Antennae Basics

Outline

- Essentials
- Antennae Examples
- Radiation Patterns
- Idealized Models
  - 2D
  - 3D

Ultimate Goal:
Understanding antennae basics will help us build the right models and answer the right questions!

Essentials

What is an antenna?

- An antenna is a converter!
  - **Transmission:** converts radio-frequency electric current to electromagnetic waves, radiated into space.
  - **Reception:** collects electromagnetic energy from space and converts it to electric energy.
- In two-way communications, the same antenna can be used for transmission and reception

Essental Characteristic: Wavelength

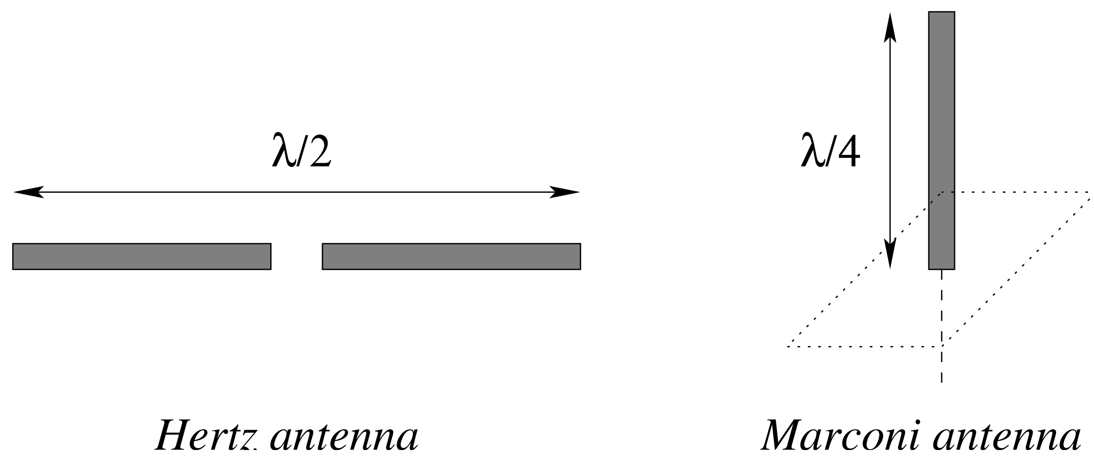
- **Wavelength:** is the distance, in free space, traveled during one complete cycle of a wave
- **Wave velocity:** Speed of light
- Therefore wavelength is given by

$$\lambda_{meters} = \frac{300 \times 10^6 \text{ meters/sec}}{\text{frequency } f \text{ in Hertz}}$$

- **Example:** You have a tooth filling that is 5 mm (= 0.005 m) long acting as a radio antenna (therefore it is equal in length to one-half the wavelength). What frequency do you receive?

Examples

- **Dipoles** are the simplest type of antenna



The **Hertz** (or half-wave) dipole consists of two straight collinear conductors of equal length separated by a small feeding gap. Length of antenna is half of the signal that can be transmitted most efficiently.

- The **Marconi** (or quarter-wave) is the type used for portable radios.

Types of Antennae

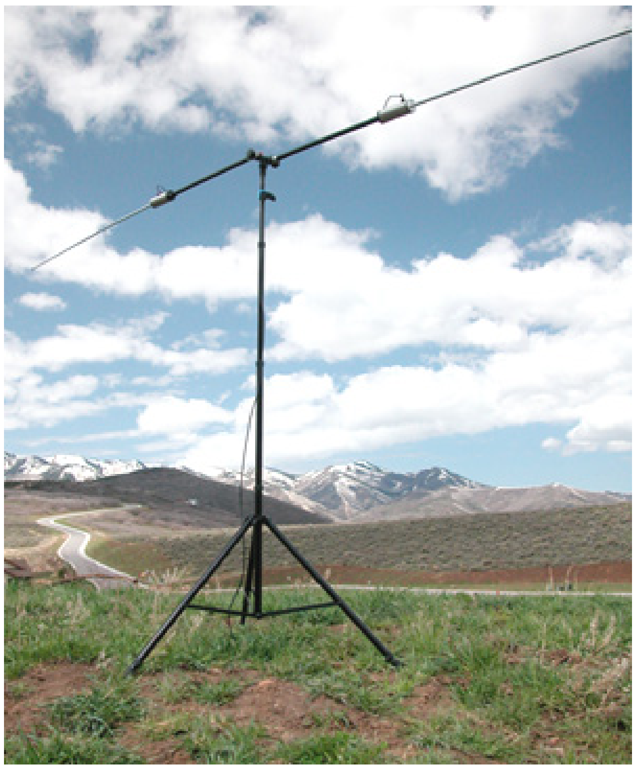
- **Isotropic**
  - Idealized, point in space
  - Radiates power equally in all directions
  - True isotropic radiation does not exist in practice!
- **Dipole**
  - Half-wave dipole (Hertz antenna)
- **Omnidirectional**
  - 2D isotropic Vertical, 1/4–wave monopole, Marconi, Groundplane
- **Directional**
  - Yagi
  - Parabolic Reflective

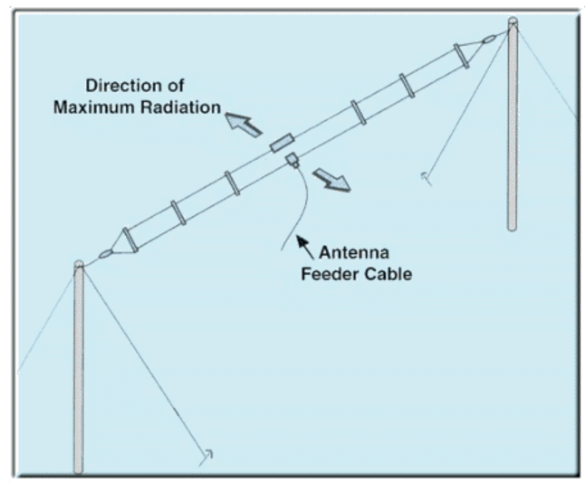
Antennae Examples

Dipole (1/2)

- Emission is maximal in the plane perpendicular to the dipole and zero in the direction of wires which is the direction of the current.

