Radar Systems Engineering
Lecture 19
Electronic Counter Measures

Dr. Robert M. O'Donnell
IEEE New Hampshire Section
Guest Lecturer

Block Diagram of Radar System

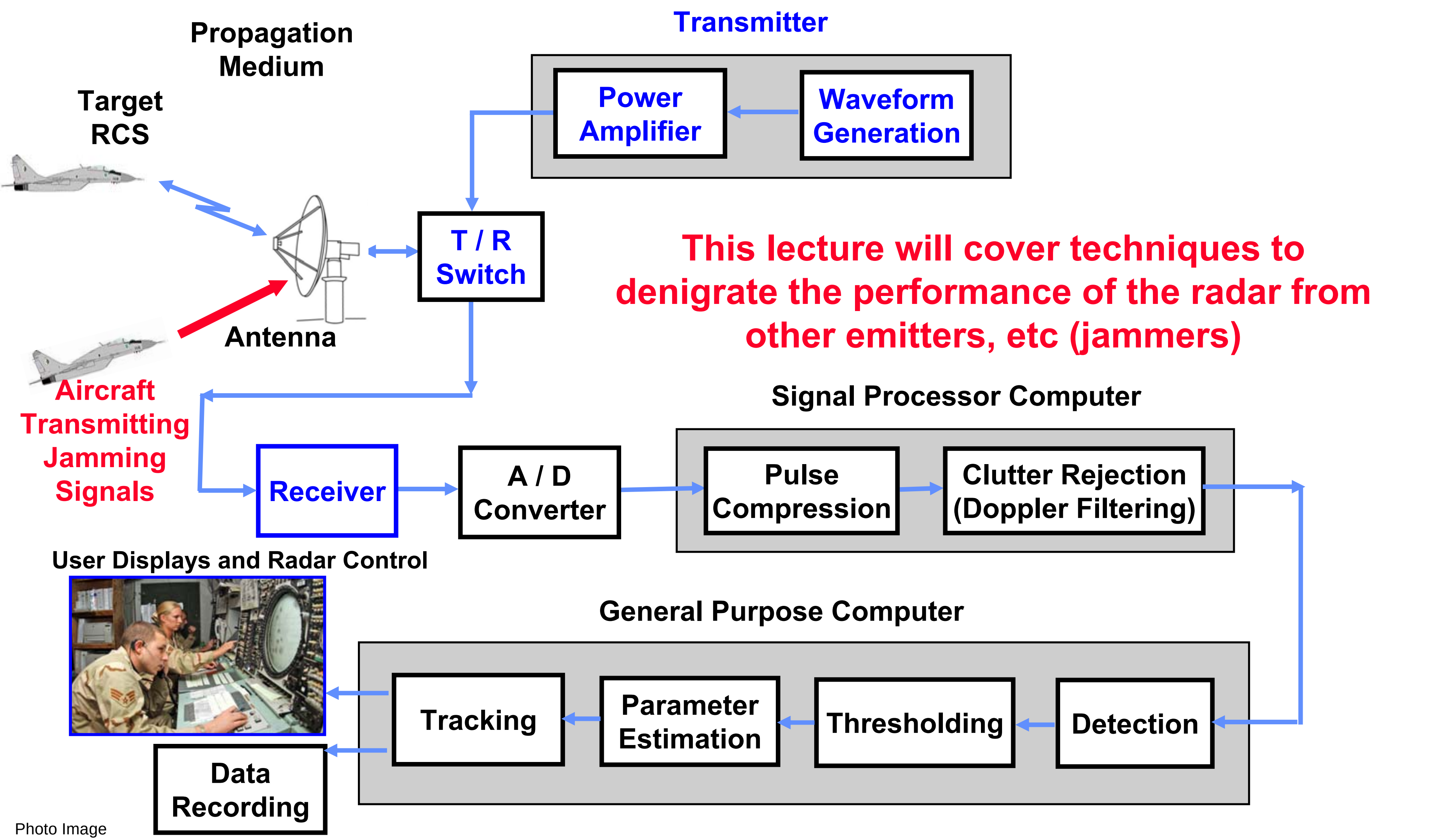


Photo Image
Courtesy of US Air Force

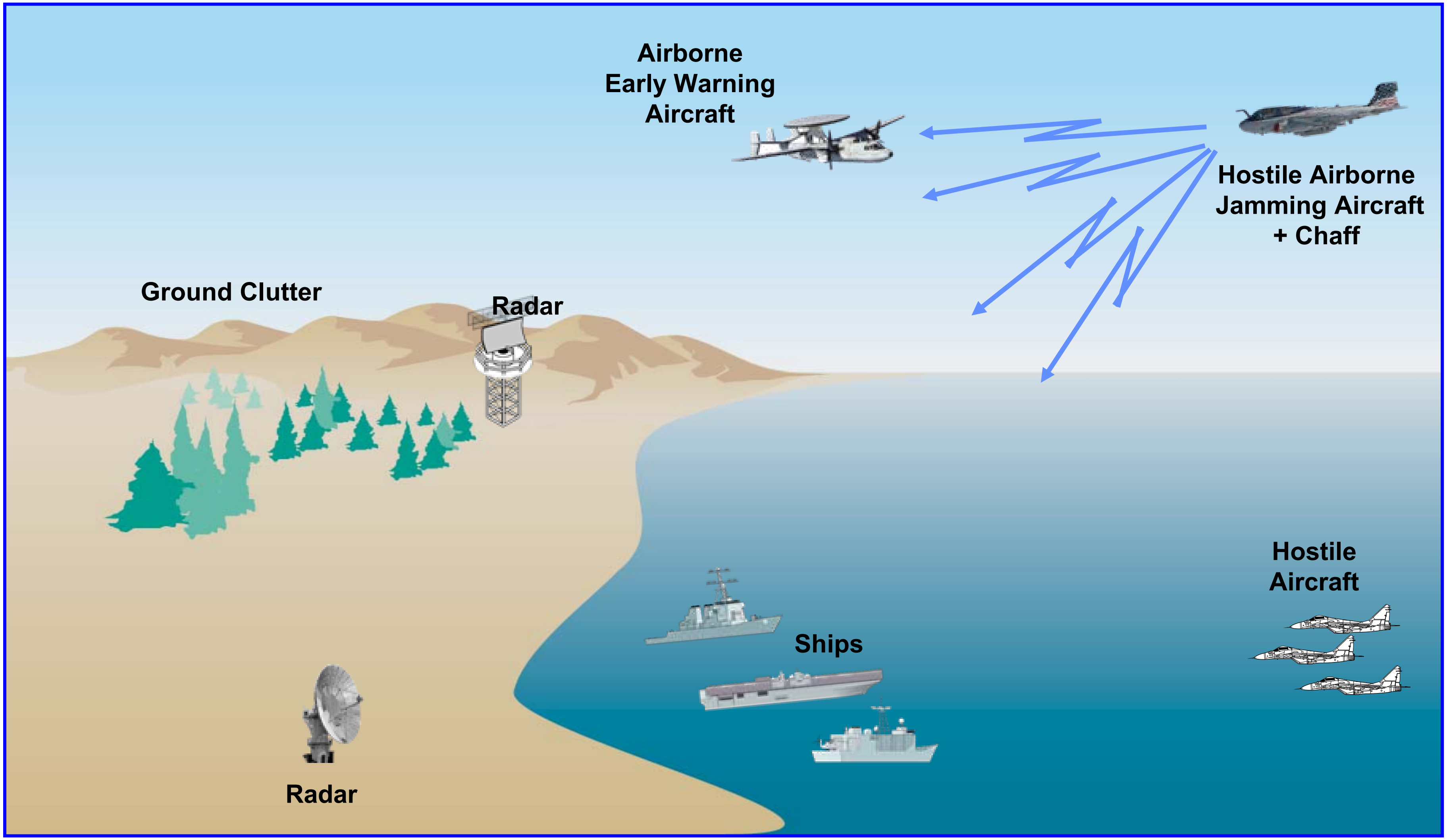
By "RMOD Radar Systems"

Outline

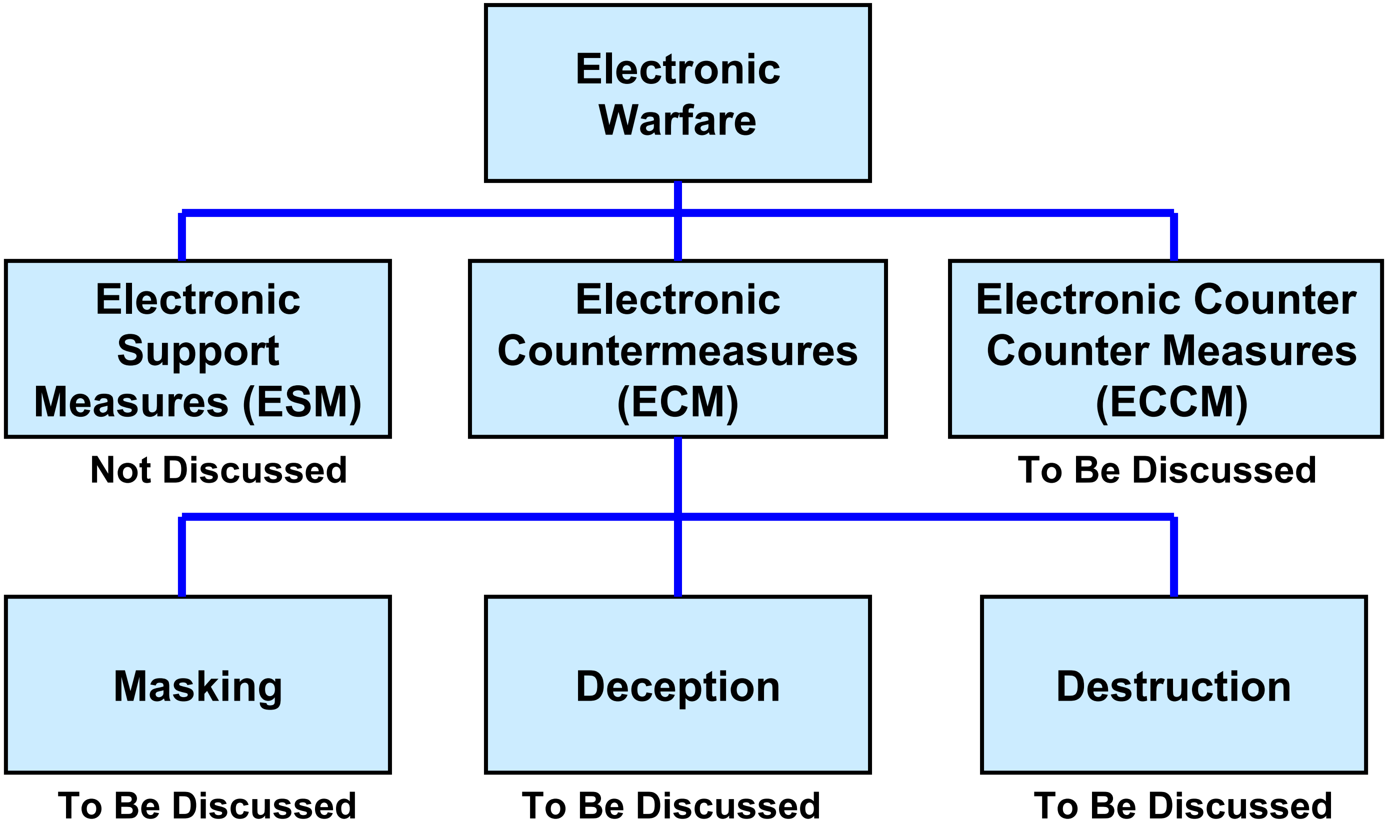
- Introduction
- Electronic Counter Measures (ECM)
- Electronic Counter Counter Measures (ECCM)
- Summary

