Intro to Radio Propagation,Antennas and Link Budget

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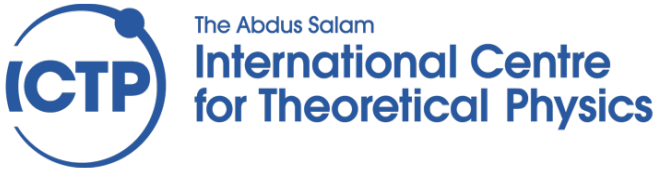


Unlicensed bands

- There are some frequency bands that can be used without the need for the end user to apply for the license, these are the so called “unlicensed bands”, although often the license has been awarded to the manufacturer of the equipment.
- ISM (Industrial, Scientific and Medical) bands are meant to be used for purposes other than telecommunications, but they are also been used nowadays for WiFi and many other devices.
- WiFi success has prompted the designation of other “lightly licensed” bands for telecommunications applications.

Behavior of radio waves

There are a few simple rules of thumb that can prove extremely useful when planning a wireless network:

- The ***longer*** the wavelength, the further it goes
- The ***longer*** the wavelength, the better it travels through and around things
- The ***shorter*** the wavelength, the more data it can transport

Traveling radio waves

Radio waves do not move in a strictly straight line. On their way from “point A” to “point B”, waves may be subject to:

- Absorption
- Reflection
- Diffraction
- Refraction

Absorption

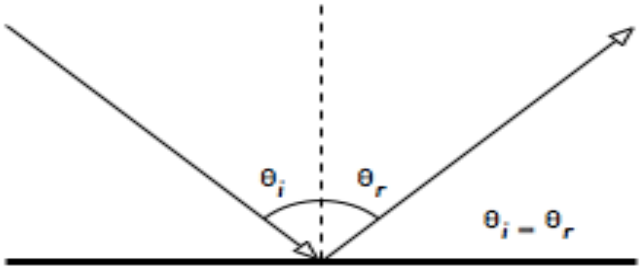
When electromagnetic waves go through some material, they generally get weakened or dampened.

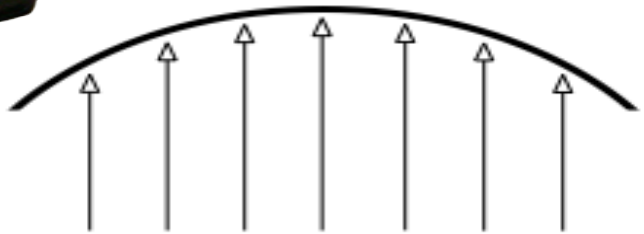
Materials that absorb energy include:

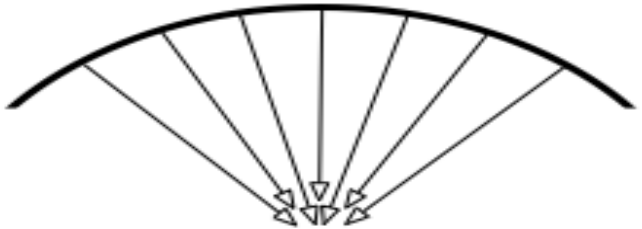
- ***Metal***. Electrons can move freely in metals, and are readily able to swing and thus absorb the energy of a passing wave.
- ***Water*** molecules jostle around in the presence of radio waves, thus absorbing some energy.
- ***Trees*** and ***wood*** absorb radio energy proportionally to the amount of water contained in them.
- ***Humans*** are mostly water: we absorb radio energy quite well!

Reflection

The rules for reflection are quite simple: the angle at which a wave hits a surface is the same angle at which it gets deflected. **Metal** and **water** are excellent reflectors of radio waves.

