Introduction to Radar Systems

Propagation Effects

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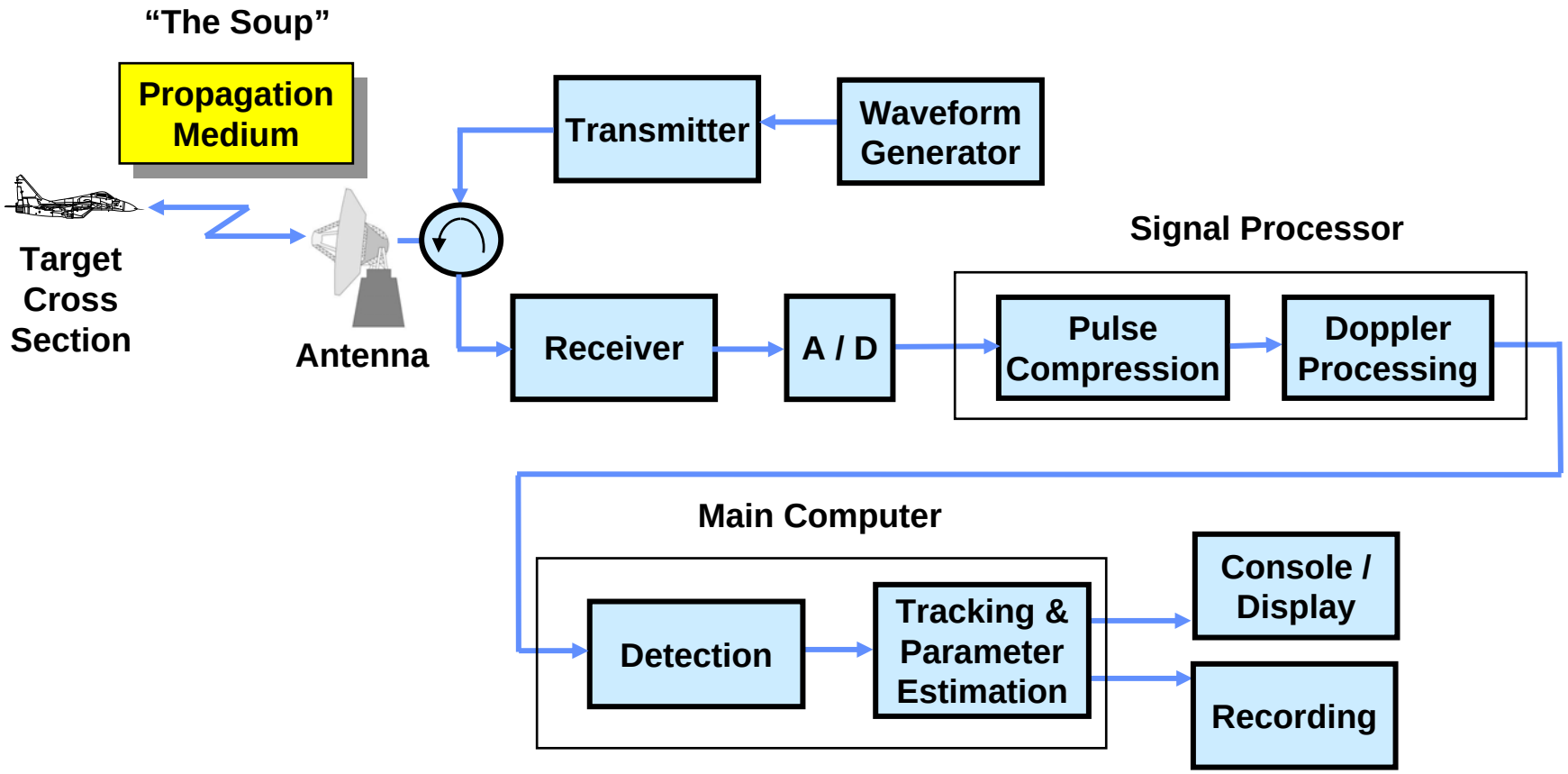
Radar Block Diagram



Radar Classes

- Ground based
- Sea based
- Airborne

Patriot

Courtesy of Raytheon. Used with permission.

AWACS

Courtesy of U.S. Air Force.

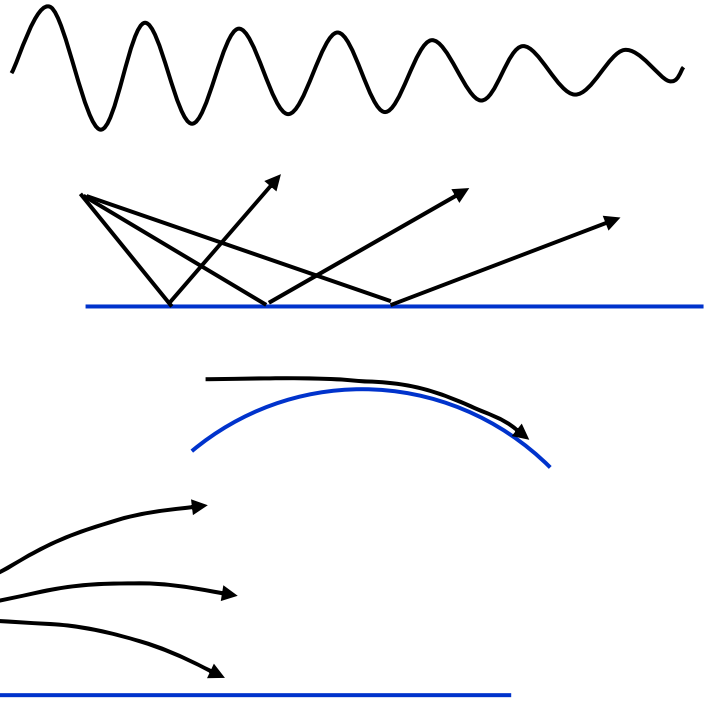
AEGIS

Courtesy of U.S. Navy.