By “RMOD Radar Systems”

Radar Environment



Introduction



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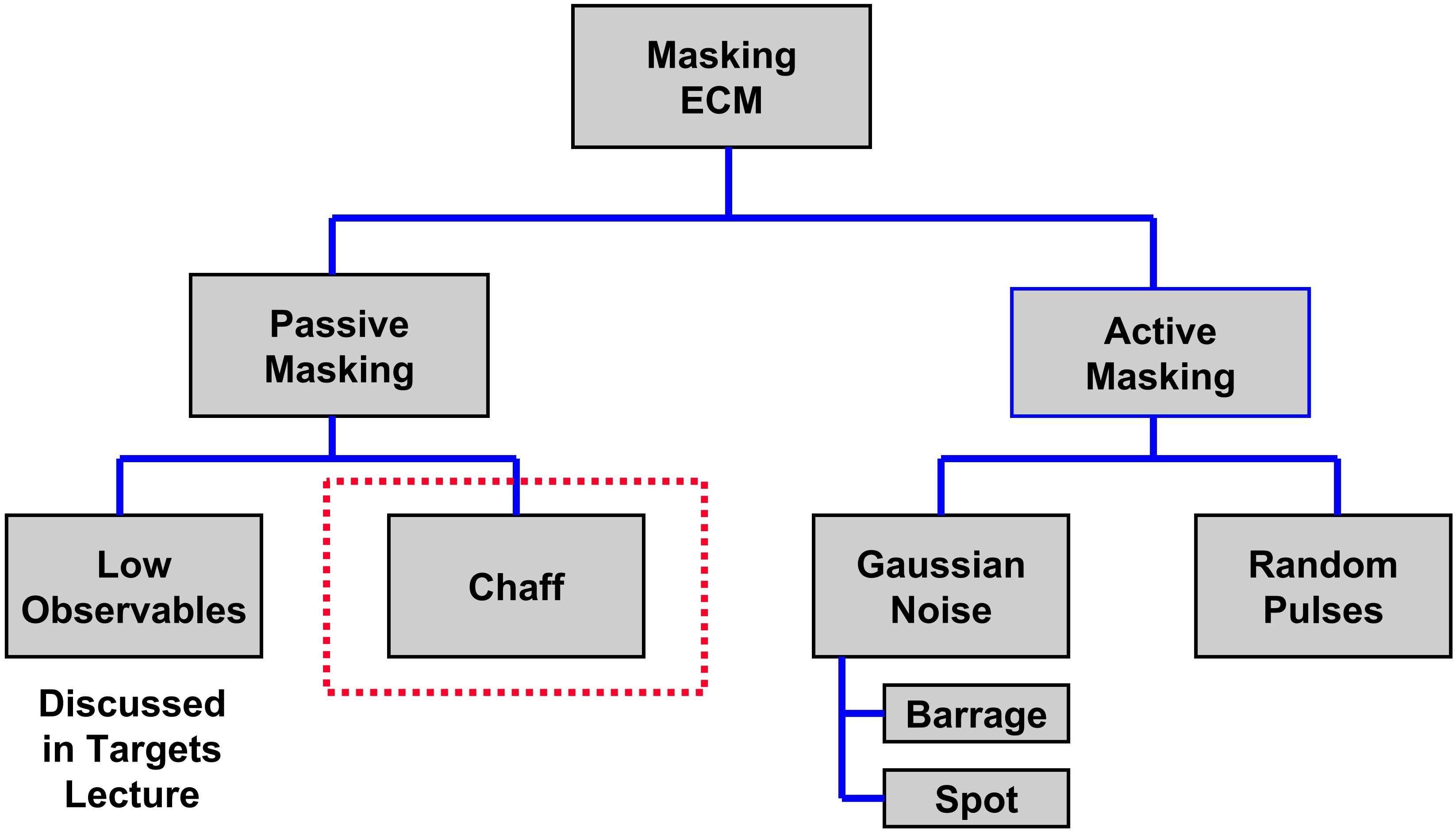
Outline

- **Introduction**
- **Electronic Counter Measures (ECM)**
  - **Masking**
  - **Deception**
  - **Destruction**
- **Electronic Counter Counter Measures (ECCM)**
- **Summary**

Masking ECM against Radar



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Attributes of Chaff

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

- Uses of chaff
  - Masking
    - Large cloud can shield aircraft or missiles in or near the cloud
    - Diffuse clutter similar in characteristics to rain

  - Deception
    - Chaff "puff" can emulate a missile or aircraft and cause false detections
    - Packets of chaff seeded in a row can cause radar tracker to track the chaff rather than the aircraft being tracked

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Chaff Reflectivity and Density

- **Resonant Dipoles (Metallic)**
  - $\sigma = .86\ \lambda^2$ (in m^2) (Maximum Cross Section per Dipole)
  - λ = Wavelength in meters
- **Random Orientation of a Large Number of Dipoles**
  - $\sigma = .18\ \lambda^2$ (in m^2) (Average Cross Section per Dipole)
- **Aluminum foil dipoles (.001 in. thick, .01 in. wide, $\lambda/2$ long)**

  $\sigma = 3000\ W / f$ (in m^2)
  - W = weight in lb
  - f = frequency in GHz
- **At S-Band, 400 lb yields = 400,000 m^2 or 56 dBsm**

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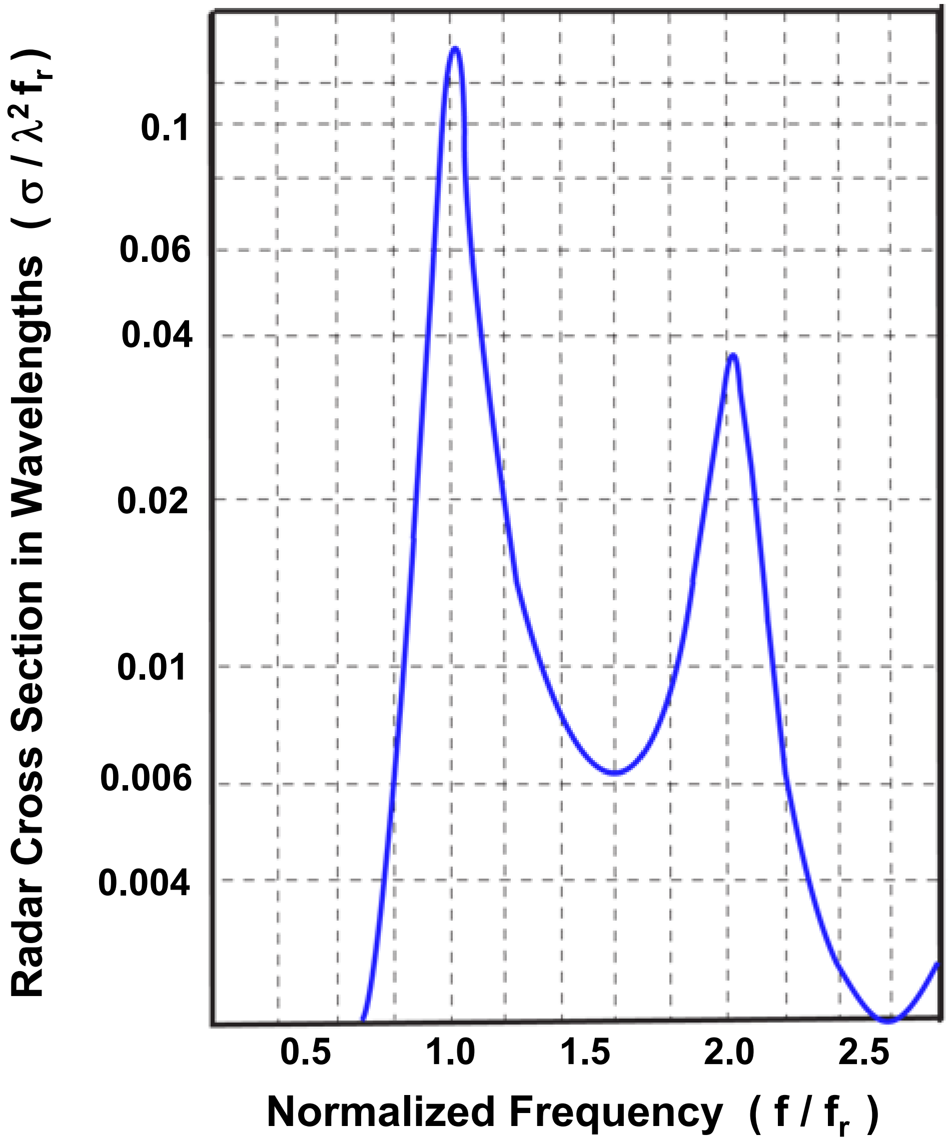
Chaff Properties

