Communications (COMM) Subsystem

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Exploration Research and Technology Programs

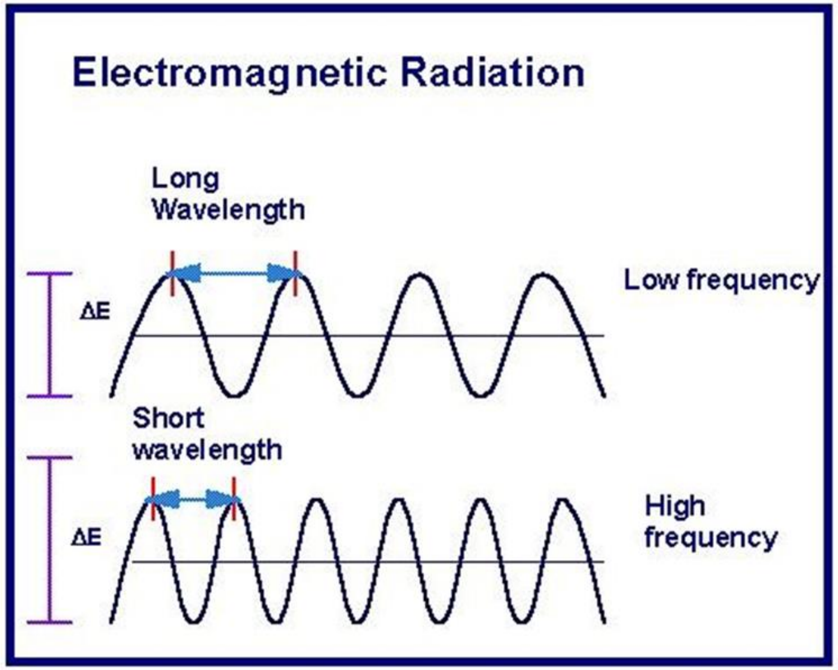
Purpose

- RF system provides communication with the satellite
  - Only way to access the spacecraft once in orbit
  - Uses antennas, radios, and ground stations to communication via electromagnetic waves
- System design must allow adequate communication between satellite and ground
  - This is done with a link budget, balancing transmit power and gains with losses, receiver sensitivity, modulation, data rates, etc.
  - Healthy margin should be applied to analysis

Background

Radio Waves, Frequency, and Wavelength

- Radio waves are electromagnetic radiation (EMR)
  - A form of energy that exists all around us
  - Travels in cables as an alternating current, and through space in the form of a wave
- EM waves travel at the speed of light
- Frequency and wavelength are inversely proportional
- As wavelength gets shorter (smaller) frequency gets higher



https://www.bulbapp.com/u/wavelength-and-frequency

Common Frequencies, Data Rates, and Traits

IEEE Frequency Band	Frequency Range	Rough Data Rate Range
VHF	30 – 300 MHz	9.6 – ~30 kbps
UHF	300 – 1000 MHz	9.6 – 38.4 kbps
L	1 – 2 GHz	0.1 – 10 Mbps
S	2 – 4 GHz	0.1 – 20 Mbps
C	4 – 8 GHz	10 – 100 Mbps
X	8 – 12 GHz	10 – 150 Mbps
Ku	12 – 18 GHz	25 – 1000 Mbps
K	18 – 27 GHz	25 – 1000 Mbps
Ka	27 – 40 GHz	25 – 1000 Mbps

- Lower data throughput
- Narrower spectrum bands
- Larger antenna size/wider beamwidth
- Lower susceptibility to rain
- Cheaper, simpler hardware
- More power efficient hardware

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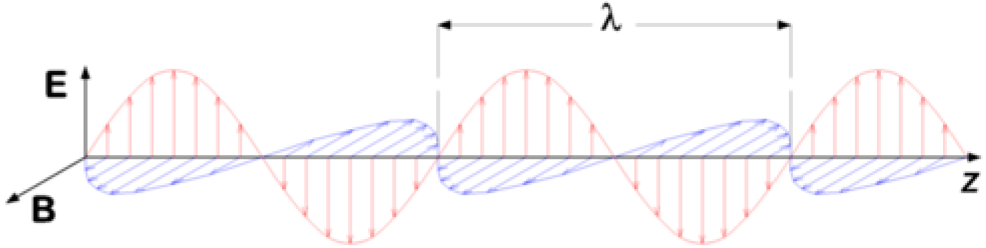
- Higher data throughput
- Wider spectrum bands
- Smaller antenna size/narrower beamwidth
- Higher susceptibility to rain
- More expensive, more complex hardware
- Less power efficient hardware