Dipole (2/2)

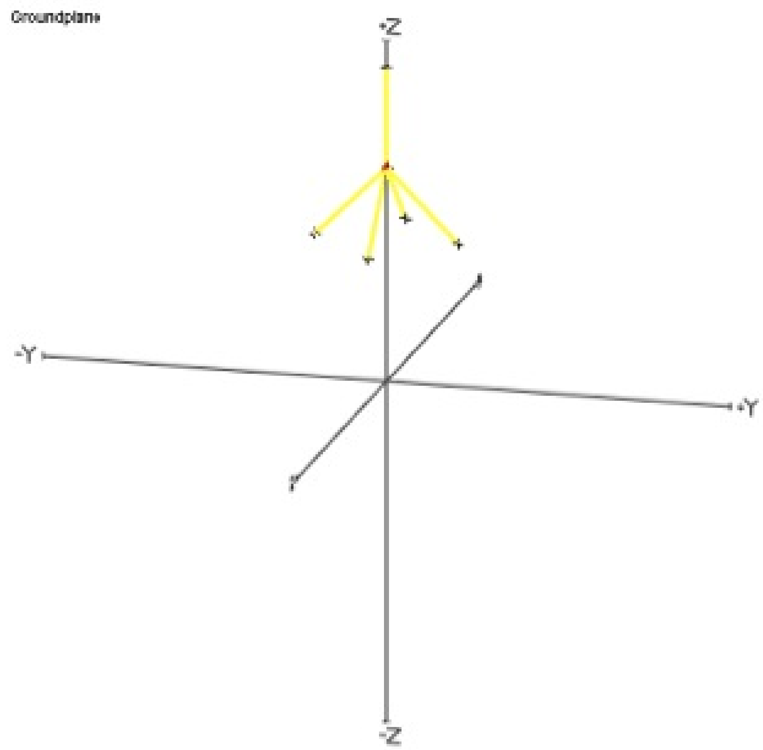




Groundplane (1/2)

- Main element of a ground-plane antenna is almost always oriented vertically.
- This results in transmission of, and optimum response to, vertically polarized wireless signals.
- When the base of the antenna is placed at least 1/4 wavelength above the ground or other conducting surface, the radials behave as a near-perfect ground system for an electromagnetic field, and the antenna is highly efficient.

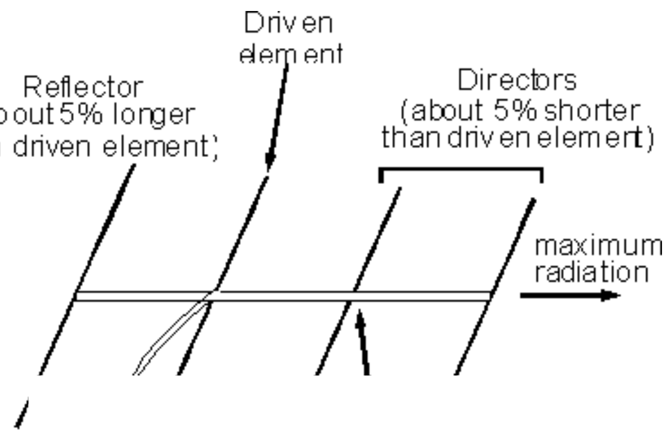
Groundplane (2/2)

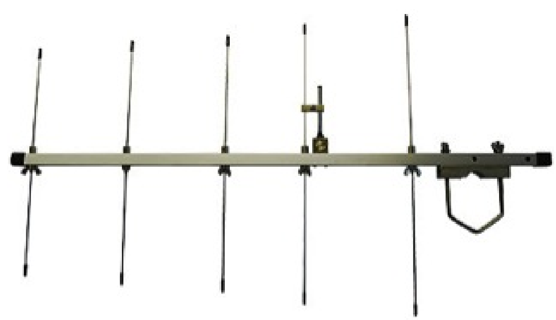


Yagi (1/2)

- Is a directional antenna consisting of a driven element (typically a dipole or folded dipole) and additional elements (usually a so-called reflector and one or more directors).
- It is directional along the axis perpendicular to the dipole in the plane of the elements, from the reflector toward the driven element and the director(s).

