AJOU UNIVERSITY

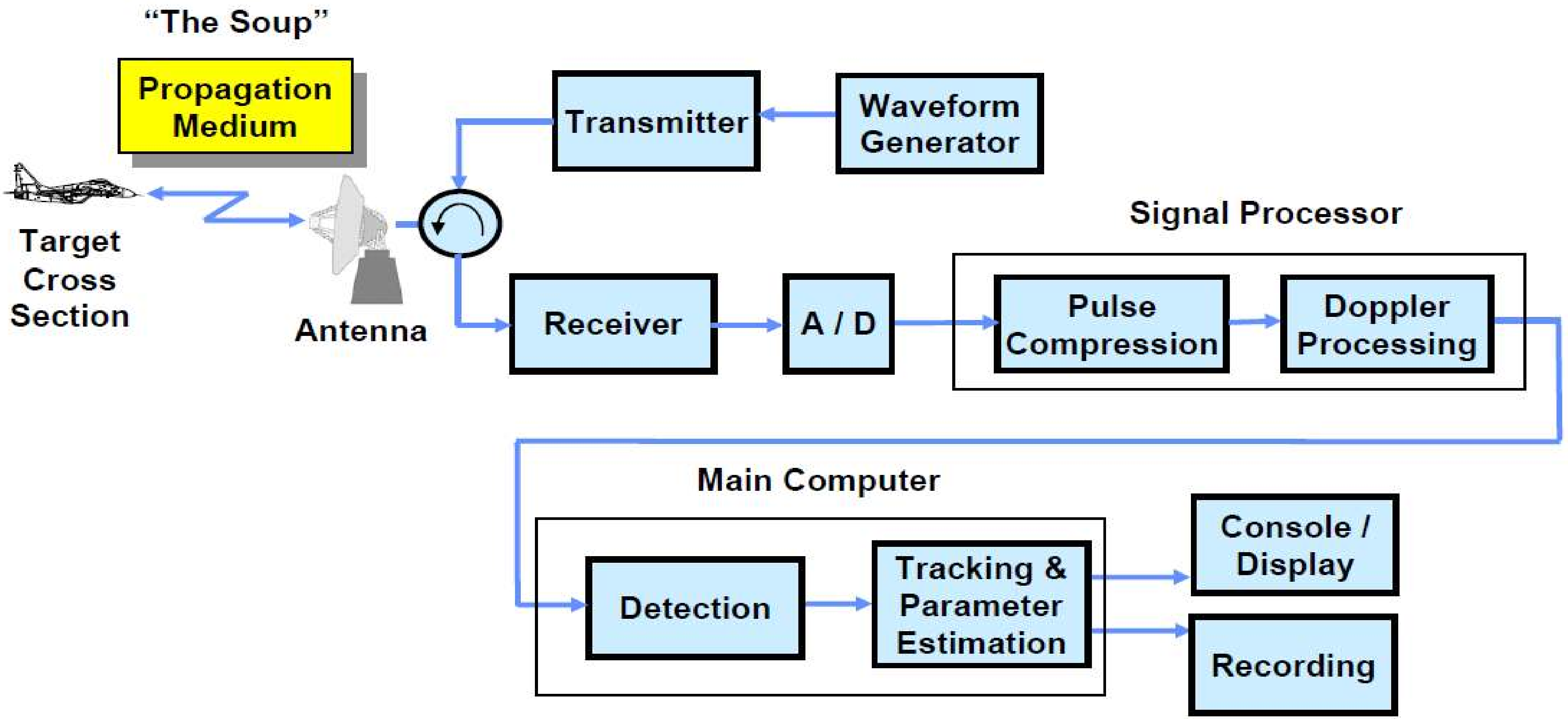
1973

Radar Systems

Lecture 3. Propagation Effects

구 자 열

Radar Block Diagram



Radar Classes

- Ground based
- Sea based
- Airborne

Patriot

Courtesy of Raytheon. Used with permission.

AWACS

Courtesy of U.S. Air Force.

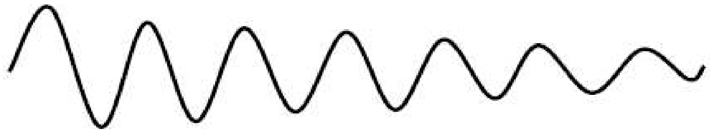
AEGIS

Courtesy of U.S. Navy.

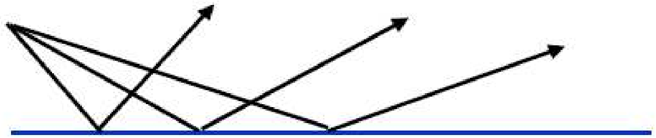
Nearly all radar systems operate through the atmosphere and near the Earth's surface

Propagation Effects on Radar Performance

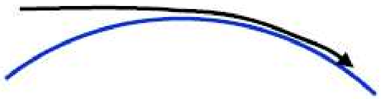
- **Atmospheric attenuation**



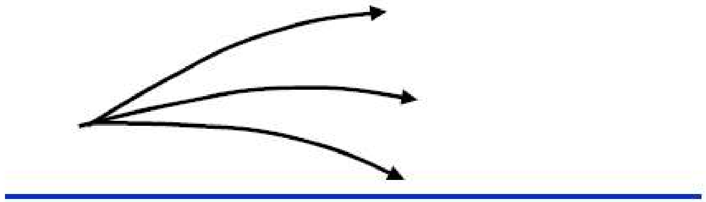
- **Reflection off of Earth's surface**



- **Over-the-horizon diffraction**



- **Atmospheric refraction**



Radar beams can be attenuated, reflected and bent by the environment

What’s in the Soup?

- Atmospheric parameters vary with altitude
  - Air density and humidity
  - Rain rate
  - Fog/cloud water content
  - Index of refraction
- Earth’s surface
  - Surface material (water vs land)
  - Surface roughness (waves, mountains)
  - Earth’s curvature

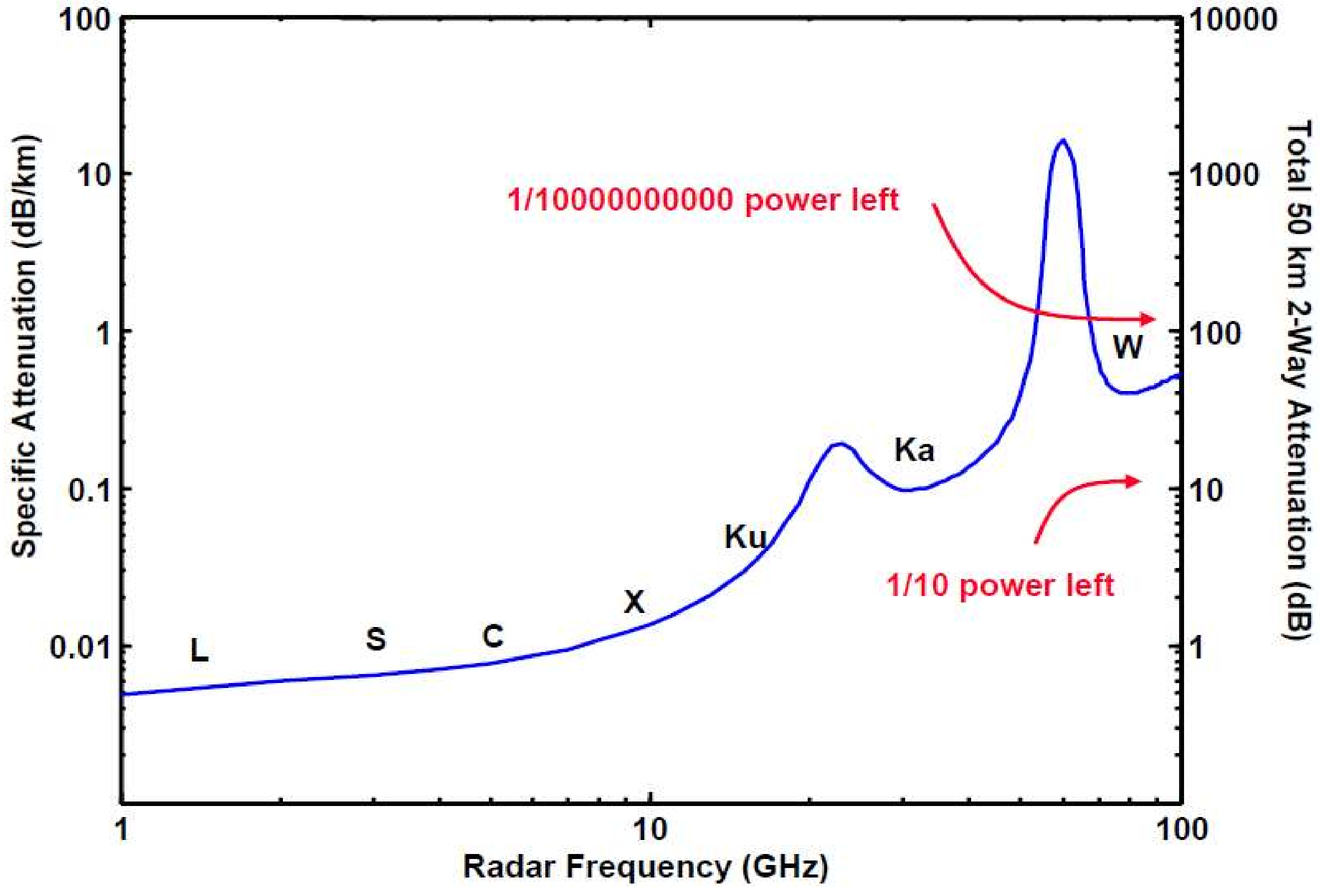
차 례

- **Atmospheric attenuation**
- **Reflection from the Earth’s surface**
- **Over-the-horizon diffraction**
- **Atmospheric refraction**
- **Ionospheric propagation**

