Radar Systems Engineering
Lecture 9
Antennas
Part 2 - Electronic Scanning and Hybrid Techniques

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Guest Lecturer
Block Diagram of Radar System

Transmitter
- Power Amplifier
- Waveform Generation

Signal Processor Computer
- Pulse Compression
- Clutter Rejection (Doppler Filtering)

General Purpose Computer
- Tracking
- Parameter Estimation
- Thresholding
- Detection

User Displays and Radar Control

Data Recording

Photo Image
Courtesy of US Air Force
Used with permission.
Antenna Functions and the Radar Equation

• “Means for radiating or receiving radio waves”*
  – A radiated electromagnetic wave consists of electric and magnetic fields which jointly satisfy Maxwell’s Equations

• Direct microwave radiation in desired directions, suppress in others

• Designed for optimum gain (directivity) and minimum loss of energy during transmit or receive

\[
\text{Track Radar Equation: } \frac{S}{N} = \frac{P_t G^2 \lambda^2 \sigma}{(4 \pi)^3 R^4 k T_s B_n L}
\]

\[
\text{Search Radar Equation: } \frac{S}{N} = \frac{P_{av} A_e t_s \sigma}{4 \pi \Omega R^4 k T_s L}
\]

G = Gain
\[A_e = \text{Effective Area}\]
\[T_s = \text{System Noise Temperature}\]
L = Losses

Radar Antennas Come in Many Sizes and Shapes

Electronic Scanning Antenna

Mechanical Scanning Antenna

Hybrid Mechanical and Frequency Scanning Antenna

Courtesy US Army

Courtesy of MIT Lincoln Laboratory Used with Permission

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Courtesy of Raytheon Used with Permission

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Mechanical Scanning Antenna

Electronic Scanning Antenna

Hybrid Mechanical and Frequency Scanning Antenna
Outline

• Introduction
• Antenna Fundamentals
• Reflector Antennas – Mechanical Scanning
• Phased Array Antennas
  – Linear and planar arrays
  – Grating lobes
  – Phase shifters and array feeds
  – Array feed architectures
• Frequency Scanning of Antennas
• Hybrid Methods of Scanning
• Other Topics
Arrays

- Multiple antennas combined to enhance radiation and shape pattern

Isotropic Element

Array

Array

Phased Array

 Courtesy of MIT Lincoln Laboratory
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Two Antennas Radiating

*driven by oscillating sources (in phase)

[Graph depicting two dipoles labeled Dipole 1* and Dipole 2*.]

Courtesy of MIT Lincoln Laboratory
Used with Permission
Array Beamforming (Beam Collimation)

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

**Broadside Beam**

**Scan To 30 deg**

<table>
<thead>
<tr>
<th>Element Number</th>
<th>Signal Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

- Courtesy of MIT Lincoln Laboratory
- Used with Permission
Controls for an N Element Array

- Geometrical configuration
  - Linear, rectangular, triangular, etc

- Number of elements $N$

- Element separation $D$

- Excitation phase shifts $\phi_n$

- Excitation amplitudes $a_n$

- Pattern of individual elements
  - Dipole, monopole, etc.

Element Number | Element Excitation
--- | ---
$N$ | $a_N e^{j\phi_N}$
4 | $a_4 e^{j\phi_4}$
3 | $a_3 e^{j\phi_3}$
2 | $a_2 e^{j\phi_2}$
1 | $a_1 e^{j\phi_1}$

Array Factor
Antenna Element

Courtesy of MIT Lincoln Laboratory
Used with Permission
The “Array Factor”

- The “Array Factor” AF, is the normalized radiation pattern of an array of isotropic point-source elements

\[
AF(\theta, \phi) = \sum_{n=1}^{N} a_n e^{j\phi_n} e^{jk \hat{r}_n \cdot \hat{r}}
\]

Source Element \( n \):

- Excitation: \( a_n e^{j\phi_n} \)
- Position Vector: \( \vec{r}_1 = \hat{x}x_n + \hat{y}y_n + \hat{z}z_n \)

Observation Angles \((\theta, \phi)\):

- Observation Vector: \( \hat{r} = x \sin \theta \cos \phi + \hat{y} \sin \theta \sin \phi + \hat{z} \cos \theta \)

