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Analysis Of The Impact Of Occultation Distance To The Path Length Ratio On The Performance Of Various Approximate Methods For Computing The Radius Of Curvature For Rounded Edge Diffraction

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Abstract— The analysis of the impact of occultation distance to the path length ratio on the performance of various approximate methods for computing the radius of curvature for rounded edge diffraction is presented. Two path profiles were considered, a path with hilly obstruction and another path with plateau obstruction. Empirical method is used to obtain the exact radius of curvature of circle fitted to the apex of each of the two obstructions. Two other approximate methods used to estimate the circle radius based on occultation distance and few other parameters that pertain to the elevation profile of the path are presented along with a parabolic curve fitting method proposed by International Telecommunication Union (ITU). The results from the empirical method showed that the occultation distance of the hilly obstruction is 2,310.76 m whereas the occultation distance of the plateau obstruction about 2.89 times the occultation distance of the hilly obstruction. The ratio of the occultation distance to the path length for the plateau obstruction is 0.92 whereas the ratio of the occultation distance to the path length for the hilly obstruction is 0.3173. Furthermore, the exact radius of the fitted circle for the rounded edge is 23,783.66 m for the hilly obstruction whereas that of the plateau obstruction is 8,740.98. For the various approximate methods considered in the study Mathlab program was used to perform the computation for the two paths at a Ku-band frequency of 12 GHz . In all, the approximate method that is given as $R = \frac{D_{occ}}{\alpha}$ gave the best approximation results in the two path profiles with a maximum of ± 0.20 % estimation error. Similarly, the approximate method that is given as $R = \frac{2(D_{occ})(d1)(d2)}{(\alpha)[(d1^2)+(d2^2)]}$ gave good approximation results in the two profiles with a maximum of ± 3.9 % estimation error. On the other hand, the ITU gave the worst estimation results in the two cases considered; it had -95.24 % estimation error for the hilly obstruction and 21.27% estimation error for the plateau obstruction. This can be explained by the fact that while the other methods are computing the radius of a circle the ITU method is computing the radius of curvature for a parabolic curve. Finally, given the results obtained in this paper, it will be recommended that the ITU method may be used in situations where the rounded edge diffraction loss will be computed using ITU method for rounded edge diffraction loss.

Keywords — Rounded Edge Diffraction , Radius Of Curvature, Path Profile, Path Length , Occultation Distance

I. INTRODUCTION

Nowadays, wireless communication has dominated the various telecommunication technologies [1]. However, the main challenges of wireless communication technologies is attenuation due to free space pathloss [2] , losses due to terrain roughness index [3,4], losses due to rain [5,6] and other atmospheric conditions [7,8], as well as losses due to obstructions [9,10]. In wireless communication systems, obstructions in the signal path can cause diffraction loss [11,12,13,14,15]. Diffraction loss due to the presence of obstructions in the signal path is a common phenomenon but how to effectively determine the value of the diffraction loss the signal is subjected to has been a major challenge. For isolated hilly obstruction, earlier approach employed single knife edge approximation [16,17,18,19,20]. However, subsequently, researchers resorted to rounded edge approximation for isolated hilly obstruction since it was found that the single knife edge approximation underestimates the diffraction loss posed by the hilly obstruction [16,17,21,22] In the computation of rounded edge diffraction loss, one key parameter required is the radius of curvature [23]. As such, some approximate methods have been formulated to compute the radius of curvature for rounded edge diffraction obstructions.

However, the different approximate methods give different values for the diffraction loss [24,25]. Particularly, the disparity among the values obtained from the different approximate methods depends on the shape of the obstruction. In this paper, the different hilly obstruction can be characterized using their occultation distance and the path length ration.

