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

Ezenugu Isaac A., Ikechukwu H. Ezeh, Swinton C. Nwokonko

Department of Electrical/Electronic Engineering, Imo State University, Owerri, Nigeria

Email address:
isaac.ezenugu@yahoo.com (Ezenugu I. A.)

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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 show 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 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 knife edge diffraction methods have been 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 the Giovaneli method is presented for a 10GHz Ku-band microwave link. Furthermore, the computation of a single knife edge equivalent of the triple knife edge is presented.
2. Giovanelli Multiple Knife Edge

Diffraction Loss Method

Let \( \lambda \) be the wavelength of the radio wave; let \( c \) be the speed of the radio wave (where \( c = 3 \times 10^8 \) 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 \( d_{r(x)} \) from the transmitter and at a distance of \( d_{r(x)} \) from the receiver, then:

\[
r_x = \sqrt{\frac{\lambda(d_{r(x)})}{(d_{r(x)} - d_{r(x)})}}
\]

(1)

\( \lambda \) in metres is given as:

\[
\lambda = \frac{c}{f}
\]

(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 \( q_1 \) the ratio of the obstruction i LOS clearance height \( h_i \) and \( r_1 \) which is the radius of the first Fresnel zone at obstruction’s location. From figure 1, for the knife edge obstruction \( M_1 \):

\[
r_1 = \sqrt{\frac{\lambda(d_1)(d_2+d_3+d_4)}{(d_1 + d_2 + d_3 + d_4)}}
\]

(3)

\[
q_1 = \frac{h_1}{r_1}
\]

(4)

For the knife edge obstruction \( M_2 \):

\[
r_2 = \sqrt{\frac{\lambda(d_1+d_2)(d_3+d_4)}{(d_1 + d_2 + d_3 + d_4)}}
\]

(5)

\[
q_2 = \frac{h_2}{r_2}
\]

(6)

For the knife edge obstruction \( M_3 \):

\[
r_3 = \sqrt{\frac{\lambda(d_1+d_2+d_3)(d_4)}{(d_1 + d_2 + d_3 + d_4)}}
\]

(7)

\[
q_3 = \frac{h_3}{r_3}
\]

(8)

The dominant obstruction is the obstruction with the maximum value for \( q_1 \). After the dominant obstruction is identified, then two observation planes \( TT' \) and \( RR' \) 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]:

\[
H_1 = h_1 - h_2 \left( \frac{d_1}{d_3 + d_4} \right)
\]

(9)

\[
D_{1(1)} = d_1
\]

(10)

\[
D_{2(1)} = d_2
\]

(11)

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

\[
V_1 = H_1 \sqrt{\frac{2}{\lambda} \left( \frac{1}{D_{1(1)}} + \frac{1}{D_{2(1)}} \right)}
\]

(12)

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

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

(13)

\[
D_{1(2)} = d_1 + d_2
\]

(14)

\[
D_{2(2)} = d_3 + d_4
\]

(15)

where \( T' \) and \( R' \) are given by:

\[
T' = h_1 - (h_2 - h_1) \left( \frac{d_1}{d_2} \right)
\]

(16)

\[
R' = h_3 - (h_2 - h_3) \left( \frac{d_1}{d_3} \right)
\]

(17)

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

\[
V_2 = H_2 \sqrt{\frac{2}{\lambda} \left( \frac{1}{D_{1(2)}} + \frac{1}{D_{2(2)}} \right)}
\]

(18)

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

\[
H_3 = h_3 - h_2 \left( \frac{d_4}{d_3 + d_4} \right)
\]

(19)

\[
D_{1(3)} = d_3
\]

(20)

\[
D_{2(3)} = d_4
\]

(21)

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

\[
V_3 = H_3 \sqrt{\frac{2}{\lambda} \left( \frac{1}{D_{1(3)}} + \frac{1}{D_{2(3)}} \right)}
\]

(22)

