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Investigation and Modeling of Diffraction Loss at 1.8 GHZ in a Mountainous Terrain: A Case Study of Olumo Rock, Abeokuta, Nigeria

T.L. Adebayo and F.O. Edeko
Department of Electrical/Electronic and Computer Engineering,
University of Benin, Benin City, Nigeria

Abstract: This study presents an investigation on the diffraction loss due to knife-edge obstruction in a mountainous environment at 1.8 GHZ using Olumo rock as a case study. The method employed here involved measurement of the power received for line of sight, no line of sight, line of sight distance from the test base station to the test point, the distance from the mobile to the test point. Computation of the diffraction loss, diffraction angle and the normalized dimensionless quantity V using Fresnel model was done for the purpose of comparisons. The results obtained shows that for a diffraction angle between -20 to -8°, a linear equation can sufficiently describe the diffraction loss while the diffraction loss for angle between -9 to 0° can be modeled with a sixth order polynomial equation.

Key words: Olumo rock, polynomial equation

INTRODUCTION

Cellular radio signals are subject to multi-path propagation caused by diffraction, scattering etc from the object in the vicinity of the transmitter and receiver. It is not always possible to install a communication link such that there are no obstruction such as hills or large buildings that block part of the field from the transmitting antenna, thereby impeding its arrival at the receiving end[1,2].

In a mountainous terrain, the mountain may be visible to both transmitter and receiver and therefore act as large reflector. The performance and reliability of digital cellular systems may adversely be affected by the multi-path signal if not taken into consideration while predicting the power received.

Previous researchers have demonstrated that radio frequency signal propagates in an obstacle environment with a high attenuation. However, it is not practicable to move such an obstacle in the interest of improved radio service[3,4]. Thus, one can investigate what happens to the radio signal when it comes in contact with such obstacle with a view to know the signal characteristics. This study therefore investigates diffraction loss in a mountainous environment at 1.8GHZ using Olumo rock as a case study.

GENERAL DIFFRACTION LOSS DETERMINATIONS

The diffraction loss for an ideal knife-edge obstruction can be calculated from the famous Fresnel integral which is often evaluated using tables, graphs, or numerical methods[2,4]. This integral originated in studies of optics by Augustin-Jean Fresnel in the early 19th century. In application to radio propagation, formulas based on this integral have frequently provided close approximations to the diffraction effects of isolated mountain ridges.

In classical electromagnetic theory applications, the field strength of a diffracted radio wave associated with a knife edge can be expressed as;[5,6]

$$\frac{E}{E_0} = Fe^{j\Delta\phi} \tag{1}$$

Where E is the electromagnetic field with knife-edge diffraction,

E_0 is the electromagnetic filed without knife-edge diffraction

F is the diffraction co-efficient.

The diffraction co-efficient can be determined using the following equation;[5-7]

$$F = \frac{S + 0.5}{1.414\sin(\Delta\phi + \frac{\pi}{4})} \tag{2}$$

$$\Delta\phi = \tan^{-1}\left(\frac{S + 0.5}{C + 0.5}\right) - \frac{\pi}{4} \tag{3}$$

Corresponding Author: T.L. Adebayo, Department of Electrical /Electronic and Computer Engineering, University of Benin, Benin City, Nigeria

Where C, S and $\Delta\phi$ are the Fresnel cosine, Fresnel sine and phase difference with respect to the path of direct wave respectively as expressed below;

$$C = \int_0^v \cos\left(\frac{\pi}{2}x^2\right)dx \quad (4)$$

$$S = \int_0^v \sin\left(\frac{\pi}{2}x^2\right)dx \quad (5)$$

Auxiliary parameter (v) is often used in modeling the diffracting object as an infinitely thin knife edge. This auxiliary parameter is used to normalize the calculations. It is a dimensionless parameter defined as[8-10]

$$v = -hp\sqrt{\frac{2}{\lambda}}\left(\sqrt{\frac{1}{r1}+\frac{1}{r2}}\right) \quad (6)$$

The angle of diffraction (θ) for a signal that comes in contact with an obstacle can be calculated thus;[8-9].

$$\theta = -hp\left[\frac{1}{r1}+\frac{1}{r2}\right] \quad (7)$$

Often, theoretical determination of diffraction loss is done in relation with this auxiliary parameter as a shortcut. The equation that relates the auxiliary parameter to the diffraction loss is given as;[8-11].

$$\text{For } v < -2.4; \quad L = 20\log\left(\frac{-0.225}{v}\right) \quad (8)$$

For -2.4 =< v <-1;

$$L = 20\log\left(0.4 - \sqrt{\left(0.1184 - (0.1v + 0.38)^2\right)}\right) \quad (9)$$

DESCRIPTION OF THE ENVIRONMENT INVESTIGATED

The rock is situated in the City of Abeokuta the capital of Ogun State. The test area covered was 150 m by 150 m where the slopes met the flatness and clear line of sight criteria.

For the purpose of ease of data representation, the rock was partitioned into five different zone designated as Z1, Z2, Z3, Z4 and Z5, respectively as shown in Fig.1. The ground floor height to the first, second, third, fourth and fifth test point hilltops are 11.8, 41.3, 58.6, 80.4 and 94.7 m, respectively.

Fig. 1: View of the olumo rock

Table 1: Measured parameters for the environment investigated

Zone	r_b (m)	r_1(m)	r_2(m)	P_{LOS} (dBm)	P_{NLOS} (dBm)	Loss(dB)
1	1683	1680	5.1	-77.6	-94.6	-30.50
2	1722	1720	11.4	-74.0	-81.1	-28.11
3	1881	1880	15.3	-67.7	-72.5	-25.11
4	1928	1927	17.2	-61.3	-63.1	-22.83
5	2011	2010	21.7	-55.4	-56.0	-12.96

EXPERIMENTAL PROCEDURE

For each test hilltop investigated, a test point was chosen such that the Base station and the mobile had a clear line of sight to the mountain slope[9,10]. Consequently, measurement was conducted, parameters such as LOS distance between the Base station to the test point (r_1), distance between the mobile to the test point (r_2), power received for both the line of sight and that of no line of sight respectively using a GARMIN E-TREX hand held GPS receiver and 8210 handset equipped with Net-monitor software.

At each test point, fifty samples of power received were taken in active mode during the downlink transmission.

Figure 2 and 3 depict the schematic representation of the test points in different zones and the block diagram of the measurement procedure adopted in this study.

Presentation of data for the investigated environment: The measurements were conducted at five different times between August 2004 and February 2005. Weather condition was clear in each session and the temperature ranged from 31 to 35°C.

The average measurements for the five sessions are presented in Table 1.

METHOD OF DETERMINING OTHER PARAMETERS

A program was written in Mat-Lab to compute the Fresnel integral and other parameters that characterize the investigated environment using the geometry in Fig. 4.

