EE302 Lesson 14: Antennas

Loaded antennas

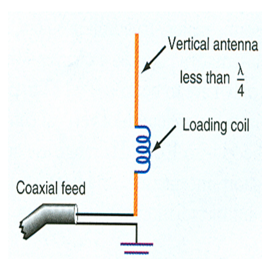
- λ/4 antennas are desirable because their impedance is purely resistive.
- At low frequencies, full λ/4 antennas are sometime impractical (especially in mobile applications).
- Consider λ/4 when f = 3 MHz. (100 m)

Loaded antennas

- However, antennas < $\lambda/4$ in length appear highly **capacitive** and become inefficient radiators.
- For example,
  - the impedance of a $\lambda/4$ antenna is 36.6 + j0 Ω.
  - the impedance of a $\lambda/8$ antenna is 8 – j500 Ω.
- To remedy this, several techniques are used to make an antenna "*appear*" to be $\lambda/4$.

Antenna Length and Loading Coil

- In low-frequency applications, it may not be practical to have an antenna with a full ¼ wavelength (low freq.→ large wavelength)
- If a vertical antenna is less than ¼ wavelength, it no longer resonates at the desired operating frequency (it looks more like a capacitor).
- The capacitive load does not accept energy from the transmitter well.



- To compensate, an inductor (loading coil) is added in series.
- The coil is often variable in order to tune the antenna for different frequencies.

Loading Coil

Antenna arrays

- An **antenna array** is group of antennas or antenna elements arranged to provide the desired directional characteristics.
- Used to “shape” a beam

Localizer antenna array for instrument
landing system.

Directional Antennas

- For many applications, we desire to focus the energy over a more limited range
- Directional antennas have this capability

Advantages

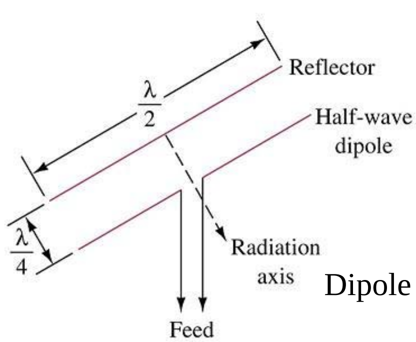
- Because energy is only sent in the desired direction, the possibility of interference with other stations is reduced
- The reduced beamwidth results in increased gain
- Controlling the direction of the beam improves information security
- Frequencies can be reused (wireless modems)

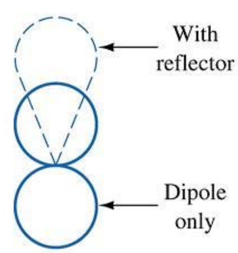
Disadvantages

- Directional antennas don’t work well in mobile situations

Antenna arrays

- If some antenna elements are not electrically connected, these elements are called **parasitic elements**.
- Consider the half-wave dipole with a single half-wave parasitic element below.
- Shown is the radiation pattern (very simplistic) with and without the reflector.





Dipole becomes the “driven” element

Parasitic Elements

- Radiation from the driven element excites the parasitic elements
- Two Types:
  - Reflectors
    - Are made electrically long, 5% longer than the driven element
    - Reverses the direction of energy emitted from rear of antenna
  - Directors
    - Made electrically short, 5% shorter than the driven element
    - Reinforces and focuses energy from the front of the antenna

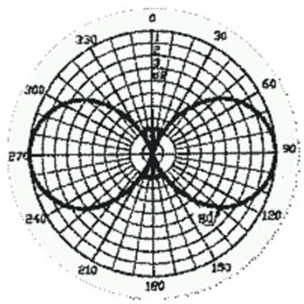
Parasitic Elements

- More parasitic elements means more gain
- Adding more directors is more effective than adding more reflectors
- The greater the number of directors, the higher the gain and the narrower the beam angle
- Most Yagi antennas have 1 reflector and 1-20 directors

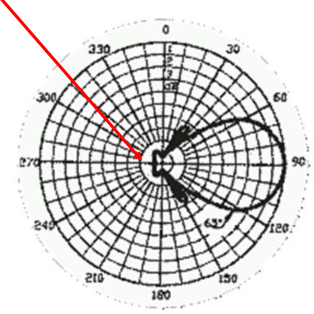
Operation of parasitic element

- This doubling results in a 3 dB gain compared to a half-wave dipole antenna.

