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ANALYSIS OF SINGLE KNIFE EDGE DIFFRACTION LOSS FOR A FIXED TERRESTRIAL LINE-OF-SIGHT MICROWAVE COMMUNICATION LINK

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***Abstract*— In this paper, parametric analysis of single knife edge diffraction loss for a fixed terrestrial line-of-sight (LOS) microwave communication link is conducted with respect to LOS percentage clearance, Pc (%) of the first Fresnel zone. In practice, the required LOS clearance is specified in terms of Pc(%) but the computation of diffraction parameter, V is expressed in terms of clearance height which requires more elaborate and complex computations. In this paper, a simpler approach that computes the diffraction parameter using the LOS percentage clearance, Pc (%) is presented. Also, the single knife edge diffraction loss, the excess path length for the diffracted signal, the phase difference between the direct and the diffracted signal and the number of Fresnel zones that are blocked by the obstruction are computed for a given Pc(%) and frequency. The results show that at PC (%) = 0, V is zero but the diffraction loss is about -6.021 dB and at Pc(%) = -60% the diffraction loss, is about 0.221 dB , which is negligible when compared with other path losses that are above 10 dB. Also, at PC (%) = 0, V= 0 and there is no excess path (Δp = 0) and no phase difference (Φp = 0) between the direct and the diffracted signal. Furthermore, for various values of Pc(%) the minimum value for Δp and Φp occurred at Pc (%) = 0%. Finally, the results showed that the values of V, G(dB) and Φp did not change with frequency as the Pc(%) remains constant. However, the value of excess path length (Δp) changes with frequency even when Pc(%) remains constant.**

Keywords*— *Diffraction loss, Diffraction parameter, microwave , line-of-sight, percentage clearance, knife edge diffraction

1. INTRODUCTION

When wireless signals encounter obstruction they can be reflected, refracted, diffracted or scattered [1,2,3]. Each of these effects causes reduction in the received signal strength. Diffraction occurs when the signal spread around the object [4,5,6,7,8]. In this case, when compared with the direct signal, the diffracted signal travels extra distance before it arrives at the receiver. Also, there is phase difference between the diffracted signals and the direct signals (that is, signals that did not experience diffraction effect) [9,10,11,12].

Diffraction effect caused by isolated obstruction like hill is modeled as knife edge diffraction which is explained using the Huygens-Fresnel principle [13,14,15]. Specifically, the Fresnel diffraction parameter, V is normally used to determine the resultant knife edge diffraction loss, the excess path length, the phase difference between the direct and the diffracted waves and also the number of Fresnel zones that are blocked by the obstruction.

Over the years, the diffraction parameter has been determined using the line-of-sight clearance height (h), the distance of the obstruction from the transmitter and the distance of the obstruction from the receiver [16,17]. However, this approach is quite difficult. In most cases, the effect of diffraction obstruction is specified in terms of percentage clearance (Pc) of the first Fresnel zone. As such, in a recent study, a formula has been derived for calculating the diffraction parameter, V directly from the specified percentage clearance (Pc) of the first Fresnel zone [16,17]. Consequently, in this paper, this recent formula for V expressed in terms of Pc is used to determine V and then to compute the other relevant parameters associated with knife edge obstruction. In particular, the Lee composite function for knife edge diffraction loss [16,17,18,19] is used to determine the diffraction loss. Sample numerical examples are used to demonstrate the application of the ideas presented in this paper.

2. THE THEORETICAL FRAMEWORK FOR THE SINGLE KNIFE EDGE DIFFRACTION LOSS COMPUTATION

In Figure 1, the transmitter, T and the receiver, R antennas are aligned to give the line-of-sight, LT.

