WAVE PROPAGATION

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Wave Propagation

- Is the behaviour of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere.
- Like light waves, radio waves are affected by the phenomena of
  - Reflection
  - Refraction
  - Diffraction
  - Absorption
  - Polarization
  - Scattering

Propagation Mechanisms

- Reflection

  Propagating wave impinges on an object which is large as compared to wavelength

  - e.g., the surface of the Earth, buildings, walls, etc.

- 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

- Diffraction

  Radio path between transmitter and receiver obstructed by surface with sharp irregular edges

  Waves bend around the obstacle, even when LOS (line of sight) does not exist

Propagation Mechanisms (Contd..)

- Absorption
  The energy of a photon is taken up by matter, typically the electrons of an atom
  When a radio wave reaches an obstacle, some of its energy is absorbed and converted into another kind of energy

- Polarisation
  The polarization of an antenna is the orientation of the electric field with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation

- Scattering
  Objects smaller than the wavelength of the propagating wave
  - e.g. foliage, street signs, lamp posts

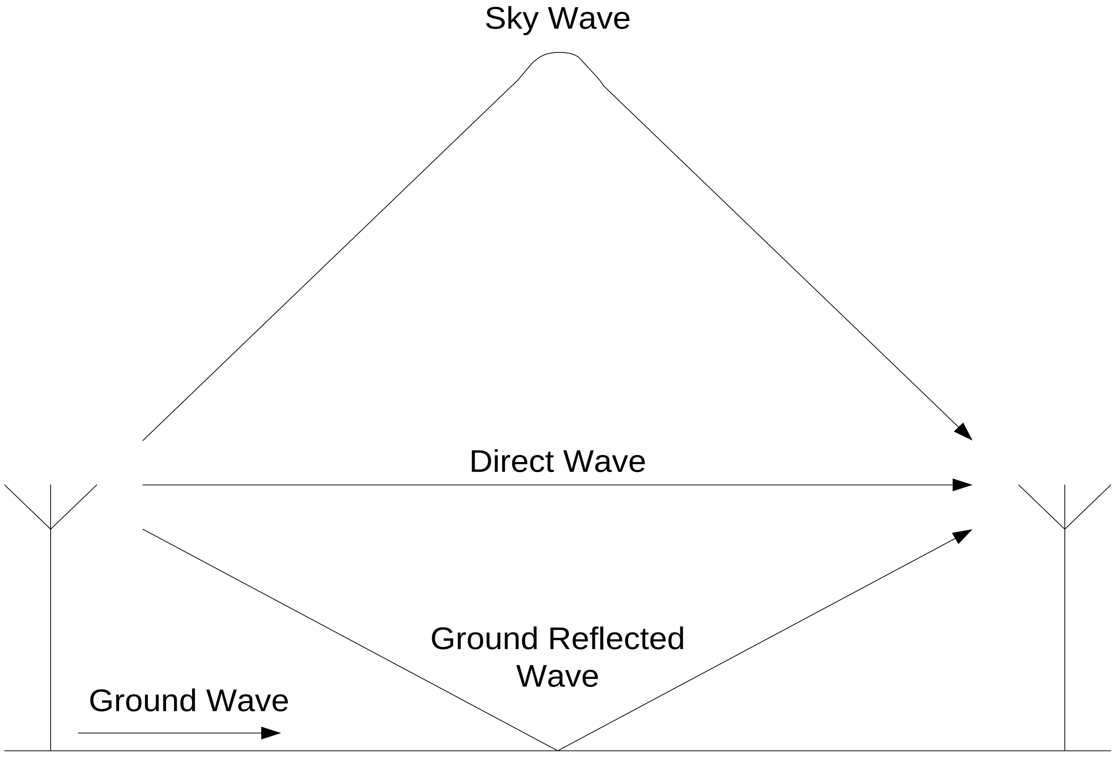
Propagation Mechanisms (Contd..)