Free-Space Propagation Constant:

\[
k = \frac{2\pi}{\lambda} = \frac{2\pi f}{c}
\]
Array Factor for N Element Linear Array

\[
AF(\theta, \phi) = \sum_{n=1}^{N} a_{n-1} e^{j\phi_{n-1}} e^{j k \hat{r}_{n-1} \cdot \hat{r}} = A \sum_{n=0}^{N-1} e^{j n (k d \cos \theta + \beta)} = A \sum_{n=0}^{N-1} e^{j n \psi (\theta)}
\]

Where: \( \psi (\theta) = k d \cos \theta + \beta \) and,

It is assumed that:

- Phase progression is linear, \( e^{j \phi_n} = e^{j n \beta} \), \( a_n \) is real.
- The array is uniformly excited \( a_n = A \)

Using the identity:

\[
\sum_{n=0}^{N-1} c^n = \frac{c^N - 1}{c - 1}
\]

The Normalized Array Factor becomes:

\[
AF(\theta, \phi) = \frac{\sin(N \psi / 2)}{N \sin(\psi / 2)}
\]

Main Beam Location

\[
\psi = k d \cos \theta + \beta = 0
\]

\[
\frac{\psi}{2} = \frac{1}{2} (k d \cos \theta + \beta) = \pm m \pi
\]
Properties of N Element Linear Array

• Major lobes and sidelobes
  – Mainlobe narrows as $N$ increases
  – No. of sidelobes increases as $N$ increases
  – Width of major lobe = $2\pi/N$
  – Height of sidelobes decreases as $N$ increases

• Changing $\beta$ will steer the peak of the beam to a desired $\theta = \theta_o$
  – Beam direction varies from $0$ to $\pi$
  – $\psi$ varies from $-kd + \beta$ to $kd + \beta$

• Condition for no grating lobes being visible:

$$\frac{d}{\lambda} < \frac{1}{1 + |\cos \theta_o|}$$

$\theta_o =$ angle of broadside

Note how $\theta$ is defined.
Array and Element Factors

Ten Element Linear Array – Scanned to 60 °

- Total Pattern = Element Factor X Array Factor

- Element Factor \( E_e(\theta) = \sqrt{\cos \theta} \)

- Array Factor \( E_a(\theta) = \frac{\sin 5\pi (\sin \theta - 0.866)}{10 \sin((\pi / 2)\sin \theta - 0.866)} \)

Adapted from Frank in Skolnik Reference 2
Array Gain and the Array Factor

The Overall Array Gain is the Product of the Element Gain and the Array Factor Gain

\[
\text{Array Gain (dBi)} = \text{Element Gain (dBi)} + \text{Array Factor Gain (dBi)}
\]

Array Factor Gain

\[
G_{\text{AF}}(\theta, \phi) = \frac{4\pi |\text{AF}(\theta, \phi)|^2}{P_{\text{RAD}}}
\]

\[
P_{\text{RAD}} = \int_{0}^{2\pi} \int_{0}^{\pi} |\text{AF}(\theta, \phi)|^2 \sin \theta \, d\theta \, d\phi
\]

Individual Array Elements are Assumed to Be Isolated
Homework Problem – Three Element Array

• Student Problem:
  
  – Calculate the normalized array factor for an array of 3 isotropic radiating elements. They are located along the x-axis (center one at the origin) and spaced $\lambda/2$ apart. Relevant information is 2 and 3 viewgraphs back.

  – Use the results of this calculation and the information in viewgraph 28 of “Antennas Part 1” to calculate the radiation pattern of a linear array of three dipole, $\lambda/2$ apart on the x-axis.
Increasing Array Size by Adding Elements

Linear Broadside Array
Isotropic Elements
Element Separation \( d = \lambda/2 \)
No Phase Shifting

- **Gain ~ 2N(d / \lambda)** for long broadside array

\( N = 10 \text{ Elements} \)

\( N = 20 \text{ Elements} \)

\( N = 40 \text{ Elements} \)

Figure by MIT OCW.

