Planning a Microwave Link: It's Not Just Line of Sight!

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Topics we will cover:

- Some theory
- Making sure you have a clear path (including the Fresnel Zone!)
- Accounting for propagation conditions
- Setting your fade margin
- Adding up your gains and losses
- What to watch out for
- A few ways to improve performance

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Types of Radio Link Waves

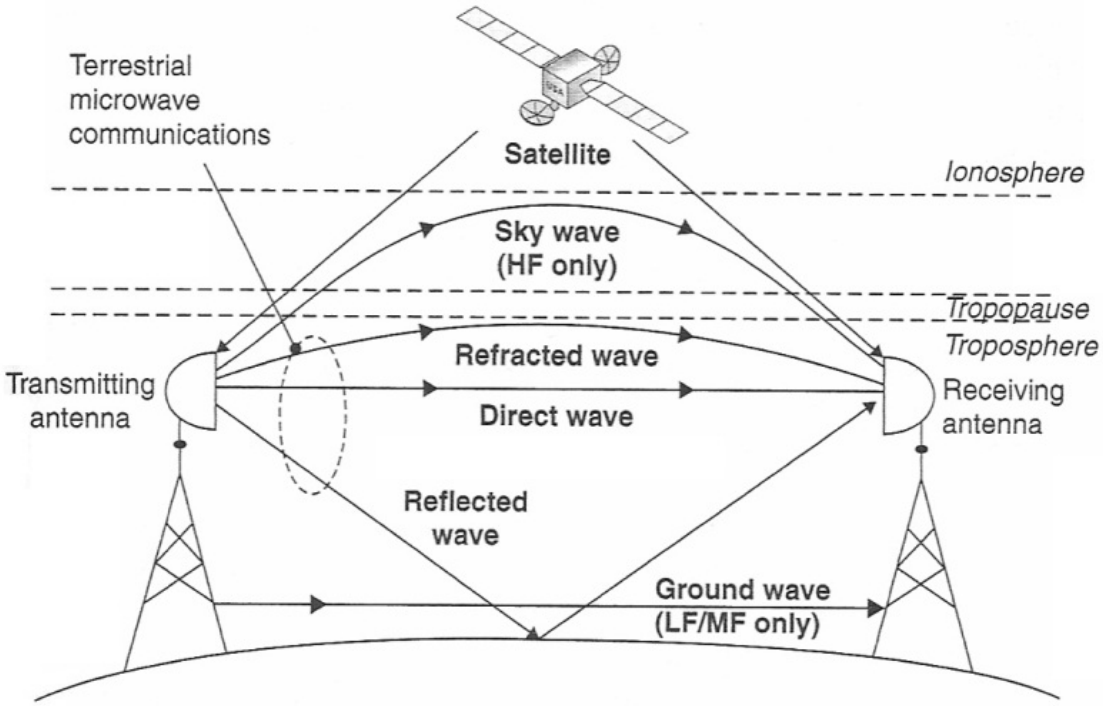

Figure 2.2 Radio wave propagation

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

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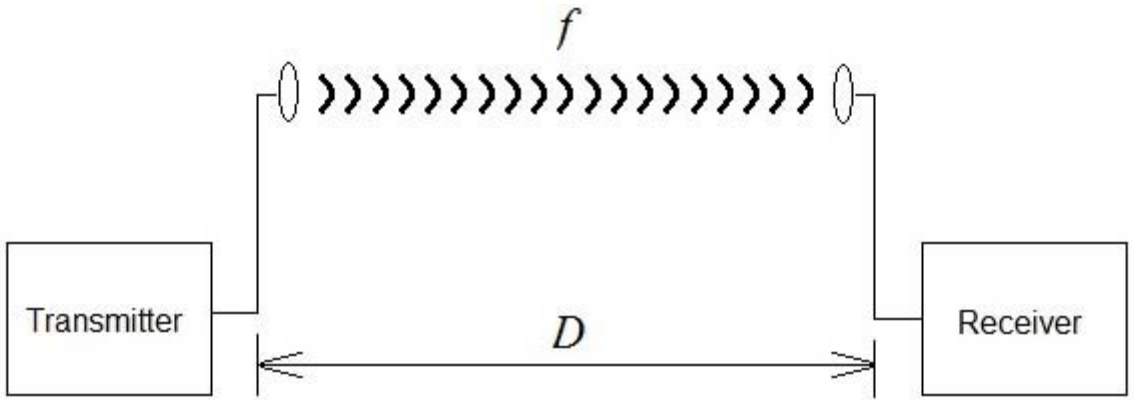
Consider a signal from a transmit point to a receive point:



The *free space path loss (FSL)* is:

$$FSL_{dB} = 92.44 + 20 \log D_{km} + 20 \log f_{GHz}$$

or

$$FSL_{dB} = 96.6 + 20 \log D_{mi} + 20 \log f_{GHz}$$

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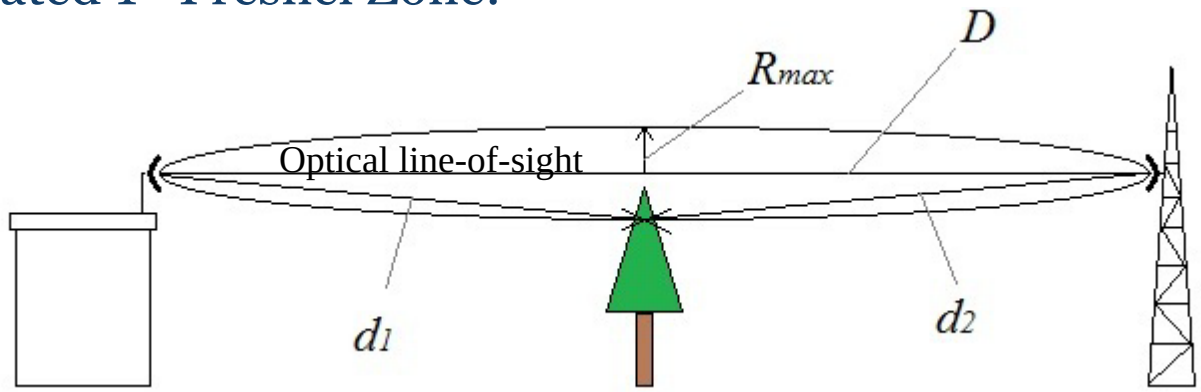
For “Fresnel clearance” of a microwave link, we consider the calculated 1st Fresnel Zone:



