An Introduction to Antennas

Dr. José Ernesto Rayas-Sánchez

1

Outline

- Antenna definition
- Main parameters of an antenna
- Types of antennas
- Antenna radiation (Poynting vector)
- Radiation pattern
- Far-field distance, directivity, efficiency, gain, etc.
- Friis equation
- Equivalent circuits

Dr. J. E. Rayas-Sánchez 2

Definition of an Antenna

It is a component that converts an EM wave propagating on a transmission line to a plane EM wave propagating in free-space, or vice versa (transmission or reception)

Main Parameters of an Antenna

- Radiation pattern: 3D plot of the power density (transmit or receive)
- Far-field: region where the radiated wave has the form of a plane wave
- Directivity: ability to transmit/receive in a given direction
- Efficiency: the ratio of the radiated power to the input power
- Gain: the product of efficiency and directivity
- Impedance: the driving-point impedance offered to the source or to the load

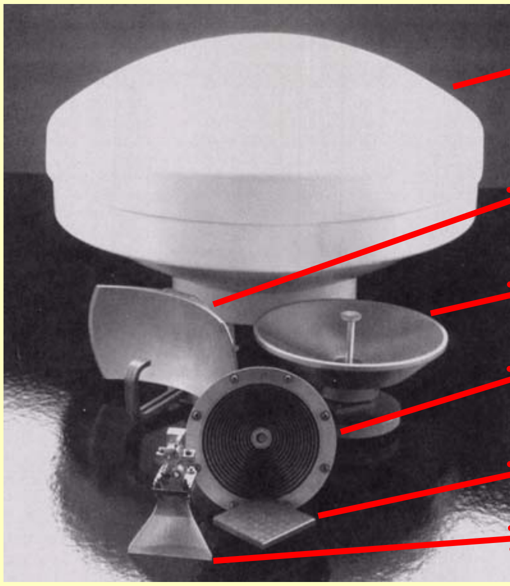
Main Parameters of an Antenna (cont)

- Bandwidth: usable frequency bandwidth (affected by matching networks)
- Polarization: polarization of the electric field intensity vector of the radiated wave (vertical, horizontal, circular, etc.)
- Size/complexity: geometrical structure and size affect radiation pattern, gain, bandwidth, etc. Efficient operation implies a minimum size of $\lambda/2$

Types of Antennas

- Wire antennas: simplest type; used at lower frequencies (HF to UHF); low gain; lightweight
- Aperture antennas: based on an open-ended waveguide; used at microwave frequencies; low gain
- Printed antenna: compatible with planar technology; used at microwave frequencies; low gain
- Reflector antennas: high gain (focused radiation); used at microwave frequencies; bulky and heavy

Types of Antennas (cont)



reflector antenna with radome

multibeam reflector antenna

parabolic antenna

corrugated conical horn antenna

microstrip array antenna

pyramidal horn antenna

Dr. J. E. Rayas-Sánchez

(D. M. Pozar, Microwave Engineering, Wiley, 2005)

7

Wire of Antennas

Yagi-Uda beam antenna

Yagi array antenna (TV)

dipole antenna
(& loop antenna)

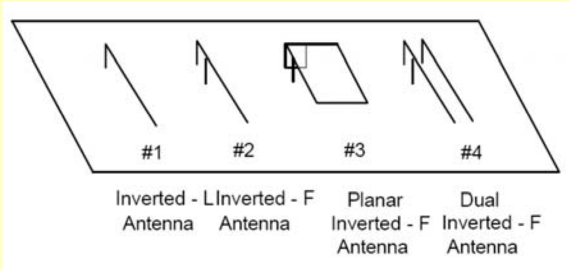
rotatable logarithmic periodic antenna

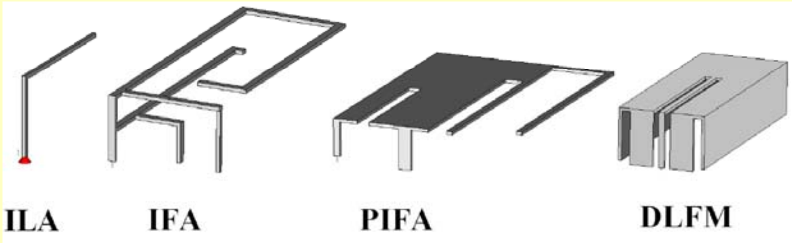
Dr. J. E. Rayas-Sánchez

(Wikipedia, 2010)

