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Comparative Analysis of the Impact of Frequency on the Radius of Curvature of Single and Double Rounded Edge Hill Obstruction

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Abstract

In this paper, comparative analysis of the impact of frequency on the radius of curvature of single and double rounded edge hill obstruction is studied, particularly when the International Telecommunication Union (ITU) recommendation 526 version 13 method is used to compute the radius of curvature. The study is conducted with two path profiles of microwave links, one with isolated single edged hilltop and a second profile with isolated double edged hilltop. The frequencies considered are from the 1.5 GHz in the L-band to 36GHz in the K-band. The radius of curvature decreases with frequency in the case of single edged hilltop whereas the radius of curvature increases with frequency in the case of double edge hilltop. Essentially, other factors are responsible for determining whether the radius of curvature will increase or decrease with frequency. One of such factors is the occultation distance. For all the frequencies considered, the occultation distance is 80.923 m for the single edged hilltop and 532.203m for the double edged hilltop. Further studies are therefore required to ascertain the factors that determine the exact impact of frequency on the radius of curvature for rounded edge obstructions.

Keywords: Radius of Curvature; Rounded Edge Obstruction; ITU 526-13 Method; Occultation Distance; Double Edged Hilltop; Single Edged Hilltop; Fresnel Zone; Radius of Fresnel Zone

1. Introduction

In wireless communication, propagation paths encounter one or more obstacles which will introduce diffraction loss depending on the extent of the obstruction to the signal path [1-6]. In order to make such calculations it is necessary to idealize the form of the obstacles, either assuming a knife-edge of obstruction with negligible thickness or a thick smooth obstacle with a well-defined radius of curvature at the top [7-11]. Real obstacles have, of course, more complex forms, so knife-edge or rounded edge is approximation of real obstructions.

Studies have shown that diffraction over rounded edge obstruction is more than the diffraction over knife edge obstruction. As such, the diffraction over rounded edge obstruction is a combination of the original knife edge diffraction loss and the excess diffraction loss caused by the rounded edge [12-14]. Over the years, the International

Telecommunication Union (ITU) has developed several versions of the methods for evaluating the effect of diffraction on the received field strength. Particularly, Recommendation ITU-R P.526-13 offers a method of calculating diffraction by both knife-edge or rounded edge obstructions [3,15,16]. In this paper, the diffraction loss over single and double rounded edge hill obstruction is considered. Specifically, the effect of frequency on the ITU 526-13 method-based radius of curvature for single and double rounded edge hilltop is studied. The study became necessary seeing that according to ITU 526-13 method the value of the radius of curvature fitted to the vertex of the obstruction depends on the radius of the first Fresnel zone which is a function of frequency. As such, for a given path profile, the radius of curvature do vary with frequency when the ITU 526-13 method is used. Meanwhile, the diffraction loss over rounded edge is a function of the radius of curvature. This implies that there is additional influence of frequency on the diffraction loss due to the variation in the radius of curvature. In this paper, the radius of curvature for both single and double rounded edge hilltop is computed for various microwave frequency bands. The results are used to demonstrate the possible effect of frequency on the radius of curvature for different kinds of rounded edge hill obstructions.

2. Theoretical Background

2.1. The Rounded Edge Diffraction Geometry

Figure 1 shows the path profile of an isolated hill obstruction. Figure 2 shows the path profile of the isolated hill to which a rounded edge of radius, R is fitted in the vicinity of the hilltop. Tangent line referred to as Tangent 1 is drawn from the transmitter to the path profile at point T1. Another tangent line referred to as Tangent 2 is drawn from the receiver to the path profile at point T2 and extended to intersect the Tangent T1 above the hill vertex. The LOS clearance, h is the height from the LOS to the point of intersection of Tangent 1 and tangent 2, as shown in figure 2 . The occultation distance, D of the obstruction is the distance between T1 and T2. The angle Tangent 1 makes with the LOS is denoted as α_1 while the angle Tangent 2 makes with the LOS is denoted as α_2. The angle the LOS makes with the horizontal is denoted β.The angle β is given as;

