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APPLICATION NOTE

Line of Sight Obstruction

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Line of Sight Obstruction

1. Introduction

One of the Golden Rules of RF link design is to ensure an unobstructed line of sight (LOS) between transmitting and receiving antennas. This may seem intuitively obvious, but what exactly is LOS and what is meant by an unobstructed LOS?

Electromagnetic (EM) energy will radiate from an antenna and propagate through space as a sequence of ever-expanding, spherical wavefronts. Depending on the particular type of antenna, energy may be radiated equally in all directions or may be preferentially concentrated or “directed” into a chosen direction. The classic analogy is the light from a candle, illuminating in all directions, versus the focused beam of a flashlight. Radio signals and light waves are each manifestations of EM radiation, differing chiefly in frequency. In either case, the expanding wavefront will illuminate an angular area that increases with the distance from the source.

Some portion of the EM wavefront will follow the shortest direct path between transmitting and receiving antennas, and this direct path is often referred to as the line-of-sight path of propagation. From the perspective of the receiving antenna, this direct path contains the bulk of the received signal, but an obstacle need not block the direct path of propagation to have some effect on the level of the received signal. Therefore, to be considered as being unobstructed, the LOS path, as well as some minimum volume of space normal to this path, must be free of obstructions. It is precisely this condition that defines line-of-sight propagation. The required keep-out area adjacent to the LOS path is defined via the concept of Fresnel zones (pronounced, fray-nel) and will be discussed subsequently.

Physical elements along the path of propagation, such as buildings, metallic structures, or even the surface of the intervening terrain (particularly, bodies of water), can cause some portion of the propagating wavefront to be reflected. Should the reflected wavefront arrive at the receiving antenna coincident with the LOS wavefront, the effect could be an increase or a decrease in the received signal level. The signal level resulting from the combination of the two wavefronts will be equal to the vector sum (phase and amplitude) of the electric fields. If the wavefronts are equal in amplitude but phase shifted by 180° (or some multiple of one-half wavelength) as shown in FIGURE 1-1 , the wavefronts will sum to zero and no signal will be received. Conversely, if the wavefronts arrive inphase (a zero phase shift or some multiple of a whole wavelength), there will be an increase in the received signal level relative to the signal derived from the LOS path alone.

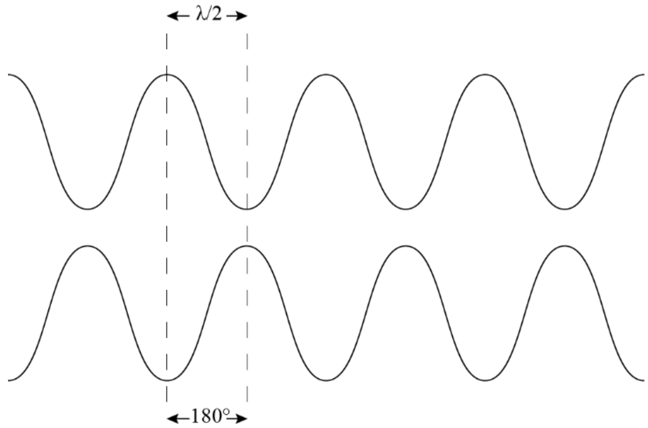

FIGURE 1-1. Wavefronts with 180° Phase Shift

This phenomenon is referred to as *multipath reception* and is illustrated schematically in FIGURE 1-2. From this, it is clear that the reflected wavefront travels a longer distance to reach the receiving antenna than the LOS wavefront. The difference in the direct path length and the reflected path length is referred to as the *excessive path length*. The total phase difference between direct and reflective wavefronts is equal to the phase shift due to the *excessive path length* plus any phase shift induced in the reflected wavefront at the point of reflection. The signals will sum at the receiving antenna constructively or destructively depending on the total phase difference.

