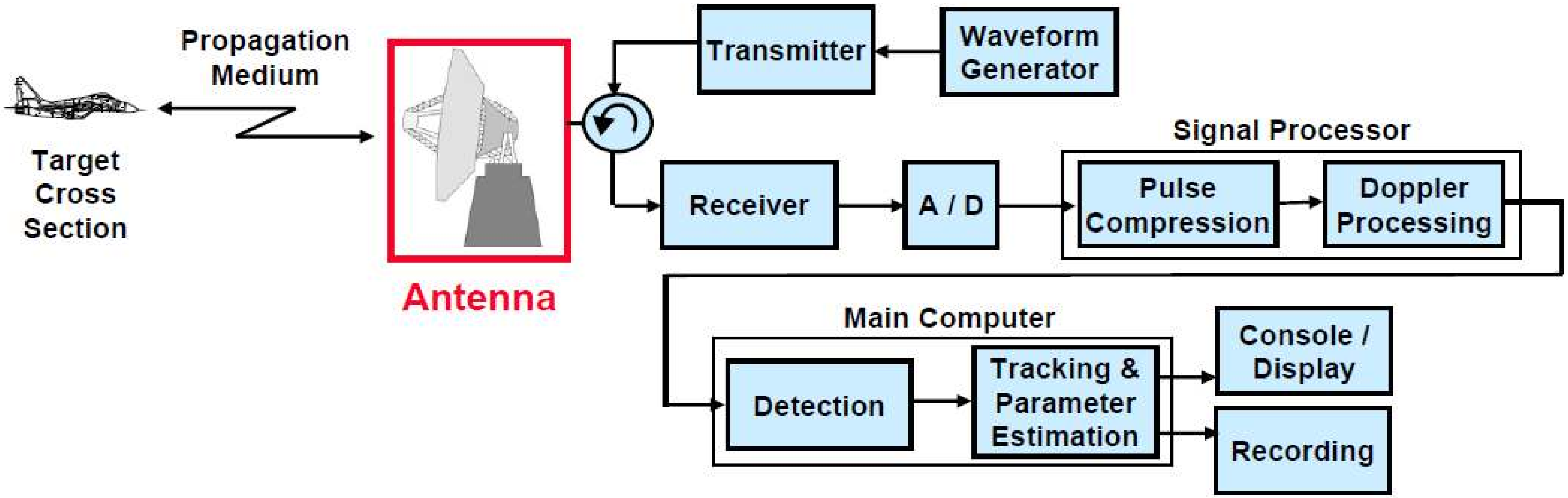
AJOU UNIVERSITY
1973

Radar Systems

Lecture 6. Radar Antennas

구 자 열

Radar Block Diagram



Track Radar Equation

$$S / N = \frac{P_t \, G^2 \lambda^2 \sigma}{(4 \pi)^3 R^4 k \, T_s \, B_n \, L}$$

Search Radar Equation

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

G = Gain

A_e = Effective Area

This Lecture

T_s = System Noise Temperature

L = Losses

Radar Equation Lecture

Antenna Definition

- "Means for radiating or receiving radio waves"*
  - A radiated electromagnetic wave consists of electric and magnetic fields which jointly satisfy Maxwell's Equations
- Transitional structure between guiding device and free space

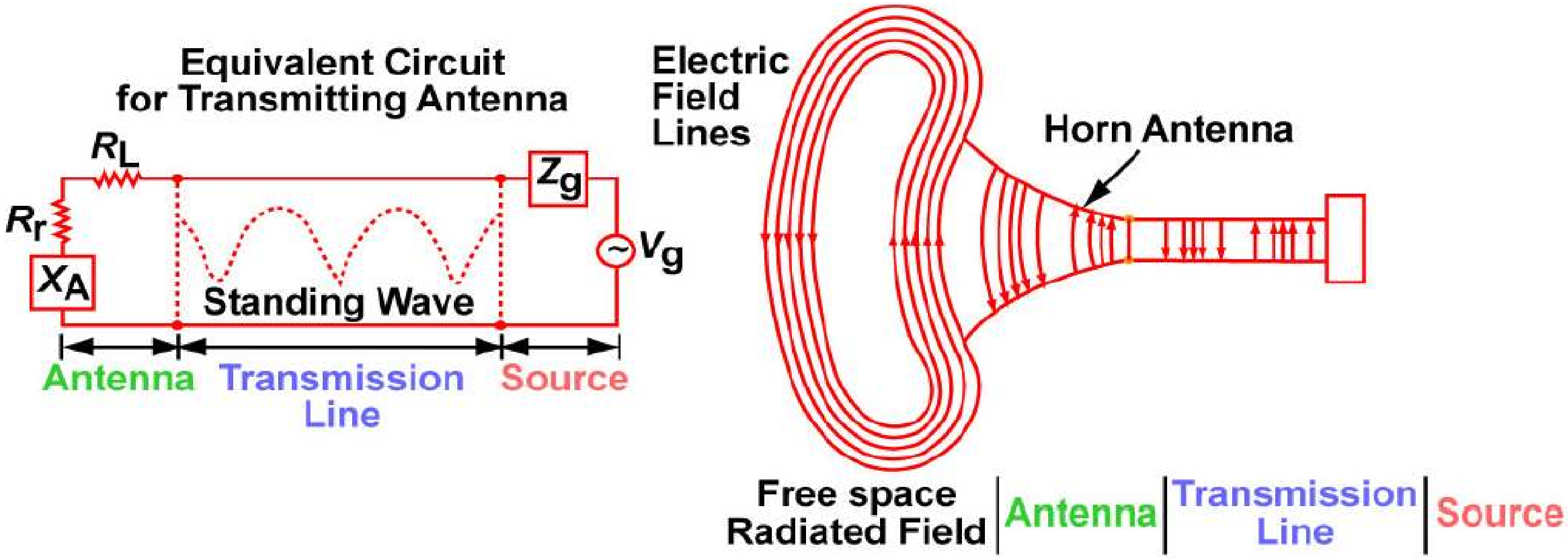
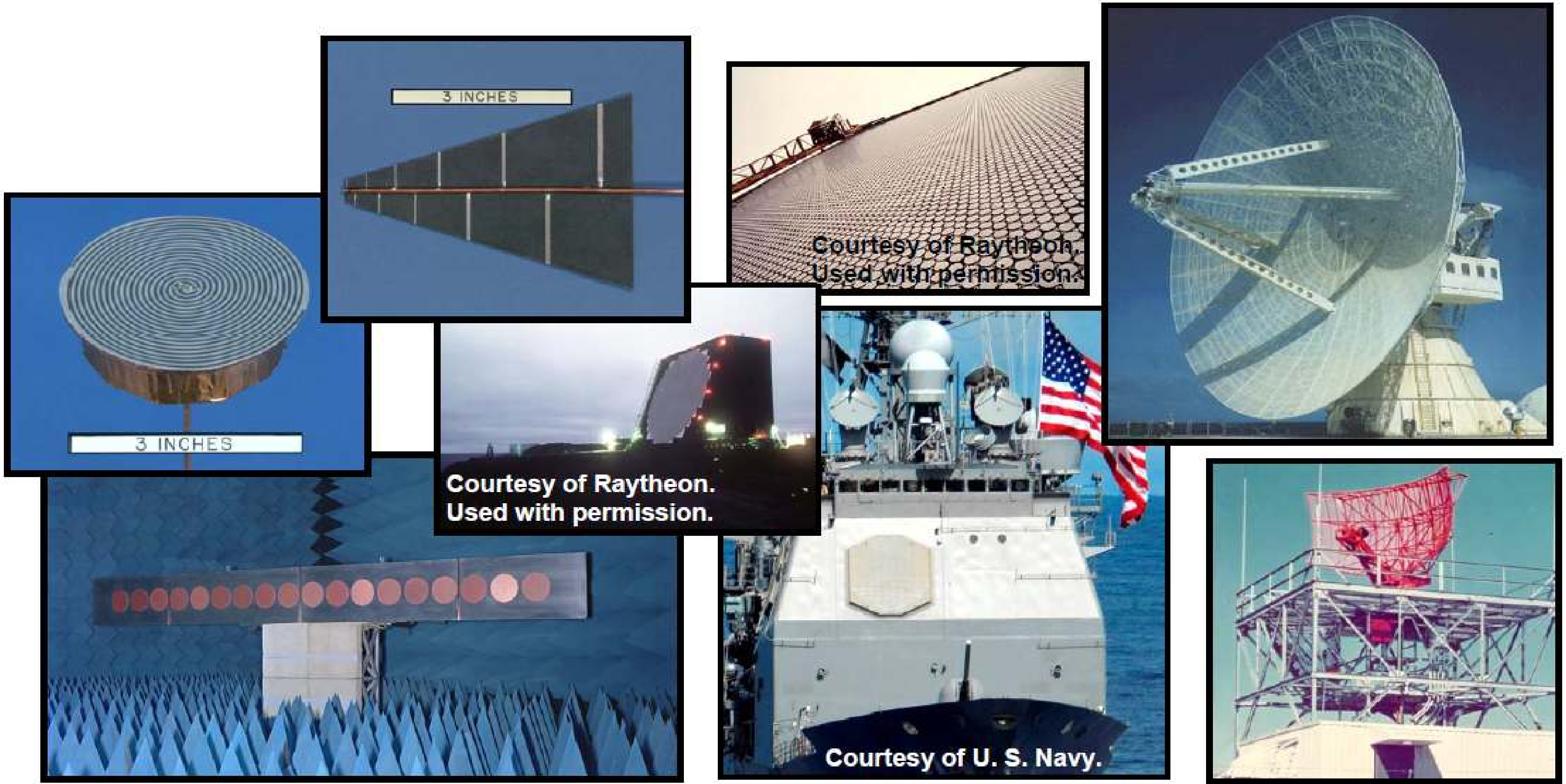


Figure by MIT OCW.

Antenna Characteristics

- Accentuates radiation in some directions, suppresses in others
- Designed for both directionality and maximum energy transfer



