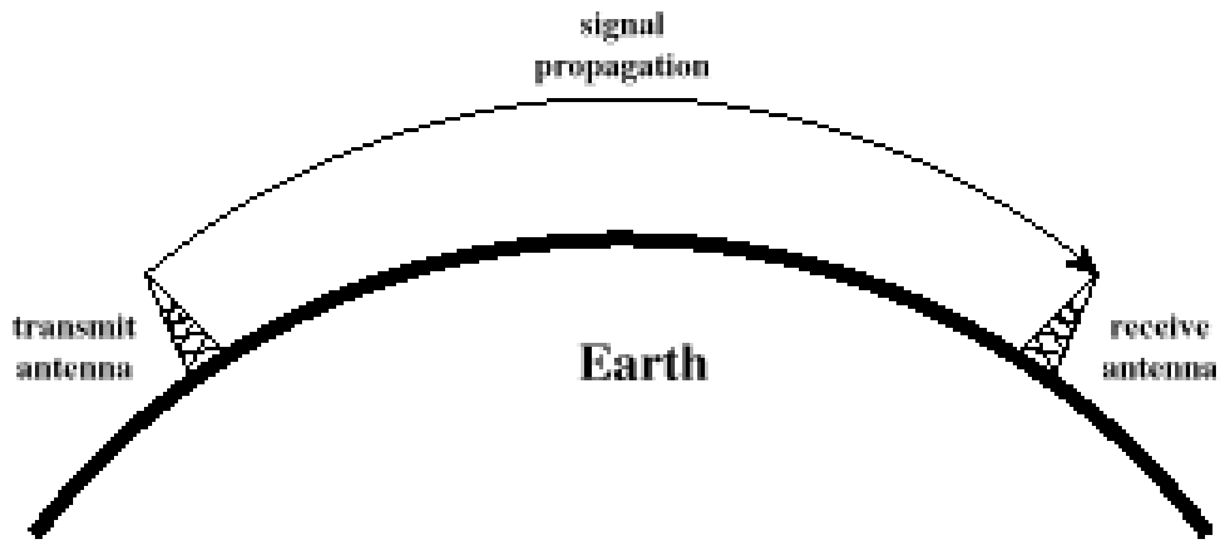
ANTENNA AND WAVE PROPAGATION

Propagation Modes

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

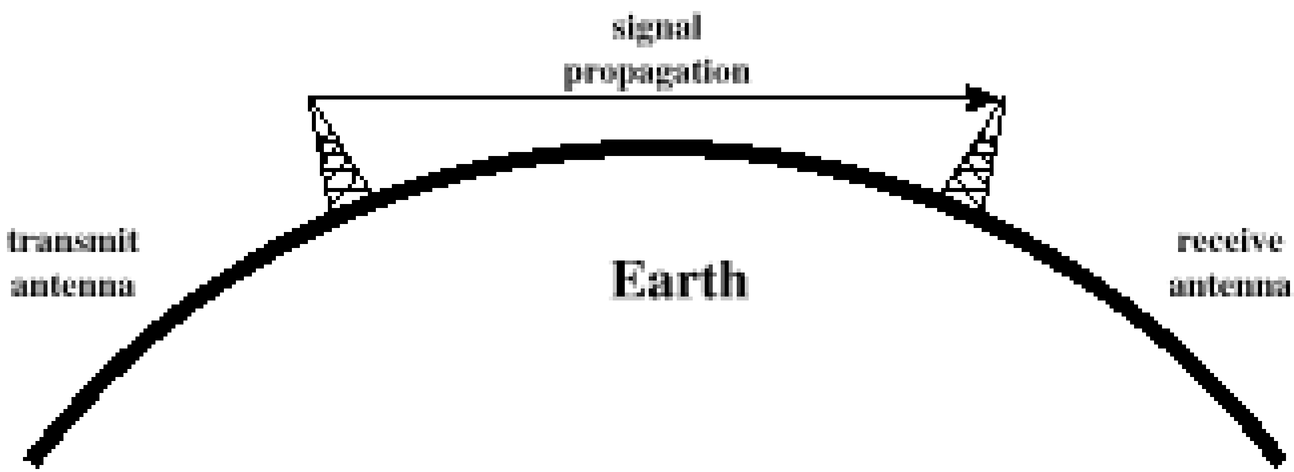
Ground Wave Propagation



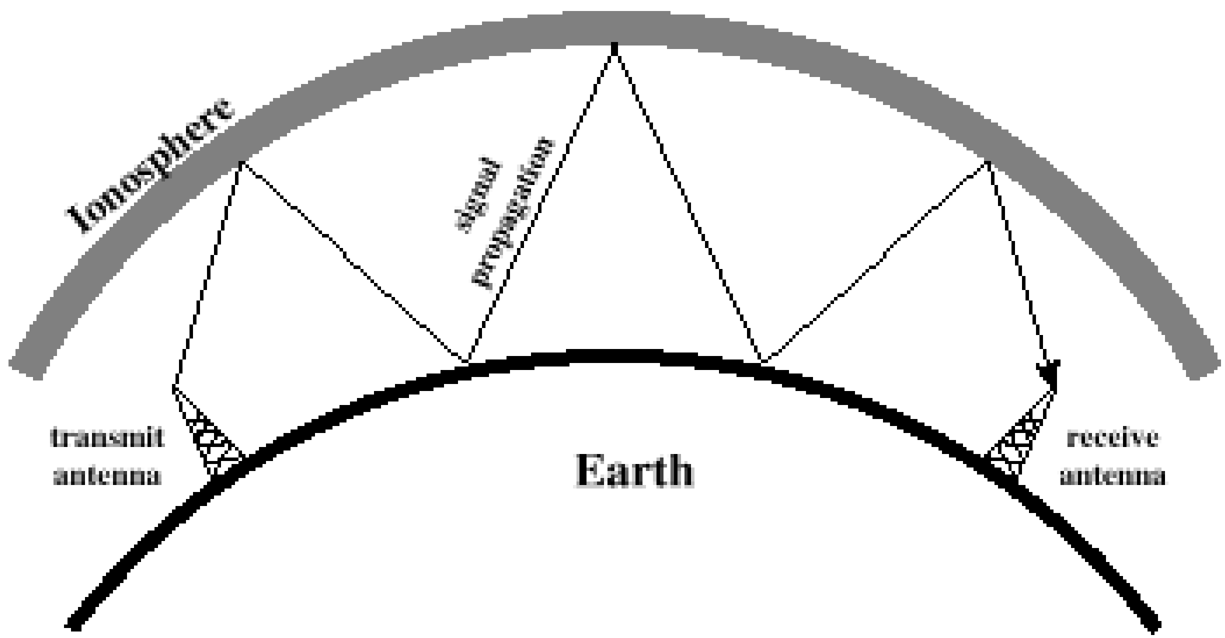
Ground Wave Propagation

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

Ground Wave


signal
propagation
transmit
antenna
Earth
receive
antenna

Plane Earth Reflection



Space Wave

- 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

- 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

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

  - 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

- 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 (» 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:

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

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

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

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
- 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:

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

  - 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):

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

or, in decibel-watts

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

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

$$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{\mathrm{k}TR}$$

- 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