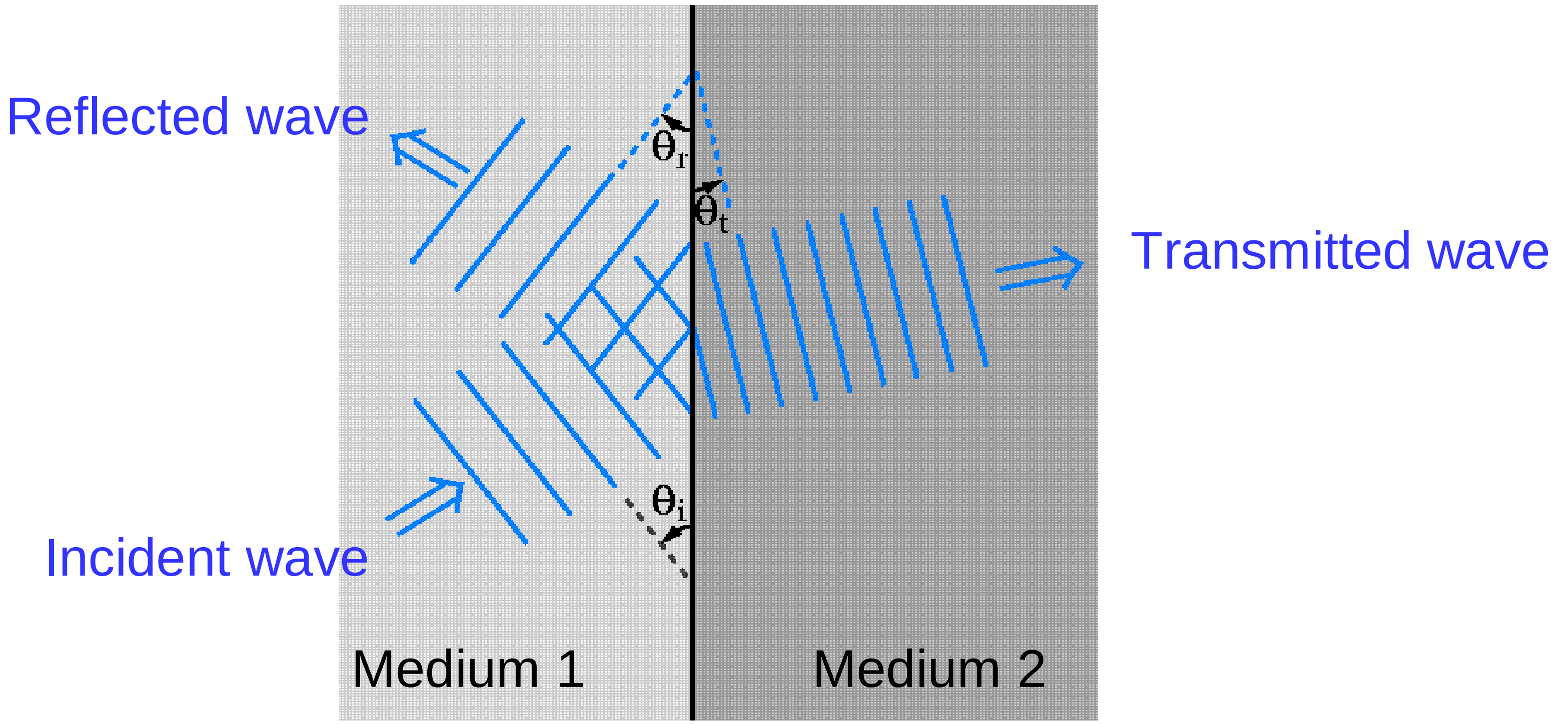
EE303 Lesson 26:
Radio Wave Propagation

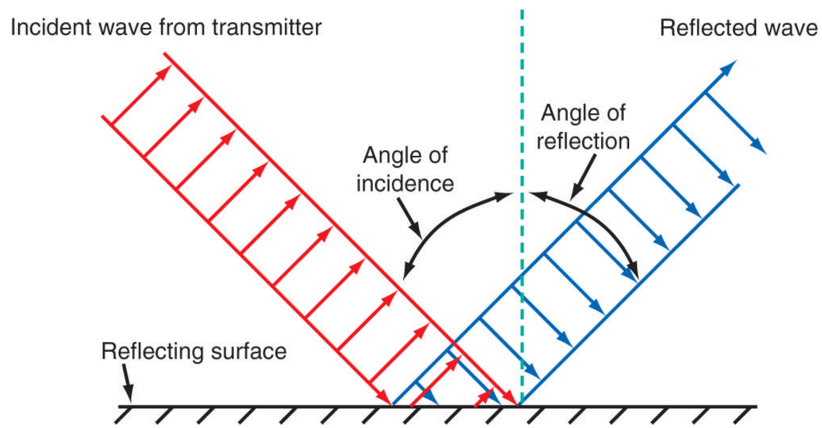
Electromagnetic waves at boundaries

- When an EM wave encounters a boundary between different media, part of wave is reflected back and part is transmitted across the boundary.



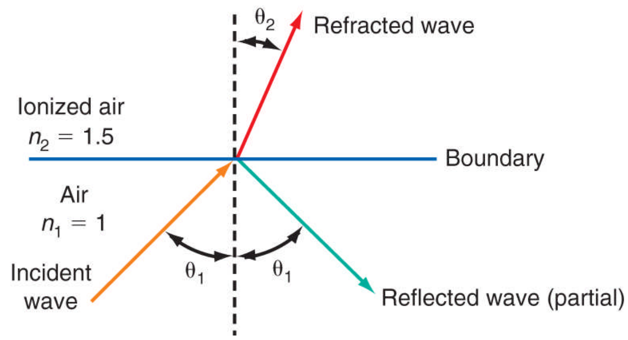
Reflection

- Just as light is reflected by a mirror, any **conducting surface** looks like a mirror to a radio wave.
- Examples of conducting surfaces include any metallic object (towers, vehicles) and bodies of water.
- Just as with light, the angle of reflection is equal to the angle of incidence.



Refraction

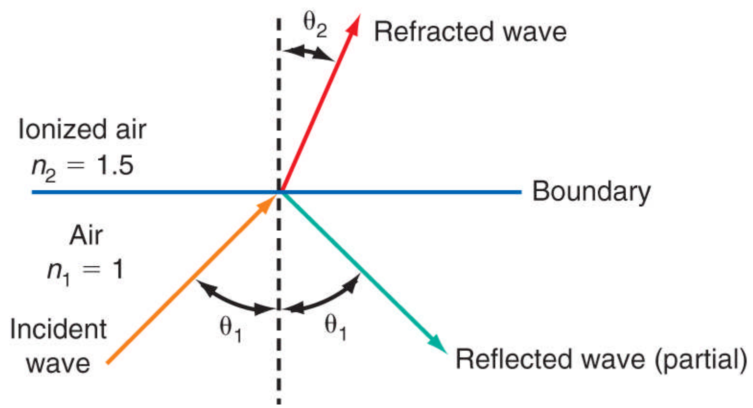
- When EM waves are incident on the boundary between two different media, some of the energy is reflected and some is transmitted.
- **Refraction** refers to the bending of EM waves as they pass through a boundary.
- This bending is due to change in the speed of wave propagation (speed of light) in the different media.
  - The speed of light in a vacuum $c = 300{,}000{,}000$ m/s.
  - In other media (like ionized air), the EM wave travels more slowly.