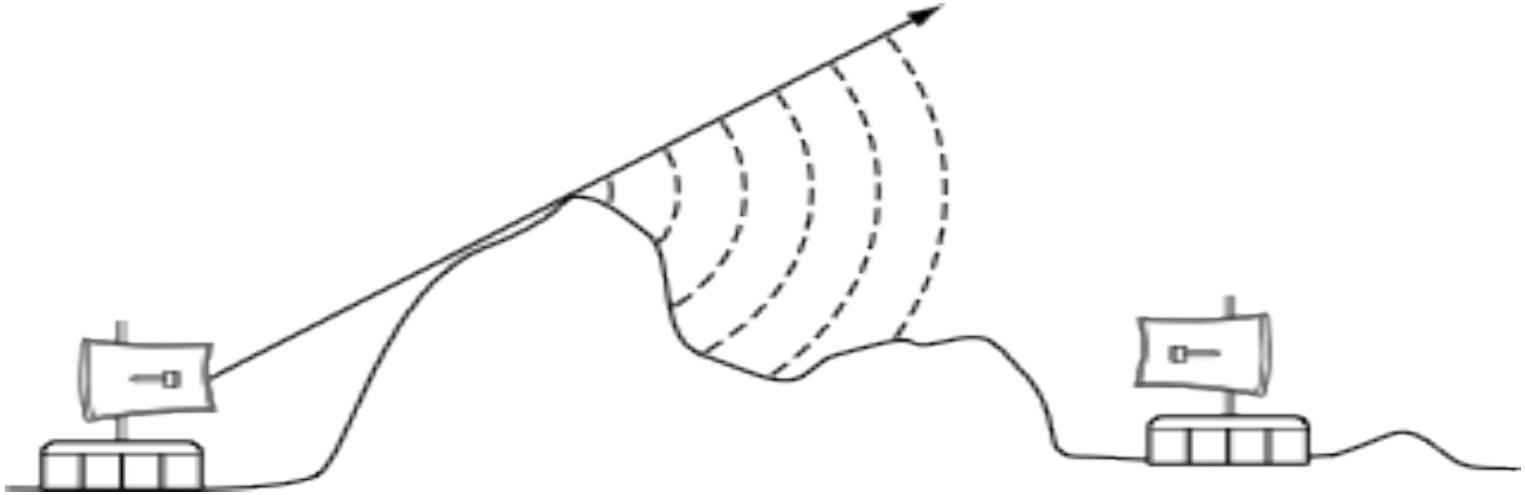






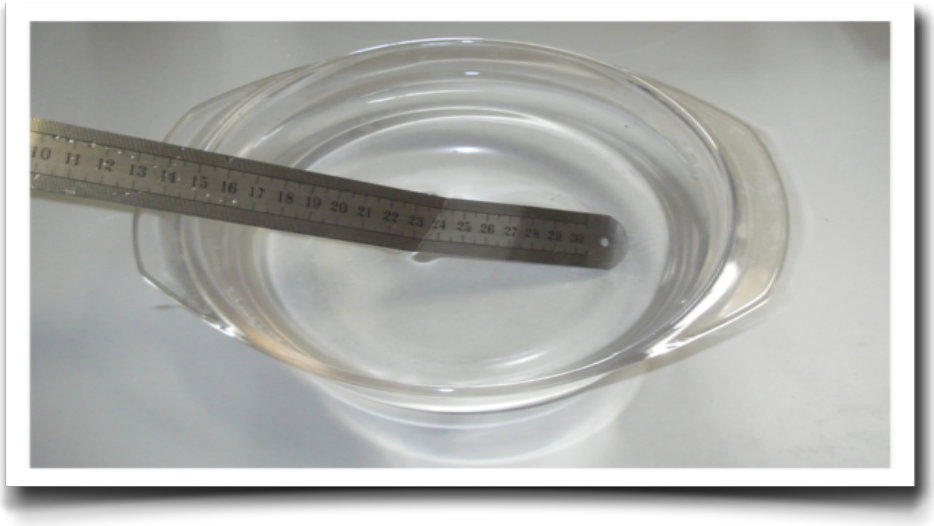
Diffraction

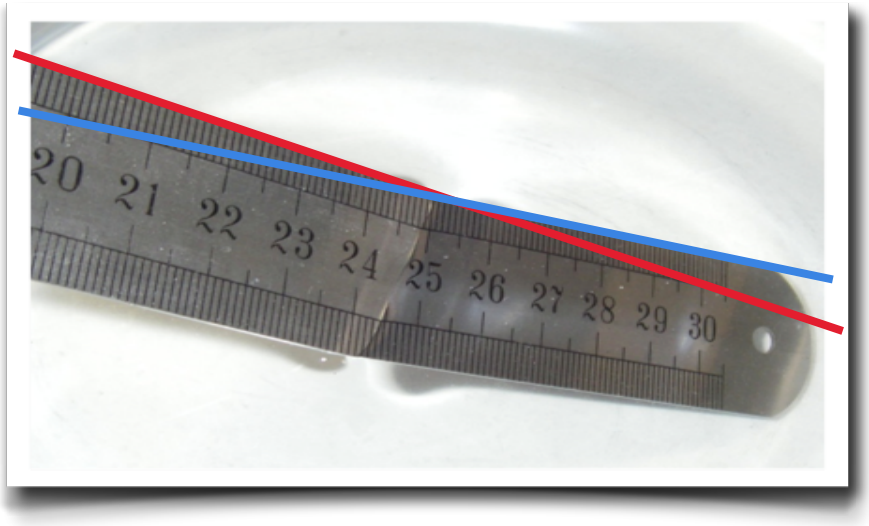
Because of the effect of diffraction, waves will "bend" around corners or through an opening in a barrier.



Refraction

Refraction is the apparent "bending" of waves when they meet a material with different characteristics. When a wave moves from one medium to another, it changes speed and direction upon entering the new medium.

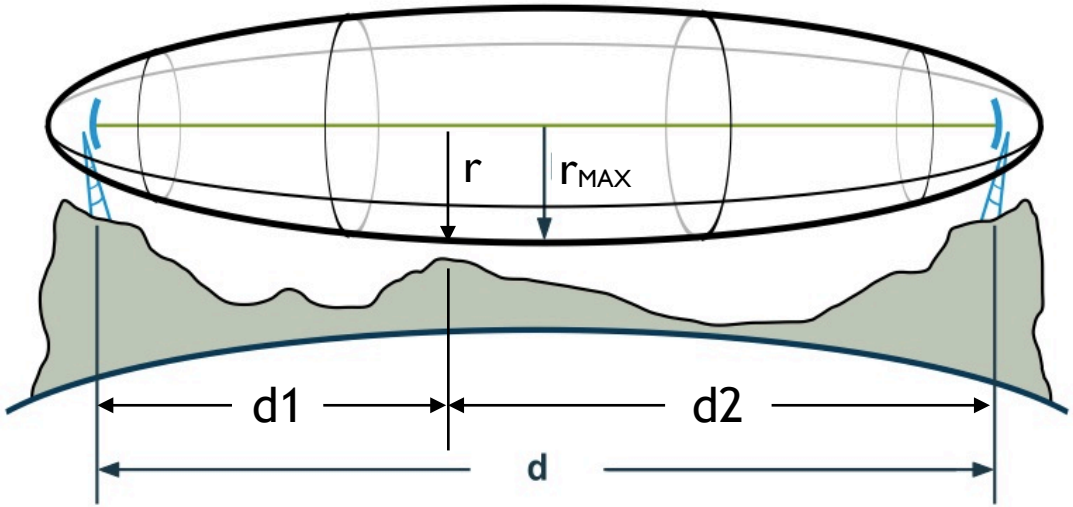




Fresnel Zone

- The First Fresnel Zone is an ellipsoid-shaped volume around the Line-of-Sight path between transmitter and receiver.
- The Fresnel Zone is important to the integrity of the RF link because it defines a volume around the LOS that must be clear of any obstacle for the the maximum power to reach the receiving antenna.
- Objects in the Fresnel Zone as trees, hilltops and buildings can considerably attenuate the received signal, even when there is an unobstructed line between the TX and RX.

