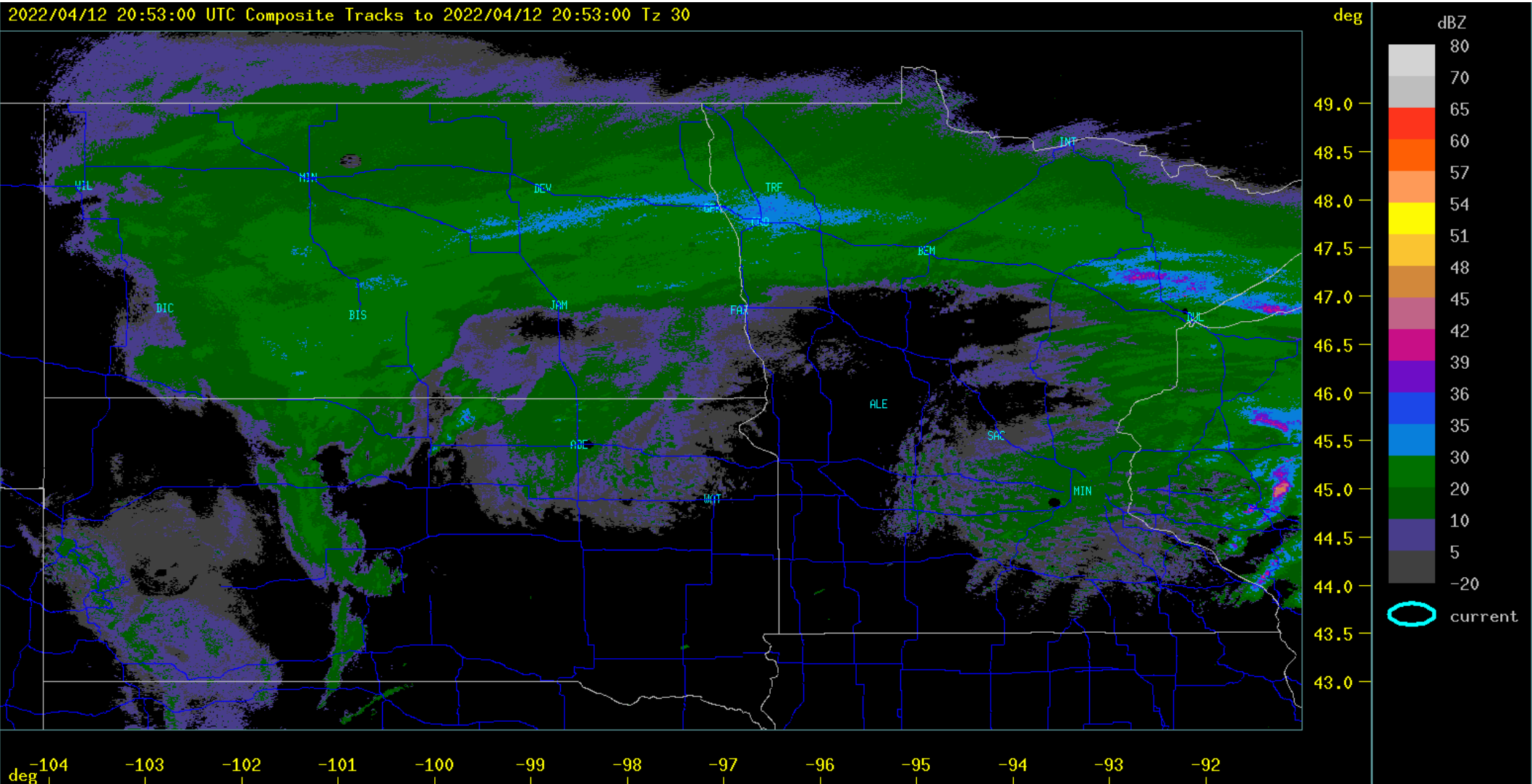
Radar for Weather Modification



Radio Detection And Ranging (RADAR)

- Radar Uses
  - Military
  - Weather
  - Aviation
  - Traffic Control (police)
  - Shipping
  - Research
  - Agriculture

Weather Detection

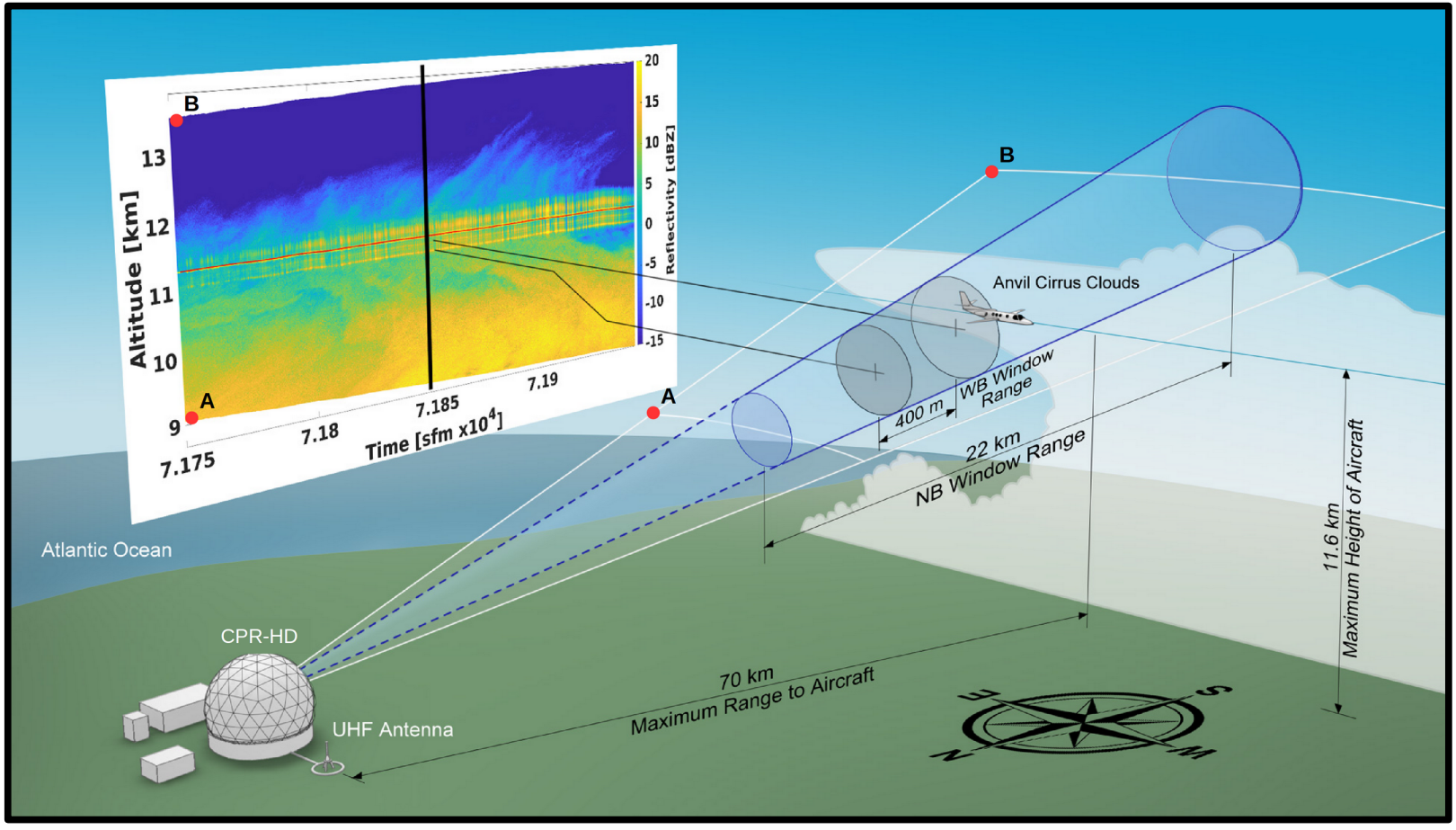
- Precipitation Measurements
- Storm Detection & Tracking
- Snow Detection
- Cloud Detection
- Weather Modification
- Wind Measurements

Pulsed Radars

- Pulsed radars transmit short pulses of energy and wait for returned signals.
- Can detect and resolve individual echoes.
- Most weather and aircraft radars are pulsed radars.

Measurements Conducted with Radar

- Distance
- Position
- Time
- Power
- Velocity



Radar Measurement of **Distance**

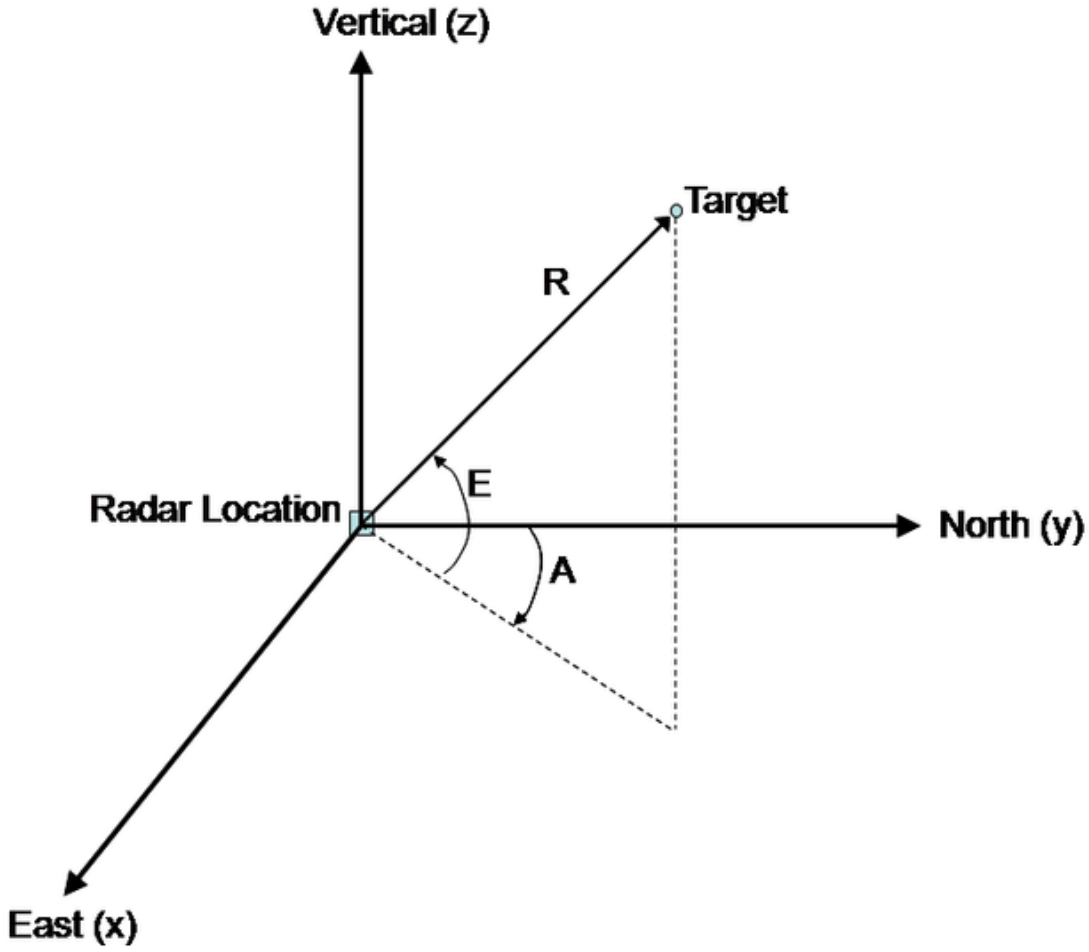
- Range - Radar's Middle Name
- Distance = Rate • Time
- Distance is "Range"
- Rate is speed of light (c)
  - 299,792,458 m/s
  - 6.702 x 10^8 miles/hr

https://www.weather.gov/mkx/using-radar

- Time is what radar measures easily and accuracy

Position Radar Measurement Parameters

- Range (R)
- Azimuth (A)
  - Requires a horizonta scanning antenna.
- Elevation (E)
  - Requires a vertically scanning antenna.