Some radiation is still directed in the reverse direction



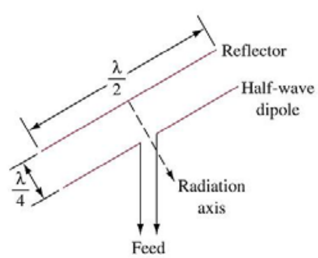
Dipole without reflector



Dipole with reflector

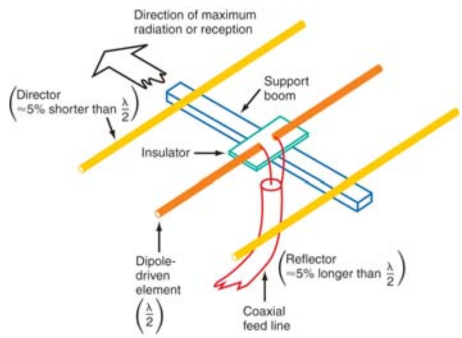
Operation of parasitic element

- The driven element radiates as normal.
- This induces voltages and currents in the parasitic element causing it to radiate also. Reflection introduces a 180° phase shift.
- Radiation arriving back at the dipole is in phase.



Yagi-Uda Antenna (Yagi)

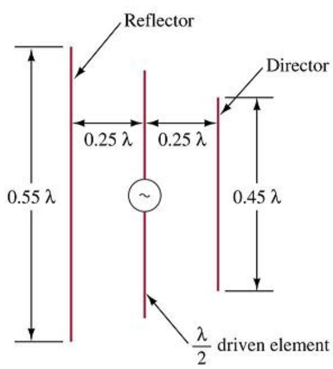
- One driven element and one or more parasitic elements
- Normally made to operate in a single band (not a wide-band antenna)



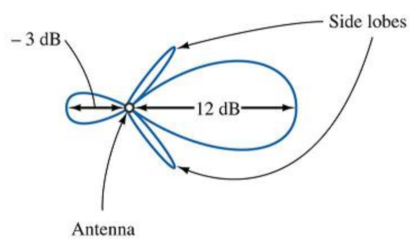
Yagi Antennas

Yagi Antenna

- A 3 element Yagi



Associated radiation pattern



Yagi Antenna

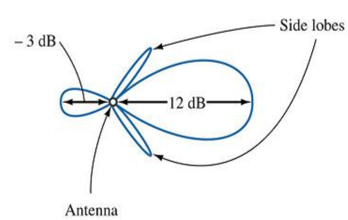
- The front-to-back ratio (F/B ratio) is the ratio of the power radiated in the forward direction to the power radiated in the backward direction.

$$F / B = 10 \log \frac{P_f}{P_b} \quad \text{dB}$$

P_f = Forward power

P_b = Backward power

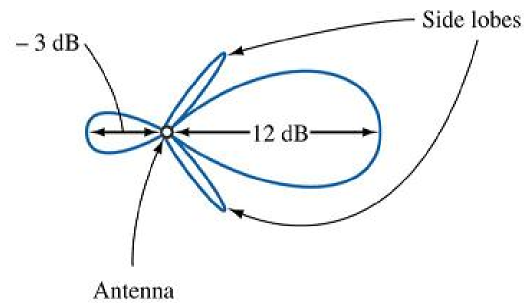
If the radiation patterns are plotted in decibels, the F/B ratio is simply the difference between the forward value and the backward value, in dB



*Most Yagi antennas are designed to maximize F/B ratio rather than gain. This minimizes the radiation and reception from the rear of the antenna.

Example Problem

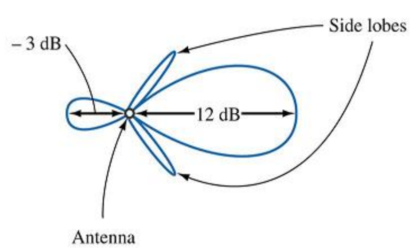
1. What is the front to back ratio for the radiation pattern shown below?



2. What is the power ratio?

Example Problem (Solution)