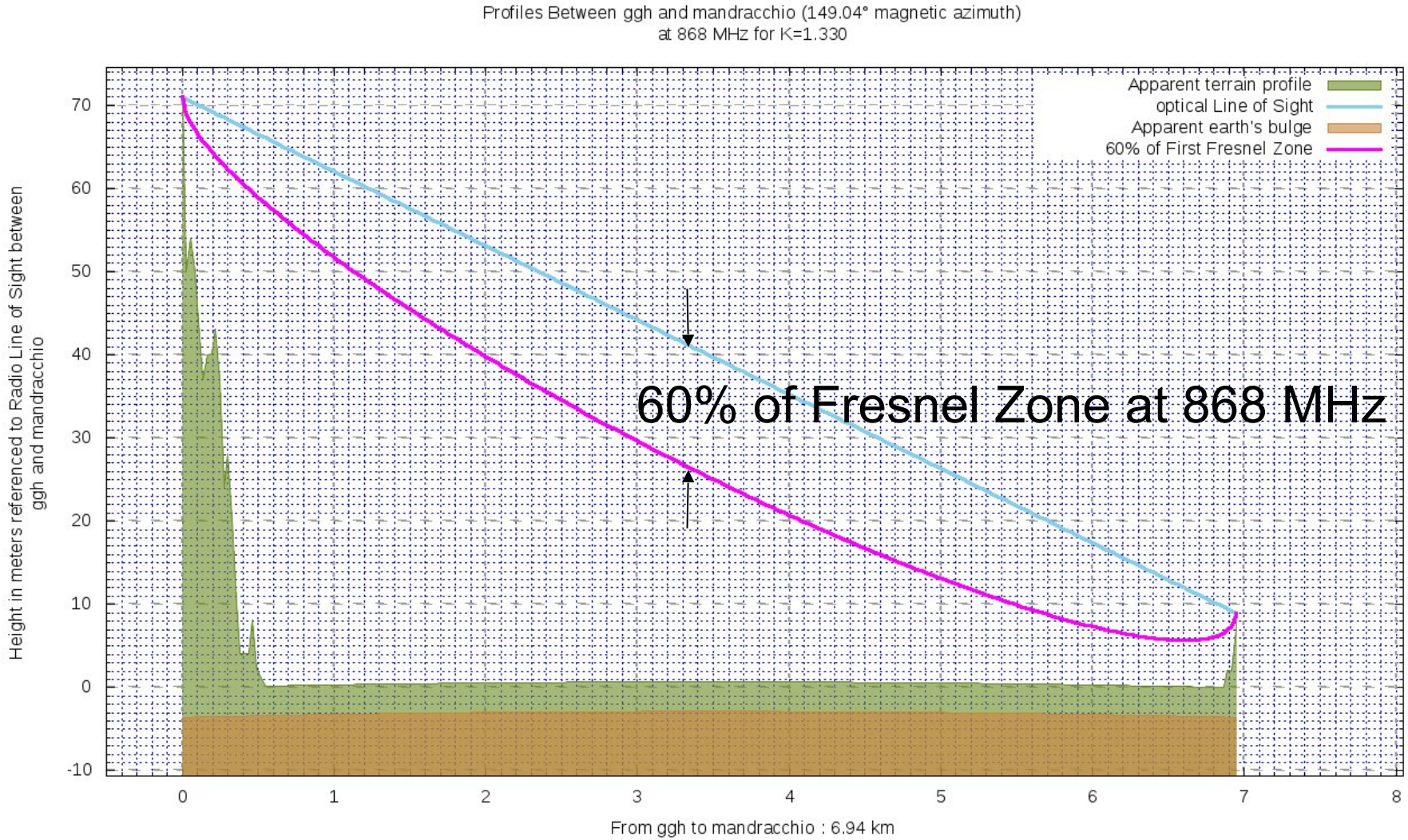
Line of Sight and Fresnel Zones

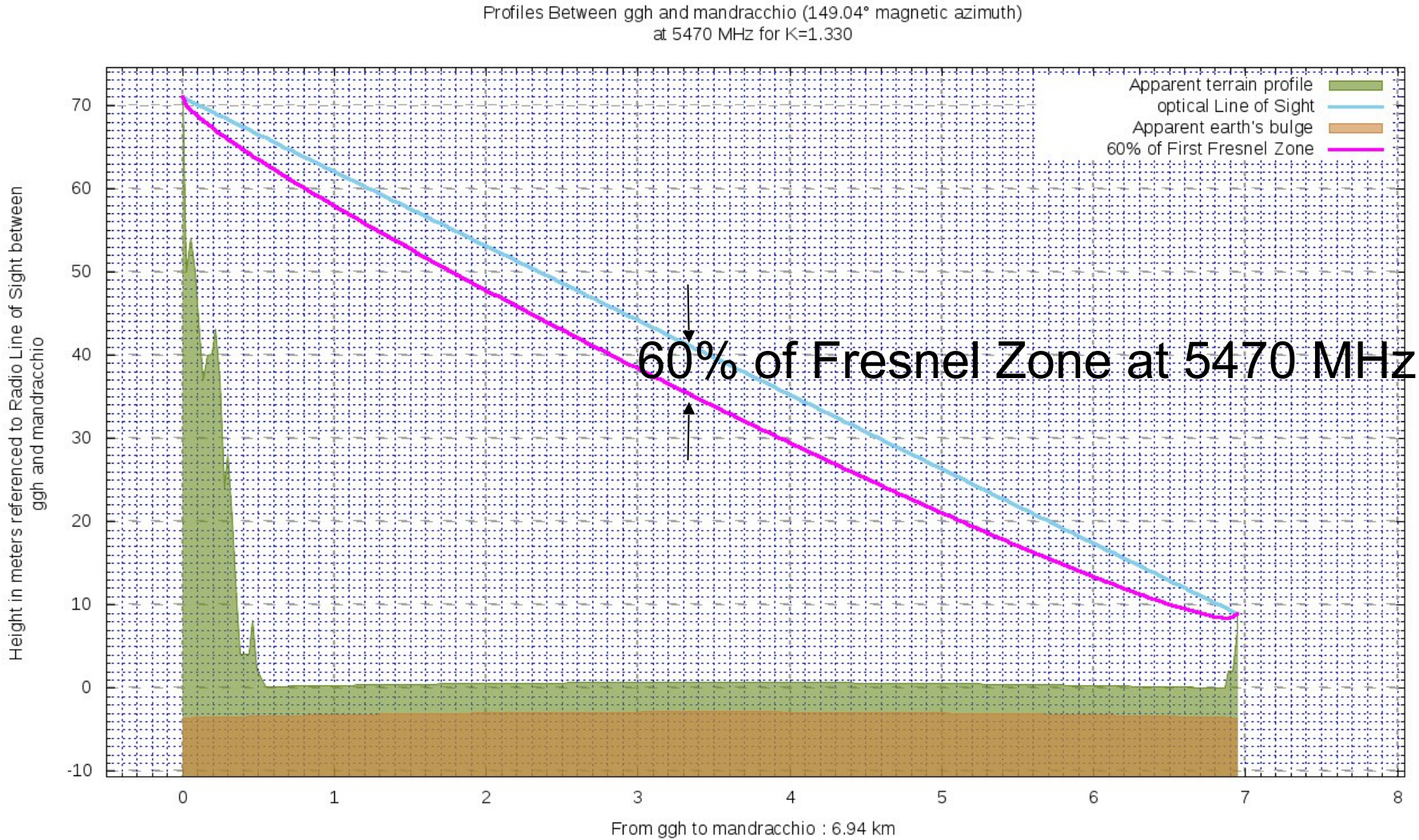


$$r = \sqrt{d1 * d2 * \lambda / d}$$

Optical and Radio LOS

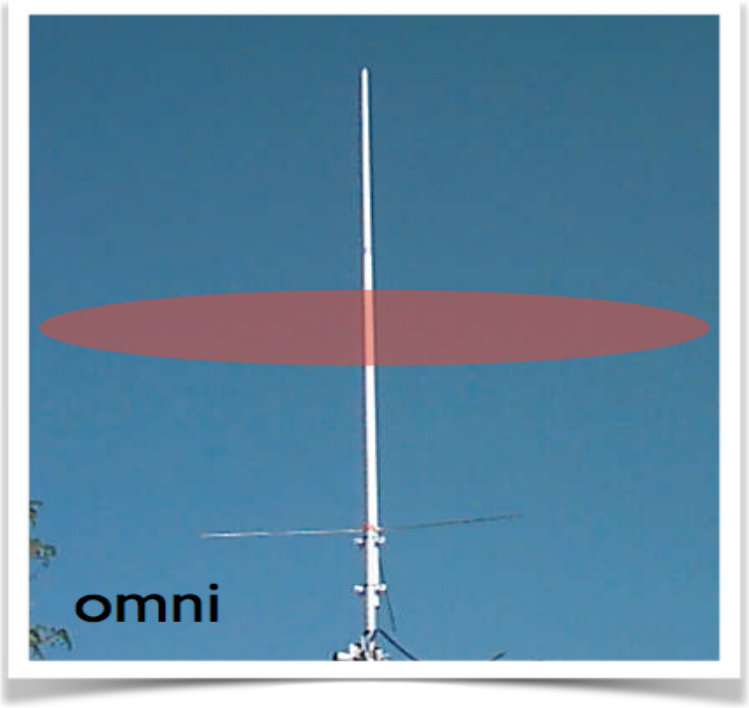
- Optical signals also occupy a Fresnel zone, but since the wavelength is so small (around 10^{-6} m), we don't notice it.
- Therefore, clearance of optical LOS does not guarantee the clearance of RADIO LOS.
- The lower the frequency, the bigger the Fresnel zone; but the diffraction effects are also more significant, so lower radio frequencies can reach the receiver even if there is No Line of Sight.

