Introduction to Radar Systems

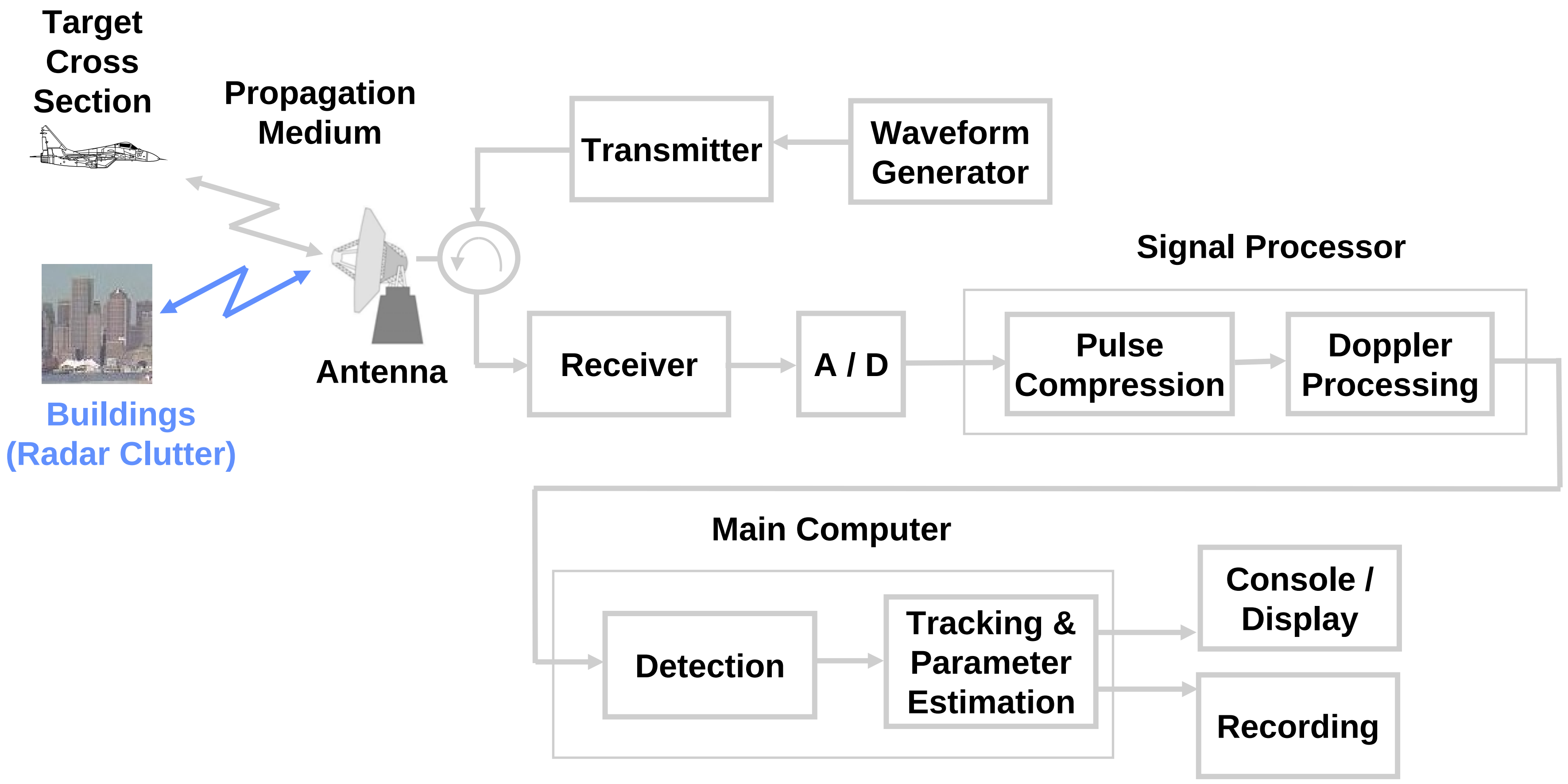
Radar Clutter and Chaff

Disclaimer of Endorsement and Liability

- The video courseware and accompanying viewgraphs presented on this server were prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor the Massachusetts Institute of Technology and its Lincoln Laboratory, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, products, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors or the Massachusetts Institute of Technology and its Lincoln Laboratory.

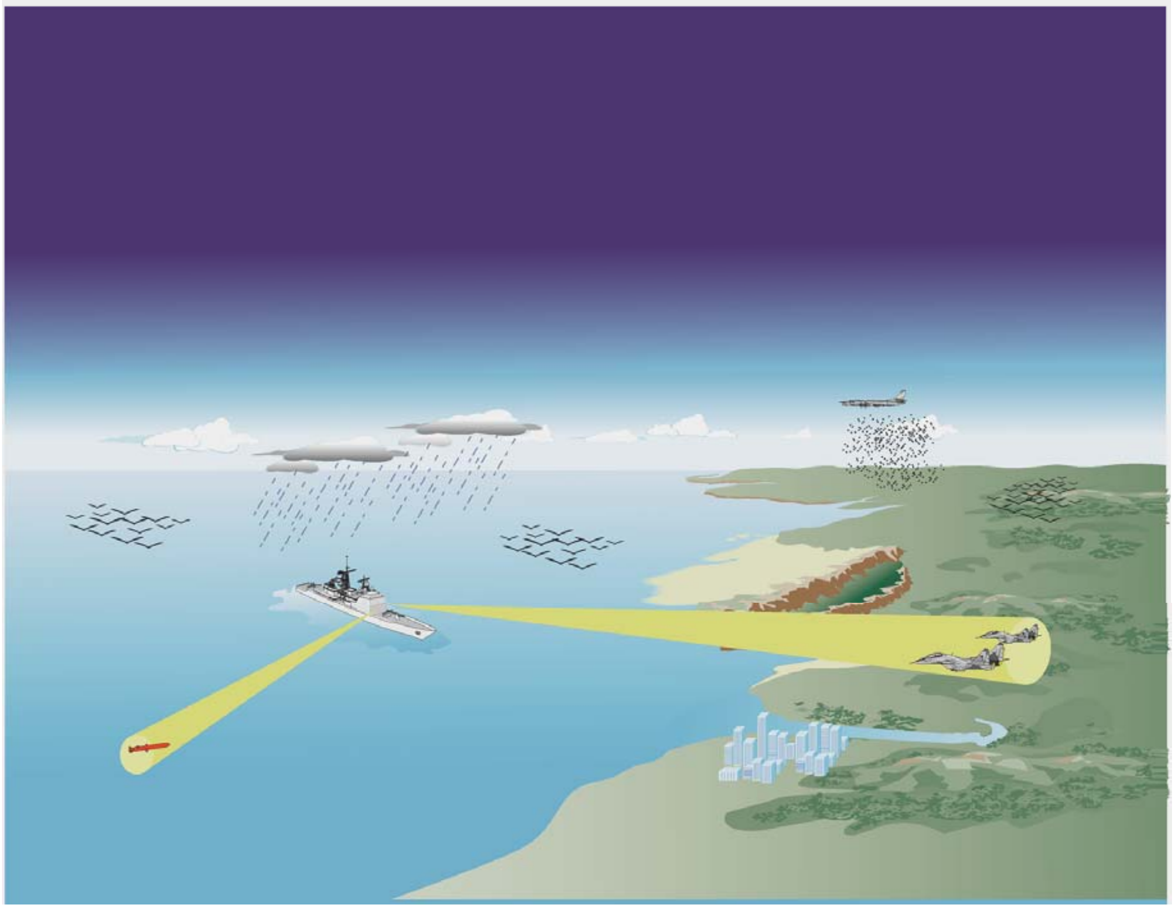
- The views and opinions expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or any of their contractors or subcontractors

Radar Clutter



Why Understand Radar Clutter?

Naval Air Defense Scenario



Radar echo is composed of:

- Backscatter from target of interest
- Receiver noise
- Atmospheric noise
- Interference
  - From other radars
  - Jammers
- Backscatter from unwanted objects
  - Ground
  - Sea
  - Rain
  - Chaff
  - Birds
  - Ground traffic

Outline

- Motivation
- Ground Clutter
- Sea Clutter
- Rain
- Chaff
- Birds and Insects

Attributes of Ground Clutter

- **Mean value of backscatter from ground clutter**
  - **Very large size relative to aircraft**
  - **Varies statistically**
    - **Frequency, spatial resolution, geometry, terrain type**
- **Doppler characteristics of ground clutter return**
  - **Innate Doppler spread small (few knots)**
    - **Mechanical scanning antennas add spread to clutter**
  - **Relative motion of radar platform affects Doppler of ground clutter**
    - **Ship**
    - **Aircraft**

Photographs of Ground Based Radar's PPI
(Different Levels of Attenuation)

Mountainous Region of Lakehead, Ontario, Canada
PPI Set for 30 nmi.

