Radar Transmitter & Receiver
Outline

- Introduction
- Radar Transmitter
- Radar Waveform Generator and Receiver
- Radar Transmitter/Receiver Architecture
- Radar Antennas
- Radar Displays
- Summary
Radar Block Diagram
Simplified Radar Transmitter/Receiver System Block Diagram

- Radar transmitter and receiver can be divided into two important subsystems
  - High power transmitter sections
  - Low power sections

Radar waveform generator and receiver
Radar Range Equation Revisited
Parameters Affected by Transmitter/Receiver

- Radar range equation for search \((S/N = \text{signal to noise ratio})\)

\[
S/N = \frac{P_{av} A_e t_s \sigma}{4\pi \Omega R^4 k T_s L}
\]

\( \Delta S/N \) of target can be enhanced by
- Higher transmitted power \( P_{av} \)
- Lower system losses \( L \)
- Minimize system temperature \( T_s \)

The design of radar transmitter/receiver affects these three parameters directly.
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  - High Power Amplifier

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Power Amplification Process

Amplification occurs in multiple stages
✓ Driver amplifiers
✓ High power amplifier

☐ Requirement for power amplifier
✓ Low noise
✓ Minimum distortion to input signal
Higher transmitted power can be obtained by combining multiple amplifiers in parallel

- Lower efficiency (due to combiner losses)
- Increased complexity

HPA = High Power Amplifier
Types of High Power Amplifiers

- Vacuum tube amplifiers and solid state amplifiers

<table>
<thead>
<tr>
<th></th>
<th>Vacuum Tube Amplifiers</th>
<th>Solid State Amplifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output Power</strong></td>
<td>High ((10 \text{ kW to } 1 \text{ MW}))</td>
<td>Low ((10\text{'s to } 100\text{'s } W))</td>
</tr>
<tr>
<td><strong>Cost per Unit</strong></td>
<td>High ((10\text{'s K to } 300 \text{ K}))</td>
<td>Low ((100\text{'s }))</td>
</tr>
<tr>
<td><strong>Cost per Watt</strong></td>
<td>$1 – 3</td>
<td>Varied</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Bulky and heavy</td>
<td>Small foot print</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
<td>• Dish antenna</td>
<td>• Active array</td>
</tr>
<tr>
<td></td>
<td>• Passive array</td>
<td>• Digital array</td>
</tr>
</tbody>
</table>
Average Power Output Versus Frequency
Tube Amplifiers versus Solid State Amplifiers
Power Amplifier Examples

- **Tube amplifiers**
  - Klystrons
  - Travelling wave tubes
- **Solid State amplifiers**
  - Solid state power transistors

Criteria for choosing high power amplifier
- Average power output as a function of frequency
- Total bandwidth of operation
- Duty cycle
- Gain
- Mean time between failure (MTBF)
- etc…
MIT/LL Millstone Hill Radar

Klystron Tubes (Vacuum Devices)

- Originally designed in early 1960’s

<table>
<thead>
<tr>
<th>Output device</th>
<th>Klystrons (2)</th>
</tr>
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<tbody>
<tr>
<td>Center Frequency</td>
<td>1295 MHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Peak Power</td>
<td>3 MW</td>
</tr>
<tr>
<td>Average Power</td>
<td>120 kW</td>
</tr>
<tr>
<td>Pulse Width</td>
<td>1 ms</td>
</tr>
<tr>
<td>Beam Width</td>
<td>0.6°</td>
</tr>
<tr>
<td>Antenna Diameter</td>
<td>84 ft</td>
</tr>
</tbody>
</table>
How Big are High Power Klystron Tubes? Millstone Hill Radar Transmitter Room

- Varian X780 Klystron
  - $400,000/tube
  - 7 ft (height) x 1 ft (diameter)
  - 600 lbs
  - 3% duty cycle
  - 42 dB gain
  - 600W peak input drive level

Waveguide output

- Water Coolant Hoses, 70 Gal/min
- Vacuum Pump
- Spare Tube
- Power Amplifier Room
- Waveguide Harmonic Filter
- Flex Waveguide Output flanges
- 200' antenna waveguide
- 1 kW Peak Solid State Driver Amp.
Photograph of Traveling Wave Tubes
Another Type of Tube Amplifiers
Example of Solid State Transmitter
Radar Surveillance Technology Experimental Radar (RSTER)

