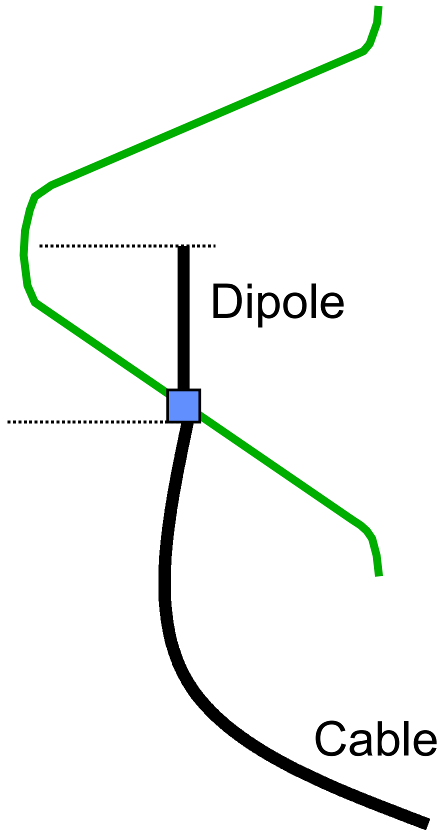
Module contents

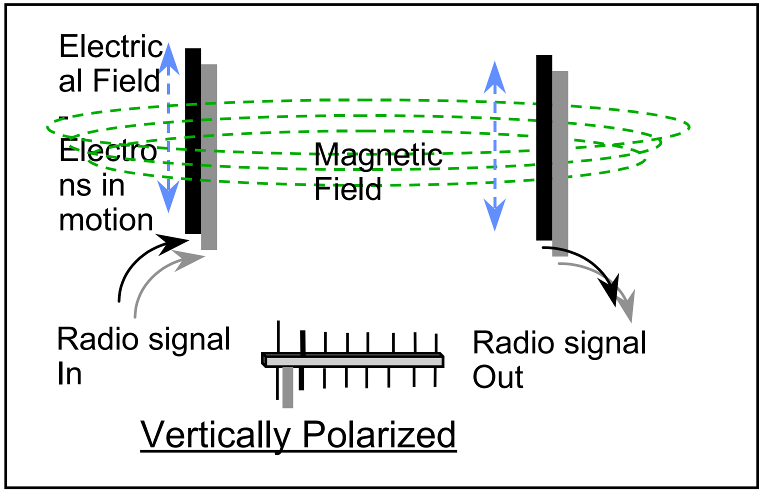
- ★ **Antenna systems**
- ★ RF propagation

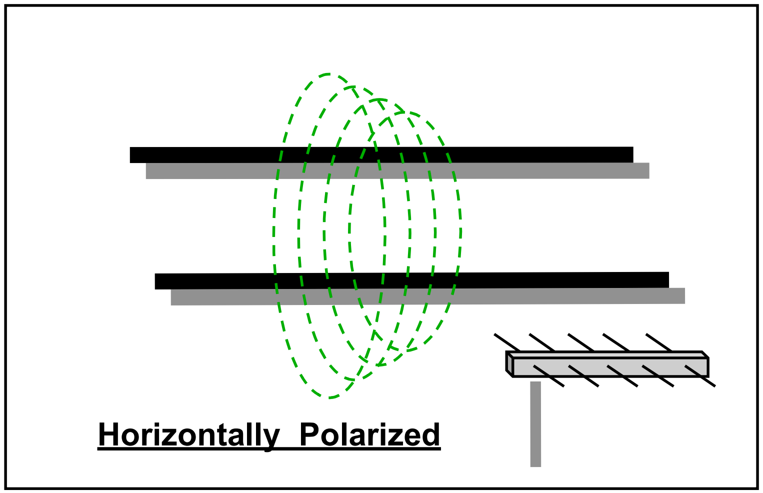
Basic antenna operation



- ★ Antennas are specific to Frequency based on dimensions of elements
- ★ 1/4 λ Dipole (Wire 1/4 of a Wavelength) creates a Standing Wave signal in at 0 impedance
- ★ MAX voltage to generate MAX Magnetic field
- ★ Signal In - Cable longer than Many λ (wavelengths) no Standing Waves

Basic antenna operation
Antenna Polarization

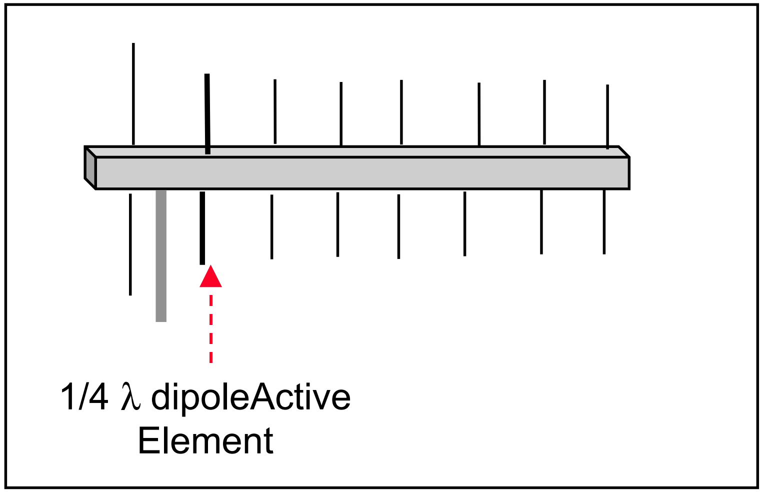


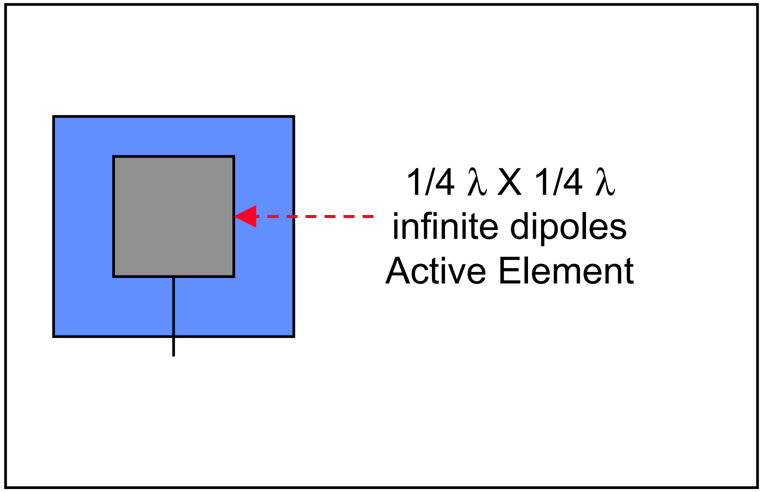


- ★ Rotating the antenna around its axis will change the polarity of the signal
- ★ In some cases a rotation can improve the quality of the link if other outdoor links are present in the same area

Basic antenna operation

Directional antenna types





<u>Yagi</u>

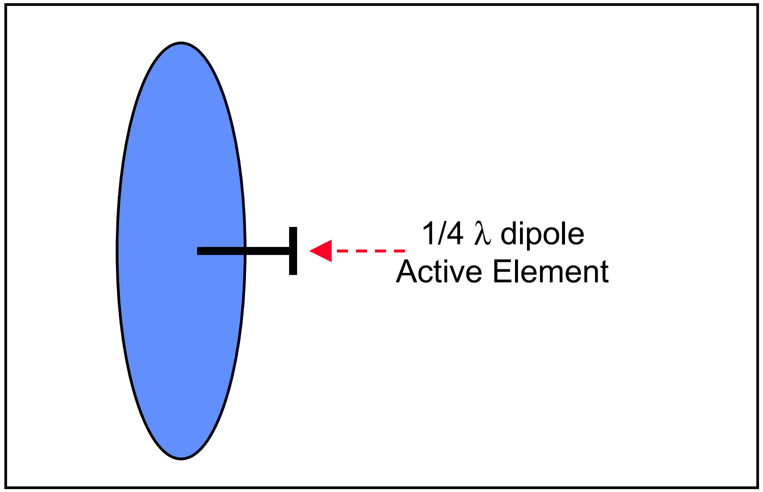
- ★ 1 Reflector
- ★ Directors
- ★ More Directors - Higher gain
- ★ 1 director = 8dBi
- ★ 15 directors = 14 dBi
- ★ Sometimes hidden in enclosure

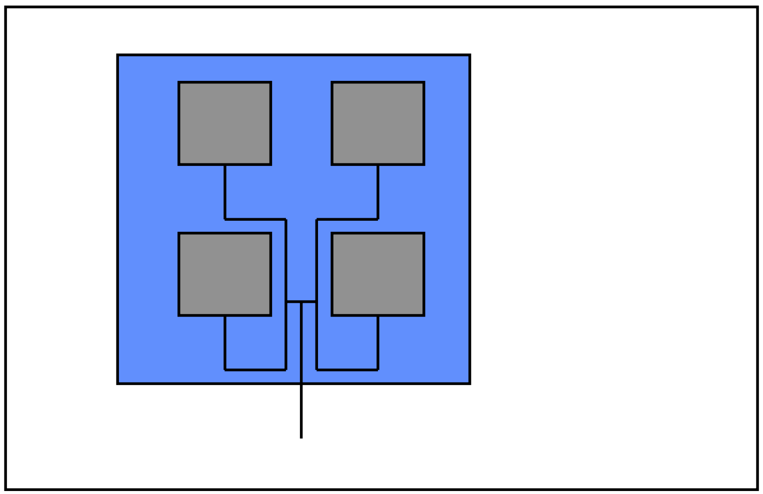
<u>Patch</u>

- ★ 1/4 λ plate conductor on reflector
- ★ 6dBi

Basic antenna operation

Directional antenna types





Parabolic

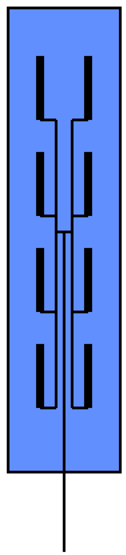
- ★ Parabolic reflector focus signal
- ★ Larger Reflector - more gain
- ★ 25 cm - 15dBi
- ★ 1 m X 50 cm - 24 dBi
- ★ 1 m full - 27 dBi
- ★ 2m full - 31 dBi
- ★ 3m full - 37 dBi