8

Combined Planar/Wire Antennas

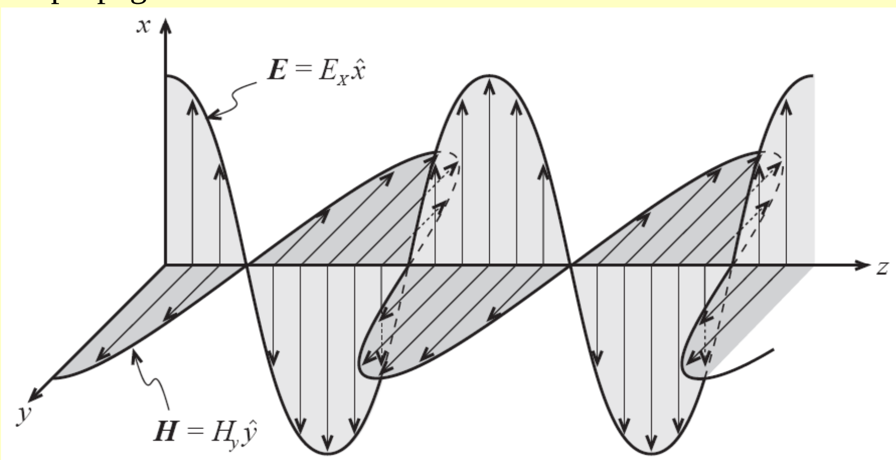




Dr. J. E. Rayas-Sánchez *(Besser Associates, CST, 2010)* 9

TEM Propagation

The electric and magnetic fields in the direction of propagation are zero



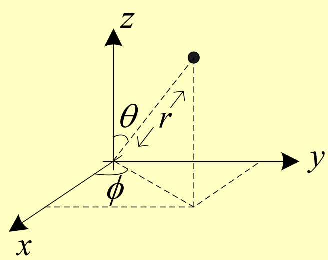
Dr. J. E. Rayas-Sánchez *(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)* 10

Antenna Radiation

- Electric field of an antenna in the far-field zone

  $\boldsymbol{E} = E_\theta \boldsymbol{u}_\theta + E_\phi \boldsymbol{u}_\phi$ (V/m)

  where $\boldsymbol{u}_\theta$ and $\boldsymbol{u}_\phi$ are the unit vector in θ and ϕ directions



- The corresponding magnetic field is

  $\boldsymbol{H} = H_\theta \boldsymbol{u}_\theta + H_\phi \boldsymbol{u}_\phi$ (A/m) $\quad H_\theta = -E_\phi / \eta_0 \quad H_\phi = E_\theta / \eta_0$

  where $\eta_0 = 377\ \Omega$ is the wave impedance of free-space

Antenna Radiation (cont)

- Electric field of an antenna in the far-field zone

$$\boldsymbol{E} = [F_\theta(\theta,\phi)\boldsymbol{u}_\theta + F_\phi(\theta,\phi)\boldsymbol{u}_\phi]\frac{e^{-jk_0 r}}{r}$$

where

$F_\theta(\theta,\phi)$ and $F_\phi(\theta,\phi)$ are the radiation pattern functions

$k_0 = 2\pi/\lambda$ is the propagation constant in free-space

$\lambda = c/f$

Antenna Radiation (cont)

- Poynting vector

$$\boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H}^* \quad (\mathrm{W/m^2})$$

- Since

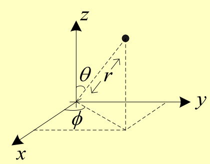
$$\boldsymbol{E} = E_\theta \boldsymbol{u}_\theta + E_\phi \boldsymbol{u}_\phi \qquad \boldsymbol{H} = H_\theta \boldsymbol{u}_\theta + H_\phi \boldsymbol{u}_\phi$$

and

$$H_\theta = -E_\phi / \eta_0 \qquad H_\phi = E_\theta / \eta_0$$

then

$$\boldsymbol{S} = \frac{1}{\eta_0}\left(| E_\theta |^2 + | E_\phi |^2\right)\boldsymbol{u}_r$$



