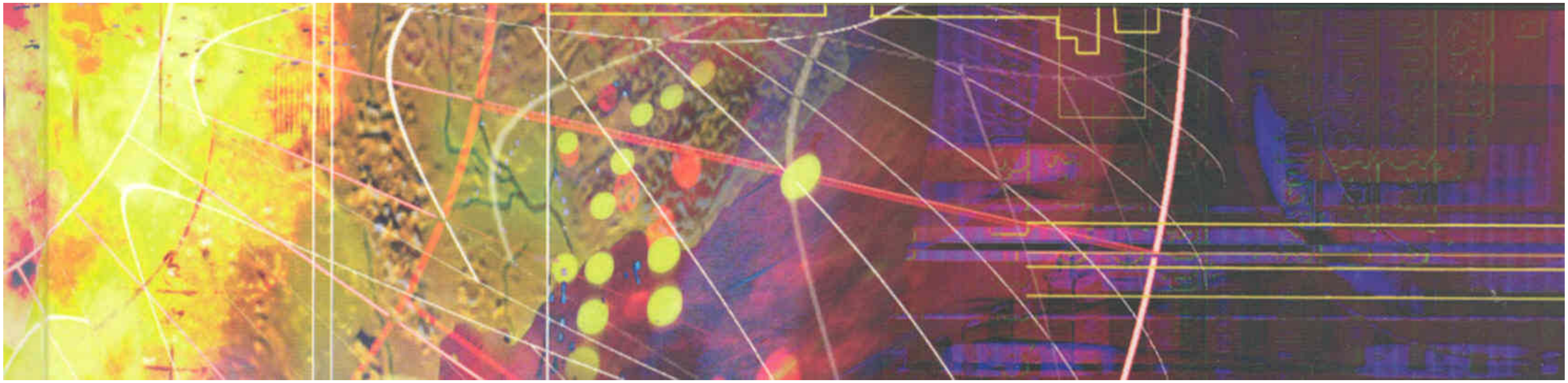


EE303 Lesson 25: Antennas

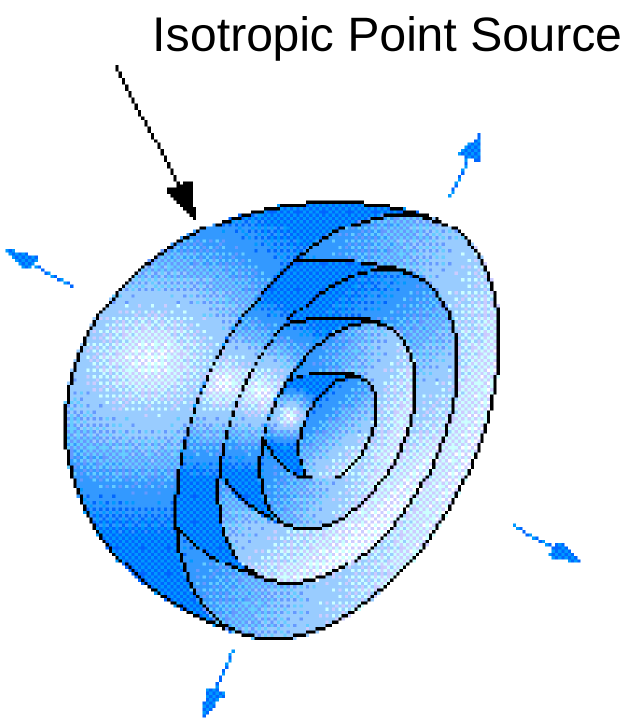
Basic Antenna

- Let’s start by looking at the radiation pattern of an **isotropic radiator**.
  - Think of it as a candle illuminating centered in a large sphere.
- Power from an isotropic point source is equally distributed in all directions and the power density (S) is given by

$$S\left(R,\theta\right)=\frac{P_t}{4\pi R^2}$$

where P_t is the transmitter power.

- It is completely **unfocused**.

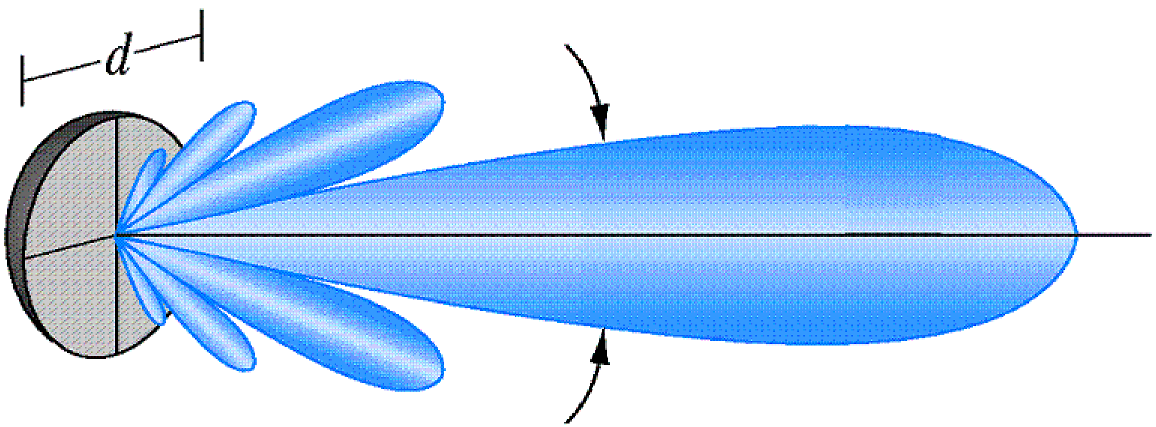


Example Problem 1

A power of 100 W is supplied to an isotropic radiator. What is the power density (W/m^2) at a distance of 10 km?

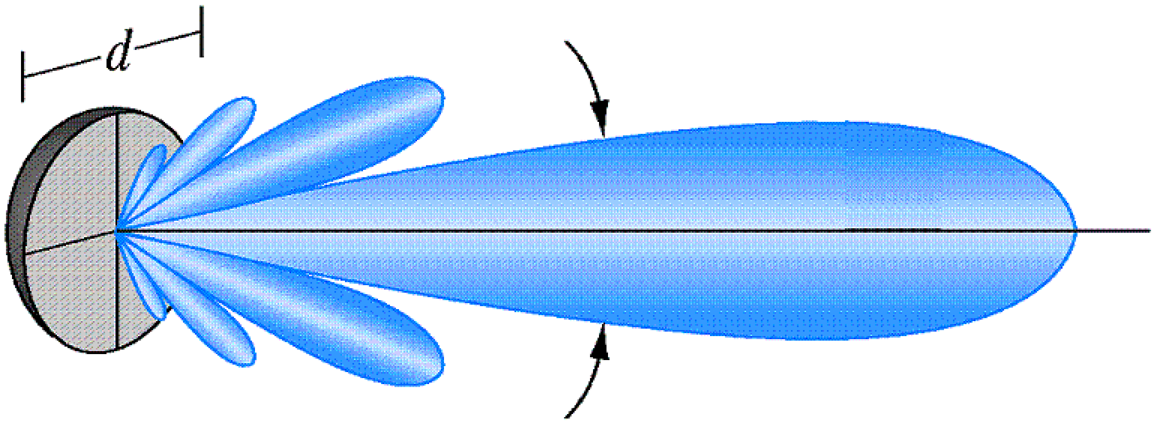
Basic Antenna

- If we want to **focus** the power we are transmitting, we need to be able to shape the electromagnetic fields, and that is what antennas allow us to do.



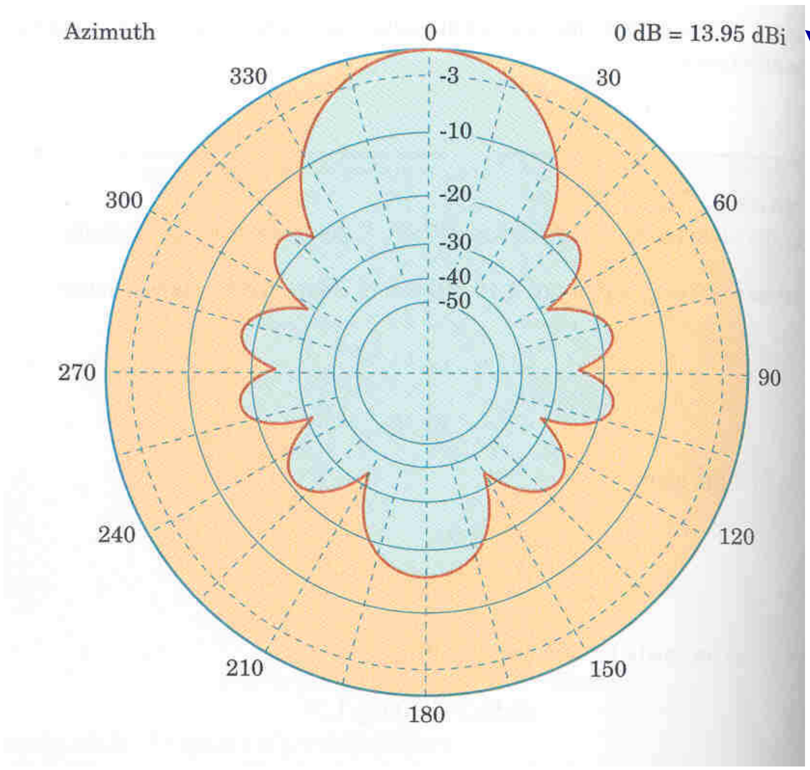
Radiation pattern

- The **radiation pattern** is a plot of the radiated electromagnetic field strength around an antenna.
- The radiation pattern for the antenna depicted below is an example of a very **directional** antenna.