- If the wave length is of the same order of magnitude (or larger), diffraction or surface effects dominate
- When the dimension of the object is:
  - Very Large compared to the wavelength
    - Reflection
  - Larger compared to the wavelength
    - Diffraction
  - Small compared to the wavelength
    - Scattering
  - Very small compared to the wavelength
    - Unaffected

Radio Spectrum

Symbol	Frequency range	Wavelength, λ	Comments
ELF	< 300 Hz	> 1000 km	Earth-ionosphere waveguide propagation
ULF	300 Hz – 3 kHz	1000 – 100 km	
VLF	3 kHz – 30 kHz	100 – 10 km	
LF	30 – 300 kHz	10 – 1 km	Ground wave propagation
MF	300 kHz – 3 MHz	1 km – 100 m	
HF	3 – 30 MHz	100 – 10 m	Ionospheric sky-wave propagation
VHF	30 – 300 MHz	10 – 1 m	Space waves, scattering by objects similarly sized to (or bigger than), a free-space wavelength, increasingly affected by tropospheric phenomena
UHF	300 MHz – 3 GHz	1 m – 100 mm	
SHF	3 – 30 GHz	100 – 10 mm	
EHF	30 – 300 GHz	10 – 1 mm	

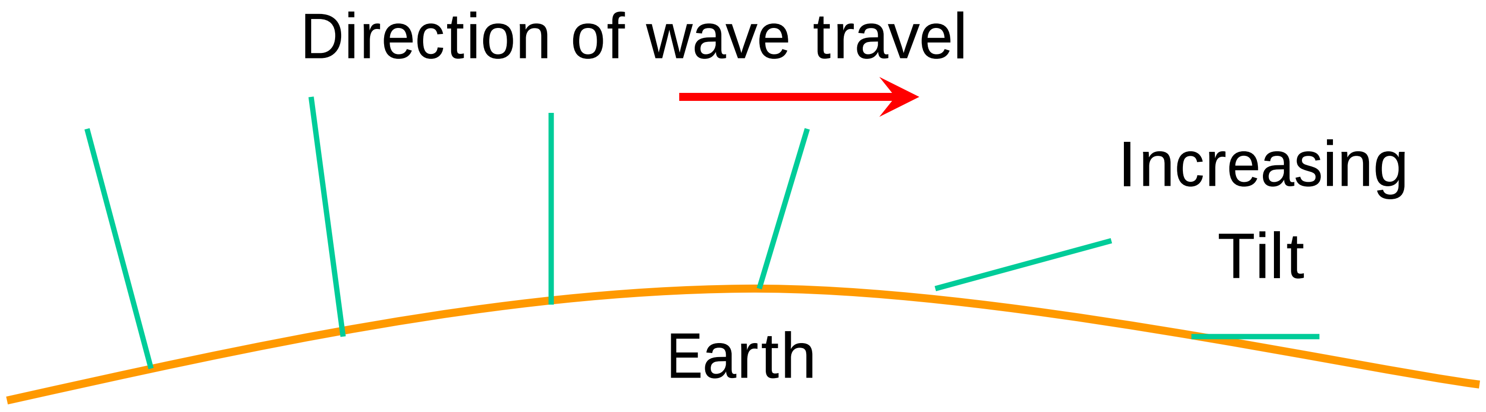
Propagation between two antennas (not to scale)



No Ground Wave for Frequencies > ~2 MHz
No Ionospheric Wave for Frequencies > ~30 MHz

Ground-Wave Propagation

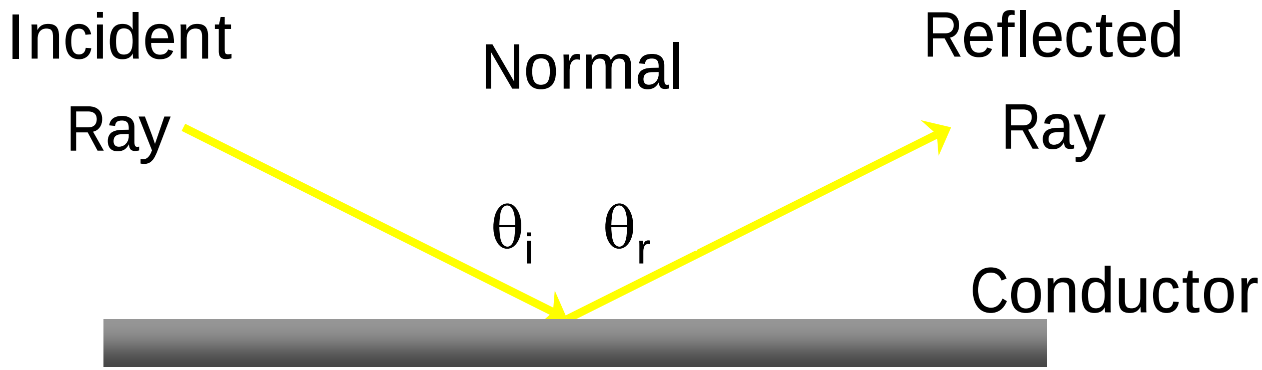
- At frequencies up to about 2 MHz, the most important method of propagation is by *ground waves* which are vertically polarized. They follow the curvature of the earth to propagate far beyond the horizon. Relatively high power is required.