Yagi (2/2)

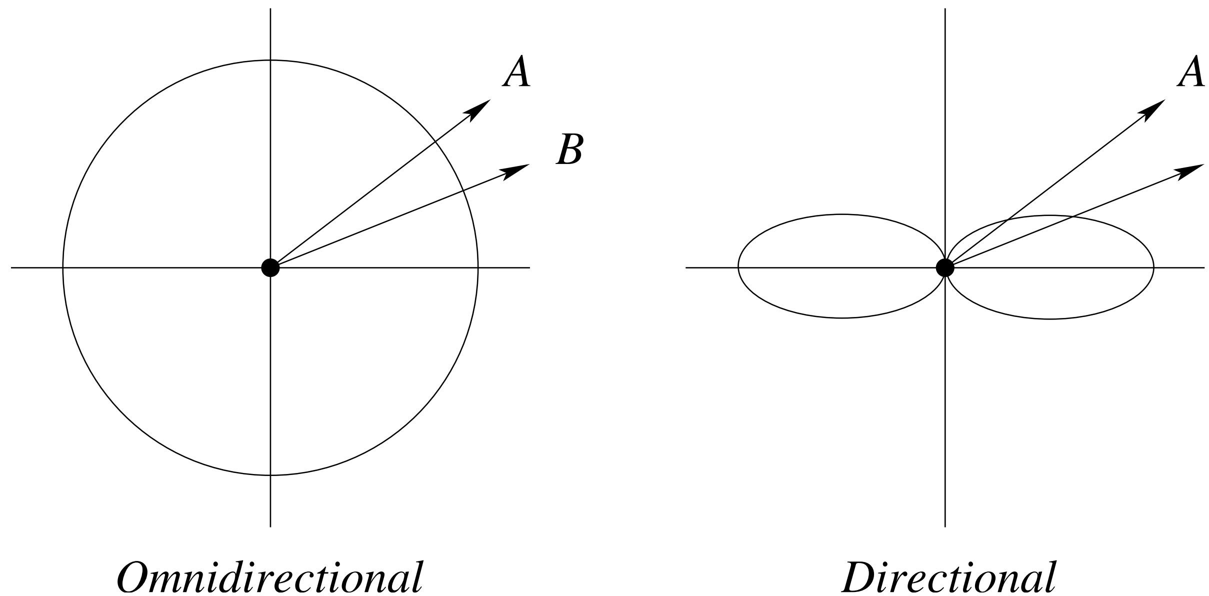

Driven element
Reflector (about 5% longer than driven element)
Directors (about 5% shorter than driven element)
maximum radiation



Radiation Patterns

Radiation Patterns of Antennae

- Antennae transmit radiation according to specific patterns:

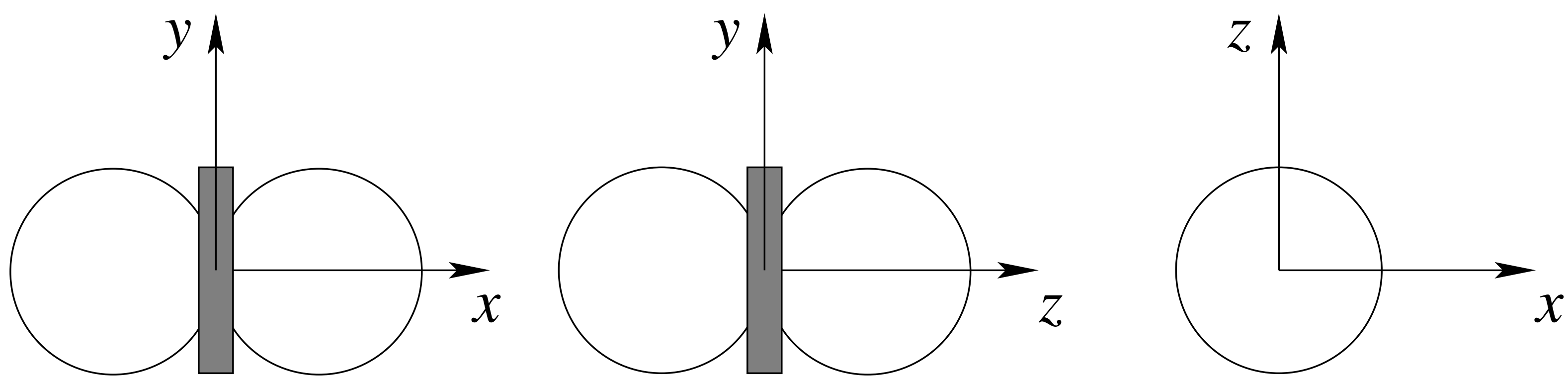


- Omnidirectional are *isotropic* in the sense that same power (radiation) is transmitted in all directions.

- Directional antennas have preferred patterns (like an ellipse): E.g., in the picture above B receives more power than A.

Dipole Radiation Patterns

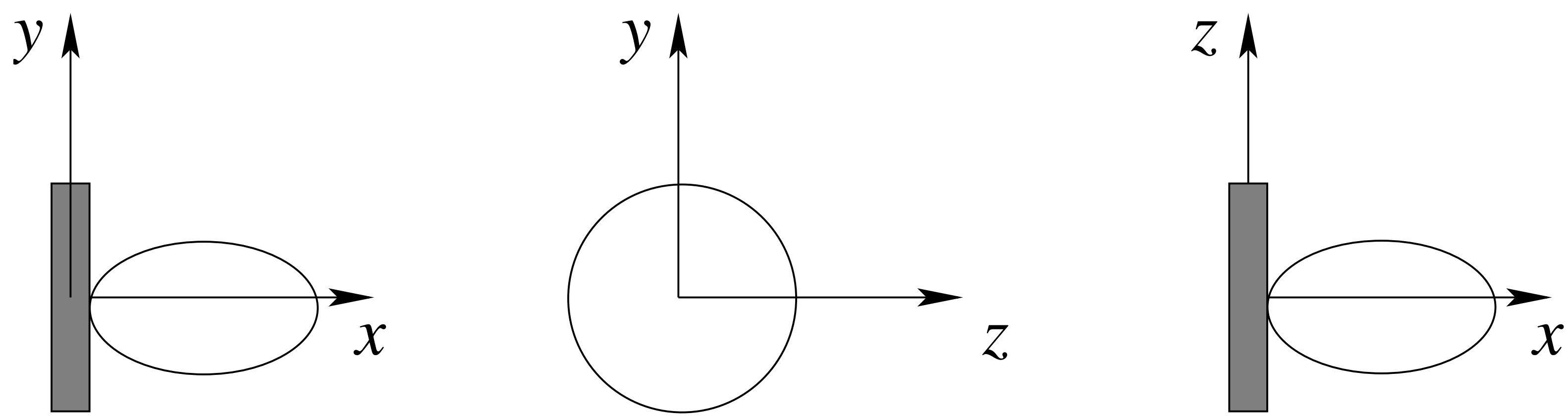
- The half-wave dipole has an omnidirectional pattern only in one planar dimension and a figure eight in the other two.



