Antennas & Transmission Lines

Network Startup Resource Center
www.nsrc.org

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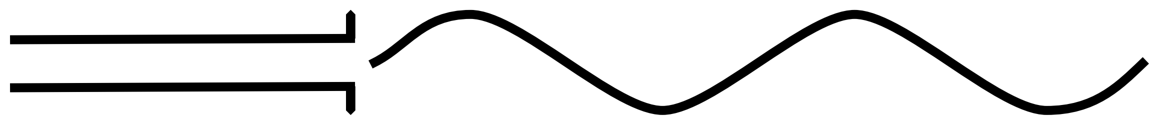
Objectives

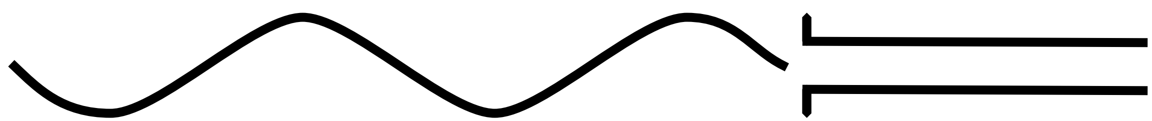
- This unit will help you to understand
  - How an antenna works
  - How to read a radiation pattern
  - How to choose the right antenna
  - How transmission lines work
  - How to choose the right transmission line

What's An Antenna?

- An antenna couples electrical current to radio waves



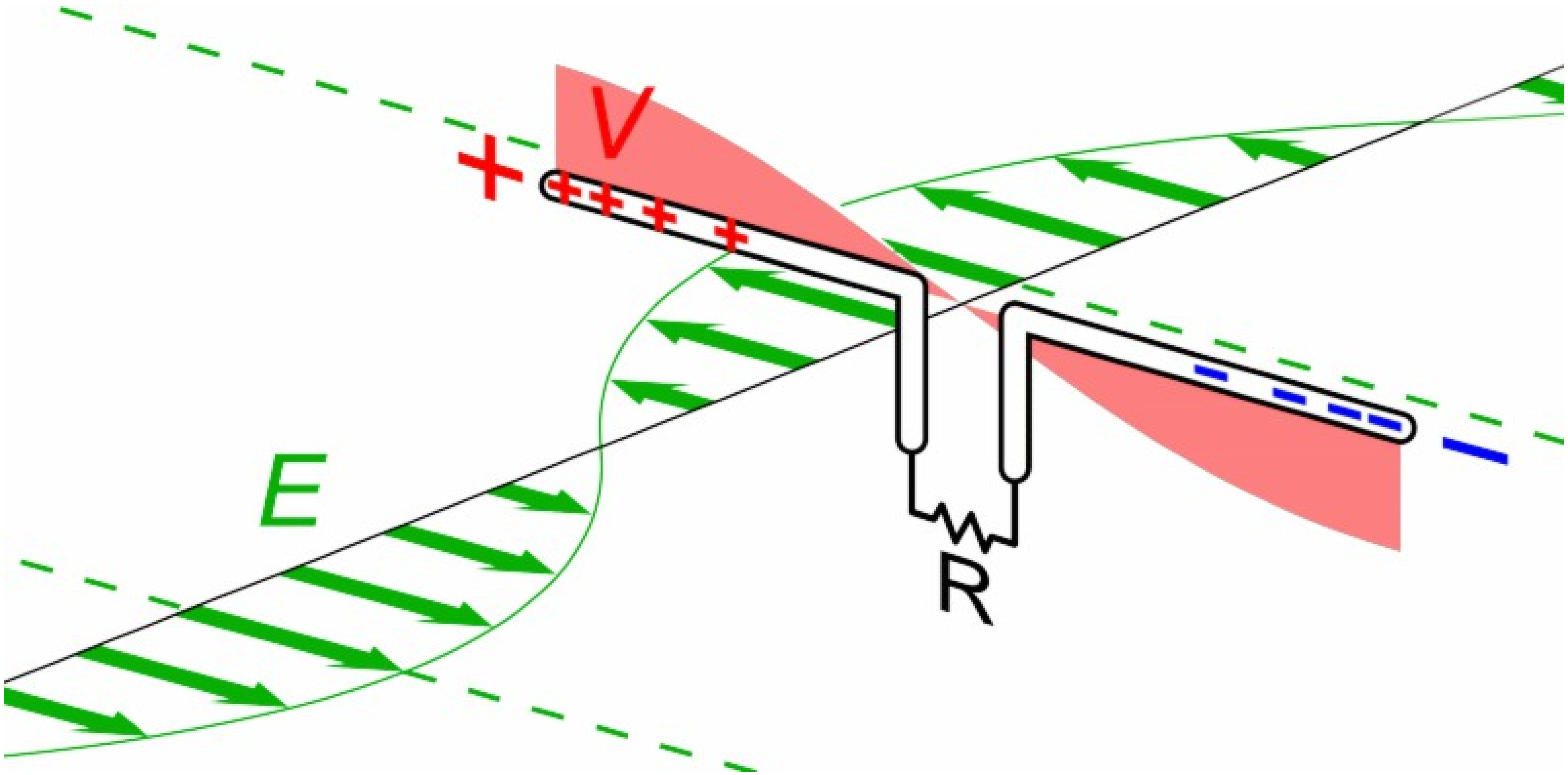
- And it couples radio waves back to electrical current