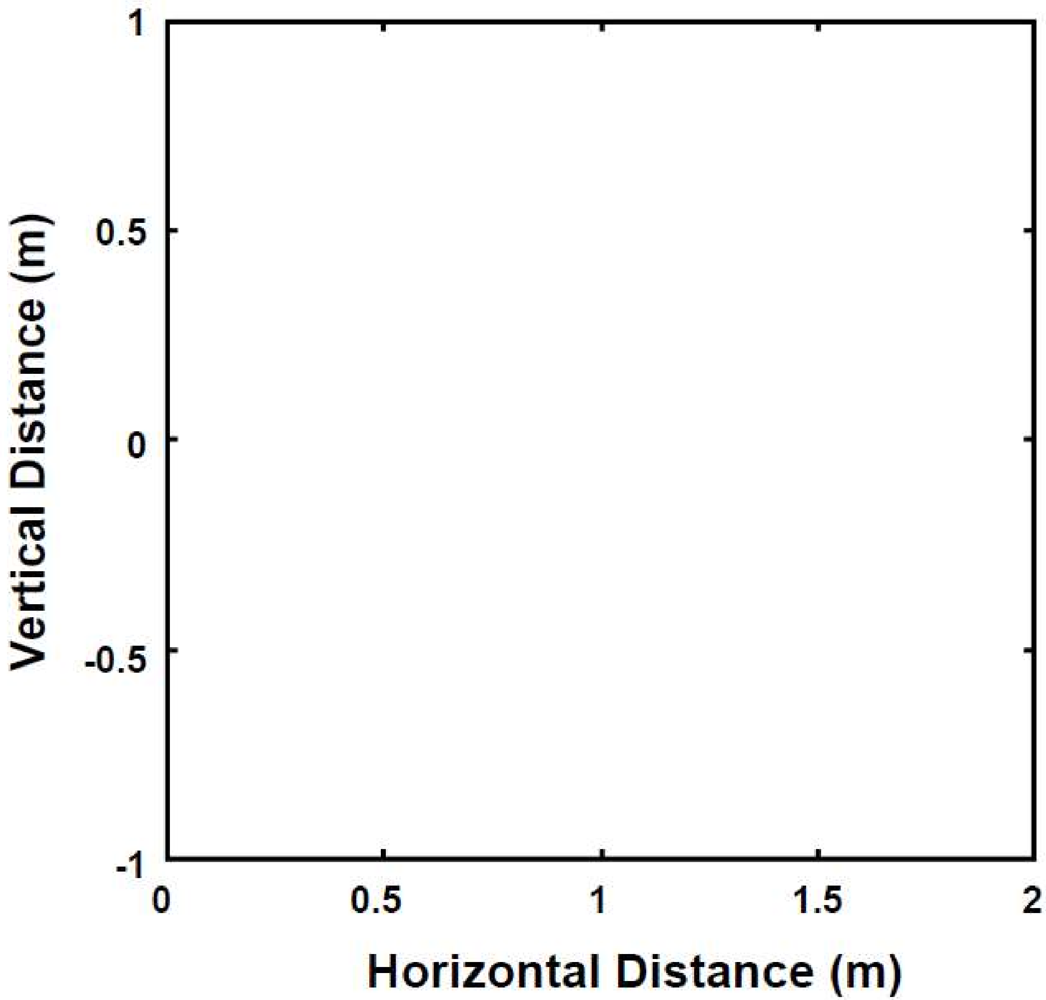
차 례

- Fundamental antenna concepts
- Reflector antennas
- Phased array antennas

AJOU UNIVERSITY

Radiation

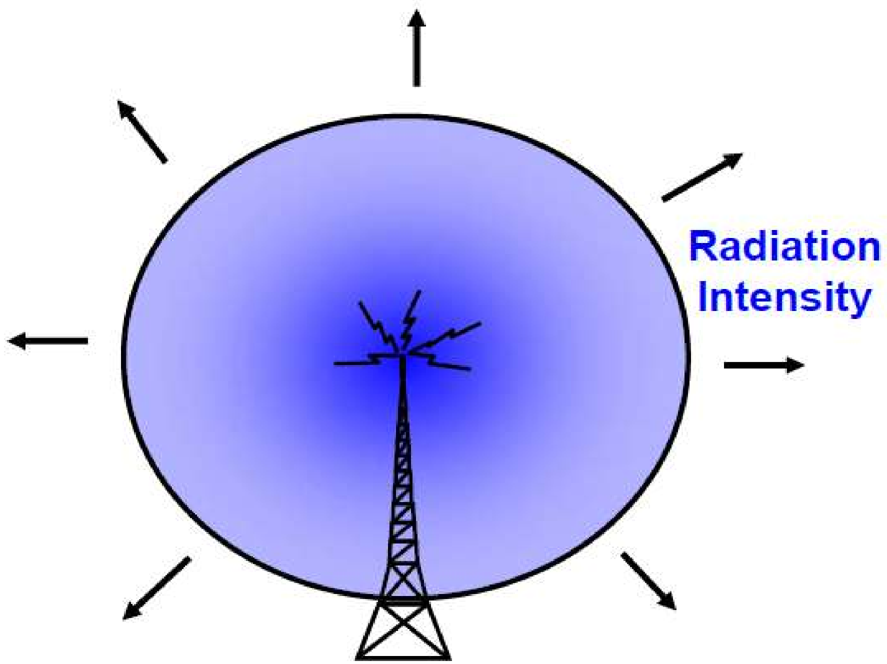
Dipole*



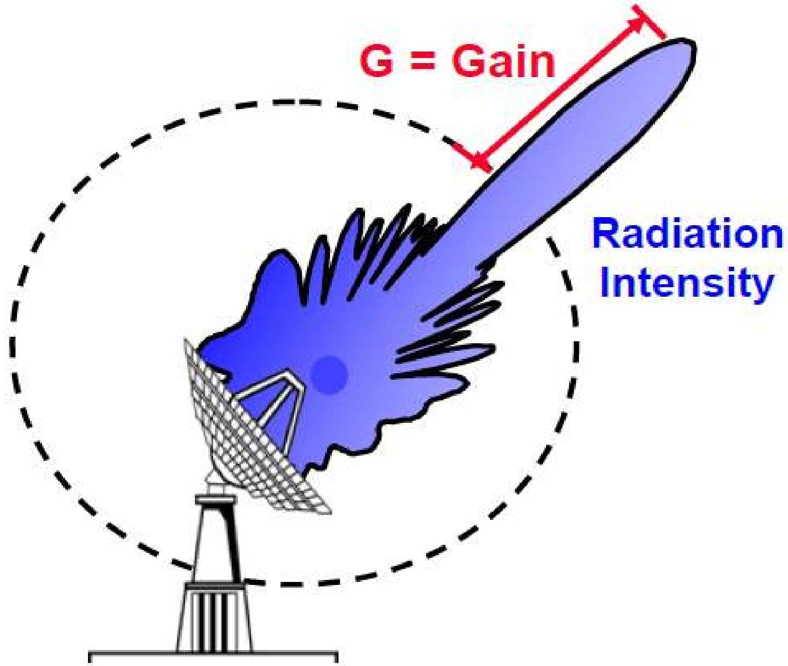
*driven by oscillating source

Antenna Gain

Isotropic Antenna



Directional Antenna



- Same power is radiated
- Radiation intensity is power density over sphere (watt/steradian)
- Gain is radiation intensity over that of an isotropic source

Antenna Pattern

- Pattern is a plot of gain versus angle
- Dipole example

$$G(\theta) = 1.643\left[\frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin^2\theta}\right]$$

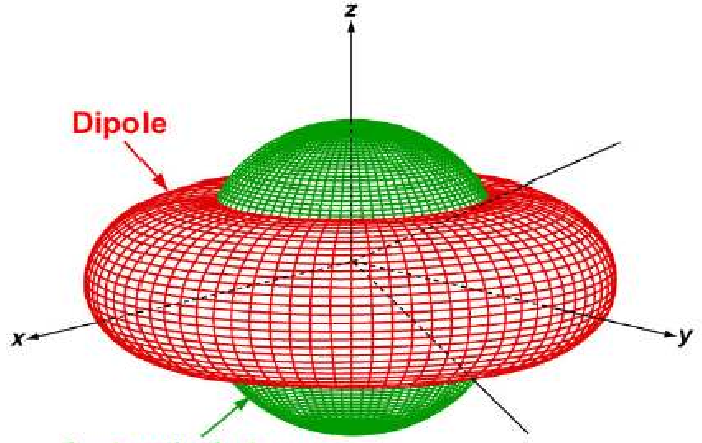
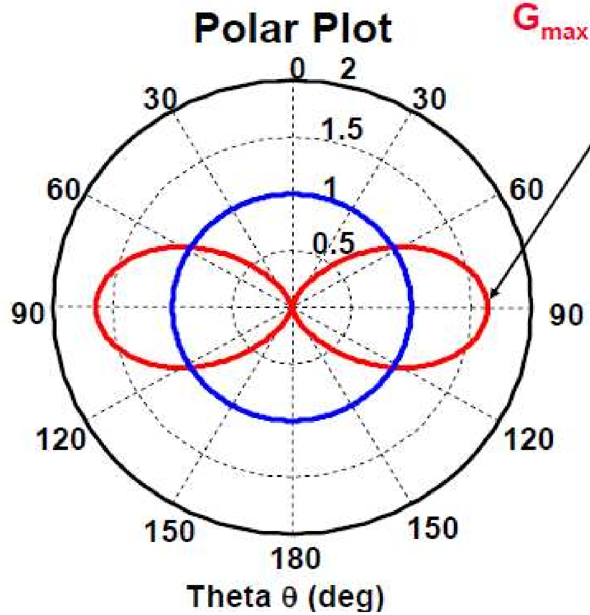
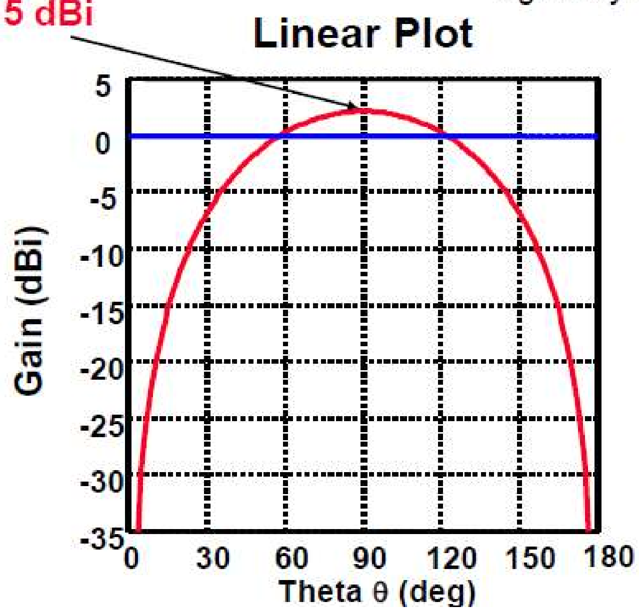


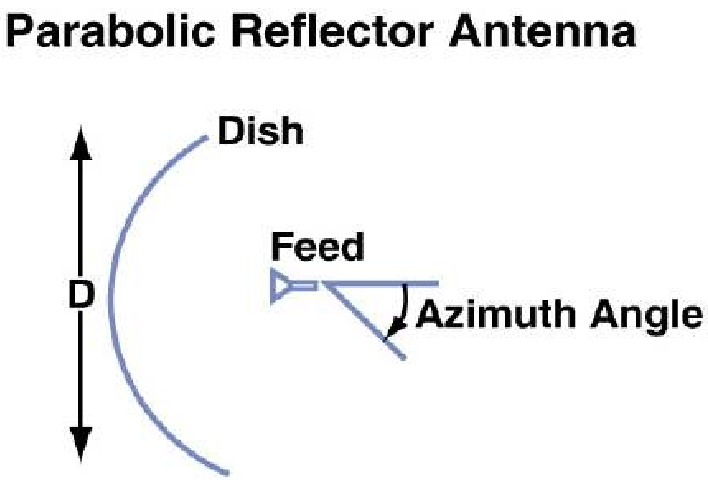
Figure by MIT OCW.

G_{max} = 1.64 = 2.15 dBi





Antenna Pattern Characteristics



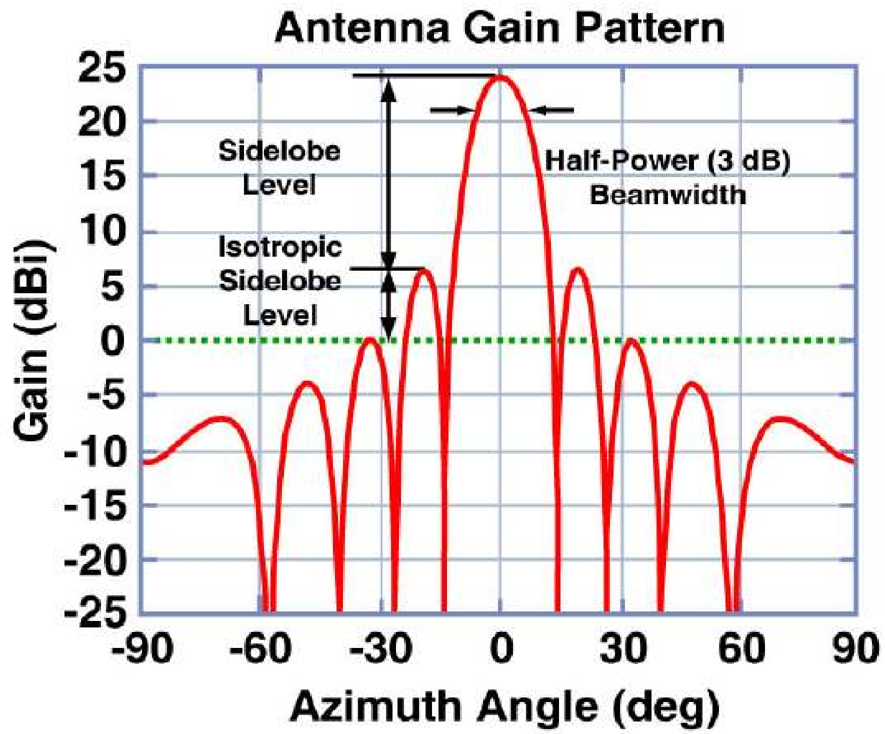


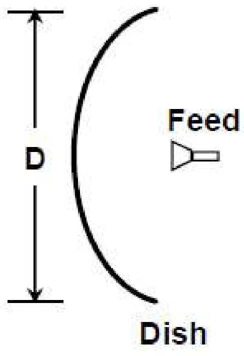
Figure by MIT OCW.

Aperture diameter D: 5 m
Frequency: 300 MHz
Wavelength: 1 m

Gain: 24 dBi
Isotropic Sidelobe Level: 6 dBi
Sidelobe Level: 18 dB
Half-Power Beamwidth: 12 deg

Effect of Aperture Size on Gain

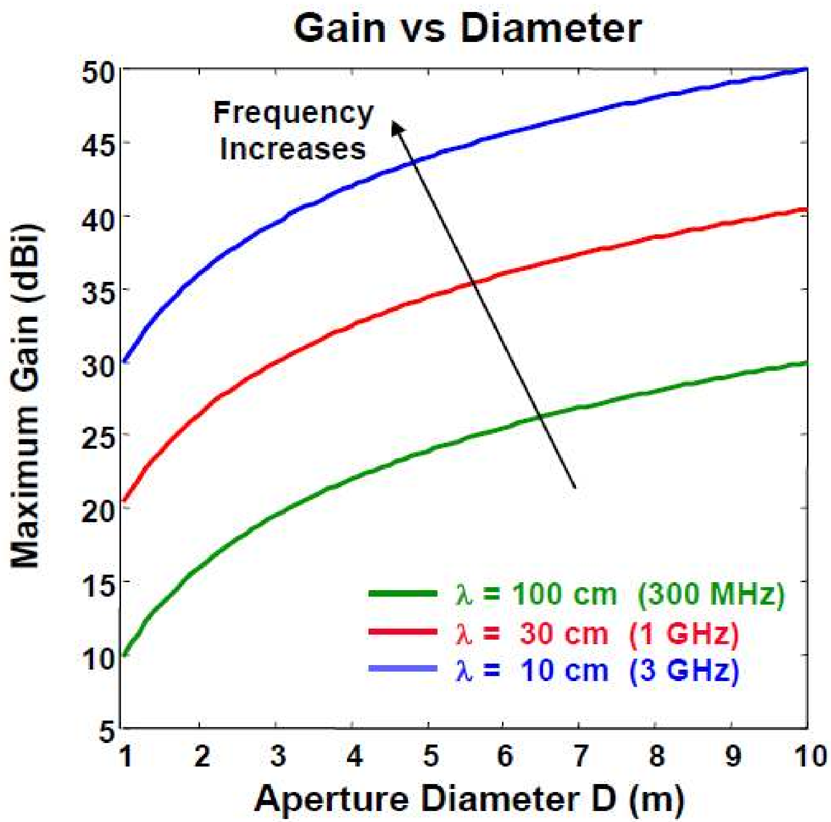
Parabolic Reflector Antenna



$$\text{Gain} = \frac{4\pi A_e}{\lambda^2} \quad \leftarrow \text{Effective Area}$$

$$\cong \frac{4\pi A}{\lambda^2} \quad \leftarrow \text{Rule of Thumb (Best Case)}$$

$$= \left(\frac{\pi D}{\lambda}\right)^2$$



Gain increases as aperture becomes electrically larger (diameter is a larger number of wavelengths)

