Channel Modeling and Characteristics

Dr. Farid Farahmand

Updated:10/15/13, 10/20/14

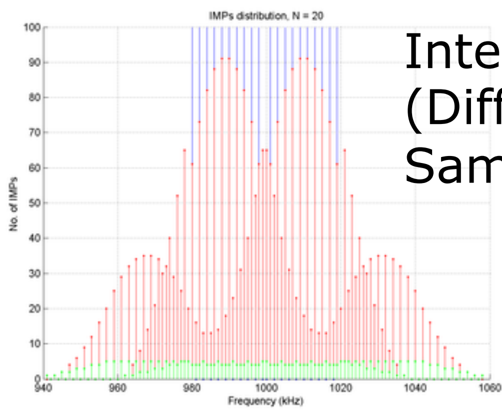
Line-of-Sight Transmission (LOS) Impairments

- The received signal is different from the transmitted signal due to transmission impairments
- Most significant impairments
  - Thermal noise
  - Free space loss
    - Attenuation and attenuation distortion
  - Atmospheric absorption
    - water vapor and oxygen contribute to attenuation
  - Noise
  - Shadowing
    - due to reflection and diffraction
  - Multipath and fading
    - due to reflection, scattering, and diffraction
  - Refraction

Review - Categories of Noise

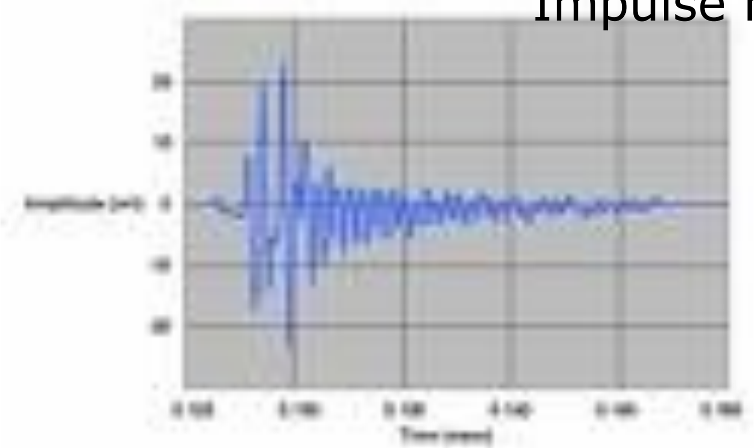
- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise

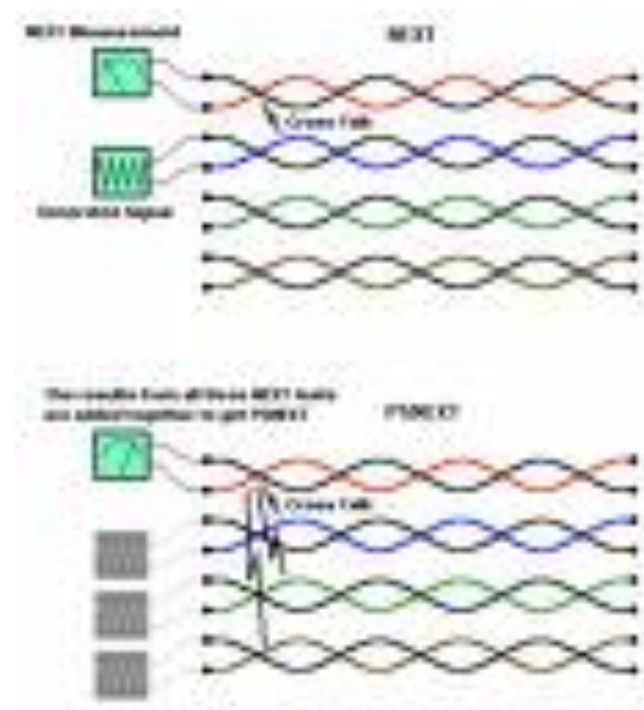
Other Types of Noise - Example



Intermodulation noise
(Diff. signals sharing the
Same medium)

Impulse noise

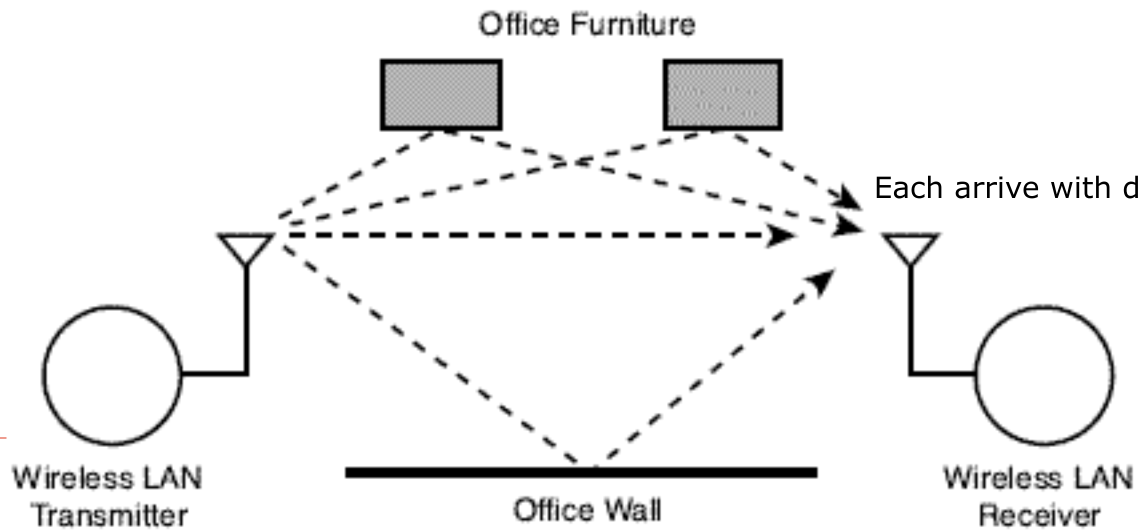




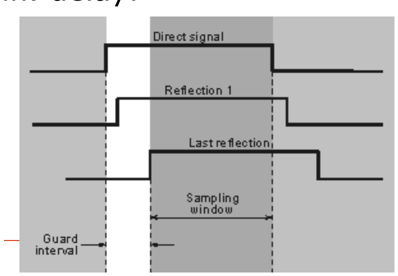
Crosstalk
(coupling)

The Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - obstacles reflect signals so that multiple copies with varying delays are received
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - Direct result of multipath→ One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

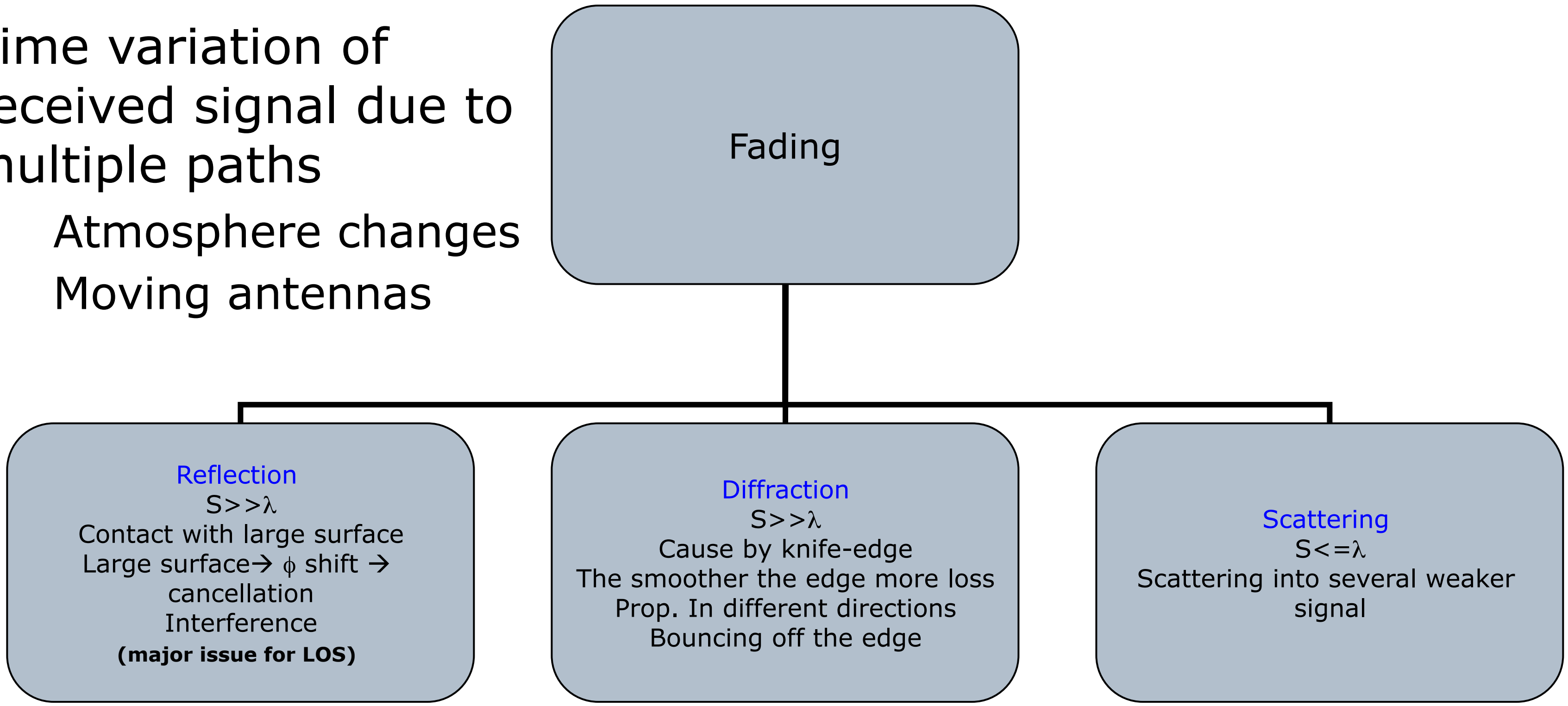


Each arrive with diff. delay!