1. What is the front to back ratio for the radiation pattern shown below?
2. What is the power ratio?



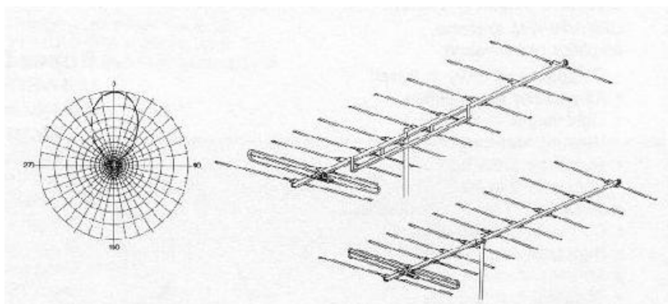
1. F/B Ratio = 12 dB – (-3 dB) = 15 dB

2. Start with $F/B = 10\log\frac{P_f}{P_b}$

$$\frac{P_f}{P_b} = 10^{\frac{F/B}{10}} = 10^{\frac{15}{10}} = 31.6$$

Yagi-Uda antenna

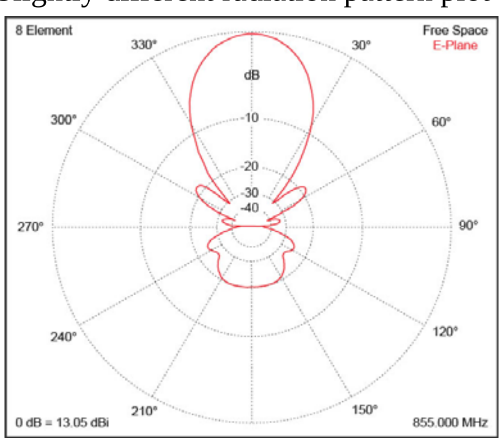
- More complicated Yagi-Uda antennas consist of a reflector and many directors to improve gain.
- This type antenna design is common of HF transmitting antennas and VHF/UHF television receiving antennas.

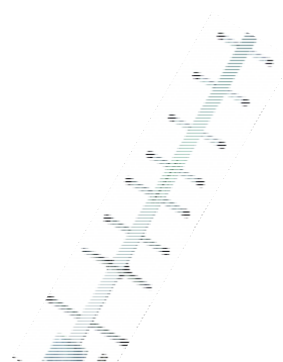


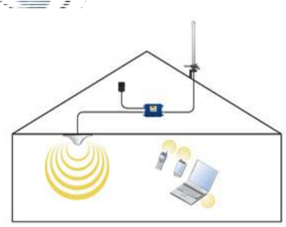
10 element Yagi VHF-TV antenna (10 dB gain)

Yagi-Uda antenna

Slightly different radiation pattern plot





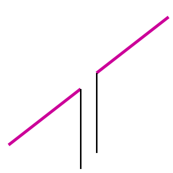


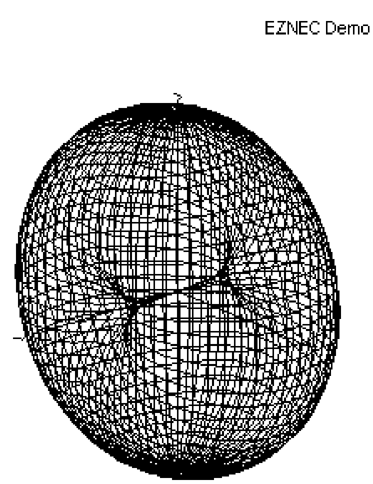
13dbi Yagi 806-939 MHz Cellular Antenna

Impact of Reflector and Director

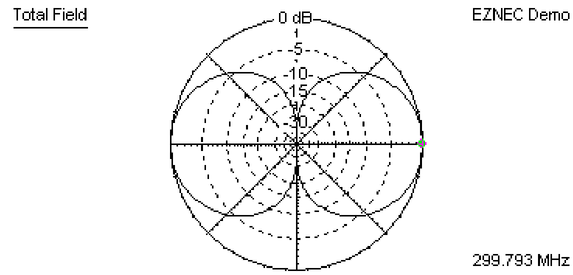
- Comparing several radiation patterns will demonstrate the effect of adding a reflector and directors to a yagi antenna

Dipole





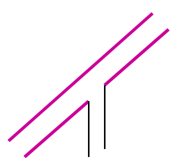
Dipole

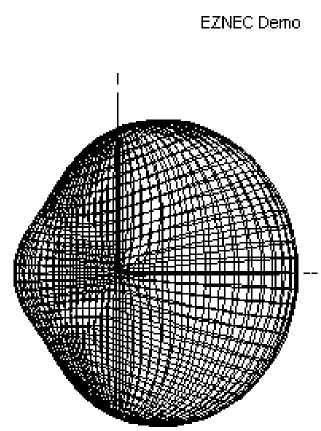


Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	2.16 dBi
Outer Ring	2.16 dBi		0.0 dBmax