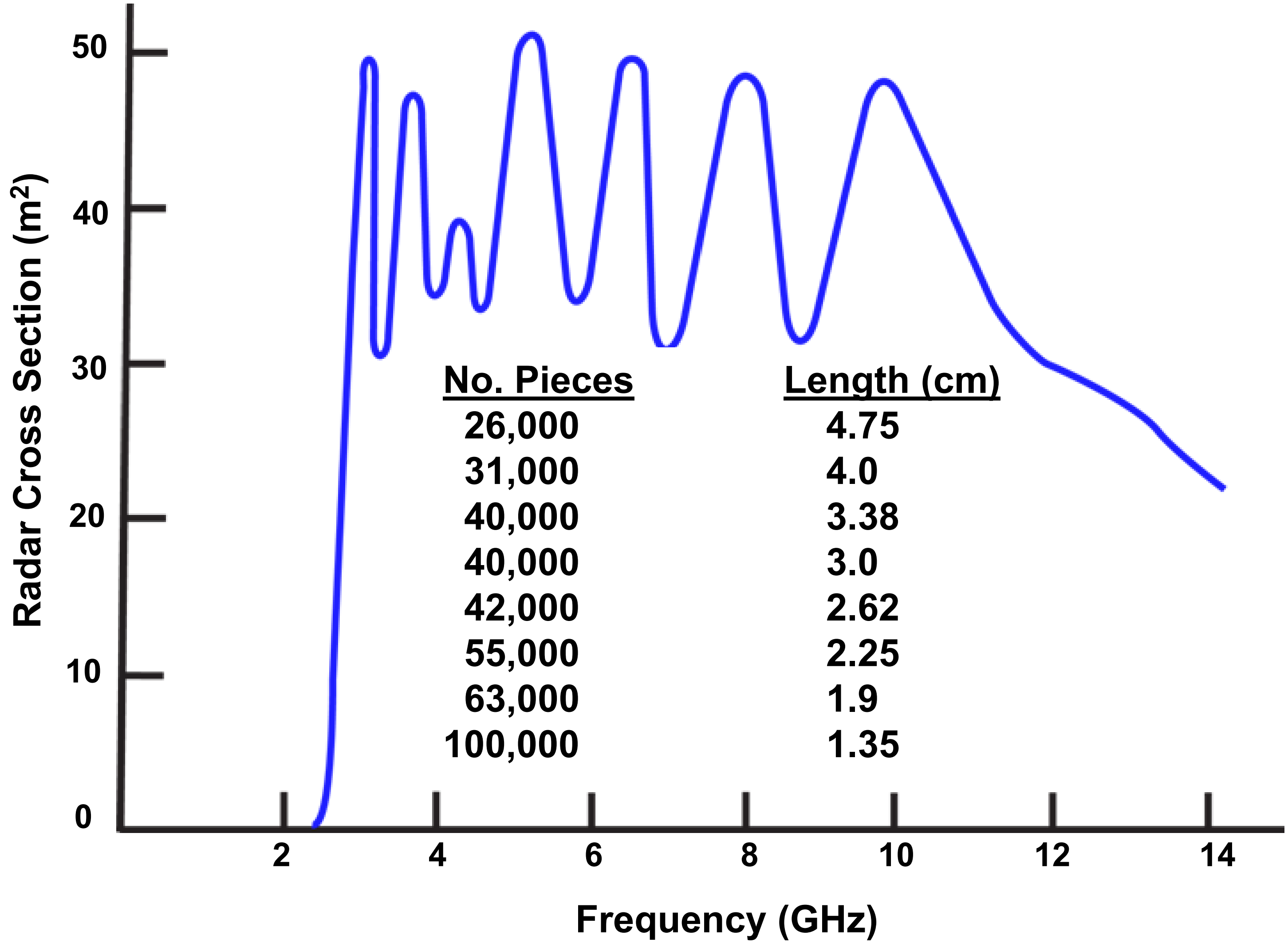
- **Bandwidth 10-15% of center frequency**
- **Wideband Chaff 1 - 10 GHz**
  - σ = 60 m^2 / lb
  - Variable length dipoles in a single package
- **Fall rates of chaff 0.5 to 3 m/s**
  - Nylon (coated) ~ 0.6 m/s
  - Aluminum ~ 1.0 m/s
  - Copper ~ 3.0 m/s

Frequency Response of Resonant Chaff



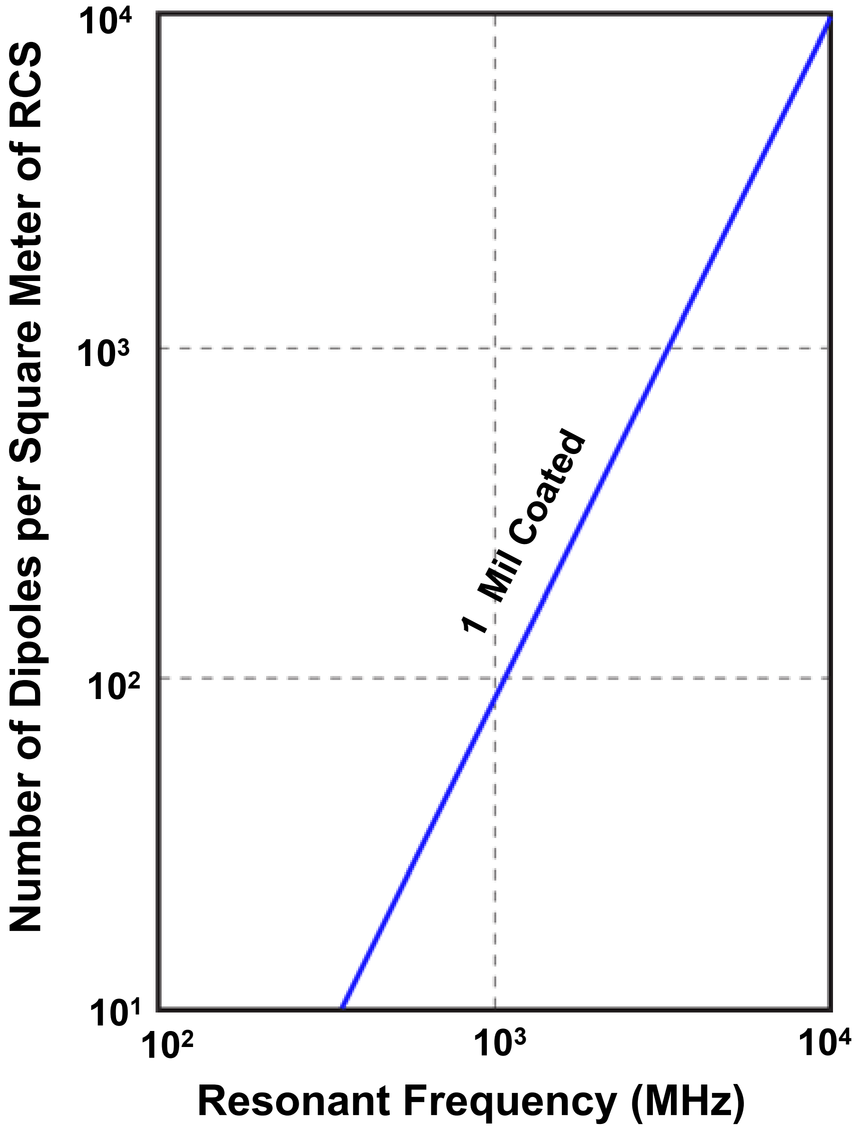
f_r = resonant frequency of chaff

RCS of Multi-band Chaff Package

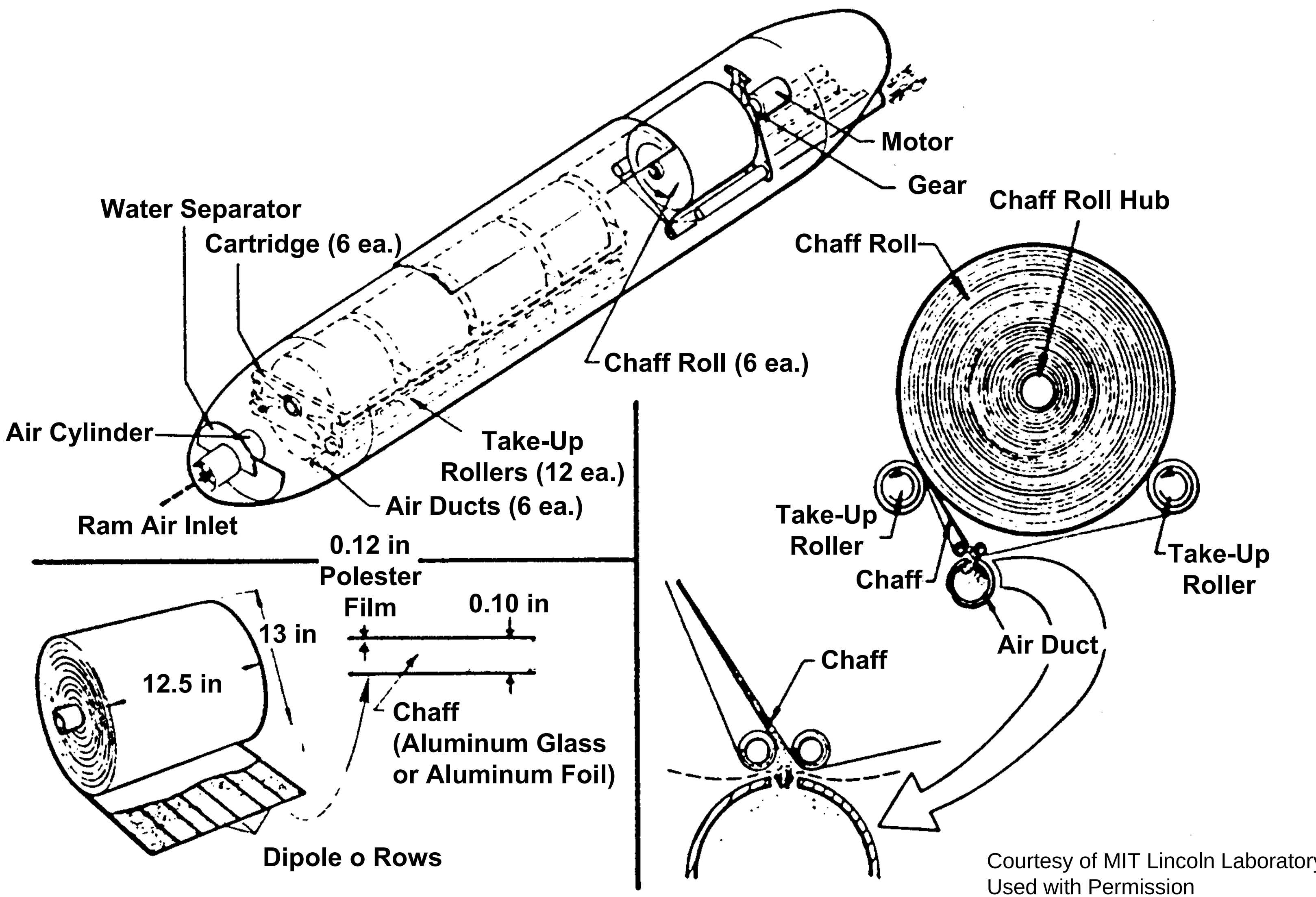


No. Pieces	Length (cm)
26,000	4.75
31,000	4.0
40,000	3.38
40,000	3.0
42,000	2.62
55,000	2.25
63,000	1.9
100,000	1.35