Reflector Comparison
Kwajalein Missile Range Example

ALTAIR
45.7 m diameter

scale by 1/3

MMW
13.7 m diameter

Operating frequency: 162 MHz (VHF)
Wavelength λ: 1.85 m

Diameter electrical size: 25 λ

Gain: 34 dB
Beamwidth: 2.8 deg

Operating frequency: 35 GHz (Ka)
Wavelength λ: 0.0086 m

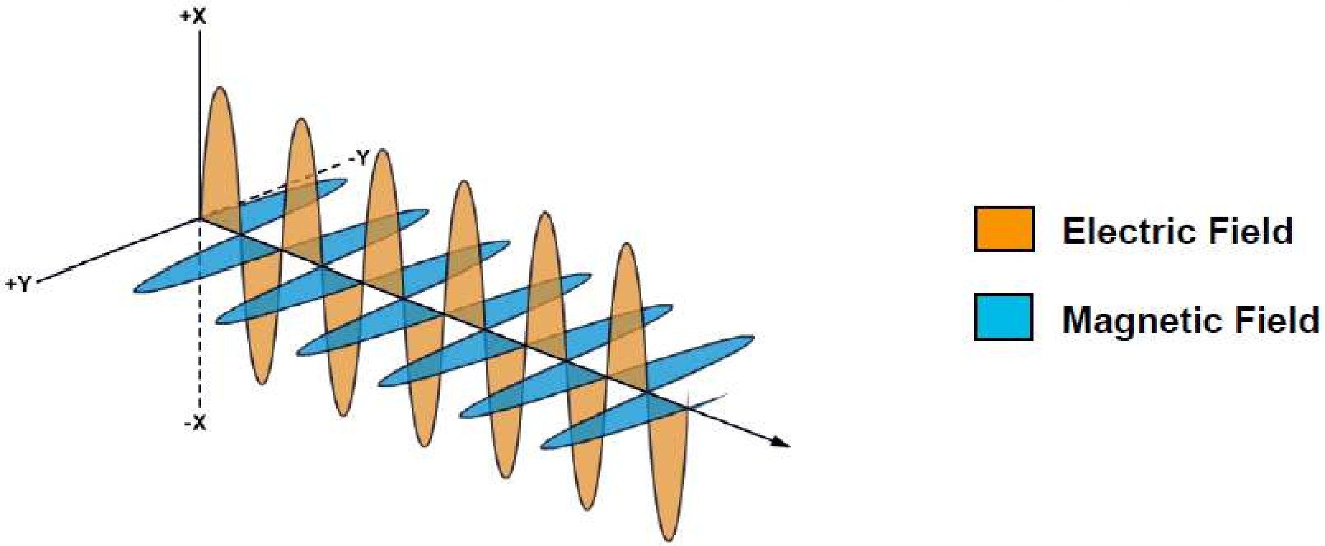
Diameter electrical size: 1598 λ

Gain: 70 dB
Beamwidth: 0.00076 deg

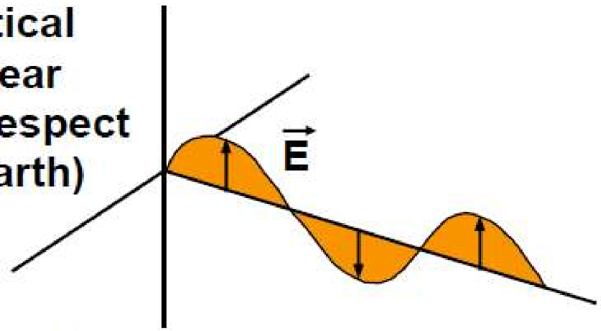
Polarization

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

Electromagnetic Wave

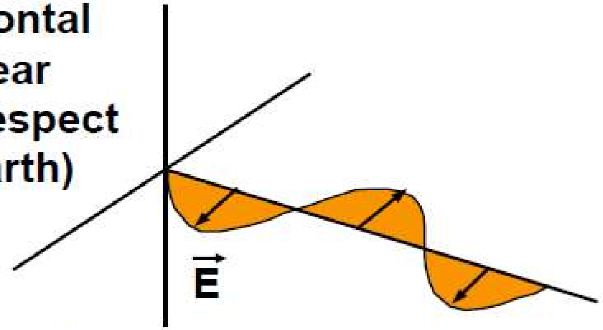


Vertical Linear (with respect to Earth)



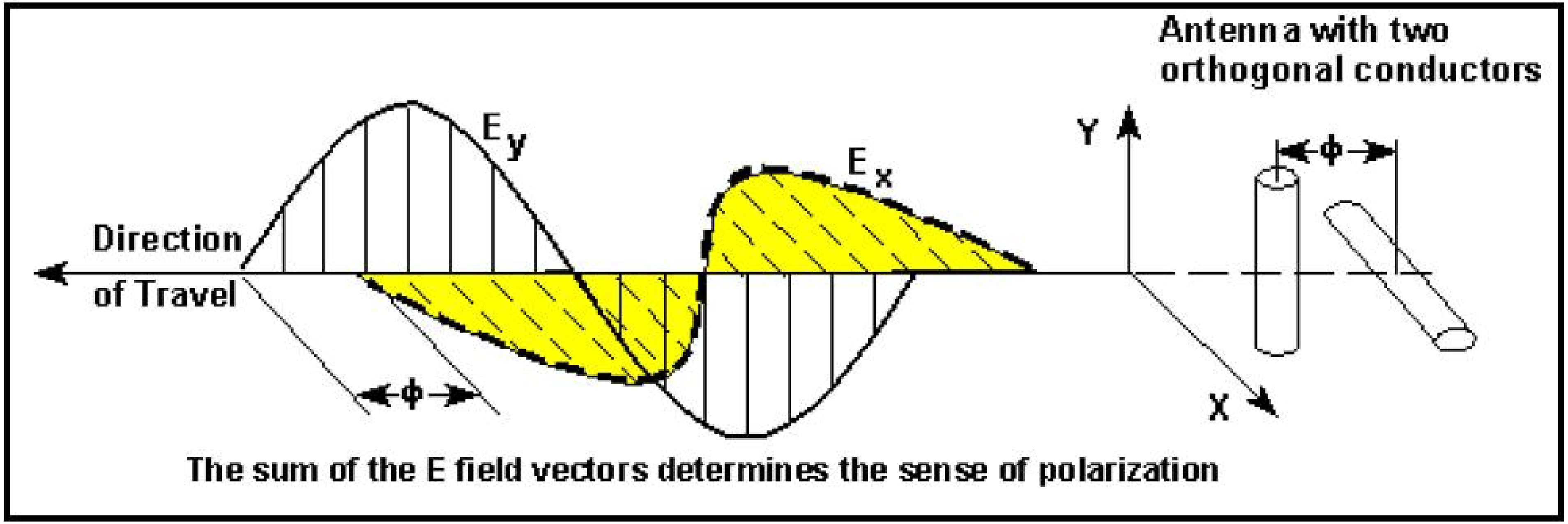
(For over-water surveillance)

Horizontal Linear (with respect to Earth)

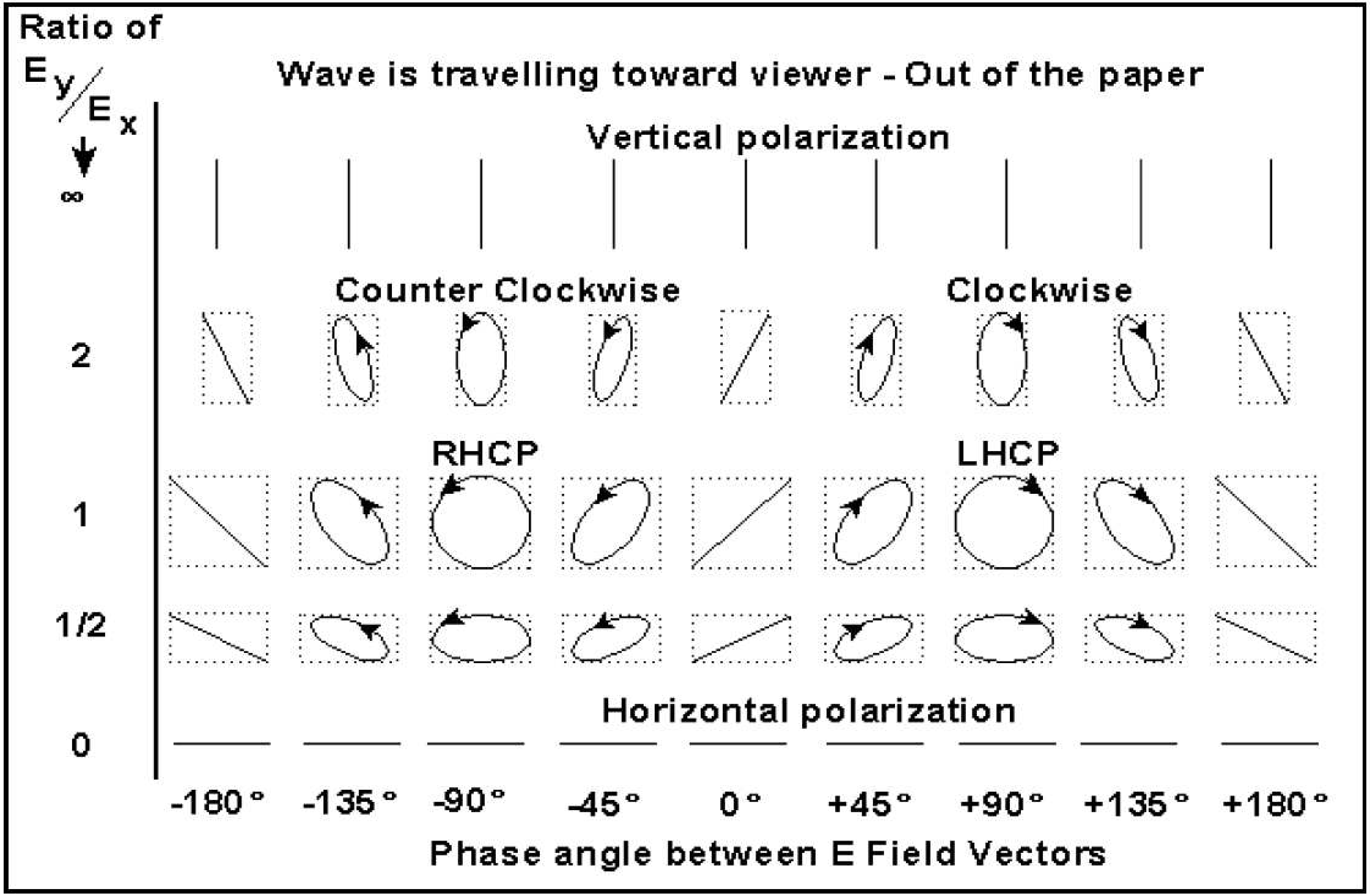


(For air surveillance looking upward)

Polarization



Polarization



Circular Polarization (CP)

- "Handed-ness" is defined by observation of electric field along propagation direction
- Used for discrimination, polarization diversity, rain mitigation

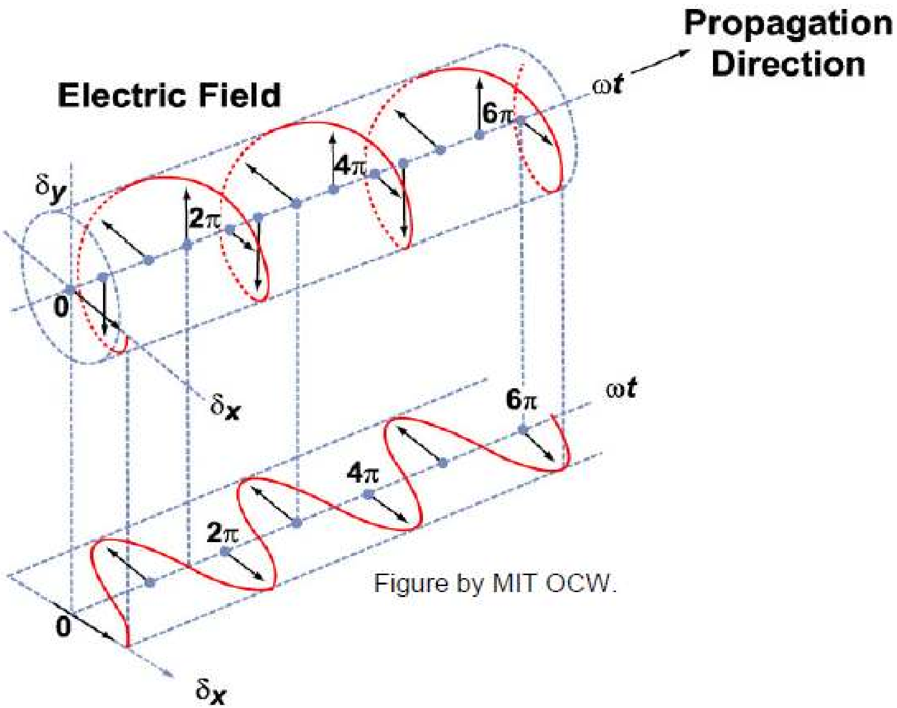
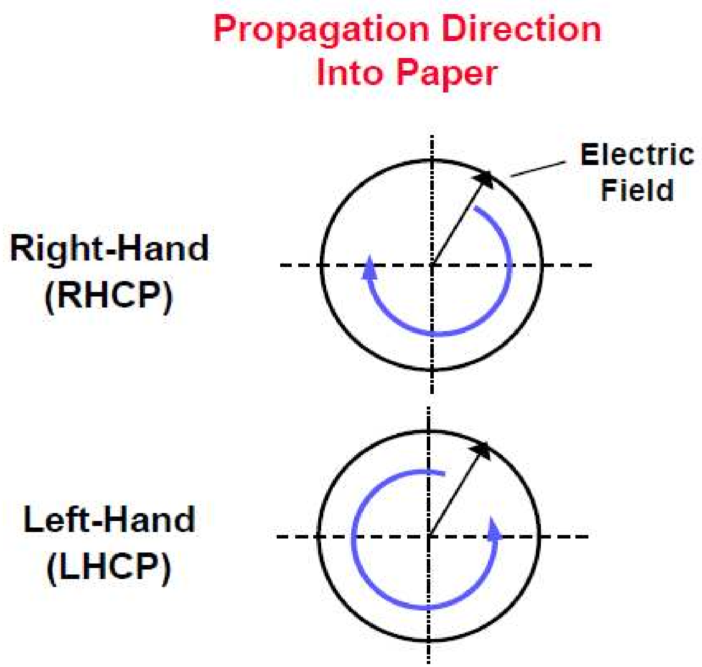


Figure by MIT OCW.