In this case, the path length is the distance between the transmitter and the receiver. The occultation distance is the horizontal distance between the tangent point of the line from the transmitter to the obstruction elevation profile and the tangent point of the line from the receiver to the obstruction elevation profile. The occultation distance indicates how wide is the part of the hilly obstruction that is actually blocking the signal. The ration of occultation distance to the path length is usually higher for plateau than the normal hilly obstruction. Accordingly, in this paper, a path with a hilly obstruction and another path with plateau obstruction are studied. The ration of occultation distance to the path length is determined for the two obstructions and the impact of the ratio on the various approximate radius of curvature methods are examined. The idea presented in this paper is particularly useful in selecting the best radius of curvature approximate method for any given hilly or plateau obstruction.

I. II. Methods For Computing The Radius Of Curvature Of The Rounded Edge Fitted In The Vicinity Of The Obstruction Apex

In order to compute diffraction loss for such obstruction as hills, it is usually modeled as rounded edge obstruction. In that case, the top of the obstruction is considered to be curved in which case a hypothetical circle or curve is fitted in the vicinity of the obstruction apex. There are different methods to fit in the curve for the rounded edge. In practice, some approximation methods can be used to determine a approximate radius. However, the exact radius can also be computed using an empirical method or plane geometry principles. In this case, an empirical method for computing the exact radius of curvature is employed. The exact radius obtained using the empirical method is compared with those obtained using different approximate methods including the ITU parabola fitting method [26,27].

II. A. The Exact Radius Of Curvature Using Empirical Method

Path profile plot for a path with hill obstruction is given in Figure 1. Particularly, Figure 1 is used to explain the empirical approach to determine the exact radius of curvature which is the radius of the circle fitted at the vicinity of the hill apex. Accordingly, the path profile plot in Figure 1 also shows the essential items needed in the empirical method for determination of the radius of curvature for rounded edge diffraction loss. The essential items shown in Figure 1 are the tangent lines from the transmitter and receiver to the path profile plot, the relevant angles and circle fitted at the vicinity of the hill apex, as well as the occultation distance denoted as Docc. Similarly, Figure 2 shows the plateau obstruction path profile plot with the tangent lines, and circle fitted at the vicinity of the apex, as well as the occultation distance.

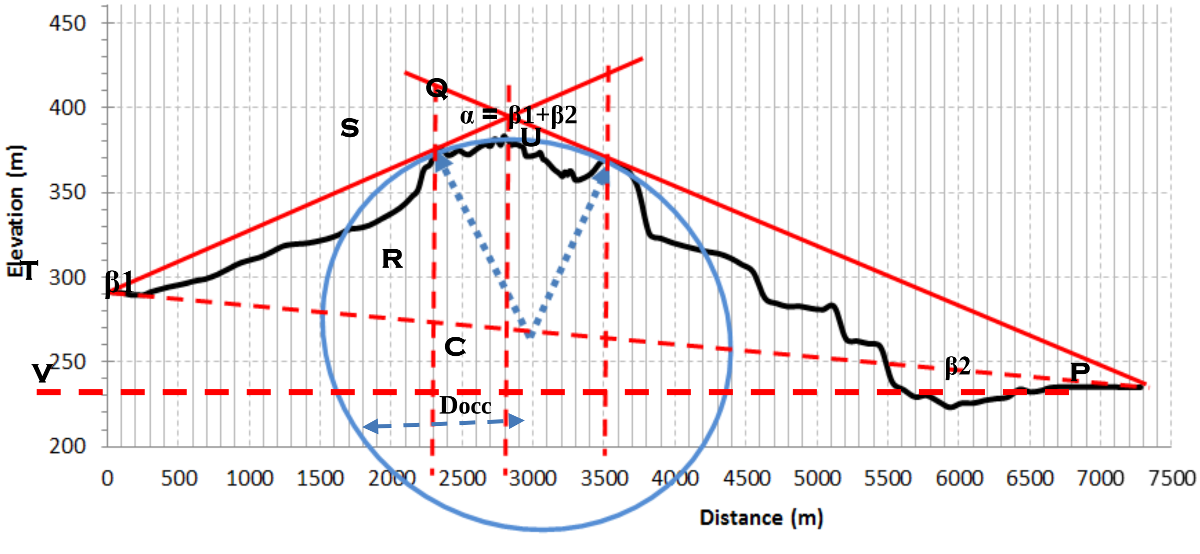

Figure 1Path profile of a hilly obstruction with moderate occultation distance showing the tangent lines, angles and circle fitted at the vicinity of the hill apex