Radiation pattern

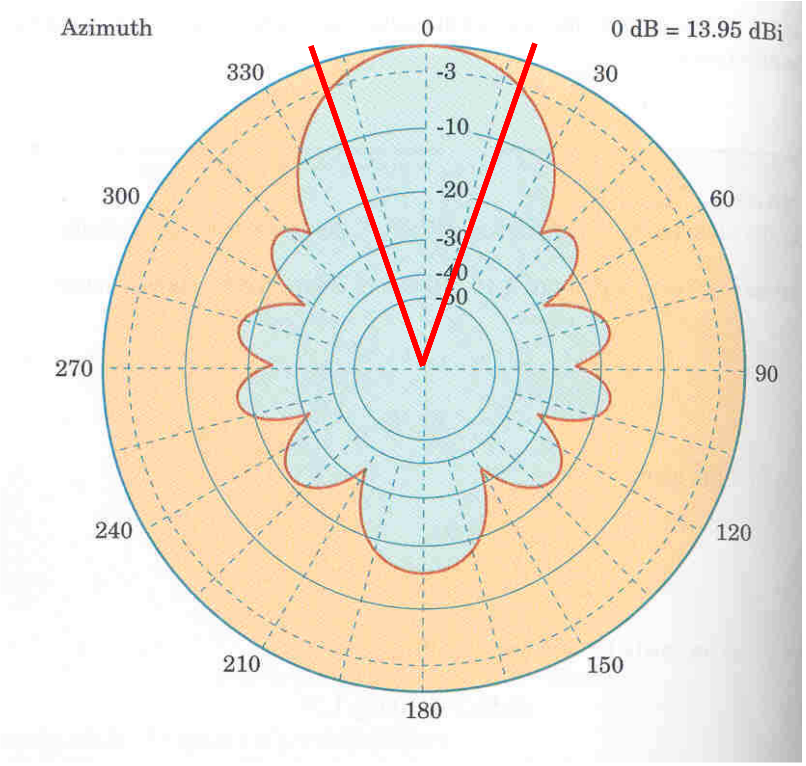
- The radiation pattern is often normalized to the point of maximum gain.



13.95 dBi at 0°

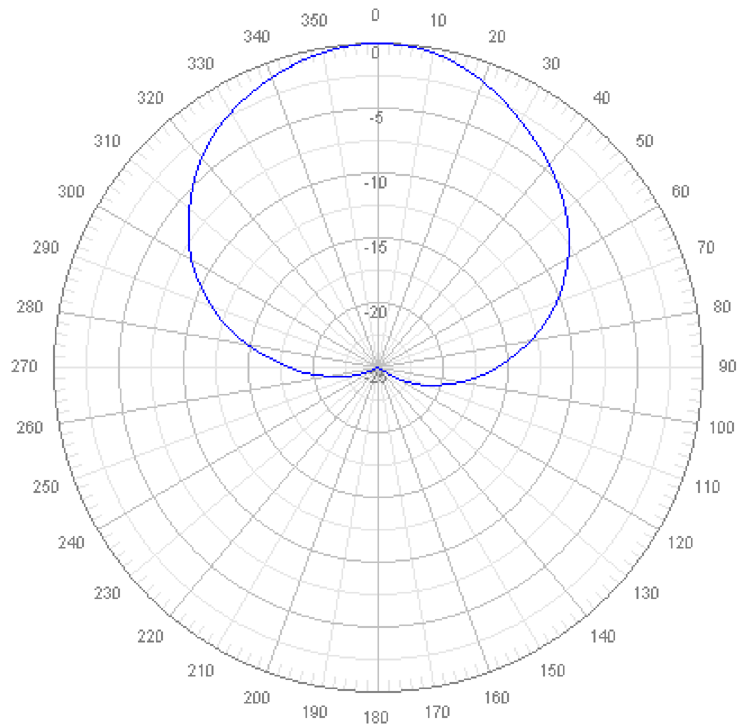
Beam width

- The **beam width** of a directional antenna is the angular separation of the half-power (3-dB) points of the radiation pattern
- Beam width is specified in degrees.



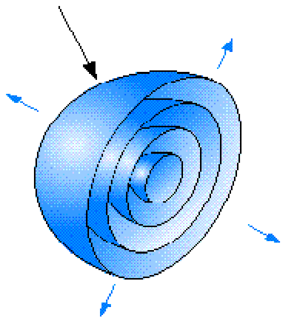
Example Problem 2

Below is an antenna used for mobile wireless applications for 1710–2180 MHz. The azimuth radiation pattern is depicted. What is the approximate beam width?



Antenna gain

- The ability of an antenna to focus electromagnetic energy is defined by its **gain**.
- Antenna gain is expressed as a ratio of the *effective radiated* output power (P_{out}) to the input power (P_{in})
- The gain of an antenna is a measure of power transmitted **relative** to that transmitted by an isotropic source.



- Antenna gain relative to an isotropic source is expressed in decibels as **dBi** (**i** for isotropic).

Effective radiated power

- The **effective radiated power** (ERP) is the power gain of an antenna (A_P, with respect to an isotropic radiator) multiplied by its input power.

$$\mathrm{ERP} = A_P \times P_t$$

- ERP can be thought of as the amount of power that would be required by an isotropic source to produce the same signal strength at the receiver as the actual antenna produces.

Example Problem 3

The 10 ft parabolic antenna below operates at 10.2–10.7 GHz and has a beam width of 0.7º and a gain of 47.2 dBi. What is the gain A_P (gain express as a ratio)? What is the effective radiated power if the transmitter power is $P_t = 10$ W.

Antenna Q and bandwidth

- The bandwidth of an antenna is determined by the frequency of operation and the Q of the antenna

$$\mathrm{BW} = f_r / Q$$

  - The higher the Q the narrower the operating bandwidth BW of the antenna
- It is difficult to determine the exact Q of an antenna
- For an antenna, a low Q is desirable so the antenna has a wider bandwidth and is able to operate over a wider range of frequencies

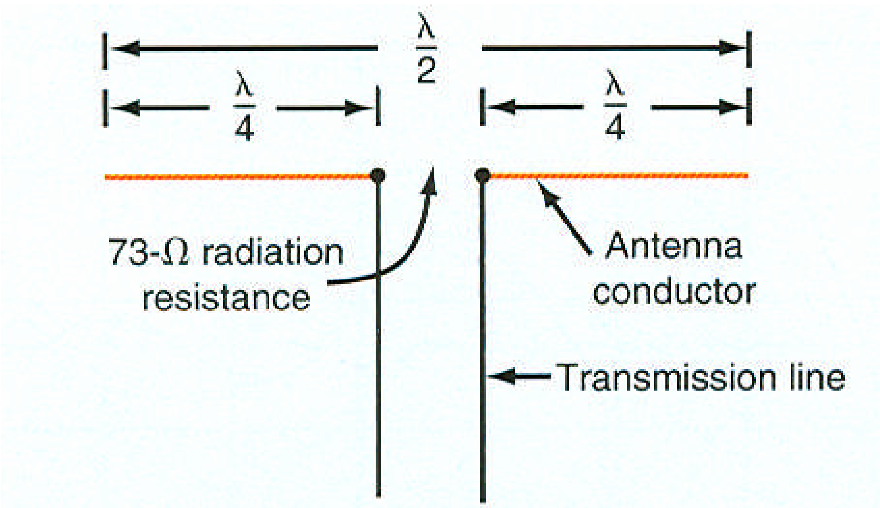
Antenna *Q* and bandwidth

- The *Q* and thus the bandwidth of an antenna are determined primarily by the ratio of the length of the conductor to the diameter of the conductor
- When thin wire is used as the conductor, the ratio is very high (10,000-30,000 range) resulting in high *Q* and narrow bandwidth
  - A ratio of 25,000 results in a *Q* of about 14
  - A ratio of 1200 results in a *Q* of about 8
- If the antenna is made of larger diameter wire or tubing, the ratio and *Q* decreases, resulting in a wider bandwidth.

Antenna Types

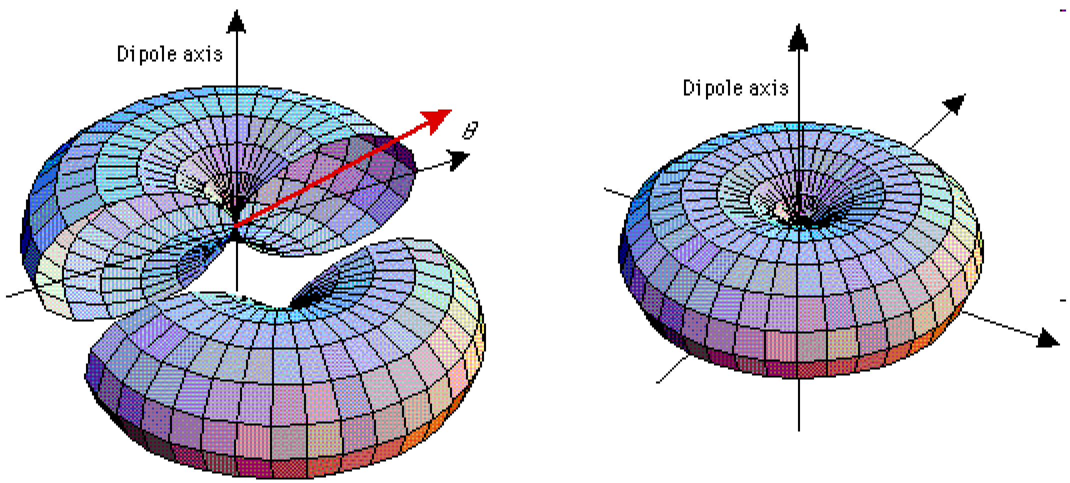
Dipole Antenna

- One of the most widely used antenna types is the half-wave dipole.
- A dipole antenna is two pieces of wire, rod, or tubing that are one-quarter wavelength long at the operating resonant frequency.



Half-wave dipole radiation

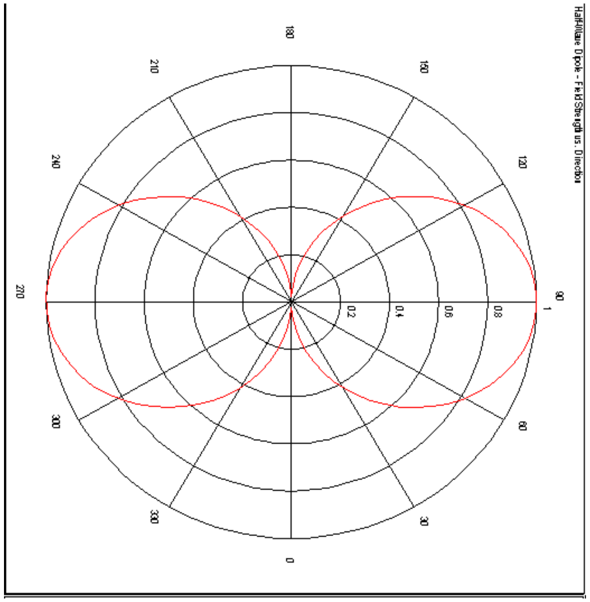
- The radiation pattern from at half-wave dipole antenna is doughnut shaped.
  - Maximum energy is radiated at right angles to the dipole.
  - There is no radiation from the end of the antenna.