Antenna Radiation (cont)

- Total average power radiated by the antenna

$$P_{\mathrm{rad}} = \oiint \frac{1}{2}\mathrm{Re}\{\boldsymbol{S}\}ds = \oiint \frac{1}{2}\mathrm{Re}\{\boldsymbol{E} \times \boldsymbol{H}^*\}ds \quad (\mathrm{W})$$

- Since

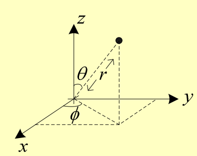
$$ds = (r sen\theta d\phi)(r d\theta) = r^2 sen\theta d\phi d\theta$$

and

$$\boldsymbol{S} = \frac{1}{\eta_0}\left(| E_\theta |^2 + | E_\phi |^2\right)\boldsymbol{u}_r \qquad \boldsymbol{E} = [F_\theta(\theta,\phi)\boldsymbol{u}_\theta + F_\phi(\theta,\phi)\boldsymbol{u}_\phi]\frac{e^{-jk_0 r}}{r}$$

then

$$P_{\mathrm{rad}} = \frac{1}{2\eta_0}\int_{\varphi=0}^{2\pi}\int_{\theta=0}^{\pi}\left(| F_\theta |^2 + | F_\phi |^2\right) sen\theta d\phi d\theta \quad (\mathrm{W})$$

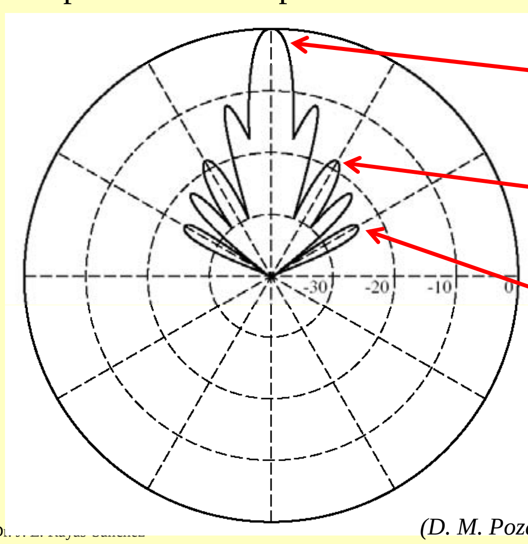


Antenna Radiation Pattern

- It is the plot of $|F_\theta(\theta,\phi)|$ or $|F_\phi(\theta,\phi)|$ versus the position around the antenna
- The choice between $F_\theta(\theta,\phi)$ and $F_\phi(\theta,\phi)$ depends on the antenna polarization
- $F_\theta(\theta,\phi)$ and $F_\phi(\theta,\phi)$ can be plotted versus θ and ϕ
- Since $F_\theta(\theta,\phi)$ and $F_\phi(\theta,\phi)$ are proportional to voltage, the plot is calculated using $20\log|\,F(\theta,\phi)\,|$

Antenna Radiation Pattern – Example

E-plane radiation pattern of a small horn antenna (versus ϕ)



main beam
(ϕ = 0°, 0dB)

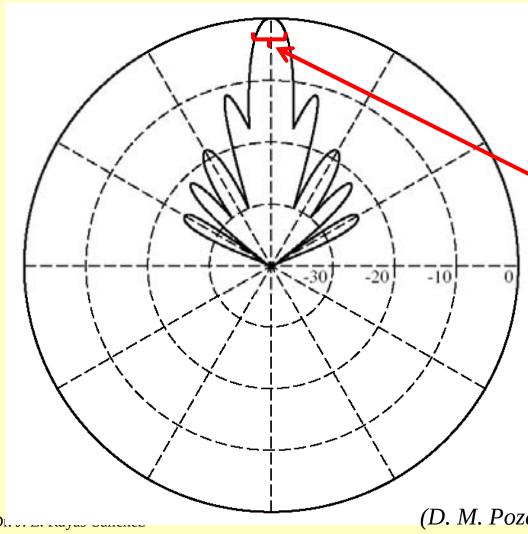
sidelobes

sidelobe at
ϕ = 30°, –23.5dB

(D. M. Pozar, Microwave Engineering, Wiley, 2005)

