Development Of Epstein-Peterson Method-Based Approach For Computing Multiple Knife Edgediffraction Loss As A Function Of Refractivity Gradient

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***Abstract*— In this paper, the development of Epstein-Peterson method-based approach for computing multiple knife edge diffraction loss as a function of refractivity gradient. Specifically, the study utilized Epstein Peterson diffraction loss methodology alongside the International Telecommunication Union (ITU) knife edge approximation model to compute multiple knife edge diffraction loss as a function of refractivity gradient. Analytical expression for the determination of obstacles height, the earth bulge and the effective obstruction height were modeled in terms of the refractivity gradient (∆). A case study of 10 knife edge obstructions located in a communication link with a path length of 36km was used as a numerical example to demonstrate the application of the procedure presented in this paper. The results showed that the maximum line of sight (LOS) clearance height was 5.73 m and it occurred at a distance of 21 km from the transmitter; the minimum LOS clearance height was 0.4 m and it occurred at a distance of 33 km from the transmitter. On the other hand, the maximum diffraction parameter was 0.33and it occurred at a distance of 1 km from the transmitter. In addition, the minimum diffraction parameter was 0.02981424 and it occurred at a distance of 33 km from the transmitter. In all, for the case study multiple knife edge obstructions, the total diffraction loss in the communication link was78.53 dB. The idea presented in this paper is very relevant for the study of the effect of changes in refractivity gradient on multiple knife edge diffraction loss computed according using the Epstein-Peterson method.**

Keywords— Diffraction, Diffraction loss, Earth bulge, multiple knife edge, Refractivity gradient, Epstein-Peterson method

I. INTRODUCTION

Radio wave propagation over irregular terrain consisting of mountain, buildings, hills and even trees and other high rising obstructions is of great concern to communication network designers [1,2,3,4]. When a wireless signal is propagated over a long distance, the signal may get distorted and attenuated due to obstacles along its path. This causes the signal to be reflected, absorbed scattered or diffracted. Diffraction occurs when a wireless signal encounter obstacles in its path [6,7,8,9,10]. The diffracted signal experiences reduction in its signal strength which is referred to diffraction loss. In the determination of diffraction loss, obstacles or obstructions are modeled as knife edges [11,12,14,15,16]. When the obstruction is more than two, it is described as multiple knife edge obstructions.

Meanwhile, the atmosphere over the earth is a dynamic medium; its properties vary with temperature, pressure and humility. These variables are related to the radio refractivity gradient N. The refractivity gradient is defined in terms of the index of refraction 'n' by N=n -1 where n is the index of refraction [18]. Mathematically, refractivity gradient is defined as shown in Equation 1;

$$N= (n-1)=\frac{77.6}{T}\left(P+4810\ \frac{e}{T}\right) \quad (1)$$

Where T= absolute temperature (K),P=atmospheric pressure (hpa) ,e = water vapour pressure. Usually, in a communication network, the earth is curved between the transmitter and the receiver. The curvature of the earth surface which limits the range of communication that requires line of sight is term earth bulge. Variation in refractivity gradient changes the earth bulge. This change in earth bulge varies the height of obstructions as seen by the signal. Diffraction loss is proportional to the height of obstructions. Therefore, changes in the atmospheric refractivity gradient affects the earth bulge which in turn affect the obstruction height and then the overall diffraction loss that can result from the multiple knife edge obstruction. This paper presents an approach to determine the multiple knife edge diffraction loss as a fuction of the refractivity gradient. The work is based on the Epstein-Peterson multiple knife edge diffraction loss method.

II. REVIEW OF RELATED WORKS

Adams [21] presented an algorithm on the remodeling and parametric analysis of multiple knife edge diffraction loss. The study used the three knife edge obstrctions in Figure 1 in the development and application of n-knife edge diffraction loss computation based on Epstein-Peterson and Shibuya method alongside ITU knife edge approximation models. In most cases, the analysis of multiple knife edge diffraction loss is limited to a maximum of three obstructions because of the complexity of the analysis [22,23,24]. In the work by Adams [21], the approach for the determination of the multiple knife edge diffraction loss for any number of obstructionswas developed.