Reflection

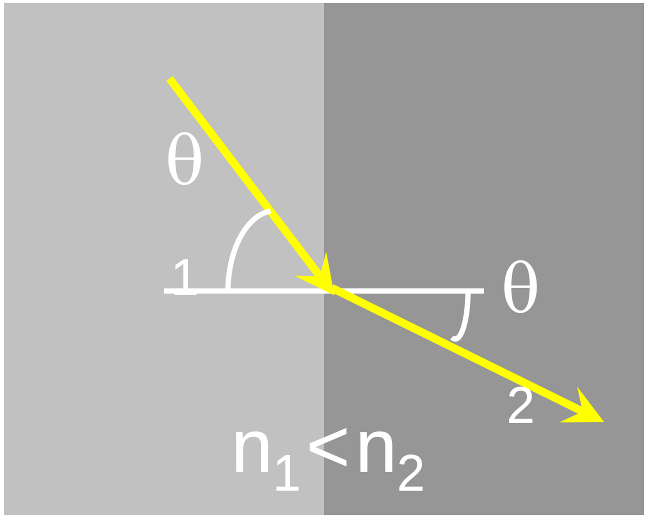
Radio waves behave like light waves:

- They *reflect* from a surface where the angle of incidence (θ_i) = the angle of reflection(θ_r). To minimize reflective losses, the surface should be an ideal conductor and smooth.



Refraction

- Radio waves will bend or *refract* when they go from one medium with refractive index, n_1 to another with refractive index, n_2. The angles involved are given by :

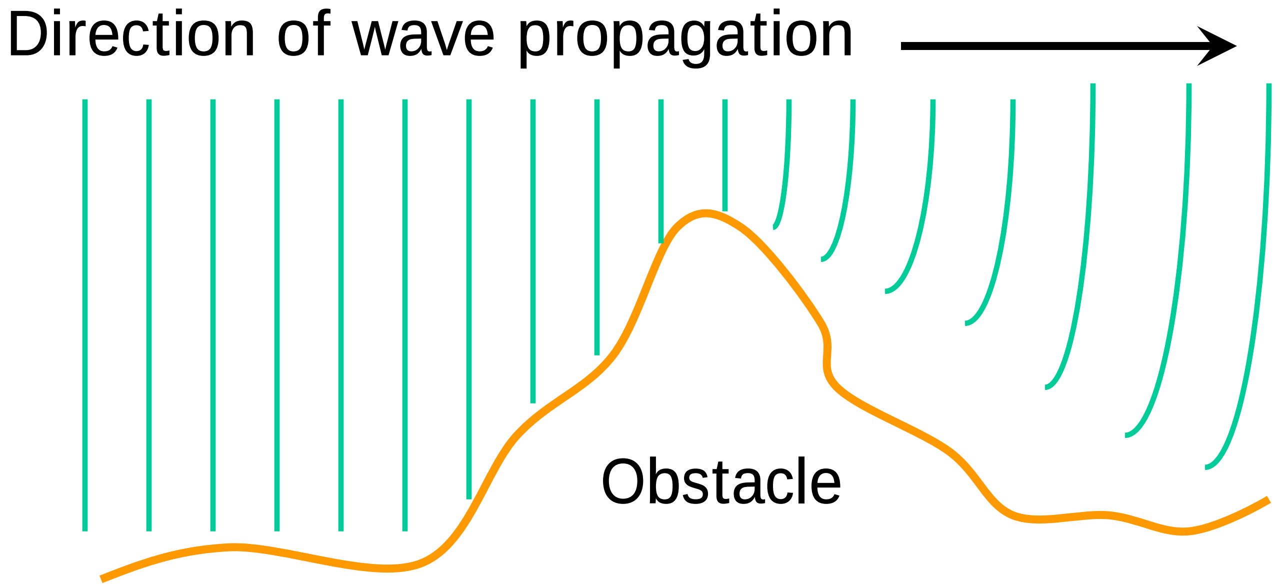


$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \sqrt{\frac{\epsilon_{r2}}{\epsilon_{r1}}}$$

where ϵ_r = relative permittivity of medium

Diffraction

- *Diffraction* is the phenomenon which results in radio waves that normally travel in a straight line to bend around an obstacle.