Antenna Radiation Pattern – Example (cont)

E-plane radiation pattern of a small horn antenna (versus ϕ)

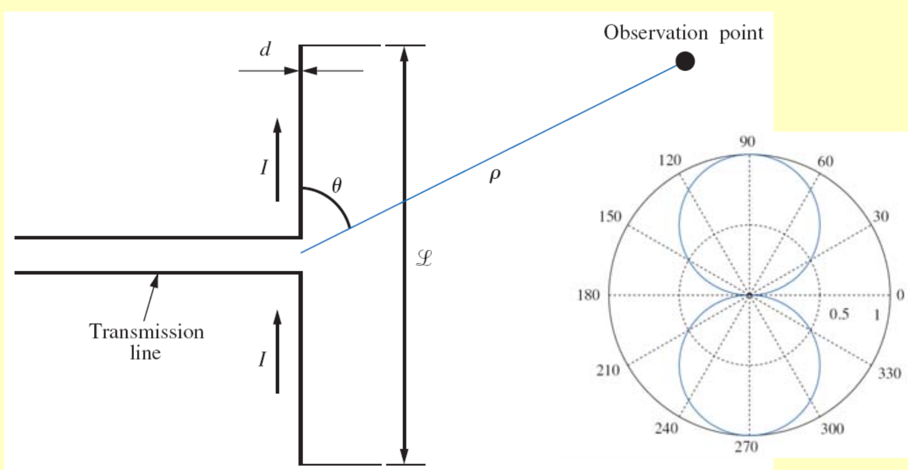


3-dB beam width

(D. M. Pozar, Microwave Engineering, Wiley, 2005)

Radiation Pattern of an Infinitesimal Dipole

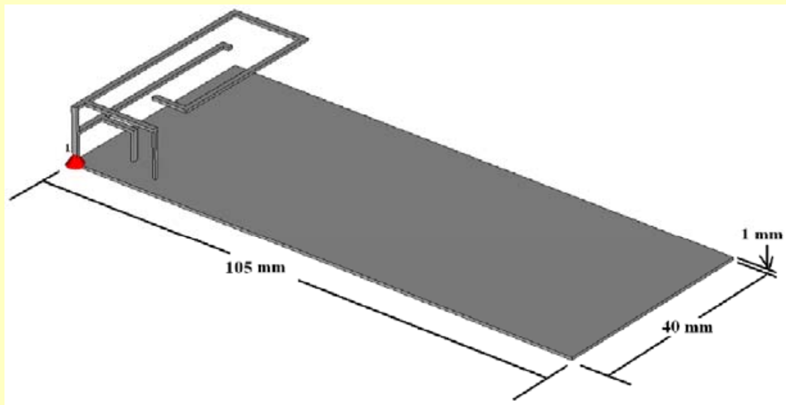
It is assumed that $\mathscr{L} << \lambda$ ($\mathscr{L} = \lambda/50$)



(Lonngren et al., Fundamentals of Electromagnetics with Matlab, PHI, 2009)

IFA Antenna – Radiation Pattern

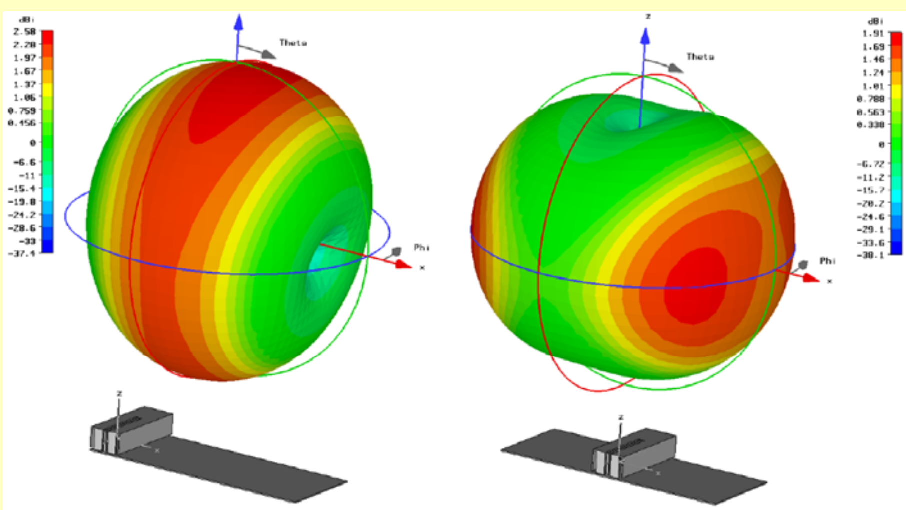
- Effects of the finite ground plane on the radiation pattern of an IFA antenna