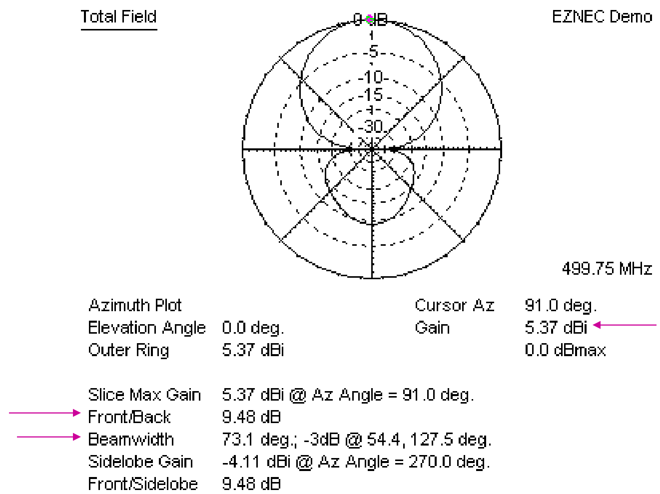
Slice Max Gain	2.16 dBi @ Az Angle = 0.0 deg.
Front/Side	99.99 dB
Beamwidth	77.4 deg.; -3dB @ 321.3, 38.7 deg.
Sidelobe Gain	2.16 dBi @ Az Angle = 180.0 deg.
Front/Sidelobe	0.0 dB

2 Element Yagi

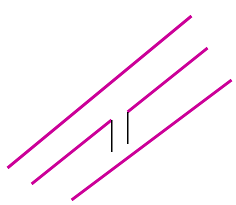


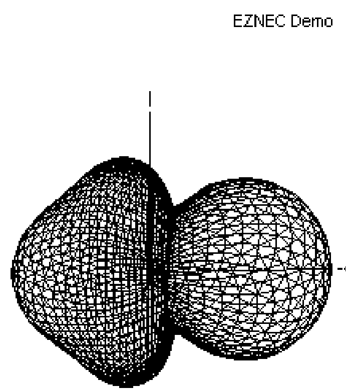


2 Element Yagi

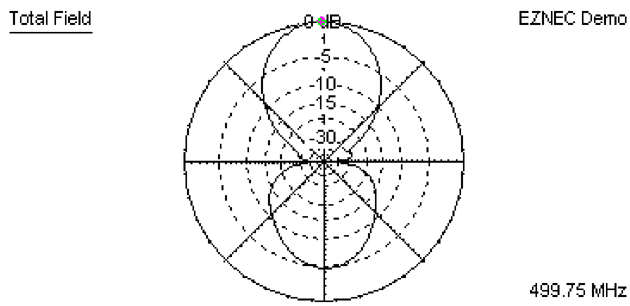


3 Element Yagi





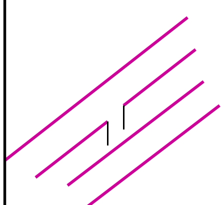
3 Element Yagi



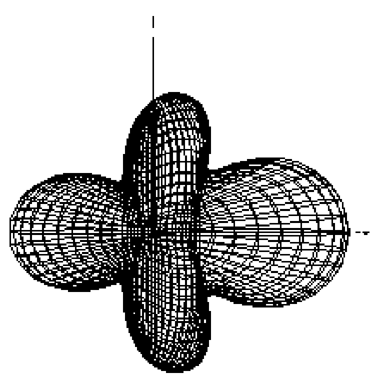
Azimuth Plot		Cursor Az	91.0 deg.
Elevation Angle	0.0 deg.	Gain	7.94 dBi
Outer Ring	7.94 dBi		0.0 dBmax

Slice Max Gain	7.94 dBi @ Az Angle = 91.0 deg.
Front/Back	4.71 dB
Beamwidth	53.2 deg.; -3dB @ 65.0, 118.2 deg.
Sidelobe Gain	3.23 dBi @ Az Angle = 271.0 deg.
Front/Sidelobe	4.71 dB