Courtesy of MIT Lincoln Laboratory
Used with Permission
Increasing Broadside Array Size by Separating Elements

Design Goal
Maximum at $\theta = 90^\circ$

\[ \psi = k d \cos \theta + \beta \Big|_{\theta=90^\circ} = 0 \]

Required Phase
$\beta = 0$

\[ L = (N-1) d \]

$N = 10$ Elements

Limit element separation to $d < \lambda$ to prevent grating lobes for broadside array

Courtesy of MIT Lincoln Laboratory
Used with Permission
Ordinary Endfire Uniform Linear Array

**Design Goal**

Maximum at $\theta = 90^\circ$

$$\psi = k d \cos \theta + \beta \bigg|_{\theta = 90^\circ} = 0$$

**Required Phase**

$$\beta = 0$$

$L = (N-1) d$

**N = 10 Elements**

- No grating lobes for element separation $d < \lambda / 2$
- Gain $\sim 4N(d / \lambda) \sim 4L / \lambda$ for long endfire array without grating lobes

Figure by MIT OCW.

Courtesy of
MIT Lincoln Laboratory
Used with Permission
### Linear Phased Array

Scanned every 30 deg, \( N = 20, \ d = \lambda / 4 \)

![Graph showing the gain and beamwidth for different scans](image)

#### Design Goal

Maximum at \( \theta = \theta_o \)

At Design Frequency \( f_o \)

\[
\psi = k_o \ d \cos \theta_o + \beta = 0
\]

#### Required Phase

\[
\beta = -k_o \ d \cos \theta_o \\
k_o = \frac{2 \pi f_o}{c}
\]

To scan over all space without grating lobes, keep element separation \( d < \lambda / 2 \)

---

To scan over all space without grating lobes, keep element separation \( d < \lambda / 2 \).
Uniform Planar Array

Two Dimensional Planar array
(M x N Rectangular Pattern)

AF_n(\theta,\phi) = \left\{ \begin{array}{l} \frac{1}{M} \sin\left(\frac{M\psi_x}{2}\right) \\ \frac{1}{N} \sin\left(\frac{N\psi_y}{2}\right) \end{array} \right\}

where \psi_x = kd_x \sin \theta \cos \phi + \beta_x \n\psi_y = kd_y \sin \theta \sin \phi + \beta_y

Progressive phase to scan to (\theta_o, \phi_o):

\beta_x = -kd_x \sin \theta_o \cos \phi_o \n\beta_y = -kd_y \sin \theta_o \sin \phi_o

- To scan over all space without grating lobes: \(d_x < \lambda / 2\) and \(d_y < \lambda / 2\)
\[ \Lambda F_n(\theta, \phi) = \begin{vmatrix} \frac{1}{M} \sin \left( \frac{M\psi_x}{2} \right) & \frac{1}{N} \sin \left( \frac{N\psi_y}{2} \right) \\ \sin \left( \frac{\psi_x}{2} \right) & \sin \left( \frac{\psi_y}{2} \right) \end{vmatrix} \]

where \( \psi_x = kd_x \sin \theta \cos \phi + \beta_x \)
\( \psi_y = kd_y \sin \theta \sin \phi + \beta_y \)

Progressive phase to scan to \((\theta_o, \phi_o)\):
\[ \beta_x = -kd_x \sin \theta_o \cos \phi_o \]
\[ \beta_y = -kd_y \sin \theta_o \sin \phi_o \]

- To scan over all space without grating lobes: \( d_x < \lambda / 2 \) and \( d_y < \lambda / 2 \)

Figure by MIT OCW.
Change in Beamwidth with Scan Angle

• The array beamwidth in the plane of scan increases as the beam is scanned off the broadside direction.
  – The beamwidth is approximately proportional to $1 / \cos \theta_o$
  – where $\theta_o$ is the scan angle off broadside of the array

• The half power beamwidth for uniform illumination is:
  $$\theta_B \approx \frac{0.886\lambda}{Nd \cos \theta_o}$$

• With a cosine on a pedestal illumination of the form:
  $$A = a_o + 2a_1 \cos (2\pi n / N)$$
  – And the corresponding beamwidth is:
  $$\theta_B \approx \frac{0.886\lambda}{Nd \cos \theta_o} \left[1 + 0.636(2a_1 / a_o)\right]$$

