Radar Systems Engineering
Lecture 8
Antennas
Part 1 - Basics and Mechanical Scanning

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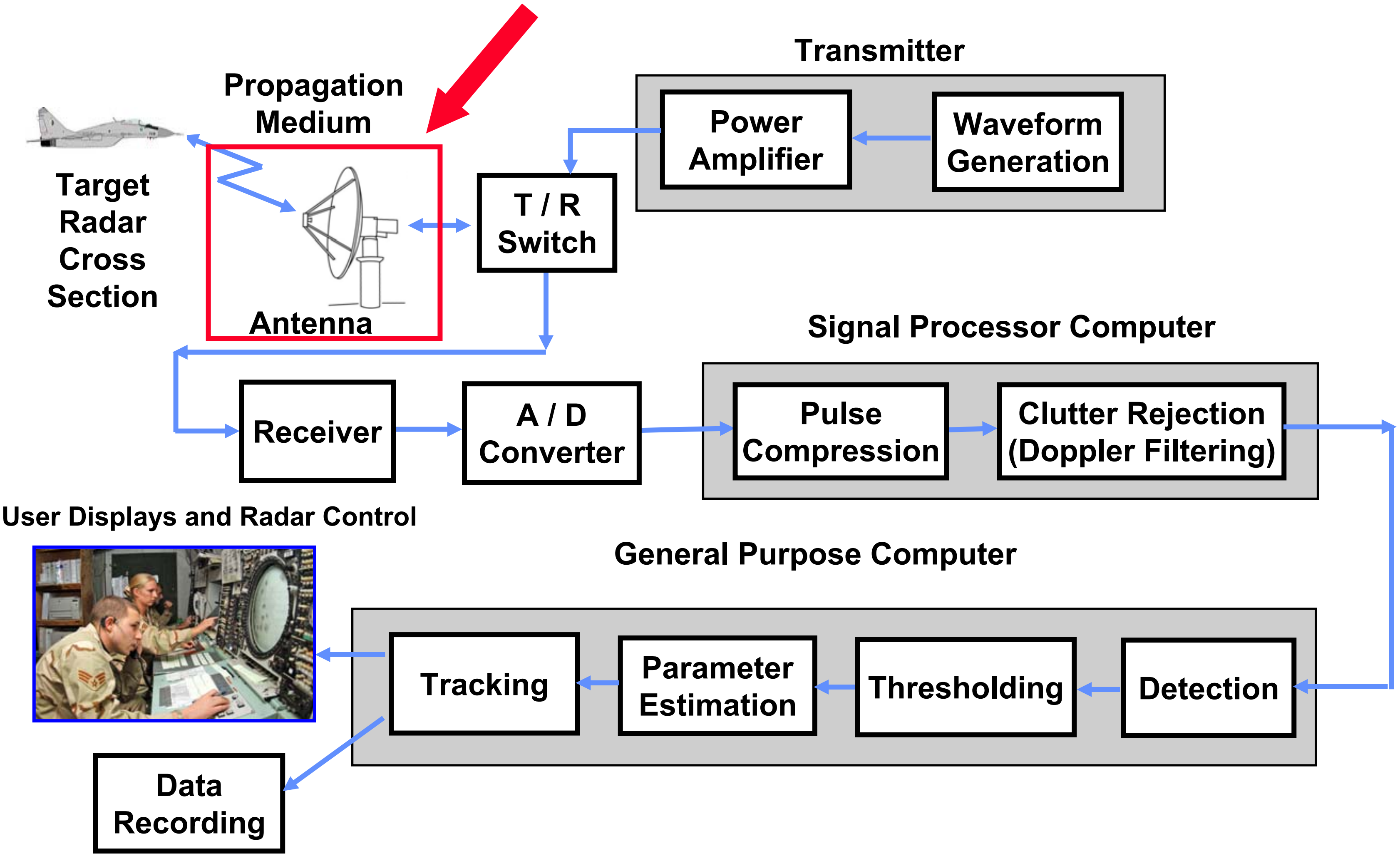
IEEE New Hampshire Section
Guest Lecturer

Block Diagram of Radar System



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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

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

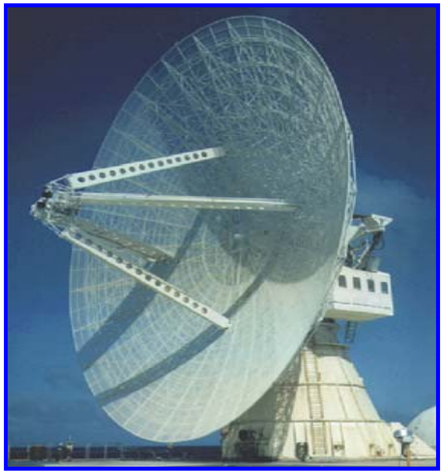
} *Radar Equation Lecture*

* IEEE Standard Definitions of Terms for Antennas (IEEE STD 145-1983)

Radar Antennas Come in Many Sizes and Shapes

Electronic Scanning Antenna

Mechanical Scanning Antenna



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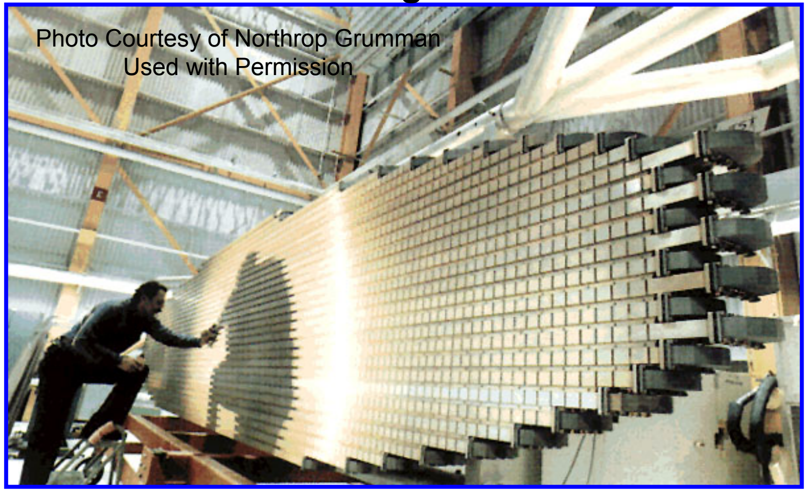
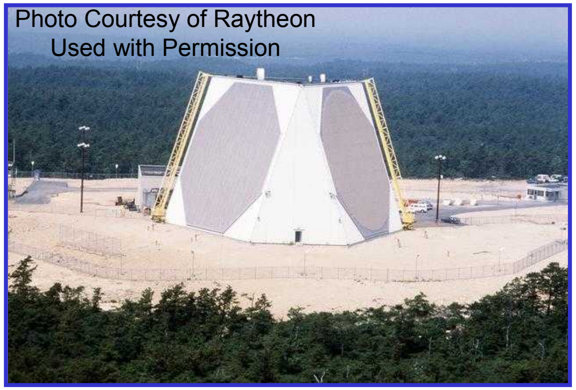
Hybrid Mechanical and Frequency Scanning Antenna



Mechanical Scanning Antenna



Electronic Scanning Antenna

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Hybrid Mechanical and Frequency Scanning Antenna

Outline

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

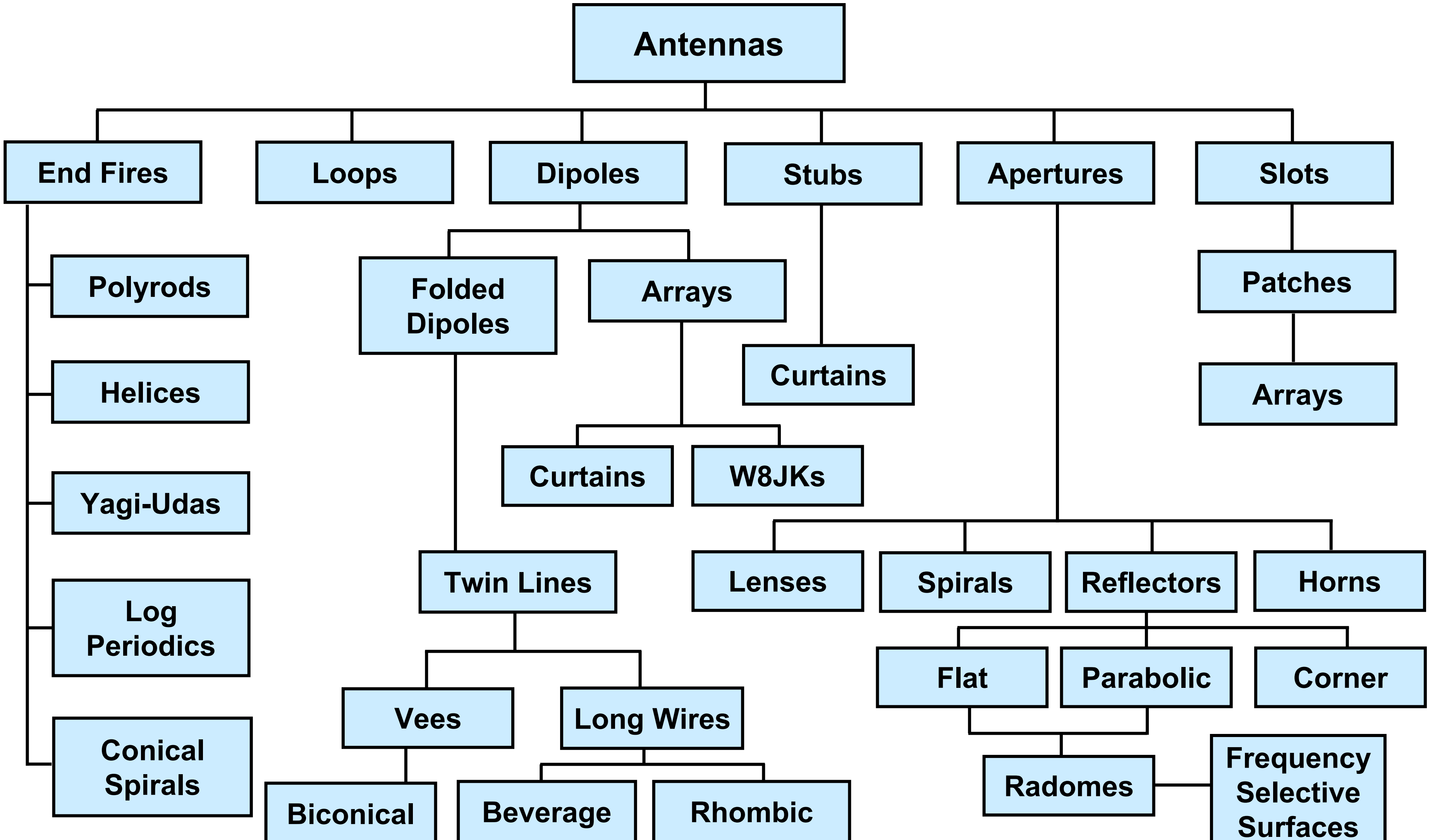
Part One: Introduction; Antenna Fundamentals; Reflector Antennas – Mechanical Scanning

Part Two: Phased Array Antennas; Frequency Scanning of Antennas; Hybrid Methods of Scanning; Other Topics

Outline

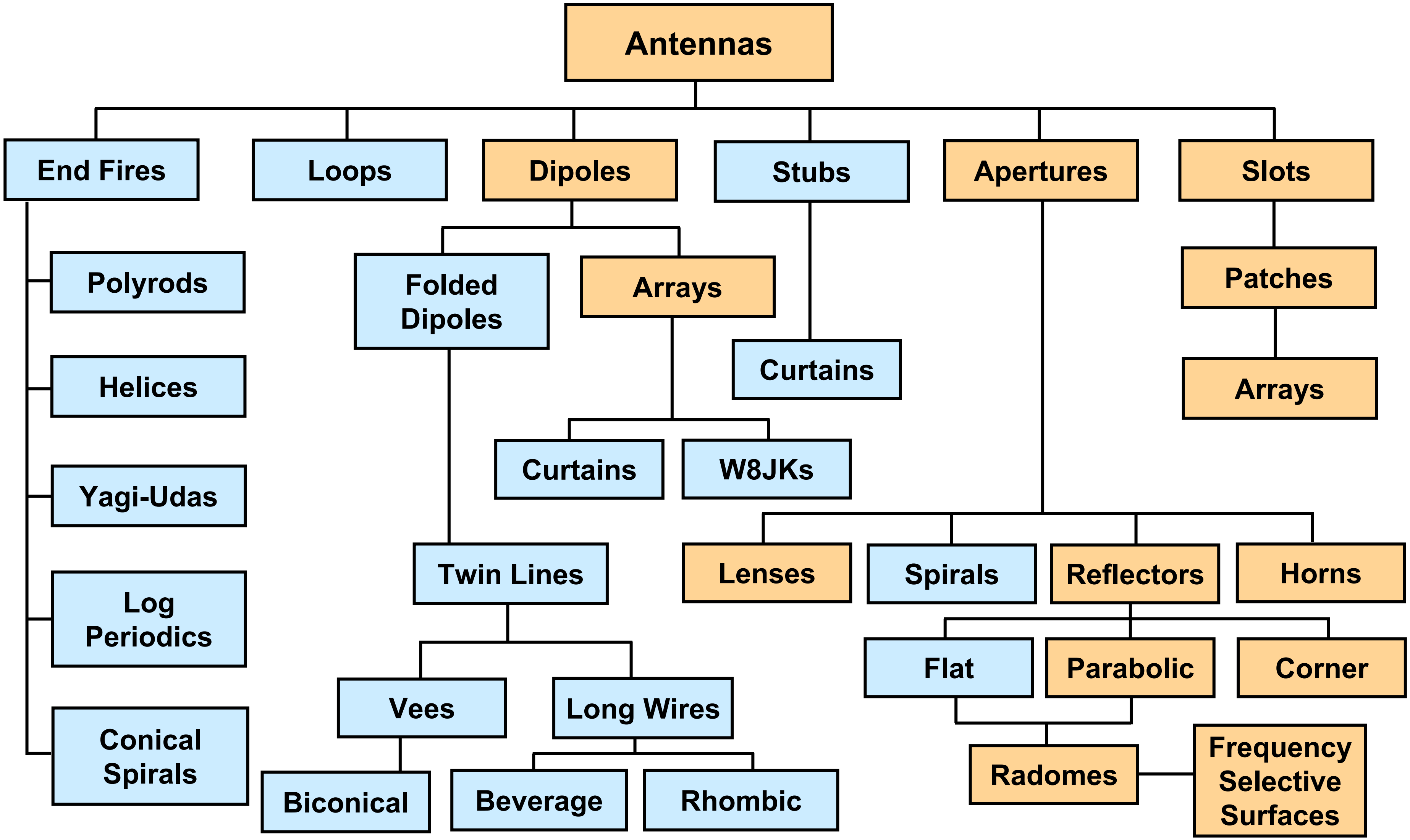
- Introduction
- Antenna Fundamentals
  - – Basic Concepts
  - – Field Regions
    - Near and far field
  - – Electromagnetic Field Equations
  - – Polarization
  - – Antenna Directivity and Gain
  - – Antenna Input Impedance
- Reflector Antennas – Mechanical Scanning

Tree of Antenna Types



Adapted from Kraus, Reference 6

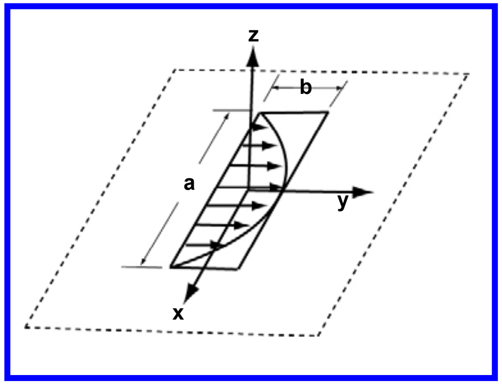
Tree of Antenna Types



Adapted from Kraus, Reference 6

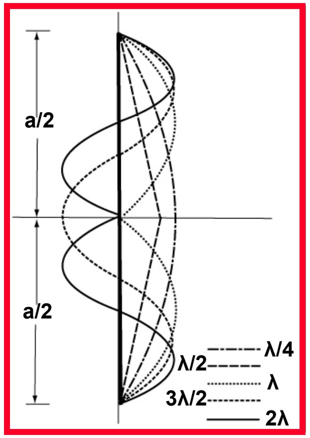
Generation of Electromagnetic Fields & Calculation Methodology

- Radiation mechanism
  - Radiation is created by an acceleration of charge or by a time-varying current
  - Acceleration is caused by external forces
    - Transient (pulse)
    - Time-harmonic source (oscillating charge
- EM wave is calculated by integrating source currents on antenna / target
  - Electric currents on conductors or magnetic currents on apertures (transverse electric fields)
- Source currents can be modeled and calculated using numerical techniques
  - (e.g. Method of Moments, Finite Difference-Time Domain Methods)



Electric Field Distribution
(~ Magnetic Current) in an Aperture

Electric Current on Wire Dipole



Antenna and Radar Cross Section Analyses Use "Phasor Representation"

Harmonic Time Variation is assumed : $e^{j\omega t}$

$$\underbrace{\vec{E}(x,y,z;t)}_{\text{Instantaneous Electric Field}} = \text{Real}\left[\underbrace{\tilde{E}(x,y,z)}_{\text{Phasor}}\, e^{j\omega t}\right]$$

Calculate Phasor : $$\tilde{E}(x,y,z) = \hat{e}\left|\tilde{E}(x,y,z)\right| e^{j\alpha}$$