- It's the interface between guided waves from a cable and unguided waves in space

Radio Waves to Electrical Current

This antenna is receiving energy from radio waves



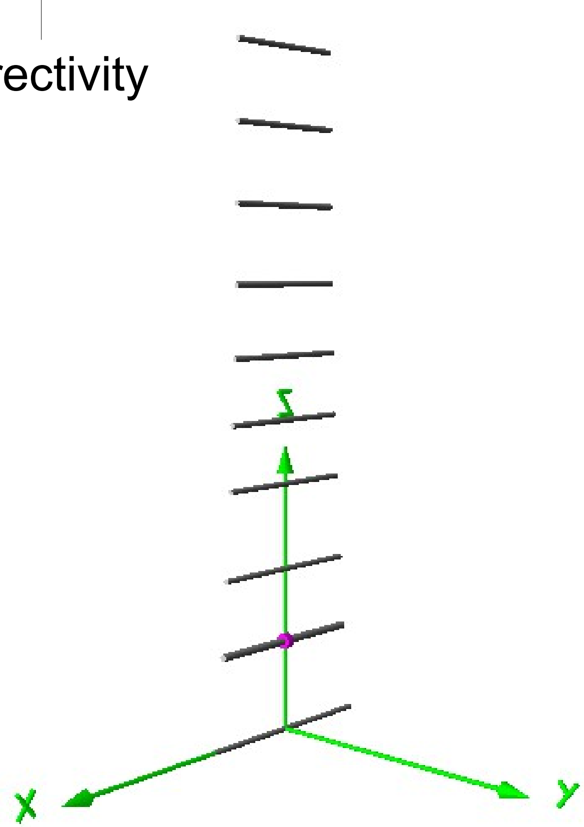
https://commons.wikimedia.org/wiki/File:Dipole_receiving_antenna_animation_6_800x394x150ms.gif

General Antenna Properties

- Antennas can have
  - Directivity
  - Gain, shown by Radiation Patterns
    - Beamwidth, Lobes, Sidelobes, Nulls, Front to Back Ratios
  - Polarization
  - Center Frequency
  - Bandwidth (How far above & below the center Frequency?)
  - Physical Size
- Technically, they also have Impedance & Return Loss
- Antennas never amplify signal, they only shape it!

