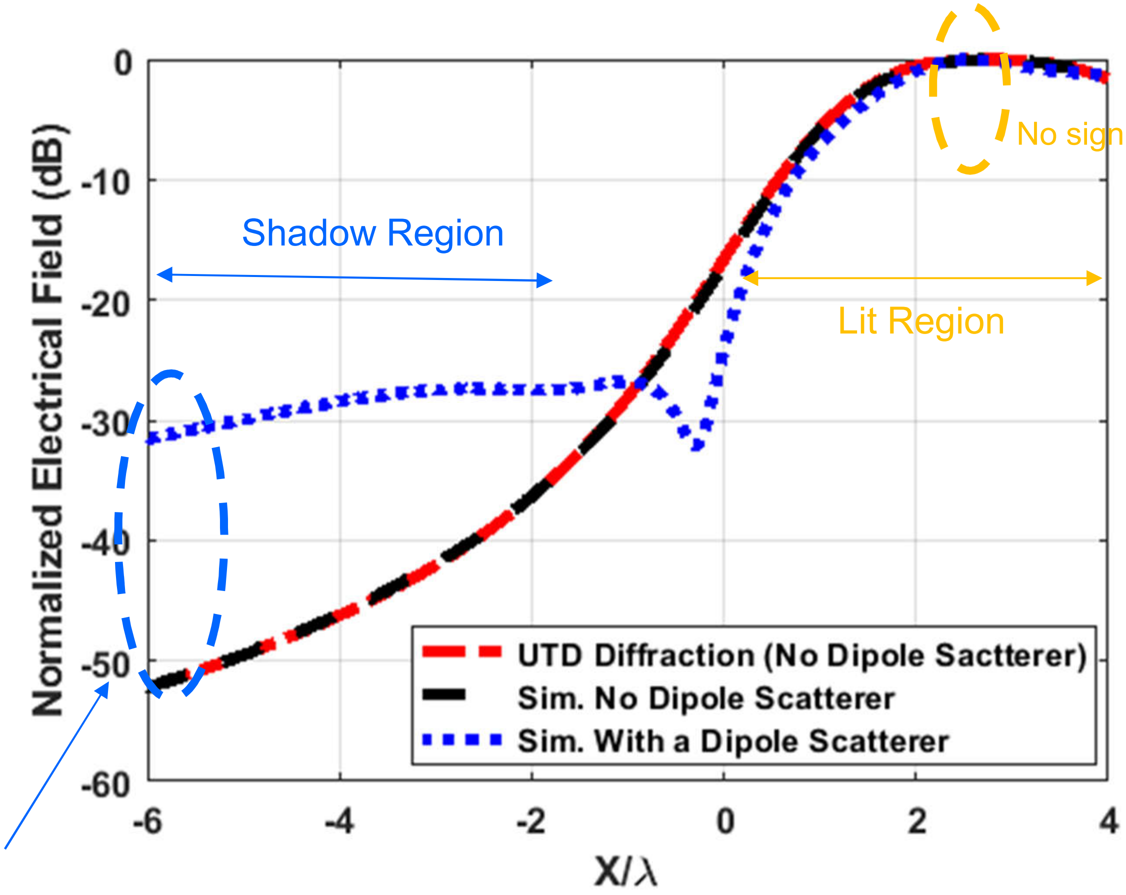
Diffraction by a Corner - UTD

❑ The reflection coefficients of each facet are R1 (lit side) and R2 (shadow side).

Incident field	$E_i = E_0 \frac{e^{-jks'}}{s'}$
Spreading factor	$A\left(s\right) = \sqrt{\frac{s'}{s(s'+s)}}$
Distance factor	$\mathcal{L} = \frac{ss'}{s+s'}$
Transition function	$F\left(x\right) = 2j\sqrt{x}e^{jx}\int_{\sqrt{x}}^{\infty} e^{-ju^2}\,du$