Instantaneous Harmonic Field is : $$\vec{E}(x,y,z;t) = \hat{e}\left|\tilde{E}(x,y,z)\right| \cos(\omega t + \alpha)$$

Any Time Variation can be Expressed as a Superposition of Harmonic Solutions by Fourier Analysis

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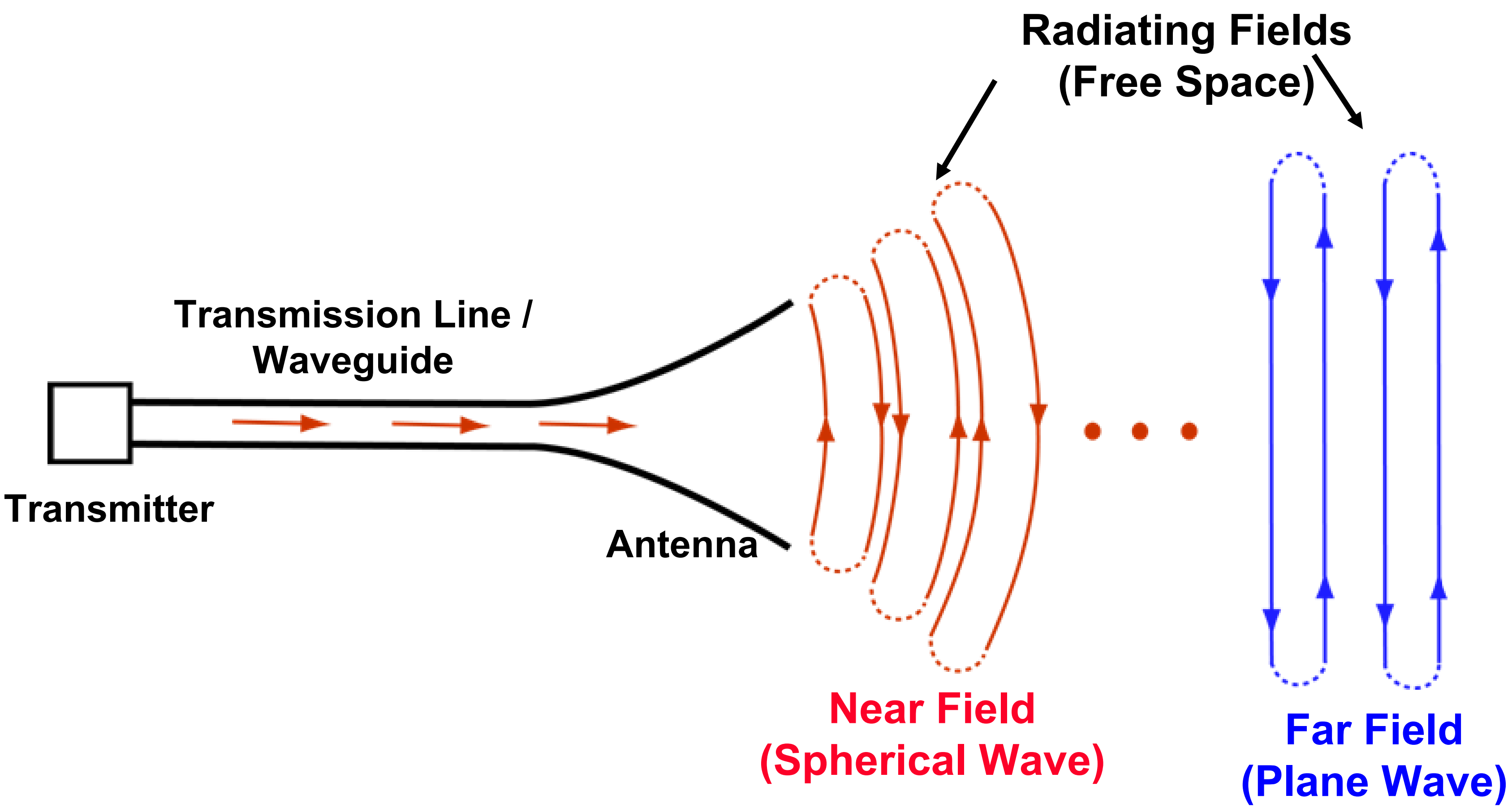
Regions of Radiation



Adapted from Kraus, Reference 6

* IEEE Standard Definitions of Terms for Antennas (IEEE STD 145-1983)

Field Regions

Reactive Near-Field Region

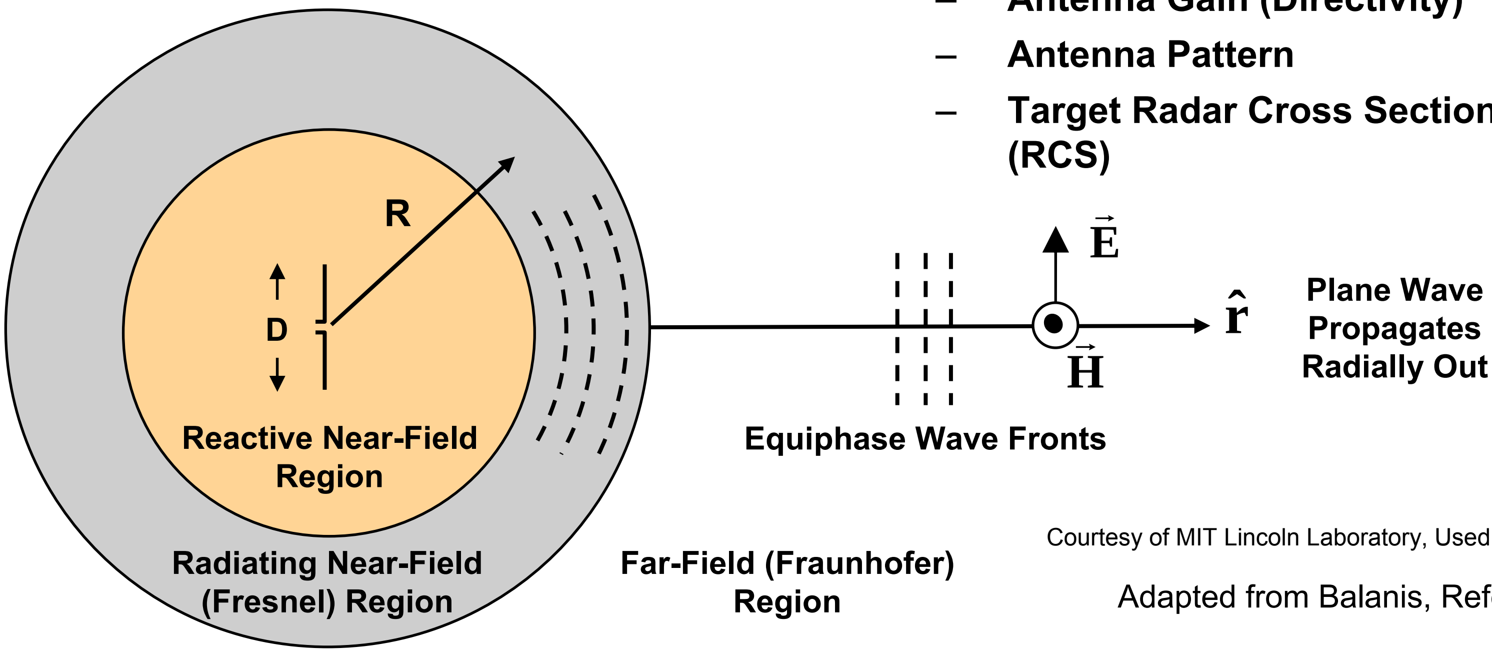
$$R < 0.62\sqrt{D^3/\lambda}$$

- Energy is stored in vicinity of antenna
- Near-field antenna Issues
  - 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 EM wave properties
  - Polarization
  - Antenna Gain (Directivity)
  - Antenna Pattern
  - Target Radar Cross Section (RCS)



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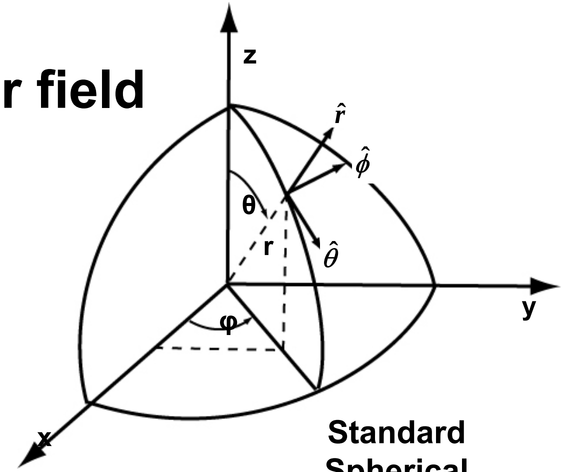
Adapted from Balanis, Reference 1

Far-Field EM Wave Properties

- In the far-field, a spherical wave can be approximated by a plane wave
- There are no radial field components in the far field
- The electric and magnetic fields are given by:

$$\vec{E}^{ff}(r,\theta,\phi) \cong \vec{E}^{o}(\theta,\phi)\frac{e^{-jkr}}{r}$$

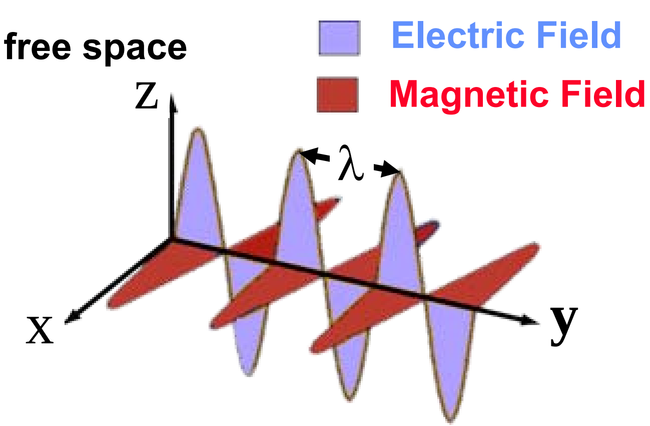
$$\vec{H}^{ff}(r,\theta,\phi) \cong \vec{H}^{o}(\theta,\phi)\frac{e^{-jkr}}{r} = \frac{1}{\eta}\hat{r}\times\vec{E}^{ff}$$



Standard Spherical Coordinate System

where $\eta \equiv \sqrt{\frac{\mu_o}{\varepsilon_o}} = 377\,\Omega$ is the intrinsic impedance of free space

$k = 2\pi/\lambda$ is the wave propagation constant



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Propagation in Free Space

- **Plane wave, free space solution to Maxwell's Equations:**
  - No Sources
  - Vacuum
  - Non-conducting medium

$$\vec{E}(\vec{r},t) = E_{\circ} e^{j(\vec{k}\cdot\vec{r} - \omega t)}$$

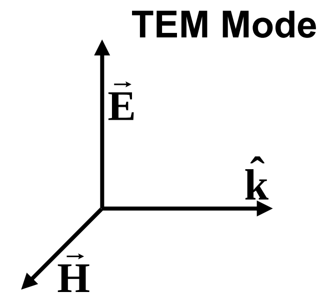
$$\vec{B}(\vec{r},t) = B_{\circ} e^{j(\vec{k}\cdot\vec{r} - \omega t)}$$

- **Most electromagnetic waves are generated from localized sources and expand into free space as spherical wave.**

- **In the far field, when the distance from the source great, they are well approximated by plane waves when they impinge upon a target and scatter energy back to the radar**

Modes of Transmission For Electromagnetic Waves

- **Transverse electromagnetic (TEM) mode**
  - Magnetic and electric field vectors are transverse (perpendicular) to the direction of propagation, $\hat{k}$, and perpendicular to each other
  - Examples (coaxial transmission line and free space transmission,
  - TEM transmission lines have two parallel surfaces



- **Transverse electric (TE) mode**
  - Electric field, $\vec{E}$, perpendicular to $\hat{k}$
  - No electric field in $\hat{k}$ direction

- **Transverse magnetic (TM) mode**
  - Magnetic field, $\vec{H}$, perpendicular to $\hat{k}$
  - No magnetic field in $\hat{k}$ direction

Used for Rectangular Waveguides (TE and TM modes)

- **Hybrid transmission modes**

Pointing Vector – Power Density

- The **Poynting Vector**, $\vec{S}$, is defined as:

$$\vec{S} \equiv \vec{E} \times \vec{H} \qquad (\text{W/m}^2)$$

- It is the power density (power per unit area) carried by an electromagnetic wave

- Since both $\vec{E}$ and $\vec{H}$ are functions of time, the **average power density** is of greater interest, and is given by:

$$\langle \vec{S} \rangle = \frac{1}{2} \mathrm{Re}\left(\vec{E} \times \vec{H}^* \right)$$

- For a plane wave in a lossless medium

$$\langle \vec{S} \rangle = \frac{1}{2\eta} \left| \vec{E} \right|^2 \equiv W_{AV} \qquad \text{where} \quad \eta = \sqrt{\frac{\mu_o}{\varepsilon_o}}$$

Radiation Intensity and Radiated Power

- **Radiation Intensity** = Power radiated per unit solid angle

$$U(\theta,\phi) \cong r^2 W_{rad}(\theta,\phi) = \frac{r^2}{2\eta}\left|\vec{E}(r,\theta,\phi)\right|^2$$

$$\cong \frac{r^2}{2\eta}\left[\left|\vec{E}_\theta(r,\theta,\phi)\right|^2 + \left|\vec{E}_\phi(r,\theta,\phi)\right|^2\right]$$

$$\cong \frac{1}{2\eta}\left[\left|\vec{E}^o_\theta(r,\theta,\phi)\right|^2 + \left|\vec{E}^o_\phi(r,\theta,\phi)\right|^2\right] \quad \text{(W/steradian)}$$

where $\vec{E}(r,\theta,\phi) = \vec{E}^o(\theta,\phi)\dfrac{e^{-jkr}}{r}$ = far field electric field intensity

E_θ, E_ϕ = far field electric field components

and $\eta = \sqrt{\dfrac{\mu_o}{\varepsilon_o}}$

- **Total Power Radiated**

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta\, d\theta\, d\phi \quad \text{(W)}$$

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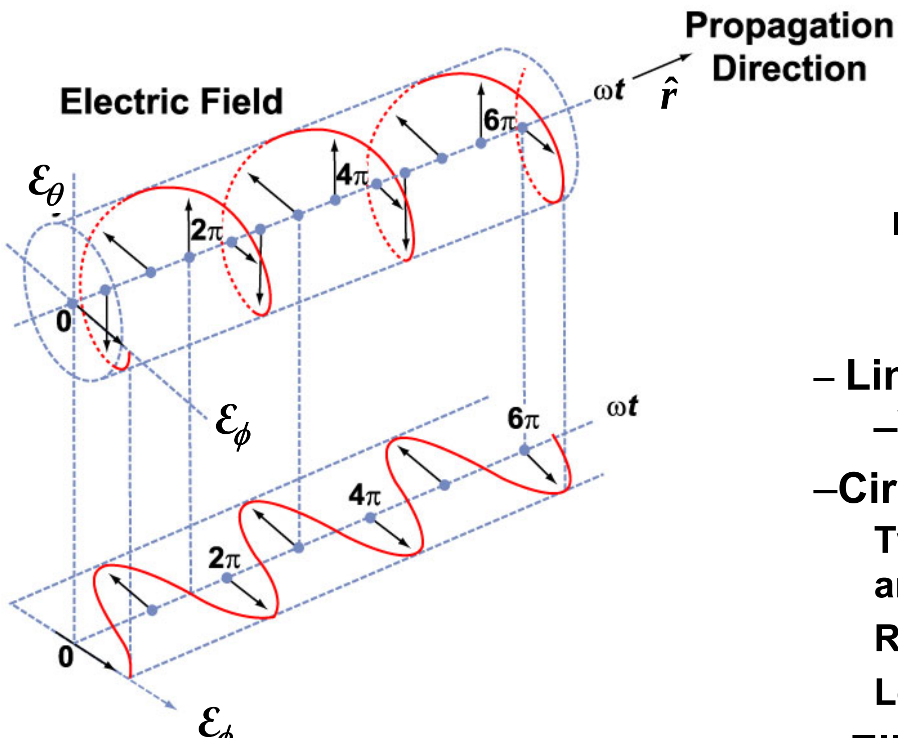
Antenna Polarization

- Defined by behavior of the electric field vector as it propagates in time *as observed along the direction of radiation*
- Circular used for weather mitigation
- Horizontal used in long range air search to obtain reinforcement of direct radiation by ground reflection



