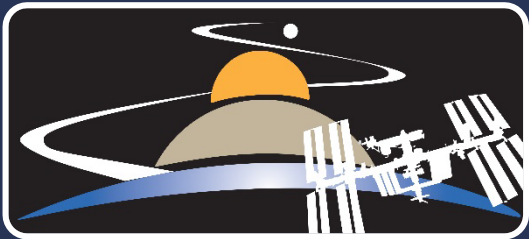


UNIP



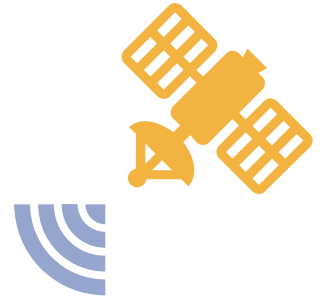
Communications (COMM) Subsystem



**Exploration Research and
Technology Programs**



- 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



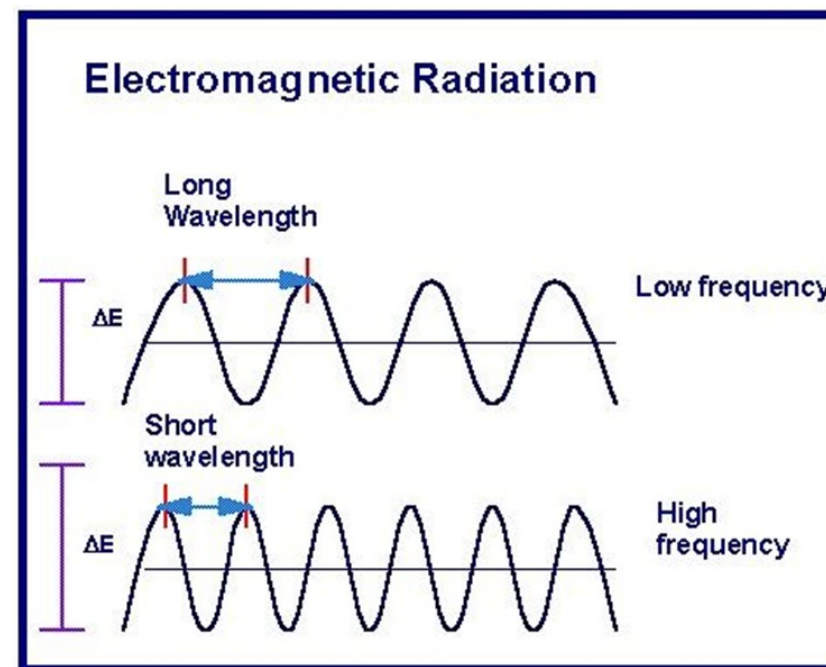


Background

UNP 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>

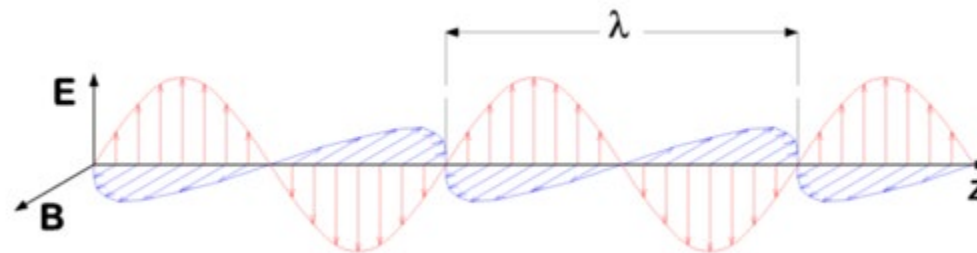
IEEE Frequency Band	Frequency Range	Rough Data Rate Range
VHF	30 – 300 MHz	9.6 – ~30 kbps
UHF	300 – 1000 MHz	9.6 – 38.4 kbps
L	1 – 2 GHz	0.1 – 10 Mbps
S	2 – 4 GHz	0.1 – 20 Mbps
C	4 – 8 GHz	10 – 100 Mbps
X	8 – 12 GHz	10 – 150 Mbps
Ku	12 – 18 GHz	25 – 1000 Mbps
K	18 – 27 GHz	25 – 1000 Mbps
Ka	27 – 40 GHz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