Atmospheric Attenuation at Sea Level

Radar power absorbed by water vapor and oxygen

Attenuation is a loss of power characterized by L in radar range equation



High frequencies are not well suited for long-range low-altitude surveillance

Attenuation in Rain and Fog

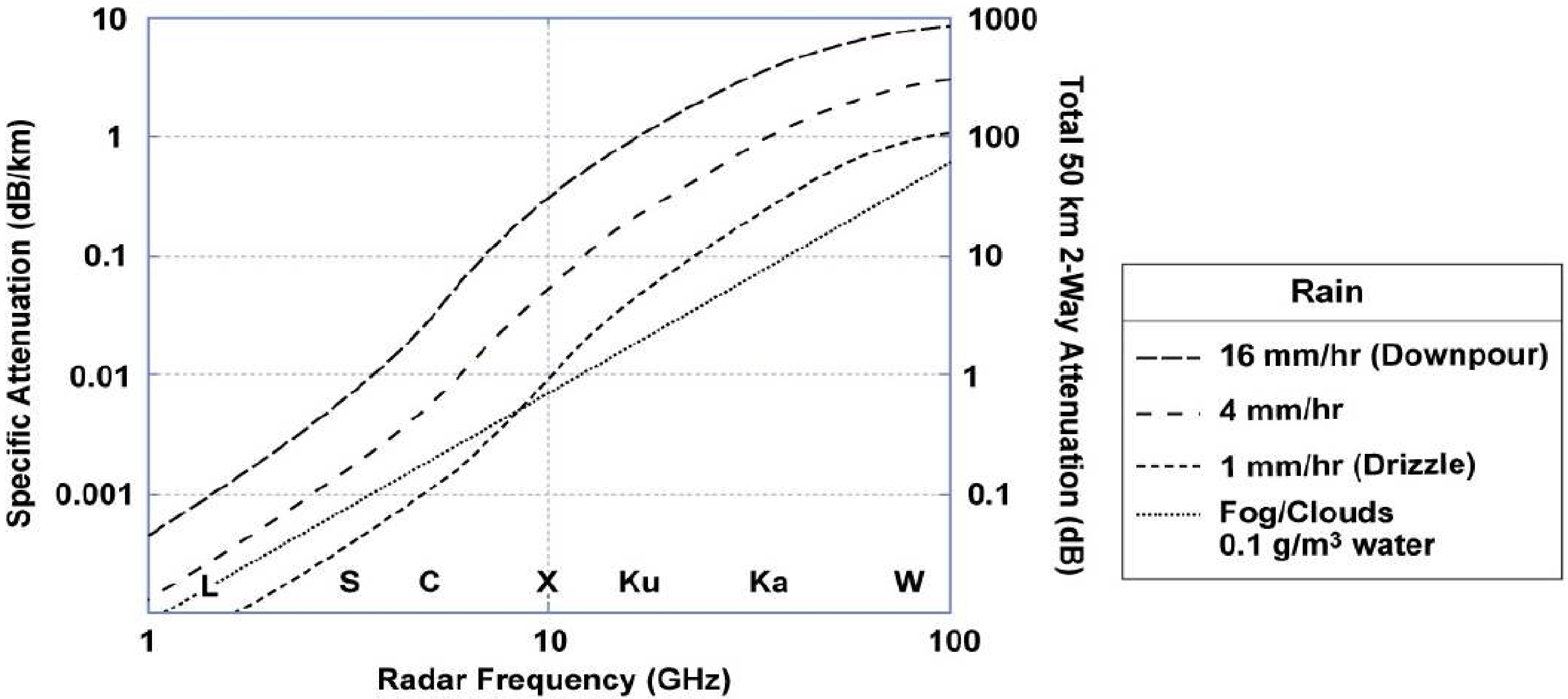


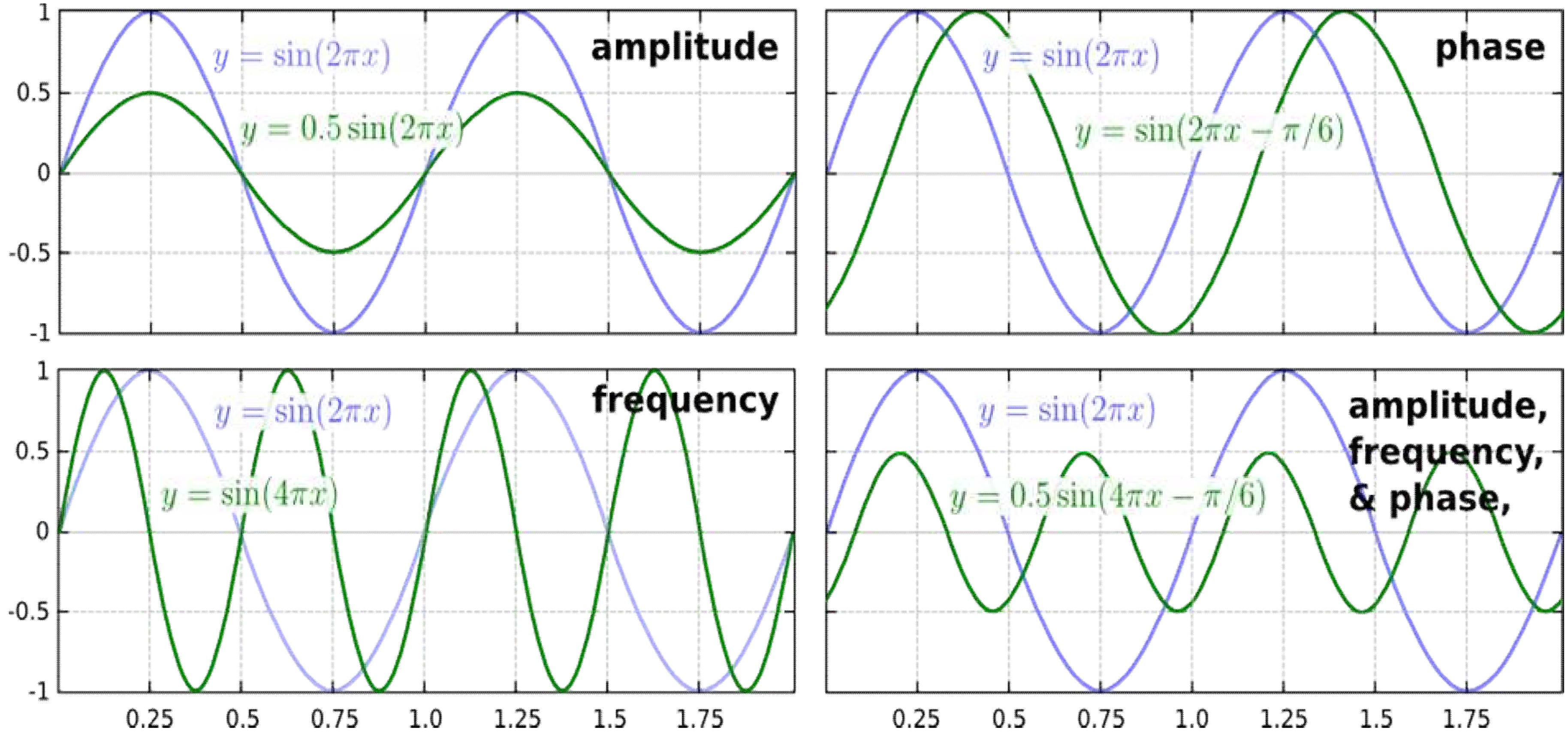
Figure by MIT OCW.

Radar performance at high frequencies is highly weather dependent

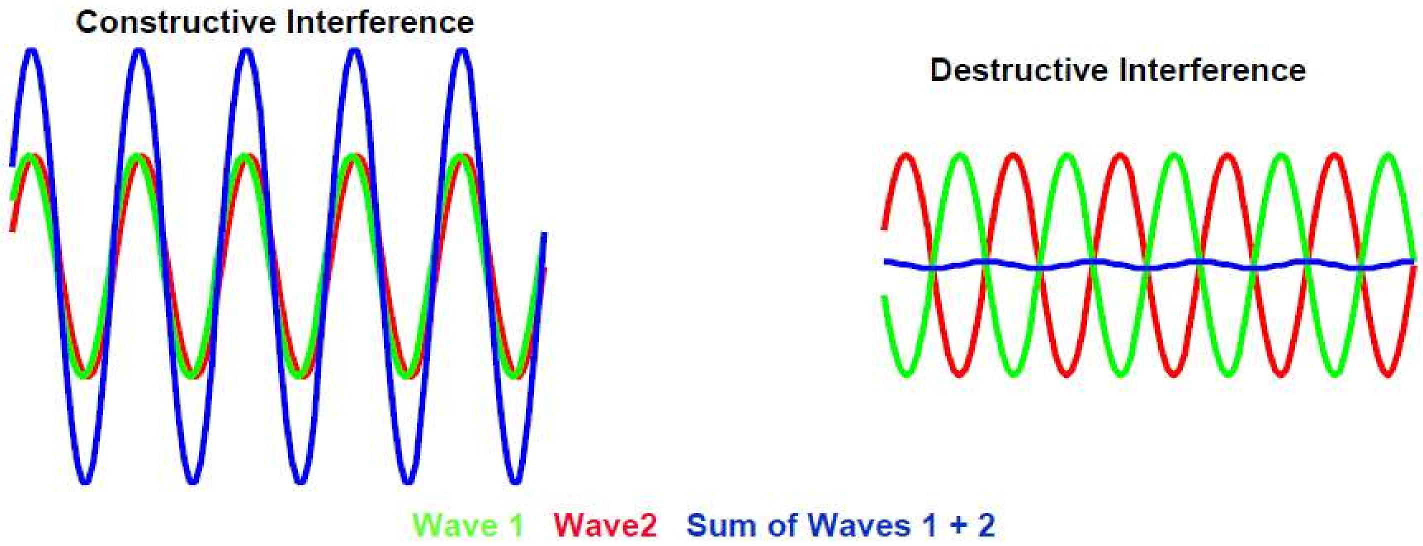
차 례

- Atmospheric attenuation
- Reflection from the Earth's surface ⟸
- Over-the-horizon diffraction
- Atmospheric refraction
- Ionospheric propagation