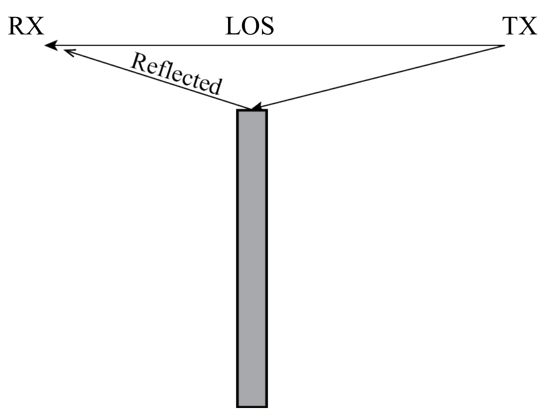

FIGURE 1-2. Multipath Reception

The reflection mechanism for propagating EM wavefronts is very complex and the resultant changes to the amplitude and phase of the reflected wavefront are dependent on a number of variables. The primary factors include the frequency of the propagation wavefront, the angle of incidence, the conductivity of the reflecting surface, and the polarization (vertical or horizontal) of the incident wavefront.

Loss in the reflected wavefront is attributable to a portion of the incident energy being transmitted into (refracted) or absorbed by the reflecting material. The electrical properties of the reflecting material (permittivity, permeability, and conductance) and, to a lesser degree, the frequency of the wavefront are the primary factors determining the change in amplitude of the reflected wavefront.

Phase shift in the reflected wavefront is primarily a function of the electric-field polarization of the incident wavefront and the angle of incidence. In summary, horizontally polarized wavefronts will always exhibit at least 180° of phase shift at the point of reflection, while vertically polarized wavefronts are phase shifted only for an angle of incidence that is less than 30°.

When the direct LOS path is totally obstructed, as shown in FIGURE 1-3, diffraction becomes the dominant propagation mechanism for wavefronts reaching the receiving antenna and the loss, relative to an unobstructed LOS, will be significant.

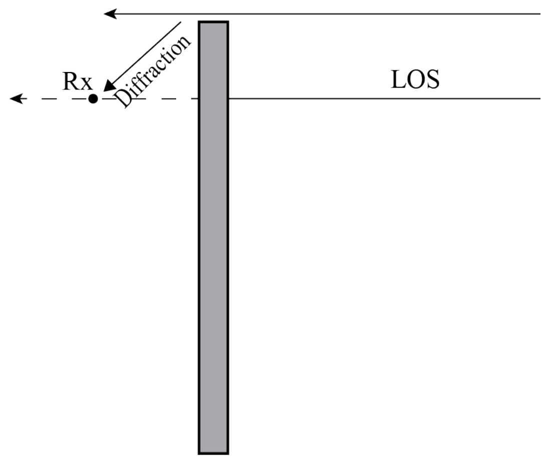

FIGURE 1-3. Totally Obstructed LOS

The diffraction or bending of EM wavefronts around an obstacle is explained by the Huygens-Fresnel Principle, which states, in essence, that every point on the plane of an EM wavefront acts as a point source of secondary wavelets radiating in the direction of propagation. If a knife-edge type obstruction is located adjacent to a wavelet source, a portion of the wavefront will propagate into the shadow region behind the obstruction. This is graphically illustrated in FIGURE 1-4. The field strength at a point located in the shadow region is equal to the vector sum of the electric fields arriving from all of the secondary sources. A receiver located in the shadow region may still be presented with a viable signal, albeit greatly attenuated. As will be shown, the signal level will depend largely on the path geometry.