Plane of EM Wave

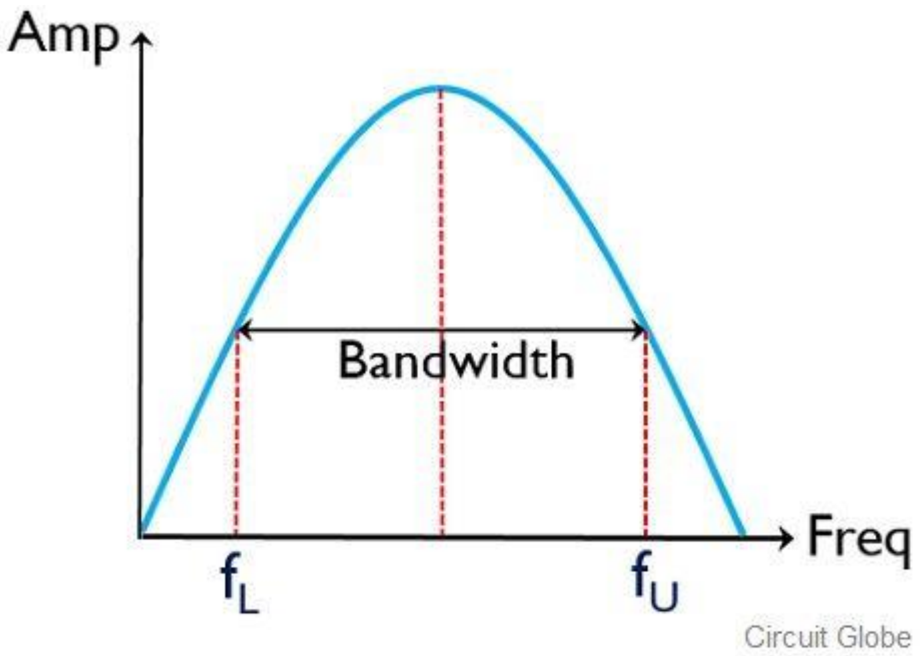
- EM waves have an E plane and H plane
    E = Electric wave
    H = Magnetic wave
- Perpendicular to each other
- Generally refer to the E plane when referencing polarization
- Most antennas are aligned in the E plane



https://commons.wikimedia.org/wiki/File:Electromagnetic_wave.png

Modulation and Bandwidth

- For a radio signal to carry information it must be varied in some way (modulated)
- Just turned on/off (Continuous Wave, CW)
- Changed in frequency (FM), or amplitude (AM)
- The width of the modulated signal in frequency is the bandwidth
  - AM broadcast radio = about 6 KHz
  - Max audio frequency = about 2,500 Hz



https://circuitglobe.com/difference-between-frequency-and-bandwidth.html

Impedance and Matching

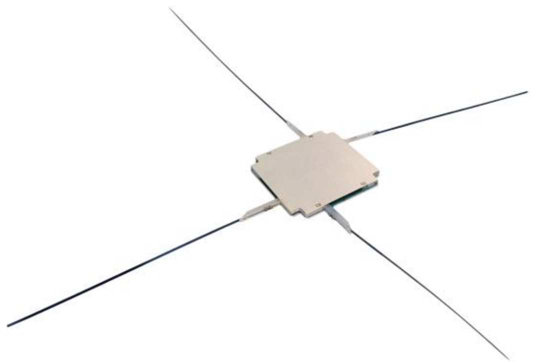
- Impedance (AC resistance) of the radio, feed line, and antenna must all match or be made to match
  - If they don't, reflections occur where impedance changes
  - Reflected power turns into heat, not useable radiated power
  - Reduces overall system efficiency and may damage transmitters
- Radios, feed lines, antenna are nearly always 50 ohms
- Non-resonant antennas can be made to match feed line by using inductors or capacitors
  - Lumped (SMD or through hole)
  - Etched into a PCB (stripline)
  - ¼ wave long coax of a different impedance
  - 'Stubs' and other wire or metal additions to the exposed part of the antenna

Components

What is an Antenna?

- A conductive object whose purpose is to effectively transfer radio frequency energy between a radio (and/or feed line) and space
- Characteristics of Effective Antennas
  - Commonly made of metal
  - Clear of surrounding objects
  - Attached to radio through a low loss, leak free feed line
  - Electrically (impedance) matched to the feed line
  - Large capture area
  - At least ¼ wavelength long
  - Physically robust
  - Emits RF energy outside the satellite
  - Most often resonant: multiple of a quarter wavelength

Band	Frequency (MHz)	Quarterwave (Inches)
VHF	145	19.4
UHF	435	6.5
L	1260	2.2
S	2410	1.2
X	10000	0.3

