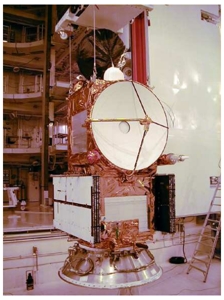


Introduction to Antennas

Dr. Sandra Cruz-Pol
Electrical and Computer Engineering
University of Puerto Rico at Mayaguez

What is an antenna?

- An antenna is a passive structure that serves as transition between a transmission line and air used to transmit and/or receive electromagnetic waves.

Antenna

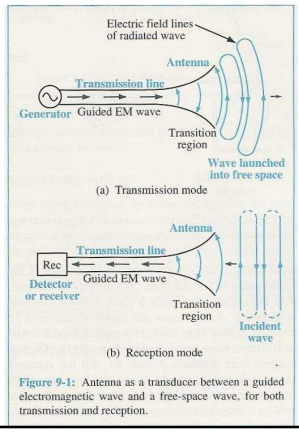
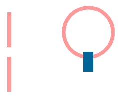


Figure 9-1: Antenna as a transducer between a guided electromagnetic wave and a free-space wave, for both transmission and reception.

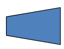
Ulaby, 1999

Types of antennas

- Can be divided into two groups
  - **Wire** antennas:
    - dipoles, loops, Yagi-Uda…



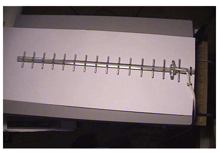
  - **Aperture** antennas:
    - parabolic, horns, microstrip antennas…



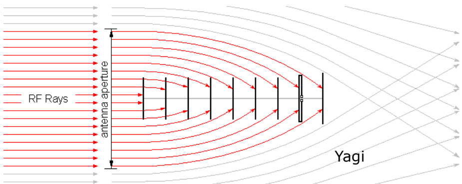
http://www.kyes.com/antenna/antennatypes/antennatypes.html
http://en.wikipedia.org/wiki/Antenna_(electronics)#Overview

Wire antennas

Log periodic

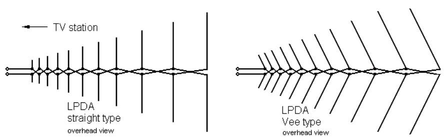


Yagi

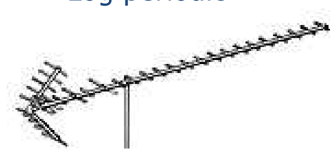


Yagi

Wire antennas

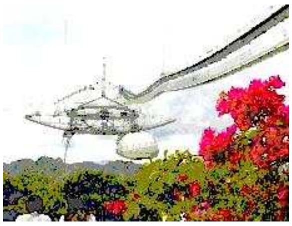


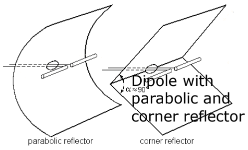
Log periodic



Yagi-Uda with reflector

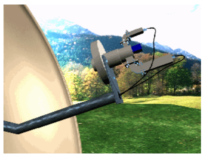
Aperture antennas

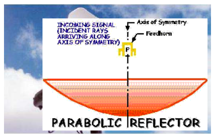


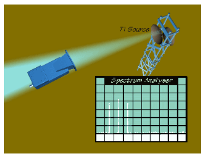


Spherical (main reflector)
with Gregorian feed

Reflector and Pyramidal horn antennas







Outline

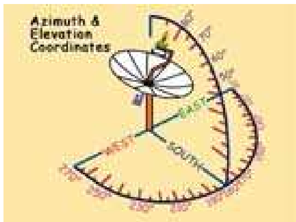
Antenna parameters

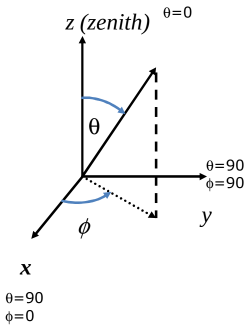
- Solid angle, Ω_A and Radiation intensity, U
- Radiation pattern, P_n, sidelobes, *HPBW*
- Far field zone, r_{ff}
- Directivity, D or Gain, G
- Antenna radiation impedance, R_{rad}
- Effective Area, A_e

All of these parameters are expressed in terms of a **transmission** antenna, but are identically applicable to a **receiving** antenna. We'll also study:

- Friis Transmission Equation
- Radar Equation

Spherical coordinates

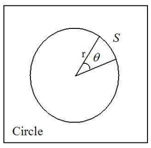


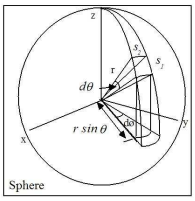


ϕ= azimuth

θ= elevation

Solid Angle





$s = \theta r$ = arco

θ = ángulo plano

•El arco total en un círculo: $= 2\pi r$

•Angulo total: $= 2\pi$ [radianes]

$s_1 = r\,d\theta \quad s_2 = r \sin\theta\, d\phi$

$dA = s_1 s_2$

$dA = r^2 \sin\theta\, d\phi\, d\theta$

$= r^2\, d\Omega$

$d\Omega$ = elemento de ángulo sólido

• *El área total en una esfera:* $= 4\pi r^2$

•*Angulo sólido total:* $= 4\pi$ [rad^2] $= 4\pi$ [sr]

1 steradian (sr) = (1 radian)^2

Radiation Intensity

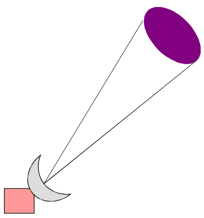
- Is the **power density per solid angle**:

$U = r^2\, \mathscr{P}_r$ [W/sr]

where

$\mathscr{P}_r = ½\, \mathrm{Re}\{E \times H^*\}\hat{r}$ [W/m^2]

is the power density also known as Poynting vector.



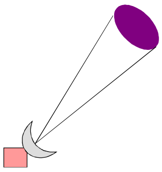
Total radiated power by antenna

- Can be calculated as;

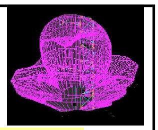
$$P_{rad} = \int U \cdot d\Omega \, [\mathrm{W}]$$

or

$$P_{rad} = \int \mathcal{P}_r \cdot dS \;\; [\mathrm{W}]$$



Radiation Pattern



- Radiation pattern is the 3D plot of the gain, but usually the 2D horizontal and vertical cross sections of the radiation pattern are considered.
- Refers to the variation of the relative amplitude of the radiation as a function of **direction**.

Field pattern:

$$E_n(\theta,\phi) = \frac{E(\theta,\phi)}{E_{\max}(\theta,\phi)}$$

Power pattern:

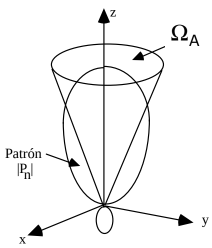
$$F_n(\theta,\phi) = \frac{\mathcal{P}(\theta,\phi)}{\mathcal{P}_{\max}(\theta,\phi)} = \frac{U(\theta,\phi)}{U_{\max}(\theta,\phi)}$$

Where U is the radiation intensity to be defined later.

Total Solid Angle of an antenna

$$\Omega_A = \iint_{4\pi} F_n(\theta,\phi) d\Omega$$

Is as if you changed the **radiation pattern beam** of an antenna into a **pencil beam shape** and find out what's the equivalent solid angle occupied by this pattern.



Isotropic antenna

- It's an hypothetic antenna, i.e., it does not exist in real life, yet it's used as a measuring bar for real antenna characteristics.
- It's a point source that occupies a negligible space. Has no directional preference.

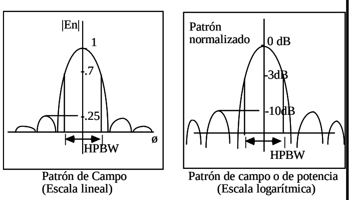
$$\Omega_{isotropic} = \iint_{4\pi} (1) d\Omega$$

$$\int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} (1) \sin\theta \, d\theta \, d\phi = 4\pi$$

- Its pattern is simply a sphere so it has $\Omega_A = \Omega_{isotropic} = 4\pi$ [steradians].

Radiation Pattern

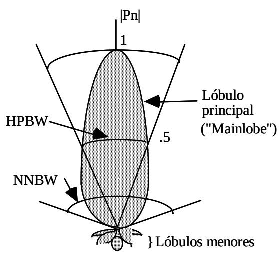
- Whenever we speak of radiation patterns, we normally mean we are at a distance far enough from the antenna known as the **far field**.