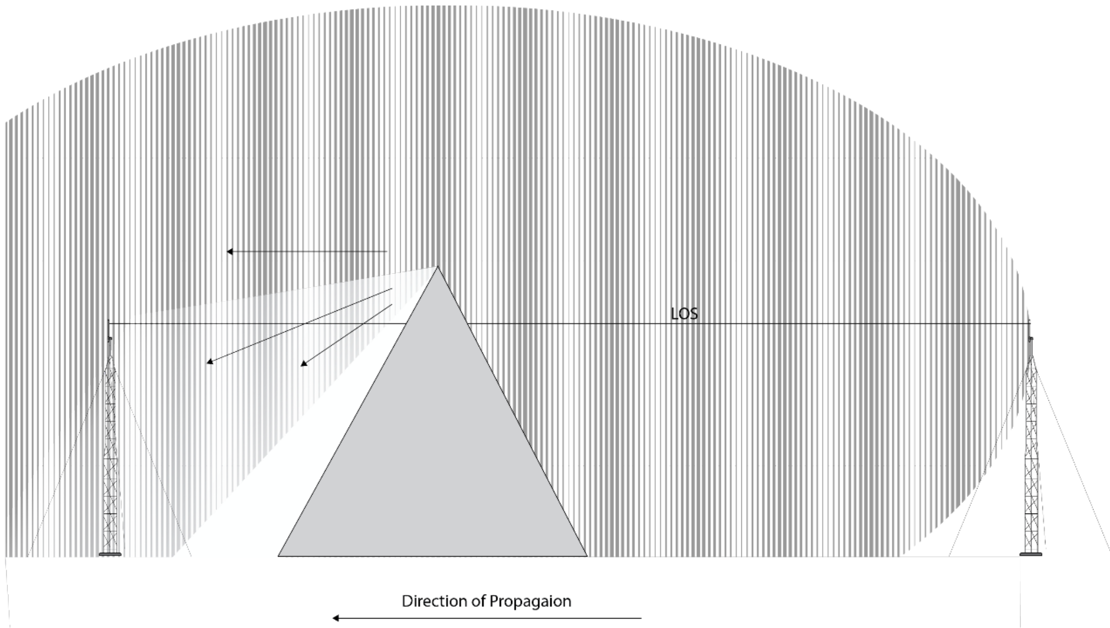

FIGURE 1-4. Knife-Edge Type Obstruction

2. Fresnel Zones

The vertical line in FIGURE 2-1 represents the leading edge of a propagating EM plane wave at a point in time. The rays represent paths passing through potential points of reflection or diffraction on the wavefront and converging on the receiving antenna. The points are chosen such that the excess path length of the associated ray is equal to a multiple of one-half wavelength ($\lambda/2$). The center ray represents the direct LOS path. If we let the vertical distance of each point from the LOS path represent the radius of a circle whose circumference is tangent to that point, we have described a number of concentric, but mutually exclusive, areas about the LOS path called Fresnel zones.

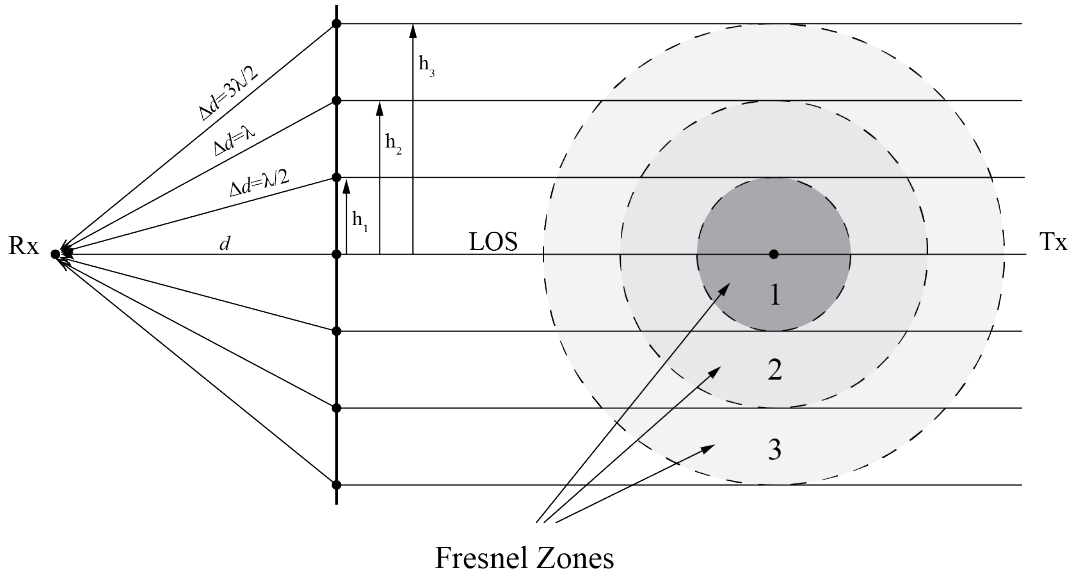

FIGURE 2-1. Fresnel Zones

In theory, there are an infinite number of Fresnel zones about a given point, but it is the first (inner-most) Fresnel zone that defines the critical keep-out area for an unobstructed LOS.

For obstacles that intrude into the first Fresnel zone but do not block the LOS path, it is the constructive or destructive interference from the reflected wavefront that is of concern. Bear in mind that a Fresnel zone constitutes a three-dimensional area, so obstructions can intrude from above, below, or from the sides of the LOS path. An obstruction at the outer boundary of the first Fresnel zone will give rise to a relative phase shift of 180° due to the excess path length of one-half wavelength. With an additional 180° shift induced at the point of reflection, the total relative phase shift will be a whole wavelength and the wavefronts will sum constructively; with as much as a 6 dB gain in received signal level. As the obstruction moves further into the Fresnel zone, the phase shift will decrease in proportion to the decreasing excess path length and the obstacle-induced phase shift will be become the dominant factor. An intrusion into the inner most area of the first Fresnel zone will result in a decrease or *fading* of the received signal level. At the point where the obstruction becomes tangent to the LOS path, signal losses will be as much as 6 dB or more. Best practice is to maintain at least 60% of the first Fresnel zone radius free of obstructions to avoid fading of the received signal.

When an obstacle in the path of propagation blocks the direct LOS path, the results can be catastrophic. Any signal reaching a receiving antenna located in an obstacle's shadow depends heavily on the shape of the obstacle. For smooth, rounded surfaces, such as the top of a grassy hill, the signal could be totally obliterated. On the other hand, if the obstacle exhibits a sharp, knife-edge type profile, some portion of the wavefront could be diffracted around or over the obstacle; such is the case with some forested or rocky mountain tops. As has been said, the level of diffracted signal reaching the receiving antenna depends on the path geometry; the relative height of the obstacle above the direct LOS path, and the location of the obstacle along the path of propagation.

3. Fresnel Zone Clearance

FIGURE 3-1 illustrates the effective ellipsoid shape—the radius will be maximum at the midpoint of the path—traced by the first Fresnel zone radius at successive points along the path of propagation.

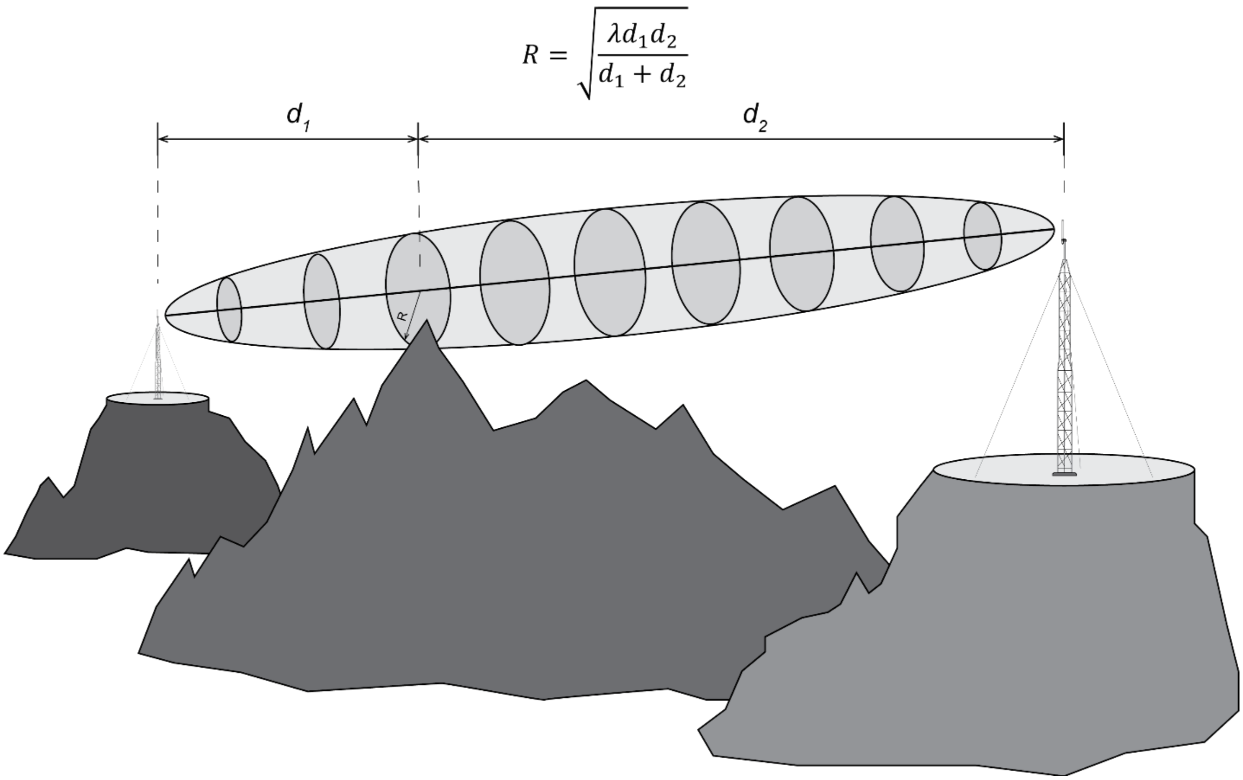

FIGURE 3-1. Effective Ellipsoid Shape

For a point at a given distance along the path of propagation, the radius of the first Fresnel zone, R_{FFZ}, can be determined from the equation:

$$R_{FFZ} = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}} \tag{3-1}$$

Where:

R_{FFZ} is the radius of the first Fresnel zone in meters.

λ is wavelength of the propagating signal in meters.

d_1 is the distance in meters of the point from one end of the path.

d_2 is the distance in meters of the point from the opposite end of the path.

Wavelength is related to the frequency of the propagating signal by:

$$\lambda = \frac{c}{f} \tag{3-2}$$

Where:

f is the frequency in megahertz (MHz).

c is the speed of light in meters per second ($299.792 \bullet 10^6$ m/s).

To determine whether or not the first Fresnel zone radius at some point along the path of propagation is free of obstructions, one must construct a path profile that accurately depicts the location and elevation of potential obstructions. FIGURE 3-2 shows the path profile of an RF link traversing uneven terrain containing a knife-edge type obstruction.

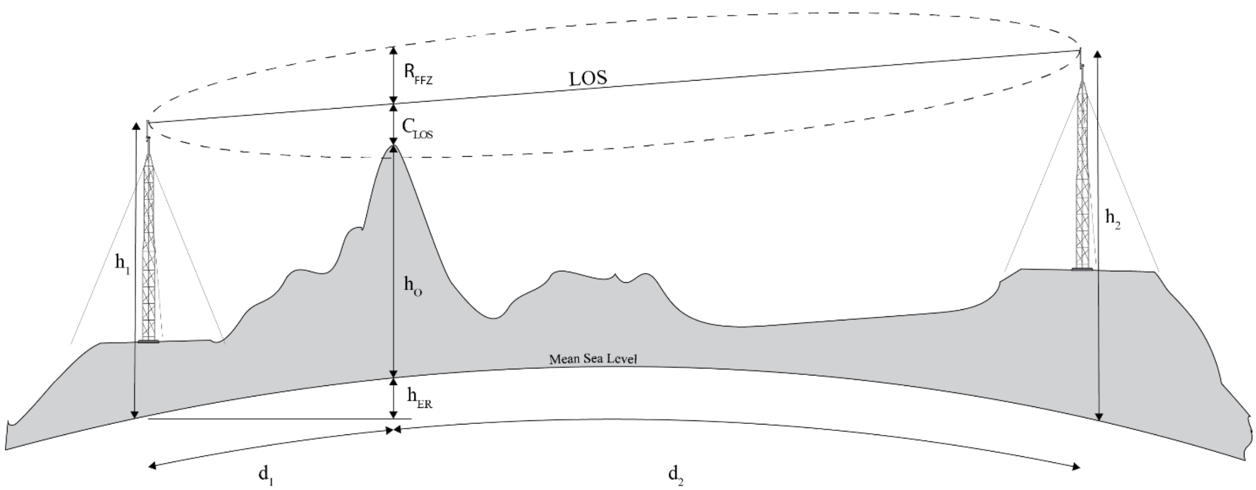

FIGURE 3-2. Path Profile Traversing Uneven Terrain with Knife-Edge Obstruction

Where:

LOS is the direct LOS path of propagation between the link's antennas.

R_{FFZ} is the radius of the first Fresnel zone at the location point.