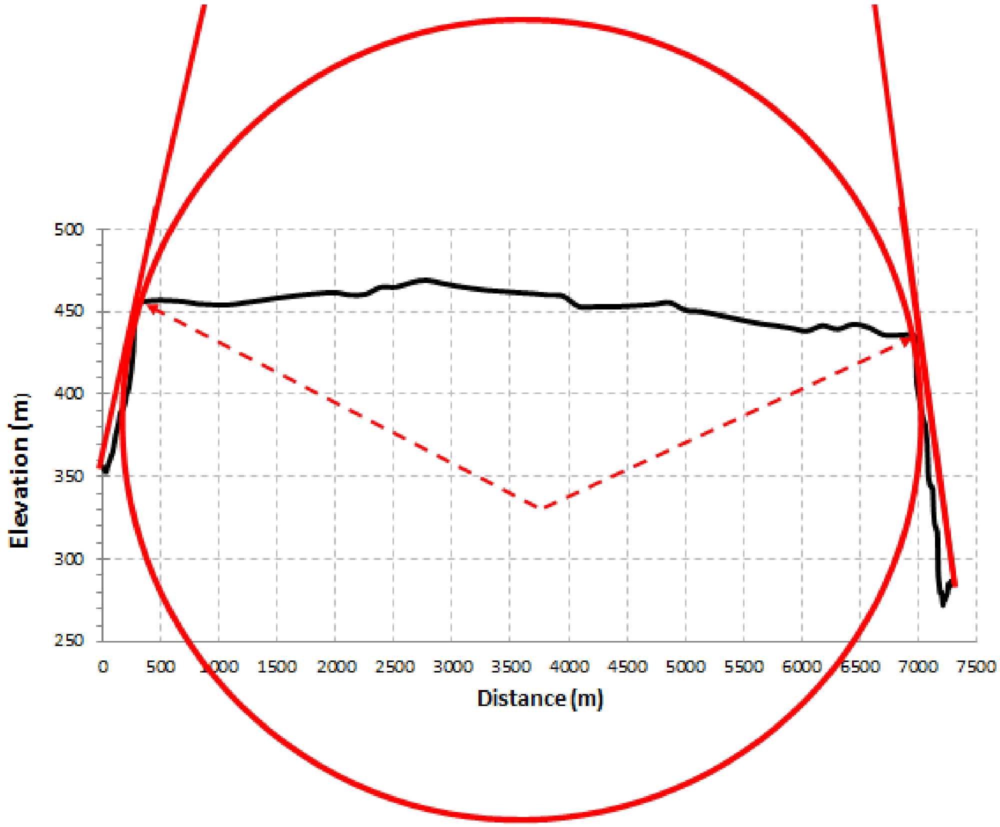

Figure 2 Path profile of a plateau obstruction with very high occultation distance showing the tangent lines and circle fitted at the vicinity of the apex

The procedure for using the empirical measurements to determine the exact radius of curvature and the other relevant parameters are as follows;

1) Draw a lane from the transmitter, T that is tangential to the path profile; in the case of Figure 1 the line is tangential to the path profile at point S.
2) Draw a lane from the receiver, P that is tangential to the path profile; in the case of Figure 1 the line is tangential to the path profile at point U.
3) Measure out the occultation distance, Docc which is the horizontal distance between point S and point U.
4) At point S, draw a line perpendicular to tangential line TS
5) At point U, draw a line perpendicular to tangential line PU
6) The intersection of two perpendicular lines gives the center, C of the circle. Measure the length of line CS or CU and that is the radius , R of the required circle.
7) Use a protractor to measure the relevant angles namely, β1, β2and α.
8) Measure out the path length, D which is the horizontal distance between point T and point P.
9) Determine the ratio of the path length to occultation distance which is given as $\frac{D_{occ}}{D}$.
10) Measure d1 which is the horizontal distance from the transmitter, (T) to the intersection point, (Q) of the two tangents in Figure 1
11) Measure d2 which is the distance horizontal from the receiver, (P) to the intersection point, (Q) of the two tangents.