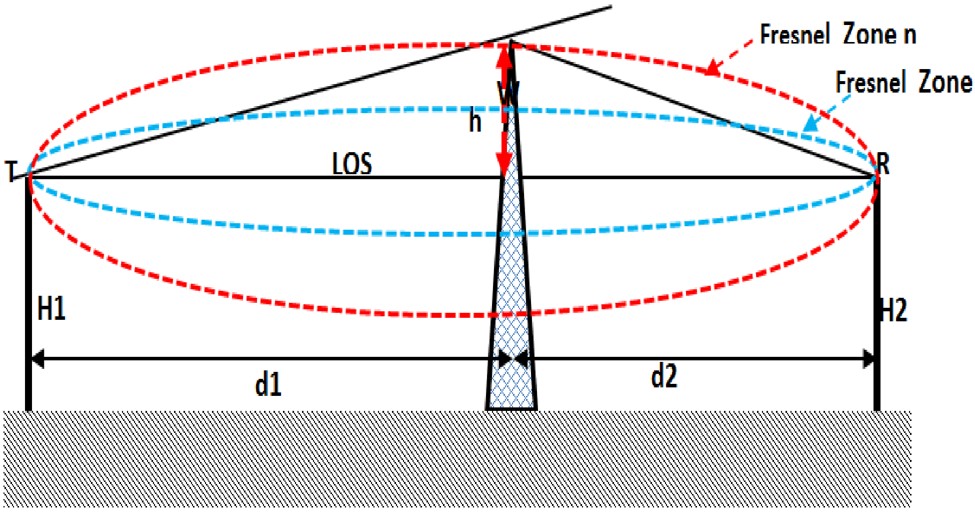

Figure 1 The Geometry of a single knife edge diffraction obstruction along a line-of-sight signal path

There is an obstruction at distance, d1 from the transmitter and distance, d2 from the receiver. The obstruction extends above the LOS up to point, W blocking Fresnel zone 1, 2,…n. The path length of the diffracted signal is TWR while the path length of the direct (non-diffracted) signal is TR. The excess path length denoted as Δ_p and the phase difference (ϕ_p) between the diffracted and the direct signal can be calculated in terms of the Fresnel-Kirchoff diffraction parameter, V. On the other hand, the diffraction parameter, V can be expressed in terms of line-of-sight (LOS) percentage clearance, P_c of the first Fresnel zone as follows [16,17];

$$V_{(x,pc)} = \frac{(P_c\sqrt{2})}{100} \quad (1)$$

According to Lee's approximation model, the knife edge diffraction loss in dB, denoted as $G_d(dB)$ is given in terms of diffraction parameter, V as follows [16,17,18,19];

$$\begin{cases} G_d(dB) = 0 & \text{for} \quad V < -1 \\ G_d(dB) = 20\log(0.5 - 0.62V) & \text{for} \ -1 \le V \le 0 \\ G_d(dB) = 20\log(0.5\exp(-0.95V)) & \text{for} \ 0 \le V \le 1 \\ G_d(dB) = 20\log\left(0.4 - \sqrt{0.1184 - (0.38 - 0.1V)^2}\right) & \text{for} \ 1 \le V \le 2.4 \\ G_d(dB) = 20\log\left(\frac{0.225}{V}\right) & \text{for} \quad V > 2.4 \end{cases} \quad (2)$$

The excess path length travelled by the diffracted signal is denoted as Δ_p where

$$\Delta_p = \frac{\lambda(V)^2}{4} \quad (3)$$

The wavelength, λ is in metres and it is given as;

$$\lambda = \frac{c}{f} \quad (4)$$

Where, f is the frequency in Hz and c is the speed of the radio wave (c $= 3x10^3 m/s$)

The phase difference between the diffracted signal and the direct (non-diffracted) is denoted as ϕ_p , where ;

$$\phi_p = \left(\frac{\pi}{2}\right)(V)^2 \quad (5)$$

There are infinite number of Fresnel zones ranging from 1,2,3,…, ∞. In practice, Fresnel zone 1 is the most significant. The number of Fresnel zones blocked by the obstruction is denoted as n_{blk} , where.

$$n_{blk} = \frac{(V)^2}{2} \quad (6)$$

The percentage of excess path length to the wave length is denoted as Δ_λ and it is given as;

$$\Delta_\lambda = \left(\frac{\Delta_p}{\lambda}\right) 100\ \% \quad (7)$$

3. NUMERICAL COMPUTATION RESULTS AND DISCUSSION

Sample numerical example is computed for a Ku-band microwave signal at 12 GHz. Additional numerical computations are performed for frequencies ranging from 1 GHz to 20 GHz. The results for the numerical computation for the 12 GHz Ku-band frequency with wavelength of 0.25 m is shown in Table 1 and Figure 1. In Table 1 and Figure 1, positive Pc (%) means that the object tip projects above the line of sight (LOS) and a negative value of Pc (%) means that the tip of the obstruction is below the LOS. A Pc (%) = 0 means that the tip of the obstruction is on the LOS.