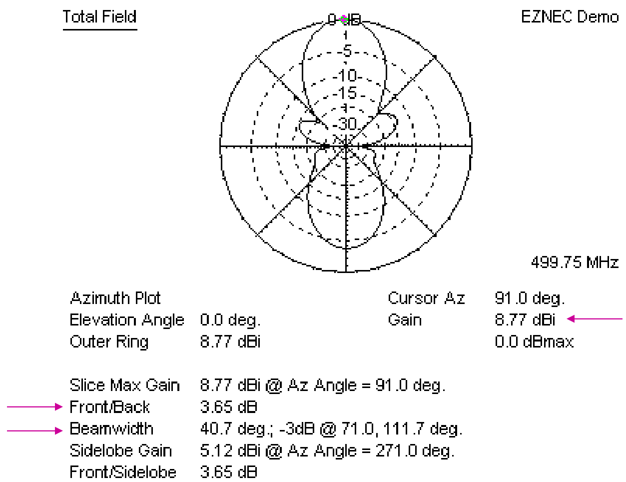
4 Element Yagi



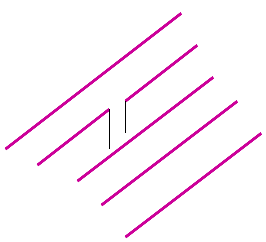
EZNEC Demo

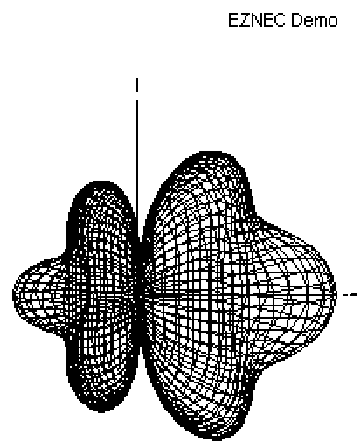


4 Element Yagi

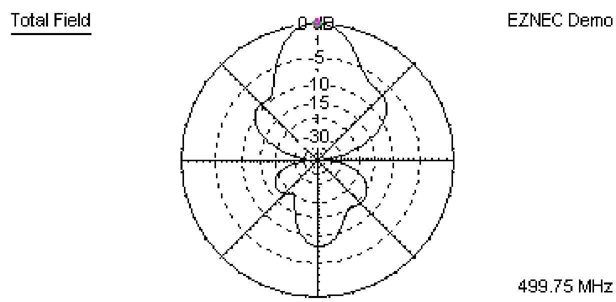


5 Element Yagi





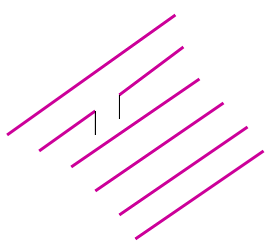
5 Element Yagi

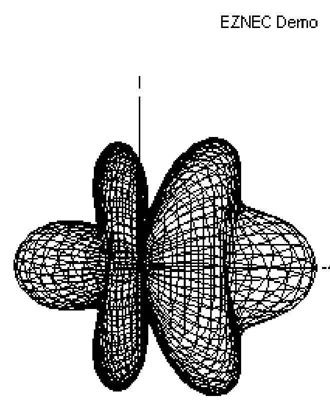


Azimuth Plot		Cursor Az	90.0 deg.
Elevation Angle	0.0 deg.	Gain	8.6 dBi
Outer Ring	8.6 dBi		0.0 dBmax

Slice Max Gain	8.6 dBi @ Az Angle = 90.0 deg.
Front/Back	8.02 dB
Beamwidth	37.7 deg.; -3dB @ 71.2, 108.9 deg.
Sidelobe Gain	0.59 dBi @ Az Angle = 271.0 deg.
Front/Sidelobe	8.01 dB

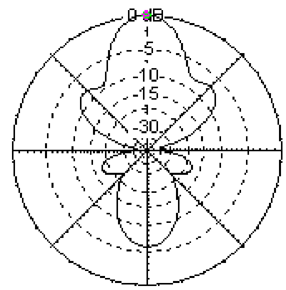
6 Element Yagi





6 Element Yagi

Total Field | EZNEC Demo

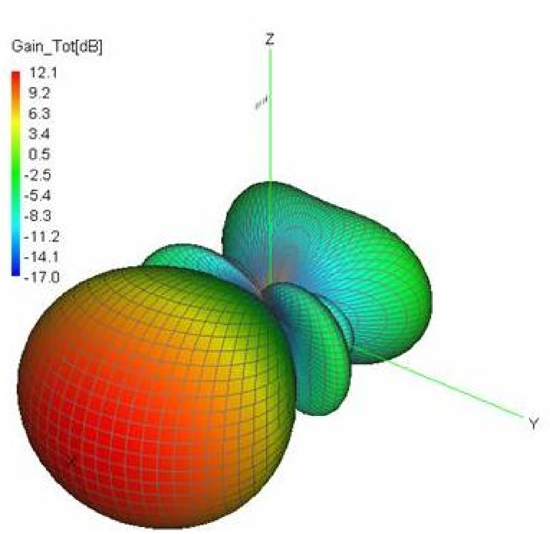


499.75 MHz

Azimuth Plot		Cursor Az	90.0 deg.
Elevation Angle	0.0 deg.	Gain	8.38 dBi
Outer Ring	8.38 dBi		0.0 dBmax

Slice Max Gain	8.38 dBi @ Az Angle = 90.0 deg.
Front/Back	5.88 dB
Beamwidth	34.8 deg.; -3dB @ 72.9, 107.7 deg.
Sidelobe Gain	2.5 dBi @ Az Angle = 270.0 deg.
Front/Sidelobe	5.88 dB

6 Element Yagi-Uda (Another View)



Driven arrays

- Yagi antenna produces good forward gain
- But, has a limited operating frequency range
- A **driven array** is a multi-element antenna in which **all** of the elements are excited through a transmission line.