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

Propagation Effects on Radar Performance

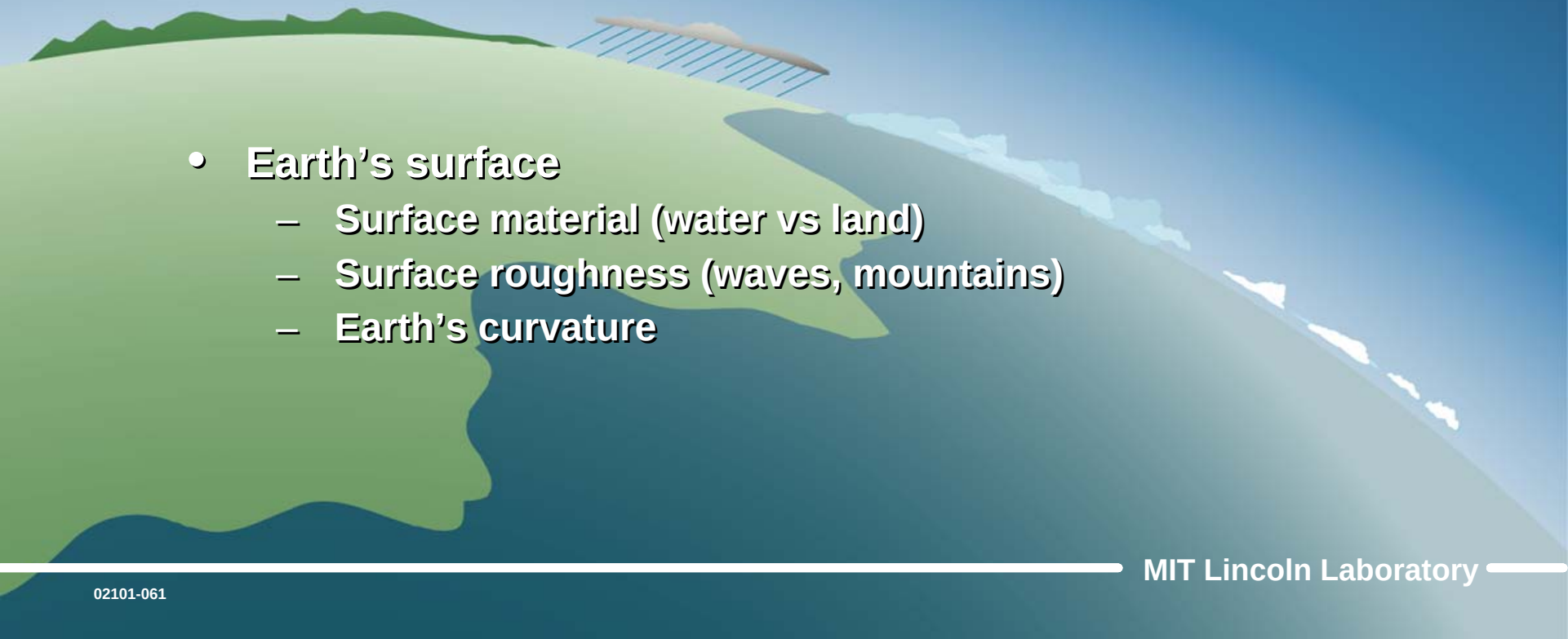
- Atmospheric attenuation
- Reflection off of Earth's surface
- Over-the-horizon diffraction
- Atmospheric refraction



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

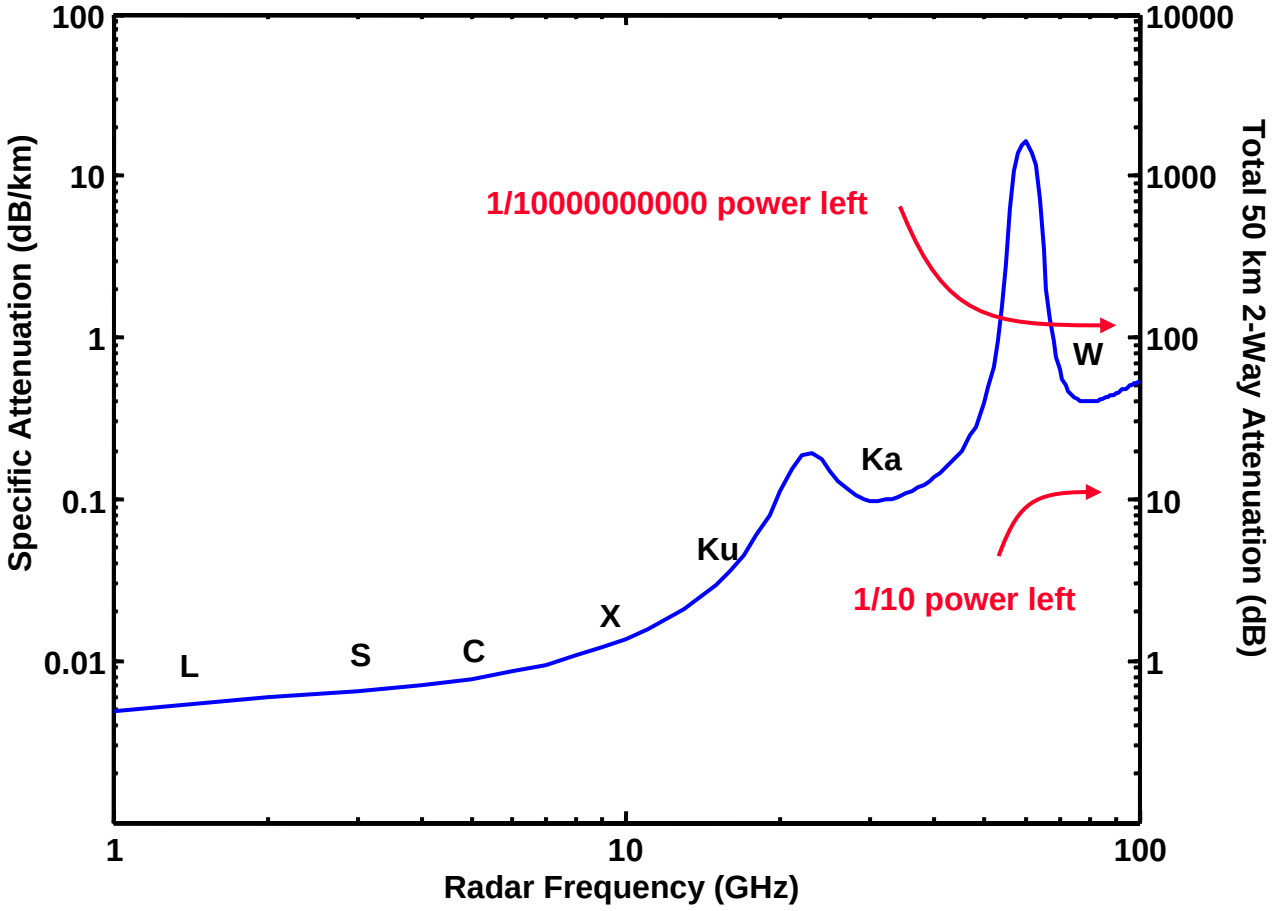
Outline

- **Atmospheric attenuation**
- **Reflection from the Earth's surface**
- **Over-the-horizon diffraction**
- **Atmospheric refraction**