Multiple element patch

- ★ 4 element - 12 dBi
- ★ 12 element - 17 dB

Basic antenna operation

Directional antenna types



Multiple 1/4 λ dipole

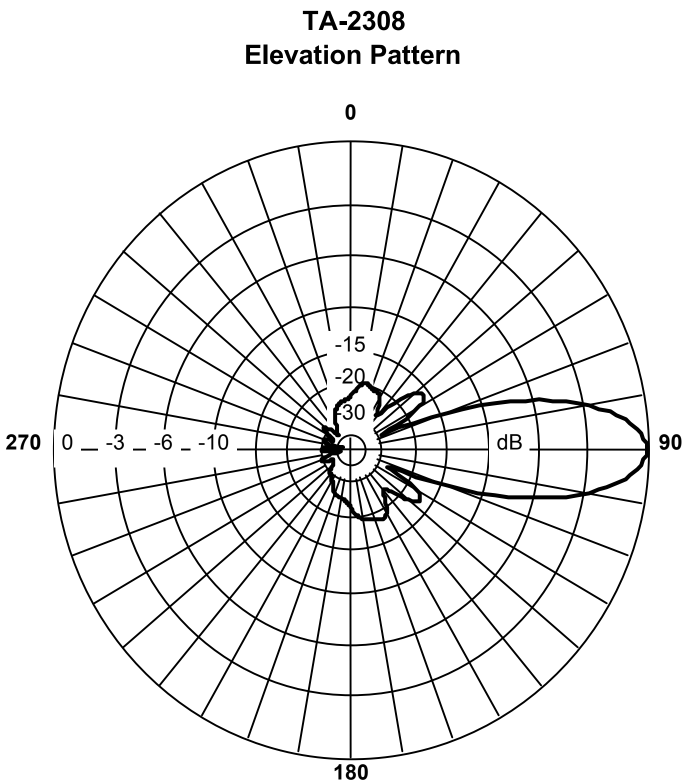
Active Elements

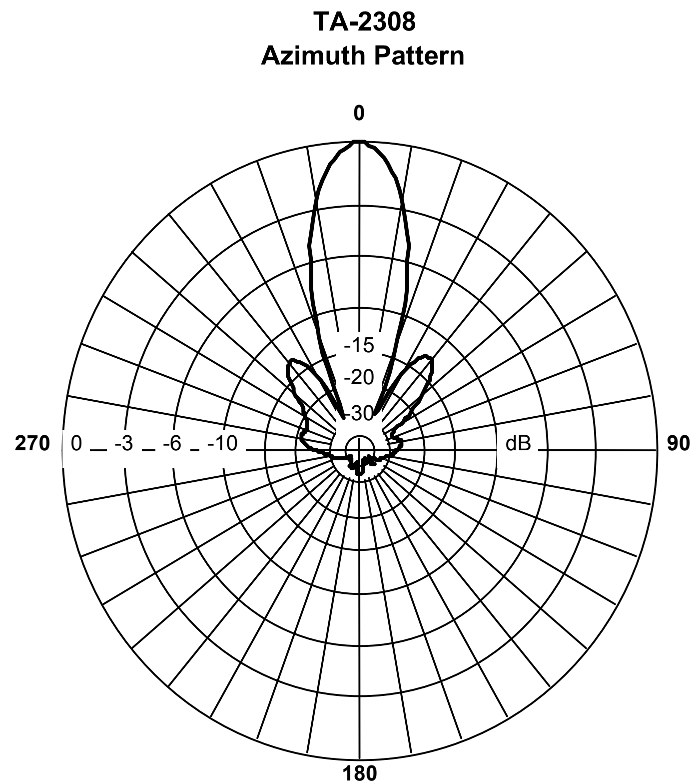
Parabolic

- ★ Sectoral Dipole Array
- ★ Multiple dipoles arranged to give
- ★ large Azimuth pattern for horizontal coverage
- ★ 12 dBi - 120°
- ★ 16 dBi - 90°

Basic antenna operation

Polar Diagram - Parabolic

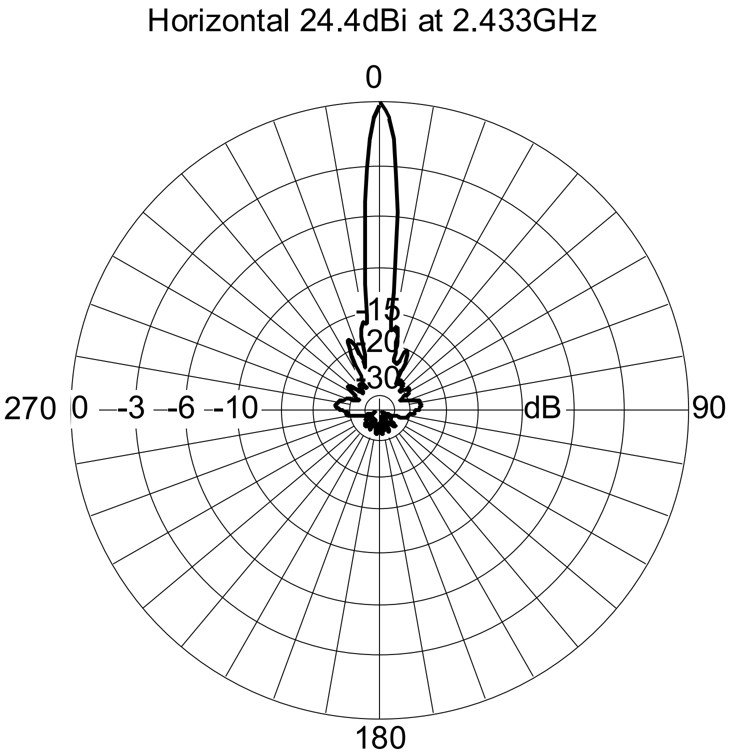


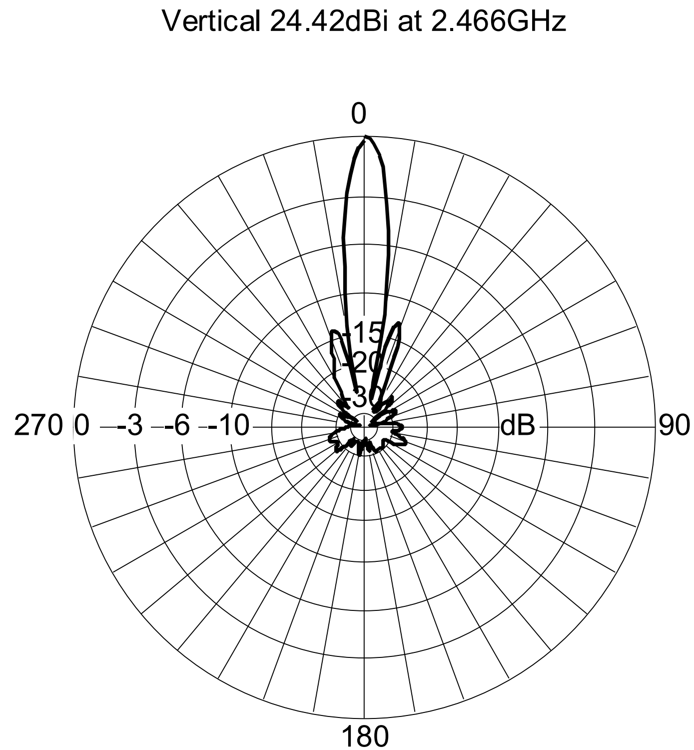


AVAYA communication

Basic antenna operation

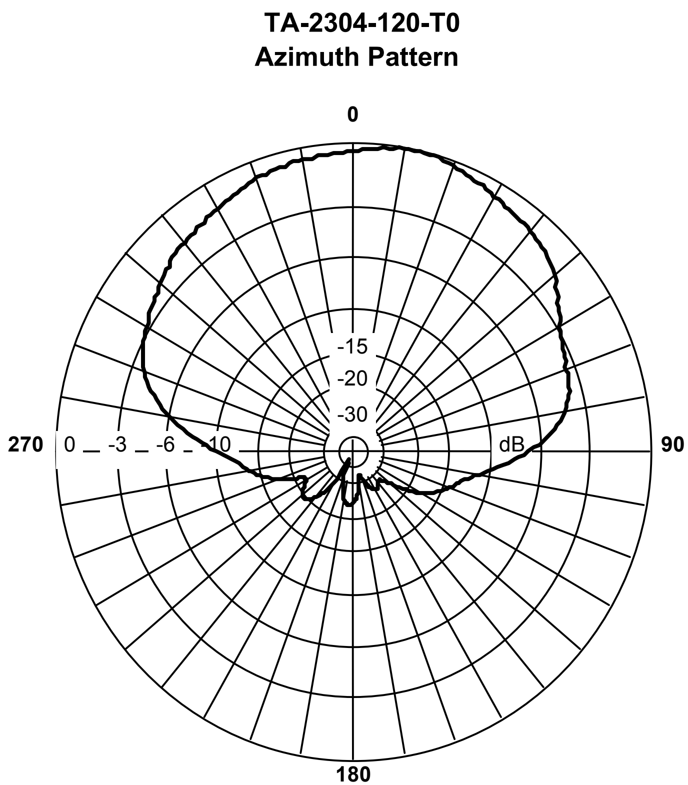
Polar Diagram - Parabolic Directional Antenna