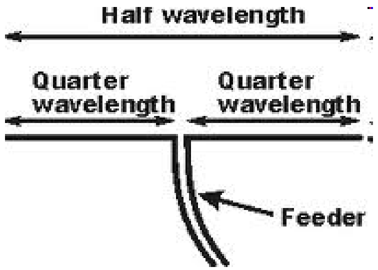


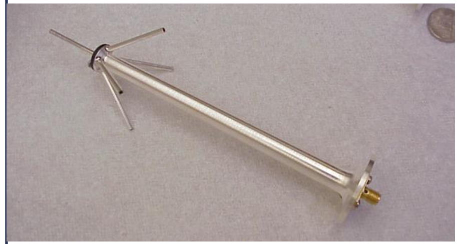
Isispace UHF/VHF 1U ANT

Resonant Antennas

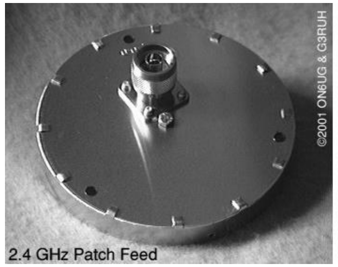
Dipole and Ground Plane

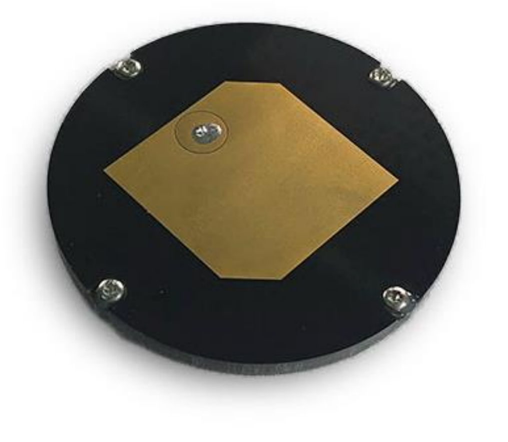
- Dipole
  - Half wave long metal
  - Often used for HF
- Ground plane
  - ¼ wave elements
  - ‘ground’ elements canted