Radius of F.Z. at any point along the path (in meters):

$$R = 17.3 \text{ SQRT}[d_1 d_2 / f_{\text{GHz}} (d_1 + d_2)]$$

F.Z. Radius at the path midpoint (where it’s at maximum):

$$R_{max} = 8.66 \text{ SQRT}(D_{km} / f_{\text{GHz}})$$

Rule of thumb for clearance is 60% of the F.Z. Radius. To simplify, we can use R_{max} over entire path (e.g., for map overlays).

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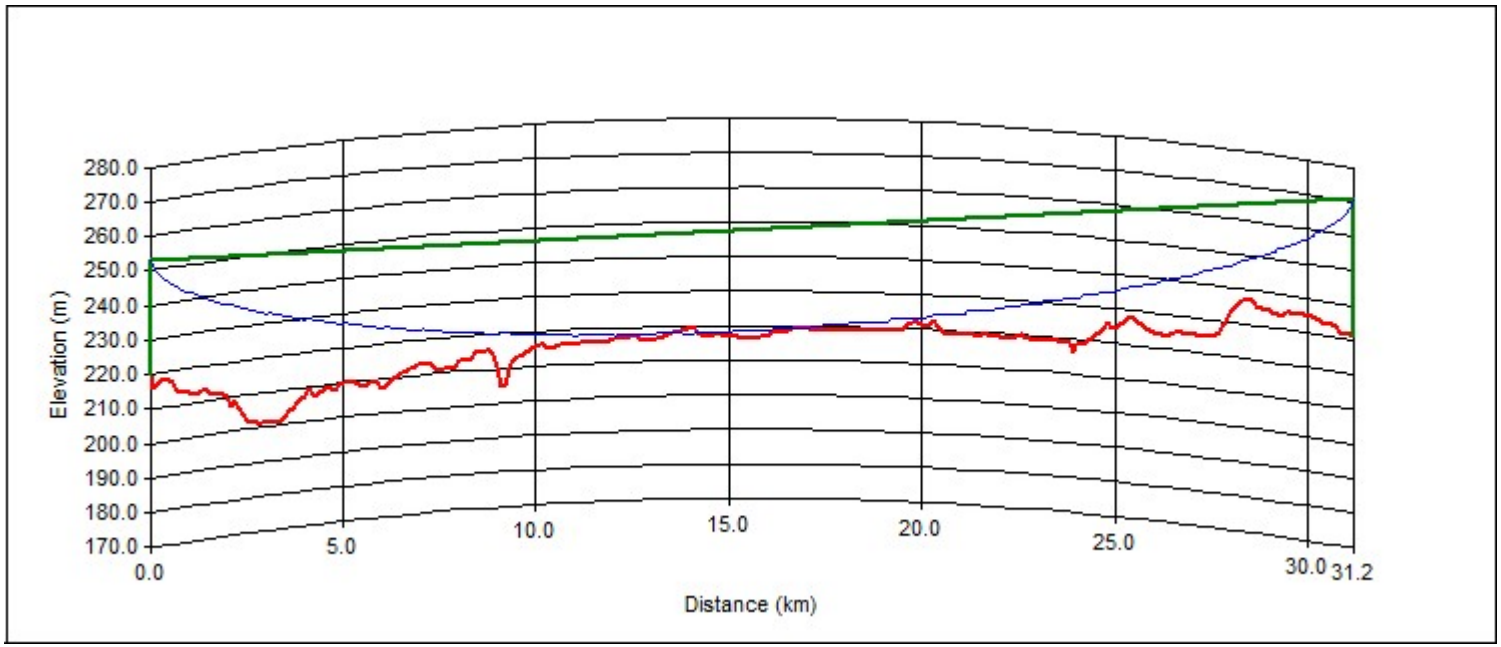
The path and F.Z. should be plotted on a terrain profile graph with earth curvature. There are many software programs available for this.



Path profile for a 950 MHz link, using earth radius factor (K) of 4/3

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What's this "K-factor" in path studies about?

The K-factor takes into account the refractivity in the atmosphere which bends the beam either up or down.

K = effective earth radius/true earth radius

In effect, the bending of the beam either up or down makes it appear as though the radius of the earth is less than or greater than the true radius. A K-factor of >1.0 means the beam is bent towards the earth, <1.0 means the beam is bent upwards.

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K-Factor Considerations

- For K>1, the radio horizon is longer than the optical horizon, which allows shorter towers.
- K-factor of 4/3 (or 1.33) is used is most cases for planning a link.
- In wet coastal areas, however, K can be as low as 0.5. Lower K requires higher antennas.