Space-Wave Propagation

- Most terrestrial communications in the VHF or higher frequency range use *direct*, *line-of-sight*, or *tropospheric* radio waves. The approximate maximum distance of communication is given by:

$$d = \sqrt{17}\left(\sqrt{h_T} + \sqrt{h_R}\right)$$

where d = max. distance in km

h_T = height of the TX antenna in m

h_R = height of the RX antenna in m

Space-Wave Propagation (cont’d)

- The *radio horizon* is greater than the optical horizon by about one third due to refraction of the atmosphere.
- Reflections from a relatively smooth surface, such as a body of water, could result in partial cancellation of the direct signal - a phenomenon known as *fading*.   Also, large objects, such as buildings and hills, could cause *multipath distortion* from many reflections.

Tropospheric propagation

- Variations of refractive index (therefore Dielectric constant)
- The dielectric constant of the air at the earth's surface of (approx.) 1.0003 falls to 1.0000 at great heights where the density of the air tends to zero
- "Normal" change with height causes greater than line-of-sight range. Often taken into account by assuming increased radius for the earth – e.g. (4/3)
- Over long-distances, more than a few tens of km, and heights of up to 10 km above the earth's surface, clear air effects in the troposphere become non-negligible

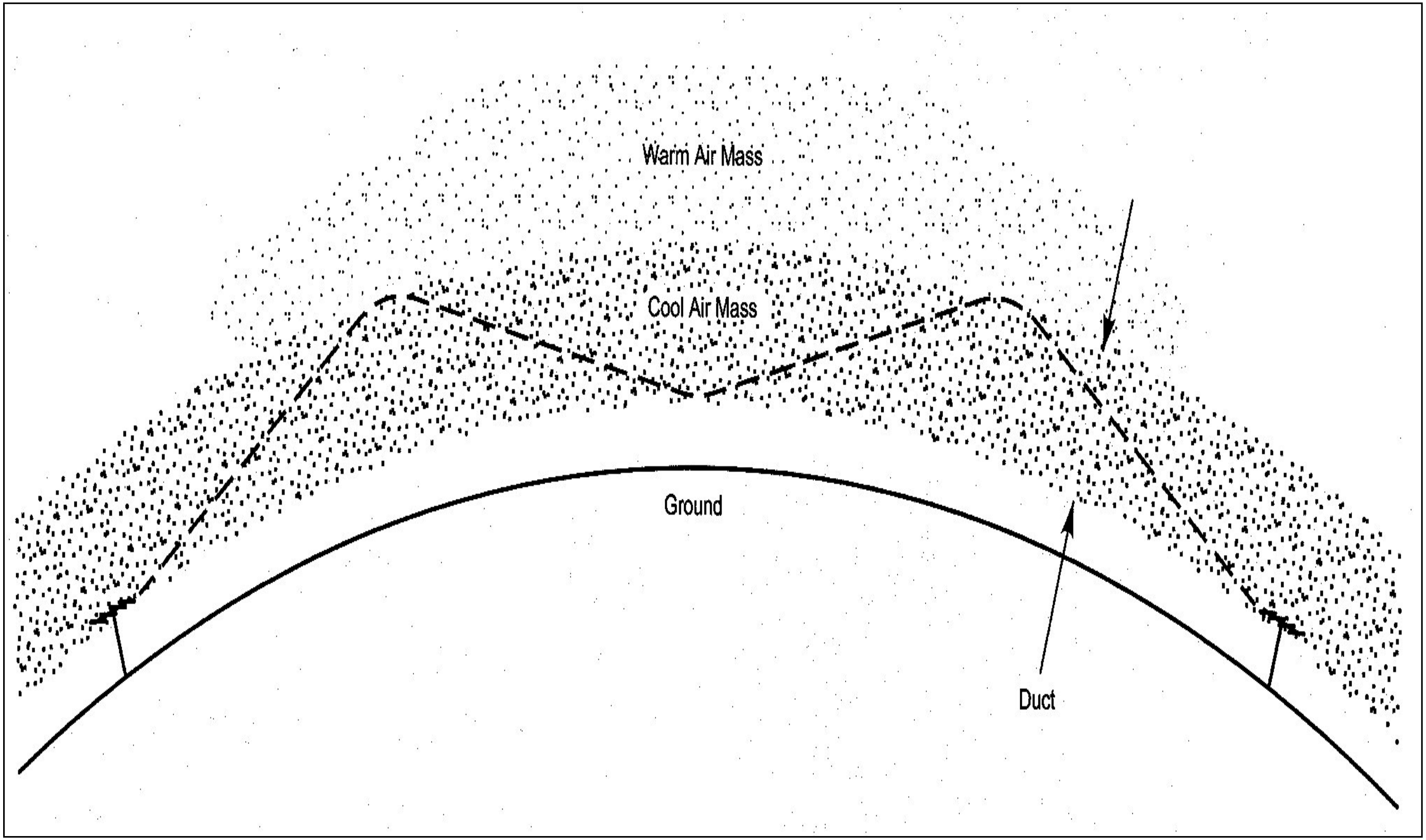
Tropospheric propagation

- A consequence of Snell’s law of refraction is that radio waves follow curved, rather than straight-line trajectories
- Temperature inversions can cause ducting, with relatively low attenuation over large distances beyond the horizon