- For example, the side view along the xy- and zy-plane are figure eight, while in the zx-plane it is uniform (or omnidirectional).

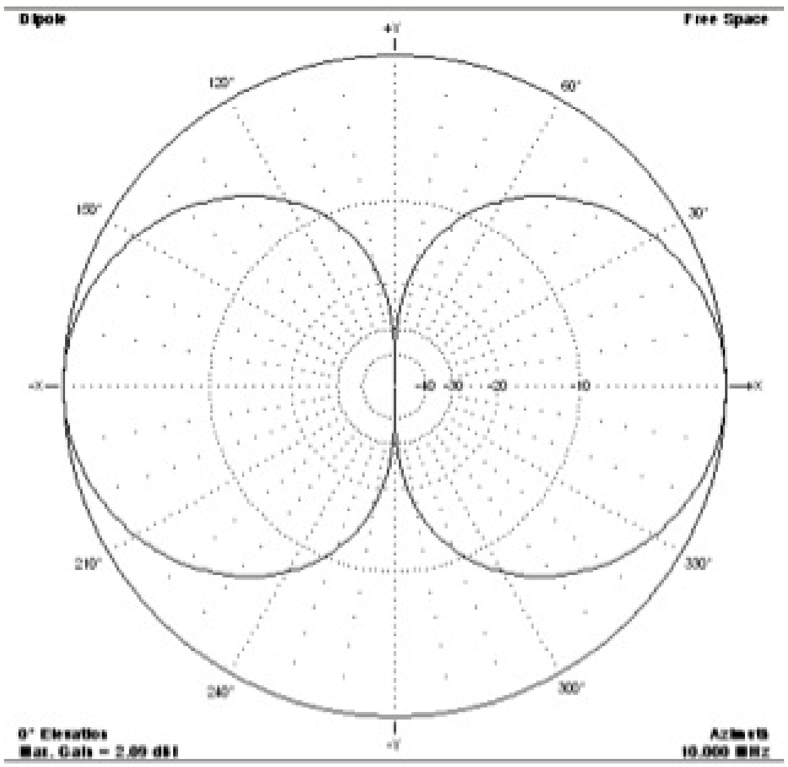
Dipole Radiation Patterns

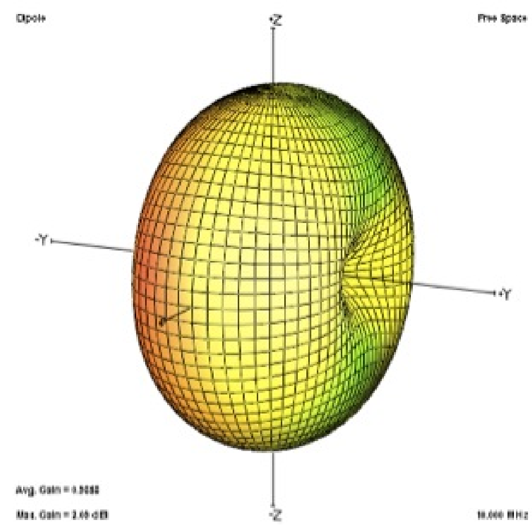
- A typical directional radiation pattern is shown below.



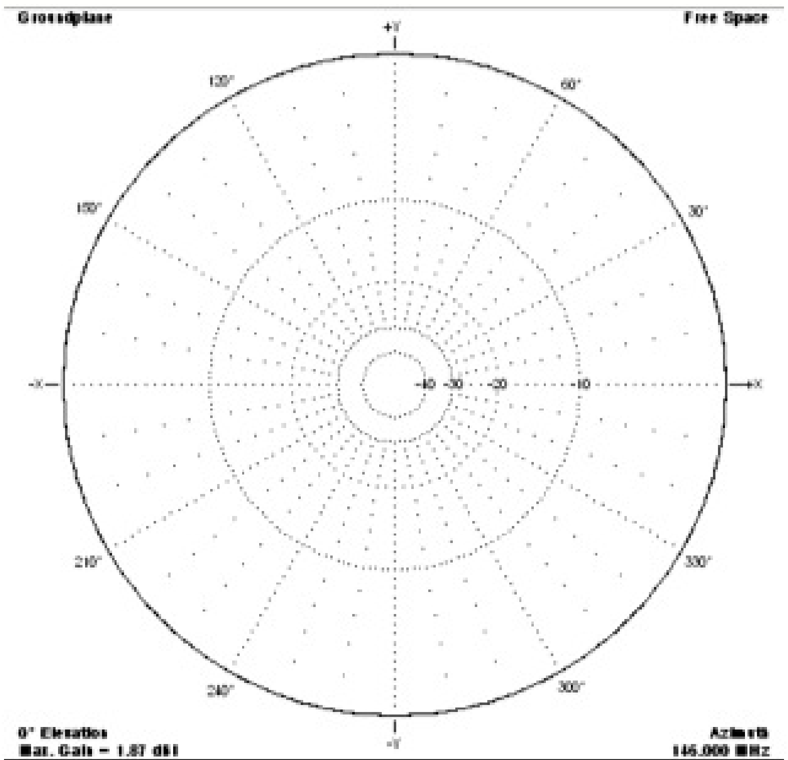
- Here the main strength of the signal is on the x-direction.