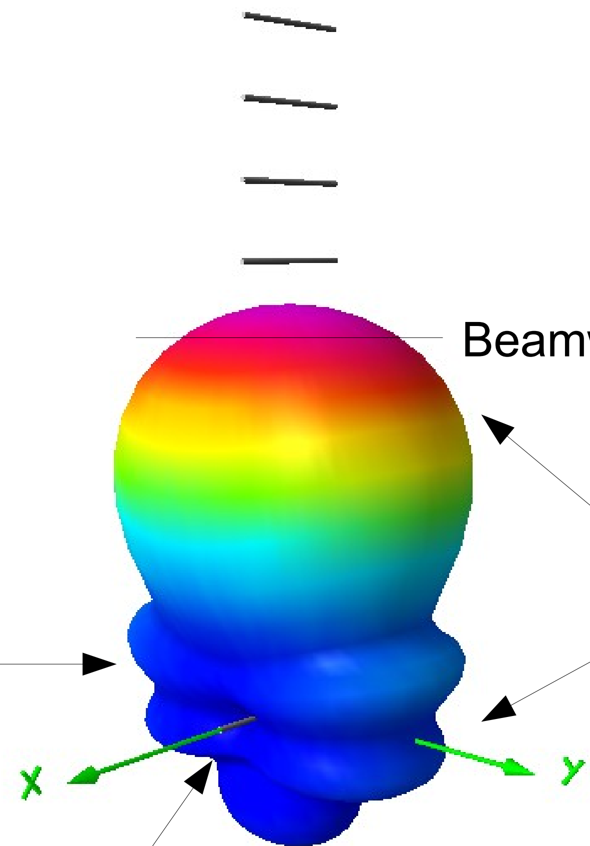
General Antenna Properties

Directivity



Polarization

- Size
- Frequency
- Bandwidth



Beamwidth

Front:Back

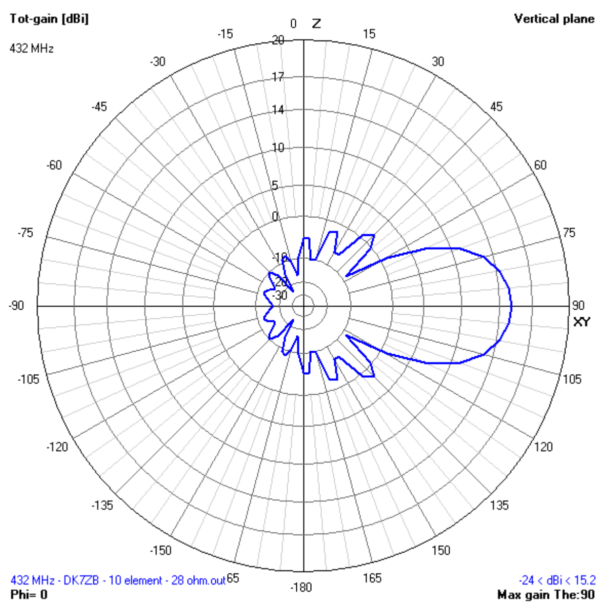
Side Lobe

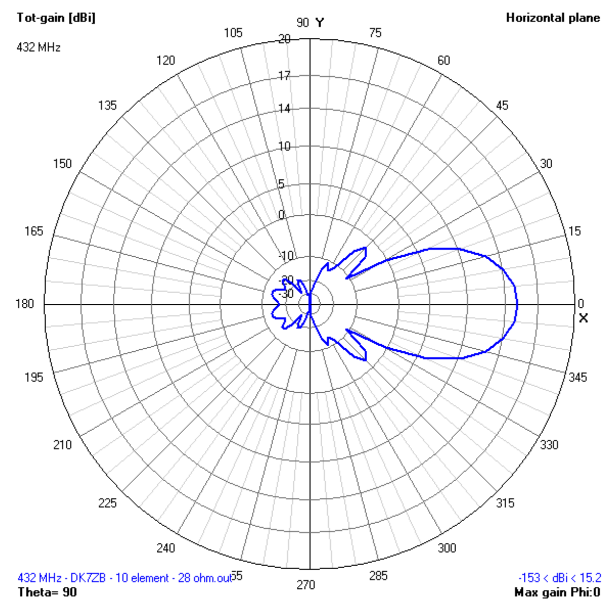
Null

Back Lobe

Radiation Patterns

- A representation of the distribution of power radiated from or received by the antenna
- Shown as a function of direction angles from the antenna
- Patterns usually use a polar projection
- Directional antennas have differing Vertical & Horizontal gain





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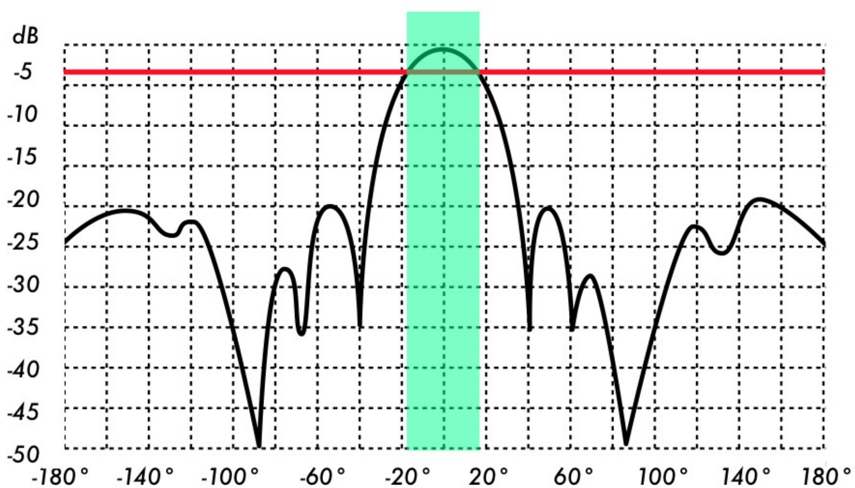
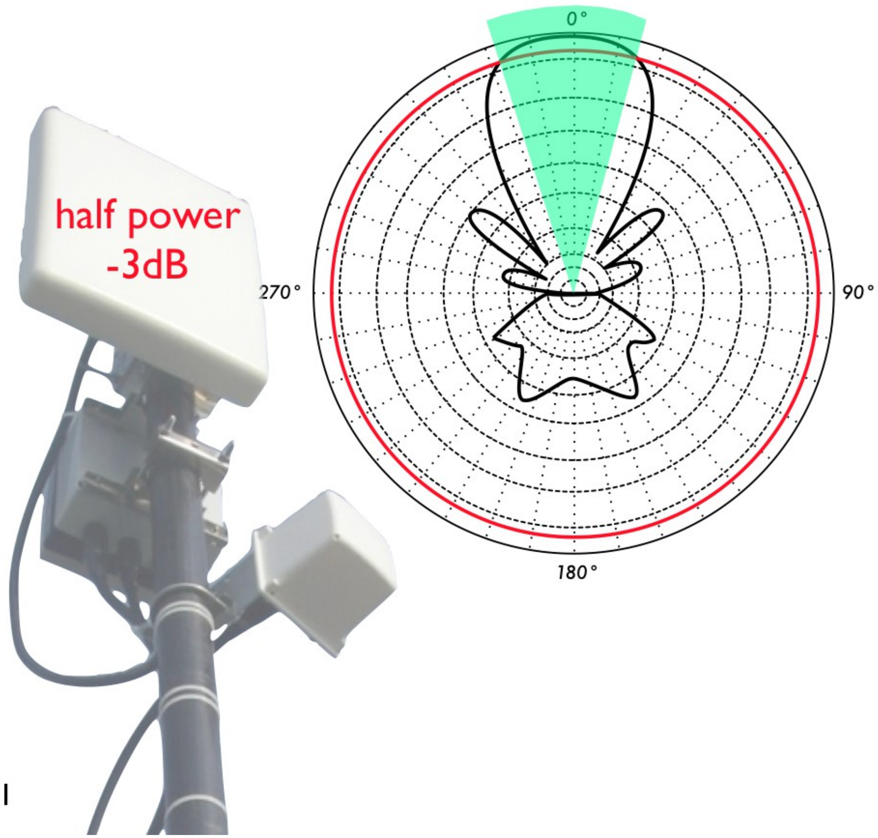
Beamwidth

