BSA Technical Information

Effect of Obstructions on RF Signal Propagation

Radio path clearance between antennas is an essential criterion for any point-to-point communication system, and is one critical element of propagation conditions of a mobile communication system. If a fairly large object exists in the radiation path between two antennas, reduced received signal strength will occur because the radio link relies increasingly on energy diffracted around the obstructing object, rather than direct (line-of-sight) radiation. We can analyze this situation quite easily using the concept of Fresnel zones.

Fresnel zone analysis applies to the situation where the obstruction is quite large – a large building, smokestack, church steeple, etc. However, the obstruction must be far enough from either antenna such that the electrical characteristics of the antennas are unchanged – the obstruction does not distort the far field antenna pattern or the return loss of either antenna. Other electromagnetic simulations must be performed if the obstruction (mounting pole, other antennas, etc.) is close enough to either antenna to distort the antenna pattern, return loss, port-to-port isolation, or other electrical parameter of the antenna.

Diffraction allows radio signals to propagate behind obstructions. Although the received signal strength decreases rapidly as a receiver moves deeply into the obstructed (shadowed) region, the diffraction field still exists and often has sufficient strength to produce a useful signal.

The phenomenon of diffraction can be explained by Huygen's principle, which states that all points on a wavefront can be considered as point sources for the production of secondary wavelets, and that these wavelets combine to produce a new wavefront in the direction of propagation. Diffraction is caused by the propagation of secondary wavelets into a shadowed region. The field strength of a diffracted wave in the shadowed region is the vector sum of the electric field components of all the secondary wavelets in the space around the obstacle.[1]

Fresnel zones represent successive regions where secondary waves have a path length from the transmitter to receiver which are $n\lambda$ greater than the total path length of a line-of-sight path. Figure 1 shows a transparent plane located between a transmitter and receiver. The concentric circles on the plane represent the origin points of secondary wavelets which propagate to the receiver such that the total path length increases by $\lambda 2$ for successive circles. These circles are the boundaries of the Fresnel zones. The successively Fresnel zones have the effect of alternately providing constructive and destructive interference to the total received signal. The radius of the *n*th Fresnel zone circle is denoted by R_n and can be expressed in terms of n, λ, d_1, and d_2 by

$$R_n \approx \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \qquad (1)$$

This approximation is valid for $d_1, d_2 >> R_n$.[1]

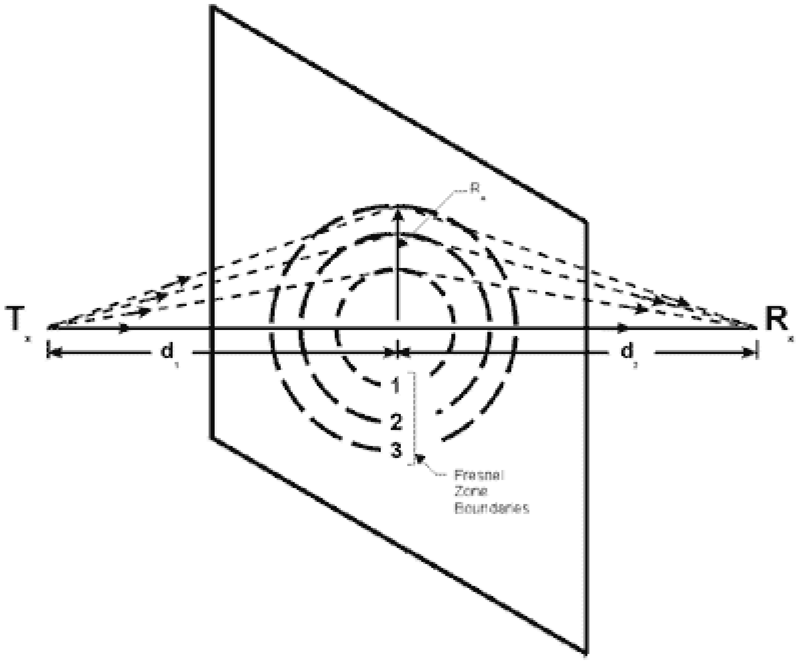

Figure 1: Fresnel Zone Boundaries

A diagram of a typical radio path showing this radius is shown in Figure 2.