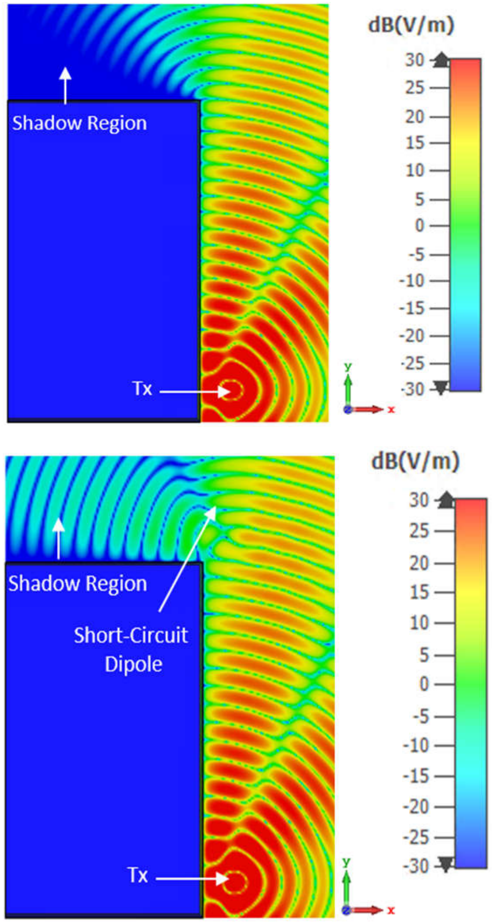


Parallel Dipole Scatterer over the Corner

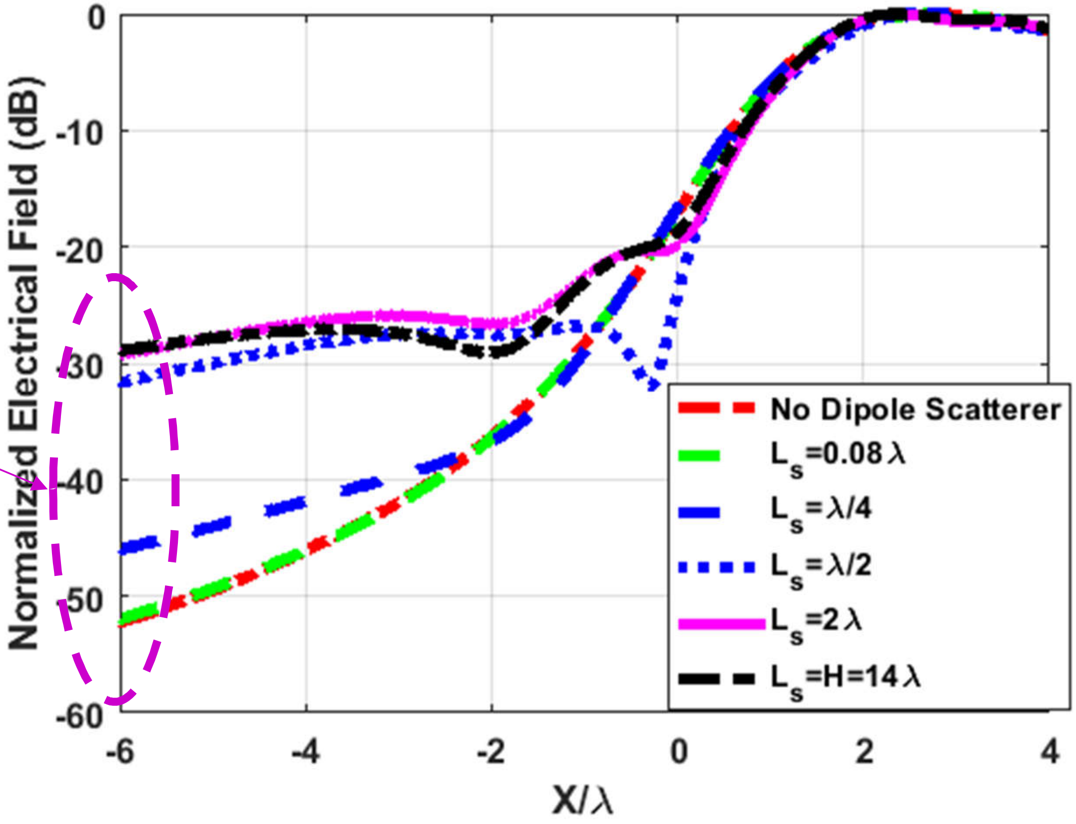


No significant energy loss in Lit Region
(dB scale)!

The enhancement of ~20dB in the Shadow Region.



