Antenna Fundamentals

Microwave Engineering
EE 172
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Reference

*Antenna Theory and Design*

*Microstrip Antennas*

http://www.antenna-theory.com/
Tentative Topics

- What is antenna?
- Types
- Spec & Definitions
- Polarization
- Common commercial antenna
- Examples
- Array
1887 Hert’z Spark Gap setup

Verified Maxwell’s Equations on Electromagnetic Waves

Time-varying field (current) radiate EM wave !!
Telegraphy – Morse Code

VCO
On-Off Key ?!
Electromagnetic Compliance (EMC)

- It’s hard not to radiate (RF)
- Use absorber, conductive seal, paint or tape to block EM waves in or out.
- Uncover transmission line (such as microstrip line) is an radiating element.
# Spec example (simplified)

## General Specifications
- **Antenna Type**: PD Series Parabolic
- **Diameter, nominal**: 0.4 m | 1.25 ft
- **Polarization**: Single

## Electrical Specifications
- **Beamwidth, Horizontal**: 16.0 °
- **Front-to-Back Ratio**: 20 dB
- **Gain, Mid Band**: 19.0 dBi
- **Operating Frequency Band**: 2.400 – 2.500 GHz
- **Return Loss**: 12.0 dB
- **VSWR**: 1.70

## Mechanical Specifications
- **Mounting Pipe Diameter**: 32 mm–60 mm | 1.25 in–2.375 in
- **Net Weight**: 3 kg | 6 lb
Radiation Intensity Measurement

e.g. dipole - dipole

normalized intensity in dB

normalized intensity in dB
Polar Coordinates

3D donut
Radiation Pattern

- Dipole
- EM simulation
- Far Field condition
Half-Power Beamwidth (HPBW)

Intensity $U = U_m \sin^2 \theta$

for an ideal dipole

$\sin^2(45^\circ) = \frac{1}{2}$

HPBW = $90^\circ$ for an ideal dipole
Example of radiation patterns

- Broadside (e.g. line source, modified “donut”)
- Intermediate
- Endfire

side lobes (diffraction)
Example – dish antenna

- high gain
- many side lobes
Directivity (D) & Gain (G)

(analogy – light bulb & flash light)

D = Gain of the “lossless” antenna
no cable loss, no mismatch loss, no conduction loss, no dielectric loss.

e.g. D for an ideal pole = 3/2. G ≤ 1.5
D & G are often mixed up in literature.
Radiation Efficiency (e)

\[ e = \frac{P_{\text{radiated}}}{P_{\text{input}}} = \frac{G}{D} \]

evaluated at max power direction

\[ 0 \leq e \leq 1 \]

\[ G_{\text{dB}} = 10 \log_{10} G \]

\[ D_{\text{dB}} = 10 \log_{10} D \]

\[ G_{\text{dB}} = D_{\text{dB}} - \log_{10} |e| = D_{\text{dB}} - \text{loss(dB)} \]

e.g. Ideal dipole: \( D = 3/2 = 1.76 \text{ dB}, \ G = 1.76\text{dB} - \text{loss(dB)} \)

sometimes referred to dBi (with respect to isotropic radiation)
Gain Measurement
using a reference (with known gain)

e.g. Reference antenna $G = 6$ dB

measurement at a distance
$S_{21}(\text{ref}) = -12$ dB
(with respect to source)
& for antenna under test
$S_{21}(\text{test}) = -10$ dB

$G(\text{ant}) = G(\text{ref}) - S_{21}(\text{ref}) + S_{21}(\text{ant})$

Here, $G(\text{ant}) = 6\text{dB} - (-12\text{dB}) + (-10\text{dB}) = 8\text{ dB}$
Side Lobe Level (SLL)

SLL = \frac{P(\text{max})}{P(\text{lobe})}

in dB: \quad = G(\text{max}) - G(\text{lobe})
Polarization

- Linear
  - Vertical
  - Horizontal
- Circular (or elliptical)
  - RHCP
  - LHCP

- Can a vertical polarized antenna pick up a horizontal wave?
- Can a vertical polarized antenna pick up a RHCP wave?
- Should a vertical polarized antenna have the same gain as a horizontal one?
Cross-Polarization (X-pol)

Ratio of (orthogonal X-pol field strength)/(desired co-pol field) expressed in dB (power)

e.g. For a vertical polarized antenna, the X-polarization is horizontal. For a RHCP, the x-pol is LHCP.

Ideally, X-pol is = 0 (- infinity dB). In reality, x-pol is usually between -15 to -40 dB. due to non-ideal alignment, depolarization of wave in media (such as Faraday Rotation).

X-pol is more commonly used in linear polarization.
Axial Ratio (AR)

Ratio of the 2 orthogonal field strength to indicate the purity of the polarization.

Convention: $\text{AR} \geq 1$.

Used mostly in circular (or elliptical) polarization.  
* e.g. For a CP, $\max E_x = \max E_y$, so $\text{AR} = 1$ (ideal).

For an elliptical polarization, $\text{AR} > 1$.

For a linear polarization, $\text{AR} = \infty$.

$\text{AR}$ is a function of angle (circular would appears to be elliptical).

Quite often, $\text{AR}$ is expressed in dB.
Front-to-Back Ratio

For directional antenna, ratio of the radiated power in front of / behind the antenna.

In dB, $= \text{difference of the D(dB)}$
EIRP  Effective (or Equivalent) Isotropic Radiation Power

is the amount of power that a theoretical isotropic antenna would emit to produce the peak power density observed in the direction of maximum antenna gain.

$$EIRP = P(\text{total in dBm}) - D(\text{dB})$$

An indication of how effective the antenna is.

and...

A way to specify max power radiation into any given direction..... to limit interference with other systems.
Effective Aperture ($A_e$)

is the effectiveness (or effective area) of the antenna to receive a EM wave:

$$P_{\text{receive}} = A_e S_{\text{av}}$$

where $S_{\text{av}}$ is the $|\text{Poynting Vector}| = \text{power intensity of the wave}.$

Since $S = \text{Power/Area},$ so $A_e$ is equivalent to the effective “area” of the antenna. It is related to the Gain of the antenna by:

$$A_e = \frac{\lambda^2}{4\pi} G$$

Bigger aperture means higher gain.
Antenna Temperature

Noise Temperature of the antenna.

Noise Temperature is defined (for any device) as:

\[ P(\text{noise}) = kTB \]

where \( k \) is the Boltzmann constant,
- \( T \) is the effective noise temperature in kelvin,
- \( B \) is the noise bandwidth in Hz. (Broadband antenna has higher noise!)

The noise here is the Johnson noise (thermal fluctuation of charged particles).

So if the antenna is pointing into deep space, the noise temp is lower.

If the receiver has a noise temp \( T_R \), and antenna’s noise temp \( T_A \)
then, the total system noise (temp) is \( T_R + T_A \).
Antenna Measurement

- Far Field
- Near Field
- Compact Range
Far Field Measurement

outdoor in the field

or indoor in a large room with lots of absorber
Range

Far Field conditions

\[
R \gg D \\
R \gg \lambda \\
R > \frac{2D^2}{\lambda}
\]
Near Field Measurement

Software correction -
to keep track of all radiation power
Compact Range
Compact Range Measurement
Types

- Radiators
  - Apertures
  - Current elements
- Focusing Elements
  - Directors
  - Reflectors
  - Lenses
  - Array Feeds
Apertures

Easier to view these in terms of Fields

- Waveguide
- Horns
- Waveguide Slots
- Ground Plane Slots (microstrip)
- Leaky Cables
Waveguide

Thank you once again Joe, without your skills, this waveguide system would not have been ready in time...
Horn
Flare angle shapes the beam
Potter Horn (1963)

Simple step structure for pure polarization
Equal beamwidth for E & H
Waveguide Slots

- Broadwall slot
  - Slanted to reduce sidelobe
- Edge wall slot
Microstrip Ground Slot

$L_s \sim \frac{\lambda_{\text{eff}}}{2}$

$E_{\min}$ and $I_{\max}$ on the line at slot opening

$L_{o} \sim \frac{\lambda'_{\text{eff}}}{4}$
Leaky Cable

Commonly used in buildings
Current elements

Easier to view these in terms of Current

- dipoles
- monopoles
- helix
- patches
Dipole Antenna

150MHz Dipole

Current
V or E
Half-wave

Folded dipole
Monopole

Half of a dipole ($\lambda/4$). Use the ground plate & Image theory. Basically is a dipole.
Helical Antenna

(dipole type) (more directional)

- easy construction
- with copper stripe
- with copper wire
Patch Antenna

Fringing Electric Field along one direction

Looks like a dipole from a distance

Linear Polarized
Patch - pattern

directional
Patch Examples

- GPS high dielectric
- Circularly polarized
- UHF RFID array
Miniature printed antenna optimization
Focusing elements

- Directors
- Reflectors
- Yagi
- Log-periodic
- Dish (reflectors)
- Lens
- Array
Director & Reflector

Original donut-shaped pattern

Shorter poles in-front of dipole.
Capacitive \((< \lambda/2) \sim \text{open}\)
Front: in-phase (constructive)
Back: out-of-phase (destructive)

Longer poles behind the dipole.
Inductive \((> \lambda/2)\)
Front: in-phase (constructive)
Back: out-of-phase (destructive)
Not as effective... usually only 1 reflector.
Yagi-Uda Antenna
Log-Periodic Antenna

All elements driven, 180-deg phase shift, Broadband, unidirectional Narrow beam
Z follows the log function.

microstrip version
Parabolic Dish (reflectors)

Equal phase? Yes.

Parabolic equation
\[ y = 4fx^2 \]

Highest efficiency Antenna. Aperture dictate the gain.

LNB
Low-noise block - downconverter
Variations

- Parabolic reflector
- Hyperboloidal reflector
- Sub-reflector
- Offset feed
- Wire pieces
- 22 deg offset dish
- 63 deg elevation
- In action – news report
Microwave Lenses

antenna lens for a distance sensor
Array Antenna

Combine elements to make a higher gain antenna. Highly effective for beam-steering and tracking.