- 14 channels with 140 kW total peak power
  - 8 kW average power
- Each channel is supplied by a power amplifier module
  - 10 kW peak power
Solid State Active Phased Array Radar
PAVE PAWS

PAVE PAWS
- First all solid state active aperture electronically steered phased array radar
- UHF Band
- 1792 active transceiver T/R modules, 340 W of peak power each
Outline

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- Radar Transmitter Overview
  --- High Power Amplifier
  --- Duplexer

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Sensitive radar receiver must be isolated from the powerful radar transmitter:
- Transmitted power typically 10 kW – 1 MW
- Receiver signal power in 10’s μW – 1 mW

*Isolation provided by duplexer switching*

PRI = Pulse Repetition Interval
**Duplexer Function**

- **Transmitter ON**
  - Connect antenna to transmitter with low loss
  - Protect receiver during transmit interval

- **Receiver ON**
  - Connect Antenna to receiver with low loss (transmitter must be turned off in this interval)
  - Limiter/switch is used for additional protection against strong interference

HPA = High Power Amplifier
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Waveform generator and receiver share several similar functions:
- Amplification
- Filtering
- Frequency conversion
Frequency Conversion Concepts

- Up converter translates the waveform frequency to a higher frequency

  **Reason:**
  Waveform generation less expensive at lower frequency

- Down converter translates the receive frequency to a lower frequency

  **Reason:**
  Dynamic range of A/D converter higher at lower frequency
This example shows only a single stage conversion
-----In general, design based on multiple stage of frequency conversion are employed

Multiple stages of amplification and filtering are also used
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Dish Radars

Conventional radar transmitter/receiver design employed
### Radar Antenna Architecture Comparison

<table>
<thead>
<tr>
<th>Dish Radar</th>
<th>Passive Array Radar</th>
<th>Active Array Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Dish Radar Diagram" /></td>
<td><img src="image2" alt="Passive Array Radar Diagram" /></td>
<td><img src="image3" alt="Active Array Radar Diagram" /></td>
</tr>
<tr>
<td><strong>PRO</strong></td>
<td><strong>PRO</strong></td>
<td><strong>PRO</strong></td>
</tr>
<tr>
<td>* Very low cost</td>
<td>* Beam agility</td>
<td>* Beam agility</td>
</tr>
<tr>
<td>* Frequency diversity</td>
<td>* Effective radar resource management</td>
<td>* Effective radar resource management</td>
</tr>
<tr>
<td><strong>CON</strong></td>
<td><strong>CON</strong></td>
<td><strong>CON</strong></td>
</tr>
<tr>
<td>* Dedicated function</td>
<td>* Higher cost</td>
<td>* Low loss</td>
</tr>
<tr>
<td>* Slow scan rate</td>
<td>* Requires custom transmitter and high-power phase shifters</td>
<td>* High cost</td>
</tr>
<tr>
<td>* Requires custom transmitter</td>
<td>* High loss</td>
<td>* More complex cooling</td>
</tr>
<tr>
<td>* High loss</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Active Phased Array Radar

- Transmit/Receive function distributed to each module on array.
Large Phased Arrays

Passive Array Radar

Cobra Dane
15.3K active elements

Active Array Radar

THAAD Radar

25,344 elements
Each active analog T/R module is followed by an A/D for immediate digitization. Multiple received beams are formed digitally by the digital beamformer.
Digital Array Example

Digital On Receive

RSTER
(14 Digital Receivers)
Both waveform generation and receiver digitization are performed within each T/R module.

------Complete flexibility on transmit and receive
Summary

- Radar transmit function is accomplished in two stages:
  - Waveform generator creates low power waveform signal and up converts it to RF.
  - Transmitter amplifies waveform signal

- Radar receiver performs filtering, amplification and down conversion functions
  - Final received signal is fed to an A/D for digitization

- Radar transmit/receive architecture is highly dependent on the antenna type
  - Centralized architecture: dish radars, passive array radars
  - Distributed architecture: active array and digital array radars
Radar Antennas
Fundamental parameters:

Coverage
maximum range (R) \[ R^4 \propto P \times A \]

Resolution
ability to recognize closely spaced targets

Beam Width: \[ \propto 1/A(\lambda) \]

- Determines the radar's angular resolution
- Typically fall between 1 and 10°.
Fundamental parameters:

Sizes

From proximity fuses used in artillery shells to phased-array radars housed in multistory buildings for detecting and tracking objects in space.

