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Antennas and Propagation

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



Radiation Patterns

- Radiation pattern
 - Graphical representation of radiation properties of an antenna
 - Depicted as two-dimensional cross section
- Beam width (or half-power beam width)
 - Measure of directivity of antenna
- Reception pattern
 - Receiving antenna's equivalent to radiation pattern



Types of Antennas

- Isotropic antenna (idealized)
 - Radiates power equally in all directions
- Dipole antennas
 - Half-wave dipole antenna (or Hertz antenna)
 - Quarter-wave vertical antenna (or Marconi antenna)
- Parabolic Reflective Antenna



Antenna Gain

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



Antenna Gain

- Relationship between antenna gain and effective area

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

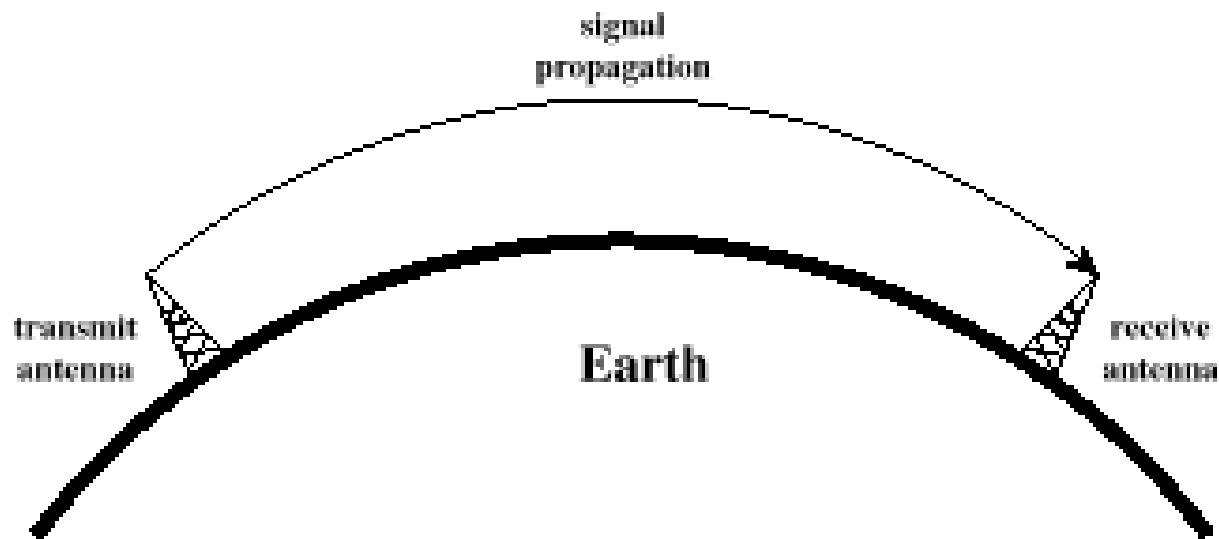
- G = antenna gain
- A_e = effective area
- f = carrier frequency
- c = speed of light ($\gg 3 \times 10^8$ m/s)
- λ = carrier wavelength