Theoretical Number of Chaff Dipoles Required per Square Meter of RCS



AN/ANE-38 Chaff-Dispensing System



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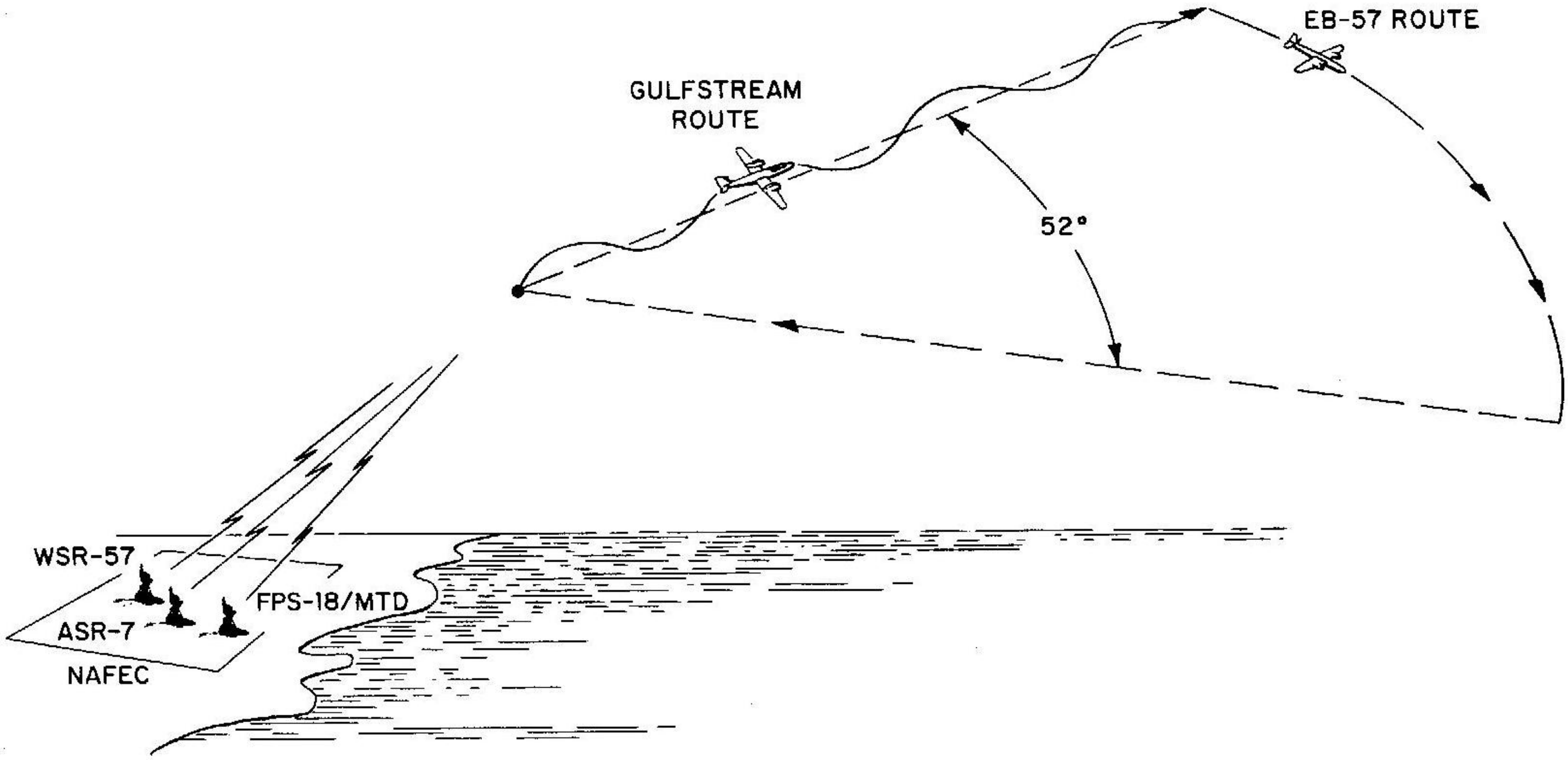
Chaff Dispersal Scenario



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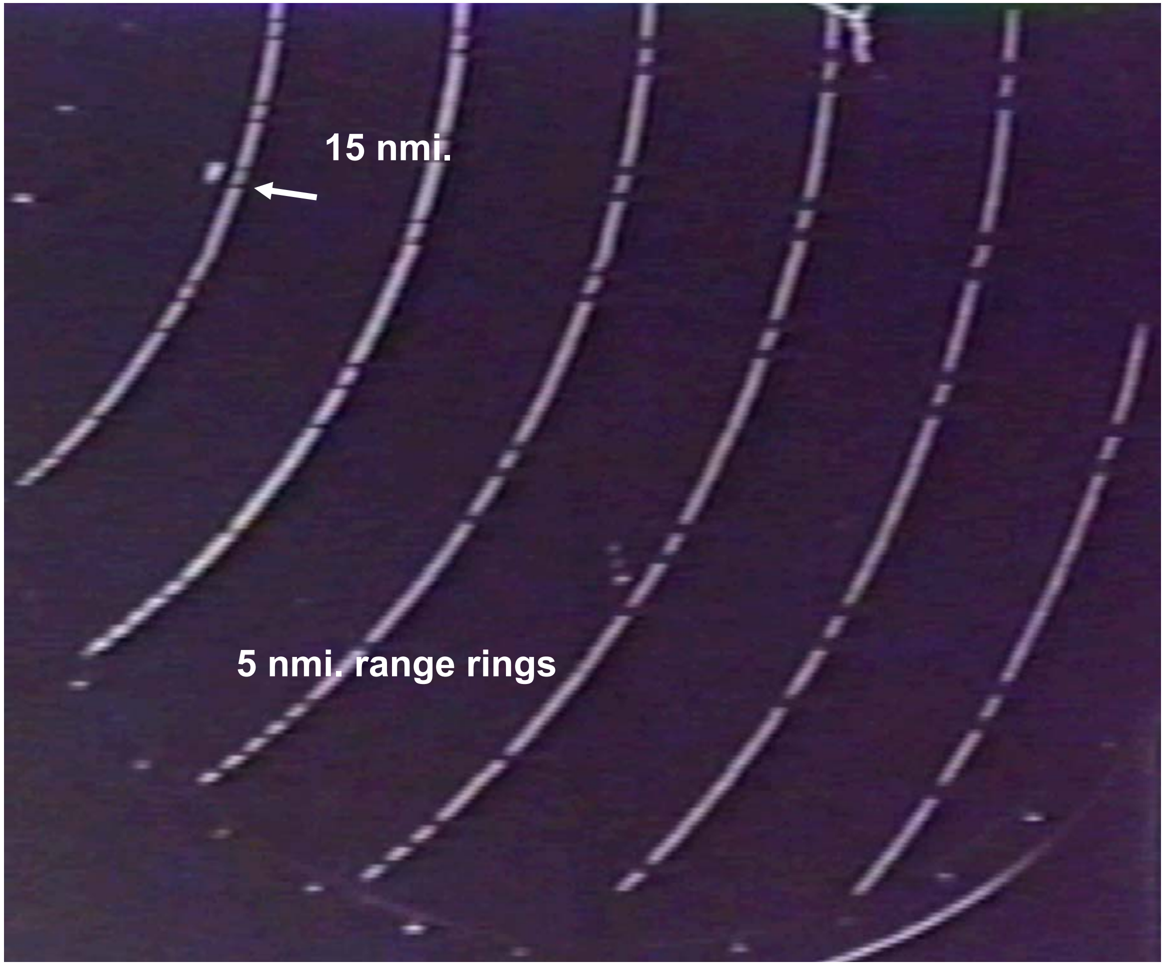
Start of Chaff Dispersal

T = 0 min.
Start of Chaff Deployment



"Normal Video"

Threshold just set just above noise level

8 ½ minutes of data displayed in 30 sec.

5 nmi range rings

Southeast quadrant from radar is displayed

Notice:

1. **The 30 knot wind moves the chaff cloud to the northeast**
2. **How the gradient of the wind with height spreads the chaff cloud**

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Movie of Chaff Dispersal

"Normal Video"

Threshold just set just above noise level

8 ½ minutes of data displayed in 30 sec.

5 nmi range rings

Southeast quadrant from radar is displayed

Notice:

1. **The 30 knot wind moves the chaff cloud to the northeast**
2. **How the gradient of the wind with height spreads the chaff cloud**

Courtesy of MIT Lincoln Laboratory
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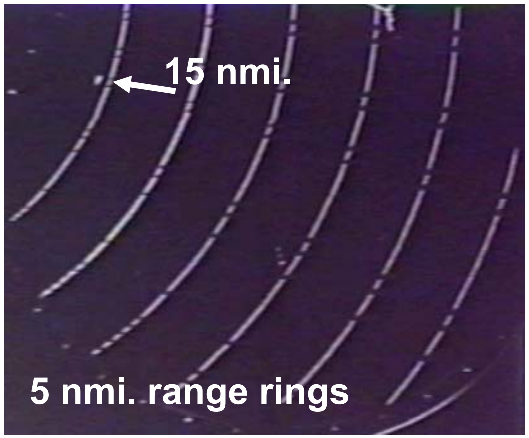
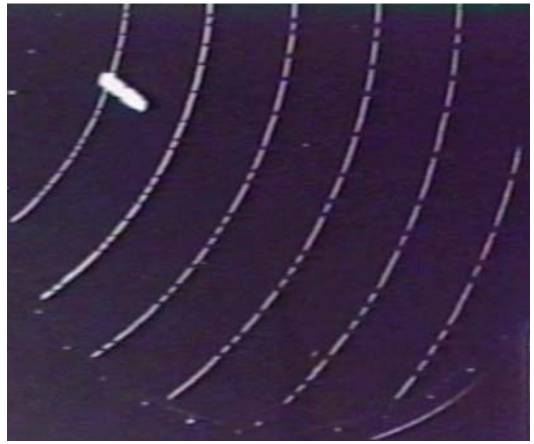
Sequential PPI Displays of Chaff Deployment and Drift by Wind

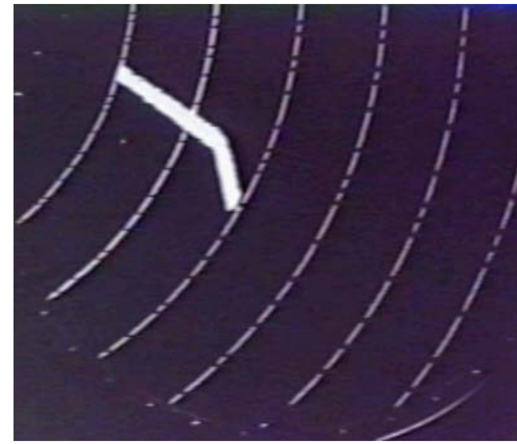
T = 0 min.
Start of Chaff Deployment

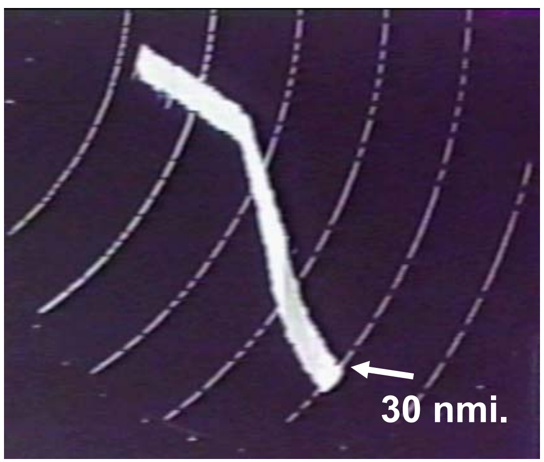


T = 1.2 min.