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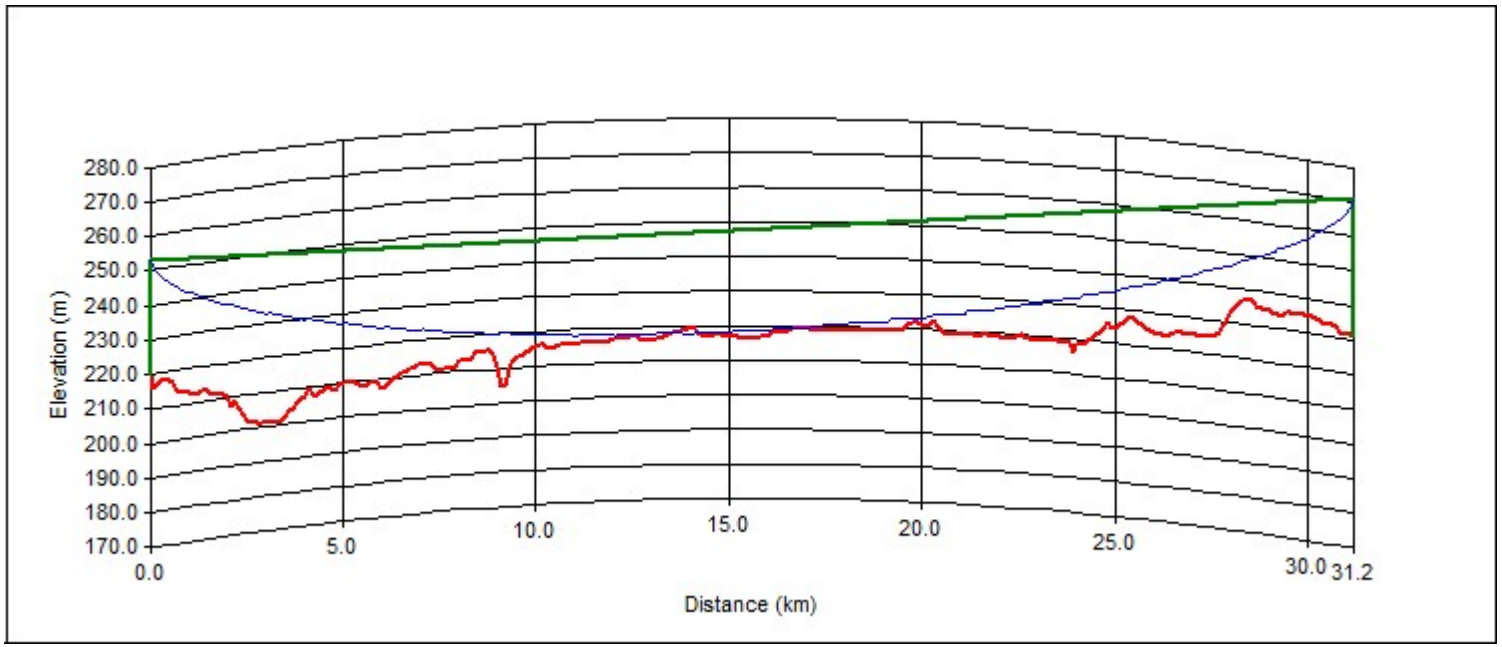
Going back to our STL path, with K = 4/3 …



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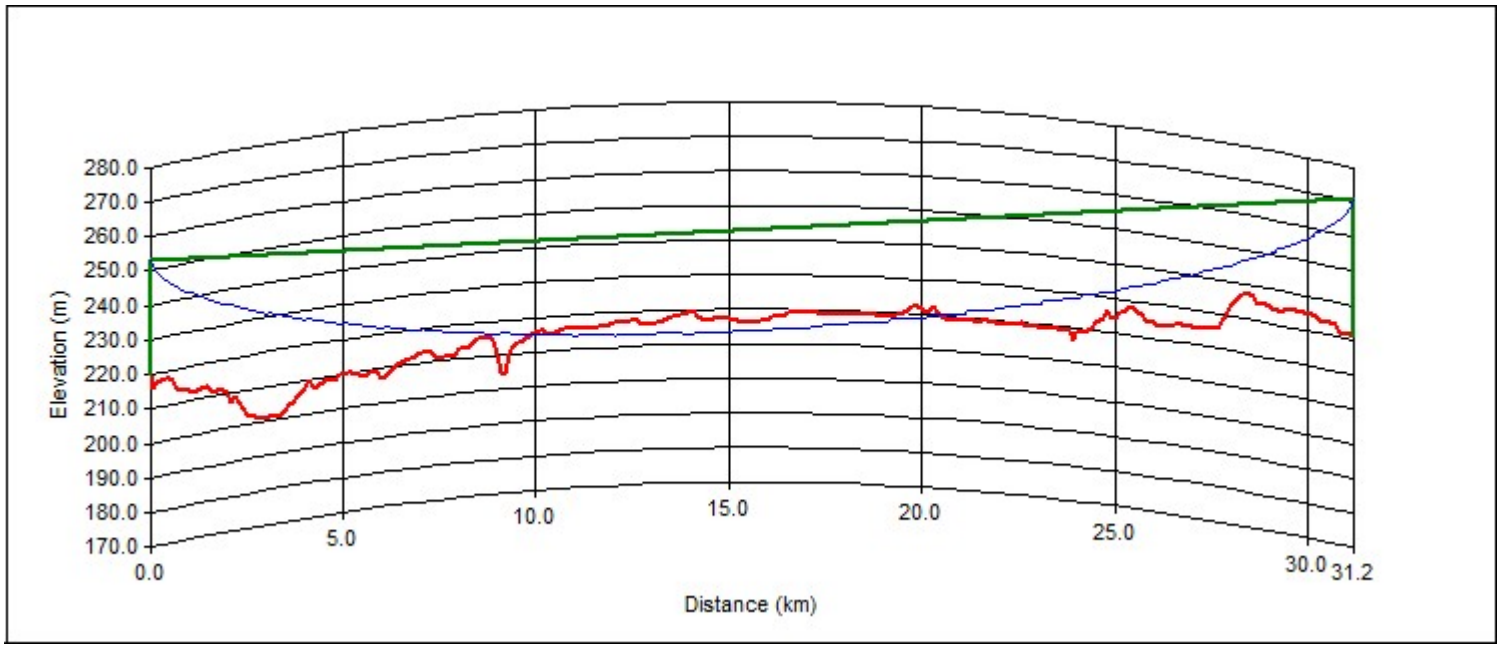
Path is re-drawn for K=1 (true earth radius).