COORDENADAS RECTANGULARES

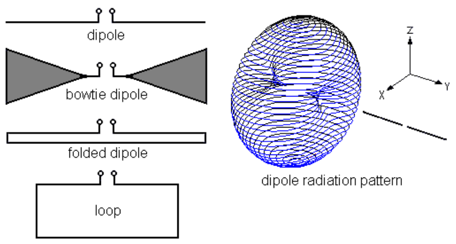
Note that when plotted in decibels, the power and field patterns look exactly the same.

Pattern – polar plot



PATRON TIPICO
(Coordenadas polares esféricas, 2 dimensiones)

Dipole antenna pattern

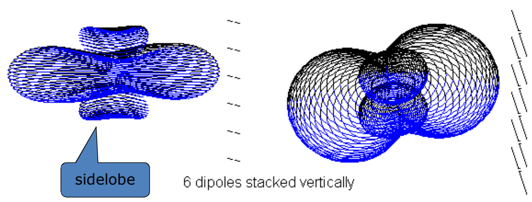


Note the radiation pattern is donut shaped.

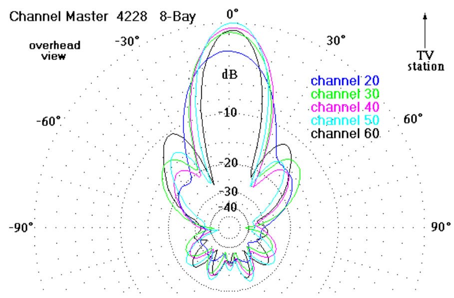
Sidelobes

- Antennas sometimes show **side lobes** in the radiation pattern.
- Side lobes are peaks in gain other than the main lobe (the "beam").
- Side lobes have bad impact to the antenna quality whenever the system is being used to determine the direction of a signal, for example in RADAR systems.

Sidelobes of dipole arrays

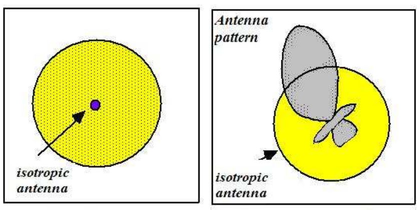


Antenna Pattern with sidelobes



Many applications require sidelobe levels (SLL) to be below -20dB.

Gain or Directivity



Isotropic Pattern

Comparison of regular antenna pattern with isotripic

An isotropic antenna and a practical antenna fed with the same power. Their patterns would compare as in the figure on the right.

Directivity and Gain

- All practical antennas radiate more than the isotropic antenna in some directions and less in others.
- Gain is inherently directional; the gain of an antenna is **usually measured in the direction which it radiates best**.

$$D = D_{\max}(\theta,\phi) = \wp_{\max} / \wp_{ave} = U_{\max} / U_{ave}$$

If lossless antenna, $G=D$

Gain or Directivity

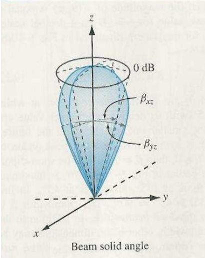
- Gain is measured by comparing an antenna to a model antenna, typically the isotropic antenna which radiates equally in all directions.

$$D(\theta,\phi) = \mathcal{P}/\mathcal{P}_{AVE} = \frac{\Re(\theta,\phi)}{\frac{1}{A}\iint \mathcal{P}\, dA} = \frac{4\pi r^2 \mathcal{P}(\theta,\phi)}{P_{rad}}$$

$$D_o = \frac{4\pi U_{\max}}{P_{rad}} = 4\pi/\Omega_A = \Omega_{\text{isotropic}}/\Omega_A$$

Directivity

- For an antenna with a single main lobe pointing in the z-direction , Ω_A can be approximated to the product of the HPBW



$$\Omega_A \cong \beta_{xz}\beta_{yz}$$

then

The Directivity:

$$D = 4\pi/\Omega_A \cong \frac{4\pi}{\beta_{xz}\beta_{yz}}$$

Far field

- The distance at which the fields transmitted by an antenna (spherical) can be approximated to plane waves.
- It's defined as

$$r_{ff} = 2D^2/\lambda$$

D = is the largest physical dimension of the antenna
λ = wavelength of operation
r_{ff} = distance from the antenna to the observation point