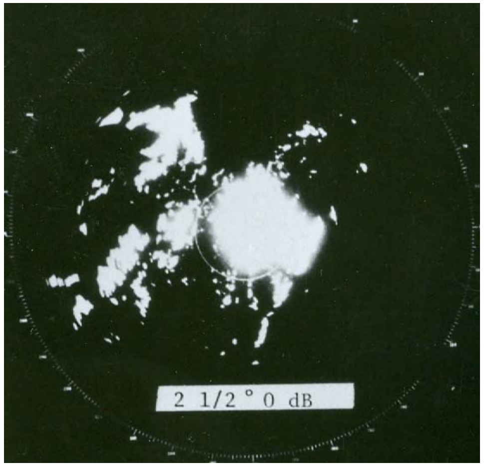
0 dB

60 dB

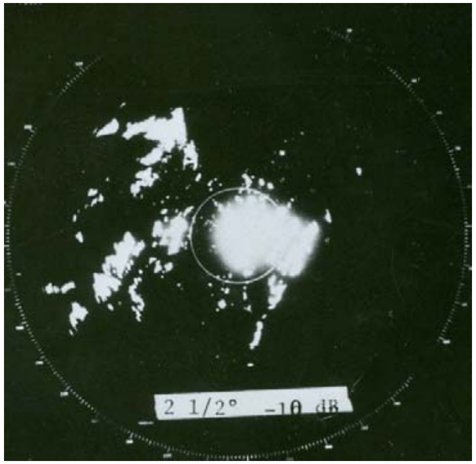
Source: Shrader, W. "Radar Technology Applied to Air Traffic Control," IEEE Transactions on Communications, Vol COM-21, No. 5, May 1973. © IEEE.

Photographs of Ground Based Radar's PPI
(Different Levels of Attenuation)

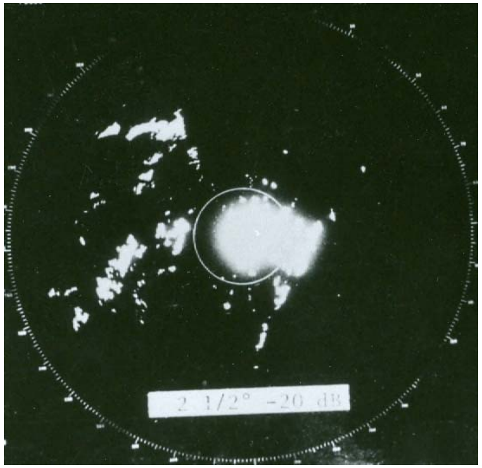
0 dB



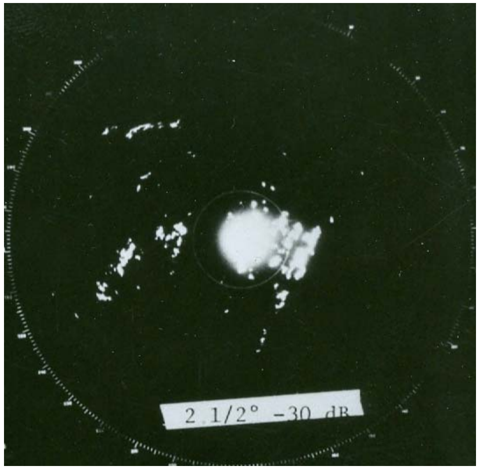
10 dB



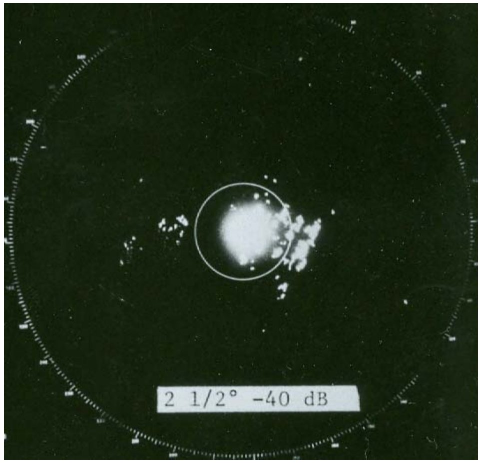
20 dB



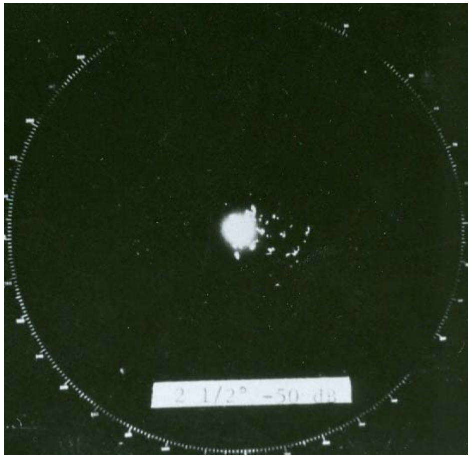
30 dB



40 dB

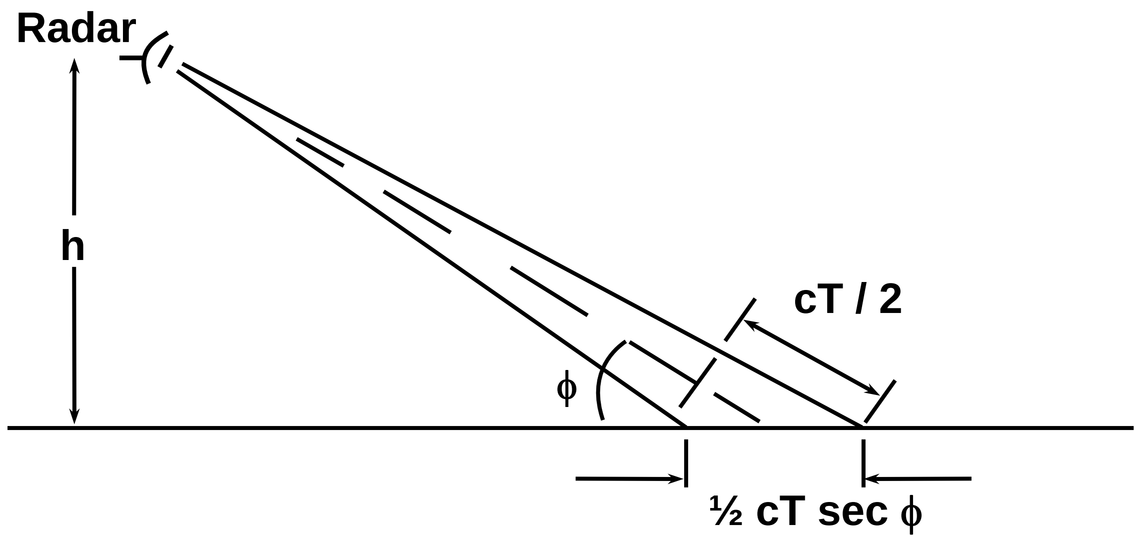


50 dB

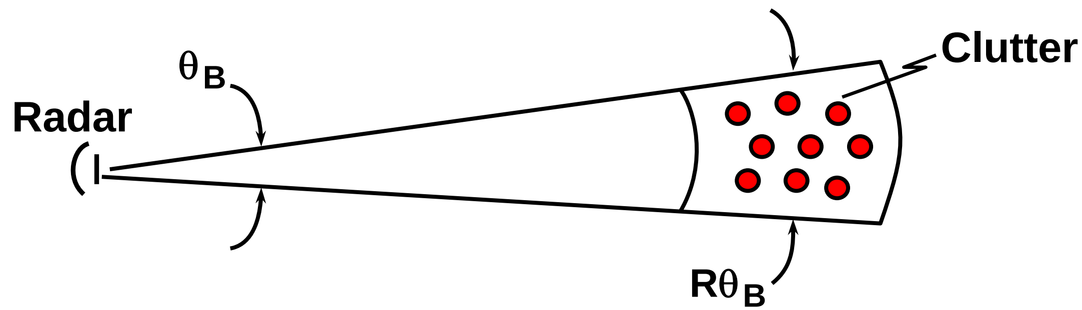


Geometry of Radar Clutter

Elevation View



Plan View



$$\sigma_0 = \frac{\sigma}{A} \qquad A = R\theta_B \left[\tfrac{1}{2}\, cT \sec\phi\right]$$

Calculation of Ground Clutter

- Typical Value of σ_o = -20 dB = $\dfrac{0.01\ m^2}{m^2}$

- $\sigma_{\text{Clutter}} = \sigma_o A = \sigma_o \dfrac{c\,T}{2} R\,\theta_B$

  – For ASR-9 (Airport Surveillance Radar)

  $\dfrac{c\,T}{2} = 100\text{m}$ $\qquad$ R = 60 km $\qquad$ $\theta_B = 1.5^o = 0.026$ radians

- $\sigma_{\text{Clutter}} = \dfrac{0.01\ m^2}{m^2}$ x 100 m x 60,000 m x 0.026 radians = 1500 m^2