In any one application:

Size and cost may be limited either by the physical space available or by the importance of the radar information.
Beam Scanning and Target Tracking.

To search for targets in a volume of space

- Mechanically
- Electronically
- or both,

Electronic Scanning

Allows the beams to be scanned more rapidly by avoiding the inertia associated with moving mechanical components.

Accurate pointing is a requirement inherent in all radar applications that measure target location.
Radar functions

**Search**  
Examine a volume of space at regular intervals to seek out targets of interest

**Track**  
One or more targets are kept under continuous surveillance so that more accurate and higher-data-rate measurements may be made of the target's location

Certain radar systems combine search and track functions by time sharing the agile beam of a phased-array antenna.
Because of the great variety of radar applications, radar antennas are required to operate in many different environments.

**At fixed sites**  The larger radar antennas are often protected by a radome, especially in arctic regions that experience heavy winds, ice, and snow.

**Transportable systems**  Generally require that the antenna be **disassembled** for transport.

**Mobile systems**  Prepared to move rapidly from place to place and usually do not allow time for antenna disassembly.

**Marine radar systems**  Smaller antenna and larger transmitter than would be used in a comparable land-based application are recommended.
The basic role
Transducer between the free-space propagation and the guided-wave propagation of electromagnetic waves.

During transmission
Concentrate the radiated energy into a shaped directive beam which illuminates the targets in a desired direction.

During reception
Collect the energy contained in the reflected target echo signals and delivers it to the receiver.

Highly directive beam width is needed to:
Achieve angular accuracy
Resolve targets close to one another.
Radar-Antenna Parameters

- Peak power
- Average power
- Directivity & Gain
- Radiation Patterns (Beamwidth & Sidelobe levels)
- Polarization
- Cross-polarization rejection Bandwidth
- Antenna Impedance:
  - Mismatch, SWR, Return Loss
- Scan volume
- Scan time
- Pointing accuracy
- Size
The maximum directivity is defined as

\[ D(\theta, \phi) \max = D_0. \]

The directivity range for any antenna is

\[ 0 < D(\theta, \phi) < D_0. \]

The directivity of an isotropic radiator is

\[ D(\theta, \phi) = 1. \]

The ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

\[
D(\theta, \phi) = \frac{U(\theta, \phi)}{U_{\text{avg}}} = \frac{4\pi U(\theta, \phi)}{P_{\text{rad}}}
\]
Directivity in dB

\[ D(\theta, \phi) \ [dB] = 10 \log_{10} D(\theta, \phi) \]

**Gain** = Directivity \times efficiency

**Effective aperture**

\[ A_{\text{eff}} = \frac{\lambda^2 G}{4\pi} \]
Antenna Radiation Patterns

Common parameters

- main lobe (boresight)
- half-power beamwidth (HPBW)
- front-back ratio (F/B)
- pattern nulls

Typically measured in two planes:

- Vector electric field referred to E-field
- Vector magnetic field referred to H-field
Antenna Pattern Parameters

- Main lobe (Major lobe)
- Side lobes (Minor lobes)
- First Null Beamwidth (FNBW)
- Half-power beamwidth (HPBW)
- Half-power point
- Back lobe
In the transmit mode: Wasted radiated power

In the receive mode: Receive from undesired directions

Example
A radar for detecting low flying aircraft targets can receive strong ground echoes (*clutter*) through the sidelobes which mask the weaker echoes coming from low radar cross-section targets through the main beam..

The optimum compromise (*tradeoff*) between sidelobes, gain, and beamwidth is an important consideration for choosing or designing radar antennas.
The *sidelobe levels* of an antenna pattern can be specified or described in several ways:

(1) The *relative sidelobe level* (the most common)

(2) *Average level* of all the sidelobes.
   (Airborne radar to suppress ground clutter)

(3) *Median level* half of the angular space has sidelobe levels above it and the other half has them below that level.
   (not often used)
(HPBW)

Example

Find the (HPBW) of an antenna having

\[ E(\theta) = \cos^2 \theta \quad \text{for } 0^\circ < \theta < 90^\circ \]

Solution

\[ E(\theta) \text{ at half power} \]

\[ 0.707 = \cos^2 \theta \]

\[ \theta = 33^\circ \]

\[ \text{BW} = 66^\circ \]
Polarization

Defined relative to the E-field of antenna.