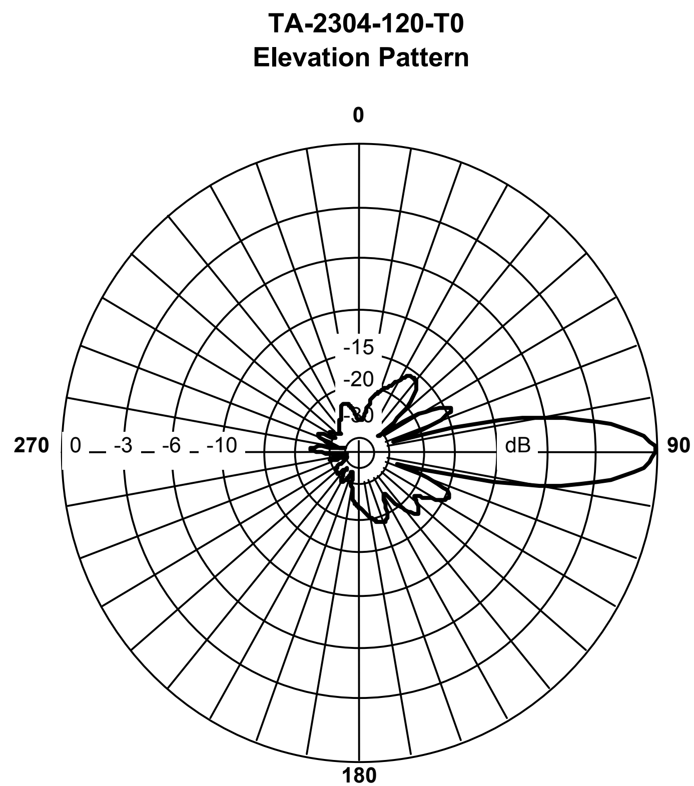




Basic antenna operation

Polar Diagram - Sector





Basic antenna operation

Antenna Specifications

- Gain in dBi
- Pattern , Azimuth (Horizontal) and Elevation (Vertical) shown in Polar diagram dB loss per angle
- Impedance at operating Frequency (50 ohms)
- Bandwidth, gain vs frequency graph
- Front to back ratio - signal behind a directional antenna
- Mechanical properties, weather resistance, mounting methods

RF propagation

Coverable distance

The distance that a wireless link can bridge is depends on:

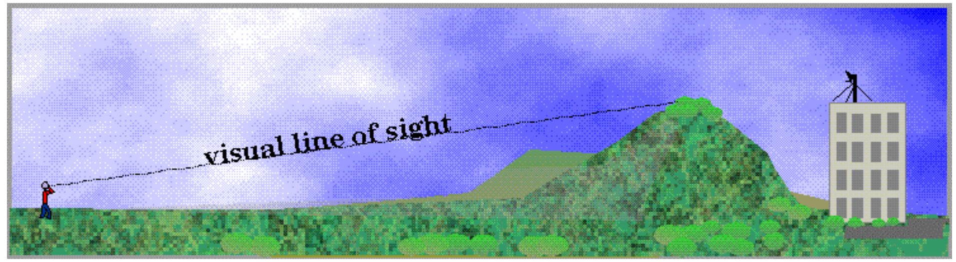
- ★ RF budget
  - ★ gain
  - ★ Insertion loss
  - ★ Receiver sensitivity
- ★ Path loss
  - ★ Environmental Conditions (influencing the path loss)
  - ★ free space versus non free space
  - ★ line of sight
  - ★ Reflections / Interference
  - ★ Weather

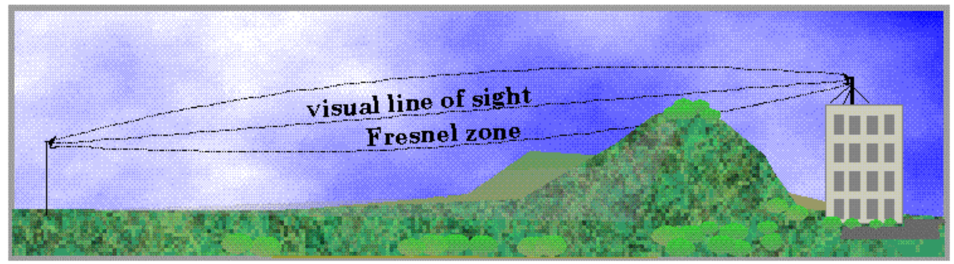
RF propagation

Free space versus non free space

Non-free space

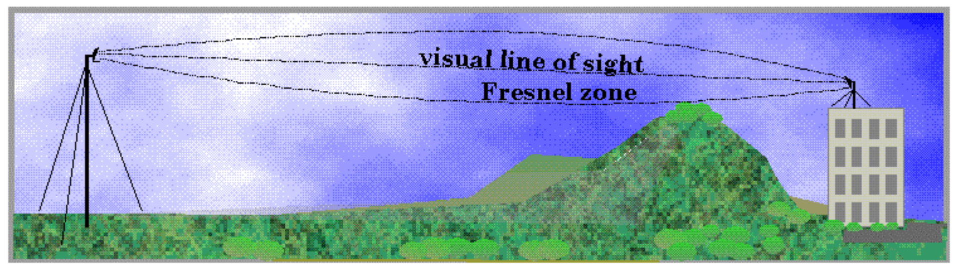
- ★ Line of sight required
- ★ Objects protrude in the fresnel zone, but do not block the path





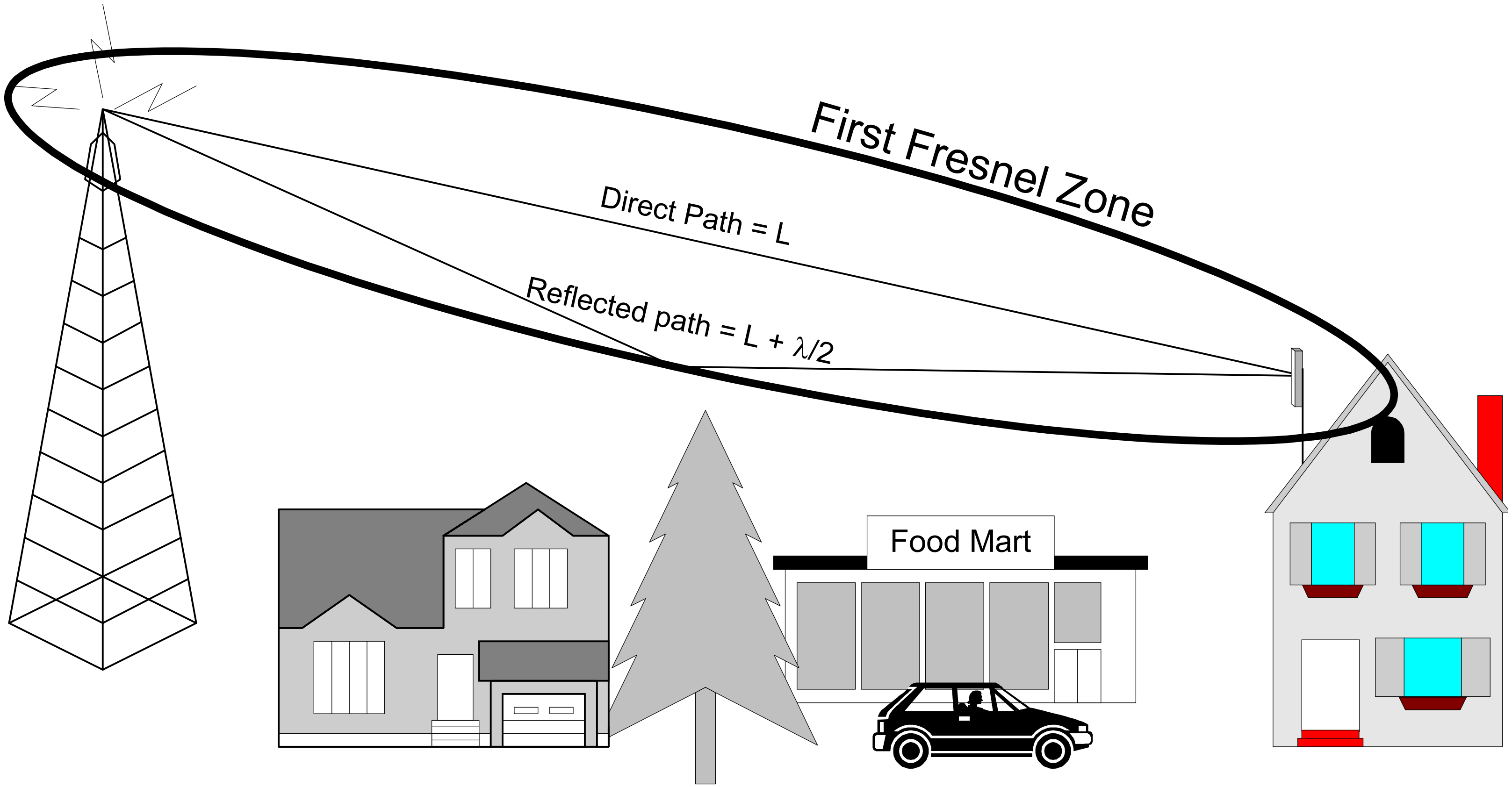
Free Space

- ★ Line of sight
- ★ No objects in the fresnel zone
- ★ Antenna height is significant
- ★ Distance relative short (due to effects of curvature of the earth)