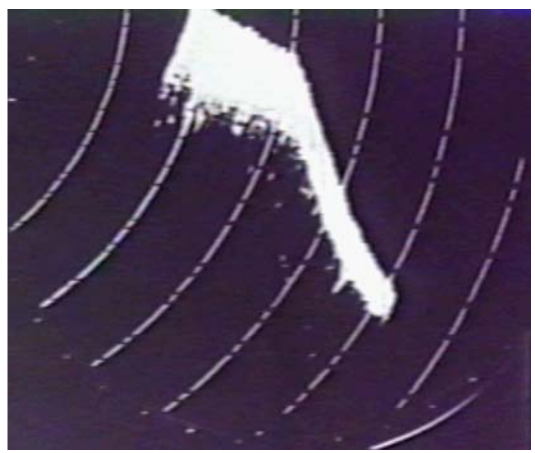


T = 2.7 min.

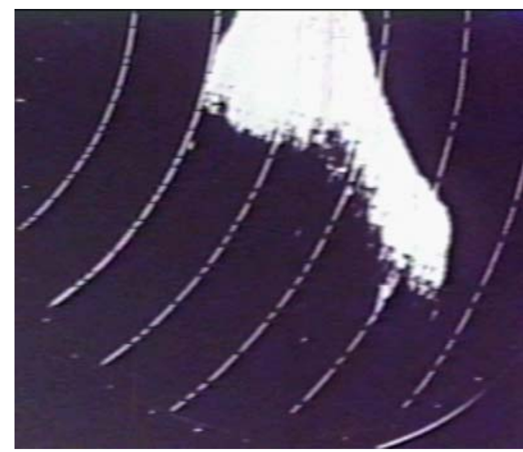




T = 6.7 min.
End of Chaff Deployment



T = 14.5 min.



T = 22 min.

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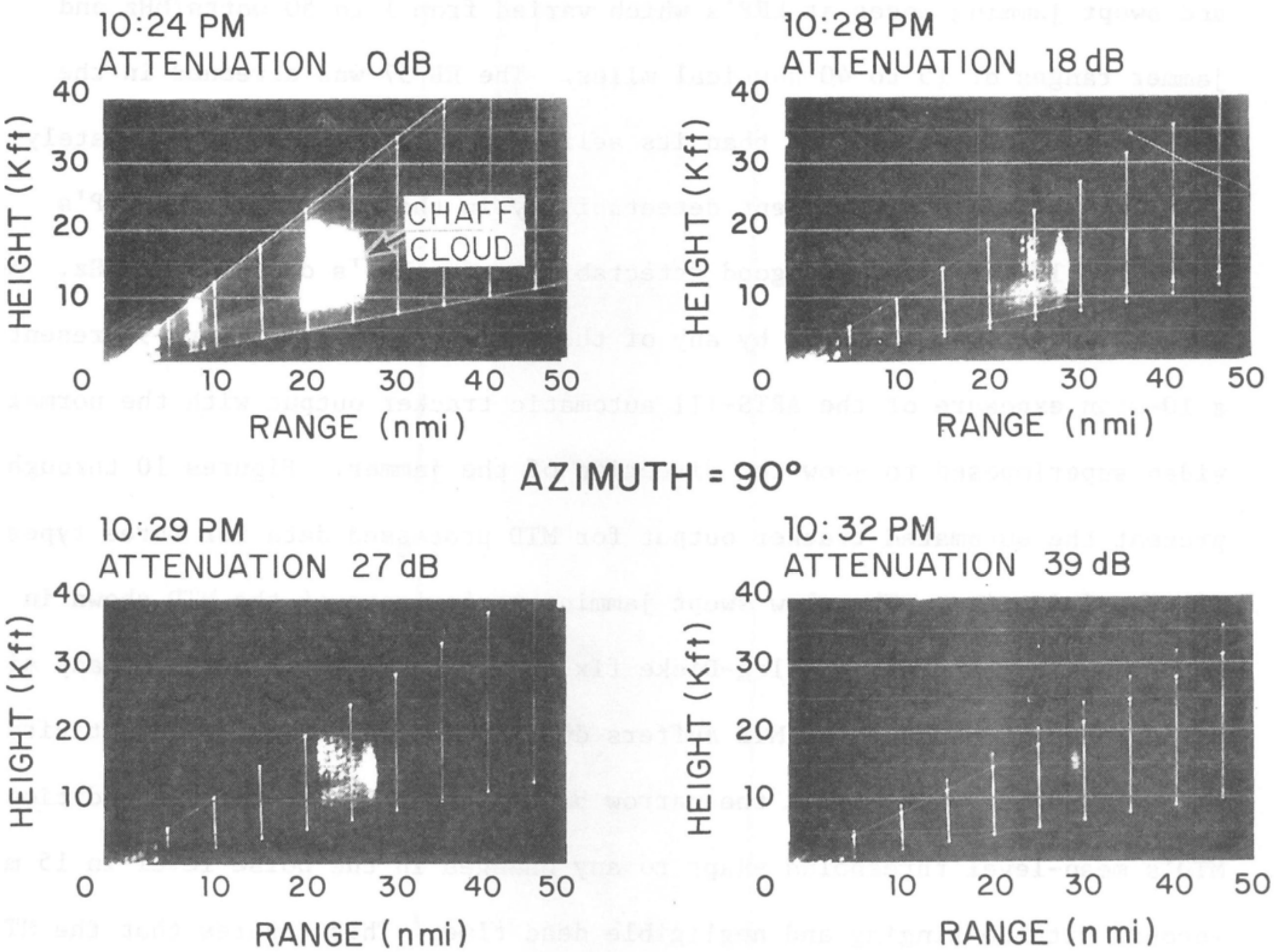
Range - Height Displays of Chaff Cloud



WSR-57 Weather Radar S-Band

Courtesy of MIT Lincoln Laboratory
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Automated Tracker Output on Aircraft During Chaff Exercise

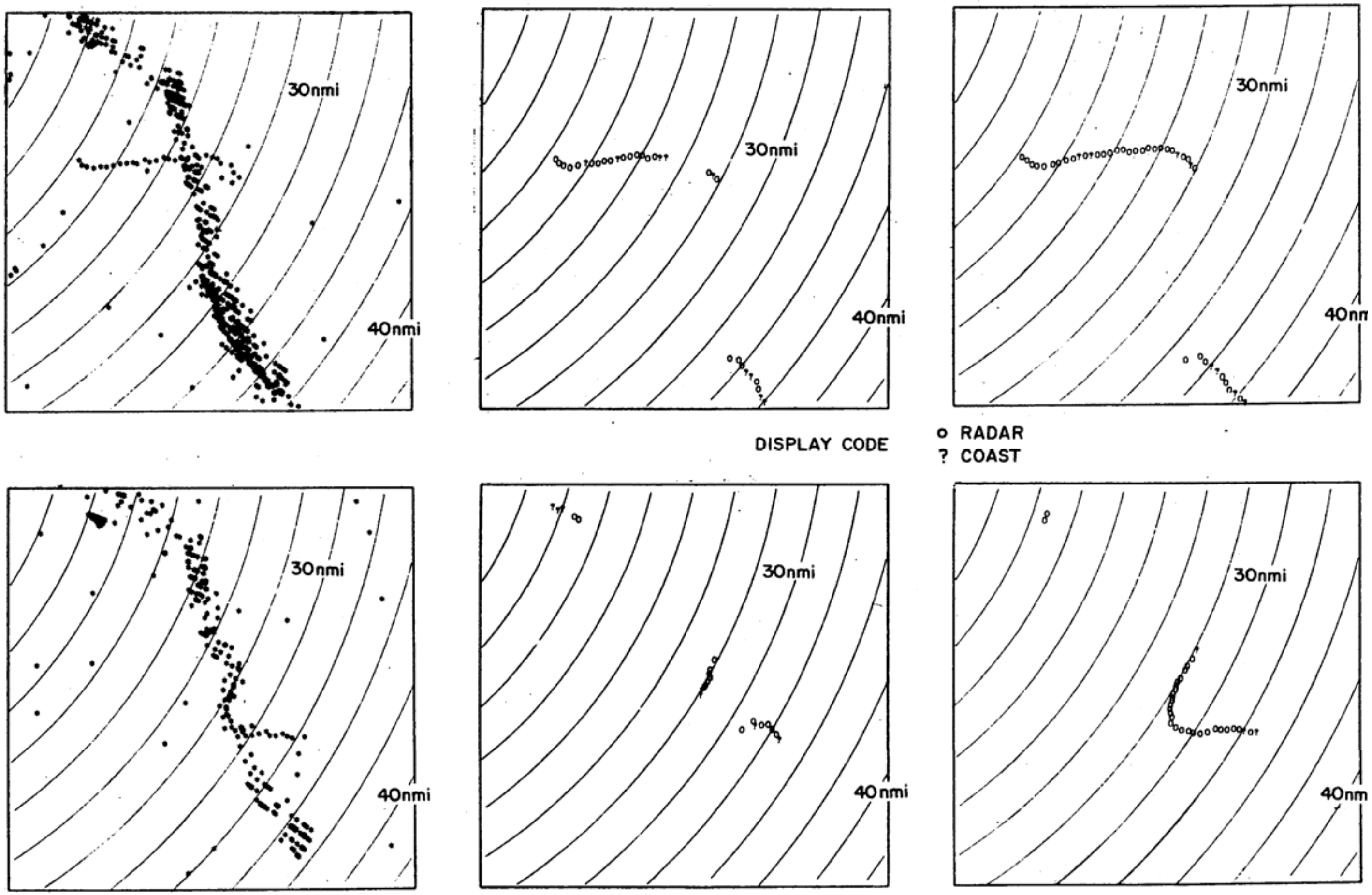
Raw Radar Reports Before Tracker

Tracker Output 3 Pulse MTI and Sliding Window Detector

Tracker Output Moving Target Detector (MTD) (Pulse Doppler Processor)