III. B. Approximate Radius Of Curvature Method I

In this case, the radius of curvature of the round edge fitted in the vicinity of the hill apex is given as [24,25];

$$R = \frac{D_{occ}}{\alpha} \quad (1)$$

Where D_{OCC} is the occultation distance, which is the horizontal distance between point S and point U, andα is the angle between the tangent lines at their point of intersection in the vicinity of the hill apex .

IV. C. Approximate Radius Of Curvature Method II

In this case, the radius of curvature of the round edge fitted to in the vicinity of the hill apex is given as [24,25];

$$R = \frac{2(D_{OCC})(d1)(d2)}{(\alpha)[(d1^2)+(d2^2)]} \quad (2)$$

Where d1 is the horizontal distance from the transmitter, (T) to the intersection point, (Q) of the two tangents in Figure 1 andpointd2 is the distance horizontal from the receiver , (P) to the intersection point, (Q) of the two tangents. So, the sum of d1 and d2 is equal to the path length, D.

V. D. Radius By International Telecommunication Union (ITU) Parabola Curvature Method

The International Telecommunication Union (ITU) proposed the parabolic curve fitting approach [26,27] shown in Figure 3 as well as in equation 3 and equation 4.

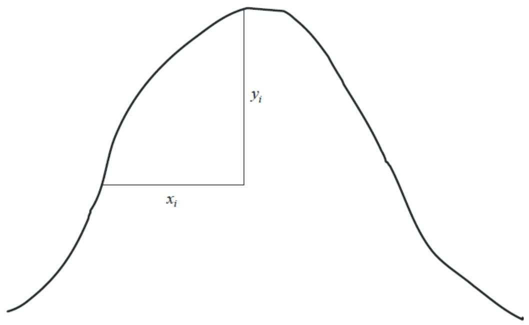

Figure 3The parameters used in the ITU Parabola fitting method

The parabola is fitted to the vicinity of the obstruction apex such that the maximum vertical distance, y_i (from the apex of the obstruction) to be used in the procedure of equation 4 should be not exceed the radius of the first Fresnel zone computed at the location of the obstacle apex.

$$r_i = \frac{x_i^2}{2(y_i)} \qquad (3)$$

For n elevation data points that satisfied the condition that $y_i \leq R_{fr}$, the radius of curvature of the fitted parabolic curve is given by:

$$R = \frac{1}{n}\left[\sum_{i=1}^{i=n}(r_i)\right] \qquad (4)$$

The radius of the first Fresnel zone, R_{fr}in meters is given as ;

$$R_{fr} = 17.32\left(\sqrt{\frac{(d_t)(d_r)}{f(d_t+d_r)}}\right) \qquad (5)$$

d_t = Distance in km from transmitter antenna to the obstruction

d_r = Distance in km from point of obstruction to receiver antenna

f = Frequency in GHz

VI. III. Dataset For The Case Study Path Profiles

In order to examine the impact of occultation distance to the path length ratio on the various radius of curvature methods, two path profiles with different occultation to the path length ratios are considered, as shown in Table 1 and Table 2 as well as in Figure 4 and Figure 5.

Table 1 Path profile data of the hilly obstruction with moderate occultation distance