Received **Power** (Echo Strength)

- Used to calculate radar Reflectivity (Z)
- Z is used to estimate Rain Rate (R)

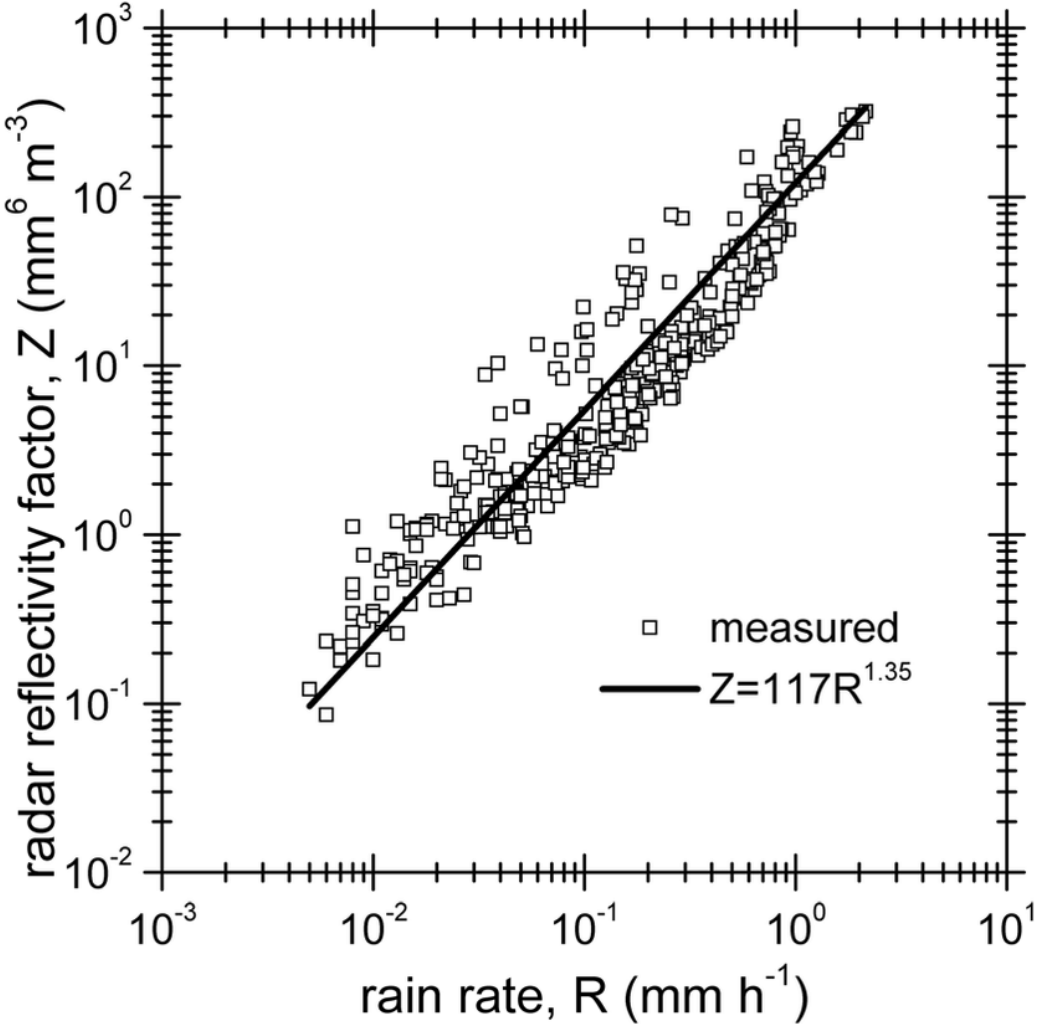
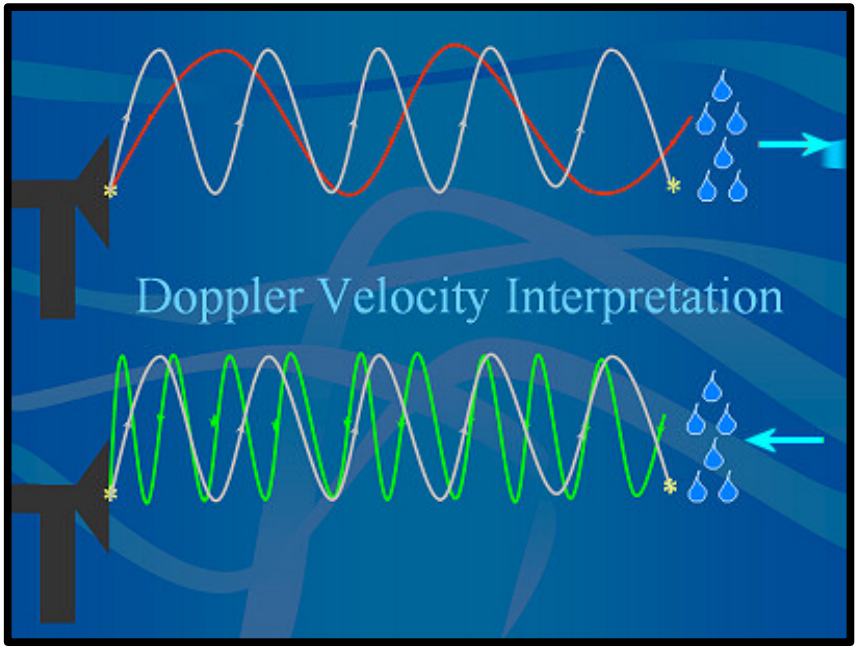


Figure 12 from Baojun Chen, Characteristics of the raindrop size distribution for freezing precipitation observed in Southern China, Journal of Geophysical Research Atmospheres 116(D6), 2011, DOI:10.1029/2010JD015305

Velocity Radar Measurements

- Obtained by tracking echoes and knowing the time between measurements.
- Doppler Shift - Moving targets change the frequency of the returned signal.
- Transmit known frequency and measure the frequency shift of returned signal.

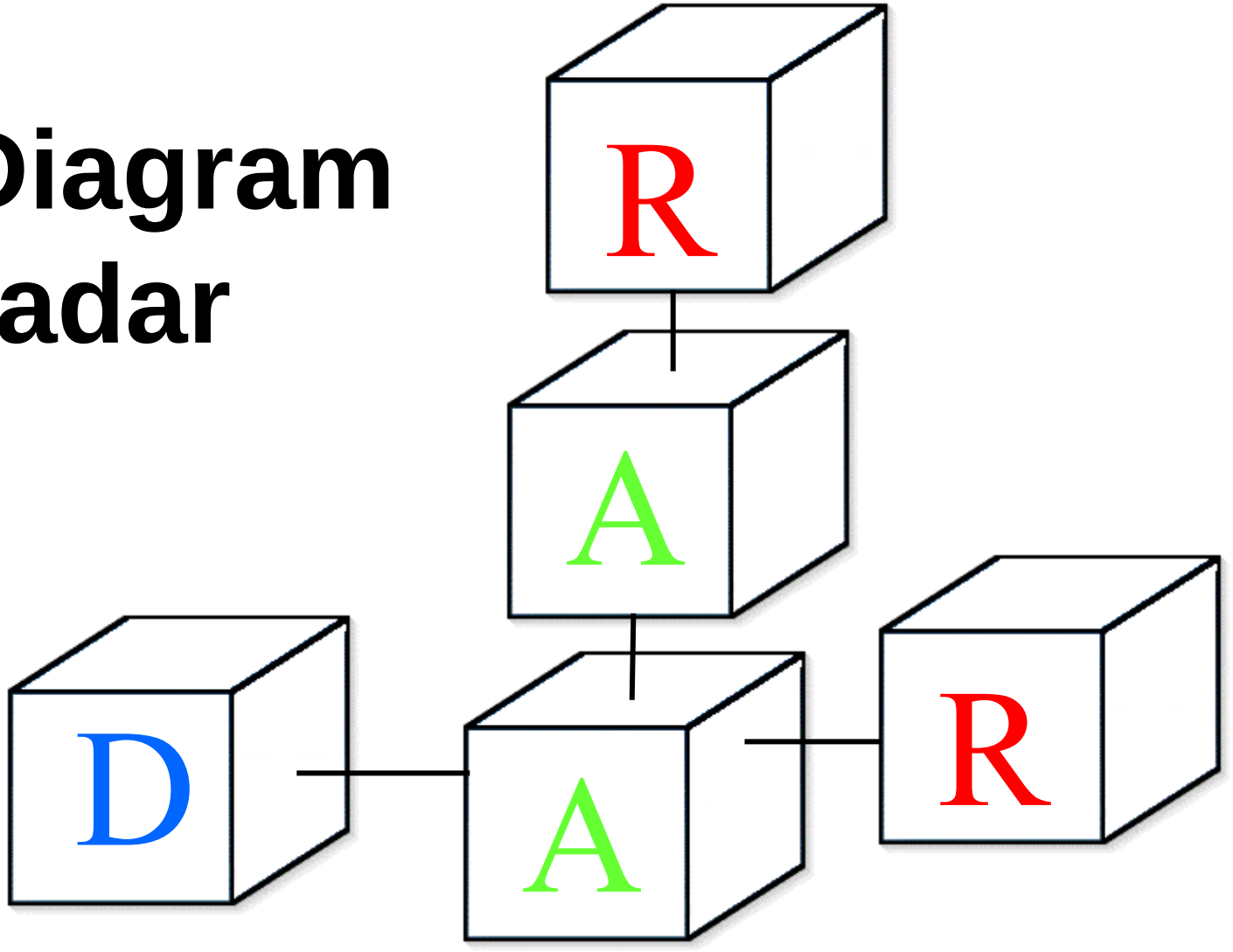


Grey line is the transmitted signal. The returned energy changes its wavelength when it hits a target moving away (red line) or toward the radar (green line) https://www.weather.gov/mkx/using-radar

