Wireless Supporting Information

Free-space Loss. The Friis free-space propagation equation is commonly used to determine the attenuation of a signal due to spreading of the electromagnetic wave.

Free space loss is given as:

Attenuation (dB) = $92.467 + 20 \log_{10}(f_{GHz}) + 20 \log_{10}(D_{km})$; or,
Attenuation (dB) = $96.6 + 20 \log_{10}(f_{GHz}) + 20 \log_{10}(D_{mi})$

Where: f_{GHz} = frequency in GHz, and
D_{km} = distance between antennas (link) in *kilometers*; or,
D_{mi} = distance between antennas (link) in *miles*.

Frequencies above 10 GHz. For frequencies above 10 GHz there are several additional issues that effect propagation, including:

- Absorption due to gasses or water vapor;
- Attenuation due to mist, fog, or rainfall.

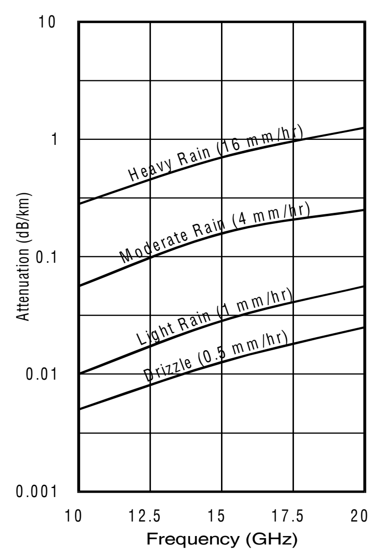
Many gasses and pollutants have absorption lines in the millimeter bands but, due to their low densities, their effect is negligible in microwave and millimeter wave frequencies below 30 GHz. Water vapor, though, has an absorption line at 22.235 GHz and can effect microwave frequencies above 10 GHz. The amount of water vapor in the atmosphere at sea level can vary from 0.001 grams per cubic meter in a cold, dry climate to as much as 30 grams per cubic meter in hot, humid climates. In addition, the effects of precipitation can be significant at microwave frequencies above 10 GHz. The attenuation due to rainfall is dependent on the size and distribution of the water droplets. Because snowfall rates are generally less than rainfall rates, propagation is less effected by snowfall. For both snow and fog, the attenuation loss is a function of temperature and can vary by a factor of 3 between 0°C and 40°C [1].

Total transmission loss for a microwave/millimeter link is given by Freeman [2] as:

Attenuation (dB) = $96.6 + 20 \log_{10}(f_{GHz}) + 20 \log_{10}(D_{mi})$ + excess attenuation (dB) due to water vapor, mist, fog, and rainfall.

Where: f_{GHz} = frequency in GHz, and D_{mi} = distance between antennas (link) in miles.

To the right is a chart showing specific attenuation verses frequency for various rainfall rates including Drizzle, Light Rain, Moderate Rain, and Heavy Rain [1].



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Total Path Loss. The total path loss (dB) is the gain of both antennas (dB) added together, minus the free space loss (dB) and any additional loss (water vapor, mist, fog, rainfall, and Fresnel reflection loss).

Fading. Fades, or variations with time, in path loss are encountered during abnormal propagation conditions. The most common type of fading is that due to multipath transmission. Combinations of irregularities and fluctuations in atmospheric temperature, humidity, and pressure cause more than one and often many propagation paths to exist between the transmitting antenna and the receiving antenna. As the atmospheric conditions vary, the routes and distances of paths also vary, causing signals of differing phases and amplitudes to arrive at the receiving antenna at the same instant. Multipath, or interference, fading is characterized by rapid fluctuations of received carrier power.

Fade Margin. Fade margin is the depth of fade, expressed in dB, that a microwave receiver can tolerate while still maintaining acceptable circuit quality [4].

Fresnel Loss. The primary component to path loss is the free-space signal loss from the transmitting antenna to the receiving antenna. But additional path loss may also exist from multi-path reflections (sometimes called Fresnel reflective loss) due to reflective surfaces such as water near the direct wave, and intervening obstacles such as buildings, mountain peaks, etc., in the Fresnel zone.

Fresnel Zone. Fresnel (frä nel'), named after Jean Augustin Fresnel, 1788-1827, French physicist. The Fresnel zone is an elliptically shaped conical zone of power that propagates from the transmitting antenna to the receiving antenna due to cancellation of some part of the wavefront by other parts that travel different distances. If the total path distance between the transmitting antenna, mountain peak, and receiving antenna is one wavelength greater than the direct distance between antennas, then the clearance is said to be two Fresnel zones [4].

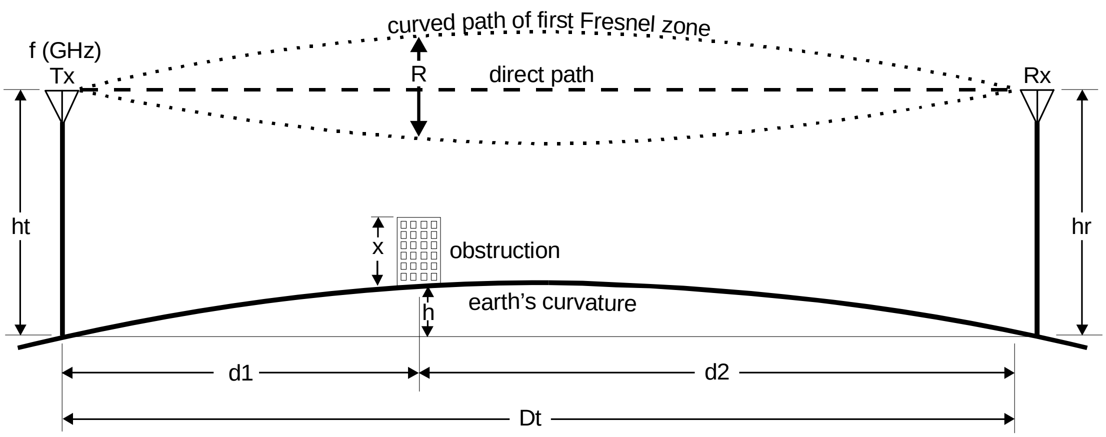
Fresnel boundaries. The outer boundary of the first Fresnel zone is defined as the additional path length of all paths, which are one-half wavelength ($1/2\ \lambda$) of the frequency transmitted longer than the direct line-of-sight path between antennas. If the total path distance is one wavelength (1λ) longer than the direct path, then the outer boundary is said to be two Fresnel zones. There are an infinite number of Fresnel zones located coaxially around the center of the direct wave path. Odd number Fresnel zones reinforce the direct wave path and even order number Fresnel zones cancel the direct wave path.

Clearance. For reliability, point-to point links are designed to have at least 0.6 of the first Fresnel zone clearance from any obstruction from all sides (top, bottom, left and right of the first Fresnel zone).

Refraction. The earth's curvature, as well as atmospheric conditions (temperature, pressure, and water vapor), can refract or bend electromagnetic waves either up, away from, or down toward the earth's surface. This bending can change frequently, hour to hour, day to night, season to season, and weather pattern to weather pattern. Refractivity is usually greatest close to the earth's surface and becomes smaller the higher above the surface you go. To compensate for this effect, a refractivity gradient, or 'K' factor, is used when designing point-to-point communication links. The 'K' factor is the ratio of the effective Earth radius to the actual Earth radius. A 'K' factor of 1 indicates no bending of the signal; a 'K' factor of less than one means the electromagnetic wave is bent up, away from the surface. A 'K' factor greater than one indicates a slight bending downward, towards the earth. The 'K' factor value commonly used for microwave links is 1.333 (4/3) for normal atmospheric conditions, which means that the radio horizon is further away than the visual horizon.

Link design. Links should be designed, using the above information, to accommodate obstructions (mountains, buildings, trees) and atmospheric conditions (large bodies of water, weather conditions, and other natural reflectors and absorbers of electromagnetic energy).

Following is a graphic of a typical microwave point-to-point link and the basic formulas for reliable link design.



Where:

- R = Curved path of the first Fresnel zone radius (at the obstruction)(in feet)
- ht = Height above the earth's surface at the transmitting antenna (in feet)
- hr = Height above the earth's surface at the receiving antenna (in feet)
- x = Height of obstruction (in feet)
- h = Earth's curvature, from a flat plane between antennas, at the obstruction (in feet)
- d1 = Distance from transmitting antenna to obstruction (in miles)
- d2 = Distance from receiving antenna to obstruction (in miles)
- Dt = Total path distance between antennas (in miles)
- f = Transmitted frequency (in GHz)

As an example, where:

- d1 = 1.6 miles
- d2 = 2.1 miles
- Dt = 3.7 miles
- x = 100 feet
- f = 0.880 GHz (880 MHz)

The first Fresnel zone:

$R = 72\sqrt{((d1)(d2) / (Dt)(f))}$

$R = 72\sqrt{((1.6)(2.1) / (3.7)(0.88))}$

$R = 72\sqrt{(3.36 / 3.256)}$

R = 73.14 feet

for 0.6 clearance from the first Fresnel zone = (73.14)(0.6) = 43.9 feet

Earth's curvature at obstruction:

$h = ((d1)(d2) / (1.5)(K))$

$h = ((1.6)(2.1) / (1.5)(4/3)) = 1.7$ ***feet***

If Tx and Rx antennas are the same altitude above sea level:

The earth's curvature:	1.7 feet
0.6 first Fresnel clearance for 880 MHz:	43.9 feet
Obstruction height:	100.0 feet
then the minimum ht and hr (antenna height above ground) =	***145.6 feet.***

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Wave Length (λ). The wavelength for a microwave frequency is given as: $30 / f_{GHz} = \lambda_{cm}$
where: f_{GHz} = Frequency in Giga Hertz, and
λ_{cm} = wave length in centimeters
e.g.: 30 GHz = 1 cmλ; 20 GHz = 1.5 cmλ; 10 GHz = 3 cmλ.