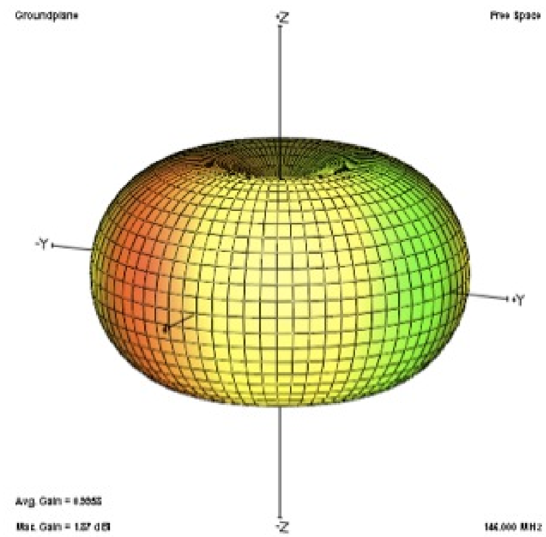
Dipole: Radiation Pattern



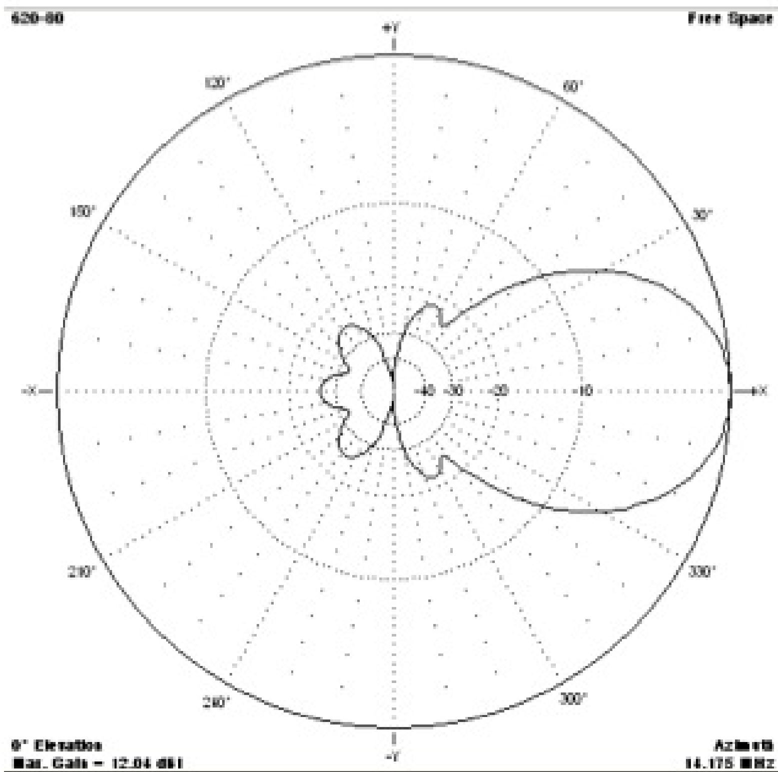


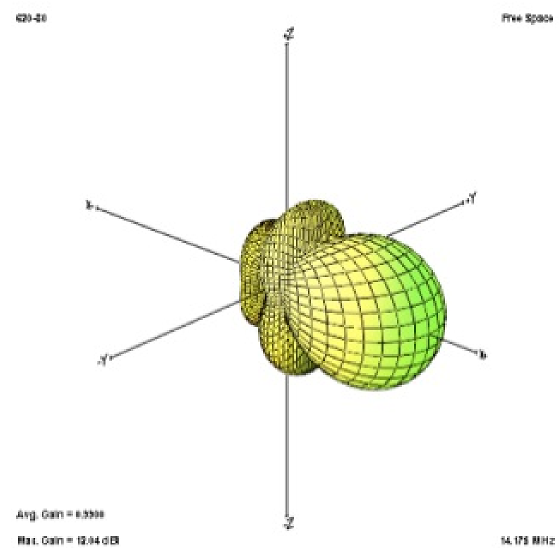
Groundplane: Radiation Pattern





Yagi: Radiation Pattern

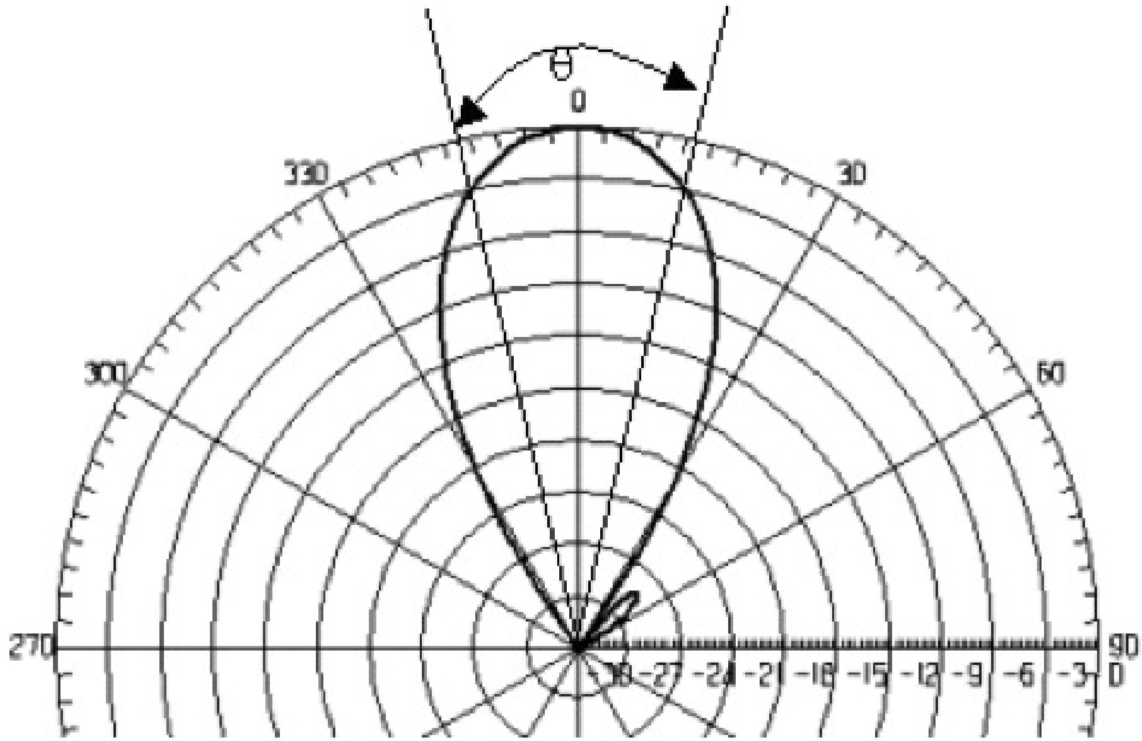




Beamwidth of Antennae

- The **beamwidth** is a measure of the directivity of the antenna.
- It is the angle within which the power radiated by the antenna is at least half of what it is in the most powerful direction.
- For this reason it is called **half-power beam width**.
- When an antenna is used for reception, then the radiation pattern becomes **reception** pattern.

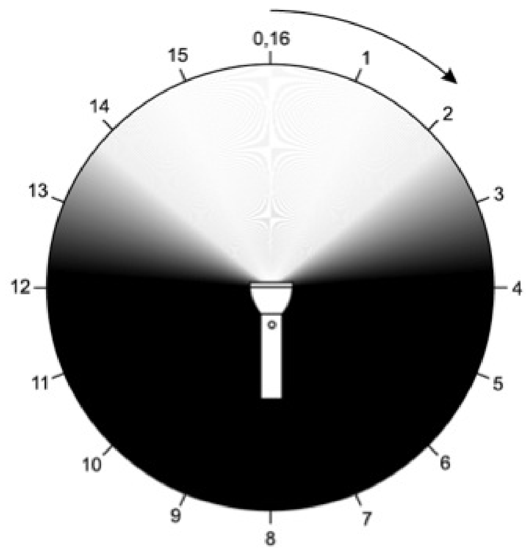
Beamwidth

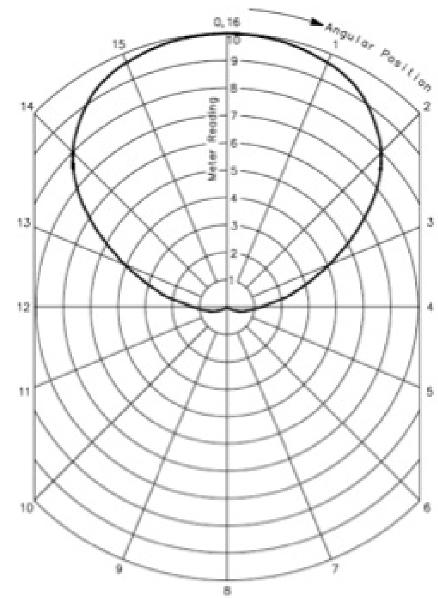


Value of θ in degree = 3 dB beamwidth.