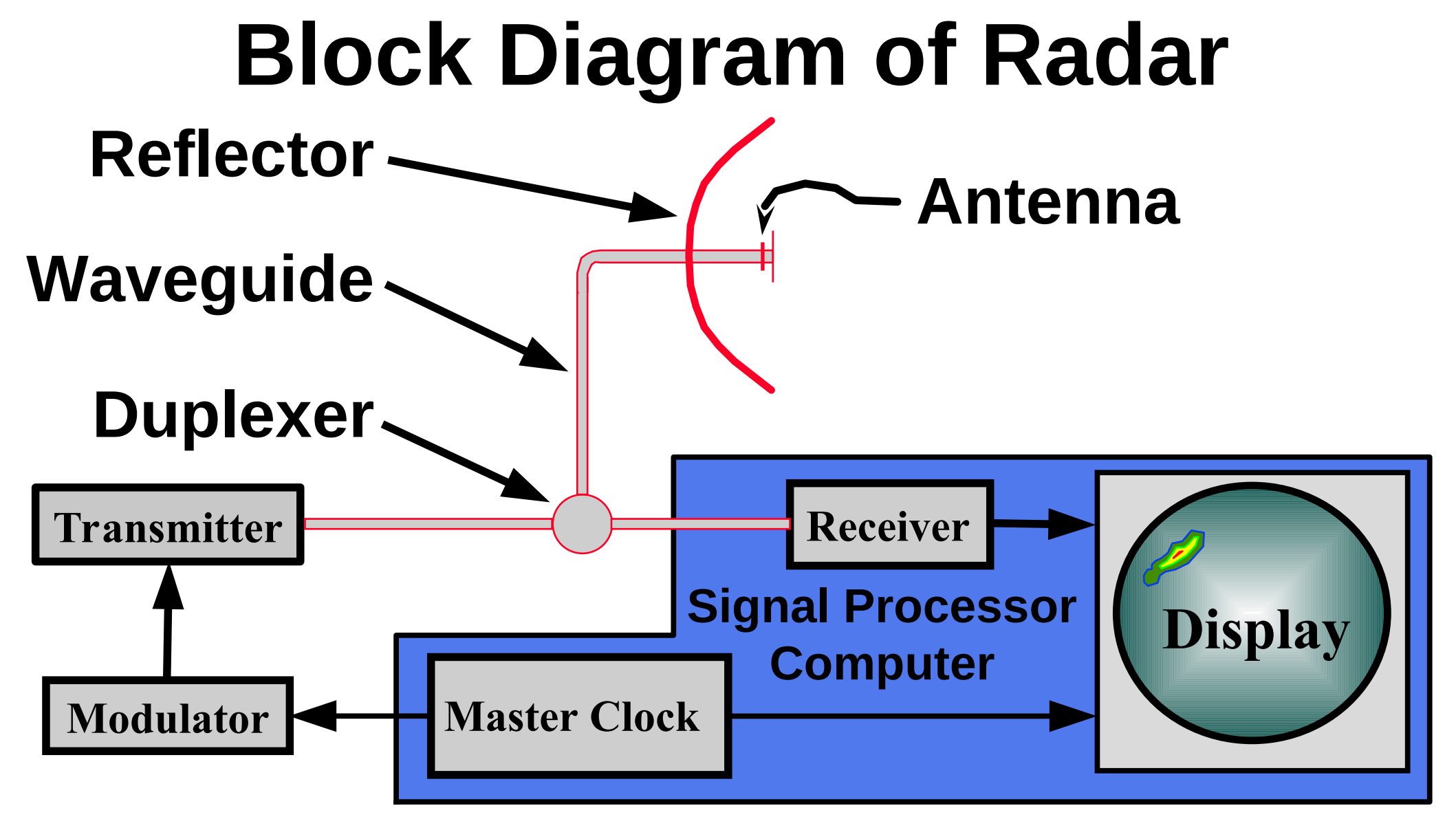
Radar Measurements from Aircraft

- Must be small, light weight and low power.
- Scan ahead of aircraft (±60° or ±90°).
- Limited vertical tilt capability.
- Size dictates use of short wavelength.
  - Short wavelength radar is attenuated!
  - **Cannot always see storms through storms.**
- Used for storm avoidance, not penetration.

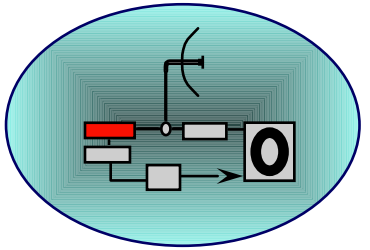
Block Diagram of Radar



Block Diagram of Radar

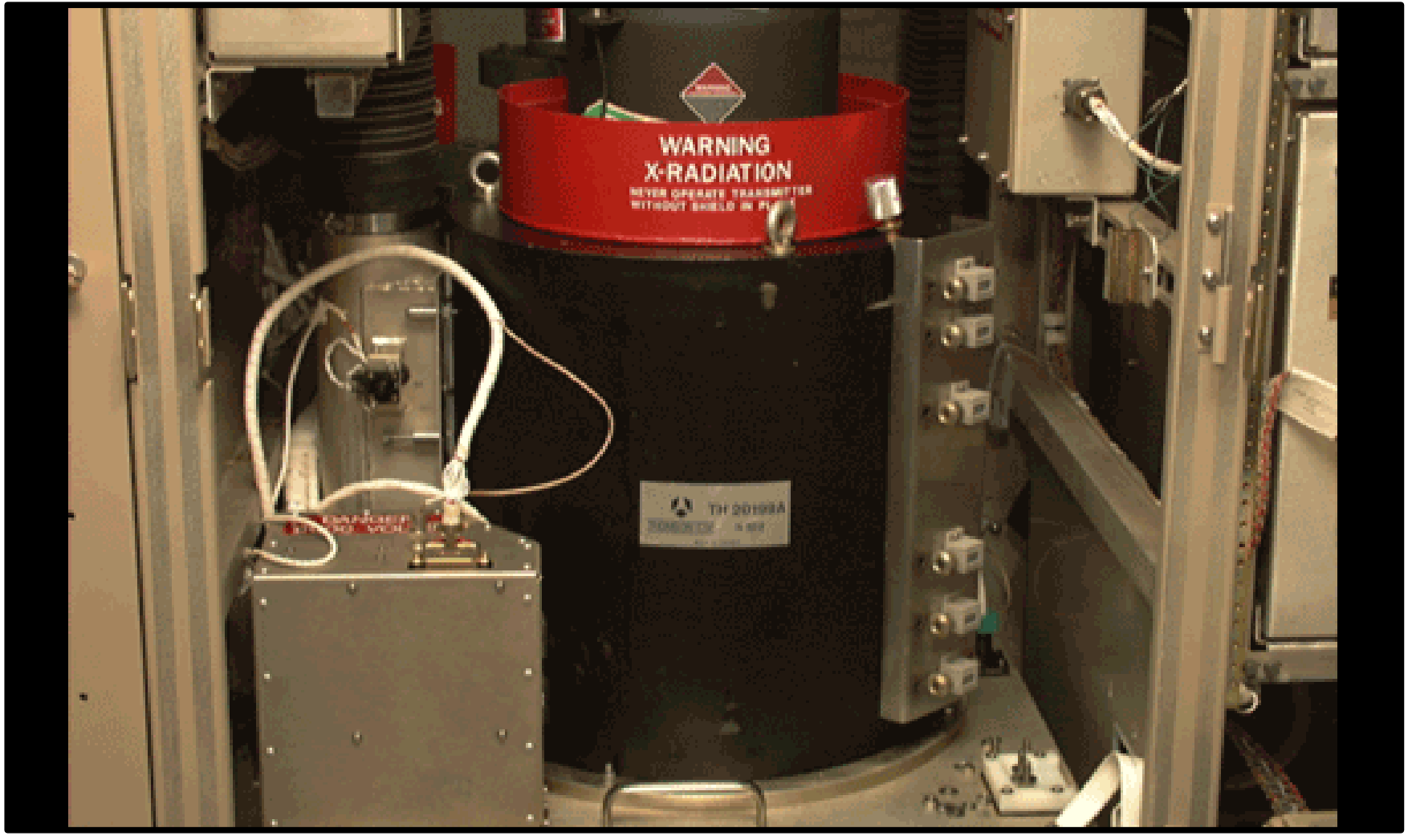


Radar Transmitter



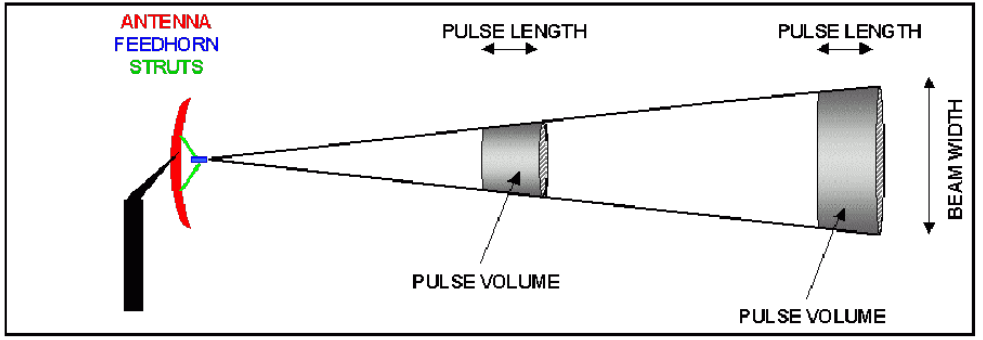
- Generates the microwave signal.
- Transmits a short burst of power at some frequency.
- Typical power from a few watts (W) to a couple of megawatts (mW).
  - UND Radar Transmits 250,000 W or 250 kW.
  - CPR-HD Radar Transmits 3 mW
- Frequency from 30 MHz to 300 GHz
- UND / CPR-HD Radars use 5550 MHz = 5.55 GHz

WSR 88D Radar Transmitter



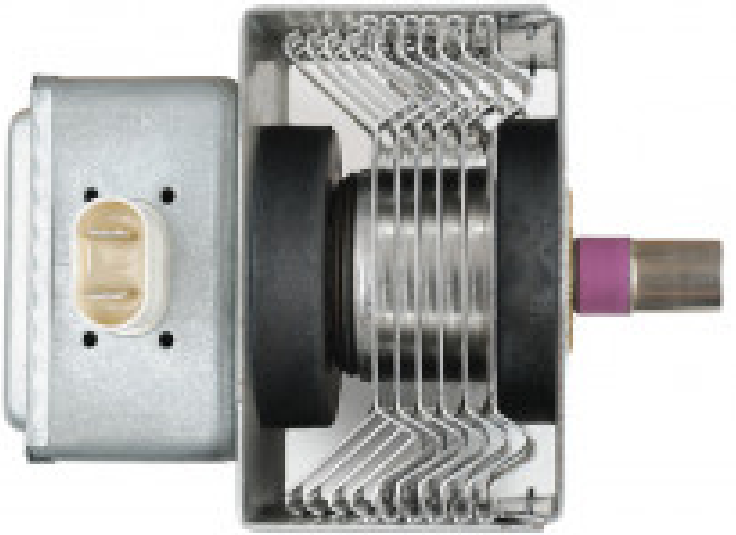
Transmitter Pulse Parameters

- Duration of transmitted pulse is called pulse duration (t) or pulse length (h)
  - Typically 0.25 μs to 10 μs or longer
  - 1 μs = 10^{-6} s (~150 m effective length)
- Transmitted pulse is repeated many times, called pulse repetition frequency (PRF)
- Typically, 150 to 5000 Hz
- UND upper limit - 1200 Hz