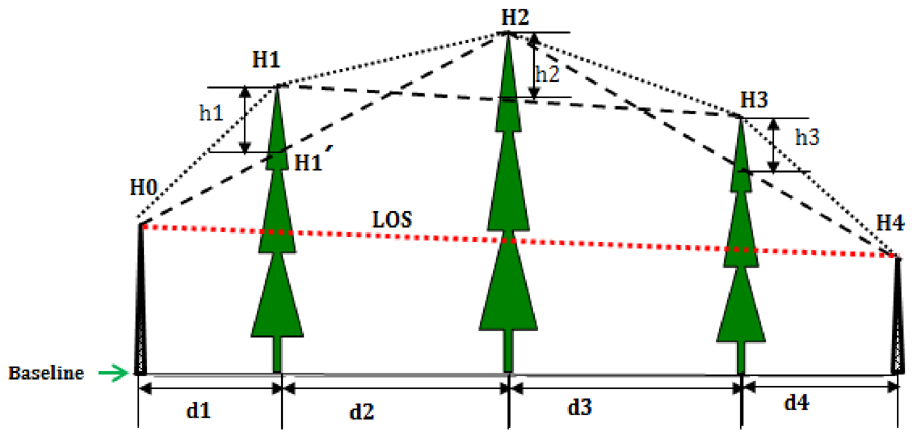

Figure 1: None line-of sight link with three knife edge obstructions

Similar to the three knife edge obstrctions in Figure 1, in the N multiple knife edge computations, there are N knife edge obstructions and the distance from the knife edge obstruction n-1 to obstruction n be denoted as d_n where n = 1,2,3 ,…N . Then, if the knife edge obstruction is located at a distance of $d_{t(n)}$ from the transmiter, then

$$d_n = d_{t(n)} - d_{t(n-1)} \quad n= 1,2,3,\ldots N \qquad (2)$$

Based on the N multiple knife edge description, Adams [1] presented a procedure for computaing N multiple knife edge diffraction loss using the Epstein-Peterson method. This method formed the basis for the study in this paper and its key idea are prsented in this section.

In the communication link of Figure 1, each of the obstruction that blocks the line of sight constitutes an edge that will cause diffraction loss and also introduces a virtual hop in the link. Each virtual hop has an edge that causes diffraction. In Figure 1, there are three virtual hops, namely ;

i. Hop1 : H_0-H_1-H_2 with H_1-H_2 as the diffraction edge
ii. Hop2 : H_1 - H_2 - H_3 with H_2 as the diffraction edge
iii. Hop3 : H_2 - H_3 - H_4 with H_3 as the diffraction edge

Consider hop 1 in Figure 1, the clearance height , h_1 is given in Equation 3,

$$h_1 = H_1 - H_1 \qquad (3)$$

Where $H_1{}'$ is the hop 1 line of sight (H_0 To H_2) height at a distance of d_1 from H_0. $H_1$is given by similar traingle as shown in Equation 4 and 5,

$$\frac{H'_1{}' - H_0}{d_1} = \frac{H_2 - H_0}{d_1 + d_2} \qquad (4)$$

$$H'_1 = \frac{d_1 (H_2 - H_0)}{d_1 + d_2} + H_0 \qquad (5)$$

Hence, the clearance height is given in Equation 6,

$$h_1 = H_1 - H_0 - \left(\frac{d_1 (H_2 - H_0)}{d_1 + d_2}\right) \qquad (6)$$

Similarly, for hop2, the clearance height is given in Equation 7,

$$h_2 = H_2 - H_1 - \left(\frac{d_2(H_3 - H_1)}{d_2 + d_3}\right) \quad (7)$$

Generally, for any given hop j, the clearance height to its LOS is given as h_j shwon in Equation 8 where;

$$h_j = h_{Epstein(j)} = H_j - H_{j-1} - \left(\frac{d_j(H_{j+1} - H_{j-1})}{d_j + d_{j+1}}\right) \quad (8)$$

The knife-edge diffraction parameter for any hop j is given as v_j in Equation 9 where;

$$v_j = h_{Epstein(j)}\sqrt{\frac{2(d_j + d_{j+1})}{\lambda(d_j)(d_{j+1})}} \quad (9)$$