Wave Amplitude, Phase and Frequency

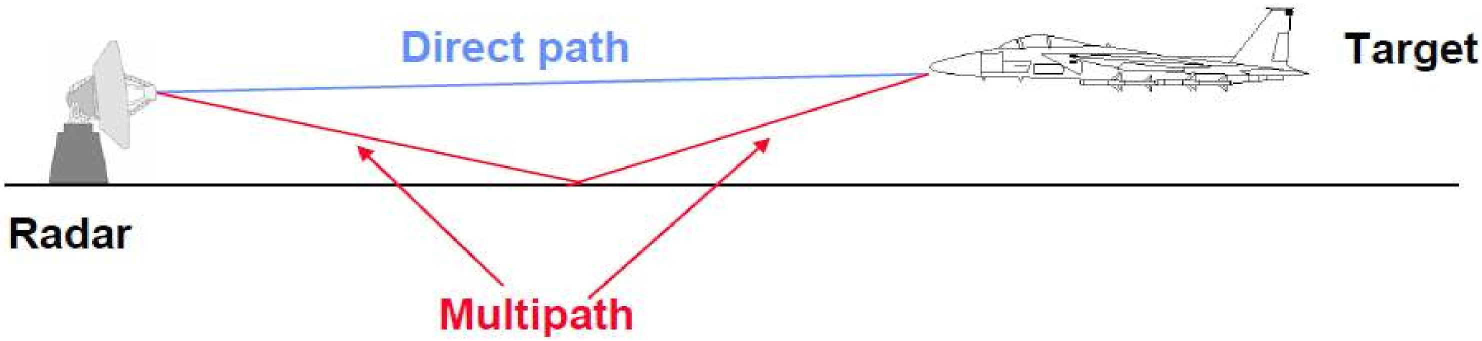


Interference Basics



- Two waves can interfere constructively or destructively
- Resulting field strength depends only on relative amplitude and phase of the two waves
  - Radar voltage can range from 0-2 times single wave
  - Radar power is proportional to $(\text{voltage})^2$ for 0-4 times the power
  - Interference operates both on outbound and return trips for 0-16 times the power

Propagation over a Plane Earth



Reflection from the Earth's surface results in interference of the direct radar signal with the signal reflected off of the surface

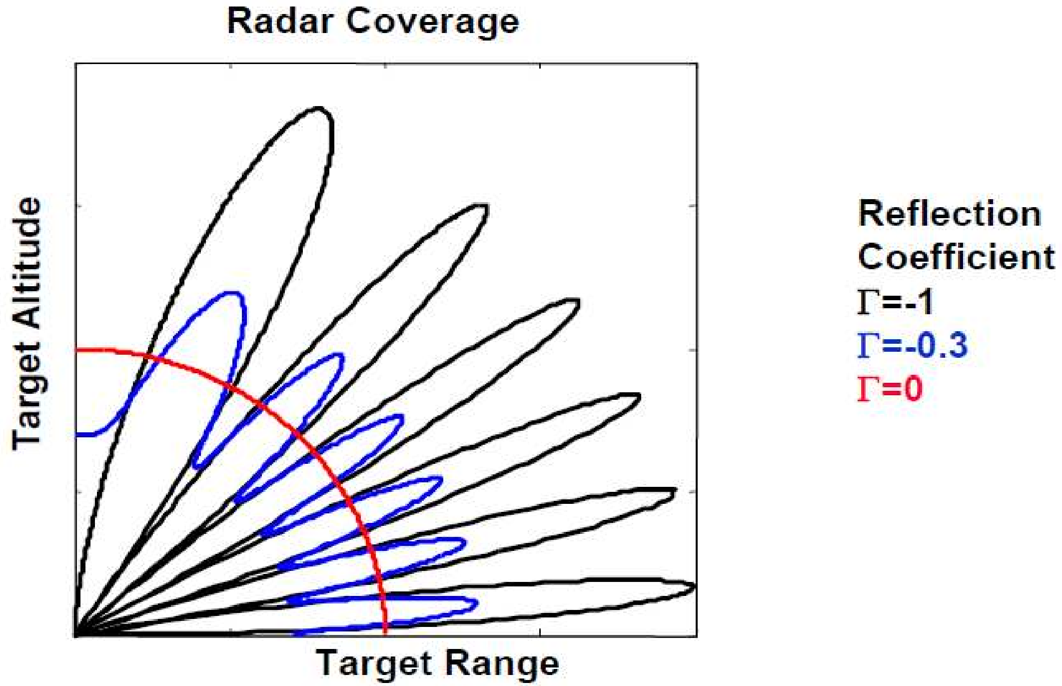
Surface reflection coefficient (Γ) determines relative signal amplitudes

- Dependent on: surface material, roughness, polarization, frequency
- Close to 1 for smooth ocean, close to 0 for rough land

Relative phase determined by path length difference and phase shift on reflection

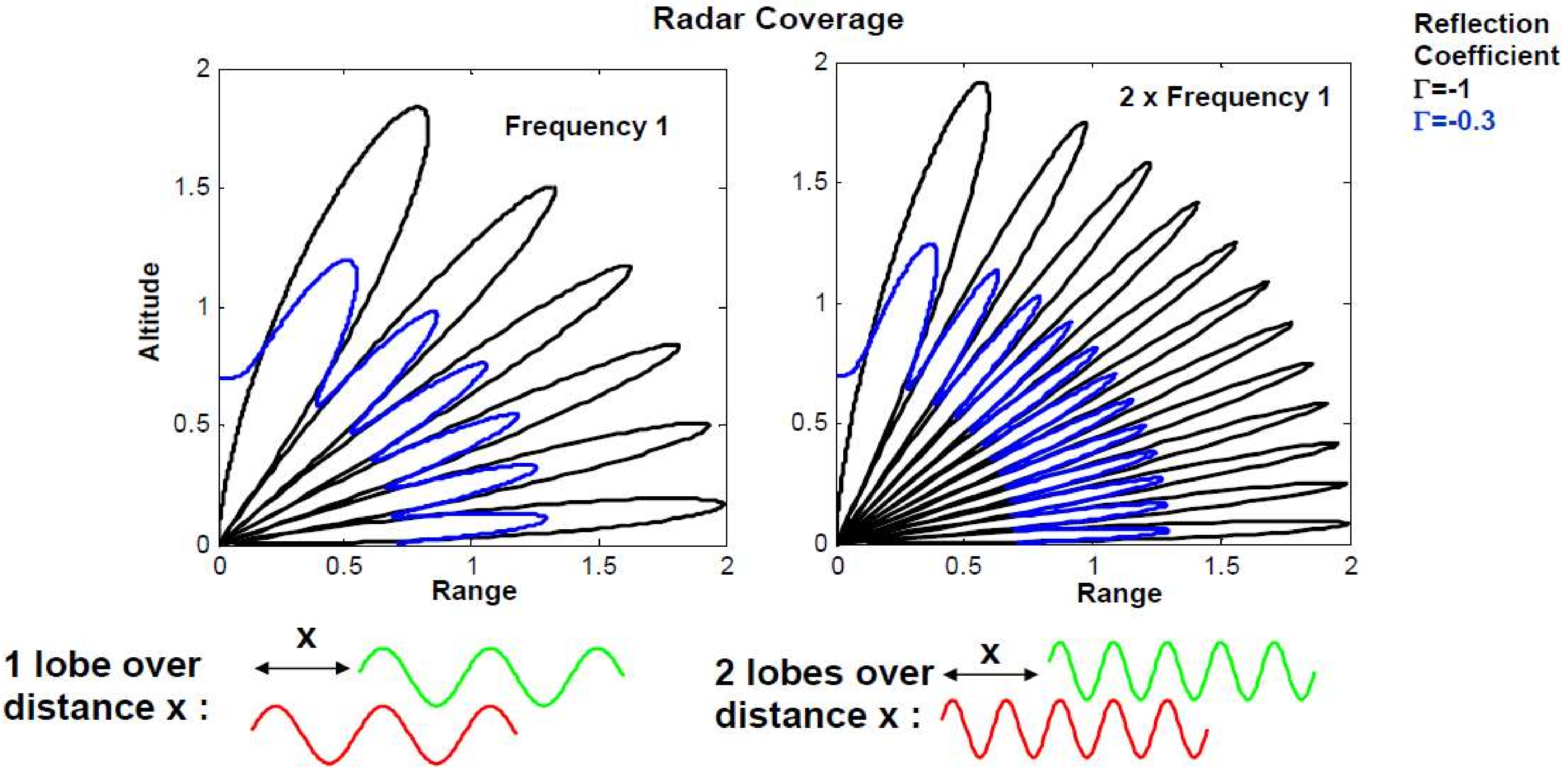
- Dependent on: height, range and frequency

Multipath Effect on Radar Detection Range



- Multipath causes elevation coverage to be broken up into a lobed structure
- A target located at the maximum of a lobe will be detected as far as twice the free-space detection range
- At other angles the detection range will be less than free space and in a null no echo signal will be received