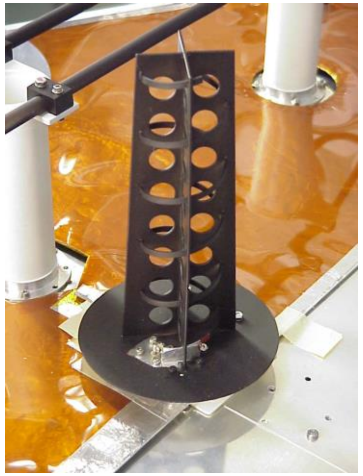


Patch





Helix



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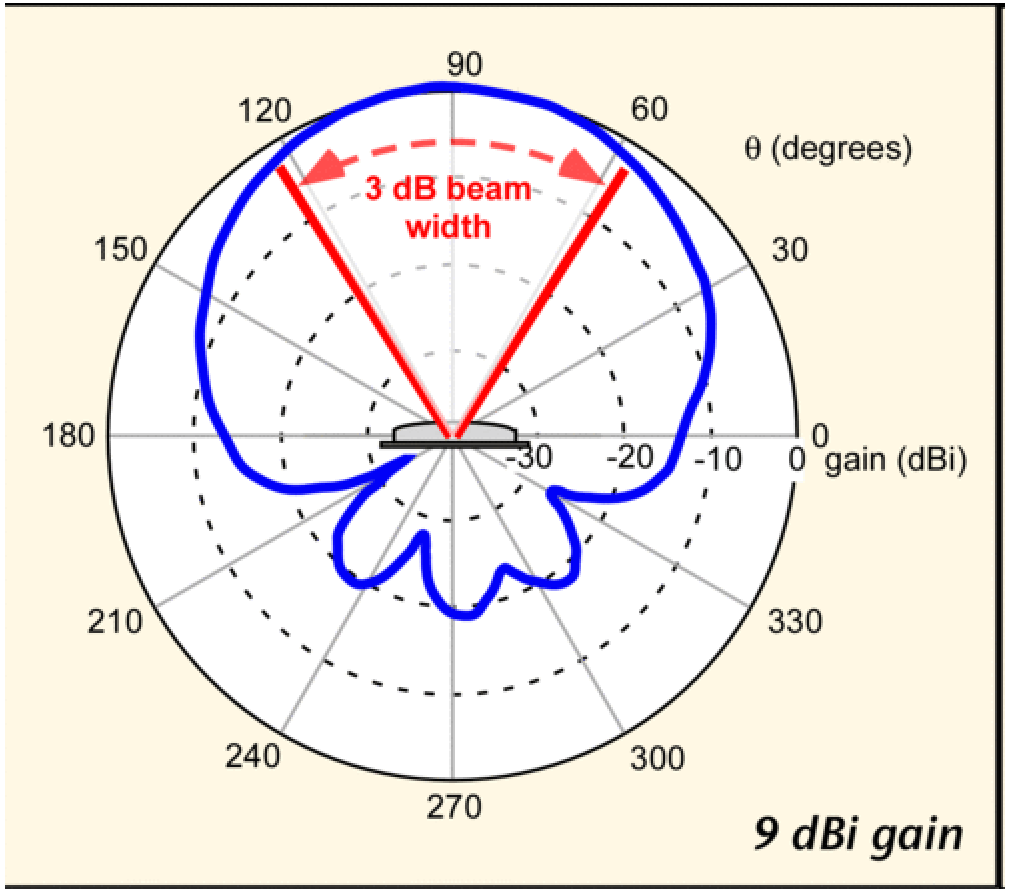
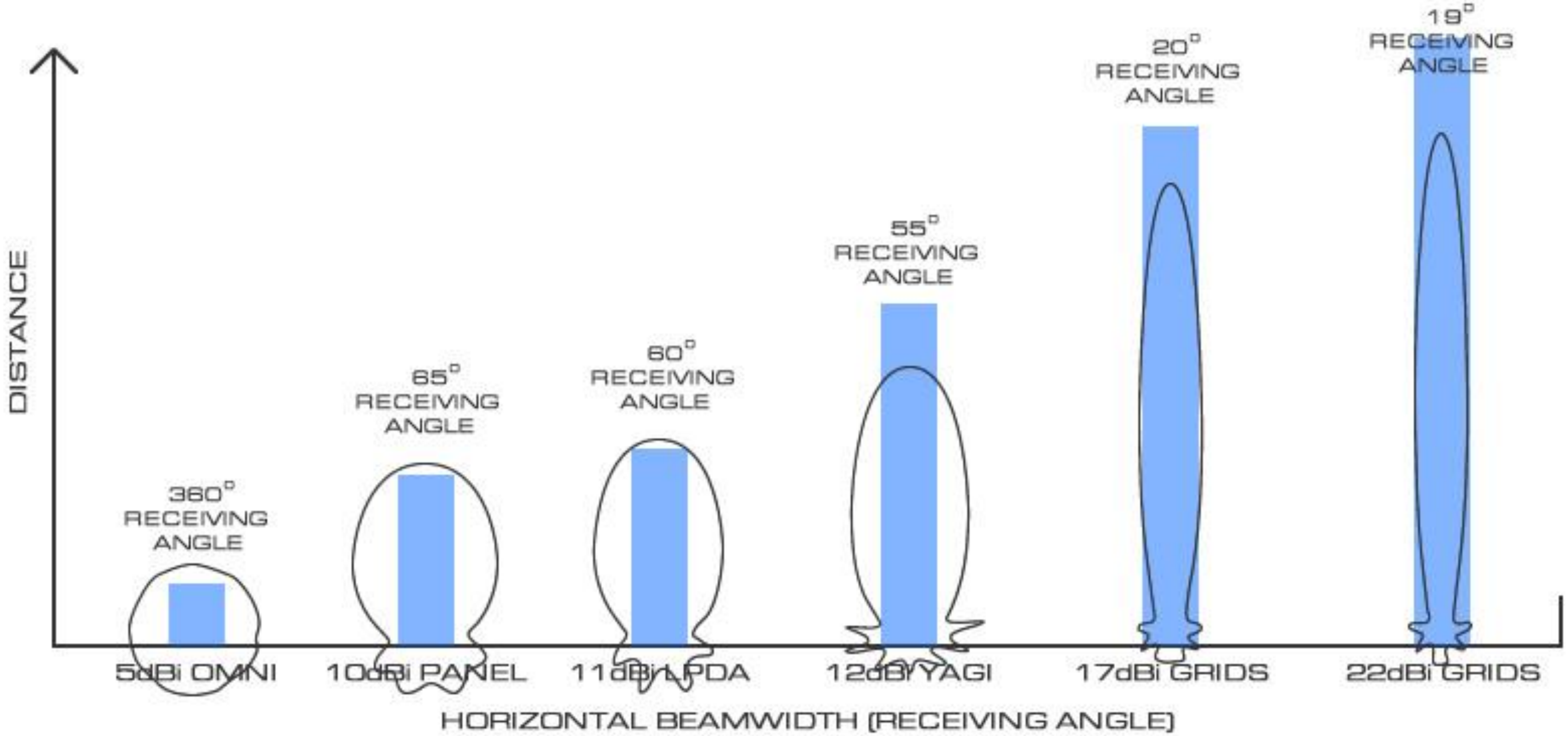
Patterns - Beamwidth