Fading

- Time variation of received signal due to multiple paths
  - Atmosphere changes
  - Moving antennas



Propagation Mechanism (1) Reflection

- Occurs when signal encounters a surface that is large relative to the wavelength of the signal
  - Generally flat surface
  - Examples: Building, walls, Earth surface
  - The surface can be dielectric or conductor
  - The reflected field is diminished

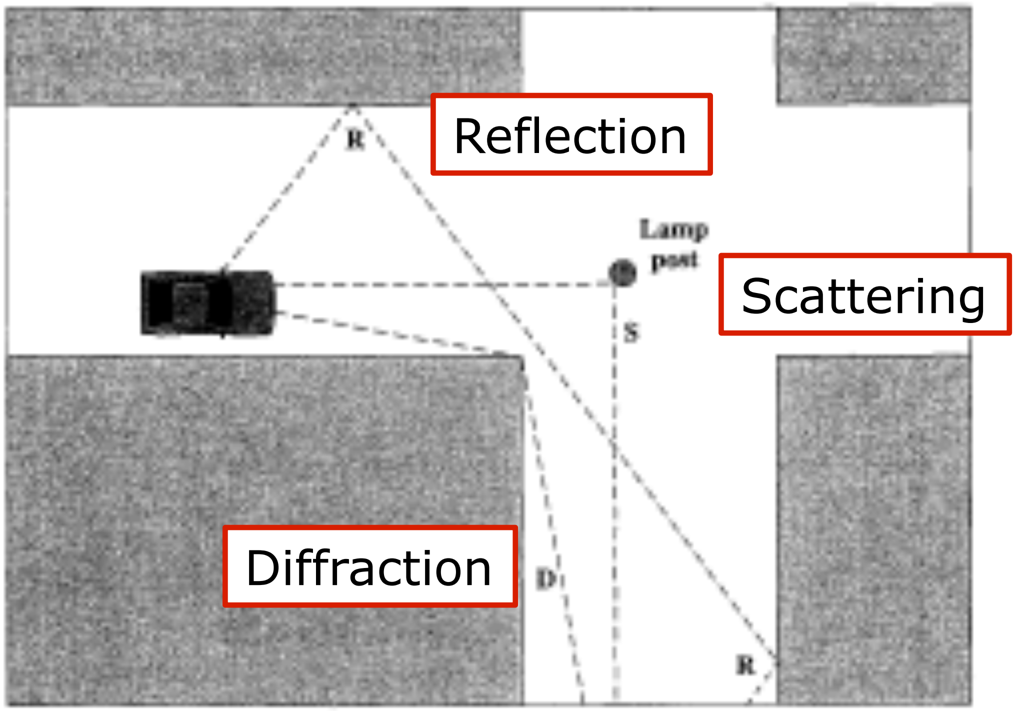
Propagation Mechanism (2) Diffraction

- Occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- Radio path is obstructed by a surface with sharp edges
- Secondary waves are generated

Propagation Mechanism (3) Scattering

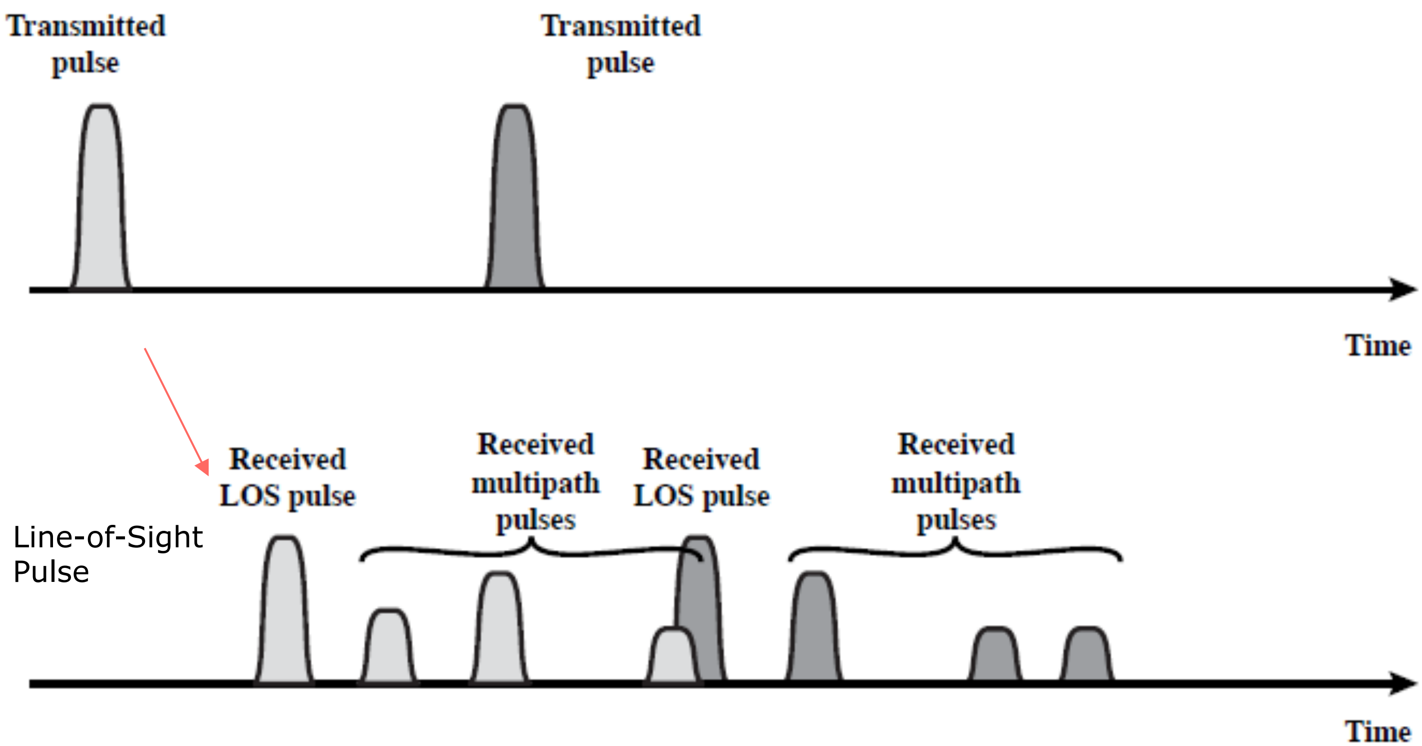
- occurs when incoming signal hits an object whose size is the order of the wavelength of the signal or less
- The flat surfaces can cause protuberance (projection)
- Surface can be rough or smooth
- Example: foliage, street signs, etc.

Different Propagation Mechanisms



Sketch of Three Important Propagation Mechanisms:
Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

Impact of Fading

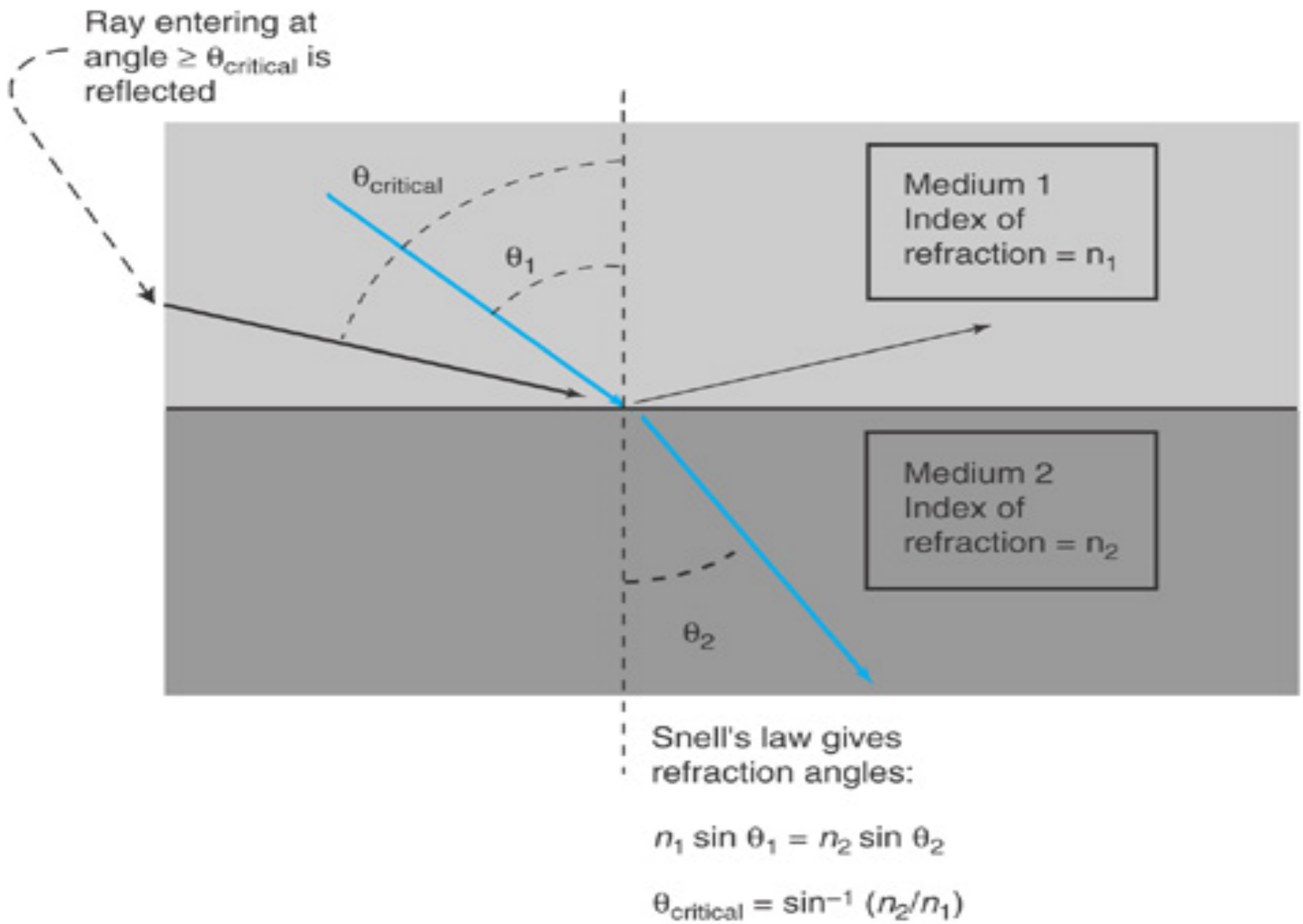


Impact of Fading

- Beam bending
- Ducting
- Fast fading
- Slow fading
- Flat fading
- Selective fading
- Rayleigh fading
- Rician fading

