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Determination of Single Knife Edge Equivalent Parameters for Triple Knife Edge Diffraction Loss by Giovanelli Method

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Abstract: In this paper, the computation of triple knife edge diffraction loss by Giovanelli multiple knife edge diffraction loss method is presented for a 10 GHz Ku-band microwave link. Also, the computation of equivalent single knife edge obstruction that will replace the triple obstruction by giving the same diffraction loss as the dual obstructions is presented. The results shows that for the triple obstructions (M1, M2 and M3) the total diffraction loss is 59.5095778 dB as computed by the Giovanelli method. The individual diffraction loss from obstructions M1, M2 and M3 are 13.3856983 dB, 29.59291 dB and 16.5309693 dB respectively. Furthermore, a single knife edge obstruction located at the middle of the link (dt = dr = 4475m) and with LOS clearance height of 1237.591 m will be give the same diffraction loss as the three knife edge obstructions M1, M2 and M3. Essentially, the line of sight clearance height of the equivalent single knife edge obstruction are much more than the sum of the line of sight clearance height of the three original obstructions.

Keywords: Diffraction Parameter, Diffraction Loss, Knife Edge obstruction, Multiple Knife Edge Obstruction, Equivalent Single Knife Edge Obstruction, Giovanelli Method

1. Introduction

In wireless communication systems, pathloss is one of the major components used in link budgeting to determine the expected received signal strength [1-6]. Basically, pathloss is the reduction in power density of an electromagnetic wave as it propagates through space [7-10]. Pathloss can be caused by many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Diffraction loss occurs when the line of sight (LOS) is blocked by an obstruction. In that case, the signal bends around the obstacle [11-17].

The concept of diffraction is explained by the Huygens-Fresnel principle [18-20]. The common practice is that isolated obstruction like hill or building are considered as knife edge obstruction [21-23]. When there are two or more of such knife edge obstructions, then multiple knife edge diffraction loss methods can be employed to determine the effective diffraction loss of all the knife edge obstructions [24]. Several multiple knigfe edge diffraction methods hase bee developed such as Bullington, Epstein and Peterson, Deygout, Shibuya and Giovaneli methods. The listed are approximation method for determination of the effective diffraction loss that can be caused by a given set of multiple knife edge obstructions in the signal path. knife edge diffraction using he Giovaneli method is presented for a 10GHz Ku-band microwaave link. Furthermore, the computation of a single knife edge equivalent of the triple knife edge is presented.

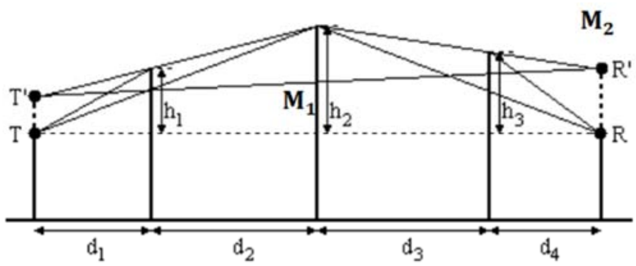

Figure 1. *The Geometry for the Giovanelli method [25].*

2. Giovanelli Multiple Knife Edge Diffraction Loss Method

Let λ be the wavelength of the radio wave; let c be the speed of the radio wave (where $c = 3x10^8 m/s$ and let f be the frequency of the radio wave in Hz, then, the radius of the first Fresnel zone at location x is denoted as r_x which is at a distance of $d_{t(x)}$ from the transmitter and at a distance of $d_{r(x)}$ from the receiver, then;

$$r_x = \sqrt{\frac{\lambda(d_{t(x)})(d_{r(x)})}{(d_{t(x)} + d_{r(x)})}} \quad (1)$$