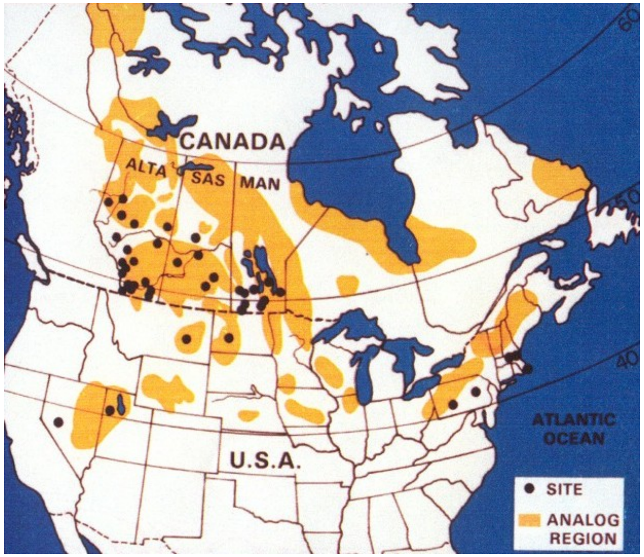
For $\sigma_{\text{Target}} = 1\ m^2$ $\Rightarrow$ $\dfrac{\sigma_{\text{Target}}}{\sigma_{\text{Clutter}}} = \dfrac{1}{1500}$ $\Rightarrow$ $\dfrac{\sigma_{\text{Target}}}{\sigma_{\text{Clutter}}} = 20$

Small single-engine aircraft

For good detection

∴ Must suppress clutter by a factor of
1500 x 20 = 30,000 = 45 dB

Joint U.S./Canada Measurement Program



- Phase One radar
  - VHF, UHF, L-, S-, X-bands
- Measurements conducted 1982 – 1984
- Archival data at Lincoln Laboratory

- 42 sites
- Data shared with Canada and the United Kingdom

Clutter Physics

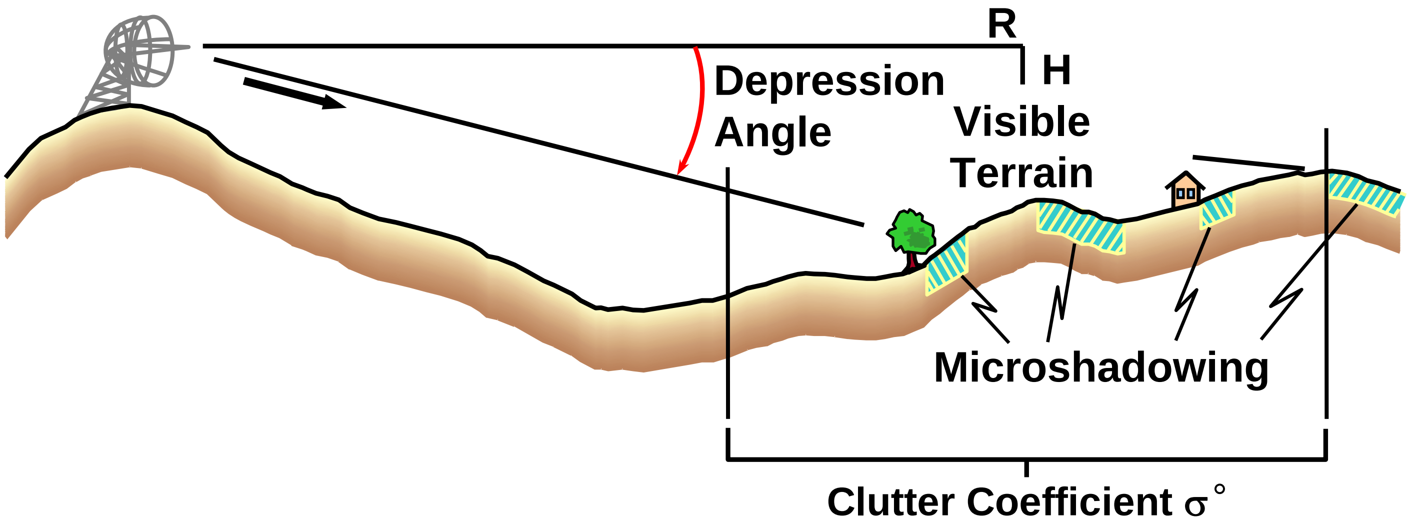


Image from Billingsley, J. B. *Ground Clutter Measurements for Surface Sited Radars*. Tech Report 786, Rev. 1. Lexington, MA: Lincoln Laboratory, February 1, 1993. Courtesy of Lincoln Laboratory