Antenna Gain. For a paraboloid reflector microwave antenna (greater than 960 MHz) consisting of a dish-shaped surface illuminated by a feed horn mounted at the focus of the reflector, the antenna gain is given as [6]:

$\textit{Antenna Gain}$ (dBi) = $20 \log_{10}(D_{ft}) + 20 \log_{10}(f_{GHz}) + 7.5$; or,
$\textit{Antenna Gain}$ (dBi) = $20 \log_{10}(D_{m}) + 20 \log_{10}(f_{GHz}) + 17.82$

Where: dBi = decibels over an isotropic radiator
D_{ft} = Antenna dish diameter in feet; or,
D_{m} = Antenna dish diameter in meters, and
f_{GHz} = Frequency in GHz.

Note: The above formula is based on the efficiency of a paraboloid antenna being on the order 55% [6]. Some manufacturers may be able to improve on this number, therefore, the gain given by a manufacturer for a specific antenna should be used, when available, otherwise the above formula will suffice.

The general formula for computing the gain of any antenna is given as: $4\pi A / \lambda^2$
Where A = effective area of antenna (≅55% for a parabolic dish reflector antenna)
λ = wave length
Area and Wavelength must be in same unit (feet, meters, etc.)

Beamwidth. Antenna beamwidth refers to the width of the main radiated beam (main lobe) between two equal power levels that are 3 dB down from the peak power of the center of the main beam. Antenna gain and beamwidth are interrelated quantities and are inversely proportional; thus the higher the gain an antenna has, the smaller the beamwidth[3]. Therefore, increased care must be taken when aligning high gain antennas to insure that the antenna is accurately aligned on the center of the main beam…which could be only a few degrees wide. For example; a 6-foot parabolic dish antenna at 6 GHz has an antenna gain of 38.63 dB *and a beamwidth of only 1.91°.*

Beam Width is given as:
$(70 * \lambda_{cm} \div 100) \div (\text{antenna } ø_{ft} * 0.3048)$, or
$(70 * \lambda_{cm} \div 100) \div \text{antenna } ø_{meters}$
where λ_{cm} = wave length in centimeters

Radiation Fields. The space around any antenna is usually divided into three traditional radiation fields (regions) in free space as a result of the radiated power of an antenna. These three radiation fields, where the boundary r (radius) around the antenna, are known as:

1. The ***near-field***, also called the reactive near-field region, is that region that is closest to the antenna and for which the reactive field dominates over the radiative fields.

2. The, ***Fresnel zone***, also called the radiating near-field, is that region between the reactive near-field and the far-field regions and is the region in which the radiation fields dominate and where the angular field distribution depends on distance from the antenna (see earlier definition of Fresnel Zone).

3. The ***far-field, or Rayleigh distance*** (historically called the Fraunhofer region), is that region where the radiation pattern is independent of distance.

These distances, where D is >> λ, and r is >> than λ, can be summarized as follows:

Region	Distance from antenna (r)
Near-field	0 to $0.62\sqrt{(D^3/\lambda)}$
Fresnel zone	$0.62\sqrt{(D^3/\lambda)}$ to $2(D^2/\lambda)$
Far-field	$2(D^2/\lambda)$ to ∞

Where: D = The maximum dimension of the antenna;
r = The distance from the antenna (boundary radius); and,
λ = Wavelength [5].

Polarization. The polarization of an antenna refers to the orientation of the electric field vector in the radiated wave. For linear polarization (horizontal or vertical), the vector remains in one plane as the wave propagates through space. To eliminate polarization mismatch loss, the receiving antenna must have the same polarization orientation as the transmitting antenna [3] (*Note:* If the waveguide connection at the antenna is vertically oriented, the antenna is said to have horizontal polarization and vice-versa).

Order Wire. The term 'Order Wire', or 'Engineering Order Wire', is currently used with spread spectrum radios to describe the ability to have voice communications over the radio link. This term comes from the telegraph/telephone days when an 'order wire' was equipment and the circuit (specific cable pair within multi-pair cable) providing a telephone company with the means to establish voice contact between the central office and carrier repeater locations [4].

References.

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