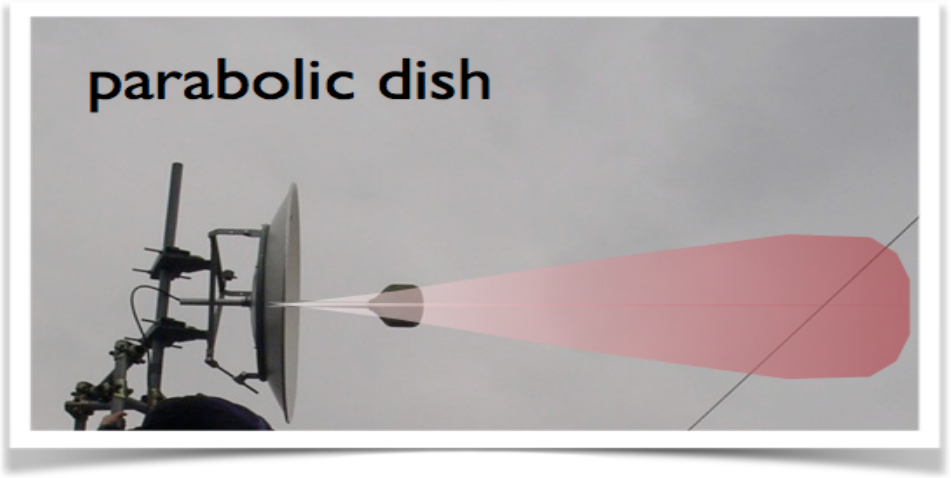

Profiles Between ggh and mandracchio (149.04° magnetic azimuth)
at 868 MHz for K=1.330
Apparent terrain profile
optical Line of Sight
Apparent earth's bulge
60% of First Fresnel Zone
60% of Fresnel Zone at 868 MHz
Height in meters referenced to Radio Line of Sight between ggh and mandracchio
From ggh to mandracchio : 6.94 km
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8


Profiles Between ggh and mandracchio (149.04° magnetic azimuth)
at 5470 MHz for K=1.330
Apparent terrain profile
optical Line of Sight
Apparent earth's bulge
60% of First Fresnel Zone
60% of Fresnel Zone at 5470 MHz
Height in meters referenced to Radio Line of Sight between ggh and mandracchio
From ggh to mandracchio : 6.94 km
70
60
50
40
30
20
10
0
-10
0
1
2
3
4
5
6
7
8

Antennas

Directional vs. Omnidirectional





Adapters & Pigtails

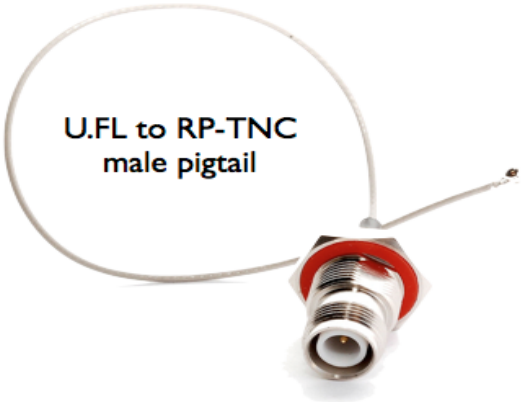
Adapters and pigtails are used to interconnect different kinds of cable or devices.

SMA female to N male

N male to N male

N female to N female

SMA male to TNC male



U.FL to RP-TNC male pigtail

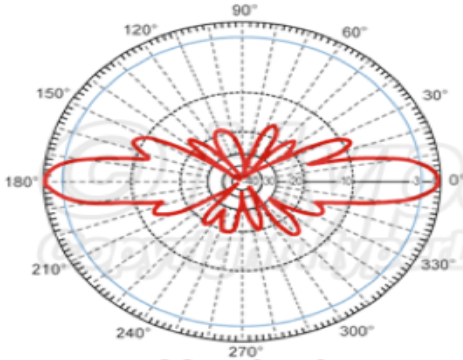
U.FL to N male pigtail

SMA male to N female

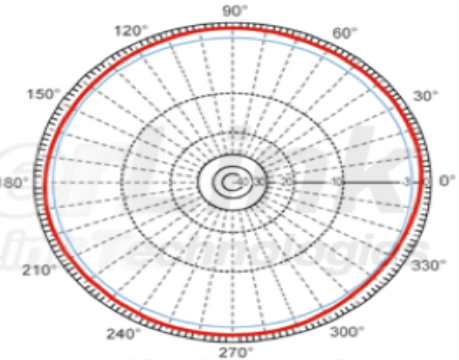
Radiation pattern

The ***radiation pattern*** of an antenna is a pictorial representation of the distribution of the power radiated from, or received by, the antenna. This is presented as a function of direction angles centered on the antenna.

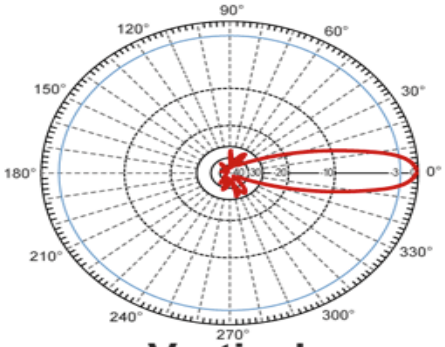
Radiation patterns usually use a polar projection.



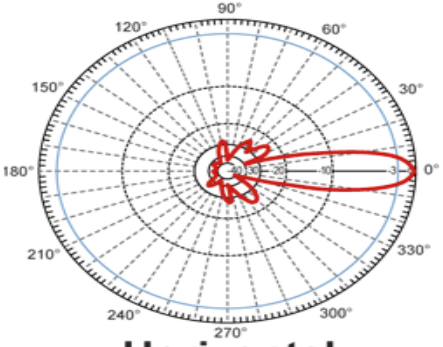
Vertical



Horizontal



Vertical



Horizontal

Reciprocity

Antenna characteristics like gain, beamwidth, efficiency, polarization, and impedance are independent of the antenna's use for either transmitting or receiving.

Another way to state this is that an antenna's transmitting and receiving characteristics are ***reciprocal***.

Link budget calculation

Free space loss

- Signal power is diminished by geometric spreading of the wavefront, commonly known as ***Free Space Loss***.
  - The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes.