The knife edge diffraction loss due to \( v_t \) is denoted as \( A_t \) and according to ITU-RP 526-13 [28] the knife-edge diffraction loss \( A_t \) is defined as:

\[
A_t = 6.9 + 20 \log \left( \sqrt{\left( \frac{v_t - 0.1}{v_t - 0.1} \right)^2 + 1} + v_i - 0.1 \right)
\]

(23)

The total diffraction loss due to the three knife edge
obstructions (M₁, M₂ and M₃) 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;

\[ A = 6.9 + 20 \log \left( \sqrt{(V - 0.1)^2 + 1} + V - 0.1 \right) \]  \( (24) \)

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

\[ A = 6.9 + 20 \log \frac{m}{d_M} + \frac{1}{4} + V - 0.1 \]  \( (24) \)

Let \( P \) be defined as

\[ P = \frac{10^{(A-6.9) / 20}}{10} \]  \( (25) \)

Also, let \( U \) be defined as

\[ U = V - 0.1 \]  \( (26) \)

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

\[ \sqrt{(U^2 + 1)} + U = P \]  \( (27) \)

Hence,

\[ \sqrt{(U^2 + 1)} = P - U \]  \( (28) \)

\[ U^2 + 1 = P^2 - 2(P)(U) + U^2 \]  \( (29) \)

\[ U = \frac{P^2 - 1}{2P} \]  \( (30) \)

Then

\[ V = \left( \frac{10^{(A-6.9) / 20} - 1}{2 \times 10^{(A-6.9) / 20}} \right) + 0.1 \]  \( (32) \)

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 \( d_{el(x)} \) from the transmitter and at a distance of \( d_{el(x)} \) from the receiver, then, the diffraction parameter, \( V \) is given as;

\[ V = \frac{2(d_{el(x)} + d_{el(x)})}{\lambda d_{el(x)}(d_{el(x)})} \]  \( (33) \)

Then form

\[ h = \frac{V}{\sqrt{(d_{el(x)} + d_{el(x)})/\lambda d_{el(x)}}} \]  \( (34) \)

The Percentage Clearance, \( P_c(\%) \) is given as;

\[ P_c(\%) = \left( \frac{h}{r_{el}} \right) \times 100\% \]  \( (35) \)

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

\[ \Delta_{path} = \left( \frac{r}{2} \right) V^2 \]  \( (36) \)

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

\[ \phi = \left( \frac{\pi}{2} \right) V^2 \]  \( (37) \)

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

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

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 obstructions 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 shows the total diffraction loss of 59.509778 dB as computed by the Giovanelli method. The individual diffraction loss from obstructions M₁, M₂ and M₃ are 13.385693 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 | 5.48797952 |
| Diffraction Parameter, V(j)                                | 0.9180405 | 6.800678 | 1.45039296 |
| Diffraction Loss, A(j) in dB                                | 13.3856983 | 29.59291 | 16.5309693 |
| Total Diffraction Loss, A in dB                            | 59.5095778 | 59.5095778 | 59.5095778 |
| T’                                                          | 6400   | R’     | 7472.2222 |

| Table 4. The Single Knife Edge Equivalent Of The Three Knife Edge Obstructions. |
|------------------------------------|--------|--------|--------|
| Single Knife Edge Diffraction Loss | 59.50958 | Single Knife Edge Radius of First Fresnel Zone |
| G(dB)                              | Fr1    | 8.192985 |
| Single Knife Edge Diffraction Parameter | V    | 213.6239 | P(%)  |
| Single Knife Edge Obstruction Distance | From transmitter | 4475 | Excess path length |
| Single Knife Edge Obstruction Distance | From transmitter | 4475 | The phase difference |
| 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 |
| Percentage Clearance Of The Single Knife Edge Obstruction | Fr1    | 15105.49 |
| Excess path length | Δpath (m) | 342.2368 |
| The phase difference | Φ (radians) | 71692.86 |
| 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 Giovaneli 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.

References