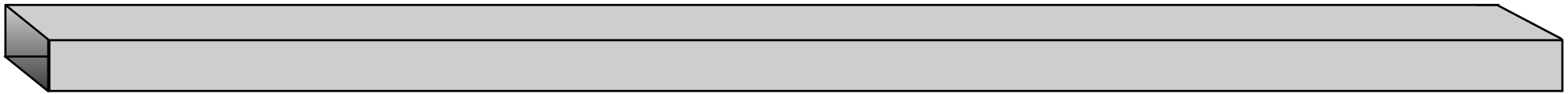
Radar Transmitter Types

- Magnetron
  - Invented in 1939 by the British
  - Generate power up to 250 kW
  - Small and light weight
- Klystrons
  - Generate up to 2 MW
  - Larger/bigger than magnetrons
  - Very stable frequency output
- Solid-state Transmitters



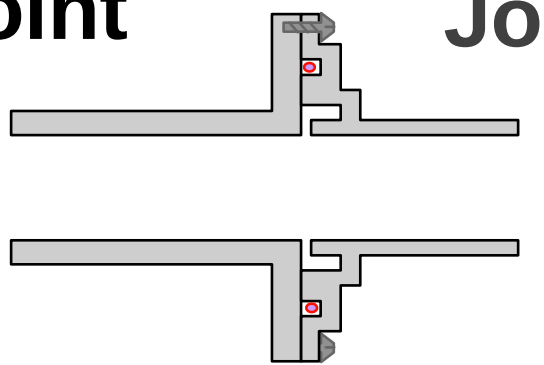
Waveguide for Radar

Rectangular Piece of Hollow Waveguide



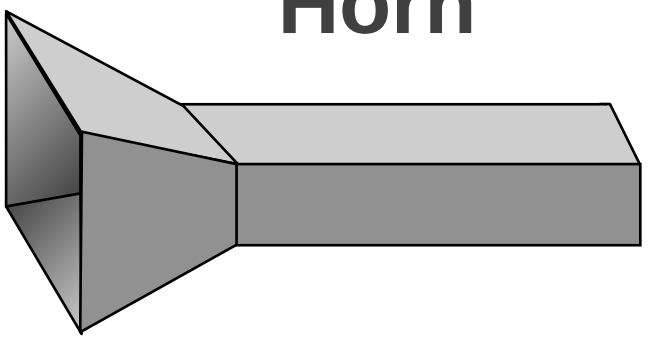
Flange Joint

Choke Joint

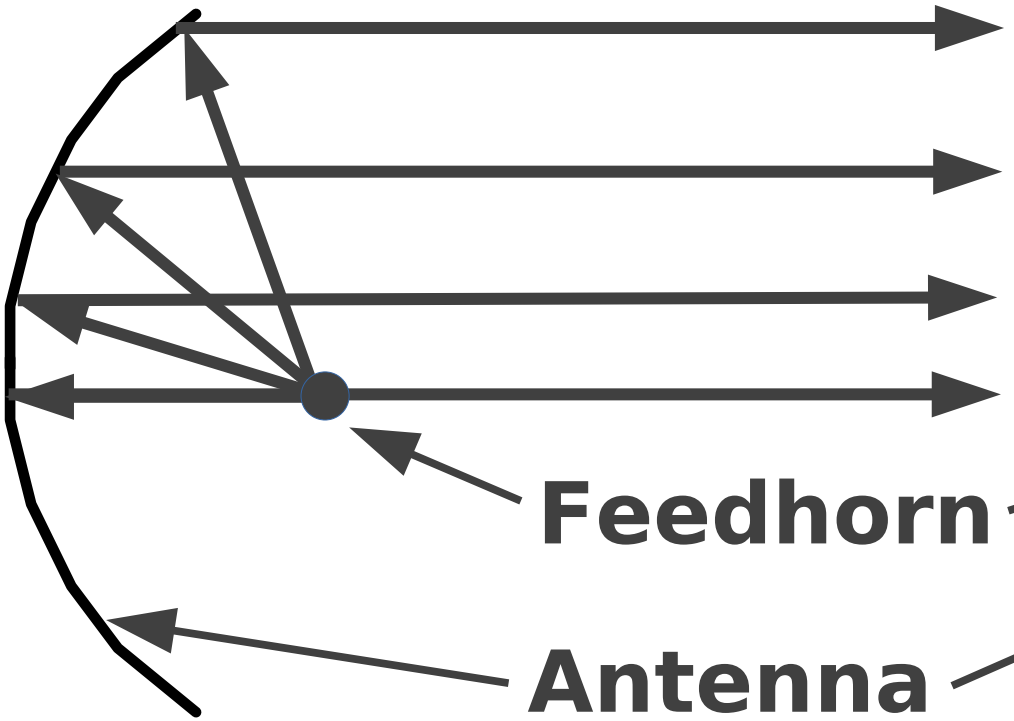


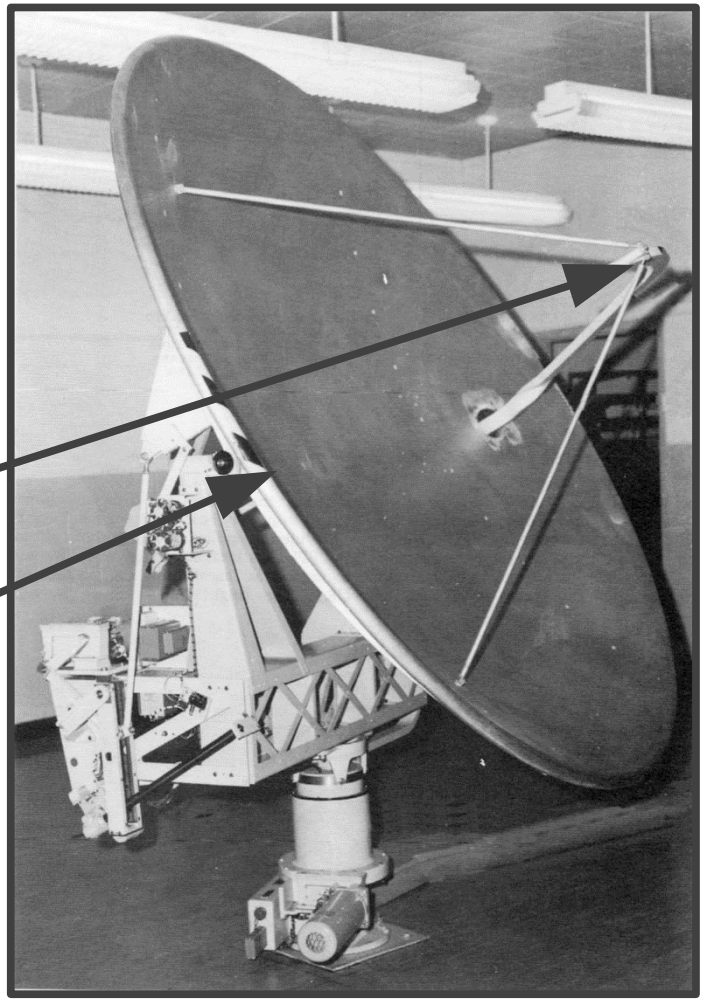
(cross-section)

Horn



Cross-Section of Parabolic Reflector

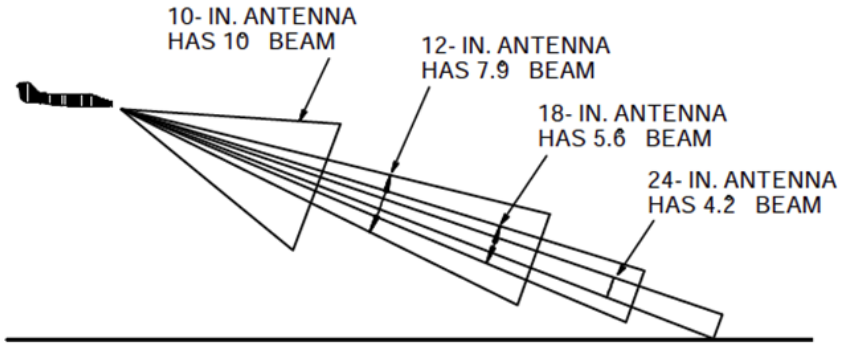




Rays from focus are reflected parallel into space.

Radar Reflector Functions

- Directs signal into space.
  - Focuses it.
- Generally parabolic in shape.



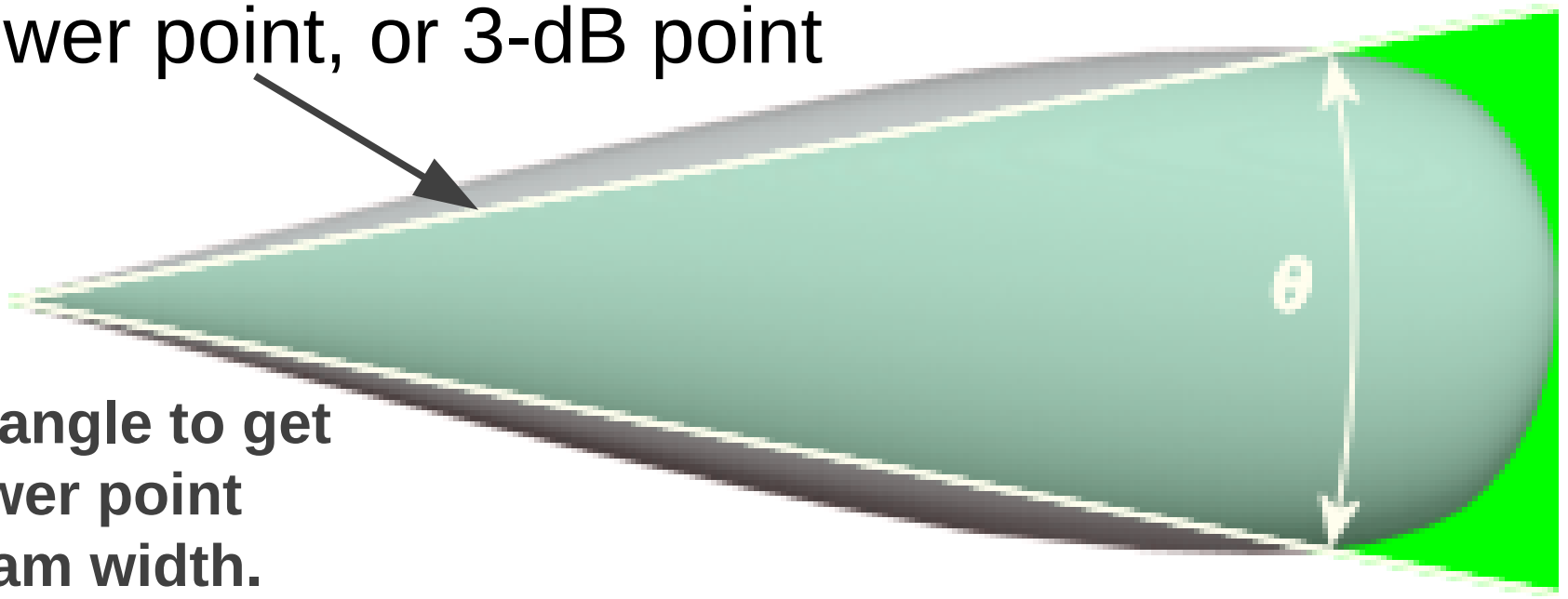
- Larger antennas give smaller beam widths for the same wavelength signal.
- Higher frequencies (shorter wavelengths) require smaller antennas for the same beam width.
  - Aircraft usually use X or C band.
  - Ground-based radars usually use S or C band.