Directivity and Gain

- Flashlight Analogy



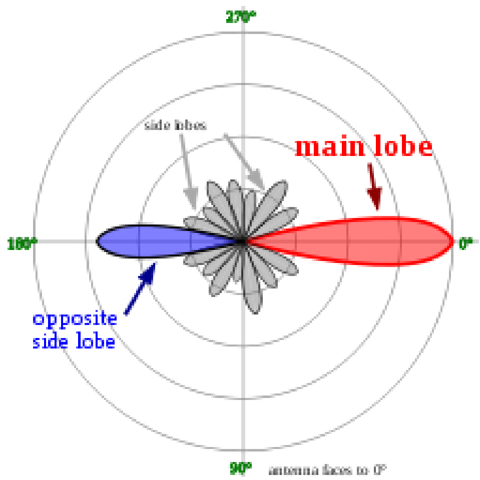


Directive Gain

- **Directive gain** compares the radiation intensity (power per unit solid angle) U that an antenna creates in a particular direction against the average value over all directions:

$$D(\theta, \phi) = \frac{U}{\text{Total radiated power}/\,(4\pi)},$$

where θ and ϕ are angles of the standard spherical coordinates.



- The **directivity** of an antenna is the maximum value of its directive gain.

Directive Gain

- The **directive gain signifies** the ratio of radiated power in a given direction relative to that of an isotropic radiator which is radiating the same total power as the antenna in question but uniformly in all directions.