F-35 와 F-22 외형

F-35 CTOL
F-22
Length 51.1 ft
Span 35 ft
Wing Area 460 ft²
Internal Fuel 18,073 lb
Length 62.1 ft
Span 44.5 ft
Wing Area 840 ft²

Field Regions

Reactive Near-Field Region

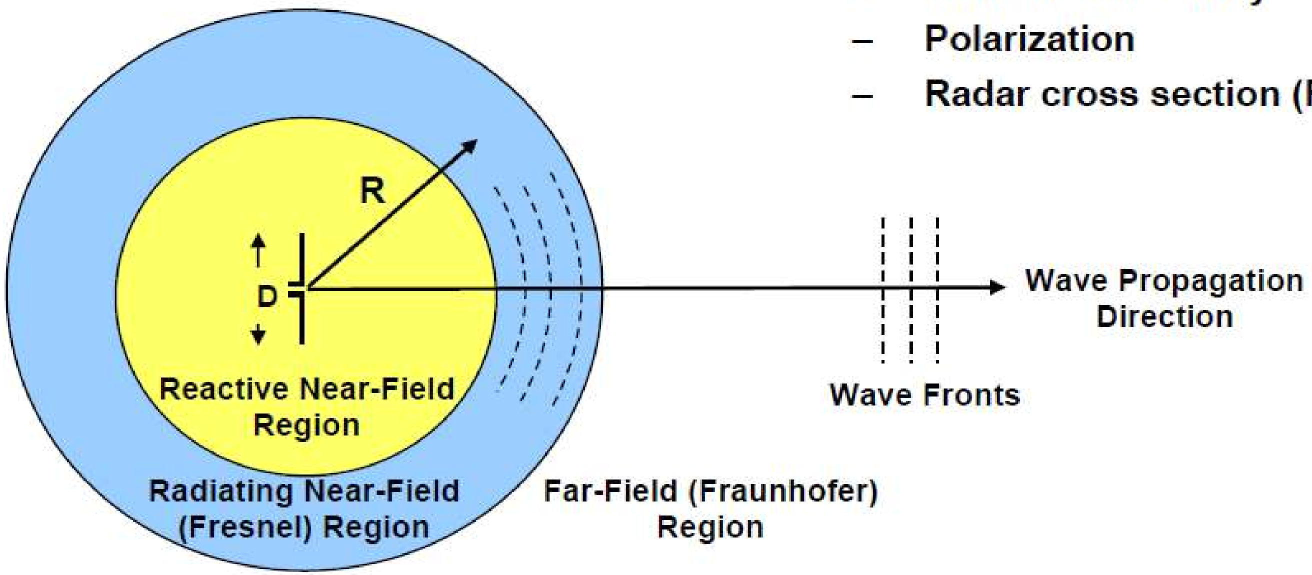
$$R < 0.62\sqrt{D^3/\lambda}$$

- Energy is stored in vicinity of antenna
- Near-field antenna quantities
  - Input impedance
  - Mutual coupling

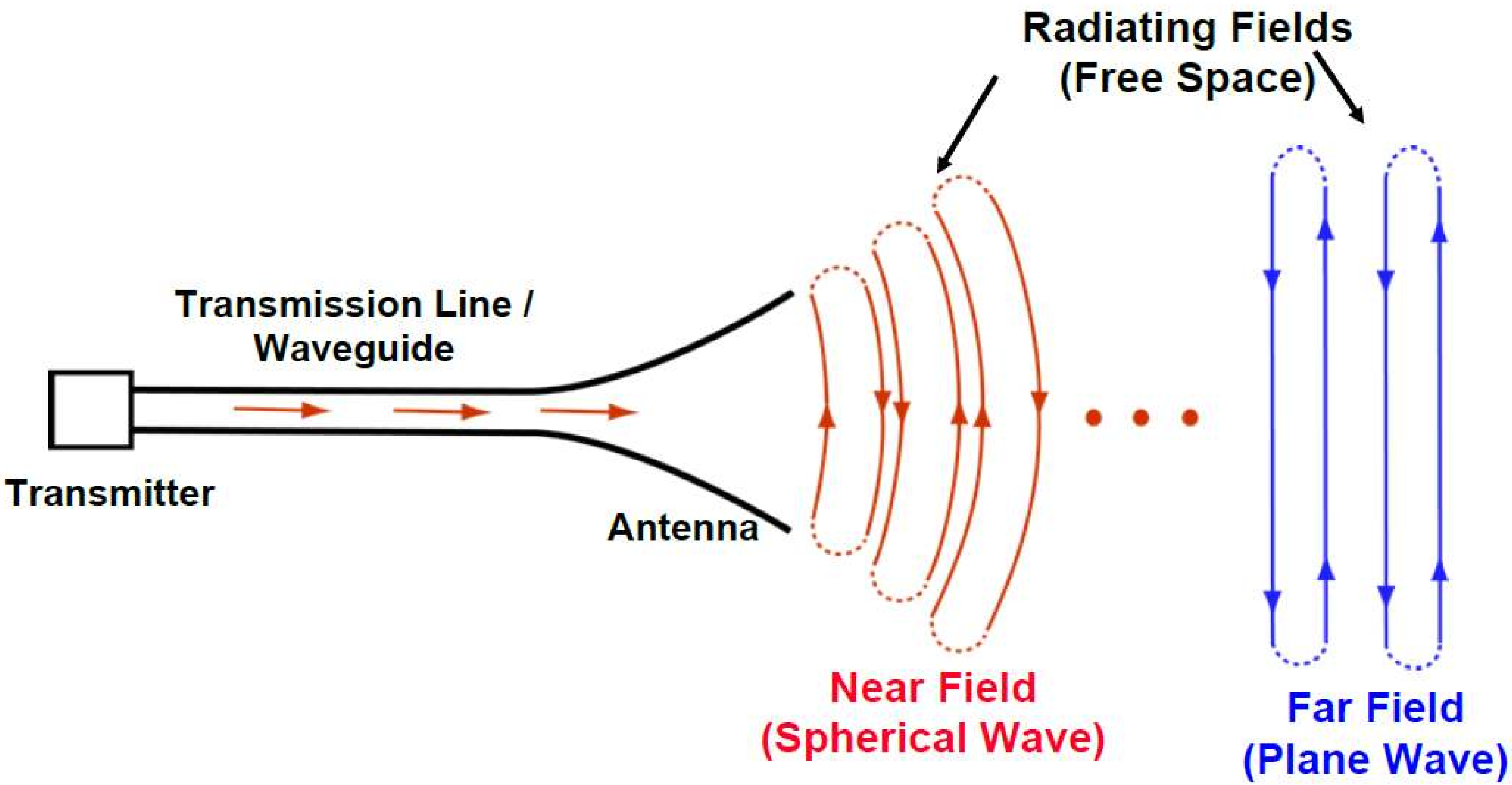
Far-field (Fraunhofer) Region

$$R > 2D^2/\lambda$$

- All power is radiated out
- Radiated wave is a plane wave
- Far-field antenna quantities
  - Pattern
  - Gain and directivity
  - Polarization
  - Radar cross section (RCS)

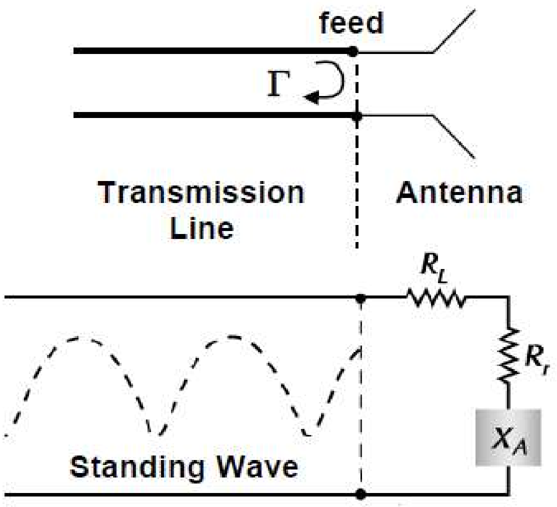


Regions of Radiation



Antenna Input Impedance

- Antenna can be modeled as an impedance
  - Ratio of voltage to current at feed port
- Design antenna to maximize power transfer from transmission line
  - Reflection of incident power sets up standing wave
- Input impedance usually defines antenna bandwidth



$\Gamma = 0$ — Incident Power is Delivered to Antenna

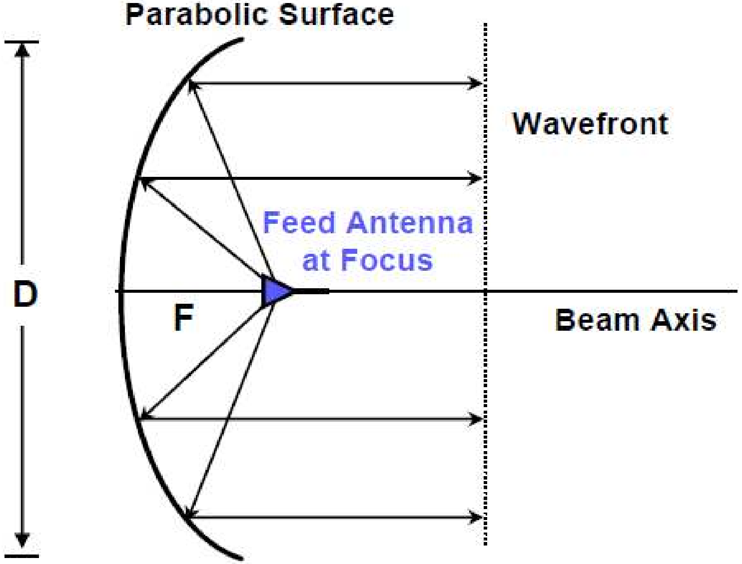
$\Gamma = 1$ — All Incident Power is Reflected

차 례

- Fundamental antenna concepts
- Reflector antennas
- Phased array antennas

AJOU UNIVERSITY

Parabolic Reflector Antenna



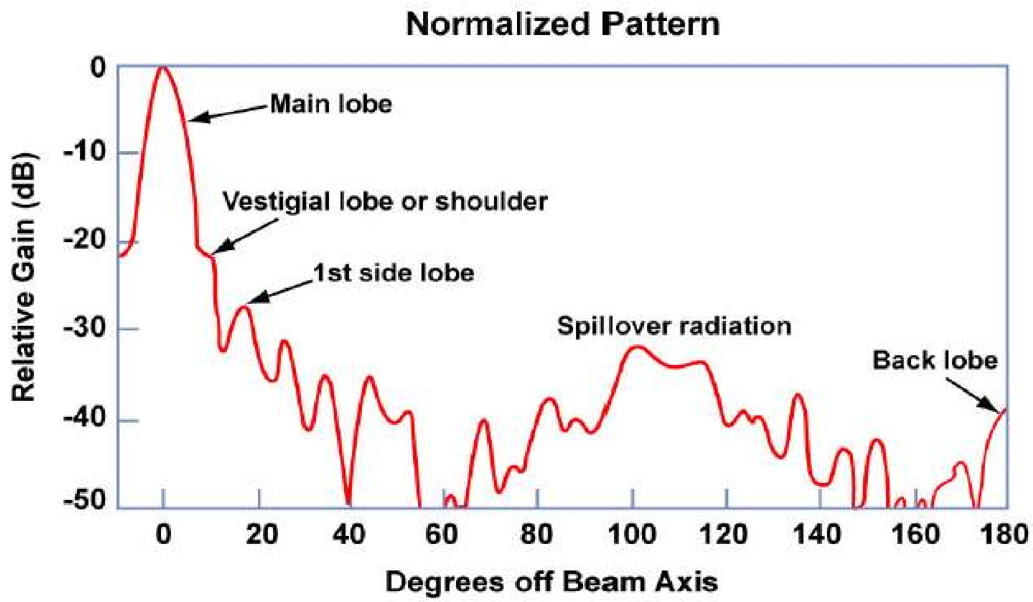
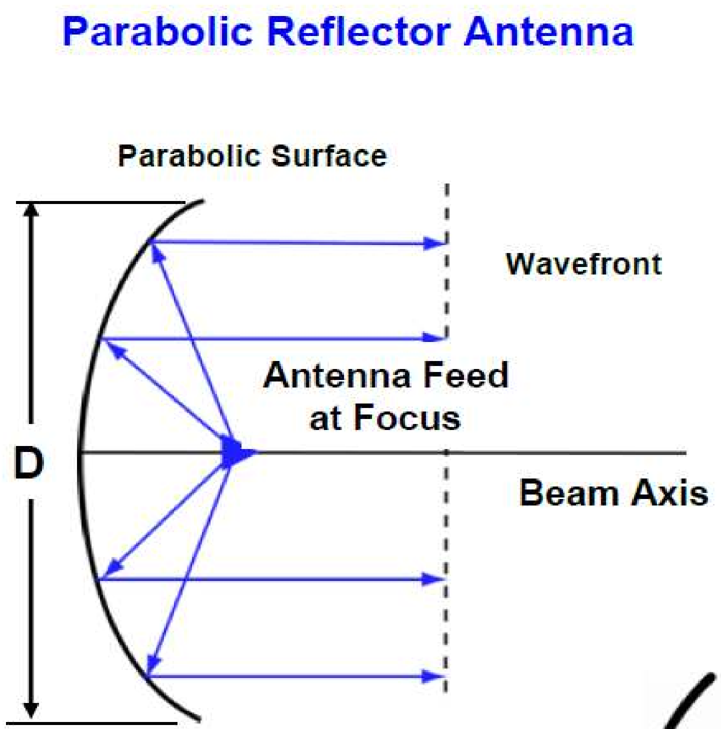


Figure by MIT OCW.