• In addition to the changes in the main beam, the sidelobes also change in appearance and position.
Time Delay vs. Phase Shifter Beam Steering

- Time delay steering requires:
  - Switched lines
- It is a relatively lossy method
- High Cost
- Phase shifting mainly used in phased array radars

Time Delay Steering
\[ \text{Time Shift} = \left(\frac{d}{c}\right) \sin \theta_o \]

Phase Shifter Steering
\[ \text{Phase Shift} = 2\pi \left(\frac{d}{\lambda}\right) \sin \theta_o \]

Adapted from Skolnik, Reference 1
The most prevalent cause of bandwidth limitation in phased array radars is the use of phase shifters, rather than time delay devices, to steer the beam.

- Time shifting is not frequency dependent, but phase shifting is.

Adapted from Skolnik, Reference 1
Phased Array Bandwidth Limitations

- With phase shifters, peak is scanned to the desired angle only at center frequency.
- Since radar signal has finite bandwidth, antenna beamwidth broadens as beam is scanned off broadside.
- For wide scan angles (≥ 60 degrees):
  - Bandwidth (%) ≈ 2 x Beamwidth (3 dB half power) (deg)
Thinned Arrays

- **Attributes of Thinned Arrays**
  - Gain is calculated using the actual number of elements
    \[ G = \pi N \]
  - Beamwidth – equivalent to filled array
  - Sidelobe level is raised in proportion to number of elements deleted
  - Element pattern same as that with filled array, if missing elements replaced with matched loads

Adapted from Frank in Skolnik, see Reference 2
Amplitude Weighting of Array Elements

16 Element Array with Two Different Illumination Weights

- These days, Taylor weighting is the most commonly used illumination function for phased array radars
  - Many other illumination functions can be used and are discussed in “Antennas-Part 1”

- Low sidelobe windows are often used to suppress grating lobes

- Amplitude and phase errors limit the attainable level of sidelobe suppression

- Phased array monopulse issues will be discussed in Parameter Estimation Lecture

Adapted from Mailloux, Reference 6
Effects of Random Errors in Array

The Effect on Gain and Sidelobes of These Different Phenomena Can Usually Be Calculated

- Random errors in amplitude and phase in element current
- Missing or broken elements
- Phase shifter quantization errors
- Mutual Coupling effects

Adapted from Hsiao in Skolnik, Reference 1
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  – Linear and planar arrays
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  – Phase shifters and array feeds
  – Array feed architectures

• Frequency Scanning of Antennas

• Hybrid Methods of Scanning

• Other Topics
Sin (U-V) Space

Spherical Coordinate System
For Studying Grating Lobes

Projection of Coordinate System
On the X-Y Plane
(view from above Z-axis)

Direction Cosines
\[
\begin{align*}
\phi &= \sin \theta \cos \phi \\
\theta &= \sin \theta \sin \phi 
\end{align*}
\]

Unit Circle
Grating Lobe Issues for Planar Arrays

Triangular Grid of Elements

\[ Lobes\ (p, q)\ at\ \begin{cases} u_p = u_o + p \frac{\lambda}{d_x} \\ v_q = v_o + q \frac{\lambda}{d_y} \end{cases} \]

Rectangular Grid of Elements

Unit Circle
Grating Lobe Issues – $\lambda/2$ Spacing

Triangular Grid of Elements

Square Grid of Elements

Lobes $\left(p, q\right)$ at

\[
\begin{align*}
    u_p &= u_o + p \frac{\lambda}{d_x} \\
    v_q &= v_o + q \frac{\lambda}{d_y}
\end{align*}
\]

For $d_x = d_y = \lambda/2$

Lobes at $\left(u_p, v_q\right) = (2p, 2q)$

No visible grating lobes
Grating Lobe Issues – $\lambda$ Spacing

Triangular Grid of Elements

Square Grid of Elements

Lobes $(p, q)$ at

\[
\begin{align*}
    u_p &= u_o + p \frac{\lambda}{d_x} \\
    v_q &= v_o + q \frac{\lambda}{d_y}
\end{align*}
\]

For $d_x = d_y = \lambda$

Lobes at $(u_p, v_q) = (p, q)$

Grating Lobes will be seen with beam pointing broadside
Grating Lobe Issues – Scanning of the Array