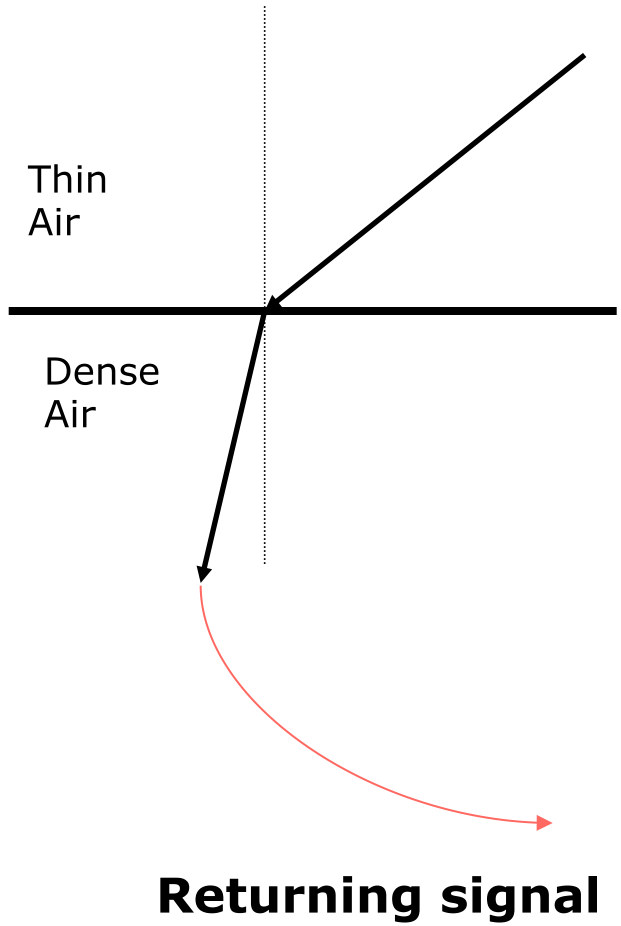
Refraction

bending of radio waves as they propagate through the atmosphere



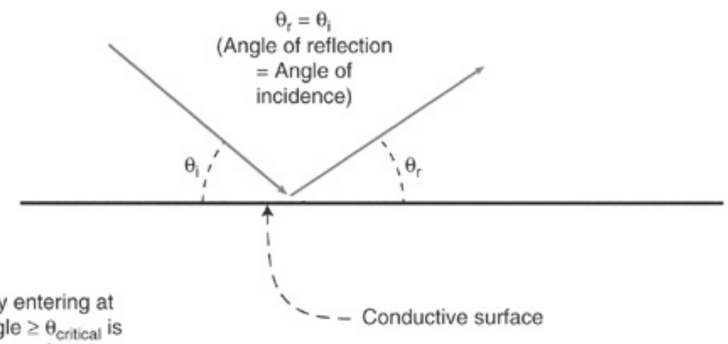
Refraction

- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums

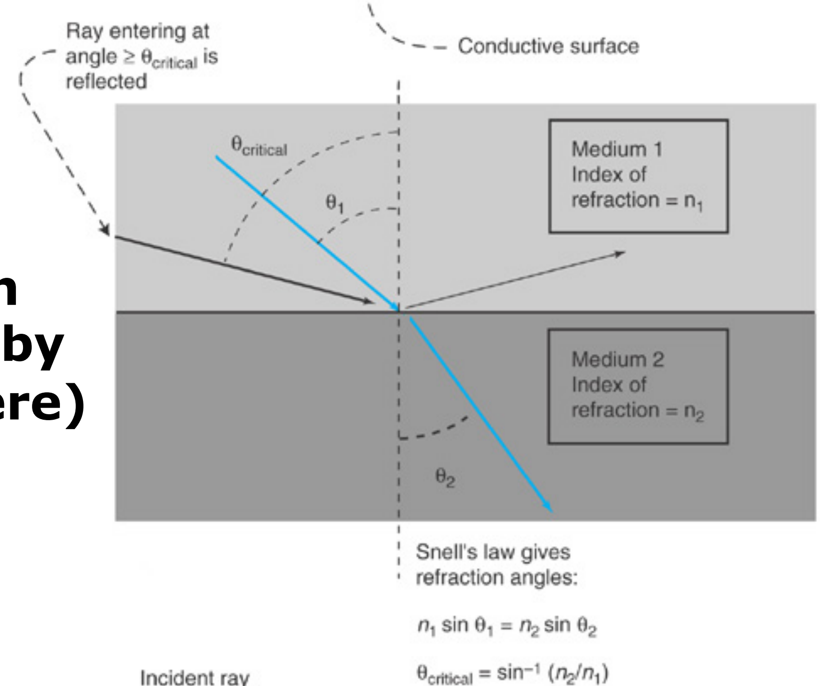


Remember:

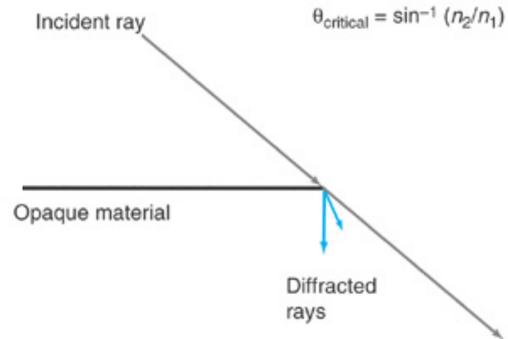
Reflection



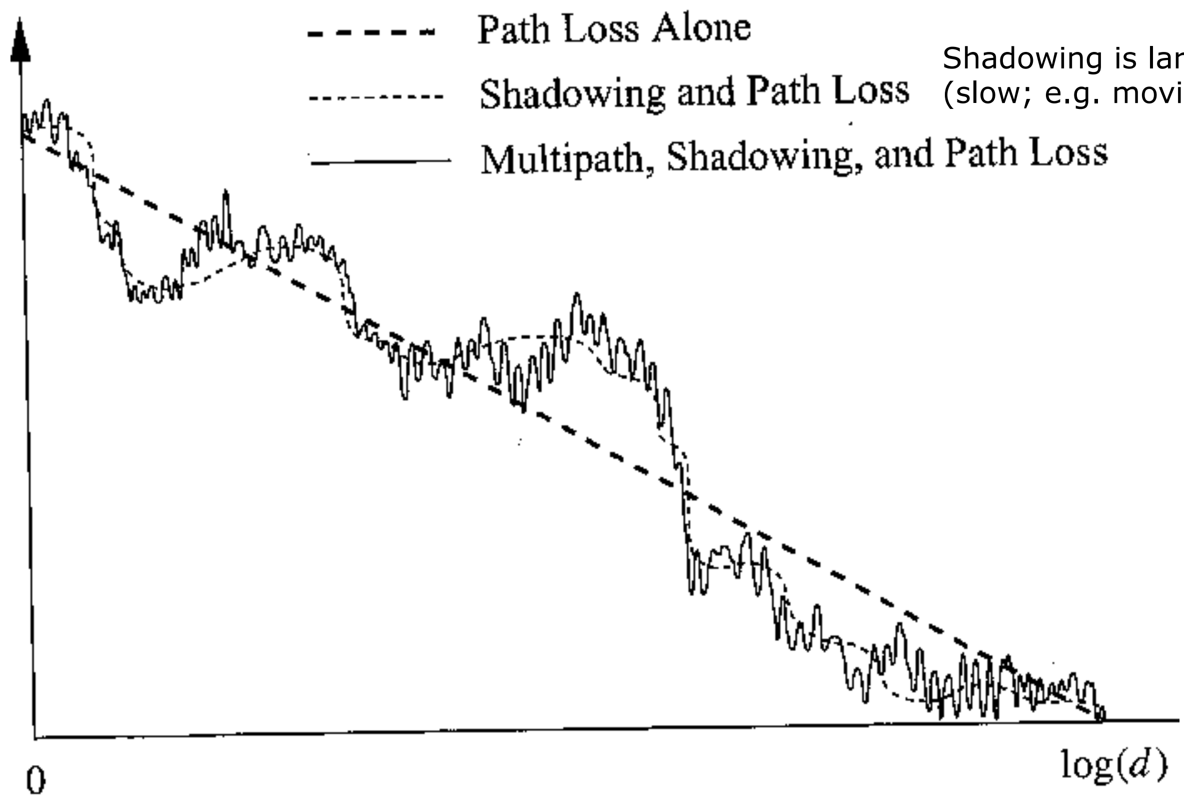
Refraction (bending by atmosphere)



Diffraction



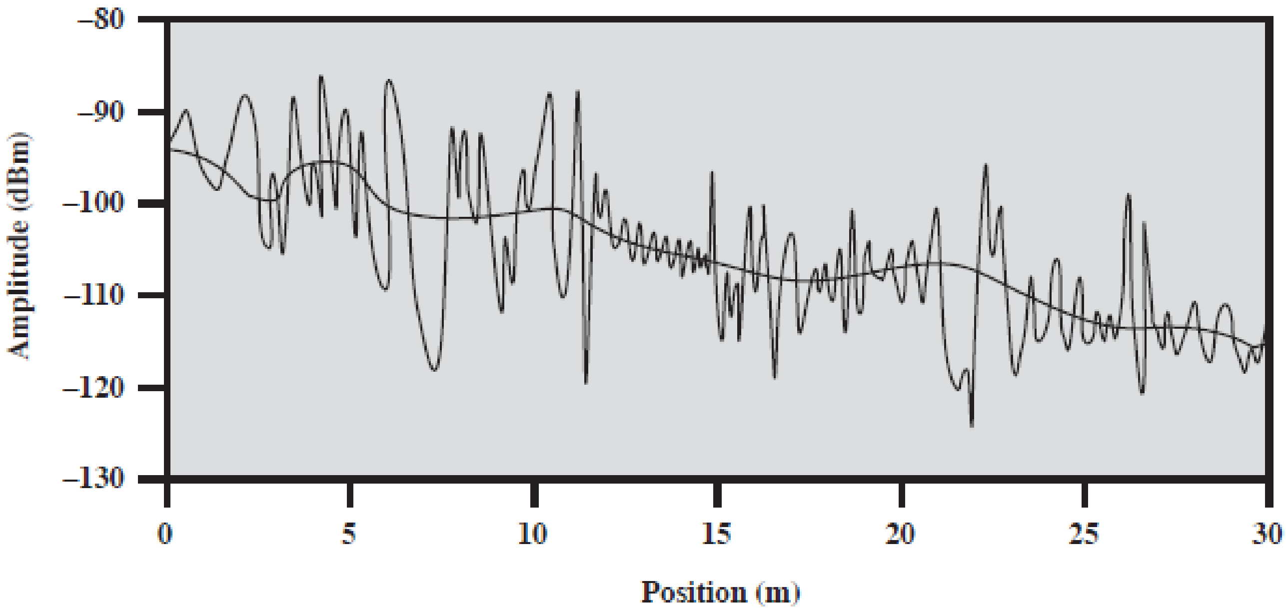
Shadowing and Multipath Impairments



Shadowing is large scale fading
(slow; e.g. moving around a building)