	Distance (m)	**Elevation (m)**	**Distance (m)**	**Elevation (m)**	**Distance (m)**	**Elevation (m)**	**Distance (m)**	**Elevation (m)**	**Distance (m)**	**Elevation (m)**
	Column 1	**Column 2**	**Column 3**	**Column 4**	**Column 5**	**Column 6**	**Column 7**	**Column 8**	**Column 9**	**Column 10**
1	0.0	355.9	1282.8	389.2	2565.6	456.2	3848.4	453.8	5398.2	382.8
2	42.8	355.1	1325.6	389.7	2608.3	454.8	3891.1	454.5	5463.2	379.7
3	85.5	354.8	1368.3	390.0	2651.1	454.2	3933.9	455.5	5528.2	375.0
4	128.3	354.0	1411.1	390.5	2693.9	454.2	3976.7	451.0	5593.2	369.4
5	171.0	353.1	1453.8	391.3	2736.6	455.4	4019.4	450.1	5658.2	350.8
6	213.8	353.1	1496.6	392.2	2779.4	456.6	4062.2	448.4	5723.2	347.0
7	256.6	353.1	1539.4	393.3	2822.1	458.0	4104.9	446.4	5788.2	344.7
8	299.3	355.0	1582.1	394.7	2864.9	459.2	4147.7	444.4	5853.2	345.0
9	342.1	356.4	1624.9	396.4	2907.7	460.3	4190.5	442.7	5918.2	343.3
10	384.8	357.6	1667.6	398.9	2950.4	461.2	4233.2	441.5	5983.2	342.5
11	427.6	358.7	1710.4	400.7	2993.2	461.8	4276.0	440.0	6048.2	328.5
12	470.4	359.7	1753.1	401.0	3035.9	460.2	4318.7	438.4	6113.3	321.5
13	513.1	360.5	1795.9	401.8	3078.7	460.6	4361.5	441.6	6178.3	319.8
14	555.9	361.5	1838.7	403.1	3121.5	465.0	4404.3	439.5	6243.3	317.9
15	598.6	362.8	1881.4	405.3	3164.2	465.0	4447.0	442.4	6308.3	315.6
16	641.4	363.7	1924.2	407.7	3207.0	467.7	4489.8	440.7	6373.3	290.5

17	684.2	364.4	1966.9	410.2	3249.7	469.2	4532.5	436.1	6438.3	284.8
18	726.9	365.9	2009.7	412.7	3292.5	467.3	4575.3	435.8	6503.3	279.6
19	769.7	367.6	2052.5	415.5	3335.3	465.6	4618.1	435.9	6568.3	280.8
20	812.4	369.9	2095.2	419.1	3378.0	464.2	4683.1	430.5	6633.3	276.4
21	855.2	372.1	2138.0	423.9	3420.8	463.1	4748.1	429.9	6698.3	272.2
22	898.0	374.5	2180.7	428.6	3463.5	462.4	4813.1	407.9	6763.3	275.2
23	940.7	376.4	2223.5	443.5	3506.3	461.7	4878.1	403.9	6828.3	275.2
24	983.5	377.7	2266.3	447.0	3549.1	461.0	4943.1	400.8	6893.4	277.2
25	1026.2	378.9	2309.0	450.0	3591.8	460.1	5008.1	397.4	6958.4	278.5
26	1069.0	380.1	2351.8	451.8	3634.6	459.5	5073.1	393.8	7023.4	279.5
27	1111.8	382.0	2394.5	453.6	3677.3	453.1	5138.1	390.7	7088.4	285.2
28	1154.5	384.1	2437.3	455.4	3720.1	453.0	5203.1	388.3	7153.4	283.2
29	1197.3	386.5	2480.1	456.8	3762.9	452.9	5268.1	386.2	7218.4	284.5
30	1240.0	388.5	2522.8	456.9	3805.6	453.3	5333.1	384.2	7283.4	286.7

The path profile data of Table 1 is used to generate the exact path profile of the hilly obstruction in Figure 4. The exact elevation profile plot of Figure 4 is essential for the empirical method of determining the radius of curvature since the method relies on accurate path profile curves to determine the exact radius of curvature for the rounded edge that will be fitted at the vicinity of the apex of the obstruction.