- Small scale irregularities are responsible for forward scatter propagation.
- Rain scatter can sometimes be a dominant mode.

Tropospheric Ducting

- Radio signals can also be trapped in the troposphere, traveling a long distance before returning to the Earth's surface.
- Results when a "duct" is formed by a temperature inversion level (warm air over cold air) over land or water.
  - Adjacent tropospheric regions having different densities will bend radio waves passing through the regions
- Most useful at VHF/UHF frequencies.
- Most frequent during spring, summer and fall.
- Can provide contacts of 1500 km or more over land and up to 4000 km over ocean

Tropospheric Ducting



Ionospheric Propagation

- The ionosphere is the region of the upper atmosphere where the Sun's ultraviolet radiation can ionize oxygen molecules to create a positive ion and a free electron.
- The ionosphere protects us from excessive ultraviolet radiation.
- There are three main layers of the ionosphere.
  - D layer is 50 to 100 km in altitude. The ions in this layer recombine at night.

Ionospheric Propagation (Contd..)

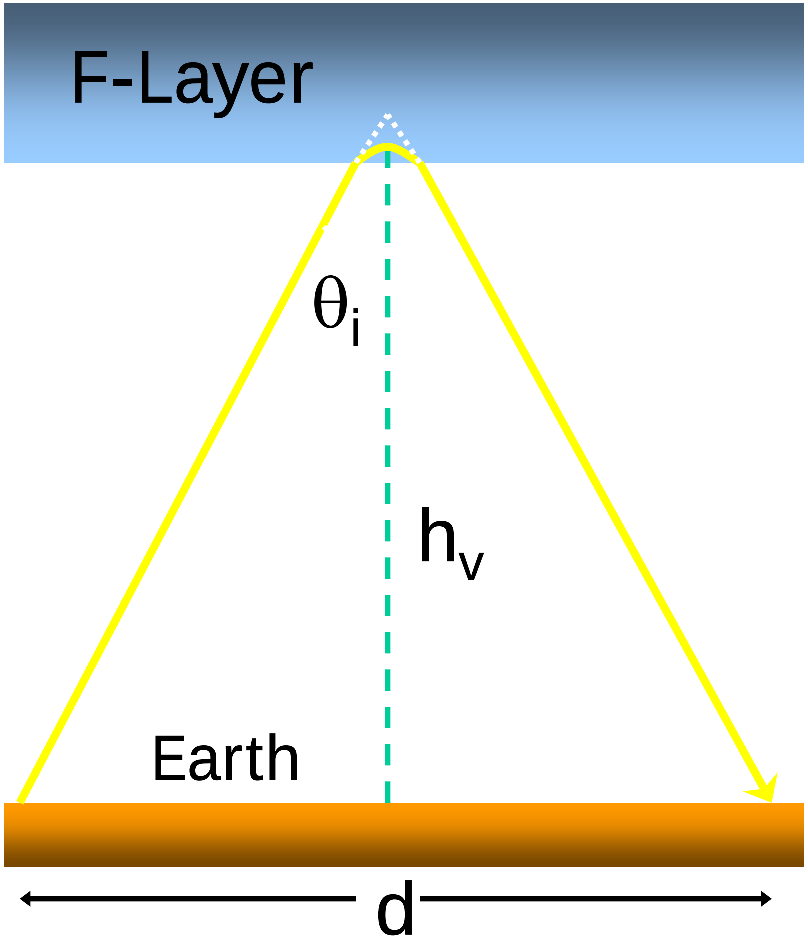
- E layer is 100 to 150 km in altitude. The ions in this layer also recombine at night, but last longer after sunset.
- F layer is 150 to 500 km and is the least dense so it can stay partially ionized all night.
  - The F layer splits into the F1 and F2 layers during the day. The layers combine into a single F layer at night.
  - When the Sun is directly overhead the F2 layer will be at its highest altitude.