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

- 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

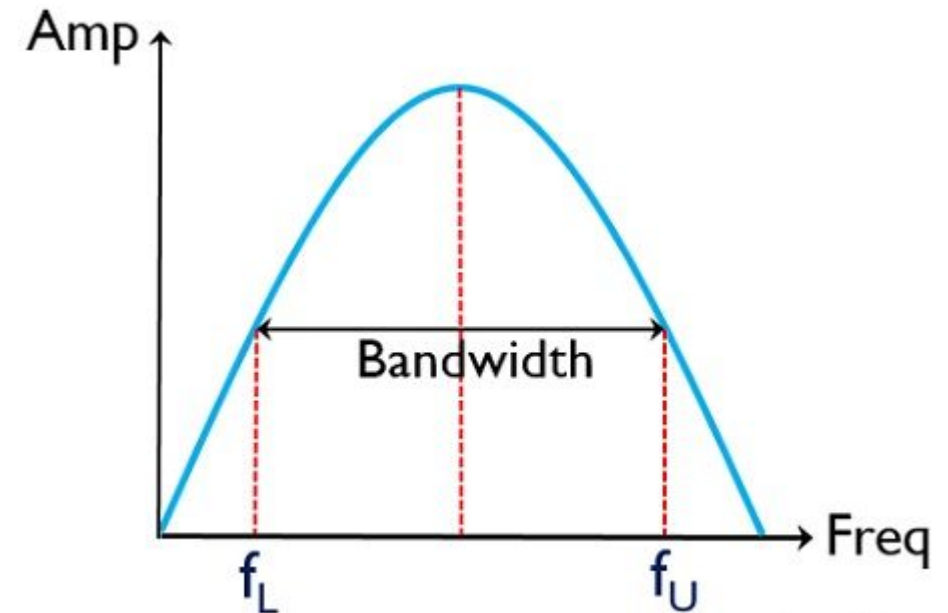


https://commons.wikimedia.org/wiki/File:Electromagnetic_wave.png

UNP 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



Circuit Globe

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



- 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)
 - $\frac{1}{4}$ wave long coax of a different impedance
 - 'Stubs' and other wire or metal additions to the exposed part of the antenna



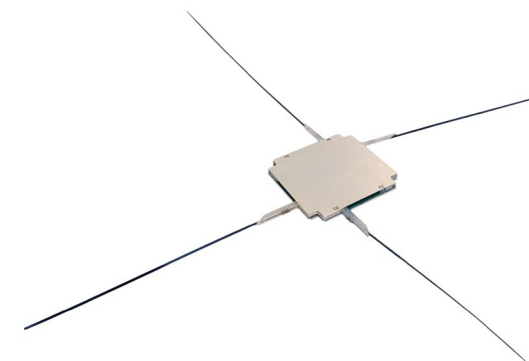
Components

UNP 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 $\frac{1}{4}$ wavelength long
 - Physically robust
 - Emits RF energy outside the satellite
 - Most often resonant: multiple of a quarter wavelength

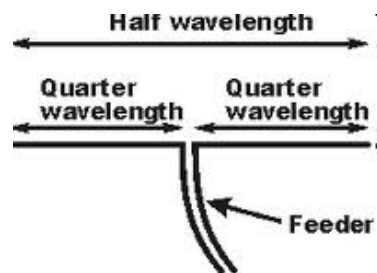
	Frequency	Quarterwave
Band	(MHz)	(Inches)
VHF	145	19.4
UHF	435	6.5
L	1260	2.2
S	2410	1.2
X	10000	0.3