Log-Periodic Antenna

- Lengths of driven elements are related logarithmically
- The longest element has a length of ½ the wavelength of the lowest frequency
- The shortest element is ½ the wavelength of the highest frequency
- Advantage is very wide bandwidth

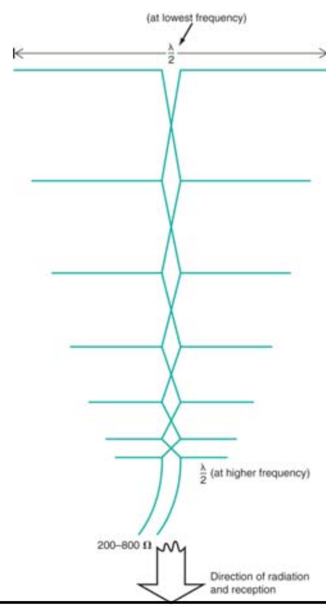
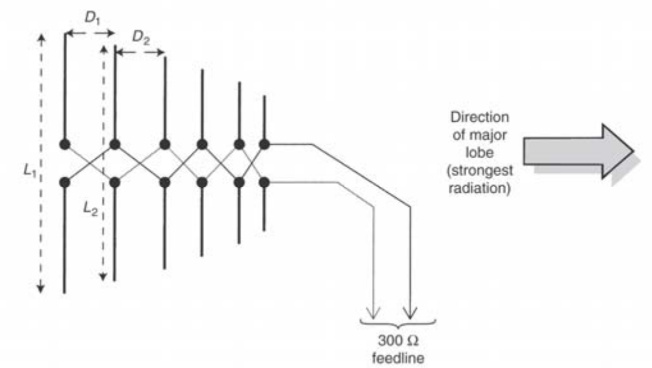


Figure 12–11 A log-periodic antenna



$$\tau = \frac{L_2}{L_1} = \frac{L_3}{L_2} = \frac{L_4}{L_3} \ldots \quad and \quad \tau = \frac{D_2}{D_1} = \frac{D_3}{D_2} = \frac{D_4}{D_3}$$

Ratio of two adjacent elements is held constant, usually 0.7-0.9

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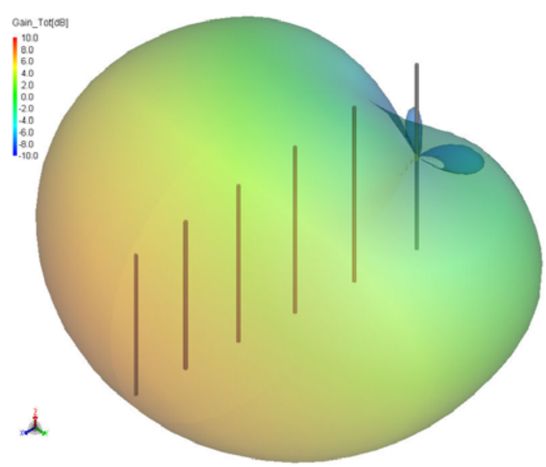
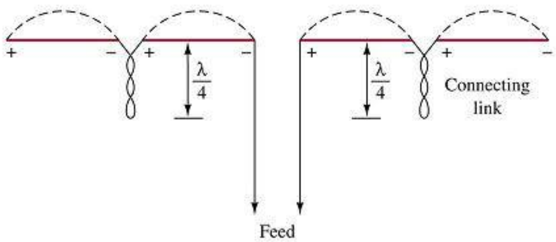
Log Periodic Antenna

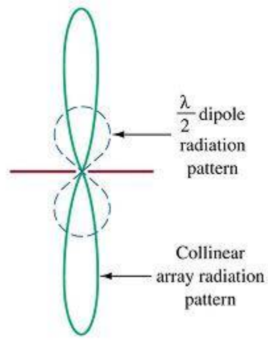


Collinear arrays

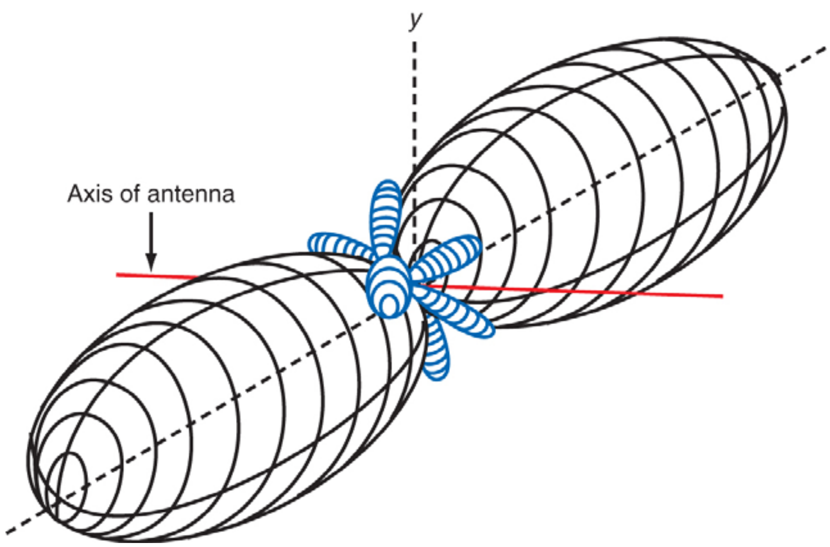
- A collinear array consists of 2 or more dipoles connected end-to-end