According to ITU (Rec 526-13, 2011) [25] the knife-edge diffraction loss, A for any given diffraction parameter, v is given in Equation 10,

$$A = 6.9 + 20\text{Log}\left(\left(\sqrt{(v - 0.1)^2 + 1}\right) + v - 0.1\right) \quad (10)$$

where A is in dB

Then, in respect of knife-edge diffraction loss for any hop j with diffraction parameter,v_j, the knife-edge diffraction loss is denoted as A_j, where ITU approximation model for A_j is given as shown in Equation 11,

$$A_j = 6.9 + 20\text{Log}\left(\left(\sqrt{(v_j - 0.1)^2 + 1}\right) + v_j - 0.1\right) \quad (11)$$

whereA_j is i. A case study of 10 knife edge obstructions spread at a distance of 36 kilometers between the transmitter and the receiver was utilized. Using Epstein- Peterson method, it was observed that the highest diffraction loss occurred at hop 1(9.5811581dB), 1 kilometer from the transmitter, with diffraction parameter of 0.33333333.

As regards refractivity gradient, Adediji and Ajewole [26] carried out an investigation on the vertical profile of radio refractivity gradient in Akure South-West Nigeria. Measurement of pressure, temperature and relative humility were made in Akure (7.15°N, 5.12°E), South Western Nigeria. Wireless weather stations (integrated sensor suite, ISS) were positioned at five different height levels beginning from the ground surface and at interval of 50m from the ground to a height of 200m(0,50,100,150 and 200m) on a 220m Nigeria Television Authority TV tower. The study utilized data of the first year of the measurement to compute the refractivity gradient using Equation 12,

$$N = 77.6\,\frac{P}{T} + 3.73 \times 10^5\,\frac{e}{T^2} \quad (12)$$

Where P =atmospheric pressure (hpa), e = water vapour pressure (hpa) and T = absolute temperature in Kelvin. Water vapour pressure is evaluated using Equation 13,

$$e = H \times \frac{6.1121\,exp\left(\frac{17.502t}{t+240.97}\right)}{100} \quad (13)$$

Where H = relative humility (%), t = temperature in Celsius. From the refractivity, its refractivity gradient was the computed. From the given parameters, the vertical distributions of the radio refractivity was then determined.

III. METHODOLOGY

In this paper, an approach to determine the multiple knife edge diffraction loss as a fuction of the refractivity gradient based on the Epstein-Peterson method along with ITU knife edge approximation model is presented. First, analytical expressions for the determination of the obstacle height using Fresnel path profile geometry are presented. The earth buldge and effective height of obstruction are then modeled in terms of refractivity gradient. Then, for a reference refractivity gradient, $\Delta_o = 4/3$, the multple knife edge diffraction geometry and n-knife edge diffraction loss analytical expressions are presented based on the Epstein-Peterson method. Also, the multple knife edge diffraction are modeled in terms of operating refractivity gradient, Δ_i . The modified ITU knife edge approximation model is presented. A case study consisting of 10 knife edge obstruction is presented.

Figure 2 shows the Fresnel geometry for the path profile to be used in the knife edge diffracion loss calulation. In Figure 2,$d_{t(x)}$ is the distance of location x from the transmitter and $d_{r(x)}$ is the distance of location x from the reciever . Let d be the distance between the transmitter and the reciever , where d = $d_{t(x)}$+ $d_{r(x)}$. Also, h_{mt} is the height of the transmitter antenna mastt; $h_{mr}$is the height of the receiver antenna mast; $h_{eb(x)}$ is earth bulge at location x; $h_{el(x)}$ is the elevation at location x and $h_{ob(x)}$ is obstruction height at location x, where Nx is the maximum number of elevation points between the transmitter and the receiver and x = 1,2,3,,…,Nx.

