Antenna & Propagation

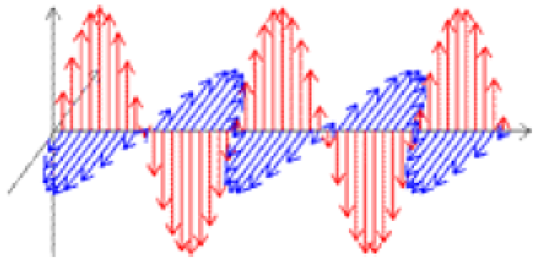
W. Stallings, Chapter 5

Introduction

- An antenna is an electrical conductor or system of conductors
  - Transmission - radiates electromagnetic energy into space
  - Reception - collects electromagnetic energy from space
- In two-way communication, the same antenna can be used for transmission and reception

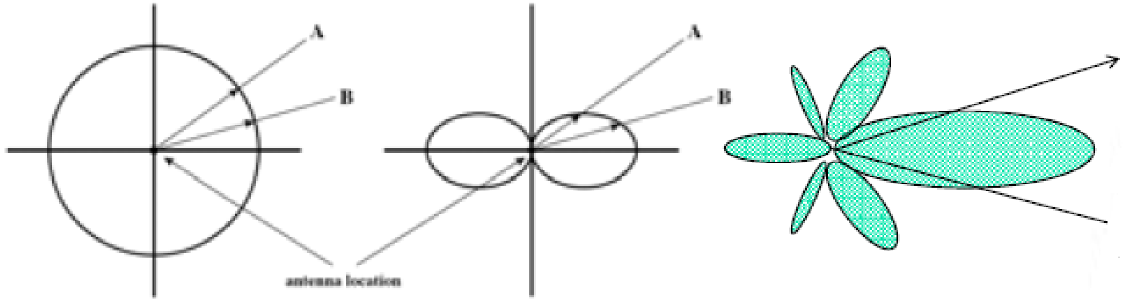
Electromagnetic propagation

- 1 - An alternating current generates an alternating magnetic field around itself.
- 2 – An alternating magnetic field generates an alternating electric field around itself.
- 3 - An alternating electric field generates an alternating magnetic field around itself and so on ...



Radiation Patterns

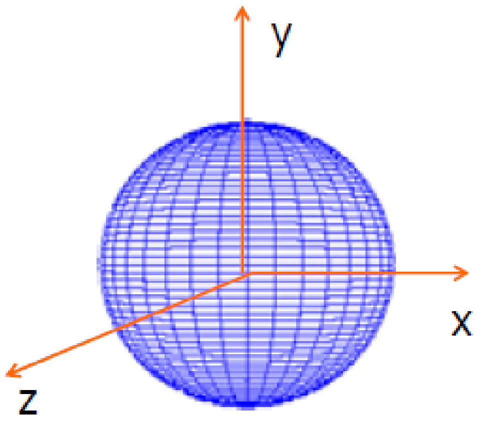
- **Radiation pattern**: Graphical representation of radiation properties, depicted as two-dimensional cross section
- **Beam width**: Measure of directivity of antenna
- **Reception pattern**: Receiving antenna's equivalent to radiation pattern



(a) Omnidirectional (b) Directional

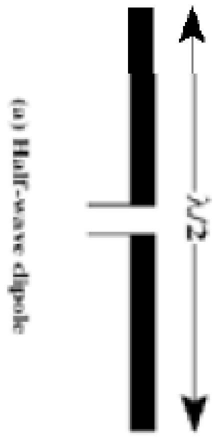
Types of Antennas

- Isotropic antenna (idealized)
  - Radiates power equally in all directions
  - Used as a reference antenna



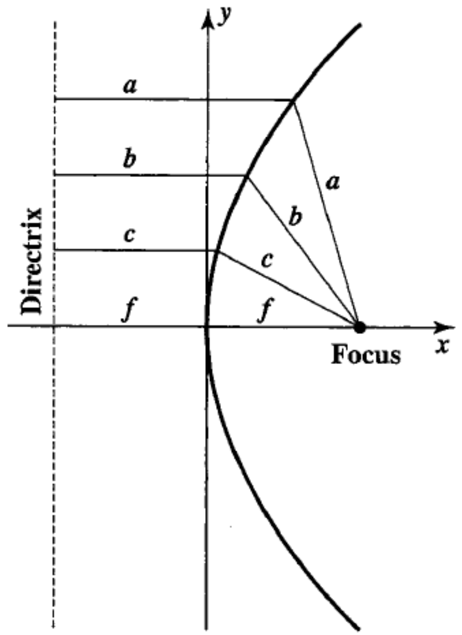
Types of Antennas

- Omni-directional antenna
  - Dipole antennas
    - Half-wave dipole antenna (or Hertz antenna)