Radiation Pattern is similar
to dipole, but more concentrated
in the horizontal plane



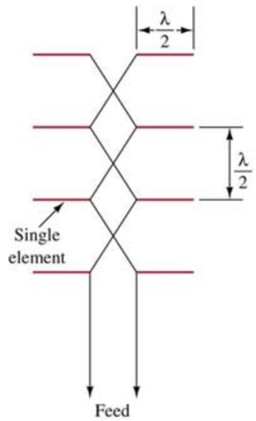


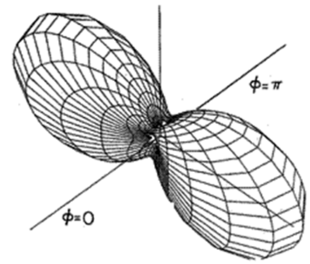
3-D Radiation pattern of a four element collinear antenna



Broadside array

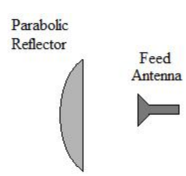
- The broadside array is a stacked collinear antenna
- The broadside array results in increased directivity in both the horizontal and vertical plane.





Parabolic Reflectors (Dish)

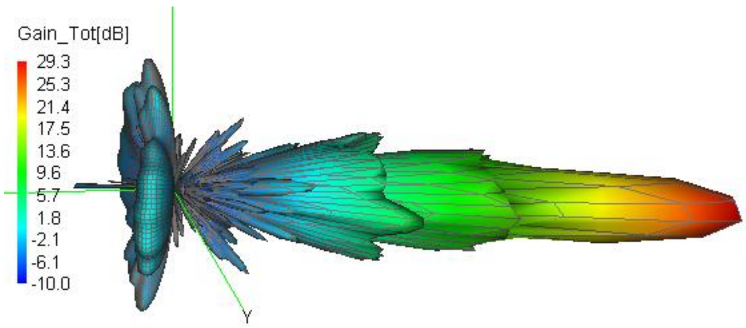
More later in Microwaves



Used at microwave frequencies
1 GHz and above

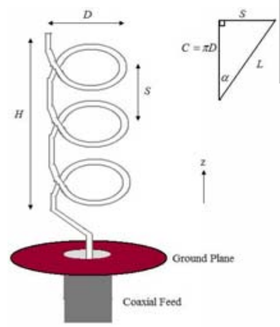
Parabolic Dish
(With a Feedhorn)

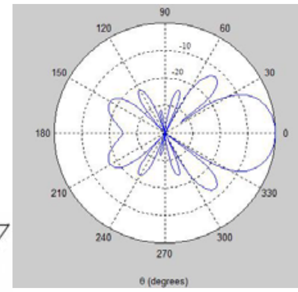
D = 11λ, Gain = 29 dB, F/B = 33 dB



Radio Telescope

Helical Antenna (more later)



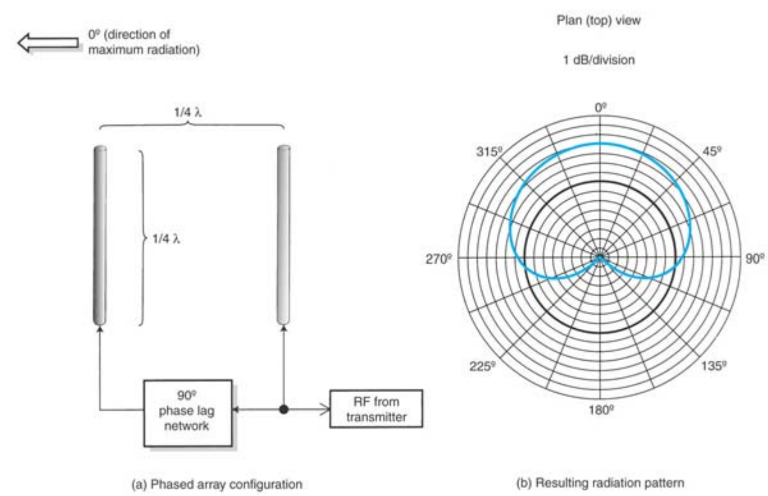


RHCP or LHCP

Phased-Array Antennas

- Antennas can be driven in sets to produce directional radiation patterns
- By controlling the amplitude and phase of the RF current driving each antenna, an infinite number of radiation patterns can be created

