

Antennas & Propagation

CS 6710

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Introduction

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

Radiation Patterns

❑ Radiation pattern

- o Graphical representation of radiation properties of an antenna
- o Depicted as two-dimensional cross section

❑ Beam width (or half-power beam width)

- o Measure of directivity of antenna
- o Angle within which power radiated is at least half of that in most preferred direction

❑ Reception pattern

- o Receiving antenna's equivalent to radiation pattern

❑ Omnidirectional vs. directional antenna

Types of Antennas

- ❑ Isotropic antenna (idealized)
 - o Radiates power equally in all directions
- ❑ Dipole antennas
 - o Half-wave dipole antenna (or Hertz antenna)
 - o Quarter-wave vertical antenna (or Marconi antenna)
- ❑ Parabolic Reflective Antenna
 - o Used for terrestrial microwave and satellite applications
 - o Larger the diameter, the more tightly directional is the beam

Antenna Gain

- Antenna gain
 - Power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)
- Expressed in terms of effective area
 - Related to physical size and shape of antenna

Antenna Gain

- Relationship between antenna gain and effective area

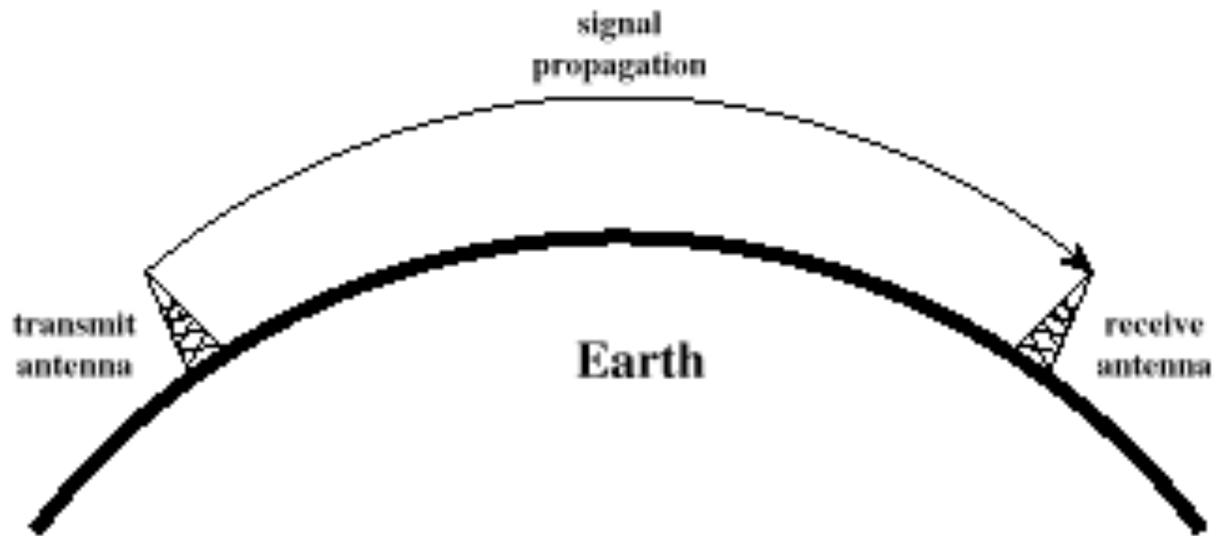
$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

- G = antenna gain
- A_e = effective area
- f = carrier frequency
- c = speed of light ($\approx 3 \times 10^8$ m/s)
- λ = carrier wavelength