Clutter Physics

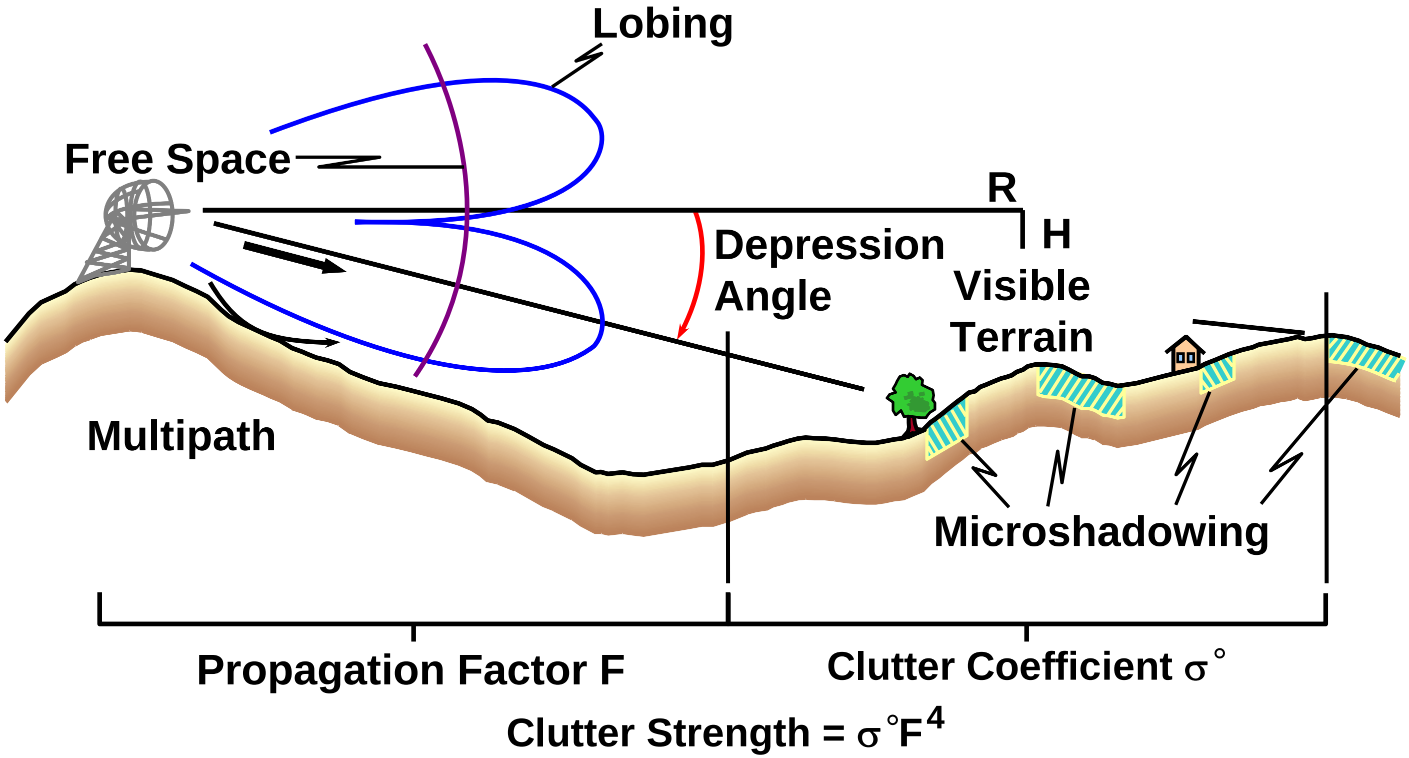


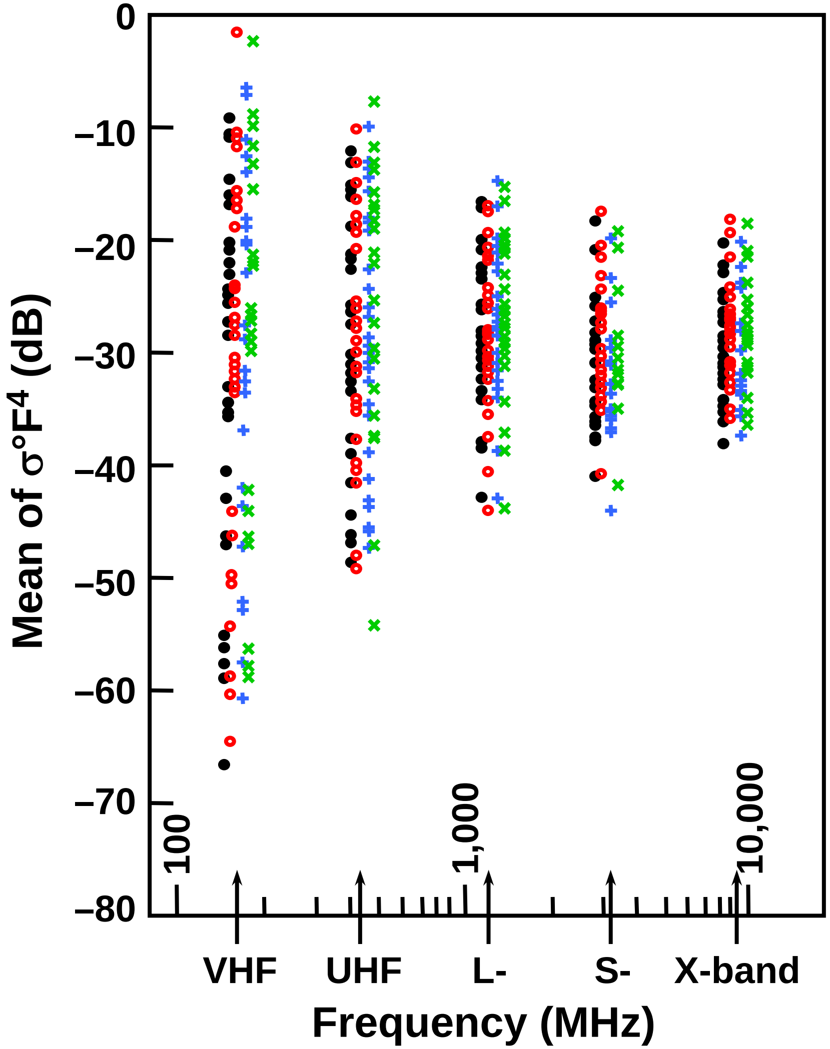
Image from Billingsley, J. B. *Ground Clutter Measurements for Surface Sited Radars*. Tech Report 786, Rev. 1. Lexington, MA: Lincoln Laboratory, February 1, 1993. Courtesy of Lincoln Laboratory

1) Radar Parameters
- **Frequency, f**
- **Spatial resolution, A**

2) Geometry
- **Depression angle (Range R, Height H)**

3) Terrain Type
- **Landform**
- **Land cover**

Mean Ground Clutter Strength vs. Frequency



General Rural (36 Sites)

Key

Range Resolution (m)	Polarization	
150	H	•
150	V	°
15/36	H	+
15/36	V	×

Outline

- Motivation
- Ground Clutter
- Sea Clutter
- Rain
- Chaff
- Birds and Insects

Attributes of Sea Clutter

- **Mean cross section of sea clutter depends on many variables**
  - Wind and weather
    - Sea State
  - Radar frequency
  - Radar Polarization
  - Range resolution
  - Cross range resolution
  - Grazing angle
  - Too many variables

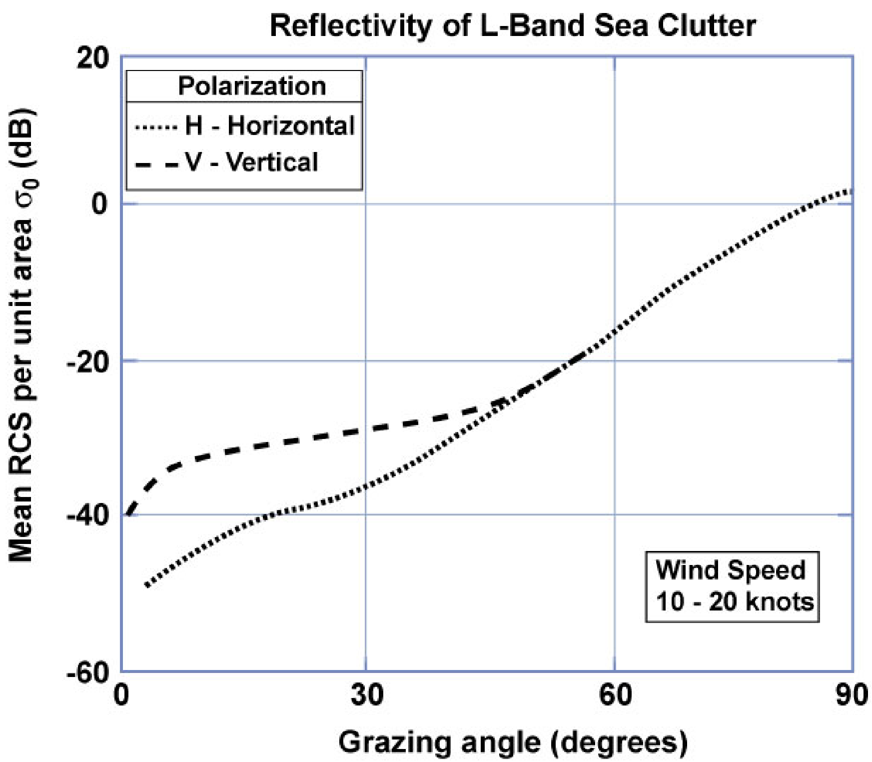


Figure by MIT OCW.

Mean sea backscatter is about 100 times less than ground backscatter

World Meteorological Organization
Sea State

Sea State	Wave Height (m)	Wind Velocity (knots)	Descriptive Term
0 to 1	0 to 0.1	0 to 6	Calm, Rippled
2	0.1 to 0.5	7 to 10	Smooth, Wavelets
3	0.6 to 1.2	11 to 16	Slight to Moderate
4	1.2 to 2.4	17 to 21	Moderate to Rough
5	2.4 to 4	22 to 27	Very Rough
6	4 to 6	28 to 47	High

Sea Spikes

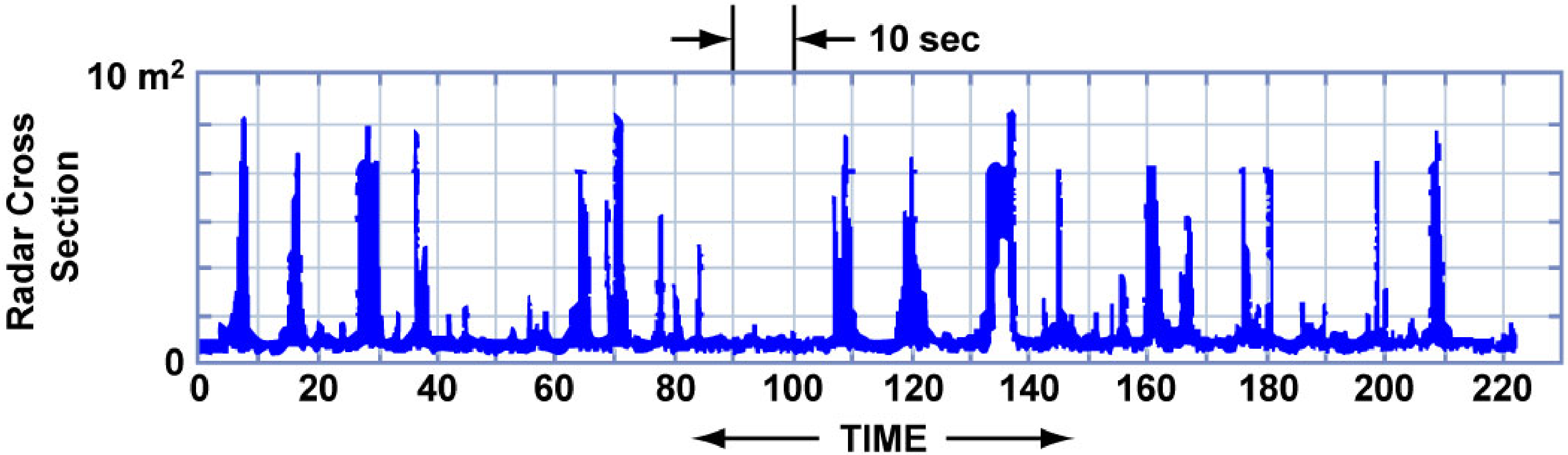


Figure by MIT OCW.

