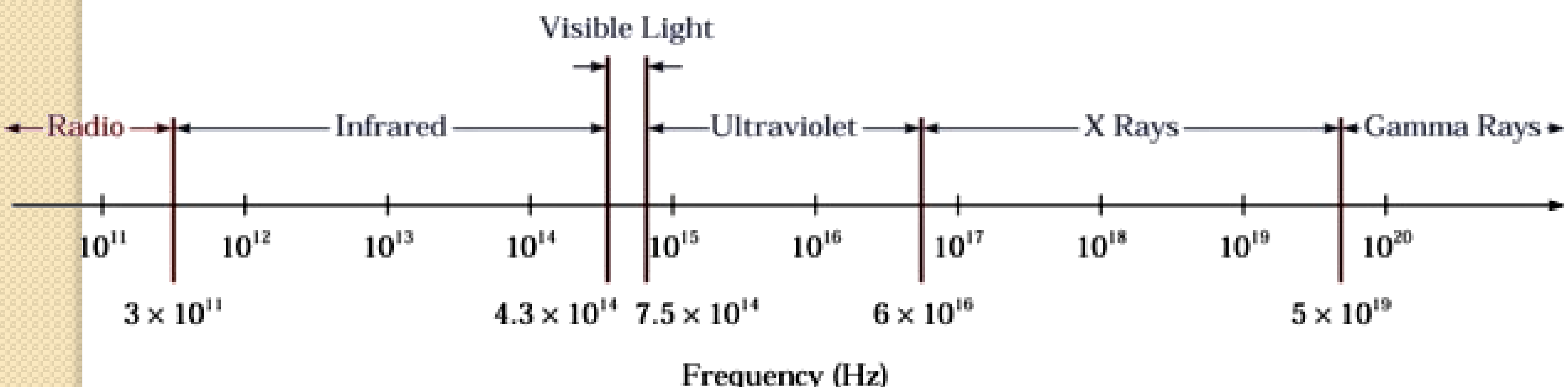
ANTENNA AND WAVE PROPAGATION

Introduction

- Radio waves are one form of electromagnetic radiation
- Electromagnetic radiation has a dual nature:
  - In some cases, it behaves as waves
  - In other cases, it behaves as particles (photons)
- For radio frequencies the wave model is generally more appropriate
- Electromagnetic waves can be generated by many means, but all them involve the movement of electrical charges

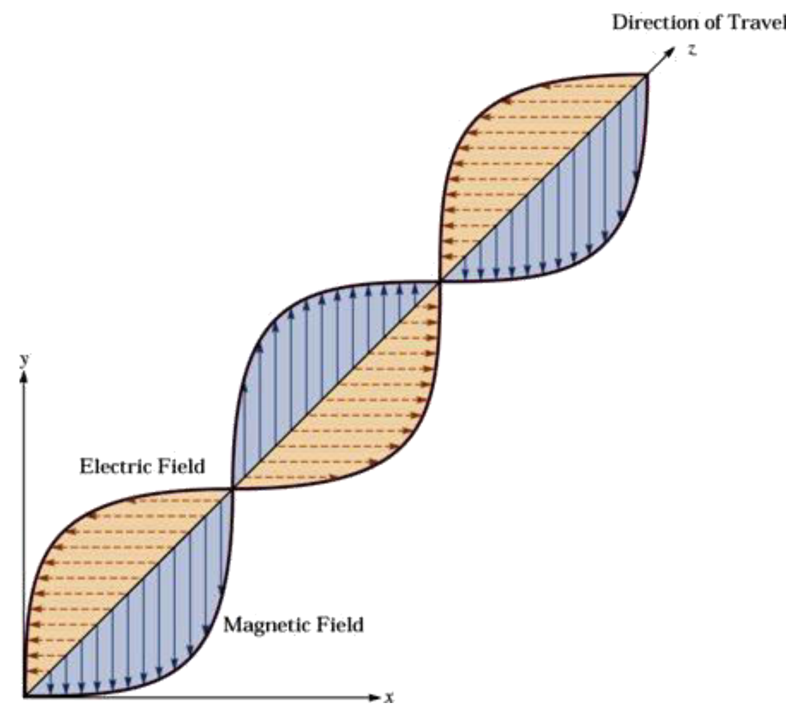
Electromagnetic Spectrum



Electromagnetic Waves

- Electromagnetic transmissions move in space as *Transverse* waves
- Waves are characterized by frequency and wavelength:

$$v = f\lambda$$



Electric and Magnetic Fields

- An electromagnetic wave propagating through space consists of electric and magnetic fields, perpendicular both to each other and to the direction of travel of the wave
- The relationship between electric and magnetic field intensities is analogous to the relation between voltage and current in circuits
- This relationship is expressed by: $Z = \frac{E}{H}$