λ in metres is given as;

$$\lambda = \frac{c}{f} \quad (2)$$

Based on the three knife edge obstructions (M_1, M_2 and M_3) in Figure 1 the following procedure is used in Giovaneli method to determine the effective diffraction loss due to the three knife edge obstructions. In Giovaneli method, first, the dominant obstruction is determined from (q_i) the ratio of the obstruction i LOS clearance height (h_i) and r_i which is the radius of the first Fresnel zone at obstruction's location. From figure 1, for the knife edge obstruction M_1;

$$r_1 = \sqrt{\frac{\lambda(d_1)(d_2+d_3+d_4)}{(d_1 + d_2+d_3+d_4)}} \quad (3)$$

$$q_1 = \frac{h_1}{r_1} \quad (4)$$

For the knife edge obstruction M_2

$$r_2 = \sqrt{\frac{\lambda(d_1 + d_2)(d_3+d_4)}{(d_1 + d_2+d_3+d_4)}} \quad (5)$$

$$q_2 = \frac{h_2}{r_2} \quad (6)$$

For the knife edge obstruction M_3

$$r_3 = \sqrt{\frac{\lambda(d_1 + d_2+d_3)(d_4)}{(d_1 + d_2+d_3+d_4)}} \quad (7)$$

$$q_3 = \frac{h_3}{r_3} \quad (8)$$

The dominant obstruction is the obstruction with the maximum value for q_i. After the dominant obstruction is identified, then two observation planes T'T and R'R are constructed as shown in the Figure 1. The diffraction loss is calculated for the dominant obstruction considering the height above the line between the "new" stations T' and R' [15]. After that the diffraction loss is calculated for the path between the original transmitter T and the main obstruction. Lastly, the diffraction loss is calculated for the path between the dominant obstruction and the original receiver R. In this paper, the dominant obstruction is M_2 and the LOS clearance (H), distance from the transmitter (D_1) and distance from the receiver (D_2) are thus determined in respect of Giovaneli method applied to the three knife edge obstructions (M_1, M_2 and M_3) in figure 1. For the knife edge obstruction M_1 the following parameters are determined [15]

$$H_1 = h_1 - h_2\left(\frac{d_1}{d_1+d_2}\right) \quad (9)$$

$$D_{1(1)} = d_1 \quad (10)$$

$$D_{2(1)} = d_2 \quad (11)$$

The Fresnel-Kirchhoff diffraction parameter is given by [25, 26, 27]:

$$V_1 = H_1\sqrt{\left(\frac{2}{\lambda}\left(\frac{1}{D_{1(1)}} + \frac{1}{D_{2(1)}}\right)\right)} \quad (12)$$

For the knife edge obstruction M_2 the following parameters are determined [25]:

$$H_2 = h_2 - T' + (T' - R')\left(\frac{d_1+d_2}{d_1+d_2+d_3+d_4}\right) \quad (13)$$

$$D_{1(2)} = d_1 + d_2 \quad (14)$$

$$D_{2(2)} = d_3 + d_4 \quad (15)$$

where T' and R' are given by:

$$T' = h_1 - (h_2 - h_1)\left(\frac{d_1}{d_2}\right) \quad (16)$$

$$R' = h_3 - (h_2 - h_3)\left(\frac{d_4}{d_3}\right) \quad (17)$$

The Fresnel-Kirchhoff diffraction parameter for the knife edge obstruction M_2 is given by:

$$V_2 = H_2\sqrt{\left(\frac{2}{\lambda}\left(\frac{1}{D_{1(2)}} + \frac{1}{D_{2(2)}}\right)\right)} \quad (18)$$

For the knife edge obstruction M_3 the following parameters are determined [25]:

$$H_3 = h_3 - h_2\left(\frac{d_4}{d_3+d_4}\right) \quad (19)$$

$$D_{1(3)} = d_3 \quad (20)$$

$$D_{2(3)} = d_4 \quad (21)$$

The Fresnel-Kirchhoff diffraction parameter for the knife edge obstruction M_3 is given by:

$$V_3 = H_3\sqrt{\left(\frac{2}{\lambda}\left(\frac{1}{D_{1(3)}} + \frac{1}{D_{2(3)}}\right)\right)} \quad (22)$$