•Grazing angle   1.5 deg.
•Horizontal polarization

- **At low grazing angles, sharp sea clutter peaks, known as "sea spikes", begin to appear**
- **These sea spikes can cause excessive false detections**

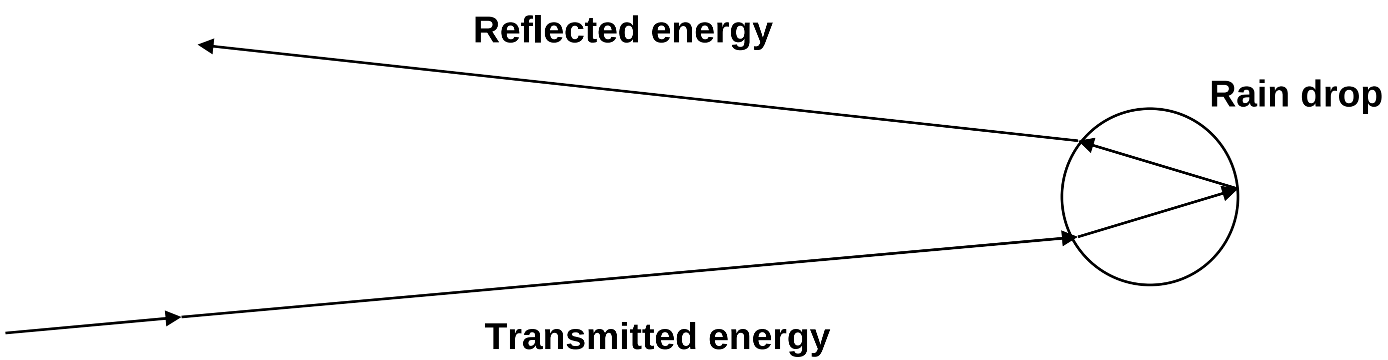
From Lewis and Olin, NRL

Outline

- Motivation
- Ground Clutter
- Sea Clutter
- Rain
- Chaff
- Birds and Insects

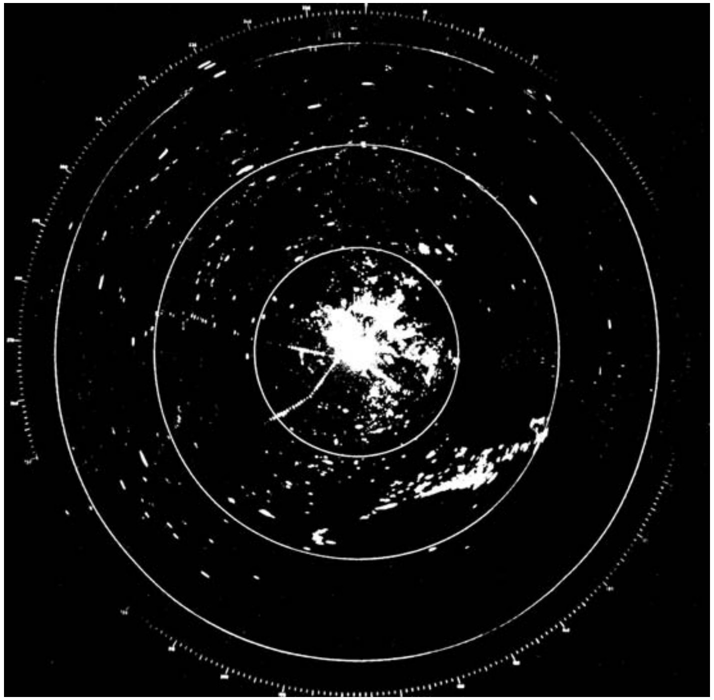
Attributes of Rain Clutter

- Rain both attenuates and reflects radar signals
- Problems caused by rain lessen dramatically with longer wavelengths (lower frequencies)
  - Much less of a issue at L-Band than X-Band
- Rain is diffuse clutter (wide geographic extent)
  - Travels horizontally with the wind
  - Has mean Doppler velocity and spread



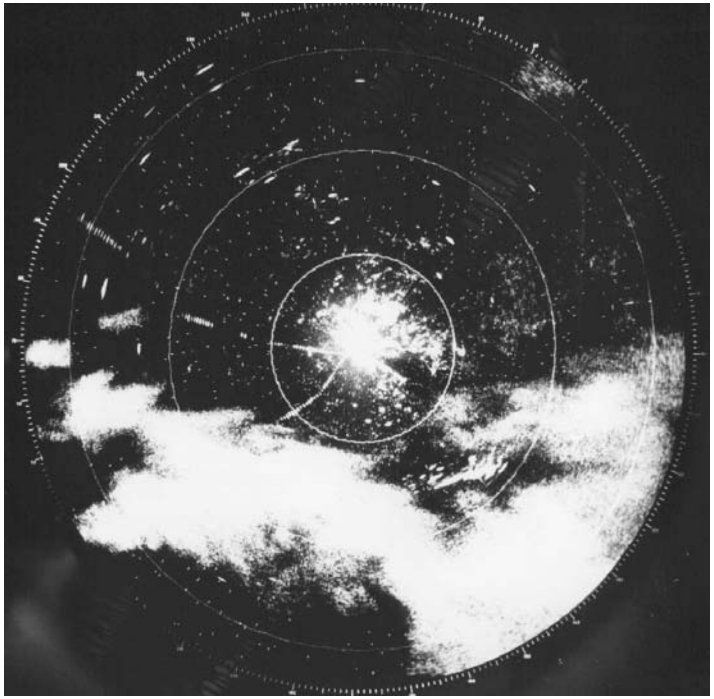
PPI Display Radar Normal Video

Clear Day (No Rain)



Airport Surveillance Radar
S Band
Detection Range - 60 nmi on a 1 m^2 target

Day of Heavy Rain



10 nmi Range Rings on PPI Display
August 1975, FAA Test Center
Atlantic City, New Jersey

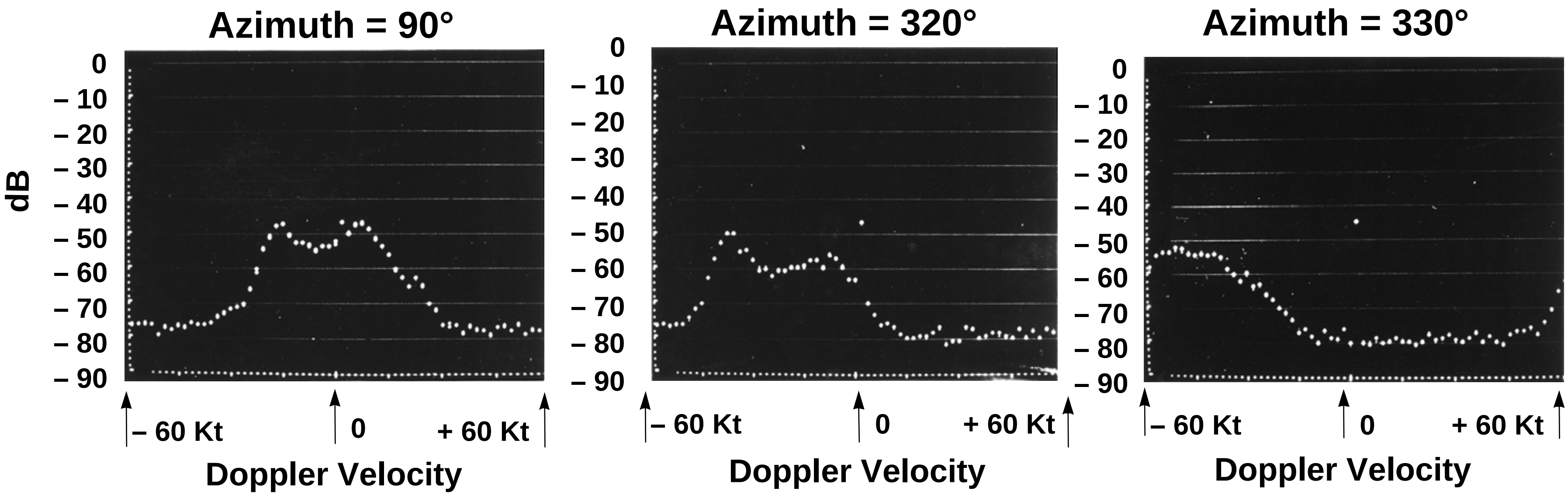
Reflectivity of Uniform Rain (σ in dBm^2/m^3)

Rain Type	Frequency			
	S 3.0 GHz	C 5.6	X 9.3	Ka 35
Drizzle, 0.25 mm/hr	–102	–91	–81	–58
Light Rain, 1 mm/hr	–92	–81.5	–72	–49
Moderate, 4 mm/hr	–83	–72	–62	–41
Heavy Rain, 16 mm/hr	–73	–62	–53	–33

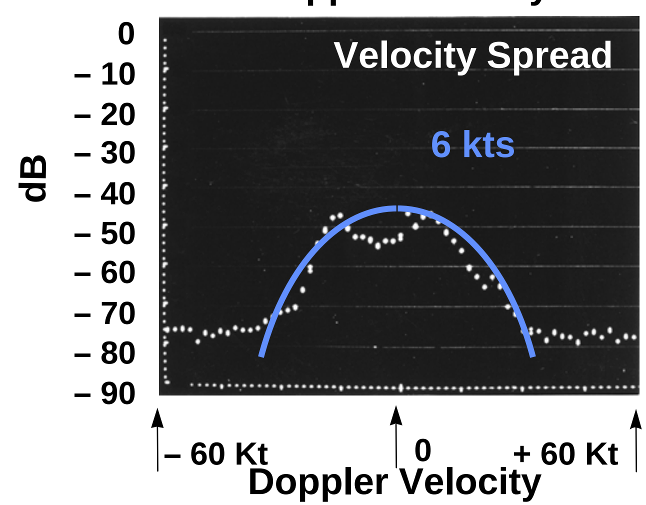
Figure by MIT OCW.