From Table 1 and Figure 1, at PC (%) = 0, V is zero but the diffraction loss is about -6.021 dB. In practice, a -60% LOC percentage clearance is normally specified and in Table 1 and Figure 1, at PC (%) = -60 % the diffraction loss is about 0.221 dB , which is negligible when compared with the other path losses that are above 10 dB.

Again, from Table 1, Figure 1 and Figure 2, at PC (%) = 0, V= 0 and there is no excess path (Δp = 0) and no phase difference (Φp = 0) between the direct and the diffracted signal. However, at PC (%) = -60 % there is excess path (Δp = 0.005 m) and no phase difference (Φp = 1.131 radian) between the direct and the diffracted signal. At that point, exactly 40% (ntip = 0.4) of the first Fresnel zone is blocked by the obstruction. It can be seen from Figure 3 that the minimum value for Δp, Φp and ntip occurred at Pc (%) = 0%.

Table 1 A numerical computation for a 12 GHz Ku-band frequency with wavelength of 0.25 m.

S/N	Pc(%)	v	G(dB)	Δp (m)	Φp (radian)	ntip	(Δp /λ)100 %
1	220	3.111	-22.815	0.061	15.207	4.8	242
2	200	2.828	-21.987	0.050	12.568	4.0	200
3	180	2.546	-21.072	0.041	10.180	3.2	162
4	160	2.263	-20.710	0.032	8.044	2.6	128
5	140	1.980	-19.333	0.025	6.158	2.0	98
6	120	1.697	-17.880	0.018	4.524	1.4	72
7	100	1.414	-16.360	0.013	3.142	1.0	50
8	80	1.131	-14.761	0.008	2.011	0.6	32
9	60	0.849	-13.022	0.005	1.131	0.4	18
10	40	0.566	-10.688	0.002	0.503	0.2	8
11	20	0.283	-8.355	0.001	0.126	0.0	2
12	0	0.000	-6.021	0.000	0.000	0.0	0
13	-20	-0.283	-3.409	0.001	0.126	0.0	2
14	-40	-0.566	-1.404	0.002	0.503	0.2	8
15	-60	-0.849	0.224	0.005	1.131	0.4	18
16	-80	-1.131	0.000	0.008	2.011	0.6	32
17	-100	-1.414	0.000	0.013	3.142	1.0	50
18	-120	-1.697	0.000	0.018	4.524	1.4	72
19	-140	-1.980	0.000	0.025	6.158	2.0	98
20	-160	-2.263	0.000	0.032	8.044	2.560	128
21	-180	-2.546	0.000	0.041	10.180	3.240	162
22	-200	-2.828	0.000	0.050	12.568	4.000	200
23	-220	-3.111	0.000	0.061	15.207	4.840	242