RF propagation

First Fresnel Zone

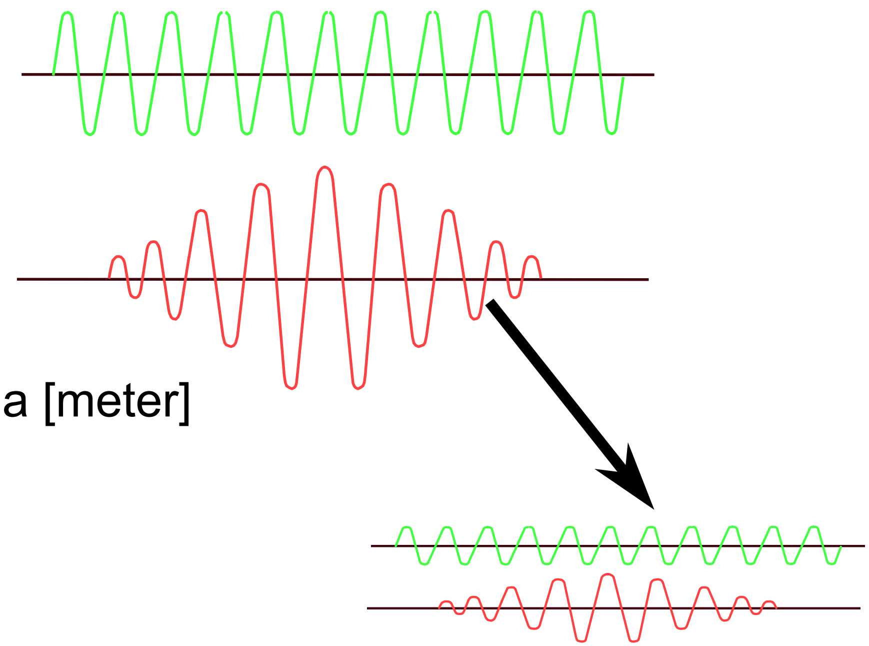


RF Propagation

Basic loss formula

Propagation Loss

$$P_R = P_T * G * (\frac{\lambda}{4\pi d})^2$$



d = distance between Tx and Rx antenna [meter]

P_T = transmit power [mW]

P_R = receive power [mW]

G = antennae gain

$Pr \sim 1/f^2 * D^2$ which means 2X Frequency = 1/4 Power

2 X Distance = 1/4 Power

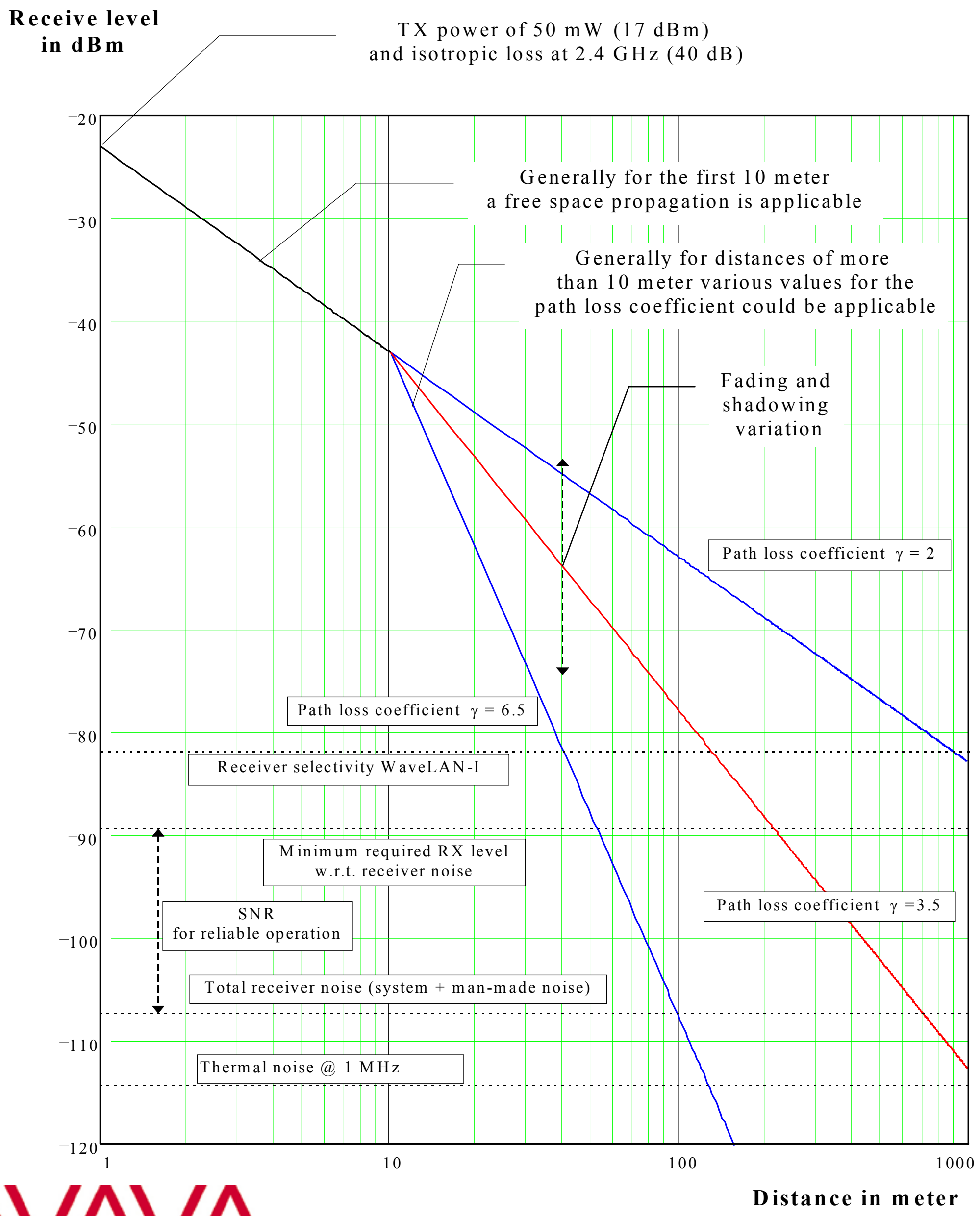
RF propagation

Propagation loss in non free space

- For outdoor usage models have been created that include
  - path loss coefficient up to a measured breakpoint (γ_1)
  - path loss coefficient beyond measured breakpoint (γ_2)
  - breakpoint depend on antenna height (d_{br})

$$L_{(2.4GHz)} = 40 + 10 * \gamma_1 * \log(d_{br}) + 10 * \gamma_2 * \log(d/d_{br})$$

AVAYA communication


Receive level in dBm
TX power of 50 mW (17 dBm) and isotropic loss at 2.4 GHz (40 dB)
Generally for the first 10 meter a free space propagation is applicable
Generally for distances of more than 10 meter various values for the path loss coefficient could be applicable
Fading and shadowing variation
Path loss coefficient γ = 2
Path loss coefficient γ = 6.5
Receiver selectivity WaveLAN-I
Minimum required RX level w.r.t. receiver noise
SNR for reliable operation
Path loss coefficient γ =3.5
Total receiver noise (system + man-made noise)
Thermal noise @ 1 MHz
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
1
10
100
1000
Distance in meter

RF propagation

Loss formulas

Free space:

$$L_p = 40 + 20 * \log(d)$$

- d is the distance between the two antennas in meters

Non-free space:

$$L_p = 40 + 10 * \gamma_1 * \log(d_{br}) + 10 * \gamma_2 * \log(d/d_{br})$$

- path loss coefficient up to a measured breakpoint (γ_1)
- path loss coefficient beyond measured breakpoint (γ_2)
- breakpoint depend on antenna height (d_{br})

RF propagation

RF Budget

The total amount of signal energy that is generated by the transmitter and the active/passive components in the path between the two radios, in relation to the amount of signal required by the receiver to be able to interpret the signal

$$L_p < P_t - P_r + G_t - I_t + G_r - I_r$$

Where:

P_t = Power on transmit

G_t = Gain of transmitting antenna

G_r = Gain of receiving antenna

L_p = path loss

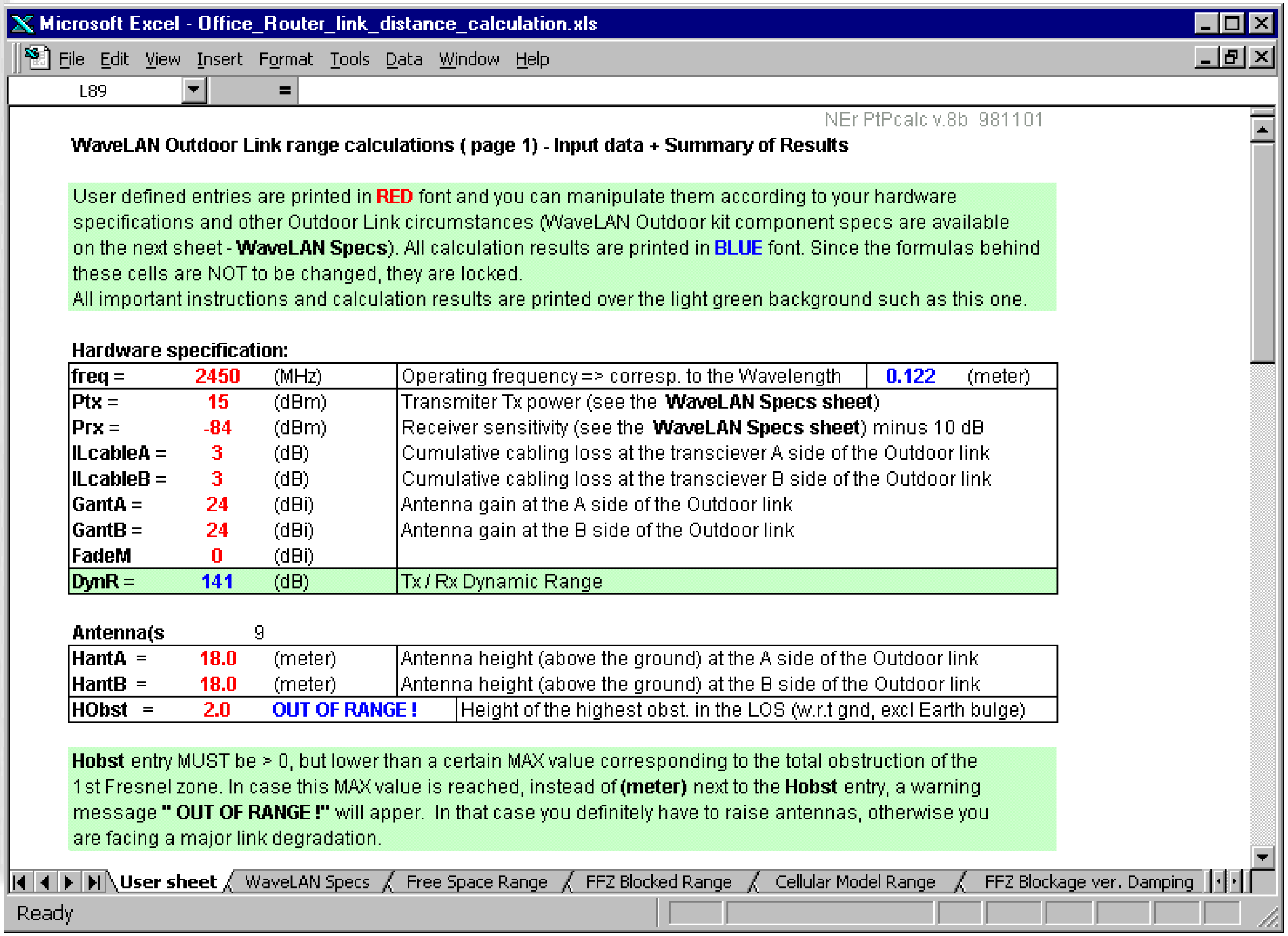
P_r = Power on receive

I_t = Insertion loss in the transmit part

I_r = Insertion loss in the receive part

RF propagation

RF Budget - spreadsheet calculation tools



Microsoft Excel - Office_Router_link_distance_calculation.xls

File Edit View Insert Format Tools Data Window Help

L89 =

NEr PtPcalc v.8b 981101

WaveLAN Outdoor Link range calculations (page 1) - Input data + Summary of Results

User defined entries are printed in **RED** font and you can manipulate them according to your hardware specifications and other Outdoor Link circumstances (WaveLAN Outdoor kit component specs are available on the next sheet - **WaveLAN Specs**). All calculation results are printed in **BLUE** font. Since the formulas behind these cells are NOT to be changed, they are locked.
All important instructions and calculation results are printed over the light green background such as this one.

Hardware specification:

freq =	2450	(MHz)	Operating frequency => corresp. to the Wavelength	0.122	(meter)
Ptx =	15	(dBm)	Transmiter Tx power (see the **WaveLAN Specs sheet**)		
Prx =	-84	(dBm)	Receiver sensitivity (see the **WaveLAN Specs sheet**) minus 10 dB		
lLcableA =	3	(dB)	Cumulative cabling loss at the transciever A side of the Outdoor link		
lLcableB =	3	(dB)	Cumulative cabling loss at the transciever B side of the Outdoor link		
GantA =	24	(dBi)	Antenna gain at the A side of the Outdoor link		
GantB =	24	(dBi)	Antenna gain at the B side of the Outdoor link		
FadeM	0	(dBi)			
DynR =	141	(dB)	Tx / Rx Dynamic Range		

Antenna(s 9

HantA =	18.0	(meter)	Antenna height (above the ground) at the A side of the Outdoor link
HantB =	18.0	(meter)	Antenna height (above the ground) at the B side of the Outdoor link
HObst =	2.0	OUT OF RANGE !	Height of the highest obst. in the LOS (w.r.t gnd, excl Earth bulge)

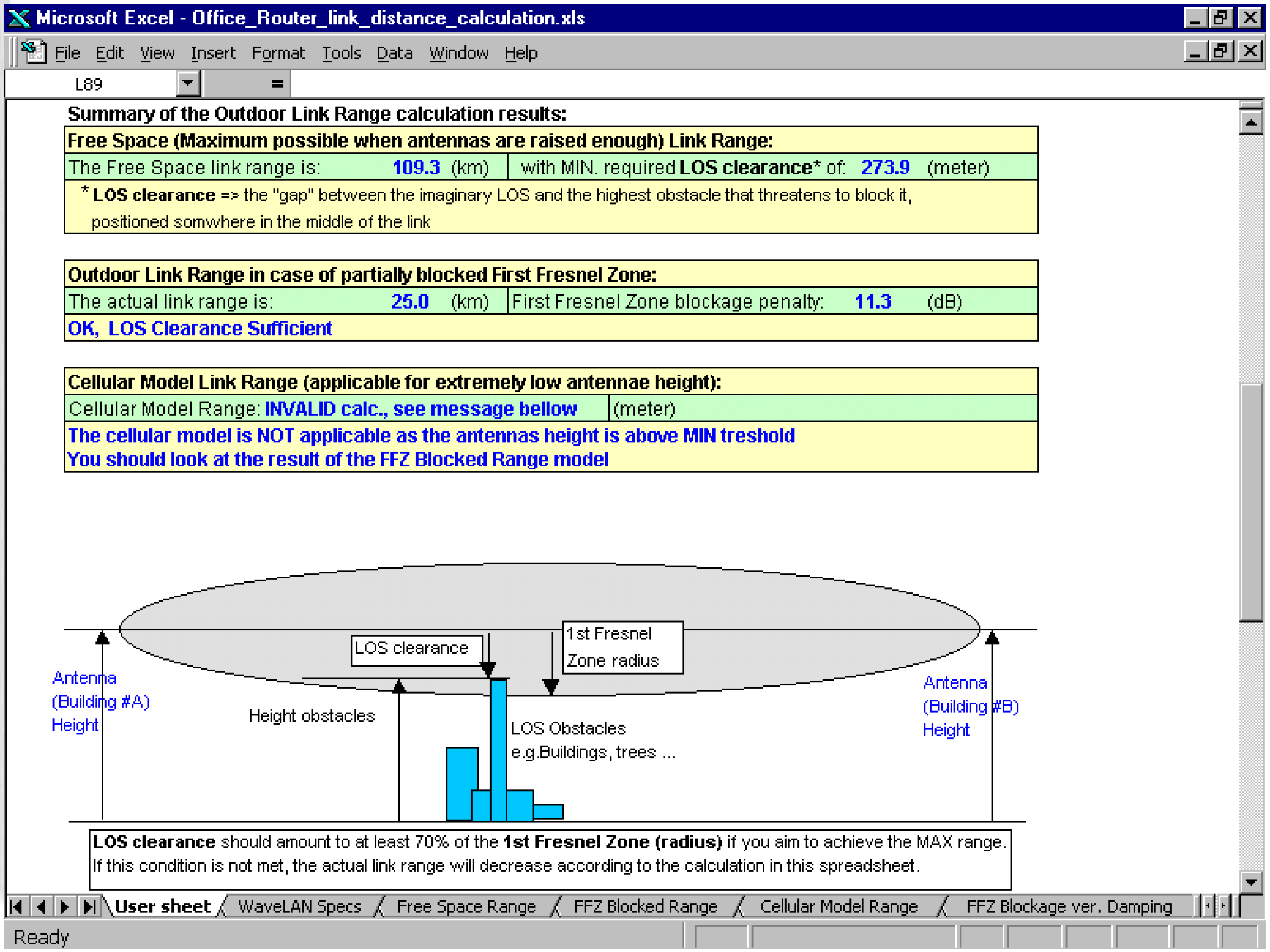
Hobst entry MUST be > 0, but lower than a certain MAX value corresponding to the total obstruction of the 1st Fresnel zone. In case this MAX value is reached, instead of **(meter)** next to the **Hobst** entry, a warning message **" OUT OF RANGE !"** will apper. In that case you definitely have to raise antennas, otherwise you are facing a major link degradation.