Fast and Slow Fading

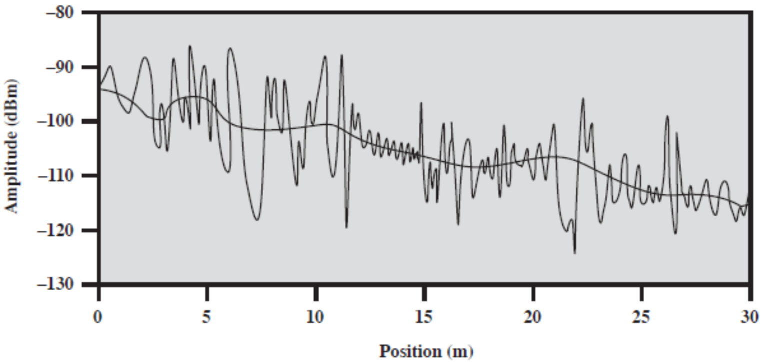
Fast (small scale) and slow (large scale) fading
Large scale fading is also called shadowing



Path Loss Channel Models

- Free space modes are limited
  - Good for satellite communications
  - Assumes line-of-sight
  - P_received is proportional to 1/d^2
- Other more realistic models
  - The receiver is not moving
  - The receiver is moving

Path Loss Channel Models -
Assume Stationary Receiver

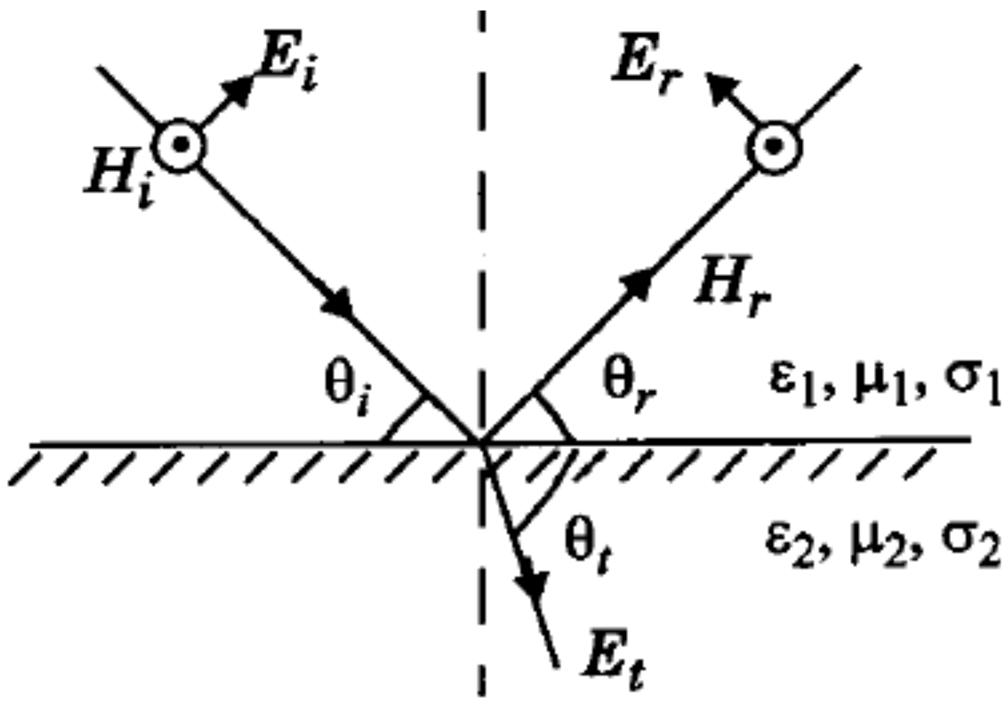


- Macroscopic Fading or large scale shadowing (fading)
  - The received power changes over as the distance varies
  - Models include:
    - 2-Ray; Statistical; Empirical
- Microscopic fading or small scale fading
  - The received power changes quickly
  - Models include:
    - 2-Ray, statistical

2-Ray Model (Earth Reflection) Assumptions

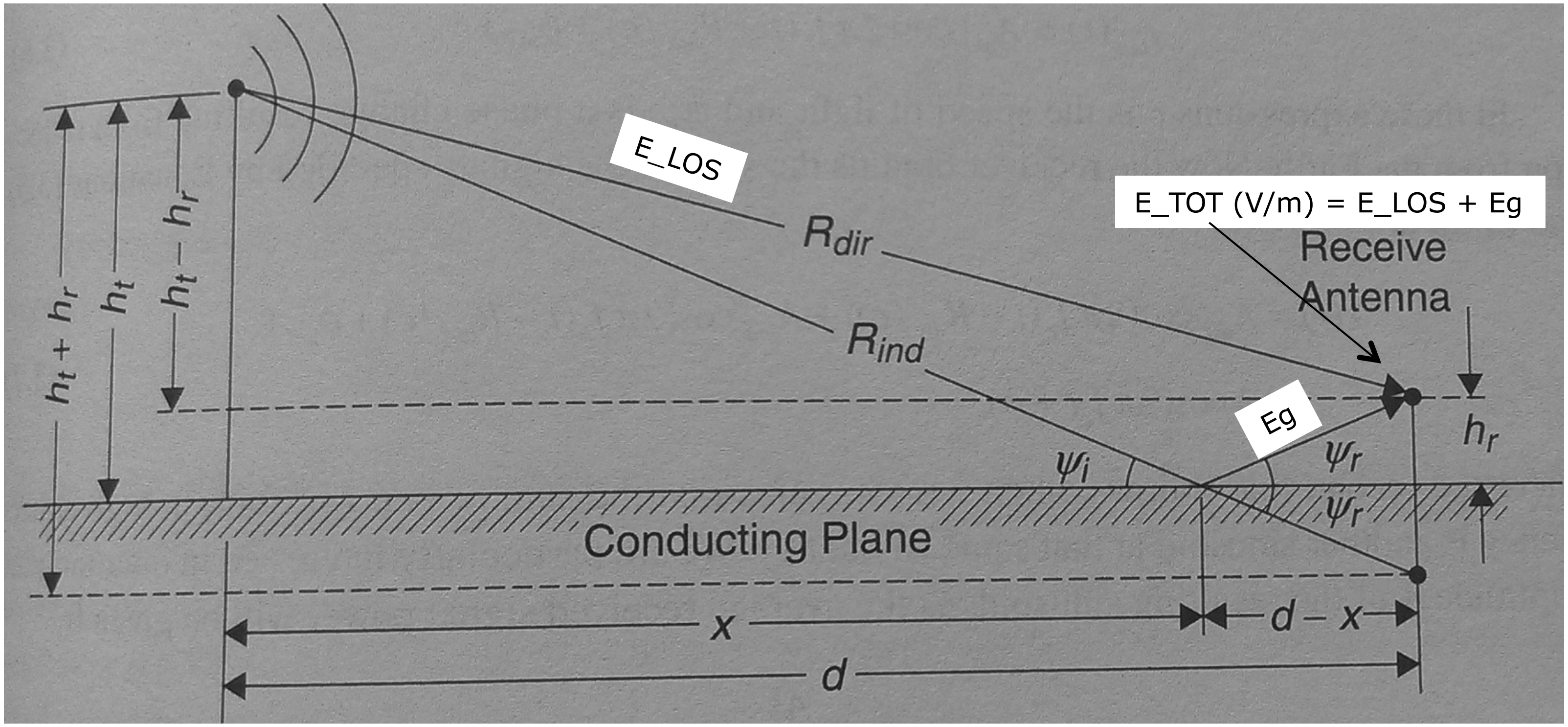
$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_2 \sin\theta_t + \eta_1 \sin\theta_i}$$

(E-field in plane of incidence)



2-Ray Propagation Model – Earth Reflection Model

Using geometric optics; We assume d >> ht+ hr



See notes

2-Ray Propagation Model – Earth Reflection Model

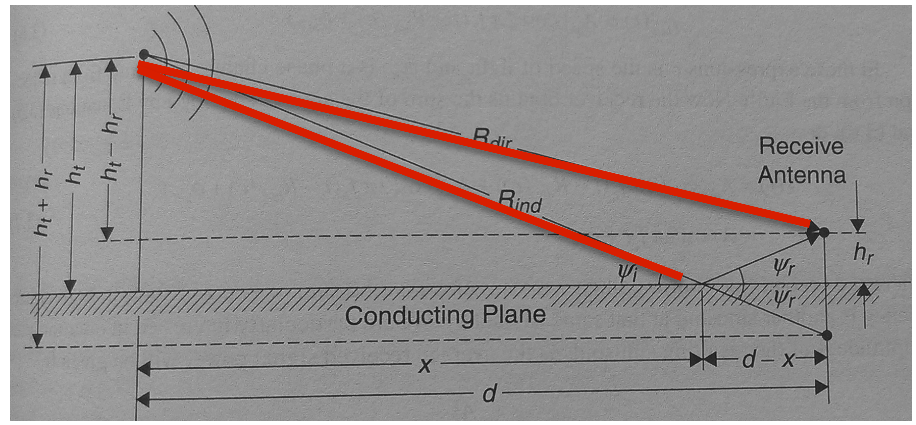
$$R_{dir} = \sqrt{(ht-hr)^2 + d^2} \approx d\left[1 + \frac{(ht-hr)^2}{2d^2}\right]$$

$$R_{indir} = \sqrt{(ht+hr)^2 + d^2} \approx d\left[1 + \frac{(ht+hr)^2}{2d^2}\right]$$

$$r_{dir}(t) = A_{dir}\cos(2\pi f_c(t - R_{dir}/c))$$

$$r_{indir}(t) = A_{indir}\cos(2\pi f_c(t - R_{indir}/c) + \phi_{ind})$$

$$r(t) = r_{dir}(t) + r_{indir}(t) = A\cos(2\pi f_c t + \phi)$$



What is A?