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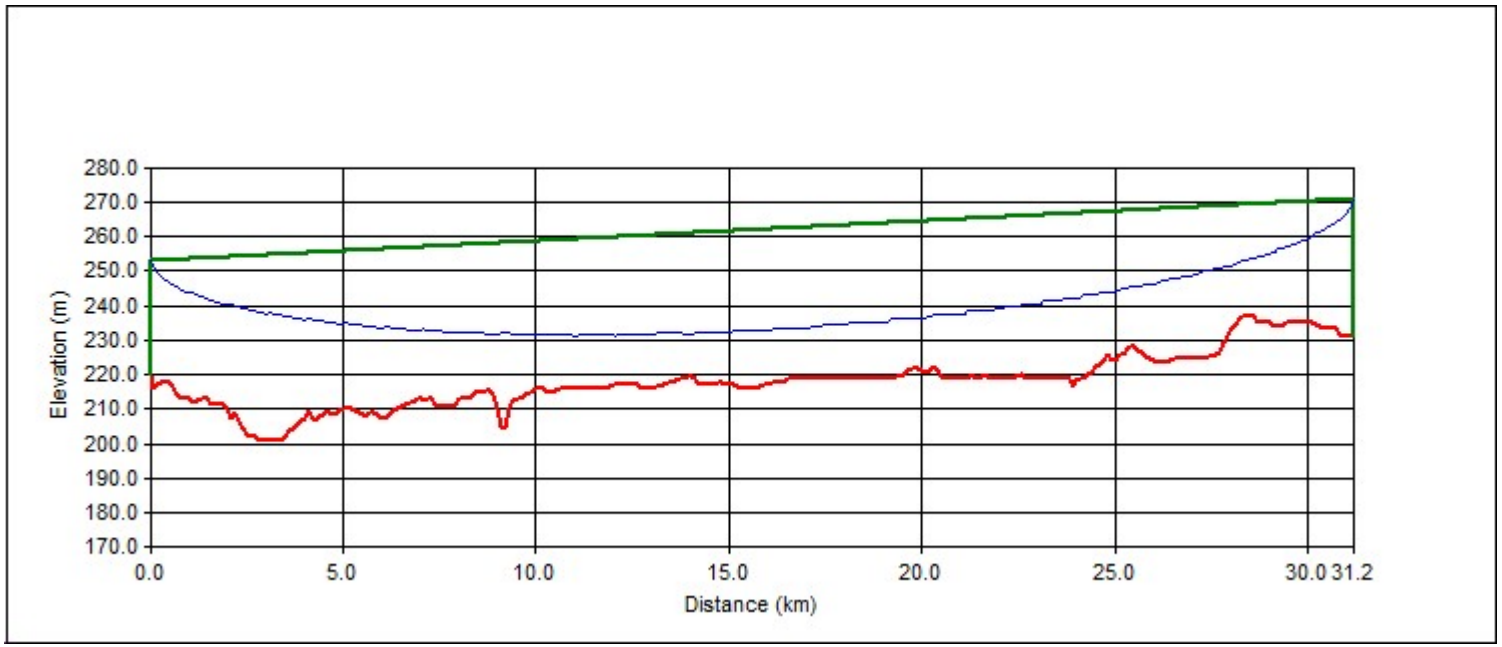
Now plotted for K = ∞ (flat earth)



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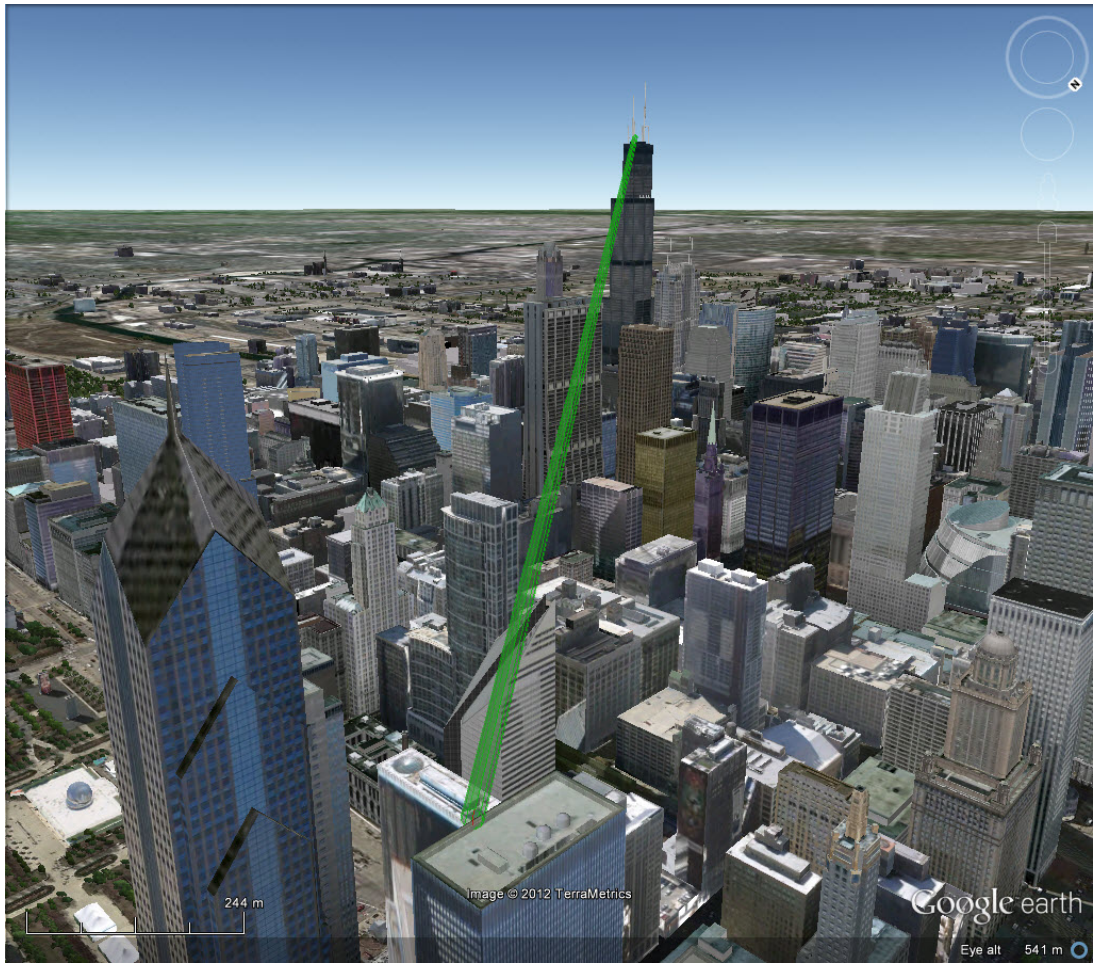
It’s also possible to plot a microwave link in Google Earth.