Refraction

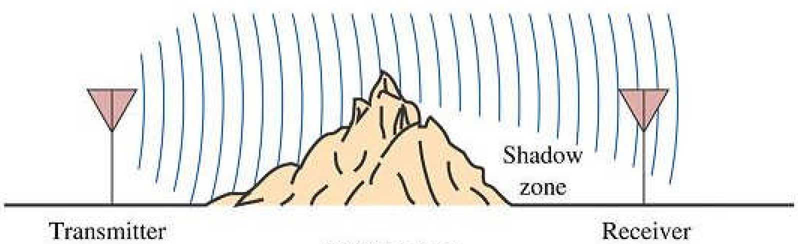
- The ratio of the speed of light in a vacuum to the speed in the medium is given by the index of refraction n.
- The relationship between the angle of incidence and the angle of angle of refraction is given by Snell's law.

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

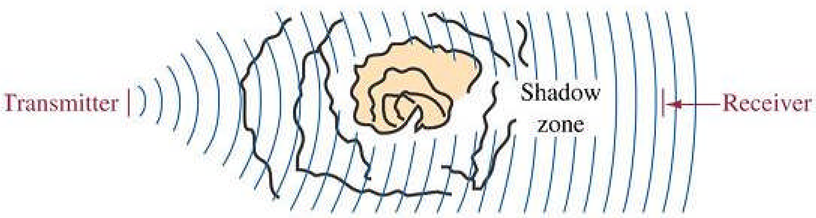


Diffraction

- **Diffraction** is the phenomena whereby waves traveling in straight paths bend around an obstacle.
- The size of the shadow zone depends upon the wavelength of the EM wave.
  - Low frequency signals diffract more quickly producing smaller shadow zones.
  - High frequency signals (microwave) diffract slowly and do not bend around obstacles.



(b) Side view

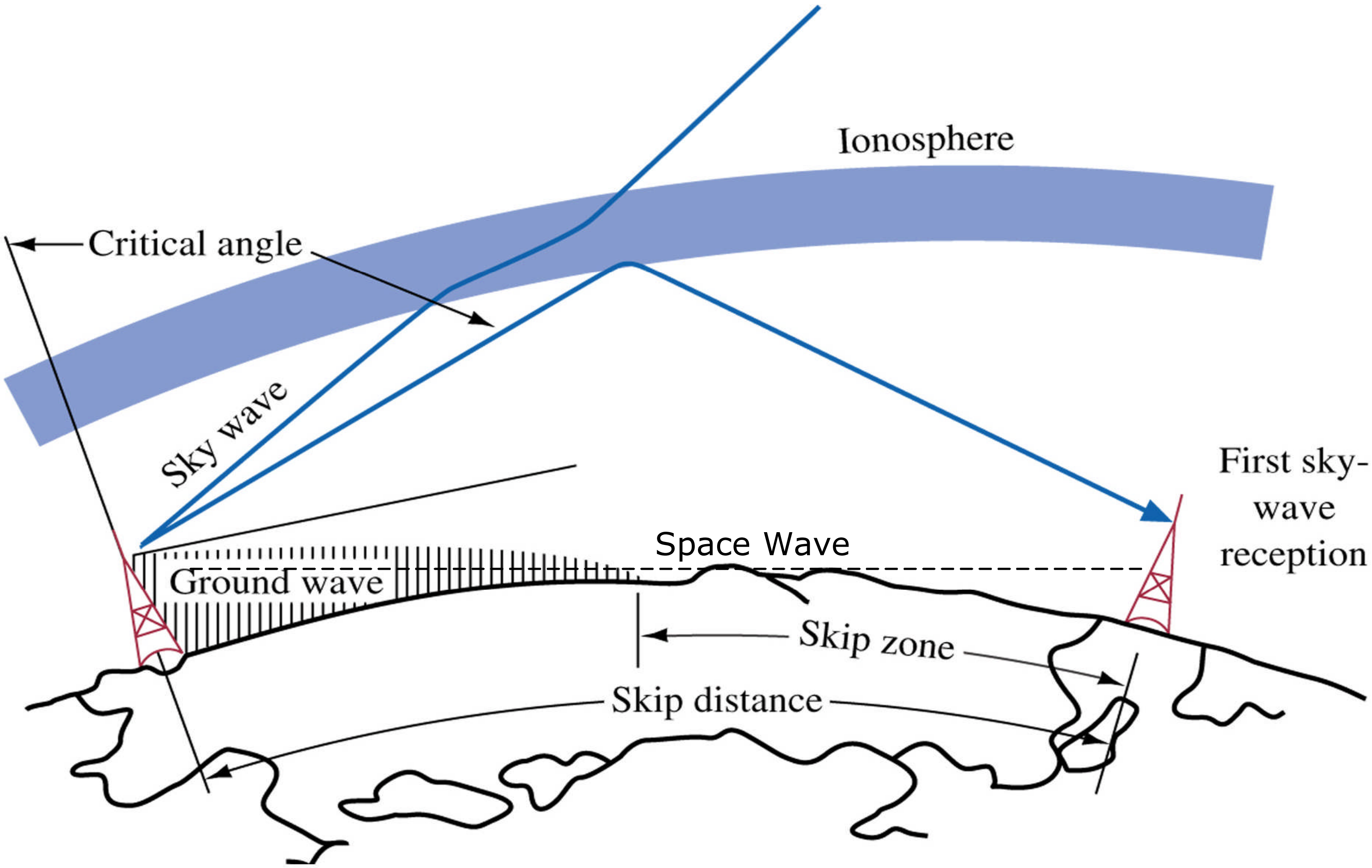


(a) Top view

Radio wave propagation

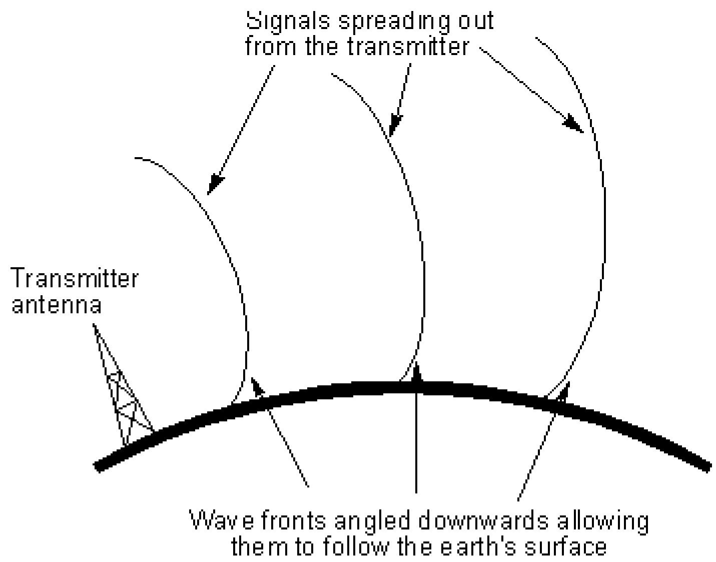
- There are 4 basic modes a radio wave travels from the transmitter to a receiving antenna.
  - Ground wave
  - Space wave
  - Sky wave
  - Satellite communications (discussed later)
- The **frequency** of the radio wave is the most important factor in determining the performance of each type of propagation.