Power Density

- Power density in space is the amount of power that flows through each square meter of a surface perpendicular to the direction of travel

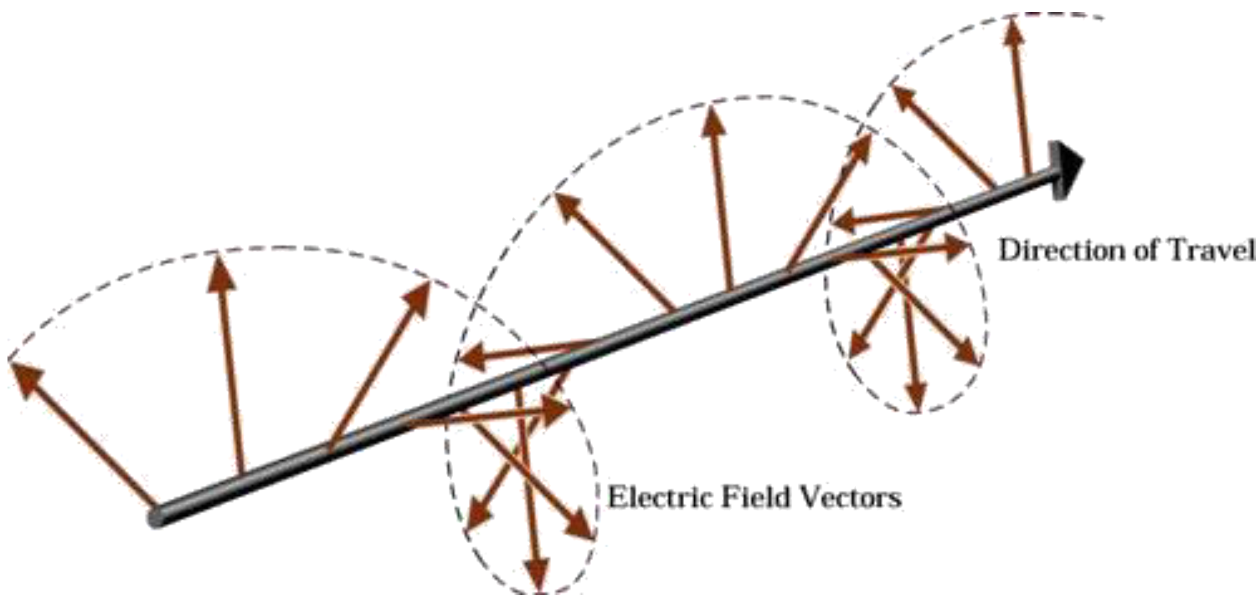
$$P_D = \frac{E^2}{Z}$$

Plane and Spherical Waves

- The simplest source of electromagnetic waves would be a point in space, with waves radiating equally in all directions. This is called an **isotropic radiator**
- A *wavefront* that has a surface on which all the waves are the same phase would be a sphere

Circular Polarization

- The polarization of a plane wave is simply the direction of its electric field vector
- The wave can rotate in either direction - it is called *right-handed* if it rotates clockwise



Free-Space Propagation

- Radio waves propagate through free space in a straight line with a velocity of the speed of light (300,000,000 m/s)
- There is no loss of energy in free space, but there is attenuation due to the spreading of the waves

Attenuation of Free Space

- An isotropic radiator would produce spherical waves
- The power density of an isotropic radiator is simply be the total power divided by the surface area of the sphere, according to the *square-law*:

$$P_D = \frac{P_t}{4\pi r^2}$$

Transmitting Antenna Gain

- In practical communication systems, it is important to know the signal strength at the receiver input
- It depends on the transmitter power and the distance from the transmitter to the receiver, but also upon the transmitting and receiving antennas
- Two important antenna characteristics are:
  - Gain for the transmitting antenna
  - Effective area for the receiving antenna
- Antennas are said to have *gain* in those directions in which the most power is radiated

Receiving Antenna Gain

- A receiving antenna absorbs some of the energy from radio waves that pass it
- A larger antenna receives more power than a smaller antenna (in relation to surface area)
- Receiving antennas are considered to have gain just as transmitting antennas do
- The power extracted from a receiving antenna is a function of its physical size and its gain