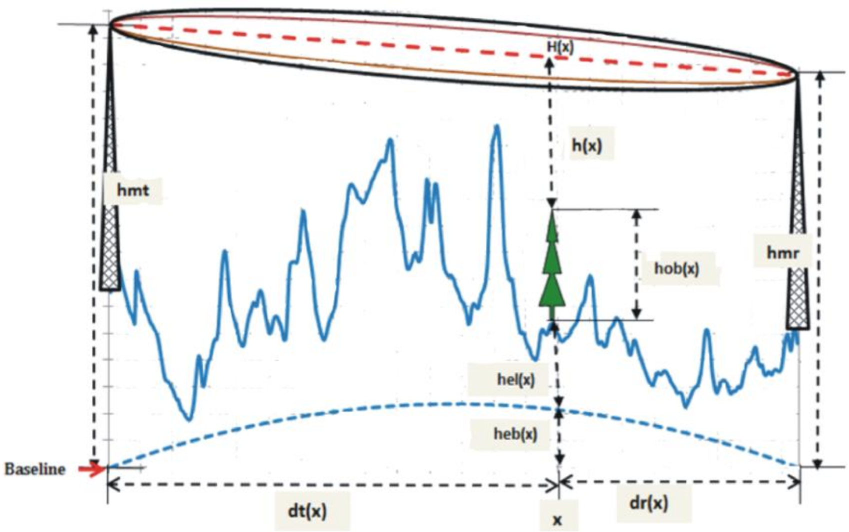

Figure 2: The Fresnel geometry for knife edge dffracion loss calulation

Let $H_{ob(x)}$ be the overal height of the obstruction from the refrence baseline, as shown in Equation 14,

$$H_{ob(x)} = h_{eb(x)} + h_{el(x)} + h_{ob(x)} \qquad (14)$$

Let H_t in Equation 15 be the overal height of the transmitter antenna from the refrence baseline and h_{elt} is elevation at the transmitter , then;

$$H_t = h_{mt} + h_{elt} \qquad (15)$$

Let H_r in Equation 16 be the overal height of the receiver antenna from the refrence baseline and h_{elr} is elevation at the reciever, then ;

$$H_r = h_{mr} + h_{elr} \qquad (16)$$

$H_{(x)}$ in Equation 17 is the height of the line of sight at location x.$H_{(x)}$ is given as ;

$$H_{(x)} = H_t + \frac{d_{t(x)}(H_t - H_r)}{d} \qquad (17)$$

In the situation where $H_t = H_r$, then $H_{(x)} = H_t = H_r$.

The earth bulge which is the height an obstruction is raised higher in elevation (into the path) owing to earth curvature is express in Equation 18,

$$H_{eb(x)} = \frac{(d_{t(x)})(d_{r(x)})}{12.75*K} \qquad (18)$$

where $H_{eb(x)}$ is the height (in meters) of the earth bulge at location x between the transmitter and the receiver, $d_{t(x)}$= distance in kilometers from location x to the transmitter antenna, $d_{r(x)}$ = distance in kilometers from location x to the receiver antenna, H_{ebt} is the height (in meters) of the earth bulge at the transmitter mast location, H_{ebr} is the height (in meters) of the earth bulge at the receiver mast location. At the transmitter, $d_{t(x)}$ = 0, hence, in Equation 19,

$$H_{ebt} = H_{eb(0)} = \frac{(0)(d_{r(x)})}{12.75*K} = 0 \qquad (19)$$

Similarly, at the receiver, $d_{r(x)}$ = 0, hence, in Equation 20,

$$H_{ebt} = H_{eb(Nx+1)} = \frac{(d_{t(x)})(0)}{12.75*K} = 0 \qquad (20)$$

In essence, at the transmitter and the receiver, the earth bulge is zero. For LoS point-to-point links design K-factor of 4/3 is often used. The refractivity gradient in the atmosphere which is a function of height and radio refractivity is expressed in Equation 21,

$$\frac{dN}{dh} = \Delta = \frac{N_2 - N_1}{h_2 - h_1} \qquad (21)$$

The effective earth radius factor (k-factor) is determined by Equation 22,

$$K = \frac{157}{157+\Delta} \qquad (22)$$

So, $H_{eb(x)}$ is expressed in Equation 23 as,

$$H_{eb(x)} = \frac{(d_{t(x)})(d_{r(x)})}{12.75\left(\frac{157}{157+\Delta}\right)} = \frac{(d_{t(x)})(d_{r(x)})(157+\Delta)}{12.75\ (157)} = \left(\frac{(d_{t(x)})(d_{r(x)})(157+\Delta)}{2001.75}\right) \qquad (23)$$

Let the reference refractivity gradient (4/3) be denoted as Δ_o and the operating refractivity gradient be denoted as Δ_i. Then, $H_{eb(x,\Delta_o)}$ in Equation 24 is given by;

$$H_{eb(x,\Delta_o)} = \left(\frac{(d_{t(x)})(d_{r(x)})(157+\Delta_o)}{2001.75}\right) \qquad (24)$$