Multipath is Frequency Dependent



Lobing density increases with increased radar frequency

차 례

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- Reflection from the Earth's surface
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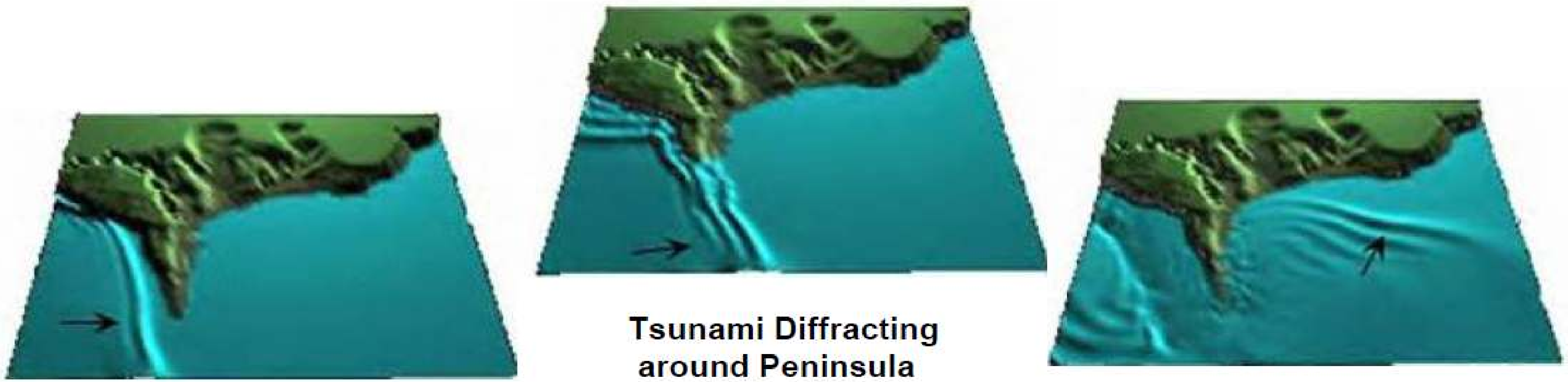
Diffraction



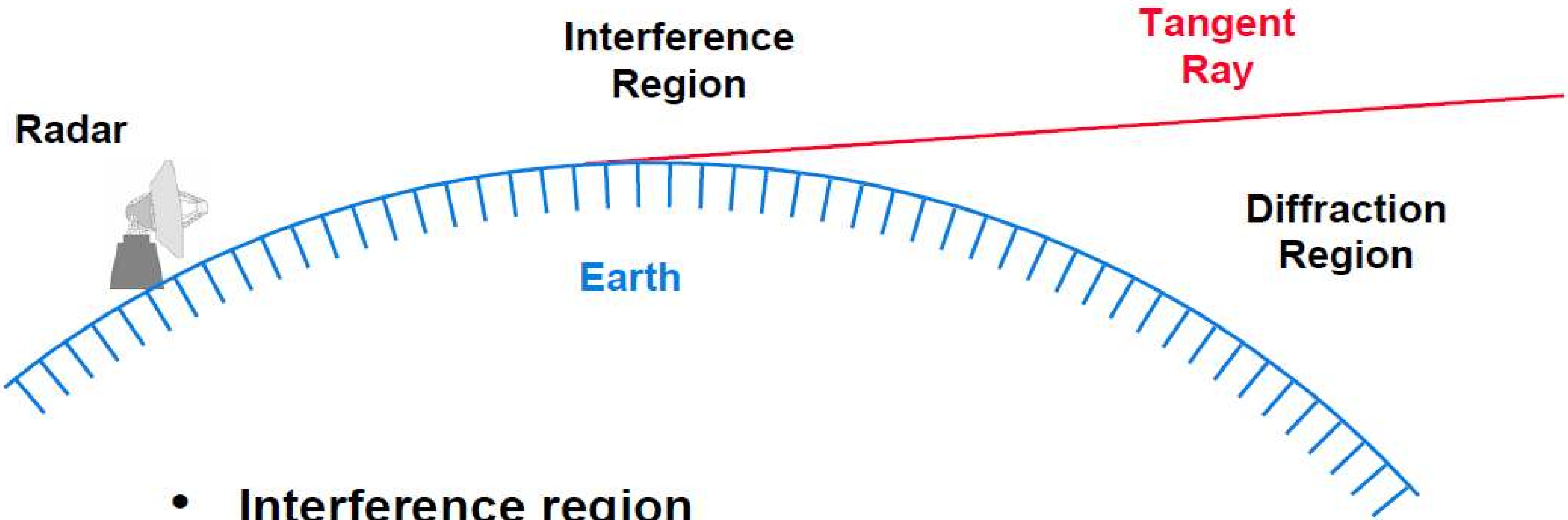
Tsunami Diffracting around Peninsula

Courtesy of NOAA / PMEL / Center for Tsunami Research.
See animation at http://nctr.pmel.noaa.gov/animations/Aonae.all.mpg

- **Radar waves are diffracted around the curved Earth just as ocean waves are bent by an obstacle**
- **Web references for excellent water wave photographic examples:**
  - **http://upload.wikimedia.org/wikipedia/commons/b/b5/Water_diffraction.jpg**
  - **http://yhspatriot.yorktown.arlington.k12.va.us/~ckaldahl/wave.gif**

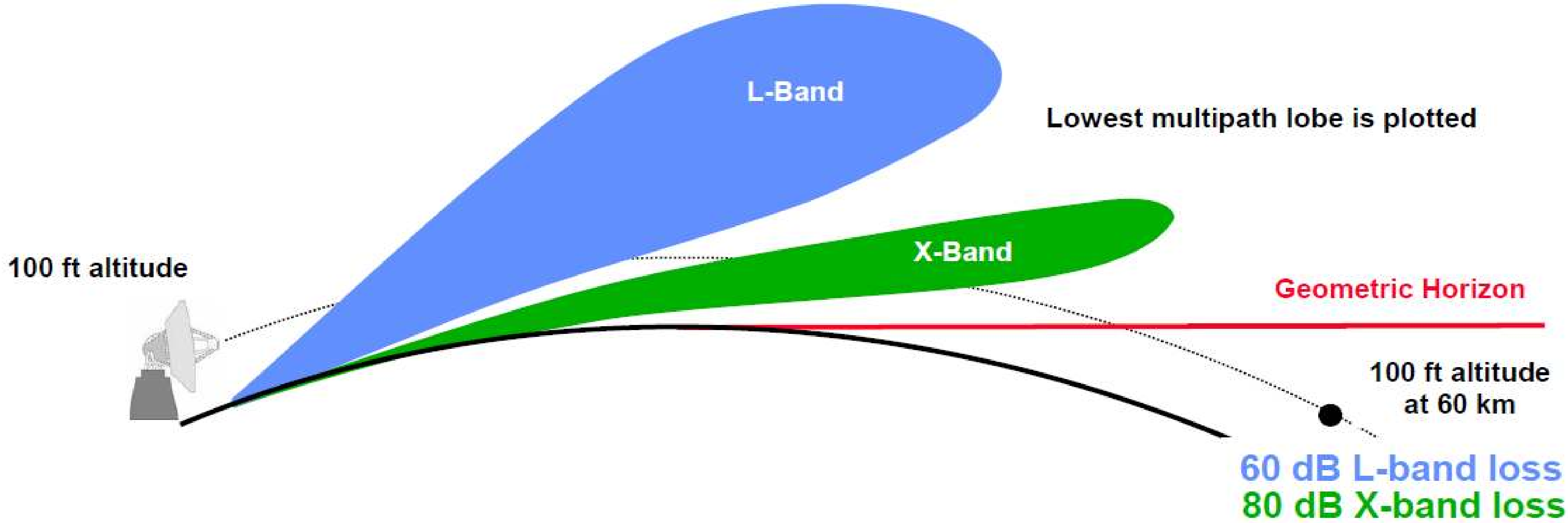
- **The ability of radar to propagate beyond the horizon depends upon frequency and radar height**

Propagation Over Round Earth



- Interference region
  - Located within line of sight radar
- Diffraction region
  - Below radar line of sight
  - Signals are severely attenuated

Combined Diffraction and Multipath vs Radar Frequency



- Low altitude multipath detection: favors higher frequencies
- Diffraction detection:
  - Favors lower frequencies
  - Is tough at any frequency

차 례

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Refraction of Radar Beams

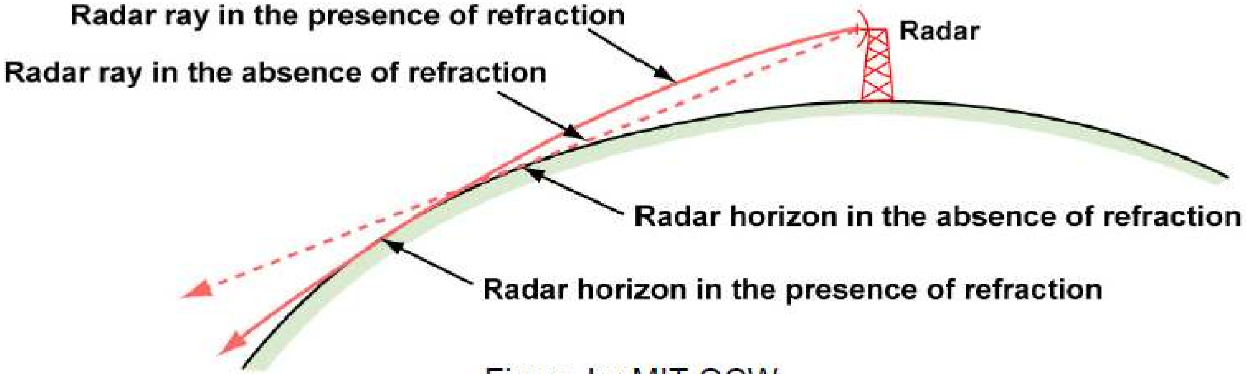


Figure by MIT OCW.