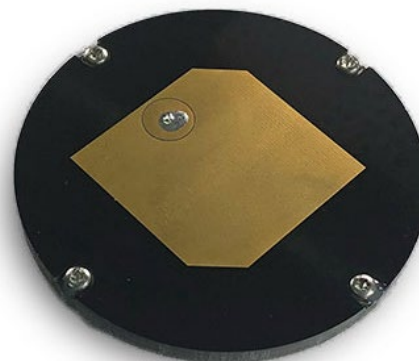
Isispace UHF/VHF 1U ANT

Dipole and Ground Plane

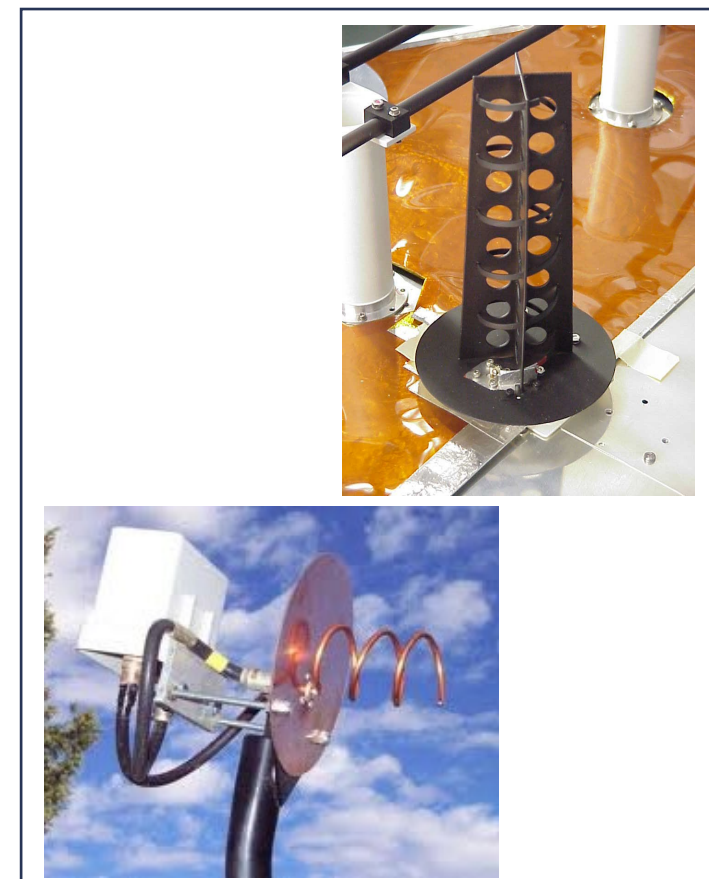
- Dipole
 - Half wave long metal
 - Often used for HF
- Ground plane
 - $\frac{1}{4}$ wave elements
 - 'ground' elements canted