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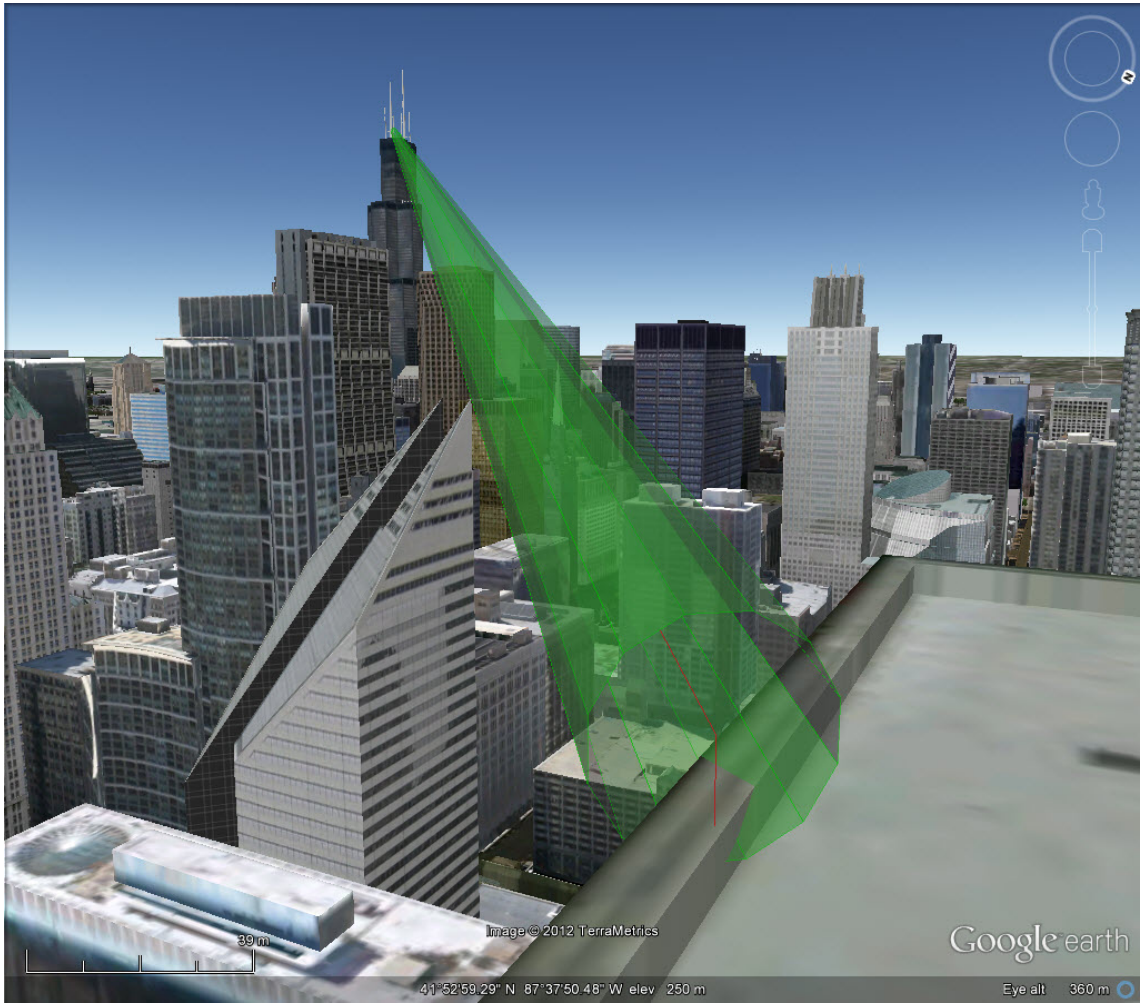
Microwave beam shown as cylinder with radius of 1st F.Z.



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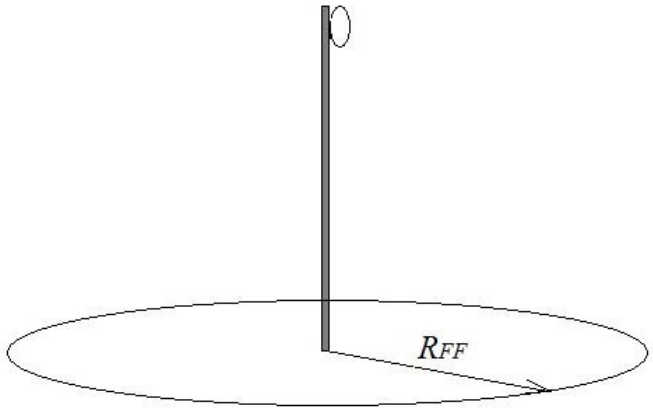
If possible, the microwave antenna should be clear of any RF-conductive objects within a horizontal spacing equal to the distance to the end of the near-field.



$$R_{FF} = 2D^2/\lambda \text{ [ft]}$$

Where D is the largest dimension of the antenna in feet and λ is the wavelength in feet. For example, a 4-ft dish operating at 6 GHz has a near-field distance of 195 feet.

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Fading

A random increase in path loss caused by unusual propagation conditions

Multipath Fading the dominant fading factor < 10 GHz and is dependent on the following factors:

- Distance of path
- Frequency
- Climate
- Terrain

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Characteristics of multipath fading in different regions:

- Least amount of fading over dry, mountainous areas.
- Worst fading over hot and humid coastal areas.
- Inland temperate regions are somewhere in between.
- Higher fading in flat terrain (such as deserts & lakes) due to increased incidence of reflections.
- Less fading in irregular, hilly terrain or forests (less reflections).