Advantages of using Radar Reflector

- Reflectors focus energy into a particular direction.
- Reflectors make the energy at some point stronger than it would have been otherwise.
- Reflectors allow us to determine direction to a target.

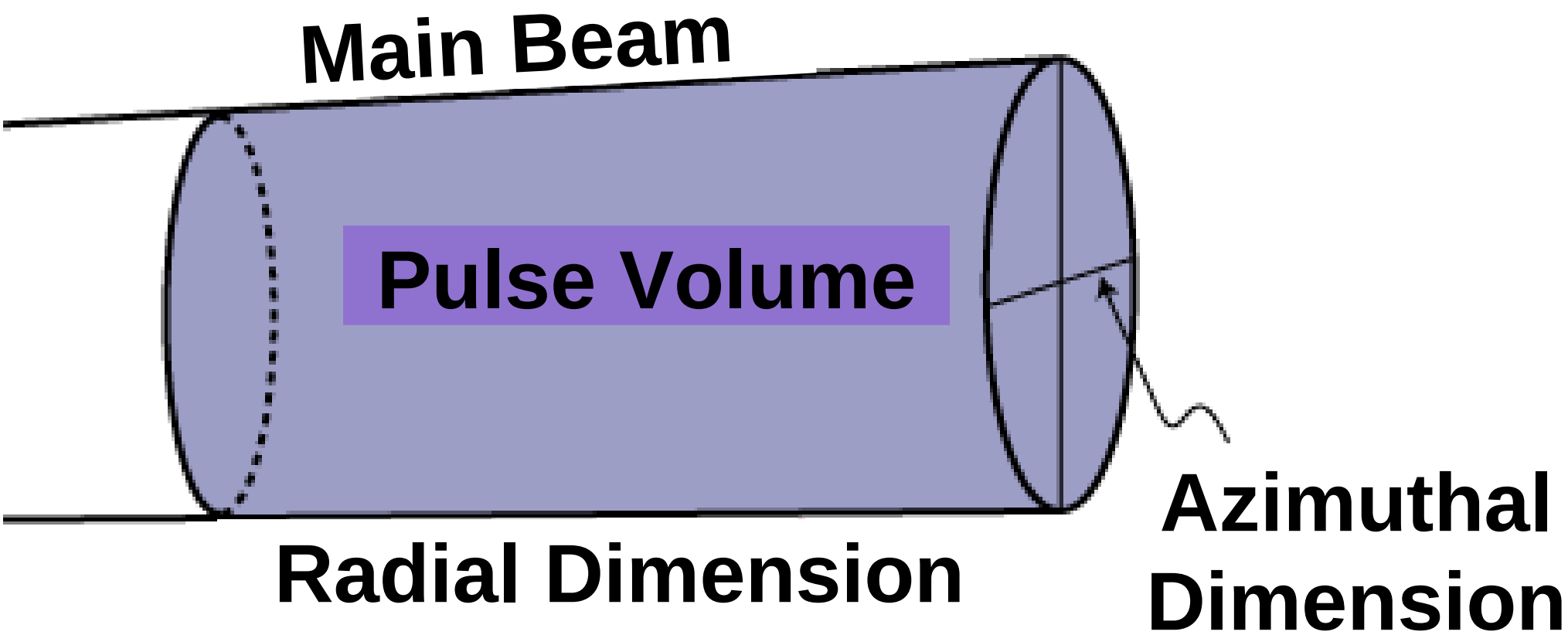
Antenna Beam Width

- The angular width of an antenna pattern.
- The angular width where the power density is one half that on the axis of the beam.
- Half-power point, or 3-dB point



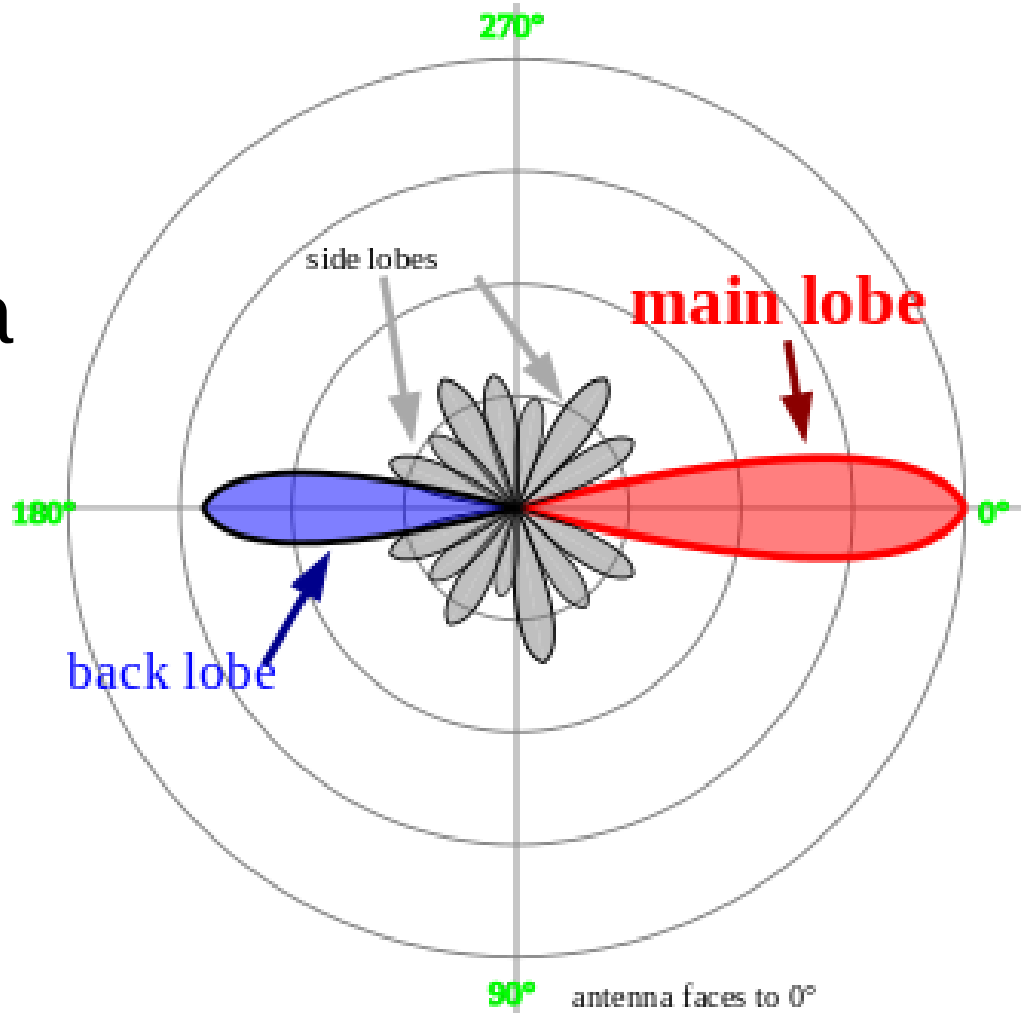
Double the angle to get the half-power point antenna beam width.

Radar Pulse Volume



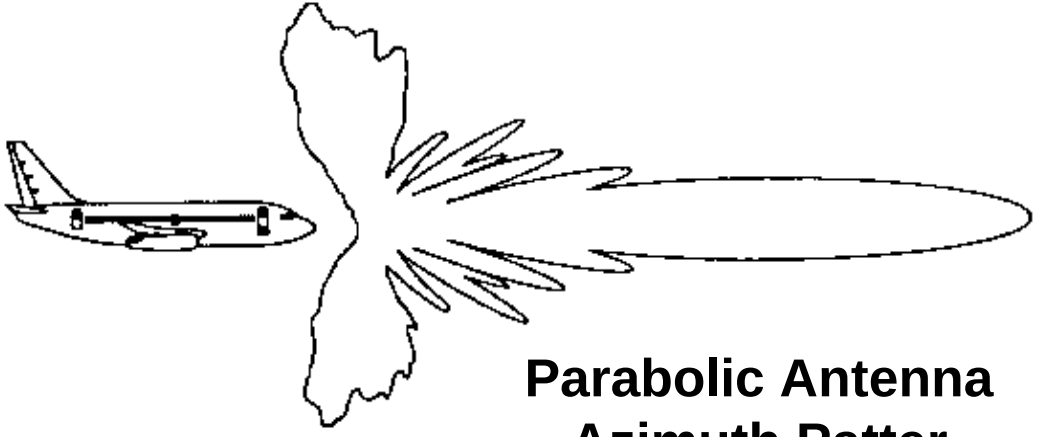
Antenna Sidelobes

- There are no perfect antennas!
- All antennas have antenna patterns which include:
  - Main lobe
  - Side lobes
  - Back lobes