$$A = 2A_{dir}\left|\sin\frac{(2\pi hr \cdot ht)}{d\lambda}\right| \approx 2A_{dir}\left|\frac{(2\pi hr \cdot ht)}{d\lambda}\right|$$

$$A_{dir} = A_0 / d$$

$$\Pr_0 = A_0^2/2 = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 L_{sys}} \rightarrow A_0^2 = \frac{2P_t G_t G_r \lambda^2}{(4\pi)^2 L_{sys}}$$

$$\Pr = A^2/2 = 2A_{dir}^2\left|\frac{(2\pi hr \cdot ht)}{d\lambda}\right|^2 = 2\frac{(2\pi hr \cdot ht)^2}{(d\lambda)^2} \times \frac{1}{d^2} \times \frac{2P_t G_t G_r \lambda^2}{(4\pi)^2 L_{sys}}$$

Key assumptions:
Aind and Adir are almost the same
The angle of incident is about 180 deg.
d>>ht.hr

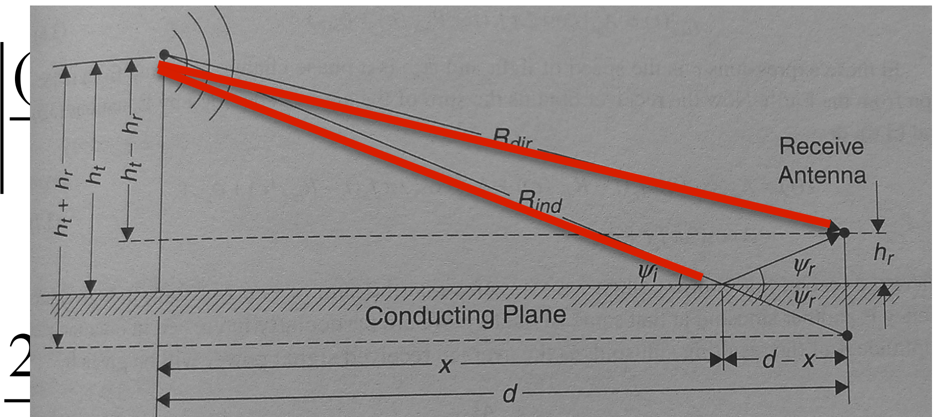
$$Path\_Loss = \frac{d^4}{G_t G_r hr^2 \cdot ht^2}$$

$$\Pr = \frac{P_t G_t G_r hr^2 \cdot ht^2}{L_{sys}} \cdot \frac{1}{d^4}$$

Power at the receiver

2-Ray Propagation Model – Earth Reflection Model

$$A = 2A_{dir}\left|\sin\frac{(2\pi hr\cdot ht)}{d\lambda}\right| \approx 2A_{dir}\left|(\right.$$



$$A_{dir} = A_0 / d$$

$$\Pr_0 = A_0^2 / 2 = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 L_{sys}} \rightarrow A_0^2 = \frac{2}{(4\pi)^2 L_{sys}}$$

$$\Pr = A^2 / 2 = 2A_{dir}^2\left|\frac{(2\pi hr\cdot ht)}{d\lambda}\right|^2 = 2\frac{(2\pi hr\cdot ht)^2}{(d\lambda)^2}\times\frac{1}{d^2}\times\frac{2P_t G_t G_r \lambda^2}{(4\pi)^2 L_{sys}}$$

Approximate to be →

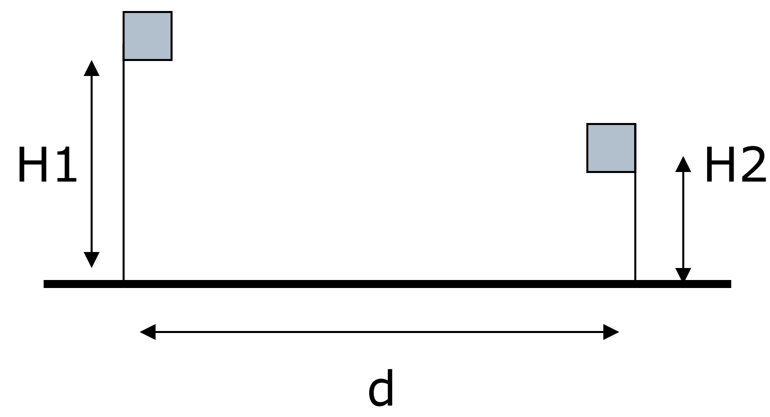
$$\Pr = \frac{P_t G_t G_r hr^2\cdot ht^2}{L_{sys}}\cdot\frac{1}{d^4}$$

$$Path\_Loss = \frac{d^4}{G_t G_r hr^2\cdot ht^2}$$

Approximated Power at the receiver

2-Ray Model (Earth Reflection)
Example – A

Ht = 30 m
Hr = 2 m
Gr = 2 dB
Gt = 6 dB
F = 850 MHz
Conductive Earth
Lsys = 2 dB
Using the 2-ray fading model find the RX power



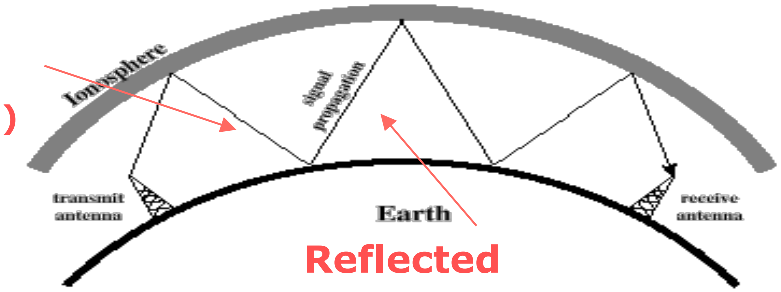
See notes

Propagation Modes

- Radio wave reaches the receiver by one of the three signal paths:
  - Sky-wave propagation
  - Direct-wave or Line-of-sight propagation
  - Ground-wave propagation

Sky Wave Propagation

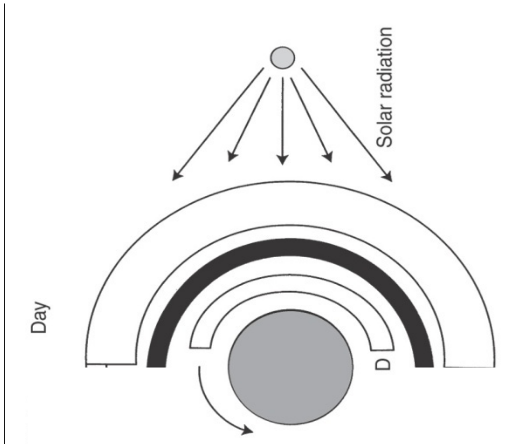
Refracted
(reflects due to bending)



- Signal reflected from ionized layer of atmosphere (ionosphere) back down to earth
  - Ionosphere is a region of atmosphere that is ionized (charged)
  - This region of atmosphere has free electrons → different index of refraction
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- Reflection effect caused by refraction (this is because the signal bends and reflects back)
- Examples
  - Amateur radio
  - CB radio

Sky Wave Propagation

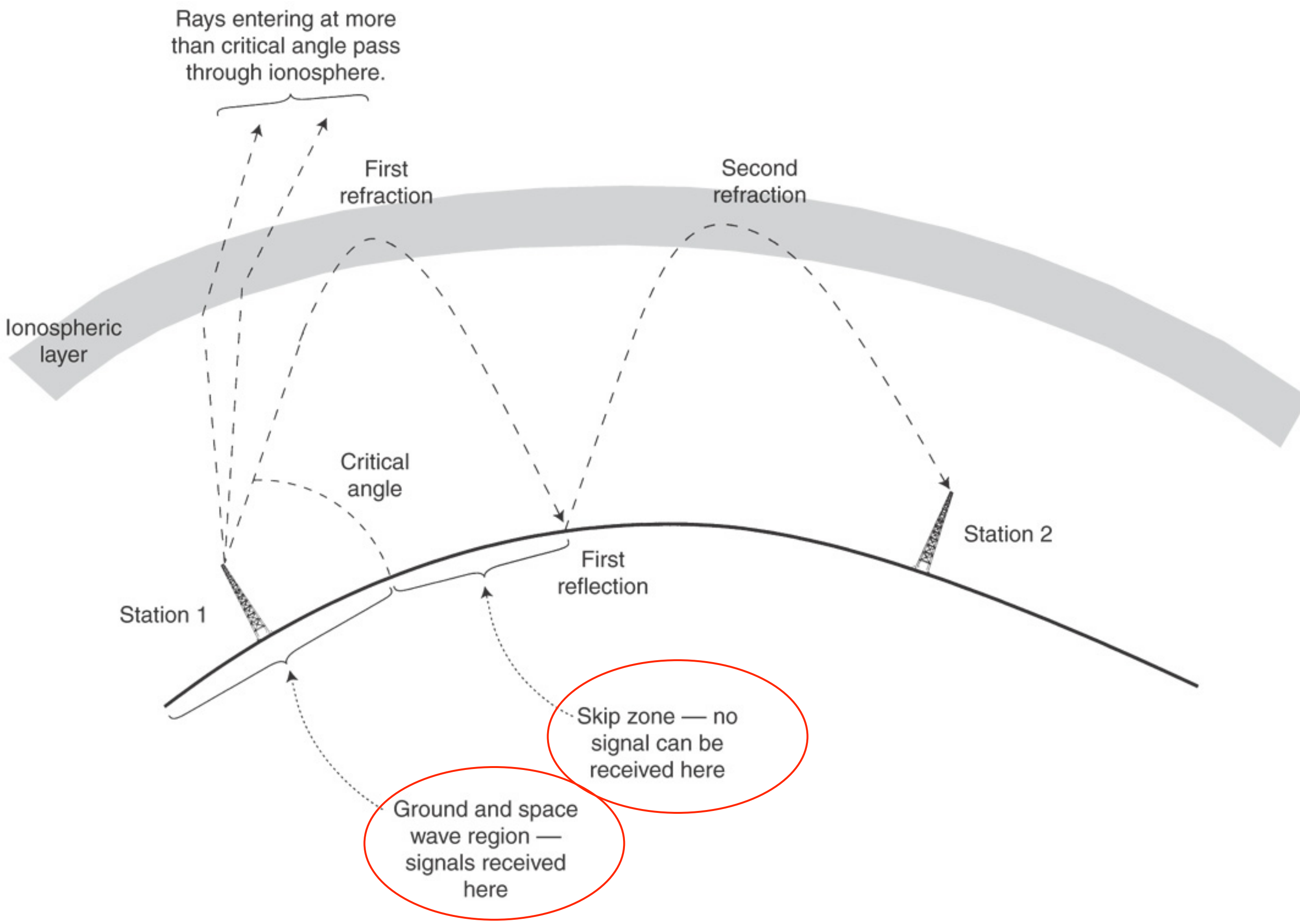
- D-layer is close to earth (45-55 miles altitude)
  - Absorbs RF (f>300MHz) – RF Sponge
  - For RF <300MHz D-layer ends the signal (refraction)
  - Ionization fades at night
  - Highly ionized during day time
    - It occupies denser atmosphere (electrons are denser)
    - Absorbs most of the RF except the ones radiated with critical angle



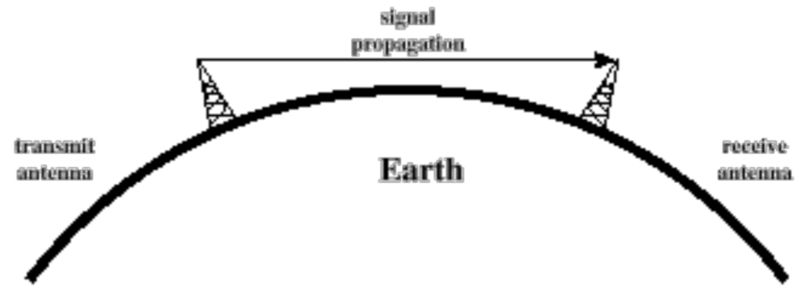
D,E, F1, F2 layers;
Each deal with RF
In different ways!