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How to set a multipath fade margin (MFM)?

First, decide on a *propagation reliability* (PR) over time. This is only one factor in overall *system reliability* however.

From Barnett/Vigants model:

$$MFM = -10LOG[(1-PR)/(2.5x10^{-6}abfD^3)]$$

Where:

PR = fraction of time of path unavailability
a = terrain factor
b = climate factor
f = frequency in GHz
D = path length in miles

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	A	B	C	D	E	F	G
1			Fade Margin Calculation based on Barnett & Vigants Method				
2							
3		a - terrain factor	4 for very smooth terrain, incl. over water, flat desert				
4			1 for average terrain with some roughness				
5			0.25 for mountains, very rough or very dry terrain				
6							
7		b - climate factor	1 for humid climate				
8			0.5 for average climate				
9			0.25 for dry climate				
10							
11		f - frequency in GHz					
12							
13		D - path length in miles					
14							
15		FM - fade margin in db					
16							
17		PR = propagation reliability in %	Example: 99.95%				
18							
19		Enter numbers starting here:					
20		a ---------->	1				
21		b ---------->	0.5				
22		f ---------->	0.95				
23		D ---------->	20				
24						Fading probability (fraction of time)	
25		PR ---------->	99.999	FM =	29.78	1E-05	
26		OR					
27		F ---------->	20	PR =	99.99050%	0.000095	
28							

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	A	B	C	D	E	F	G
1			Fade Margin Calculation based on Barnett & Vigants Method				
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19		Enter numbers starting here:					
20		a ---------->	1				
21		b ---------->	0.5				
22		f ---------->	0.95				
23		D ---------->	20				
24						Fading probability (fraction of time)	
25		PR ---------->	99.9995	FM =	32.79	5E-06	
26		OR					
27		F ---------->	20	PR =	99.99050%	0.000095	
28							

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	A	B	C	D	E	F	G
1			Fade Margin Calculation based on Barnett & Vigants Method				
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13		D - path length in miles					
14							
15		FM - fade margin in db					
16							
17		PR = propagation reliability in %	Example: 99.95%				
18							
19		Enter numbers starting here:					
20		a ---------->	1				
21		b ---------->	0.5				
22		f ---------->	0.95				
23		D ---------->	20				
24						Fading probability (fraction of time)	
25		PR ---------->	99.9995	FM =	32.79	5E-06	
26		OR					
27		F ---------->	25	PR =	99.99700%	3.00416E-05	
28							

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Other factors added to the fade margin

- Rain fade – significant for >6 GHz and long paths, very complex problem to quantify
- Equipment aging – includes antenna misalignment, DoD recommends 6 dB though more would be appropriate for higher-gain dishes
- Atmospheric absorption – only consider water vapor between 15 and 30 GHz, peaks at 22 GHz, estimate 0.2 dB/km

Use of multipath fade margin alone (plus allowance for rain > 10 GHz) is usually appropriate for gross planning below 20 GHz.

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Estimated Rain Attenuation (RA) at Specific Frequencies for 1”/hr Rainfall

Freq. (GHz)	RA (dB/km)
6	0.1
10	0.6
15	1.6
20	2.6

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If your path has obstacles in the F.Z. and you can't increase the antenna heights to avoid them, how do you estimate the diffraction losses?

From the path profile, determine the level of penetration of the 60% 1st F.Z. of each obstacle and add the losses according to the diagram.