User sheet / WaveLAN Specs / Free Space Range / FFZ Blocked Range / Cellular Model Range / FFZ Blockage ver. Damping

Ready

RF propagation

RF Budget - spreadsheet calculation tools

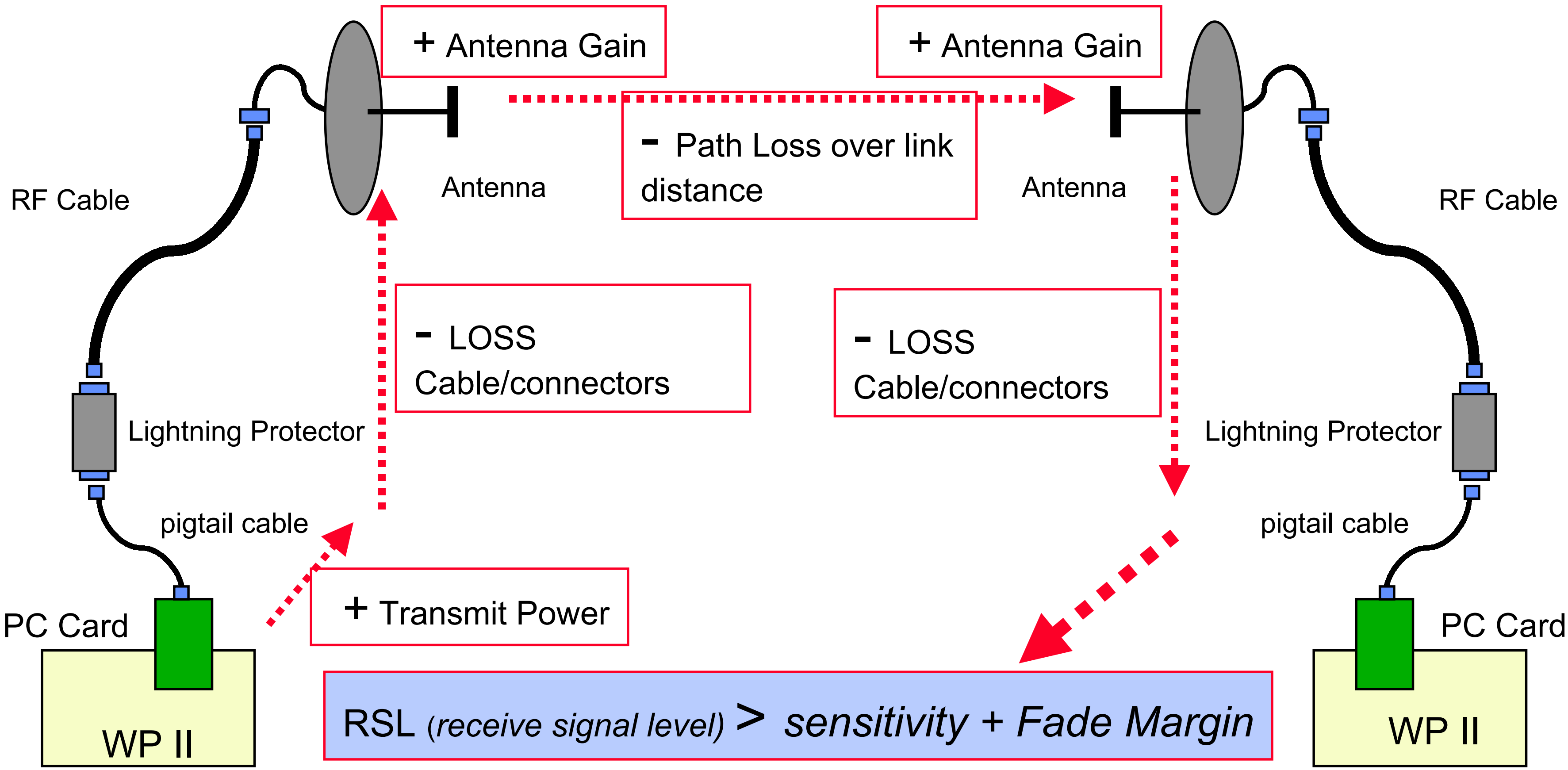


Click here to start the spreadsheet

AVAYA communication

RF propagation

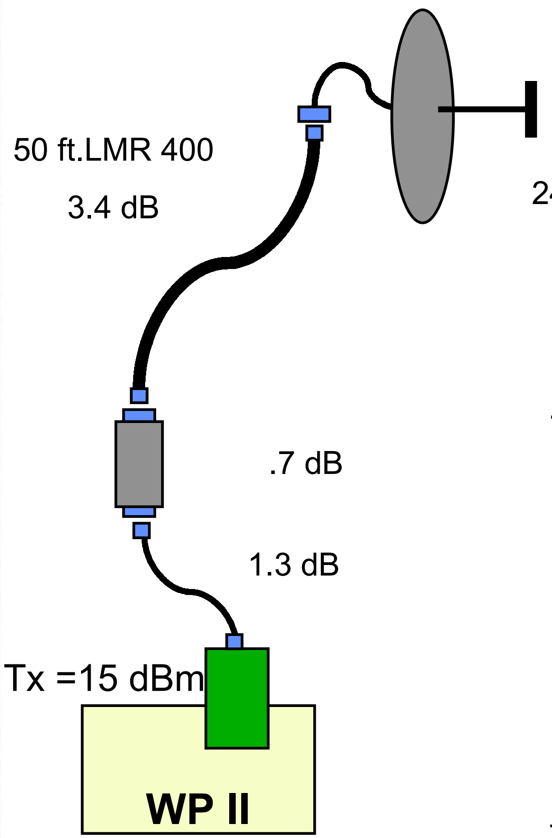
Simple Path Analysis Concept (alternative)



Calculate signal in one direction if Antennas and active components are equal

RF propagation

RSL and FADE MARGIN



For a Reliable link - the signal arriving at the receiver - RSL - should be greater than the Sensitivity of the Radio (-82dBm for 11 Mbit)