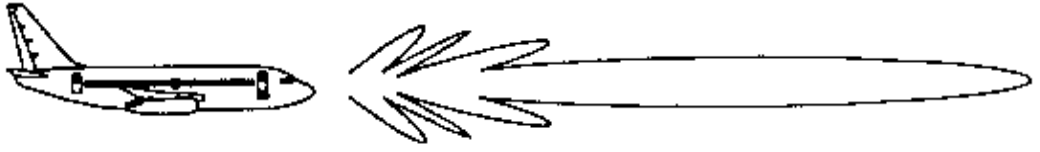


Flat-plate or Phased-array Antenna

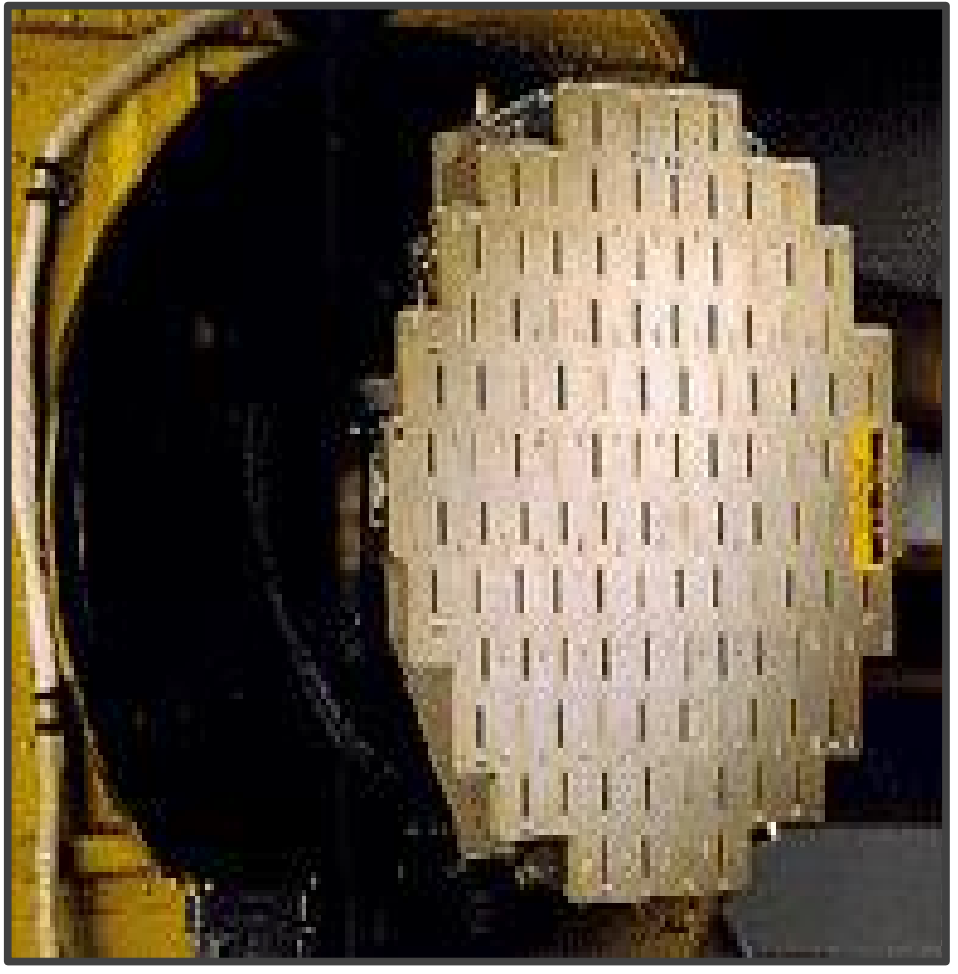
- More focused beam.
- Fewer side lobe losses



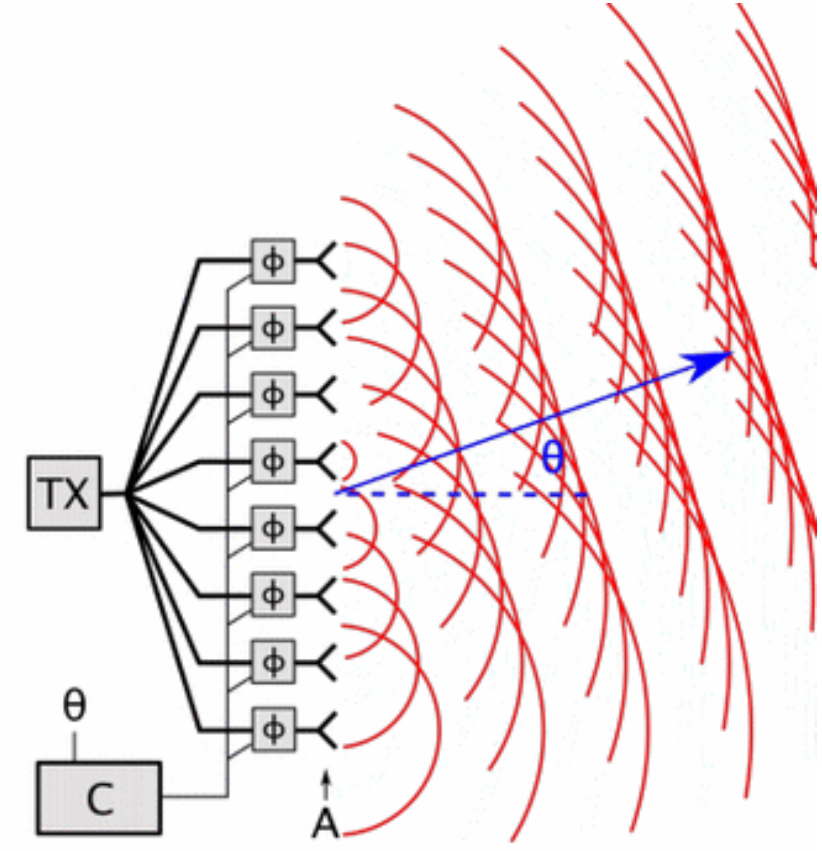
Parabolic Antenna Azimuth Patter



Flat-plate Antenna Azimuth Patter



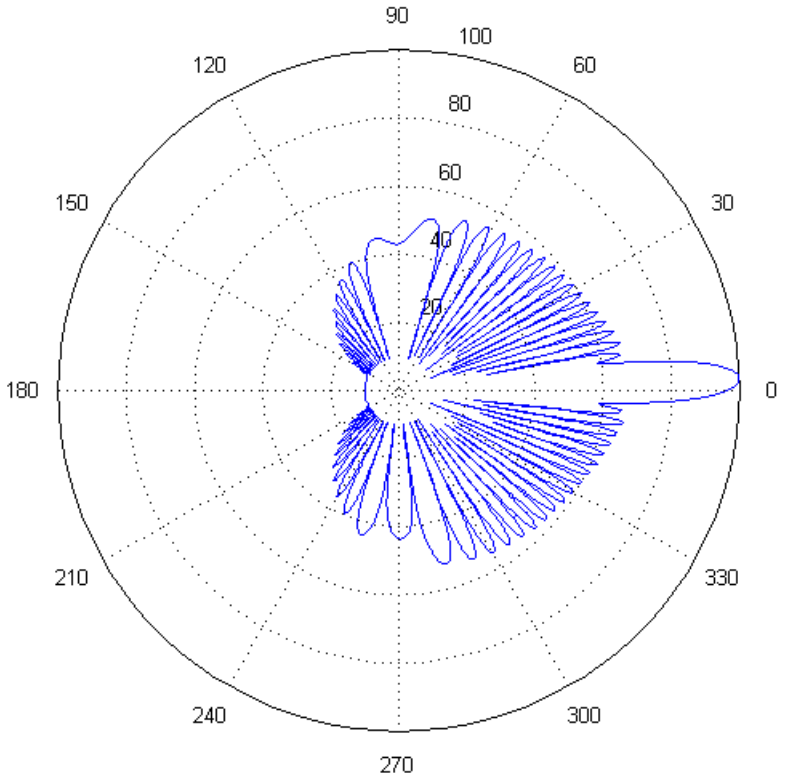
Principles of Phased Array



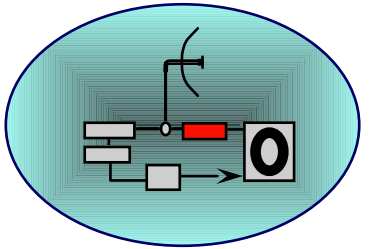
https://en.wikipedia.org/wiki/Phased_array

Sidelobes During Electronic Scanning

- Phased-array Scanning.
- There are higher-order main lobes when scan is performed wide range.



Radar Receivers

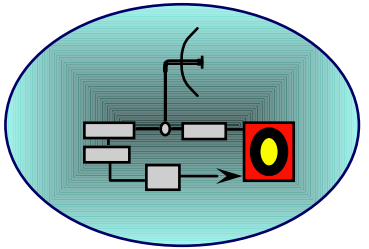


- Detect and amplify the tiny signal received by the antenna
- Must be very sensitive.
  - Typically, radar receivers can detect powers of 0.000 000 000 000 02 W.
    - This power is more conveniently expressed logarithmically as -107 dBm.
    - P (dBm) = $10*\log_{10}$(P (linear power)/1 mW)

Radar Receivers Operations

- Operate initially at radio frequencies (RF) using low-noise amplifiers.
- Signal converted to intermediate frequencies for easier amplification (IF amplifier).
- Output is a voltage.

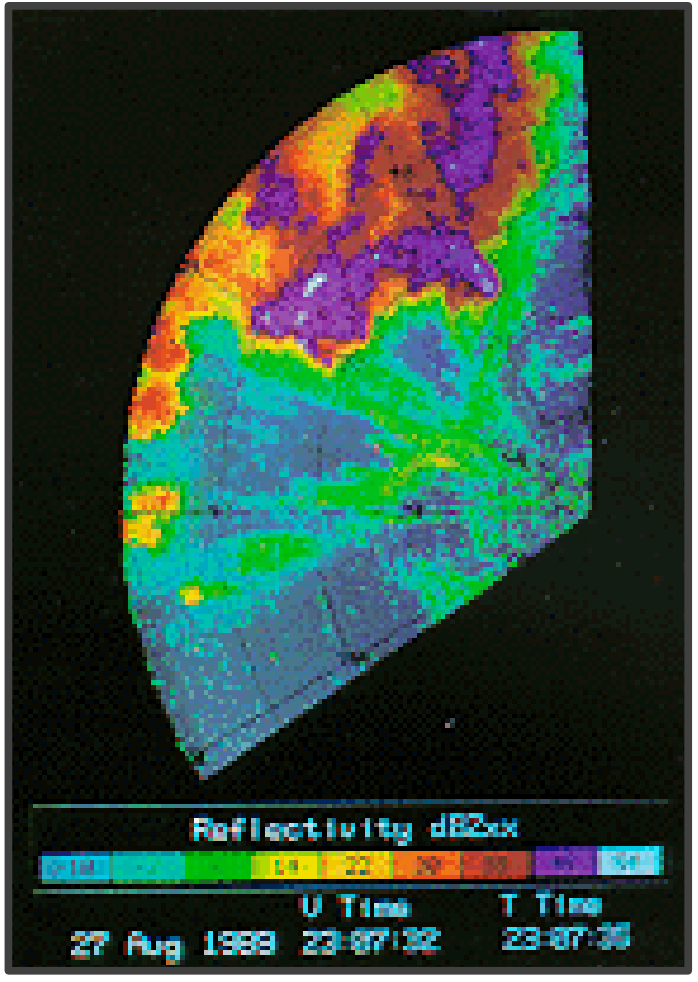
A-scope Radar Displays



- The original radar display, an oscilloscope.
- Time is x-axis, voltage or power is y axis.
- Each pulse is shown individually.

