Depolarization Due to Wedge Diffraction in Satellite Radiowave Communication

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***Abstract*—In this paper, the depolarization effect due to the electromagnetic wave diffraction from the rooftop wedge of a building at 1.575 GHz frequency is presented. Diffraction measurement was performed using a dual circularly polarized (CP) antenna system. The Right Hand Circularly Polarized (RHCP) Global Positioning System (GPS) satellite transmission was utilized for measurement. The orbital motion of a single satellite enabled diffraction measurement as a function of the receiver depth in the shadow region, while the receiver was static. The experimental result of RHCP signal was compared with a theoretical knife-edge diffraction model, and they were in good agreement. In case of the deep shadow region, we found the levels of left- and right circular polarized signals to be equal, which indicates a strong depolarization of the incident RHCP wave. The observed depolarization for conductive wedge is explained by the geometrical theory of diffraction.**

***Index Terms*—carrier-to-noise ratio, diffraction, dual CP antenna, geometrical theory of diffraction, multipath, polarization.**

I. Introduction

Satellite communication is vital in today's communication era. It is capable of providing multiple services such as cellular, television broadcasting, navigation, positioning, weather, etc. The signals from satellite travel thousands of kilometers before arriving at the receiver. The key parameters to be considered for satellite communications are the frequency and the polarization of the radio waves. Atmospheric perturbation of circularly polarized signals is significantly smaller compared to linearly polarized signal. Therefore, circularly polarized signals are used in satellite communication. Major changes in transmitted signals occur due to varying environment near the receiver and have to be carefully studied to design a reliable radio channel model.

In urban environment, signals travel with different paths as electromagnetic waves (EM) undergo phenomena such as reflection, scattering or diffraction upon interaction with an obstacle before arriving at the receiver. Geometrical optics (GO) can be used to predict the reflection and scattering of EM waves. However, GO fails to predict field in the signal blockage region (shadow region). Therefore, study of diffracted field in the area of signal blockage is of utmost importance. This paper investigates the diffraction phenomenon from the conductive rooftop wedge of the building in satellite communication and is arranged in following order. Section II includes the theoretical study for diffraction phenomenon. Section III, explains the propagation scenario and measurement setup. Results and analysis are discussed in Section IV. The conclusions are presented in Section V.

II. Knife-edge and Geometrical Theory of Diffraction

When EM waves illuminate an object, some of the waves are bent from the corner or edges of the object and signal present in the shadow region of the object is known as diffracted signal. This phenomenon is explained by Huygen's Principle, which states that, each element of a wavefront at a point in time may be regarded as the centre of a secondary disturbance giving rise to spherical wavelets [1]. Since GO fails to estimate the presence of signal in the shadow region, the single knife-edge (KE) diffraction model can be applied to predict the diffracted field using the Huygen's principle.

The nature and geometry of an obstacle in the propagation path determines the conditions for occurrence of diffraction. This can be explained by the Fresnel ellipsoid. A line-of-sight (LOS) radio link can be assumed to consist of n number of successive ellipsoids where the transmitter and receiver are situated at opposite focal points of the ellipsoid. The maximum power is delivered within the first Fresnel ellipsoid or first Fresnel zone. Hence, obstacles within the first Fresnel zone will contribute most in the attenuation of the signal. The obstruction is considered significant if it occupies 0.6 times the radius of first Fresnel zone [1]. At this point, the obstruction loss is 0 dB. The propagation loss due to diffraction is given by

$$L_{ke}(v) = -20log|F(v)|, \tag{1}$$

where $F(v)$ is the Fresnel integral and v is the diffraction parameter [1]. Integral is further defined as

$$F(v) = \frac{1+j}{2}\int_{v}^{\infty} exp\bigg(-\frac{j\pi t^2}{2}\bigg)dt, \tag{2}$$

where v is defined by geometrical parameters of the obstacle in relation to the LOS path and for satellite communication, it is given by [2]

$$v = h\sqrt{\frac{2}{\lambda d}}. \tag{3}$$

Here, h is the height of the obstacle above the LOS path between the satellite and the receiver, and d is the distance from the diffraction edge to the receiver.

In general, the KE model can be used to characterize a diffraction phenomenon. However, it does not take into account the effect of material properties and polarization behavior due to diffraction, which are important parameters in practical scenarios. Therefore, for more detailed description of diffraction phenomenon, the geometrical theory of diffraction (GTD) is used, that takes in account the polarization, permittivity and conductivity of the material. GTD introduces diffraction coefficients which are functions of diffraction angle, permittivity of the medium, frequency and polarization of electromagnetic wave. GTD introduces the term shadow boundary for reflected and incident waves based on geometry of propagating environment. A perfectly conducting right-angled wedge is considered for this study, which also resembles a building roof-top. The side view of a right angle wedge is shown in Fig. 1.