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

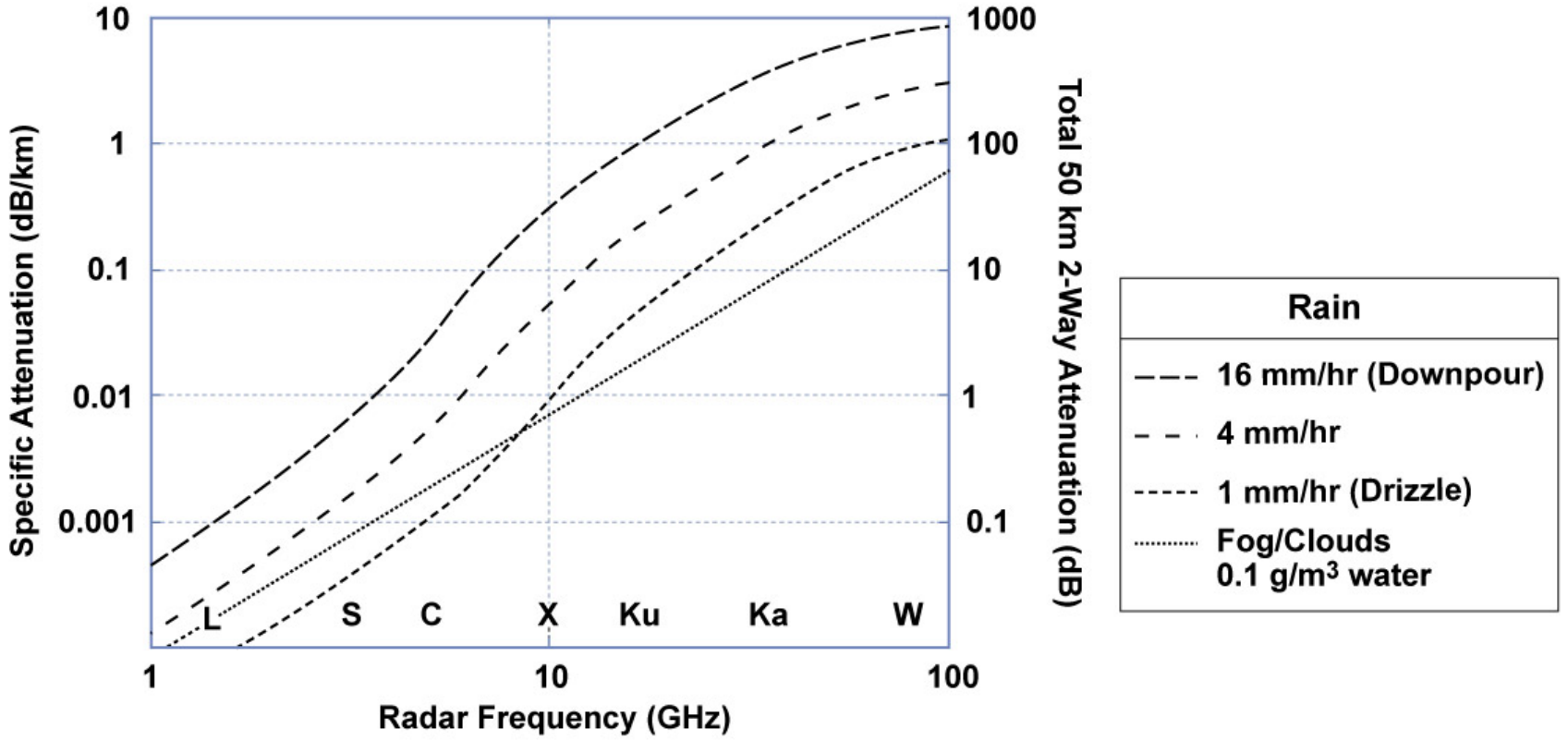


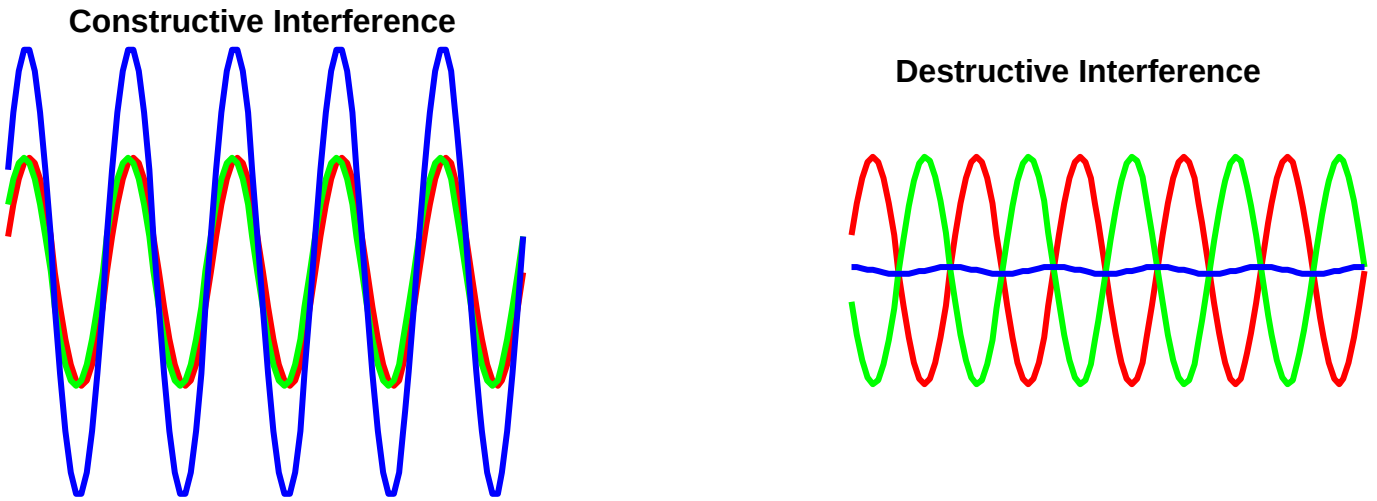
Figure by MIT OCW.