Basic Modes of Propagation



Ground wave propagation

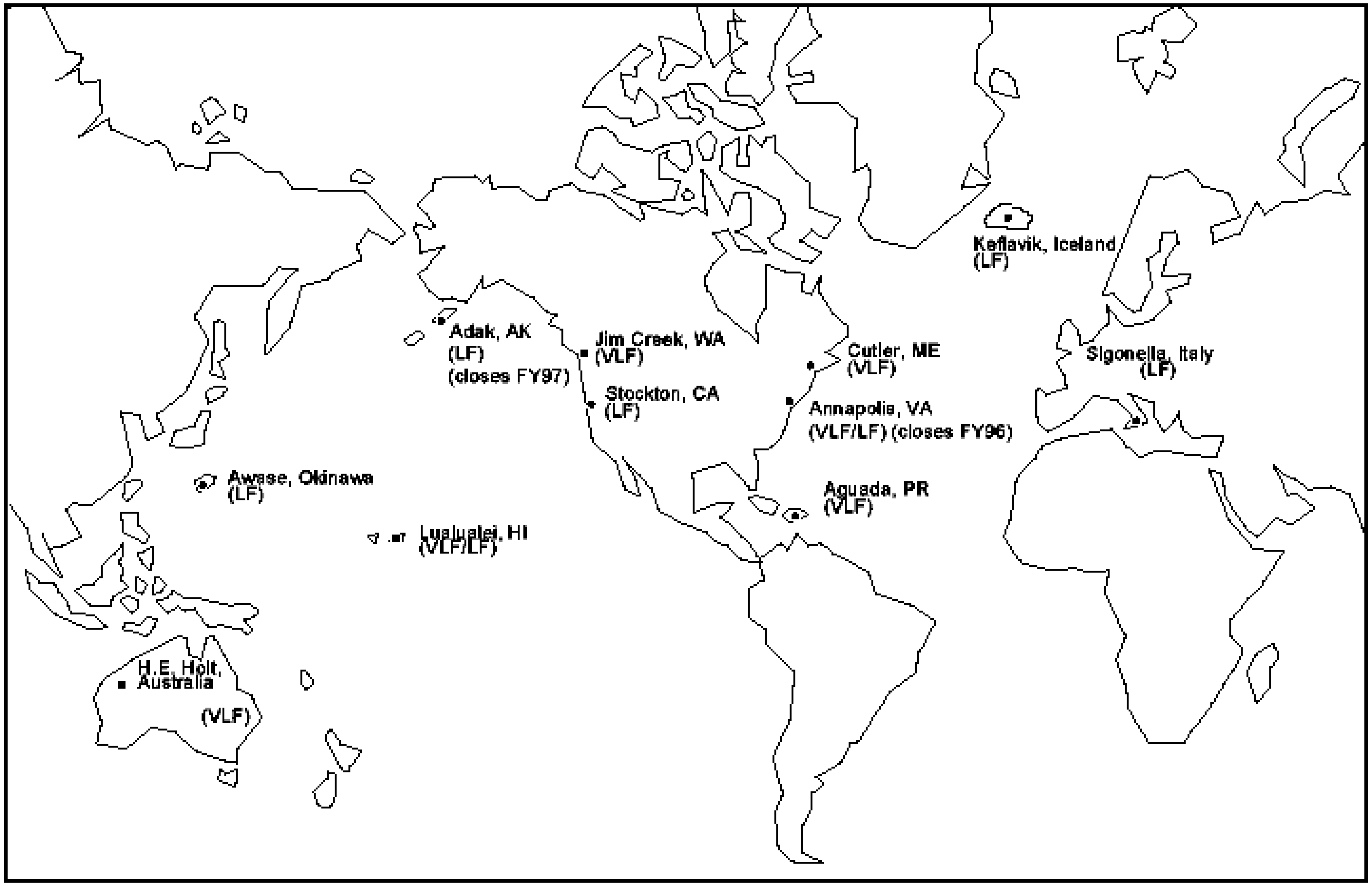
- A **ground wave** is a radio wave that travels along the earth's surface (also referred to as a **surface wave**).
- A ground wave must be vertically polarized.



Ground wave propagation

- Lower frequencies travel efficiently as ground waves because they are **diffracted** (or bent) by the surface of the earth.
- Ground wave propagation is strongest in the Low and Medium frequency ranges
  - Medium frequency (MF, 300-3000 kHz)
  - Low frequency (LF, 30-300 kHz) signals are capable of traveling long distances.
  - Extreme low frequency signals (ELF, 30-300 Hz) were used to communicate with submarines.

VLF sites worldwide



Very Low Frequency/Low Frequency Site Locations

http://www.fas.org/man/dod-101/navy/docs/scmp/part07.htm

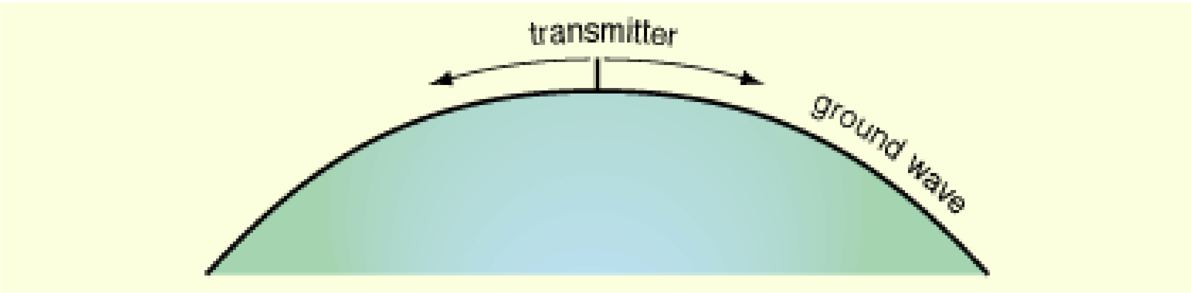
LF/VLF site at Annapolis

LF/VLF site at Annapolis

Demolished
November 13, 1999

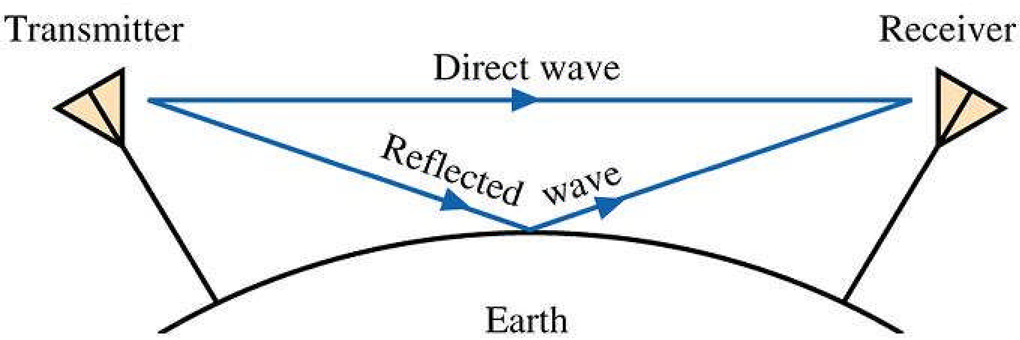
Ground wave propagation

- Another factor that affects ground wave propagation is **surface conductivity**.
- Ground wave propagation is very good over highly conductive surfaces such as salt water.
- Very dry surfaces such as deserts have low conductivity.