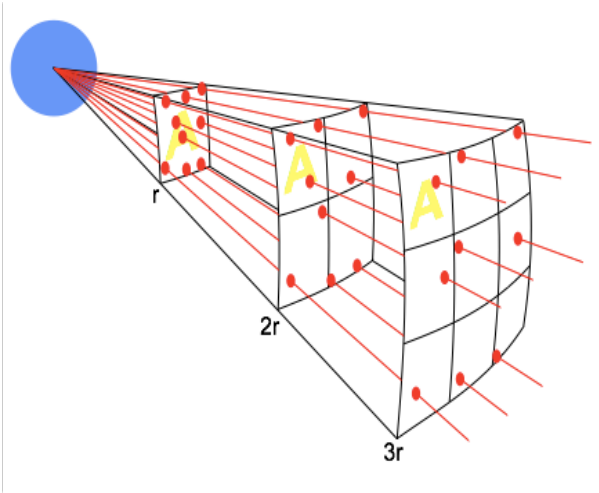


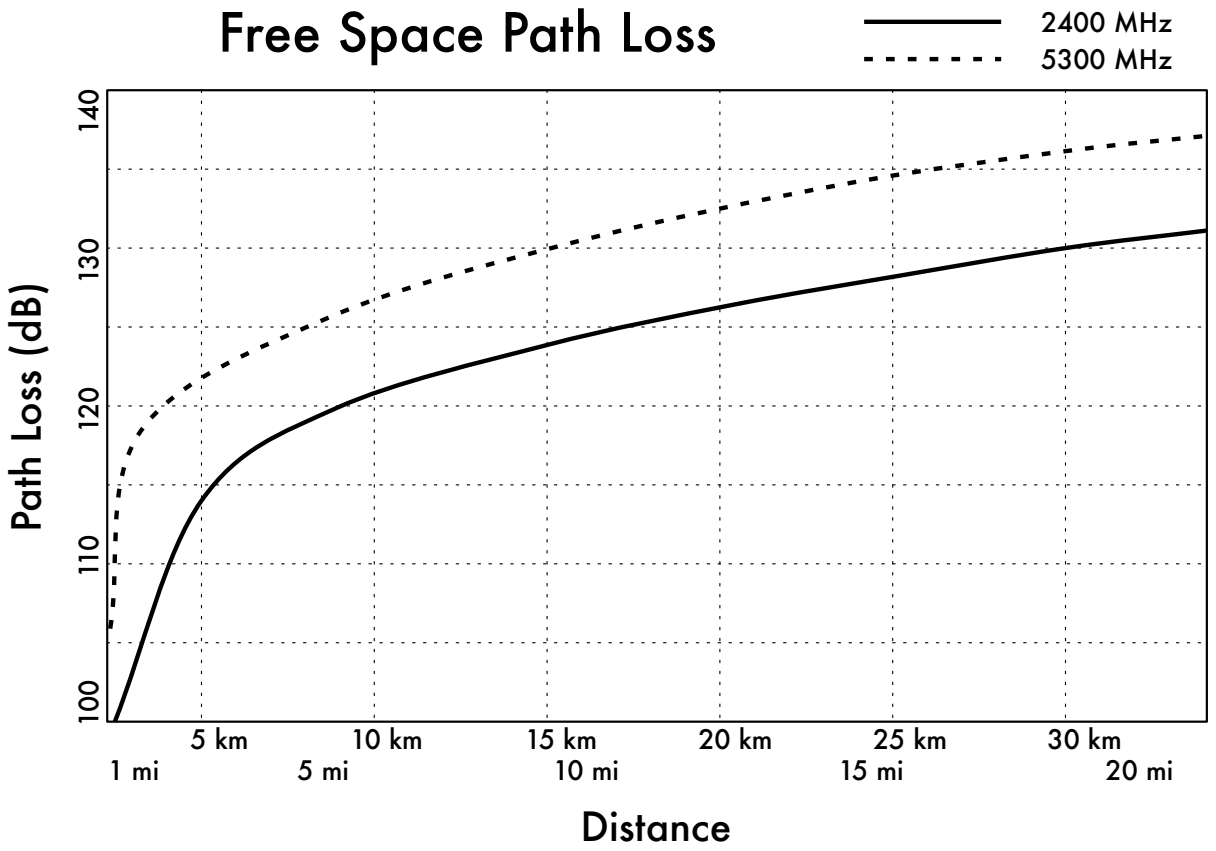
Figure from *http://en.wikipedia.org/wiki/Inverse_square*

Free Space Loss (any frequency)

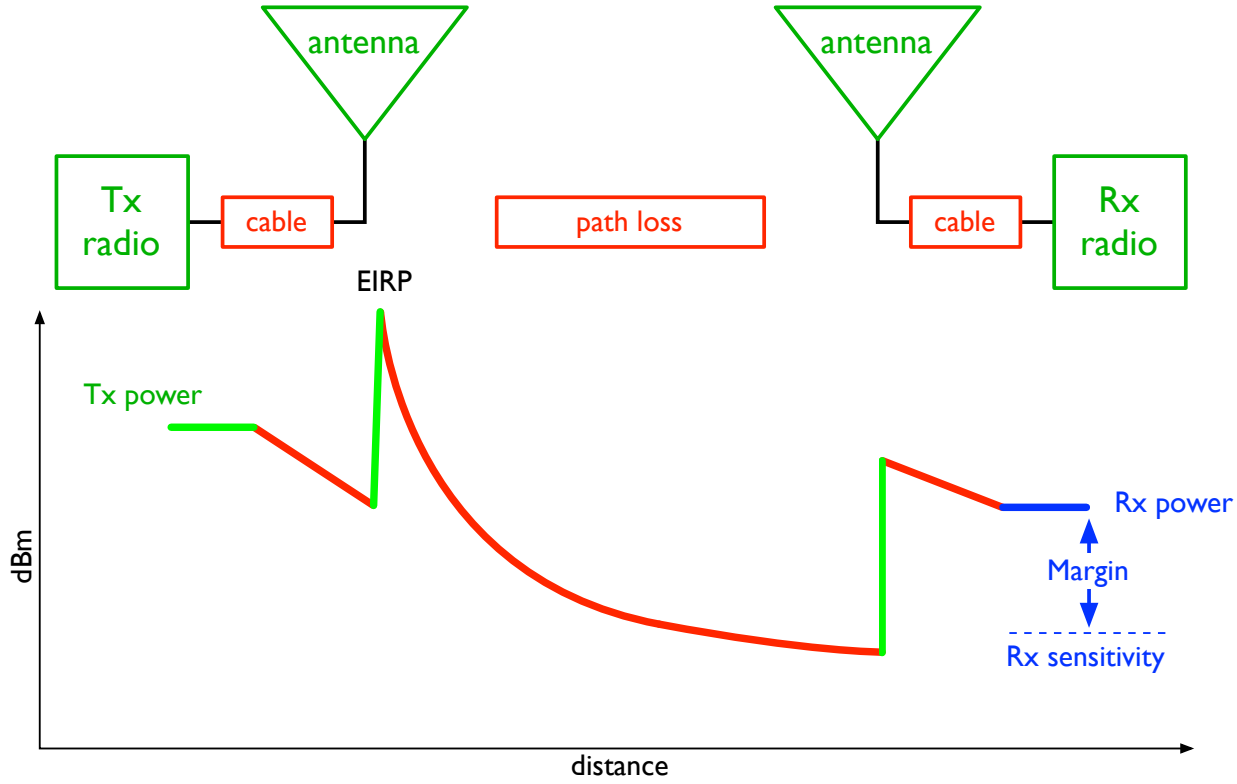
- Using decibels to express the loss and using a generic frequency f, the equation for the Free Space Loss is:

$$L_{fs} = 100 + 20*\log(D) + 20*\log(f)$$

- ...where ***L_{fs}*** is expressed in dB, ***D*** is in kilometers and **f** is in GHz.


Free Space Path Loss
2400 MHz
5300 MHz
Path Loss (dB)
140
130
120
110
100
5 km
10 km
15 km
20 km
25 km
30 km
1 mi
5 mi
10 mi
15 mi
20 mi
Distance