Radar performance at high frequencies is highly weather dependent

Outline

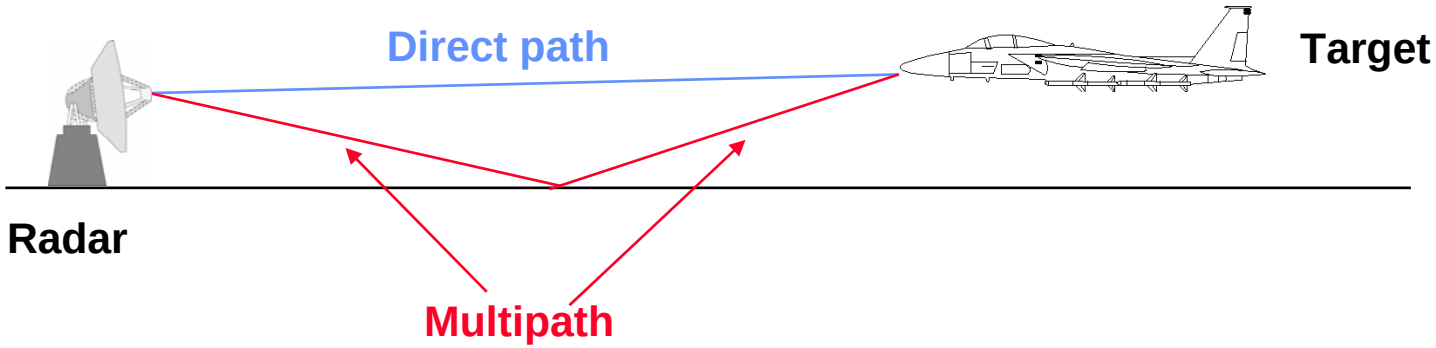
- Atmospheric attenuation
- Reflection from the Earth's surface
- Over-the-horizon diffraction
- Atmospheric refraction

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 (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

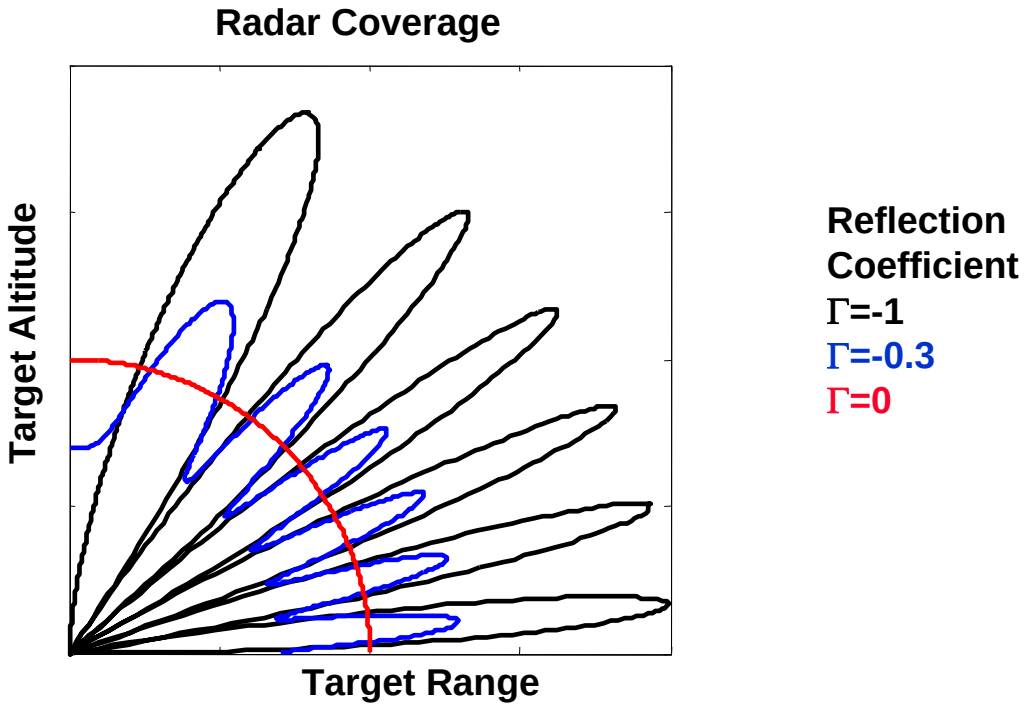
Surface reflection coefficient (Γ) determines relative signal amplitudes

- **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

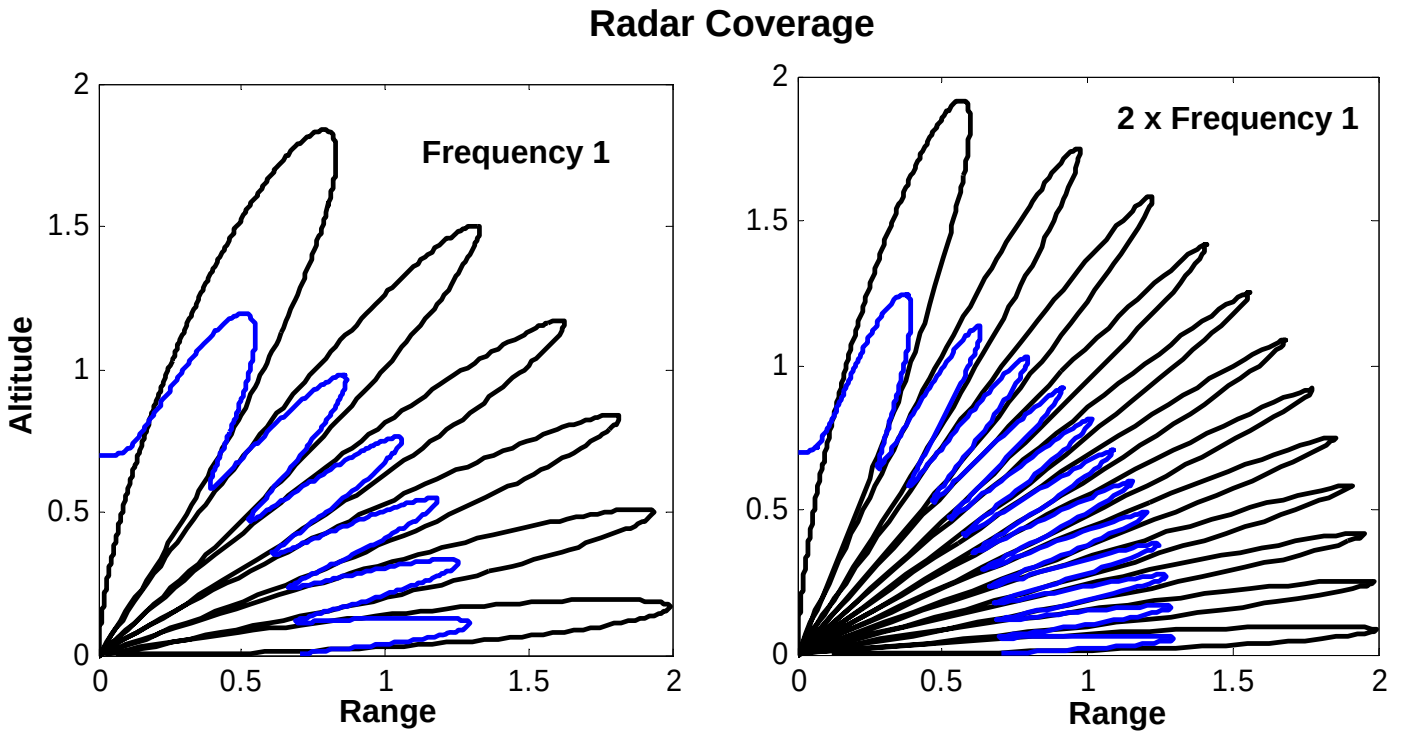
- **Dependent on: height, range and frequency**