For \( d_x = d_y = \lambda / 2 \)

Lobes at \( (u_p, v_q) = (1.0 + 2p, 2q) \)

Grating lobes visible as pattern shifts to right

\[ \phi = 0, \theta = 0 \]

\[ 90^\circ, 0 \]

Beam Scanned \( \phi = 0^\circ, \theta = 90^\circ \)
Triangular grid used most often because the number of elements needed is about 14% less than with square grid
- Exact percentage savings depends on scan requirements of the array
- There are no grating lobes for scan angles less than 60 degrees

For a rectangular grid, and half wavelength spacing, no grating lobes are visible for all scan angles
Mutual Coupling Issues

Do All of these Phased Array Elements Transmit and Receive \textit{without} Influencing Each Other?
Mutual Coupling Issues

COBRA DANE Radar
Shemya, Alaska

Close-up Image Array Face

Do All of these Phased Array Elements Transmit and Receive \textit{without} Influencing Each Other?
Answer- No ..... Mutual Coupling

- Analysis of Phased Arrays based on simple model
  - No interaction between radiating elements

- “Mutual coupling” is the effect of one antenna element on another
  - Current in one element depends on amplitude and phase of current in neighboring elements; as well as current in the element under consideration

- When the antenna is scanned from broadside, mutual coupling can cause a change in antenna gain, beam shape, side lobe level, and radiation impedance

- Mutual coupling can cause “scan blindness”

In addition ... mutual coupling can sometimes be exploited to achieve certain performance requirements

Adapted from J. Allen, “Mutual Coupling in Phased Arrays” MIT LL TR-424
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    – Phase shifters and radiating elements
    – Array feed architectures

• Frequency Scanning of Antennas

• Hybrid Methods of Scanning

• Other Topics
Phase Shifters - Why

• If the phase of each element of an array antenna can be rapidly changed, then, so can the pointing direction of the antenna beam
  – Modern phase shifters can change their phase in the order of a few microseconds!
  – This development has had a revolutionary impact on military radar development
    Ability to, simultaneously, detect and track, large numbers of high velocity targets
  – Since then, the main issue has been the relatively high cost of these phased array radars

The “quest” for $100 T/R (transmit/receive) module

<table>
<thead>
<tr>
<th>TRADEX Radar</th>
<th>Patriot Radar MPQ-53</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to move beam ~20° order of magnitude seconds</td>
<td>Time to move beam ~20° order of magnitude microseconds</td>
</tr>
</tbody>
</table>
Phase Shifters- How They Work

• The phase shift, $\phi$, experienced by an electromagnetic wave is given by:

$$\phi = 2\pi \frac{fL}{v} = 2\pi fL \sqrt{\mu\varepsilon}$$

  – $f =$ frequency, $L =$ path length $v =$ velocity of electromagnetic wave
  – Note: $v$ depends on the permeability, $\mu$, and the dielectric constant, $\varepsilon$

• Modern phase shifters implement phase change in microwave array radars, mainly, by two methods:

  – Changing the path length (Diode phase shifters)
    Semiconductors are good switching devices

  – Changing the permeability along the waves path (Ferrite phase shifters)
    EM wave interacts with ferrite’s electrons to produce a change in ferrite’s permeability
Examples of Phase Shifters

- **Diode phase shifter implementation**
  - Well suited for use in Hybrid MICs and MMICs
  - At higher frequencies:
    - Losses increase
    - Power handling capability decreases

- **Ferrite Phase Shifter Implementation**
  - At frequencies > S-Band, ferrite phase shifters often used
    - Diode phase shifters may be used, above S-Band
    - On receive - after low noise amplifier (LNA)
    - Before power amplifier on transmit

Adapted from Skolnik, Reference 1
Radiating Elements for Phased Array Antennas

- Metal Strip Dipole
- Printed Circuit Dipole
- Slot Cut in Waveguide
  - Radiating Edge Slot
- Notch Radiator in Stripline
  - Notch
  - Stripline
- Rectangular Patch Radiator
  - Metal Patch
  - Ground Plane
  - Substrate
- Open End Waveguide

Adapted from Skolnik, Reference 1
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Phased Array Architectures

• How is the microwave power generated and distributed to the antenna elements?