Radar rays bend downwards due to decreasing index of refraction of air with altitude

Same effect as refraction of light beam shining from water into air

Earth's Radius Modified to Account for Refraction Effects

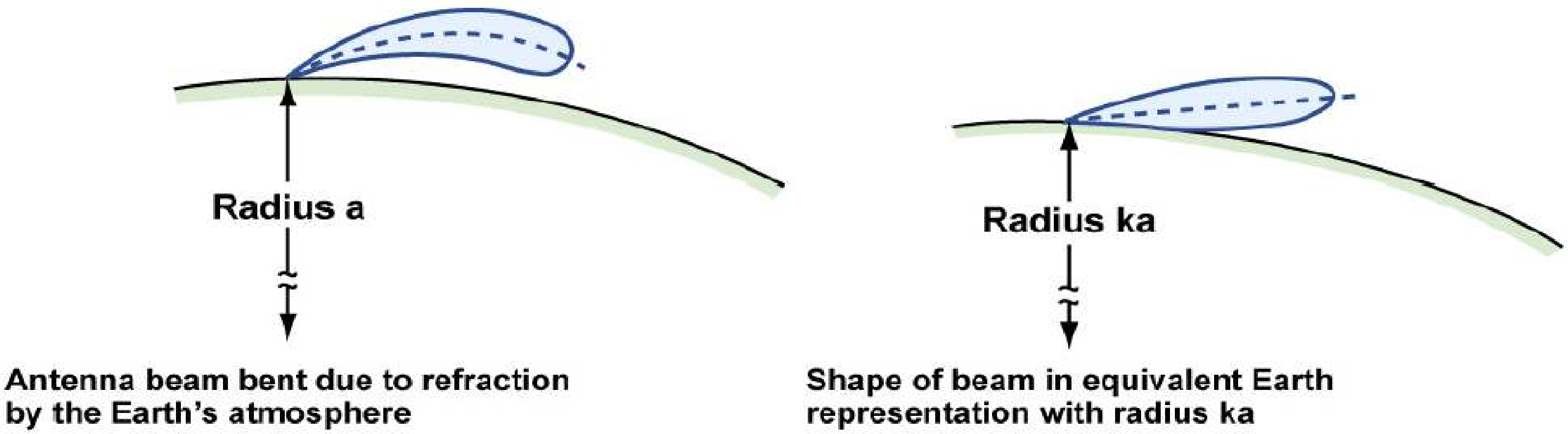


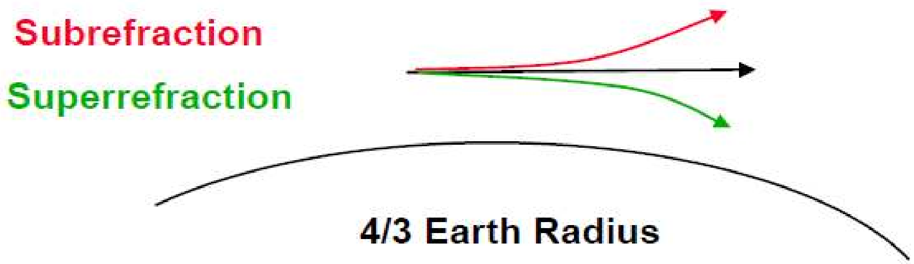
Figure by MIT OCW.

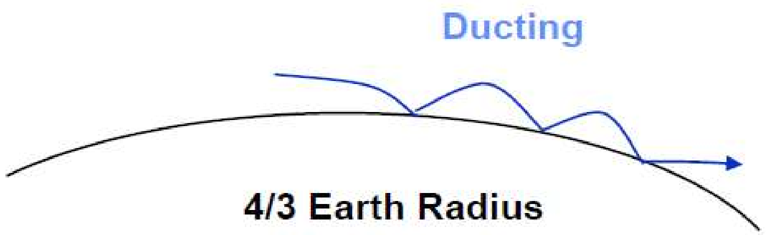
Atmospheric refraction is accounted for by replacing the actual Earth radius a, in calculations, by an equivalent earth radius ka and assuming straight line propagation

4/3 is a typical value for k

Average propagation is referred to as a "4/3 Earth"

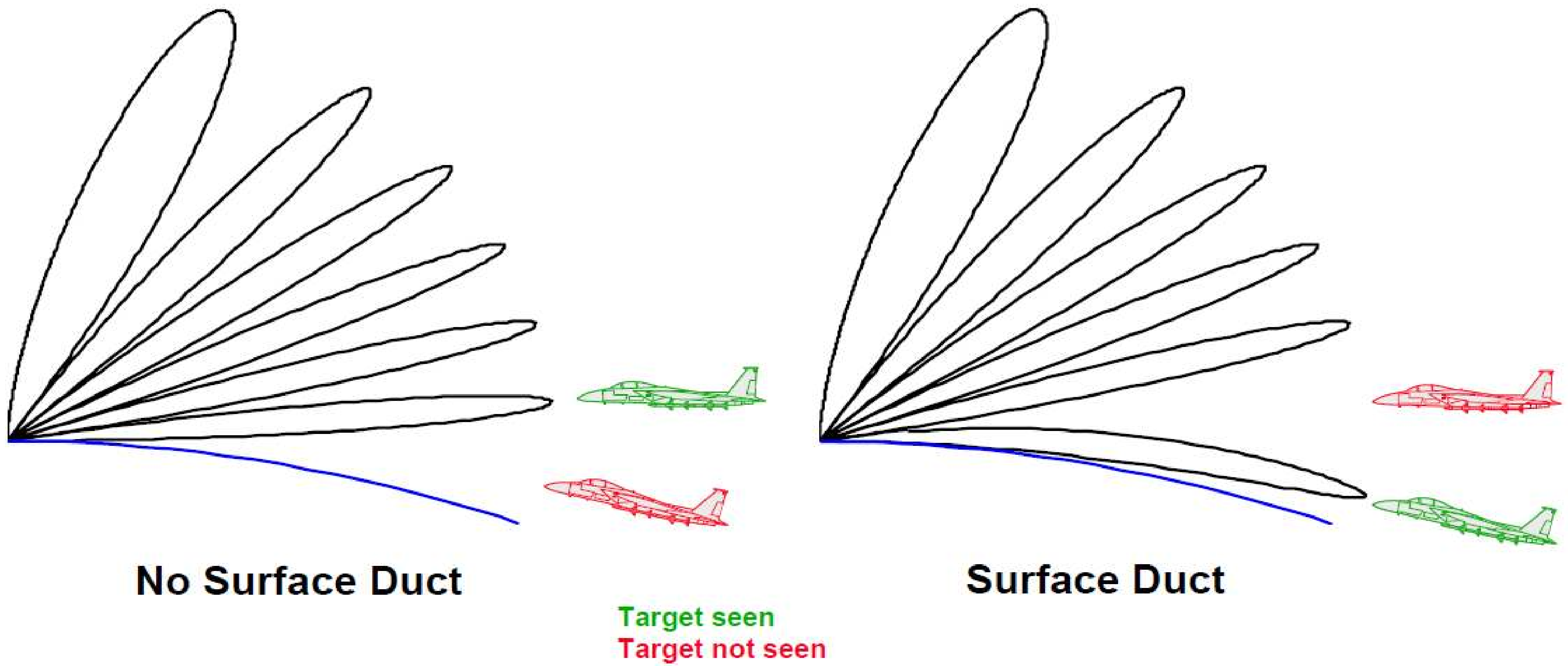
Anomalous Propagation





- Occurs when k not equal to 4/3
- Categorized as: superrefraction, subrefraction and ducting
  - Superrefraction extends the radar horizon
  - Subrefraction limits the radar horizon
  - Ducting traps radar energy near the Earth's surface

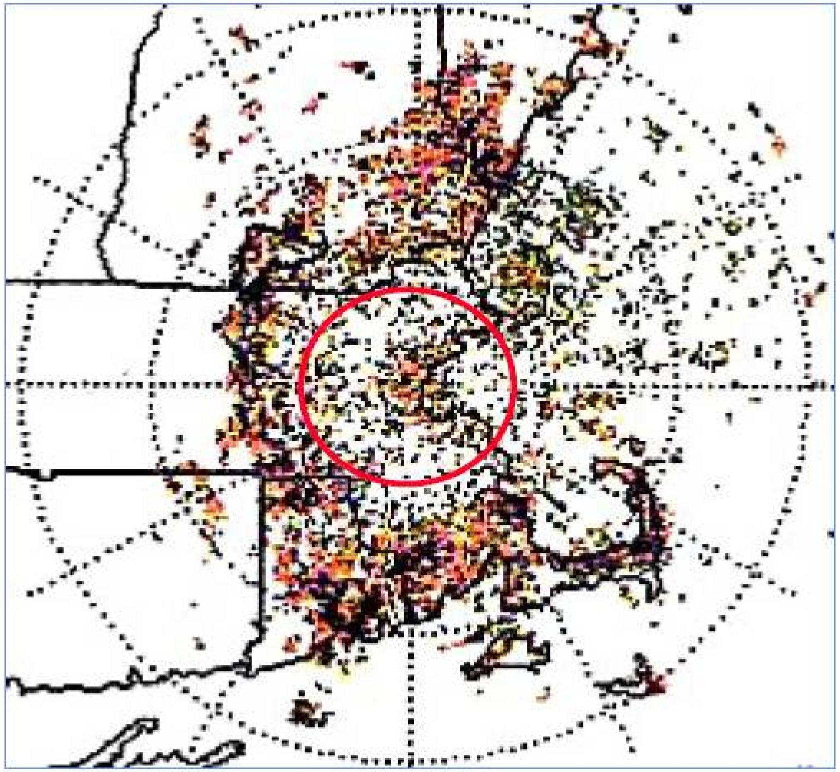
Ducting Effects on Target Detection



Ducting extends low-altitude detection ranges but can cause unexpected holes in radar coverage