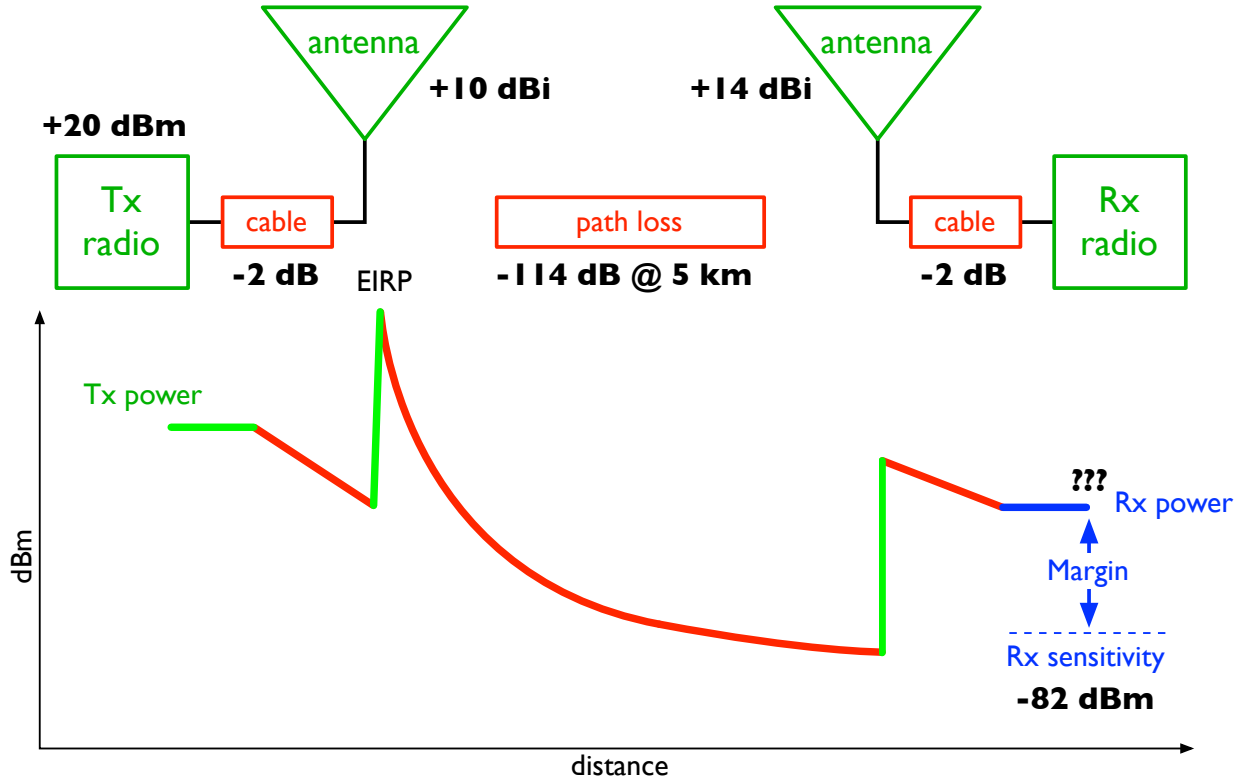
Power in a wireless system



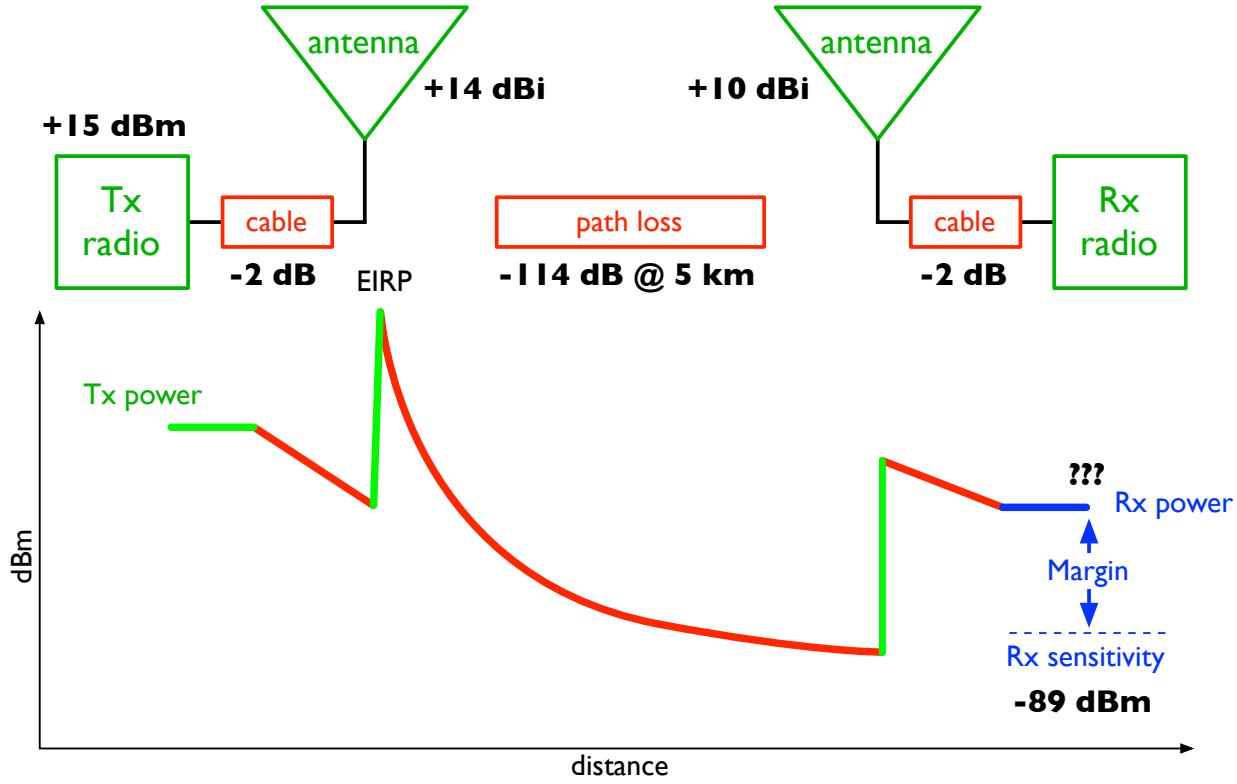
Link budget

- The performance of any communication link depends on the quality of the equipment being used.
- ***Link budget*** is a way of quantifying the link performance.
- The received power in a link is determined by three factors: ***transmit power***, ***transmitting antenna gain***, and ***receiving antenna gain***.
- If that power, minus the ***free space loss*** of the link path, is greater than the ***minimum received signal level*** of the receiving radio, then a link is possible.
- The difference between the minimum received signal level and the actual received power is called the ***link margin***.
- The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links).

AP to Client link



Opposite direction: Client to AP



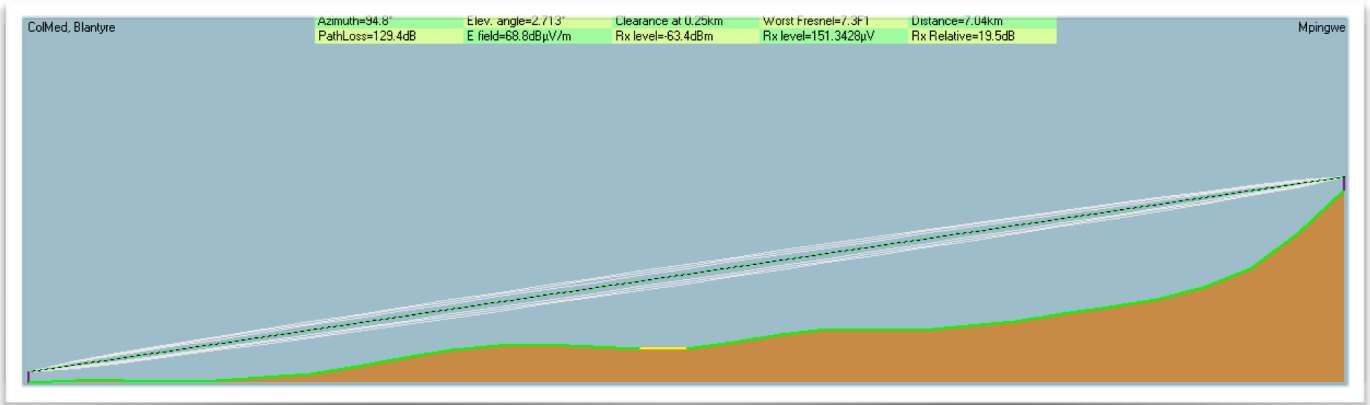
Radio Mobile

- Radio Mobile is a free tool to aid in the design and simulation of wireless systems.
- It can automatically calculate the power budget of a radio link, calculating the Fresnel zone clearance. It can use digital maps, GIS (Geographical Information Systems), or any other digital map, including maps provided by yourself.
- Runs on Windows 95, 98, ME, NT, 2000 and XP.
- There is also an on-line version that can used by any web browser without performing any software installation.