The width in degrees between the -3dB points

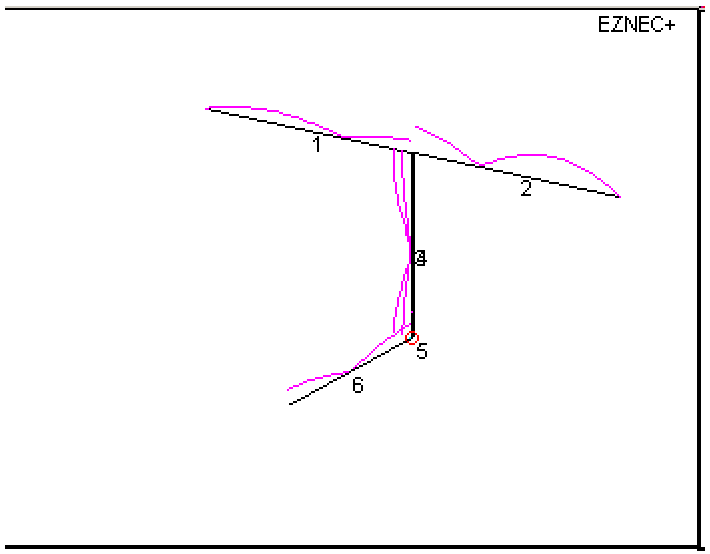


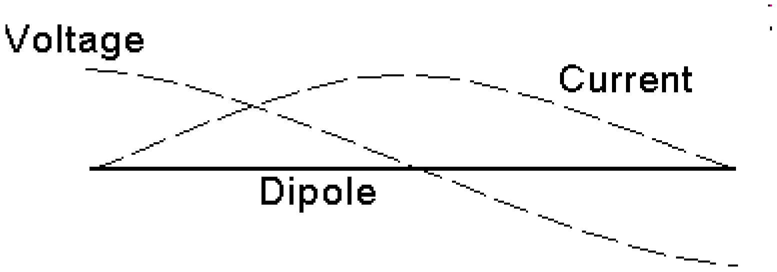
Gain vs. Beamwidth



V and I in Resonant Antenna

- In a resonant antenna the V and I are at min and max at the center and end points
- In non-resonant the min and max not at the end points or center
- The non-resonant is less effective at radiating the RF



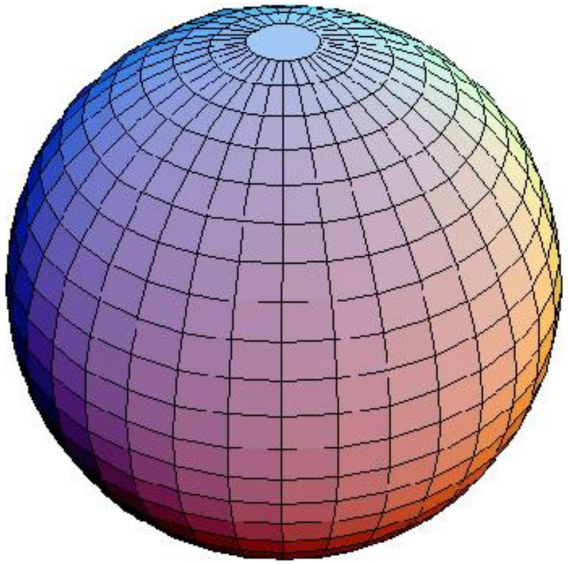


Non-resonant Antennas

- Generally anything not some multiple of ¼ wavelength long, or fed ‘off center’
- Non-resonant antennas will
  - Be less efficient because power is not transferred efficiently to the antenna
  - Not be close to 50 ohms impedance
  - Be difficult to match to 50 ohms
  - Usually have complex radiation patterns
- A resonant antenna can become non-resonant due to things around it

Antenna Patterns

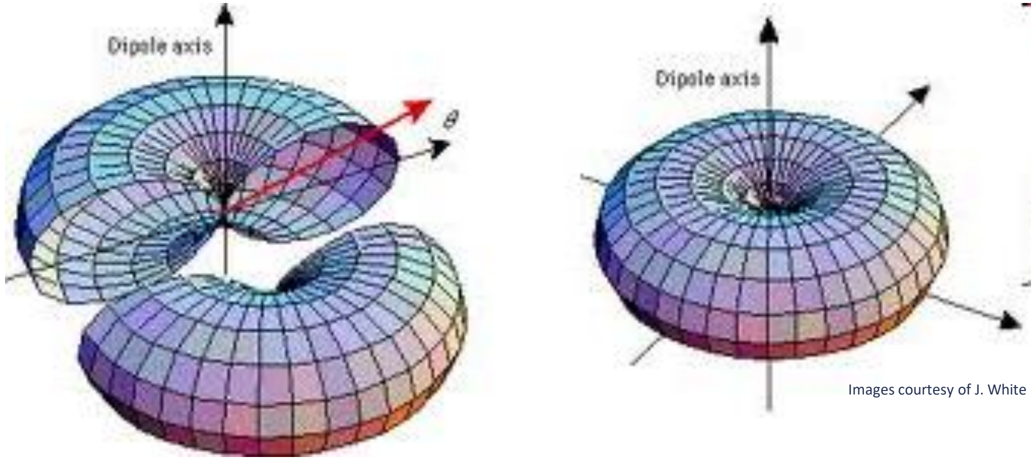
- The direction and amount of RF energy radiated by the antenna
- Isotropic antenna: Spherical pattern
  - Radiates equally in all directions
  - Theoretical only, can't make an antenna that is a point in space
  - Most antennas focus the RF
  - Antenna gain is most often specified in dBi