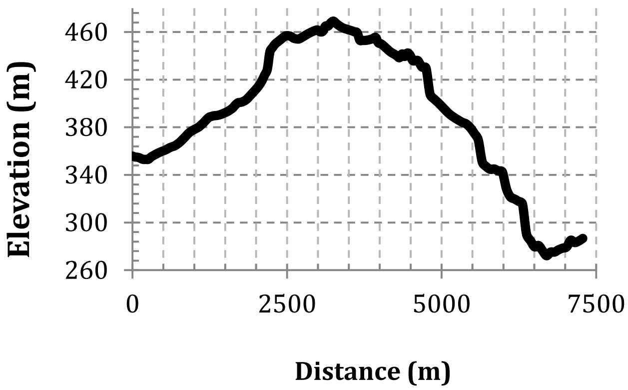

Figure 4 Path profile of a hilly obstruction with moderate occultation distance

Again, the path profile data of Table 2 is used to generate the exact path profile of the hilly obstruction in Figure 5. In this case, the obstruction is a plateau with approximately flat top.

Table 2 Path profile data of the plateau obstruction with very high occultation distance

	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10
1	0.0	355.9	154.2	389.2	685.4	456.2	4608.9	453.8	7056.7	382.8
2	5.1	355.1	159.4	389.7	816.2	454.8	4739.6	454.5	7064.5	379.7
3	10.3	354.8	164.5	390.0	947.0	454.2	4870.4	455.5	7072.4	375.0
4	15.4	354.0	169.7	390.5	1077.8	454.2	5001.2	451.0	7080.2	369.4
5	20.6	353.1	174.8	391.3	1208.5	455.4	5132.0	450.1	7088.0	350.8
6	25.7	353.1	180.0	392.2	1339.3	456.6	5262.8	448.4	7095.8	347.0
7	30.8	353.1	185.1	393.3	1470.1	458.0	5393.5	446.4	7103.6	344.7
8	36.0	355.0	190.2	394.7	1600.9	459.2	5524.3	444.4	7111.4	345.0
9	41.1	356.4	195.4	396.4	1731.7	460.3	5655.1	442.7	7119.3	343.3

10	46.3	357.6	200.5	398.9	1862.4	461.2	5785.9	441.5	7127.1	342.5
11	51.4	358.7	205.7	400.7	1993.2	461.8	5916.7	440.0	7134.9	328.5
12	56.6	359.7	210.8	401.0	2124.0	460.2	6047.4	438.4	7142.7	321.5
13	61.7	360.5	215.9	401.8	2254.8	460.6	6178.2	441.6	7150.5	319.8
14	66.8	361.5	221.1	403.1	2385.6	465.0	6309.0	439.5	7158.3	317.9
15	72.0	362.8	226.2	405.3	2516.4	465.0	6439.8	442.4	7166.2	315.6
16	77.1	363.7	231.4	407.7	2647.1	467.7	6570.6	440.7	7174.0	290.5
17	82.3	364.4	236.5	410.2	2777.9	469.2	6701.4	436.1	7181.8	284.8
18	87.4	365.9	241.7	412.7	2908.7	467.3	6832.1	435.8	7189.6	279.6
19	92.5	367.6	246.8	415.5	3039.5	465.6	6962.9	435.9	7197.4	280.8
20	97.7	369.9	251.9	419.1	3170.3	464.2	6970.7	430.5	7205.2	276.4
21	102.8	372.1	257.1	423.9	3301.0	463.1	6978.6	429.9	7213.1	272.2
22	108.0	374.5	262.2	428.6	3431.8	462.4	6986.4	407.9	7220.9	275.2
23	113.1	376.4	267.4	443.5	3562.6	461.7	6994.2	403.9	7228.7	275.2
24	118.3	377.7	272.5	447.0	3693.4	461.0	7002.0	400.8	7236.5	277.2
25	123.4	378.9	277.6	450.0	3824.2	460.1	7009.8	397.4	7244.3	278.5
26	128.5	380.1	282.8	451.8	3954.9	459.5	7017.6	393.8	7252.1	279.5
27	133.7	382.0	287.9	453.6	4085.7	453.1	7025.5	390.7	7260.0	285.2
28	138.8	384.1	293.1	455.4	4216.5	453.0	7033.3	388.3	7267.8	283.2
29	144.0	386.5	423.8	456.8	4347.3	452.9	7041.1	386.2	7275.6	284.5
30	149.1	388.5	554.6	456.9	4478.1	453.3	7048.9	384.2	7283.4	286.7

The two path profiles have the same value for the path length which is 7283.4 m , the same value for the elevation of the transmitter which is 355.9 m and the same value for the elevation of the receiver which is 286.7 m . However, the two path profiles differ in the location of the maximum elevation and the curvature of the obstruction top. Hence, the occultation distance that will be obtained in each of the two path profiles will differ. The occultation distance can be determined through empirical measurements.