Half-wave dipole radiation

- The power gain of a half-wave dipole antenna is 1.64 that of an isotropic source.
- Expressed in decibels, the gain is 2.15 dBi

$$10\log_{10}(1.64) = 2.15 \text{ dBi}$$



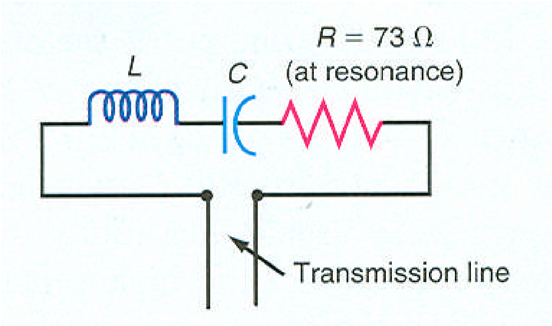
- Antenna gain relative to a dipole antenna is often expressed in decibels as **dBd**.

$$\text{dBi} = \text{dBd} + 2.15$$

- Thus, an antenna with a gain of 3 dBd would have a gain of 5.15 dBi (3 dB + 2.15 dB)

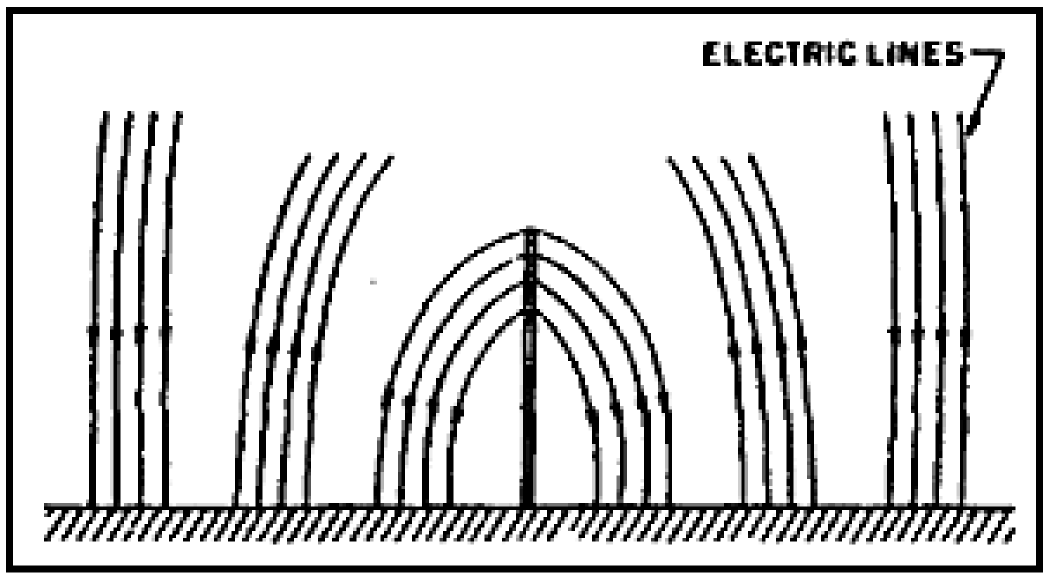
Half-wave dipole radiation resistance

- A half-wave dipole acts as a resonant circuit.
- At its resonant frequency, the antenna appears to be a pure resistance of 73 Ω.
  - Conveniently, RG-11 coaxial cable with an impedance of 75 Ω provides an excellent match.
- This **radiation resistance** does not dissipate power in the form of heat; the power is dissipated as radiated electromagnetic energy.



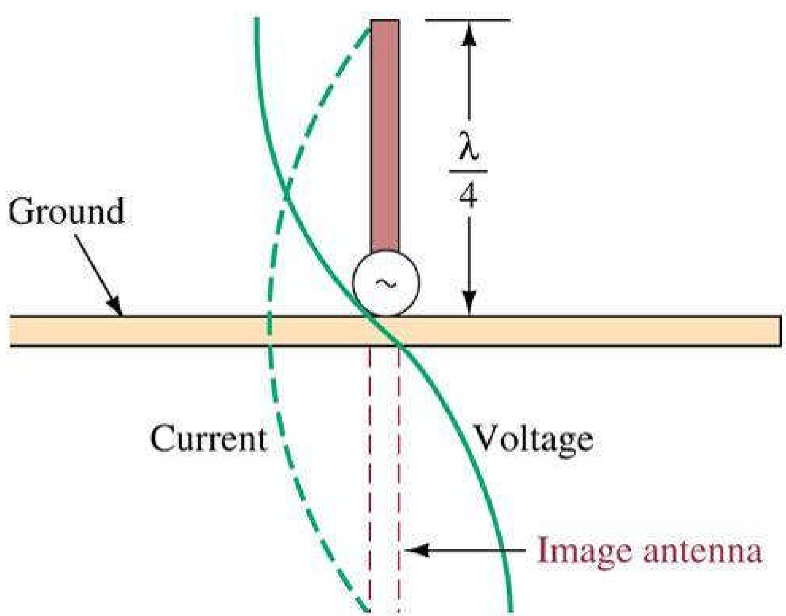
Monopole antenna

- A monopole antenna is vertical antenna, typically $\lambda/4$ long (also referred to as a *Marconi antenna*).
- Monopole antennas are primarily used for frequencies below 2 MHz.



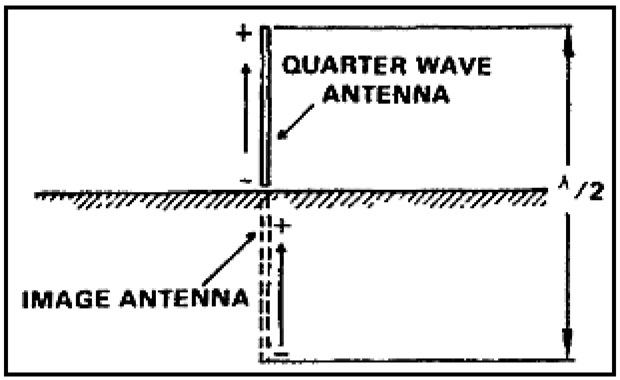
Monopole antenna

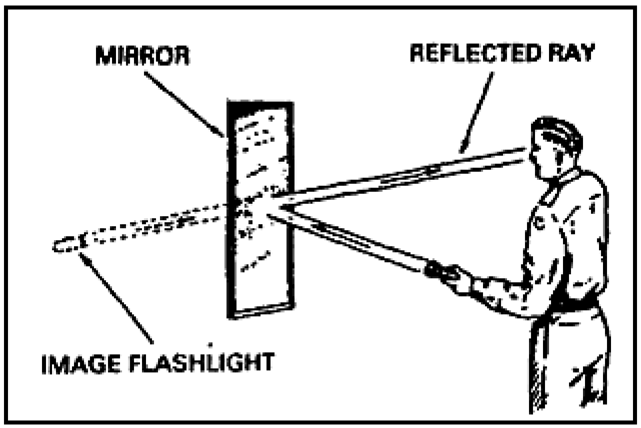
- To function properly, a monopole antenna must be connected the ground.
- The ground, a good conductor for medium and low frequencies, acts as a large mirror for the radiated energy.



Monopole antenna

- The reflection from the earth (ground) is equivalent to what would be produced by another $\lambda/4$ section.
- This is known as the **image antenna**.

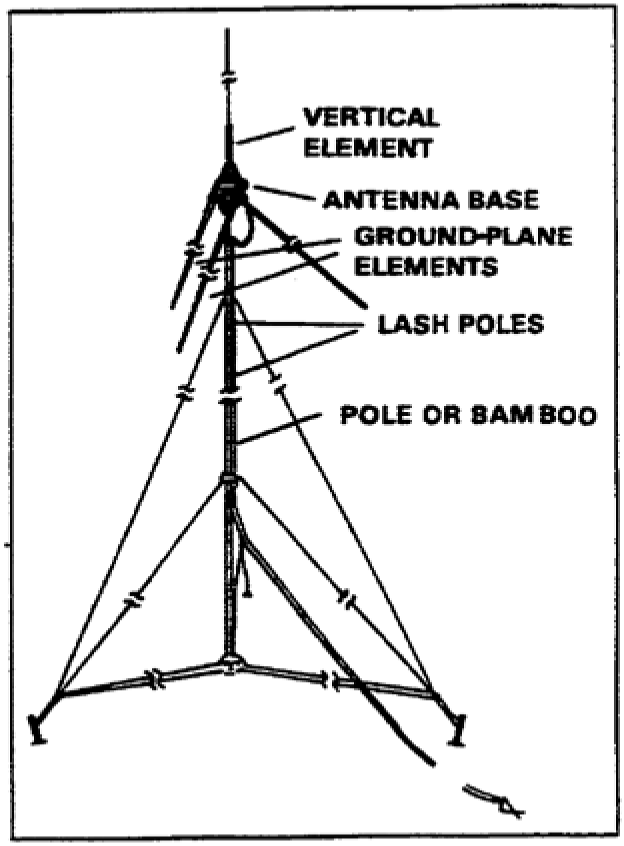




Counterpoise

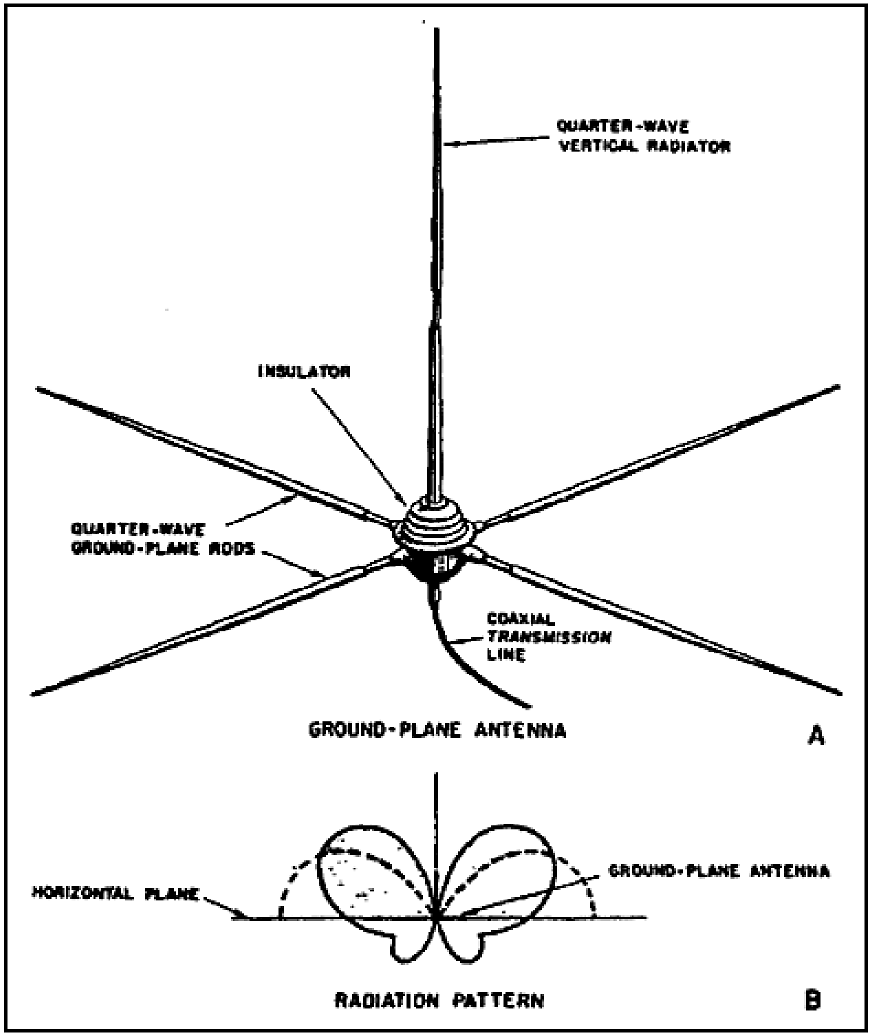
- Sometimes connecting a monopole antenna to the ground is not feasible.
  - Antennas mounted on buildings or towers
  - Soil is highly resistive (dry)

Ground material	Relative conductivity
Sea water	4,500
Flat, rich soil	15
Average flat soil	7
Fresh water lakes	6
Rocky hills	2
Dry, sandy, flat soil	2
City residential area	2
City industrial area	1



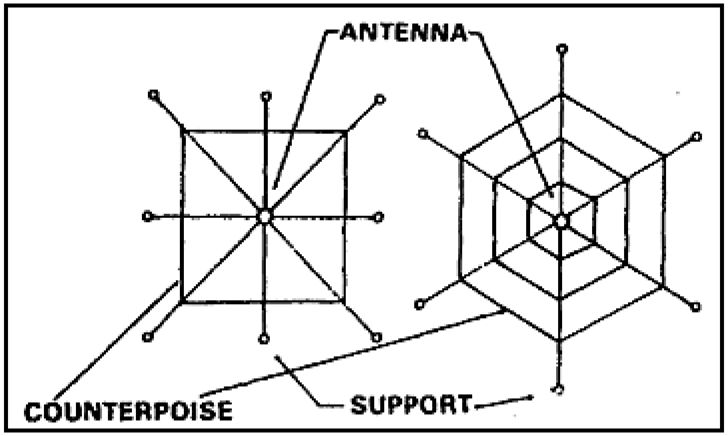
Counterpoise

- A **counterpoise** is a flat structure of wire or screen that forms an artificial reflecting surface for the monopole antenna if the actual earth cannot be used.



Counterpoise

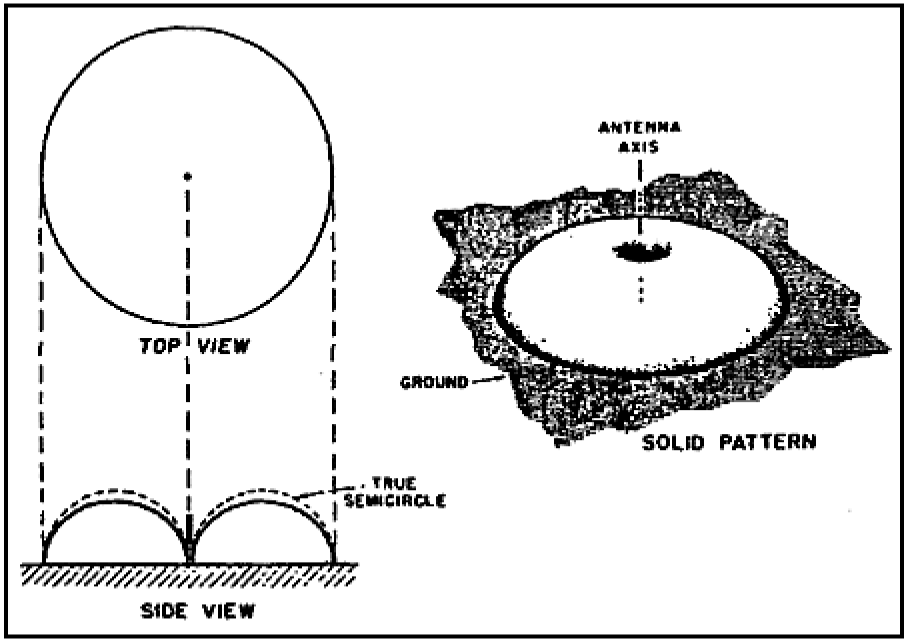
- Counterpoise requirements
  - Must be at least equal to or larger than the antenna.
  - Should extend in equal distances from the antenna.
  - Must be insulated from the ground.
- The performance of monopole antenna (either well-grounded or using a counterpoise) is the same as a half-wave dipole antenna.



Counterpoise

Radiation pattern

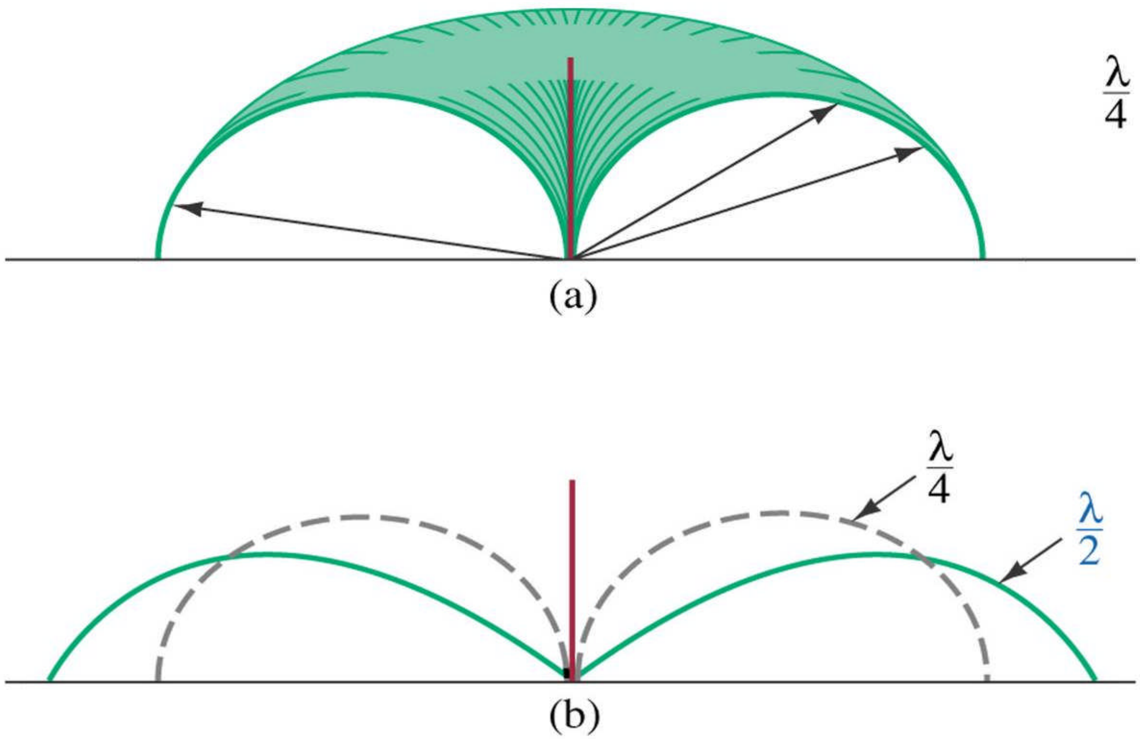
- The voltage, current and impedance relationships for a λ/4 monopole antenna are identical to λ/2 dipole antennas (except the impedance is 36.6 Ω).
- The radiation pattern is omnidirectional in the horizontal plane.



Radiation pattern

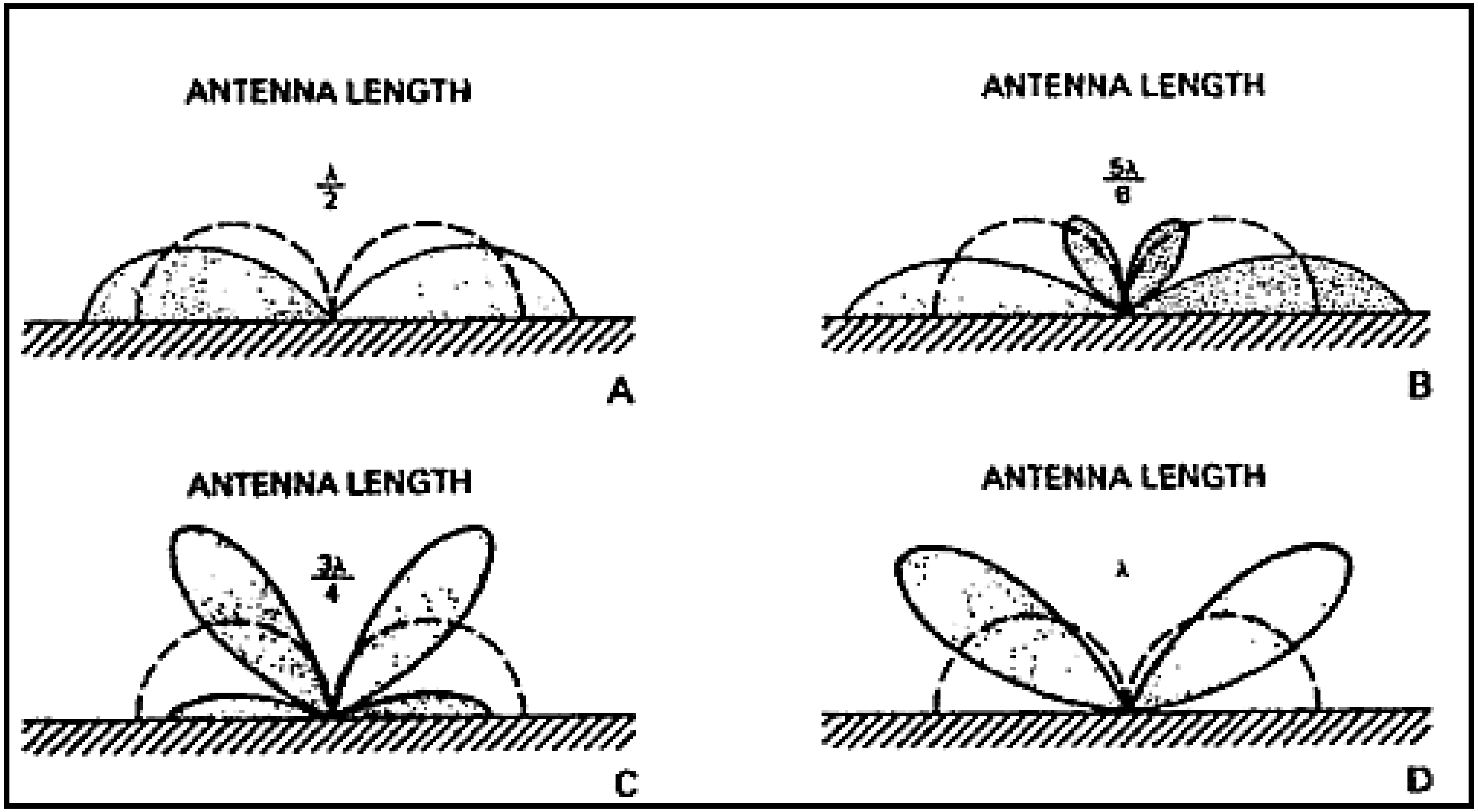
- Monopole antennas can have lengths other than $\lambda/4$ and these will produce different radiation patterns.
- Consider the following:
  - A $\lambda/4$ antenna has large ground wave component and appreciable sky wave energy.
  - Increasing length to $\lambda/2$ produces a larger ground wave component.
  - Maximum ground wave is achieve at 5/8 λ.
  - At length 1 λ, no ground wave is produced.

Figure 9-8 Radiation patterns for λ/4 and λ/2 antennas.



Jeffrey S. Beasley and Gary M. Miller
Modern Electronic Communication, 8e

Radiation pattern



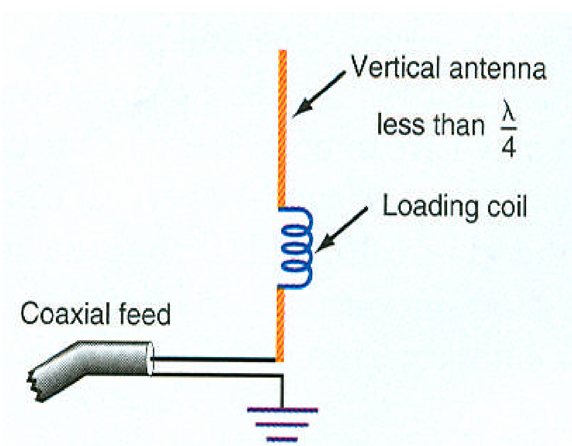
Loaded antennas

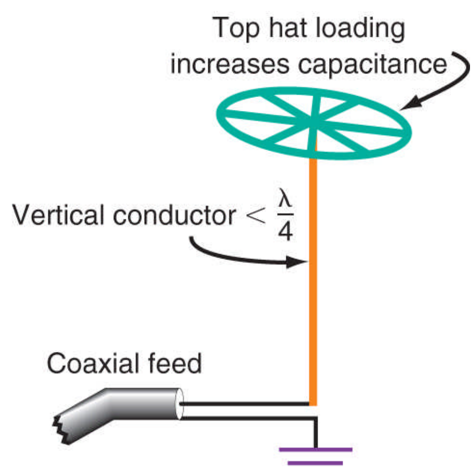
- $\lambda/4$ antennas are desirable because their impedance is purely resistive (36.6 Ω).
- At low frequencies, full $\lambda/4$ antennas are sometimes impractical (especially in mobile applications).
- Consider $\lambda/4$ when f = 3 MHz. (100 m)

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 $36.6 + j0\ \Omega$.
  - the impedance of a $\lambda/8$ antenna is $8 - j500\ \Omega$.

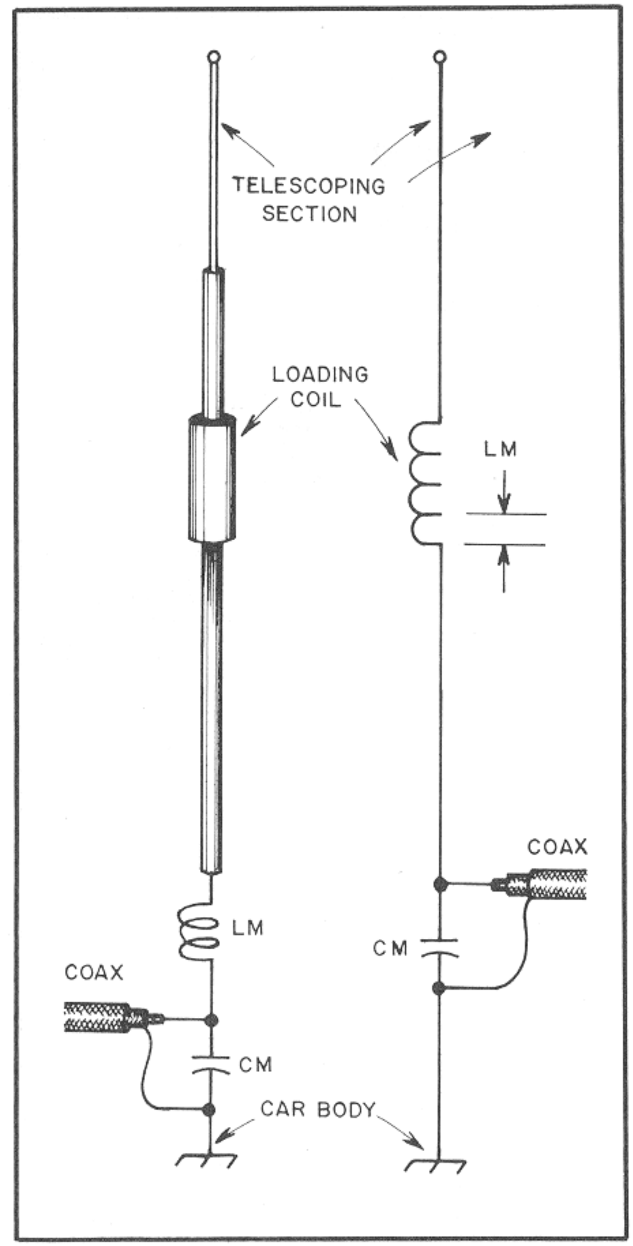
- To remedy this, several techniques are used to make an antenna *appear* to be $\lambda/4$.





Loading coil

- A **loading coil** is a series inductance used to cancel out the capacitance of an antenna (lowering the resonant frequency)
- The coil is often variable in order to tune the antenna for different frequencies.



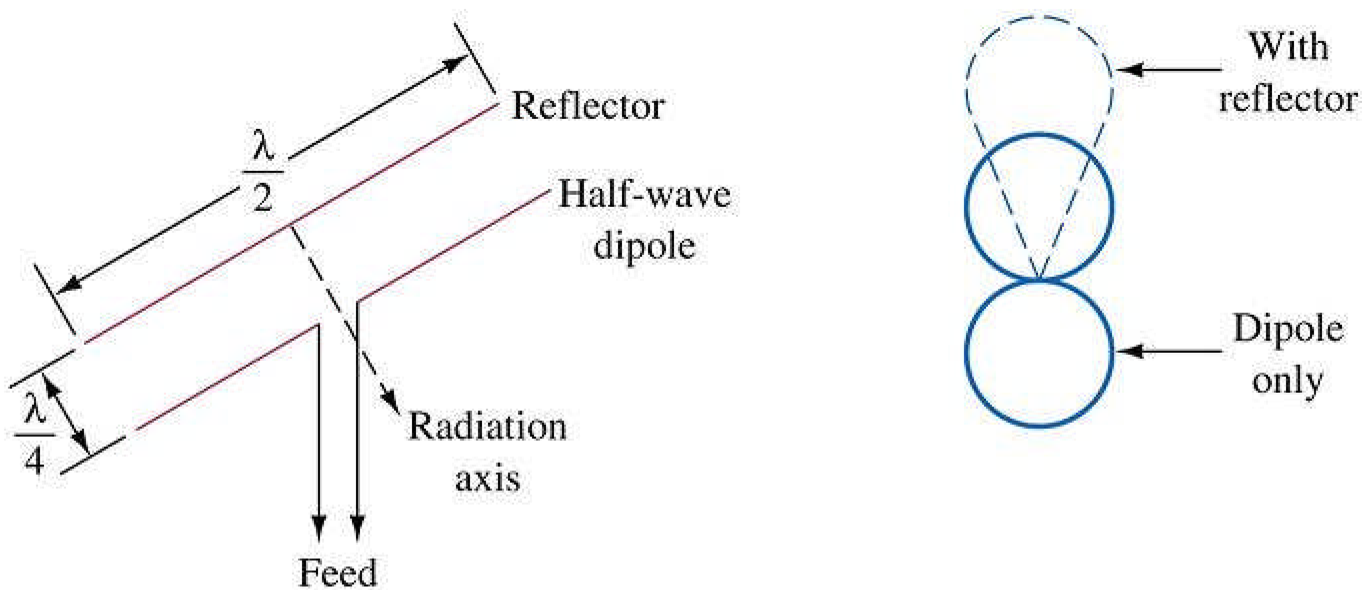
Antenna arrays

- 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.

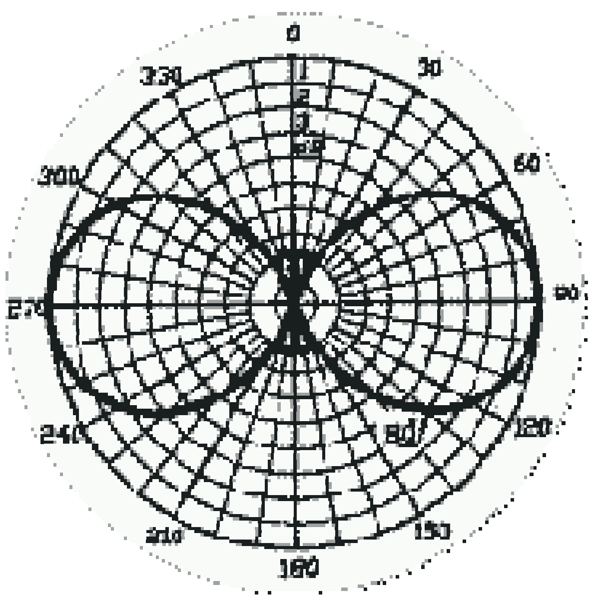
Antenna arrays

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

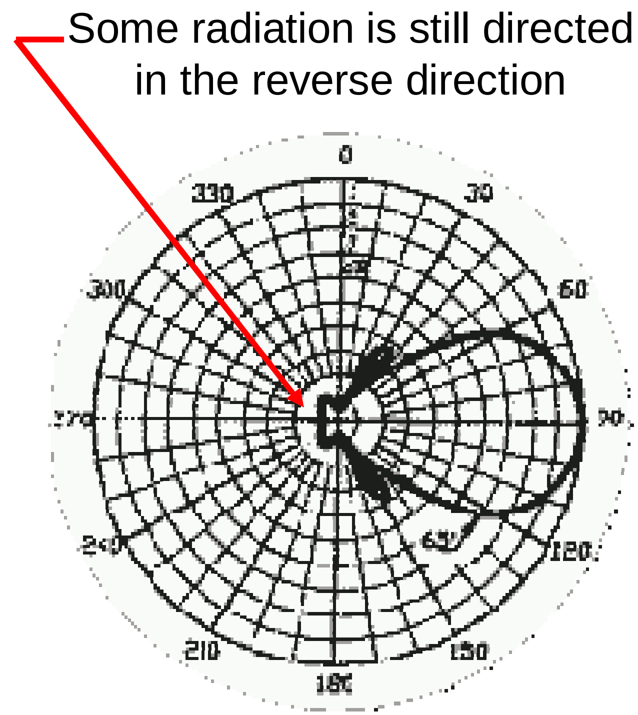


Operation of parasitic element

- The parasitic element is also called a reflector because it reflects the energy of the driven element.
- This doubling results in a 3 dB gain compared to a half-wave dipole antenna.



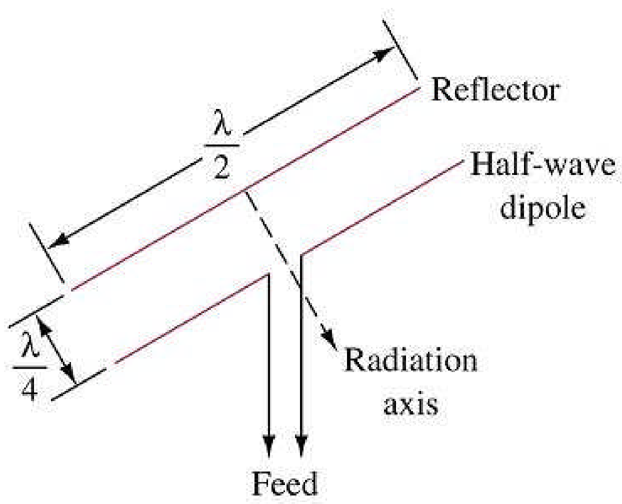
Dipole without reflector



Dipole with reflector

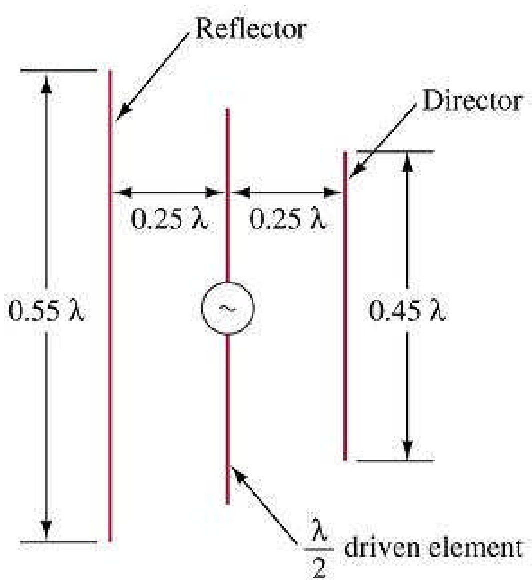
Operation of parasitic element

- 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, while the radiation going in the reverse direction is out of phase and causes cancellation.

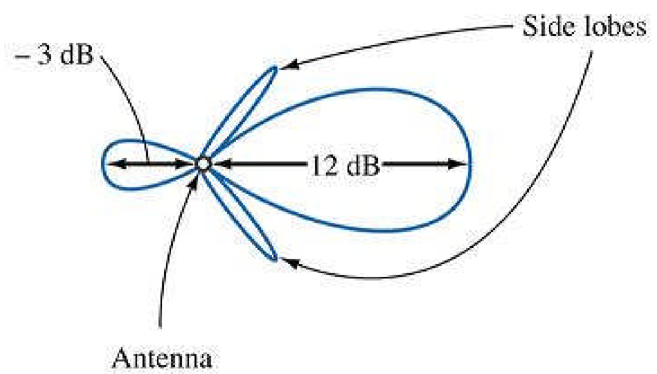


Yagi-Uda antenna

- A Yagi-Uda (inventors) antenna consists of a driven element and one or more parasitic elements called reflectors and directors.
- The director is a parasitic element that "directs" electromagnetic energy in the desired direction.
- Typical beam widths are 20-40º.



Associated radiation pattern



Yagi-Uda antenna

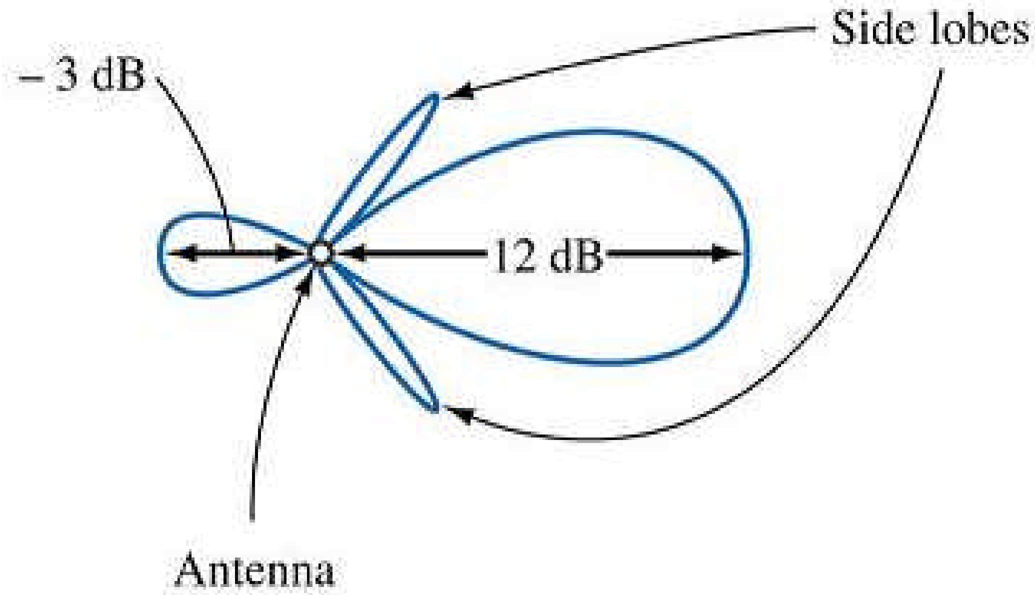
- The front-to-back ratio (F/B ratio) is the ratio of the power radiated in the forward direction to the power radiated in the backward direction.

$$F/B = 10\log\frac{P_f}{P_b} \quad [\mathrm{dB}]$$

  where P_f = forward power and 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.

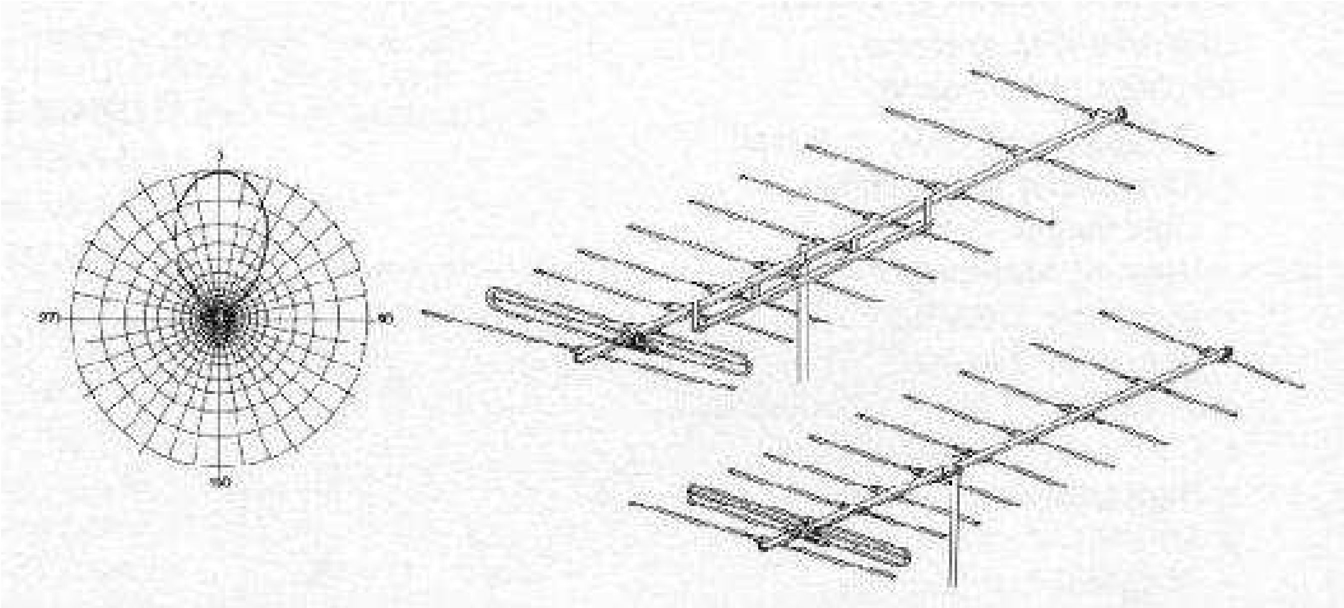
Example Problem 4

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



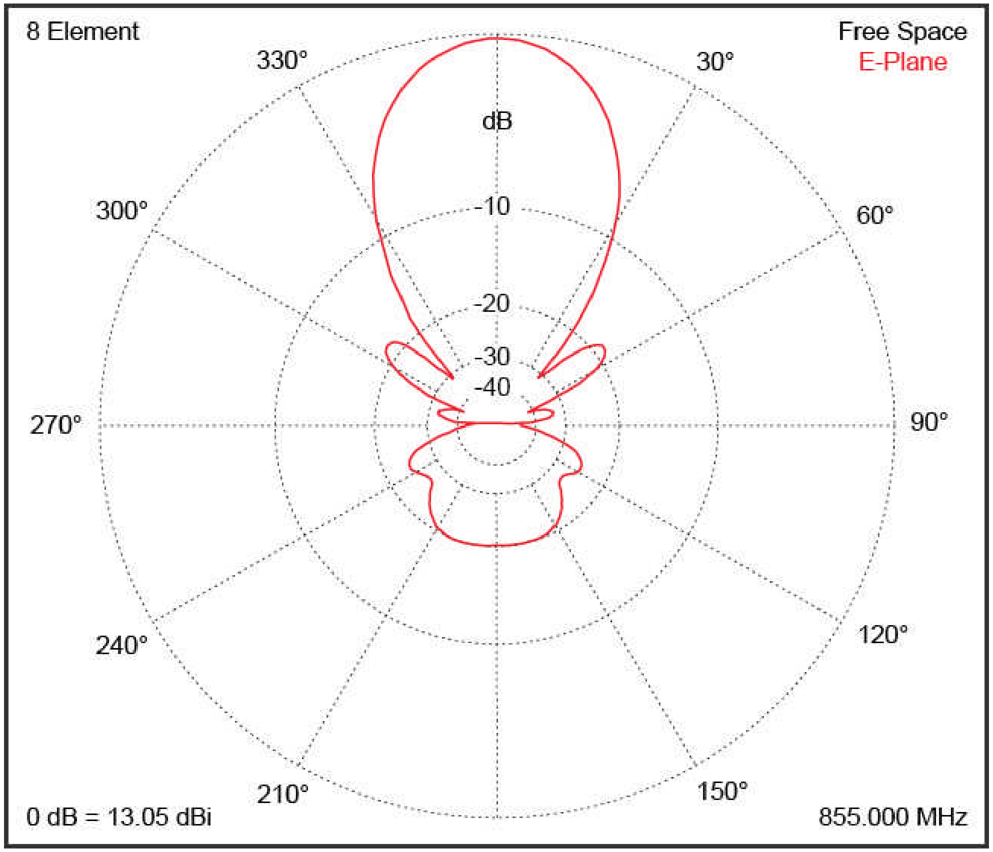
Yagi-Uda antenna

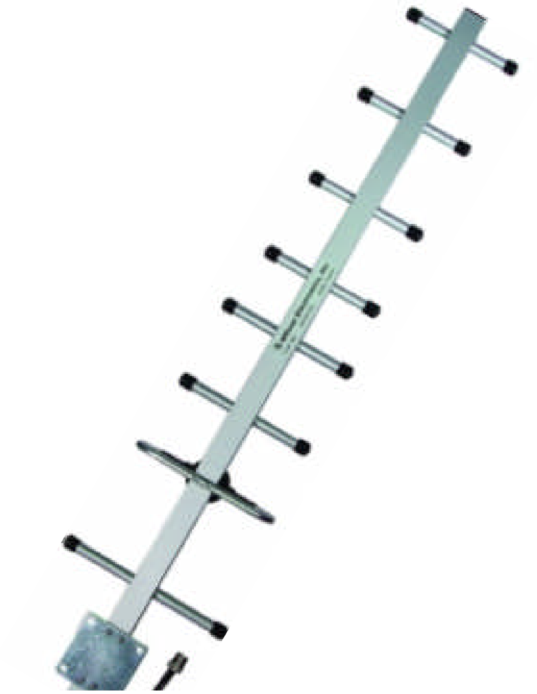
- More complicated Yagi-Uda antennas consist of a reflector and many directors to improve gain.
- This type antenna design is common of HF transmitting antennas and VHF/UHF television receiving antennas.

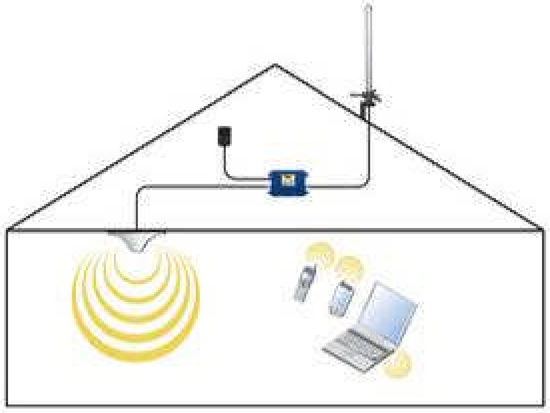


10 element Yagi VHF-TV antenna (10 dB gain)

Yagi-Uda antenna



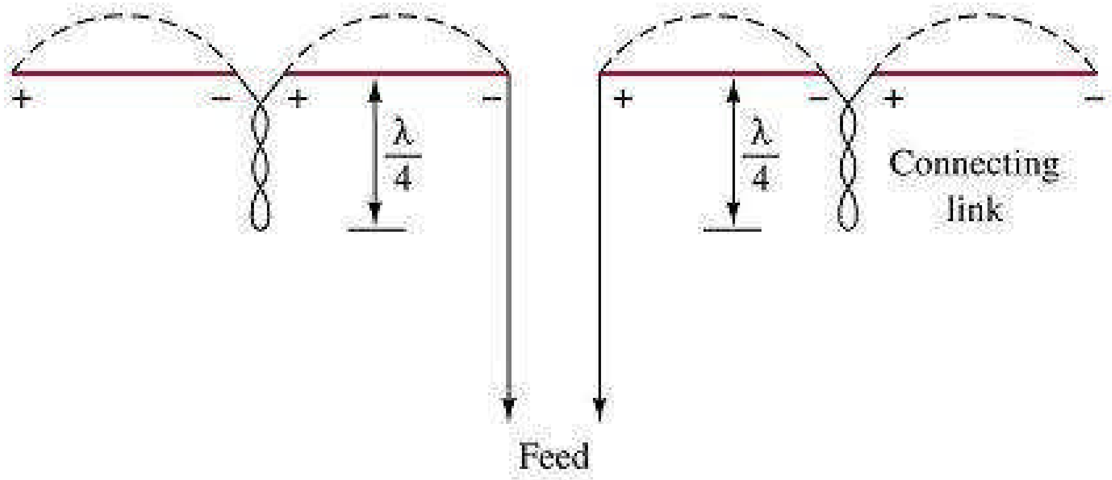


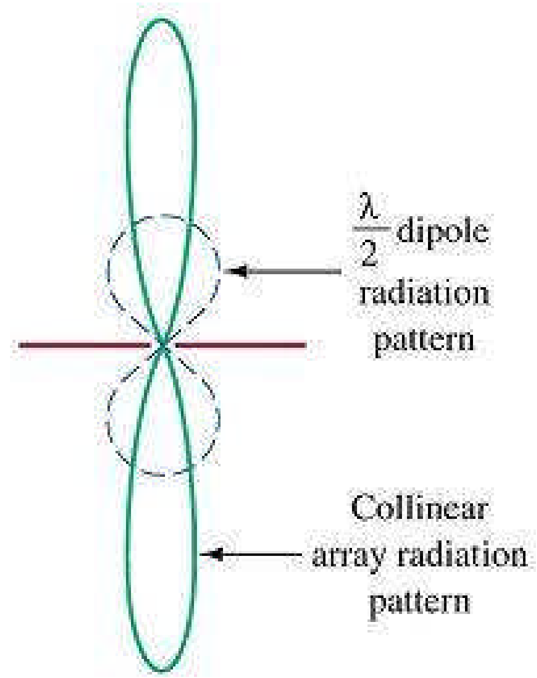


13dbi Yagi 806-939 MHz Cellular Antenna

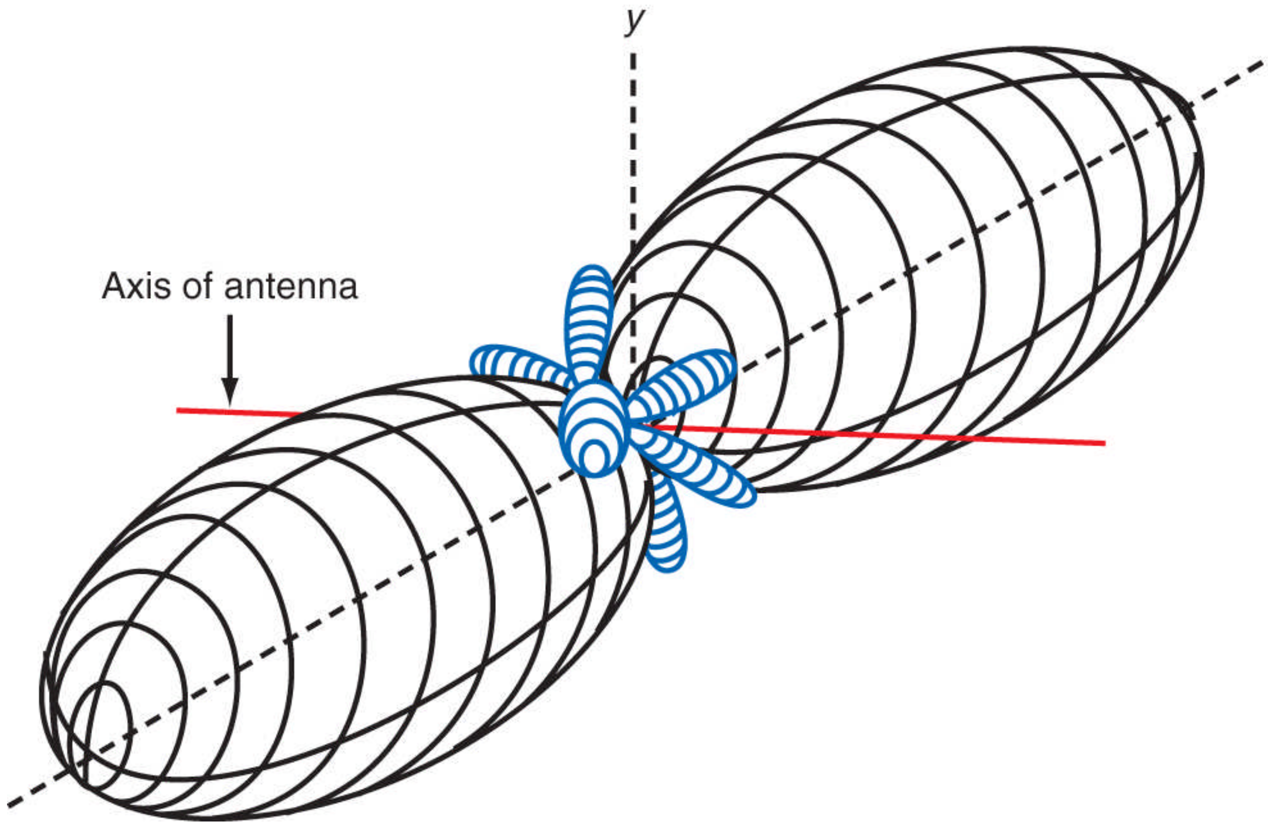
Driven arrays

- A **driven array** is a multi-element antenna in which **all** of the elements are excited through a transmission line.
- Consider the four element collinear array below.
- A collinear array consists of 2 or more dipoles connected end-to-end



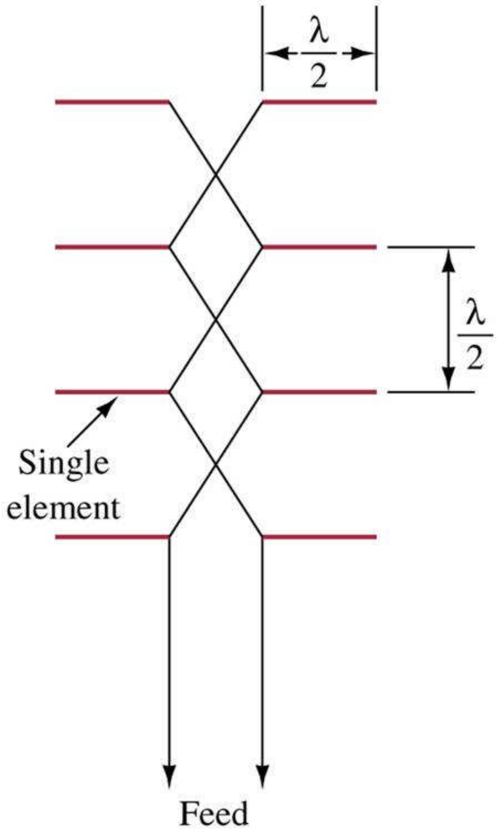


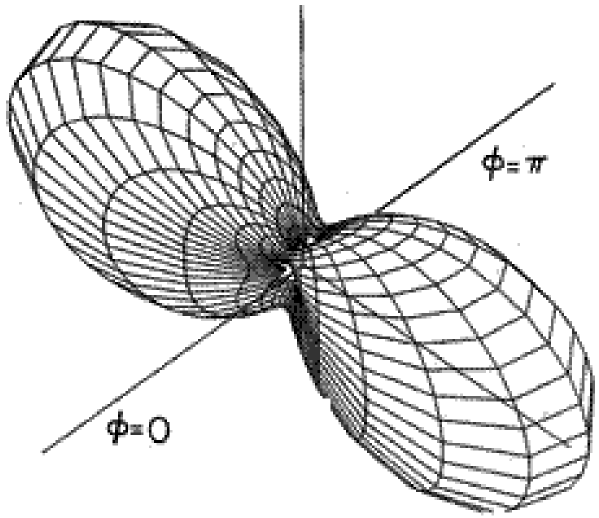
Four element collinear antenna radiation pattern



Broadside array

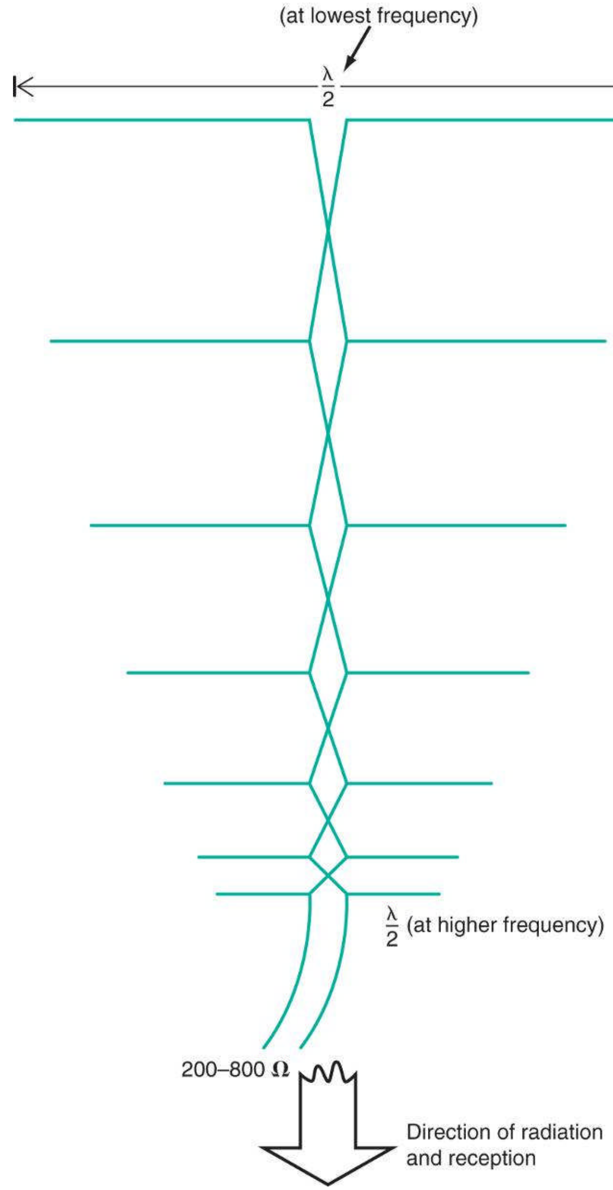
- The broadside array is a stacked collinear antenna
- The broadside array results in increased directivity in both the horizontal and vertical plane.





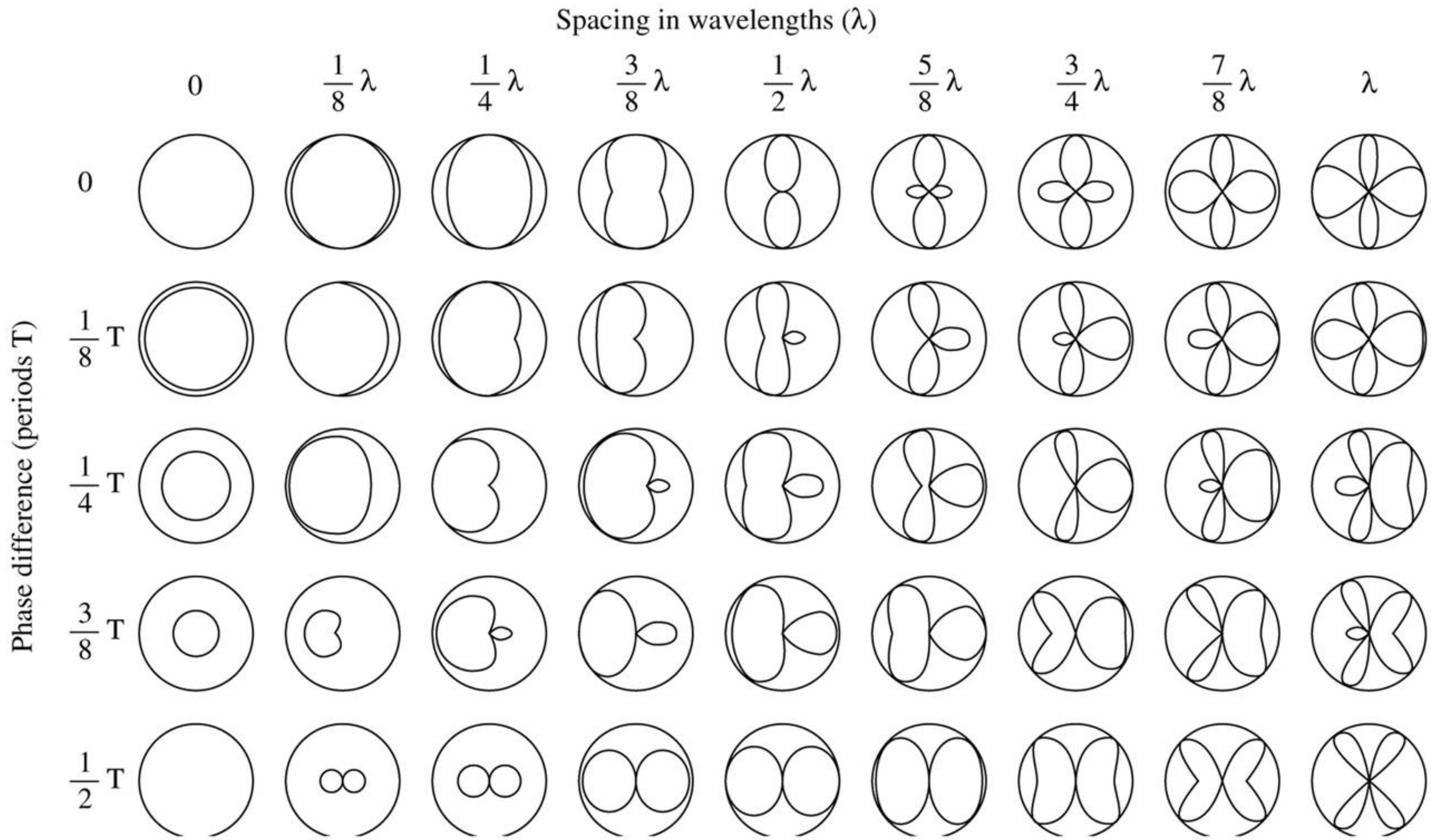
Log-Periodic Antenna

- 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



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 in the fleet
- Eliminating rotating antennas saves weight and significant maintenance costs

Eliminates the large, rotating antenna topside

Phased Array Radar

Patriot Missile Phased Array