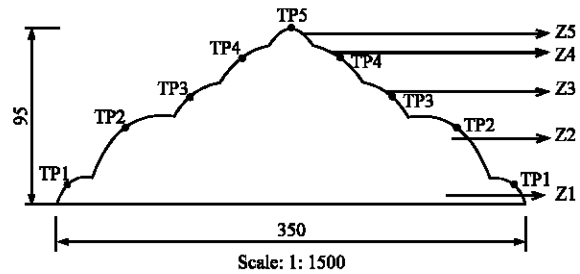

Fig. 2: Schematic diagram of test points on the rock

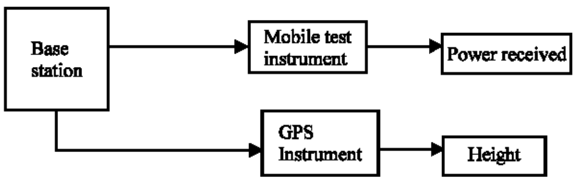

Fig. 3: Block diagram of measurement procedure

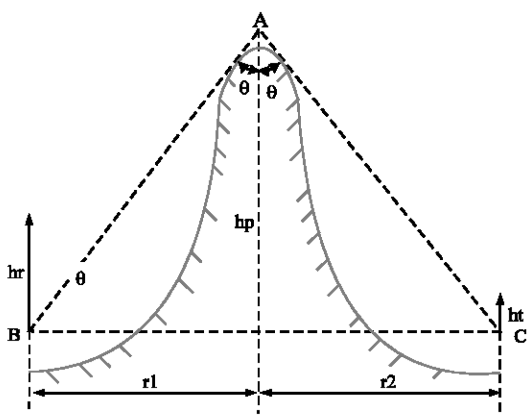

Fig. 4a: Geometry adopted

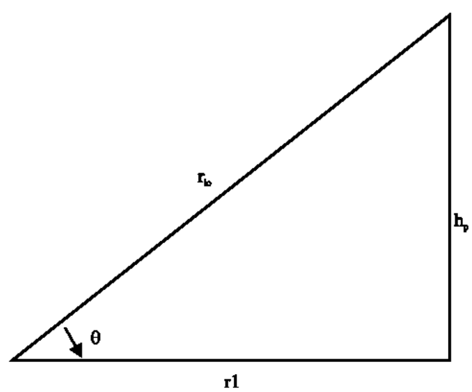

Fig. 4b: Simplified geometry

Table 2: Calculated parameters for the environment investigated

Zone	v	h_p(m)	Δϕ(°)	θ(°)	L(dB)
1	-12.12	11.8	86.58	18.62	-34.63
2	-6.90	41.3	81.23	-7.10	-29.73
3	-4.34	58.6	81.13	-3.86	-25.71
4	-2.89	80.4	81.15	-2.42	-22.17
5	-0.73	94.7	81.19	-0.55	-12.27

From Fig. 4b, h_p can be computed as

$$h_p = \sqrt{(r_{1o})^2 - (r_1)^2} \qquad (10)$$

Steps involved in determining diffraction parameters: The steps involved in determining the various diffraction parameters using Mat-lab application are presented below;

- Specifying the values of r_1, r_2 and hp.
- Specifying the number of test point in the investigated environment.
- Forming the diffraction co-efficient matrix with respect to distance.
- Computing the Fresnel sine and cosine integrals,
- Plotting of the solutions

After going through the steps in section 6.1 using the math-lab program written, the following parameters were determined using Eq. 1, 2, 3, 4, 5, 6, 7, 8 and 9.

The calculated parameters for the environment investigated yields the data as tabulated in Table 2.

Analysis of data: A plot of the parameters was done and a model was obtained to fit the graphs. In this study, Mat lab program was used to analyze the data and the result obtained for the model is presented in Fig. 5-10, respectively.

RESULT

The results of this analysis are presented in Fig. 5-10. Fig. 5 presents the plot of diffraction loss behaviour with distance while Fig. 6 presents the plot of measured and computed diffraction loss with hilltop height, respectively.