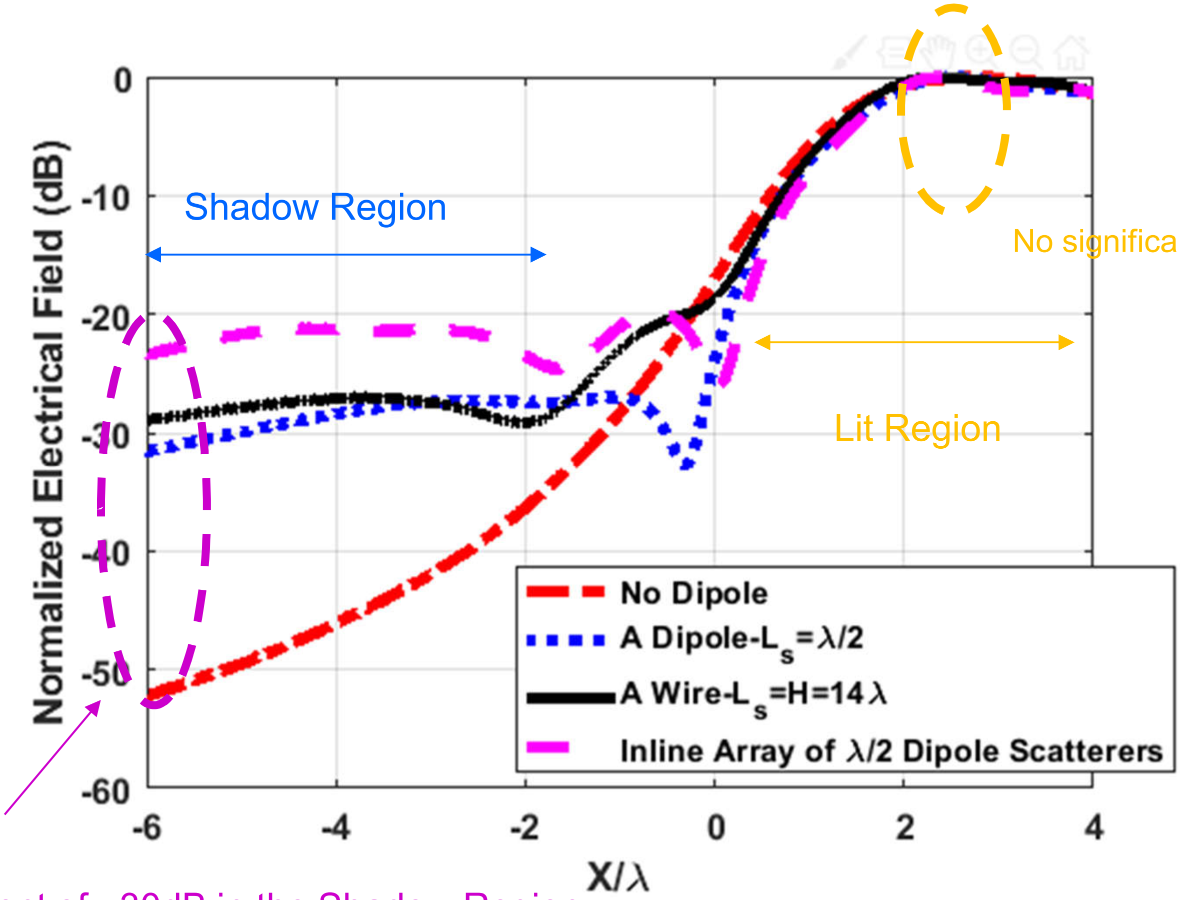
Is It Wideband?



By changing the electrical size of the dipole (Ls), a large gain is obtained from1 to 28!

A large gain is available in the immediate shadow region over a wide range of frequencies.