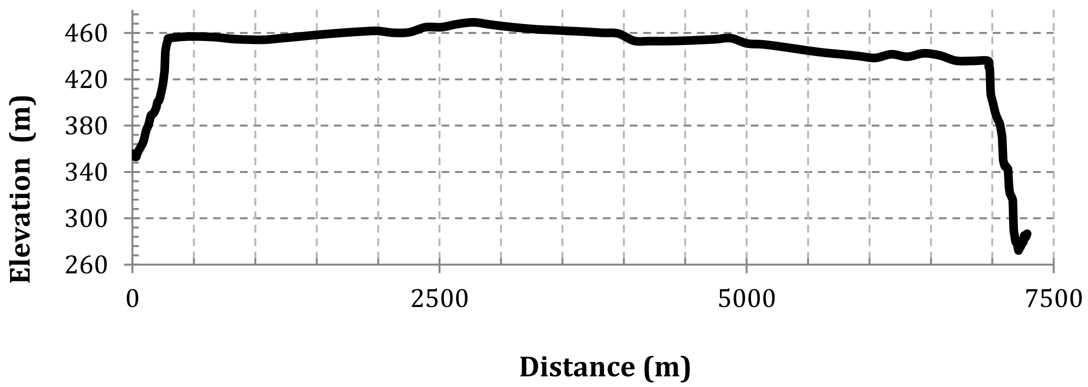

Figure 5 Path profile of a plateau obstruction with very high occultation distance

VII. IV. Result and Discussions

Each of the two path profile datasets was plotted in Microsoft Excel software and the plots were printed. Empirical measurement procedure described in section 2.1 were conducted on the print out to obtain the relevant parameter values for the two path profiles as shown in Table 3. The results in Table 3 shows that the occultation distance of the hilly obstruction is 2,310.76 m whereas the occultation distance of the plateau obstruction is 6,685.49 m . In comparison, the occultation distance of the plateau obstruction is about 2.89 times the occultation distance of the hilly obstruction. The ratio of the occultation distance to the path length for the plateau obstruction is 0.92 whereas the ratio of the occultation distance to the path length for the hilly obstruction is 0.3173. Furthermore, the exact radius of the fitted circle for the rounded edge is 23,783.66 m for the hilly obstruction whereas that of the plateau obstruction is 8,740.98

Table 3 Parameter values obtained from the empirical measurement procedure for the exact radius of curvature for the rounded edge in the two path profiles

S/N	Description	Symbol and unit	Value for the hilly obstruction	Value for the plateau obstruction
1	Path Length	D(in m)	7,283.41	7,283.41
2	Occultation Distance	Docc(in m)	2,310.76	6,685.49
3	The angle (in radians) the tangent line from the transmitter makes with the LOS	β (in radian)	0.0503	0.3369
4	The angle (in radians) the tangent line from the receiver makes with the LOS	α (in radian)	0.0469	0.4295
5	Horizontal distance from the transmitter, (T) to the intersection point, (Q) of the two tangent lines	d1(in m)	3,516.10	4,141.34
6	Horizontal distance from the receiver, (P) to the intersection point, (Q) of the two tangent lines	d2 (in m)	3,767.31	3,142.07
7	Ratio of the occultation distance to thepath length	ε	0.3173	0.92
8	The exact radius of curvature by the empirical measurement method	**R**(in m)	23,783.66	8,740.98

Mathlab program was used to perform the computation for the radius of curvature using the various approximate methods. The computation was done for a Ku-band frequency of 12 GHz which gives a wavelength of 0.025 m. Table 4 shows the radius of curvature obtained with the different methods for the for the path with hilly obstruction while Table 5 shows the radius of curvature obtained with the different methods for the for the path with plateau obstruction.