- **Rain reflectivity increases as f^4 (or $1/\lambda^4$)**
  - **Rain clutter is an issue at S-Band and a significant one at X-Band or higher frequencies**

Measured S-Band Doppler Spectra of Rain



- Rain is not Gaussian
- Mean velocity varies as storm moves by radar
- In these examples the rainfall rate was approximately 20 mm/hr
- Winds 30 kts on ground, 50 kts at 6000 ft



Outline

- Motivation
- Ground Clutter
- Sea Clutter
- Rain
- Chaff
- Birds and Insects

Attributes of Chaff

- Large number of dipoles (metallic or metallic coated)
  - High reflectivity per pound
  - Optimum length 1/2 of radar wavelength
  - Moves with the wind
- Uses of chaff
  - Masking

    Large cloud can shield aircraft or missiles in or near the cloud
  - Deception

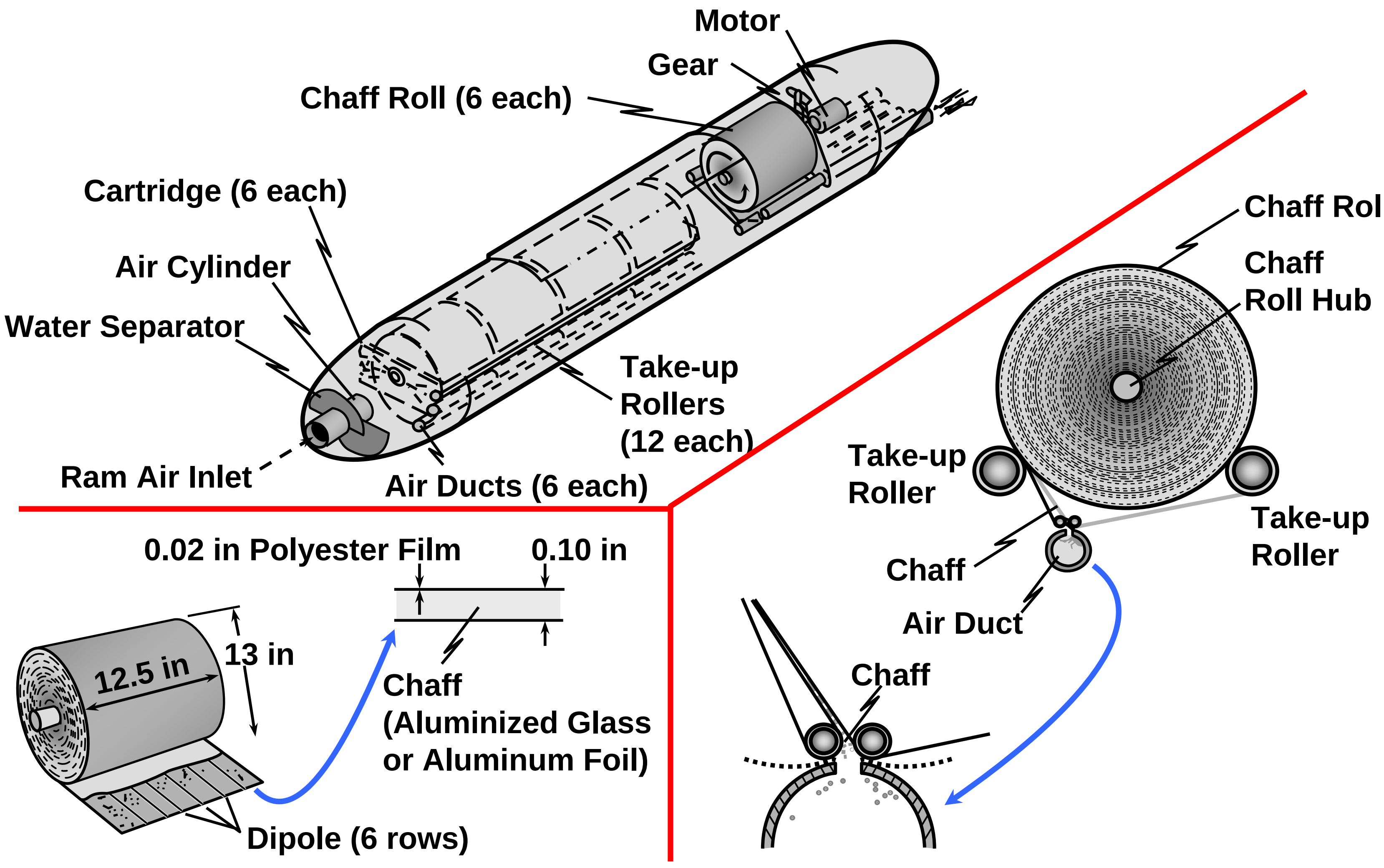
    Chaff “puff” can emulate a missile / aircraft and cause false detections

    Packets of chaff can divert radar tracker from target

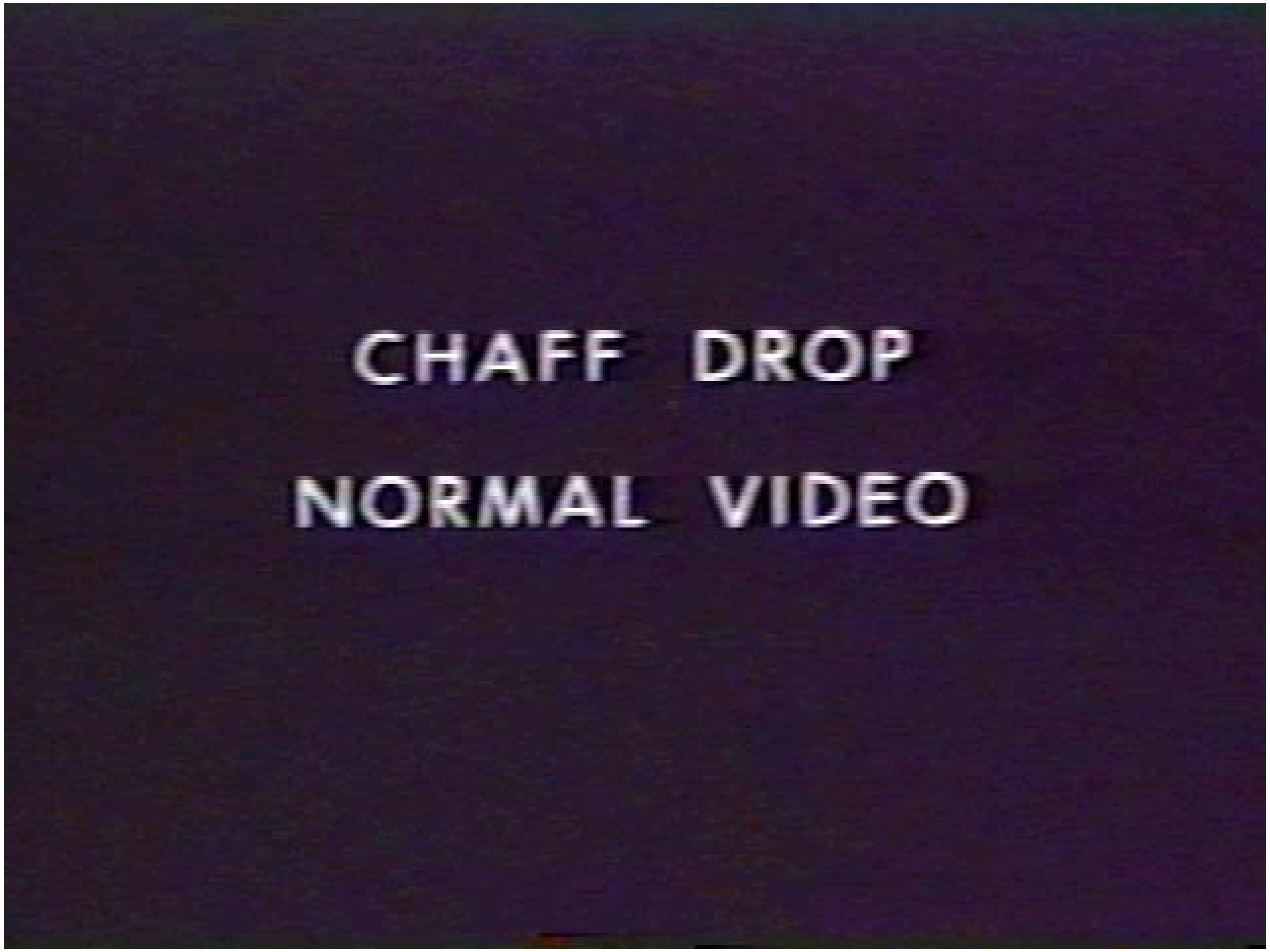
Chaff Reflectivity and Density

- **Resonant Metallic Dipoles**
  - **σ = .18 λ^2 (in m^2) Average Cross Section per Dipole**
  - **Bandwidth 10-15% of center frequency**
  - **Fall rates 0.5 to 3 m/s**
- **Aluminum foil dipoles (.001 in. x .01 in. x $\lambda/2$ long)**
  - **σ = 3000 W / f (in m^2)**
  - **W = weight in lb, f = frequency in GHz**
  - **At S-Band, 400 lb yields = 265,000 m^2 or 54.3 dBsm**

AN/ALE-38 Chaff-Dispensing System



Movie of Chaff



Outline

- Motivation
- Ground Clutter
- Sea Clutter
- Rain
- Chaff
- Birds and Insects

Bird Breeding Areas and Migration Routes

Gadwall

Northern Flicker

Virginia Rail

Photos courtesy of vsmithuk, sbmontana, and khosla.