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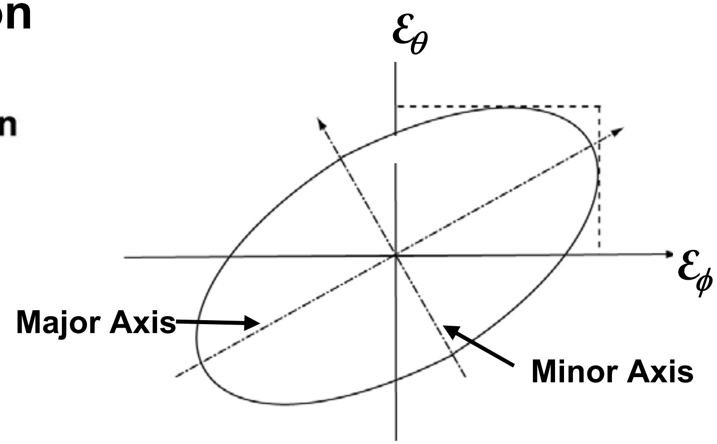
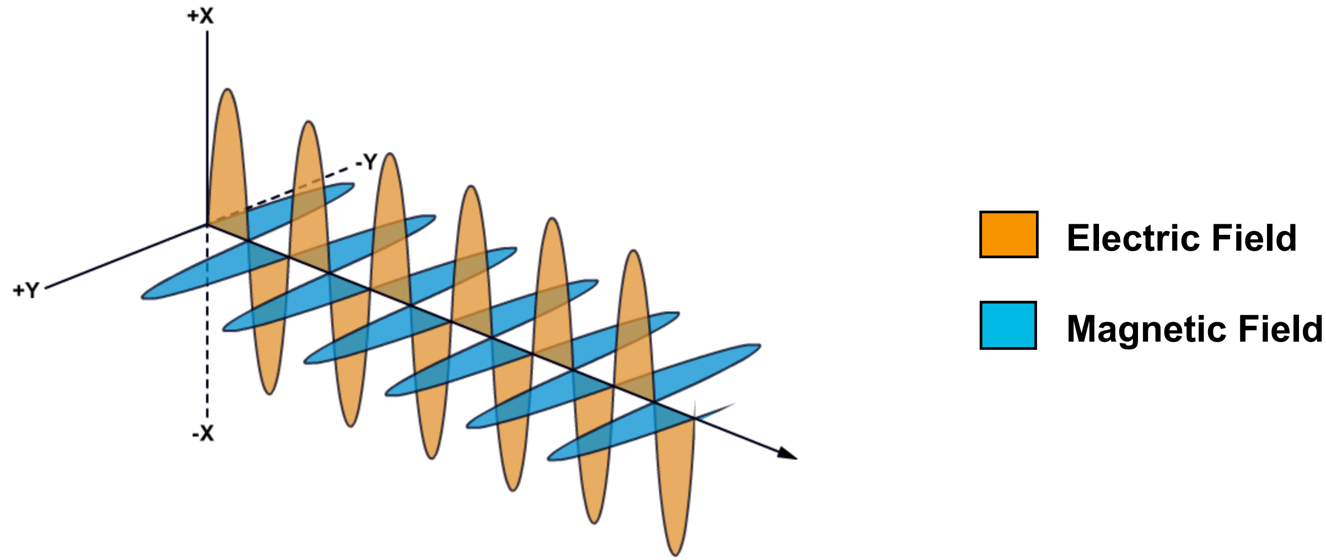


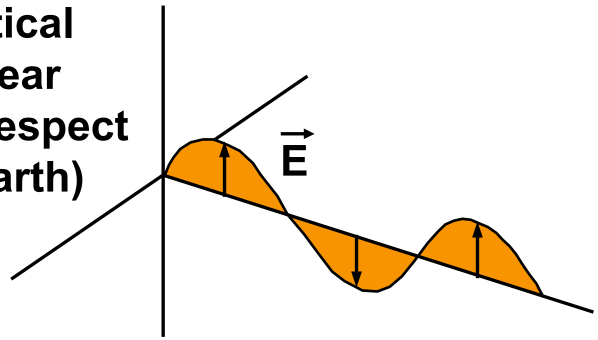
- Linear
  - Vertical or Horizontal
- Circular
  - Two components are equal in amplitude, and separated in phase by 90 deg
  - Right-hand (RHCP) is CW above
  - Left-hand (LHCP) is CCW above
- Elliptical

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

Electromagnetic Wave

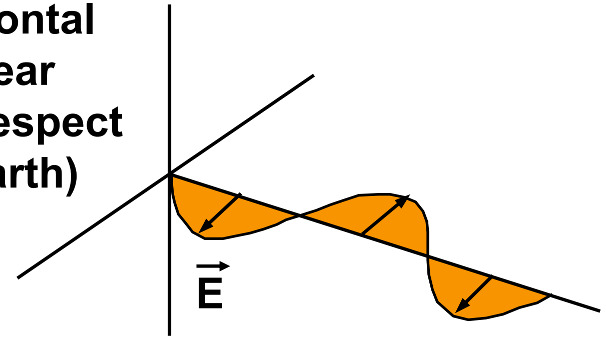


Vertical Linear (with respect to Earth)



(For over-water surveillance)

Horizontal Linear (with respect to Earth)



(For air surveillance looking upward)

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Circular Polarization (CP)

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

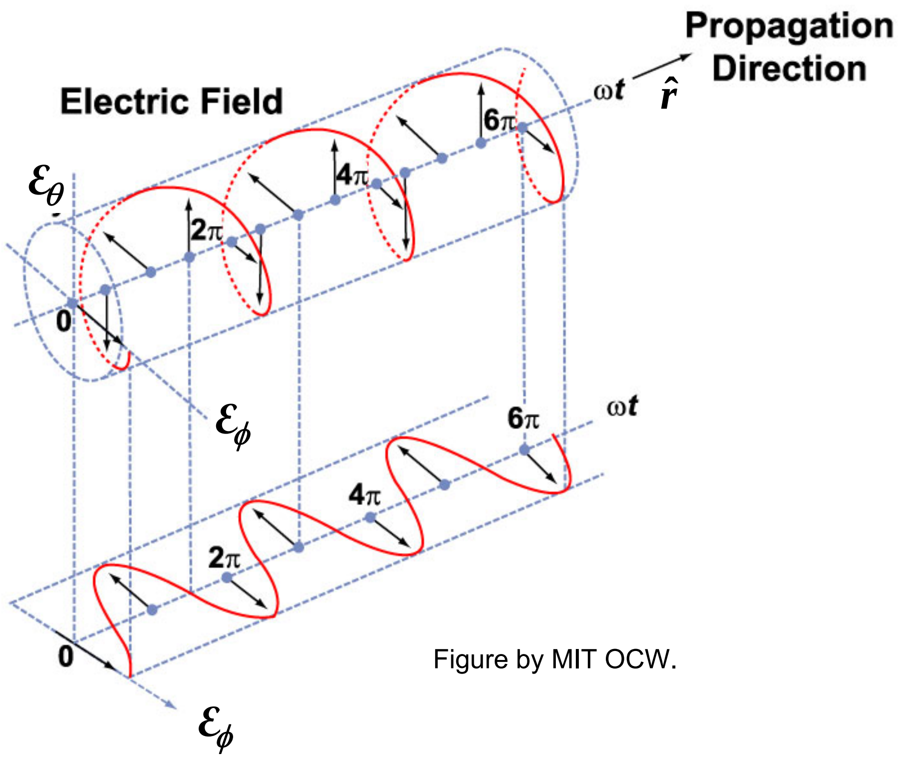
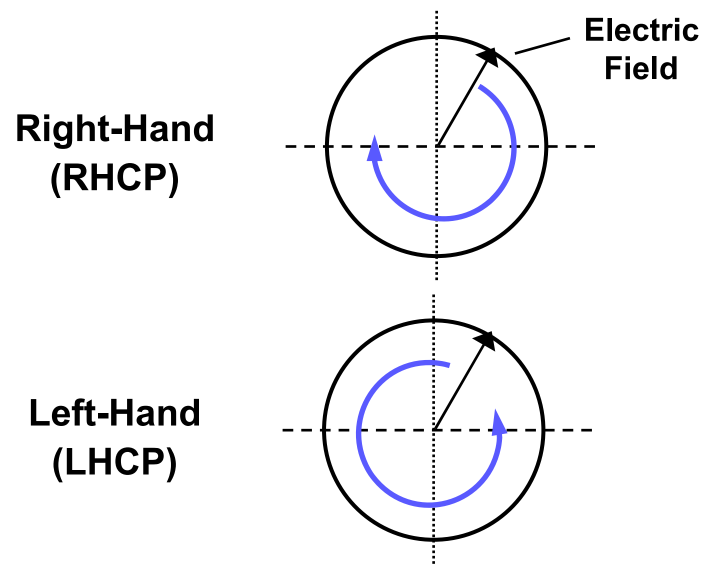


Figure by MIT OCW.



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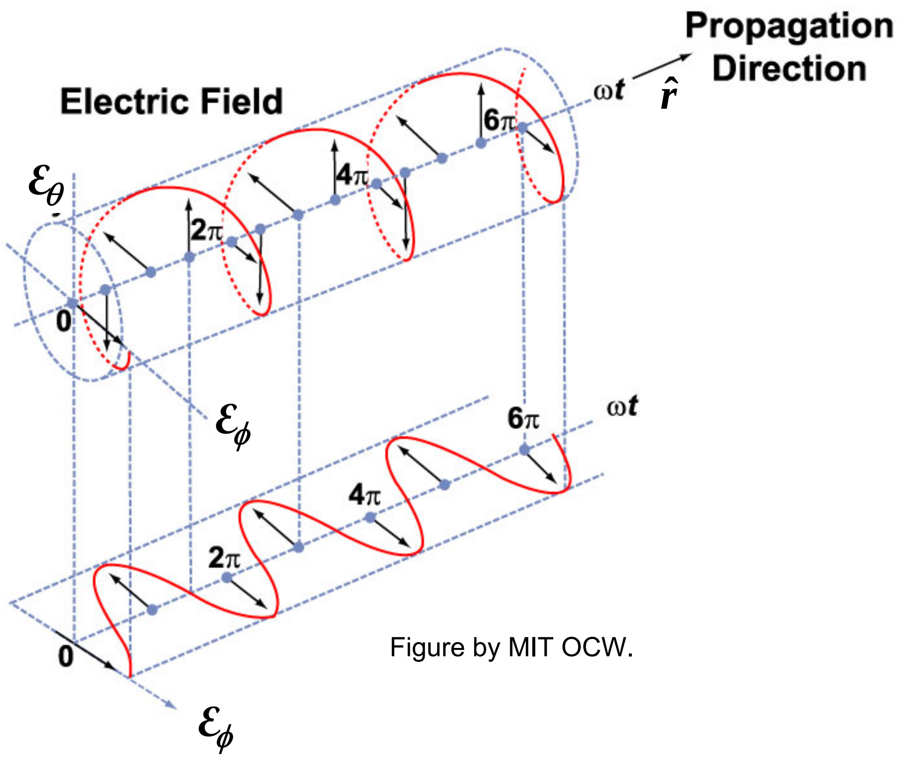

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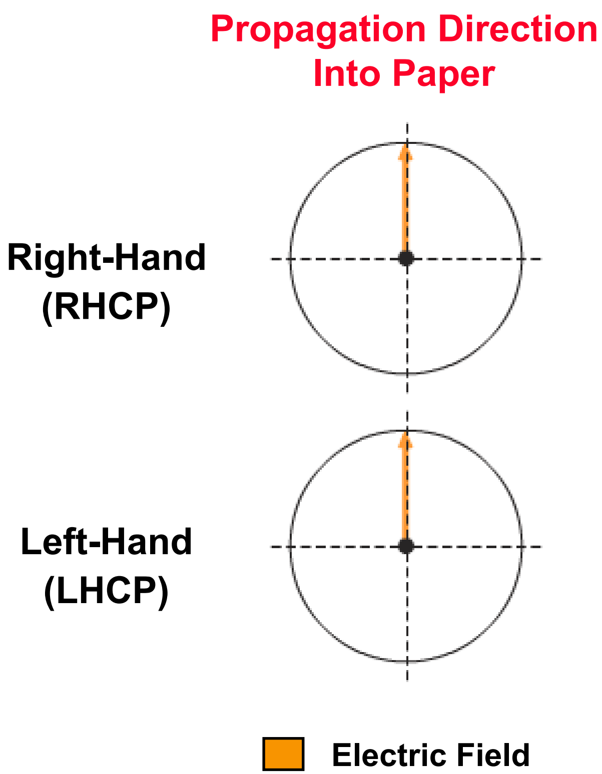

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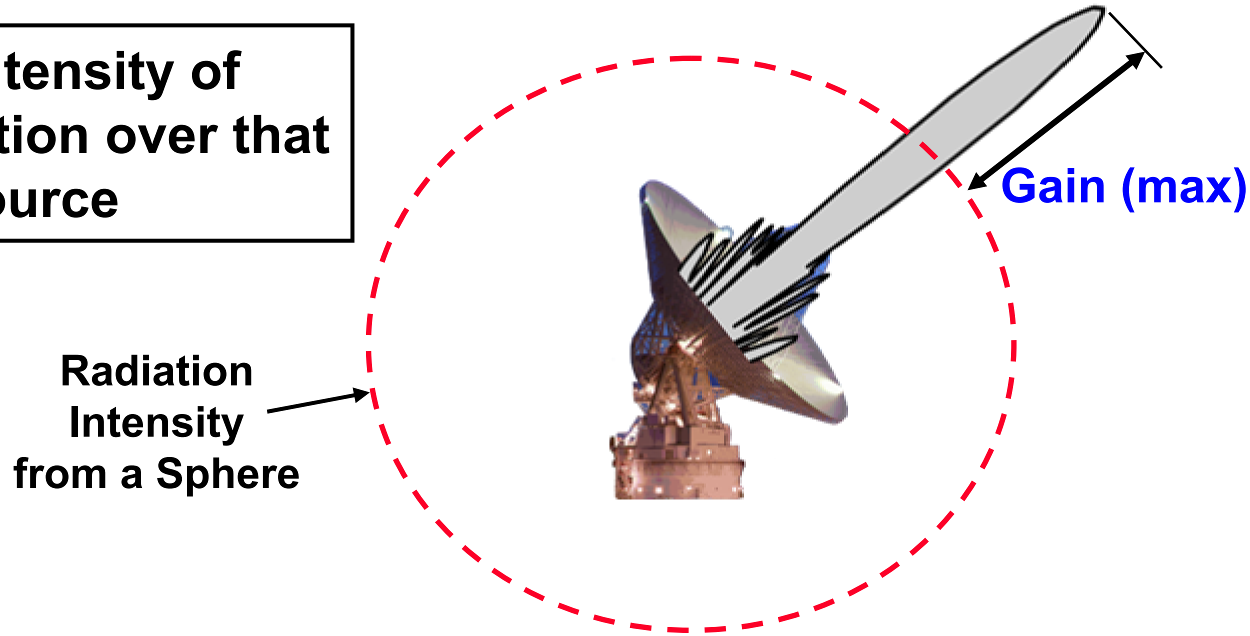
Antenna Gain

Gain = Radiation intensity of antenna in given direction over that of isotropic source



Maximum Gain

$$G = \frac{4\pi A_{eff}}{\lambda^2} = \frac{4\pi\, \eta A}{\lambda^2}$$

- Difference between gain and directivity is **antenna loss** $G = \dfrac{D}{L_A}$

- "Rules of Thumb"

$$G = \frac{26{,}000}{\theta_B\, \phi_B} \quad \text{(degrees)}$$

θ_B and ϕ_B are the azimuth and elevation half power beamwidths

$$\theta_B = \frac{65\,\lambda}{D}$$

(degrees)

Directivity & Gain

- **Radiation Intensity** = $U(\theta,\phi)$ = Power radiated / unit solid angle
- **Directivity** = Radiation intensity of antenna in given direction over that of an isotropic source radiating same power

$$D(\theta,\phi) = \frac{4\pi\, U(\theta,\phi)}{P_{rad}} \quad \text{(dimensionless)}$$

- **Gain** = Radiation intensity of antenna in given direction over that of isotropic source radiating *available* power
  - Difference between gain and directivity is antenna loss
  - Gain $\leq$ Directivity

$$G(\theta,\phi) = \frac{4\pi\, U(\theta,\phi)}{P_{in}} \quad \text{(dimensionless)}$$

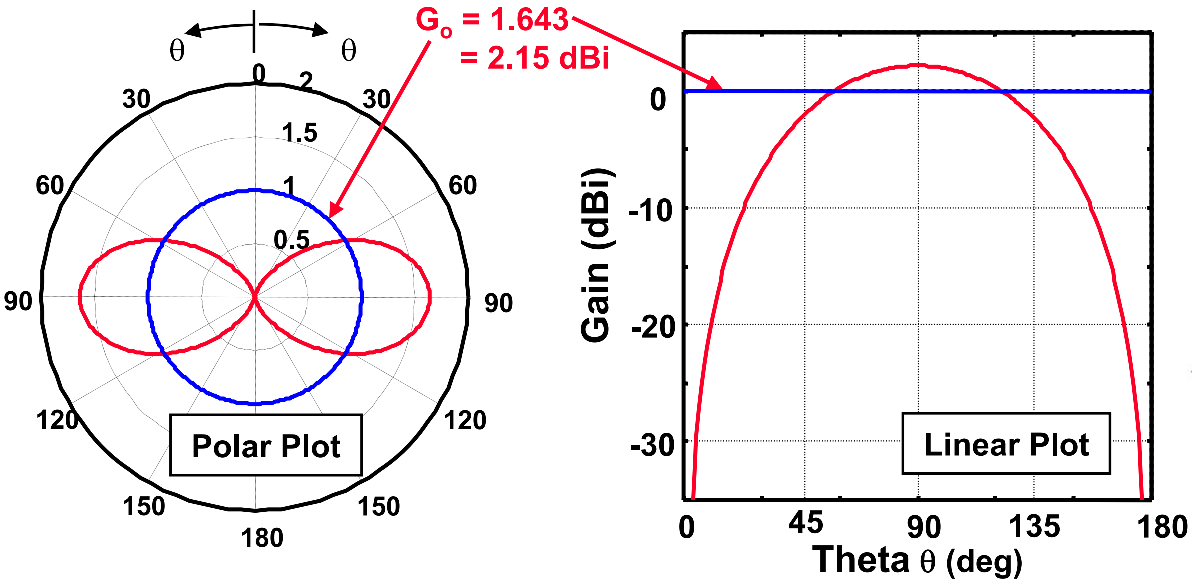
- **Maximum Gain** = Radiation intensity of antenna at peak of beam