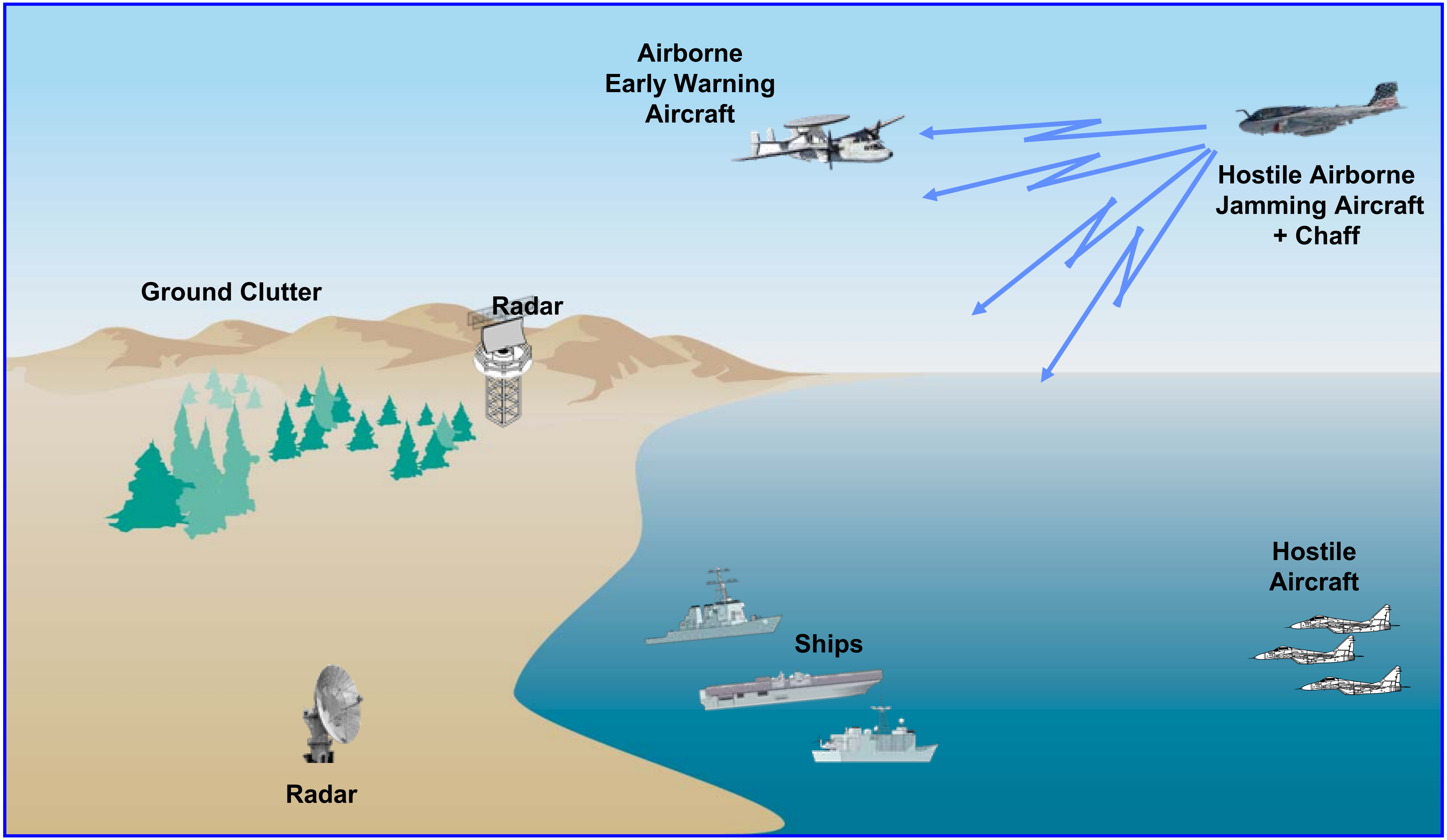
Scans 980 -1009

Scans 1010 -1039

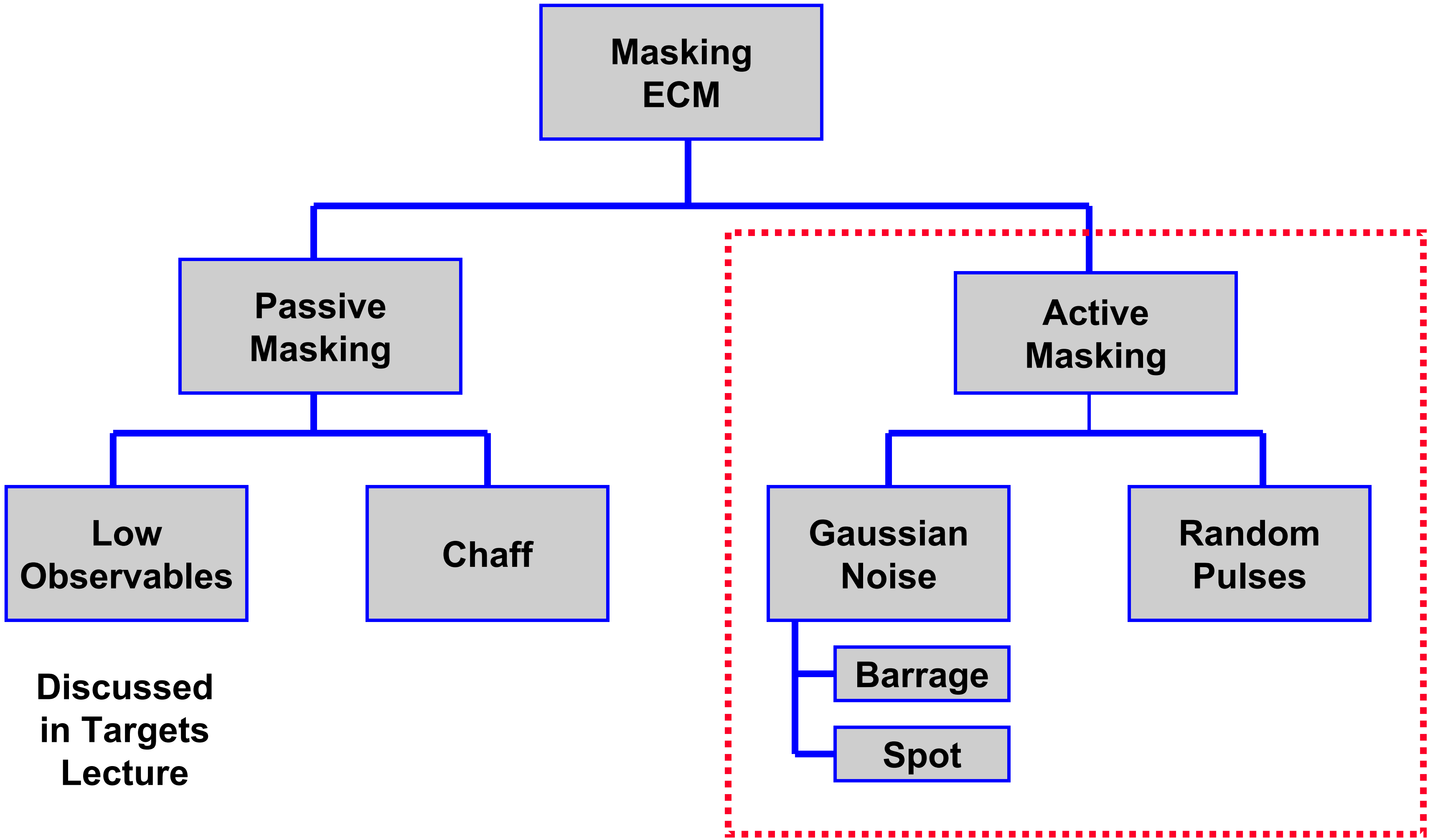


Two nmi Range Rings

Radar Environment



Masking ECM against Radar



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US Radar Jamming Systems

US Air Force EF-111A Raven

Courtesy of US Air Force

US Navy EA-6B Prowler

Courtesy of US Navy

- **Jammers generate a noise-like signal in the radar's frequency band**
- **There are a number of different types of noise jamming which will be examined**
  - **Standoff, escort, and self screening jammers (location)**
  - **Spot vs. barrage jamming (bandwidth)**

Active Masking

- **Receiver noise generally limits the sensitivity of most microwave radars**
  - Raising the noise level with a jammer will further degrade the sensitivity of the radar
  - Strobe - in main lobe
  - Massive false alarms - sidelobe jamming

- **Spot Jammer**
  - A jammer whose noise energy is concentrated within the receiver bandwidth
  - Frequency agility of the radar will force the jammer to distribute the jamming energy over a wide bandwidth
  - A large number of similar radars in a geographic area may also force the jammer to barrage mode

- **Barrage Jammer**
  - A jammer which radiates over a wide band of frequencies

Review - Radar Range Equation

Power density from isotropic antenna

$$\frac{P_T}{4\pi R_T^2}$$

R_T = **peak transmitter power**

Power density from directive antenna

$$\frac{P_T G_T}{4\pi R_T^2}$$

G_T = **transmit gain**

Power density of echo signal at radar

$$\frac{P_T G_T}{4\pi R_T^2} \frac{\sigma}{4\pi R_T^2}$$

σ = **radar cross section**

Power received by radar

$$P_R = \frac{P_T G_T}{4\pi R_T^2} \frac{\sigma A_E}{4\pi R_T^2}$$

P_R = **power received**

A_E = **effective area of receiving antenna**

Review - Radar Range Equation (continued)

Power received by radar from target
$$P_R = \frac{P_T G_T}{4\pi R_T^2} \frac{\sigma A_E}{4\pi R_T^2}$$

Target Signal-to Noise Ratio
$$\frac{P_R}{P_N} = \frac{P_T G_T}{4\pi R_T^2} \frac{\sigma A_E}{4\pi R_T^2 L} = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R_T^4 L k T_S B_N}$$

Where:
- L = Radar System Losses
- G_R = Receive Gain of Antenna
- k = Boltzmann Constant
- B_N = Receiver Bandwidth
- T_S = System Noise Temperature
- λ = Radar Wavelength

Need to calculate
Target Signal-to (Noise + Interference) Ratio = $\frac{P_R}{P_N + P_J}$

Jammer Power at Radar (P_J)

Jammer Noise Power at Radar

Jammer Effective Power Density (W/MHz) In the Receive Bandwidth of the Radar Δ_J

Jammer Effective Power Density (W/MHz) from directive antenna $\Delta_J G_R(\theta_J)$

Jammer Power at Received at Radar $$P_J = \frac{\Delta_J G_J(\theta_J)\lambda^2}{(4\pi)^2 R_J^2 L_J}$$

L_J = Jammer Receive Losses

R_J = Range from Radar to Jammer

$G_J(\theta_J)$ = Receive Gain in Jammer Direction

Note: The Jammer Effective Power Density includes the effects of jammer system's antenna gain, rf jammer losses, etc., that would alter the jammer signal, that is transmitted toward the radar to be jammed

$$\frac{P_R}{P_J + P_N} = \frac{\dfrac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R_T^4 L}}{\dfrac{\Delta_J G_J(\theta_J)\lambda^2}{(4\pi)^2 R_J^2 L_J} B_N + k T_S B_N}$$

Jammer Radar Range Equation (continued)

$$\frac{P_R}{P_J + P_N} = \frac{\dfrac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R_T^4 L}}{\dfrac{\Delta_J G_J(\theta_J)\lambda^2}{(4\pi)^2 R_J^2 L_J} B_N + k T_S B_N}$$

In many cases P_N is much less than P_J , therefore P_N can be neglected

Then:

$$\frac{S}{J} = \frac{P_R}{P_J} = \frac{P_T G_T G_R \sigma R_J^2 L_J}{4\pi R_T^4 L \Delta_J G_J(\theta_J) B_N}$$

- Assumes Bandwidth of jamming pulse matched to that of radar pulse

Standoff Jamming

- To avoid producing a beacon like emission from the target, masking jammers are operated from either standoff platforms or from escort vehicles
- Standoff jammers operate at a range which places it beyond the range of defensive systems supported by the radar
  - Orbits behind and/or side of the penetration corridor
  - One standoff jammer may cover several radars
- For a stand off jammer within one beamwidth of the target, the temperature due to the jammer often is 50 to 60 dB greater than that of the receiver