\( \gamma \) Horizontally Polarized  
(If the E-field is horizontal)

\( \gamma \) Vertically Polarized  
(If the E-field is vertical)

Many existing radar antennas are *linearly polarized*, usually either *vertically* or *horizontally*; although these designations imply an earth reference, they are quite common even for airborne or satellite antennas.
Co-Polarization and Cross-Polarization

Co-Polarization
The desired polarization (the *main polarization*) (COPOL)

Cross-Polarization
The undesired orthogonal polarization (CROSSPOL).

A well designed antenna will have CROSSPOL components at least **20 dB** below the COPOL in the main-beam region, and **5 to 10 dB** below in the side lobe regions.
Antenna Impedance

The complex antenna impedance is

\[ Z_A = R_A + j X_A \]

- **RA** - Antenna resistance [(dissipation) + radiation]
- **XA** - Antenna reactance [(energy storage) antenna near field]

\[ R_A = R_r + R_L \]

- **Rr** - Antenna radiation resistance (radiation)
- **RL** - Antenna loss resistance (ohmic loss)
A proper Impedance Match:

$$Z_A = 50 \, \Omega$$

Voltage Standing Wave Ratio (VSWR), is an indicator of how well an antenna matches the transmission line that feeds it.

$$VSWR = \frac{1 + \text{(Reflection Coefficient)}}{1 - \text{(Reflection Coefficient)}}$$
Return Loss (RL)  \[ 10 \log \left( \frac{\text{Pin}}{\text{Pr}} \right) \]

RL = 13.9 dB \quad \sim \text{VSWR} = 1.5

RL = 20 dB \quad \sim \text{VSWR} = 1.2

<table>
<thead>
<tr>
<th>VSWR</th>
<th>Return Loss</th>
<th>Transmission Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0:1</td>
<td>\infty</td>
<td>0.0 dB</td>
</tr>
<tr>
<td>1.2:1</td>
<td>20.83 dB</td>
<td>0.036 dB</td>
</tr>
<tr>
<td>1.5:1</td>
<td>13.98 dB</td>
<td>0.177 dB</td>
</tr>
<tr>
<td>5.5:1</td>
<td>3.19 dB</td>
<td>2.834 dB</td>
</tr>
</tbody>
</table>
Reflector Antennas
Some Types of Reflector Antennas

- Paraboloid
- Parabolic cylinder
- Stacked beam
- Monopulse
- Cassegrain
- Shaped
Parabolic reflectors still serve as a basis for many radar applications. They provide:

- Maximum available gain
- Minimum beamwidths
- Simplest and smallest feeds.

Mathematically:

\[ G_a \text{(dBi)} = 10 \log_{10} \eta \left[ 4 \pi \frac{A_a}{\lambda^2} \right] \]

and \( \beta = 70 \frac{\lambda}{D} \)

- \( G_a \): Antenna Directive Gain
- \( \eta \): Aperture Efficiency (50-55%)
- \( A_a \): Antenna Aperture Area
- \( \lambda \): Wavelength
- \( \beta \): 3 dB HPBW
Basic Geometry and Operation

For a parabolic conducting reflector surface of focal length $f$ with a feed at the focus $F$.

In rect. coordinates

$$z = \frac{x^2 + y^2}{4f}$$

In spherical coordinates

$$\rho = f \sec^2 \frac{\psi}{2}$$

$$\tan \frac{\psi}{2} = \frac{D}{4f}$$
Aperture angle $\theta = 2\psi_0$
A spherical wave emerging from $F$ and incident on the reflector is transformed after reflection into a plane wave traveling in the positive $z$ direction.

Reflectors with the longer focal lengths, which are flattest and introduce the least distortion of polarization and of off-axis beams, require the narrowest primary beams and therefore the largest feeds.
For example, the size of a horn to feed a reflector of $f/D = 1.0$ is approximately \textbf{4 times} that of a feed for a reflector of $f/D = 0.25$. Most reflectors are chosen to have a focal length between 0.25 and 0.5 times the diameter.

As side lobe levels are reduced and feed blockage becomes intolerable, offset feeds become necessary.

Offset results unsymmetrical illumination.
The corners of most paraboloidal reflectors are rounded or mitered to minimize the area and especially to **minimize the torque required** to turn the antenna.

The deleted areas have low illumination and therefore least contribution to the gain.