• Passive vs. Active Array
  – Passive Array - A single (or a few) transmitter(s) from which high power is distributed to the individual array elements
  – Active Array – Each array element has its own transmitter / receiver (T/R) module
    T/R modules will be discussed in more detail in lecture 18

• Constrained vs. Space Feed
  – Constrained Feed Array
  – Space Fed Array
Feed Systems for Array Antennas

- Concepts for feeding an array antenna:
  - **Constrained Feed**
    - Uses waveguide or other microwave transmission lines
    - Convenient method for 2-D scan is frequency scan in 1 dimension and phase shifters in the other (more detail later)
  
  - **Space Feed**
    - Distributes energy to a lens array or a reflectarray
    - Generally less expensive than constrained feed
    - no transmission line feed network
    - Not able to radiate very high power
  
  - **Use of Subarrays**
    - The antenna array may be divided into a number of subarrays to facilitate the division of power/ receive signal to (and from) the antenna elements
    - The AEGIS radar’s array antenna utilizes 32 transmit and 68 receive subarrays
Phased Array Antenna Configurations
(Active and Passive)

Active Array

Passive Array

Phase Shifter
In Each T/R Module

Low Power
Transmit Pulse to
T/R Module

Receiver Output to
A/D and Processing

Adapted from Skolnik, Reference 1
Examples – Active Array Radars

- **Active Array**

- **Phase Shifter**
  - In Each T/R Module

- **Low Power**
  - Transmit Pulse to T/R Module

- **Receiver Output**
  - To A/D and Processing

---

**UHF Early Warning Radar**

- Courtesy of Raytheon
- Used with Permission

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**THAAD X-Band Phased Array Radar**

- Courtesy of Raytheon
- Used with Permission
More Examples – Active Array Radars

Active Array

Phase Shifter In Each T/R Module

Low Power Transmit Pulse to T/R Module

Receiver Output to A/D and Processing

Counter Battery Radar (COBRA)

APG-81 Radar for F-35 Fighter

Courtesy of Thales Group Used with Permission

Courtesy of Northrop Grumman Used with Permission
Examples – Passive Array Radars

S- Band AEGIS Radar

L- Band COBRA DANE Radar

Passive Array

High Power Transmitter

Duplexer

Receiver & Signal Processor

Subarray

Phase Shifter

Courtesy of US Air Force

Courtesy of US Navy
Space Fed Arrays
Reflectarrays and Lens Arrays

Phase front after Steering by Reflectarray

Phase front after Steering by Lens Array

Curved Phase From Offset Feed

Curved Phase From Feed

Offset Feed

Short Circuit

Phase Shifter
Example: Space Fed - Lens Array Radar

8192 phase shifters (in a plane) take the place of the dielectric lens. The spherical wave of microwave radiation is phase shifted appropriately to form a beam and point it in the desired direction.
Examples: Space Fed - Lens Array Radars

Patriot Radar MPQ-53

S-300 “30N6E” X-Band Fire Control Radar*

- * NATO designation “Flap Lid” – SA-10
- Radar is component of Russian S-300 Air Defense System

* Courtesy of L. Corey, see Reference 7
Example of Space Fed - Reflectarray Antenna

S-300 “64N6E” S-Band Surveillance Radar*

- Radar system has two reflectarray antennas in a “back-to-back” configuration.
- The antenna rotates mechanically in azimuth; and scans electronically in azimuth and elevation

- * NATO designation “Big Bird” – SA-12
- Radar is component of Russian S-300 Air Defense System

Radar System and Transporter

Radar Antenna

Courtesy of Martin Rosenkrantz
Used with Permission

Courtesy of Wikimedia / ajkol
Two Examples of Constrained Feeds (Parallel and Series)

- **Parallel (Corporate) Feed**
  - A cascade of power splitters, in parallel, are used to create a tree like structure
  - A separate control signal is needed for each phase shifter in the parallel feed design

- **Series Feed**
  - For end fed series feeds, the position of the beam will vary with frequency
  - The center series fed feed does not have this problem
  - Since phase shifts are the same in the series feed arraignment, only one control signal is needed to steer the beam

- **Insertion losses with the series fed design are less than those with the parallel feed**
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Frequency Scanned Arrays

Beam steering in one dimension has been implemented by changing frequency of radar.