C_{LOS} is the LOS clearance relative to the obstruction.

h_1 is the antenna height in meters associated with distance, d_1.

h_2 is the antenna height in meters associated with distance, d_2.

h_O is the height in meters of the obstruction.

d is the total path distance ($d_1 + d_2$) in kilometers.

h_{ER} is the height in meters of surface curvature at the location point as a result of the *effective earth radius*.

NOTE All heights are relative to mean sea level. Unless otherwise noted, all heights are in meters, and all distances are in kilometers.

4. Effective Earth Radius

It could be reasonably assumed that the direct LOS path of propagation follows a straight line; such as shown in our path profile. The reality is that the refractive properties of the earth's atmosphere can cause the path to bend slightly toward or away from the earth's surface. This curved path makes the determination of adequate obstacle clearance problematic—prior to computerized propagation models, path profiles were drawn by hand on paper. To allow for a straight-line path of propagation, a correction factor, *k*, is applied to the earth's radius; in effect, increasing or decreasing the surface curvature to compensate for the refracted path. This corrected radius is called the *effective earth radius*.

The *k-factor* used to derive the *effective earth radius* is a function of the atmosphere's refractive index. For a non-refractive atmosphere, in which the path of propagation is a straight line, $k = 1$. For the more realistic atmosphere where the path of propagation is refracted towards the surface, $k > 1$. In the rare case where the path of propagation is refracted away from the surface, generally associated with a coastal sea adjacent to a large desert, $k < 1$. Values of *k* will vary by geographical region, time of year, and local weather conditions. In lieu of specific data, propagation models utilize a standard atmosphere where the *k-factor* is defined as: $k = 1.33$.

The height of surface curvature at a given point along the path of propagation as a result of the *effective earth radius* is given by:

$$h_{ER} = \frac{d_1 \cdot d_2}{12.74 \cdot k} \tag{4-1}$$

The LOS clearance relative to the obstruction, C_{LOS}, can be calculated as follows:

$$C_{LOS} = h_1 + \frac{h_2 - h_1}{d} \cdot d_1 - h_{ER} - h_O \tag{4-2}$$

Where positive values indicate that the obstruction is below the LOS; while negative values indicate that the obstruction is above the LOS.

The relative clearance between 60% of the first Fresnel zone radius and the obstruction can now be calculated:

$$C_{FFZ} = C_{LOS} - 0.6 \cdot R_{FFZ} \tag{4-3}$$

Where negative values indicate an intrusion into the first Fresnel zone that will result in an attenuation of the signal at the receiving antenna.

Given the parameters:

$f = 900$ MHz

$d_1 = 8$ km

$d_2 = 12$ km

$h_1 = 110$ meters

h_2 = 150 meters

h_O = 120 meters

$d = d_1 + d_2$

k = 1.33

Equation (3-2) gives: λ = 0.333 meters.

Equation (3-1) gives: R_{FFZ} = 39.986 meters.

Equation (4-1) gives: h_{ER} = 5.666 meters.

Equation (4-2) gives: C_{LOS} = 0.334 meters.

Equation (4-3) gives: C_{FFZ} = –23.657 meters.

From the preceding, one can see that over 99% of the first Fresnel zone radius is obstructed and that the obstacle protrudes 23.7 meters into the critical 0.6R area. Clearly, there will be a significant loss of signal at the receiving antenna. The amount of loss is approximated in the next section.

5. Signal Loss Due to Diffraction

The signal attenuation due to diffraction caused by a knife-edge type obstruction can be calculated using the Fresnel-Kirchoff diffraction parameter, v, and the complex Fresnel integral shown below.

$$f(v) = \int_{v}^{\infty} \left(\frac{1+j}{2}\right) exp\left(\left(\frac{-j\pi t^2}{2}\right)\right) dt \qquad (5\text{-}1)$$

The value of the diffraction parameter, v, is related to the height, h, of the obstructing knife-edge **above** the LOS, such that v and h are positive when the obstacle is above the LOS and negative when below.