Table 4 Radius of curvature obtained with the different methods for the for the path with hilly obstruction

	Exact radius of curvature by the empirical method	$R = \frac{D_{OCC}}{\alpha}$	$R = \frac{2(D_{OCC})(d1)(d2}{(\alpha)[(d1^2)+(d2^2}$	ITU Method
Radius of curvature (m)	23,783.66	23,769.22	23,712.73	1,133.19
Percentage of the exact radius of curvature (%)	100	99.94	99.70	4.77
Percentage error with respect to the exact radius of curvature (%)	0	-0.061	-0.30	-95.24
Path and obstruction profile parameters at frequency of 12 GHz				
d(m)	the distance from the transmitter to the receiver			7283.40852
Docc(m)	the occultation distance			2310.76365
$\frac{D_{OCC}}{d}$	Ratio of occultation distance to the path length			0.317264045

In Table 4 and Table 5, the computations were carried out at Ku-band microwave frequency of 12 GHz for paths with path length of 7283.409126 m. The hilly obstruction gave 0.317264045 as the ratio of occultation distance to the path length whereas plateau obstruction gave 0.917906014 as the ratio of occultation distance to the path length. In all, the approximate method in equation 1 given as $R = \frac{D_{OCC}}{\alpha}$ gave the best approximation results in the two profiles with a maximum of ±0.20 % estimation error. Similarly, the approximate method in equation 2 given as $R = \frac{2(D_{OCC})(d1)(d2)}{(\alpha)[(d1^2)+(d2^2)]}$gave good approximation results in the two profiles with a maximum of ± 3.9 % estimation error. On the other hand, the ITU gave the worst estimation results in the two cases considered; it had -95.24 % estimation error for the hilly obstruction and 21.27% estimation error for the plateau obstruction.

Table 5 Radius of curvature obtained by the different methods for the for the path with plateau obstruction

	Exact radius of curvature by empirical method	$R = \frac{D_{OCC}}{\alpha}$	$R = \frac{2(D_{OCC})(d1)(d2)}{(\alpha)[(d1^2)+(d2^2)]}$	ITU Method
Radius of curvature (m)	8,740.98	8,723.18	8,40	10,60
Percentage of the exact radius of curvature (%)	100	99.80	96.11	121.27
Percentage error with respect to the exact radius of curvature (%)	0	-0.204	-3.89	21.27
Path and obstruction profile parameters at frequency of 12 GHz				
d(m)	the distance from the transmitter to the receiver			7283.409126
Docc(m)	the occultation distance			6685.485042
$\frac{D_{OCC}}{d}$	Ratio of occultation distance to the path length			0.917906014

In all, the ITU method gave radius values that are significantly different from the other method . This can be explained by the fact that while the other methods are computing the radius of a circle the ITU method is computing the radius of curvature for a parabolic curve. Finally, given the results obtained in this paper, it will be recommended that the ITU method may be used in situations where the rounded edge diffraction loss will be computed using ITU method for rounded edge diffraction loss.

VIII. V Conclusion

Different methods for computing the radius of curvature of the rounded edge fitted in the vicinity of the obstruction apex of hilly obstruction and plateau obstruction are presented. The empirical method is used to obtain the exact radius of curvature of circle fitted to the apex of the obstruction. Two other approximate methods that are used to estimate the circle radius using occultation distance and a few other parameters that pertain to the elevation profile of the path are presented. Lastly, a parabolic curve fitting method proposed by International Telecommunication Union (ITU)is also presented . Sample path profile data for two path profiles with different occultation to the path length ratios were used in the study. The results showed that the ITU method gives results that are different from the exact radius obtained from the empirical method. The other two methods gave good estimation in the cases studies. It was recommended that the parabolic curvature fitting approach by ITU should be restricted to cases where the ITU method will be used in computing the rounded edge diffraction loss.

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