Patch



Helix

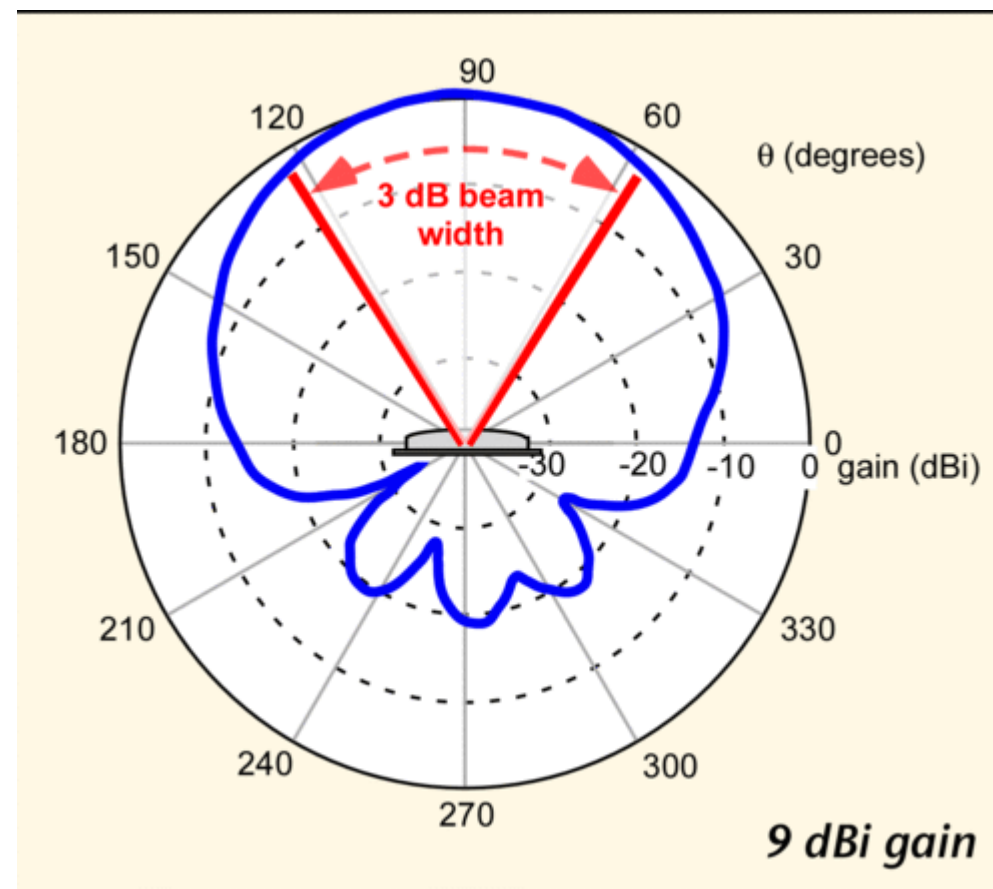


Images courtesy of J. White

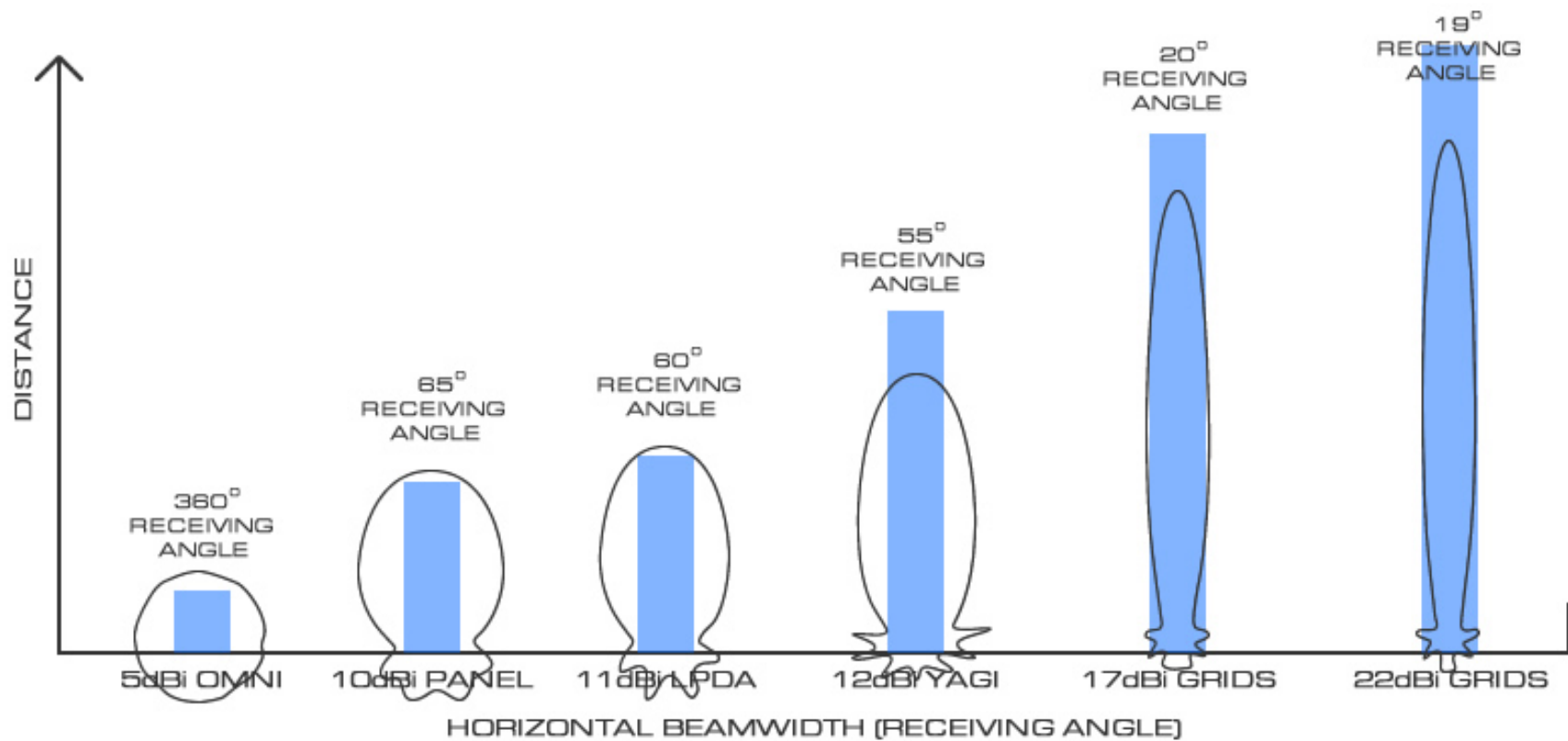
UNP Patterns - Beamwidth



The width in degrees between the
-3dB points



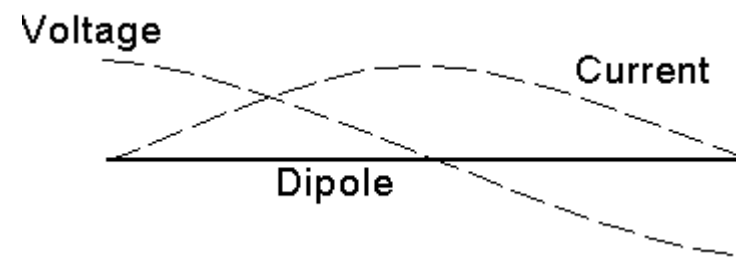
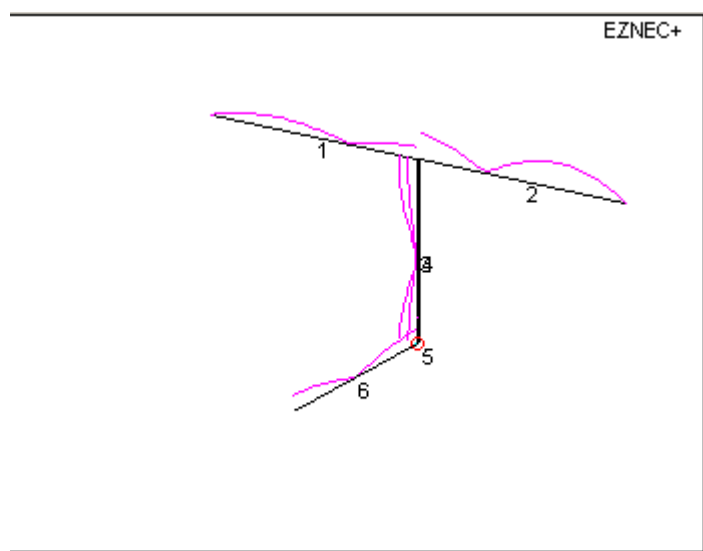
UNP Gain vs. Beamwidth



UNP V and I in Resonant Antenna



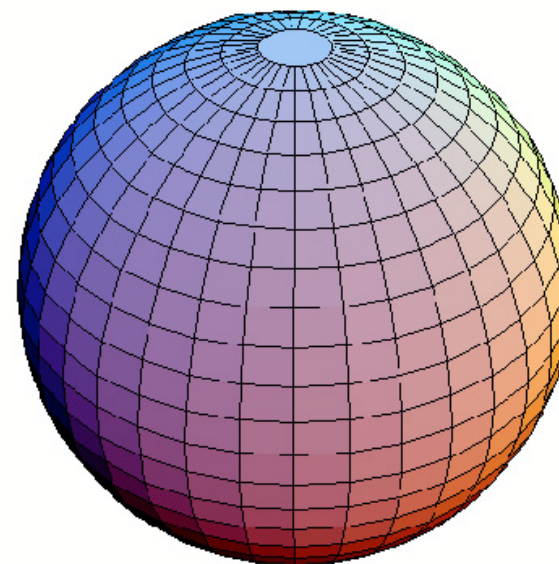
- In a resonant antenna the V and I are at min and max at the center and end points
- In non-resonant the min and max not at the end points or center