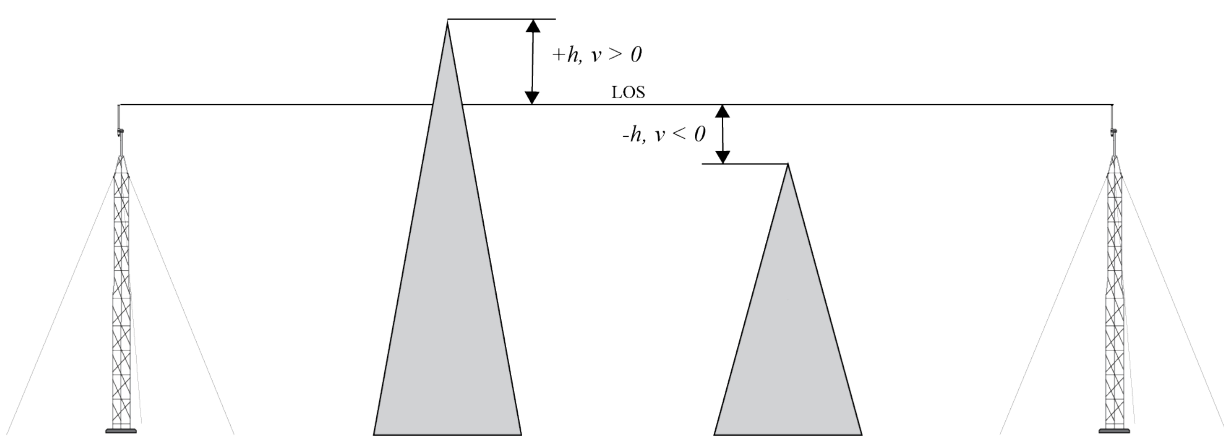

FIGURE 5-1. Diffraction Parameter

The height of the obstruction relative to the LOS is given by a rearrangement of equation (4-2):

$$h = h_O + h_{ER} - h_1 - \frac{h_2 - h_1}{d} \cdot d_1 \tag{5-2}$$

The Fresnel-Kirchoff diffraction parameter can now be calculated as follows:

$$v = h \cdot \sqrt{\frac{2(d_1 + d_2)}{\lambda \cdot d_1 \cdot d_2}} \tag{5-3}$$

Where d_1 and d_2 are in meters.

Equation (5-2) gives: $h = -0.334$ meters.

Equation (5-3) gives: $v = -0.012$.

Given the diffraction parameter, the signal loss, in positive values of dB, due to diffraction can be calculated. Below, is a more user friendly approximation of the Fresnel integral shown in equation (5-1) that is reasonably accurate for values of $v \geq -0.7$.

$$Loss_{Diff}(v) = 6.9 + 20\, log\left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1\right) \tag{5-4}$$

Given all of the preceding parameters, equation (5-4) gives: $Loss_{Diff}(v) = 5.93$ dB.

In summary, the following points can be derived from this analysis:

- For a path of propagation where the first Fresnel zone is clear of obstructions ($v \leq -1$), signal loss due to reflections or diffraction will be negligible.
- For a path of propagation where more than 60% of the first Fresnel zone radius is obstructed by a single knife-edge type obstruction, but the direct LOS is not obstructed ($-1 \leq v \leq -0$), signal loss due to reflections can be up to 6 dB.
- For a path of propagation where a single knife-edge type obstruction occludes the direct LOS plus more than 60% of the first Fresnel zone radius above the LOS ($0 \leq v \leq 1$), signal loss due to diffraction can be up to 14 dB.
- For a path of propagation where a single knife-edge type obstruction occludes the direct LOS plus the complete First Fresnel zone ($1 \leq v \leq 2.4$), signal loss due to diffraction can be greater than 20 dB.

It should be noted that the above analysis applies to a single knife-edge type obstruction in the path of propagation. For a path with multiple such obstructions, a popular approach is to segment the path into individual profiles and to simply sum the losses calculated for each segment.

6. Conclusion

The point of this discussion has been to instill some understanding of the real-world effects that must be factored into designing a reliable telemetry link. Free space propagation losses are the norm for calculating link budgets, but, since most telemetry links exist on the earth's surface and not in outer space, such calculations by themselves are insufficient. Indeed, there are numerous other factors to be considered such as ground-wave reflections and atmospheric losses due to scattering, absorption and ducting, but we will leave those subjects for future discussions. For a discussion on link budgets, see *The Link Budget and Fade Margin* app note.

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