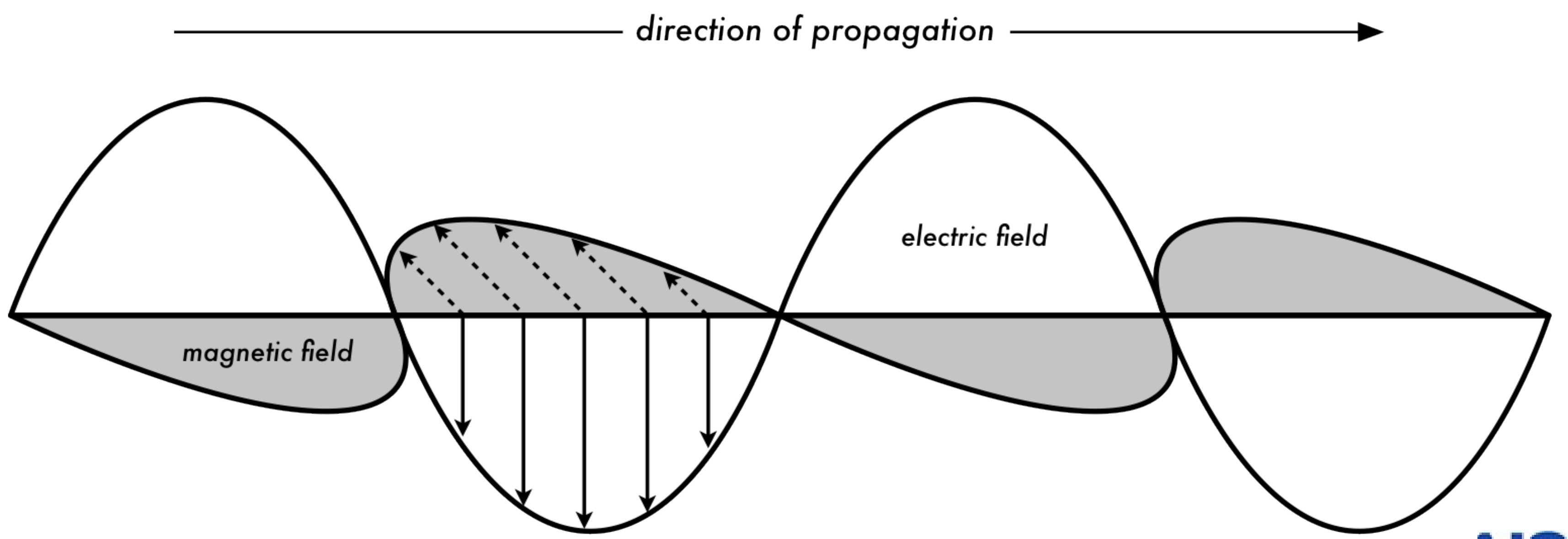
- Angular measure where radiated power is equal or greater than half its maximum value





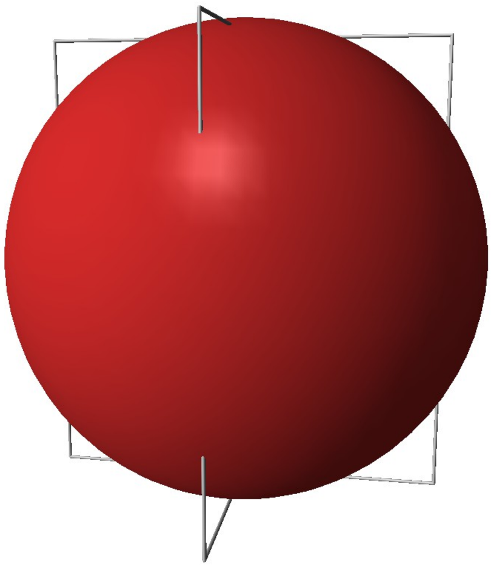
Polarization

- Electromagnetic waves are polarized
- Polarization of transmitting & receiving antennas must match for optimal communications
- Waves can be linear (H/V) or circular (RH/LH) polarized
- Many new antennas have multiple polarizations



Isotropic Antenna

- Theoretically radiates energy equally
- Used as a basis of measurement
  - dBi: decibels relative to an isotropic antenna
  - EIRP: Equivalent Isotropic Radiated Power
- Is a candle an isotropic radiator?
- Is the sun an isotropic radiator?