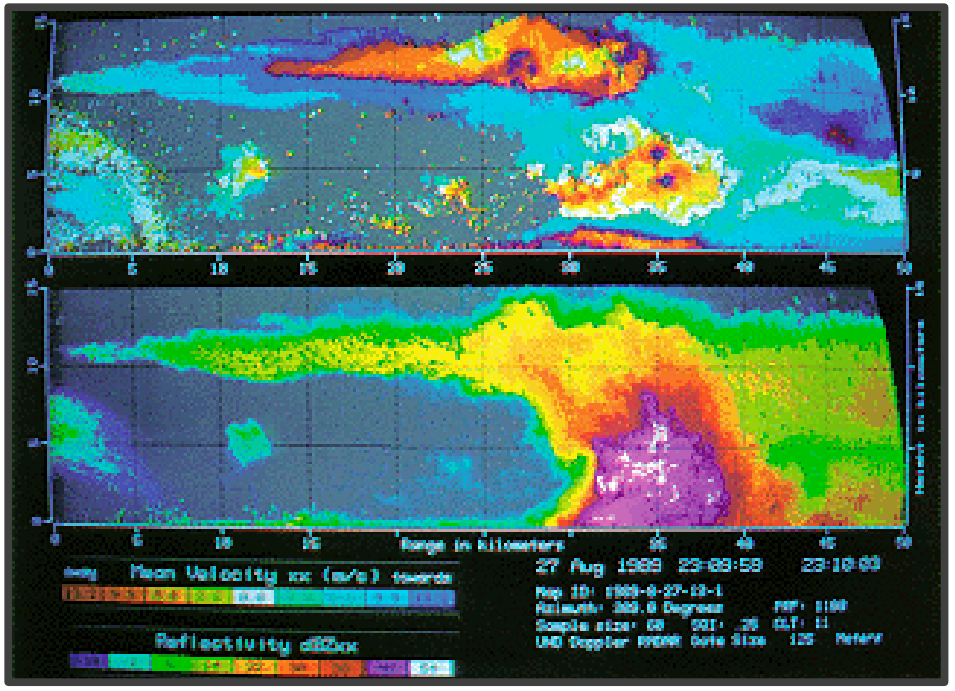
Plan Position Indicator (PPI) Displays

- Map-like display with radar (usually) at center, north to top, east to right.
- Range rings give distance.
- Intensity shown by brightness (monochrome displays) or color (modern displays).



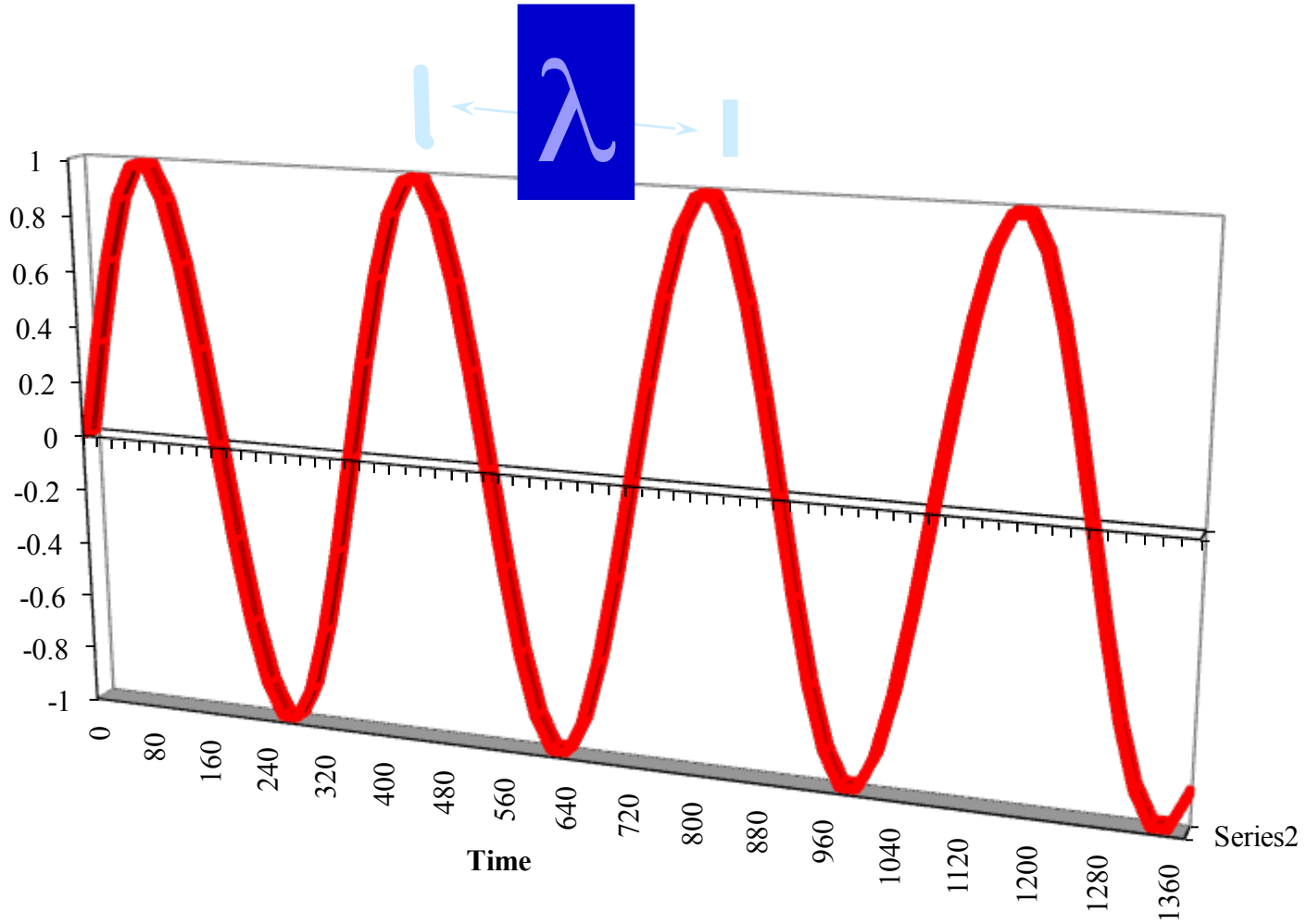
Range-height Indicator (RHI) Displays

- Shows a vertical profile along a particular direction (azimuth).
- Scans up and down.
- Display shows range in x direction and height in y direction.
- Intensity shown by brightness or color.

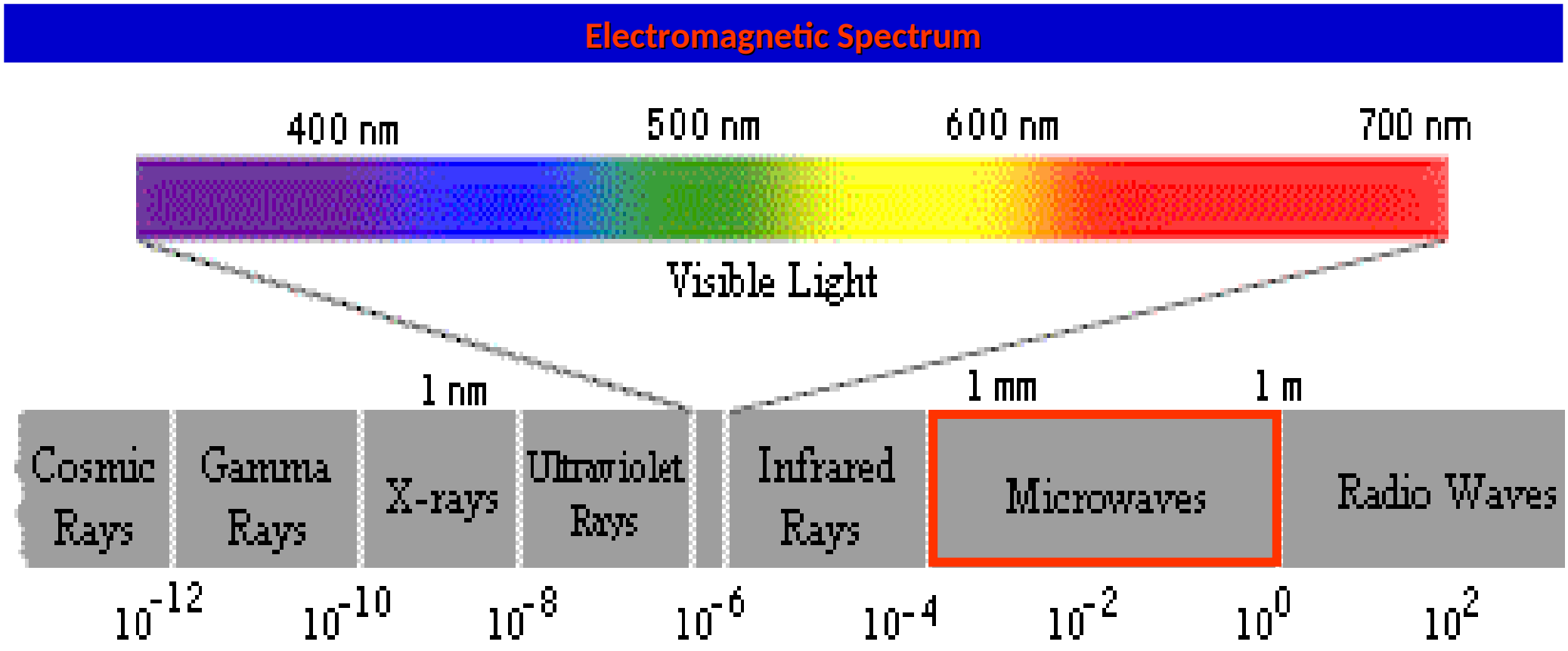


Electromagnetic Radiation Characteristics

- Wavelength
- Frequency
- Amplitude
- Polarization



Radars Transmits at Microwave Wavelengths



Radar Wavelength Band Types

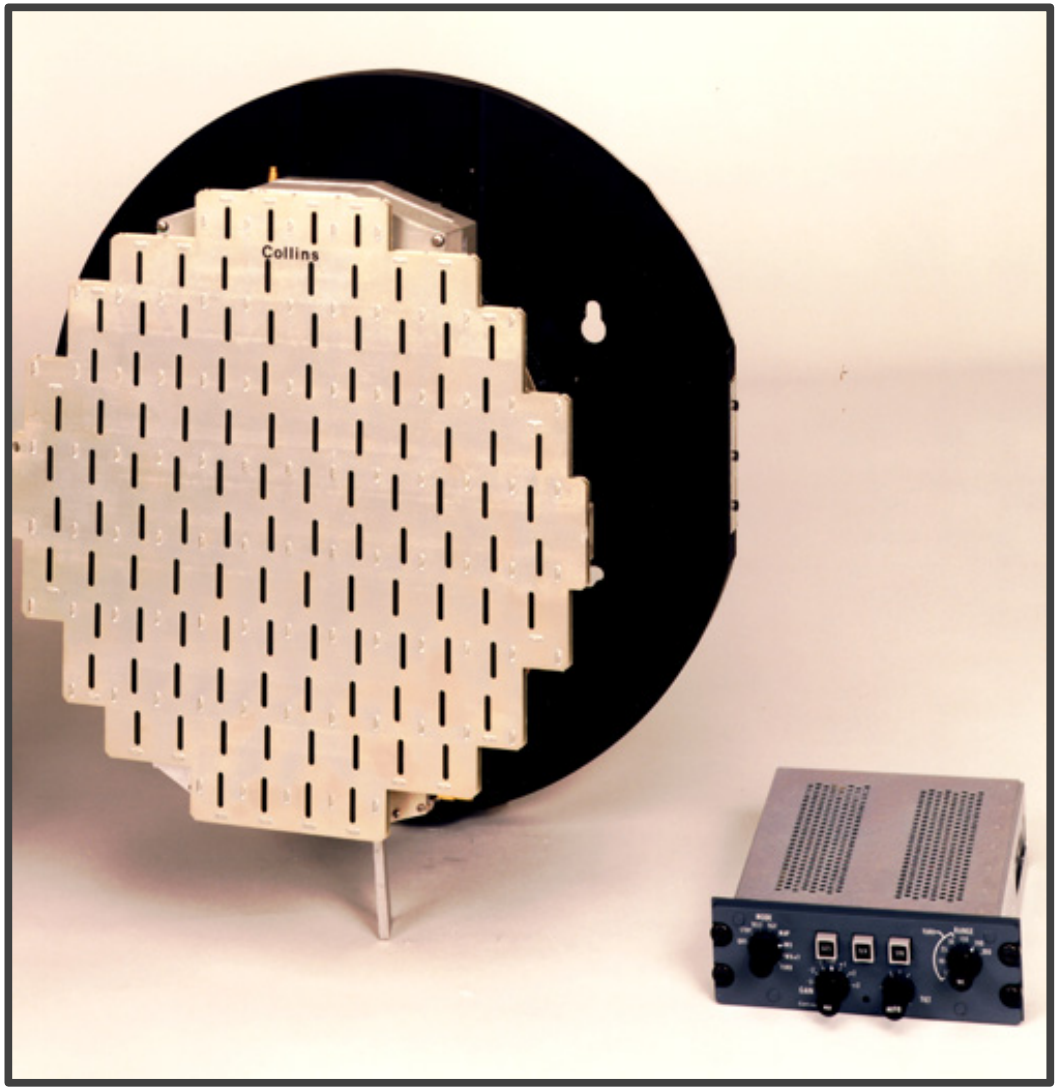
Band Designation	Frequency	Wavelength
HF	3-30 MHz	100-10 m
VHF	30-300 MHz	10-1 m
UHF	300-1000 MHz	1-0.3 m
L	**1-2 GHz**	**30-15 cm (20 cm)**
S	**2-4 GHz**	**15-8 cm (10 cm)**
C	**4-8 GHz**	**8-4 cm (5 cm)**
X	**8-12 GHz**	**4-2.5 cm (3 cm)**
K_u	12-18 GHz	2.5-1.7 cm
K	18-27 GHz	1.7-1.2 cm
K_a	27-40 GHz	1.2-0.75 cm