Multipath Alters Radar Detection Range



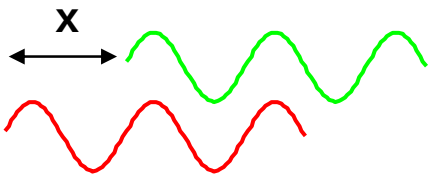
- Multipath causes elevation coverage to be broken up into a lobed structure
- A target located at the maximum of a lobe will be detected as far as twice the free-space detection range
- At other angles the detection range will be less than free space and in a null no echo signal will be received

Multipath is Frequency Dependent

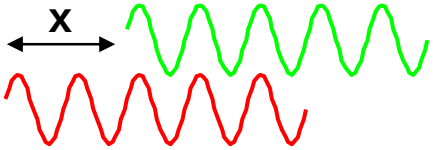


Reflection Coefficient
Γ=-1
Γ=-0.3

1 lobe over distance x :



2 lobes over distance x :



Lobing density increases with increased radar frequency

Outline

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- Reflection from the Earth's surface
- Over-the-horizon diffraction
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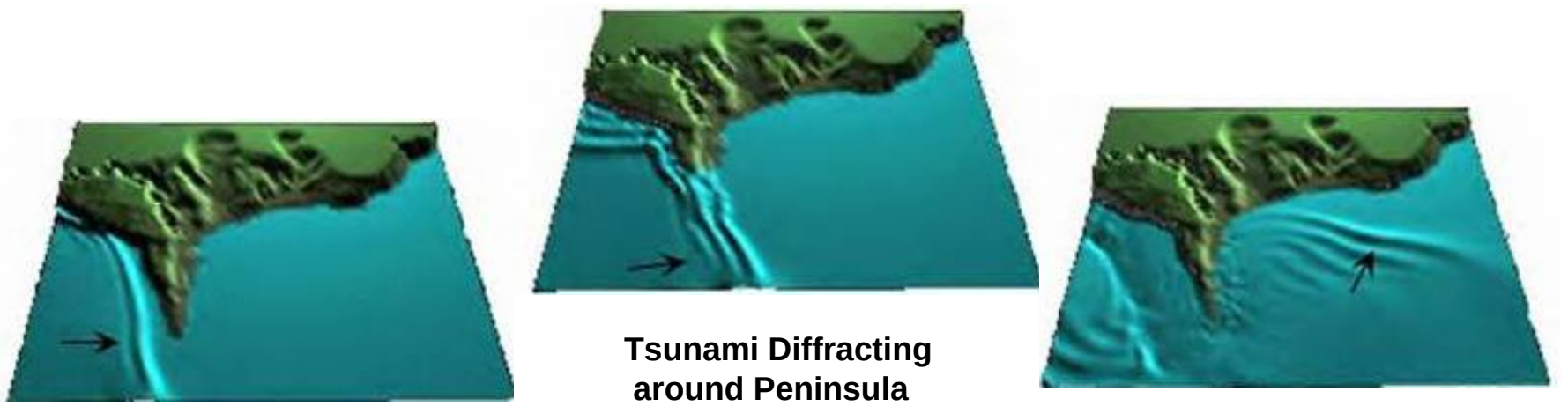
Diffraction