Circular and elliptical outlines produce side lobes at all angles from the principal planes. **If low side lobes are specified away from the principal planes**, it may be necessary to maintain square corners, as
Parabolic-Cylinder Antenna

It is quite common that either the elevation or the azimuth beam must be steerable or shaped while the other is not.

A parabolic cylindrical reflector fed by a line source can accomplish this at a modest cost.

The line source feed may assume many different forms ranging from a parallel-plate lens to a slotted waveguide to a phased array using standard designs.

The parabolic cylinder has application even where both patterns are fixed in shape.
Elevation beam shaping incorporates a steep skirt at the horizon.

Allow operation at low elevation angles without degradation from ground reflection.

A vertical array can produce much sharper skirts than a shaped dish of equal height can, since a shaped dish uses part of its height for high-angle coverage.

Parabolic cylinders suffer from large blockage if they are symmetrical, and they are therefore often built offset. Properly designed, however, a cylinder fed by an offset multiple-element line source can have excellent performance.
Fan beams with a specified shape are required for a variety of reasons. The most common requirement is that the elevation beam provide coverage to a constant altitude. The simplest way to shape the beam is to shape the reflector.

Each portion of the reflector is aimed in a different direction and, to the extent that geometric optics applies, the amplitude at that angle is the integrated sum of the power density from the feed across that portion.
Elimination of blockage.

A large fraction of the aperture is not used in forming the main beam. If the feed pattern is symmetrical and half of the power is directed to wide angles, it follows that the main beam will use half of the aperture and have double the beamwidth. This corresponds to shaping an array pattern with phase only and may represent a severe problem if sharp pattern skirts are required. It can be avoided with extended feeds.
Multiple Beams and Extended Feeds

- A feed at the focal point of a parabola forms a beam parallel to the focal axis.

- Additional feeds displaced from the focal point form additional beams at angles from the axis.

This is a powerful capability of the reflector antenna to provide extended coverage with a modest increase in hardware.

Each additional beam can have nearly full gain, and adjacent beams can be compared with each other to interpolate angle.
A parabola reflects a spherical wave into a plane wave only when the source is at the focus. With the source off the focus, a phase distortion results that increases with the angular displacement in beam widths and decreases with an increase in the focal length. The following figures show the effect of this distortion on the pattern of a typical dish as a feed is moved off axis. A flat dish with a long focal length minimizes the distortions. Progressively illuminating a smaller fraction of the reflector as the feed is displaced accomplishes the same purpose.
Patterns for off-axis feeds.
AN/TPS-43 multiple-beam antenna
Monopulse is the most common form of multiple beam antenna, normally used in **tracking** systems in which a movable antenna keeps the target near the null and measures the mechanical angle, as opposed to a surveillance system having overlapping beams with angles measured from RF difference data.

**Two basic monopulse systems**

- **Phase comparison**
- **Amplitude comparison**
Amplitude comparison is far more prevalent in radar antennas.

The sum of the two feed outputs forms a high-gain (target detection) low-side lobe beam.

The difference forms a precise deep null at boresight (Angle determination).

Azimuth and elevation differences can be provided.

If a reflector is illuminated with a group of four feed elements, a conflict arises between the goals of high sum-beam efficiency and high difference-beam slopes. The former requires a small overall horn size, while the latter requires large individual horns.
Multiple-Reflector Antennas

Some of the shortcomings of paraboloidal reflectors can be overcome by adding a secondary reflector. The contour of the added reflector determines how the power will be distributed across the primary reflector and thereby gives control over amplitude in addition to phase in the aperture.

This can be used to produce very low spillover or to produce a specific low-sidelobe distribution. The secondary reflector may also be used to relocate the feed close to the source or receiver. By suitable choice of shape, the apparent focal length can be enlarged so that the feed size is convenient, as is sometimes necessary for monopulse operation.
The Cassegrain antenna, derived from telescope designs, is the most common antenna using multiple reflectors. The feed illuminates the hyperboloidal subreflector, which in turn illuminates the paraboloidal main reflector. The feed is placed at one focus of the hyperboloid and the paraboloid focus at the other. A similar antenna is the gregorian, which uses an ellipsoidal subreflector in place of the hyperboloid.
blockage elimination
FEEDS

At lower frequencies (L band and lower) dipole feeds are sometimes used, particularly in the form of a linear array of dipoles to feed a parabolic-cylinder reflector.