Space wave propagation

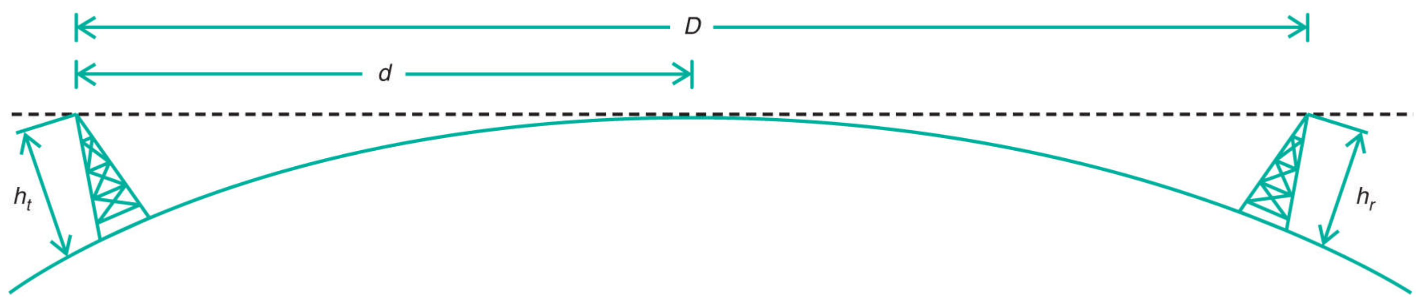
- A **space wave** refers to the radio wave that travels directly from the transmitting antenna (**direct wave**) or arrives after being reflected off the ground (**reflected wave**).
- Do not confuse *reflection* off the ground with ground wave propagation (which is *diffraction*).



Space wave propagation

- **Space wave** or direct wave transmission is by far the most widely used mode of antenna communication.
- The chief limitation of a space wave is that it is limited to **line-of-sight** distances.
- The range of space wave propagation is limited by the curvature of the earth and height of the antennas above the earth's surface.

$$d = \sqrt{2h_t}$$
$$D = \sqrt{2h_t} + \sqrt{2h_r}$$

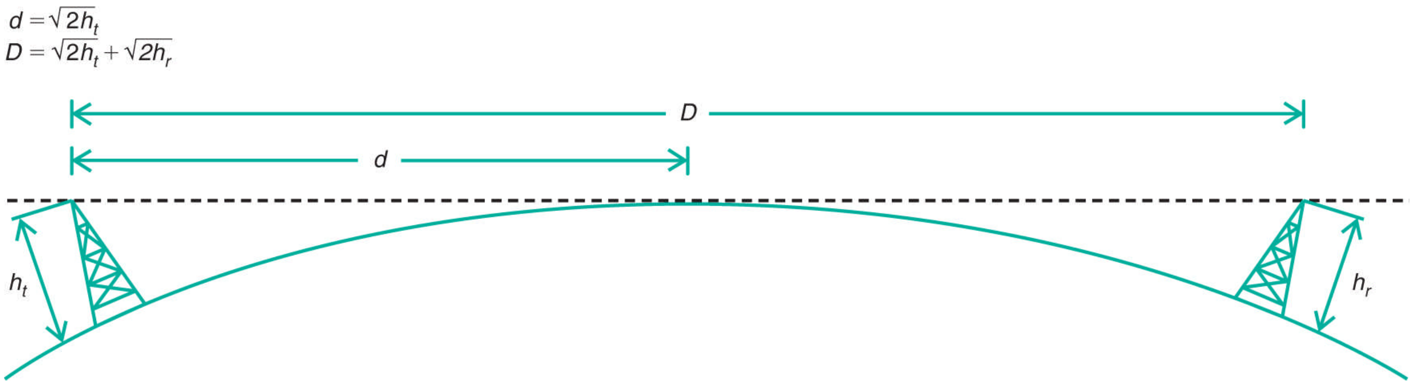


Radio horizon

- Direct wave signals travel horizontally from the antenna until the are blocked by the horizon.
- The distance to the **radio horizon** d is given by

$$d = \sqrt{2h_t}$$

where h_t = height of the transmitting antenna, ft
d = distance from transmitter to horizon, mi

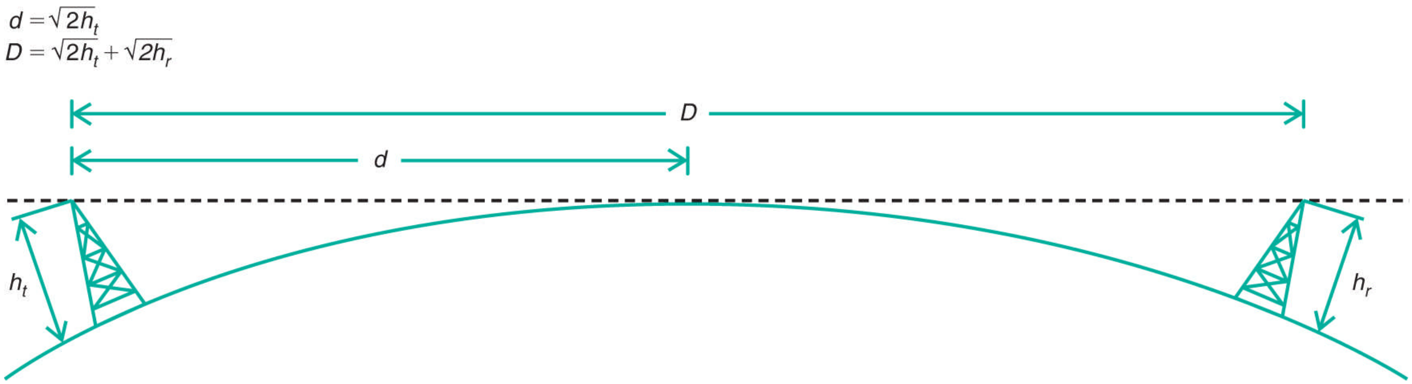


Radio horizon

- If the receiving antenna is also above the ground level, then the distance to the transmission distance D is given by

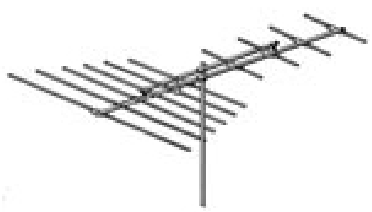
$$D = \sqrt{2h_t} + \sqrt{2h_r}$$

where h_r = height of the receiving antenna, ft



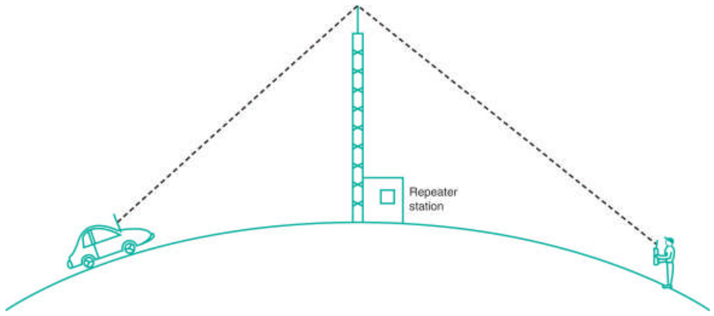
Example Problem 1

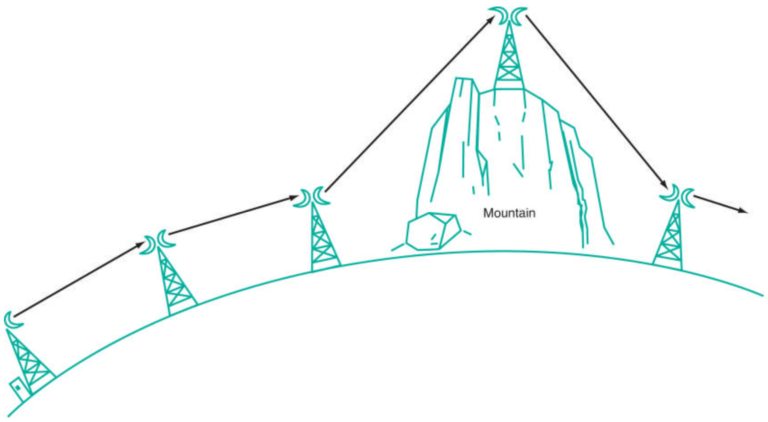
What is the range (in miles) of direct space-wave propagation for a transmitting antenna 1000 ft above the ground and a receiving antenna at 20 ft?