Power Gain

- Antenna efficiency ($E_{antenna}$) is the ratio between its input power and its radiated power.
- (Power) gain is a unitless measure combining an antenna's efficiency $E_{antenna}$ and directivity D

$$G = E_{antenna} \cdot D$$

- When considering the power gain for a particular direction given by an elevation (or "altitude") θ and azimuth ϕ, then

$$G(\theta, \phi) = E_{antenna} \cdot D(\theta, \phi)$$

- The **power gain signifies** the ratio of radiated power in a given direction relative to that of an isotropic radiator which is radiating the total amount of electrical power received by the antenna in question.

Antenna Gain

- Power output, in a particular direction, compared to that produced in any direction by an isotropic antenna
- Can be expressed as a ratio of power
- Better expressed in dBi

$$10 \log_{10} \frac{P_a}{P_i}$$

iPhone Antennae

- Uses the stainless steel band around the phone as the antenna for GSM, UMTS, WiFi, GPS and Bluetooth

- Design aximizes antenna size (for better performance) and minimizes space it occupies
- The iPad is using a similar approach where the antenna is the LCD frame around the screen.

The Future: Tunable Antennae

- Technology is being pushed to its limits having to accomodate different frequencies: they need to connect via multiple cellular bands, WiFi, Bluetooth and receive GPS signals not to mention the coming of mobile TV and video which may require even more frequencies.
- Tunable antennas seem to be the upcoming technology as a single antenna might be used for all the frequencies by changing its impedance to optimize performance at various frequencies.
- Since tunable antenna are still in development, using the space around the body of the phone is an ingenious way to free up board space that would be taken up by multiple antennas.

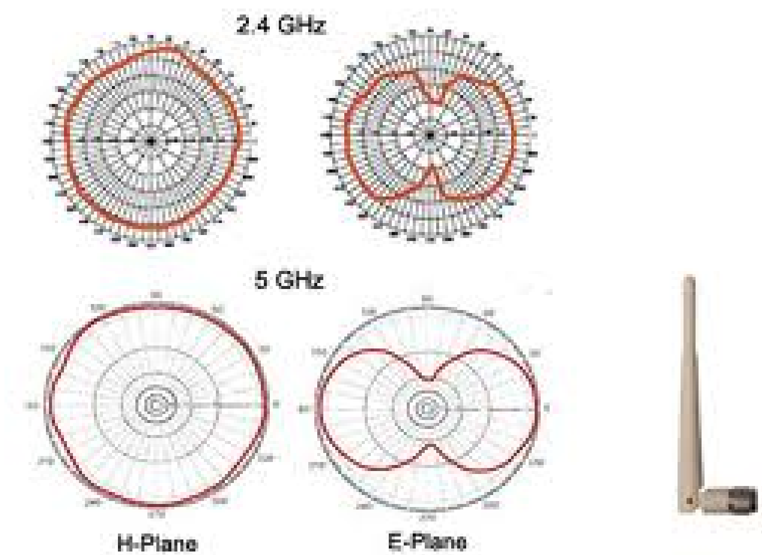
References

- The ARRL Antenna Book. R. Dean Straw, L B Cebik, Dave Hallidy, Dick Jansson. ARRL, 2007.
- Antenna theory: analysis and design. Constantine A. Balanis. John Wiley, 2005.
- Software Defined Radio: Architectures, Systems and Functions. Markus Dillinger, Kambiz Madani, Nancy Alonistioti. Wiley Series in Software Radio, 2003.

Idealized Models

Realistic Model

- Realistic models of radiation patterns are rather complex

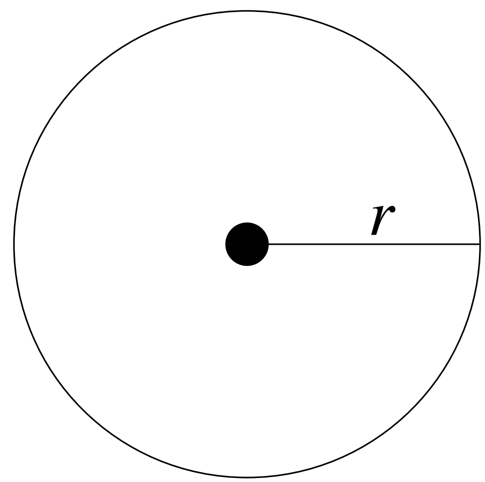


Basic (Idealized) Model

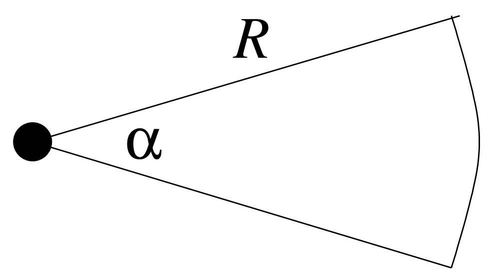
- **Isotropic Omnidirectional**
  - Idealized, point in plane/space
  - Radiates power equally in all directions
- **Isotropic Directional**
  - Idealized, point in plane/space
  - Radiates power equally in all directions within a sector/cone