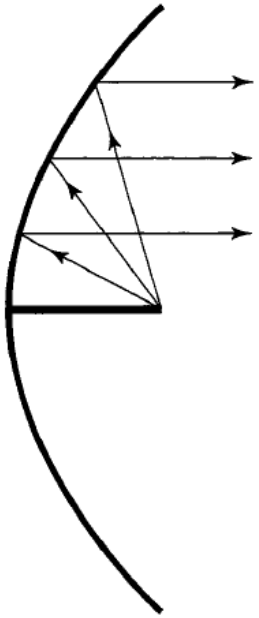


Types of Antennas

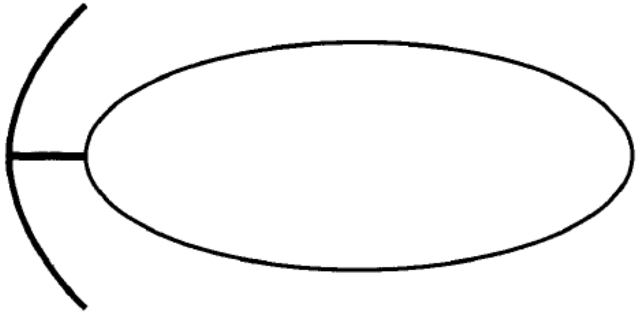
- Directional antenna
  - Yagi-Uda antenna
  - Parabolic Dish Antenna



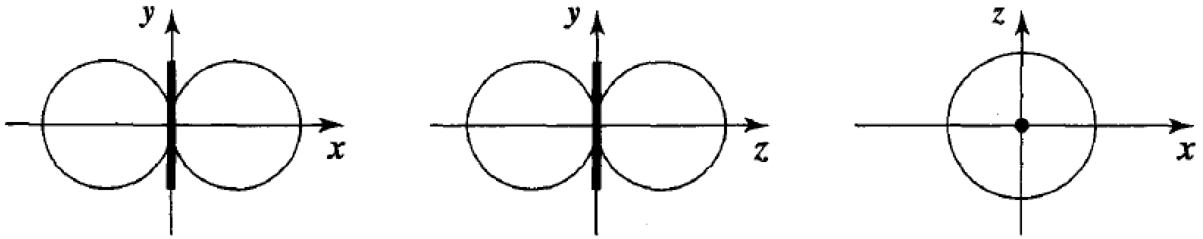
(a) Parabola



(b) Cross section of parabolic antenna showing reflective property

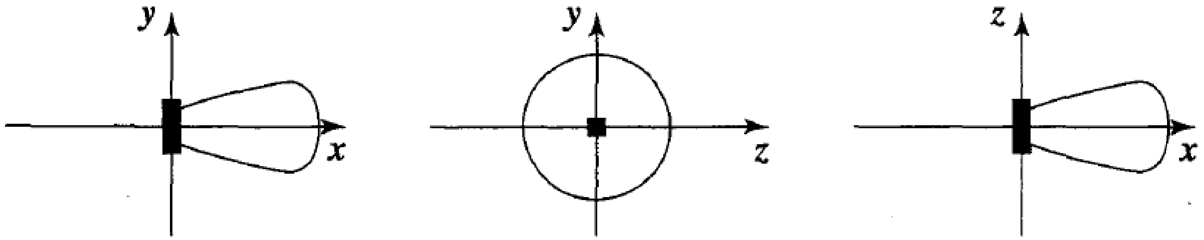


(c) Cross section of parabolic antenna showing radiation pattern



Side view (xy-plane) Side view (zy-plane) Top view (xz-plane)

(a) Simple dipole



Side view (xy-plane) Side view (zy-plane) Top view (xz-plane)

(b) Directed antenna

Radiation Patterns in Three Dimensions

Antenna Gain

- Antenna gain, G: Power output, in a particular direction, compared to that produced in any direction by a perfect isotropic antenna.