- Design is a tradeoff between maximizing dish illumination and limiting spillover
- Feed antenna choice is critical

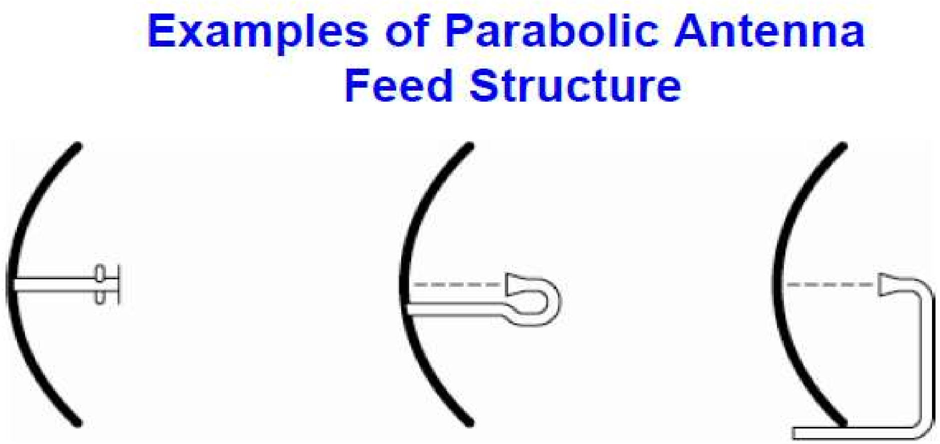
Parabolic Reflector Antenna



•Point source is evolves to plane wave (In the Far Field)

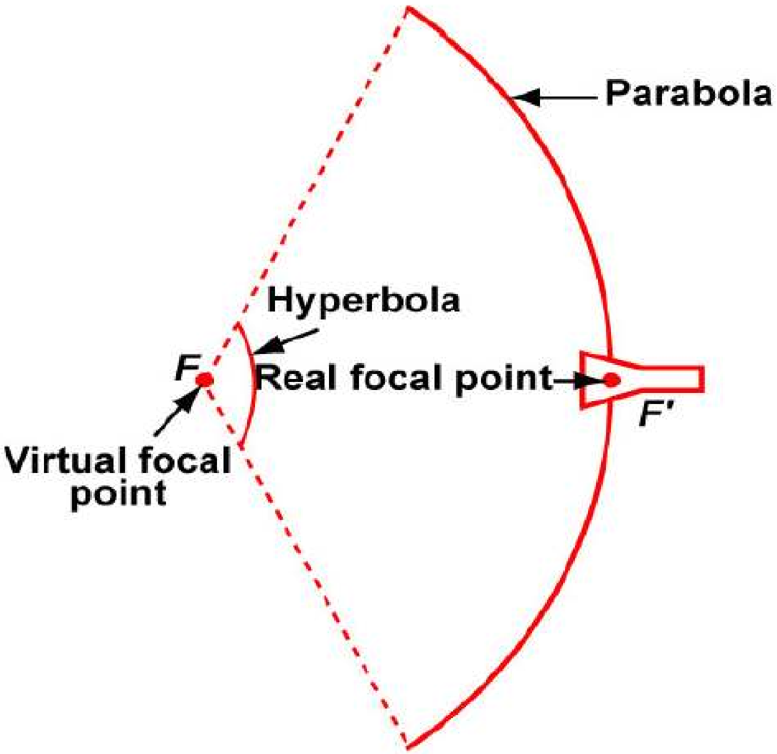
•Feed can be dipole or open-ended waveguide (horn)

•Feed structure reduces antenna efficiency



Adapted from Skolnik, Reference 2

Cassegrain Reflector Antenna



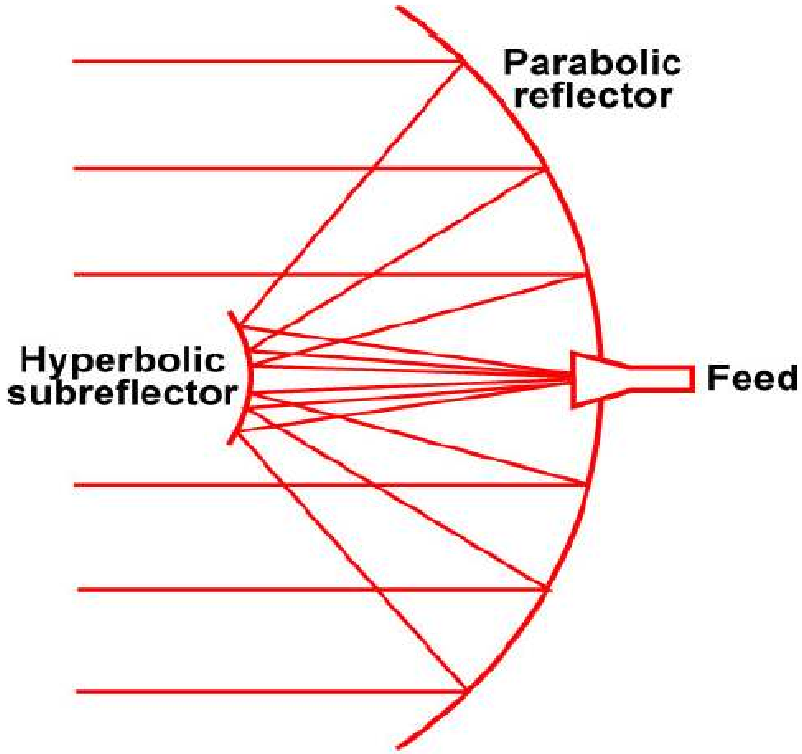


Figure by MIT OCW.

Geometry of Cassegrain Antenna

Ray Trace of Cassegrain Antenna

Advantages of Cassegrain Feed

- Lower waveguide loss because feed is not at the focus of the paraboloid, but near the dish.

- Antenna noise temperature is lower than with conventional feed at focus of the paraboloid
  - Length of waveguide from antenna feed to receiver is shorter
  - Sidelobe spillover from feed see colder sky rather than warmer earth

- Good choice for monopulse tracking
  - Complex monopulse microwave plumbing may be placed behind reflector to avoid the effects of aperture blocking

ALTAIR

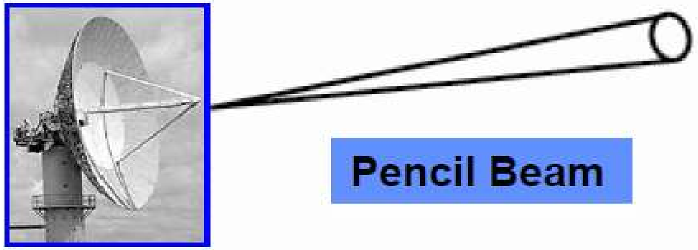
Dual frequency

VHF Parabolic

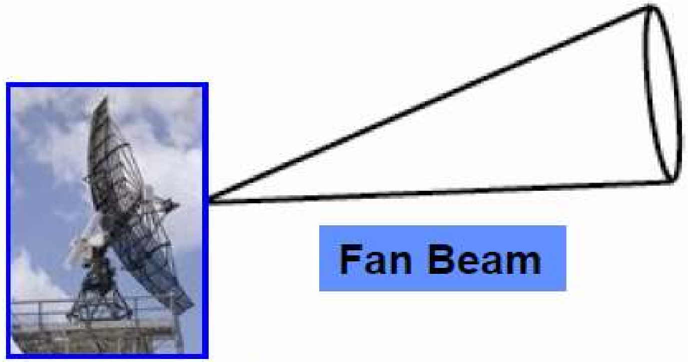
UHF Cassegrain

FSS (Frequency Selective Surface) used for reflector

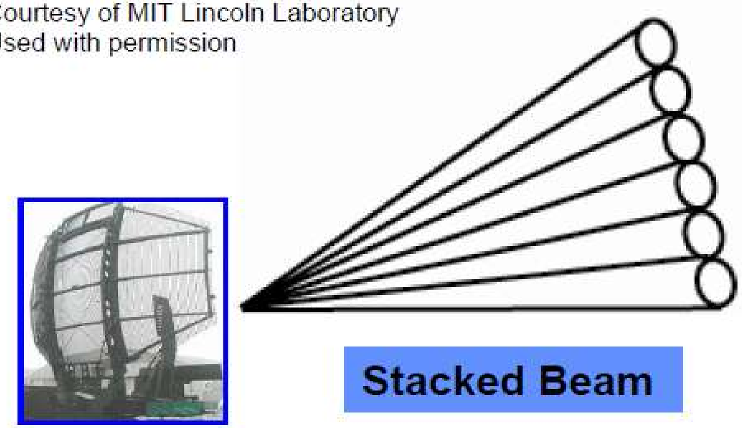
Different Types of Radar Beams



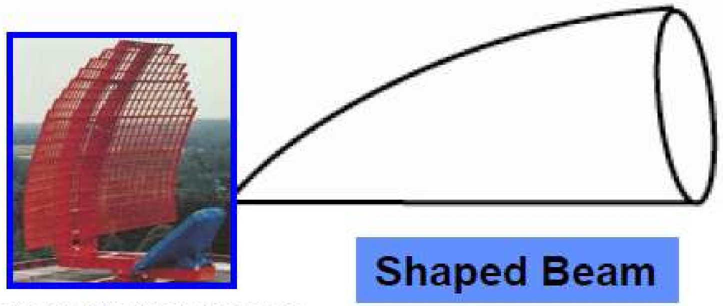
Courtesy of MIT Lincoln Laboratory
Used with permission



Courtesy of MIT Lincoln Laboratory,
Used with permission



Courtesy of US Air Force



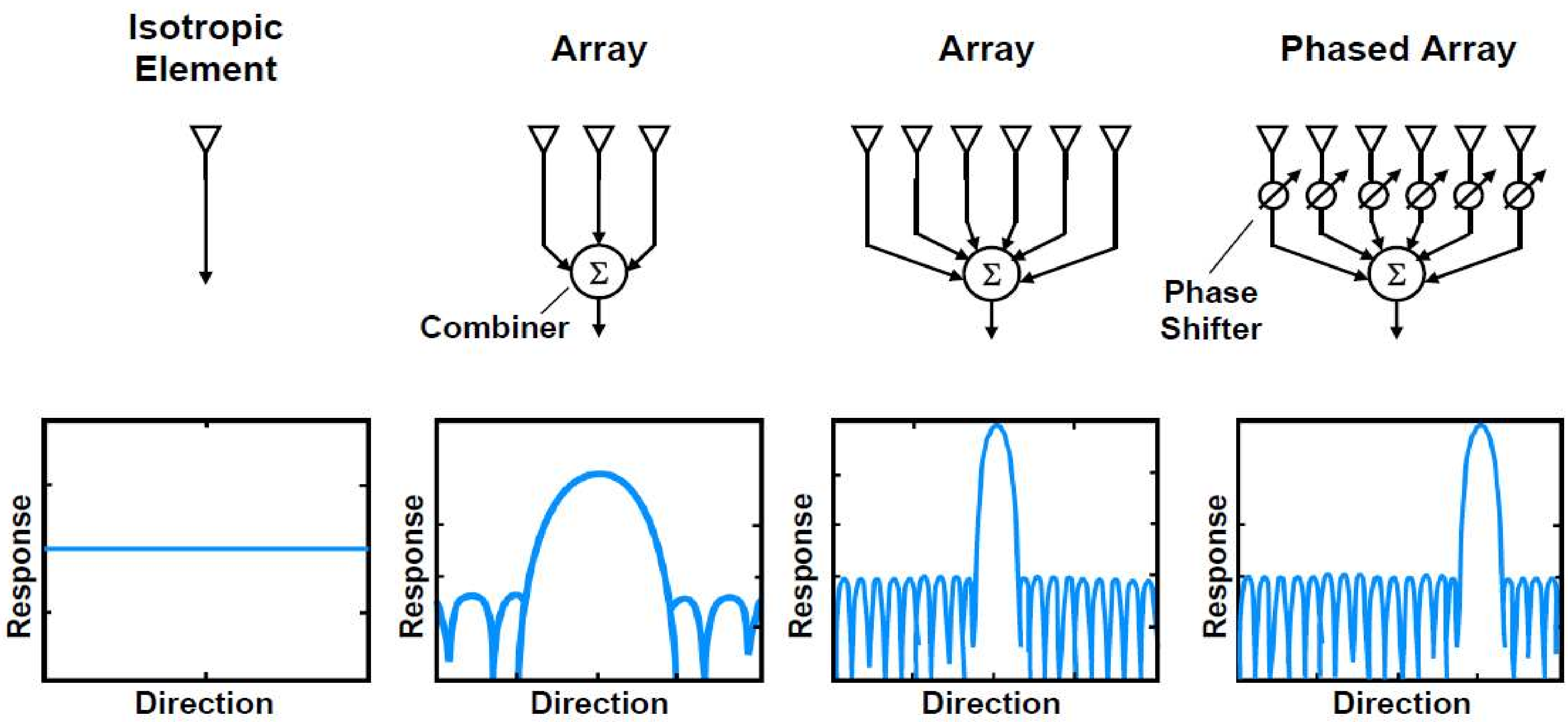
Courtesy of Northrop Grumman
Used with Permission

차 례

- **Fundamental antenna concepts**
- **Reflector antennas**
- **Phased array antennas**

Arrays

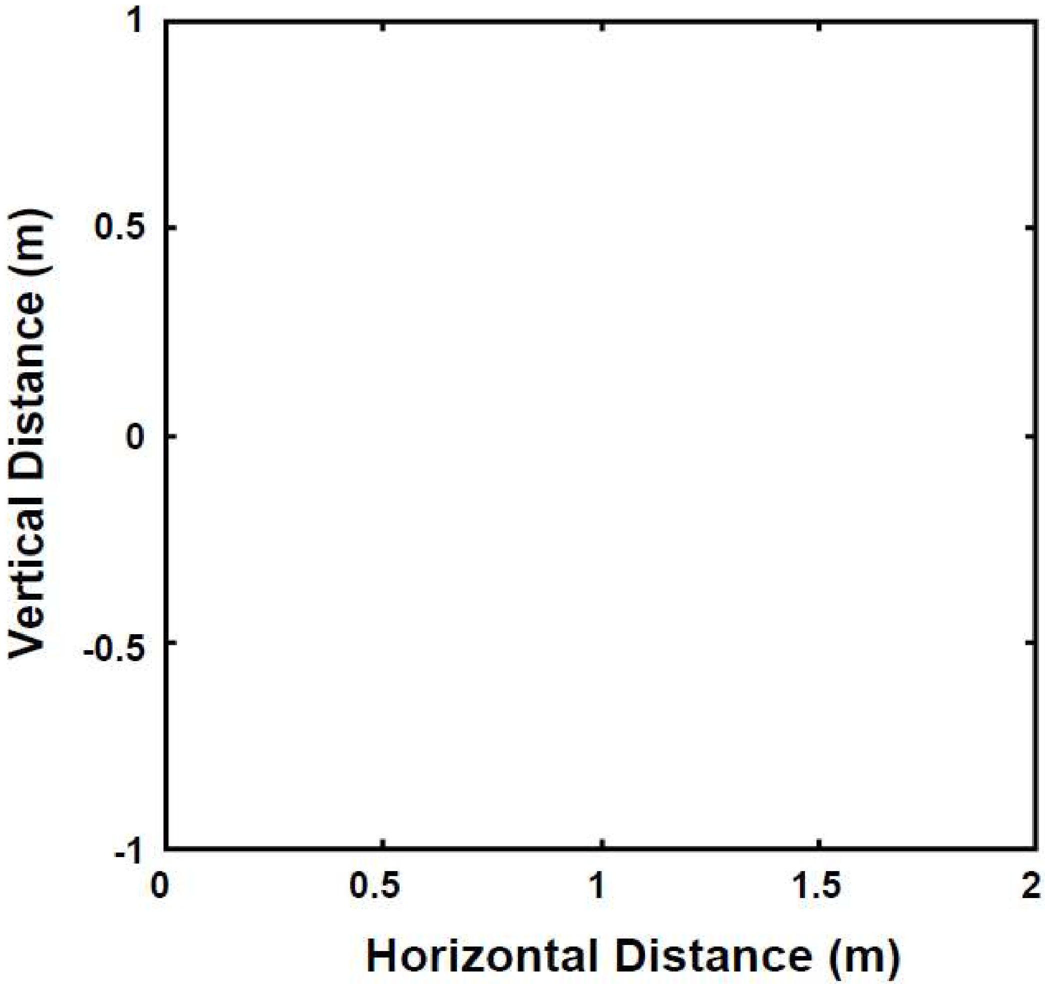
- Multiple antennas combined to enhance radiation and shape pattern