S and C Band Radar (10 / 5 cm)

- Ground Based Weather Radar
- WSR-88D or TDWR

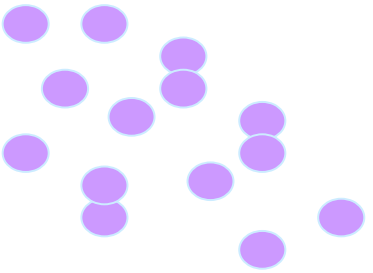
X Band Radar (3 cm)

- Airborne Weather Radar

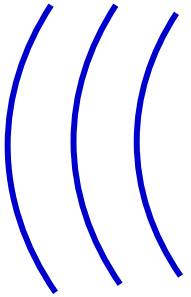


Radar Terminology

- Target
  - Object (or group of objects) that reflect radar energy.
- Echo
  - Reflected radar energy.



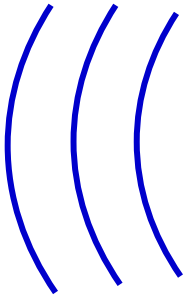
Target



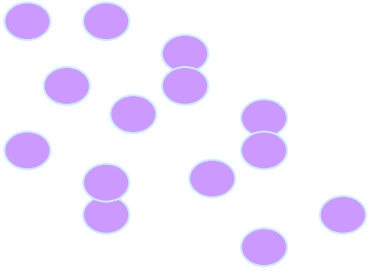
Echo

Amount of Energy (Echo) Reflected

- Size of Targets
- Number of Targets
- Composition of Targets
- Distance to Targets

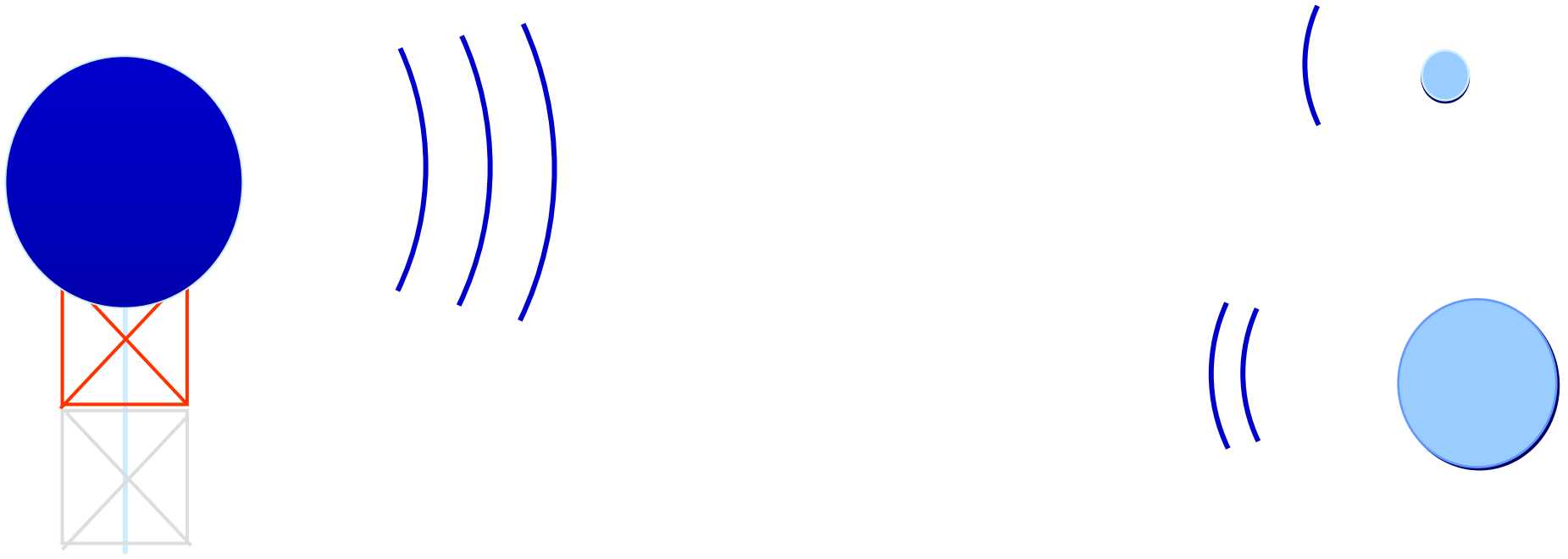


Echo

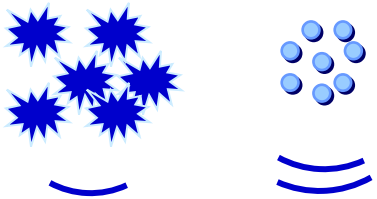


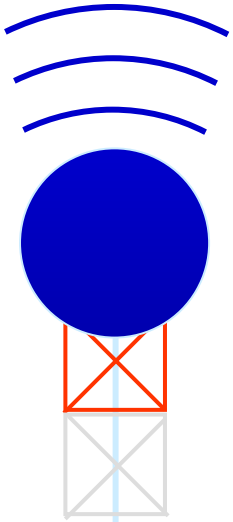
Target

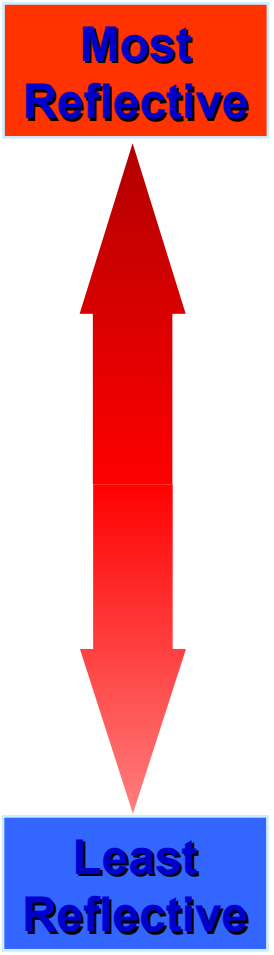
Size - Bigger Reflects More, ~D^6



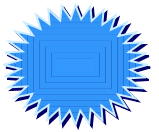
Depends on Composition of Targets







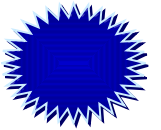
Wet Hail



Rain

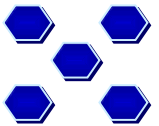
Wet Snow

Dry Hail

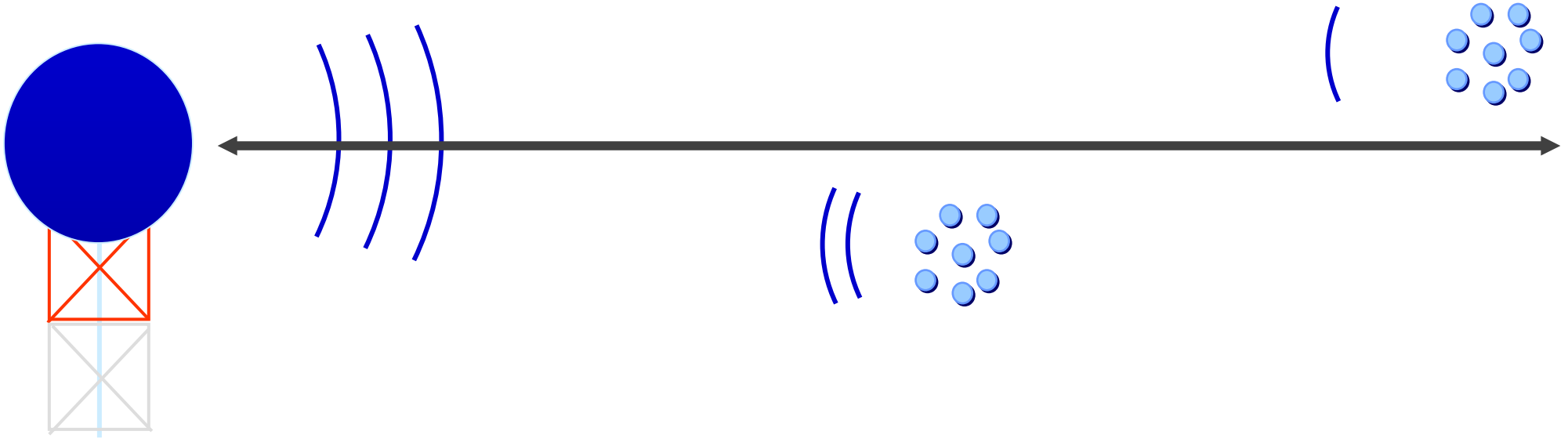


Dry Snow

Ice Crystals



Depends on Distance to Targets



Overall: Radar Reflectivity

- Function of amount of energy reflected
- Measured in dBZ
- Can be considered echo intensity or strength
- Related to rainfall rate
- Categorized into six levels
  - Digital Video Integrated Processor (DVIP)

Digital Video Integrated Processor (DVIP)

DVIP Level	Rainfall Rate	Reflectivity
1	<.1”/hr	29.5 dBZ
2	.25”/hr	35.9 dBZ
3	.5”/hr	40.7 dBZ
4	1.25”/hr	47.0 dBZ
5	2.5”/hr	51.9 dBZ
6	>4.0”/hr	55.1 dBZ