Impact of Inline Array of Dipole Scatterers



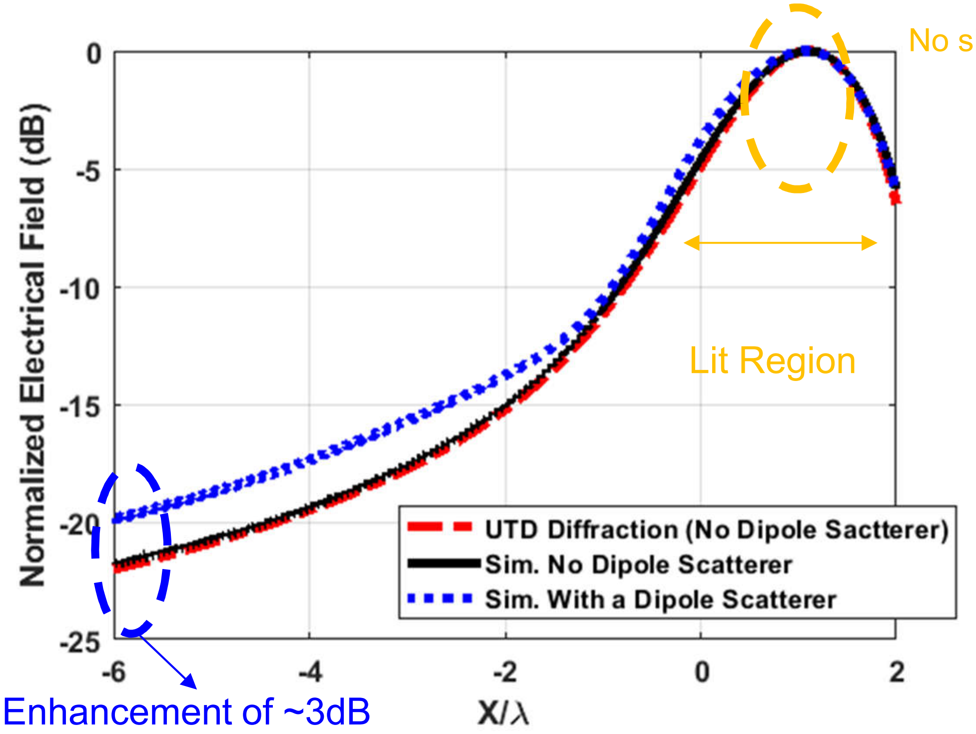
No significant energy loss in Lit Region (dB scale)!

The enhancement of ~30dB in the Shadow Region.

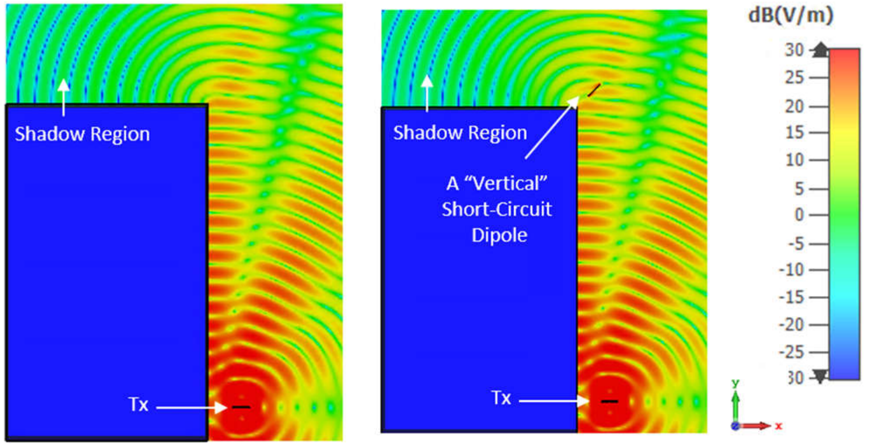
A larger scattering aperture is of obvious interest, and with an eye to array gain and beamforming possibilities using array techniques.

Perpendicular Dipole over the Corner

- ☐ The improvement is not very significant for this case (although for aspects, such as coding and modulation, a couple of dB is a large improvement):
    - The corner diffraction attenuation for horizontal (perpendicular) polarization is less than that of the vertical (parallel) polarization.
    - The diffraction attenuation problem is not as important as for the vertical polarization case.



No significant energy loss in Lit Region (dB scale)!



Summary

- ❑ We present a simple corner modification comprising a fixed scattering dipole to improve the coverage in the shadow region of the corner diffraction.

- ❑ 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.

- ❑ For the vertical polarization, a signal level increase of well over ten dB in the shadow region is demonstrated using a single half-wavelength dipole scatterer. While arrays of dipole scatterers can further improve the energy enhancement

- ❑ 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.

- ❑ As noted, a limitation of our analysis is that the building is conducting. Most real-world buildings are not conducting, but the close proximity scatterer means that the reflections off the building surfaces are at grazing angles. This in turn means that the surface detail (conductivity or roughness) is not critical for the dipole scattering mechanism to work well.

Further question can be sent to

Roshanak Zabihi - rzabihi@sfu.ca
Christopher G. Hynes - c_h@sfu.ca
Rodney G. Vaughan - rodney_vaughan@sfu.ca