$H_{eb(x)}$ with respect to operating refractivity gradient is given in Equation 32,

$$H_{eb(x,\Delta_i)} = \left(\frac{(d_{t(x)})(d_{r(x)})(157+\Delta_i)}{2001.75}\right) \quad (25)$$

The difference shown in Equation 26,

$$H_{eb(x,\Delta_i)} - H_{eb(x,\Delta_o)} \left(\frac{(d_{t(x)})(d_{r(x)})}{2001.75}\right)(\Delta_i - \Delta_o) \quad (26)$$

$H_{eb(x,\Delta_i)}$ with respect to reference refractivity gradient is shown in Equation 27,

$$H_{eb(x,\Delta_i)} = H_{eb(x,\Delta_o)} + \left(\frac{(d_{t(x)})(d_{r(x)})}{2001.75}\right)(\Delta_i - \Delta_o) \quad (27)$$

LetH_{rf} denote the height of the reference line for the determination of the effective obstruction height. In practice, the transmitter height and the receiver height are considered and the lower of the two is used as the reference line for the determination of the effective obstruction height. Also, the elevation at the transmitter is $h_{elt} = h_{el(0)}$ and that of the receiver is $h_{elr} = h_{el(N+1)}$. The effective obstruction height is H_n where n = 0 at the transmitter and n = N+1 at the receiver. In that case, as shown in Equation 28,

$$H_{rf} = \text{minimum}\left(\left(h_{el(0)} + H_{eb(0)} + h_{obst(0)}\right), \left(h_{el(N+1)} + H_{eb(N+10)} + h_{obst(N+1)}\right)\right) \quad (28)$$

Then, H_n is expressed in Equation 29,

$$H_n = \left(h_{el(n)} + H_{eb(n)} + h_{obst(n)}\right) - H_{rf} \text{ for n = 1 to N} \quad (29)$$

IV RESULTS AND DISCUSSIONS

A. Numerical Example

The schematic diagram of the 10-knife edge obstructions used for the numerical example in the study is shown in Figure 3. In Figure 3, $H_i$is the height of the knife edge obstruction i where i is 0, 1,2,3N+1 and N is the number of knife edge obstructions in the link. Also, h_i is the clearance height for the knife edge obstruction in the virtual hop j, where j is 1,2,3,…,N. in the numerical examples in this study, N =10.

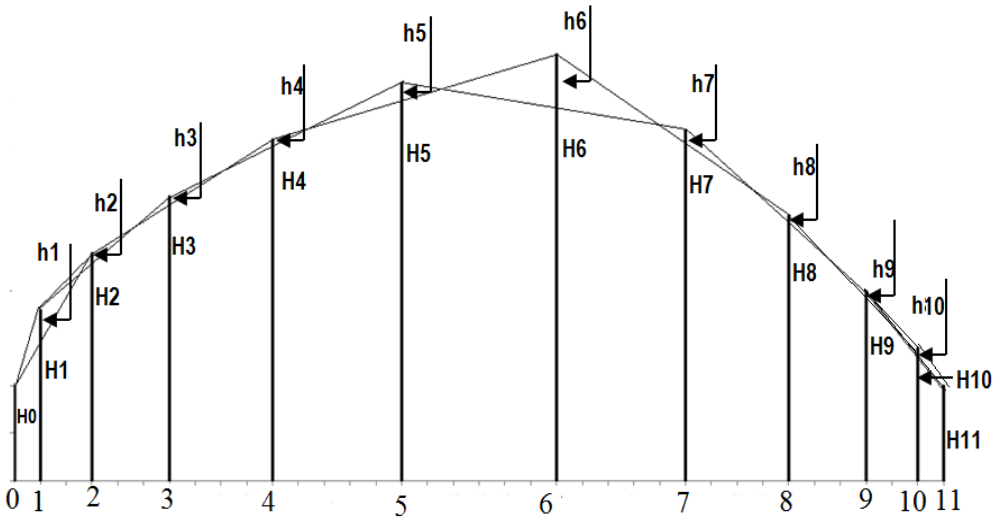

Figure 3: Schematic diagram of the 10-knife edge obstructions used in the study.