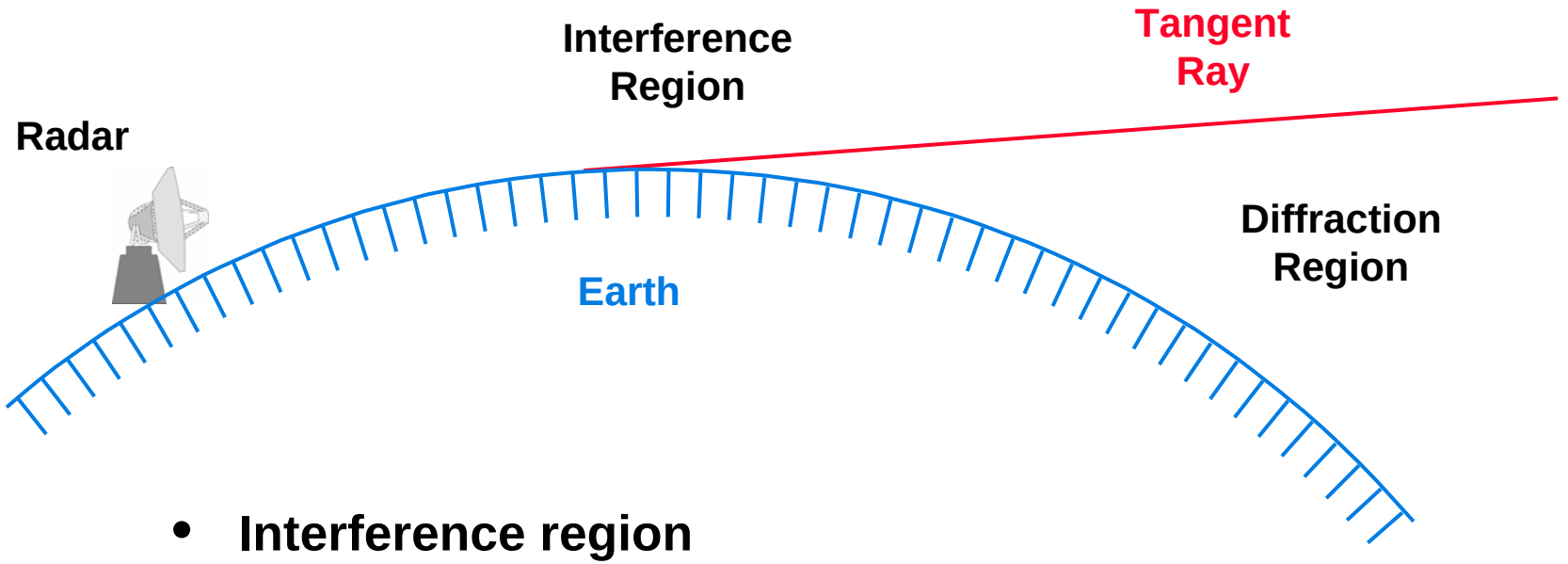


Tsunami Diffracting around Peninsula

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

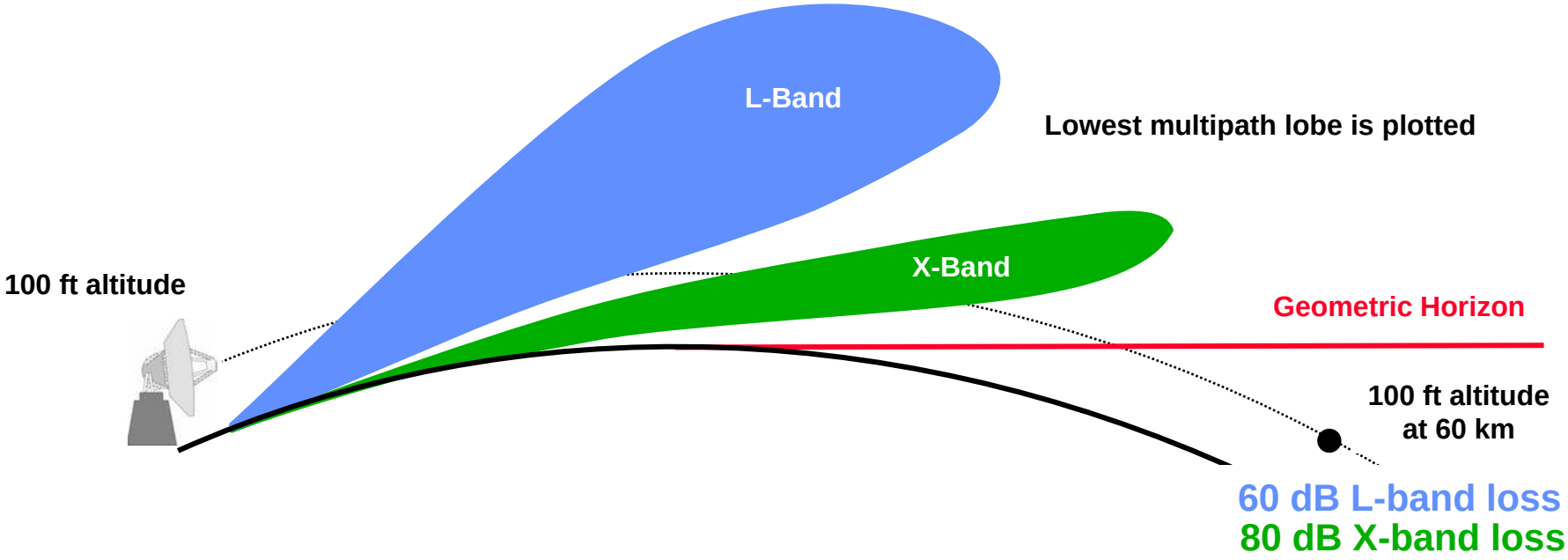
- **Radar waves are diffracted around the curved Earth just as ocean waves are bent by an obstacle**
- **Web references for excellent water wave photographic examples:**
  - **http://upload.wikimedia.org/wikipedia/commons/b/b5/Water_diffraction.jpg**
  - **http://yhspatriot.yorktown.arlington.k12.va.us/~ckaldahl/wave.gif**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

Outline

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Refraction of Radar Beams

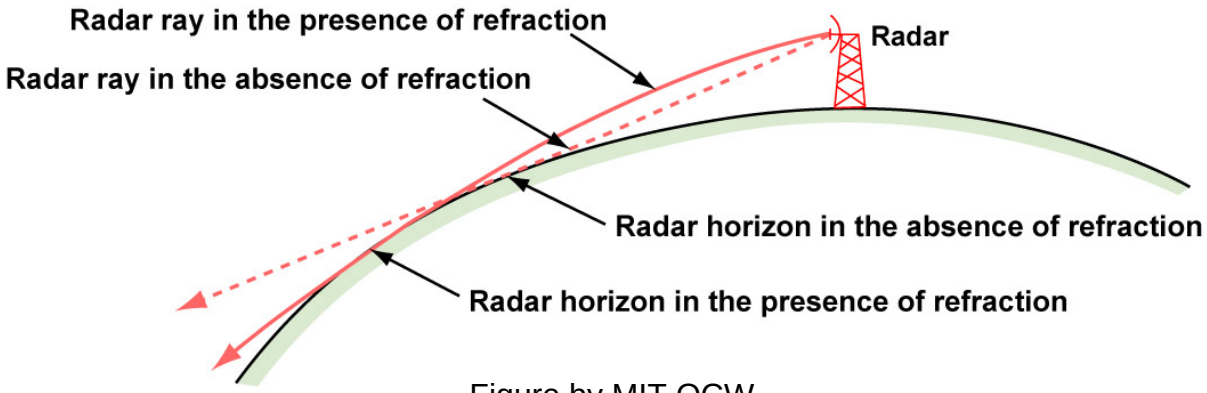
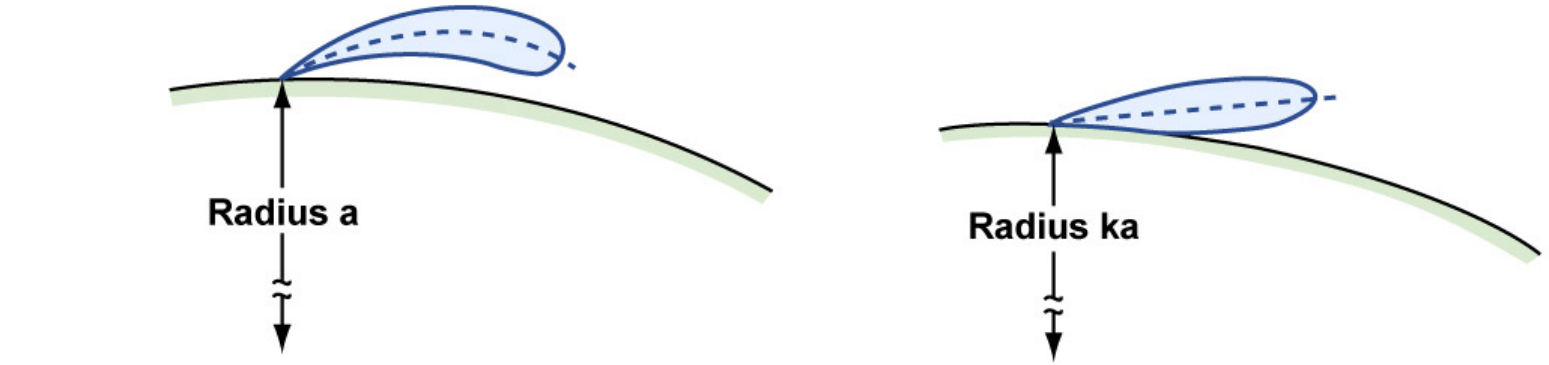


Figure by MIT OCW.