Images courtesy of J. White

Antenna Patterns

- Dipole
  - A half wave fed in the middle
  - Pattern like a doughnut
  - Sometimes used as a reference (dBd) in gain specifications
  - Max gain 2.15dBi
  - Linear polarization



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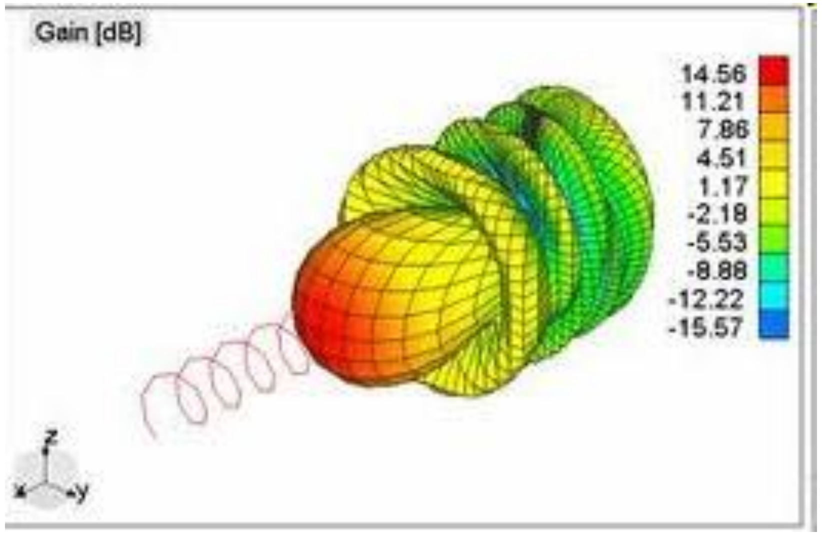
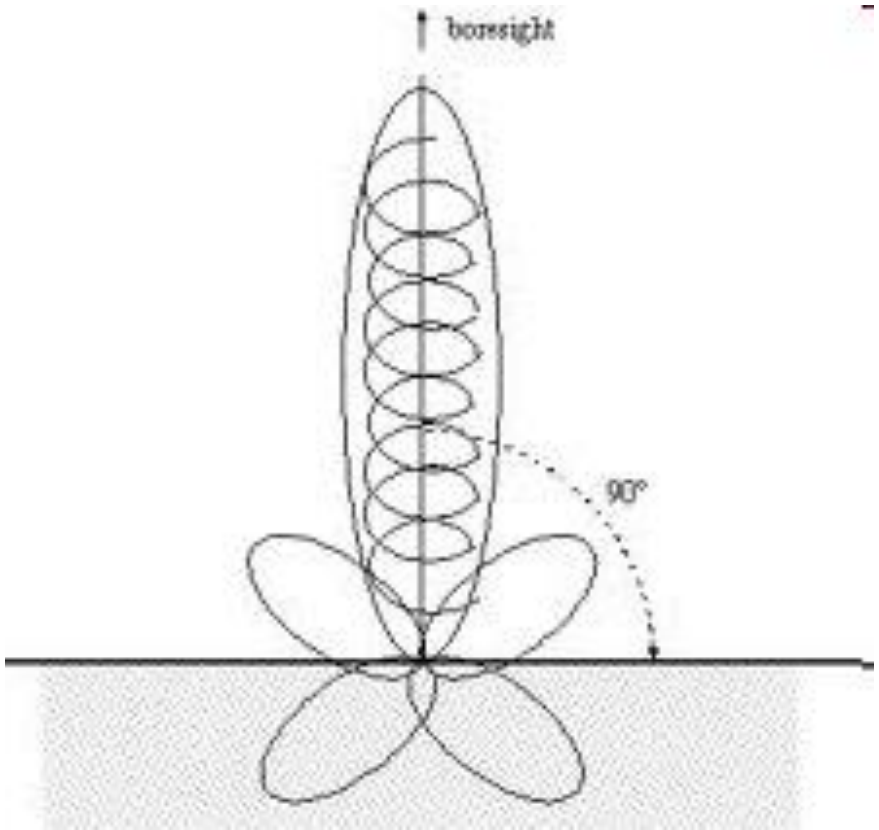
Antenna Patterns

- Helix
  - Can have 3 to ~24dBi
  - Inherently circular





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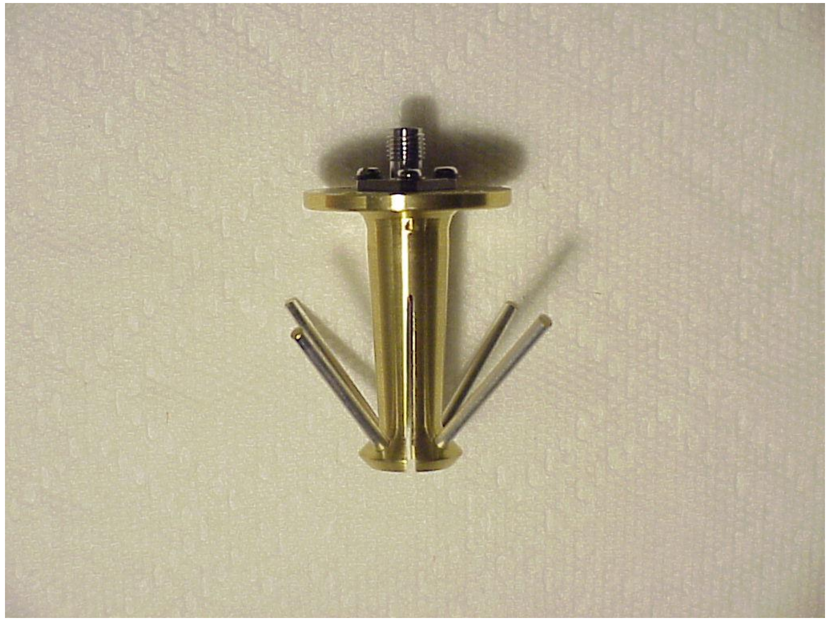
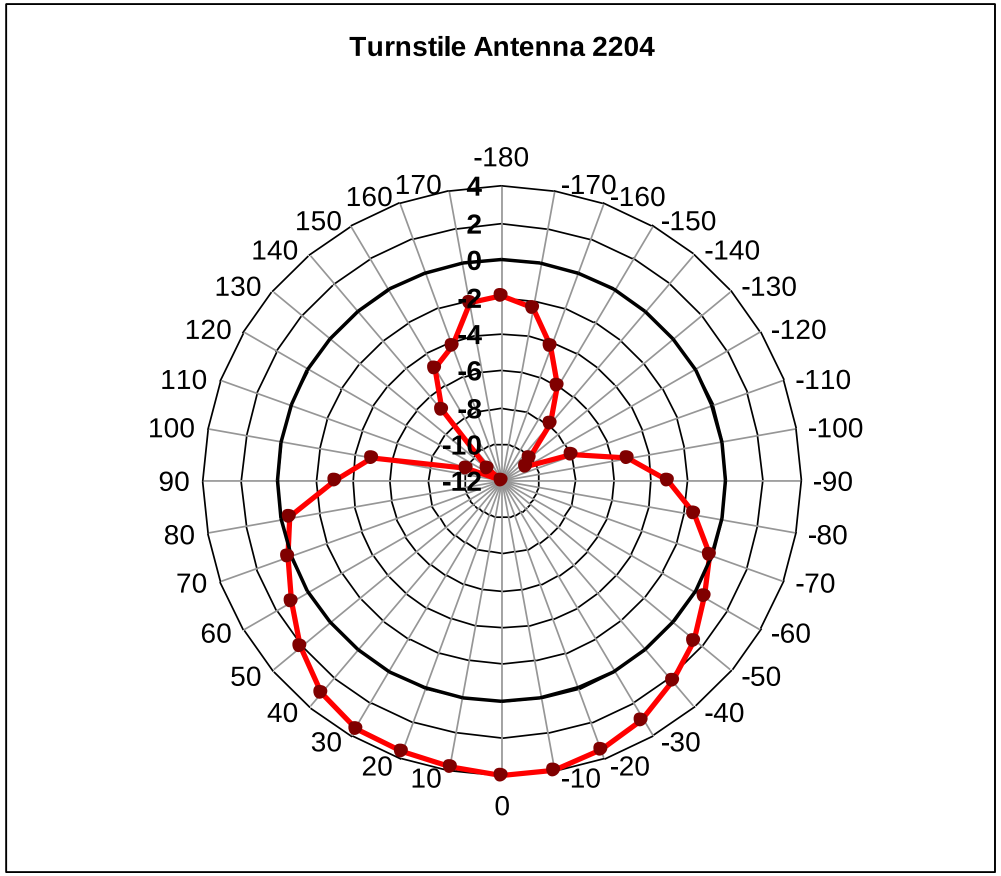
Antenna Patterns

- Canted Turnstile
  - Circular off the end
  - Nearly hemispherical





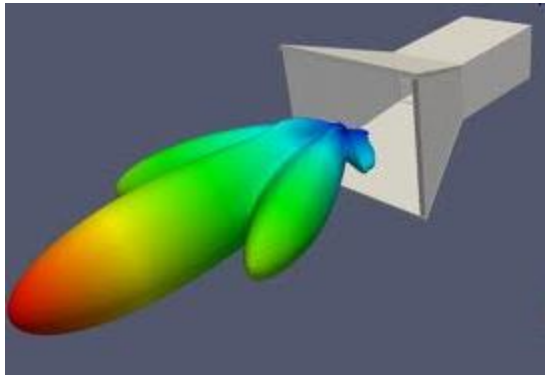
Images courtesy of J. White

Antenna Patterns

- Horn
  - Useful above about 3 GHz, particularly at 8 to 10 GHZ
  - Can be linear or circular
  - Length determines gain, angle sets impedance

ahsystems.com/catalog/SAS-584.php

microwaveeng.com/product/corrugated-conical-horn-antennas/



everythingrf.com/search/waveguide-horn-antennas

Polarization

- Linear (the E plane)
  - Horizontal
  - Vertical
- Circular
  - RHCP
  - LHCP
- Faraday rotation on linear signals
  - Rotates plane of E field as it passes through the ionosphere
  - If linear on sat and ground -> deep fades lasting several seconds every 30 seconds to one minute (at UHF)
  - Random time and depth of fade

Polarization Practicalities

- If linear on sat (whip, ground plane…)
  - Use circular on the ground
- If circular from the sat (canted turnstile, helix…)
  - Use circular of the same sense on the ground (RHCP to RHCP)
    - If a dish note that the feed must be opposite sense
  - If the sat attitude will change assure the sense on the ground can be changed

Practical Antennas for Small Satellites

- Not many choices due to small size of the satellite
  - VHF and UHF
    - ¼ wave whip, especially from a corner, up to 3dB gain
  - S-band and above
    - Whip for omni, 0dB gain
    - Canted turnstile for hemispherical (use 2), 0dB
    - Patch, gain to 3 to 4 dB
    - Folded dipole for near hemispherical, 0dB
    - Helix for more gain, up to 20dB

CONOPS and Requirements

Common Comm System Requirements

- Mission requirements include
  - Control the satellite and downlink data
  - Meet licensing and legal requirements
- Derived comm and data requirements regularly include
  - Transmit housekeeping and science data in specific amounts and intervals
  - Beacon an amount of data at a specific rate and power level
  - Receive commands from authorized stations only
  - Accommodate uplink data in specific amounts and intervals
  - Meet the LV and integrator requirements (EMI, RFI, handling safety, etc.)
  - Stay within the allowed volume and payload space on the LV
  - Survive the launch and space environments
  - Close the uplink and downlink given the other link parameters
  - Ensure safe deployment (if applicable), sharp edges and ends, etc.

Systems Engineering is Required

- A systems engineering approach is needed to assure those requirements can be met with the antennas
- Should take into account
  - Data budget, both directions
  - Capability of ground station
  - Transmitter power on satellite, and from the ground
  - Available volume and mounting locations
  - Attitude of the satellite under all conditions
  - Orbit parameters
  - Contact time and duration
  - Number of earth stations
  - Licensing constraints

Include the antenna requirements from the start of preliminary design

Analyses and Testing

Analysis: Link Budget

- Ensures the link will close and that you can communicate with your satellite
- UNP requirement: There shall be a minimum of 6dB margin in the telecommunications link analysis both for the uplink and downlink at 10-degree elevation mask.
- Link budget should capture all the expected losses and gains, transmitter and receiver power and data to downlink
- Received Power = Transmitted Power + Gains - Losses

Testing: Antenna Pattern

- Why measure antenna patterns ?
  - Assure your estimates/models of the pattern are about right
  - Educational
- Otherwise it is not of much value
  - Very hard to make measurements better than about 3dB unless on an expensive professional range
  - If you have a robust design a few bumps in the pattern will not adversely effect the mission
  - Modeling is often about as accurate if done right

Testing: Comm System

- UNP requires simulated communications test. Includes long range communications and testing of antenna pattern
  - Antenna pattern
    - Assure your estimates/models of the pattern are about right
      - Modeling is often about as accurate if done correctly
    - Very hard to make measurements better than about 3dB without professional setup
    - Some bumps in the pattern will not adversely affect a mission with an otherwise robust comm system design
  - Long range test
    - Ensures system functions under somewhat realistic conditions
    - Avoids multi-path effects
    - May help validate link budget