Other feed types used in some cases include waveguide slots, troughs, and open-ended waveguides, but the flared waveguide horns are most widely used.
Front Feed  Offset Feed  Cassegrain Feed
Gregorain Feed

Simple Pyramidal horn

Simple Conical

Corrugated Conical Horn
Other considerations include operating bandwidth and whether the antenna is a single-beam, multibeam, or monopulse antenna.

The feeder in the receive mode

- Must be point-source radiators

In the transmit mode, it

- Must radiate spherical phase fronts if the desired directive antenna pattern is to be achieved.
- Must also be capable of handling the required peak and average power levels without breakdown under all operational environments.
- Must provide proper illumination of the reflector with a prescribed amplitude distribution and minimum spillover and correct polarization with minimum cross polarization.
Rectangular (pyramidal) waveguide horns propagating the dominant $\text{TE}_{01}$ mode are widely used because they meet the **high power and other requirements**, although in some cases circular waveguide feeds with conical flares propagating the $\text{TE}_{11}$ mode have been used.

These single-mode, simply flared horns suffice for pencil-beam antennas with just one linear polarization.
Shielded-Aperture Reflectors

In some applications it is desirable to have very low sidelobes from a pencil-beam reflector. In this instance, considerable improvement can be obtained by the use of metal shielding around the reflector aperture.

The typical sidelobes are at about 0 dBi, which for most reflectors represents a value of the order of -30 to -40 dB below the peak gain. With a shielding technique, the far-out sidelobes can be reduced to -80 dB.
Shielded-Aperture Reflectors

The simplest approach to shielding the reflector is a cylindrical "shroud," or tunnel, of metal around the edge of a circular reflector. If the aperture is elliptical in cross section, an elliptical cylinder can be used.

Radome:
Reducing wind loading & Protection against Ice, Snow and Dirt
Typical Antenna Performance

### Standard Parabolic

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Diameter</th>
<th>Gain</th>
<th>HPBW</th>
<th>F/B Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 GHz</td>
<td>1.5 m</td>
<td>27 dB</td>
<td>7° 20'</td>
<td>34/ dB</td>
</tr>
<tr>
<td>2 GHz</td>
<td>3.0 m</td>
<td>34 dB</td>
<td>4° 00'</td>
<td>42/60 dB</td>
</tr>
<tr>
<td>4 GHz</td>
<td>1.0 m</td>
<td>33 dB</td>
<td>3° 40'</td>
<td>40/ dB</td>
</tr>
<tr>
<td>4 GHz</td>
<td>3.0 m</td>
<td>39 dB</td>
<td>1° 50'</td>
<td>50/70 dB</td>
</tr>
<tr>
<td>6 GHz</td>
<td>1.5 m</td>
<td>37 dB</td>
<td>2° 20'</td>
<td>45/ dB</td>
</tr>
<tr>
<td>6 GHz</td>
<td>3.0 m</td>
<td>43 dB</td>
<td>1° 15'</td>
<td>52/70 dB</td>
</tr>
<tr>
<td>11 GHz</td>
<td>1.5 m</td>
<td>42 dB</td>
<td>1° 15'</td>
<td>50/ dB</td>
</tr>
<tr>
<td>11 GHz</td>
<td>3.0 m</td>
<td>43 dB</td>
<td>0° 50'</td>
<td>58/74 dB</td>
</tr>
<tr>
<td>13 GHz</td>
<td>1.5 m</td>
<td>43 dB</td>
<td>1° 05'</td>
<td>52/ dB</td>
</tr>
<tr>
<td>13 GHz</td>
<td>3.0 m</td>
<td>49 dB</td>
<td>0° 30'</td>
<td>60/74 dB</td>
</tr>
</tbody>
</table>

- Without Shroud
- With Shroud

Cross-polar of all types is of the order of 30 dB
Trade-off between different dish principles

<table>
<thead>
<tr>
<th></th>
<th>Centre focus</th>
<th>Cassegrain</th>
<th>Offset</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D/λ at main application</strong></td>
<td>D&gt;20λ</td>
<td>D&gt;75λ</td>
<td>D&gt;10λ</td>
</tr>
<tr>
<td><strong>Area efficiency</strong></td>
<td>Good</td>
<td>Very good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Sidelobe attenuation</strong></td>
<td>Good</td>
<td>Good</td>
<td>Very good</td>
</tr>
<tr>
<td><strong>Construction</strong></td>
<td>Good</td>
<td>Complex</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
## Typical Parabolic Antenna Gain in dBi