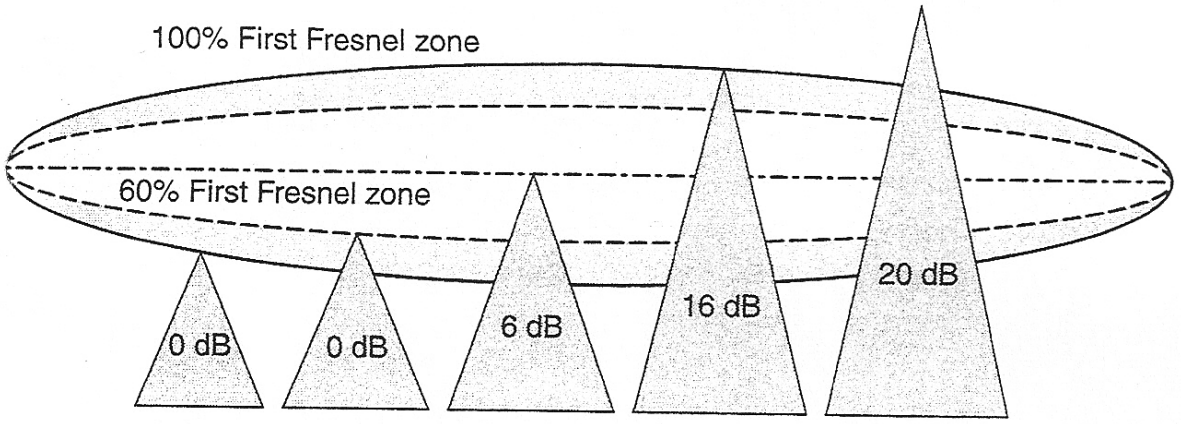

Figure 3.4 Obstacle losses and knife-edge approximation

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

Putting together the radio link budget, with gains and losses…

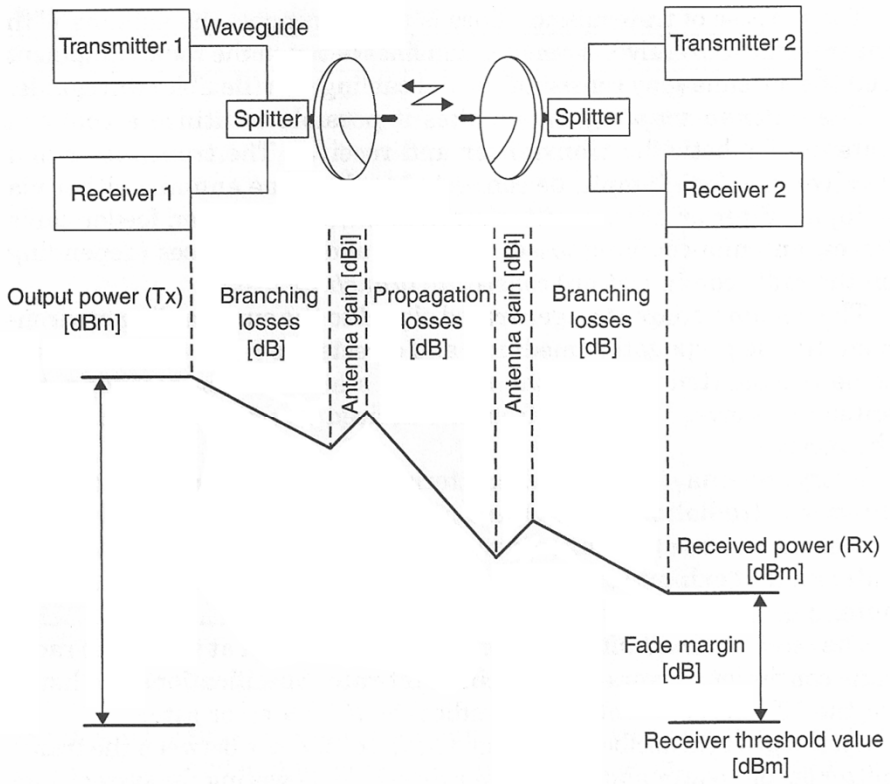

Figure 2.11 Radio path link budget

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

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Calculation of Received Signal (RSL) with Fading

$$RSL = P_o - L_{tx} + G_{atx} - FSL - MFM - RA - L_{rc} + G_{rc} - L_m$$

P_o = Transmitter power output (dBm)
L_{tx} = All losses between transmitter and its antenna (dB)
G_{atx} = Gain of transmitting antenna (dBi)
FSL = Free space loss (dB)
MFM = Multipath fade margin (dB)
RA = Rain attenuation (dB)
L_{rc} = All losses between receiver and its antenna (dB)
G_{rc} = Gain of receiving antenna (dBi)
L_m = Miscellaneous losses (obstacle, misalignment, aging) (dB)

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Example

A digital QAM modulated radio link is to be built with a path distance of 25.5 km. Frequency is 11.0 GHz. Transmitter power is 23.0 dBm. Gain of both transmitting and receiving antennas is 37.6 dBi. The receiver threshold level is -75 dBm. Assume no combiner or transmission line losses. Rain attenuation is estimated to be 0.3 dB/km for ½" rain per hour, or 7.7 dB over the entire path. Assume no obstacle losses. A propagation reliability of 99.95% is desired. The MFM is calculated as 20.4 dB for that reliability, assuming a terrain factor of 2 and a climate factor of 0.25. Miscellaneous loss is assumed to be 6.0 dB.

RSL = 23.0 + 37.6 - 141.4 - 20.4 - 7.7 + 37.6 - 6.0
= -77.3
This is 2.3 dB below the receiver threshold level.

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A few things to watch out for

The reliability (or availability) calculation does not include equipment failure or the reliability of your telecom company or ISP that delivers content to your microwave site. These have to be taken into account.

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A radio link path mostly over water is a received signal cancellation hazard due to reflections from the surface. Antenna heights should be adjusted so that the 2nd F.Z. is below the surface. Also, use vertical polarization instead of horizontal polarization.

