Antenna Basics 2

Circular Polarization of EM wave

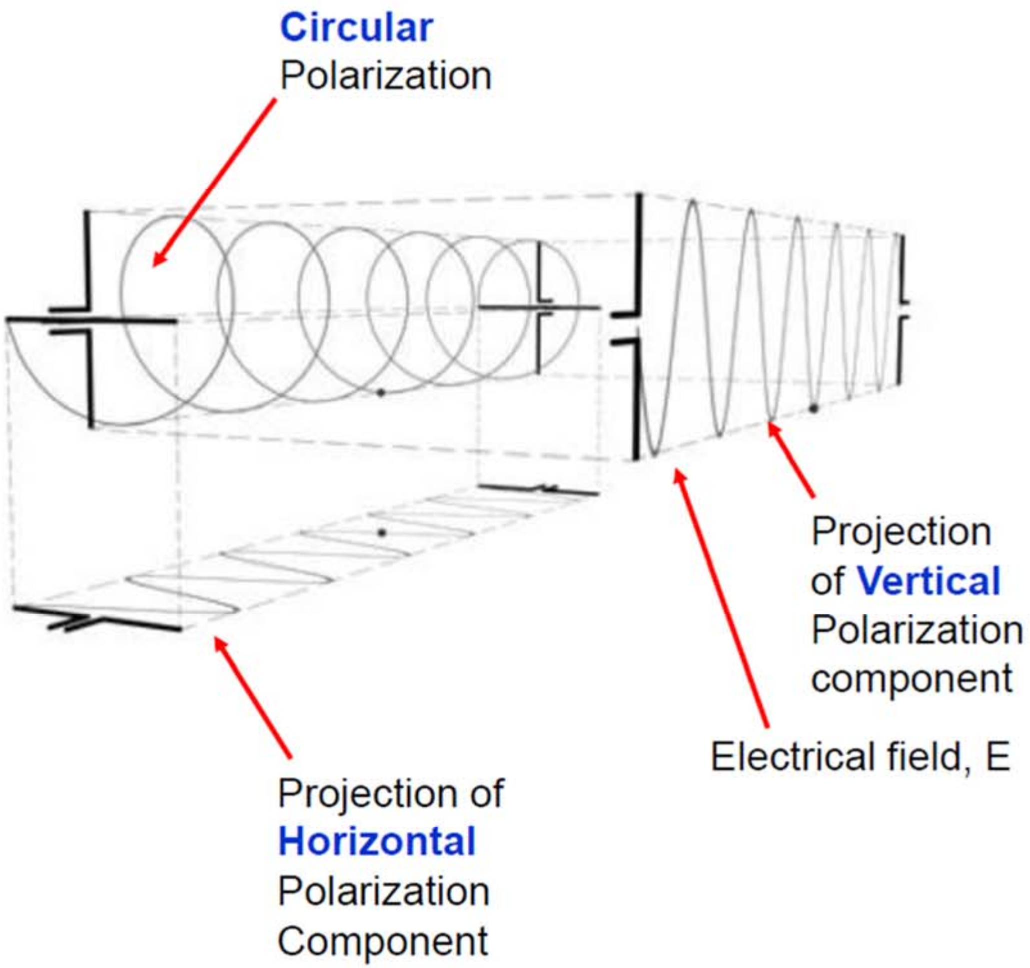
Showing projection of Horizontal & Vertical components

The power received by an antenna is maximal if the polarization of the incident wave and the polarization of the antenna have:

- ✓ The same axial ratio.
- ✓ The same sense of polarization.
- ✓ The same spatial orientation.

Antenna Polarization \ Field Polarization	Vertical	Horizontal	Right hand Circular	Left hand Circular
Vertical	0 dB	∞	3 dB	3 dB
Horizontal	∞	0 dB	3 dB	3 dB
Right hand Circular	3 dB	3 dB	0 dB	∞
Left hand Circular	3 dB	3 dB	∞	0 dB

Attenuation due to Polarization Mismatch



Power Transfer into Free Space

Friis' Transmission Equation

1. In any communication link, there is a transmitting antenna with directional gain G_t radiating to a receive antenna with directional gain G_r that are separated by a distance R.
2. The power flux density, PFD, at any given range: R meters, from an ideal lossless isotropic antenna radiating a transmit power P_t is:

$$PFD_{isotropic} = \frac{P_t}{4\pi R^2}, Watts/m^2 \text{ ,where the area of a sphere is: } A_{sphere} = 4\pi R^2, m^2$$

3. The power flux density focused in the direction of maximum radiation by a transmit antenna having a directional gain G_t is:

$$PFD_t = PFD_{istropic} \bullet G_t = \frac{P_t G_t}{4\pi R^2}, watts/m^2 \quad \text{where: } EIRP = P_t G_t$$

4. The signal power received (P_{rec}) by an antenna having an effective aperture area: $A_{e,r}$ is:

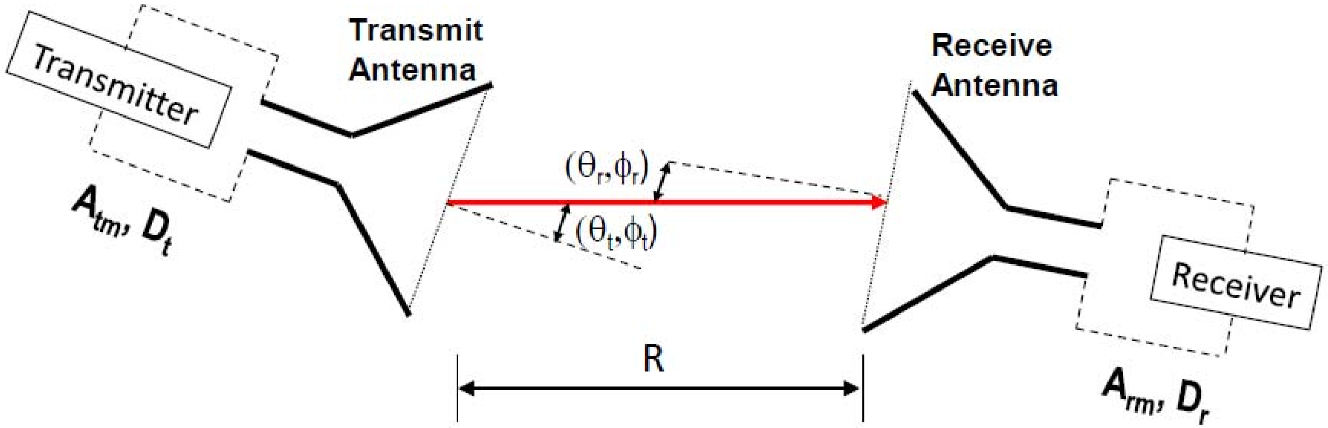
$$P_{rec} = PFD_t \bullet A_{e,r} = \left(\frac{P_t G_t}{4\pi R^2}\right) \bullet A_{e,r} = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2, watts \quad \text{where: } A_{e,r} = \frac{\lambda^2}{4\pi} \cdot G_r$$