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



Antenna beam bent due to refraction by the Earth's atmosphere

Shape of beam in equivalent Earth representation with radius ka

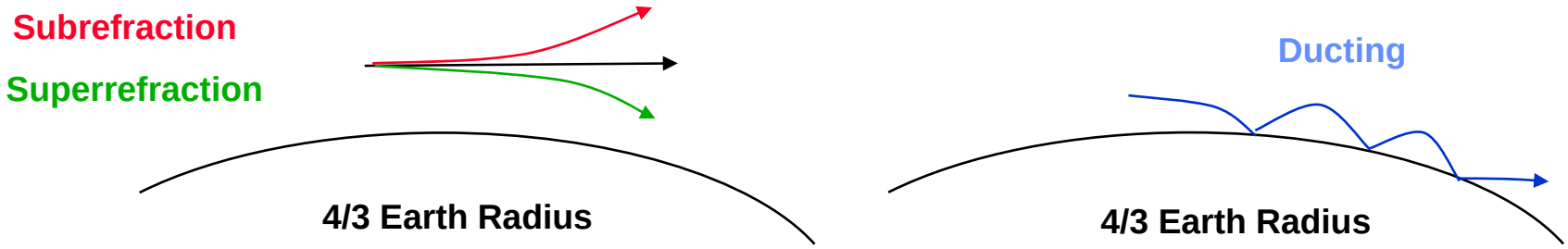
Figure by MIT OCW.

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

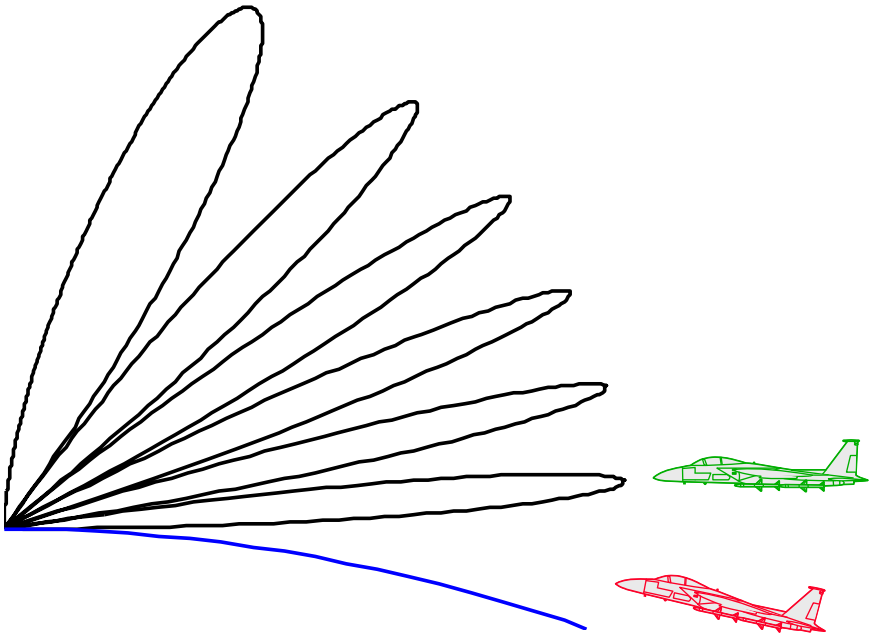
Average propagation is referred to as a "4/3 Earth"

Anomalous Propagation

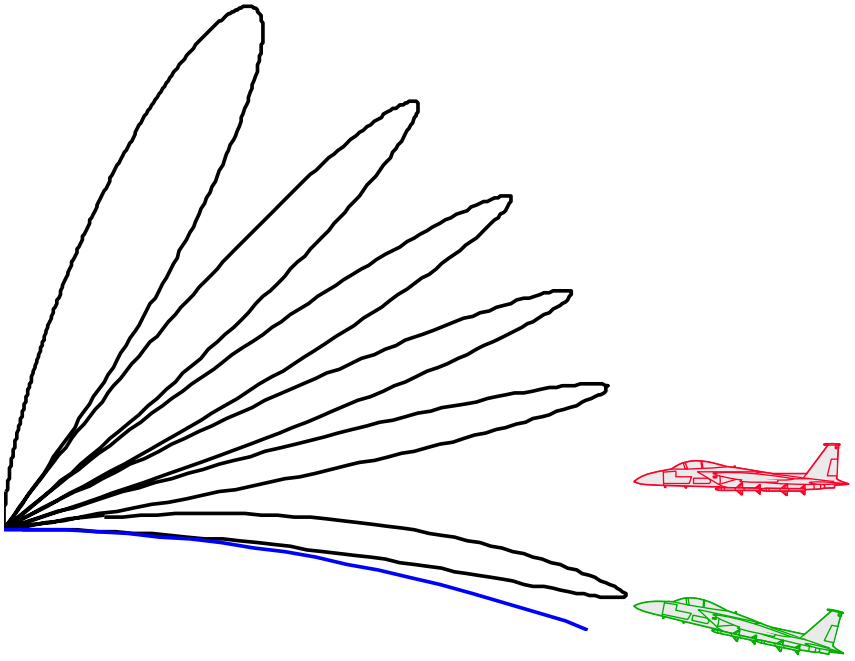


- Occurs when k not equal to 4/3
- Categorized as: superrefraction, subrefraction and ducting
  - Superrefraction extends the radar horizon
  - Subrefraction limits the radar horizon
  - Ducting traps radar energy near the Earth's surface