Example # 1a
Standoff Spot Mainlobe Jamming

- **Radar Parameters (ASR example)**
  - $G_T = G_R$ = 33 dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 ^oK
  - σ= 1 m^2 Target range 60 nmi
  - No. Pulses integrated 21

S/N = 14.4 dB

S/J = -4.1 dB

- **Scenario Parameters**
  - Range from radar to jammer aircraft 100 nmi
  - Range from radar to target 60 nmi
  - Jammer aircraft illuminates radar mainlobe

- **Airborne Standoff Jammer Parameters**
  - S-Band 2800 MHz
  - ERP (Δ_J) = 1000 W/MHz
  - Jammer Loss=1 dB

Example # 1b
Standoff Barrage Sidelobe Jamming

- Radar Parameters (ASR example)
  - $G_T = G_R = 33$ dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 ^{o}K
  - $\sigma = 1\ m^2$ Target range 60 nmi
  - No. Pulses integrated 21

S/N = 14.4 dB

S/J = 18.9 dB

- Scenario Parameters
  - Range from radar to jammer aircraft 100
  - nmi
  - Range from radar to target 60 nmi
  - Jammer aircraft illuminates radar sidelobes
  - Sidelobes down 23 dB from mainlobe
- Airborne Standoff Jammer Parameters
  - S-Band 2800 MHz
  - ERP (Δ_J) = 1000 W/MHz
  - Jammer Loss=1 dB

Example # 1c
Standoff Spot Sidelobe Jamming

- Radar Parameters (ASR example)
  - $G_T = G_R = 33$ dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 ^{o}K
  - $\sigma = 1\ m^2$ Target range 60 nmi
  - No. Pulses integrated 21

Ultra-low sidelobes on radar

S/N = 14.4 dB

S/J = 49.0 dB

- Scenario Parameters
  - Range from radar to jammer aircraft 100
  - nmi
  - Range from radar to target 60 nmi
  - Jammer aircraft illuminates radar sidelobes
  - Sidelobes down 55 dB from mainlobe
- Airborne Standoff Jammer Parameters
  - S-Band 2800 MHz
  - ERP (Δ_J) = 1000 W/MHz
  - Jammer Loss=1 dB

Example # 1d
Standoff Barrage Sidelobe Jamming

- Radar Parameters (ASR example)
  - $G_T = G_R$ = 33 dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 ^{o}K
  - σ= 1 m^2 Target range 60 nmi
  - No. Pulses integrated 21

S/N = 14.4 dB

S/J = 41.9 dB

- Scenario Parameters
  - Range from radar to jammer aircraft 100
  - nmi
  - Range from radar to target 60 nmi
  - Jammer aircraft illuminates radar sidelobes
  - Sidelobes down 23 dB from mainlobe

- Airborne Standoff Jammer Parameters
  - S-Band 2800- 3000 MHz
  - ERP (Δ_J) = 5 W/MHz
  - Jammer Loss=1 dB

Jammer forced to transmit over 200 MHz because of radar frequency hopping

Escort Screening Jamming

- **The escort screening jammer operates in a manner similar to the standoff jammer, but accompanies the penetrating raid, with some assigned range and cross range positions**
- **Calculation same as for standoff jammer**
  - **Range and angle to target will vary with target range reflecting approach of jammer with the raid**
- **Increasing the radar energy in the direction of the jammer in the hope of increasing the radar echo power above the jamming noise is called <u>burn-through</u>**
  - **The range when this occurs is the "burn-through range"**
- **Escort screening jammer is a tougher problem than the stand off jammer because the range is decreasing**
  - **Received jammer energy increasing**

Example # 2a
Escort Spot Mainlobe Jamming

- Radar Parameters (ASR example)
  - $G_T = G_R = 33$ dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 °K
  - $\sigma = 1\ m^2$ Target range 60 nmi
  - No. Pulses integrated 21

S/N = 14.4 dB

S/J = -0.5 dB

- Scenario Parameters
  - Range from radar to jammer aircraft 40 nmi
  - Range from radar to target 40 nmi
  - Jammer aircraft illuminates radar mainlobe
- Airborne Escort Jammer Parameters
  - S-Band 2800 MHz
  - ERP (Δ_J) = 100 W/MHz
  - Jammer Loss=1 dB

Escort jammers usually have less power than standoff jammers

Example # 2b
Escort Barrage Mainlobe Jamming

- Radar Parameters (ASR example)
  - $G_T = G_R$ = 33 dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 ^{o}K
  - σ= 1 m^2 Target range 60 nmi
  - No. Pulses integrated 21

S/N = 14.4 dB

S/J = 22.5 dB

- Scenario Parameters
  - Range from radar to jammer aircraft 60 nmi
  - Range from radar to target 60 nmi
  - Jammer aircraft illuminates radar mainlobe
- Airborne Escort Jammer Parameters
  - S-Band 2800- 3000 MHz
  - ERP (Δ_J) = 0.50 W/MHz
  - Jammer Loss=1 dB

Escort jammers usually have less power than standoff jammers

Jammer forced to transmit over 200 MHz because of radar frequency hopping

Self Screening Jamming

- "Self screening range" or "crossover range"
  - Range when radar echo will exceed the jammer signal
    - Jammer power, received at radar, varies with inverse square of the distance between the radar and the jammer
    - Radar echo power varies with inverse fourth power of the distance between the radar and the jammer
  - Even a small stand off jammer, operating in the barrage mode, can guarantee masking of the target echo

$$R_{SS}^{2} = \frac{P_T G_T G_R \sigma \; L_J}{4\pi \, L \, \Delta_J \; B_N} \left(\frac{J}{S}\right)_{MASK}$$

$\left(\frac{J}{S}\right)_{MASK}$ = Jammer to signal (power) ratio at the output of the IF required to mask the radar signal

Example # 3
Self-Screening Range Calculation

- Radar Parameters (ASR example)
  - $G_T = G_R = 33$ dB
  - Pulsewidth .6 μsec
  - Bandwidth = 1.67 MHz
  - Wavelength = 0.103 meters
  - Peak power of radar 1.4 Mw
  - Radar Losses 8 dB
  - Ts = 950 °K
  - $\sigma = 1\ m^2$ Target range 60 nmi
  - No. Pulses integrated 21

For this case R_{SS} = 20 nmi

- Scenario Parameters
  - Jammer aircraft flies straight toward radar
  - Jammer aircraft illuminates radar mainlobe
- Airborne Jammer Parameters
  - S-Band 2800 MHz
  - ERP (Δ_J) = 100 W/MHz
  - Jammer Loss= 1 dB

$\left(\frac{J}{S}\right)_{MASK}$ = Jammer to signal (power) ratio at the output of the IF required to mask the radar signal ≈ 10 dB

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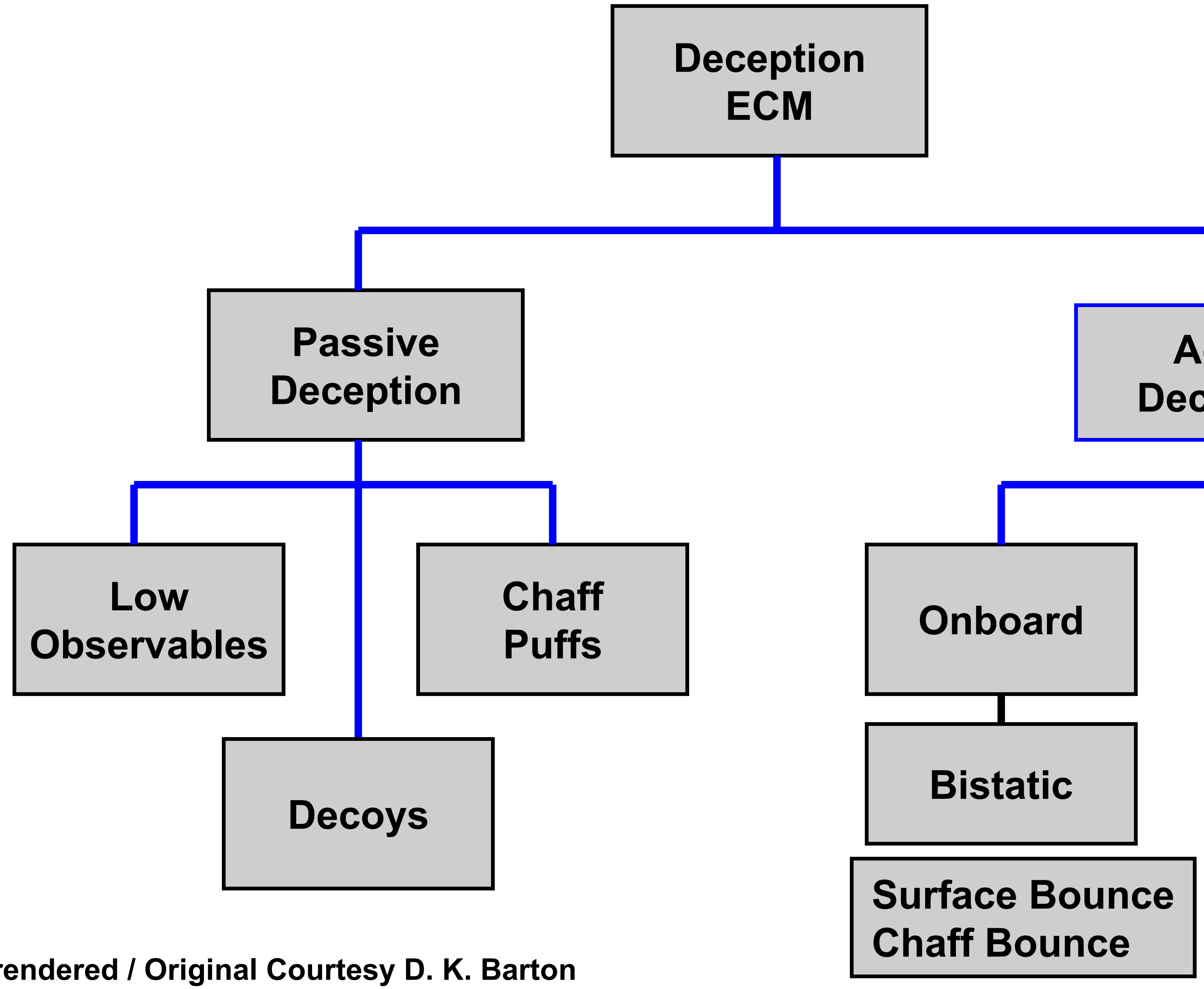
- Electronic Counter Measures (ECM)
  - Masking
  - Deception
  - Destruction
- Electronic Counter Counter Measures (ECCM)
- Summary