Space wave propagation

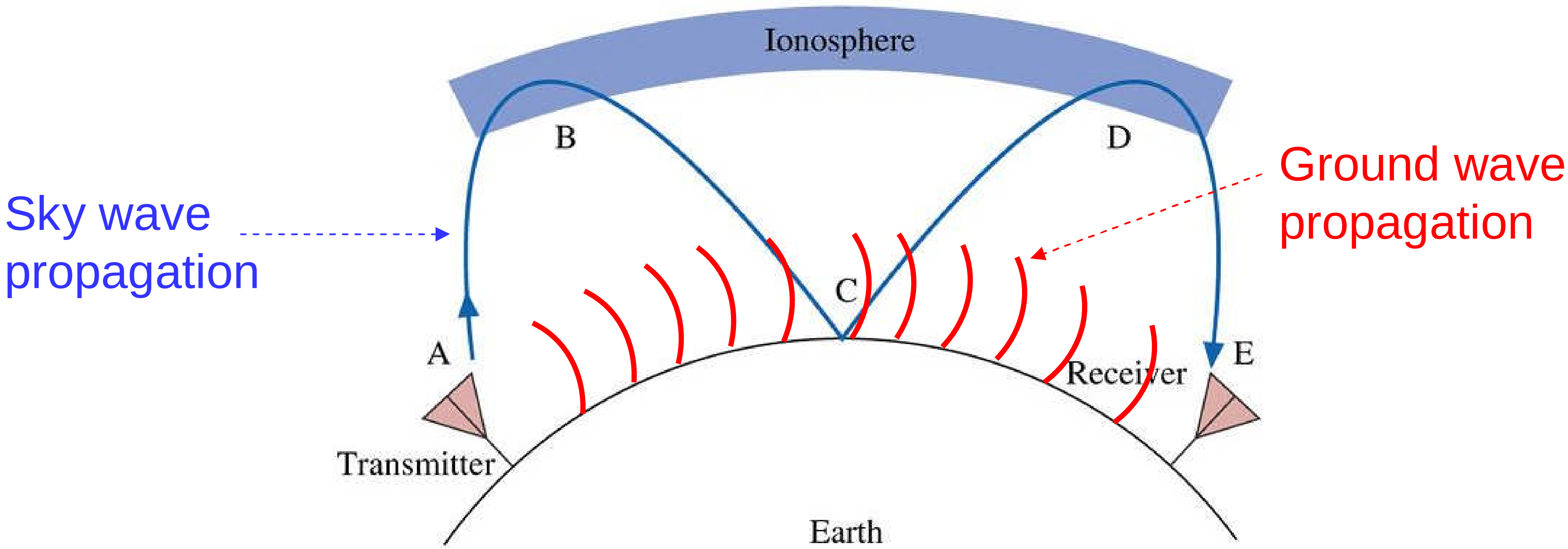
- Line-of-sight communication is characteristic of most signals above 30 MHz
  - particularly VHF,UHF and microwave.
- The fact that transmission distance are limited necessitates the use of very high transmitting antennas for FM and TV broadcasts.
  - To extend the range of these, repeater stations are often used.





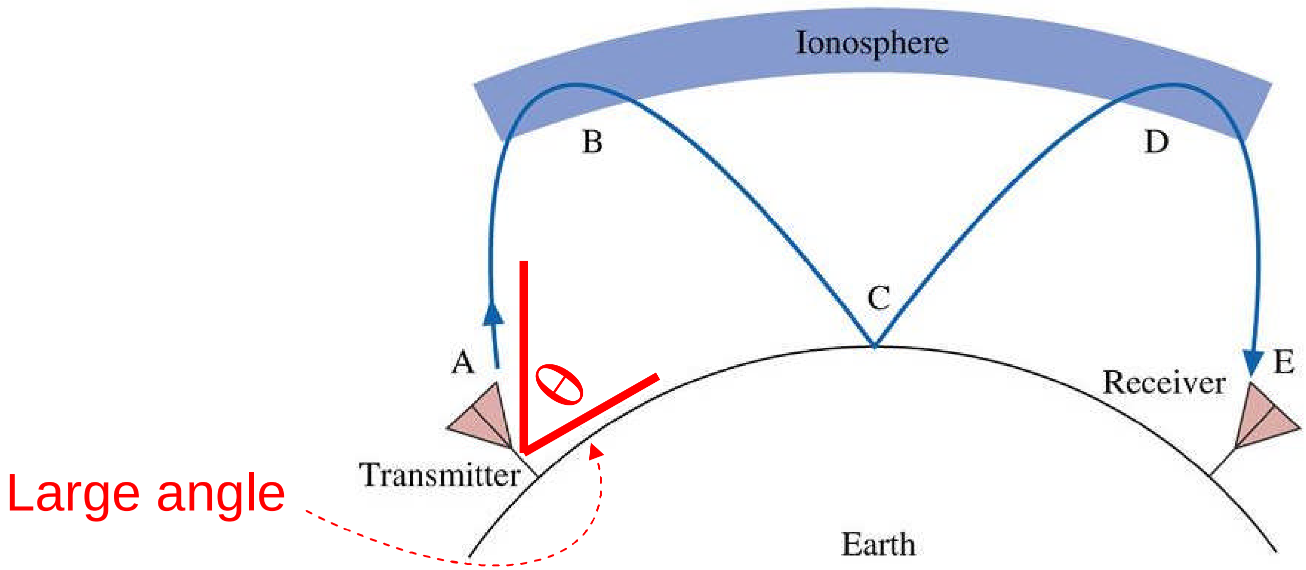
Long-distance transmission

- For long-distance radio transmission,
  - we can use low frequencies which bend around the earth (**ground wave** propagation)
  - we can bounce radio waves off the ionosphere (**sky wave** propagation)