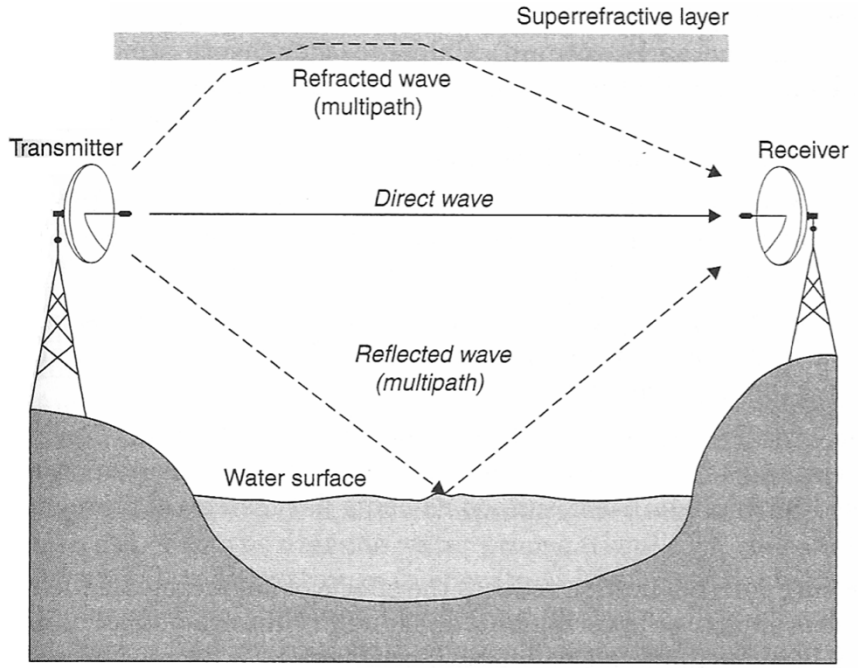

Figure 3.6 Multipath fading

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

Way to improve performance

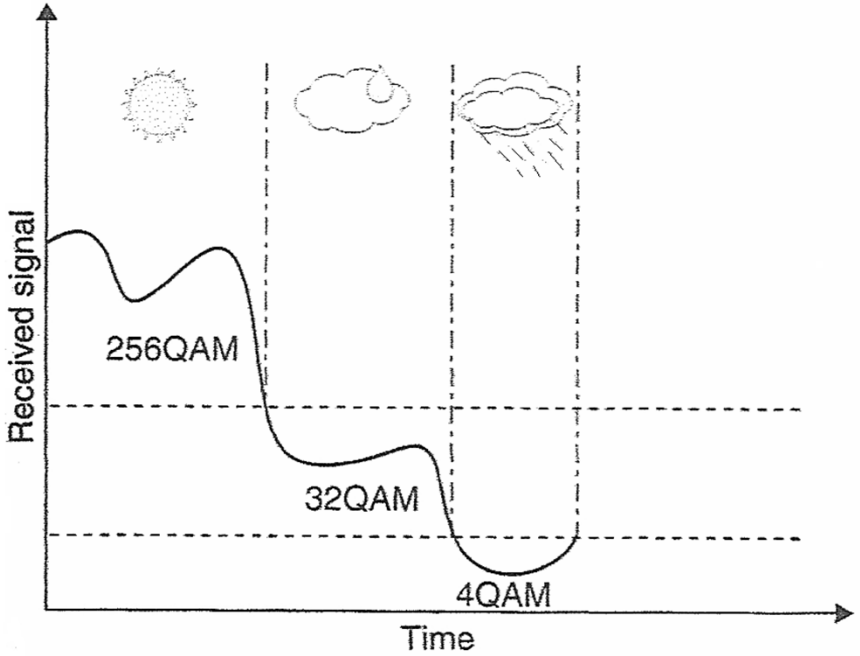

Figure 3.10 Adaptive modulation

Adaptive modulation automatically reduces modulation rate as fading increases, so link is uninterrupted.

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

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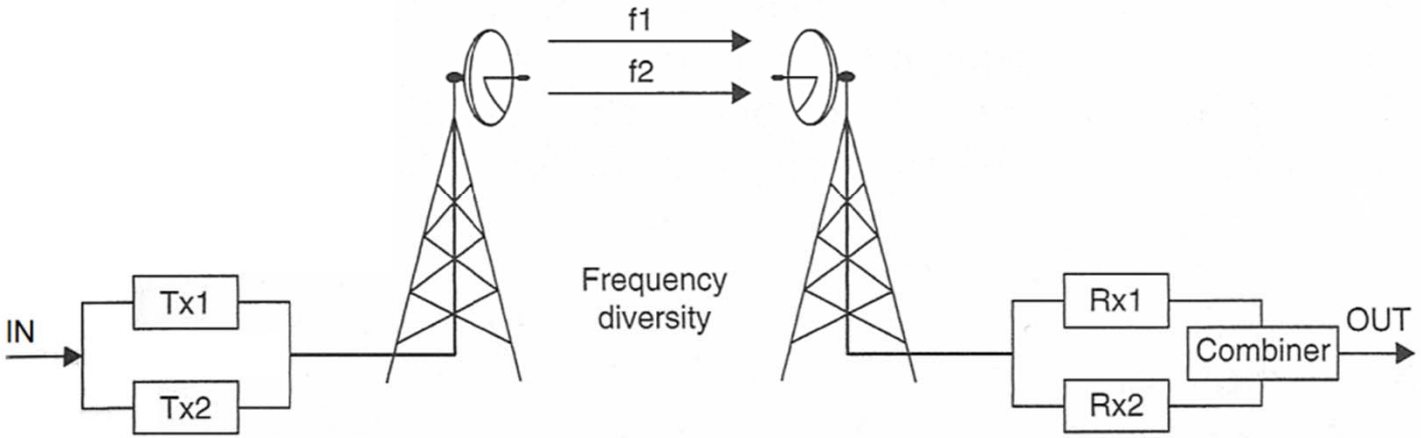
Ways to improve propagation reliability
Frequency Diversity



The signals are transmitting on two frequencies usually separated by 2%. Reduces fading by up to 15 dB.

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

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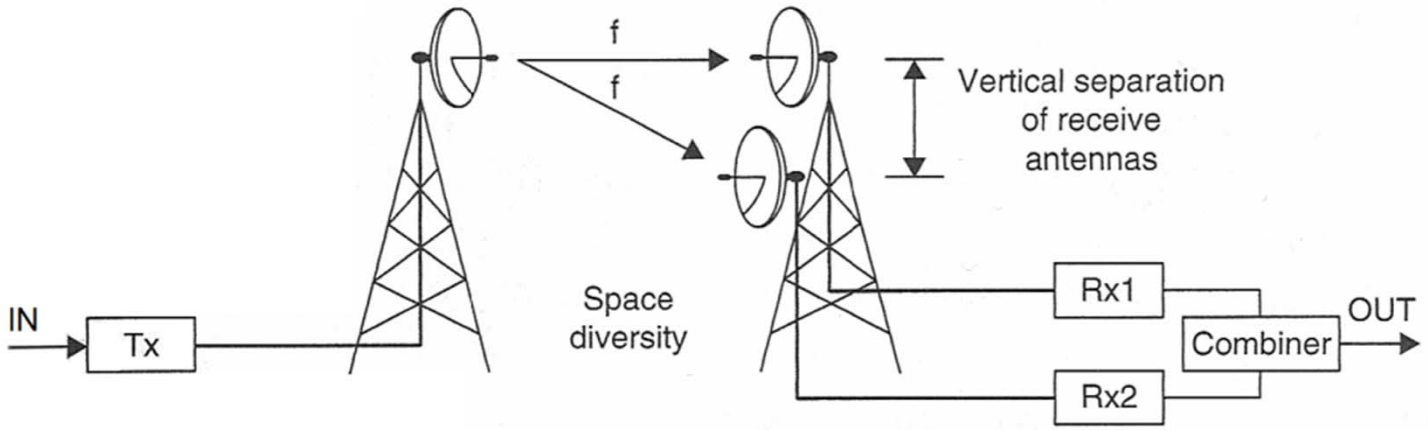
Space Diversity



Two receiving antennas separated vertically by a spacing that creates two paths not simultaneously affected by fading. Separation can be between 100 and 200 wavelengths (e.g., for 6 GHz, between 16.5 and 33 feet).

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

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Thanks for listening!

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