- The ionosphere is a weak conductor because of the ions and free electrons.
  - The ionosphere can cause radio waves to bend (refract)
  - The more dense the ionization the higher the degree of refraction, and at higher frequencies.
  - VHF and higher radio waves usually pass through the ionosphere into space.
  - HF radio waves are most affected by refraction.

Sky-wave Propagation: Pros & Cons

- Sky-wave propagation allows communication over great distances with simple equipment and reasonable power levels : 100 W to a few kW.
- However, HF communication via the ionosphere is noisy and uncertain. It is also prone to phase shifting and frequency-selective fading. For instance, the phase shift and signal attenuation may be different for the upper and lower sidebands of the same signal.
- Data transmission is restricted to very low rates.

Sky-Wave Propagation



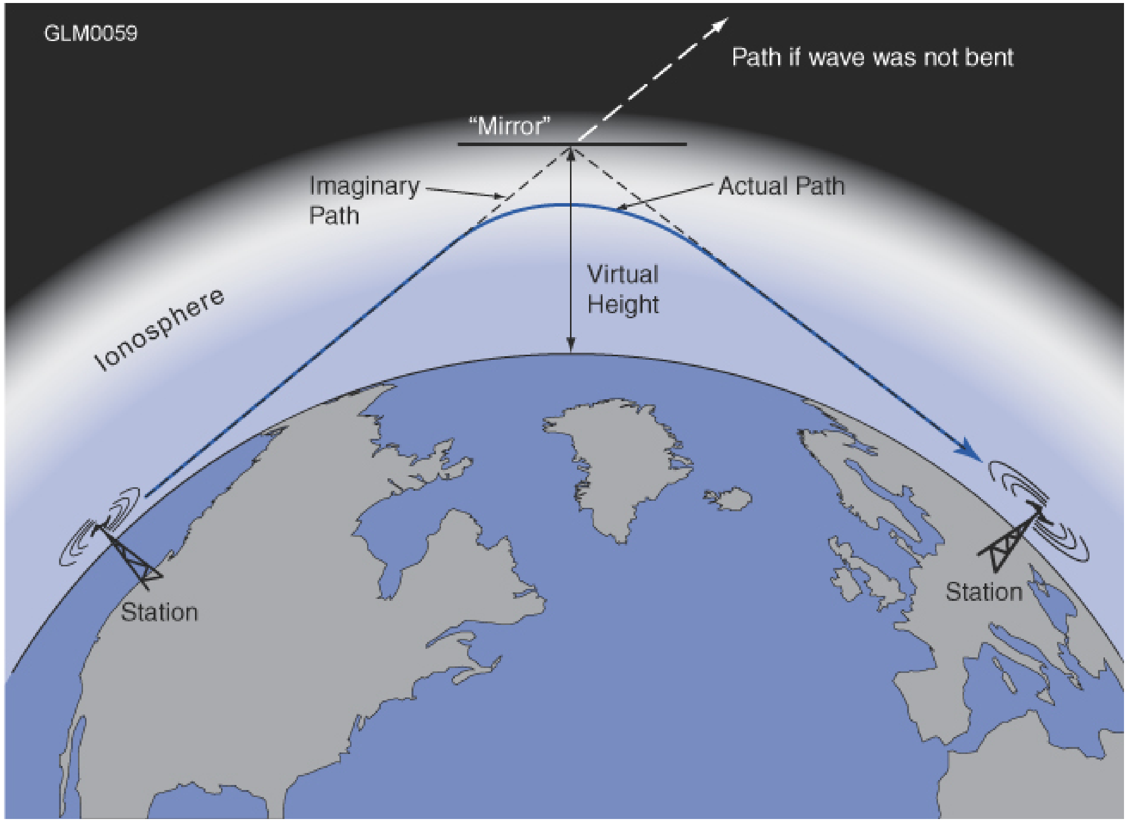
- From geometry (assuming flat earth):