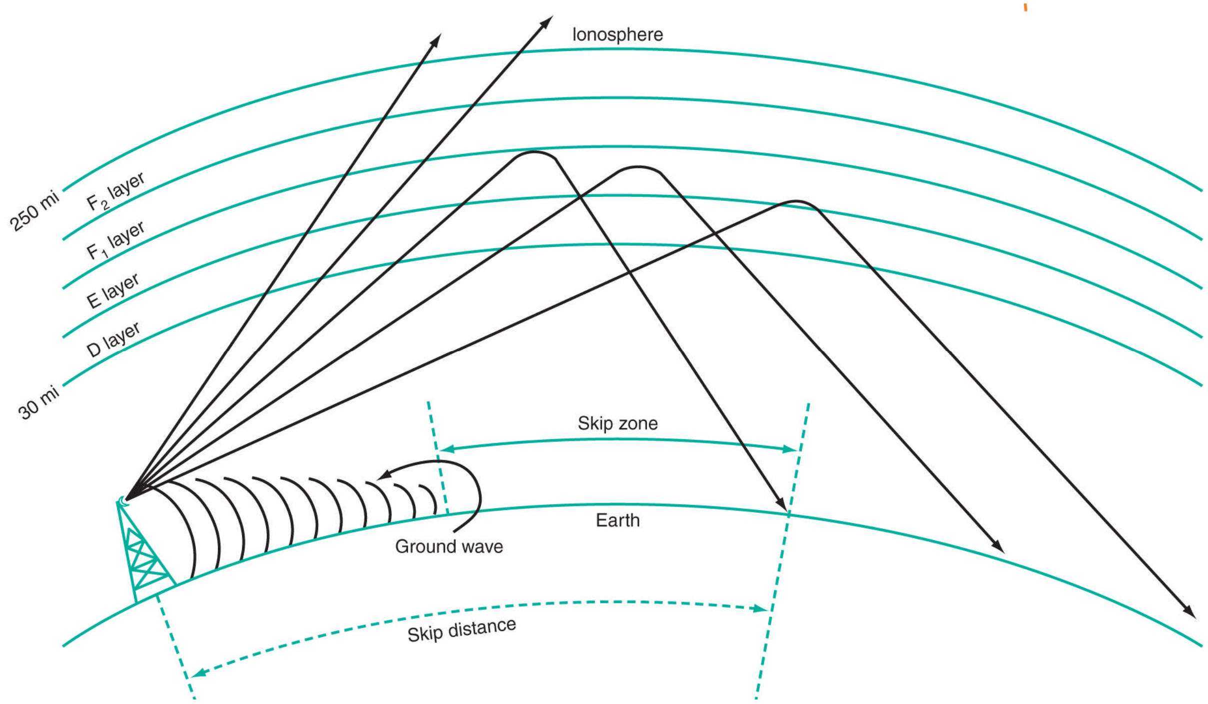
Sky wave propagation

- Sky waves are EM waves transmitted with a large angle (A) with reference to the earth.
- These waves strike the ionosphere (B) and are **refracted** back towards the earth.
- Upon striking the ground (C) they can be **reflected** back to the ionosphere.



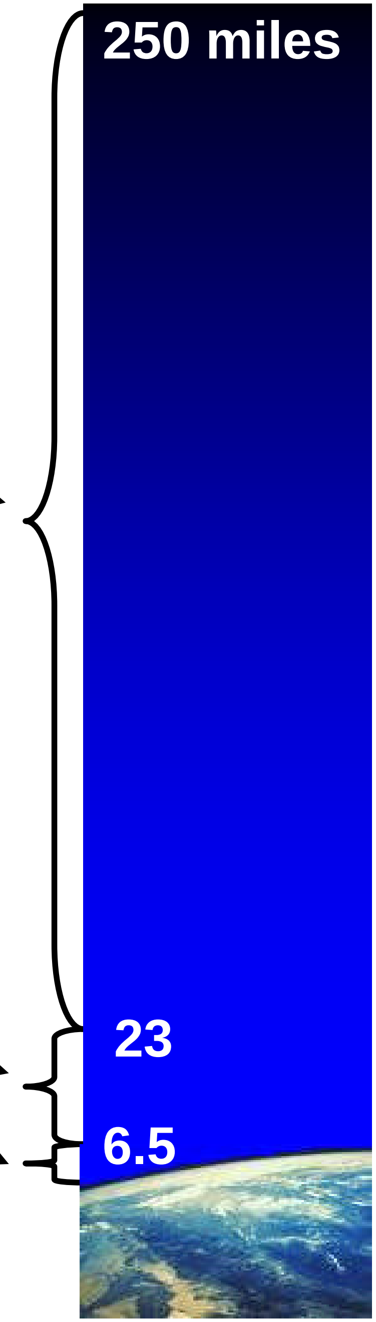
Sky wave propagation

- They can be refracted again (D) before arriving at the receiver (E).
- This process of refracting a reflecting is called **skipping**.



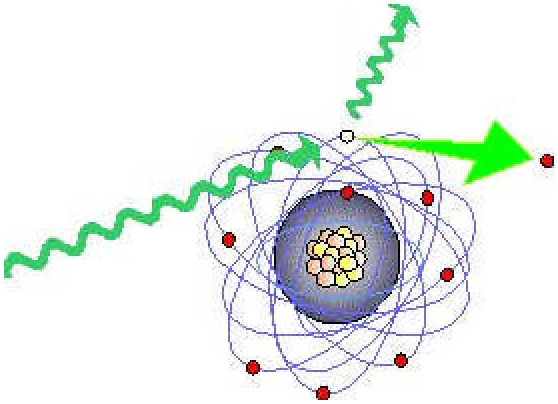
Layers of the atmosphere

- The **ionosphere**, the top layer extending to space (~250 miles), is composed of ionized particles.
- The **stratosphere**, mid-layer extending to 23 miles, has a relatively constant temperature (isothermal).
- The **troposphere**, the lower layer from surface to 6.5 miles, contains all of the moisture in the atmosphere.



Ionosphere

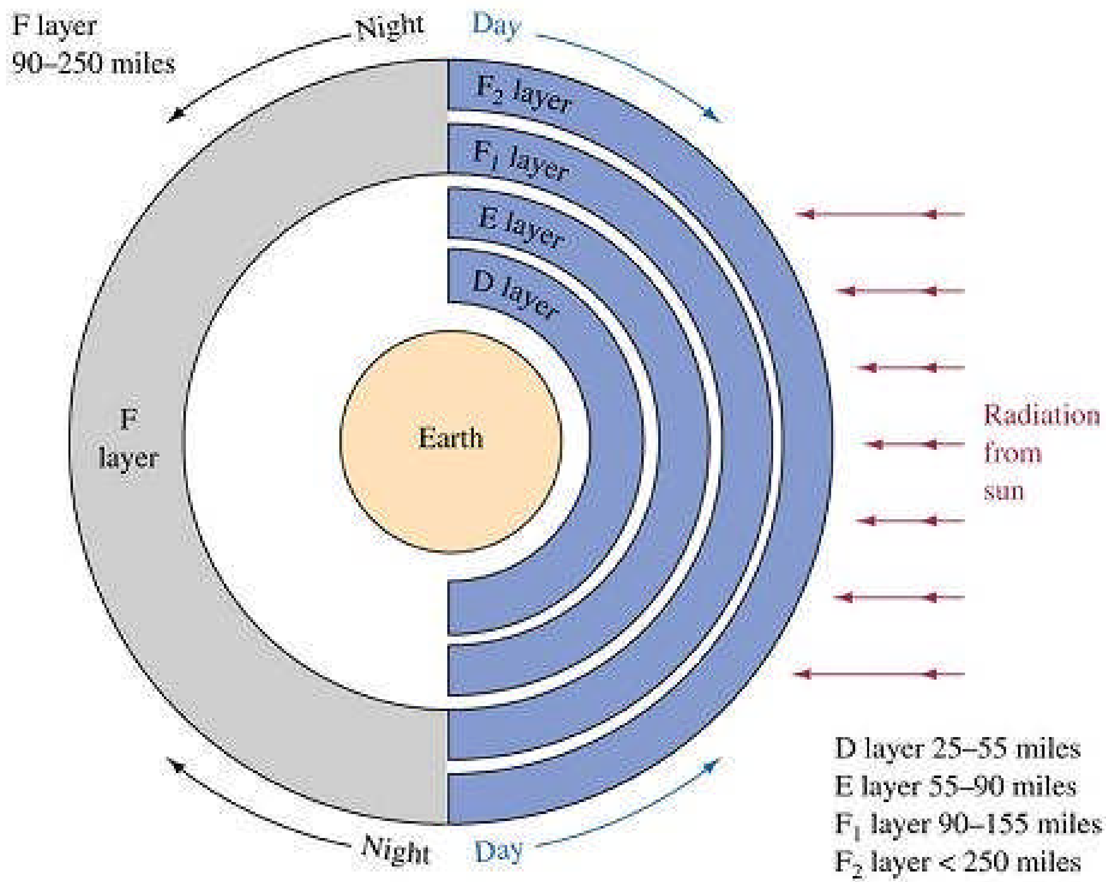
- The air molecules of the ionosphere are subject to severe radiation from the sun.
- Ultraviolet radiation causes the molecules to **ionize**, or separate into charged particles, positive and negative ions.



