Phased Array Radar Basics

Jeffrey Herd

MIT Lincoln Laboratory

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• History and Evolution of Phased Arrays
• Phased Array Radar Fundamentals
  – Array Beamforming
  – Electronic Scanning
  – Active Transmit-Receive Modules
• Summary
# Radar Antenna Architectures

<table>
<thead>
<tr>
<th><strong>Dish Antenna</strong></th>
<th><strong>Passive Phased Array</strong></th>
<th><strong>Active Phased Array</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Dish Antenna Diagram" /></td>
<td><img src="image2.png" alt="Passive Phased Array Diagram" /></td>
<td><img src="image3.png" alt="Active Phased Array Diagram" /></td>
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<tr>
<td><strong>PRO</strong></td>
<td><strong>CON</strong></td>
<td><strong>PRO</strong></td>
</tr>
<tr>
<td>- Very low cost</td>
<td>- High distribution loss</td>
<td>- Highest performance</td>
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<tr>
<td>- Frequency diversity</td>
<td>- Higher cost</td>
<td>- Effective radar resource management</td>
</tr>
<tr>
<td>- Slow scan rate</td>
<td>- Highest cost</td>
<td>- Low distribution loss</td>
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<td></td>
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</tbody>
</table>

**MILLSTONE**

**SPY-1**

**THAAD**
Dish Radar Example

• MIT LL Millstone Radar
  – 2 Klystrons with 3 MW peak power
  – 120 kW avg power
  – Center Frequency of 1295 MHz
  – 8 MHz bandwidth

• Advantages
  – High output power
  – Low cost per watt

• Disadvantages
  – Single point of failure
  – Large size

Millstone Klystron Tube

• $400,000/tube
• 7 ft x 1ft
• 600 lbs
• 3% duty cycle
• 42 dB gain
Solid State Array Radar Example

- **PAVE PAWS**
  - First all-solid-state array radar
  - UHF Band
  - 1800 active transceiver T/R modules, 340 W of peak power each

- Advantages
  - Electronic beam agility
  - Low maintenance (no moving parts)
  - Graceful degradation

- Disadvantages
  - Higher cost per watt
Phased Array Radar Evolution

Passive Arrays
(Phase Shifter at Element)

Airborne
- B-1B
  - X-Band
- JSTARS
  - X-Band

Surface
- Patriot
  - C-Band
- SPY-1
  - S-Band

Active Arrays
(Amplifiers + Phase Shifter at Element)

- F/A-22
  - X-Band
- JSF
  - X-Band
- MP-RTIP
  - X-Band

Increasing Beam Agility

Timeline:
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010
- 2015

Increasing Beam Agility
Outline

• History and Evolution of Phased Arrays

• Phased Array Radar Fundamentals
  – Array Beamforming
  – Electronic Scanning
  – Active Transmit-Receive Modules

• Summary
Array Beamforming

- Multiple antennas combined to enhance radiation and shape pattern.
Array Beamforming (Beam Collimation)

- Want fields to interfere constructively (add) in desired directions, and interfere destructively (cancel) in the remaining space.

**Broadside Beam**

- Elements 1 through N with phase differences to form a broadside beam.

**Scan To 30 deg**

- Diagram showing the beam scan to 30 degrees, with phase adjustments at each element to maintain the beam direction.

Scan Angle

- Elements 1 through N with phase differences to form a broadside beam.

d

- Space between elements.
**Broadside Uniform Linear Array**

**Design Goal**
- Maximum at $\theta = 90^\circ$
- $\psi = k_d \cos \theta + \beta|_{\theta=90^\circ} = 0$

**Required Phase**
- $\beta = 0$

$L = (N-1) d$  
$N = 10$ Elements

- $d = \lambda/4$ separation
  - 7 dBi

- $d = \lambda/2$ separation
  - 10 dBi

- $d = \lambda$ separation
  - 10 dBi

Limit element separation to $d < \lambda$ to prevent grating lobes for broadside array
Increasing Broadside Linear Array Size by Adding Elements

- Element Separation $d = \lambda / 2$

**Graphs:**
- **N = 10 Elements**
  - Directivity (dBi): 10 dBi
  - Angle off Array $\theta$ (deg): 0, 30, 60, 90, 120, 150, 180

- **N = 20 Elements**
  - Directivity (dBi): 13 dBi
  - Angle off Array $\theta$ (deg): 0, 30, 60, 90, 120, 150, 180

- **N = 40 Elements**
  - Directivity (dBi): 16 dBi
  - Angle off Array $\theta$ (deg): 0, 30, 60, 90, 120, 150, 180

**Equation:**
Gain $\approx 2N(d / \lambda) \approx 2L / \lambda$

for long broadside array without grating lobes

* $d < \lambda$
Excitation Amplitudes
Tapers Across 10 Element Linear Array

**Uniform Amplitude**
- Amplitude: Uniform
- Sidelobe Level (SLL): 13 dB

**26 dB Dolph-Tschebyscheff**
- Amplitude: 26 dB
- Sidelobe Level (SLL): 26 dB

**Binomial**
- Amplitude: Binomial
- Sidelobe Level (SLL): -

Amplitude & Phase Errors Limit the Sidelobe Level (SLL) That Can Be Achieved in Practice: > 40 dB is Challenging

MIT Lincoln Laboratory
Radar Course
JSH -12
Polarization

- Defined by behavior of the electric field vector as it propagates in time

Electromagnetic Wave

- Vertical Linear (with respect to Earth)
- Horizontal Linear (with respect to Earth)
Active Array T/R Module

Critical Technologies:
- Power amplifiers
  - High gain
  - High efficiency
- Low noise amplifiers
  - Low signal intermodulation
  - Low drain power
- Packaging
  - Thermal management
  - Light weight
- High levels of integration reduce unit cost
- Automated assembly and test reduces touch labor cost
Summary

- Phased array provides improvements in radar functionality and performance
  - Beam agility
  - Effective radar resource management
  - Graceful degradation with module failures

- Current trend is towards active arrays with distributed T/R modules
  - Large number of distributed active components and control
  - High levels of integration required to achieve low cost
References

• General Antenna Theory and Design:

• Special Topics:

• Handbooks: