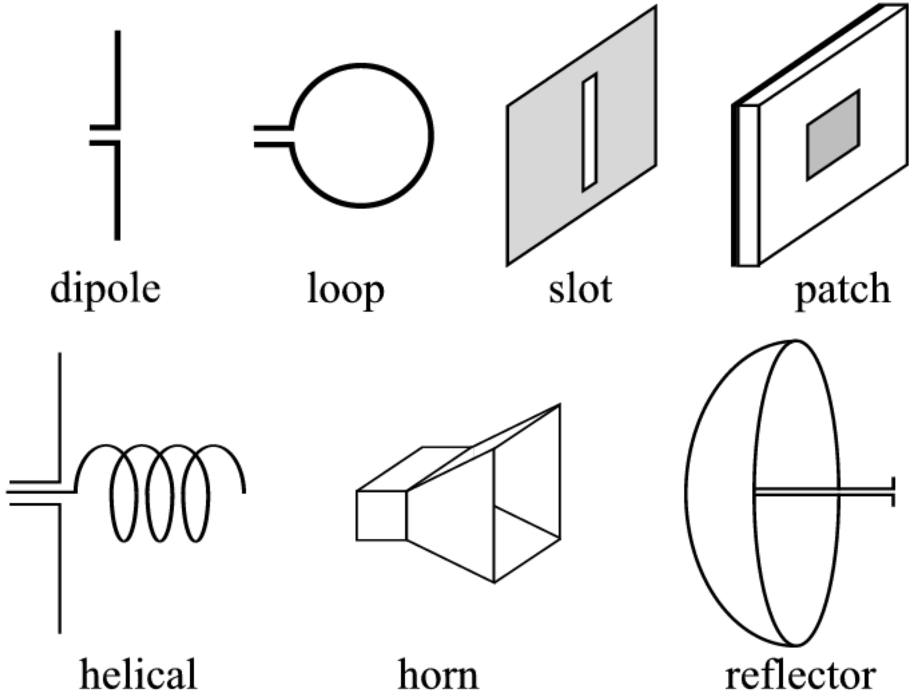
Antenna and Propagation

“Antenna Types & Beamforming”

Dr. Cahit Karakuş, 2018

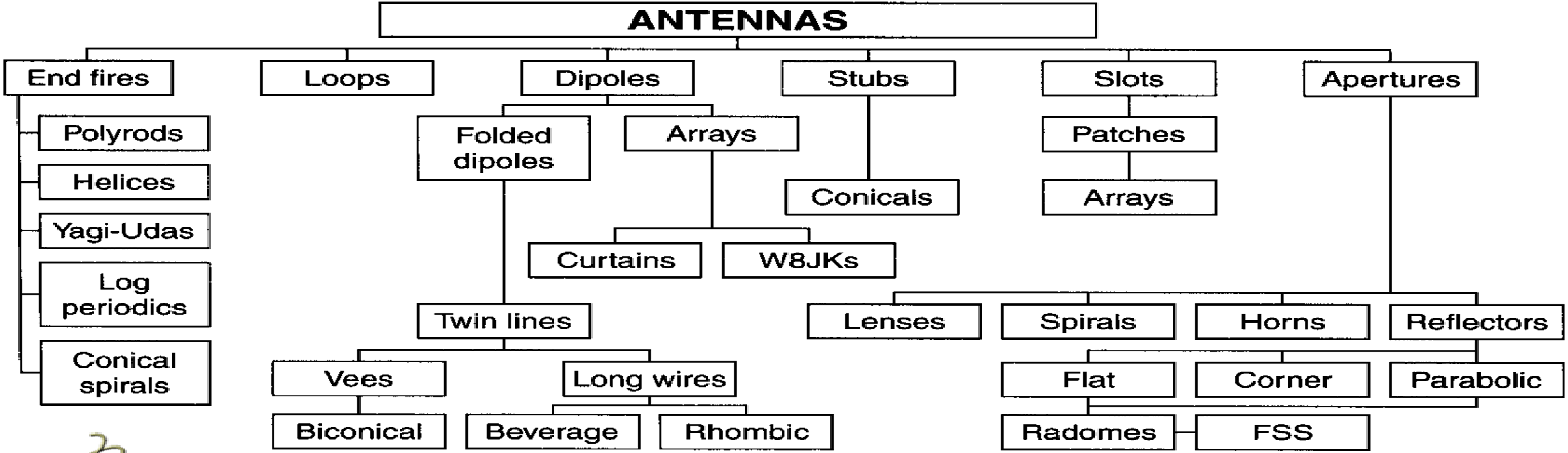
Types of Antennas

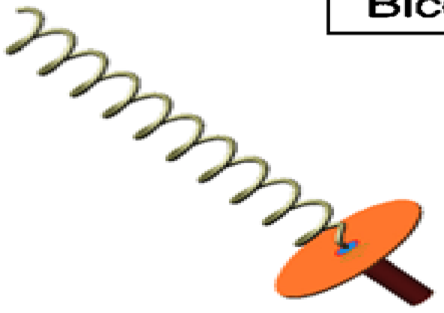
- Wire antennas
- Aperture antennas
- Array antennas
- Reflector antennas
- Lens antennas
- Patch antennas



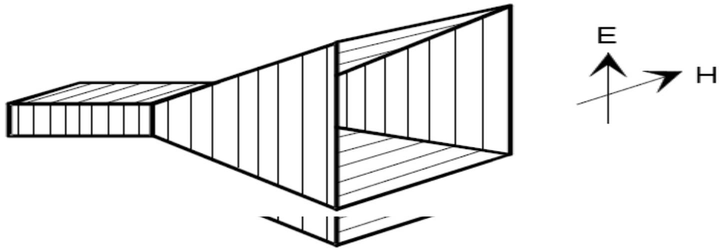
Antennas come in a wide variety of sizes and shapes

Antenna types

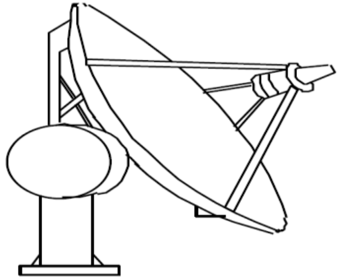




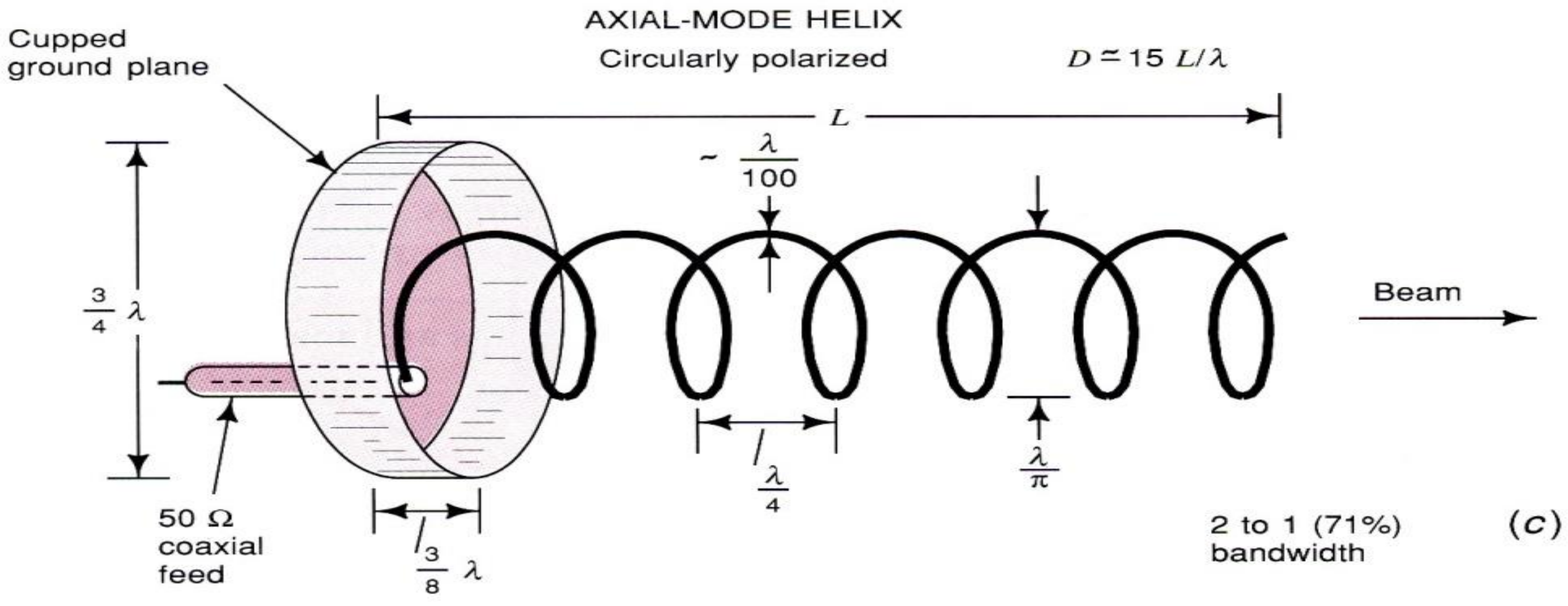
Helical antenna



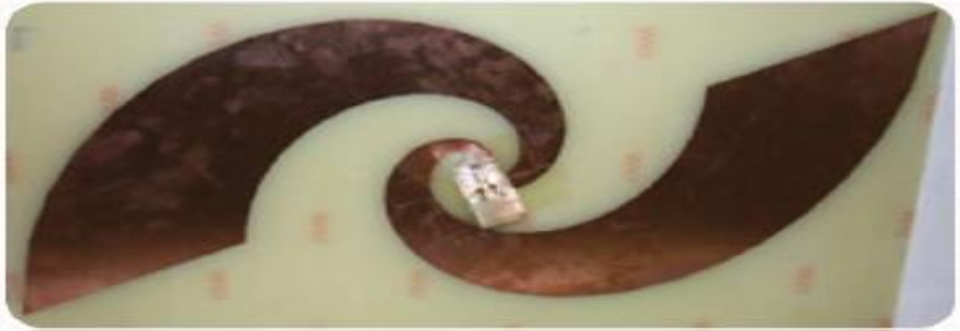
Horn antenna



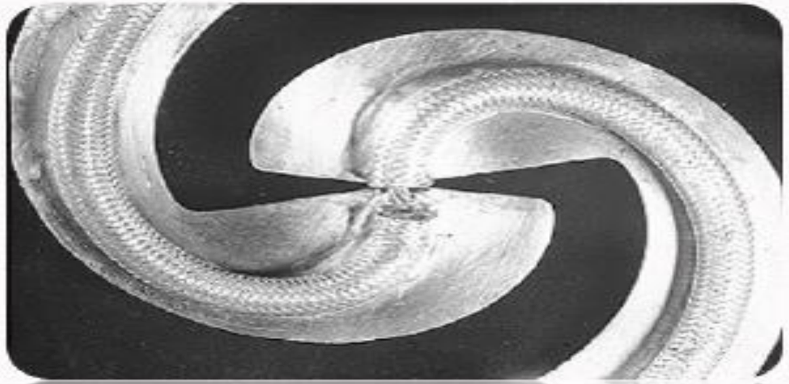
Parabolic reflector antenna


AXIAL-MODE HELIX
Circularly polarized
D ≃ 15 L/λ
Cupped
ground plane
L
~ λ/100
3/4 λ
Beam
l
λ/4
λ/π
50 Ω
coaxial
feed
l
3/8 λ
2 to 1 (71%)
bandwidth
(c)

Spiral Antenna

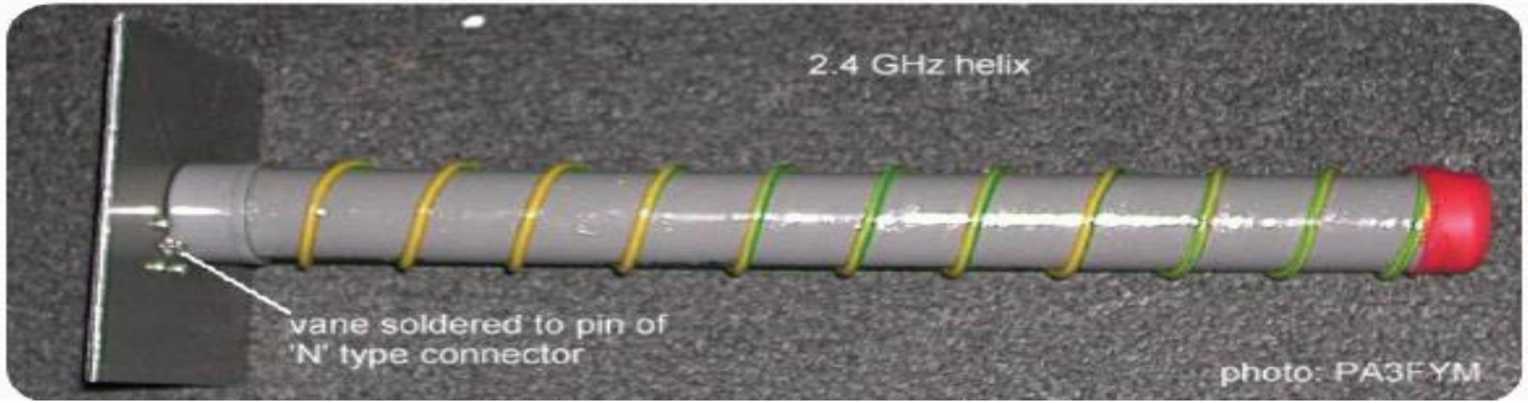


- The spiral antenna is used primarily as a receiving antenna
- Vertically polarized
- Frequency Independent
  - Designed to minimize finite lengths and maximize angular dependence



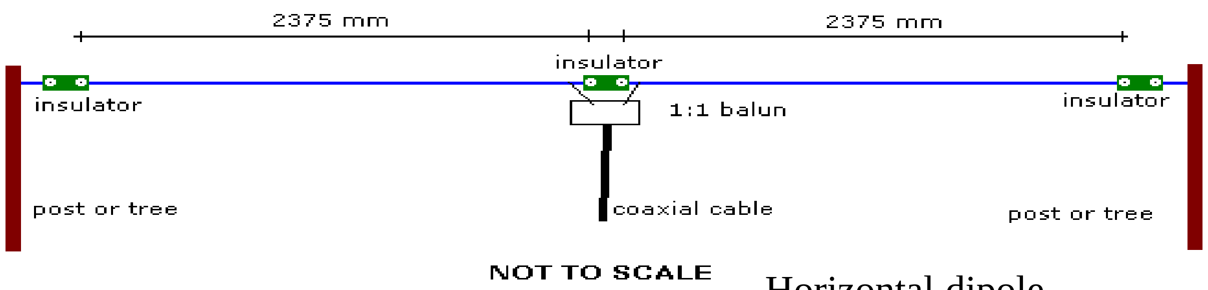
Helical Antenna

- Directional
- Circularly Polarized
  - Polarization changes with time
- Both high gain and wide band



Wire antenna

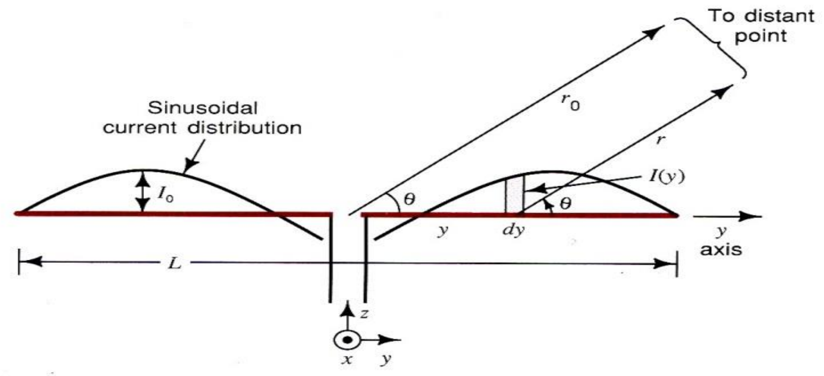
- Dipole
- Loop
- Folded dipoles
- Helical antenna
- Yagi (array of dipoles)
- Corner reflector
- Many more types



Horizontal dipole

Thin wire antenna

- Wire diameter is small compared to wavelength
- Current distribution along the wire is no longer constant



$$\text{e.g.} \quad I(y) = I_0 \sin\left(\frac{2\pi}{\lambda} \left(\frac{L}{2} \pm y \right) \right)$$

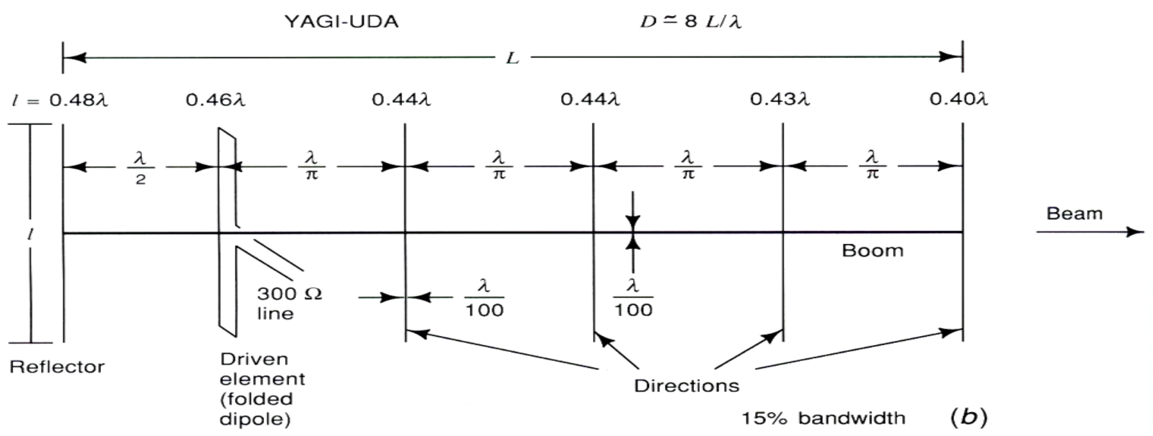
centre-fed dipole

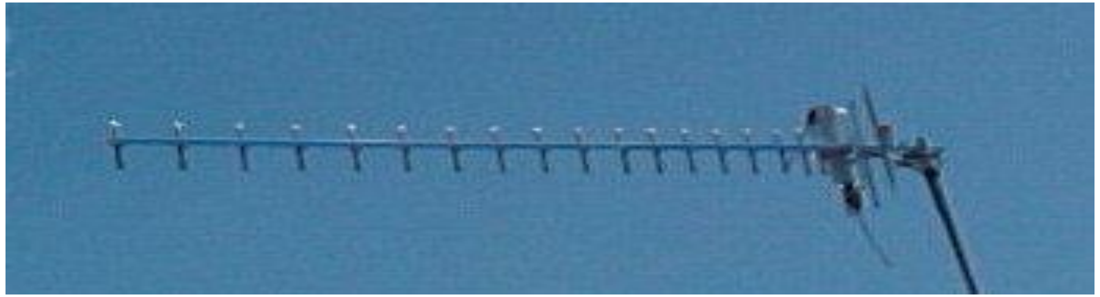
- Using field equation for short dipole, replace the constant current with actual distribution

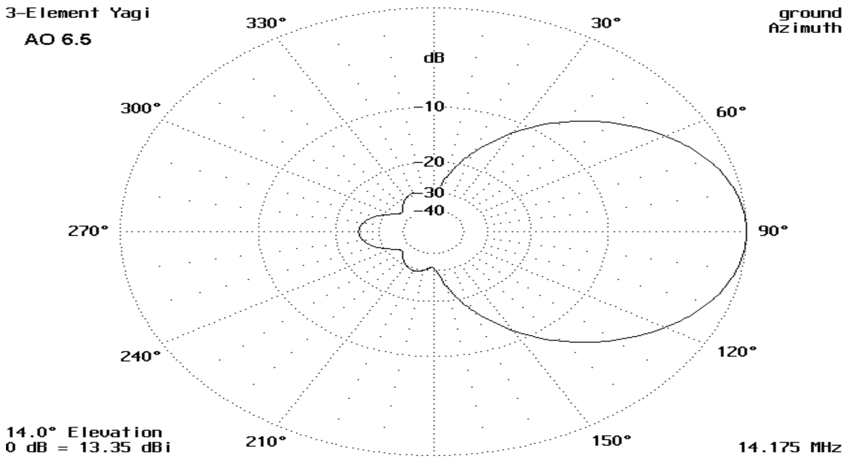
$$E_\theta = \frac{j60 I_0 e^{j(\omega t - \beta r)}}{r} \left(\frac{\cos\left(\frac{\beta L \cos(\theta)}{2} \right) - \cos\left(\frac{\beta L}{2} \right)}{\sin(\theta)} \right)$$

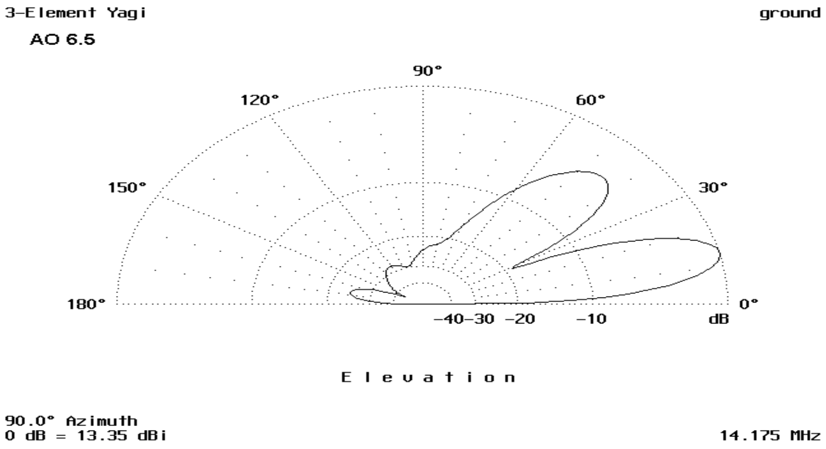
centre-fed dipole, I_0 = current at feed point

Yagi-Uda









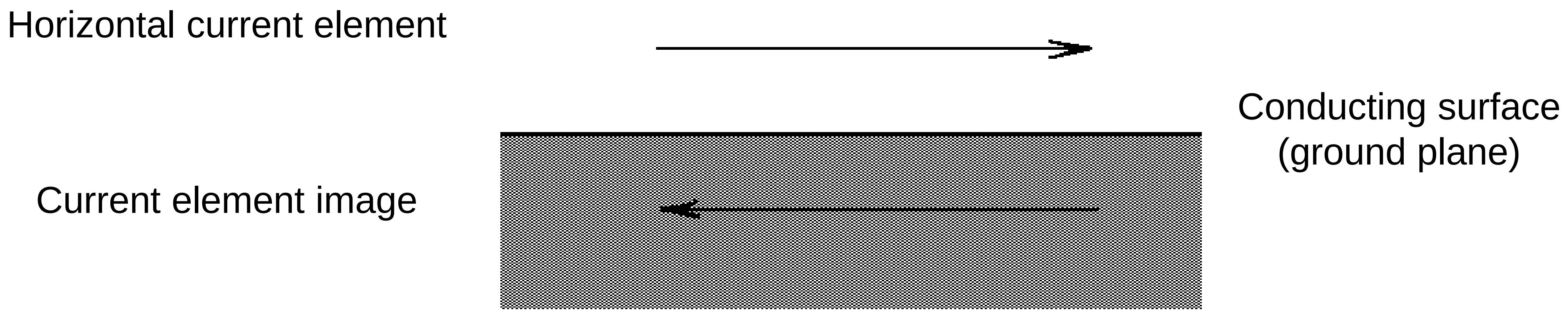
Elements	Gain dBi	Gain dBd
3	7.5	5.5
4	8.5	6.5
5	10	8
6	11.5	9.5
7	12.5	10.5
8	13.5	11.5

The Hertz Antenna
(Dipole)

Ground plane

A ground plane will produce an image of nearby currents. The image will have a phase shift of 180° with respect to the original current. Therefore as the current element is placed close to the surface, the induced image current will effectively cancel the radiating fields from the current.

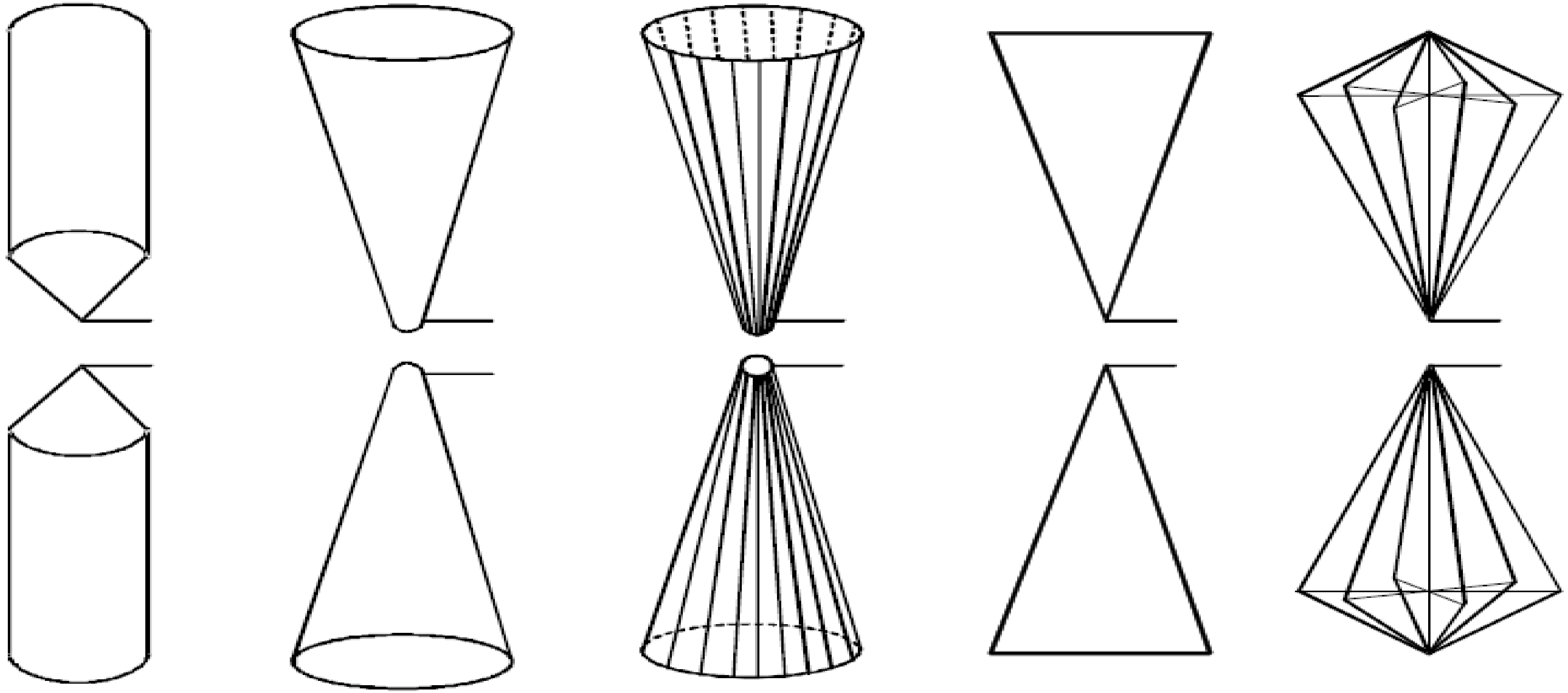
The ground plane may be any conducting surface including a metal sheet, a water surface, or the ground (soil, pavement, rock).



- Isotropic Antenna
  - A hypothetical antenna that radiates or receives equally in all directions.
  - Isotropic antennas do not exist physically but represent a convenient reference antenna for expressing directional properties of physical antennas.
  - The radiation pattern for the isotropic antenna is a sphere with the antenna at its center.

- Elementary Dipole
  - An antenna too short, for the frequency of interest, to be of practical value.
  - They are, however, used in antenna (numerical) modelling to calculate characteristics of real antennas.

Dipole antennas



Versions of broadband dipole antennas

Dipole antennas

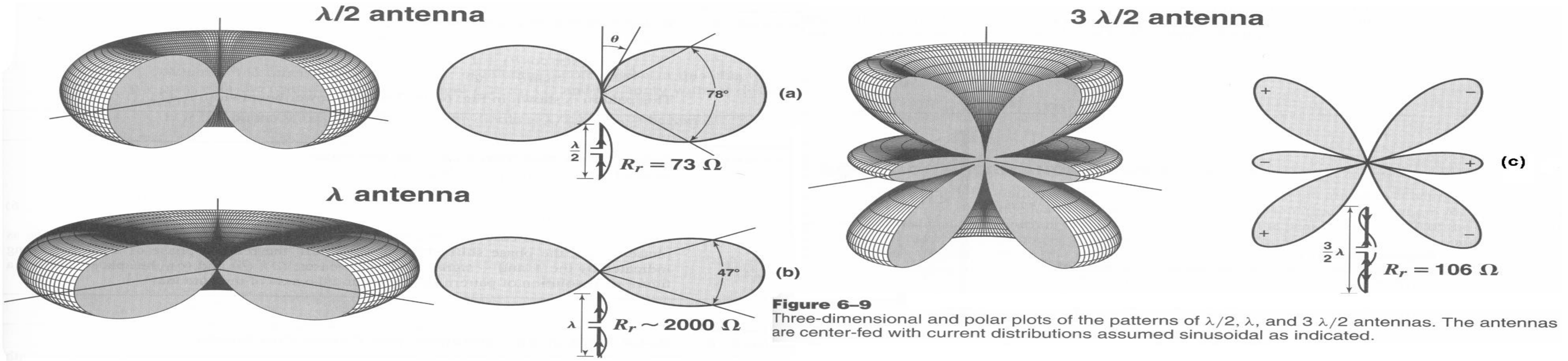
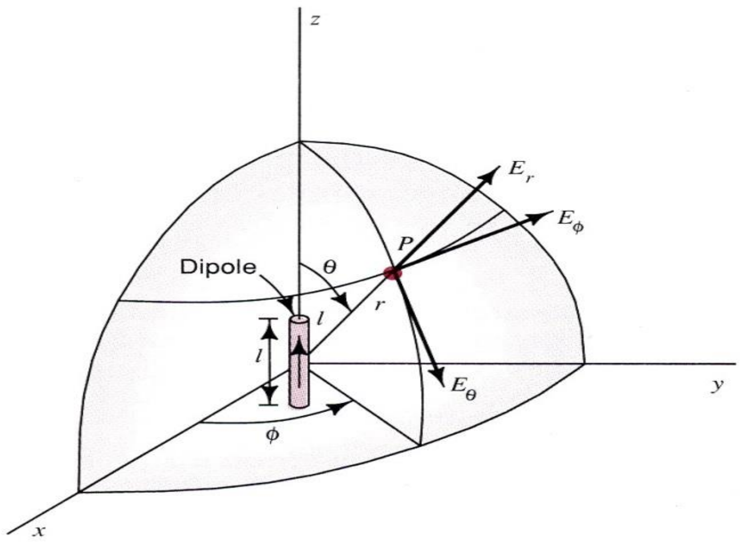


Figure 6–9
Three-dimensional and polar plots of the patterns of $\lambda/2$, λ, and 3 $\lambda/2$ antennas. The antennas are center-fed with current distributions assumed sinusoidal as indicated.

Short dipole



$$E_r = \frac{I_0 l e^{j(\omega t - \beta r)}\cos(\theta)}{2\pi\varepsilon_0}\left(\frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

$$E_\theta = \frac{I_0 l e^{j(\omega t - \beta r)}\sin(\theta)}{4\pi\varepsilon_0}\left(\frac{j\omega}{c^2 r} + \frac{1}{cr^2} + \frac{1}{j\omega r^3}\right)$$

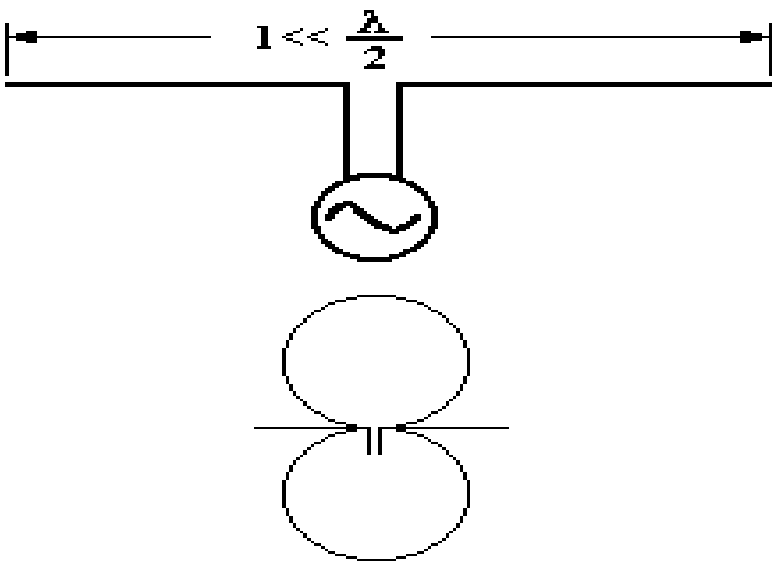
$$H_\phi = \frac{I_0 l e^{j(\omega t - \beta r)}\sin(\theta)}{4\pi}\left(\frac{j\omega}{cr} + \frac{1}{r^2}\right)$$

- Length much shorter than wavelength
- Current constant along the length
- Near dipole power is mostly reactive
- As r increases E_r vanishes, E and H gradually become in phase

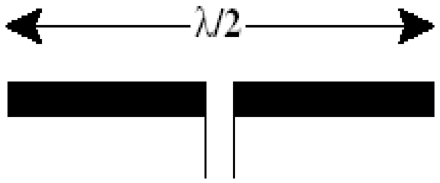
$$for\ r >> \frac{\lambda}{2\pi}, \qquad \mathrm{E}_\theta\ and\ \mathrm{H}_\phi\ \text{vary as } \frac{1}{\mathrm{r}} \longrightarrow E_\theta = \frac{j60\pi I_0 e^{j(\omega t - \beta r)}\sin(\theta)}{r}\frac{l}{\lambda}$$

$$\text{P varies as } \frac{1}{\mathrm{r}^2}$$

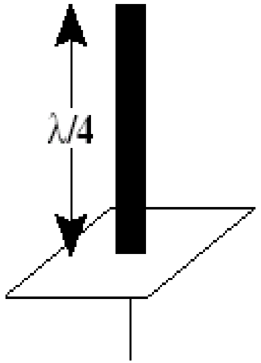
The Short Dipole



- A dipole is antenna composed of a single radiating element split into two sections, not necessarily of equal length.
- The RF power is fed into the split.
- The radiators do not have to be straight
- The length is less than $\lambda/2$.
- The self impedance is generally capacitive.
- The radiation resistance is quite small and ohmic losses are high
- SWR bandwidth is quite small, < 1% of design frequency.
- Directivity is ~1.8 dBi. Radiation pattern resembles figure

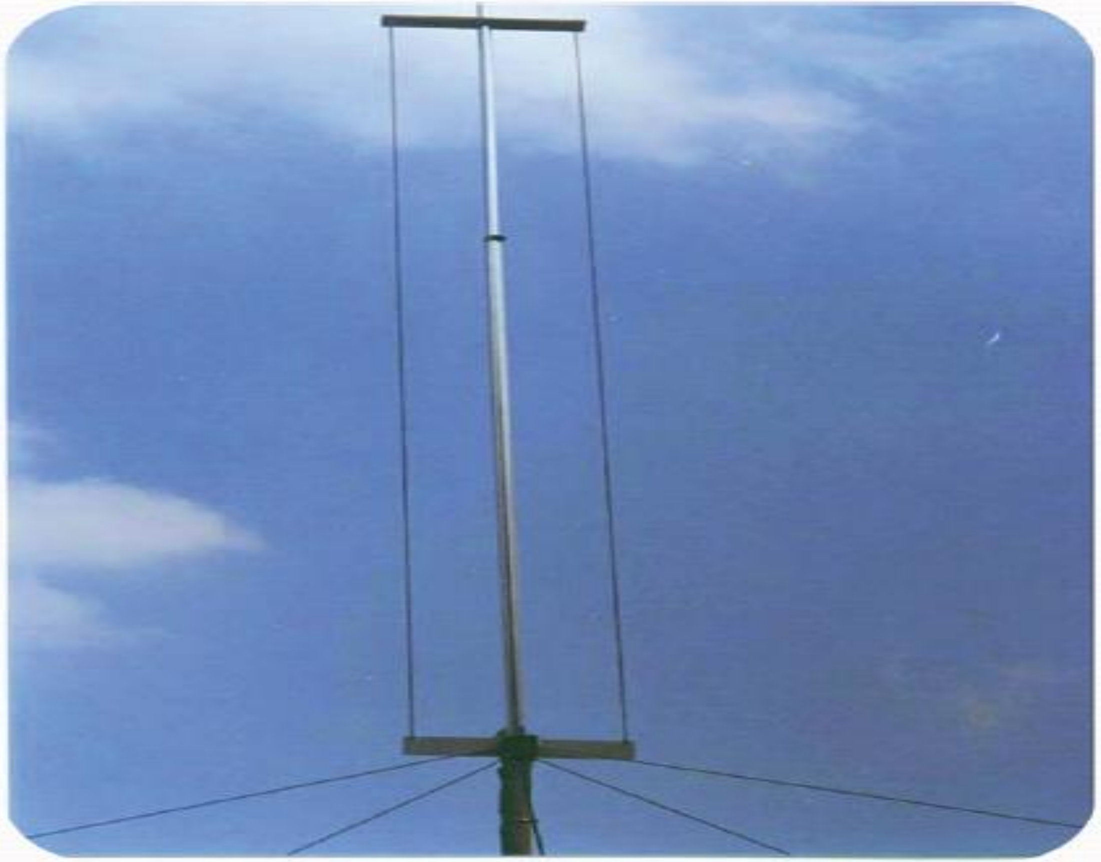


(a) Half-wave dipole



(b) Quarter-wave antenna

Sleeve Antenna



The sleeve antenna is used primarily as a receiving antenna. It is a broadband, vertically polarized, omnidirectional antenna.

Its primary uses are in broadcast, ship-to-shore, and ground-to-air communications.

Although originally developed for shore stations, there is a modified version for shipboard use.

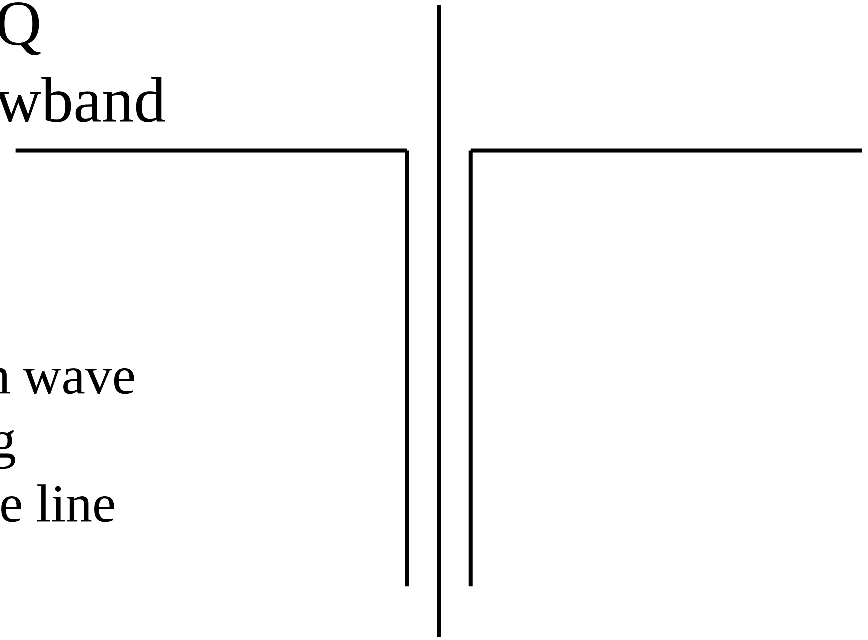
Biconical Antenna

- Types of Biconical
  - Infinite Biconical
  - Finite Biconical
  - Discone

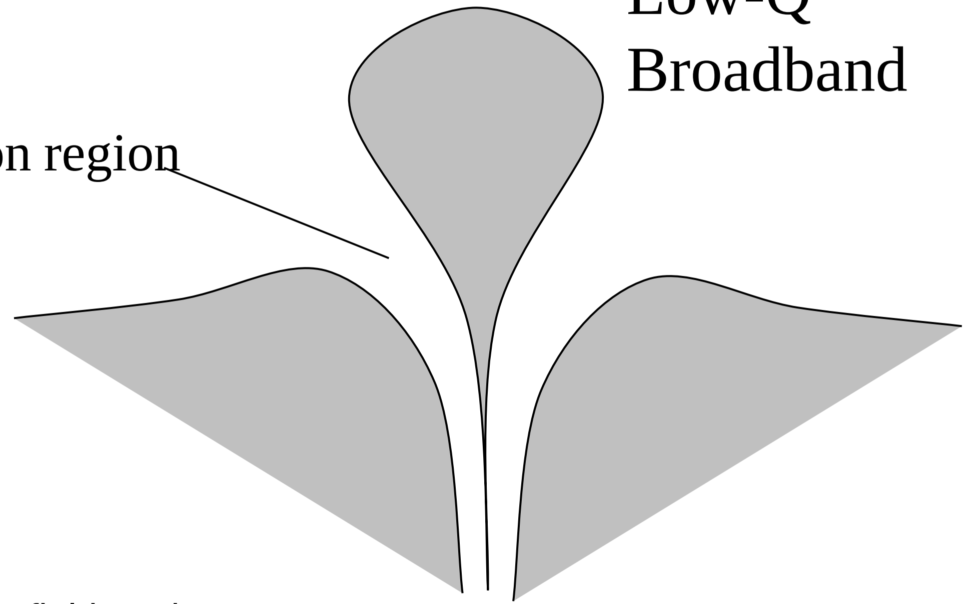
Monopole (dipole over plane)

High-Q
Narrowband

Uniform wave
traveling
along the line



Smooth
transition region



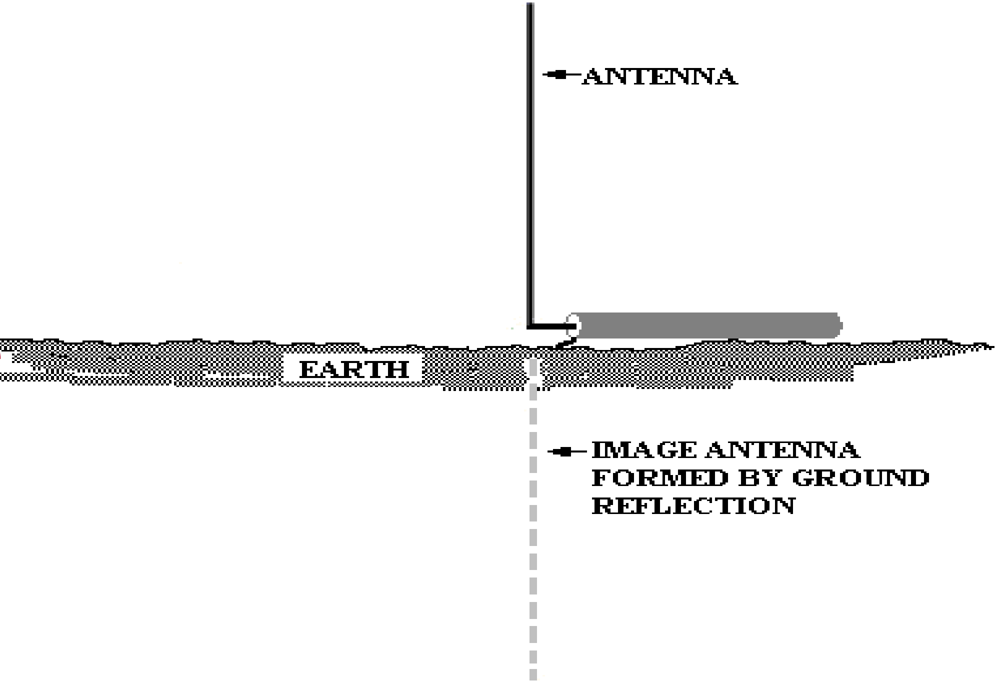
Low-Q
Broadband

- If there is an inhomogeneity (obstacle) a reflected wave, standing wave, & higher field modes appear
- With pure standing wave the energy is stored and oscillates from entirely electric to entirely magnetic and back
- Model: a resonator with high Q = (energy stored) / (energy lost) per cycle, as in LC circuits
- Kraus p.2

The Marconi Antenna (vertical monopole)

Vertical Fundamentals

- A vertical antenna consists of a single vertical radiating element located above a natural or artificial ground plane. Its length is < 0.64λ
- RF is generally fed into the base of the radiating element.
- The ground plane acts as an electromagnetic mirror, creating an image of the vertical antenna. Together the antenna and image for a virtual vertical dipole.



The Importance of the Ground

- The ground is part of the vertical antenna, not just a reflector of RF, unless the antenna is far removed from earth (usually only true in the VHF region)
- RF currents flow in the ground in the vicinity of a vertical antenna. The region of high current is near the feed point for verticals less that $\lambda/4$ long, and is ~ $\lambda/3$ out from the feed point for a $\lambda/2$ vertical.
- To minimize losses, the conductivity of the ground in the high current zones must be very high.
- Ground conductivity can be improved by using a ground radial system, or by providing an artificial ground plane known as a counterpoise.

Notes on ground system construction

- Ground radials can be made of almost any type of wire
- The radials do not have to be buried; they may lay on the ground
- The radials should extend from the feed point like spokes of a wheel
- The length of the radials is not critical. They are not resonant. They should be as long as possible
- For small radial systems ($N < 16$) the radials need only be $\lambda/8$ long. For large ground systems ($N > 64$) the length should be ~ $\lambda/4$
- Elevated counterpoise wires are usually $\lambda/4$ long

Marconi or Ground-Plane Vertical Antenna

- The quarter-wavelength vertical antenna, also called a Marconi antenna is widely used.
- It is similar in operation to a vertically mounted dipole antenna.
- The Marconi antenna is half the length of a dipole antenna.

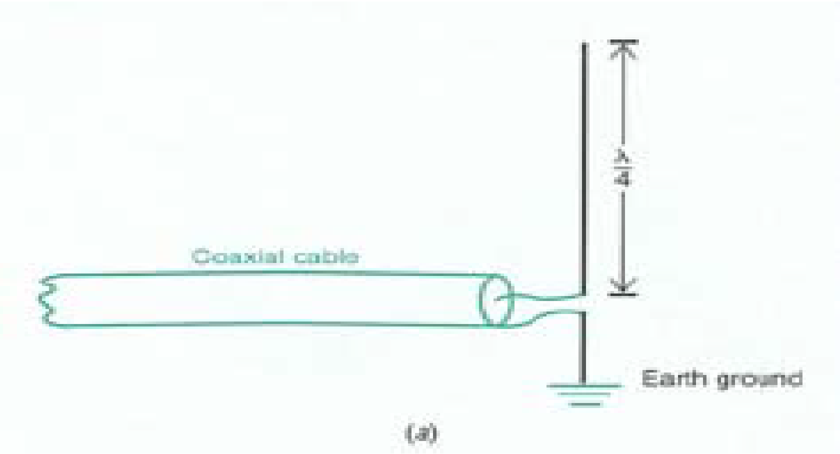
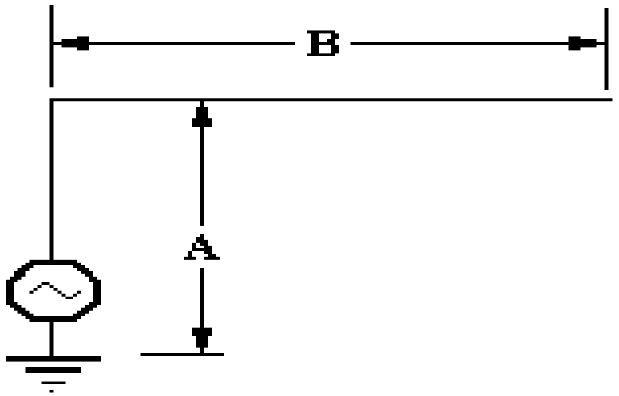


Fig. 14-20a

- The earth acts as a type of electrical "mirror," effectively providing the other quarter wavelength making it equivalent to a vertical dipole.

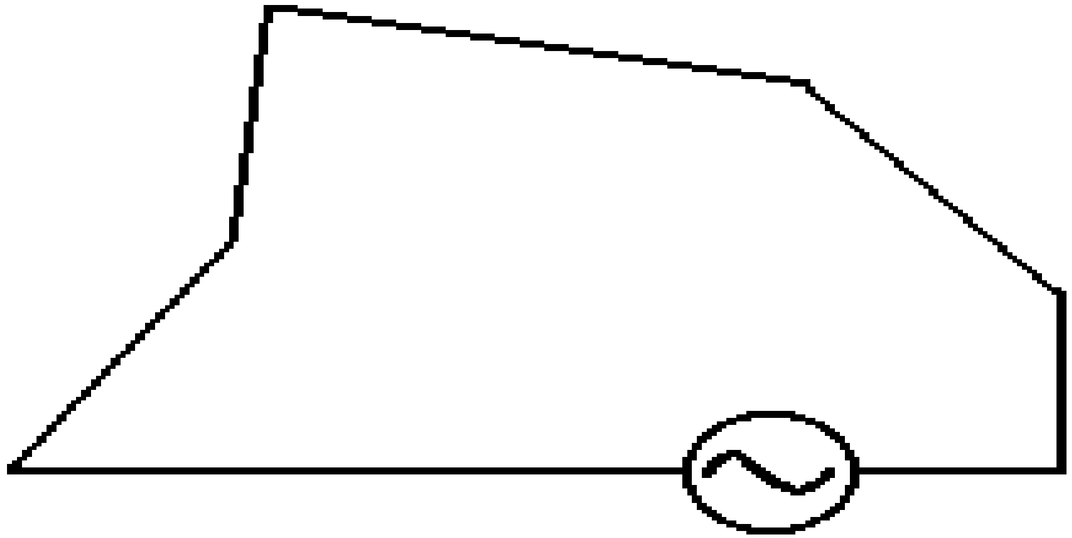
Inverted L

- The inverted L is a vertical monopole that has been folded so that a portion runs horizontally
- Typically the overall length is ~ 0.3125λ and the vertical portion is ~ 0.125λ long
- Self impedance is ~ 50 + j200Ω
- Series capacitor can be used to match antenna to coax



Loop Fundamentals

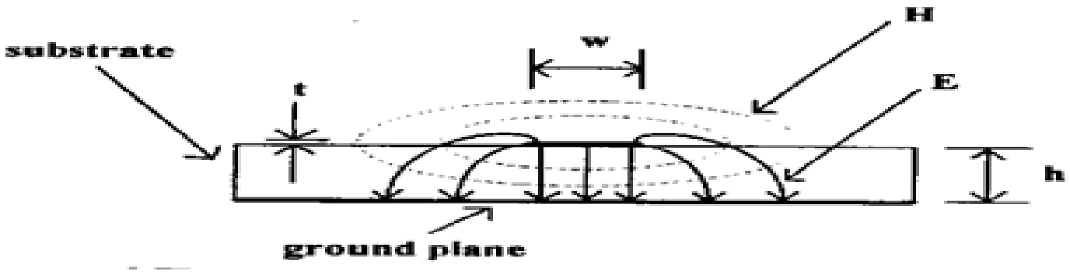
- A large loop antenna is composed of a single loop of wire, greater than a half wavelength long.
- The loop does not have to be any particular shape.
- RF power can be fed anywhere on the loop.

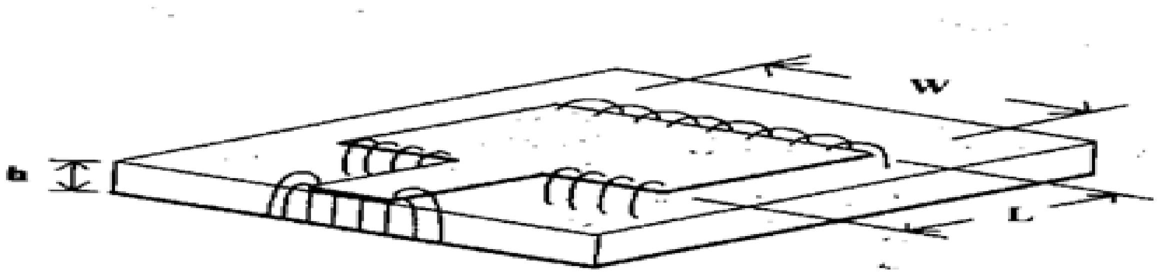


MICROSTRIP ANTENNA

Microstrip Antennas

- MICROSTRIP LINE:
- In a microstrip line most of the electric field lines are concentrated underneath the microstrip.
- Because all fields do not exist between microstrip and ground plane (air above) we have a different dielectric constant than that of the substrate. It could be less, depending on geometry.(effective ε_r)
- The electric field underneath the microstrip line is uniform across the line. It is possible to excite an undesired transverse resonant mode if the frequency or line width increases. This condition behaves like a resonator consuming power.
- A standing wave develops across its width as it acts as a resonator. The electric field is at a maximum at both edges and goes to zero in the center.





Microstrip Antennas

- Microstrip discontinuities can be used to advantage.
- Abrupt truncation of microstrip lines develop fringing fields storing energy and acting like a capacitor because changes in electric field distribution are greater than that for magnetic field distribution.
- The line is electrically longer than its physical length due to capacitance.
- For a microstrip patch the width is much larger than that of the line where the fringing fields also radiate.
- An equivalent circuit for a microstrip patch illustrates a parallel combination of conductance and capacitance at each edge.
- Radiation from the patch is linearly polarized with the E field lying in the same direction as path length.

Microstrip Antennas

$$\lambda = \frac{\lambda_o}{\sqrt{\varepsilon_{re}}}$$

λ

$$where\ \lambda_o\ is\ free\ space\ wavelength$$

$$\varepsilon_{re} = relative\ dielectric\ constant$$

$$L = 0.5\lambda_o / \sqrt{\varepsilon_{re}}$$

Where: L = patch length

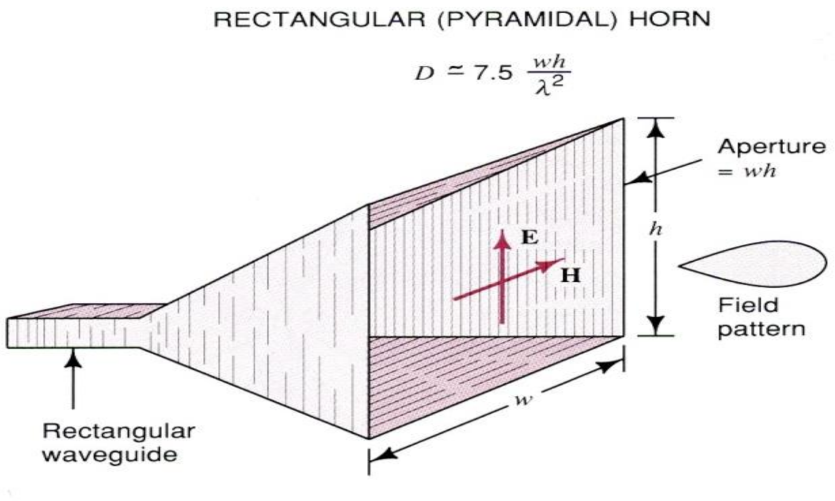
$$\varepsilon_{effr} = 0.5\left[(\varepsilon_r + 1) + (\varepsilon_r - 1)\left(1 + \frac{12H}{W}\right)^{-1/2}\right]$$

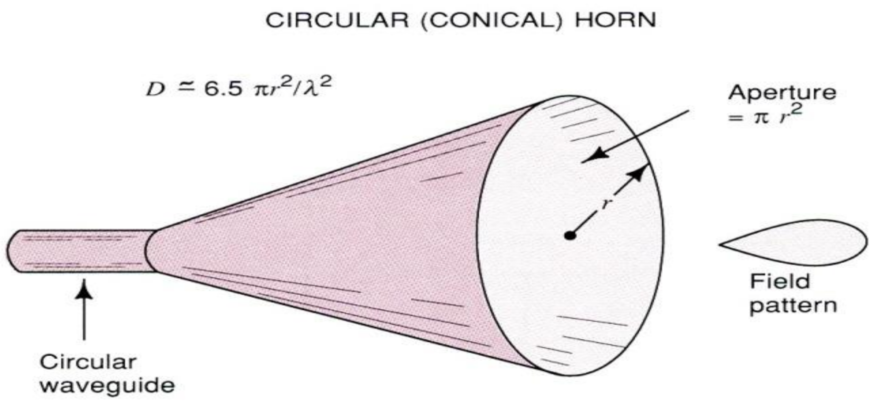
W = 0.5 to 2 times the guide wavelength.

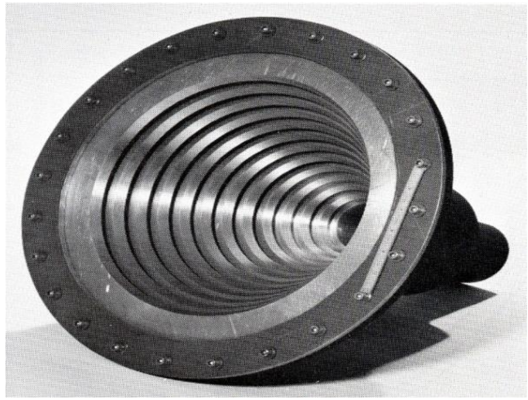
Where: W = patch width

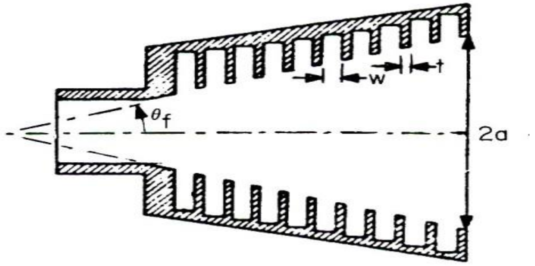
Horn antenna

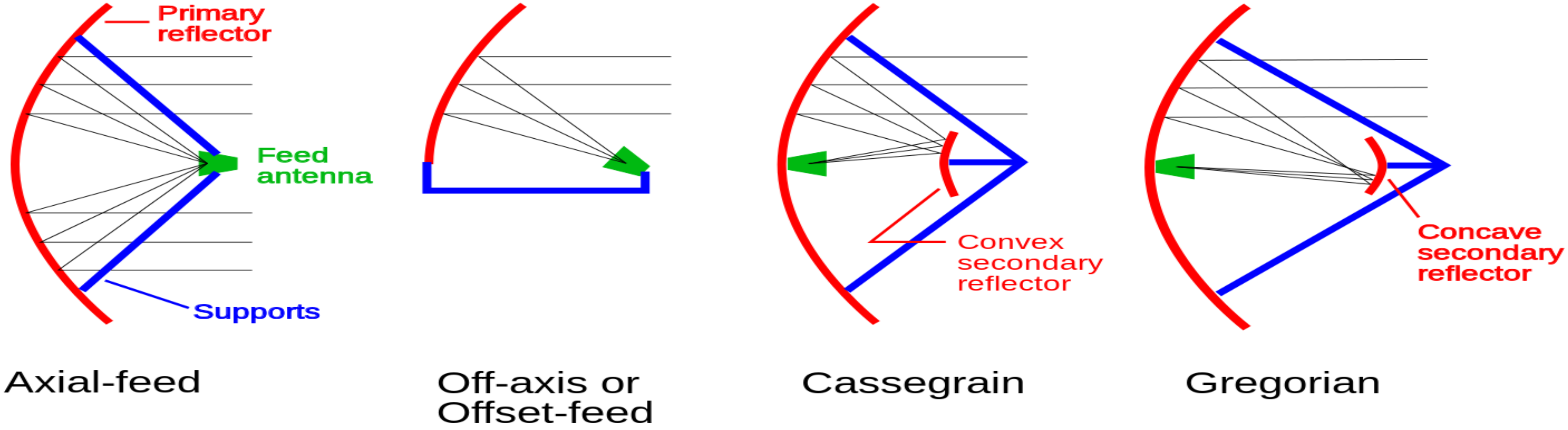
- Rectangular or circular waveguide flared up
- Spherical wave fronts from phase centre
- Flare angle and aperture determine gain
- Aperture antennas derived from waveguide technology (circular, rectangular)
- Can transfer high power (magnetrons, klystrons)
- Above few GHz
- Will be explored inprace during the school



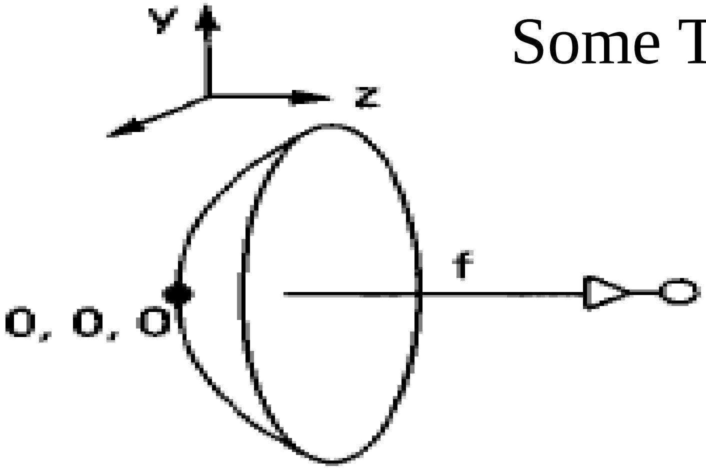




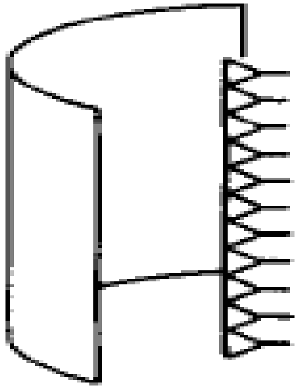



Primary
reflector
Feed
antenna
Supports
Convex
secondary
reflector
Concave
secondary
reflector
Axial-feed
Off-axis or
Offset-feed
Cassegrain
Gregorian

Some Types of Reflector Antennas

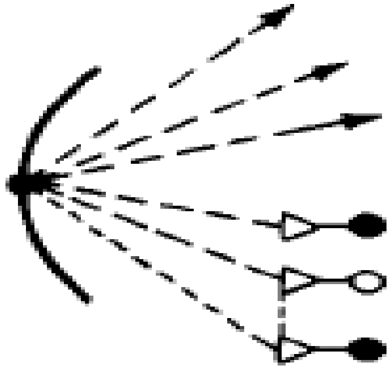


Paraboloid

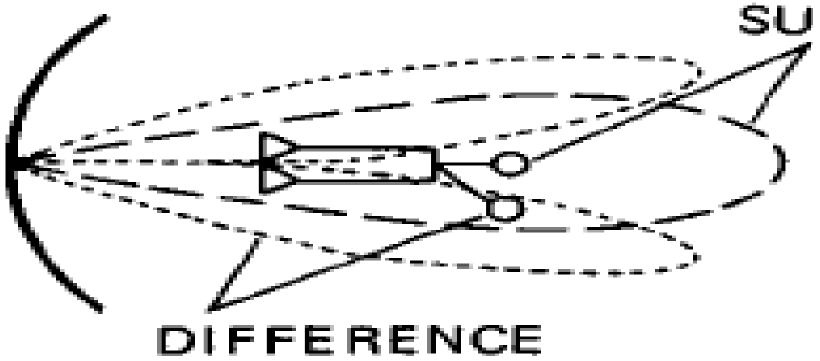


Parabolic cylinder

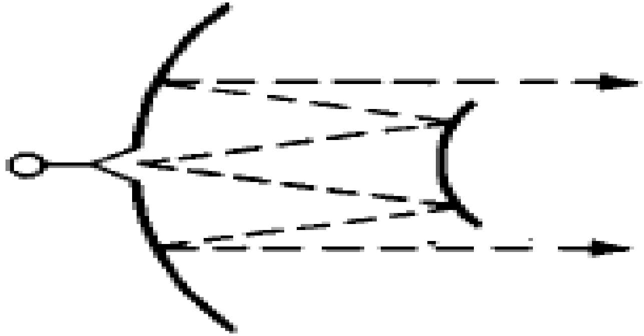
Shaped



Stacked beam



Monopulse



Cassegrain

Basic Geometry and operation

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

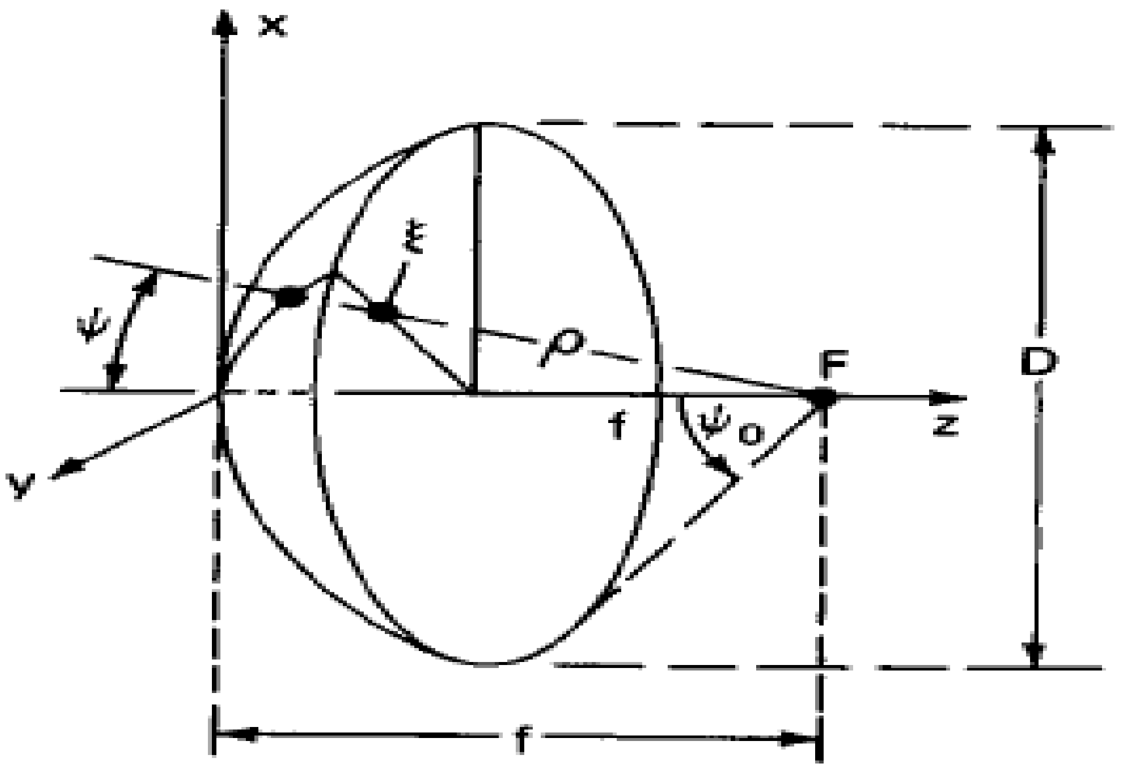
In rect. coordinates

$z = (x^2 + y^2)/4f$

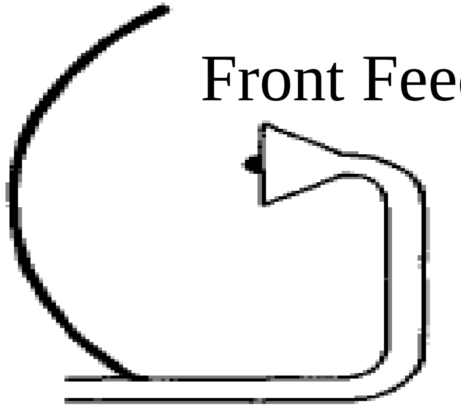
In spherical coordinates

$\rho = f \sec^2 \psi/2$

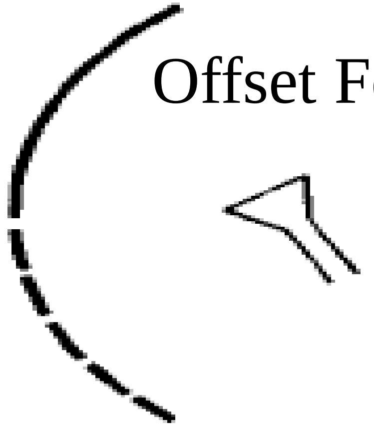
$\tan \psi_o/2 = D/4f$



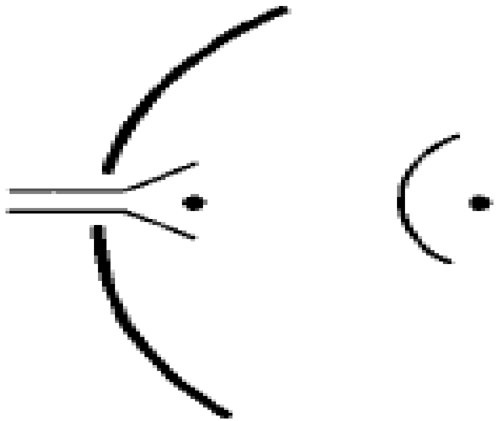
“Feeds”



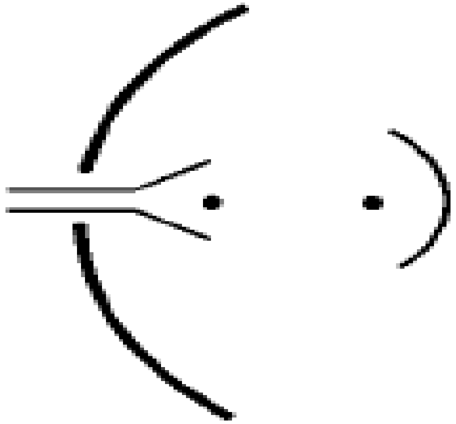
Front Feed



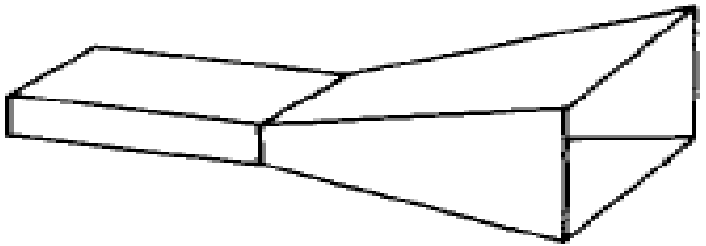
Offset Feed



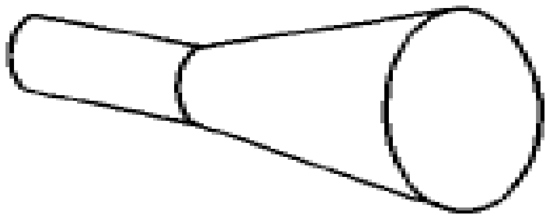
Cassegrain Feed



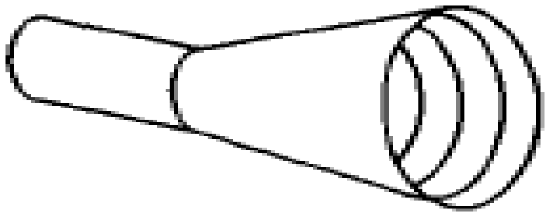
Gregorain Feed



Simple Pyramidal horn



Simple Conical



Corrugated Conical Horn

Antenna Arrays

Antenna Arrays: Benefits

- Possibilities to control electronically
  - Direction of maximum radiation
  - Directions (positions) of nulls
  - Beam-width
  - Directivity
  - Levels of sidelobes

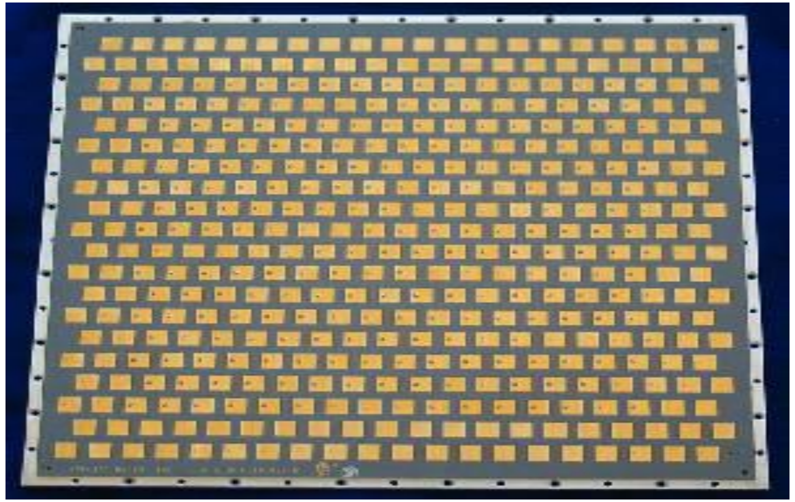
  using standard antennas (or antenna collections) independently of their radiation patterns
- Antenna elements can be distributed along straight lines, arcs, squares, circles, etc.

Antenna arrays

Antenna array composed of several similar radiating elements (e.g., dipoles or horns).

Element spacing and the relative amplitudes and phases of the element excitation determine the array’s radiative properties.

Linear array examples



Two-dimensional array of microstrip patch antennas

Antenna arrays

The far-field radiation characteristics $S_r(\theta, \phi)$ of an N-element array composed of identical radiating elements can be expressed as a product of two functions:

$$S_r(\Theta,\phi) = F_a(\Theta,\phi)\, S_e(\Theta,\phi)$$

Where $F_a(\theta, \phi)$ is the array factor, and $S_e(\theta, \phi)$ is the power directional pattern of an individual element.

This relationship is known as the *pattern multiplication principle*.

The array factor, $F_a(\theta, \phi)$, is a range-dependent function and is therefore determined by the array's geometry.

$$F_a(\Theta,\phi) = \left| \sum_{i=0}^{N-1} A_i\, e^{-jkr_i} \right|^2$$

The elemental pattern, $S_e(\theta, \phi)$, depends on the range-independent far-field radiation pattern of the individual element. (Element-to-element coupling is ignored here.)

Beam steering effects

Inter-element separation affects linear array gain and grating lobes

- The broadside array gain is approximately

$$G_{array} \approx \frac{2\pi N d}{\lambda} G_{element} \;, \quad \text{for } N > \sim 5$$

  where d is the inter-element spacing and N is the number of elements in the linear array

- To avoid grating lobes, the maximum inter-element spacing varies with beam steering angle or look angle, θ, as

$$d_{max} < \frac{\lambda}{1 + \sin\theta}$$

Antenna arrays

Beamwidth and gain

An 2-D planar array with uniform spacing, $N \times M$ elements in the two dimensions with inter-element spacing of $\lambda/2$ provides a broadside array gain of approximately

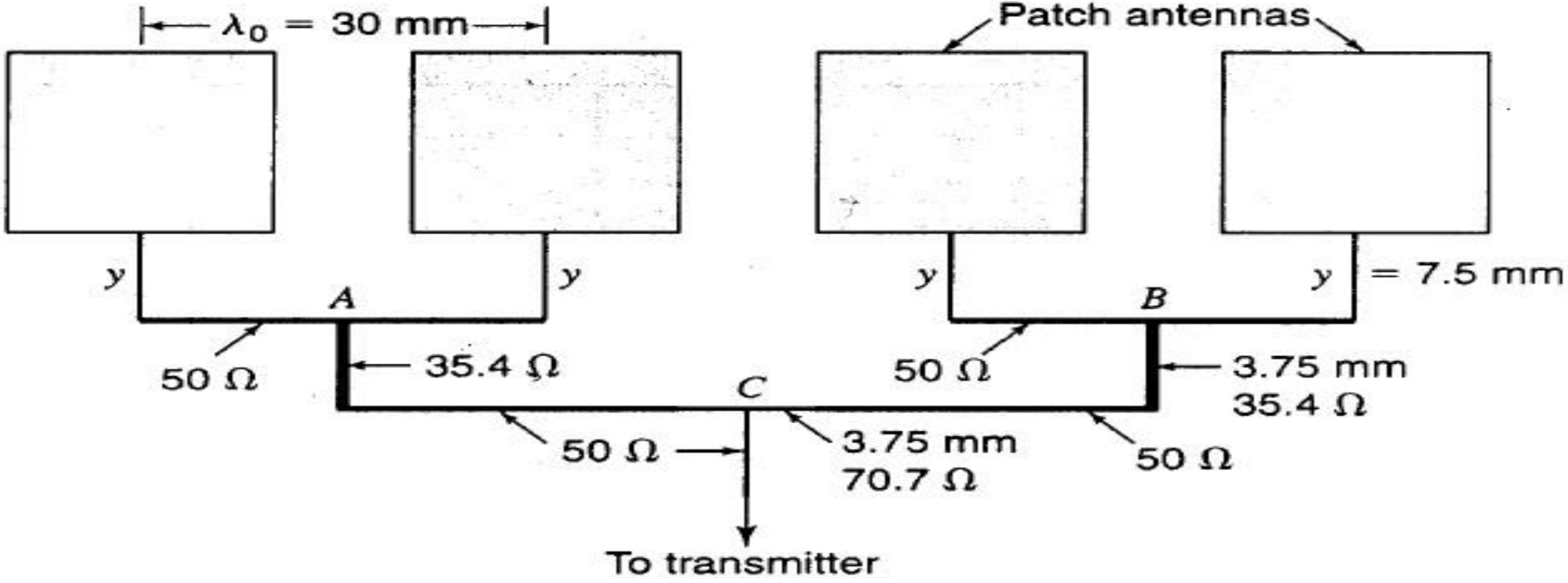
$$G_{array} \approx N \cdot M \cdot G_{element} \ , \ \text{for } N, M > 5$$

The beamwidth of a steered beam from a uniform N-element array is approximately (for $N > \sim 5$)

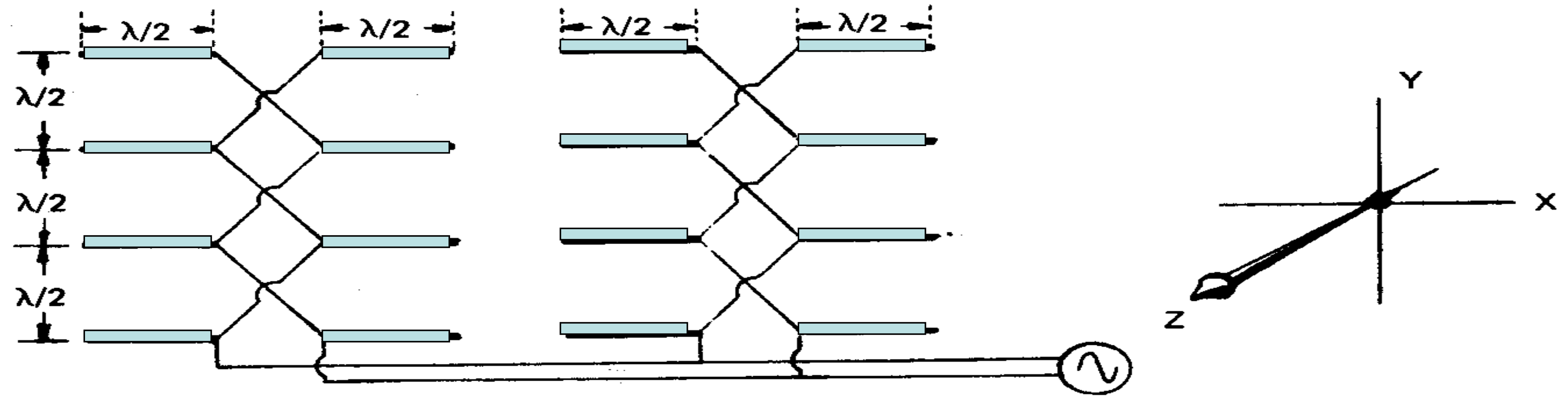
$$\beta \approx \frac{0.866}{\sin\theta} \cdot \frac{\lambda\, b}{N\, d} \ , \ (\text{radians}) \ \text{for } 0° < \theta < 180°$$

where b is the window function broadening factor ($b = 1$ for uniform window function) and d is the inter-element spacing

Array Antennas

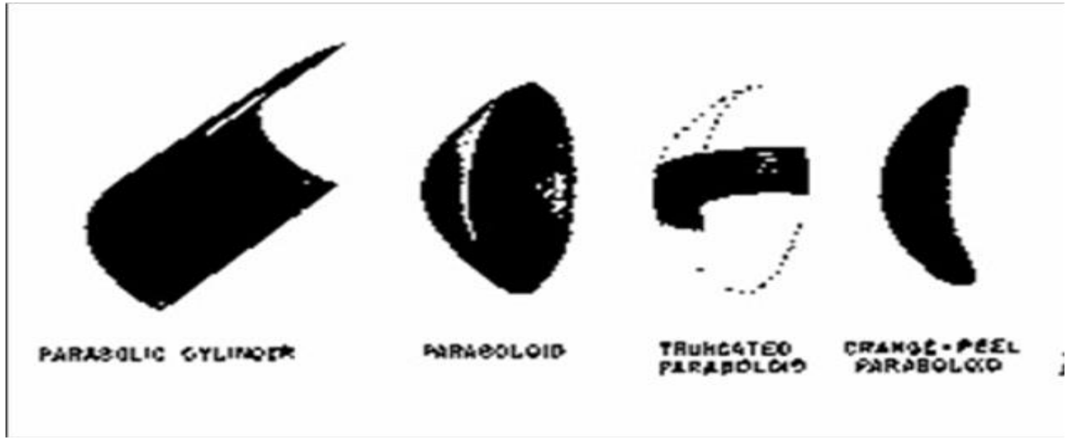


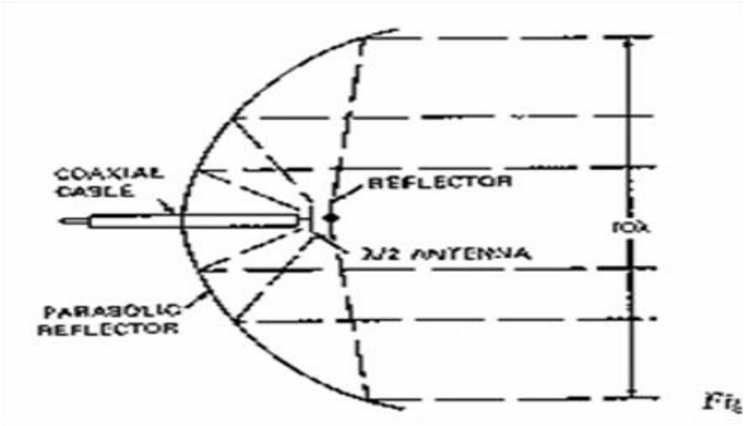
Phased Array



Quasi-Optical Systems

- Parasitic Elements - used to concentrate the beam in one direction only .
  - A current is induced in the element to cause destructive interference in specific direction.
- Reflectors
  - Reflective material placed near radiating antennas.
    - Parabolic shapes (dishes) used to concentrate energy into a narrow beam (i.e. radar reflectors).



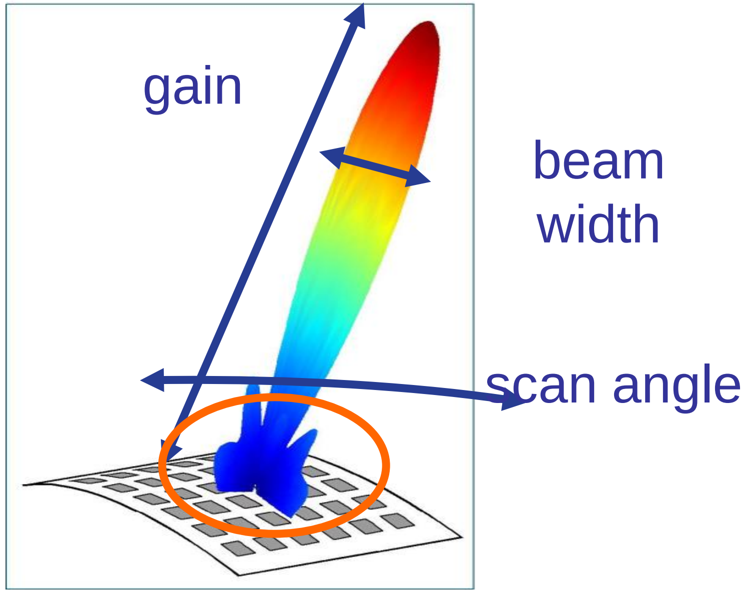


BEAMFORMING

Beamforming

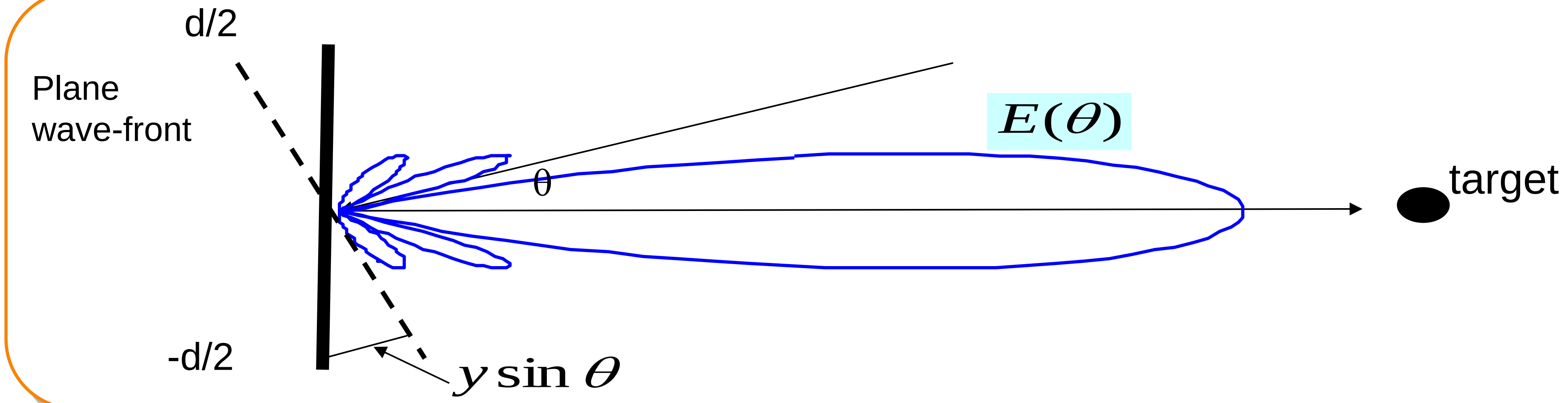
Smart Antenna systems: Switched beam: finite number of fixed predefined patterns
Adaptive array: Infinite number of (real time) adjustable patterns
Passive Beamforming - Adaptive Beamforming

- Adjusting signal amplitudes and phases to form a desired beam
- Estimation of signal arriving from a desired direction in the presence of noise by exploiting the spatial separation of the source of the signals.
- Applicable to radiation and reception of energy.
- May be classified as:
  - Data Independent
  - Statistically optimum
  - Adaptive
  - Partially Adaptive



Beampattern of Antennas

Beampattern is the **antenna gain** as a function of **angle of arrival**.



Fourier transform

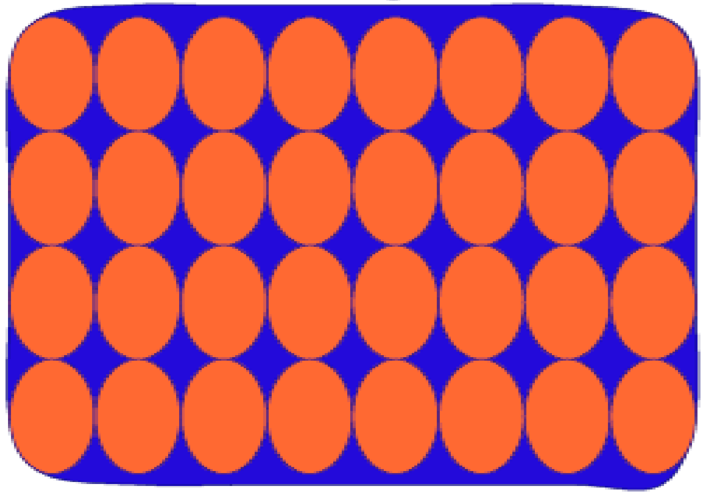
$$E(\theta) \propto \int_{-d/2}^{d/2} A_0 e^{j\frac{2\pi y}{\lambda}\sin\theta} dy = \int_{-d/2}^{d/2} A_0 e^{j\omega} dy \Big|_{\omega=\frac{2\pi y}{\lambda}\sin\theta} = \mathrm{sinc}\left(\frac{d\sin\theta}{\lambda}\right)$$

Volume Surveillance with Radar

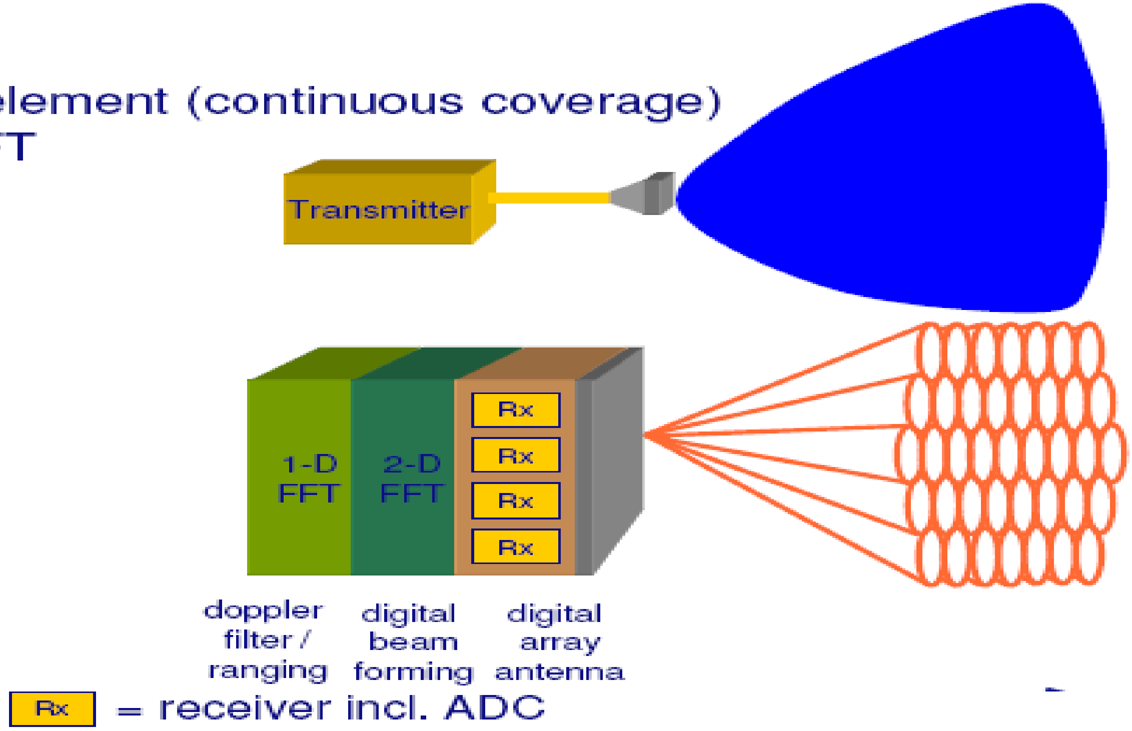
Volume Surveillance with Radar

Digital multiple beam radar

- Floodlight transmit beam
- Multiple beams on receive
- Receiver behind each antenna element (continuous coverage)
- Digital beamforming with 2-D FFT
- Doppler filtering with FFT



Digital MultiBeam Radar



Direction of Arrival Estimation(DOA)

- DOA involves computing the spatial spectrum and determining the maximas.
  - Maximas correspond to DOAs
- Typical DOA algorithms include:
  - Multiple SIgnal Classification(MUSIC)
  - Estimation of Signal Parameters via Rotational Invariance Techniques(ESPRIT)
  - Spectral Estimation
  - Minimum Variance Distortionless Response(MVDR)
  - Linear Prediction
  - Maximum Likelihood Method(MLM)
- MUSIC is explored in this presentation

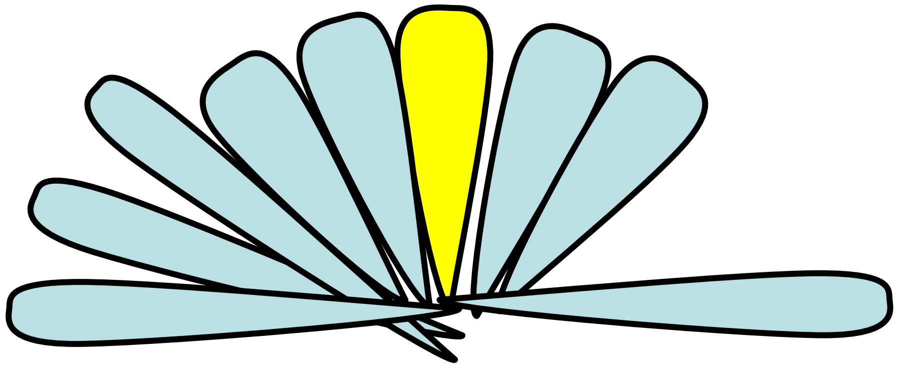
MUSIC Algorithm

- MUSIC algorithm is a high resolution **MU**ltiple **SI**gnal **C**lassification technique based on exploiting the eigenstructure of the input covariance matrix.

- Provides information about the number of incident signals, DOA – direction of arrival of each signal, strengths and cross correlations between incident signals, noise power, etc.