5. Rearranging, one obtains Friis' Transmission Equation:

$$\frac{P_{rec}}{P_t} = \frac{G_t G_r}{(4\pi R/\lambda)^2} \quad \text{, where Free Space Path Loss: } FSPL = (4\pi R/\lambda)^2$$

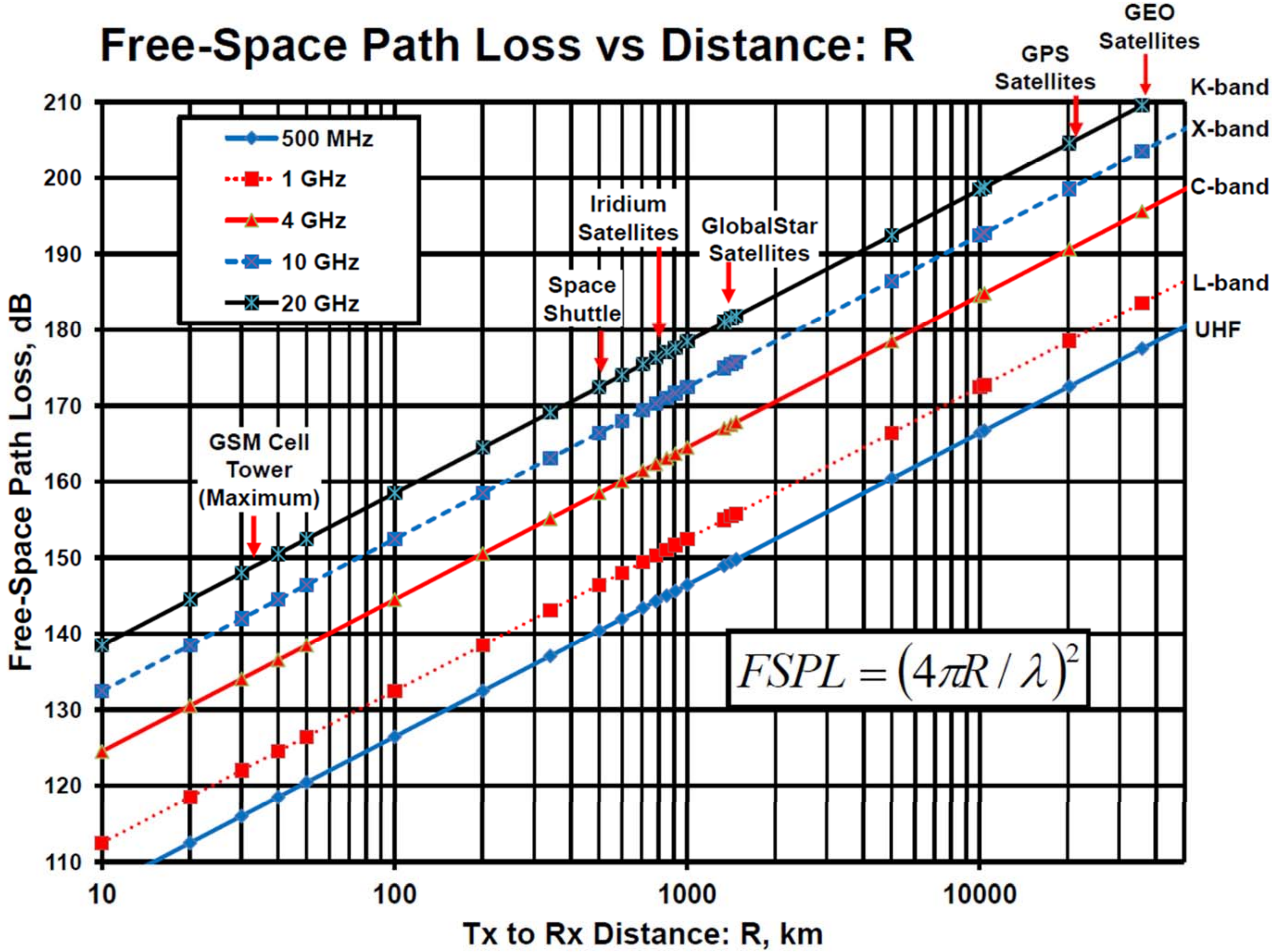
"Note on a Simple Transmission Formula", Harald Friss,
Proceeding of IRE, Vol 34, p 254-256, May 1946.

Friis' Transmission Equation with Loss



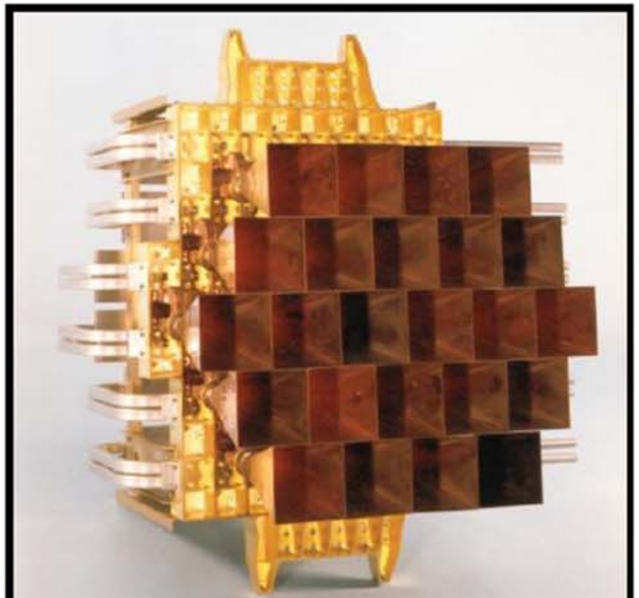
$$\frac{P_r}{P_t} = \eta_{cdt}\eta_{cdr}(1-|\Gamma_r|^2)(1-|\Gamma_t|^2)\left(\frac{\lambda}{4\pi R}\right)^2 D_{gt}(\theta_t,\phi_t)D_{gr}(\theta_r,\phi_r)\left|\hat{\rho}_w\cdot\hat{\rho}_a^{\,*}\right|^2$$

- η_{cdr}: Conductor and Dielectric losses in Receive antenna.
- η_{cdt}: Conductor and Dielectric losses in Transmit antenna.
- $(1-|\Gamma_r|^2)$: Reflection loss in Receive antenna (impedance mismatch).
- $(1-|\Gamma_t|^2)$: Reflection loss in Transmit antenna (impedance mismatch).
- $\left(\frac{\lambda}{4\pi R}\right)^2$: Free Space Path Loss.
- $D_{gt}(\theta_t,\phi_t)$: Directivity of Transmit antenna.
- $D_{gr}(\theta_r,\phi_r)$: Directivity of Receive antenna.
- $\left|\hat{\rho}_w\cdot\hat{\rho}_a^{\,*}\right|^2$: Polarization Mismatch.



Free-Space Path Loss vs Distance: R
500 MHz
1 GHz
4 GHz
10 GHz
20 GHz
GPS Satellites
GEO Satellites
K-band
X-band
C-band
L-band
UHF
Iridium Satellites
GlobalStar Satellites
Space Shuttle
GSM Cell Tower (Maximum)
FSPL = (4πR / λ)²
Free-Space Path Loss, dB
Tx to Rx Distance: R, km
210
200
190
180
170
160
150
140
130
120
110
10
100
1000
10000

Phased Array Antennas



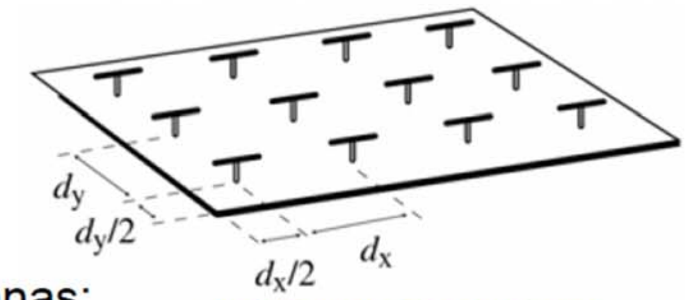
24 horn Phased Array Antenna

1. A single antenna may not provide the radiation pattern nor the agility needed to satisfy the performance requirements of a system or network . However, a proper combination of many antennas might satisfy those requirements.
2. An antenna array is a cluster of N antennas arranged in a linear, planar or conformal spatial configuration (line, circle, grid, etc.). Each individual antenna is called an element of the array, and they are typically identical antenna elements.
3. The excitation applied to each individual antenna element (both amplitude and phase) is electronically-controlled ("software defined") to enable the composite array to radiate beams of energy quickly (~msec) with a desired radiation pattern across a selected coverage area, like: Narrow focused beams, Fan-shaped beams, and Multiple beams (array thinning) from AESAs.
   A. The amplitude (RF power level) applied to each individual antenna element is controlled by a Transmit/Receive (T/R) module in Active Electronically Scanned Arrays (AESAs).
   B. The phase excitation applied to each individual antenna element is controlled by phase shifters: Diode phase shifters, MEMS phase shifters or ferrite phase shifters in Passive Electronically Scanned Arrays (PESA), while T/R Modules also contain phase shifters for AESAs.

Benefits of Phased Array Antennas

1. Phased array antennas can steer the main radiation beam rapidly (~msec) without physically moving the antenna: Inertia-less beamforming & scan.
   A. Rotating a single antenna is slow. . . . .reaction time is long (many seconds).
   B. Can eliminate mechanical errors during beam scan.
   C. Higher reliability then mechanically rotating antennas → Low maintenance.

2. Phased Array Antennas can electronically-control the:
   A. Instantaneous beam position → Beam agility.
      1) Multi-mode operation: Frequency scan, time-delay scan, phase scan.
      2) Multi-target capability: Search, Track & Scan.
   B. Half-power beamwidth (HPBW).
   C. Antenna's Directivity/Gain.
   D. Level of radiated sidelobes.
   E. Direction/position of amplitude nulls.

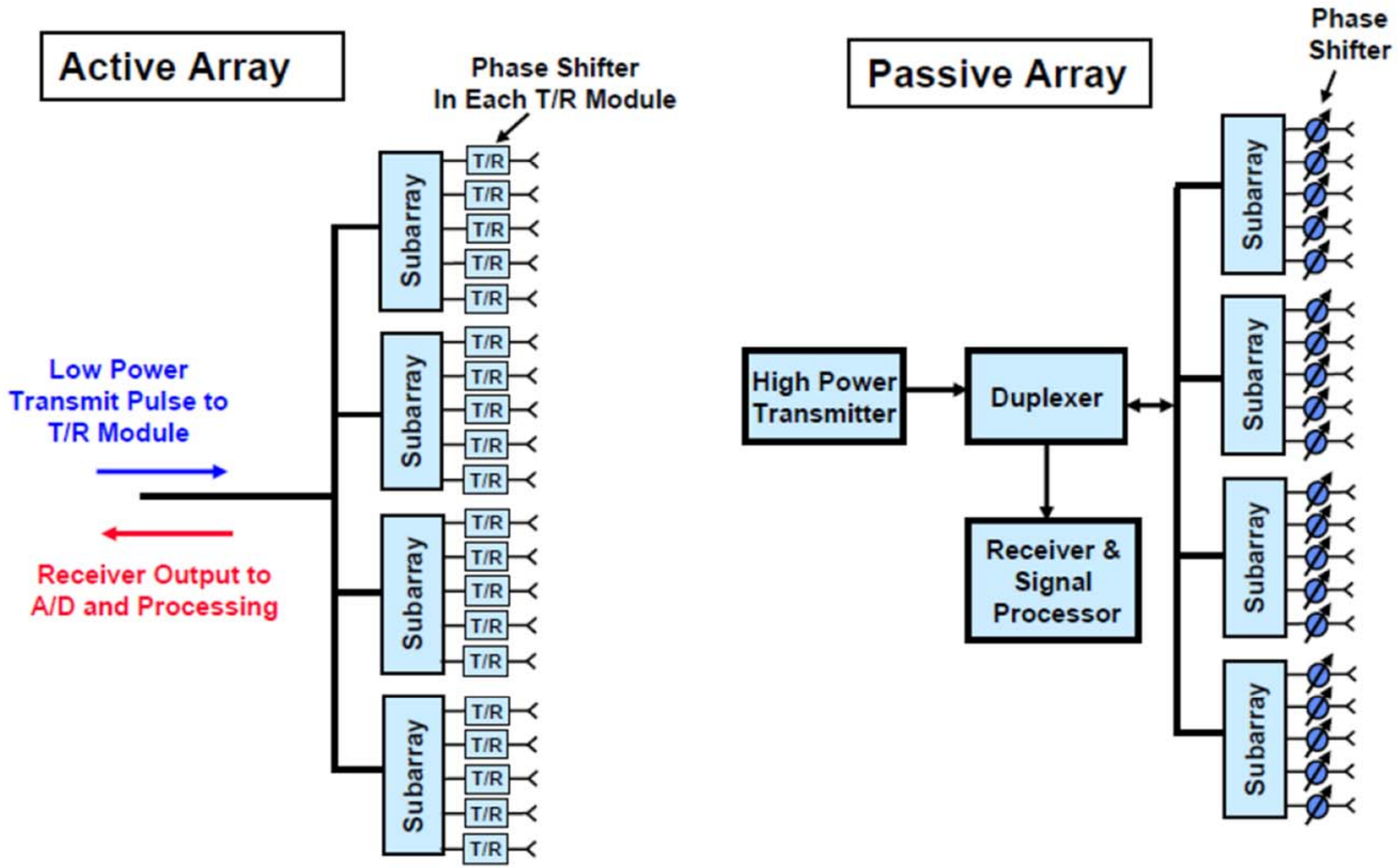


3x4-element Dipole Array

3. General design trade-offs for Phased Array Antennas:
   A. Array configuration: Linear, circular, planar, etc.
   B. Element spacing; typically 0.5λ to 0.6λ to prevent grading lobes in visible space.
   A. Amplitude excitation applied to each element.
   B. Phase excitation applied to each element.
   C. Patterns of array elements.

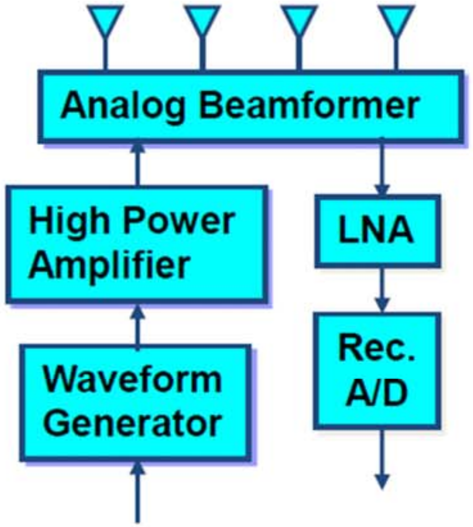
Phased Array Antenna Configurations

Active Phased Array & Passive Phased Array

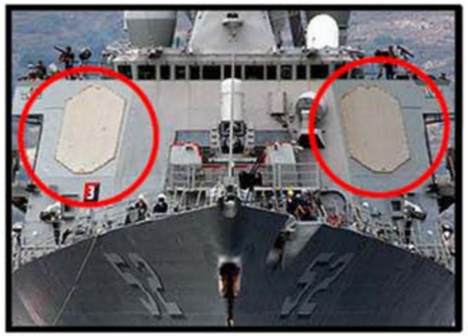


Military/Defense Phased Array Evolution

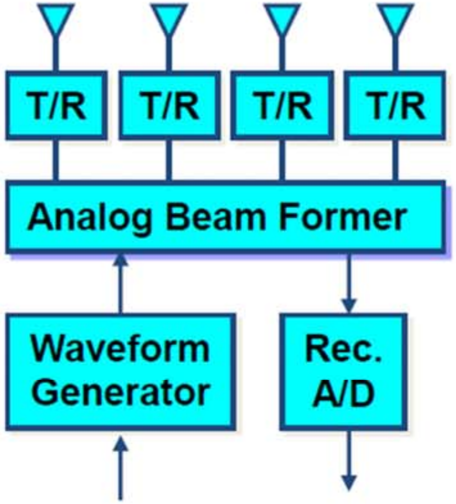
Passive Array



Installed on AEGIS ship; AN/SPY-1 Radar

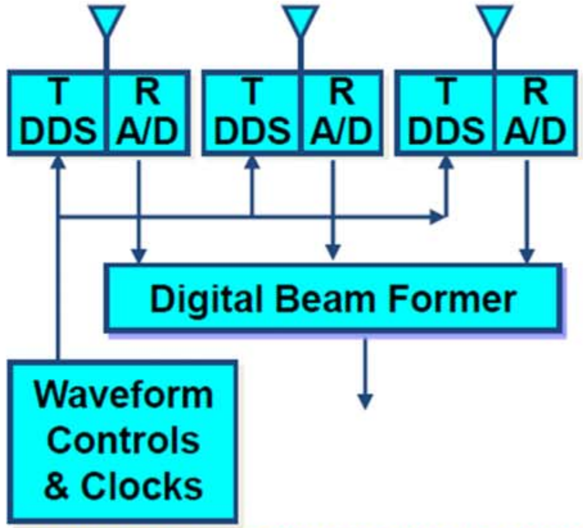


Active Element



Used for Volume Search Radar

Digital Array



Future Radar

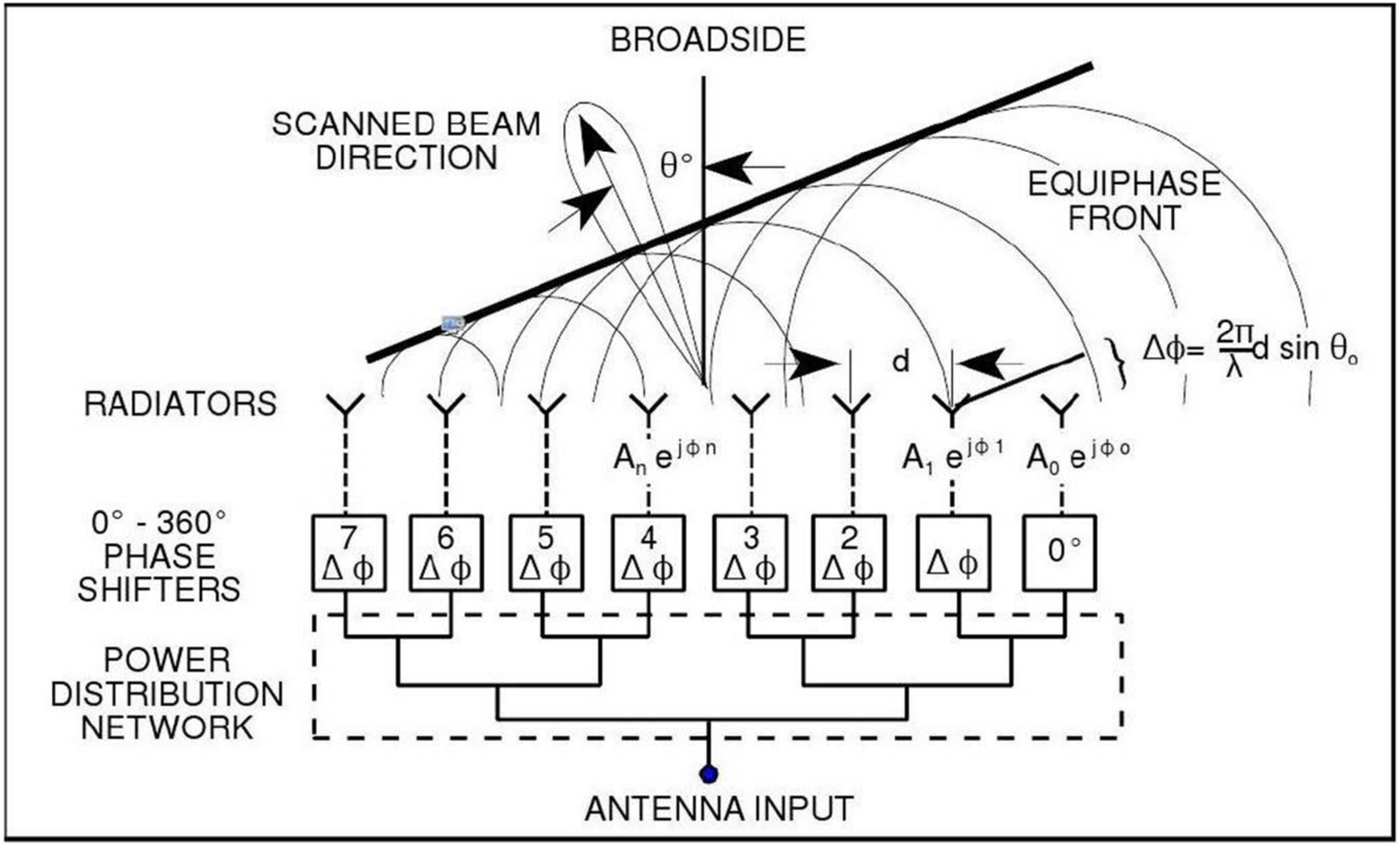
Digital Beam Forming
- Multi-beam operation

Flexible time energy management

Power Aperture Gain Improvement
- Large high power aperture

Beam Steering using Phase Shifters

Passive Electronically Scan Array (PESA)



Phased Array Antenna's Gain & Beamwidth

1. The Gain of a phase array antenna is a function of the number of elements, N, in the array and the gain of the individual elements: G_e.
   A. For half-wavelength element spacing, the gain at boresight is given by:

      $$\text{Gain} = 10 \log_{10} (N) + G_e \text{ , dB}$$

   B. The gain off-boresight is reduced by the cosine of the steering angle, φ_s:

      $$\text{Gain} = 10 \log_{10} (N) + G_e + 10 \log_{10} (\cos \varphi_s)$$

2. The Beamwidth of a phased array antenna is a function of the number of elements, N:
   A. For a half-wavelength phased array of dipole elements, the half-power beamwidth (HPBW) is given by:

      $$\theta_{3dB} = 102/N$$

   B. The beamwidth at steering angles off boresight increases with the cosine of φ_s :

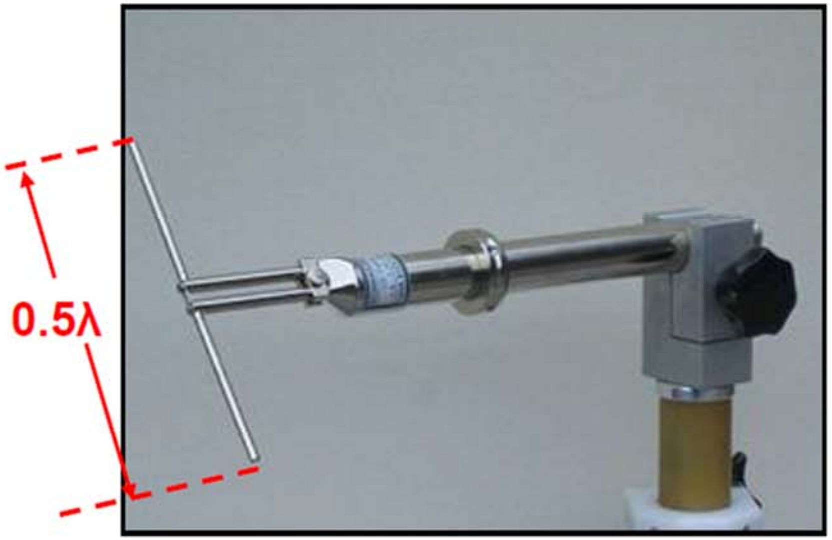
      $$\theta_{3dB} = (102/N) / \cos(\varphi_s)$$

Characteristics of Antennas

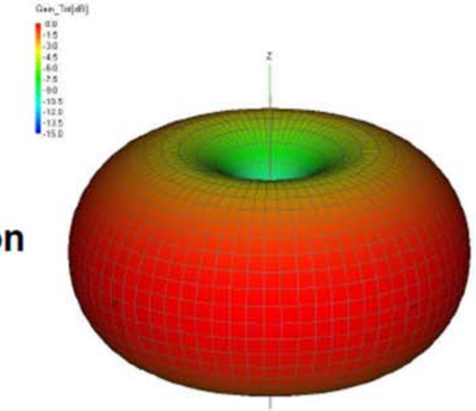
Some **characteristics** and typical **applications** for certain antennas:

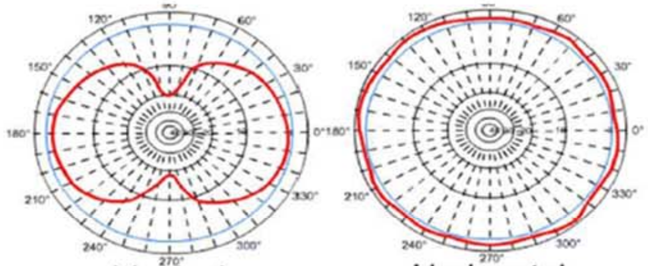
1. Half-Wave Dipole Antenna.
2. Monopole Antenna.
3. Loop Antenna.
4. Axial-Mode Helical Antenna.
5. Yagi Antenna.
6. Log Periodic Antenna.
7. Cavity-backed Spiral Antenna.
8. Conical Spiral Antenna.
9. Horn Antenna.
10. Parabolic Antenna.
11. Phased Array Antenna.

Half-wave Dipole Antenna



Typical Radiation Field Pattern





Vertical Horizontal

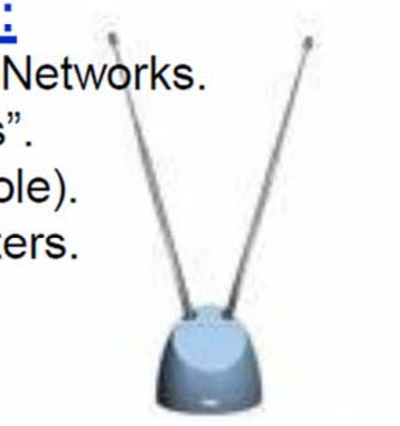
Typical Radiation Pattern Polar Plot

Characteristics:

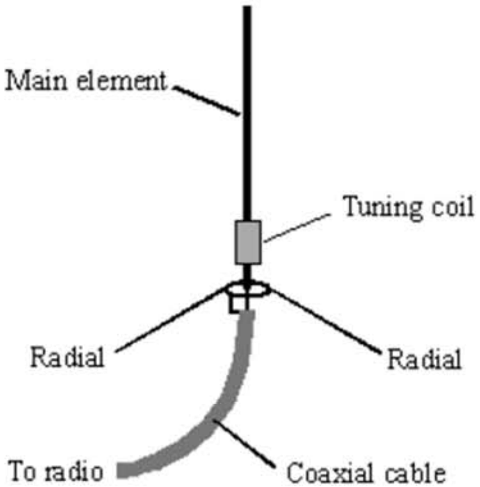
- Polarization: Vertical.
- Beamwidth: ~78° x 360°(Az).
- Frequency Limit:
  - Lower Limit: ~2 MHz.
  - Upper Limit: ~8 GHz.
- Bandwidth: 10% (1.1:1).
- Gain: 2.15 dB.

Typical Applications:

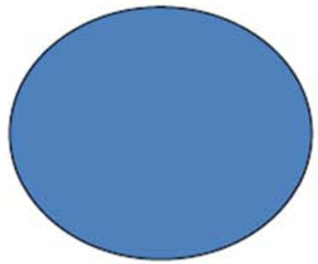
- Wireless Local Area Networks.
- VHF TV "Rabbit ears".
- FM radio (folded dipole).
- Radio mast transmitters.



Monopole (Whip) Antenna



Elevation Radiation Pattern



Azimuth Radiation Pattern

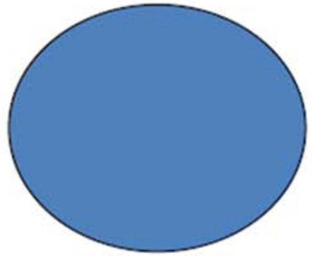
Characteristics:

- Polarization: Linear.
- Beamwidth: ~45° x 360°(Az).
- Frequency Limits:
  - Lower Limit: None.
  - Upper Limit: None.
- Bandwidth: 10% (1.1:1).
- Gain: 0 dB to 2 dB.

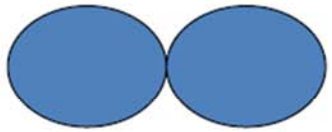
Typical Applications:

- Automobile radio and satellite signal reception.
- Military communications.

Loop Antenna



Elevation Radiation Pattern



Azimuth Radiation Pattern

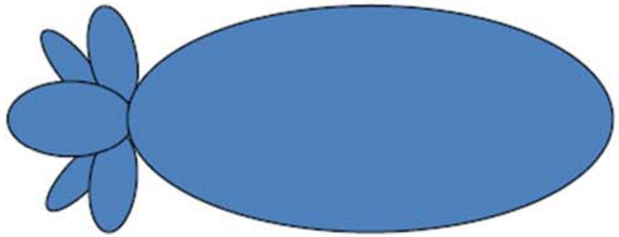
Characteristics:

- Polarization: Horizontal.
- Beamwidth: ~80° x 360°(Az).
- Frequency Limits:
  - Lower Limit: 50 MHz.
  - Upper Limit: 1 GHz.
- Bandwidth: 10% (1.1:1).
- Gain: -2 dB to 2 dB.

Typical Applications:

- TV reception: UHF channels.
- AM Broadcasting.

Axial-Mode Helical Antenna



El & Az Radiation Pattern

$$Gain \approx 15 \frac{N \times S \times C^2}{\lambda^3}$$

where:
C = Circumference of helix(~λ).
S = Turn spacing between coils.
N = Number of turns (>3).

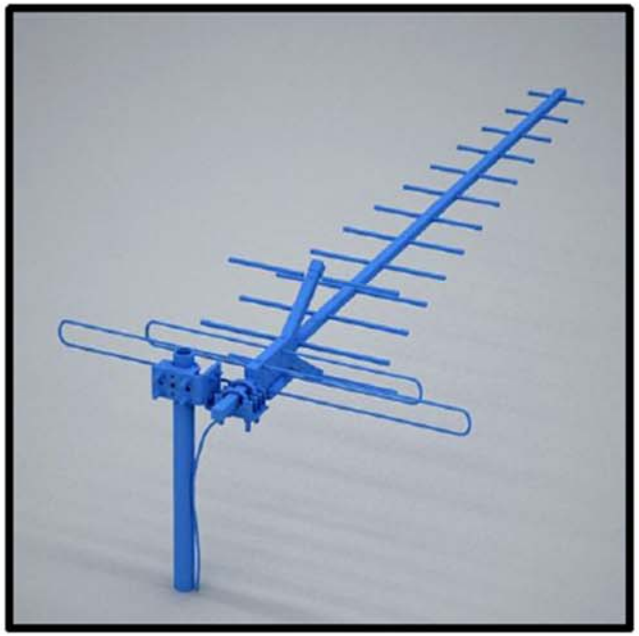
Characteristics:

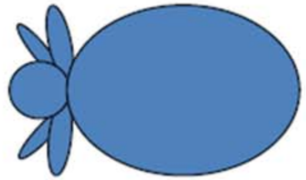
- Polarization: Circular.
- Beamwidth: 50° x 50°.
- Frequency Limits:
  - Lower Limit: 100 MHz.
  - Upper Limit: ~8 GHz.
- Bandwidth: 20% to 70%.
- Gain: 10 dB to 20 dB.

Typical Applications:

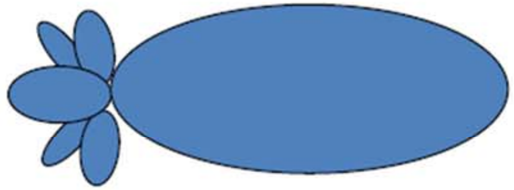
- Mobile communications.
- Global Positioning System.
- Space communication.
- Animal tracking.

Yagi Antenna





Elevation Radiation Pattern



Azimuth Radiation Pattern

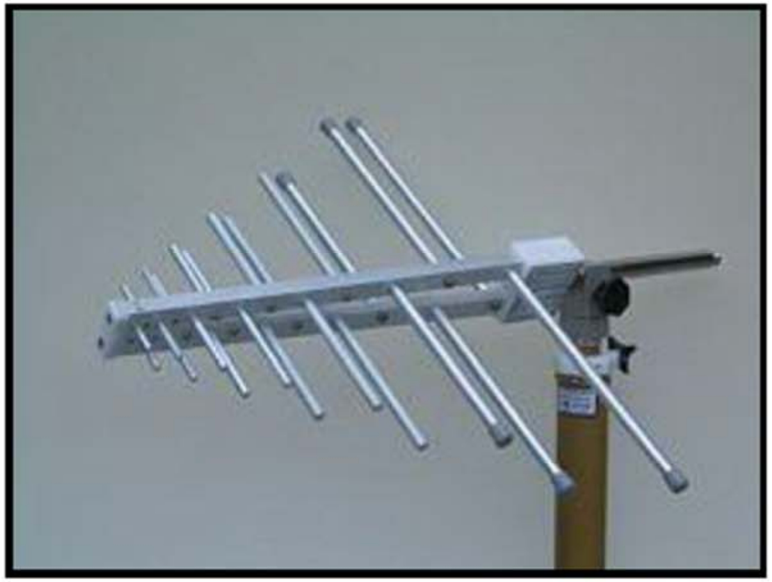
Characteristics:

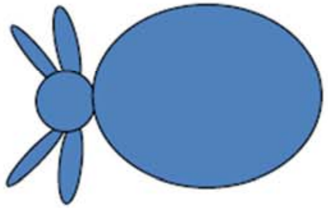
- Polarization: Horizontal.
- Beamwidth: 50° x 50°
- Frequency Limits:
  - Lower Limit: 50 MHz.
  - Upper Limit: 2 GHz.
- Bandwidth: 5% (1.05:1).
- Gain: 5 dB to 15 dB.

Typical Applications:

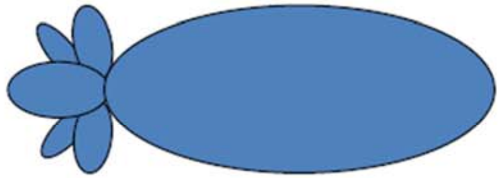
- WWII airborne radar.
- Amateur radio.
- TV reception: UHF & VHF.
- FM Radio reception.

Log Peroidic Antenna





Elevation Radiation Pattern



Azimuth Radiation Pattern

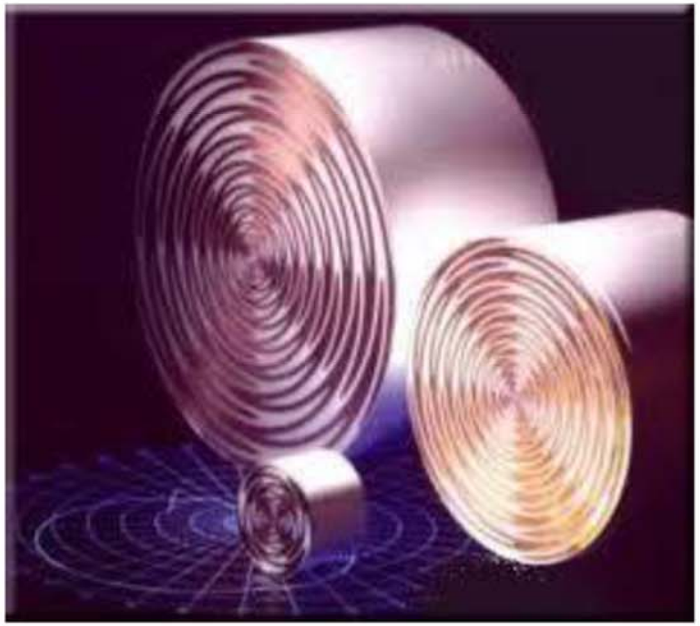
Characteristics:

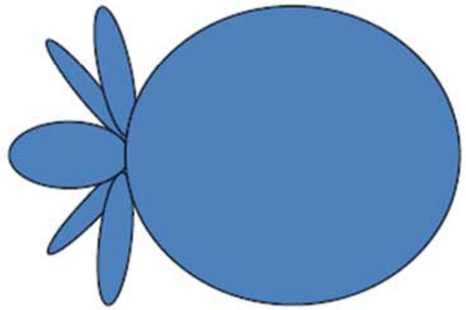
- Polarization: Linear.
- Beamwidth: 60° x 80°
- Frequency Limits:
  - Lower Limit: 3 MHz.
  - Upper Limit: 18 GHz.
- Bandwidth: 163% (10:1).
- Gain: 6 dB to 8 dB.

Typical Applications:

- TV reception: UHF & VHF.
- FM Radio reception.
- Amateur radio.

Cavity-Backed Spiral Antenna





El & Az Radiation Pattern

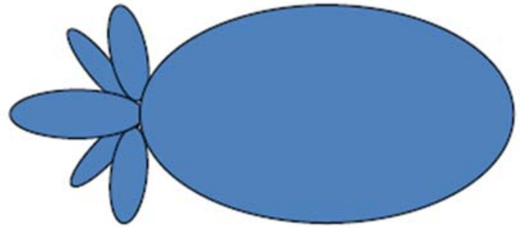
Characteristics:
- Polarization: Circular.
- Beamwidth: 80° x 80°.
- Frequency Limits:
  - Lower Limit: 500 MHz.
  - Upper Limit: 18 GHz.
- Bandwidth: 160% (9:1).
- Gain: 2 dB to 4 dB.

Typical Applications:
- Radar altimeter.
- Electronic warfare.

Conical Spiral Antenna

Radome installed

Radome removed



El & Az Radiation Pattern

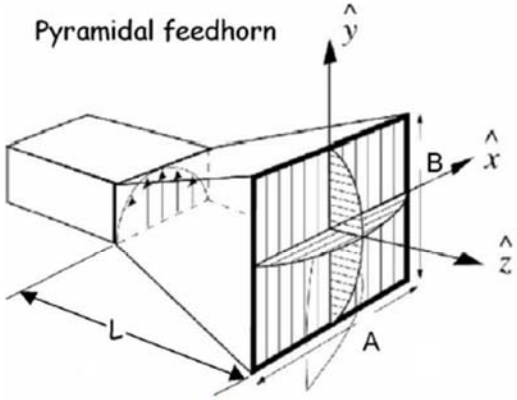
Characteristics:

- Polarization: Circular.
- Beamwidth: 60° x 60°.
- Frequency Limits:
  - Lower Limit: 50 MHz.
  - Upper Limit: ~40 GHz.
- Bandwidth: 120% (4:1).
- Gain: -9 dB to +8 dB.

Typical Applications:

- Direction Finding Radar.
- Ground penetrating radar.
- Electronic warfare.
- Feeds for reflector antennas.
- Telemetry.

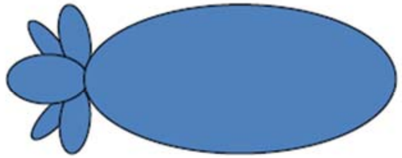
Horn Antenna



$$D_{rec} = \frac{4\pi}{\lambda^2}(a \bullet b)$$

$$HPBW_{xz(\theta)} \approx 51^o \frac{\lambda}{a}$$

$$HPBW_{yz(\phi)} \approx 51^o \frac{\lambda}{b}$$



Elevation Radiation Pattern

Azimuth Radiation Pattern

Characteristics:

- Polarization: Linear / Circular.
- Beamwidth: ~40° x ~40°.
- Frequency Limits:
  - Lower Limit: 50 MHz.
  - Upper Limit: 40 GHz.
- Bandwidth:
  - Ridged: 120% (4 :1).
  - Not Ridged: 67% (2:1) .
- Gain: 5 dB to 20 dB.

Typical Applications:

- Satellite Communication.
- Radio astronomy.
- Electronic warfare.
- Antenna testing.

$$D_{circular} = \frac{4\pi}{\lambda^2}(\pi r^2)$$

$$HPBW^o{}_{circular} \approx 58^o \frac{\lambda}{2r}$$

Parabolic Antenna: Prime Focus

El & Az Radiation Pattern

$$Gain = \eta_{eff} D = \eta_{eff}\left(\frac{4\pi A}{\lambda^2}\right) = \eta_{eff}\left(\frac{\pi D}{\lambda}\right)^2$$

$$HPBW \approx \frac{70^o \lambda}{D}$$

Characteristics:

- Polarization: Depends on feed.
- Beamwidth: 0.5° x 30°.
- Frequency Limits:
  - Lower Limit: 400 MHz.
  - Upper Limit: 30^+ GHz.
- Bandwidth: 33% (1.4:1).
- Gain: 10 dB to 55 dB.

Typical Applications:

- Satellite TV.
- Point-to-Point Backhaul.
  - Cellular telephony, Wi-Fi
- Radio astronomy.
- Search & track radar.

Typical Parabolic Antenna Gain & HPBW

Gain versus Dish Diameter (η_{eff} = 55%)

Diameter: Freq.	2 ft (0.6 m)	4 ft (1.2 m)	6 ft (1.8 m)	8 ft (2.4 m)	10 ft (3.0 m)	12 ft (3.7 m)	15 ft (4.5 m)
2 GHz	19.5dBi	25.5dBi	29.1dBi	31.6dBi	33.5dBi	35.1dBi	37dBi
4GHz	25.5dBi	31.6dBi	35.1dBi	37.6dBi	39.5dBi	41.1dBi	43.1dBi
6 GHz	29.1dBi	35.1dBi	38.6dBi	41.1dBi	43.1dBi	44.6dBi	46.6dBi
8 GHz	31.6dBi	37.6dBi	41.1dBi	43.6dBi	45.5dBi	47.1dBi	49.1dBi
11 GHz	34.3dBi	40.4dBi	43.9dBi	46.4dBi	48.3dBi	49.9dBi	51.8dBi
15 GHz	37dBi	43.1dBi	46.6dBi	49.1dBi	51dBi	52.6dBi	NA
18 GHz	38.6dBi	44.6dBi	48.2dBi	50.7dBi			
22 GHz	40.4dBi	46.4dBi	49.9dBi	NA			
38 GHz	45.1dBi	51.1dBi	NA	NA			

$$Gain = \eta_{eff} D = \eta_{eff}\left(\frac{4\pi A}{\lambda^2}\right) = \eta_{eff}\left(\frac{\pi D}{\lambda}\right)^2$$

$$HPBW = \frac{70^o \lambda}{D}$$

Half-Power Beamwidth (HPBW) versus Dish Diameter

Diameter: Freq.	1 ft (0.3 m)	2 ft (0.6 m)	4 ft (1.2 m)	6 ft (1.8 m)	8 ft (2.4 m)	10 ft (3.0 m)	12 ft (3.7 m)	15 ft (4.5 m)
2 GHz	35°	17.5°	8.75°	5.83°	4.38°	3.5°	2.84°	2.33°
4 GHz	17.5°	8.75°	4.38°	2.92°	2.19°	1.75°	1.42°	1.17°
6 GHz	11.67°	5.83°	2.92°	1.94°	1.46°	1.17°	0.95°	0.78°
8 GHz	8.75°	4.38°	2.19°	1.46°	1°	0.88°	0.71°	0.58°
11 GHz	6.36°	3.18°	1.59°	1°	0.8°	0.64°	0.52°	0.42°
14 GHz	5°	2.5°	1.25°	0.83°	0.63°	0.5°	0.41°	0.33°
18 GHz	3.89°	1.94°	0.97°	0.65°	0.49°	0.39°	0.32°	0.26°
23 GHz	3°	1.52°	0.76°	0.51°	0.38°	0.3°	0.25°	0.2°
38 GHz	1.84°	0.92°	0.46°	0.31°	0.23°	0.18°	0.15°	0.12°

Some Earth Station Antennas

Four reflector antenna configurations are commonly used for earth station applications:

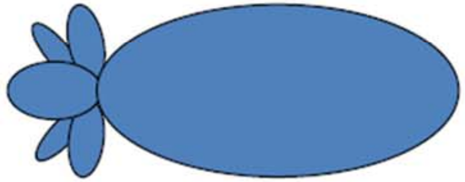
Type of Reflector Antenna	Configuration	Dish Diameters
1. Prime Focus Axisymmetric	Prime focus	0.6 to 7.0 meters
2. Axisymmetric Dual Reflector	Cassegrain	2.0 to 32. meters
3. Single offset	Offset feed	0.6 to 3.6 meters
4. Dual offset	Offset feed	0.6 to 8.0 meters


Prime Focus Axisymmetric


Axisymmetric Dual Reflector


Dual Offset Reflector Antenna

Phased Array Antenna



Elevation Radiation Pattern

Azimuth Radiation Pattern

Characteristics:

- Polarization: Linear / Circular.
- Beamwidth: 0.5° x 30°
- Bandwidth: Varies.
- Gain: 10 to 40⁺ dB.

Typical Applications:

- Radio broadcasting.
- Search & track Radar & Sonar.
- Earth crust mapping; oil exploration.
- High resolution imaging of universe.
- Synthetic Aperture Radar.
- Weather radar (MPAR).