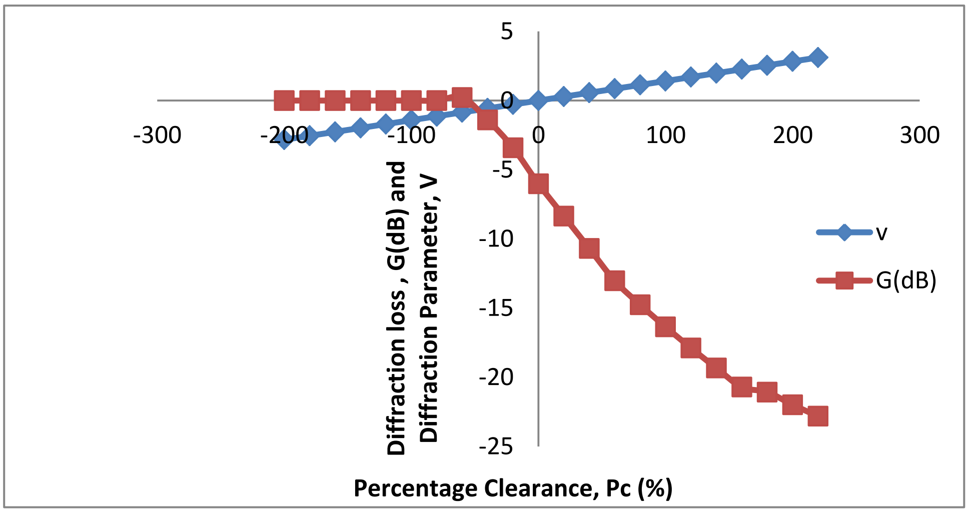

Figure 1 **Diffraction loss, G(dB) and Diffraction Parameter, Versus LOS Percentage Clearance, Pc (%)**

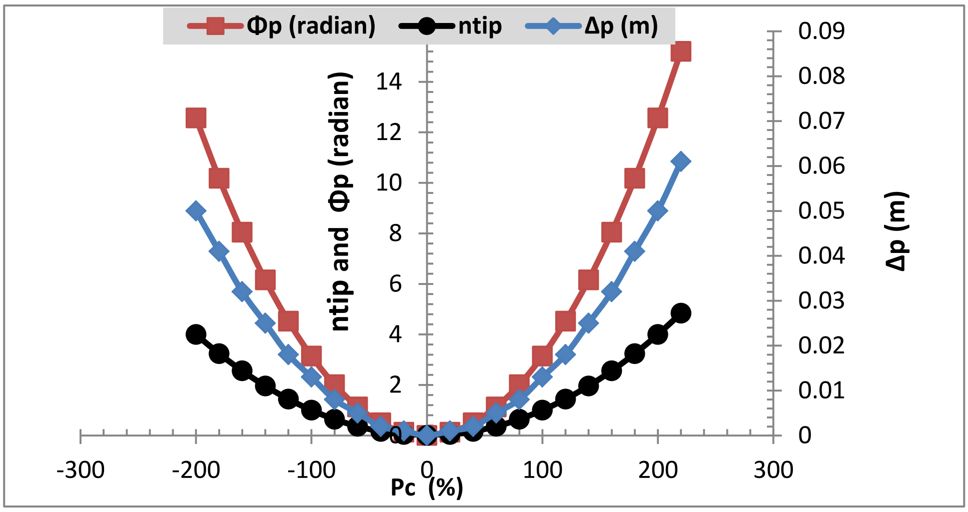

Figure 2 Δp (m), Φp (radian) and ntip versus LOS Percentage Clearance, Pc (%)

The results of the numerical computations at PC (%) = -60% and for frequencies ranging from 1 GHz to 20 GHz are given in Table 2 and Figure 3. The results showed that the values of V, G(dB), Φp and ntip did not change with frequency as the Pc(%) remains constant, however, the value of excess path length (Δp) changes with frequency, as shown in Figure 3. However, the change in the excess path length (Δp) is observed to follow a patter given as;

$$k_p = \frac{\Delta p}{\lambda} = \frac{f(\Delta p)}{c} \quad (8)$$

Where k_p is a constant that relate the excess path length (Δp) with frequency, f is the frequency in Hz and c is the speed of the radio wave ($c = 3x10^3 m/s$) . In the numerical example, k_p is expressed in percentage by multiplying it by 100 and the result in Table 2 shows that for the given wireless link and diffraction obstruction, the value of k_p is 0.18 or 18%.