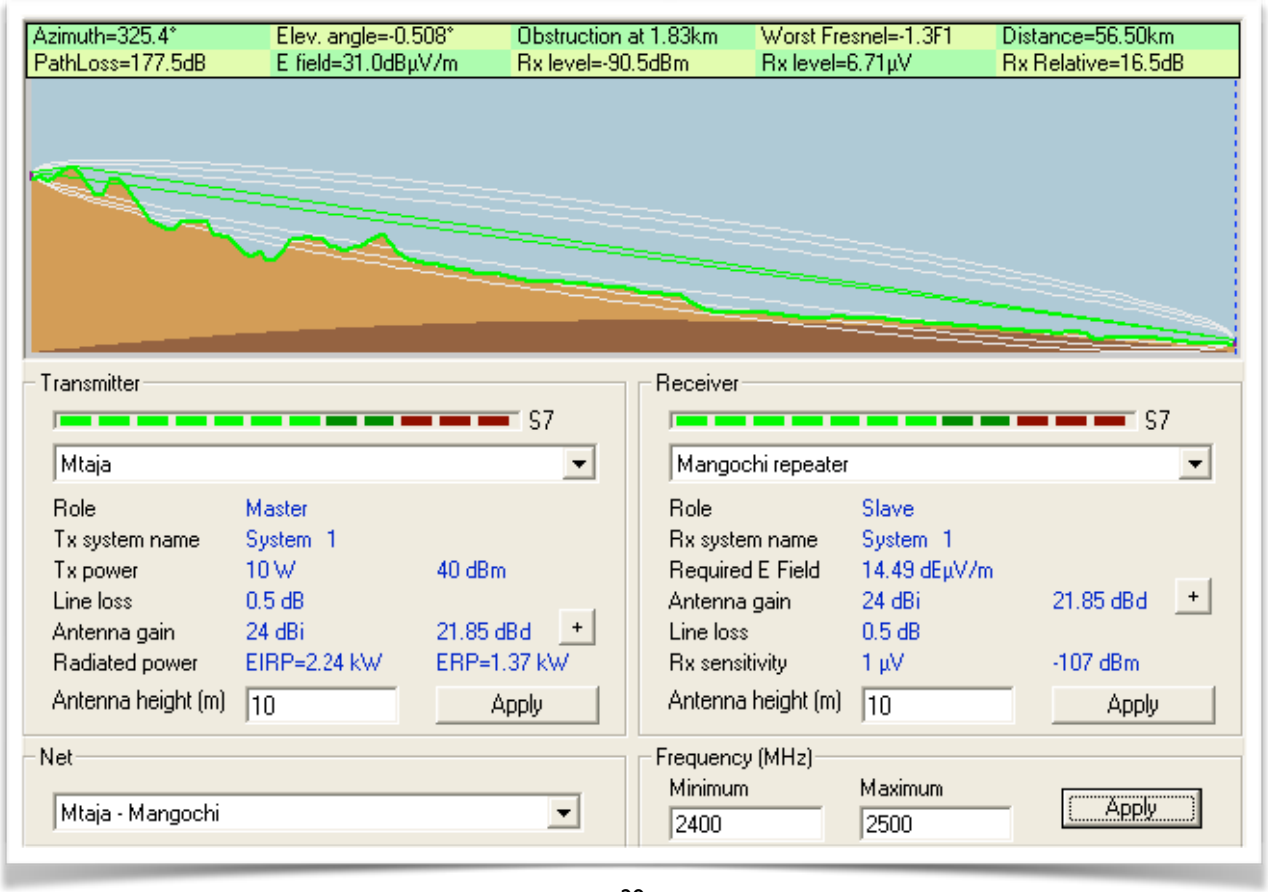
http://www.cplus.org/rmw/english1.html

Radio Mobile

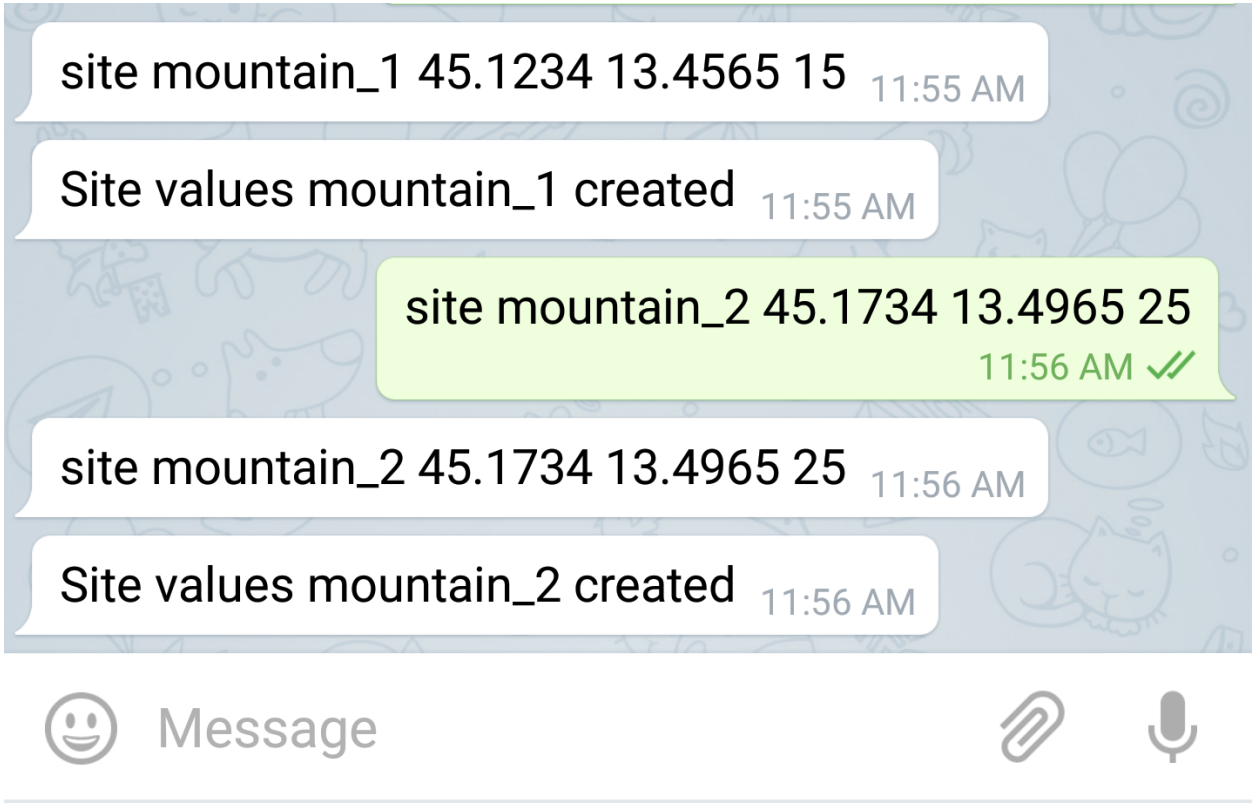
- Uses Digital terrain Elevation Model for the calculation of coverage, indicating received signal strength at various point along the path.
- Radio Mobile automatically builds a profile between two points in the digital map showing the coverage area and 1st Fresnel zone.
- Different antenna heights can be tried to achieve optimum performance.