This EXTRA signal strength is FADE MARGIN

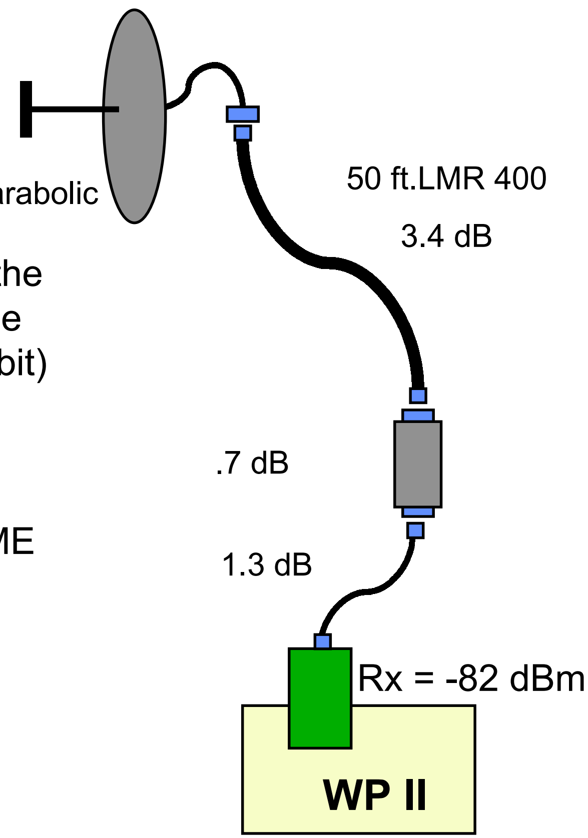
FADE MARGIN can be equated to UPTIME

Minimum Fade Margin = 10 dB

Links subject to interference (city) = 15dB

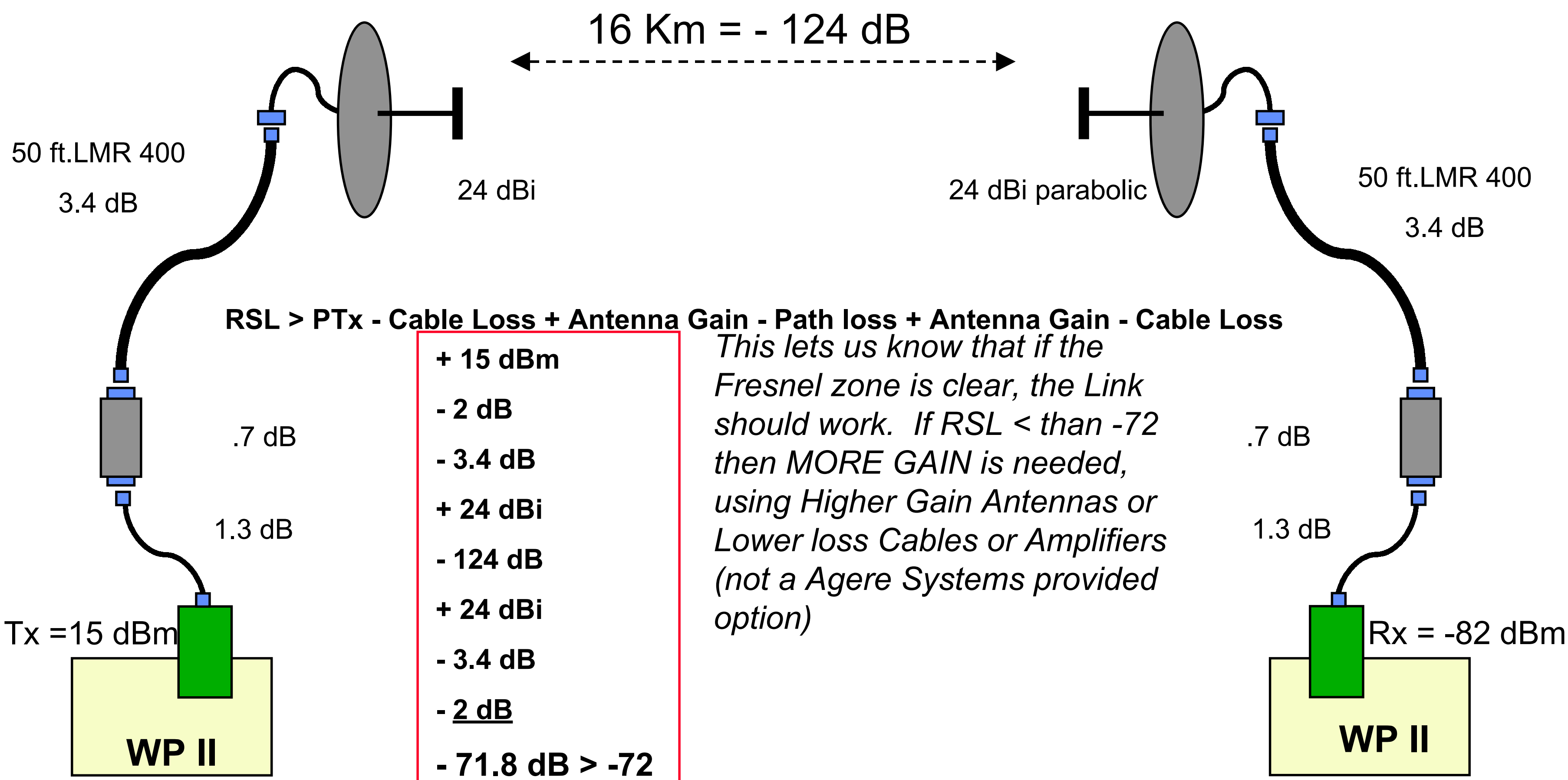
Links with Adverse Weather = 20dB

<u>Calculate RSL > -82 + 10 = -72dBm</u>



RF propagation

Sample Calculation



RSL > PTx - Cable Loss + Antenna Gain - Path loss + Antenna Gain - Cable Loss

+ 15 dBm
- 2 dB
- 3.4 dB
+ 24 dBi
- 124 dB
+ 24 dBi
- 3.4 dB
- <u>2 dB</u>
- 71.8 dB > -72

This lets us know that if the Fresnel zone is clear, the Link should work. If RSL < than -72 then MORE GAIN is needed, using Higher Gain Antennas or Lower loss Cables or Amplifiers (not a Agere Systems provided option)

RF Propagation

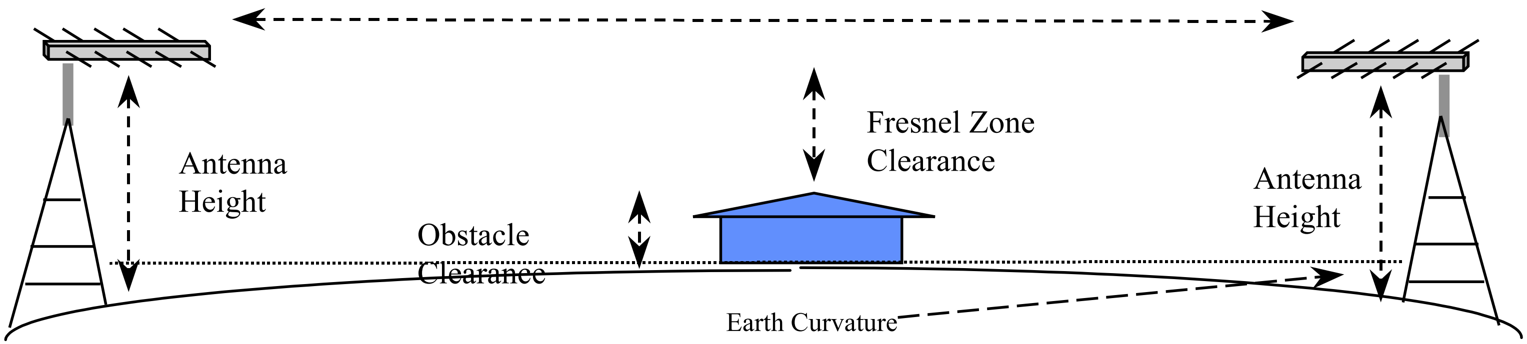
Antenna Height requirements

Fresnel Zone Clearance = 0.6 first Fresnel distance (Clear Path for Signal at mid point) • 30 feet for 10 Km path •57 feet for 40 Km path	Clearance for Earth's Curvature •13 feet for 10 Km path •200 feet for 40 Km path

Midpoint clearance = 0.6F + Earth curvature + 10' when K=1

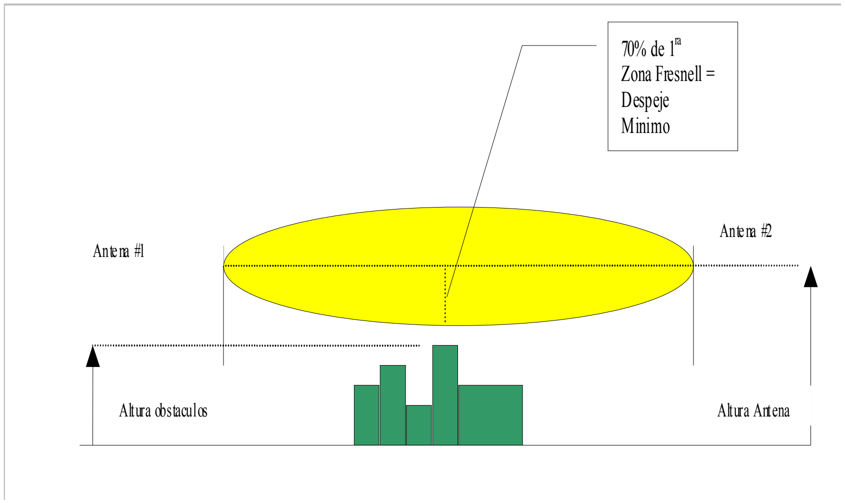
First Fresnel Distance (meters) **F1= 17.3 [(d1*d2)/(f*D)]$^{1/2}$** where D=path length Km, f=frequency (GHz) , d1= distance from Antenna1(Km) , d2 = distance from Antenna 2 (Km)

Earth Curvature **h = (d1*d2) /2** where h = change in vertical distance from Horizontal line (meters), d1&d2 distance from antennas 1&2 respectively



RF Propagation

Antenna Heights



Distancia en km	1ra Zona de Fresnel	0.7 *1ra Zona de Fresnel @ 2.4 GHz en metros	Curvatura Terrestre	TOTAL metros
1	5.5	3.9	0.0	3.9
2	7.8	5.5	0.2	5.6
3	9.6	6.7	0.4	7.1
4	11.1	7.7	0.7	8.4
5	12.4	8.7	1.0	9.7
6	13.6	9.5	1.5	11.0
7	14.6	10.2	2.0	12.3
8	15.6	11.0	2.7	13.6
9	16.6	11.6	3.4	15.0
10	17.5	12.2	4.2	16.4
11	18.4	12.8	5.0	17.9
12	19.2	13.4	6.0	19.4
13	19.9	14.0	7.0	21.0
14	20.7	14.5	8.2	22.7
15	21.4	15.0	9.4	24.4
16	22.1	15.5	10.7	26.2
17	22.8	16.0	12.0	28.0
18	23.5	16.4	13.5	29.9
19	24.1	16.9	15.0	31.9
20	24.7	17.3	16.7	34.0
25	27.7	19.4	26.0	45.4
30	30.3	21.2	37.5	58.7

RF Propagation

Antenna Heights vs. Range

Fundamental limitation of technology is the requirement for very High Antenna Heights for full Fresnel zone clearance - But this requires more cable, thus more loss and thus less Range - NO FREE LUNCH.

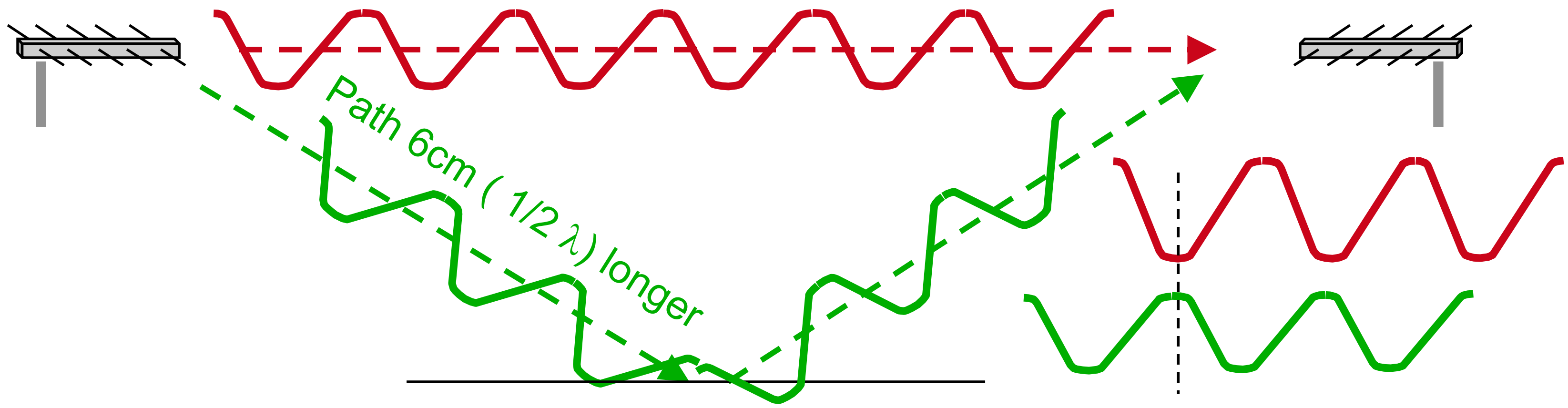
Suggestions:

- ★ Use better quality cable (lower loss per foot) LMR 400 = 6.8 dB 100 ft, LMR 600 = 4.5dB/100ft, LMR 1800 = 2.5dB/100ft, 2 1/4” Helix = .98 dB foot BUT the better cable the harder to install (large and inflexible) and the more expensive.
- ★ Remote mount the AP-1000 in a Environmental Box (ventilated) and drop UTP of Fiber into building - requires Lightning protection and 110VAC BUT Maintenance requires climbing Tower.
- ★ Use remote Mounted amplifiers (not available from Agere Systems) to overcome the cable loss. Amplifiers still have minimum input power requirements so better cable may still be needed for long runs. Amplifiers are specified by Max transmit Power (1/2 or 1 Watt), Tx Gain, Rx Gain, Input signal levels BUT amplifiers add noise to the system and may not actually increase SNR as much as expected - also they are another point of failure.