B. Results of the Numerical Example for Epstein-Peterson Method at the Reference Refractivity gradient of 4/3 or 1.33333

The dataset for the 10-knife edge obstructions and the clearance heights,$h_i$computed for each of the 10 knife edge obstructions using the Epstein-Peterson method are shown in Table 1.The obstruction heights of the 10-knife edge obstructions used in the Epstein-Peterson method are shown in Figure 4 while the variation of LoS clearance heights (m) and the distance between the obstruction are shown in Figure 5. Figure 6 shows the variation of line of sight(Los) clearance height, hi and diffraction parameter computed by Epstein-Peterson methods.

Table 1: The dataset for the 10-knife edge obstructions and the clearance heights,h_i and diffraction parameter computed by Epstein-Peterson method for each of the 10 knife edge obstructions.

Distance , dn (km)		Effective Knife Edge Obstruction Height, Hn		LOS Clearance Height, hn (m)		Diffraction Parameter, V		Diffraction Loss, G(dB)
d0	0	H0	0					
d1	1	H1	8	h1	3.333333	v1	0.333333	9.5811581
d2	2	H2	14	h2	1.200000	v2	0.089443	7.6850703
d3	3	H3	20	h3	0.857143	v3	0.053452	7.4052682
d4	4	H4	26	h4	0.666667	v4	0.036515	7.2735911
d5	5	H5	32	h5	1.909091	v5	0.094388	7.7235164
d6	6	H6	35	h6	5.727273	v6	0.283164	9.1911243
d7	5	H7	27	h7	1.444444	v7	0.079115	7.6047828
d8	4	H8	8	h8	0.714860	v8	0.044544	7.3360089
d9	3	H9	0	h9	0.400000	v9	0.029814	7.2214984
d10	2	H10	4	h10	0.666667	v10	0.066667	7.5080016
d11	1	H11	0				**Total Diffraction Loss, G(dB)**	**78.53**
d	36	F=1GHz	λ=0.3 m					

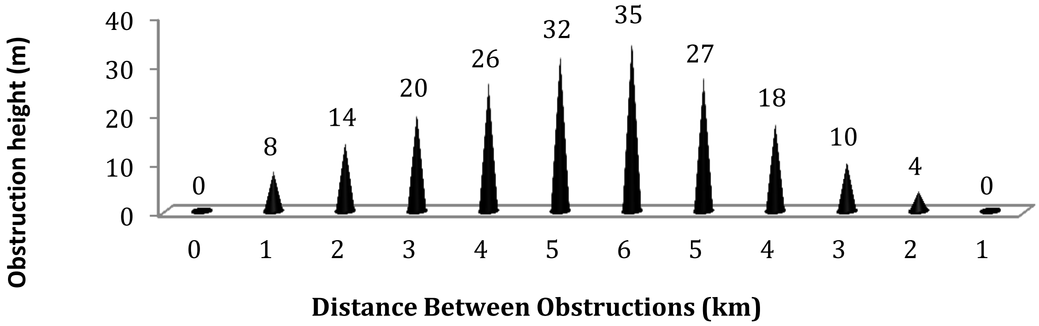

Figure 4: The obstruction height of the 10-knife edge obstructions used in the Epstein-Peterson method

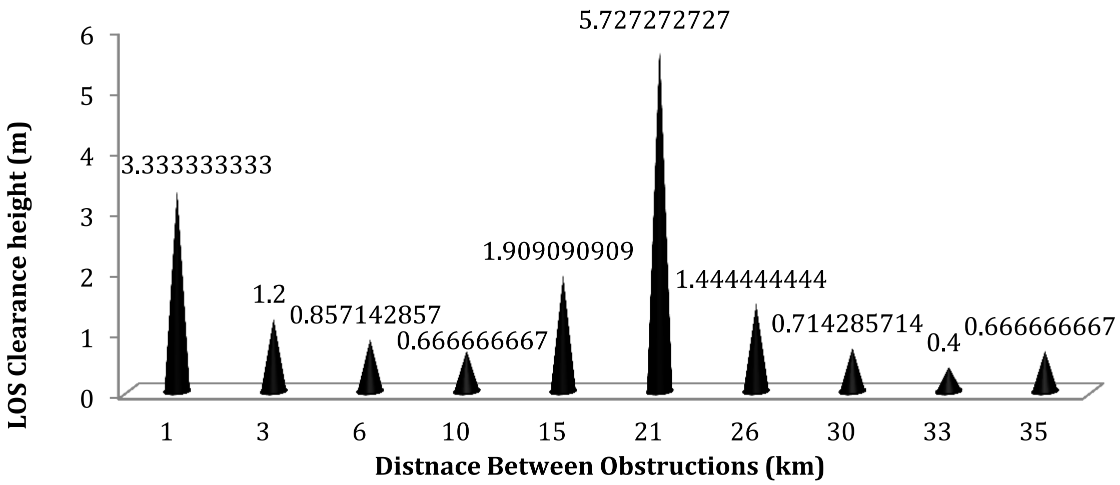

Figure 5: The clearance height computed by Epstein-Peterson method for the 10 virtual hops.