Propagation Modes

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

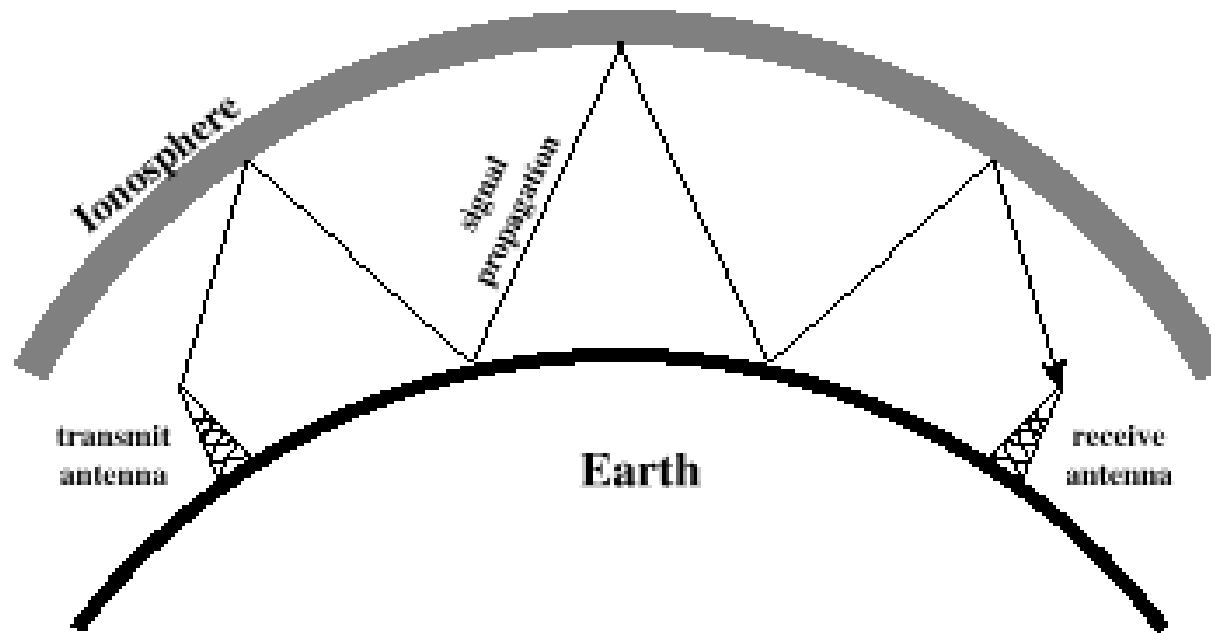
Ground Wave Propagation



Ground Wave Propagation

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

Sky Wave Propagation

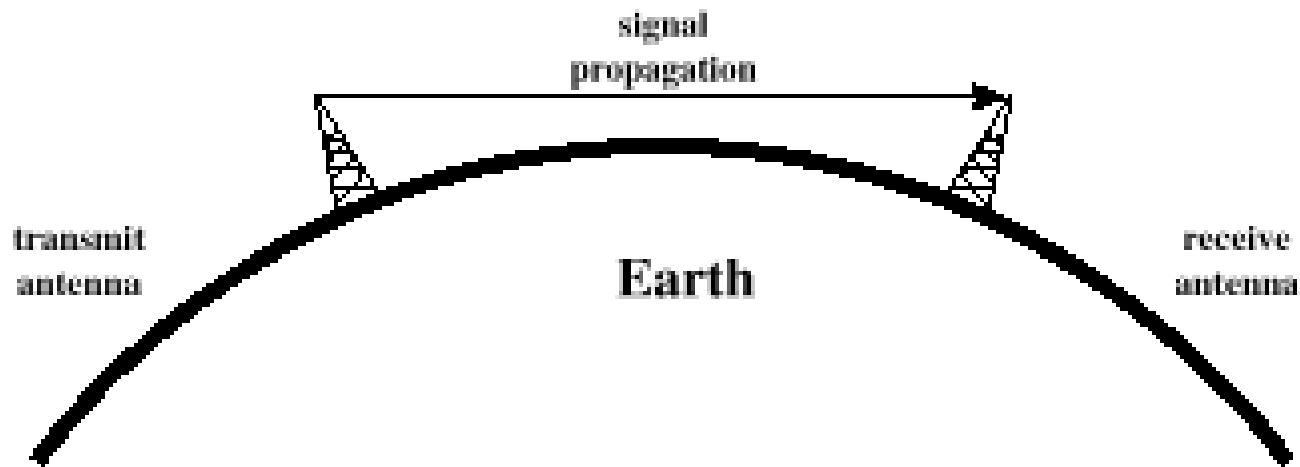




Sky Wave Propagation

- 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
 - Amateur radio
 - CB radio

Line-of-Sight Propagation



Line-of-Sight Propagation

- 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

Impairments

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



Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
 - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
 - Signal must maintain a level sufficiently higher than noise to be received without error
 - 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 ($\gg 3 \times 10^8$ 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 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
- 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