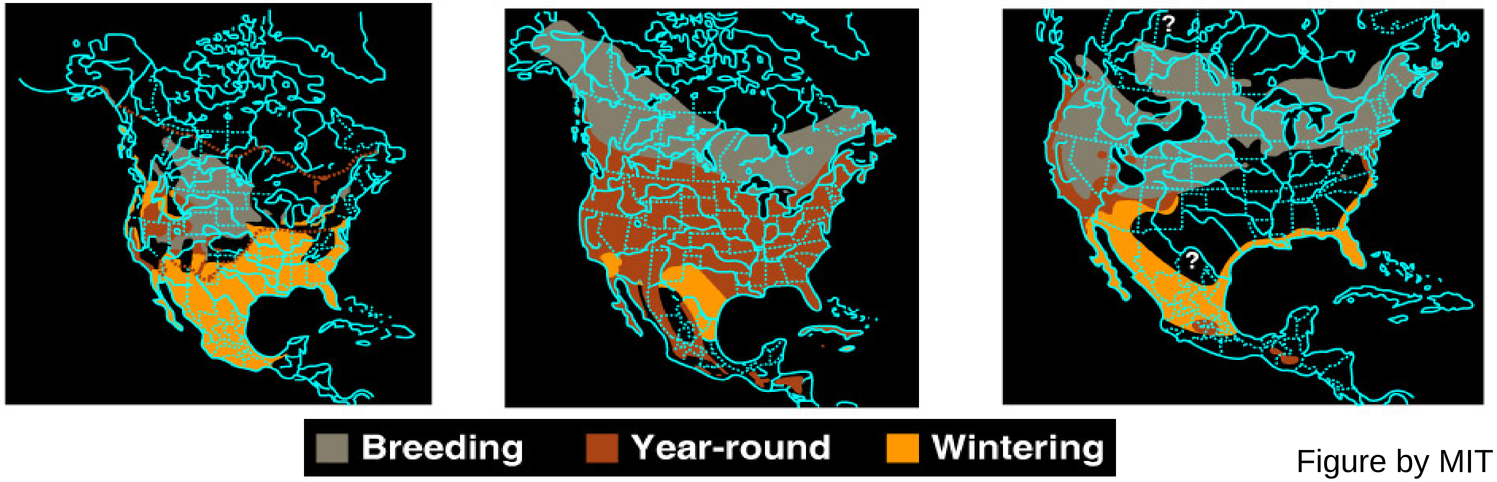


Figure by MIT OCW.

During the breeding season along the Gulf Coast, sea and wading bird colonies exist that have up to 60,000 birds. 10,000 birds are common. These birds are large; weighing up to 1 kg and having wingspreads from 0.75 to several meters.

Bird Breeding Areas and Migration Routes

Spotted Towhee

Black Tern

Northern Harrier

Photos courtesy amkhosla, Changhua Coast Conservation Action, and amkhosla.

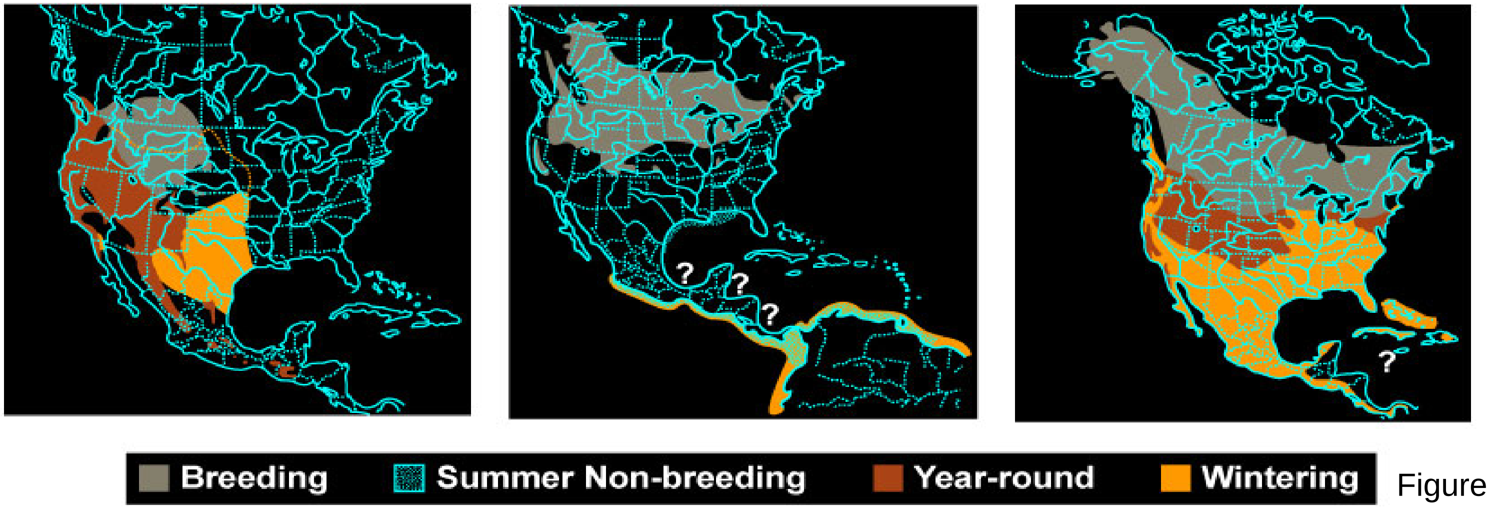
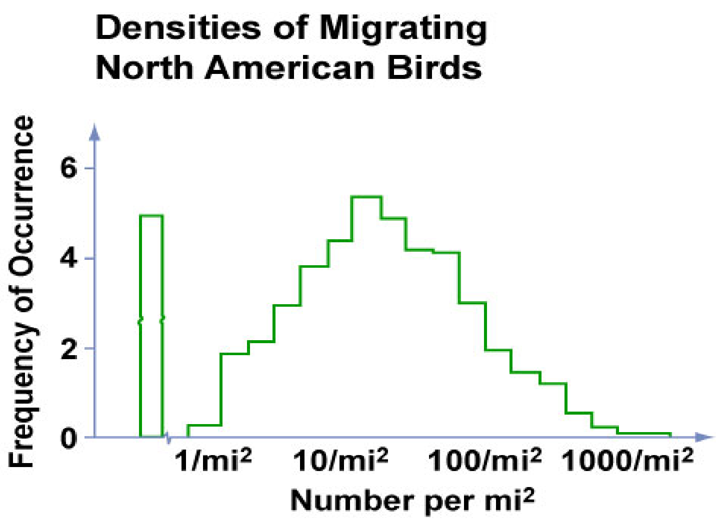
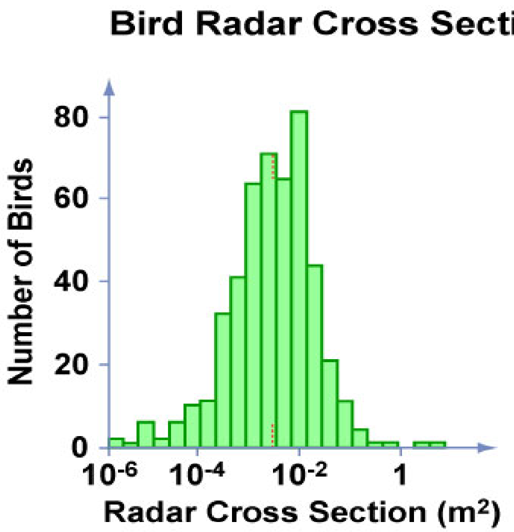


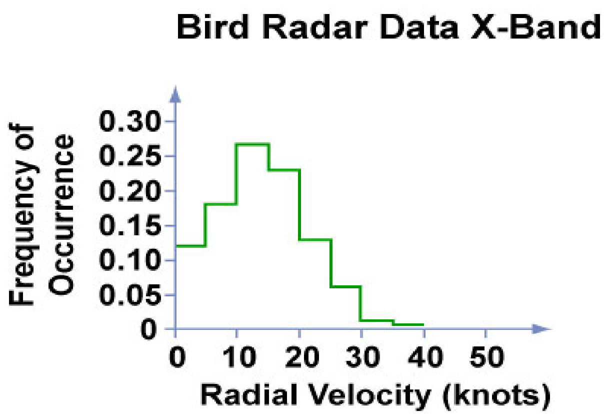
Figure by MIT OCW.