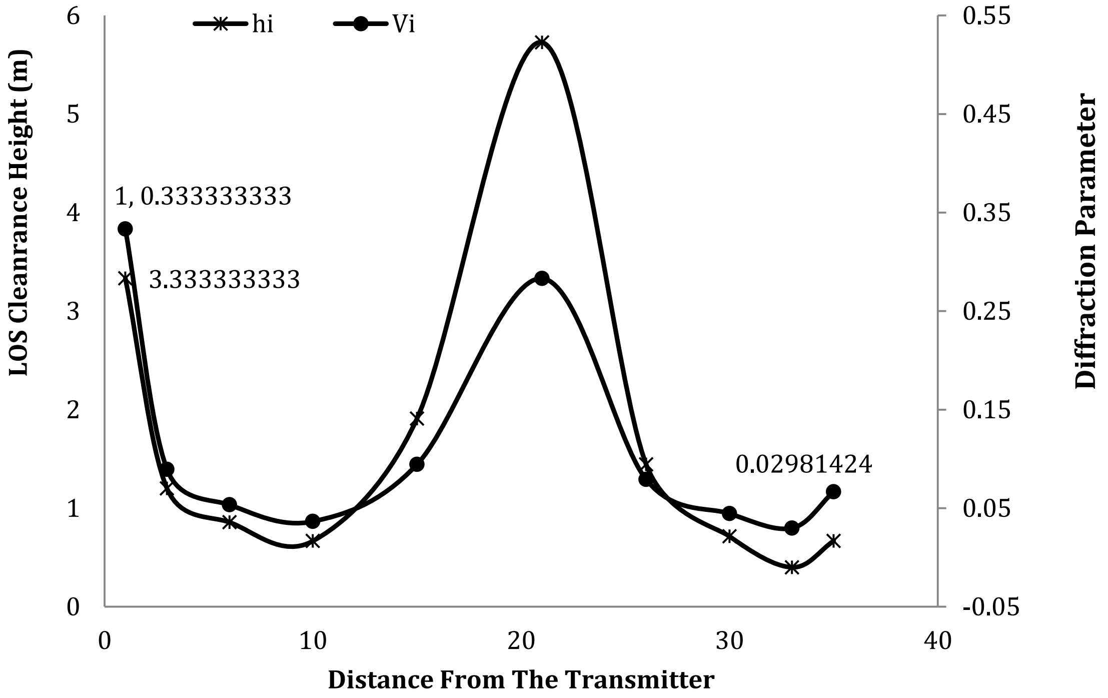

Figure 6: LoS clearance height, hi and diffraction parameter, vi computed by Epstein-Peterson method for the 10 virtual hops

The results show that the maximum LOS clearance height, hn is 5.727272727 m and it occurred at a distance of 21 km from the transmitter. Also, the minimum LOS clearance height is 0.4 m and it occurred at a distance of 33 km from the transmitter. On the other hand, the results also show that the maximum diffraction parameter, V is 0.333333333 and it occurred at a distance of 1 km from the transmitter. In addition, the minimum diffraction parameter is 0.02981424and it occurred at a distance of 33 km from the transmitter. In essence, the maximum LOS clearance height does not correspond to the maximum diffraction parameter. This shows that for the multiple knife edge diffraction loss, the diffraction parameter depends not only on the LOS clearance height, but also on the distance from the knife edge obstruction to the transmitter and the receiver. In all, the total diffraction loss caused by the 10knife edge obstructions in the communication link is 78.53dB.

V. CONCLUSION

An approach for using Epstein-Peterson method for the computation of N-knife edge diffraction loss as a function of refractivity gradient is presented. The relevant mathematical expression is presented and then a 10-knife edge obstructions were used for a numerical example for the application of the procedure presented in this paper.

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