Deception ECM against Radar



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Passive Deception

- Low Observables
  - Contribute to the effectiveness of deception jamming by making the target less conspicuous
- Chaff Puffs
  - Discrete chaff puffs can create decoy targets in some situations
    - Anti-ship missile seekers generally use non coherent processing and whose targets have insufficient Doppler shift to distinguish them from chaff and sea clutter
- Decoys
  - The use of decoys with radar cross section and motion matching those of real targets can be effective against all classes of radar

Active Deception

- **A repeater jammer generates false echoes by delaying the received signals and re-transmitting at slightly later times**
- **Delaying the signals causes them to appear at different ranges and azimuths**
- **Types of repeater jammers**
  - **A transponder repeater plays back a stored replica of the radar signal after it is triggered by the radar**
  - **A range gate stealer is a repeater jammer whose function is to cause a tracking radar to "break lock"on the target**
    - **Delay of jamming pulses slowly changed, from delay of echo of the radar pulse, causing radar to track the repeater pulses**
  - **A velocity gate stealer transmits a signal which falsifies the targets speed or pretends that it is stationary**

Active Deception (continued)

- Repeater jammers can be very effective against an unprepared radar system
  - Relatively easy to counter
- Special purpose jammers require detailed knowledge of radar
  - Details are beyond the scope of this lecture

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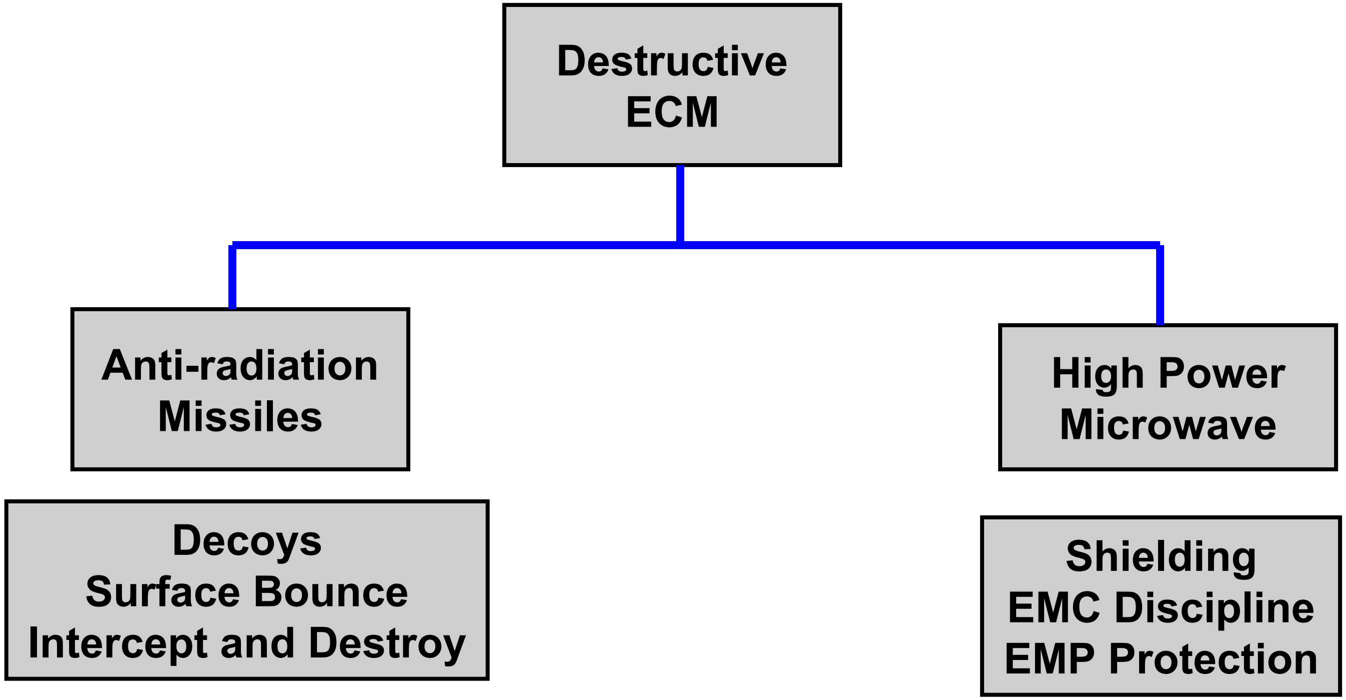
Destructive ECM against Radar



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Decoys

- **Problems of Anti-Radiation Missile (ARM) seekers**
  - **Resolution and acquisition of the correct radar signal**
  - **Maintaining a track on a signal with variable parameters**
  - **Obtaining accurate angle data on the source, especially when multiple reflections are present**

- **ESM equipment usually used to acquire and ID target**

- **Track can be maintained by angle gating of the signals from a broadband receiver accepting signals whose angle of arrival matches that of the designated victim**

- **The multi-path issue is critical to ARM operation**
  - **To reject multi-path, the ARM receiver typically uses a "leading edge tracker", in which only the first portion of each pulse is passed to the angle tracking circuits**
    - **Good for typical high elevation angle approaches of ARMs**

Outline

- Introduction
- Electronic Counter Measures (ECM)
- Electronic Counter Counter Measures (ECCM)
  - Masking
    - ⇒ Passive
    - Active
  - Deception
  - Destruction
- Summary

ECCM Against Passive Masking

- Constant False Alarm Rate (CFAR) thresholding
  - CFAR algorithms should be resistant to jamming signals
    - Rapid response to changing noise characteristics
    - The digital revolution enables this
- ECCM against chaff
  - Use of Pulse Doppler filtering banks in low PRF radars can significantly mitigate the effect of chaff
    - Diffuse wind blown clutter
    - Wind shear can be greater than rain
  - ECCM against chaff clouds requires a waveform which has a blind speed in excess of 100 m/s
    - Forces microwave radar to operate in the medium or high PRF mode with constant PRF bursts, or in the CW mode
    - UHF and lower frequencies can use staggered PRF with unambiguous range detection
      - Propagation limitations

Outline

- Introduction
- Electronic Counter Measures (ECM)
- Electronic Counter Counter Measures (ECCM)
  - Masking
    - Passive
    - ➡ Active
  - Deception
  - Destruction
- Summary

ECCM Against Active Masking - General

- **Jammer Effective Radiated Power (ERP) Dilution**
  - **Force jammer over greatest bandwidth**
  - **Direct spot jammer to wrong frequency**
- **Methods**
- **Sidelobe Jamming**
- **Mainlobe Jamming**

ECCM Against Active Masking - Methods

- **Frequency agility and diversity**
  - Burst to burst frequency agility may be sufficient
  - Use of parallel frequency diverse channels
- **Wideband transmissions**
  - Will force the jammer to a barrage mode
- **Polarization methods**
  - Since most jammers transmit circular polarization or linear at 45 degrees, two orthogonal receive channels can result in one channel orthogonal to the jammer
- **Deceptive transmissions**
  - Small off frequency (out of regular band) signals can be transmitted force the jammer much more broadband than the radar operates (good if jammer is in sidelobes)

ECCM Against Active Masking - Sidelobe Jamming

- Sidelobe Jamming
  - Low and Ultra Low Sidelobe Antennas
    - Can be reduced to -50 dB or less
    - These levels of sidelobe response make it extremely difficult for barrage jammers to raise the radar noise level by significant amounts
    - For ground based radar sites, ground reflections control the achievable sidelobe levels
  - Coherent sidelobe cancellers
    - Auxiliary antenna and receiver generate adaptive signal which cancels jamming entering main receiver
      - This increases sidelobes at other angles (use with caution)
  - Fully adaptive antennas permit both low sidelobes and sidelobe cancellation

ECCM against Active Masking - Mainlobe Jamming

- Require at least one antenna channel, independent of the main channel, with comparable gain

- Fully adaptive array meets this requirement with significant expense

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ECCM against Deception

- **Passive Deception**
  - Adequate number of detection and tracking channels to process the false targets while maintaining detection and track on true targets
  - Non-Cooperative Identification (NCID) techniques
    - High Range Resolution techniques
    - Doppler spectral analysis
    - Multiple frequency analysis of target RCS
    - Target trajectory analysis, etc, etc etc

- **Active Deception**
  - Ultra low sidelobe antennas
  - Sidelobe blanking
  - Receiver fixes
  - Monopulse radar fixes
    - Parallel channels with different time constants for AGC
  - Avoid hardware deficiencies

Outline

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ECCM against Destructive ECM

- **Destroy them with a SAM or AAM**

- **Destructive techniques**
  - **Low Probability of Intercept Radar**
    - **Use unusual waveforms (Code modulated, CW, impulses)**
    - **It is widely postulated that these waveforms cannot be detected or acquired by an ARM receiver designed to work against conventional short pulse or CW radars**
  - **Active decoys**
    - **Placement of decoys surrounding the radar and emiting similar signals can present the ARM with a confusing target**
    - **Defensive equivalent of multiple blinking jammers**
  - **Bistatic jamming**
    - **Illumination of the surrounding terrain by the radar main lobe can create the equivalent of multiple decoys**
      - **Radar pulse must have a gradually increasing leading edge to prevent ARM from using leading edge gate gating to reject the multipath**

Summary

- **Electronically active and passive techniques have been described , which can potentially degrade the performance of microwave radar systems**
- **Passive techniques – Chaff, decoys**
- **Active techniques**
  - **Jammers generate a noise-like signal in the radar's frequency band**
  - **There are a number of different types of noise jamming which will be examined**
    - **Standoff, escort, and self screening jammers (location)**
    - **Spot vs. barrage jamming (bandwidth)**
  - **Repeater jammers were also examined**
- **Techniques have been developed which mitigate these ECM techniques (ECCM) and are discussed to some degree**

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By “RMOD Radar Systems”

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By “RMOD Radar Systems”

Problems

- 1 A C-Band (wavelength = 5.5 cm) pencil beam radar has peak power of 1 MW, 1 μsec pulsewidth. Its antenna diameter is 5 meters diameter and has an efficiency of 0.6. The system noise temperature is 825°K and the total system losses are 7 dB. What is the S/N(in dB) for a single pulse on a 1 m^2 target at a range of 150 nmi?

- 2. If a mainlobe jammer has an ERP of 300 w/MHz and 1 dB jammer losses and is located at 125 nmi from the radar, what is the S/J (in dB) ratio for a single pulse on a 1 m^2 target at a range of 150 nmi? (For problems 2 through 5) assume that the bandwidth of the jammer and the radar are matched ($B_J = B_N$)

- 3. What is the S/(N+J) for the scenario and radar?

Problems

- 4.For the mainlobe jamming scenario and parameters in problem 2, what in the Self-Screening range (in nmi)? Assume

$$\left(\frac{J}{S}\right)_{MASK} = 10\,dB$$

5. If a jammer illuminates the above radar's sidelobes (assume they are 24 dB down from the mainlobe) and the jammer has an ERP of 250 w/MHz, 1 dB jammer losses and is located 50 nmi from the radar, what is the S/(N+J) (in dB) ratio for a single pulse on a 1 m^2 target at a range of 150 nmi?