Within the lower Mississippi Valley, 63 blackbird roosts have been identified with over 1 million birds each. Many smaller roosts also exits. These birds disperse 30 miles for daily feeding.

Radar Properties of Birds



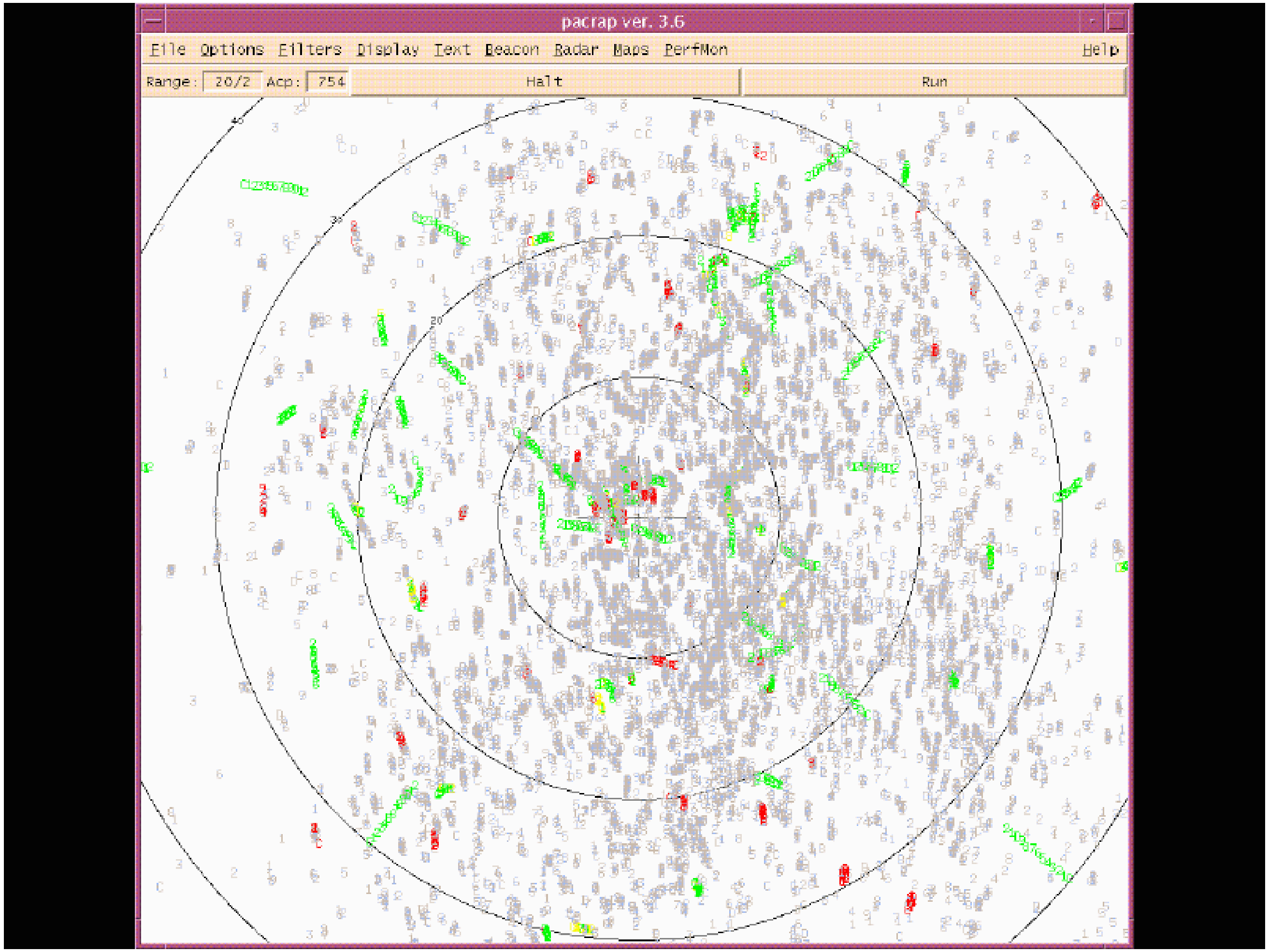




- Even though the radar echo of birds is relatively small, bird densities are so great that birds can often overload a radar with false targets
- Since birds move at relatively low velocities, their speed, if measured, can be used to preferentially threshold out the low velocity birds.

Figure by MIT OCW.

Bird Example from Dallas-Fort Worth



Radar&Beacon
Beacon-Only
Radar Uncorrelated
Radar Correlated

Attributes of Birds

- **Birds are actually moving point targets**
  - **Velocity usually less than 60 knots**
- **Mean radar cross section is small, but a fraction of bird returns fluctuate up to a high level (aircraft like)**
  - **Cross section is resonant at S-Band and L-Band**
- **Lots of birds per square mile**
  - **10 to 1000 bird / square mile**
- **Birds cause a false target problem in many radars**
  - **Significant issue for when detecting targets with low cross sections**

Insects

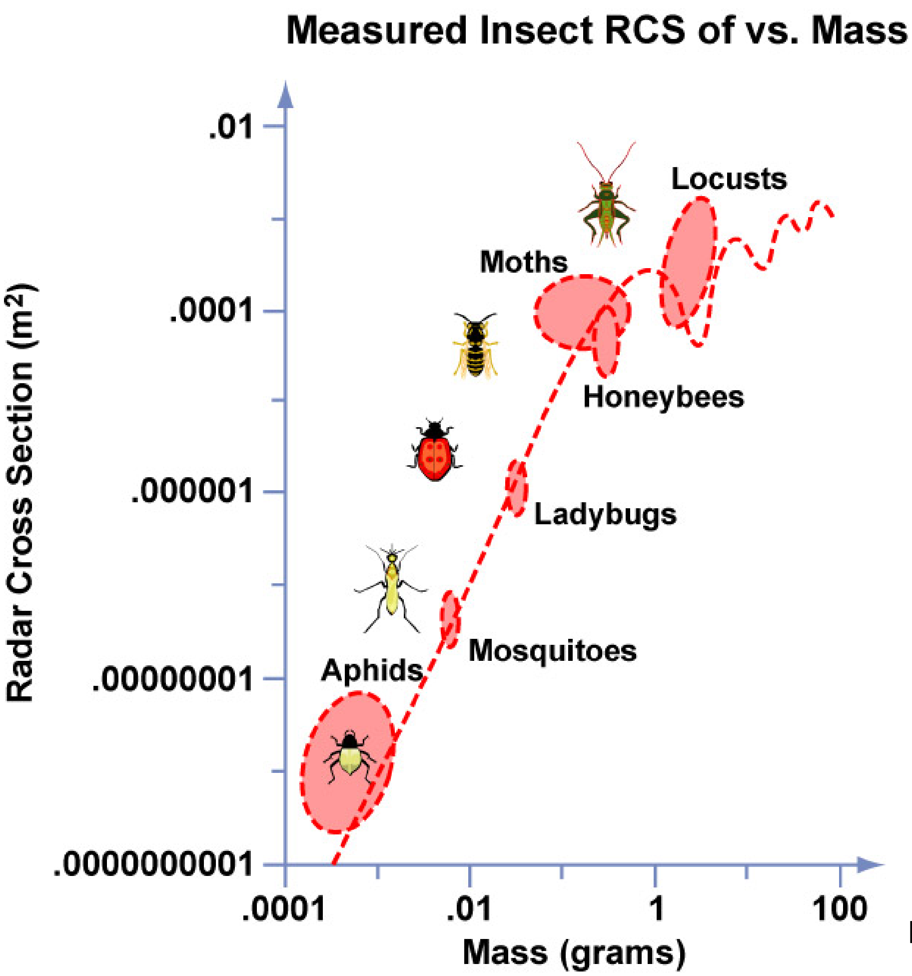


Figure by MIT OCW.

- Insects can clutter the display and prevent detection of desired targets
- Density of insects can be many orders of magnitude greater than that of birds
- Insect flight path generally follows that of the wind
- Cross section can be represented as a spherical drop of water of the same mass
- Insect echoes broad side are 10 to 1,000 times than when viewed end on

Summary

- A number of different types of radar clutter returns have been described
  - Ground, sea, rain, and birds
- These environmental and manmade phenomena will produce a variety of discrete and diffuse, moving and stationary false targets, unless they are dealt with effectively
- A number of signal and data processing techniques can be used to suppress the effect of these radar clutter returns.

References

- Skolnik, M., Introduction to Radar Systems, New York, McGraw-Hill, 3rd Edition, 2001
- Nathanson, F. E., Radar Design Principles, New York, McGraw-Hill, 2nd Edition, 1991
- Eastwood, E., Radar Ornithology, London, Methuen, 1967