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



Noise Terminology

- 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

Expression E_b/N_0

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

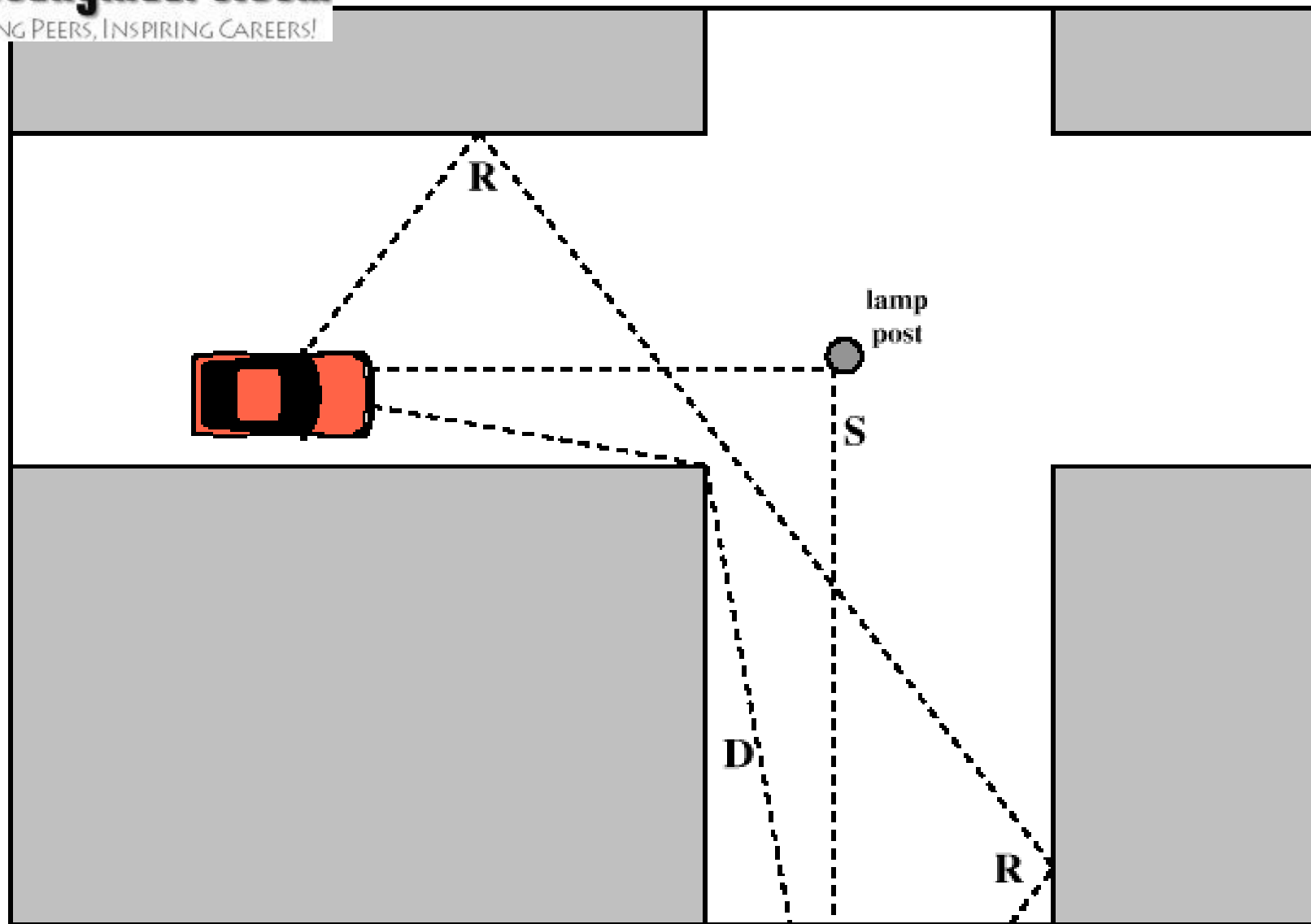
$$\frac{E_b}{N_0} = \frac{S / R}{N_0} = \frac{S}{kTR}$$

- 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



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



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

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
- Slow fading
- Flat fading
- Selective fading
- Rayleigh fading
- Rician fading



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

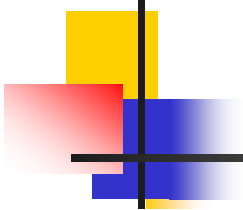
Adaptive Equalization

- 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

- Diversity is based on the fact that individual channels experience independent fading events
- Space diversity – techniques involving physical transmission path
- Frequency diversity – techniques where the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers
- Time diversity – techniques aimed at spreading the data out over time



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