$$G = \frac{A_e}{A_{iso\_e}} = \frac{A_e}{\frac{\lambda^2}{4\pi}} = \frac{4\pi f^2 A_e}{c^2}$$

  - G = antenna gain, A_e = effective area, f = carrier frequency
  - c = speed of light (appro. 3 x 10^8 m/s), λ = carrier wavelength

- Antenna Gain is very often given in decibel

$$G_{dB} = 10 \cdot \log_{10}(G) \quad [\text{dBi}]$$

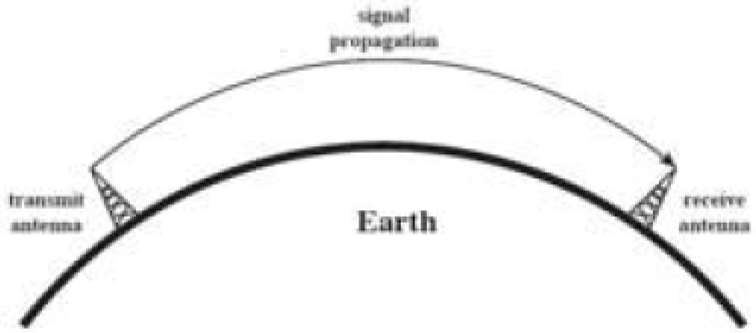
Type of Antenna	Effective Area A_e (m^2)	Power Gain (relative to isotropic)
Isotropic	$\lambda^2/4\pi$	1
Infinitesimal dipole or loop	$1.5\lambda^2/4\pi$	1.5
Half-wave dipole	$1.64\lambda^2/4\pi$	1.64
Horn, mouth area A	$0.81A$	$10A/\lambda^2$
Parabolic, face area A	$0.56A$	$7A/\lambda^2$
Turnstile (two crossed, perpendicular dipoles)	$1.15\lambda^2/4\pi$	1.15

Propagation Characteristics

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight (LOS) propagation

Ground Wave Propagation

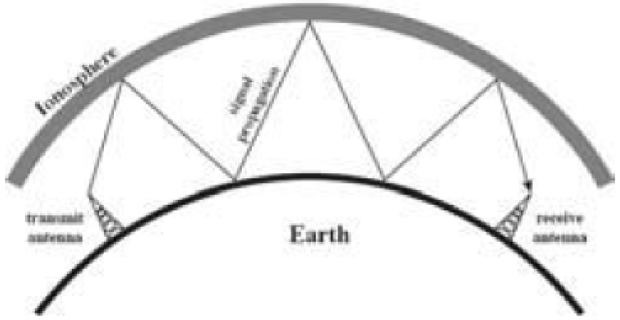
- Follows contour of the earth
- Can Propagate considerable distances
- Frequencies up to 2 MHz ($\lambda \sim 1.5$ km)
- Example: AM radio



(a) Ground-wave propagation (below 2 MHz)

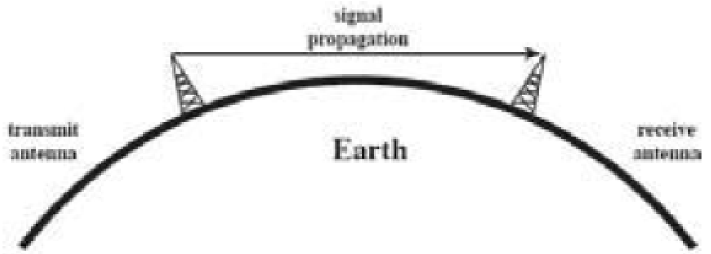
Sky Wave Propagation

- Signal "reflected" from ionized layer of atmosphere
- Signal can travel a number of hops
- Reflection effect caused by refraction
- Frequencies: 2 MHz – 30 MHz (λ ~ 100 m)
- Examples
  - Amateur radio
  - Short-wave radio



Line-of-Sight Propagation

- Transmitting and receiving antennas within line of sight
  - Satellite communication – frequency above 30 MHz λ<100m is not reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight
  - Refraction – bending of microwaves by the atmosphere
    - Velocity of electromagnetic wave is a function of the density of the medium, wave bends at the boundary between mediums



Line-of-Sight Equations

- **Optical** line of sight

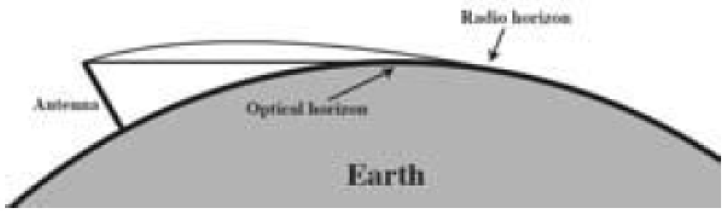
$$d = 3.57\sqrt{h}$$

(what is the line of sight for a 180 cm person?)