  $d = 2h_v \tan \theta_i$

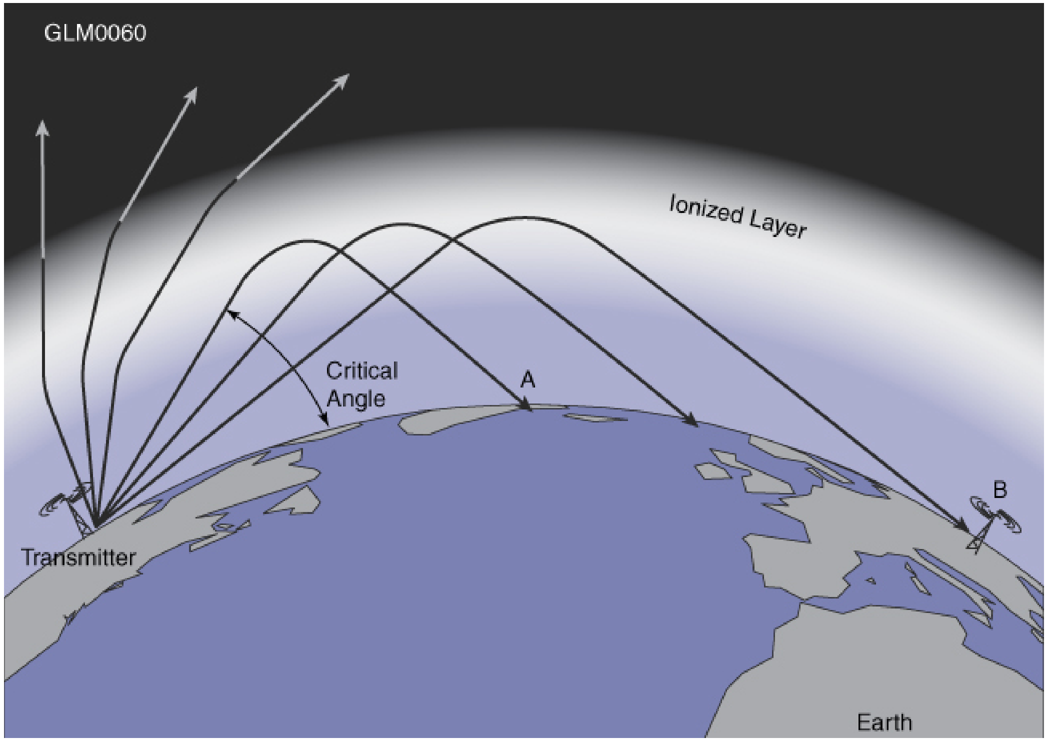
- From theory (secant law):

  $MUF = f_c \sec \theta_i$

- The virtual height is the height from which the radio wave appears to be reflecting.



- The critical angle is the angle at which a radio wave must hit the ionosphere to reflect back to the Earth.



- The critical frequency is the highest frequency that a radio wave transmitted straight up will return to the Earth.
- Radio waves that pass through the denser D and E regions are partially absorbed. Frequencies below about 10 MHz are completely absorbed.
  - 160, 80, 60, and 40 meters provide the best DX at night when the D layer is gone.
  - Shortwave broadcasters move to lower frequencies at night.

Sky-Wave and Ground-Wave Propogation

- Sky-wave propagation refers to radio wave propagation via the ionosphere. Each reflection from the ionosphere is a hop. Reception of sky-wave propagation is called skip.
- The higher the region in the ionosphere where the hop occurs, the greater the distance the wave can travel.
  - F2 skip can travel up to 4000 km
  - E skip can travel up to 2000 km

- Sky-wave propagation can include multiple hops between the Earth and the ionosphere.
- If the ionosphere is very dense, then the critical angle is high and short skip is possible.
  - Short skip distances are much shorter than the usual skip distances.
  - Short skip on the 10 M band is a good indicator that sky-wave propagation is possible on 6 M.