Two Antennas Radiating

Dipole 1*

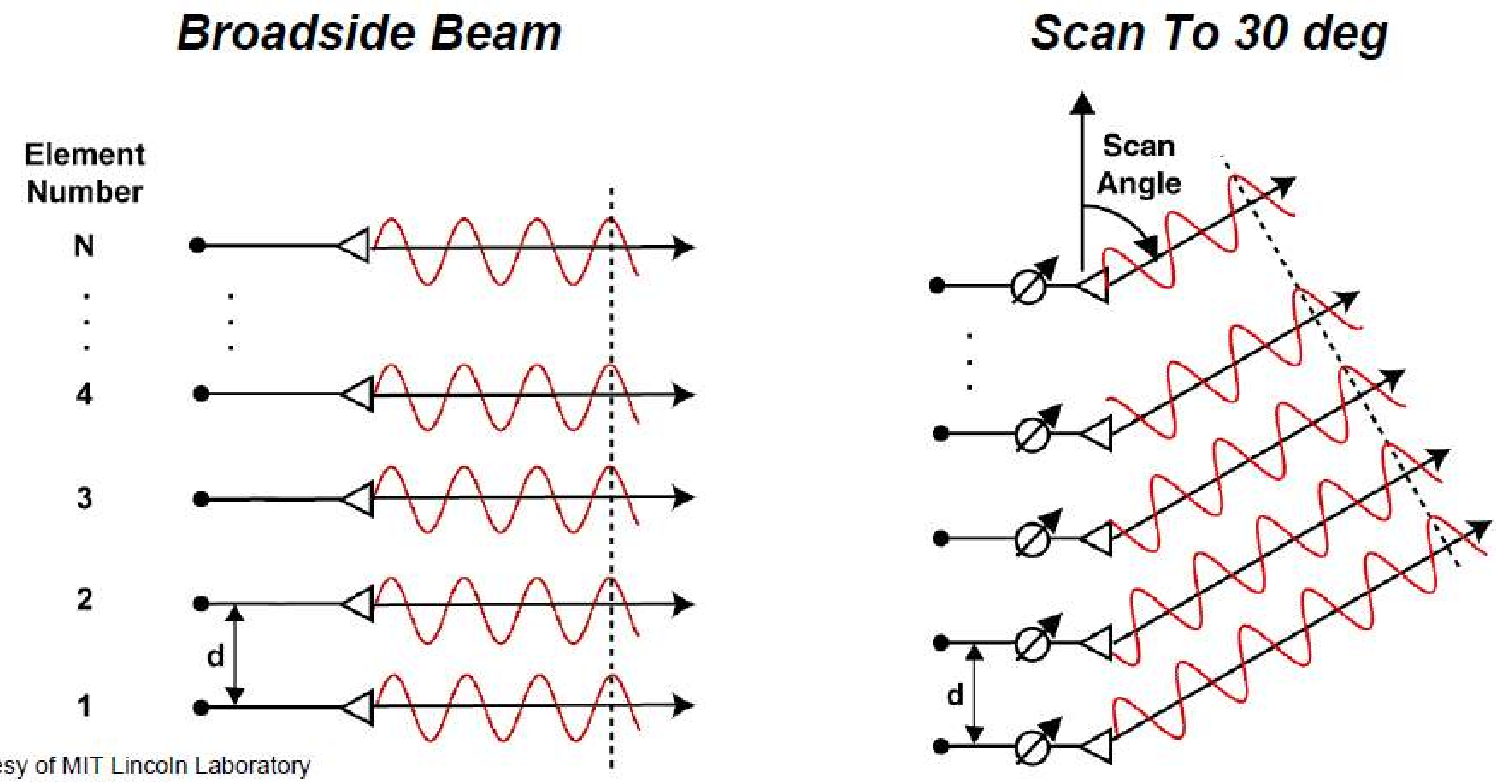
Dipole 2*



*driven by oscillating sources (in phase)

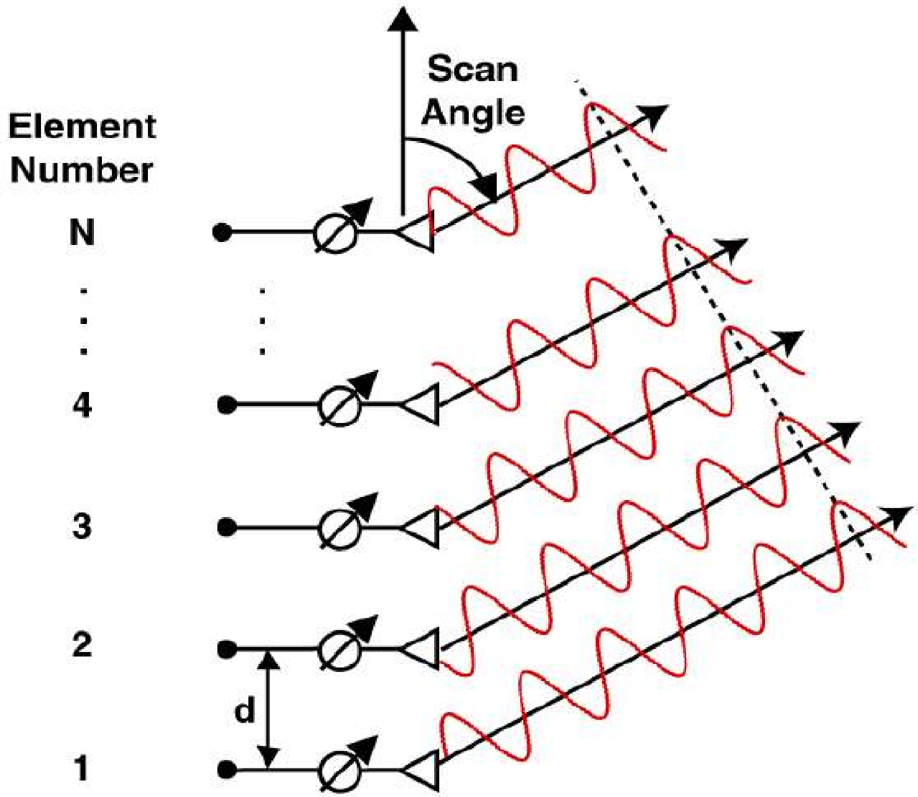
Array Beamforming (Beam Collimation)

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



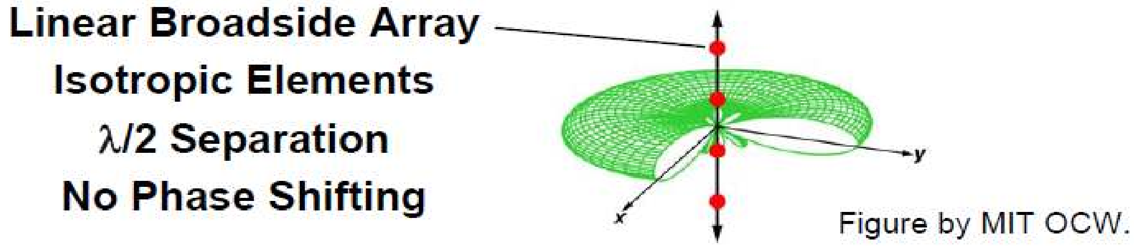
Courtesy of MIT Lincoln Laboratory
Used with Permission

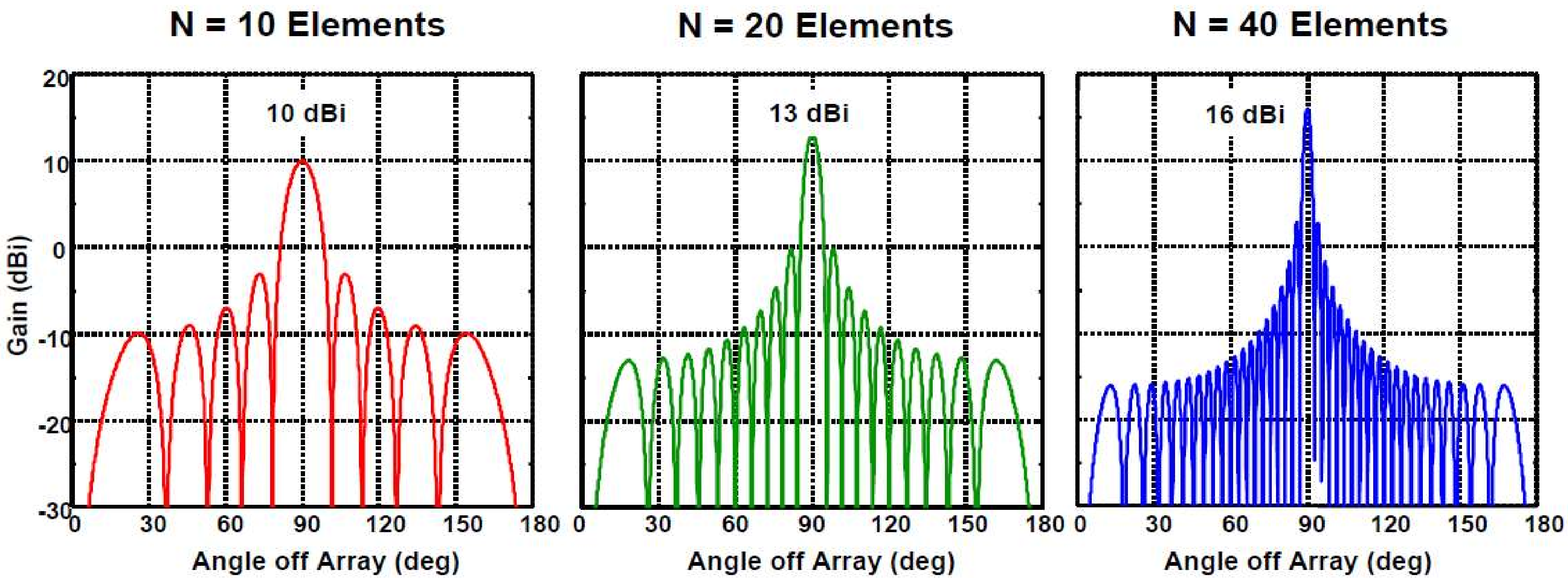
Array Controls



- Geometrical configuration
  - Linear, rectangular, triangular, circular grids
- Element separation
- Phase shifts
- Excitation amplitudes
  - For sidelobe control
- Pattern of individual elements
  - Isotropic, dipoles, etc.

Increasing Array Size by Adding Elements





- Gain ~ 2N(d / λ) for long broadside array

Increasing Array Size by Separating Elements

- Linear Broadside Array
- N = 10 Isotropic Elements
- No Phase Shifting

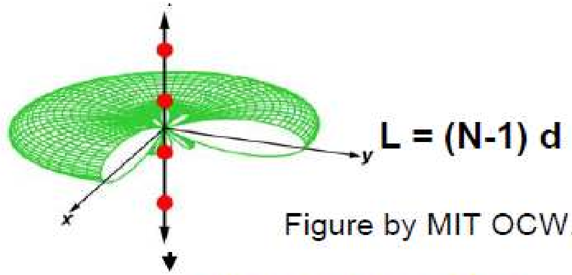
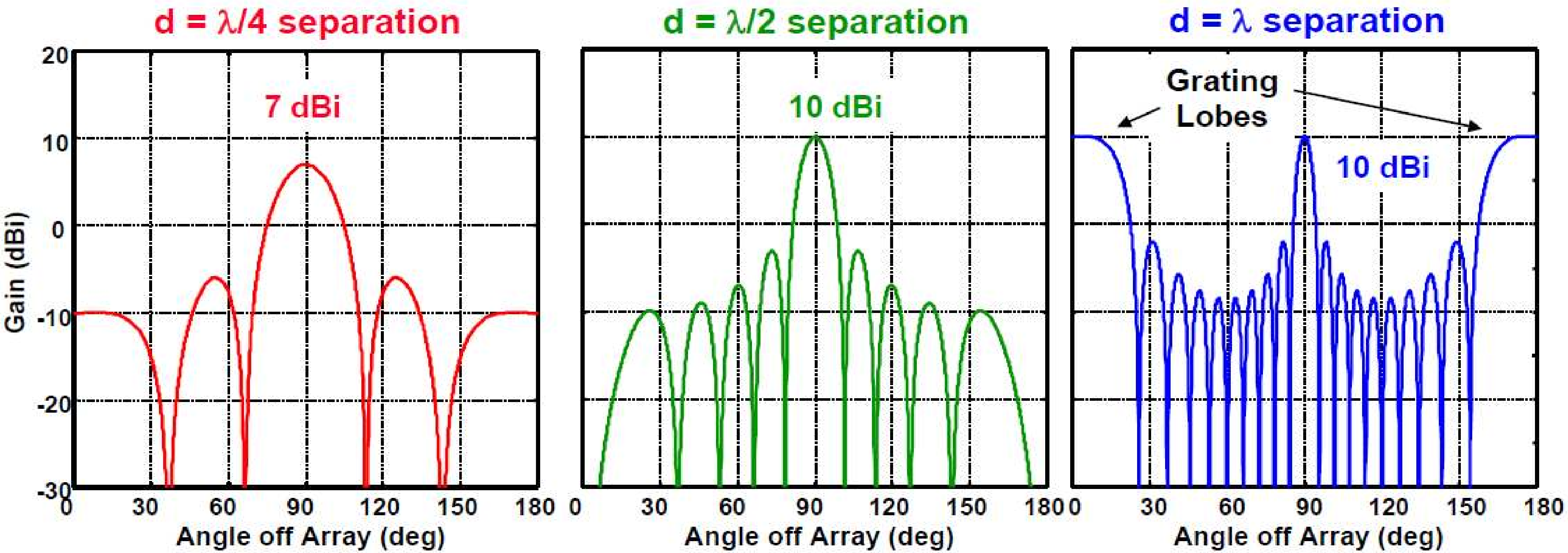


Figure by MIT OCW.