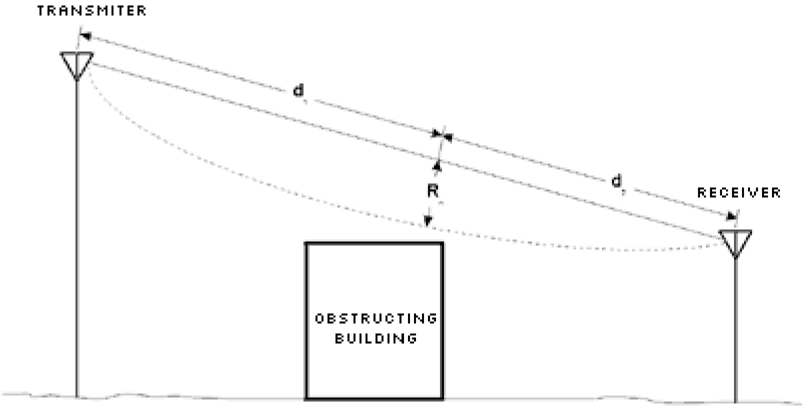

Figure 2: Obstructed Radio Path

The primary energy of the propagation wave is contained in the first Fresnel zone (n=1). In a point-to-point communication system it is desirable to have a clearance radius of at least 0.6 times the first Fresnel zone radius so that the path attenuation will approach free space loss. Note that this radius occurs in three dimensions – not only above and below the direct path between the two antennas, but from side-to-side also.[2]

Equation 1 can be easily evaluated for a typical case. The clearance radius required will vary depending on where the obstruction occurs within the radio path. The required clearance will be greatest if the obstruction occurs exactly halfway between the two antennas. If our operating frequency is 1.9 GHz, and the total path length is two miles, we can plot the required clearance, as shown in Figure 3.

Figure 3: 60% Fresnel Zone Clearance for 2-Mile 1900 Mhz Path

An important note here is that the required clearance does not truly become zero at the ends of the radio path, as the equation seems to indicate. Rather, the true clearance required is approximately equal to half the largest antenna dimension.

This type of analysis can also be used to analyze the situation of roof mounted antennas, when the antenna must be set back a considerable distance from the roof edge. This is shown in Figure 4.

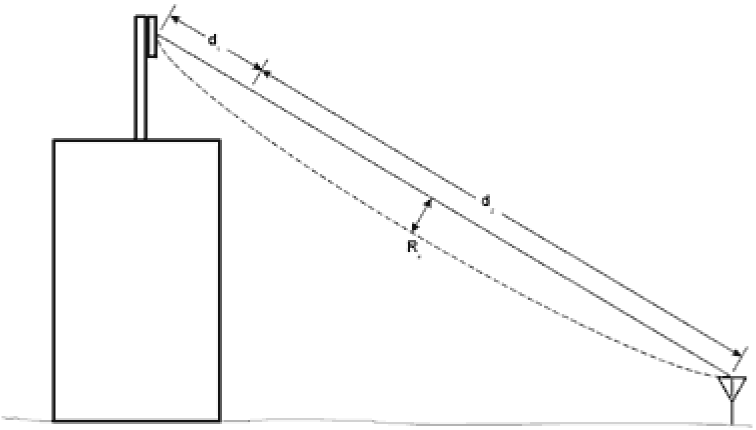

Figure 4: Roof Mounted Antenna

Again, R_n was evaluated for 1.9 GHz over a 500 foot total path length. The required clearance is plotted in Figure 5. Keep in mind that this required clearance must be used only to ensure essentially line-of-sight free space loss characteristics for the link. If sufficient signal margin is available, additional signal loss may be acceptable, and the antenna can be set further back from the building edge.

