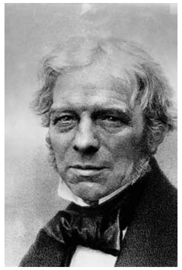
$$\nabla \times E = -\frac{\partial B}{\partial t}$$



Michael Faraday & James C. Maxwell

TELE303 Wireless Communications
Lecture 3 – Propagation

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TELE Programme / InfoSci
University of Otago, 2016

Outline

- Antenna
- Propagation modes
- Impairments

Antenna

Antenna

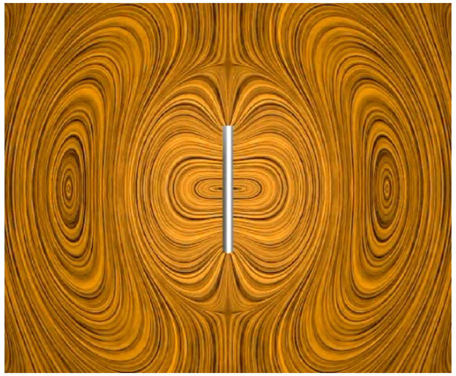
- An antenna is an electrical conductor or system of conductors
  - o Transmission - radiates electromagnetic energy into space
  - o Reception - collects electromagnetic energy from space
- In two-way communication, the same antenna can be used for transmission and reception
  - o Antenna characteristics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

Types of Antennas

- Isotropic antenna (idealized)
  - o A point of space that 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



Example: Quarter-Wave Antenna



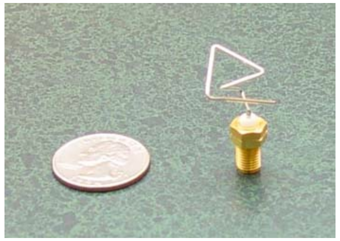
Source: A VISUAL TOUR OF CLASSICAL ELECTROMAGNETISM, MIT Physics 8.02: Electromagnetism I

Antenna: Gain and Effective Area

- Antenna **gain**: power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)
- Effective area
  - o Related to physical size and shape of antenna
- Relationship between antenna gain and effective area
  - o G = antenna gain
  - o A_e = effective area
  - o f = carrier frequency
  - o c = speed of light
  - o λ = carrier wavelength

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

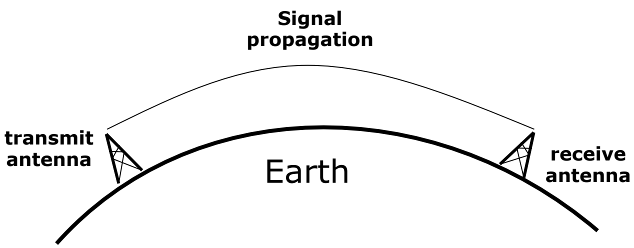
What Are These?



Propagation Modes

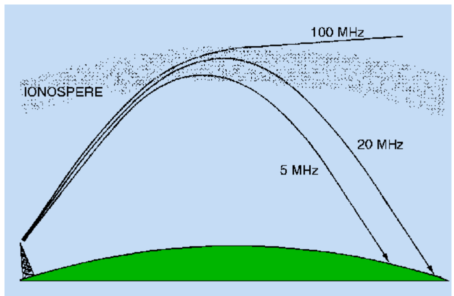
Ground Wave Propagation

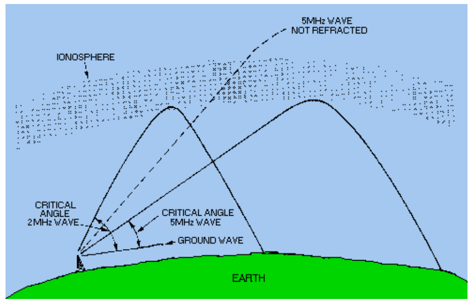
- Follows contour of the earth
- Can propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio



Ionosphere Refraction

- Reflection effect caused by refraction

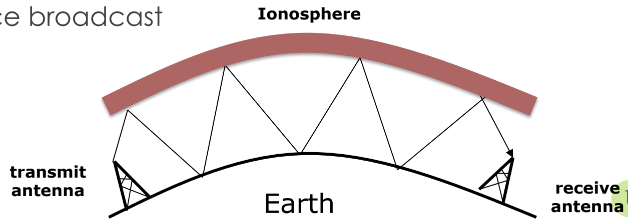




Source: http://www.tpub.com/neets/book10/40e.htm

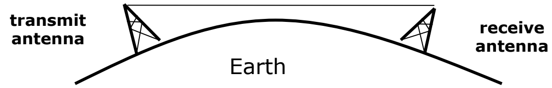
Sky Wave Propagation

- 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
- Picks up thousands of kilometers
- Examples
  - Amateur radio
  - CB radio
  - Long-distance broadcast



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 sight due to refraction



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
- Maximum distance between two antennas for LOS propagation:

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

  - h1, h2: heights of the two antennas

Impairments ☹

Transmission Impairments

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

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

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

  - Pt = signal power at transmitting antenna
  - Pr = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light
  - where d and λ are in the same units (e.g., meters)
- Recast

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

$$= 20\log(f) + 20\log(d) - 147.56\ \text{dB}$$

So Many Noises

- 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 present in a bandwidth of *B* Hz (in watts):

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

  - k = Boltzmann's constant
  - T = temperature, in Kelvins (absolute temperature)

Other Noises

- **Intermodulation** noise – occurs if signals with different frequencies share the same medium
  - A signal produced at a frequency that is the sum or difference of original frequencies
  - Nonlinearity in transmitter, receiver systems.
- **Crosstalk**
  - Unwanted coupling between signal paths
  - Dominates in unlicensed ISM bands
- **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 in digital data transmission

Other Impairments

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

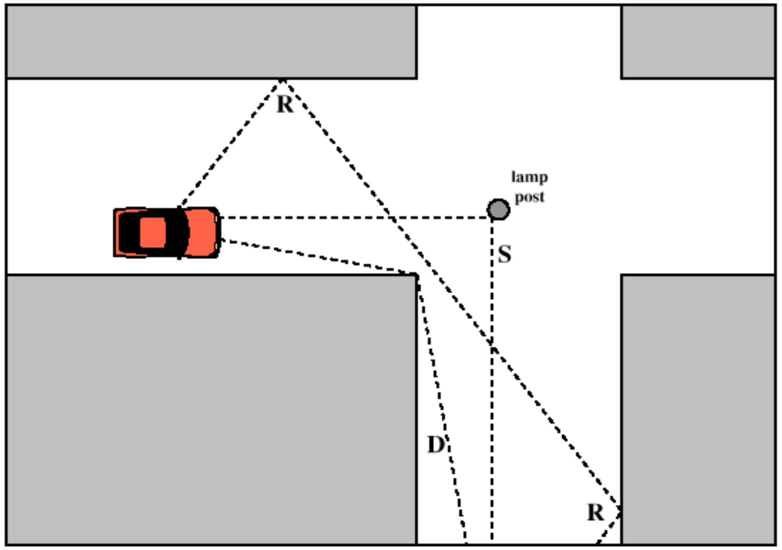


Figure 5.5 Sketch of three important propagation mechanisms: Reflection (R), Scattering (S), Diffraction (D)

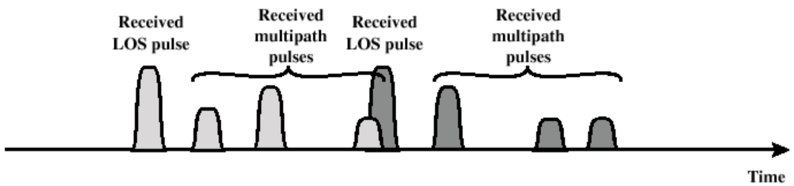
Multipath Propagation

- **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

The Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - o If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - o One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

Fig. 5.12



Fading

- Time variation of received signal power caused by changes in the medium or path, e.g., rainfall, mobility etc.
- Fading pattern on frequencies: flat fading or selective fading
- Rayleigh fading: e.g. urban settings
- Rician fading: LOS, e.g. indoor

Recap

- Antennas
- Propagation modes
- LOS loss model
- Noise: types and causes
- Other impairments esp. multipath
- Fading

- Beard & Stallings, §5.1-5.3, 6.1-6.4