Dr. J. E. Rayas-Sánchez

(Besser Associates, CST, 2010) 19

IFA Antenna – Radiation Pattern (cont)



Dr. J. E. Rayas-Sánchez

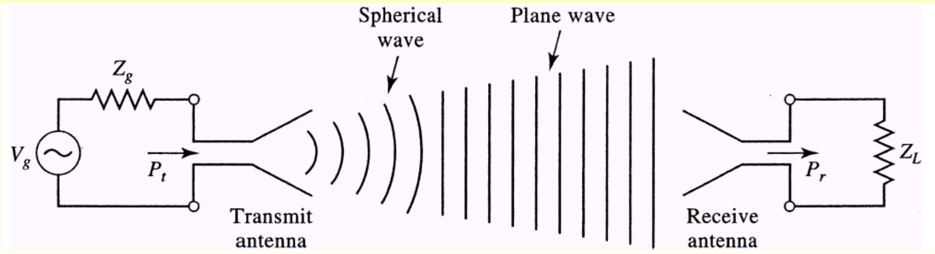
(Besser Associates, CST, 2010) 20

Far-Field Distance, R_{ff}

- It is the distance at which the spherical wave radiated by the antenna becomes almost a plane wave
- It can be estimated by

$$R_{\text{ff}} = \frac{2d^2}{\lambda}$$

where *d* is the maximum dimension of the antenna aperture



Dr. J. E. Rayas-Sánchez

(D. M. Pozar, Microwave Engineering, Wiley, 2005) 21

Far-Field Distance – Example

- A DBS parabolic reflector antenna has a plate with a diameter of 18” and operates at 12.4 GHz:

d = 18” = 45.72 cm

$\lambda = c/f$ = (0.3Gm/s)/(12.4GHz) = 2.42 cm

The far-field distance is

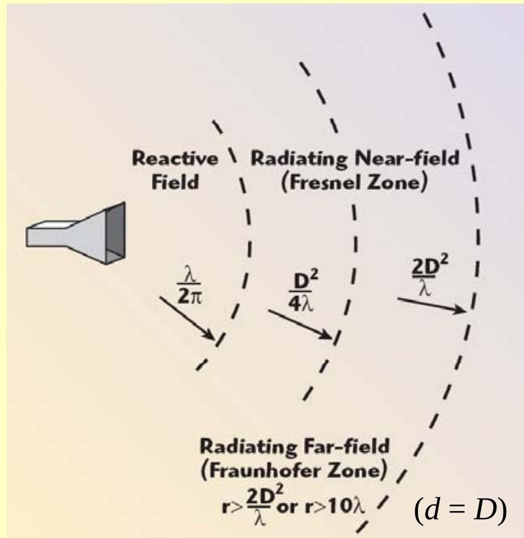
$$R_{\text{ff}} = \frac{2d^2}{\lambda} = \frac{2(45.72)^2}{2.42} = 17.27 \text{ m}$$

Dr. J. E. Rayas-Sánchez

(D. M. Pozar, Microwave Engineering, Wiley, 2005) 22

Radiating Distances

- Reactive region: $\boldsymbol{S}$ is imaginary, fields decay more rapidly than $1/r$
- Near-field region: $\boldsymbol{S}$ is complex, radiation pattern depends on r, fields decay more rapidly than $1/r$
- Far-field region: $\boldsymbol{S}$ is real, radiation pattern does not depend on r, fields decay with $1/r$



(J. F. Aubin, Microwave Journal, 2005)

Antenna Directivity, D

- It is the antenna ability to transmit/receive in a given direction, usually expressed in dB, $10\log_{10}(D)$
- It is defined as $D = 4\pi U_{\max} / U_{\text{avg}}$

  where U is the radiation intensity given by

  $$U(\theta,\phi) = \frac{1}{2\eta_0}\left(|F_\theta|^2 + |F_\phi|^2\right) \quad \text{(W per unit solid angle)}$$

- It can be estimated by

  $$D \approx \frac{32{,}400}{\theta_1\theta_2}$$

  where θ_1 and θ_2 are the beamwidths (in degrees) of two orthogonal planes of the main beam

Antenna Radiation Efficiency, e_{rad}

- It is the ratio of the radiated power to the input power

$$e_{\text{rad}} = \frac{P_{\text{rad}}}{P_{\text{in}}} = \frac{P_{\text{in}} - P_{\text{loss}}}{P_{\text{in}}} = 1 - \frac{P_{\text{loss}}}{P_{\text{in}}}$$

Antenna Gain, G

- It is the product of the antenna efficiency by the antenna directivity

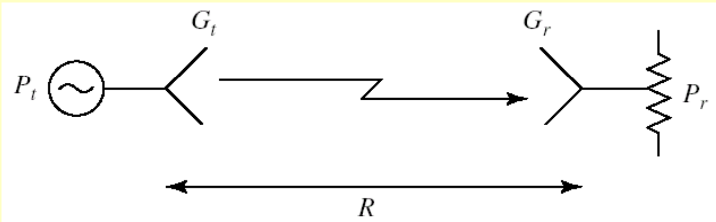
$$G = e_{\text{rad}} D$$

- It is usually expressed in dB, $10\log_{10}(G)$

The Friis Equation

- Friis equation allows us to calculate how much power is received by an antenna

$$P_r = \frac{G_t G_r \lambda^2}{(4\pi R)^2} P_t \quad \text{(W)}$$



Dr. J. E. Rayas-Sánchez

(D. M. Pozar, Microwave Engineering, Wiley, 2005) 27

The Friis Equation – Example 1

- An earth station with a transmitter power of 120 W, a frequency of 6 GHz, and an antenna gain of 42 dB transmits to a satellite repeater. The receiver antenna on the satellite has a gain of 31 dB, and the satellite is in a synchronous orbit 35,900 Km above the earth. What is the received power, in dBm?

Dr. J. E. Rayas-Sánchez

(D. M. Pozar, Microwave Engineering, Wiley, 2005) 28

The Friis Equation – Example 1

- An earth station with a transmitter power of 120 W, a frequency of 6 GHz, and an antenna gain of 42 dB transmits to a satellite repeater. The receiver antenna on the satellite has a gain of 31 dB, and the satellite is in a synchronous orbit 35,900 km above the earth. What is the received power, in dBm?

P_r = –75.31 dBm = 29.41 pW

(D. M. Pozar, Microwave Engineering, Wiley, 2005)

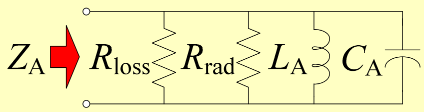
The Friis Equation – Example 2

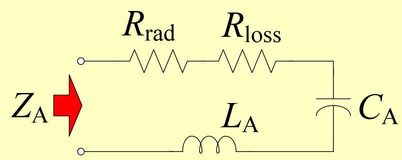
- A microwave radio link at 4.9 GHz uses transmit and receive antennas with gains of 30 dB. If the distance between the transmitter and the receiver is 27 km, and it is desired to have a minimum received power of –60 dBm, what is the required transmitter power, in dBm?

(D. M. Pozar, Microwave Engineering, Wiley, 2005)

Equivalent Circuits of an Antenna (S_{11})

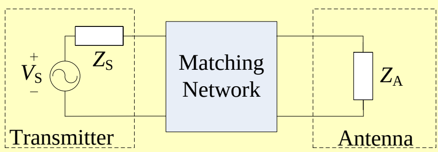
- The antenna impedance Z_A can be approximated by a resonant circuit,





- Simplified equivalent circuits for the

transmitter



receiver