<table>
<thead>
<tr>
<th>Antenna Diameter</th>
<th>2 ft (0.6m)</th>
<th>4 ft (1.2m)</th>
<th>6 ft (1.8m)</th>
<th>8 ft (2.4m)</th>
<th>10 ft (3.0m)</th>
<th>12 ft (3.7m)</th>
<th>15 ft (4.5m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 GHz</td>
<td>19.5</td>
<td>25.5</td>
<td>29.1</td>
<td>31.6</td>
<td>33.5</td>
<td>35.1</td>
<td>37</td>
</tr>
<tr>
<td>4 GHz</td>
<td>25.5</td>
<td>31.6</td>
<td>35.1</td>
<td>37.6</td>
<td>39.5</td>
<td>41.1</td>
<td>43.1</td>
</tr>
<tr>
<td>6 GHz</td>
<td>29.1</td>
<td>35.1</td>
<td>38.6</td>
<td>41.1</td>
<td>43.1</td>
<td>44.6</td>
<td>46.6</td>
</tr>
<tr>
<td>8 GHz</td>
<td>31.6</td>
<td>37.6</td>
<td>41.1</td>
<td>43.6</td>
<td>45.5</td>
<td>47.1</td>
<td>49.1</td>
</tr>
<tr>
<td>11 GHz</td>
<td>34.3</td>
<td>40.4</td>
<td>43.9</td>
<td>46.4</td>
<td>48.3</td>
<td>49.9</td>
<td>51.8</td>
</tr>
<tr>
<td>15 GHz</td>
<td>37</td>
<td>43.1</td>
<td>46.6</td>
<td>49.1</td>
<td>51</td>
<td>52.6</td>
<td>NA</td>
</tr>
<tr>
<td>18 GHz</td>
<td>38.6</td>
<td>44.6</td>
<td>48.2</td>
<td>50.7</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>22 GHz</td>
<td>40.4</td>
<td>46.4</td>
<td>49.9</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>38 GHz</td>
<td>45.1</td>
<td>51.1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Reflector Efficiency

Well-designed antennas have efficiency ratings of 45 - 65%

Efficiency Factor Affected By:
- Feed Illumination
- Aperture Blockage
- Reflector Surface Tolerance
- Efficiency can never be 100%
Unwanted Signals

Scattering

Diffraction

Spillover
Front to Back Ratio

- **Standard Parabolic Antenna**
- **Focal Plane Antenna**
- **Shielded Antenna**
## Parabolic Reflector Beamwidth

<table>
<thead>
<tr>
<th>Frequency</th>
<th>0.3 m</th>
<th>0.6 m</th>
<th>1.2 m</th>
<th>1.8 m</th>
<th>2.4 m</th>
<th>3 m</th>
<th>3.7 m</th>
<th>4.5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 GHz</td>
<td>35</td>
<td>17.5</td>
<td>8.75</td>
<td>5.83</td>
<td>4.38</td>
<td>3.5</td>
<td>2.84</td>
<td>2.33</td>
</tr>
<tr>
<td>6 GHz</td>
<td>11.67</td>
<td>5.83</td>
<td>2.92</td>
<td>1.94</td>
<td>1.46</td>
<td>1.17</td>
<td>0.95</td>
<td>0.78</td>
</tr>
<tr>
<td>8 GHz</td>
<td>8.75</td>
<td>4.38</td>
<td>2.19</td>
<td>1.46</td>
<td>1</td>
<td>0.88</td>
<td>0.71</td>
<td>0.58</td>
</tr>
<tr>
<td>11 GHz</td>
<td>6.36</td>
<td>3.18</td>
<td>1.59</td>
<td>1</td>
<td>0.8</td>
<td>0.64</td>
<td>0.52</td>
<td>0.42</td>
</tr>
<tr>
<td>14 GHz</td>
<td>5</td>
<td>2.5</td>
<td>1.25</td>
<td>0.83</td>
<td>0.63</td>
<td>0.5</td>
<td>0.41</td>
<td>0.33</td>
</tr>
<tr>
<td>18 GHz</td>
<td>3.89</td>
<td>1.94</td>
<td>0.97</td>
<td>0.65</td>
<td>0.49</td>
<td>0.39</td>
<td>0.32</td>
<td>0.26</td>
</tr>
<tr>
<td>23 GHz</td>
<td>3</td>
<td>1.52</td>
<td>0.76</td>
<td>0.51</td>
<td>0.38</td>
<td>0.3</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>38 GHz</td>
<td>1.84</td>
<td>0.92</td>
<td>0.46</td>
<td>0.31</td>
<td>0.23</td>
<td>0.18</td>
<td>0.15</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Phased Array Antennas

Antenna array - a configuration of multiple antennas (elements) arranged to achieve a given radiation pattern.