Propagation Modes

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation

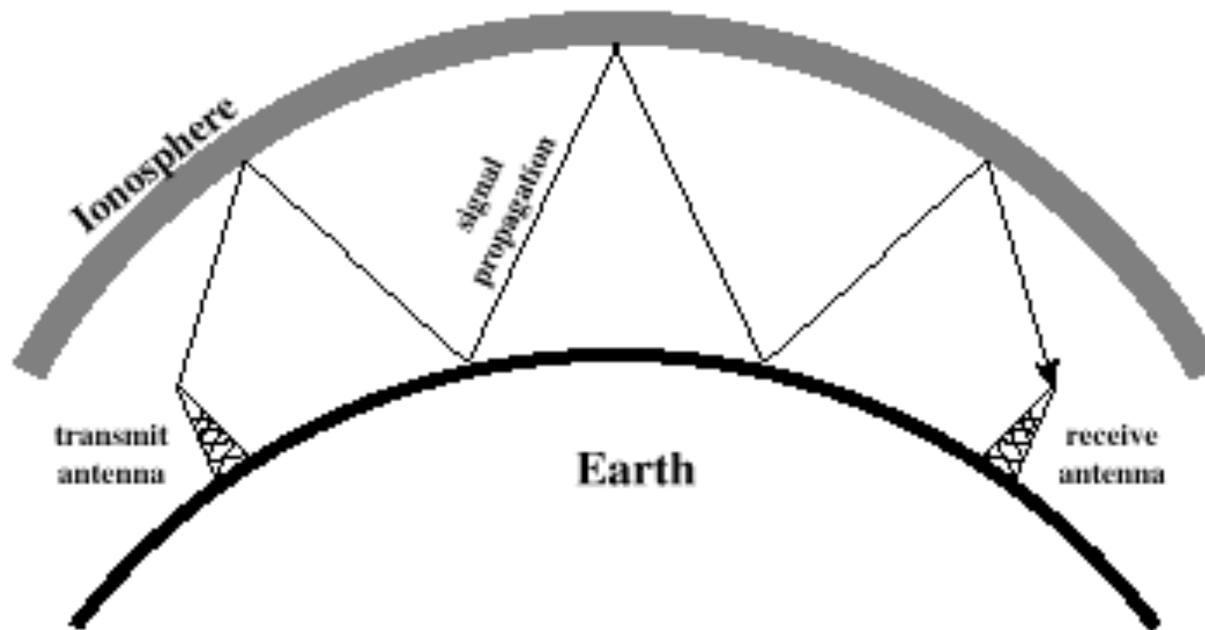
Ground Wave Propagation



Ground Wave Propagation

- ❑ Follows contour of the earth
- ❑ Can Propagate considerable distances
- ❑ Frequencies up to 2 MHz
- ❑ Example
 - o AM radio

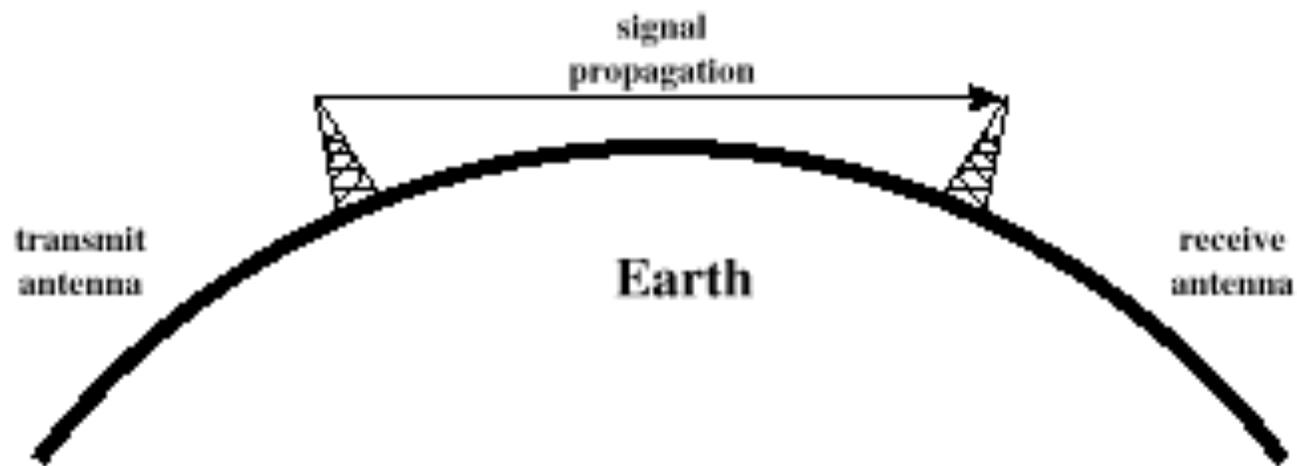
Sky Wave Propagation



Sky Wave Propagation

- ❑ Signal reflected from ionized layer of atmosphere back down to earth
- ❑ Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- ❑ Reflection effect caused by refraction
- ❑ Examples
 - o Amateur radio
 - o CB radio
 - o International broadcasts

Line-of-Sight Propagation



Line-of-Sight Propagation

- ❑ Above 30 MHz neither ground nor sky wave propagation operates
- ❑ Transmitting and receiving antennas must be within line of sight
 - Satellite communication – signal above 30 MHz not reflected by ionosphere
 - Ground communication – antennas within *effective* line of site due to 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

Line-of-Sight Equations

□ Optical line of sight

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

□ Effective, or radio, line of sight

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

- 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

LOS Wireless Transmission Impairments

- ❑ Attenuation
 - o Free space loss
- ❑ Distortion
- ❑ Dispersion
- ❑ Noise
- ❑ Other effects:
 - o Atmospheric absorption
 - o Multipath
 - o Refraction

Attenuation

- ❑ Strength of signal falls off with distance over transmission medium
- ❑ Attenuation factors for unguided media:
 - o Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
 - o Signal must maintain a level sufficiently higher than noise to be received without error
 - o Attenuation is greater at higher frequencies, causing 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 ($\approx 3 \times 10^8$ m/s)
- where d and λ are in the same units (e.g., meters)