Path Loss

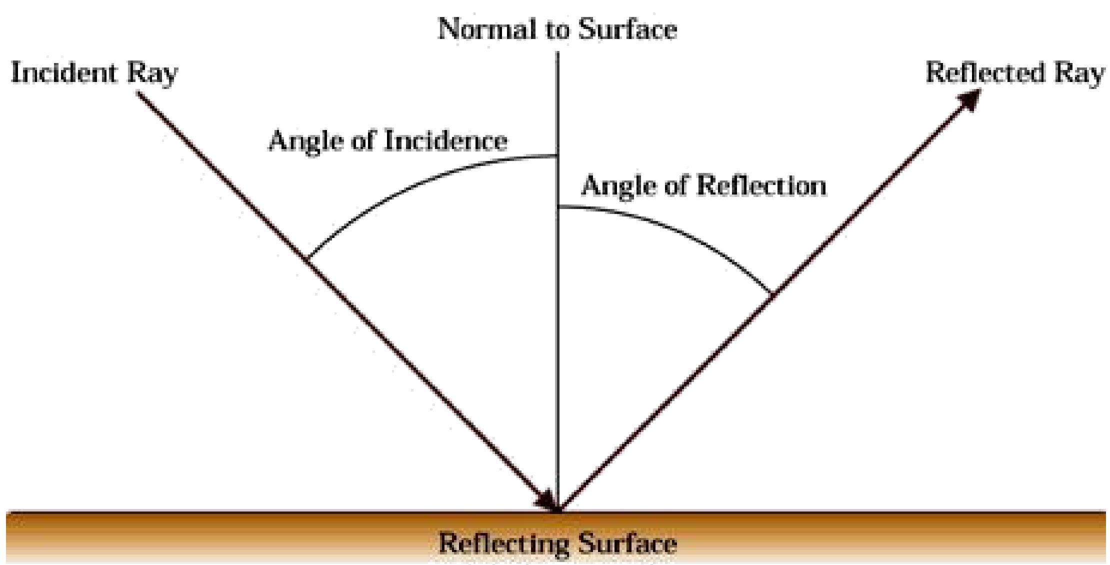
- Free-space attenuation is the ratio of received power to transmitted power
- The decibel gain between transmitter and receiver is negative (loss) and the loss found this way is called free-space loss or **path loss**

Reflection, Refraction, and Diffraction

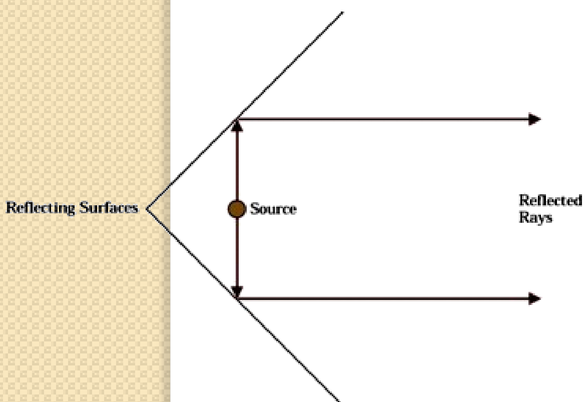
- These three properties are shared by light and radio waves
- For both reflection and refraction, it is assumed that the surfaces involved are much larger than the wavelength; if not, diffraction will occur

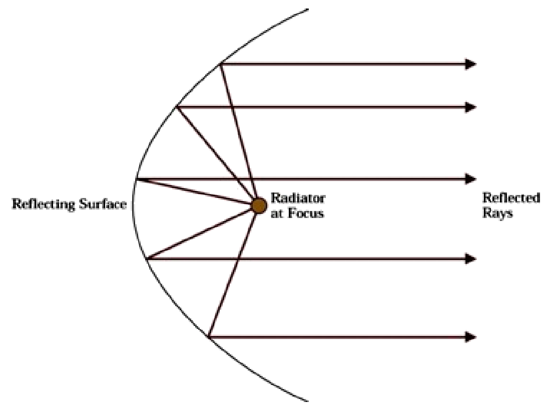
Reflection

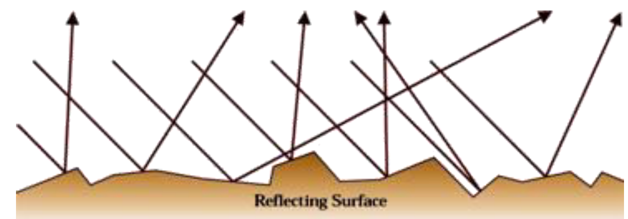
- Reflection of waves from a smooth surface (*specular reflection*) results in the angle of reflection being equal to the angle of incidence