Linear array - antenna elements arranged along a straight line.
Circular array - antenna elements arranged around a circular ring.
Planar array - antenna elements arranged over some planar surface (example - rectangular array).
Conformal array - antenna elements arranged to conform to some non-planar surface (such as an aircraft skin)
Array Design Variables

1. General array shape (linear, circular, planar, etc.).
2. Element spacing.
3. Element excitation amplitude.
4. Element excitation phase.
5. Patterns of array elements.

Phased array

An array of identical elements which achieves a given pattern through the control of the element excitation phasing.

Phased arrays can be used to steer the main beam of the antenna without physically moving the antenna.
The capability of rapidly and accurately switching beams permits:

• Multiple radar functions to be performed, interlaced in time or even simultaneously.

• An electronically steered array radar may track a great multiplicity of targets, illuminate a number of targets with RF energy and guide missiles toward them, perform complete hemispherical search with automatic target selection, and hand over to tracking.

• It may even act as a communication system, directing high-gain beams toward distant receivers and transmitters.

• Complete flexibility is possible; search and track rates may be adjusted to best meet particular situations, all within the limitations set by the total use of time.
The capability of rapidly and accurately switching beams permits:

Å The antenna beamwidth may be changed to search some areas more rapidly with less gain.

Å Frequency agility is possible with the frequency of transmission changing at will from pulse to pulse or, with coding, within a pulse. Very high powers may be generated from a multiplicity of amplifiers distributed across the aperture. Electronically controlled array antennas can give radars the flexibility needed to perform all the various functions in a way best suited for the specific task at hand. The functions may be programmed adaptively to the limit of one's capability to exercise effective automatic management and control.
RADAR DISPLAYS
General Display Types

- **RAW VIDEO**
  - display the detected and amplified target return signal (and the receiver noise).
  - It requires a human operator to interpret the various target noise and clutter signals.

- **SYNTHETIC VIDEO**
  - It uses a computer to clean up the display by eliminating noise and clutter and creating its own precise symbol for each target.
SYNTHETIC VIDEO

RAW VIDEO

SYNTHETIC VIDEO

TGT 1  TGT 2  TGT 3  ANGEL (GHOST)

NOISE

ANGEL (GHOST) - see text

TGT 3
TGT 2
TGT 1
SEARCH AND ACQUISITION RADARS

They generally use either a PPI or a sector PPI display as shown.

- PPI displays can be either raw video or synthetic video.

  **PPI scope** (plan position indicator).
  - Polar plot of direction and distance.
  - Displays all targets for 360 degrees.

- **Sector PPI scope.**
  - Polar plot of direction and distance.
  - Displays all targets within a specific sector.
  - Origin may be offset so that "your" radar position may be off the scope.
RADARS

Usually use some combination of A, B, C, or E scope displays.

There are many other types of displays that have been used at one time or another - including meters - but those listed here are the most common in use today.
Displays

Figure 2. Common Radar Displays
A-SCOPE

- Target signal amplitude vs range or velocity.
- Displays all targets along pencil beam for selected range limits.
- Displays tracking gate. Usually raw video.
- Some modern radars have raw video a-scopes as an adjunct to synthetic video displays.
- Must be used with a separate azimuth and elevation display of some sort.
- Also called a range scope (R-Scope).
B-SCOPE

- Range vs azimuth or elevation.
- Displays targets within selected limits.
- Displays tracking gate. May be raw or synthetic video.
- Surface radars usually have two. One azimuth/one elevation which can result in confusion with multiple targets.
C-SCOPE

- Azimuth vs elevation. Displays targets within selected limits of az and el.
- Displays tracking gate. May display bull's-eye or aim dot.
- May have range indicator inserted typically as a marker along one side. Usually synthetic video.
- Pilots eye view and very common in modern fighter aircraft heads up displays for target being tracked.
- Could be used in any application where radar operator needs an "aiming" or "cross hair" view like a rifle scope.
E-SCOPE

Elevation vs Range  similar to a B-scope, with elevation replacing azimuth.
QUERIES!!!

THANK YOU
References