Introduction to Radar Systems

Radar Clutter and Chaff
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Radar Clutter

Transmitter → Waveform Generator

Receiver → A / D → Pulse Compression → Doppler Processing

Main Computer

Detection → Tracking & Parameter Estimation → Recording

Console / Display
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

Courtesy of IEEE. Used with permission.
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

\[ \sigma_0 = \frac{\sigma}{A} \]

\[ A = R \theta_B \left[ \frac{1}{2} cT \sec \phi \right] \]
Calculation of Ground Clutter

• Typical Value of $\sigma_o = -20$ dB = \frac{0.01 \text{ m}^2}{\text{m}^2}$

$\sigma_{\text{Clutter}} = \sigma_o A = \sigma_o \frac{c T}{2} R \theta_B$

– For ASR-9 (Airport Surveillance Radar)

$\frac{c T}{2} = 100 \text{ m}$ \hspace{1cm} $R = 60 \text{ km}$ \hspace{1cm} $\theta_B = 1.5^\circ = 0.026 \text{ radians}$

$\sigma_{\text{Clutter}} = \frac{0.01 \text{ m}^2}{\text{m}^2} \times 100 \text{ m} \times 60,000 \text{ m} \times 0.026 \text{ radians} = 1500 \text{ m}^2$

For $\sigma_{\text{Target}} = 1 \text{ m}^2$

$\frac{\sigma_{\text{Target}}}{\sigma_{\text{Clutter}}} = \frac{1}{1500}$

$\frac{\sigma_{\text{Target}}}{\sigma_{\text{Clutter}}} = 20$

\[ \therefore \text{Must suppress clutter by a factor of} \]

$1500 \times 20 = 30,000 = 45 \text{ dB}$

Small single-engine aircraft

For good detection
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

Clutter Physics

1) Radar Parameters
   • Frequency, f
   • Spatial resolution, A

2) Geometry
   • Depression angle (Range R, Height H)

3) Terrain Type
   • Landform
   • Land cover

Clutter Strength = $\sigma^o F^4$

Mean Ground Clutter Strength vs. Frequency

Mean of $\sigma F^4$ (dB) vs. Frequency (MHz)

General Rural (36 Sites)

Key

<table>
<thead>
<tr>
<th>Range Resolution (m)</th>
<th>Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>H</td>
</tr>
<tr>
<td>150</td>
<td>V</td>
</tr>
<tr>
<td>15/36</td>
<td>H</td>
</tr>
<tr>
<td>15/36</td>
<td>V</td>
</tr>
</tbody>
</table>
Outline

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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

Mean sea backscatter is about 100 times less than ground backscatter

Reflectivity of L-Band Sea Clutter

- Polarization
  - H - Horizontal
  - V - Vertical

Wind Speed
10 - 20 knots

Figure by MIT OCW.
# World Meteorological Organization

## Sea State

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

- 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
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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 m² 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
($\sigma$ in dBm$^2$/m$^3$)

<table>
<thead>
<tr>
<th>Rain Type</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S 3.0 GHz</td>
</tr>
<tr>
<td>Drizzle, 0.25 mm/hr</td>
<td>−102</td>
</tr>
<tr>
<td>Light Rain, 1 mm/hr</td>
<td>−92</td>
</tr>
<tr>
<td>Moderate, 4 mm/hr</td>
<td>−83</td>
</tr>
<tr>
<td>Heavy Rain, 16 mm/hr</td>
<td>−73</td>
</tr>
</tbody>
</table>

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

Figure by MIT OCW.
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
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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
  – $\sigma = 0.18 \lambda^2$ (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)
  – $\sigma = 3000 \frac{W}{f}$ (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

- Cartridge (6 each)
- Air Cylinder
- Water Separator
- Ram Air Inlet
- Air Ducts (6 each)
- Chaff Roll (6 each)
- Take-up Rollers (12 each)
- Gear
- Motor
- Take-up Roller
- Chaff Roll Hub
- Chaff
- Dipole (6 rows)
- 0.02 in Polyester Film
- 0.10 in
- 12.5 in
- 13 in
- Chaff (Aluminized Glass or Aluminum Foil)
Movie of Chaff
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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 wingspans from 0.75 to several meters.

Photos courtesy of vsmithuk, sbmontana, and khosla.

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 exist. These birds disperse 30 miles for daily feeding.

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

- 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.

Figure by MIT OCW.
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


• Eastwood, E., Radar Ornithology, London, Methuen, 1967