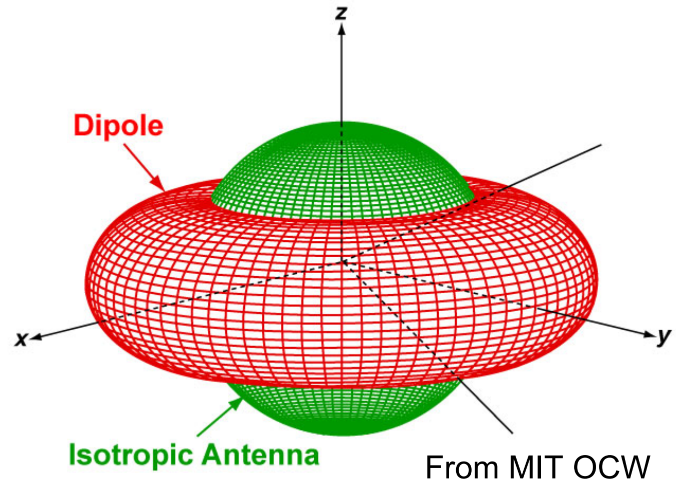
$$G = \frac{4\pi\, A_{eff}}{\lambda^2} = \frac{4\pi\, \eta A}{\lambda^2}$$

A = Area of antenna aperture

η = Efficiency of antenna

Example – Half Wavelength Dipole





θ = angle down from z-axis

Far Field

$$\overline{E}^{ff}(\theta) = \hat{\theta}\, j\eta \frac{I_o}{2\pi} \frac{e^{-jkr}}{r} \left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right]$$

$$\overline{H}^{ff}(\theta) = \hat{\phi}\, j \frac{I_o}{2\pi} \frac{e^{-jkr}}{r} \left[\frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right]$$

Radiation Intensity

$$U(\theta) = \eta \frac{|I_o|^2}{8\pi^2} \left[\frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin^2\theta} \right]$$

Radiated Power

$$P_{rad} = \eta \frac{|I_o|^2}{8\pi} C_{in}(2\pi)$$

$$C_{in}(2\pi) = \int_0^{2\pi} \frac{1-\cos y}{y}\, dy \approx 2.435$$

Gain / Pattern

$$G(\theta) = \frac{4\pi\, U(\theta)}{P_{in}} = 1.643 \left[\frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin^2\theta} \right]$$

$$G_o = \frac{4\pi\, U_{max}}{P_{in}} = 1.643$$

Effective Area

$$A_e = \frac{\lambda^2 D_o}{4\pi} = 0.13\lambda^2$$

Adapted from Balanis, Reference 1, pp182 - 184

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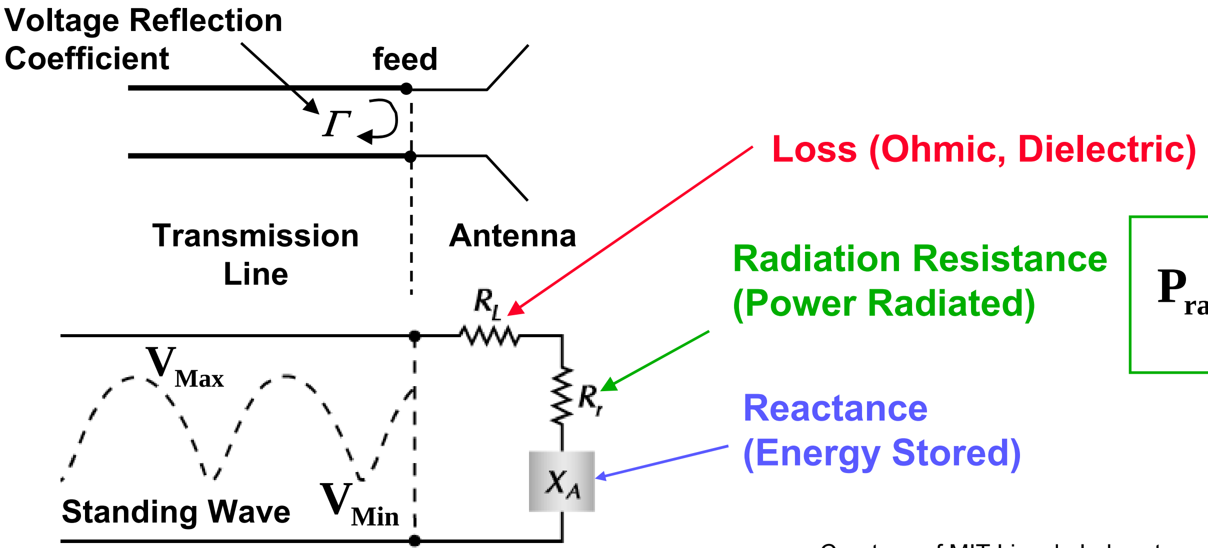
Antenna Input Impedance

- **Antenna can be modeled as an impedance (ratio of voltage to current at feed port)**
  - **Antenna "resonant" when impedance purely real**
  - **Microwave theory can be applied to equivalent circuit**
- **Design antenna to maximize power transfer from transmission line**
  - **Reflection of incident power sets up standing wave on line**
  - **Can result in arching under high power conditions**



$$P_{rad} = \frac{1}{2}|I_o|^2 R_r$$

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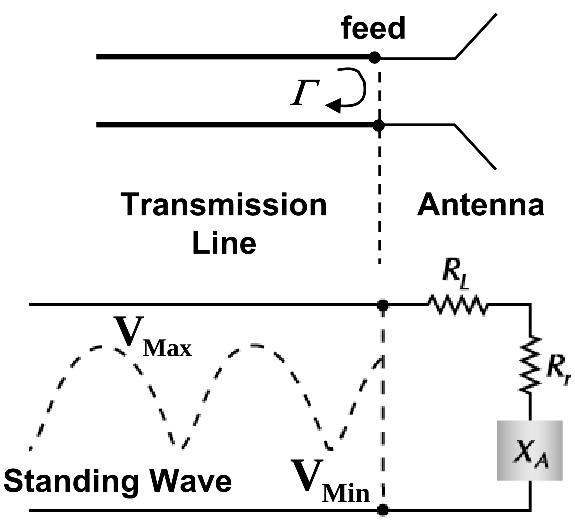
Antenna Input Impedance

- Antenna can be modeled as an impedance (ratio of voltage to current at feed port)
  - Antenna "resonant" when impedance purely real
  - Microwave theory can be applied to equivalent circuit
- Design antenna to maximize power transfer from transmission line
  - Reflection of incident power sets up standing wave on line
  - Can result in arching under high power conditions
- Usually a 2:1 VSWR is acceptable



$$\text{VSWR} = \frac{V_{Max}}{V_{Min}} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Voltage Standing Wave Ratio

$|\Gamma| = 0 \quad \text{VSWR} = 1$ — All Incident Power is Delivered to Antenna

$|\Gamma| = 1 \quad \text{VSWR} \rightarrow \infty$ — All Incident Power is Reflected

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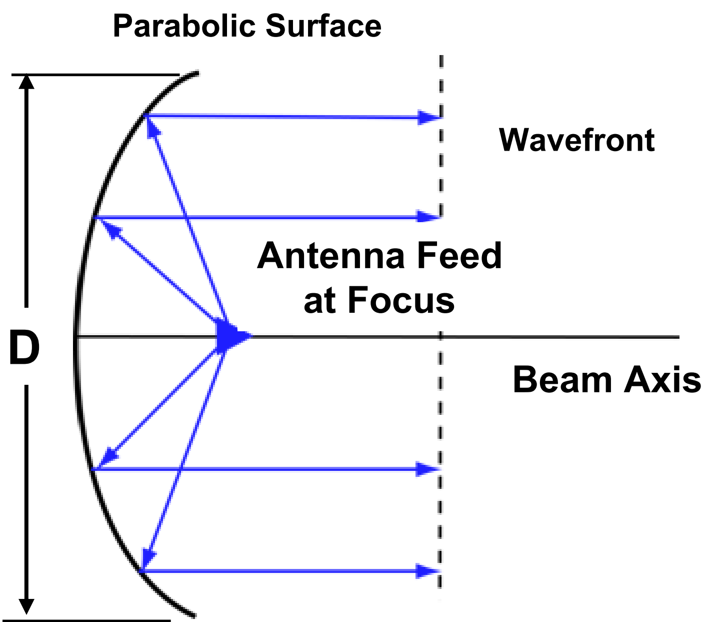
- Introduction
- Antenna Fundamentals
- Reflector Antennas – Mechanical Scanning
  - Basic Antenna (Reflector) Characteristics and Geometry
  - Spillover and Blockage
  - Aperture Illumination
  - Different Reflector Feeds and Reflector Geometries

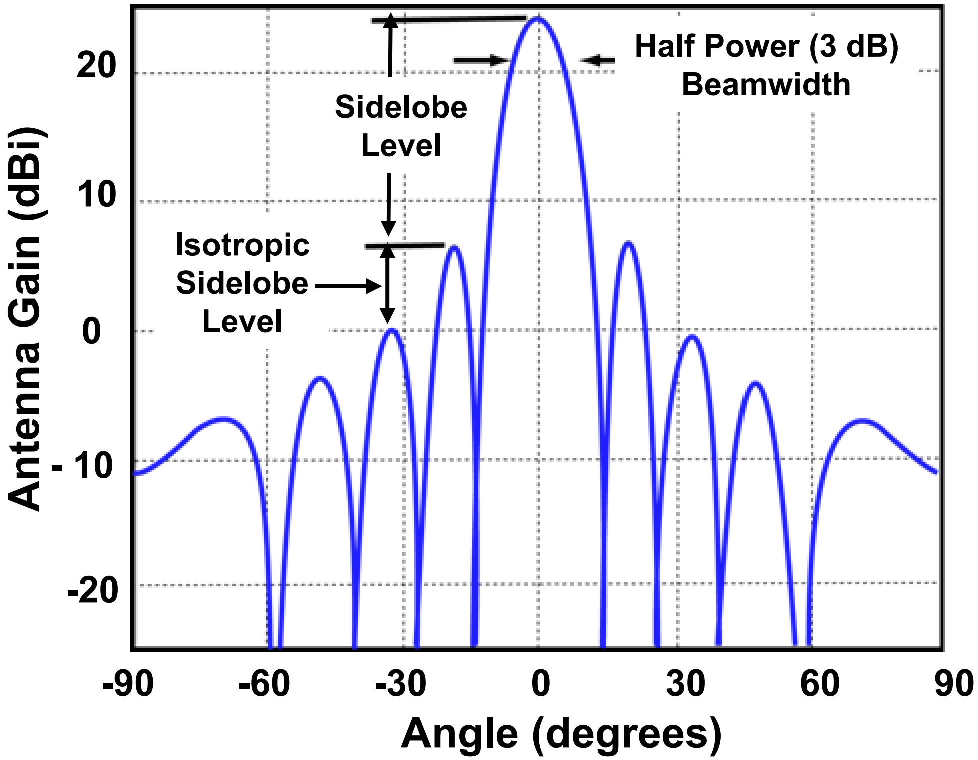
Antenna Pattern Characteristics

Parabolic Reflector Antenna



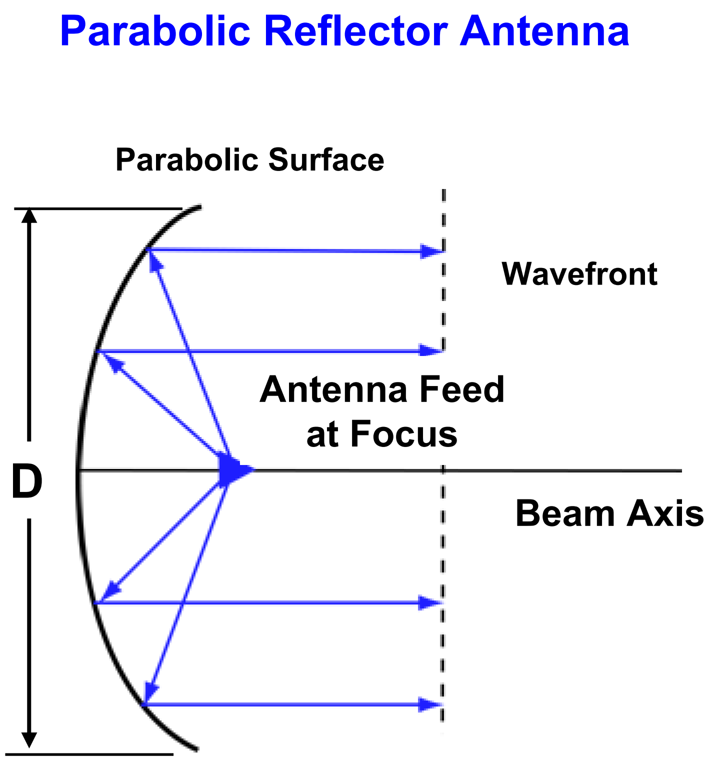
Aperture diameter D = 5 m
Frequency = 300 MHz
Wavelength = 1 m

Antenna Gain vs. Angle



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

Parabolic Reflector Antenna



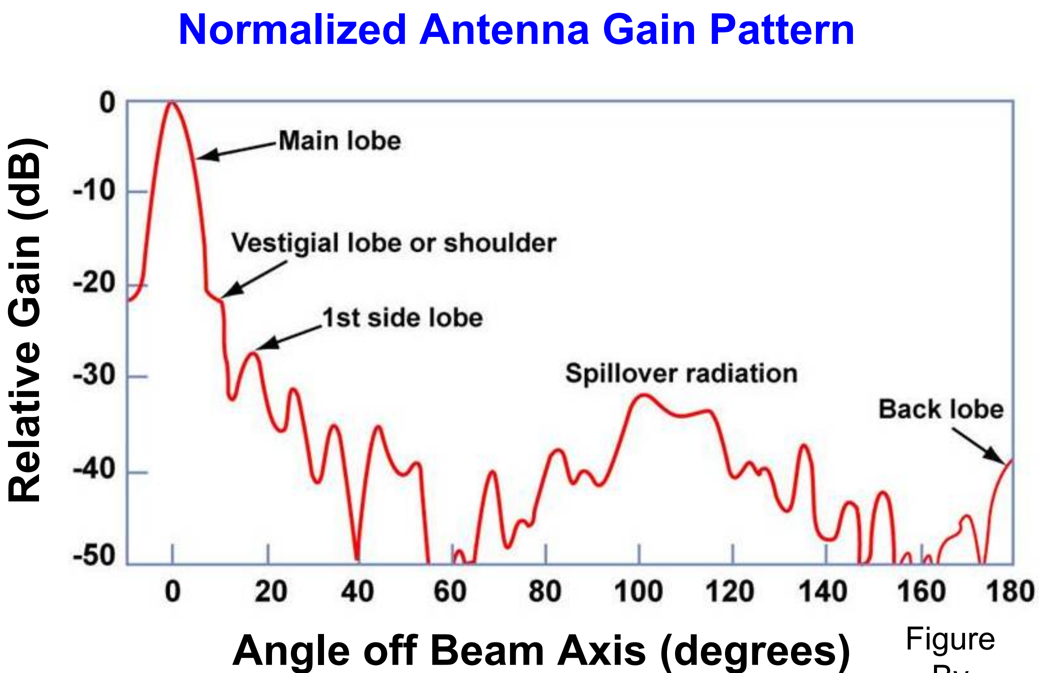
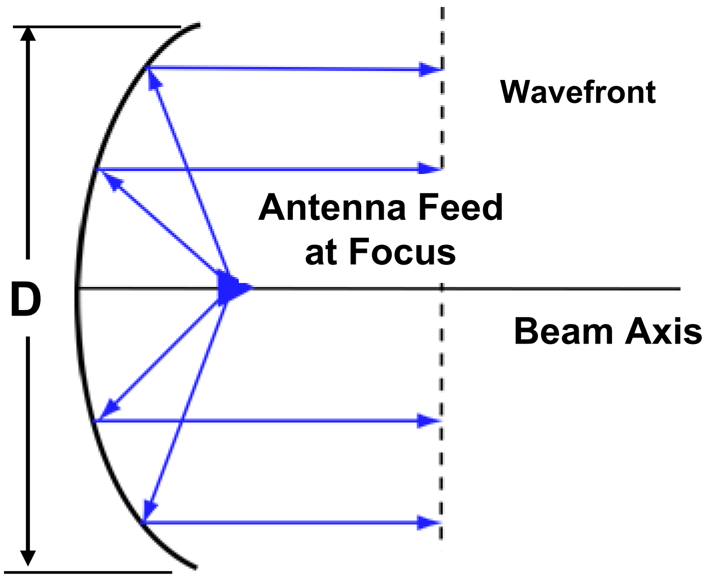


Figure By MIT OCW

- **Reflector antenna design involves a tradeoff between maximizing dish illumination while limiting spillover and blockage from feed and its support structure**
- **Feed antenna choice is critical**