For beam excursion $\pm \theta_1$, wavelength change is given by:

$$\Delta \lambda = 2\lambda_0 \left( \frac{D}{L} \right) \sin \theta_1$$

If $\theta_1 = 45^\circ$, 30% bandwidth required for $D/L = 5$, 7% for $D/L = 20$

The phase difference between 2 adjacent elements is

$$\phi = 2\pi f \frac{L}{v} = 2\pi \frac{L}{\lambda}$$

where $L$ = length of line connecting adjacent elements and $v$ is the velocity of propagation.

Adapted from Skolnik, Reference 1
Example of Frequency Scanned Array

Planar Array Frequency Scan Antenna

- The above folded waveguide feed is known as a snake feed or serpentine feed.
- This configuration has been used to scan a pencil beam in elevation, with mechanical rotation providing the azimuth scan.
- The frequency scan technique is well suited to scanning a beam or a number of beams in a single angle coordinate.

Adapted from Skolnik, Reference 1
Examples of Frequency Scanned Antennas

SPS-48E

SPS-52

Serpentine Feed

Serpentine Feed

Courtesy of ITT Corporation
Used with Permission

Courtesy of US Navy
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• Example of Hybrid Method of Scanning
• Other Topics
ARSR-4 Antenna and Array Feed

- Joint US Air Force / FAA long range L-Band surveillance radar with stressing requirements
  - Target height measurement capability
  - Low azimuth sidelobes (-35 dB peak)
  - All weather capability (Linear and Circular Polarization)
- Antenna design process enabled with significant use of CAD and ray tracing
Phased Arrays vs Reflectors vs. Hybrids

• Phased arrays provide beam agility and flexibility
  – Effective radar resource management (multi-function capability)
  – Near simultaneous tracks over wide field of view
  – Ability to perform adaptive pattern control

• Phased arrays are significantly more expensive than reflectors for same power-aperture
  – Need for 360 deg coverage may require 3 or 4 filled array faces
  – Larger component costs
  – Longer design time

• Hybrid Antennas – Often an excellent compromise solution
  – ARSR-4 is a good example array technology with lower cost reflector technology
    – ~ 2 to 1 cost advantage over planar array, while providing very low azimuth sidelobes
Outline

• Introduction
• Antenna Fundamentals
• Reflector Antennas – Mechanical Scanning
• Phased Array Antennas
• Frequency Scanning of Antennas
• Hybrid Methods of Scanning
• Other Antenna Topics
Printed Antennas

Circular Patch Array in Anechoic Chamber

Log - Periodic Antenna

Spiral Antenna

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Antenna Stabilization Issues

- Servomechanisms are used to control the angular position of radar antennas so as to compensate automatically for changes in angular position of the vehicle carrying the antenna.

- Stabilization requires the use of gyroscopes, GPS, or a combination, to measure the position of the antenna relative to its “earth” level position.

- Radars which scan electronically can compensate for platform motion by appropriately altering the beam steering commands in the radar’s computer system.
Radomes

• Sheltering structure used to protect radar antennas from adverse weather conditions
  – Wind, rain, salt spray

• Metal space frame techniques often used for large antennas
  – Typical loss 0.5 dB

• Inflatable radomes also used
  – Less loss, more maintenance, flexing in wind

ALCOR

COBRA GEMINI

MMW

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Summary

• Enabling technologies for Phased Array radar development
  – Ferrite phase shifters (switching times ~ few microseconds)
  – Low cost MMIC T/R modules

• Attributes of Phased Array Radars
  – Inertia-less, rapid, beam steering
  – Multiple Independent beams
  – Adaptive processing
  – Time shared multi-function capability
  – Significantly higher cost than other alternatives

• Often, other antenna technologies can offer cost effective alternatives to more costly active phased array designs
  – Lens or reflect arrays
  – Reflectors with small array feeds, etc.
  – Mechanically rotated frequency scanned arrays
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Homework Problems

• Skolnik, Reference 1
  – For extra credit Problem 9.40