Beamwidth, *HPBW*

- Is the "distance" in radians o degrees between the direction of the radiation pattern where the radiated power is half of the maximum.
- Can be found by solving $F_n(\theta,\phi)$=.5

$$10 \ \log \ 0.5 \ = \ \text{-3} \ dB$$

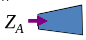
$$20 \ \log \ 0.707 \ = \ \text{-3} \ dB$$

for "pencil beam" shape;

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

Antenna Impedance

- An antenna is "seen" by the generator as a load with impedance Z_A, connected to the line.



$$Z_A = (R_{rad} + R_L) + jX_A$$

- **The real part is the radiation resistance plus the ohmic resistance**.
  - Minimizing impedance differences at each interface will reduce SWR and maximize power transfer through each part of the antenna system.
  - Complex impedance, Z_A, of an antenna is related to the electrical length of the antenna at the wavelength in use.
    - The impedance of an antenna can be matched to the feed line and radio by adjusting the impedance of the feed line, using the feed line as an impedance transformer.
    - More commonly, the impedance is adjusted at the load (see below) with an antenna tuner, a balun, a matching transformer, matching networks composed of inductors and capacitors, or matching sections such as the gamma match.

Antenna efficiency, η

- **Efficiency** is the ratio of power put into the antenna terminals to the power actually radiated
- Radiation in an antenna is caused by radiation resistance which can only be measured as part of total resistance including loss resistance.

$$P_{rad} = \eta P_{in}$$

$$G = \eta D$$

Radiation Resistance

- The antenna is connected to a T.L., and it "sees" it as an impedance.
- The power radiated is

$$P_{rad} = \frac{1}{2} I_o^2 R_{rad}$$

- The loss power is

$$P_{loss} = \frac{1}{2} I_o^2 R_L$$

$$\eta = \frac{P_{rad}}{P_{rad} + P_{loss}} = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

Radar equation

- What is a radar?
- Received power by a radar is

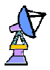
$$P_r = \frac{P_t G_o^2 \lambda_o^2}{(4\pi)^3 R^4} \sigma e^{-2\tau}$$

Where σ is the backscattering coefficient of the target [m^2]

APPLICATIONS

- Application to several research projects: CASA, NASA-FAR, NASA-TCESS
- Show results from undergrads working in NASA and NSF projects
- Relation to Grad students

Antenna polarization



- The **polarization** of an antenna is the polarization of the signals it emits.
  - The ionosphere changes the polarization of signals unpredictably, so for signals which will be reflected by the ionosphere, polarization is not crucial.
  - However, for line-of-sight communications, it can make a tremendous difference in signal quality to have the transmitter and receiver using the same polarization.
  - Polarizations commonly considered are *vertical*, *horizontal*, and *circular*.

Antenna Bandwidth

- The **bandwidth** of an antenna is the range of frequencies over which it is effective, usually centered around the operating or resonant frequency.
  - The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with *cages* to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly and allowing the natural impedance to select the correct antenna.

Effective Area

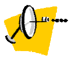
- How a Rx antenna extracts energy from incident wave and delivers it to a load?

$$A_e = \frac{P_{rec}}{\mathcal{P}_{inc}} = \frac{\lambda^2 D}{4\pi}$$

Above is valid for any antenna under matched-load conditions

Friis Transmission Eq.

- In any communication link, there is a transmitting antenna and a receiver with a receiver antenna.



TX

RX

$$\mathcal{P}_{isotr} = \frac{P_t}{4\pi R^2}$$

$$P_{tx} = G_t P_{isotr} = \frac{G_t P_t}{4\pi R^2} = \frac{A_t P_t}{\lambda^2 R^2}$$

$$P_{rec} = A_r \mathcal{P}_t = \frac{A_t A_r P_t}{\lambda^2 R^2}$$

$$P_{rec} = \frac{G_t G_r P_t \lambda^2}{(4\pi R)^2}$$

Example

- Radar and Friis

Antenna Arrays

- Uses many antennas synchronized with each other to increase
- Pattern multiplication

Example

- Determine the direction of maximum radiation , pattern solid angle, directivity and HPBW in the y-z plane for an antenna with normalized radiation intensity given by

$$F(\theta,\phi) = \begin{cases} \cos^2\theta & \text{for } 0 \le \theta \le \frac{\pi}{2} \text{ and } 0 \le \phi \le 2\pi \\ 0 & \text{elsewhere} \end{cases}$$