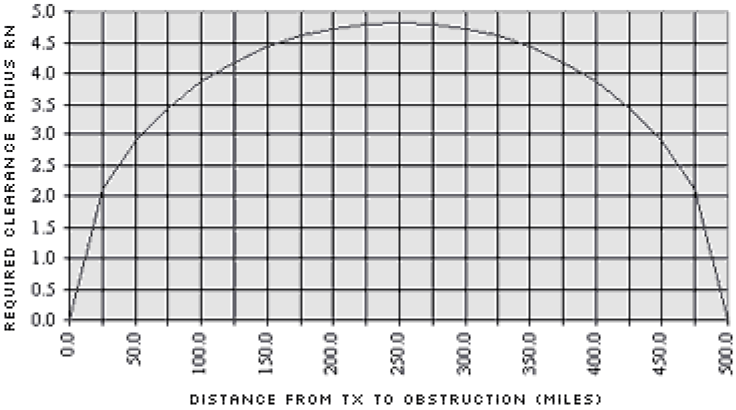

Figure 5: 60% Fresnel Zone Clearance for 500 Feet 1900 Mkz Path

This analysis can be carried further to predict the actual diffraction gain present, depending on the location and the height of the obstruction. If we model the obstruction in the propagation path as a knife-edge (which is a popular way of dealing with these types of problems), we can find the Fresnel diffraction parameter *v* as (ref. Rapport, ref. 1):

$$v = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}} \tag{2}$$

where *h* = the distance from the straight-line propagation path to the tip of the obstruction, as shown in Figure 6. Note that *h* is *negative* (< 0) if the obstruction tip does *not* protrude into the propagation path. Or, *h* = 0 if the obstruction tip is tangent with the propagation path. Otherwise, *h* is positive (> 0).

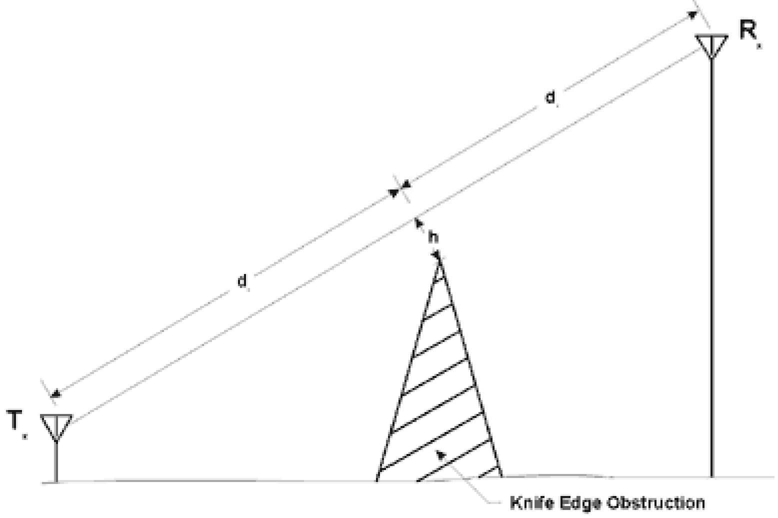

Figure 6: Knife Edge Obstruction Model

Then we can find the diffraction gain G_d, in dB, due to the obstruction by using the graph (from Rappaport, Ref. 1) in Figure 7.