- Effective, or radio, line of sight

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

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

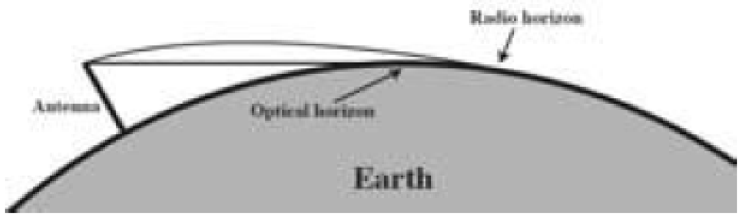


Line-of-Sight Equations

- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

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



LOS Wireless Transmission Impairments

- Free space loss
- Attenuation and attenuation distortion
- Noise
- Atmospheric absorption
- Multipath
- Refraction

Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation for unguided media more complex than number of dB per km
- Amplifiers and repeaters deals with signal level
- Attenuation is greater at higher frequencies, causing signal distortion

Free Space Loss

- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light (» 3 ´ 10 8 m/s)

  where d and λ are in the same units (e.g., meters)

Free Space Loss

- Free space loss equation can be recast:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\text{ dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\text{ dB}$$

Free Space Loss

- Free space loss accounting for gain of other antennas

$$\frac{P_t}{P_r} = \frac{(4\pi)^2 (d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$$

  - G_t = gain of transmitting antenna
  - G_r = gain of receiving antenna
  - A_t = effective area of transmitting antenna
  - A_r = effective area of receiving antenna

Free Space Loss

- Free space loss accounting for gain of other antennas can be recast as

$$L_{dB} = 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r)$$

$$= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\text{dB}$$

Categories of Noise

- **Thermal Noise**
- Intermodulation noise
- Crosstalk
- Impulse Noise

Thermal Noise

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media (transmitter, channel, repeaters, receiver)
- Particularly significant for satellite communication
- Amount:

$$N_0 = kT \left(\mathrm{W/Hz}\right)$$

  - N_0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = $1.3803 \cdot 10^{-23}$ J/K
  - T = temperature, in kelvins (absolute temperature)

Thermal Noise

- Noise is assumed to be independent of frequency
- Thermal noise present in a bandwidth of B Hertz (in watts):

$$N = \mathrm{k}TB$$

or, in decibel-watts

$$N = 10\log_{10}\mathrm{k} + 10\log_{10}T + 10\log_{10}B$$
$$= -228.6\,\mathrm{dBW} + 10\log_{10}T + 10\log_{10}B$$

Other Noise Than Thermal

- Intermodulation noise – occurs if medium has nonlinearities
  - Interference caused by signals produced at frequencies that is the sum or difference of original frequencies
- Crosstalk – unwanted coupling between signal paths
- Impulse noise – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system

The Expression E_b/N_0

- Ratio of ***signal energy per bit*** to ***noise power density*** per Hertz

$$\frac{E_b}{N_0} = \frac{S * T_b}{N_0} = \frac{S / R_b}{k * T} = \frac{S}{K * T * R_b}$$

- The bit error rate (BER)for digital data is a function of E_b/N_0
- As bit rate R_b increases, transmitted signal power must increase to maintain required E_b/N_0

Other Impairments

- **Atmospheric absorption** – water vapor and oxygen contribute to attenuation, peaks at 22 and 60 GHz respectively
- **Multipath** – obstacles reflect signals so that multiple copies with varying delays are received
- **Refraction** – bending of radio waves as they propagate through the atmosphere

Multipath Propagation

- Reflection - occurs when signal encounters a surface that is large relative to the wavelength of the signal
- Diffraction - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- Scattering – occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less