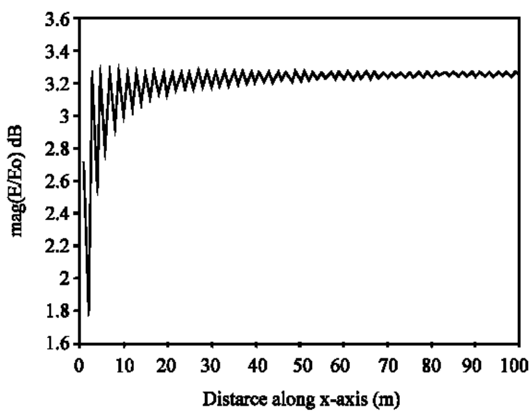

Fig. 5: Plot of diffraction co-efficient with time

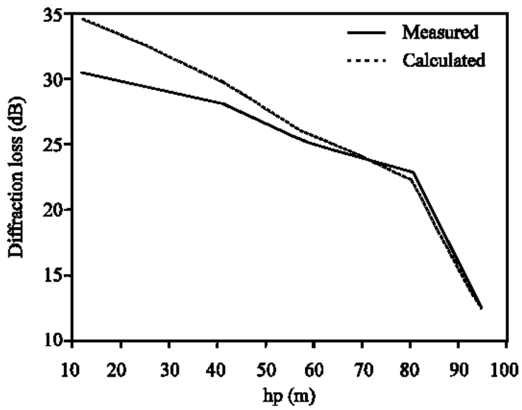

Fig. 6: Plot of diffraction loss with hp for measured and calculated

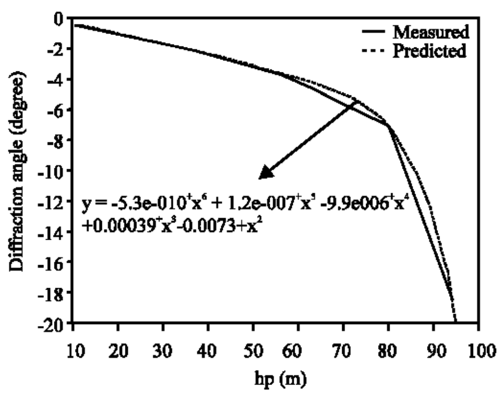

Fig. 7: Variation of diffraction angle with hilltop Height

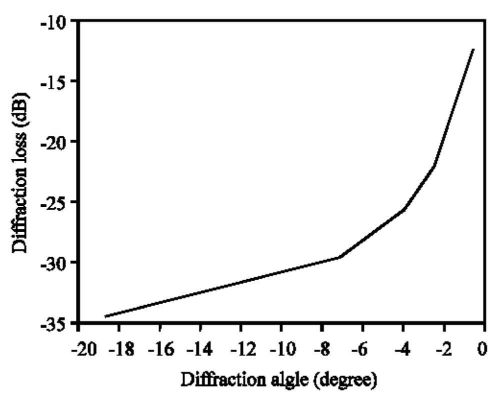

Fig. 8: Variation of diffraction loss with diffraction angle

DISCUSSION

- The diffraction losses and their respective angles starting from zone 5 to zone1 are -12.27dB at -0.55°, -22.17dB at -2.42°, -25.71dB at -3.86°, -29.73dB at -7.10° and -34.63dB at -18.62°, respectively.

Fig. 9: Variation of diffraction loss in 2-dimension when viewed along x-axis

Fig. 10: Variation of diffraction loss in 2-when viewed along y-axis

- The diffraction losses against their angles show linear characteristics for angle between -22° up till an angle of -8°, beyond which it shows logarithmic characteristics.
- As the hilltop height (hp) increases, the diffraction angle reduces exponentially which can be modeled by a sixth-order polynomial equation as evident in Fig. 7.
- The phase difference with respect to the path of direct wave ranges from 87° for zone 1 to 81° for the rest zones.
- A linear model of diffraction loss versus slope height is $L = -0.26h_p+10$.
- The diffraction angle versus the slope height yields a sixth order equation of the form;

$$\theta = -5.3e^{-10}h_p^{\,6} + 1.2e^{-7}h_p^{\,5}$$
$$-9.9e^{-6}h_p^{\,4} + 0.00039h_p^{\,3} - 0.007h_p^{\,2}$$

- There is a disparity of 3dB between the measured and calculated diffraction loss for a hilltop height between 10m and 40m as evident in Fig. 6.

CONCLUSION

The diffraction angle and the height of the hilltop are the key variables in the characterization of diffraction losses. The relationship between angle and diffraction loss for the investigated environment was linear for angles between -20 to -8° and for angles less than -8 to 0°, attenuation of diffraction loss grew more rapidly and exhibited a logarithmic growth.

A linear model was successfully developed to predict the relationship between the diffraction loss and the hilltop height for the environment investigated.

NOMENCLATURES

hp Height of the hilltop
r_1 Distance from the base station to the centre of hilltop
r_2 Distance from the mobile to the test centre of hilltop
r_{lo} Line of sight distance to the test point
λ Signal wavelength
π Constant pie
c Speed of light
f Wave frequency
x Distance
Tp Test point
L Diffraction loss
v Dimensionless parameter used to normalize Fresnel equation
E Electromagnetic field strength with knife-edge diffraction
E_o Electromagnetic field strength with no knife-edge diffraction
F Diffraction co-efficient
$\Delta\phi$ Phase difference with respect to the path of direct wave
θ Diffraction angle
h_t Base station height
h_m mobile height

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