Distant AM broadcast can be received much better at night!

Sky Wave (Skip) Propagation



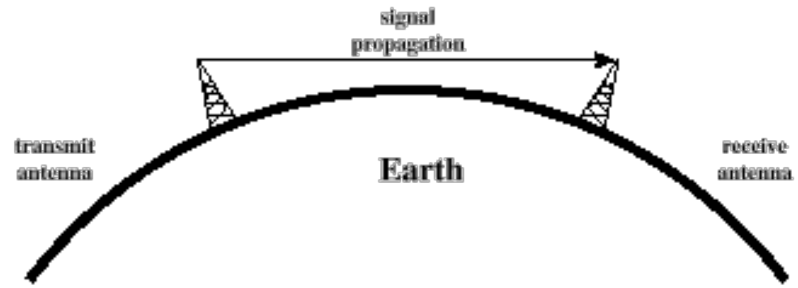
Line-of-Sight Propagation



- Transmitting and receiving antennas must be within line-of-sight
  - Example: Satellite communication
  - Dominant for signals above 30 MHz; no reflection due ionosphere → can be transmitted via LOS
  - For ground communication – antennas must be within *effective* line-of-site
    - Note that microwaves are bent or refracted by the atmosphere

Wave bending!!
Pulled toward the earth

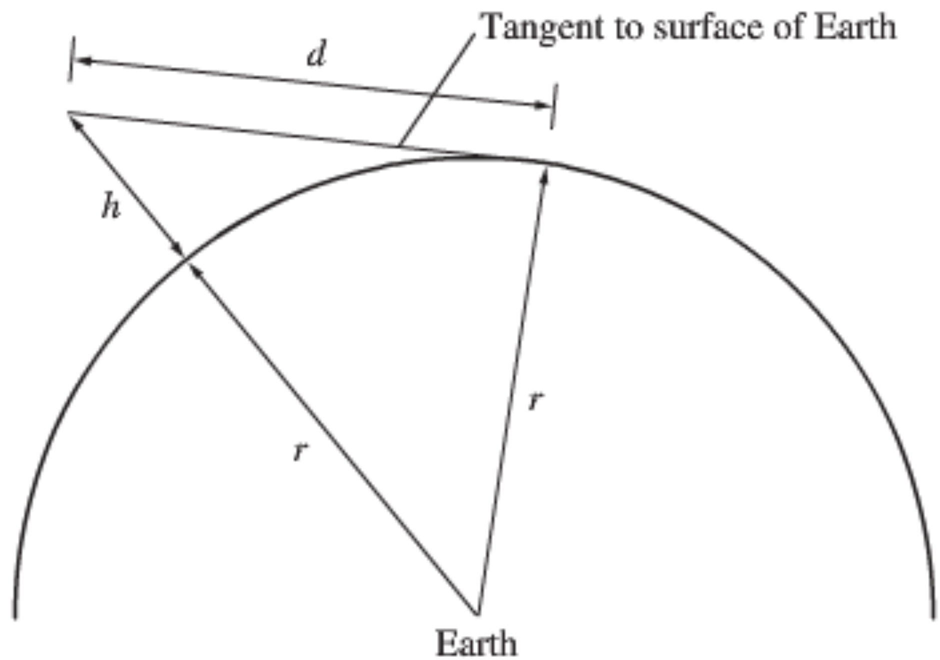
Line-of-Sight Propagation



- Requires tall antennas:

$$d^2 + r^2 = (r + h)^2$$

Note: The radius of the Earth is 3,960 statute miles. However, at LOS radio frequencies the effective Earth radius is 4/3x(3,960) miles →
4/3 is the adjustment factor K



Line-of-Sight Equations

- Optical line of sight

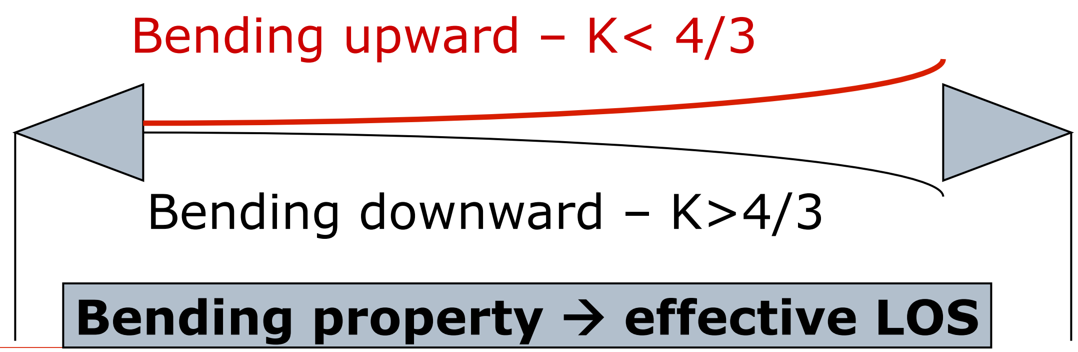
$$d = 3.57\sqrt{h}$$

Max. distance between two
Antennas for LOS when there is no obstacles

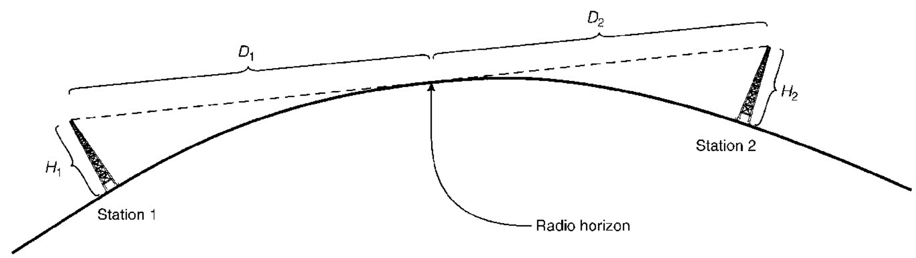
- Effective, or radio, line of sight (longer than optical)

$$d = 3.57\sqrt{\mathrm{K}h}$$

d = distance between antenna and horizon (km)
h = antenna height (m)
K = adjustment factor to account for refraction, rule of thumb K = 4/3



Line-of-Sight Equations



- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

  - h_1 = height of antenna one
  - h_2 = height of antenna two

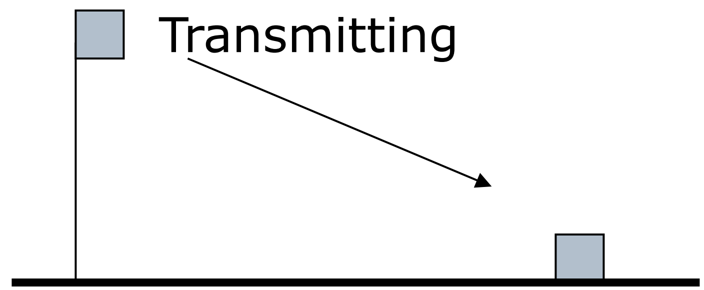
Antennas placed in higher towers can have better reception!

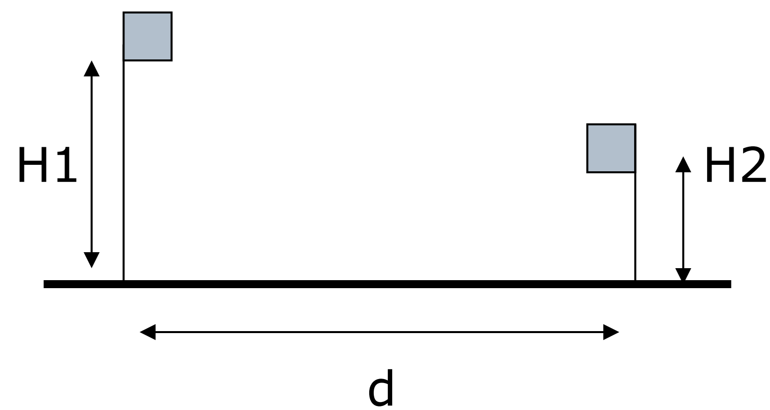
What is the benefit of raising the antenna?