Other Types of Reflection





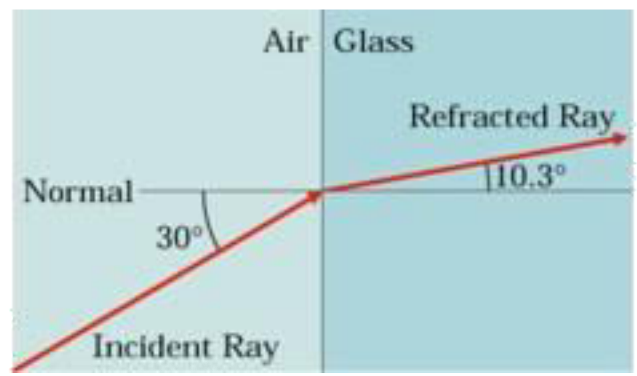


Corner reflector   Parabolic reflector Diffuse Reflection

Refraction

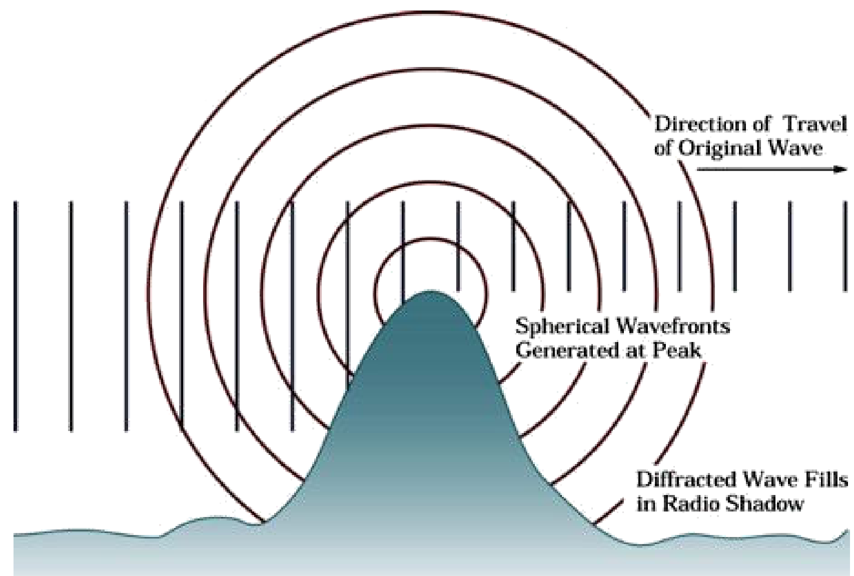
- A transition from one medium to another results in the bending of radio waves, just as it does with light
- Snell's Law governs the behavior of electromagnetic waves being refracted:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



Diffraction

- As a result of diffraction, electromagnetic waves can appear to "go around corners"
- Diffraction is more apparent when the object has sharp edges, that is when the dimensions are small in comparison to the wavelength



Ground-Wave Propagation

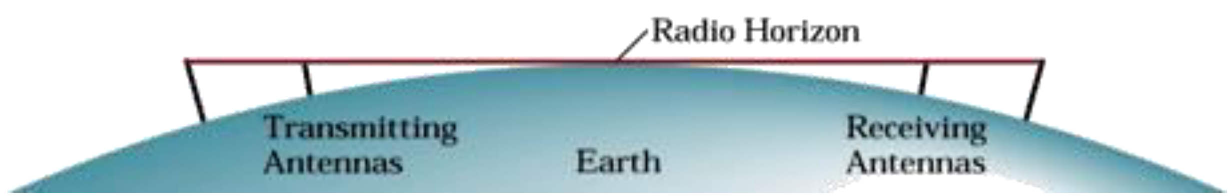
- Most of the time, radio waves are not quite in free space
- Terrestrial propagation modes include:
  - Line-of-sight propagation
  - Space-wave propagation
  - Ground waves
  - Sky waves

Ionospheric Propagation

- Long-range communication in the high-frequency band is possible because of refraction in a region of the upper atmosphere called the **ionosphere**
- The ionosphere is divided into three regions known as the D, E, and F layers
- Ionization is different at different heights above the earth and is affected by time of day and solar activity

Line-of-Sight Propagation

- Signals in the VHF and higher range are not usually returned to earth by the ionosphere
- Most terrestrial communication at these frequencies uses direct radiation from the transmitter to the receiver
- This type of propagation is referred to as *space-wave, line-of-sight,* or *tropospheric propagation*



Propagation in a Mobile/Portable Environment

- Multipath propagation creates interference for communication systems
- Mobile environments are often so cluttered that the square-law attenuation of free space does not apply (for example, in a city with many buildings)