Ducted Clutter from New England

PPI Display



50 km range rings

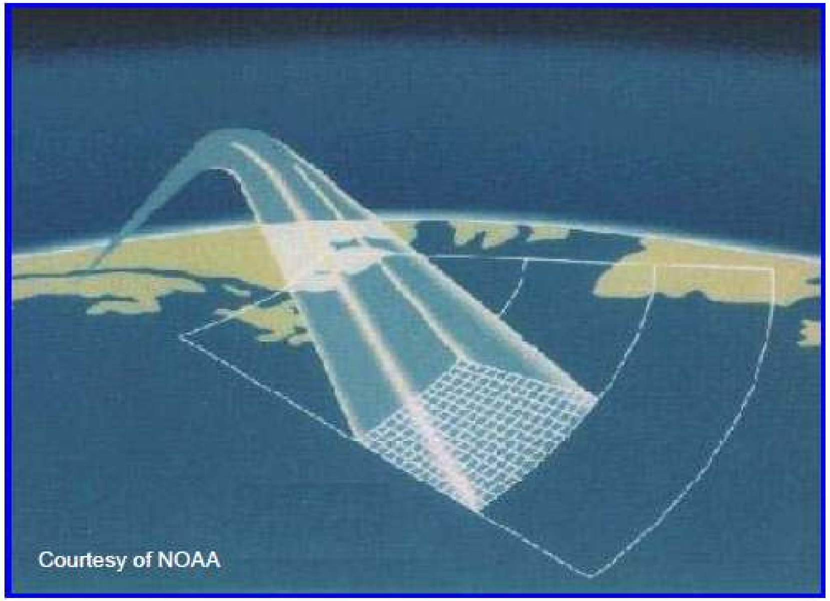
Ducting conditions can extend horizon to extreme ranges

차 례

- Atmospheric attenuation
- Reflection from the Earth's surface
- Over-the-horizon diffraction
- Atmospheric refraction
- Ionospheric propagation ⟸

Over-the-Horizon Radars

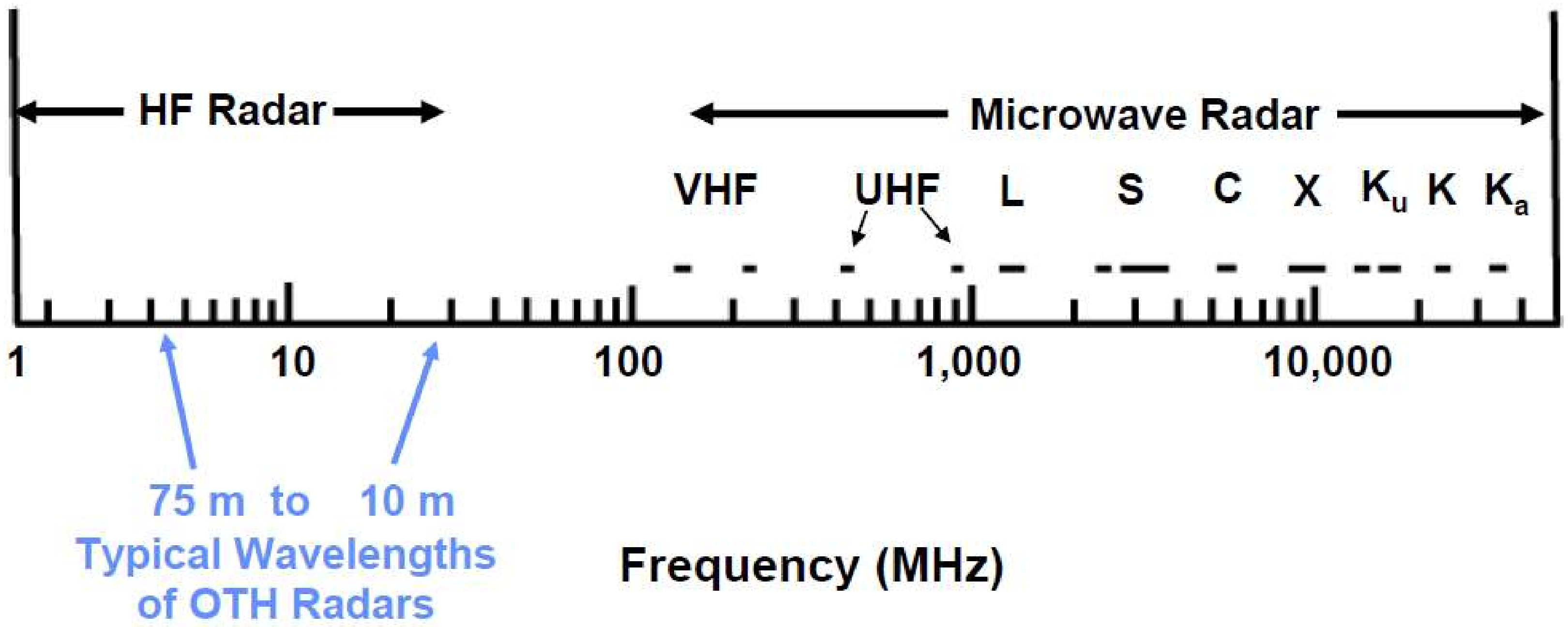
OTH Radar Beam Paths



Example
Relocatable OTH Radar (ROTHR)
Transmit Array

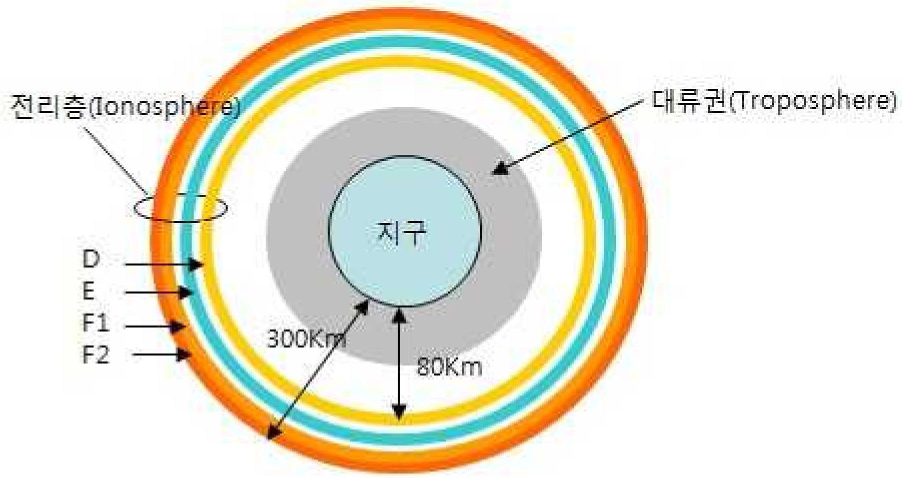
- Typically operate at 10 – 80 m wavelengths (3.5 – 30 MHz)
- OTH Radars can detect aircraft and ships at very long ranges (~ 2000 miles)

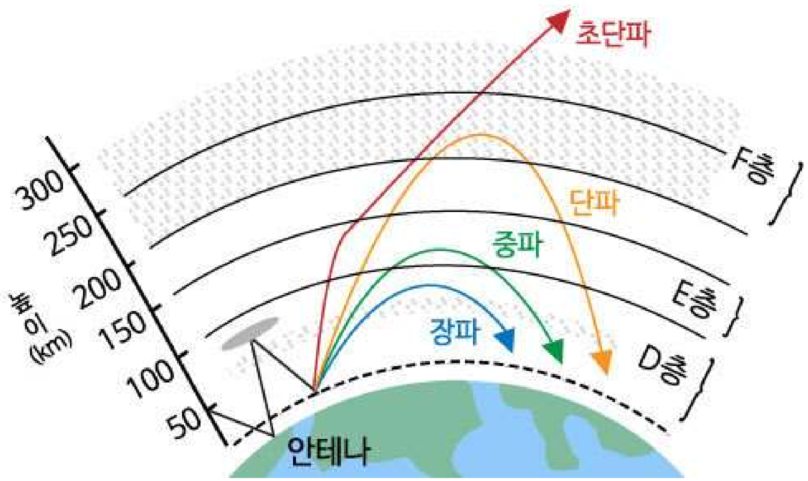
Frequency Spectrum (HF and Microwave Bands)

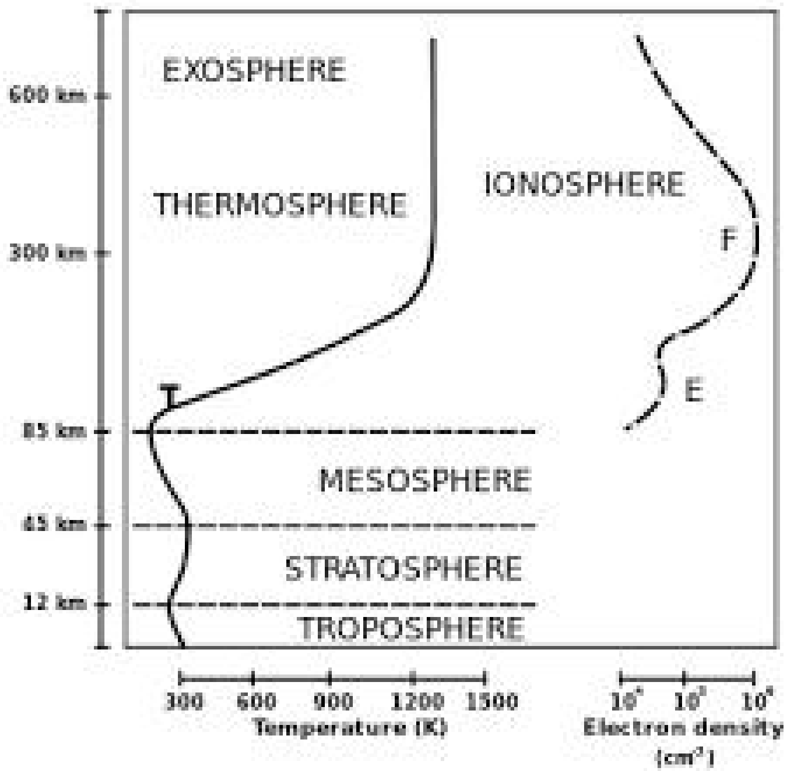


Electromagnetic Propagation at High Frequencies (HF) is very different than at Microwave Frequencies