Case 1:
H2 = 0; H1 = 100 m
K=4/3
Find d (maximum distance between the two antennas)

$$3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

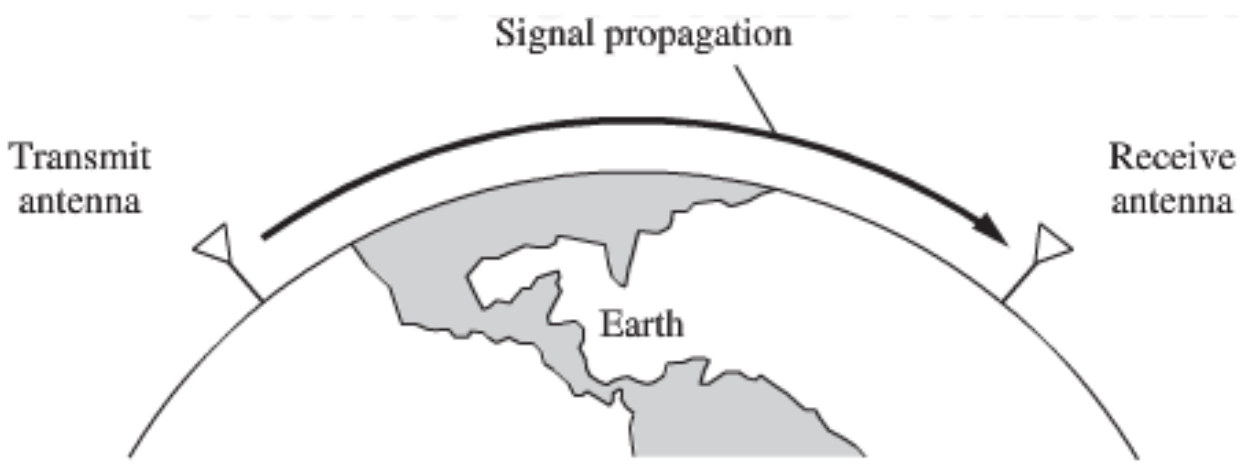
Case 2:
Let d = 41 Km
H2 = 10 m
Find H1



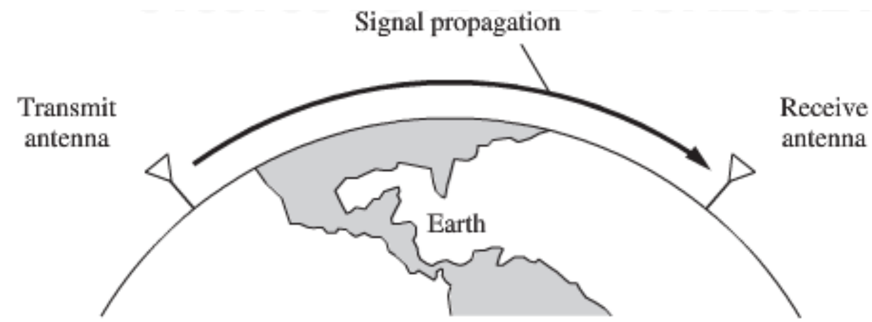


Ground-wave propagation

- Follows contour of the earth
  - Thus, goes beyond the radio horizon limit
  - RF follows the curvature of the earth
- The dominant mode of propagation
  - waves are refracted (i.e., bent) gradually in an inverted U shape



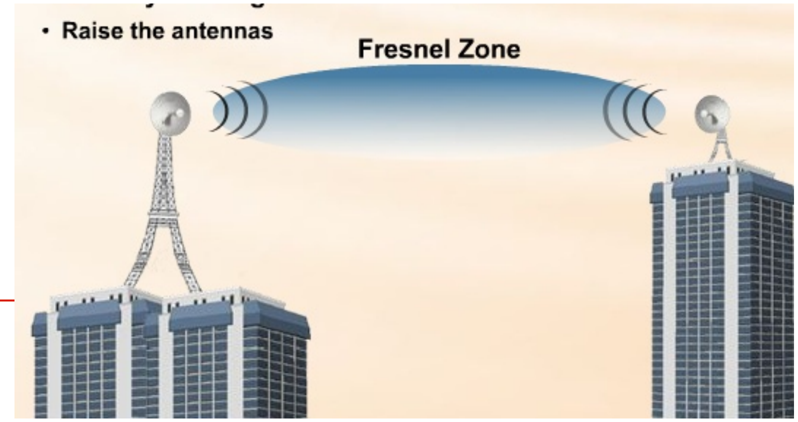
Ground-wave propagation

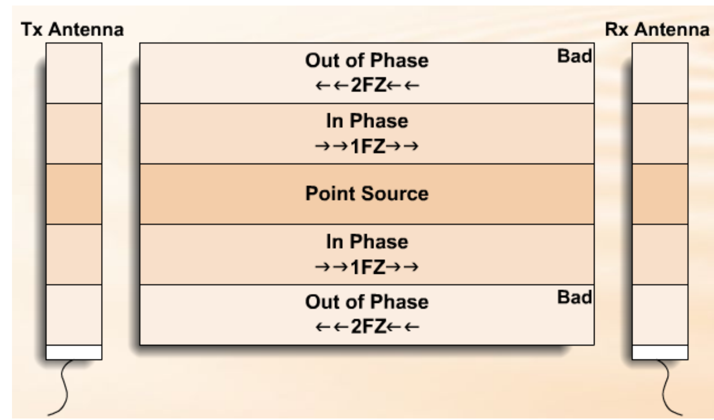


- Can Propagate considerable distances
- Does not penetrate the upper atmosphere
- Frequencies up to 2 MHz
  - Example: AM radio
- Not impacted by weather conditions s!o much
- Highly impacted by earth conductivity
  - When traveling over Salt water (good conductive) → ground wave propagation is good
  - When the ground is dry or rocky → wave propagation is bad

Diffraction: Fresnel (Freh-Nel)

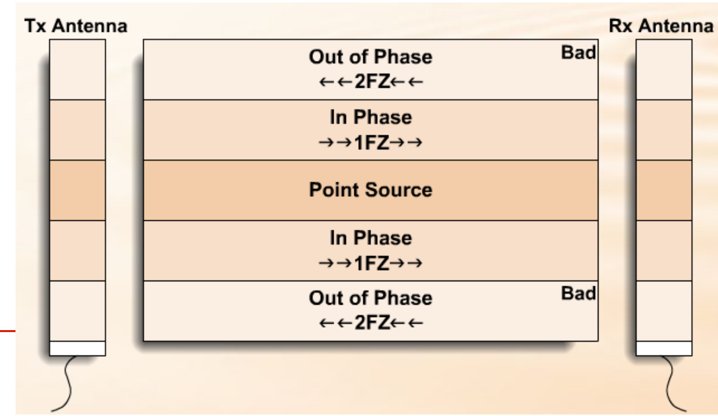
- Fresnel discovered electromagnetic waves (light and RF signals) can bend (diffract) as they travel long distance and hit objects (S>>WL)
- As a result of bending multiple signals along various paths can results
  - The paths vary n(WL)/2
  - Out of phase signals → signal cancelation!
- In order to minimize out-of-phase signals we need to make sure there is no obstacle within the first Fresnel (%60 or F1)



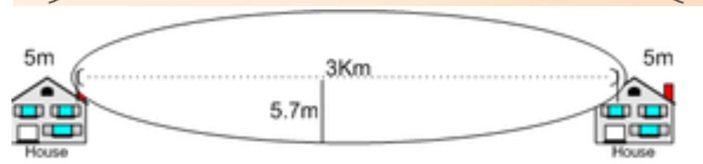


$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}.$$

Fresnel Zone

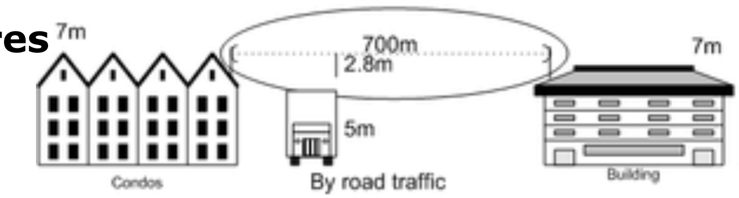


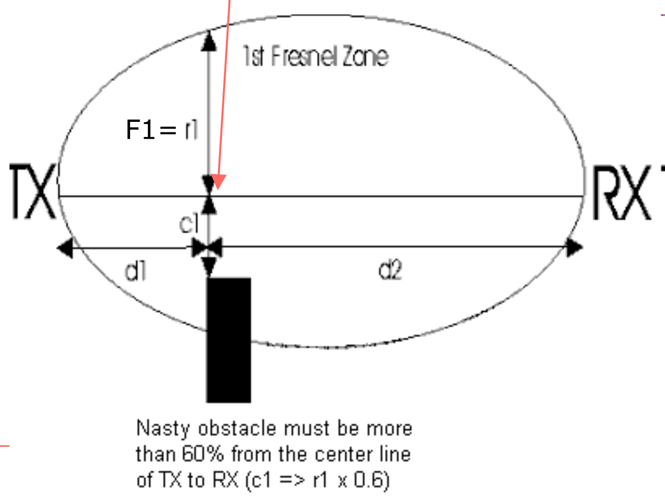
$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

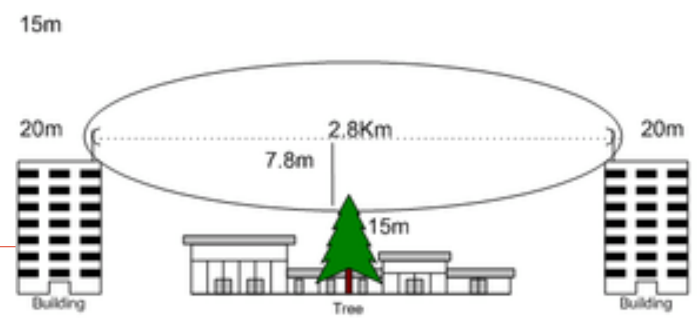


By the ground

where,
Fn = The nth Fresnel Zone radius in metres
d1 = The distance of P from one end in metres
d2 = The distance of P from the other end in metres
λ = The wavelength of the transmitted signal in metres