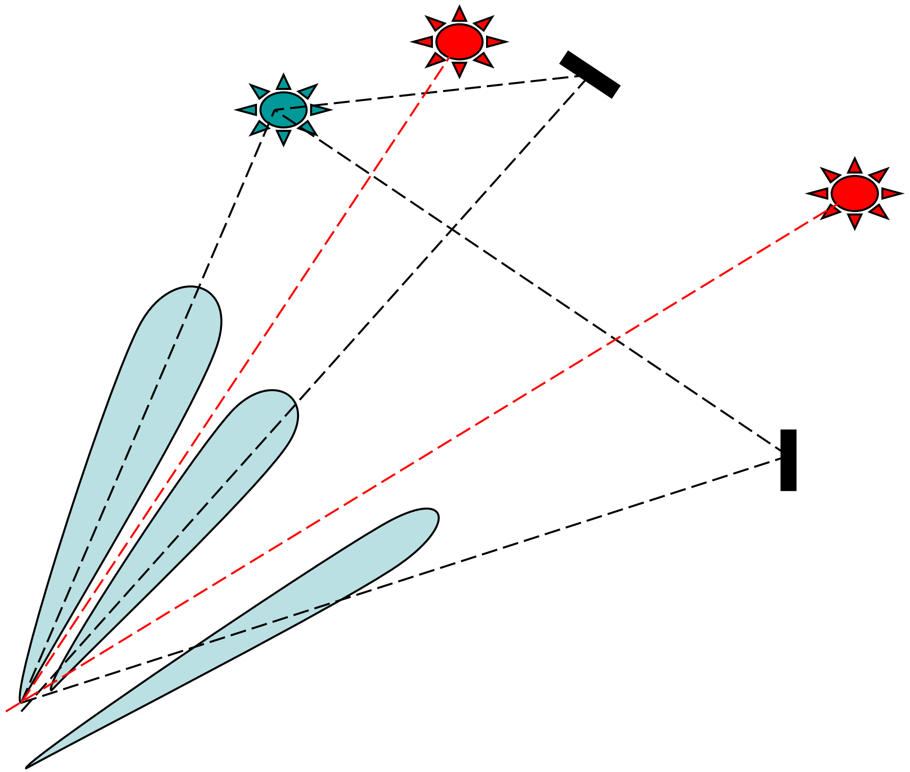
- Useful for estimating
  - Number of sources
  - Strength of cross-correlation between source signals
  - Directions of Arrival
  - Strength of noise
- Assumes number of sources < Number of antenna elements.
  - else signals may be poorly resolved
- Estimates noise subspace from available samples

Switched Beam Antennas



- *Switched beam antennas*
  - Based on switching function between separate directive antennas or predefined beams of an array
- *Space Division Multiple Access* (SDMA) = allocating an angle direction sector to each user
  - In a TDMA system, two users will be allocated to the same time slot and the same carrier frequency
  - They will be differentiated by different direction angles

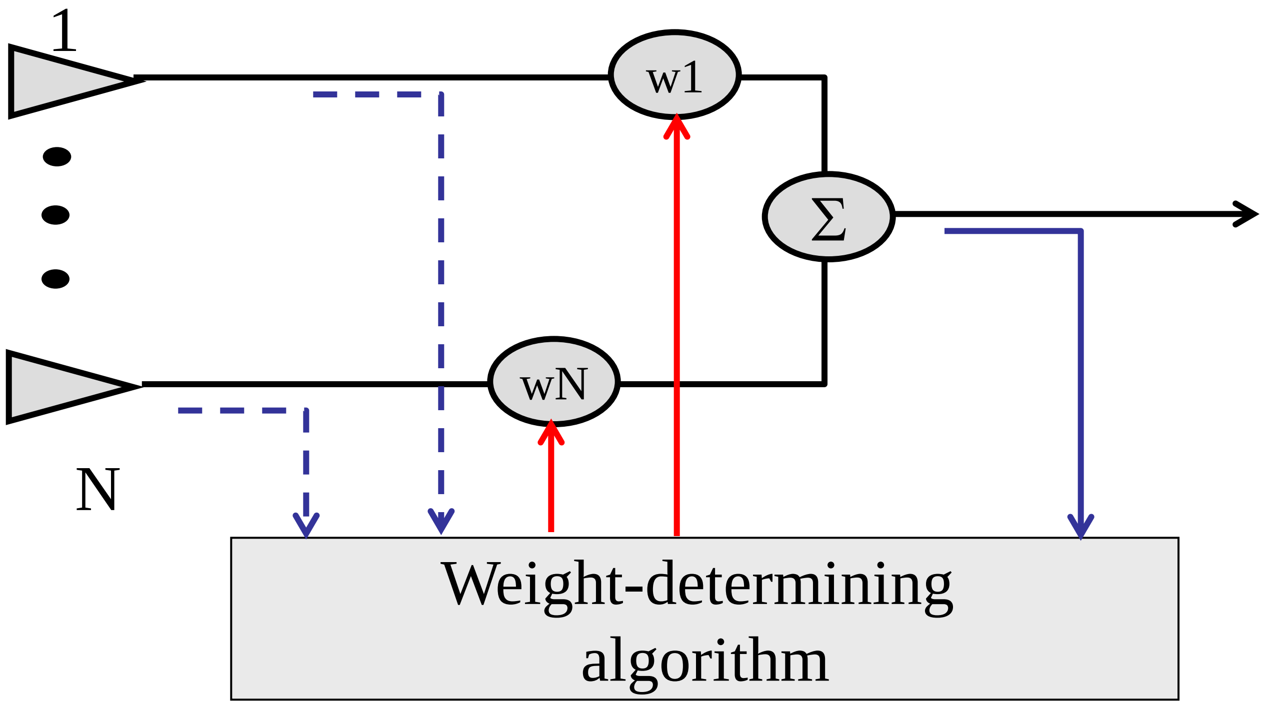
Adaptive (“Intelligent”)Antennas



- Array of N antennas in a linear, circular, or planar configuration
- Used for selection signals from desired sources and suppress incident signals from undesired sources
- The antenna pattern track the sources
- It is then adjusted to null out the interferers and to maximize the signal to interference ratio (SIR)
- Able to receive and combine constructively multipath signals

Adaptive (“Intelligent”)Antennas

- The amplitude/ phase excitation of each antenna controlled electronically (“software-defined”)
- The weight-determining algorithm uses a-priori and/ or measured information to adapt antenna to changing environment
- The weight and summing circuits can operate at the RF and/ or at an intermediate frequency



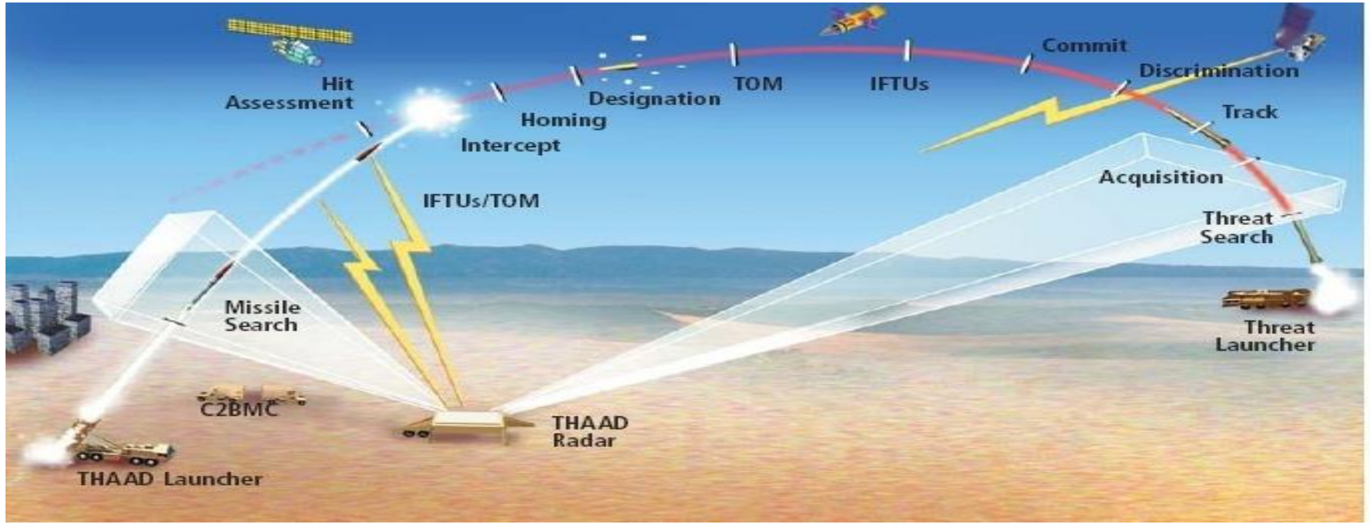
Erken Uyarı Radarı

Erken uyarı radarı yer yüzeyinin üstündeki tüm uzayı belirli bir ışıma açıklığında gözlem yapar. Füze erken uyarısında bulunduğunda füze savunma sistemi devreye girer.

Füze algılama, doğrulama ve tehdit olup olmadığı sınıflandırır.

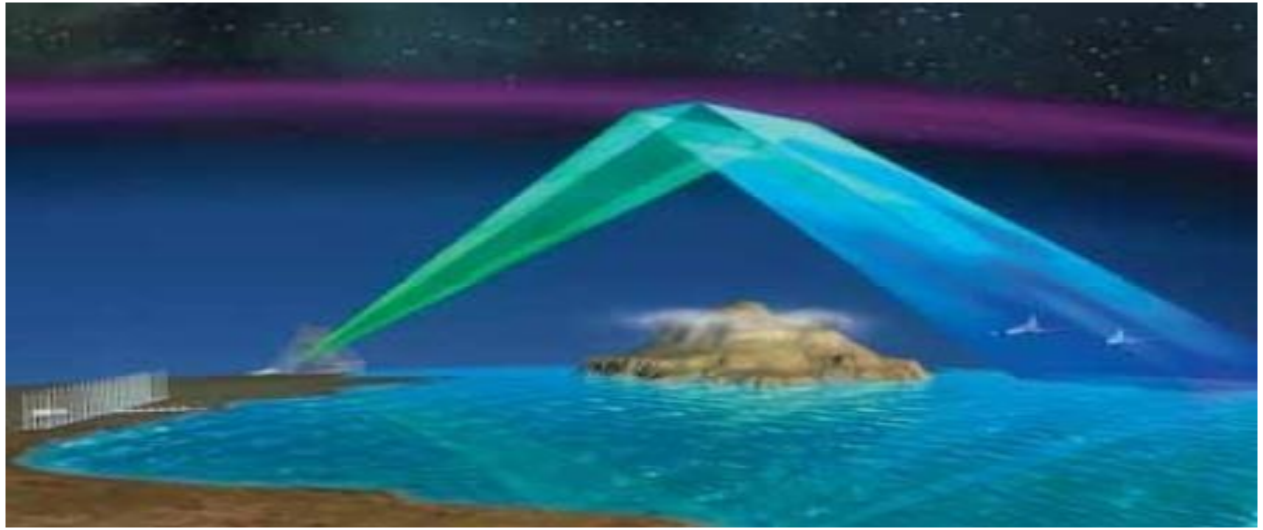
Erken uyarı radarı balistik füze savunma sisteminin bir parçası olarak görev yapar.

Patriot ve denizden fırlatmalı füze savunma sistemleri ile yüksek mertebelerde tehdit olarak algılanan ve doğrulanan füzelere müdahale eder.



İyonosferden Takip

- İyonosferden yansıyan dalgalar kullanılarak 2.000 km gibi geniş kıyı şeridinde gemileri ve uçakların konumlarını, rotalarını ve hızlarını belirleyecek.
- Tüm hava koşullarında ve tüm yüksekliklerdeki uçaklar izlenecektir.
- Uzunlukları 30m den büyük olan gemiler muntazaman izlenecektir.




Kaynaklar

- Antennas from Theory to Practice, Yi Huang, University of Liverpool UK, Kevin Boyle NXP Semiconductors UK, Wiley, 2008.
- Antenna Theory Analysis And Desıgn, Third Edition, Constantine A. Balanis, Wiley, 2005
- Antennas and Wave Propagation, By: Harish, A.R.; Sachidananda, M. Oxford University Press, 2007.
- Navy Electricity and Electronics Training Series Module 10—Introduction to Wave Propagation, Transmission Lines, and Antennas NAVEDTRA 14182, 1998 Edition Prepared by FCC(SW) R. Stephen Howard and CWO3 Harvey D. Vaughan.
- Lecture notes from internet.

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Sincerely,

Dr. Cahit Karakuş

cahitkarakus@gmail.com

Terminology

Antenna – structure or device used to collect or radiate electromagnetic waves

Array – assembly of antenna elements with dimensions, spacing, and illumination sequency such that the fields of the individual elements combine to produce a maximum intensity in a particular direction and minimum intensities in other directions

Beamwidth – the angle between the half-power (3-dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe

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

Effective area – the functional equivalent area from which an antenna directed toward the source of the received signal gathers or absorbs the energy of an incident electromagnetic wave

Efficiency – ratio of the total radiated power to the total input power

Far field – region where wavefront is considered planar

Gain – ratio of the power at the input of a loss-free isotropic antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength at the same distance

Isotropic – radiates equally in all directions

Main lobe – the lobe containing the maximum power

Null – a zone in which the effective radiated power is at a minimum relative to the maximum effective radiation power of the main lobe

Radiation pattern – variation of the field intensity of an antenna as an angular function with respect to the axis

Radiation resistance – resistance that, if inserted in place of the antenna, would consume that same amount of power that is radiated by the antenna

Side lobe – a lobe in any direction other than the main lobe

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