RF Propagation

Reflections

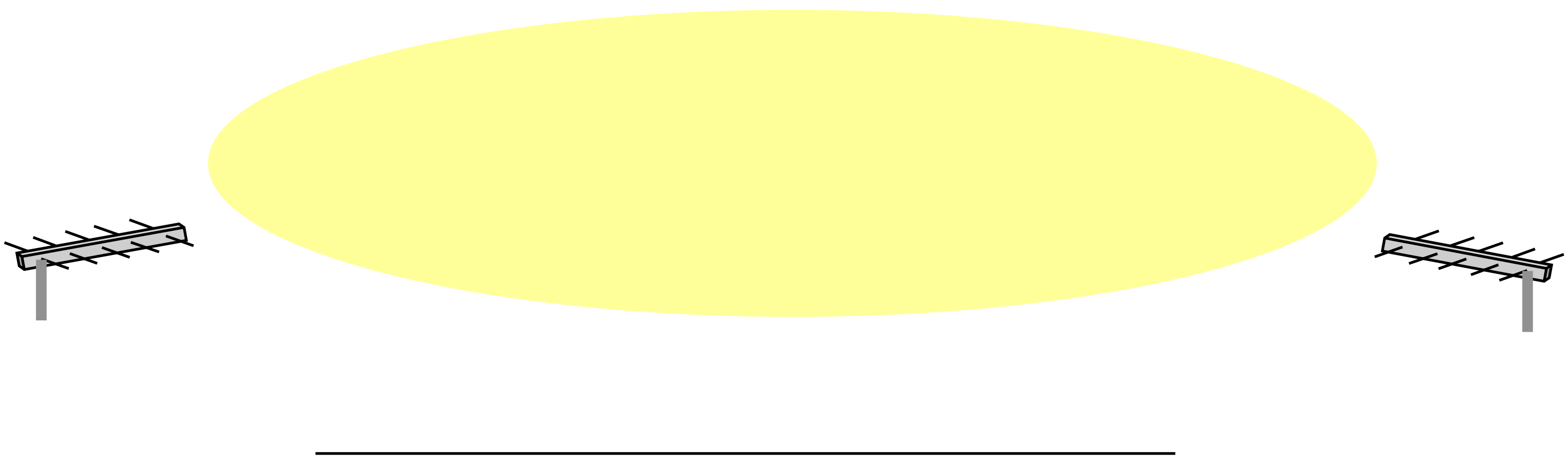
- ★ Signals arrive 180° out of phase (1/2 λ) from reflective surface
- ★ Cancel at antenna - Try moving Antenna to change geometry of link - 6cm is the difference in-phase to out of phase



RF Propagation

Reflections

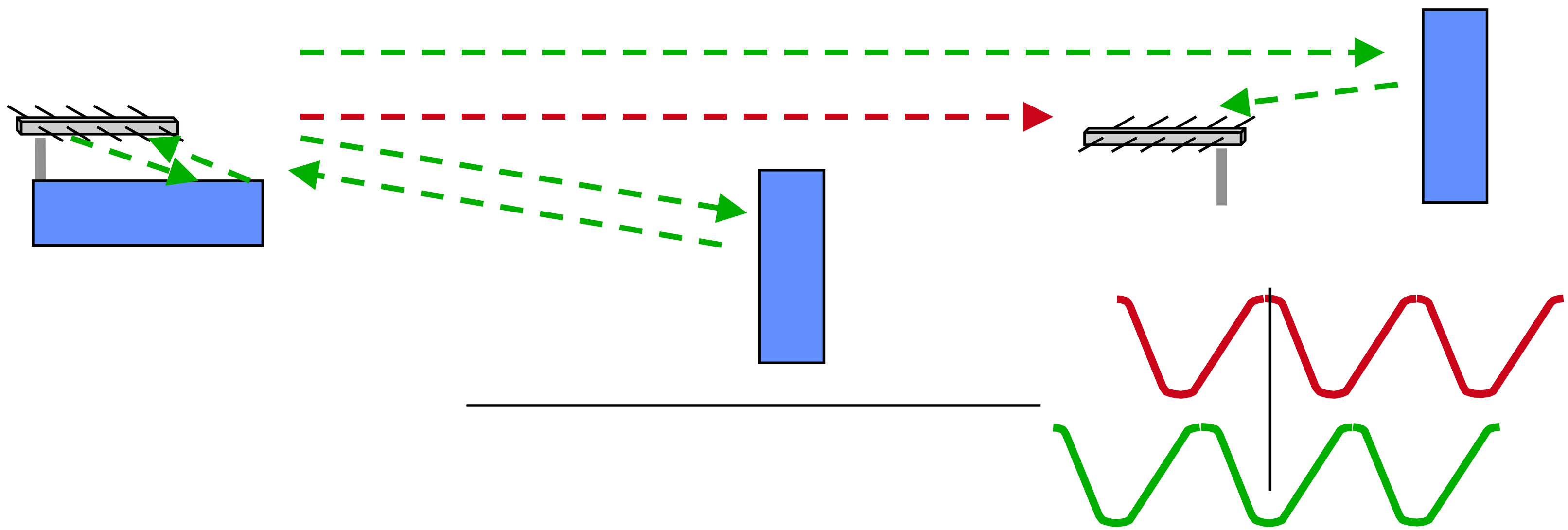
- ★ Use Higher gain, less Elevation beam-width antennas or Aim Antennas upward to use bottom of Pattern to connect less signal bouncing off ground reflector.



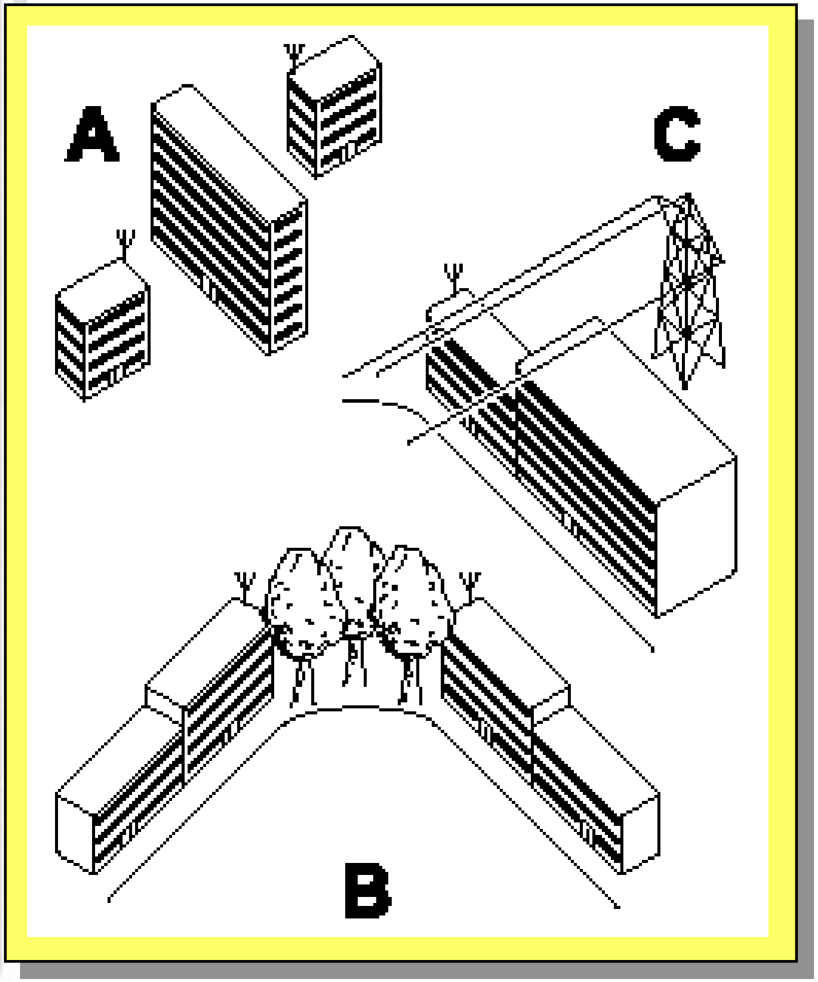
RF Propagation

Reflections

- ★ Reflections can come from ANYWHERE - behind, under, in-front
- ★ 6 cm difference can change Path geometry



RF propagation
Environmental conditions



- ★ Line of Sight
  - ★ No objects in path between antenna
  - ★ a. Neighboring Buildings
  - ★ b. Trees or other obstructions
- ★ Interference
  - ★ c. Power lines

RF propagation

Environmental conditions

Weather

- Snow
  - Ice and snow when attached to the antenna has negative impact
- heavy rain on flat panels
  - When rain creates a “water film” it will negatively impact performance
  - Rainfall in the path has little impact
- Storm
  - Can lead to misalignment
- Lightning
  - Surge protector will protect the equipment against static discharges that result of lightning. It cannot protect the system against a direct hit by lightning, but will protect the building from fire in such a case

Module Summary

★ Antenna systems

★ RF propagation