The knife edge diffraction loss due to v_i is denoted as A_i and according to ITU-RP 526-13 [28] the knife-edge diffraction loss A_i is defined as;

$$A_i = 6.9 + 20\text{Log}\left(\left(\sqrt{(v_i - 0.1)^2 + 1}\right) + v_i - 0.1\right) \quad (23)$$

The total diffraction loss due to the three knife edge obstructions (M_1, M_2 and M_3) in figure 1 is A where;

$$A = A_1 + A_2 + A_3$$

According to ITU-RP 526-13 [28] diffraction parameter v will give rise to knife-edge diffraction loss A defined as;

$$A = 6.9 + 20\text{Log}\left(\left(\sqrt{(v-0.1)^2+1}\right) + V - 0.1\right) \quad (24)$$

Conversely, the diffraction parameter v can be computed from the knife-edge diffraction loss, A as follows;

Let P be defined as

$$10^{\left(\frac{A-6.9}{20}\right)} = P \quad (25)$$

Also, let U be defined as

$$U = V - 0.1 \quad (26)$$

Then the ITU Rec 526-13 knife-edge diffraction loss gives;

$$\sqrt{(U^2+1)} + U = P \quad (27)$$

Hence,

$$\sqrt{(U^2+1)} = P - U \quad (28)$$

$$U^2 + 1 = P^2 - 2(P)(U) + U^2 \quad (29)$$

$$U^2 + 1 = P^2 - 2(P)(U) + U^2 \quad (30)$$

$$U = \frac{P^2-1}{2(P)} \quad (31)$$

Then

$$V = \left(\frac{\left(10^{\left(\frac{A-6.9}{20}\right)}\right)^2 - 1}{2\left(10^{\left(\frac{A-6.9}{20}\right)}\right)}\right) + 0.1 \quad (32)$$

So, the single knife edge equivalent of the dual knife edge is given by equation 17. Let the single knife edge equivalent obstruction be located at a distance of $d_{t(x)}$ from the transmitter and at a distance of $d_{r(x)}$ from the receiver, then, the diffraction parameter, V is given as;

$$V = h\sqrt{\frac{2(d_{t(x)}+d_{r(x)})}{\lambda(d_{t(x)})(d_{r(x)})}} \quad (33)$$

Then form

$$h = \frac{V}{\left(\sqrt{\frac{2(d_{t(x)}+d_{r(x)})}{\lambda(d_{t(x)})(d_{r(x)})}}\right)} \quad (34)$$

The Percentage Clearance, Pc(%) is given as ;

$$Pc(\%) = \left(\frac{h}{r_x}\right)100\% = \frac{(V)100}{\sqrt{2}} \quad (35)$$

The excess path length (Δ_{path}) is the difference between the direct path and the diffracted path it is given as;

$$\Delta_{path} = \left(\frac{\lambda}{4}\right)V^2 \quad (36)$$

The phase difference (ϕ) between the direct path and the diffracted path is given as;

$$\Phi = \left(\frac{\pi}{2}\right)V^2 \quad (37)$$

Let n_{tip} be the Fresnel zone in which the tip of the obstruction lies, then;

$$n_{tip} = \left(\frac{1}{2}\right)V^2 \quad (38)$$

3. Results and Discussions

The key input data for the three knife edge obstructions used in the study are shown in Table 1. Particularly, the heights of the obstructions above TR, (the transmitter-receiver line of sight) as well as the distance in kilometers between the obstructions. Table 2 shows the ratio of the LOS clearance height to the first Fresnel zone for the three obstructions. According to Table 2, among the three obtrusions considered in the study, obstruction M2 has the highest ratio of clearance height to the first Fresnel zone. Hence, obstruction M2 is the dominant obstruction.