2D

- Omnidirectional with range r

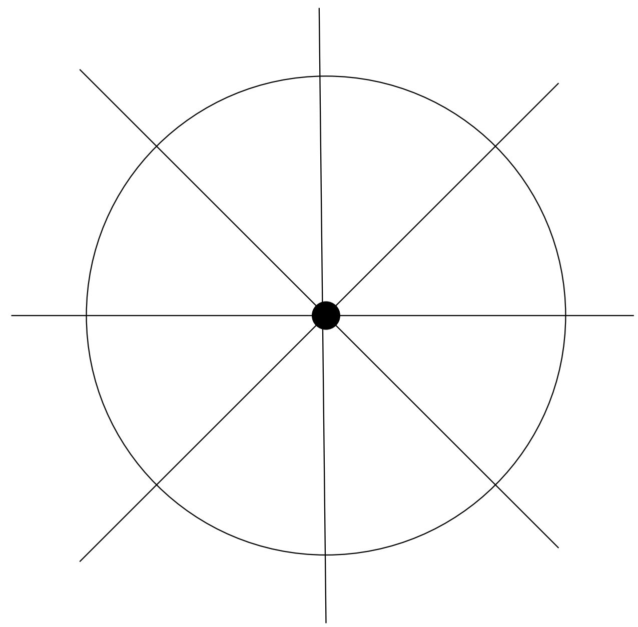


- Directional with range R and angular spread α



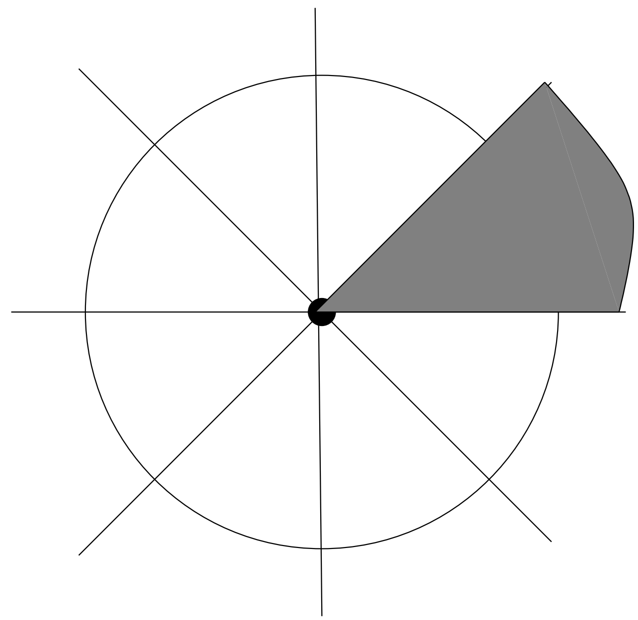
Omnidirectional as Directional Antennae (1/2)

An omnidirectional antenna consists of directional antennae each covering a different sector.



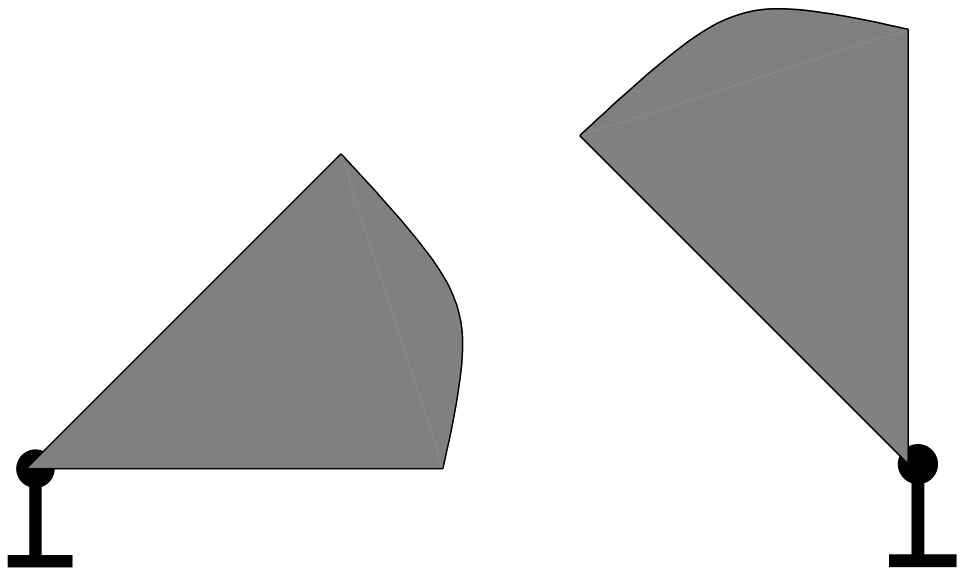
Omnidirectional as Directional Antennae (2/2)

Any of these sectors can be activated in order to connect to a neighbor.



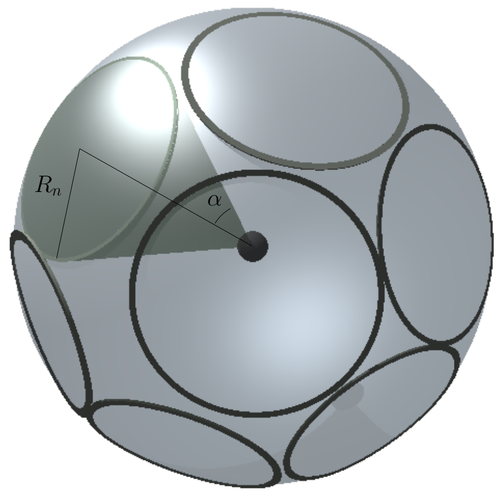
Directional Antennae on a Rotating Swivel

The sensor sits on a rotating swivel and can rotate at will in order to connect to neighbors.



3D

- Entirely analogous models and assumptions
- Omnidirectional with range r
- Directional with range R and **spherical** angular spread α



Communicating with Directional Antennae

- The range of an antenna is divided into n zones.
- Each zone has a conical radiation pattern, spanning an angle of $2\pi/n$ radians.
- The zones are fixed with non-overlapping beam directions, so that the n zones may collectively cover the entire plane.
- When a node is idle, it listens to the carrier in omni mode.
- When it receives a message, it determines the zone on which the received signal power is maximal.
- It then uses that zone to communicate with the sender.