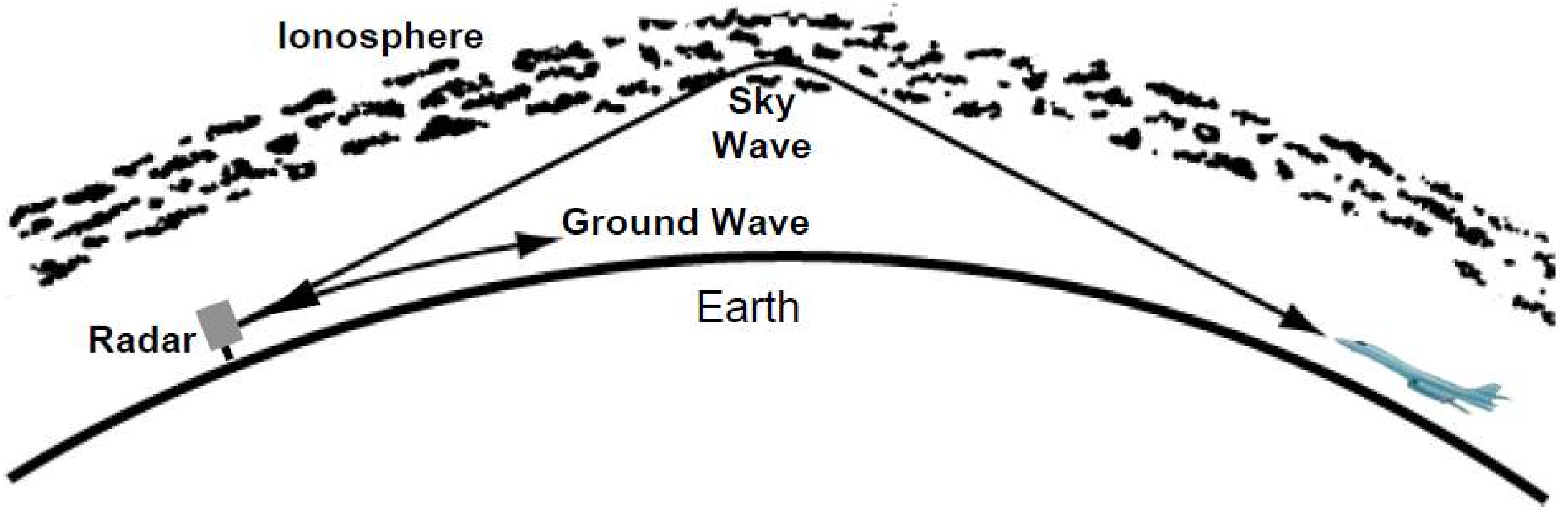
Ionospheric Characteristics







Ionospheric Propagation (How it Works- What are the Issues)

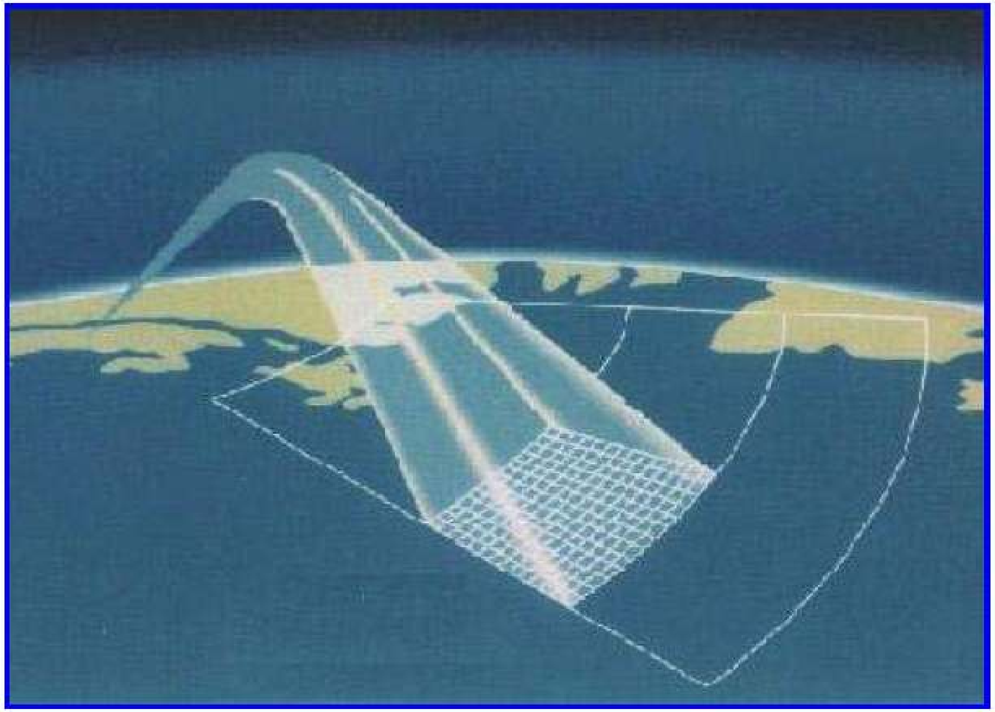


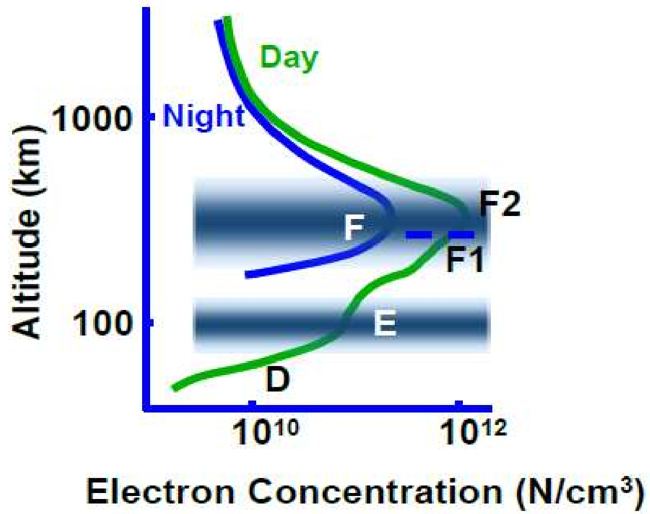
- Sky wave OTH radars:
  - Refract (bend) the radar beam in the ionosphere,
  - Reflecting back to earth,
  - Scattering it off the target, and finally,
  - Reflect the target echo back to the radar

- The performance of OTH radars vitally depends on the physical characteristics of the ionosphere, its stability and its predictability