Table 2 Numerical computation for frequencies ranging from 1 GHz to 20 GHz at PC (%) = -60%

f (GHz)	λ (m)	V	G(dB)	Δp (m)	Φp (radian)	ntip	(Δp /λ)100 %
1	0.3000	-0.849	0.224	0.0540	1.131	0.360	18
2	0.1500	-0.849	0.224	0.0270	1.131	0.360	18
3	0.1000	-0.849	0.224	0.0180	1.131	0.360	18
4	0.0750	-0.849	0.224	0.0135	1.131	0.360	18
5	0.0600	-0.849	0.224	0.0108	1.131	0.360	18
6	0.0500	-0.849	0.224	0.0090	1.131	0.360	18
7	0.0429	-0.849	0.224	0.0077	1.131	0.360	18
8	0.0375	-0.849	0.224	0.0068	1.131	0.360	18
9	0.0333	-0.849	0.224	0.0060	1.131	0.360	18
10	0.0300	-0.849	0.224	0.0054	1.131	0.360	18
11	0.0273	-0.849	0.224	0.0049	1.131	0.360	18
12	0.0250	-0.849	0.224	0.0045	1.131	0.360	18
13	0.0231	-0.849	0.224	0.0042	1.131	0.360	18
14	0.0214	-0.849	0.224	0.0039	1.131	0.360	18
15	0.0200	-0.849	0.224	0.0036	1.131	0.360	18
16	0.0188	-0.849	0.224	0.0034	1.131	0.360	18
17	0.0176	-0.849	0.224	0.0032	1.131	0.360	18
18	0.0167	-0.849	0.224	0.0030	1.131	0.360	18
19	0.0158	-0.849	0.224	0.0028	1.131	0.360	18
20	0.0150	-0.849	0.224	0.0027	1.131	0.360	18

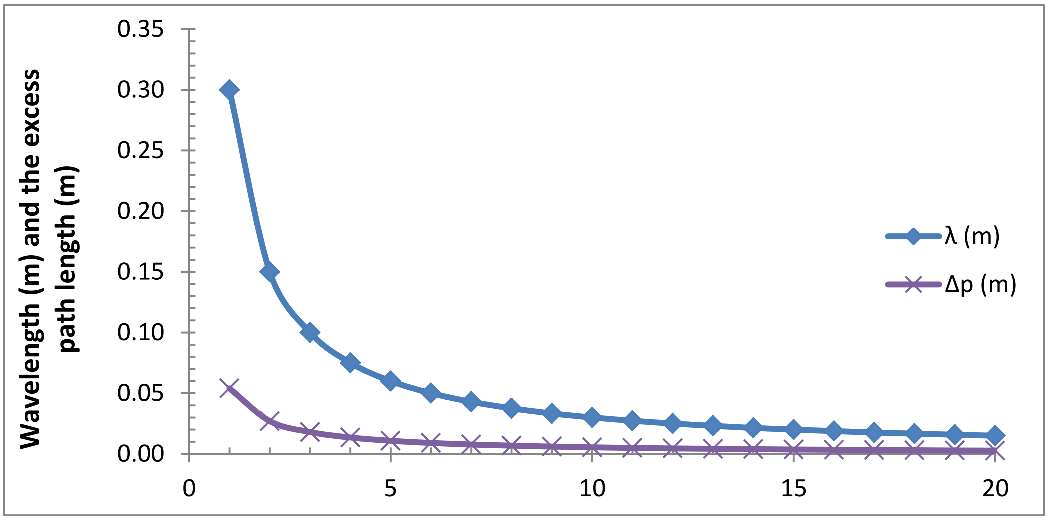

Figure 3: Variation of excess path length with frequency

4 CONCLUSION

In this paper, the knife edge diffraction loss and the associated parameters are computed. The paper utilized a simple approach that computes the diffraction parameter using the line-of-sight (LOS) percentage clearance rather than using the LOS clearance height which requires more elaborate and complex computations. Furthermore, the effect of variations in the LOS percentage clearance on the single knife diffraction parameter, diffraction loss and the other associated parameters are studied. Similar parametric analysis was also conducted at constant LOS percentage clearance but with frequency varied from 1 GHz to 20 GHz. The ideas presented in this paper provided a simpler way for researchers and wireless network designers to conduct parametric analysis of single knife edge diffraction.

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