Ducting Effects on Target Detection



No Surface Duct



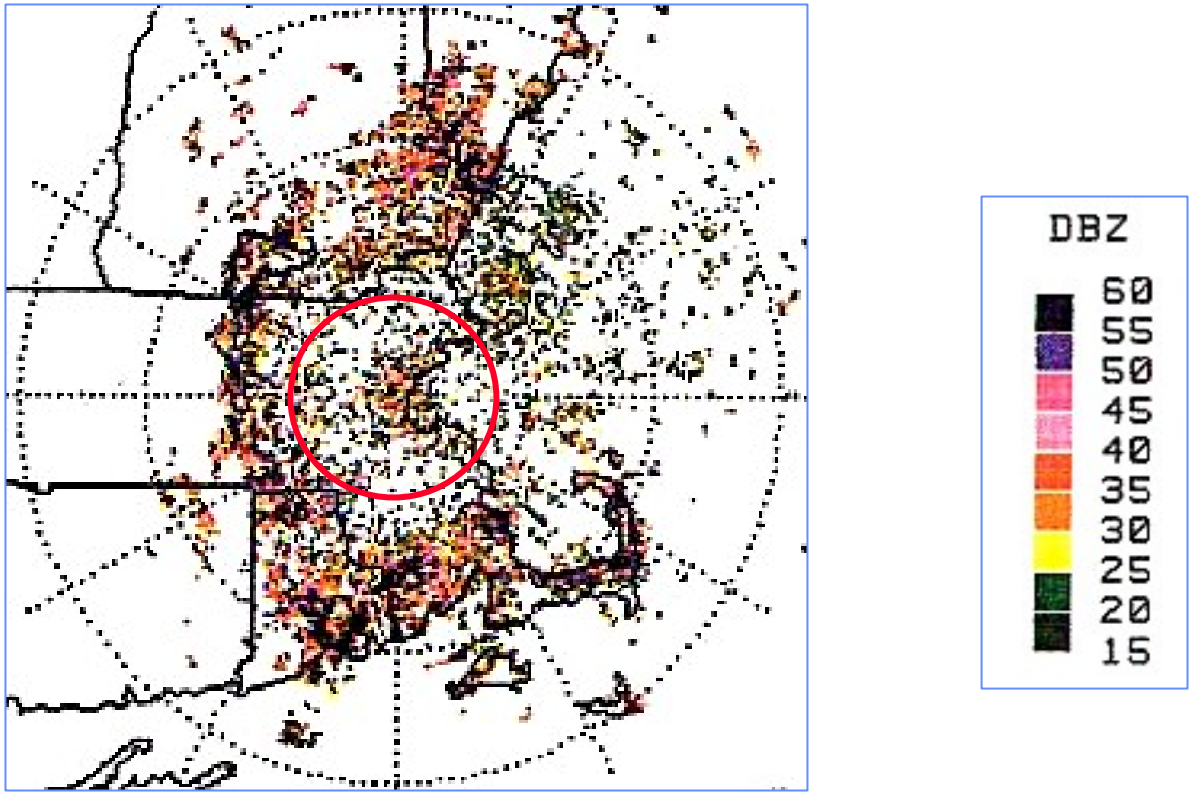
Surface Duct

Target seen
Target not seen

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

Ducted Clutter from New England

PPI Display

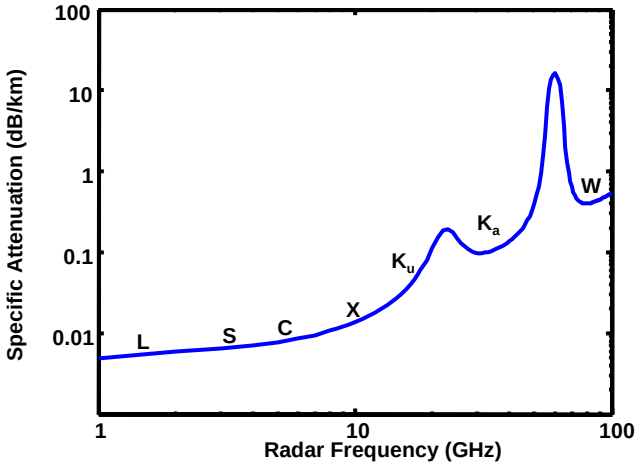


50 km range rings

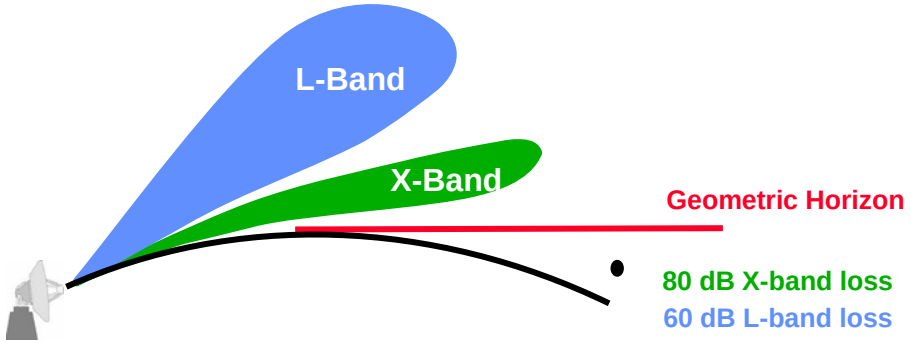
Ducting conditions can extend horizon to extreme ranges

Radar Propagation Effects Summary

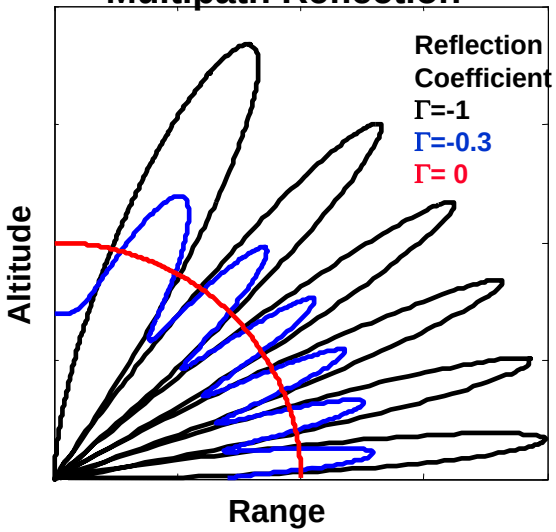
Atmospheric Attenuation



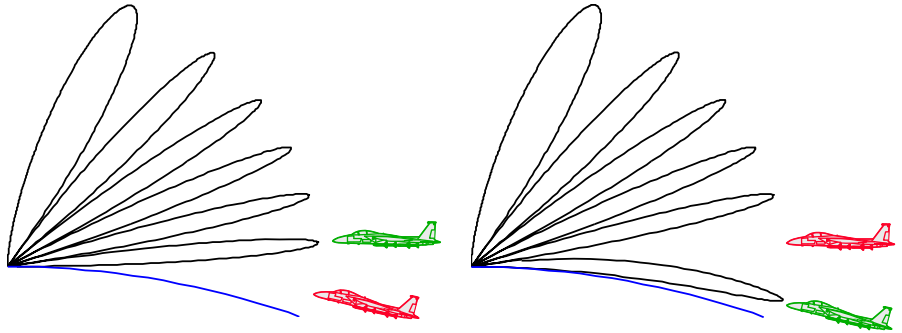
Multipath and Diffraction



Multipath Reflection



Refraction (Ducting)



4/3 Earth Radius

Target seen
Target not seen

References

- Skolnik, M., Introduction to Radar Systems, New York, McGraw-Hill, 3rd Edition, 2001
- Skolnik, M., Radar Handbook, New York, McGraw-Hill, 2rd Edition, 1990