- The highest degree of ionization occurs at the outer extremities of the ionosphere.

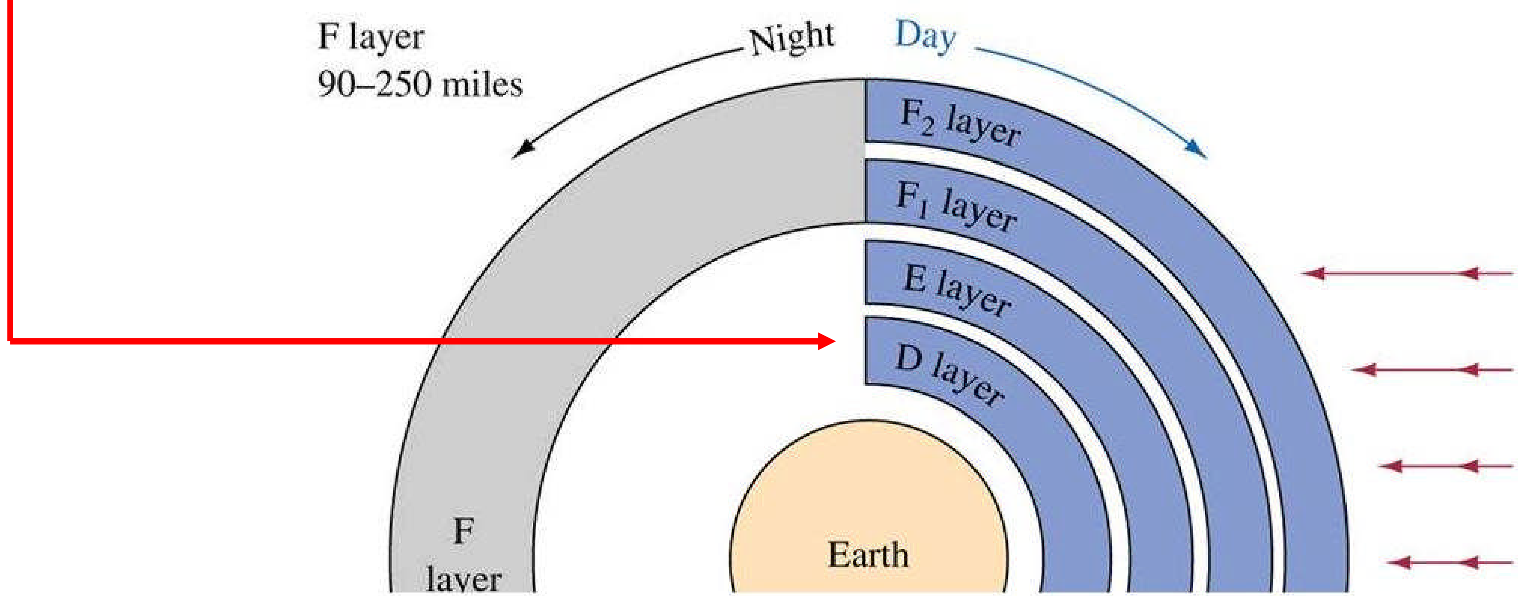
Layers of the ionosphere

- The ionosphere is composed of 3 layers, D, E and F (although F is subdivided into F_1 and F_2)



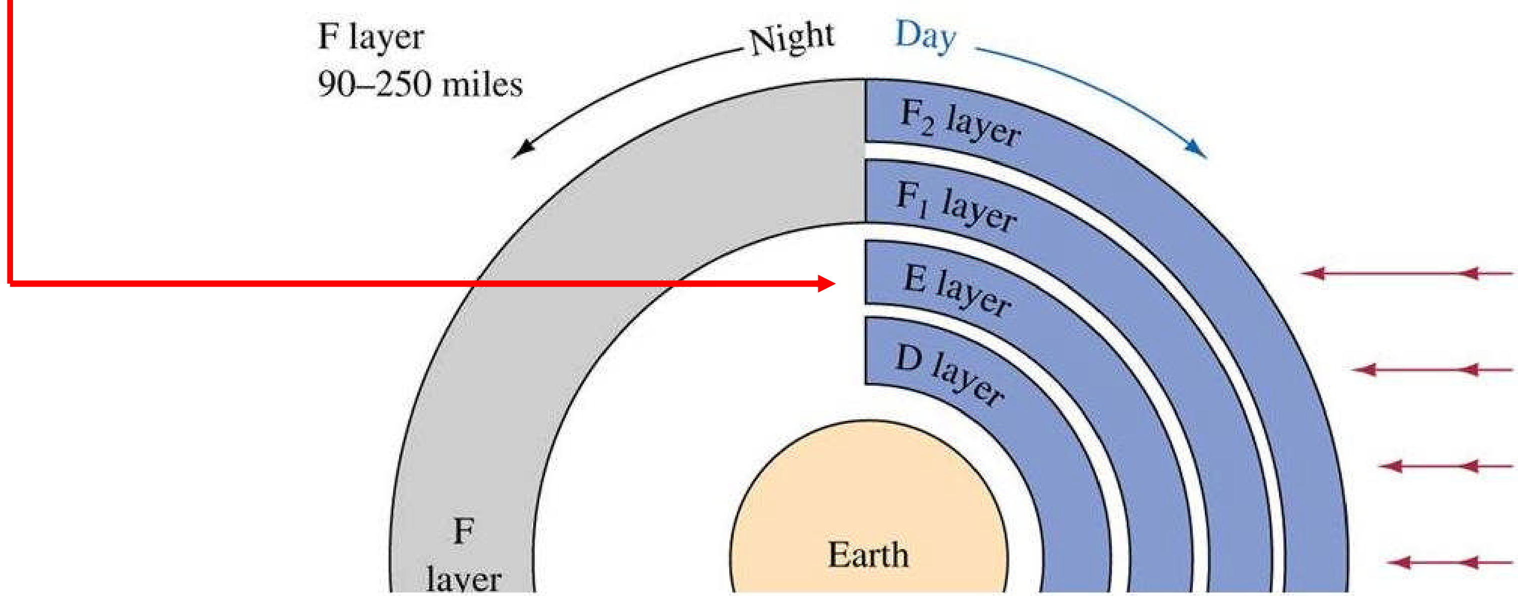
D layer

- The *D* layer ranges from 25-55 miles and has the ability to refract low frequency signals.
- The *D* layer disappears after sunset as its ions recombine rapidly.