Free Space Loss

□ Free space loss equation can be recast:

$$\begin{aligned}L_{dB} &= 10 \log \frac{P_t}{P_r} = 20 \log \left(\frac{4\pi d}{\lambda} \right) \\ &= -20 \log(\lambda) + 20 \log(d) + 21.98 \text{ dB} \\ &= 20 \log \left(\frac{4\pi f d}{c} \right) = 20 \log(f) + 20 \log(d) - 147.56 \text{ dB}\end{aligned}$$

Free Space Loss

□ Free space loss accounting for gain of 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
- o In the above formula, the powers correspond to that of the input signal at the transmitter and output at the receiver, respectively

Free Space Loss

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

$$\begin{aligned}L_{dB} &= 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r) \\ &= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\text{dB}\end{aligned}$$

Path Loss Exponents

- The free space path loss model is idealized

$$\frac{P_t}{P_r} = Ad^\alpha$$

- Here the exponent α depends on the transmission environment
 - o Urban vs suburban, medium-city vs large-city, obstructed vs unobstructed, indoors vs outdoors
 - o Generally between 2 and 4
 - o Obtained empirically
- Two-ray, ten-ray, and general statistical models

Distortion

- ❑ Signals at higher frequencies attenuate more than that at lower frequencies
- ❑ Shape of a signal comprising of components in a frequency band is distorted
- ❑ To recover the original signal shape, attenuation is equalized by amplifying higher frequencies more than lower ones

Dispersion

- ❑ Electromagnetic energy spreads in space as it propagates
- ❑ Consequently, bursts sent in rapid succession tend to merge as they propagate
- ❑ For guided media such as optical fiber, fundamentally limits the product $R \times L$, where R is the rate and L is the usable length of the fiber
- ❑ Term generally refers to how a signal spreads over space and time

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
- ❑ Cannot be eliminated
- ❑ Function of temperature
- ❑ Particularly significant for satellite communication

Thermal Noise

□ Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = kT \text{ (W/Hz)}$$

- N_0 = noise power density in watts per 1 Hz of bandwidth
- k = Boltzmann's constant = 1.3803×10^{-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):

$$N = kTB$$

or, in decibel-watts

$$\begin{aligned} N &= 10 \log k + 10 \log T + 10 \log B \\ &= -228.6 \text{ dBW} + 10 \log T + 10 \log B \end{aligned}$$

Other Kinds of Noise

- ❑ Intermodulation noise – occurs if signals with different frequencies share the same medium
 - Interference caused by a signal produced at a frequency 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
 - Primary source of error for digital data transmission

Expression E_b/N_0

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

$$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{kTR}$$

- The bit error rate for digital data is a function of E_b/N_0
 - Given a value for E_b/N_0 to achieve a desired error rate, parameters of this formula can be selected
 - As bit rate R increases, transmitted signal power must increase to maintain required E_b/N_0