Effect of Aperture Size on Gain

Parabolic Reflector Antenna

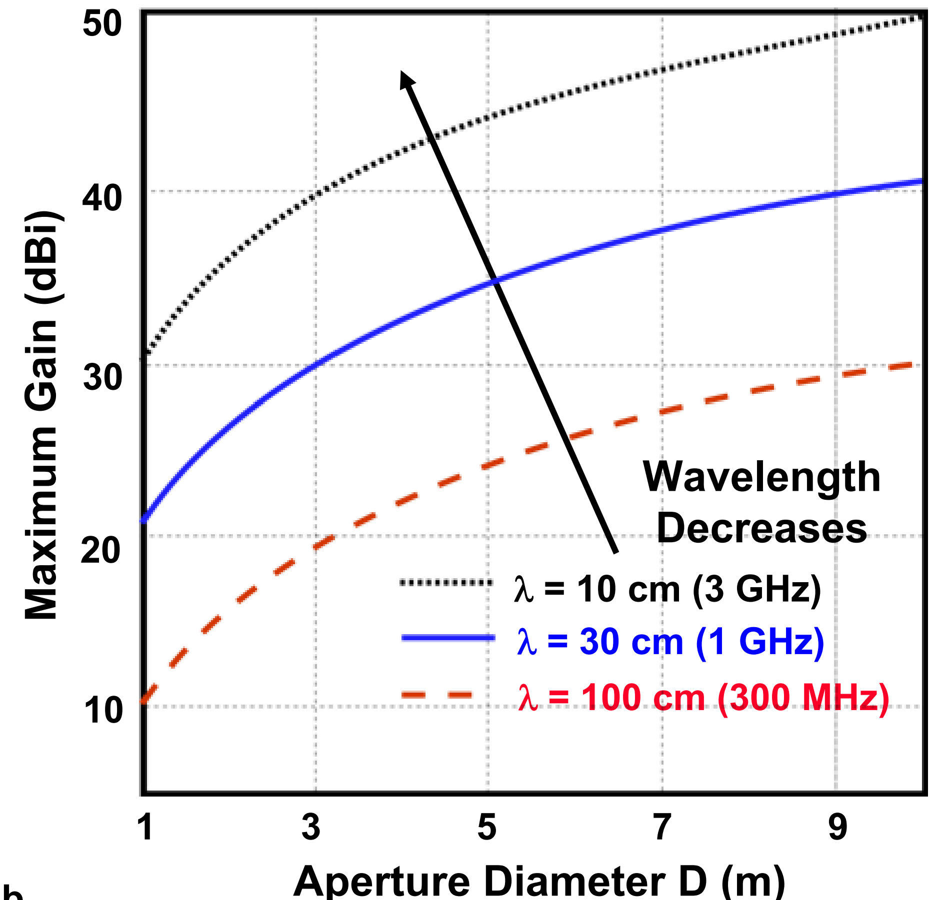


$$\text{Gain} = \frac{4\pi A_e}{\lambda^2}$$ ← Effective Area

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

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

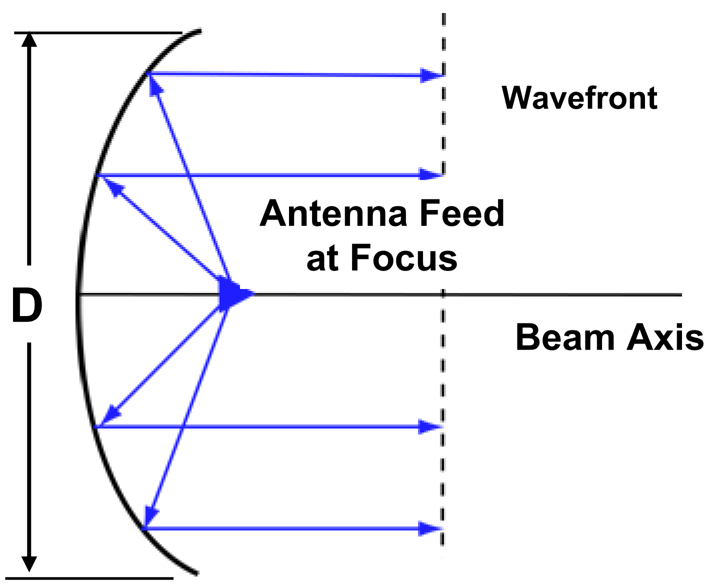
Gain vs Antenna Diameter



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

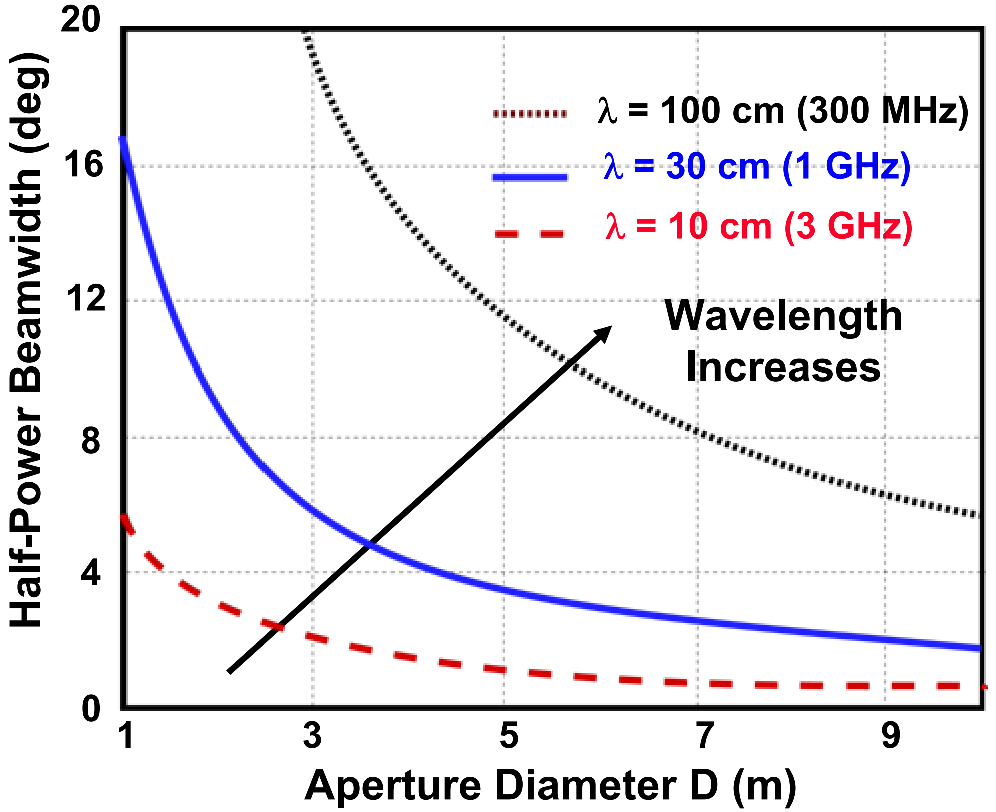
Effect of Aperture Size on Beamwidth

Parabolic Reflector Antenna



Beamwidth (deg) $\cong \dfrac{180\lambda}{\pi D}$

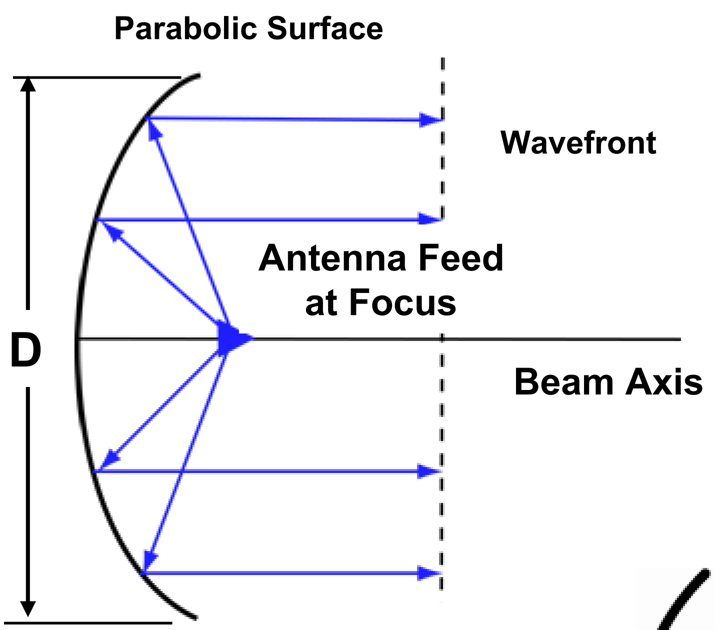
Antenna Beamwidth vs. Diameter



Beamwidth decreases as aperture becomes electrically larger (diameter larger number of wavelengths)

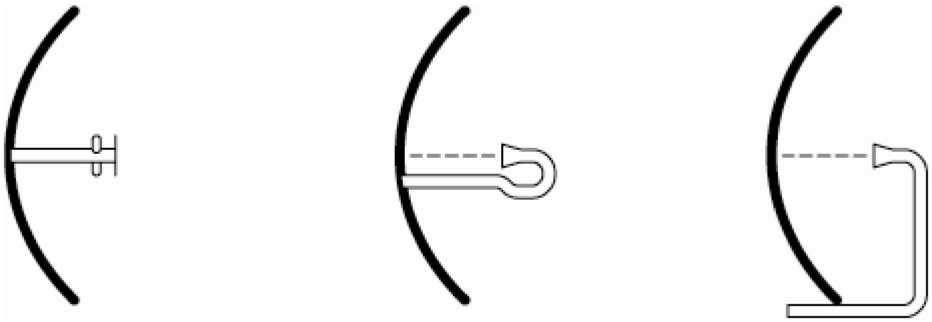
Parabolic Reflector Antenna

Parabolic Reflector Antenna



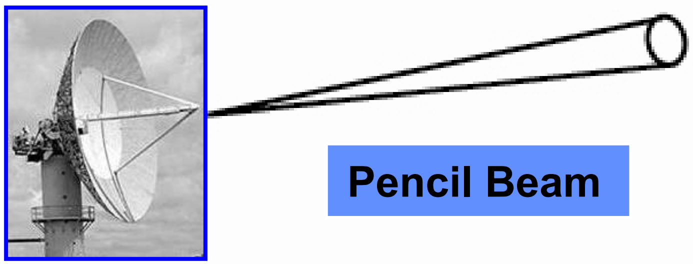
- Point source is evolves to plane wave (In the Far Field)
- Feed can be dipole or open-ended waveguide (horn)
- Feed structure reduces antenna efficiency

Examples of Parabolic Antenna Feed Structure



Adapted from Skolnik, Reference 2

Different Types of Radar Beams



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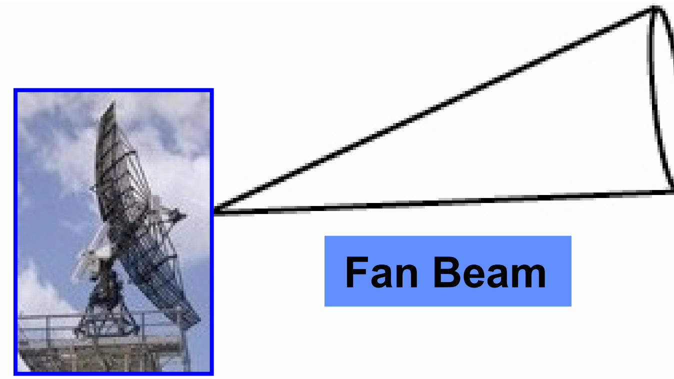

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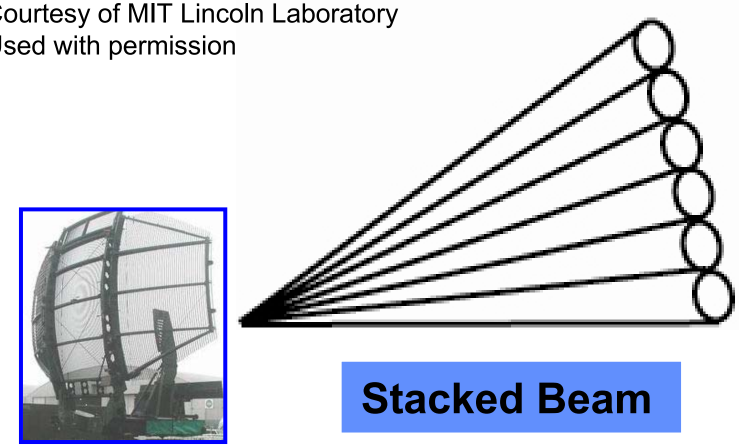
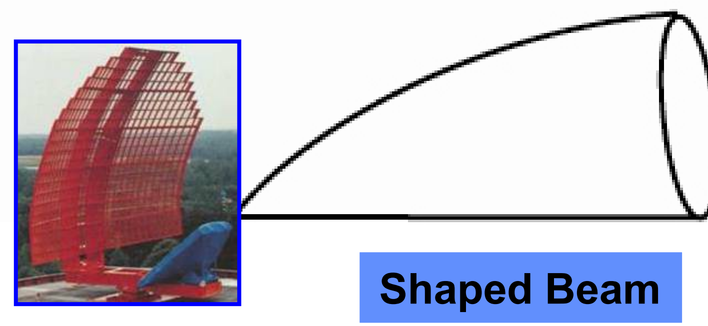


Courtesy of US Air Force



Courtesy of Northrop Grumman
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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

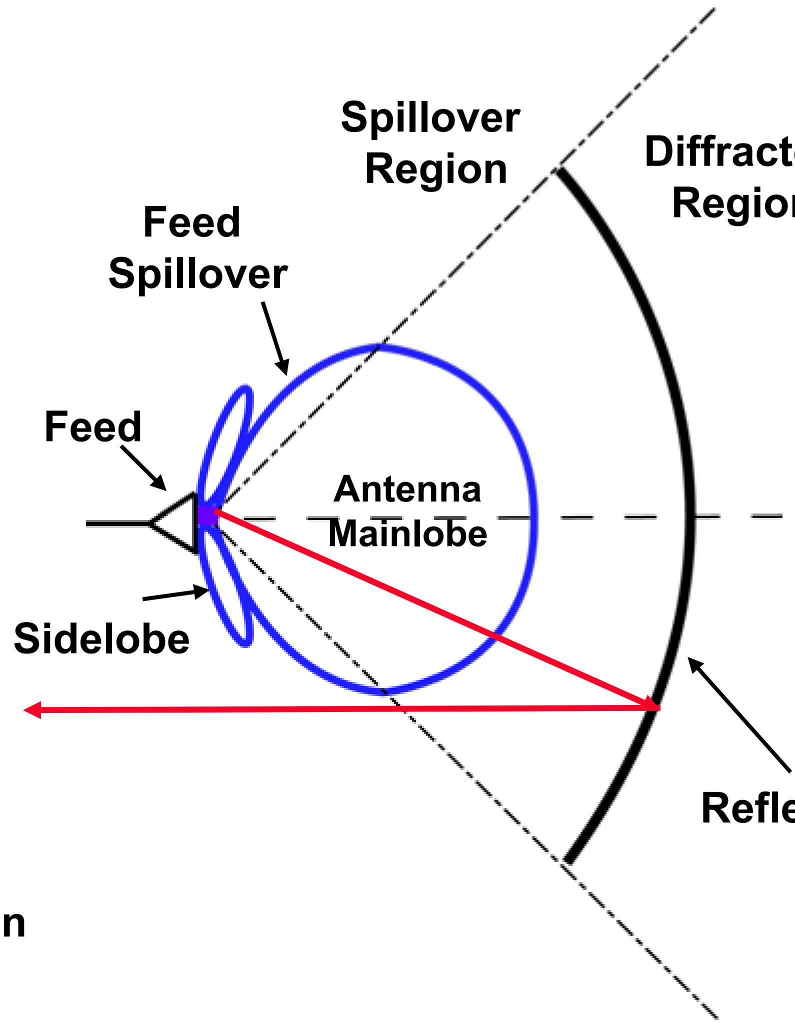
Courtesy of MIT Lincoln Laboratory, Used with permission

Outline

- Introduction
- Antenna Fundamentals
- Reflector Antennas – Mechanical Scanning
  - Basic Antenna (Reflector) Characteristics and Geometry
  - Spillover and Blockage
  - Aperture Illumination
  - Different Reflector Feeds and Reflector Geometries

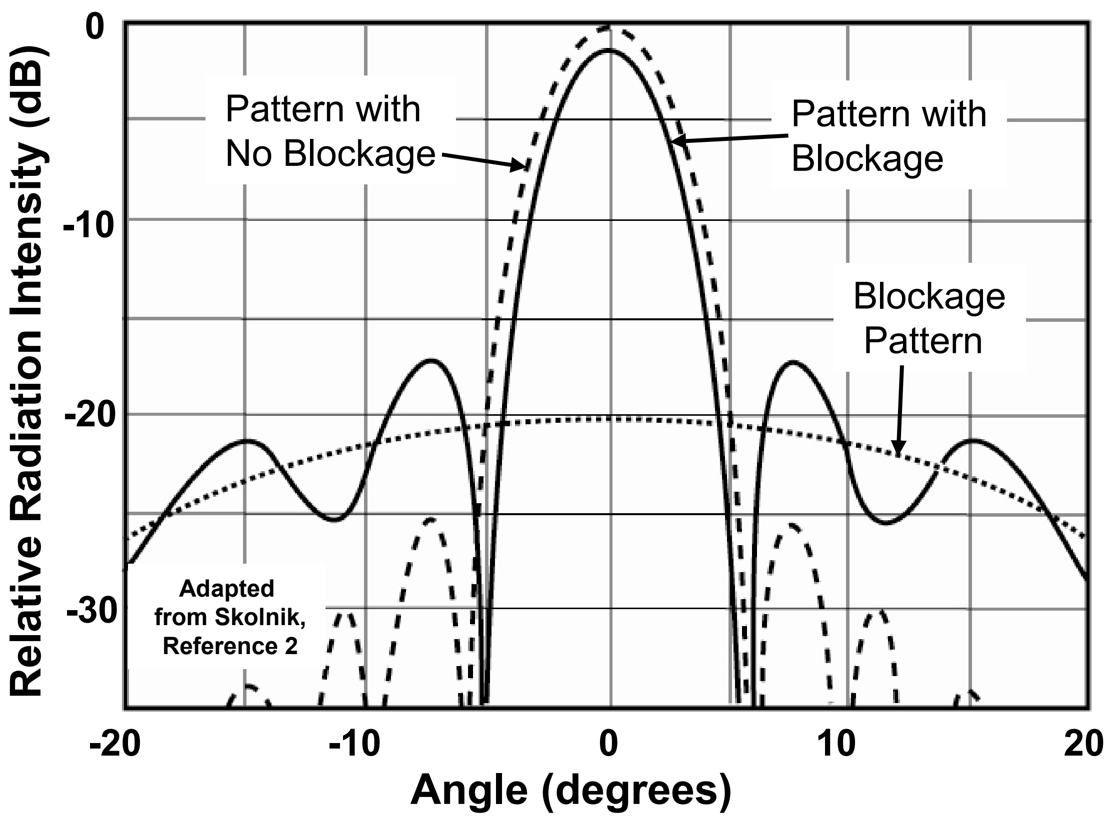
Antenna Spillover

- Even when the feed is at the exact focus of the parabolic reflector, a portion of the emitted energy at the edge of the beam will not impinge upon the reflector.
- This is called "beam spillover"
- Tapering the feed illumination can mitigate this effect
- As will be seen, optimum antenna performance is a tradeoff between:
  - Beam spillover
  - Tapering of the aperture illumination
    Antenna gain
  - Feed blockage