$$\beta = tan^{-1}\left(\frac{H_t - H_r}{d}\right) \quad (1)$$

where H_t is the height of the transmitter and H_r is the height of the receiver and d is the distance between the transmitter and the receiver. The values of d, H_t and H_r are obtained from the path profile data. As shown in figure 2 , d_1 is distance from the transmitter to the point where the LOS clearance is measured and d_2 is distance from the receiver to the point where the LOS clearance is measured. Let d be the distance between the transmitter and the receiver, then:

$$d = d_1 + d_2 \quad (2)$$

The angles α_1 and α_2 are obtain by cosine rule as follows;

$$Cos(\alpha_1) = \frac{(S_1)^2 + (S_3)^2 - (S_2)^2}{2(S_1)(S_3)} \quad (3)$$

$$\alpha_1 = Cos^{-1}\left(\frac{(S_1)^2 + (S_3)^2 - (S_2)^2}{2(S_1)(S_3)}\right) (4)$$

Similarly,

$$\alpha_2 = Cos^{-1}\left(\frac{(S_2)^2 + (S_3)^2 - (S_1)^2}{2(S_2)(S_3)}\right) \quad (5)$$

where

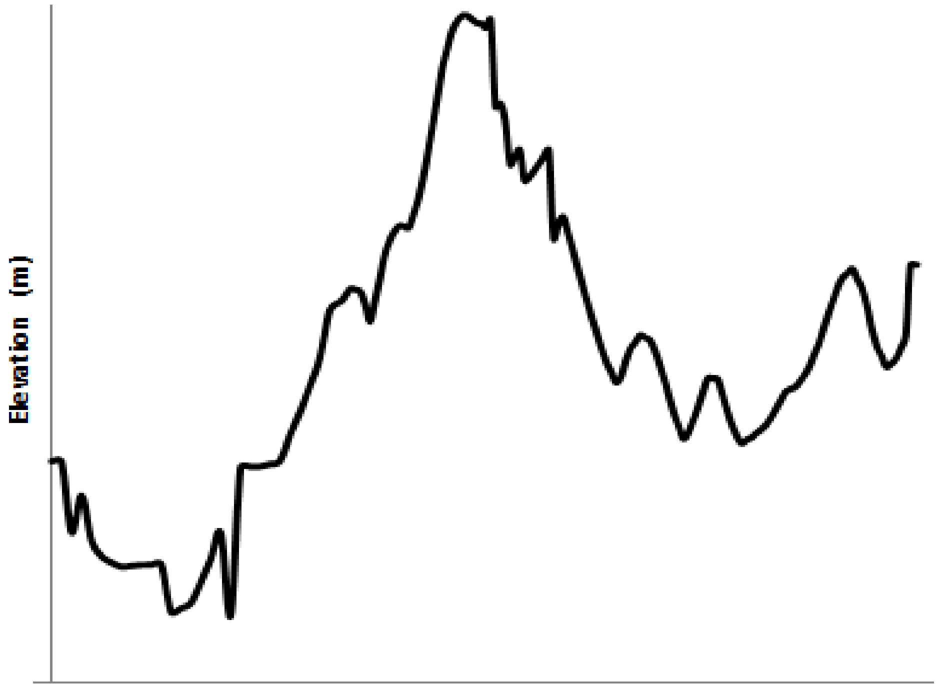

Figure 1: The Path Profile of the Isolated Hill Obstruction

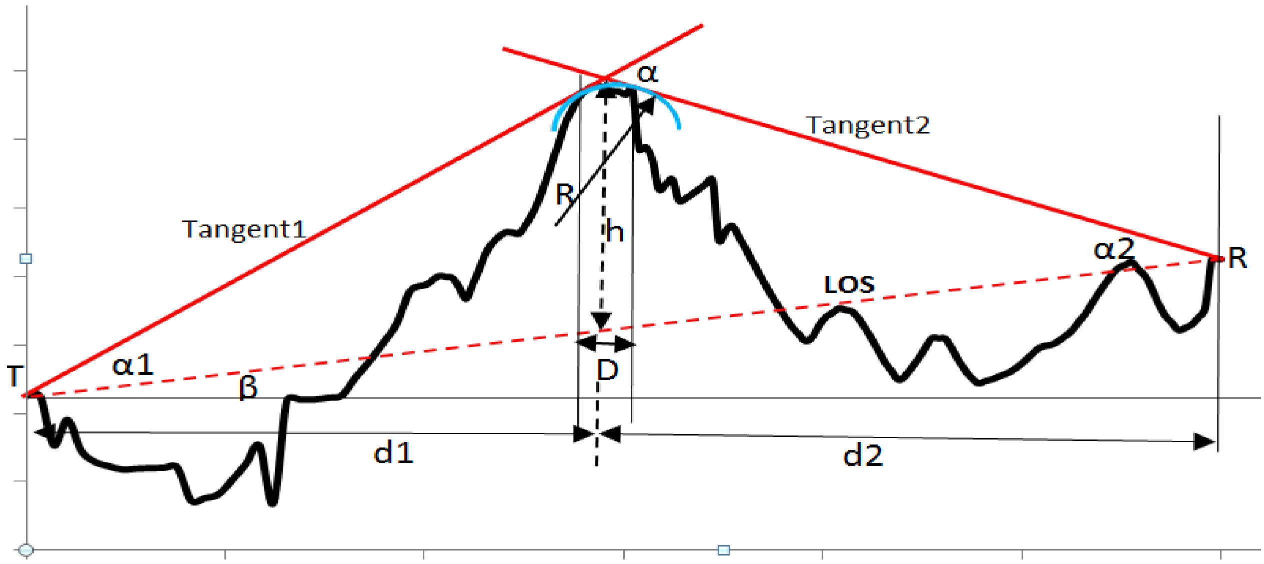

Figure 2: The Path Profile of the Isolated Hill with the Rounded Edge Diffraction Geometry

S_1 is the length of the tangent 1 measured from the transmitter to the point of intersection of tangent 1 and tangent 2, as shown in Figure 2.

S_2 is the length of the tangent 2 measured from the receiver to the point of intersection of tangent 1 and tangent 2, as shown in Figure 2.

S_3 is the length of the LOS measured from the transmitter to receiver

S_1, S_2 and S_3 are in meter and they are measured out from the path profile plot and the tangent line drawn on the path profile .

The angle α is given as:

$$\alpha = \alpha_1 + \alpha_2 \qquad (6)$$

The radius of the first Fresnel zone ($\mathbf{r}_{f1}$) at distance d_1 from the transmitter and d_2

from the receiver is given as:

$$\mathbf{r}_{f1} = \sqrt{\frac{(\lambda(d_1)(d_2))}{(d_1 + d_2)}} \quad (7)$$

where λ is the signal wavelength which is given as:

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

f is the frequency in Hz and c is the speed of light which is $3x10^8$ m/s.

2.2. The ITU Radius Of Curvature Method For The Rounded Edge Hilltop

According to ITU-R 526-13 , the obstacle radius of curvature corresponds to the radius of curvature at the apex of a parabola fitted to the obstacle profile in the vicinity of the top. Let *ri* be the radius of curvature corresponding to the sample *i* of the vertical profile of the ridge [15].