- The non-resonant is less effective at radiating the RF





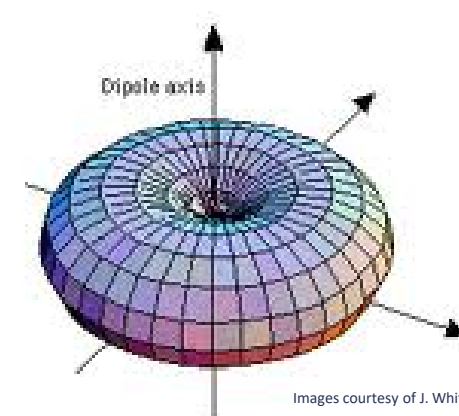
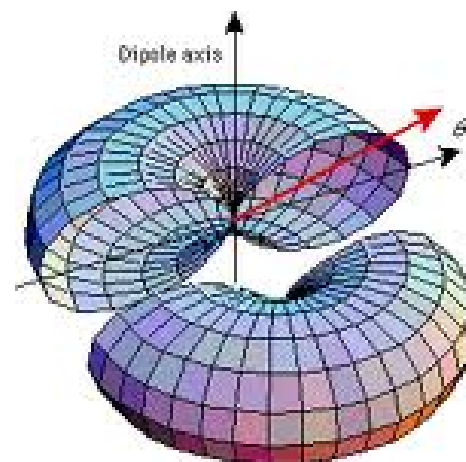
- Generally anything not some multiple of $\frac{1}{4}$ wavelength long, or fed 'off center'
- Non-resonant antennas will
 - Be less efficient because power is not transferred efficiently to the antenna
 - Not be close to 50 ohms impedance
 - Be difficult to match to 50 ohms
 - Usually have complex radiation patterns
- A resonant antenna can become non-resonant due to things around it