Adapted from Skolnik, Reference 5

Effect of Aperture Blocking in a Parabolic Reflector Antenna



Examples of Aperture Blockage

Feed and its supports

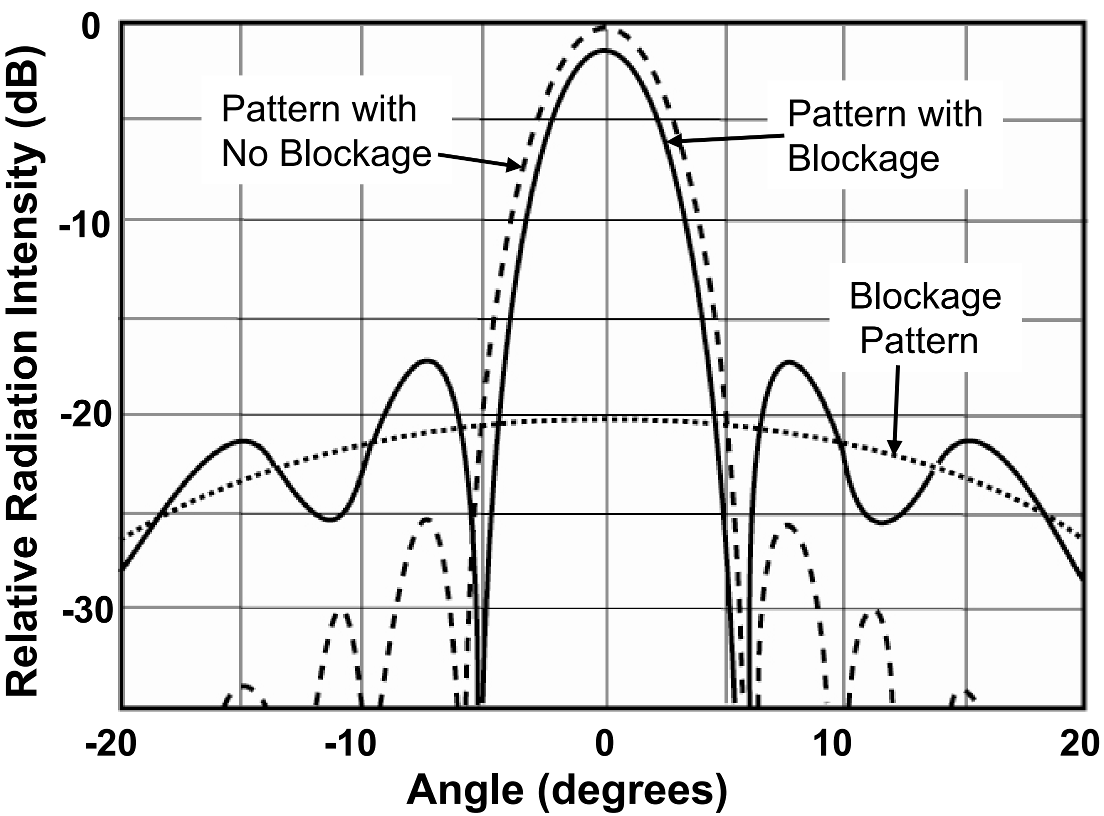
Masts onboard a ship

FPS-16

The effect of aperture blockage can be approximated by:

Antenna pattern of undisturbed aperture – Antenna pattern produced by shadow of the obstacle

Effect of Aperture Blocking in a Parabolic Reflector Antenna



This procedure is possible because of the linearity of the Fourier transform that relates the antenna aperture illumination and the radiation pattern

Examples of Aperture Blockage

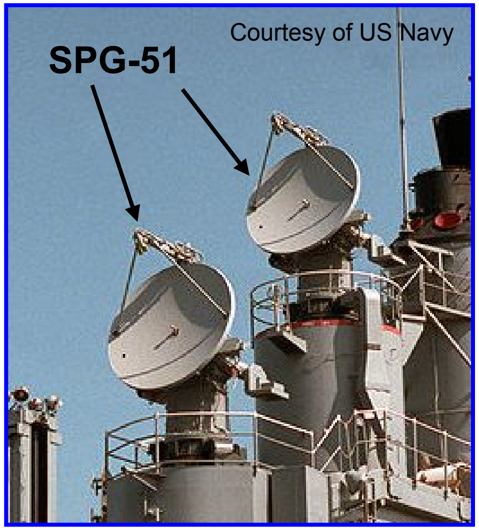
Feed and its supports

Masts onboard a ship

TRADEX

Courtesy of MIT Lincoln Laboratory, Used with permission

Examples of Antenna Blockage



NASA Tracking Radar

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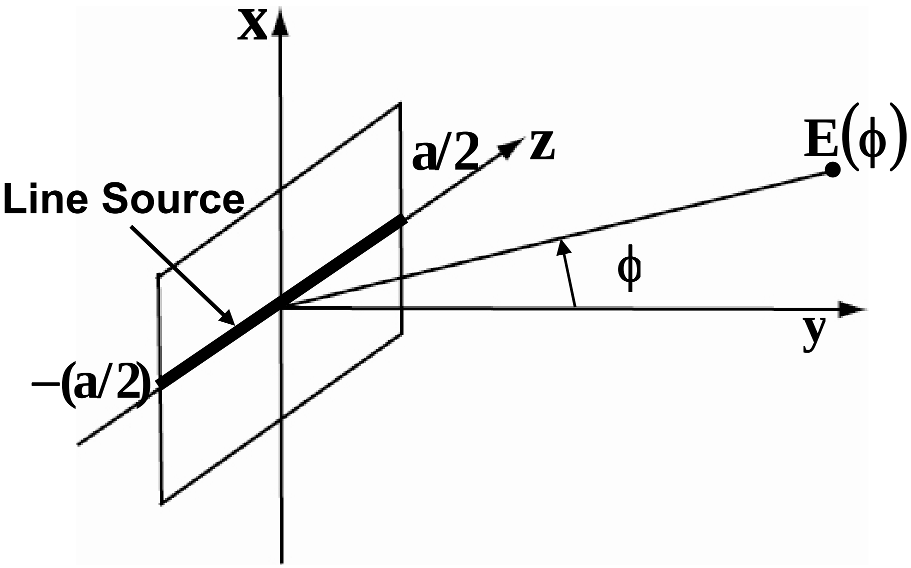
Antenna Radiation Pattern from a Line Source



$$E(\phi) = \int_{-a/2}^{a/2} A(z) \exp\left(j\, 2\pi \frac{z}{\lambda} \sin\phi \right) dz$$

- The aperture Illumination, $A(z)$, is the current a distance z from the origin (0,0,0), along the z axis
- Assumes $E(\phi)$ is in the far field, $a >> \lambda$ and $R >> a^2 / \lambda$
- Note that the electric field is the Inverse Fourier Transform of the Aperture Illumination.

Adapted from Skolnik, Reference 1

Effect of Source Distribution on Antenna Pattern of a Line Source

Uniform Aperture Distribution

$$A(z) = 1$$

$$E(\phi) = \int_{-a/2}^{a/2} \exp\left(j\,2\pi \frac{z}{\lambda} \sin\phi \right) dz$$

$$= \frac{A_0 \sin[\pi(a/\lambda)\sin\phi]}{(\pi/\lambda)\sin\phi}$$

$$E(\phi) = \frac{\sin[\pi(a/\lambda)\sin\phi]}{\pi(a/\lambda)\sin\phi}$$

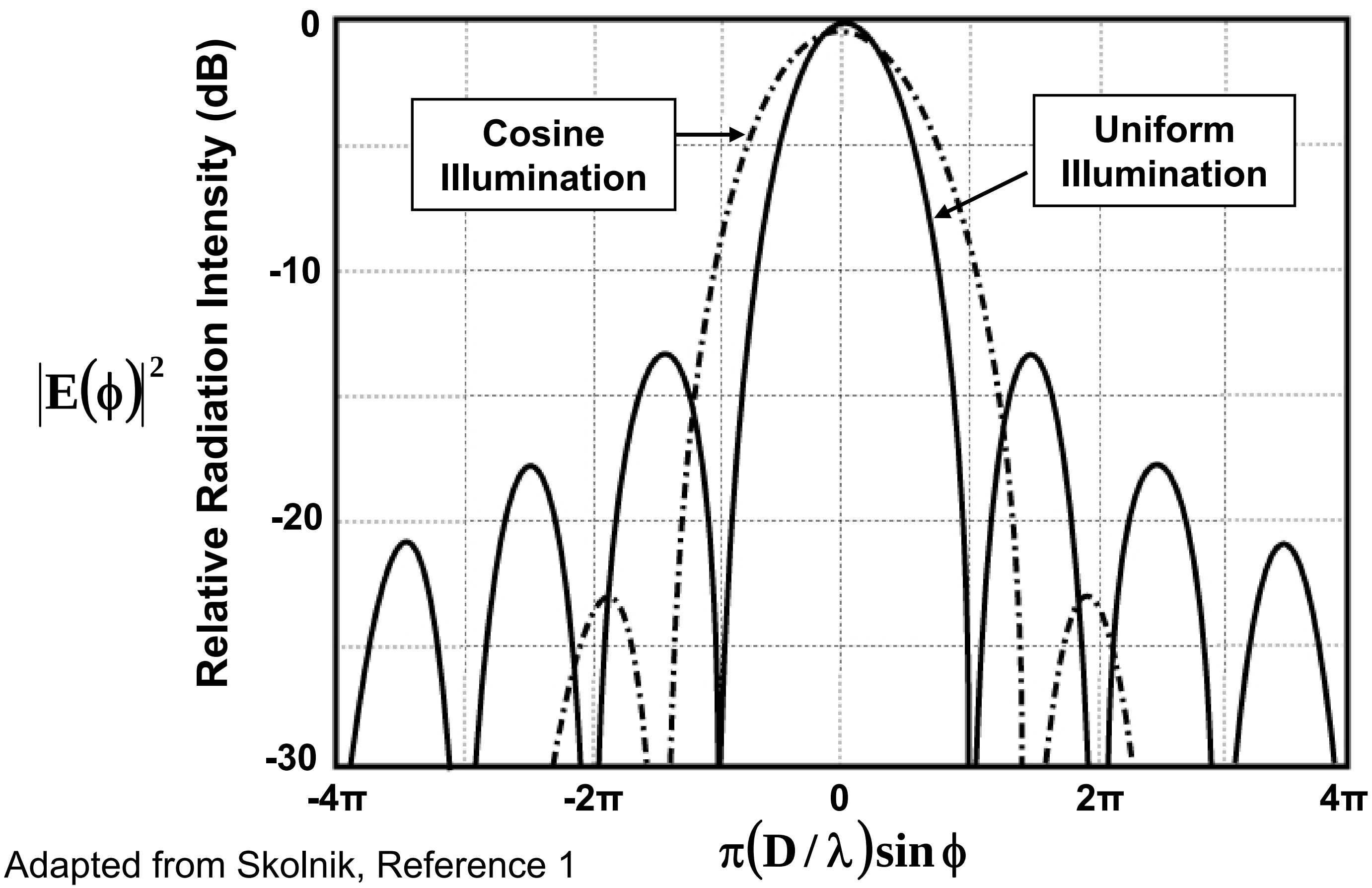
Cosine Aperture Distribution

$$A(z) = \cos\pi(a/z)$$

$$E(\phi) = \frac{\pi}{4}\left[\frac{\sin(\psi + \pi/2)}{(\psi + \pi/2)} + \frac{\sin(\psi - \pi/2)}{(\psi - \pi/2)} \right]$$

where $\psi = \pi(a/\lambda)\sin\phi$

Antenna Pattern of a Line Source
(with Uniform and Cosine Aperture Illumination)

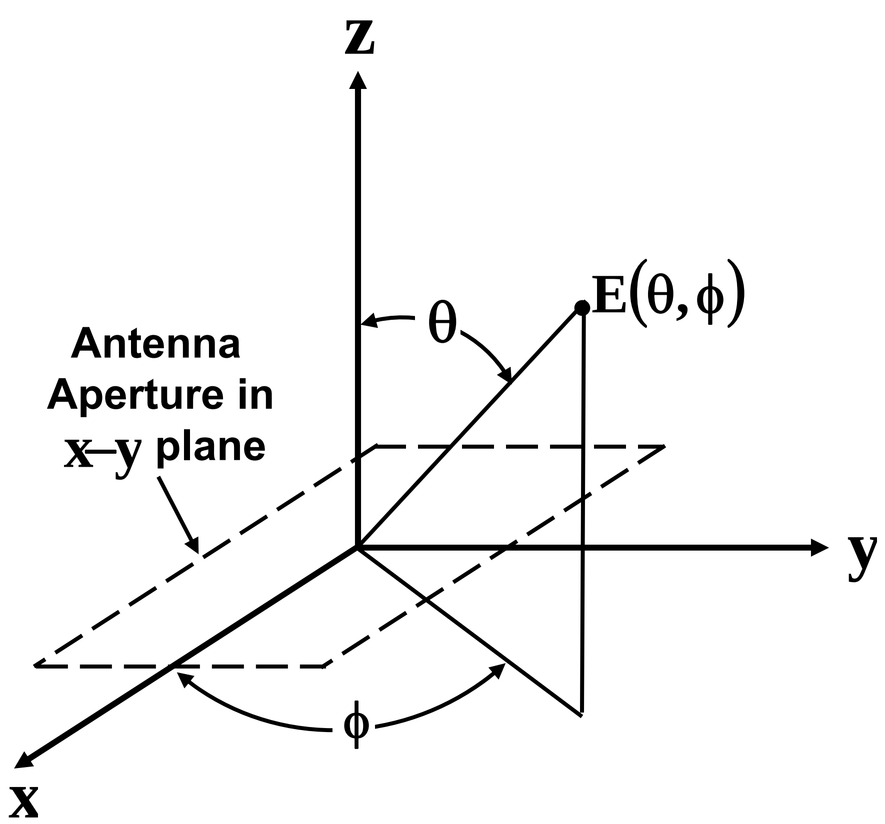


Adapted from Skolnik, Reference 1

~0.9 dB Loss

- **Weighting of Aperture Illumination**
  - **Increases Beamwidth - Lowers Sidelobes - Lowers Antenna Gain**

Illumination of Two-Dimensional Apertures



- **Calculation of this integral is non-trivial**
  - **Numerical techniques used**

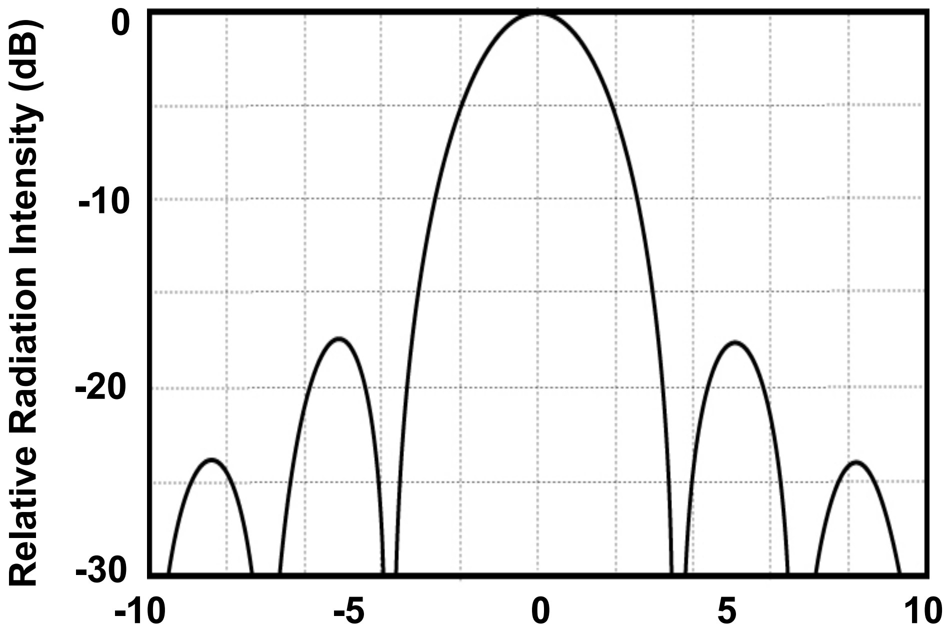
- **Field pattern separable, when aperture illumination separable**

$$A(x,y) = A_x(x)A_y(y)$$

- **Problem reduces to two 1 dimensional calculations**

$$E(\theta,\phi) = \iint A(x,y)\, e^{[(2\pi j/\lambda)\sin\theta\,(x\cos\phi + y\sin\phi)]} dx\,dy$$