$$r_i = \frac{{x_i}^2}{2(y_i)} \quad (9)$$

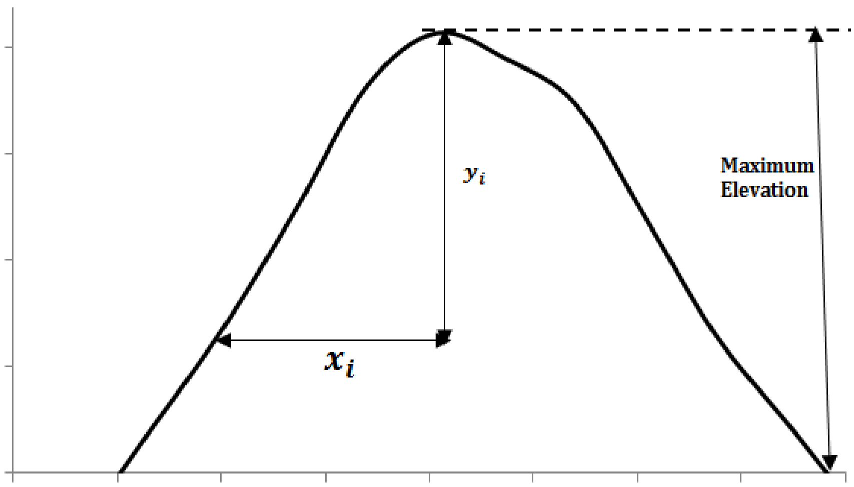

Figure 3: The Geometry of the Vertical Profile of the obstruction used for the determination of the radius of the rounded edge fitted to the vicinity of the obstruction vertex according to ITU Method.

When fitting the parabola, the maximum vertical distance from the apex to be used in this procedure should be of the order of the first Fresnel zone radius where the obstacle is located. As such, in figure 2 and figure 3, the maximum y_i is less or equal to the radius of first Fresnel zone at the point of maximum elevation. In the case of *N* samples, the median radius of curvature of the obstacle is denoted as R where [15]:

$$R = \sum_{i=1}^{i=N}(r_i) = \sum_{i=1}^{i=N}\left(\frac{{x_i}^2}{2(y_i)}\right) \quad (10)$$

According to the ITU-R 526-13 recommendation, from the obstruction apex (in figure 2) the maximum value of y_i should be within the radius of the first Fresnel zone. Essentially:

$$maximum(y_i) \leq \mathbf{r}_{f1} \quad (11)$$

Since $\mathbf{r}_{f1}$ is a function of frequency, it is expected that the frequency will affect the value of the radius or curvature. In this paper, the effect of frequency on the radius or curvature of the rounded edge obstruction is examined.

3. Results and Discussion

The study is conducted with two path profiles of microwave links, one with isolated single edged hilltop and a second profile with isolated double edged hilltop. The frequencies considered are from the 1.5 GHz in the L-band to 36GHz in the K-band.

The path profiles data for the of microwave links with isolated single edged hilltop is given in Table 1while the path profiles data for the of microwave links with isolated double edged hilltop is given in Table 2.

Table 1. The path profiles data for the microwave link with isolated single edged hilltop

Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)
0.0	390.9	1206.9	379.8	2413.8	401.7	3180.8	401.8	4876.1	366.9
40.2	390.9	1247.2	378.0	2454.1	397.3	3201.0	402.7	4921.4	367.5
80.5	390.9	1287.4	377.2	2494.3	401.8	3221.2	402.5	4966.7	368.0
120.7	390.7	1327.6	376.3	2534.5	403.9	3248.1	401.7	5011.9	368.0
160.9	390.7	1367.8	375.0	2574.8	401.8	3288.3	402.0	5057.2	368.0
201.2	390.9	1408.1	374.0	2615.0	402.3	3328.6	401.8	5102.4	368.0
241.4	390.9	1448.3	373.4	2655.2	408.8	3368.8	397.4	5147.7	368.0
281.6	390.4	1488.5	372.9	2695.5	408.9	3835.2	379.8	5193.0	368.5
321.8	389.6	1528.8	373.0	2735.7	411.8	3880.4	380.3	5238.2	369.0
362.1	388.4	1569.0	372.7	2755.9	410.9	3925.7	379.3	5283.5	369.3
402.3	387.5	1609.2	382.0	2776.1	411.7	3971.0	377.9	5328.7	369.4
442.5	386.9	1649.5	381.5	2796.4	412.4	4016.2	376.9	5374.0	368.9
482.8	386.7	1689.7	381.2	2816.6	411.9	4061.5	376.0	5419.3	368.3
523.0	386.7	1729.9	380.5	2836.8	412.4	4106.7	374.9	5464.5	368.0
563.2	386.4	1770.1	379.0	2857.1	412.4	4152.0	373.5	5509.8	367.9
603.5	386.1	1810.4	379.1	2877.3	412.8	4197.2	372.4	5555.0	368.7
643.7	385.6	1850.6	381.3	2897.5	411.7	4242.5	371.5	5600.3	367.5
683.9	385.2	1890.8	384.0	2917.8	410.5	4287.8	371.2	5645.6	366.9
724.2	385.1	1931.1	387.5	2938.0	411.0	4333.0	371.1	5690.8	366.3
764.4	385.4	1971.3	383.8	2958.2	409.2	4378.3	370.7	5736.1	366.4
804.6	385.5	2011.5	387.2	2978.5	398.5	4423.5	370.2	5781.3	366.4
844.8	385.6	2051.8	385.6	2998.7	399.0	4468.8	369.4	5826.6	366.2
885.1	384.6	2092.0	387.5	3018.9	398.7	4514.1	368.3	5871.8	367.1
925.3	383.4	2132.2	389.4	3039.1	398.8	4559.3	367.6	5917.1	366.0
965.5	380.9	2172.5	391.1	3059.4	398.9	4604.6	366.7	5962.4	366.9
1005.8	377.9	2212.7	392.8	3079.6	401.0	4649.8	366.0	6007.6	367.7
1046.0	377.0	2252.9	396.1	3099.8	400.3	4695.1	365.5	6052.9	368.6
1086.2	376.0	2293.1	396.8	3120.1	402.2	4740.4	365.9	6098.1	370.9
1126.5	375.0	2333.4	398.3	3140.3	402.0	4785.6	366.3	6143.4	370.9
1166.7	374.1	2373.6	400.3	3160.5	401.9	4830.9	366.5	6188.7	370.9

Table 2: The path profiles data for microwave links with isolated double edged hilltop

Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)	Distance (m)	Elevation (m)
0.0	390.9	1206.9	379.8	2413.8	401.7	3180.8	411.8	4876.1	366.9
40.2	390.9	1247.2	378.0	2454.1	397.3	3201.0	412.7	4921.4	367.5
80.5	390.9	1287.4	377.2	2494.3	401.8	3221.2	412.5	4966.7	368.0
120.7	390.7	1327.6	376.3	2534.5	403.9	3248.1	411.7	5011.9	368.0
160.9	390.7	1367.8	375.0	2574.8	401.8	3288.3	412.0	5057.2	368.0
201.2	390.9	1408.1	374.0	2615.0	402.3	3328.6	411.8	5102.4	368.0
241.4	390.9	1448.3	373.4	2655.2	408.8	3368.8	407.4	5147.7	368.0
281.6	390.4	1488.5	372.9	2695.5	408.9	3835.2	380.8	5193.0	368.5
321.8	389.6	1528.8	373.0	2735.7	411.8	3880.4	380.3	5238.2	369.0
362.1	388.4	1569.0	372.7	2755.9	410.9	3925.7	379.3	5283.5	369.3
402.3	387.5	1609.2	382.0	2776.1	411.7	3971.0	377.9	5328.7	369.4
442.5	386.9	1649.5	381.5	2796.4	412.4	4016.2	376.9	5374.0	368.9
482.8	386.7	1689.7	381.2	2816.6	411.9	4061.5	376.0	5419.3	368.3
523.0	386.7	1729.9	380.5	2836.8	412.4	4106.7	374.9	5464.5	368.0
563.2	386.4	1770.1	379.0	2857.1	412.4	4152.0	373.5	5509.8	367.9
603.5	386.1	1810.4	379.1	2877.3	412.8	4197.2	372.4	5555.0	368.7
643.7	385.6	1850.6	381.3	2897.5	411.7	4242.5	371.5	5600.3	367.5
683.9	385.2	1890.8	384.0	2917.8	410.5	4287.8	371.2	5645.6	366.9
724.2	385.1	1931.1	387.5	2938.0	411.0	4333.0	371.1	5690.8	366.3
764.4	385.4	1971.3	383.8	2958.2	409.2	4378.3	370.7	5736.1	366.4
804.6	385.5	2011.5	387.2	2978.5	408.5	4423.5	370.2	5781.3	366.4
844.8	385.6	2051.8	385.6	2998.7	409.0	4468.8	369.4	5826.6	366.2
885.1	384.6	2092.0	387.5	3018.9	408.7	4514.1	368.3	5871.8	367.1
925.3	383.4	2132.2	389.4	3039.1	408.8	4559.3	367.6	5917.1	366.0
965.5	380.9	2172.5	391.1	3059.4	408.9	4604.6	366.7	5962.4	366.9
1005.8	377.9	2212.7	392.8	3079.6	411.0	4649.8	366.0	6007.6	367.7
1046.0	377.0	2252.9	396.1	3099.8	410.3	4695.1	365.5	6052.9	368.6
1086.2	376.0	2293.1	396.8	3120.1	412.2	4740.4	365.9	6098.1	370.9
1126.5	375.0	2333.4	398.3	3140.3	412.0	4785.6	366.3	6143.4	370.9
1166.7	374.1	2373.6	400.3	3160.5	411.9	4830.9	366.5	6188.7	370.9