Multipath Propagation

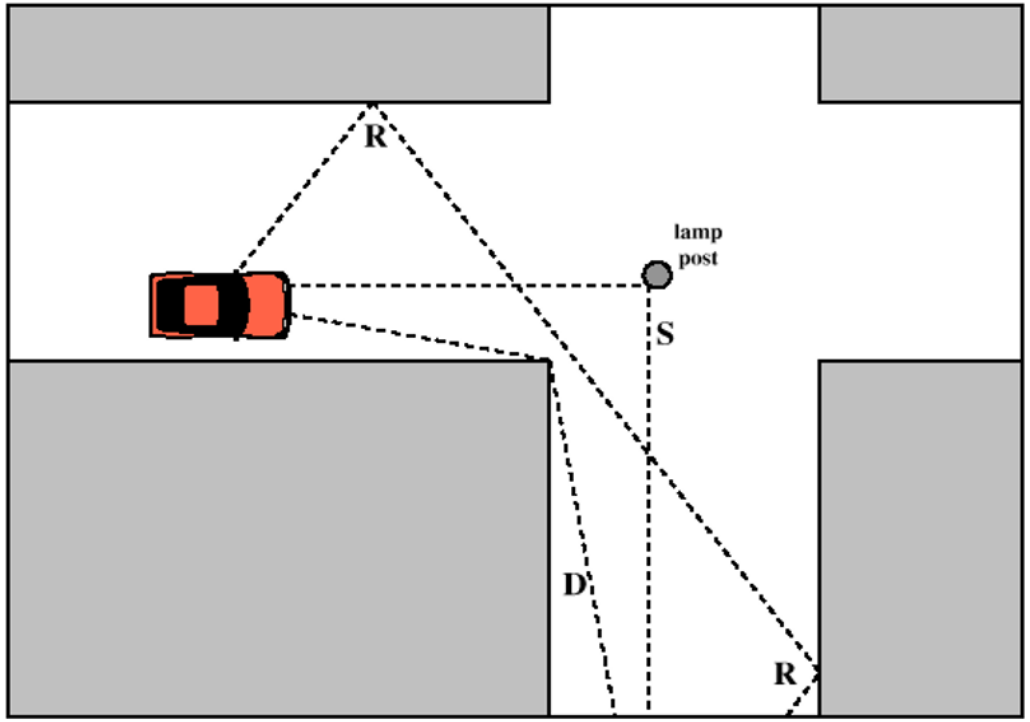
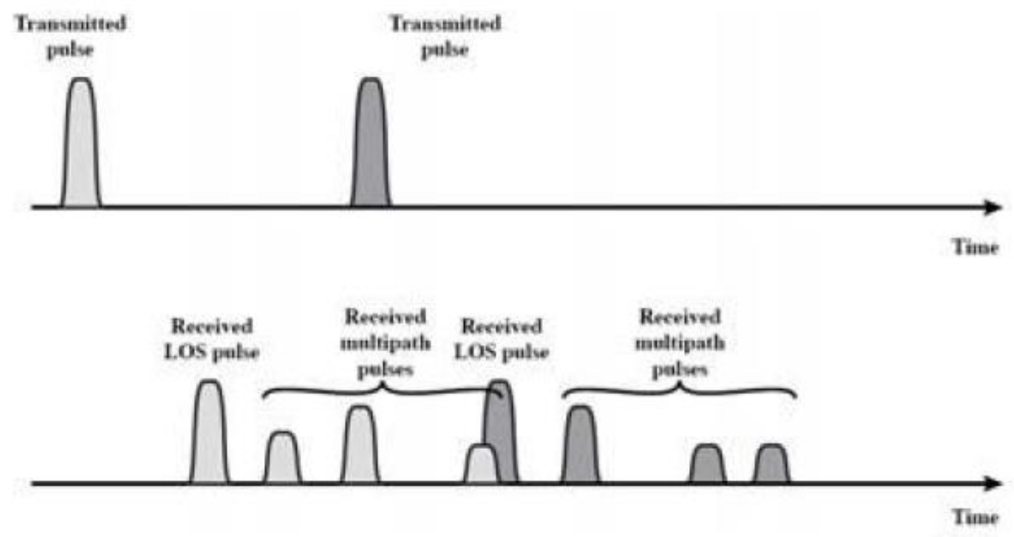


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D)