Physics of OTH Radar Propagation

Over the Horizon Propagation
Enabled by Ionospheric Refraction

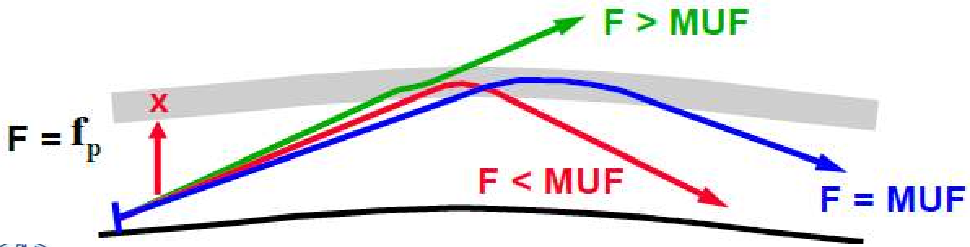




Plasma Frequency $f_p = \frac{1}{2\pi}\sqrt{\frac{Ne^2}{m\varepsilon_0}}$

Maximum Usable Frequency (MUF)
Key for oblique incidence

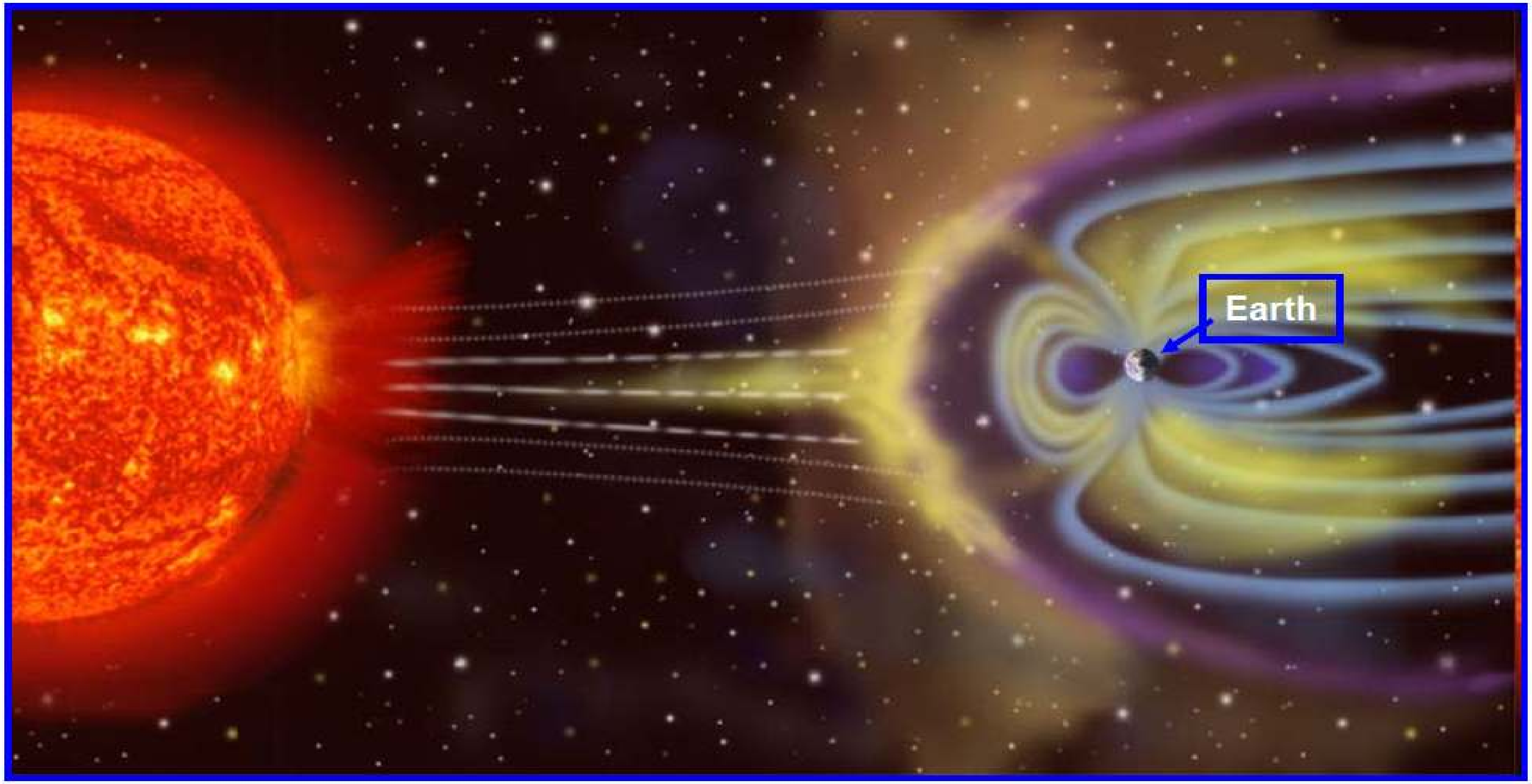
$$\mathrm{MUF} = f_p \,\mathrm{secant}\left(\theta_{inc}\right)$$



MUF = Maximum Usable Frequen

Regular Variation in the Ionosphere

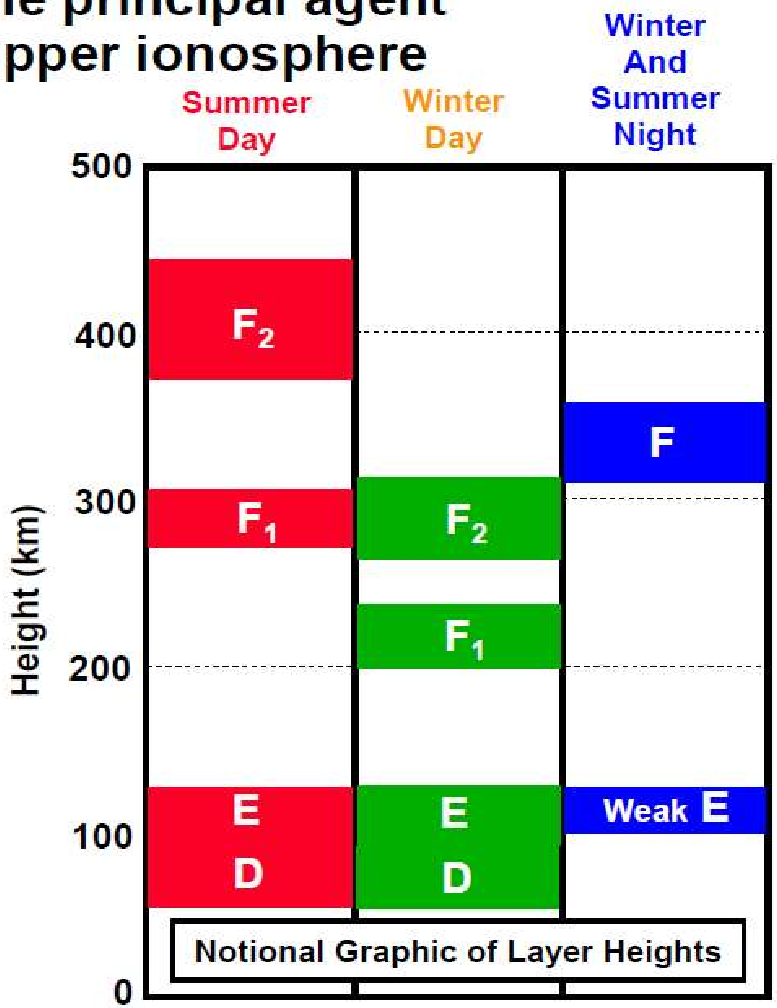
- Ultraviolet radiation from the sun is the principal agent responsible for the ionization in the upper ionosphere



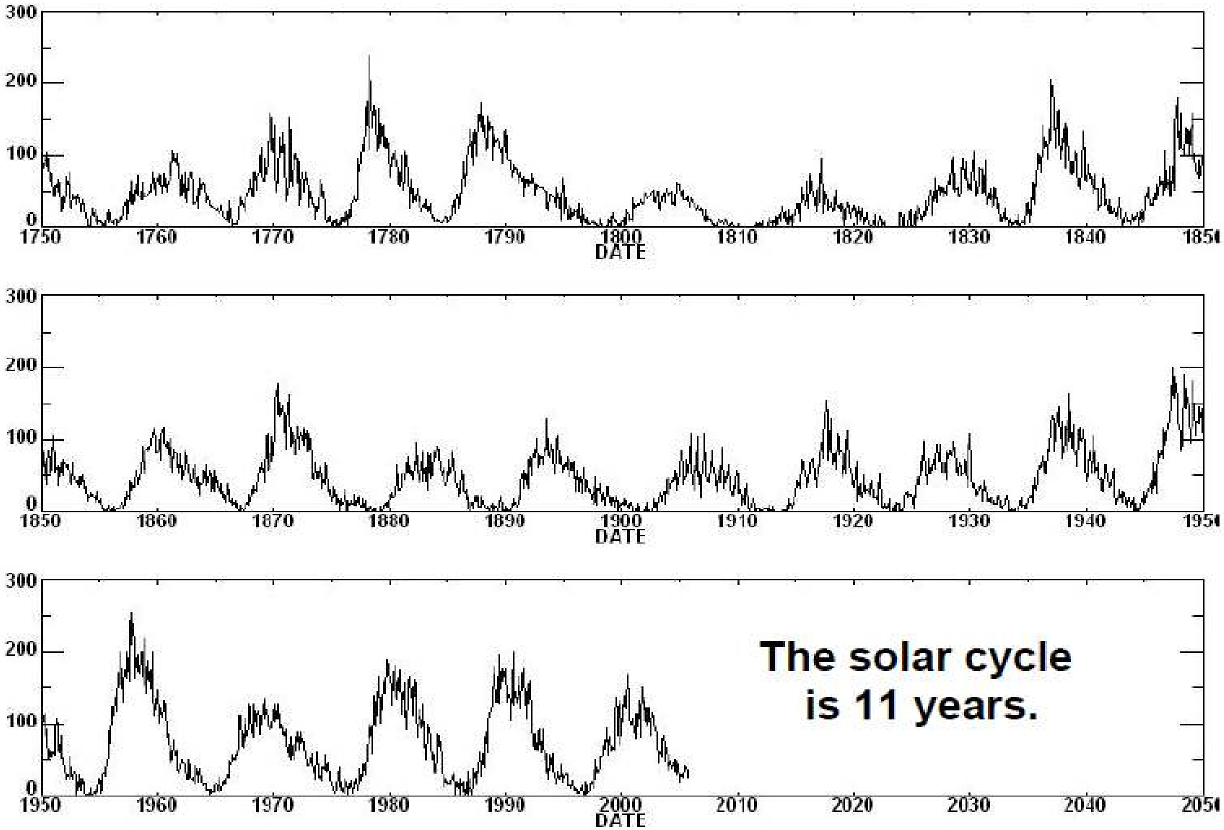
Courtesy of NASA

Different Layers of the Ionosphere

- Ultraviolet radiation from the sun is the principal agent responsible for the ionization in the upper ionosphere
- D layer (~50 to 90 km altitude
  - Responsible for major signal <u>attenuation</u> during the day
    - Absorption proportional to $1/f^2$
    - Lower frequencies attenuated heavily
  - D layer disappears at night
- E layer (~90 to 130 km altitude)
  - Low altitude of layer=> short range
  - Sporadic-E layer – few km thick
- F layer (~200 to 500 km altitude
  - <u>Most important layer</u> for HF sky wave propagation
  - During daylight, F region splits into 2 layers, the F_1 and F_2 layers
    - The F_1 and F_2 layers combine at night
    - F_2 layer is in a continual state of flux



Average Sun Spot Number (1750~present)



Courtesy of NASA

- Within each week, of each month, of each year there is significant variation in the Sun Spot number (solar flux), and thus, the electron density in the ionosphere

Propagation Issues for OTH Radars

- OTH radar detection performance is dependent on many variables and is difficult to predict because of the variability and difficulty, of reliably predicting the characteristics of the ionosphere
  - Diurnal variations
  - Seasonal variations
  - Sun Spot cycle
  - Solar flares, coronal mass ejections, etc. from the sun

- Because OTH radars can detect targets at great ranges they have very large antennas and very high power transmitters

Q & A