Table 3 and Figure 4 show the ITU radius of curvature and the radius of first Fresnel zone for the rounded edge on a single edged hilltop. Table 4 and figure 5 show the ITU radius of curvature and the radius of first Fresnel zone for the rounded edge on a single edged hilltop. For the single edged hilltop in Table 3 and figure 4 both radius of curvature and the radius of first Fresnel zone decreases with frequency. However, For the double edged hilltop in Table 4 and figure 5 the radius of curvature increases with frequency while the radius of first Fresnel zone decreases with frequency. For the single edged hilltop the occultation distance is 80.923 m for all the frequencies whereas for the double edged hilltop the occultation distance is 532.203m for all the frequencies considered in the study.

Table 3: The ITU Radius of Curvature for the Rounded Edge on a Single Edged Hilltop

f (GHz)	R (m) By ITU Method	Radius of First Fresnel Zone (m)
1500	5519.47	19.50748
3000	4657.1	13.79387
6000	3888.72	9.75374
12000	3677.88	6.896936
24000	3677.88	4.87687
36000	3677.88	3.981948

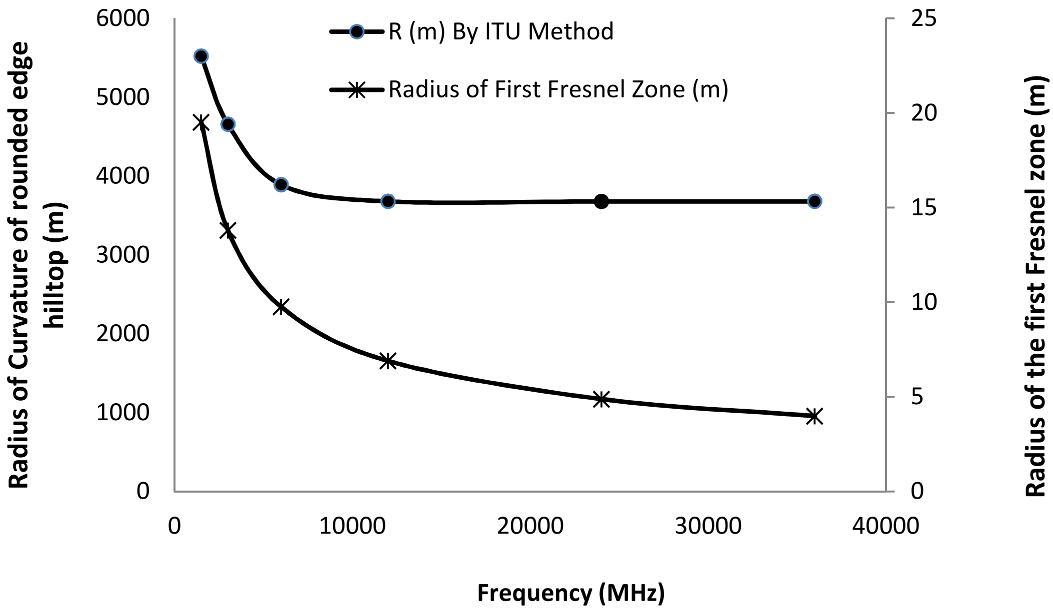

Figure 4: The ITU Radius of Curvature and Radius of First Fresnel Zone for a Single Edged Hilltop