Limit element separation to d < λ to prevent grating lobes for broadside array

Increasing Array Size of Scanned Array by Separating Elements

- Linear Endfire Array
- N = 10 Isotropic Elements
- Phase Shifted to Point Up

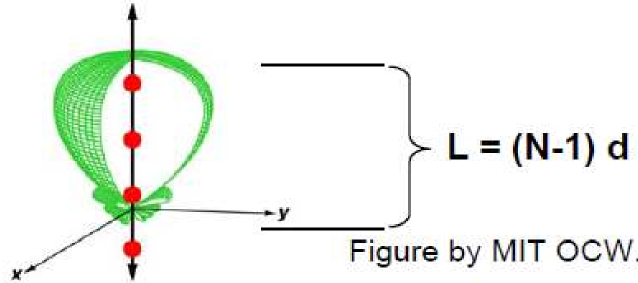
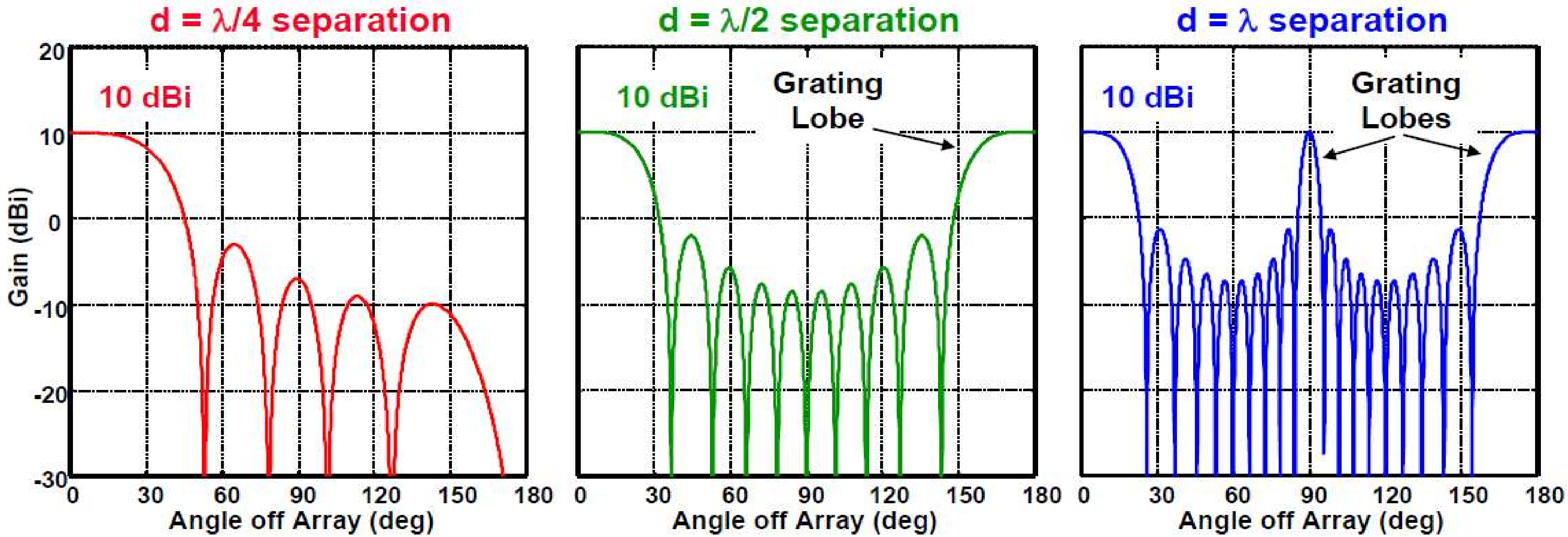


Figure by MIT OCW.



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

Linear Phased Array
Scanned every 30 deg, N = 15, d = λ/4

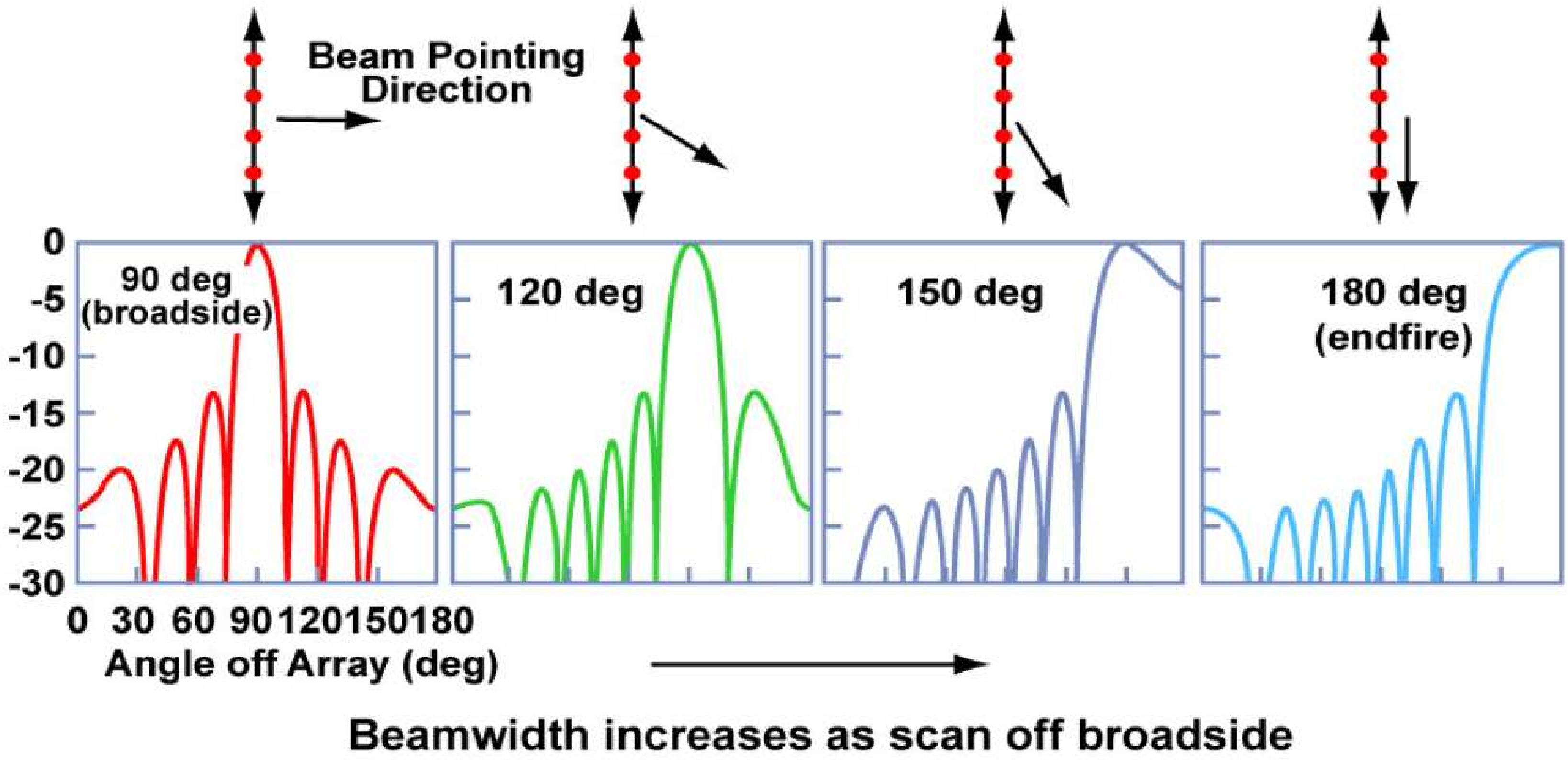


Figure by MIT OCW.

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

AJOU UNIVERSITY

Planar Arrays

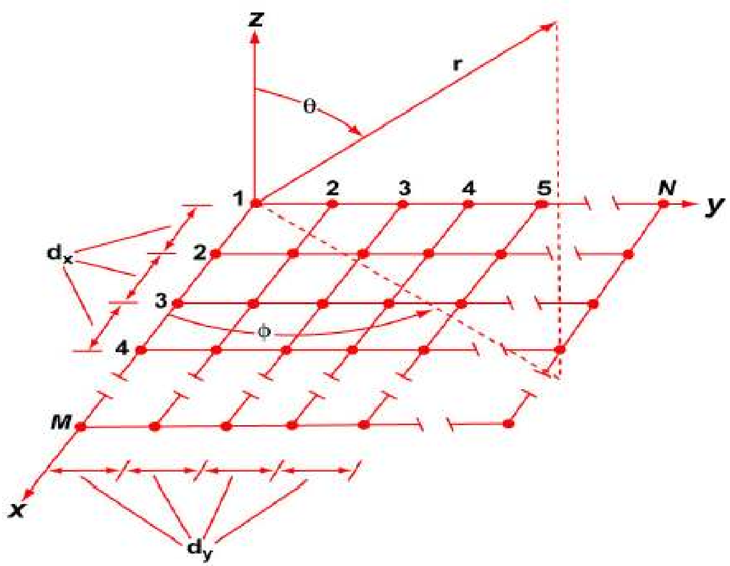


Figure by MIT OCW.

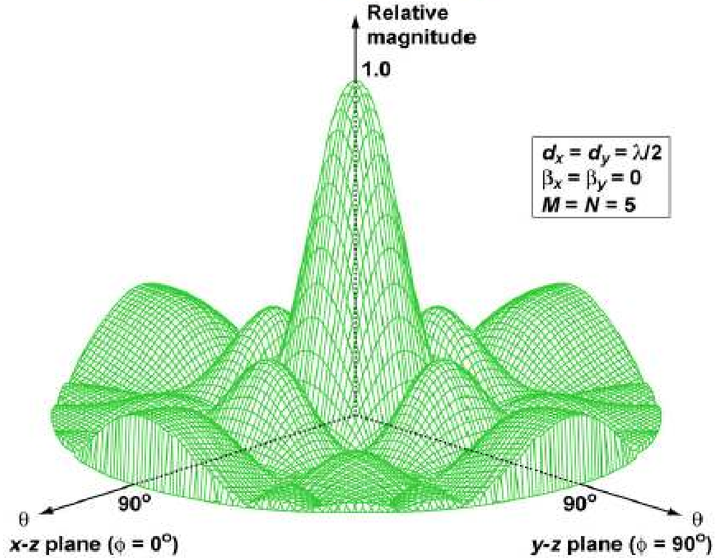
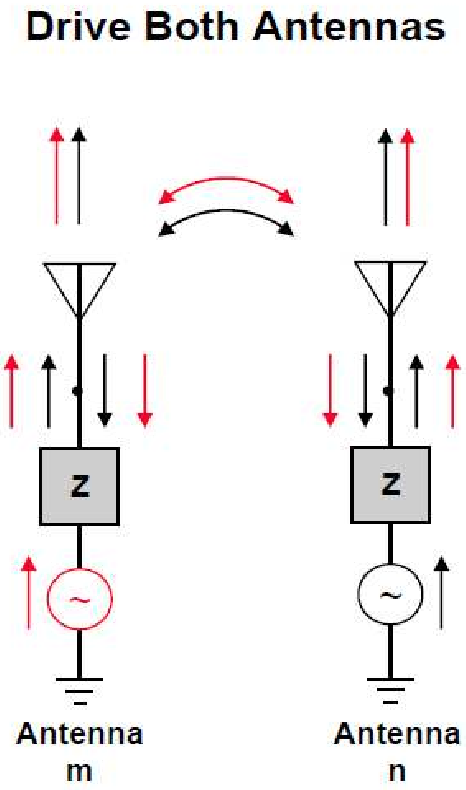


Figure by MIT OCW.

- As scan to θ_o off broadside:
  - Beamwidth broadens by $1/\cos\theta_o$
  - Directivity decreases by $\cos\theta_o$

To scan over all space without grating lobes, keep element separation in both directions < λ / 2

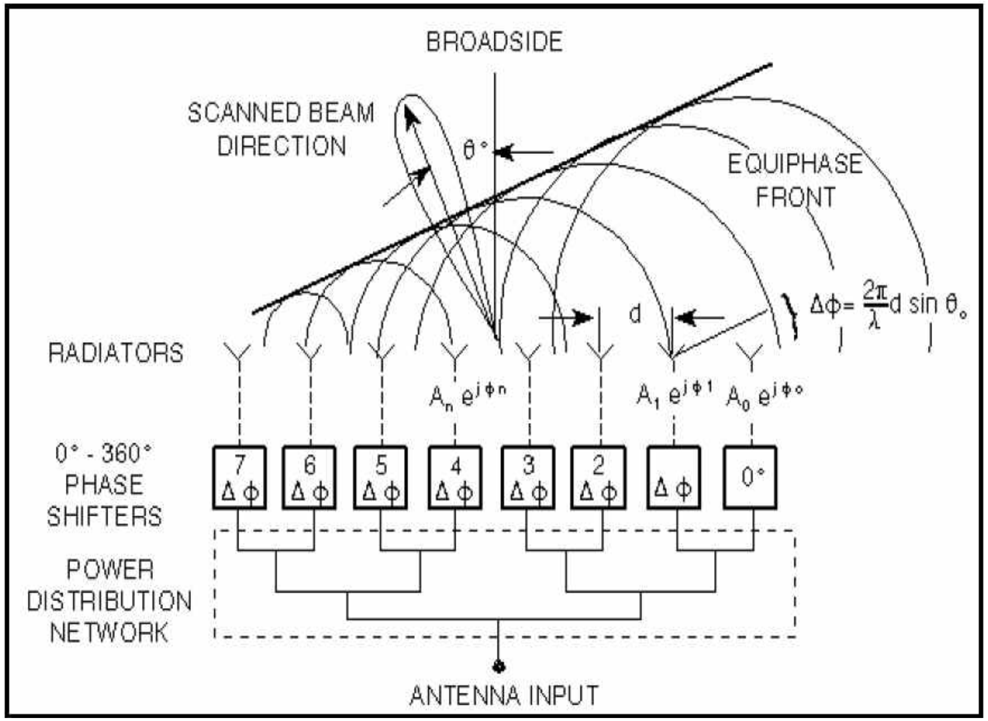
Mutual Coupling

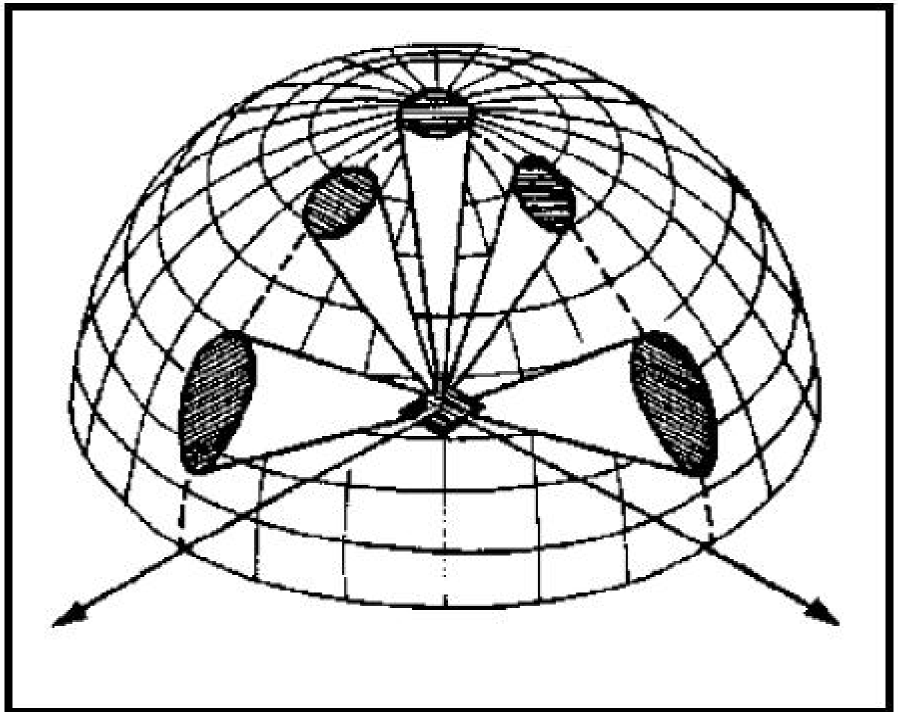


- Effect of one element on another
  - Near-field quantity
  - Makes input impedance dependent on scan angle
- Can greatly complicate array design
  - Hard to deliver power to antennas for all scan angles
  - Can cause *scan blindness* where no power is radiated
- Can limit scan volume and array bandwidth