The Effects of Multipath Propagation

- **Multiple copies** of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
  - If phases add constructively, the signal level is increased
- **Inter-symbol interference** (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit
- Gives **fading** - time variations in the received signal power

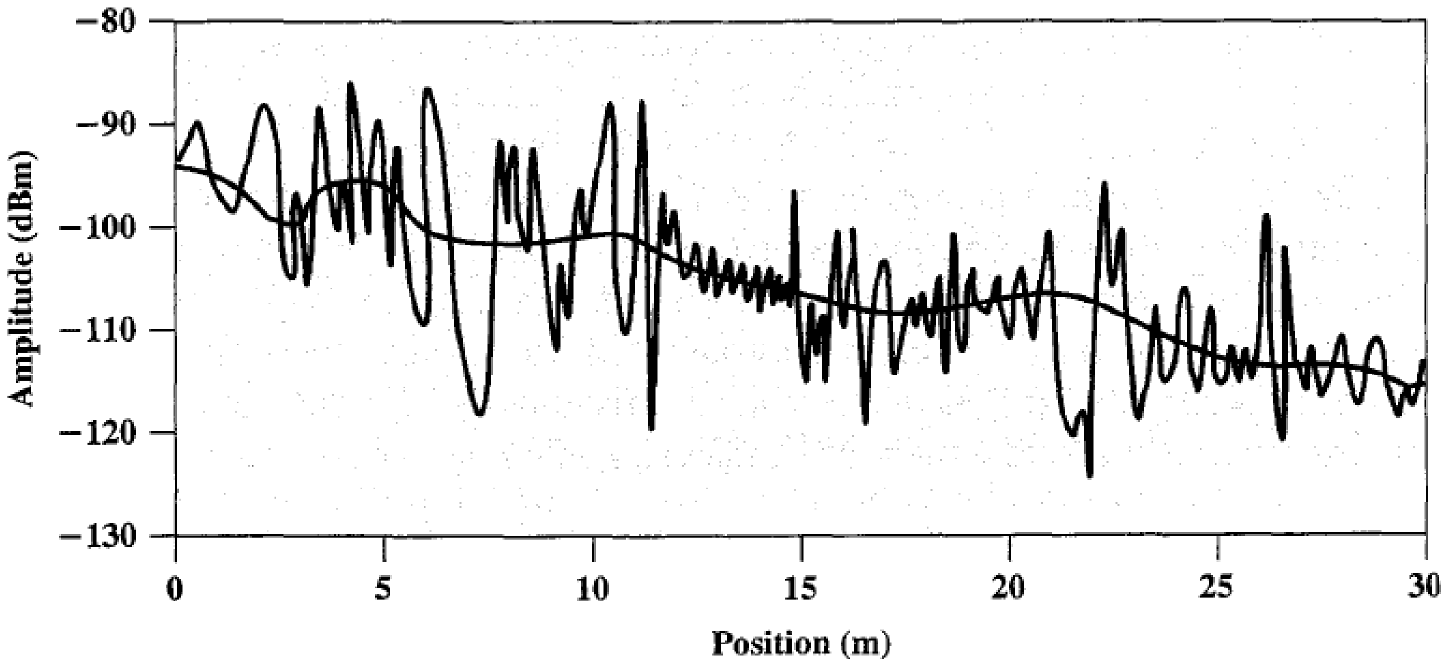
The Effects of Multipath Propagation



Types of Fading

- Fast fading
- Slow fading
- Flat fading
- Selective fading

- Rayleigh fading
- Rician fading



Rayleigh fading occurs when there are multiple indirect paths between transmitter and receiver and no distinct dominant path, such as an LOS path. This represents a worst case scenario. Fortunately, Rayleigh fading can be dealt with analytically, providing insights into performance characteristics that can be used in difficult environments, such as downtown urban settings.

Rician fading best characterizes a situation where there is a direct LOS path in addition to a number of indirect multipath signals. The Rician model is often applicable in an indoor environment whereas the Rayleigh model characterizes outdoor settings. The Rician model also becomes more applicable in smaller cells or in more open outdoor environments. The channels can be characterized by a parameter K, defined as follows:

$$K = \frac{\text{power in the dominant path}}{\text{power in the scattered paths}}$$

When $K = 0$ the channel is Rayleigh (i.e., numerator is zero) and when $K = \infty$, the channel is AWGN (i.e., denominator is zero).

Thank You