- 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

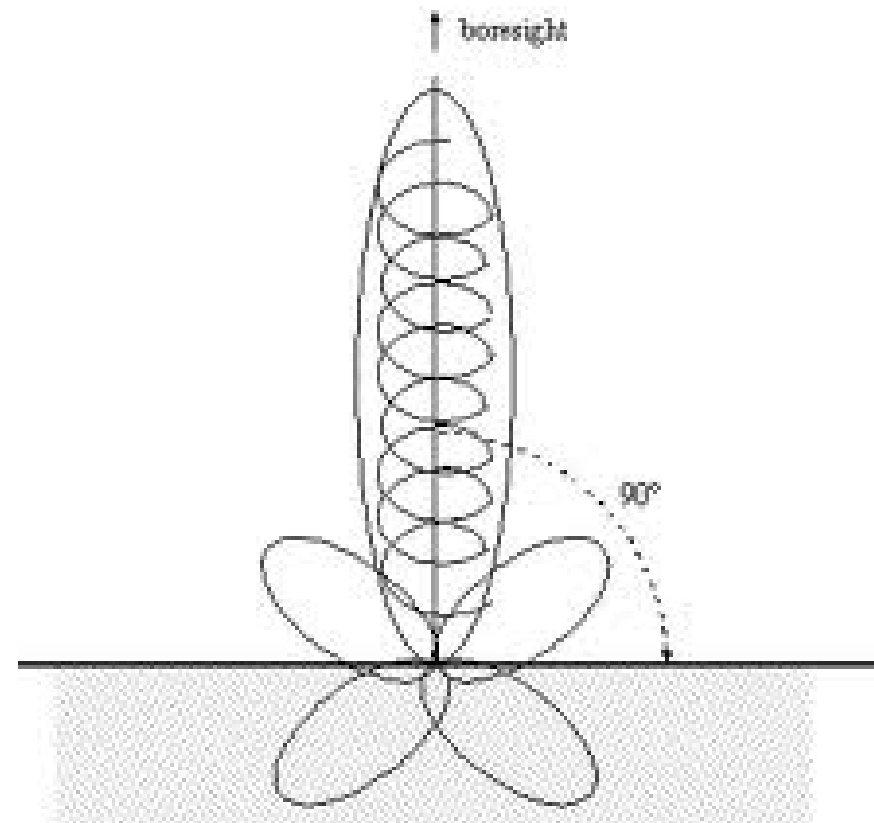
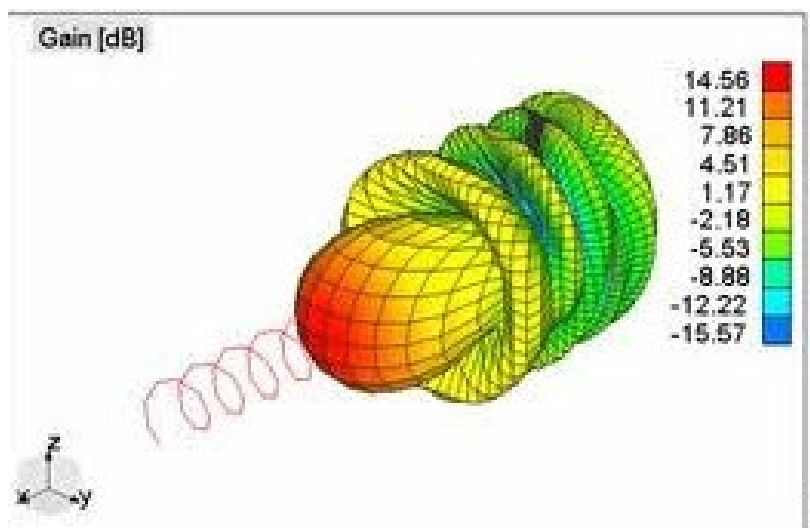