But… mutual coupling can sometimes be exploited to achieve certain performance requirements

Phased Array



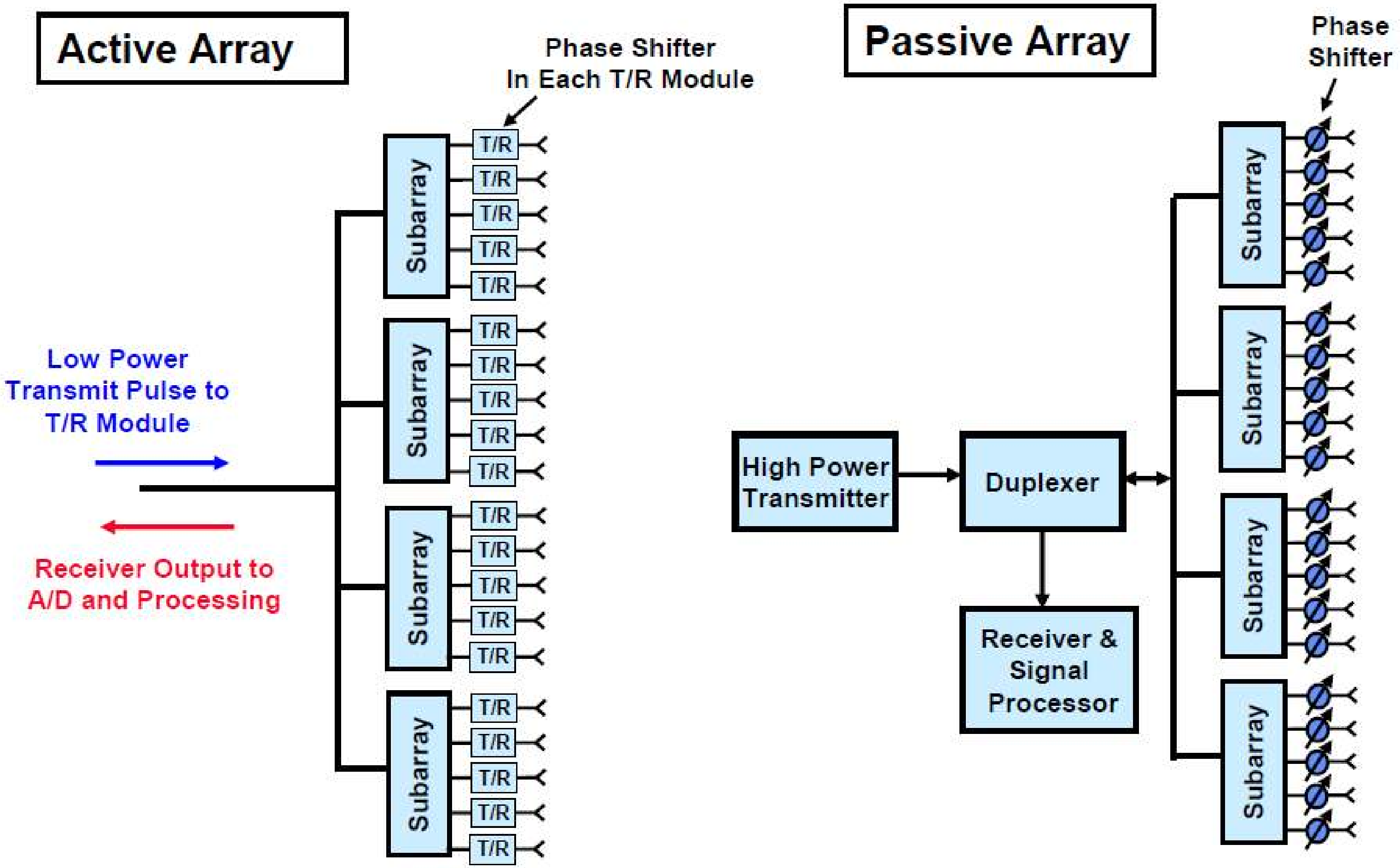


Phased Array Architectures

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

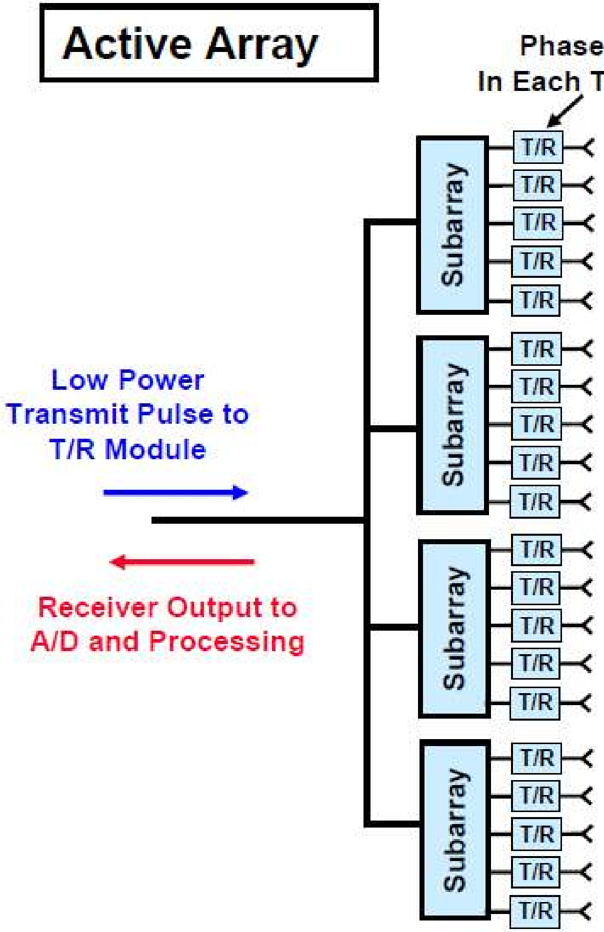
- Passive vs. Active Array
  - Passive Array - A single (or a few) transmitter (s) from which high power is distributed to the individual array elements
  - Active Array – Each array element has its own transmitter / receiver (T/R) module

Phased Array Antenna Configurations (Active and Passive)

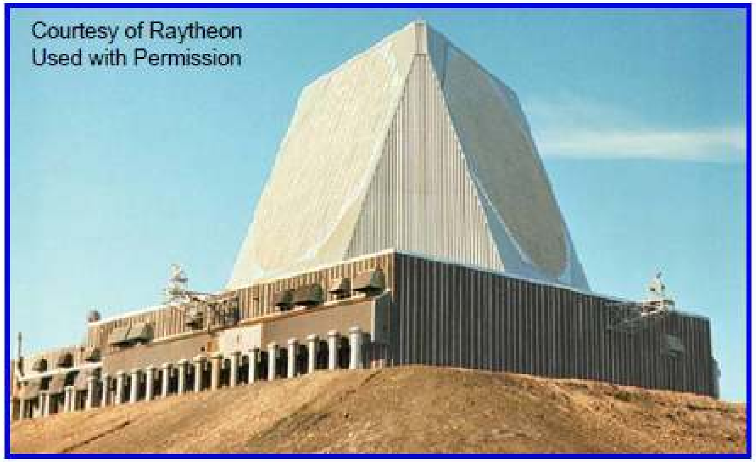


Adapted from Skolnik, Reference 1

Examples – Active Array Radars

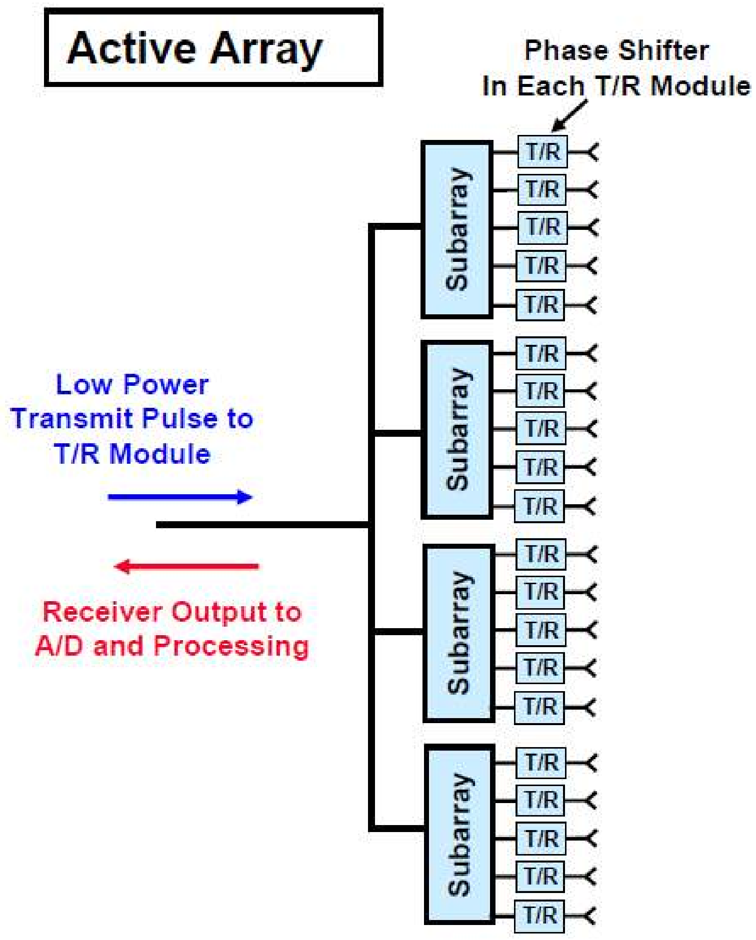


UHF Early Warning Radar



THAAD X-Band Phased Array Radar

More Examples – Active Array Radars



Counter Battery Radar (COBRA)

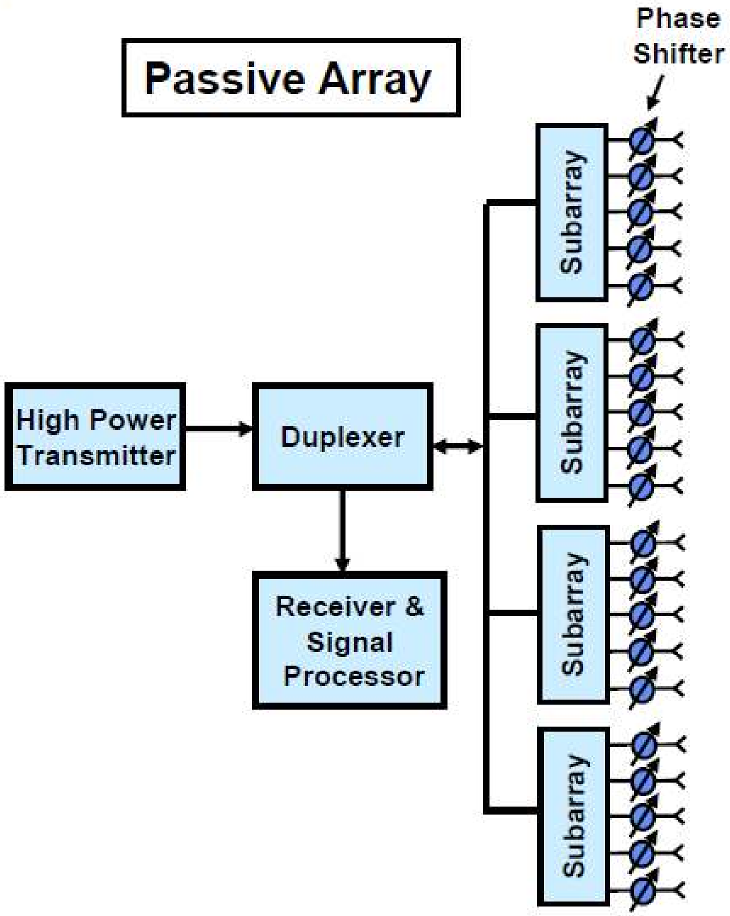
APG-81 Radar for F-35 Fighter

Examples – Passive Array Radars

S- Band AEGIS Radar

Courtesy of U S Navy

L- Band COBRA DANE Radar



Phased Arrays vs Reflectors

- Phased arrays provide beam agility and flexibility
  - Effective radar resource management (multi-function capability)
  - Near simultaneous tracks over wide field of view
- 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

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

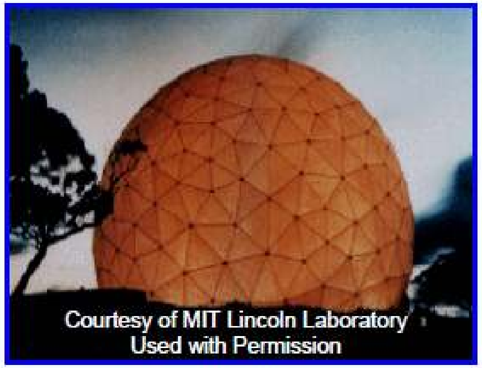
- Radars which scan electronically can compensate for platform motion by appropriately altering the beam steering commands in the radar's computer system

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

MMW

ALCOR



COBRA GEMINI

Q & A