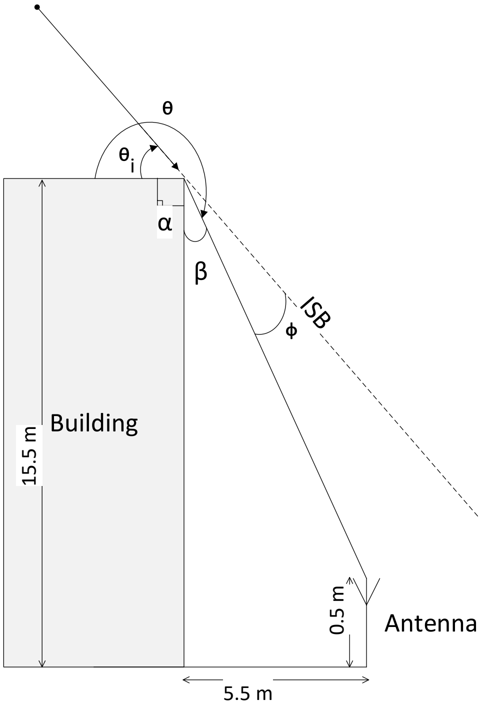

Fig. 1. Side view of the right angle wedge diffraction scenario

Here, ϕ is the angle between incident shadow boundary (ISB) and the receiving antenna, β is the angle between the diffracted ray and building roof-edge.

Diffraction coefficients give the evolution of diffracted field in and around the shadow boundaries. The diffraction coefficients for perpendicular and parallel polarization are defined as [3]

$$D_{\perp,\parallel} = \frac{-e^{-j\pi/4} sin(\frac{\pi}{n})}{2n\sqrt{2\pi k} sin\beta_0} \left[\left(\frac{1}{cos\frac{\pi}{n} - cos\frac{\theta-\theta_i}{n}} \right) \pm \left(\frac{1}{cos\frac{\pi}{n} - cos\frac{\theta+\theta_i}{n}} \right) \right]. \tag{4}$$

Here, θ and θ_i are diffraction angle and incident angle (satellite elevation angle), respectively. Further, α is the wedge interior angle which is equal to $90°$, k is the wave number, β_0 signifies the angle made by the incident wave with the edge to form the diffraction cone [4], and n is related to internal wedge angle α as

$$n = \frac{2\pi - \alpha}{\pi}. \tag{5}$$

III. Measurement Setup and Scenario

Static measurement was performed at the campus of University of Oulu, Finland. The measurement coordinates were $65°3'31.31''$N and $25°28'6.37''$E. GPS satellite (PRN 12) signal was used to study the diffraction phenomenon from roof-top of a building. The roof-edge have been constructed using metal sheet, therefore a perfectly conducting right angled wedge diffraction model is considered. The height of the building was 15.5 m. A dual circular-polarized (CP) antenna reception system was considered for measurement [5]. The dual CP antenna with high isolation and cross polarization discrimination of approx. 25dB at boresight was used [6]. The antenna was connected to two ublox GNSS evaluation kits [7], and was able to receive RHCP and LHCP signals, simultaneously. Carrier-to-noise density ratio (C/N0) in dB-Hz was recorded at the rate of 1 sample per second (sample rate 1 Hz). The side view of measurement scenario can be seen in Fig. 1 and top view of measurement site is shown in Fig. 2.

Fig. 2. Measurement Site

The reception system was at a distance of 5.5 m from the building. The satellite elevation varied from $48°$ to $78°$ and the azimuth varied from $197°$ to $241°$. The distance of the receiver from the building changed with the change in the satellite azimuth angle, which was taken into account and corrected for analysis.

IV. Result And Analysis

Satellite transmitted radio waves, incident obliquely on the roof-edge of a building is analyzed in this study. Firstly, the KE diffraction model is used to characterize the attenuation due to diffraction as a function of diffraction parameter given by (3). The modelled KE attenuation and measured response for both polarization are shown in Fig. 3. Here, the region around $v < 0$ signifies the interference region i.e., the interference between diffracted and direct signals, the ISB is located at $v = 0$, and $v > 0$ signifies the diffraction region. The theoretical and measured data in Fig. 3 agrees very well with each other. Therefore, it can be concluded that KE diffraction model can be used to characterize or estimate diffracted field in building rooftop scenario. However, it does not give any information about the polarization of the received signal. Thus, GTD will be used further to explain the effect of polarization for EM wave due to diffraction.