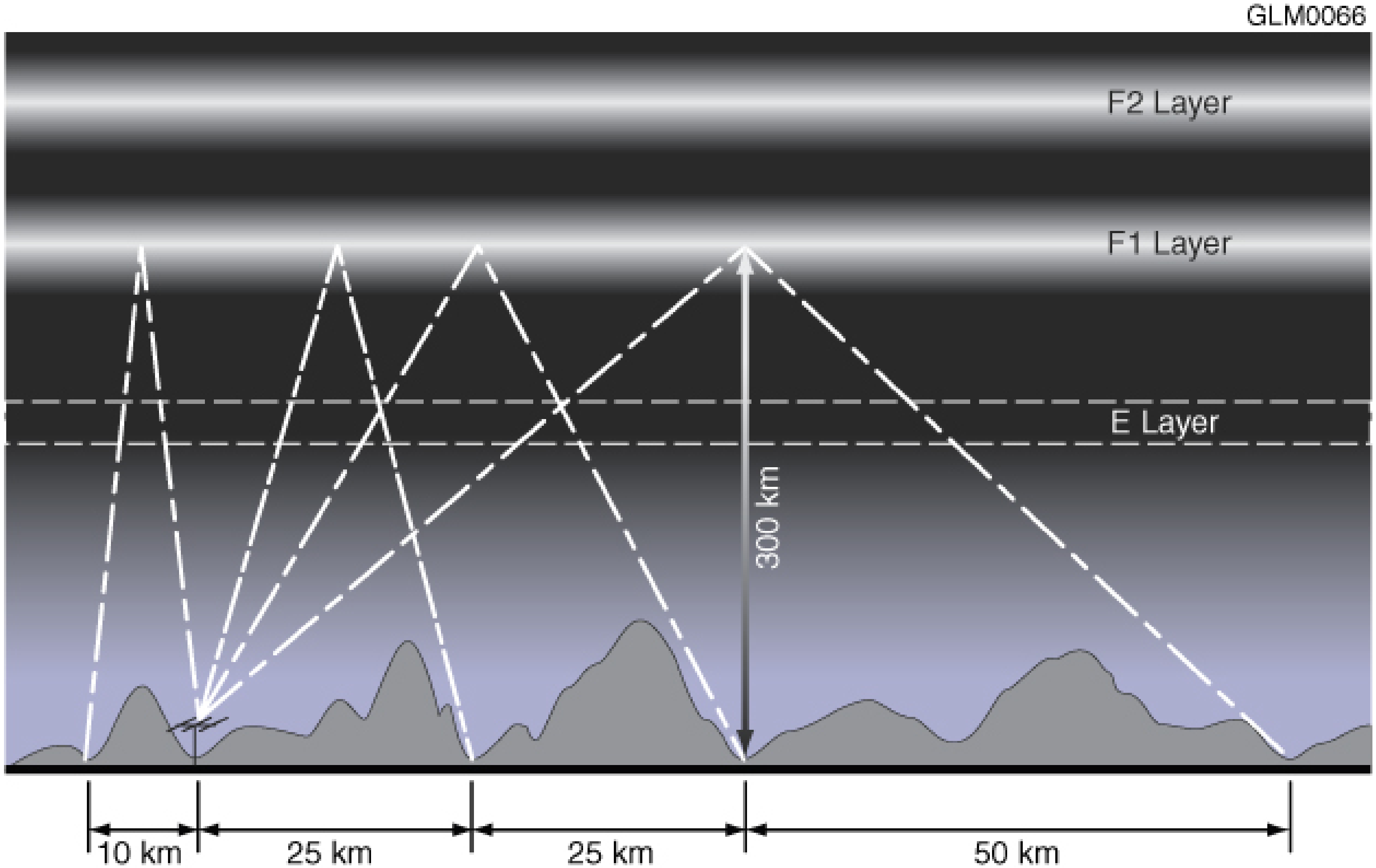
- Sky-wave signals due to fluctuations in the ionosphere which can create multiple paths for the signal (multipath). The combination of multipath signals can cause some distortion or fading.
- Ground-wave signals travel along the surface of the Earth. The ground is a poor conductor so ground wave losses are high and increase with frequency.
- The skip zone is the region between the maximum ground-wave and minimum sky-wave where a station can not be heard.

- Maximum usable frequency (MUF) is the highest frequency at which propagation exists between two points. Frequencies higher than the MUF pass through the ionsphere into space.
- Lowest usable frequency (LUF) is the lowest frequency at which propagation exists between two points. Frequencies lower than the LUF are absorbed in the ionosphere.
- The MUF and LUF are affected by:
  - Time of day
  - Season
  - Amount of solar radiation
  - Ionospheric stability

- If the LUF is greater than the MUF, then sky-wave propagation is not possible between the two points.
- Listening to beacon stations is an excellent way to determine propagation conditions.

Near Vertical Incidence Sky-Wave

- Near Vertical Incidence Sky-Wave (NVIS) can occur for radio waves below the critical frequency, which is usually below 5 MHz for most locations.
- Horizontally polarized antennas must be mounted between 1/8 to ¼ of a wavelength above the ground to use NVIS.
- The resulting skip is usable up to 320 to 480 km.


GLM0066
F2 Layer
F1 Layer
E Layer
300 km
10 km
25 km
25 km
50 km