Table 1. *Data on height of obstruction above the transmitter-receiver line of sight and the distance between the obstructions.*

Distance Between The Obstructions		Height Of Obstruction Above TR, The Transmitter-Receiver Line Of Sight	
d1 (km)	1.8	h1 (m)	23.64246
d2(km)	2.25	h2(m)	45.19553
d3(km)	3.6	h3(m)	17.48045
d4(km)	1.3		

Table 2. *The Ratio Of Clearance Height To Fresnel Zone For Obstructions* M_1, M_2 *and* M_3*).*

M_1		M_2		M_3	
h1: Clearance height for obstruction M1	23.64246	h2: Clearance height for obstruction M2	45.19553	h3: Clearance height for obstruction M3	17.48045
r1: Radius of first Fresnel zone (m) at the location of obstruction M1	43.13966	r2: Radius of first Fresnel zone (m) at the location of obstruction M2	66.51955	r3: Radius of first Fresnel zone (m) at the location of obstruction M3	33.3352
q1: Ratio Of Clearance Height To Fresnel Zone For Obstruction M1	0.548045	q2: Ratio Of Clearance Height To Fresnel Zone For Obstruction M2	0.679432	q3: Ratio Of Clearance Height To Fresnel Zone For Obstruction M3	0.524384

Table 3 shows the total diffraction loss of 59.5095778 dB as computed by the Giovanelli method. The individual diffraction loss from obstructions M1, M2 and M3 are 13.3856983 dB, 29.59291 dB and 16.5309693 dB respectively. Table 4 shows the single knife edge equivalent parameters for the three knife edge obstructions M1, M2 and M3. According to the results in Table 4, a single knife edge obstruction located at the middle of the link (dt = dr = 4475m) and with LOS clearance height of 1237.591 m will be give the same diffraction loss as the three knife edge obstructions M1, M2 and M3.

Table 3. *The Effective Diffraction Of The Three Knife Edge Computed By The Giovanelli Method.*

	M1	**M2**	**M3**
	j=1	**j=2**	**j=3**
Distance of obstruction from the transmitter, D1(j) in meter	1800	4050	3600
Distance of obstruction from the receiver, D2(j) in meter	2250	4900	1300
LOS Clearance Height, H(j) in meter	3.55555556	39.68176	5.48979592
Diffraction Parameter, V(j)	0.9180405	6.880678	1.45039296
Diffraction Loss, A(j) in dB	13.3856983	29.59291	16.5309693
Total Diffraction Loss, A in dB			59.5095778
T'	6400	R'	7472.22222

Table 4. *The Single Knife Edge Equivalent Of The Three Knife Edge Obstructions.*

Single Knife Edge Diffraction Loss	**G(dB)**	**59.50958**	**Single Knife Edge Radius of First Fresnel Zone**	**Fr1**	**8.192985**
Single Knife Edge Diffraction Parameter	V	213.6239	Percentage Clearance Of The Single Knife Edge Obstruction	P(%)	15105.49
Single Knife Edge Obstruction Distance From transmitter	dt (m)	4475	Excess path length	Δ_{path} (m)	342.2638
Single Knife Edge Obstruction Distance From transmitter	dr(m)	4475	The phase difference	Φ (radians)	71692.86
LOS Clearance Height of the Single Knife Edge Obstruction	h	1237.591	The Fresnel zone where the tip of the knife edge obstruction is located	ntip	22817.59

4. Conclusions

The computation of three knife edge diffraction loss by Giovanelli multiple knife edge diffraction loss method is presented for a 10 GHz Ku-band microwave link. Also presented are the computation of a single knife edge obstruction that will replace the three knife edge obstructions by giving the same diffraction loss as the three obstructions. The results shows that the line of sight clearance height of the equivalent single knife edge obstruction are much more than the sum of the line of sight clearance height of the three obstructions. Similar result applies to the diffraction parameter of the equivalent single knife edge obstruction in relation to the dual obstruction. Essentially, dual or multiple knife edge obstructions has more impact than a very high single knife edge obstruction.

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