Images courtesy of J. White

- 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

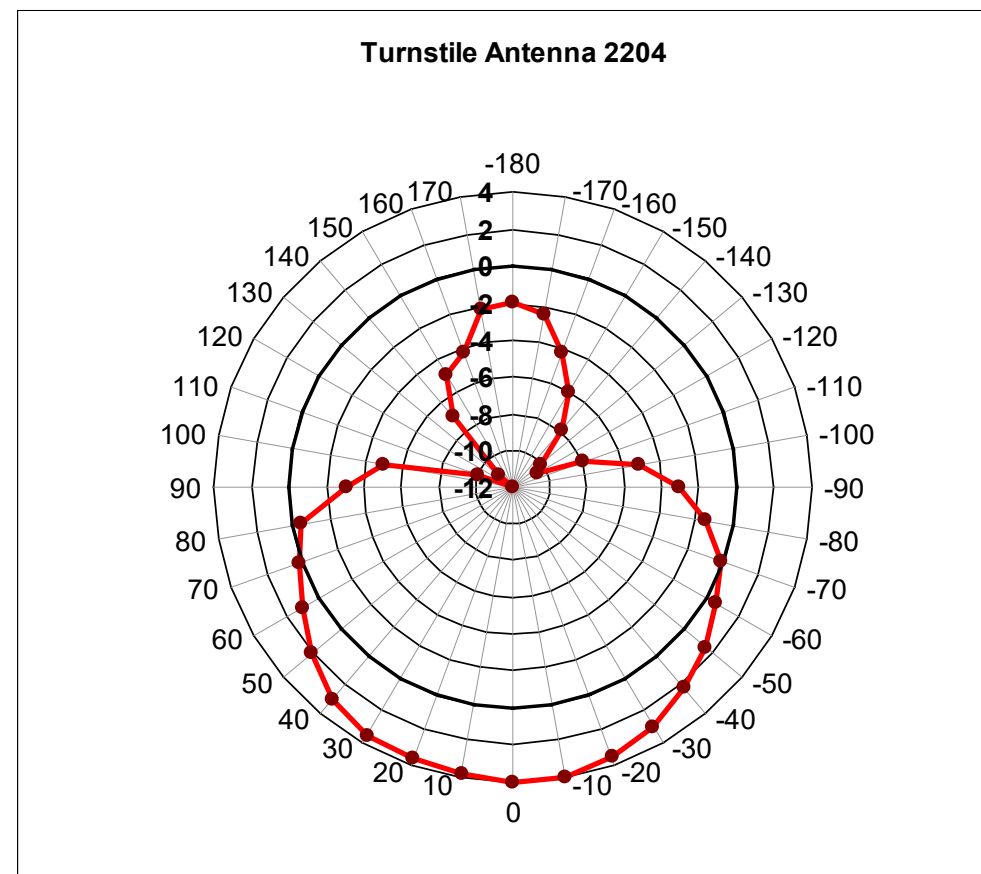


- Helix
 - Can have 3 to ~24dBi
 - Inherently circular



Images courtesy of J. White

- Canted Turnstile
 - Circular off the end
 - Nearly hemispherical



Images courtesy of J. White

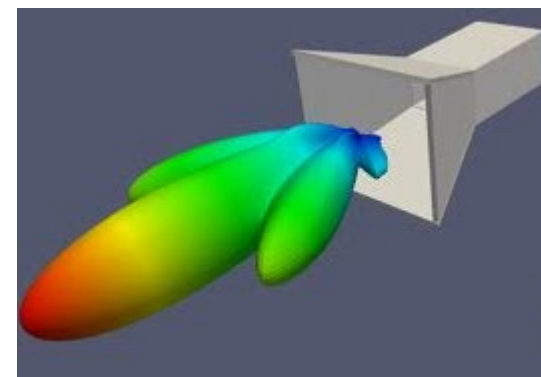
- Horn
 - Useful above about 3 GHz, particularly at 8 to 10 GHz
 - Can be linear or circular
 - Length determines gain, angle sets impedance



ahsystems.com/catalog/SAS-584.php



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



everythingrf.com/search/waveguide-horn-antennas



- 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

UNP 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

UNP Practical Antennas for Small Satellites



- Not many choices due to small size of the satellite
 - VHF and UHF
 - $\frac{1}{4}$ 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

UNP 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.

UNP 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

UNP 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

UNP 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

UNP 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