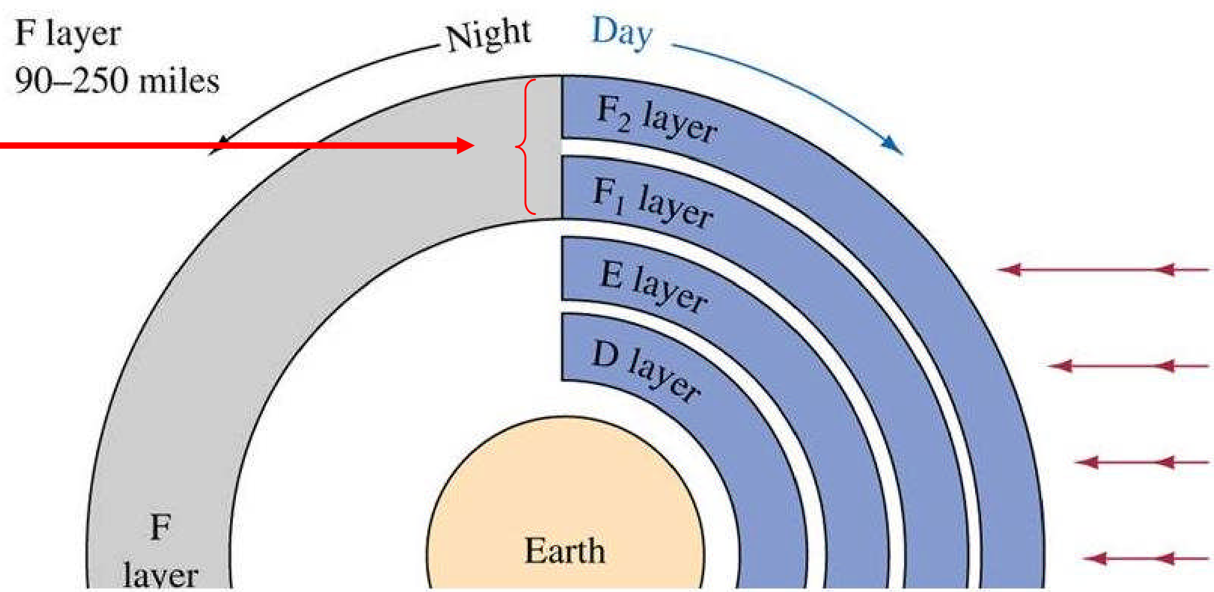
E layer

- The E layer ranges from 55-90 miles and has the ability to refract higher frequency signals (up to ~20 MHz).
- The E layer disappears by midnight as its ions recombine.



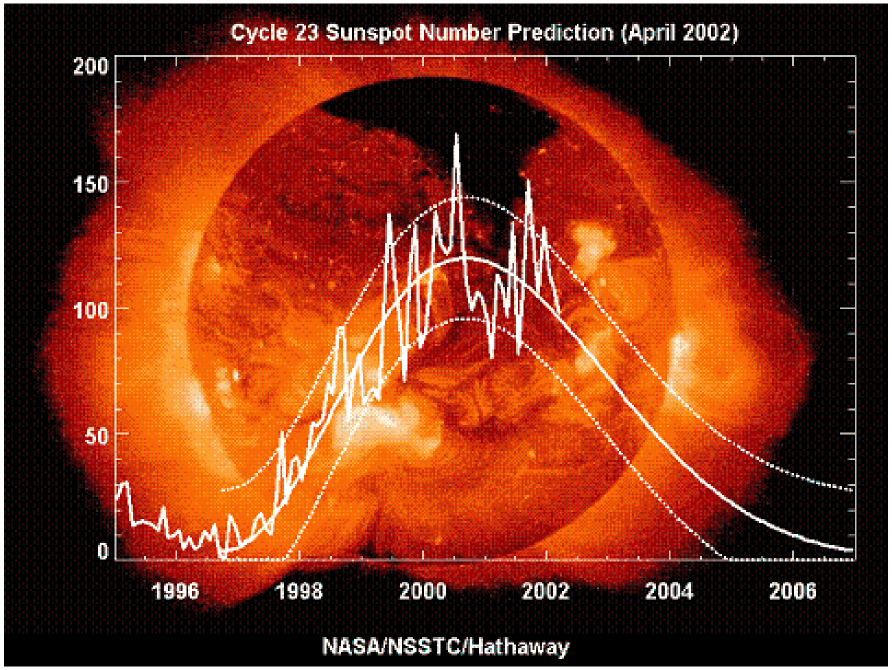
F layer

- The *F* layer ranges from 90-250 miles and reaches its maximum height a noon.
- It refracts higher frequency signals (~30 MHz).
- Ions are very far apart and thus recombine slowly leaving a fairly constant ionized layer.



Layers of the ionosphere

- At night, frequencies that would normal refract in the D and E layers are refracted at much higher altitudes which results in larger skip distances.
- The layers of the ionosphere vary greatly with solar activity.



Solar activity

- During periods of higher solar activity, the F layer is more dense and occurs at higher altitude.
- Ionization is greater in the summer than winter and also varies with the time of day.
- Solar activity can be determined by checking space weather forecasts (http://www.sec.noaa.gov/SWN/index.html)

Propagation mode by frequency

Radio Band		Frequency	Propagation Via
VLF	Very Low Frequency	3 - 30 kHz	Guided between the earth and the ionosphere
LF	Low Frequency	30 - 300 kHz	Guided between the earth and the ionosphere Ground Waves
MF	Medium Frequency	300 - 3000 kHz	Ground waves E layer ionospheric refraction at night, when D layer absorption disappears
HF	High Frequency (Short Wave)	3 - 30 MHz	E layer ionospheric refraction F layer ionospheric refraction
VHF	Very High Frequency	30 - 300 MHz	Line-of-sight
UHF	Ultra High Frequency	300 - 3000 MHz	Line-of-sight
SHF	Super High Frequency	3 - 30 GHz	Line-of-sight
EHF	Extremely High Frequency	30 - 300 GHz	Line-of-sight limited by absorption

Calculating Received Power

- Given the power level of the transmitter it is possible to predict the approximate power level at the receiver.
- Recall the case of the isotropic source, we see that the power density (W/m^2) is inversely proportional to the square of the distance from the source.

$$P_d = \frac{P_t}{4\pi d^2}$$

- However, when an antenna is used we have to modify this formula.
  - Consider if the transmitter is a half-dipole antenna

$$P_d = \frac{1.64 P_t}{4\pi d^2}$$

Calculating Received Power

- A more general formula for received power is

$$P_r = \frac{P_t G_t G_r \lambda^2}{16\pi^2 d^2}$$

λ = signal wavelength (m)
d = distance from transmitter (m)
P_r, P_t = power received and transmitted (w),
G_r, G_t = antenna gains expressed as a power ratio and referenced to a isotropic source

Example Problem 2

Consider a transmitter operating a ¼λ vertical antenna at 150 MHz with a power of 3 watts. The receiver 20 mi away and has a gain of 8 dB (with respect to a dipole). What is the received power?