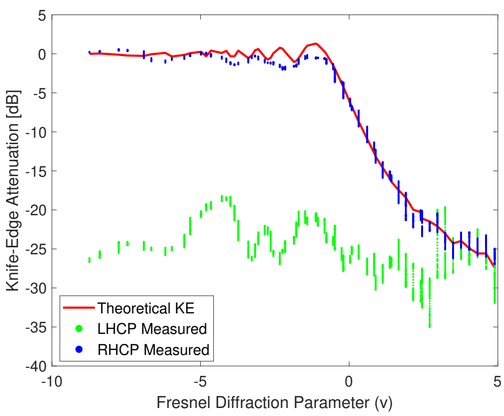

Fig. 3. Path loss vs diffraction parameter

A perfectly conducting right-angled wedge diffraction model [4], is used to analyze the polarization behavior of incident wave diffracted from the roof-edge. The behaviour of the incident RHCP wave is studied in deep shadow region. As seen in Fig. 3, the RHCP and LHCP signals are approaching same value in the deep-shadow region. This can be the result of depolarization of the incident wave. Further investigation of polarization behavior is done by evaluating the the diffraction coefficients from (4). The diffraction coefficients for circular and linear polarizations as a function of Fresnel diffraction parameter are shown in Fig. 4. It is observed, that in the deeper shadow region (v approached to 5) the diffraction coefficients for parallel and perpendicular diverge from each other.

Circularly polarized wave is combination of the orthogonal linear polarized components (perpendicular and parallel). The

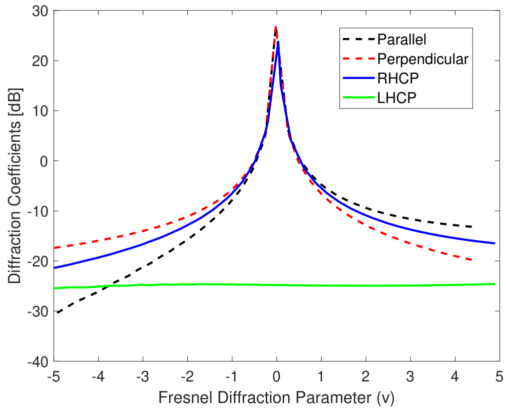

Fig. 4. Depolarization due to diffraction

attenuation of a single component will change the axial ratio of the circular polarization and result in elliptically polarized signal. At the point where one component of electric field becomes zero, the signal will be linearly polarized. According to (4), $D_{\perp}$ approaches zero at $\theta = 0$ and $n\pi$. This is because the electric field is perpendicular to the plane of incidence but tangential to the surface of the perfectly conducting wedge where the field is zero [4]. On the contrary, $D_{\parallel}$ will have some finite value at $\theta = 0$ and $n\pi$. Suppression of one component of circularly polarized wave results in depolarization of the signal. Hence, the incident RHCP signal becomes right-hand elliptical polarized (RHEP) in the shadow region and linear at deep shadow region when $D_{\perp}$ approaches zero. This yield approx. 9 dB difference in RHCP and LHCP diffraction coefficient calculated for incident RHCP wave.

This study was performed using GPS satellite signal at 1.575 GHz frequency. However, the propagation phenomenon and analysis presented here are also valid for all other radio wave propagation systems operating at different frequencies.

V. Conclusion

The effect of diffraction on polarization behavior of satellite transmitted RHCP radio waves has been investigated. KE diffraction model was used to theoretically verify the occurrence of diffraction from the wedge of the building rooftop. The theoretical and measured results agree very well with each other. However, the KE model does not give any information on the polarization behavior of the incident wave in the shadow region. Therefore, GTD was used to study the polarization behavior of radio waves in shadow region. The evidence of depolarization of circularly polarized incident wave was confirmed by the analysis of the diffraction coefficients for perfectly conducting right angled wedge using GTD. This study shows occurrence of the depolarization of satellite transmitted RHCP signal in the shadow region and presence of linearly polarized component ($D_{\parallel}$) of incident signal in the deep shadow region.

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REFERENCES

[1] S.R. Saunders, 1999. Antennas and Propagation for Wireless Communication Systems (1st ed.). John Wiley & Sons, Inc., New York, NY, USA.

[2] Hannah, Bruce M. (2001) Modelling and simulation of GPS multipath propagation. PhD thesis, Queensland University of Technology.

[3] McNamara, D. A., C. W. I. Pistorius, and J. A. G. Malherbe. 1990. Introduction to the uniform geometrical theory of diffraction. Boston: Artech House.

[4] Bertoni, H. L. (2000). Radio propagation for modern wireless systems. Upper Saddle River, N.J: Prentice Hall PTR.

[5] M. Berg, R.U.R. Lighari, J. Kallankari, V. Majava, A. Pärssinen, and E.T. Salonen, "Polarization based measurement system for analysis of GNSS multipath signals," in Proc. 10th European Antennas and Propagation Conference, Davos, Switzerland, April 2016.

[6] M. Berg, R. Lighari, T. Tuovinen, and E. T. Salonen, "Circularly Polarized GPS Antenna for Simultaneous LHCP and RHCP Reception with High Isolation," in Loughborough Antennas and Propagation Conference (LAPC), Loughborough, UK, Nov. 2016.

[7] U-blox Holding AG, "EVK-7, EVK-8, EVK-M8 u-blox GNSS Evaluation Kits," :https://www.ublox.com/en/product/evk-8evk-m8 (Accessed: September 27, 2018).