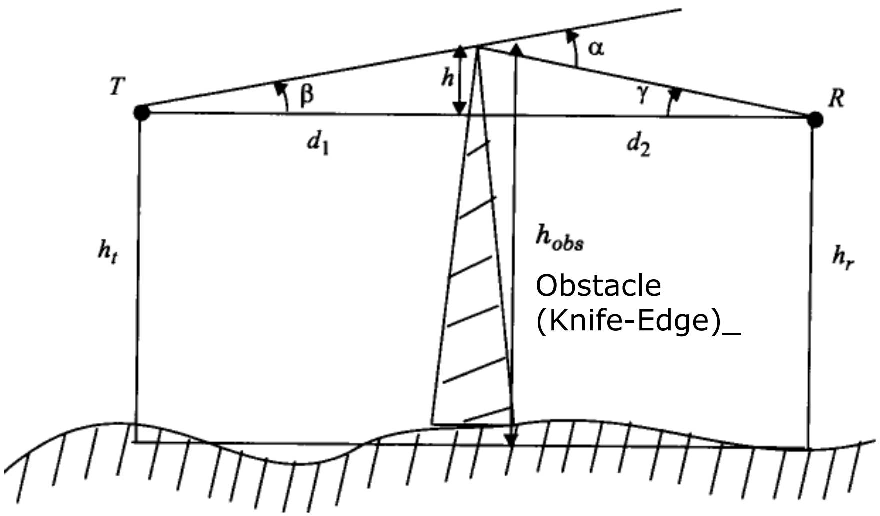






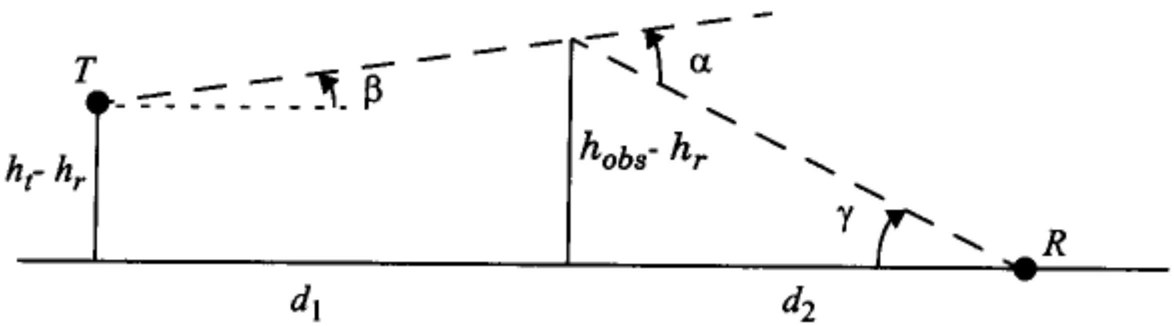
By an obstacle

Fresnel-Kirchoff Diffraction Parameter (V)

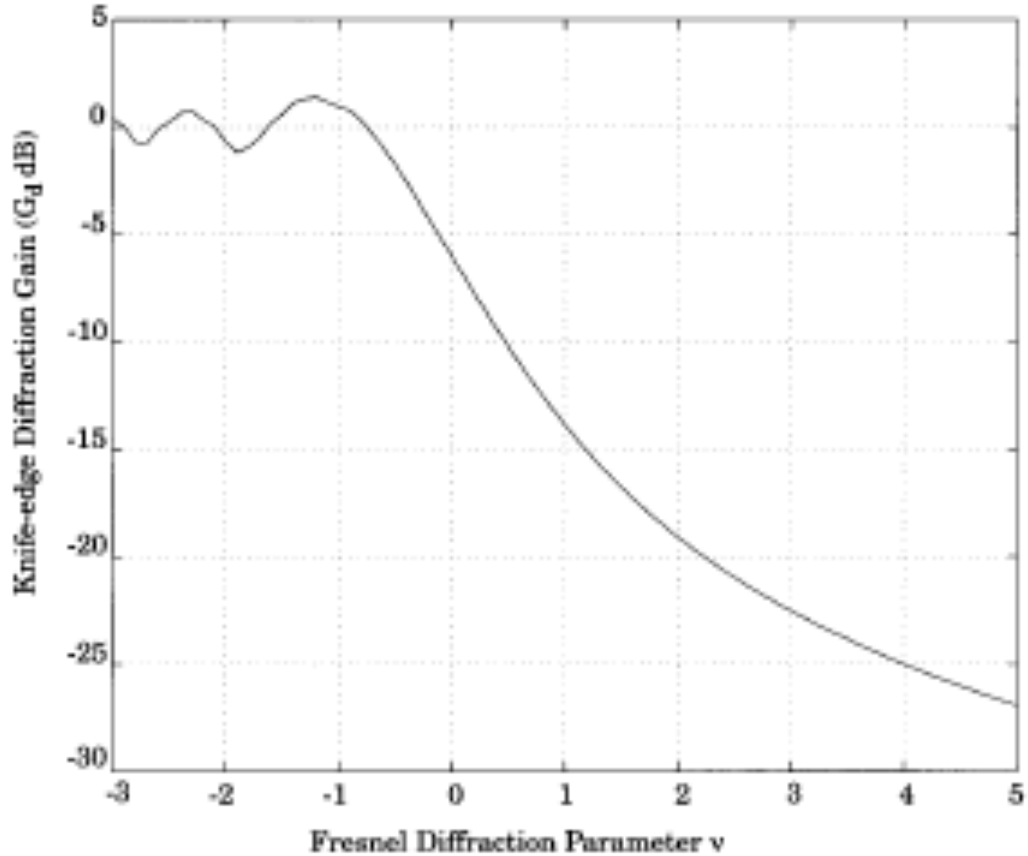


$$v = \alpha \sqrt{\frac{2 d_1 d_2}{(d_1 + d_2)\lambda}}$$

$$\alpha = \beta + \gamma$$

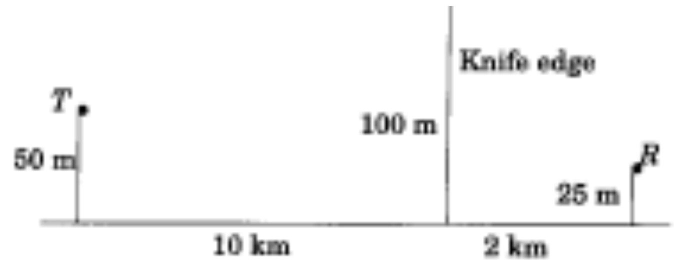


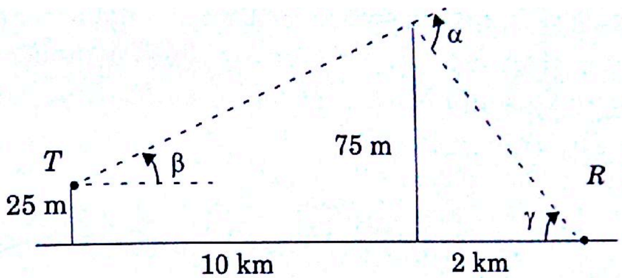
Given the Fresnel Effect (v) We can figure out the loss



EXAMPLE

Assume f=1900→ WL=1/3 m
Find the loss due to diffraction from the Knife edge obstacle





$$\beta = \tan^{-1}\left(\frac{75-25}{10000}\right) = 0.2865^o$$

$$\gamma = \tan^{-1}\left(\frac{75}{2000}\right) = 2.15^o$$

and

$$\alpha = \beta + \gamma = 2.434^o = 0.0424 \text{ rad}$$

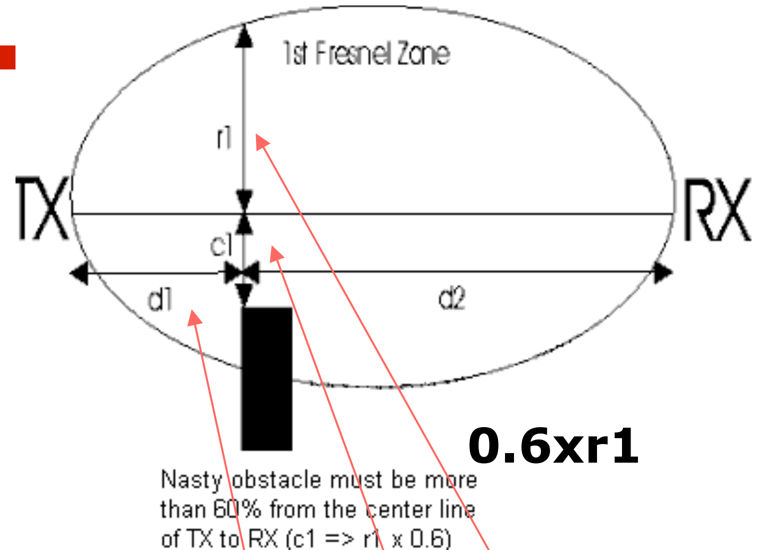
Then using equation (3.56)

$$\nu = 0.0424\sqrt{\frac{2 \times 10000 \times 2000}{(1/3) \times (10000 + 2000)}} = 4.24.$$

$$v = \alpha\sqrt{\frac{2d_1d_2}{(d_1 + d_2)\lambda}}$$

$$\alpha = \beta + \gamma$$

Fresnel Effect



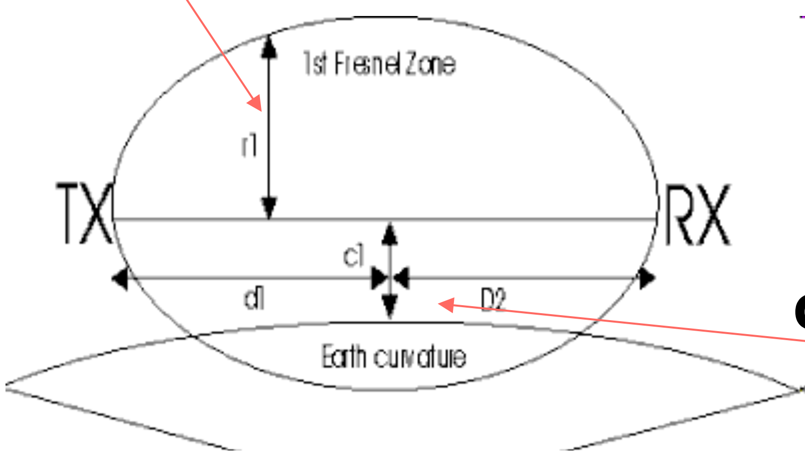
0.6xr1

At mid-point (same height antenna)

$$r = 17.32\sqrt{\frac{D}{4f}}$$

Total Link		Obstacle Distance		1st Fresnel Zone Radius			
10	Km	4	Km	17	m	56	ft
OR		OR		at		at	
				4	Km	2.484	Miles
Miles		Miles					

Frequency		60% No Obstacle Radius			
2400	MHz	10.2	m	33	ft
Calculate		Earth Height (mid-point)			
		1.47	m	4.821	ft



C1

Read: http://www.zytrax.com/tech/wireless/fresnel.htm

References

- Black, Bruce A., et al. *Introduction to wireless systems*. Prentice Hall PTR, 2008, Chapter 3
- Rappaport, Theodore S. *Wireless communications: principles and practice*. Vol. 2. New Jersey: Prentice Hall PTR, 1996, Chapter 3
- Stallings, William. *Wireless Communications & Networks, 2/E*. Pearson Education India, 2009, Chapter 5
- Leon W. Couch, Digital and Analog Communication Systems, Chapter 1-8