Repeaters and Cellular Systems

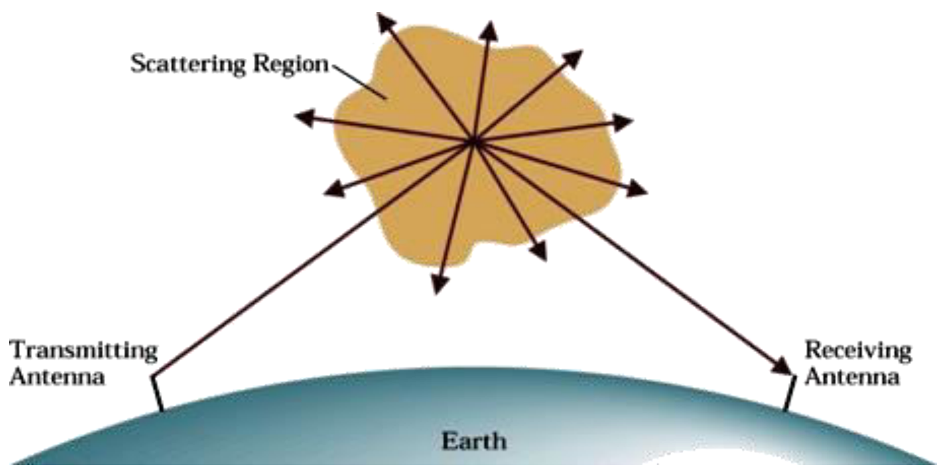
- Because mobile systems have relatively small antenna heights, systems must be in place to improve signal strength and reception capabilities
- Mobile units make use of *repeaters* that are full-duplex and use resonant cavities called a duplexer
- Cellular systems do not use the horizon as the limit of coverage
- Antennas may still be mounted high, but the range is deliberately limited by using as low a transmitter power as is possible

Control of Fading in Mobile Systems

- Fading is a problem with mobile systems and increasing power and typical frequency diversity are not workable solutions to this problem
- Spread-spectrum systems can correct fading through alternative frequency diversity systems such as CDMA
- Using a **rake receiver**, a CDMA system can receive several data streams at once

Other Propagation Modes

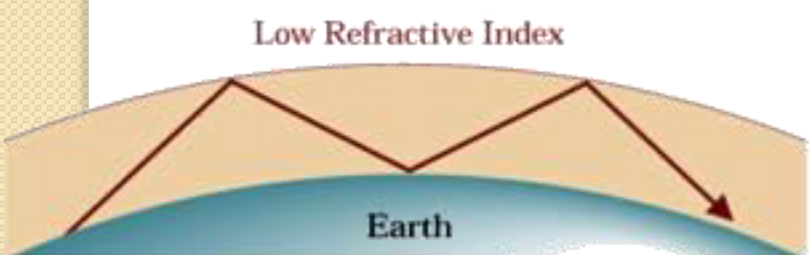
- Tropospheric Scatter - makes use of the scattering of radio waves in the troposphere to propagate signals in the 250 MHz –5 GHz range

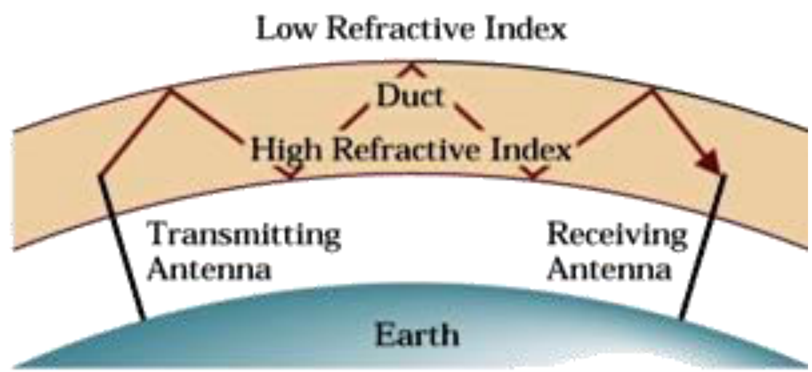


Ducting

- Under certain conditions, especially over water, a *superrefractive* layer can form in the troposphere and return signals to earth
- The signals can then propagate over long distances by alternately reflecting from the earth and refracting from the superrefractive layer
- A related condition involves a thin tropospheric layer with a high refractive index, so that a *duct* forms

Examples of Ducting





Meteor-Trail Propagation

- Meteors are constantly entering the earth’s atmosphere and being destroyed
- The meteors that enter the atmosphere leave behind an ionized trail that can be used for communication. It is not suitable for voice communication