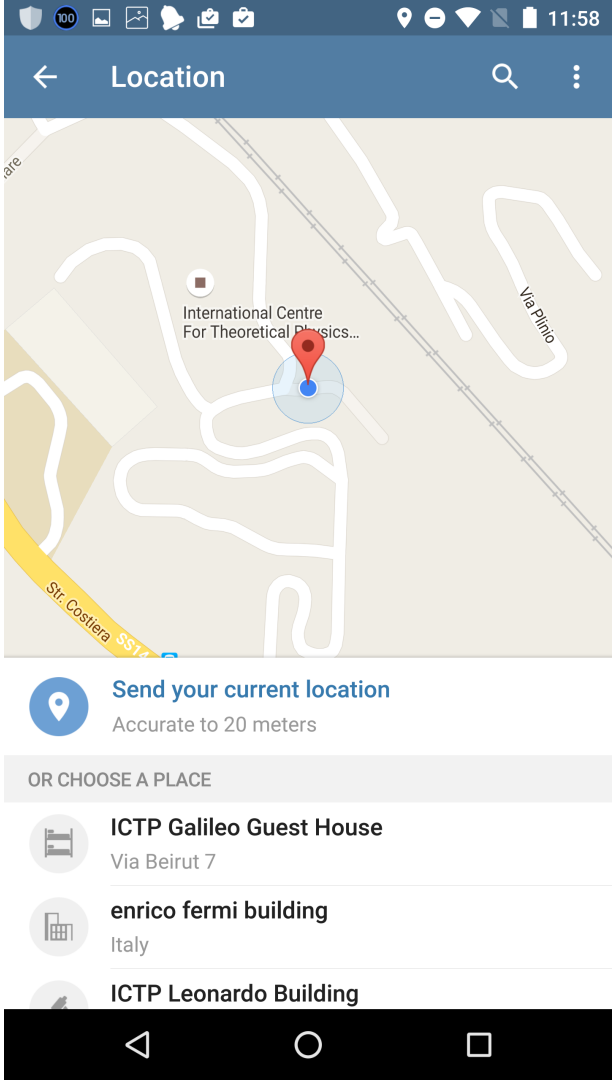


Radio Mobile

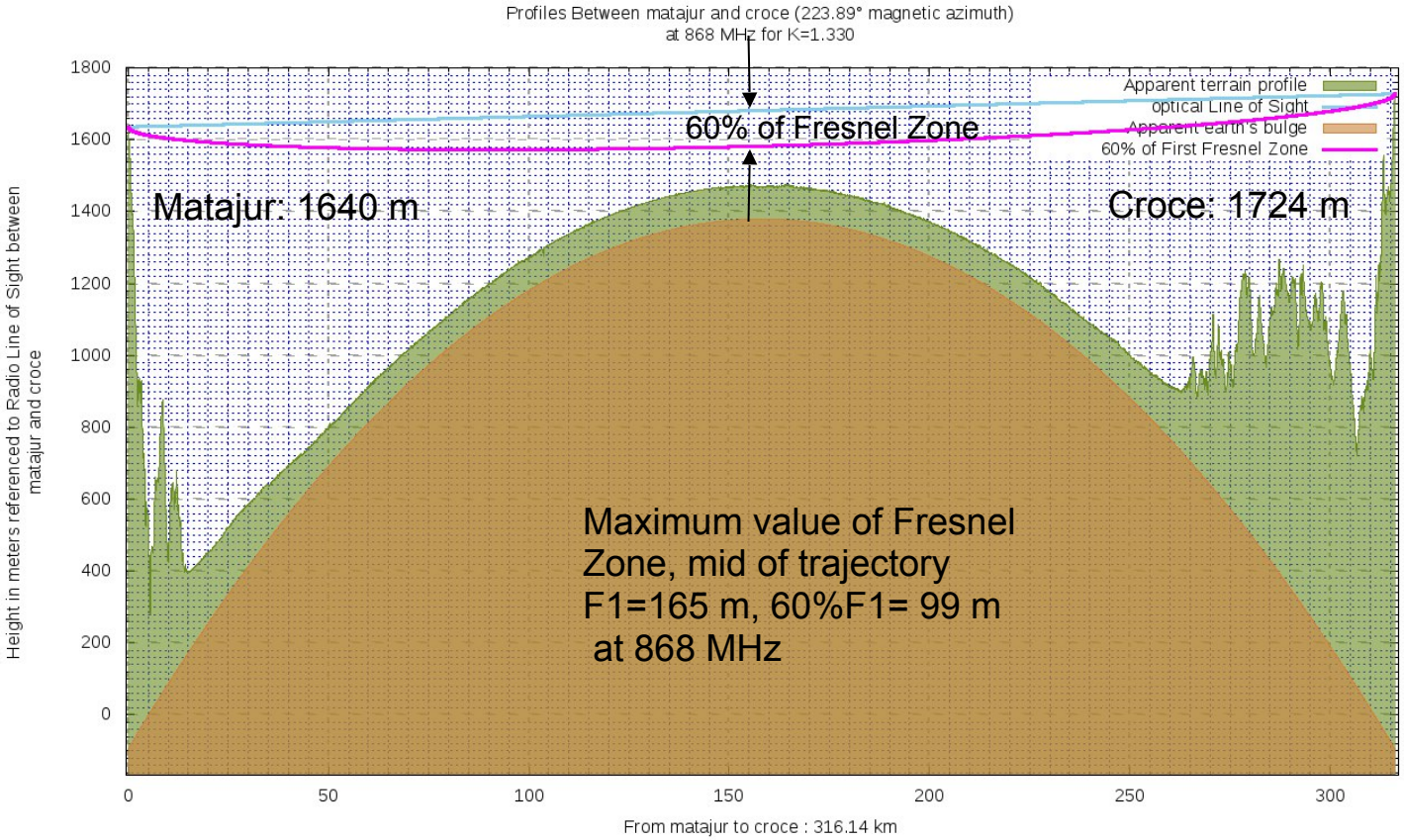


RFBot


site mountain_1 45.1234 13.4565 15
11:55 AM
Site values mountain_1 created
11:55 AM
site mountain_2 45.1734 13.4965 25
11:56 AM
site mountain_2 45.1734 13.4965 25
11:56 AM
Site values mountain_2 created
11:56 AM
Message


11:58
Location
International Centre
For Theoretical Physics...
Via Plinio
Str. Costiera
Send your current location
Accurate to 20 meters
OR CHOOSE A PLACE
ICTP Galileo Guest House
Via Beirut 7
enrico fermi building
Italy
ICTP Leonardo Building

Long distance link and Fresnel zone



Conclusions

- Radio waves have a characteristic wavelength, frequency and amplitude, which affect the way they travel through space.
- We use ISM bands, where no license is needed.
- Lower frequencies travel further, but at the expense of throughput.
- Radio waves occupy a volume in space, the Fresnel zone, which should be unobstructed for optimum reception.
- Antennas can be directional or omni-directional, and have a certain gain.
- Antennas are reciprocal!
- With the proper tools, very long links can be planned.

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net