Uniformly Illuminated Circular Aperture



$\xi = 2\pi(a/\lambda)\sin\theta$

- Field Intensity of circular aperture of radius a:

$$E(\theta) = 2\pi\int_0^a A(r) J_0\left[2\pi(r/\lambda)\sin\phi\theta\right] r\,dr$$

- For uniform aperture illumination :

$$E(\theta) = 2\pi a^2 J_1(\xi)/\xi$$

where $\xi = 2\pi(a/\lambda)\sin\theta$ and

$J_1(\xi)$ = 1st order Bessel Function

- Use cylindrical coordinates, field intensity independent of
- Half power beamwidth (degrees) = $58.5(\lambda/a)$, first sidelobe = - 17.5 dB
- Tapering of the aperture will broaden the beamwidth and lower the sidelobes

Adapted from Skolnik, Reference 1

Radiation Pattern Characteristics for Various Aperture Distributions

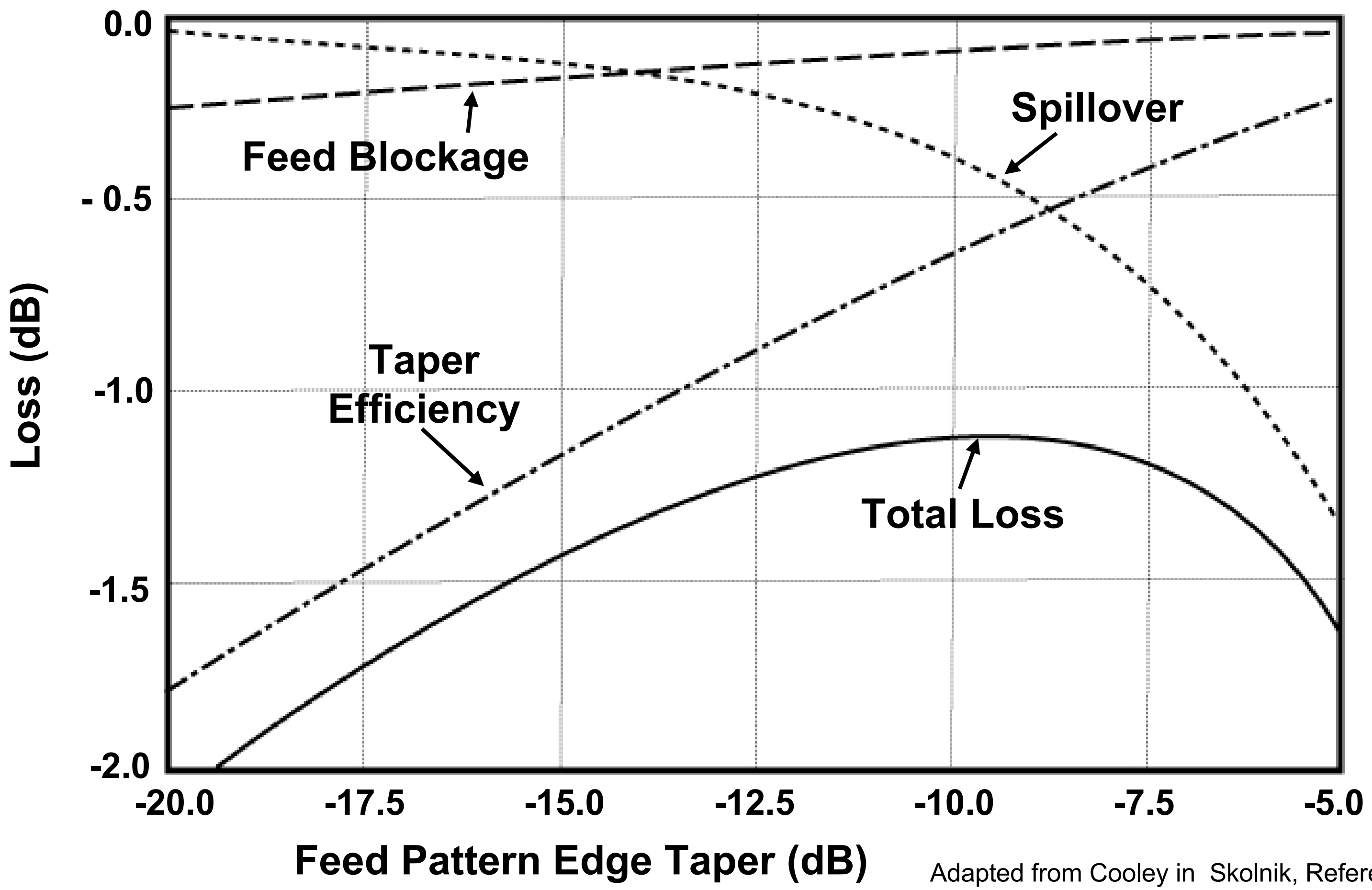
Type of Distribution $\|z\| < 1$	Gain Relative to Uniform (dB)	Beamwidth Half-Power (dB)	Intensity, 1st Sidelobe (dB below Maximum)
Uniform : $A(z) = 1$	1.0	51 λ/D	13.2
Cosine: $A(z) = \cos^n(\pi z / 2)$			
n=0	1.0	51 λ/D	13.2
n=1	0.810	69 λ/D	23
n=2	0.667	83 λ/D	32
n=3	0.515	95 λ/D	40
Parabolic: $A(z) = 1 - (1 - \Delta) z^2$			
Δ=1.0	1.0	51 λ/D	13.2
Δ=0.8	0.994	53 λ/D	15.8
Δ=0.5	0.970	56 λ/D	17.1
Δ=0	0.833	66 λ/D	20.6
Triangular: $A(z) = 1 - \|z\|$	0.75	73 λ/D	26.4
Circular: $A(z) = \sqrt{1 - z^2}$	0.865	58.5 λ/D	17.6
Cosine-squared + pedestal			
$0.33 + 0.66 \cos^2(\pi z / 2)$	0.88	63 λ/D	25.7
$0.08 + 0.92 \cos^2(\pi z / 2)$ (Hamming)	0.74	76.5 λ/D	42.8

Heavier Taper
- Lowers sidelobes
- Increases beamwidth
- Lowers directivity

Uniform distribution always has 13 dB sidelobe

Adapted from Skolnik, Reference 1

Taper Efficiency, Spillover, Blockage, and Total Loss vs. Feed Pattern Edge Taper



Adapted from Cooley in Skolnik, Reference 4

Reflector Design is a Tradeoff of Aperture Illumination (Taper) Efficiency, Spillover and Feed Blockage

Outline

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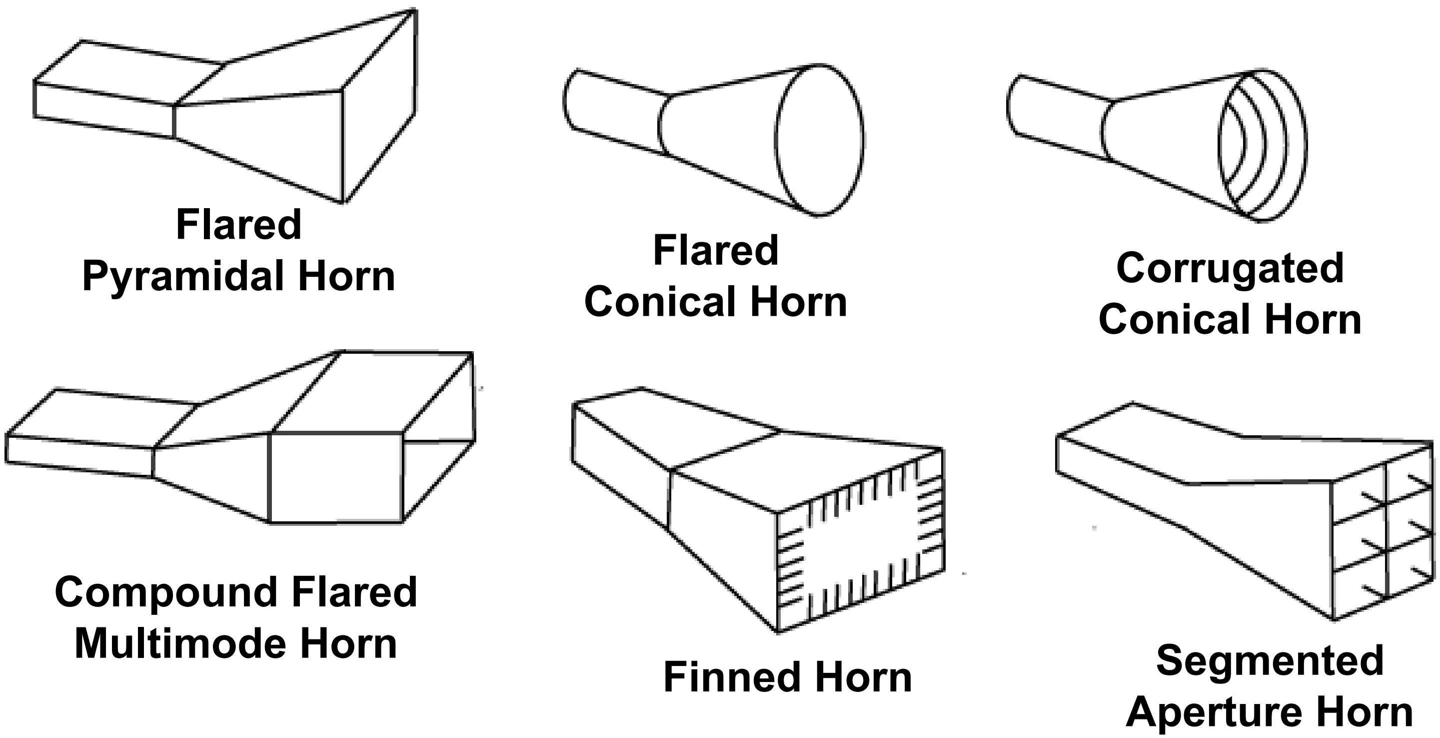
  - **Aperture Illumination**
  - **Different Reflector Feeds and Reflector Geometries**
    - **Feed Horns**
    - **Cassegrain Reflector Geometry**
    - **Different Shaped Beam Geometries**
    - **Scanning Feed Reflectors**

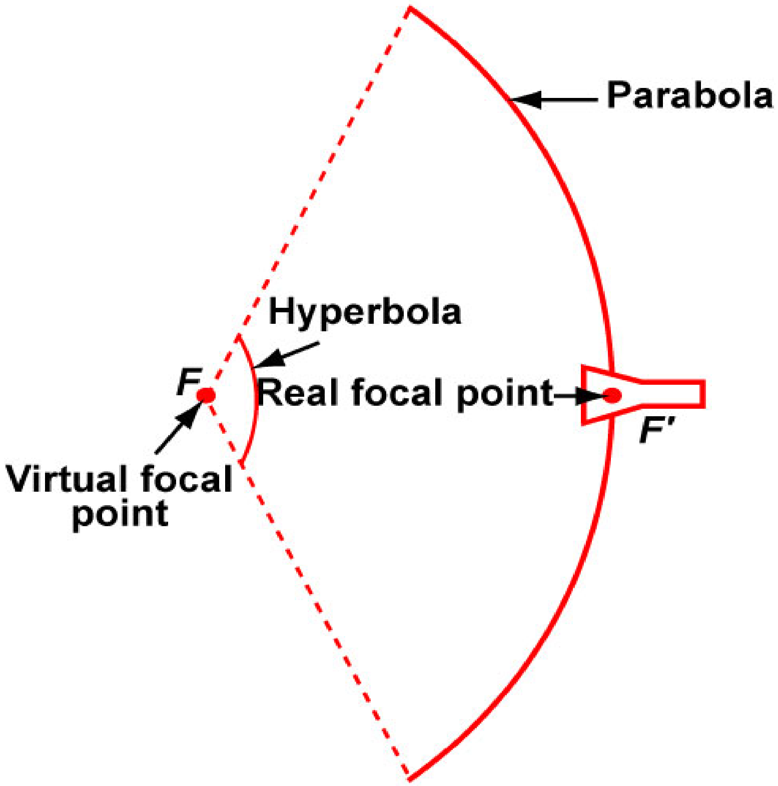
Feed Horns for Reflector Antennas



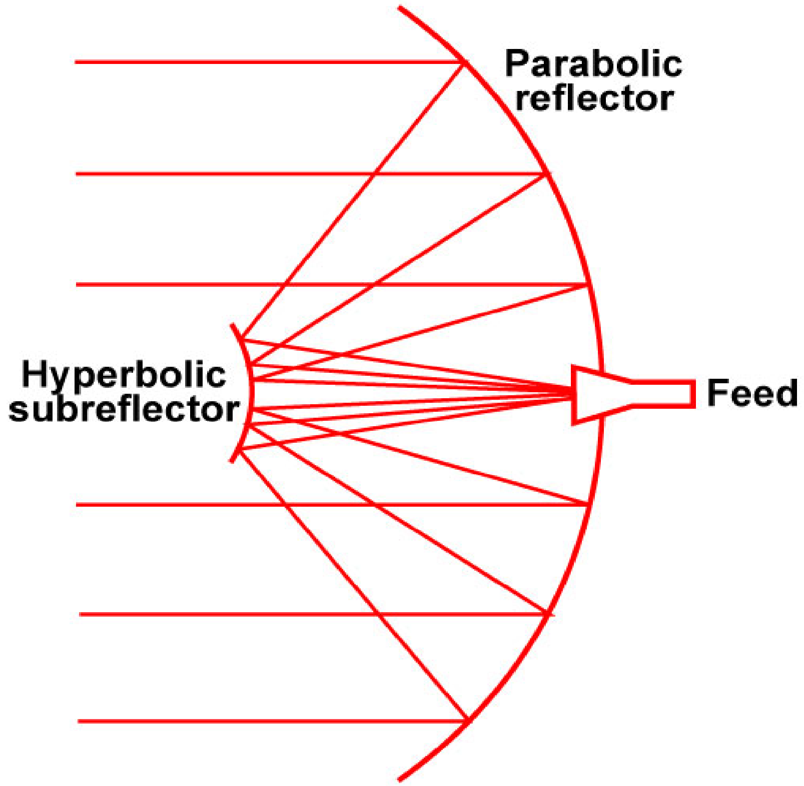
- Simple flared pyramidal (TE_{01}) and conical (TE_{11}) horns used for pencil beam, single mode applications
- Corrugated, compound, and finned horns are used in more complex applications
  – Polarization diversity, ultra low sidelobes, high beam efficiency, etc.
- Segmented horns are used for monopulse applications

Adapted from Cooley in Skolnik, Reference 4

Cassegrain Reflector Antenna



Geometry of Cassegrain Antenna



Ray Trace of Cassegrain Antenna

Figure by MIT OCW.

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- Example of Cassegrain Feed

ALTAIR Antenna

ALTAIR Antenna Feed

Note size of man

Dual Frequency Radar

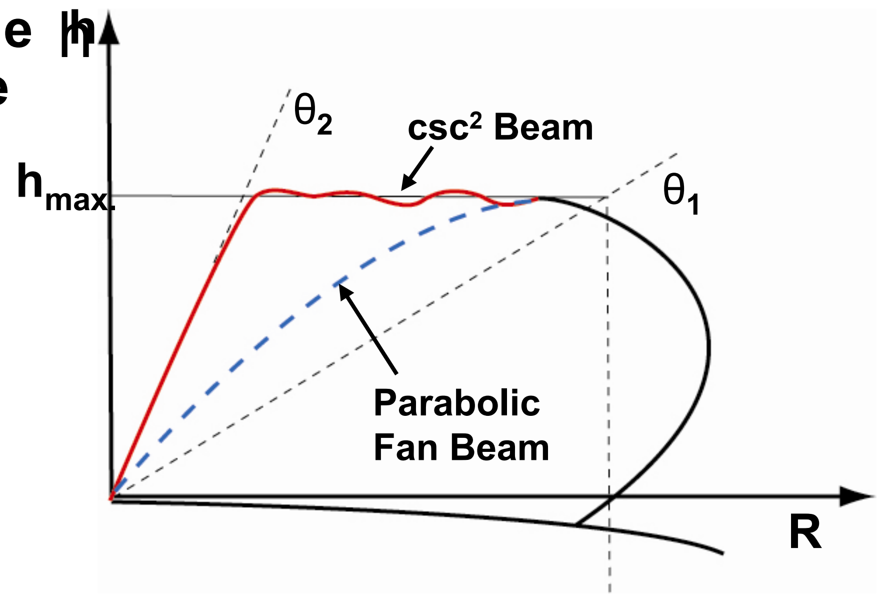
- Antenna size - 120 ft.
- VHF parabolic feed
- UHF Cassegrain feed
- Frequency Selective Surface (FSS) used for reflector at UHF

- This “saucer” is a dichroic FFS that is reflective at UHF and transparent at VHF. The “teacup” to its right is the cover for a five horn VHF feed, located at the antenna’s focal point.
- The FSS sub-reflector is composed of two layers of crossed dipoles

Antennas with Cosecant-Squared Pattern

- **Air surveillance coverage of a simple fan beam is usually inadequate for aircraft targets at high altitude and short range**
  - **Simple fan beam radiates very little energy at high altitude**