Table 4: The ITU Radius Of Curvature For The Rounded Edge On A Double Edged Hilltop

f (MHz)	R (m) By ITU Method	Radius of First Fresnel Zone (m)
1500	36975.97	20.05594
3000	40734.97	14.18169
6000	46206.97	10.02797
12000	47526.22	7.090847
24000	48379.92	5.013986
36000	50064.92	4.093902

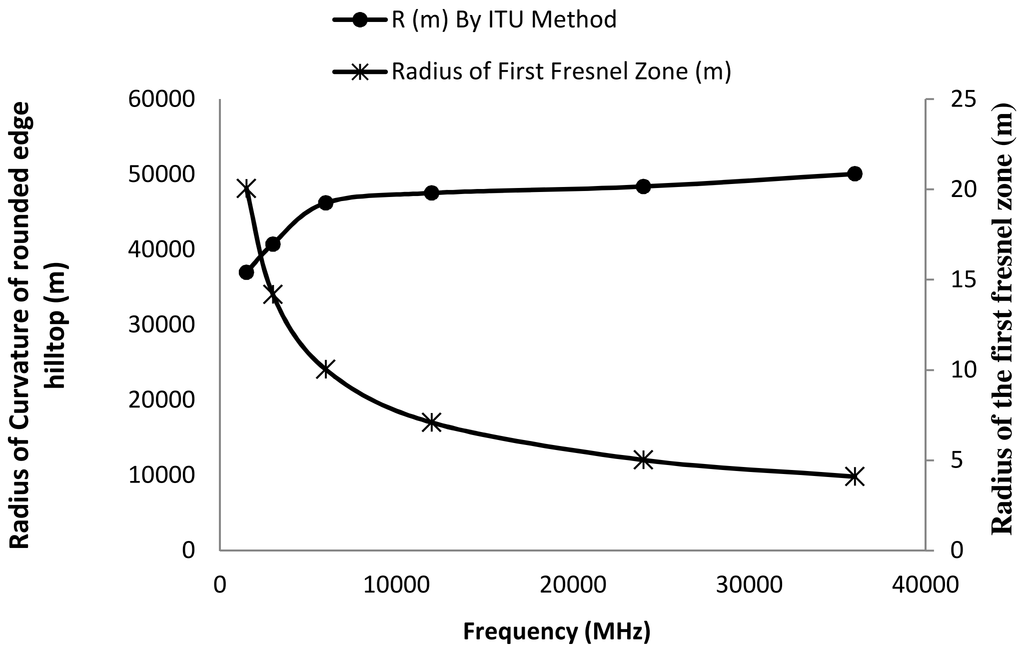

Figure 5: The ITU Radius of Curvature and Radius of First Fresnel Zone for a Double Edged Hilltop

4. Conclusion

The effect of frequency on the radius of curvature for rounded edge obstruction when the ITU 526-13 method is used to compute the radius of curvature . The results show that the radius of curvature for the rounded edge obstruction varies with frequency when the ITU 526-13 method is used to compute the radius of curvature. Particularly, the radius of curvature decreases with frequency in the case of single edged hilltop whereas the radius of curvature increases with frequency in the case of double edge hilltop. Essentially, other factors are responsible for determining whether the radius of curvature will increase or decrease with frequency. One of such factors is the occultation distance. Further studies are therefore required to ascertain the factors that determine the exact impact of frequency on the radius of curvature for rounded edge obstructions.

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