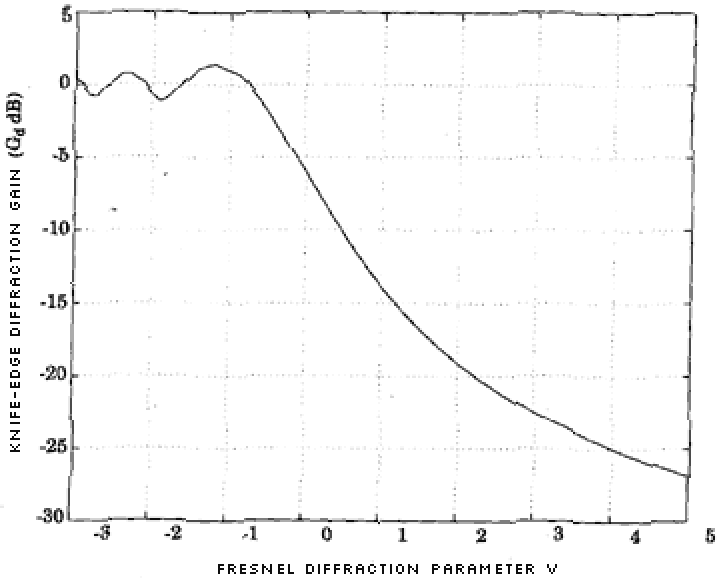

Figure 7: Diffraction Gain as a function of Fresnel Diffraction Parameter

To see how this method works, let us return to the example of the antenna mounted on a building roof, but set back from the roof edge, as shown in Figure 4. Again, we assume that the path is 500 feet long. If we let the obstructing building edge occur 75 feet from the base station antenna, we can estimate the amount of diffraction gain caused by the building blockage. This blockage will vary depending on the height of the antenna mounting pole and its distance from the roof edge. At 1900 MHz, we find n from Equation (2) for different values of h as defined in Figure 6 (Table 1):

Table 1: Fresnel Diffraction Parameter for Building Edge Problem

h (Clearance, ft.)	n (Fresnel Diffraction parameter)
-10	-2.46
-9	-2.21
-8	-1.97
-7	-1.72
-6	-1.48
-5	-1.23
-4	-0.98
-3	-0.74
-2	-0.49
-1	-0.25
0	0.00
1	0.25
2	0.49
3	0.74
4	0.98
5	1.23
6	1.48
7	1.72
8	1.97
9	2.21
10	2.46

Finally, we estimate the diffraction gain from Figure 7 and plot the results in Figure 8:

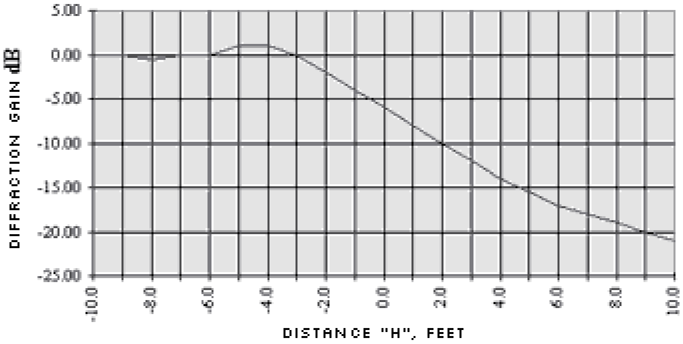

Figure 8: Diffraction Gain Caused by Building Edge

Notice that we are referring to "Diffraction Gain". That is, when the gain is negative, signal attenuation is occurring. Equation (1) can be used to see that the first Fresnel zone radius for this case is 5.75 feet. If we allow the recommended 0.6 times the first Fresnel zone radius, or 3.5 feet, we can locate this point on the graph in Figure 8 above (remember that h = -3.5 feet here, since the building edge *does not* protrude across the radio path). Indeed, the diffraction gain is nearly exactly zero dB. But, notice that as the building edge is placed closer and closer to the center of the radio path, the attenuation increases quite rapidly. If the building edge is just tangent to the path center, the attenuation is about 6 dB.

References:

1. Rappaport, Theodore S., Wireless Communications: Principles and Practice, Prentice Hall, 1996, pp. 90—94.
2. Smith, Clint, and Gervelis, Curt, Cellular System Design and Optimization, McGraw-Hill, 1996, pp. 53—55.