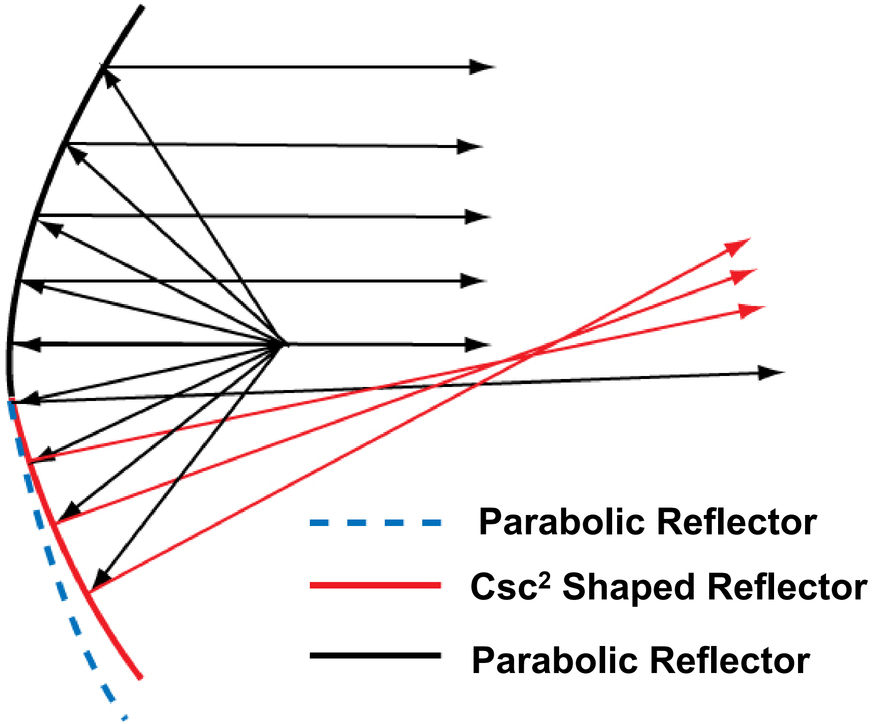
- **One technique - Use fan beam with shape proportional to the square of the cosecant of the elevation angle**
  - **Gain constant for a given altitude**



- **Gain pattern:**
  - $G(\theta) = G(\theta_1) \csc^2\theta / \csc^2\theta_1$
    for $\theta_1 < \theta < \theta_2$
  - $G(\theta) \sim G(\theta_1)\,(2 - \cot\theta_2)$

Antenna Pattern with Cosecant-Squared Beam Shaping

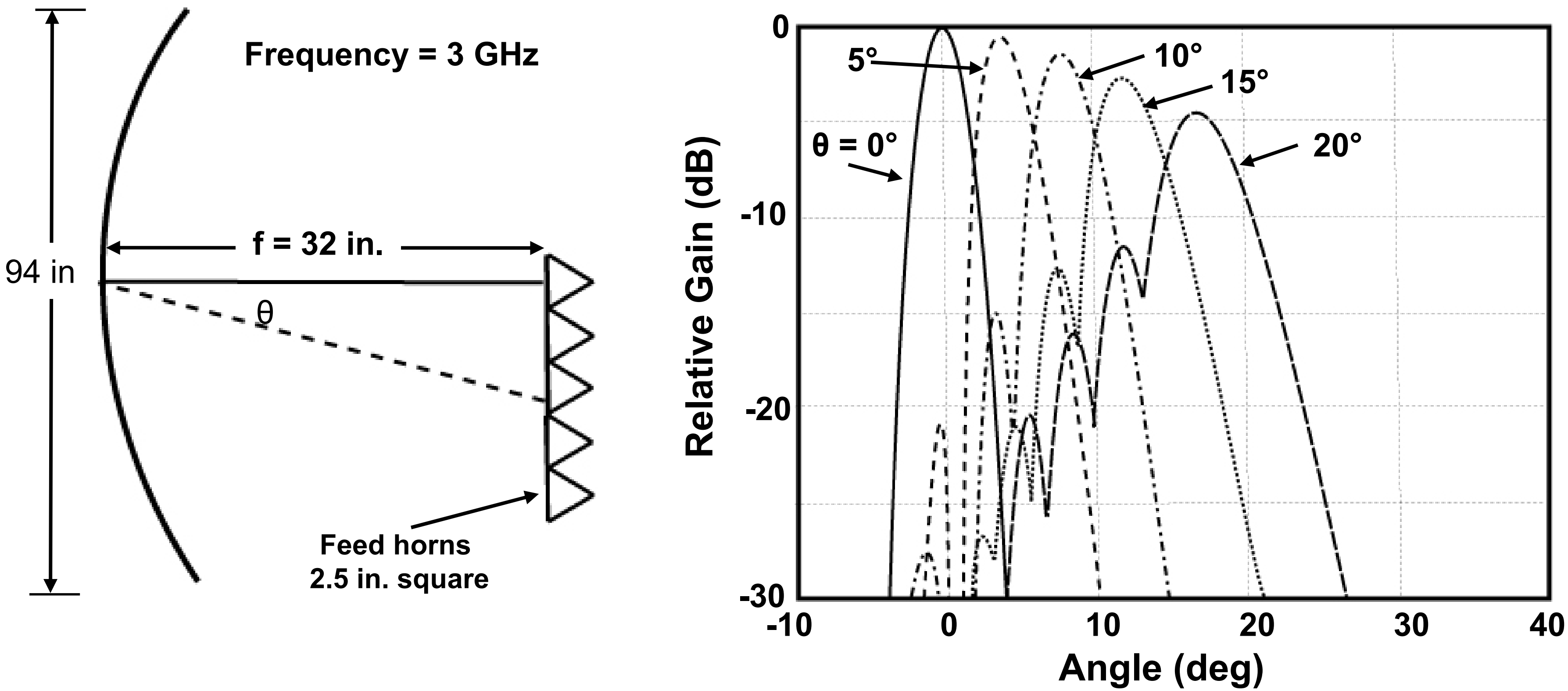
Ray Trace for csc^2 Antenna Pattern



FAA ASR Radars Use
csc^2 Antenna Reflector Shaping

ASR-9 Antenna

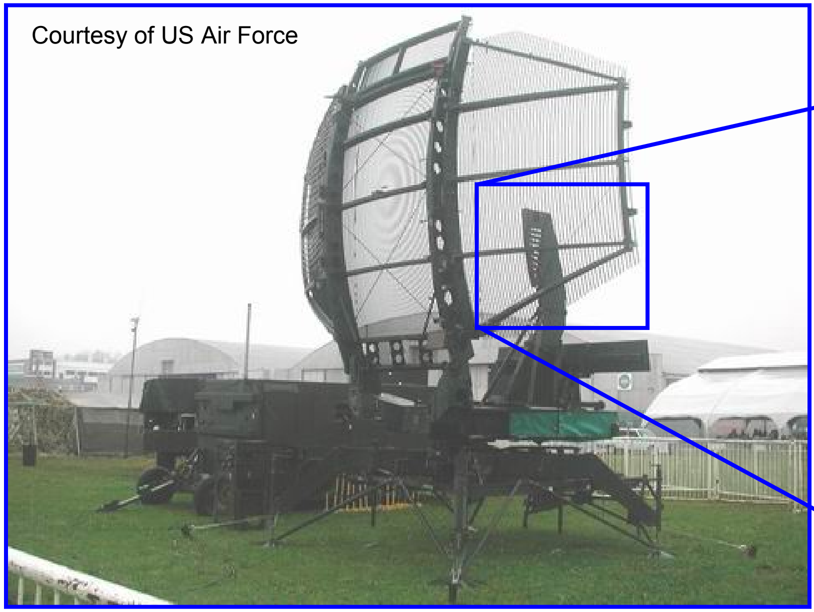
Patterns for Offset Feeds



- Notice that a vertical array of feeds results in a set of "stacked beams"
  - Can be used to measure height of target

Example of Stacked Beam Antenna

TPS-43 Radar



Courtesy of US Air Force

TPS-43 Antenna Feed

Courtesy of brewbooks

- **Stacked beam surveillance radars can cost effectively measure height of target, while simultaneously performing the surveillance function**
- **This radar, which was developed in the 1970s, under went a number of antenna upgrade in the 1990s (TPS-70, TPS-75)**
  - **Antenna was replaced with a slotted waveguide array, which performs the same functions, and in addition has very low sidelobes**

Example of Stacked Beam Antenna

TPS-43 Radar

TPS-78 Antenna

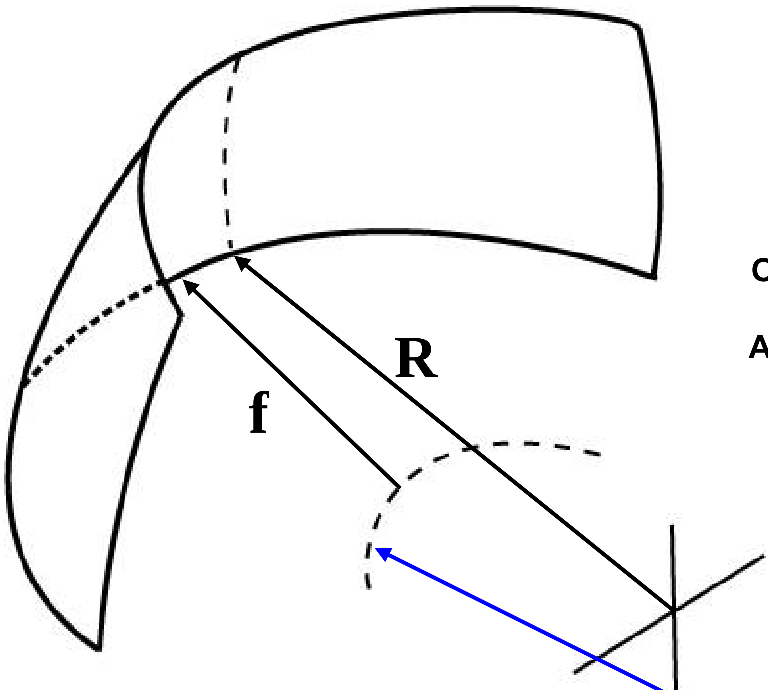
- **Stacked beam surveillance radars can cost effectively measure height of target, while simultaneously performing the surveillance function**
- **This radar, which was developed in the 1970s, was replaced in the 1990s with a technologically modern version of the radar.**
  - **New antenna, a slotted waveguide array, has all of the same functionality as TPS-43 dish, but in addition, has very low antenna sidelobes**

Scanning Feed Reflector Antennas

- **Scanning of the radar beam over a limited angle with a fixed reflector and a movable feed**
  - Paraboloid antenna cannot be scanned too far without deterioration
    - Gain of antenna, with f/D=.25, reduced to 80%when beam scanned 3 beamwidths off axis
  - Wide angle scans in one dimension can be obtained with a parabolic torus configuration
    - Beam is generated by moving feed along circle whose radius is 1/2 that of torus circle
    - Scan angle limited to about 120 deg
    - Economical way to rapidly scan beam of very large antennas over wide scan angles
  - Organ pipe scanner
    - Mechanically scan feed between many fixed feeds

Examples of Scanning Feed Reflector Configuration

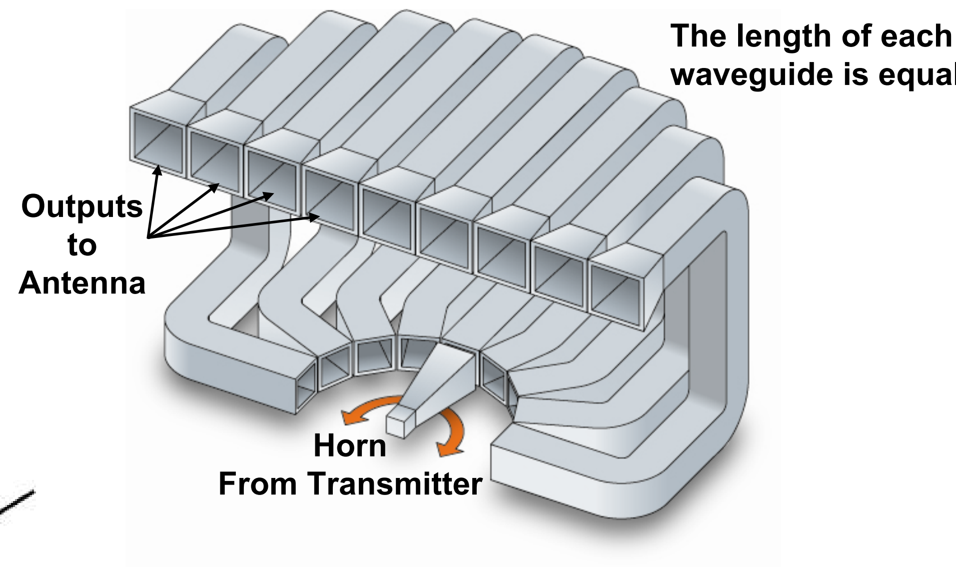
Parabolic Torus Antenna



R = Radius of Torus

f = Focal Length of Torus

Organ Pipe Scanner Feed



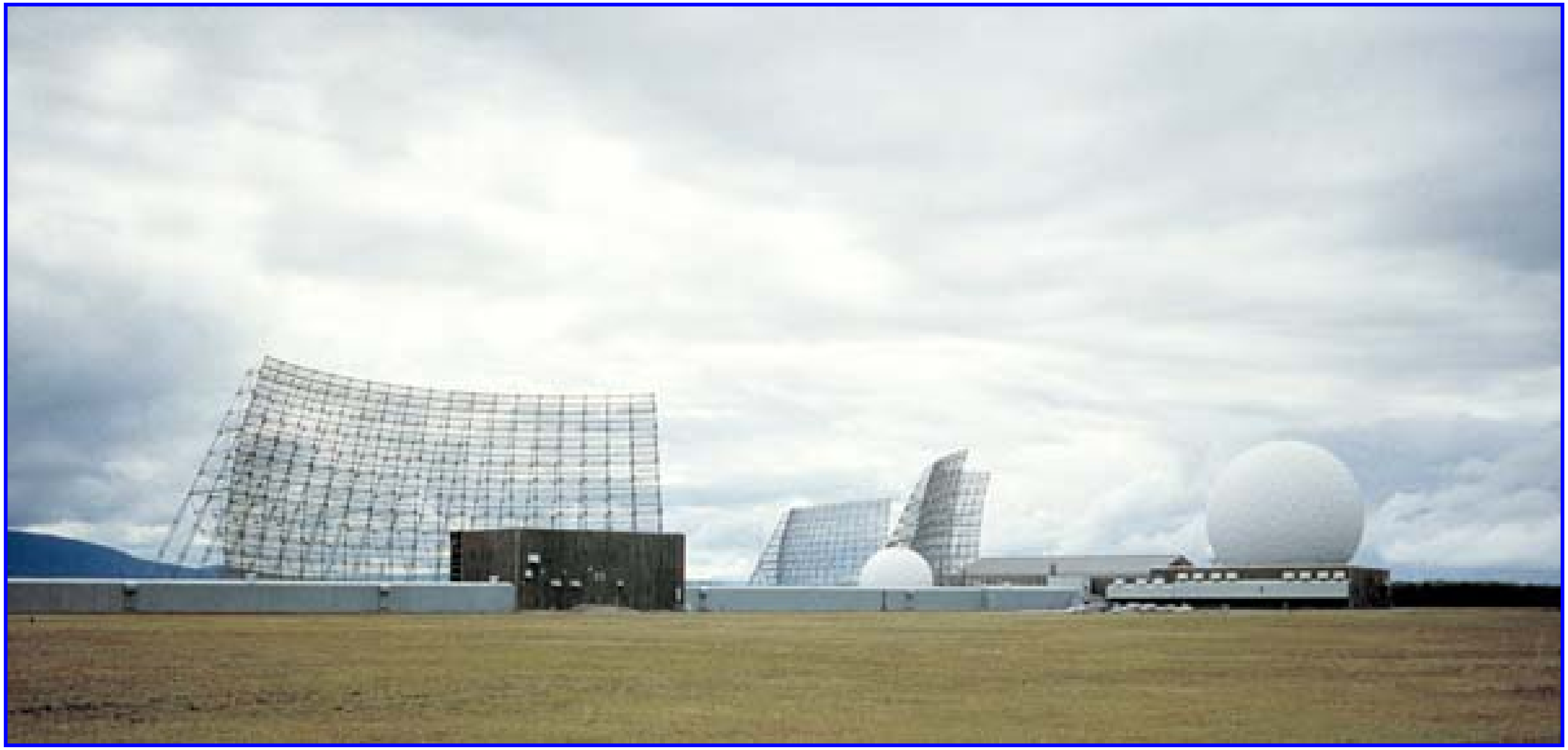
The output feed horns of the organ pipe scanner are located along this arc

Radar Example – Organ Pipe Scanner

Courtesy of MIT Lincoln Laboratory, Used with permission

Radar Example – Organ Pipe Scanner

BMEWS Site, Clear, Alaska



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Summary – Part 1

- Discussion of antenna parameters
  - Gain
  - Sidelobes
  - Beamwidth
    - Variation with antenna aperture size and wavelength
  - Polarization
    - Horizontal, Vertical, Circular
- Mechanical scanning antennas offer an inexpensive method of achieving radar beam agility
  - Slow to moderate angular velocity and acceleration
- Different types of mechanical scanning antennas
  - Parabolic reflectors
  - Cassegrain and offset feeds
  - Stacked beams
- Antenna Issues
  - Aperture illumination
  - Antenna blockage and beam spillover

Homework Problems

- **From Skolnik, Reference 2**
  - **Problem 2.20**
  - **Problems 9.2, 9.4, 9.5, and 9.8**

Outline

- Introduction
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- Phased Array Antennas
- Frequency Scanning of Antennas
- Hybrid Methods of Scanning
- Other Topics

Acknowledgement

- Dr. Pamela Evans
- Dr Alan J. Fenn

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