Figure 12–18 A two-element phased Marconi array,and horizontal pattern



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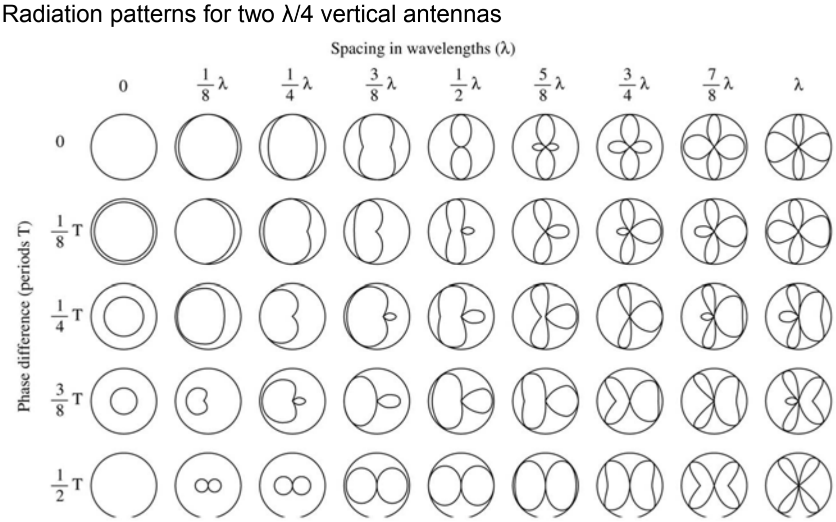
Phased array antenna patterns

Radiation patterns for two λ/4 vertical antennas



Phased Array Antenna

- The ability to shape and electronically steer a beam has resulted in advanced technology
- Eliminating rotating antennas saves weight and significant maintenance costs

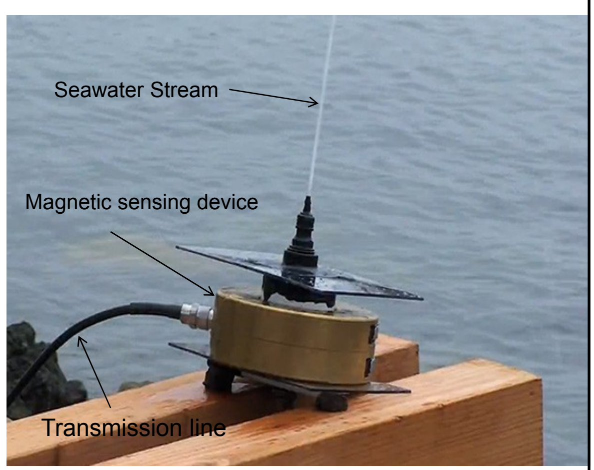
Eliminates the large, rotating antenna topside

Phased Array Radar

Patriot Missile Phased Array

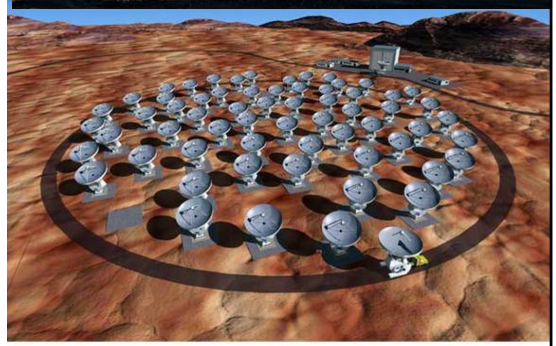
New Idea on the Horizon

- Navy ships typically have up to 80 or more antennas structures
- Topside real estate is extremely limited
- A new antenna idea is being developed by SPAWAR System Center in San Diego
- Instead of a fixed antenna structure, the antenna would be composed of a stream of sea water
- Varying the length of the salt water stream will vary the frequency response of the antenna. This concept has been tested from 2 to 4 MHz at ranges of 30 miles
-The magnetic sensing device at the bottom converts magnetic fluctuations in the salt water stream into a signal compatible with the radio receiver
- 10 seawater antennas could theoretically replace 80 fixed antennas, reducing radar footprint



New Radio Telescope Antenna Array

- New ALMA array in Chile
- 64 40-ft (12m) antennas
- Linked together they make the world's largest radio telescope
- When complete, will have a total of 66 antennas
- Will observe millimeter/sub-millimeter wavelengths



ALMA at Chajnantor