Other Impairments

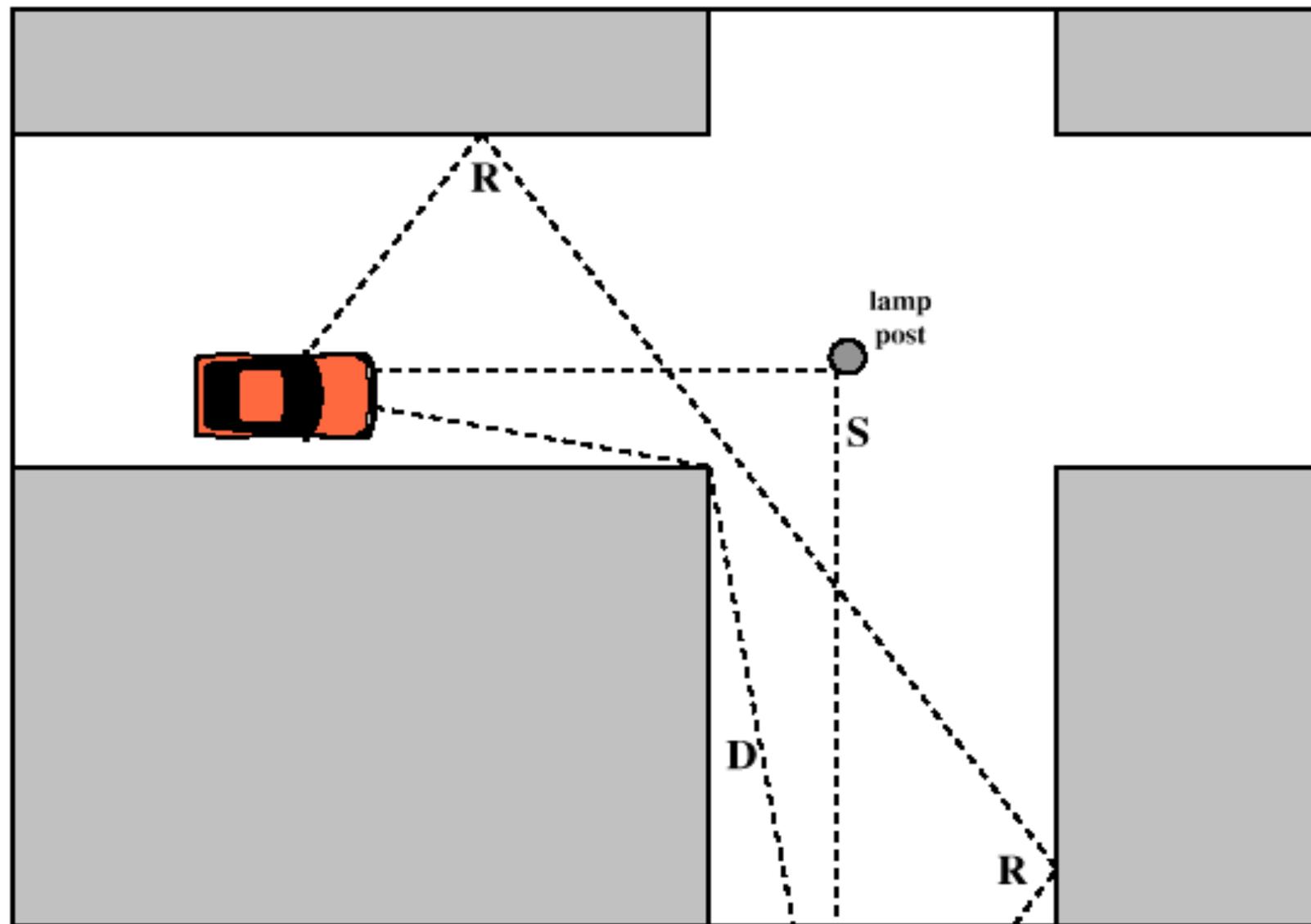
- ❑ Atmospheric absorption – water vapor and oxygen contribute to attenuation
- ❑ Multipath – obstacles reflect signals so that multiple copies with varying delays are received
- ❑ Refraction – bending of radio waves as they propagate through the atmosphere

Fading

- ❑ Variation over time or distance of received signal power caused by changes in the transmission medium or path(s)
- ❑ In a fixed environment:
 - o Changes in atmospheric conditions
- ❑ In a mobile environment:
 - o Multipath propagation

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 is in the order of the wavelength of the signal or less



**Figure 5.10 Sketch of Three Important Propagation Mechanisms:
Reflection (R), Scattering (S), Diffraction (D) [ANDE95]**

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
- ❑ Intersymbol interference (ISI)
 - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

Types of Fading

- ❑ Fast fading
 - o Changes in signal strength in a short time period
- ❑ Slow fading
 - o Changes in signal strength in a short time period
- ❑ Flat fading
 - o Fluctuations proportionally equal over all frequency components
- ❑ Selective fading
 - o Different fluctuations for different frequencies
- ❑ Rayleigh fading
 - o Multiple indirect paths, but no dominant path such as LOS path
 - o Worst-case scenario
- ❑ Rician fading
 - o Multiple paths, but LOS path dominant
 - o Parametrized by K , ratio of power on dominant path to that on other paths

Error Compensation Mechanisms

- Forward error correction
- Adaptive equalization
- Diversity techniques

Forward Error Correction

- ❑ Transmitter adds error-correcting code to data block
 - Code is a function of the data bits
- ❑ Receiver calculates error-correcting code from incoming data bits
 - If calculated code matches incoming code, no error occurred
 - If error-correcting codes don't match, receiver attempts to determine bits in error and correct

Adaptive Equalization

- ❑ Can be applied to transmissions that carry analog or digital information
 - Analog voice or video
 - Digital data, digitized voice or video
- ❑ Used to combat intersymbol interference
- ❑ Involves gathering dispersed symbol energy back into its original time interval
- ❑ Techniques
 - Lumped analog circuits
 - Sophisticated digital signal processing algorithms

Diversity Techniques

❑ Space diversity:

- o Use multiple nearby antennas and combine received signals to obtain the desired signal
- o Use collocated multiple directional antennas

❑ Frequency diversity:

- o Spreading out signal over a larger frequency bandwidth
- o Spread spectrum

❑ Time diversity:

- o Noise often occurs in bursts
- o Spreading the data out over time spreads the errors and hence allows FEC techniques to work well
- o TDM
- o Interleaving