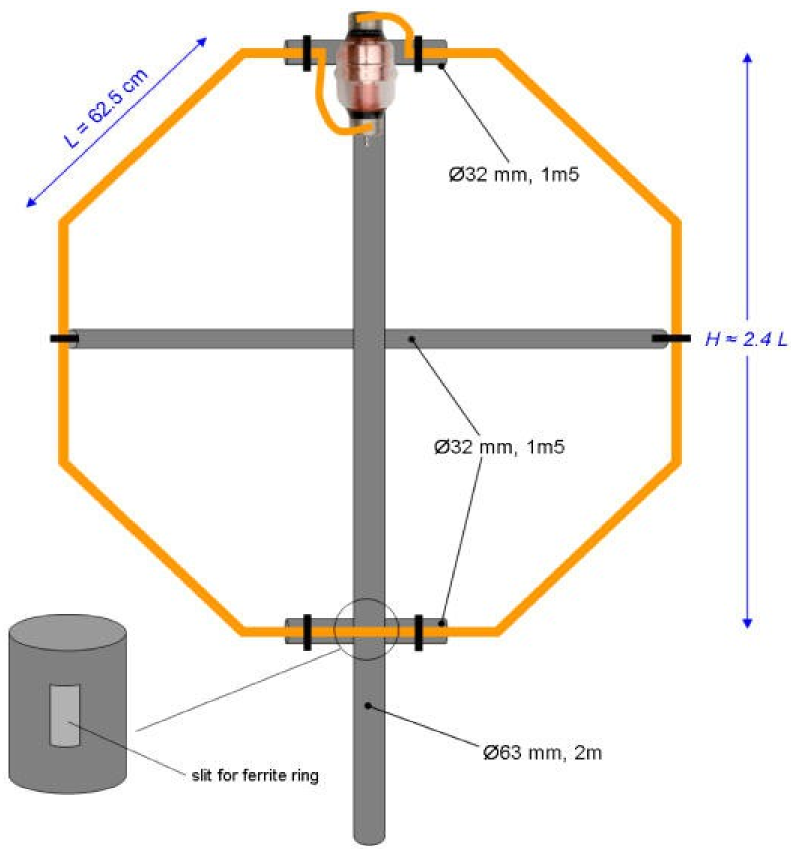


Directivity, Polarization, Lobes? No
Front to Back Ratio? 1:1

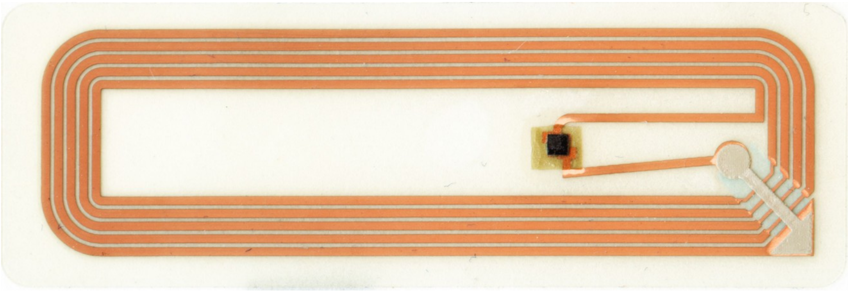
Loop Antenna

- Discovered in the 1830s by Michael Faraday
  - to detect magnetic waves
- Used by Hertz to detect radio waves in 1887
- Small Loops (1/10 λ) receive magnetic waves
- Large Loops (1 λ) act like a folded dipole
- Loops are directional, not isotropic
- Small Loops have very low gain
- Do you have any Loop Antennas with you?

Loop Antenna



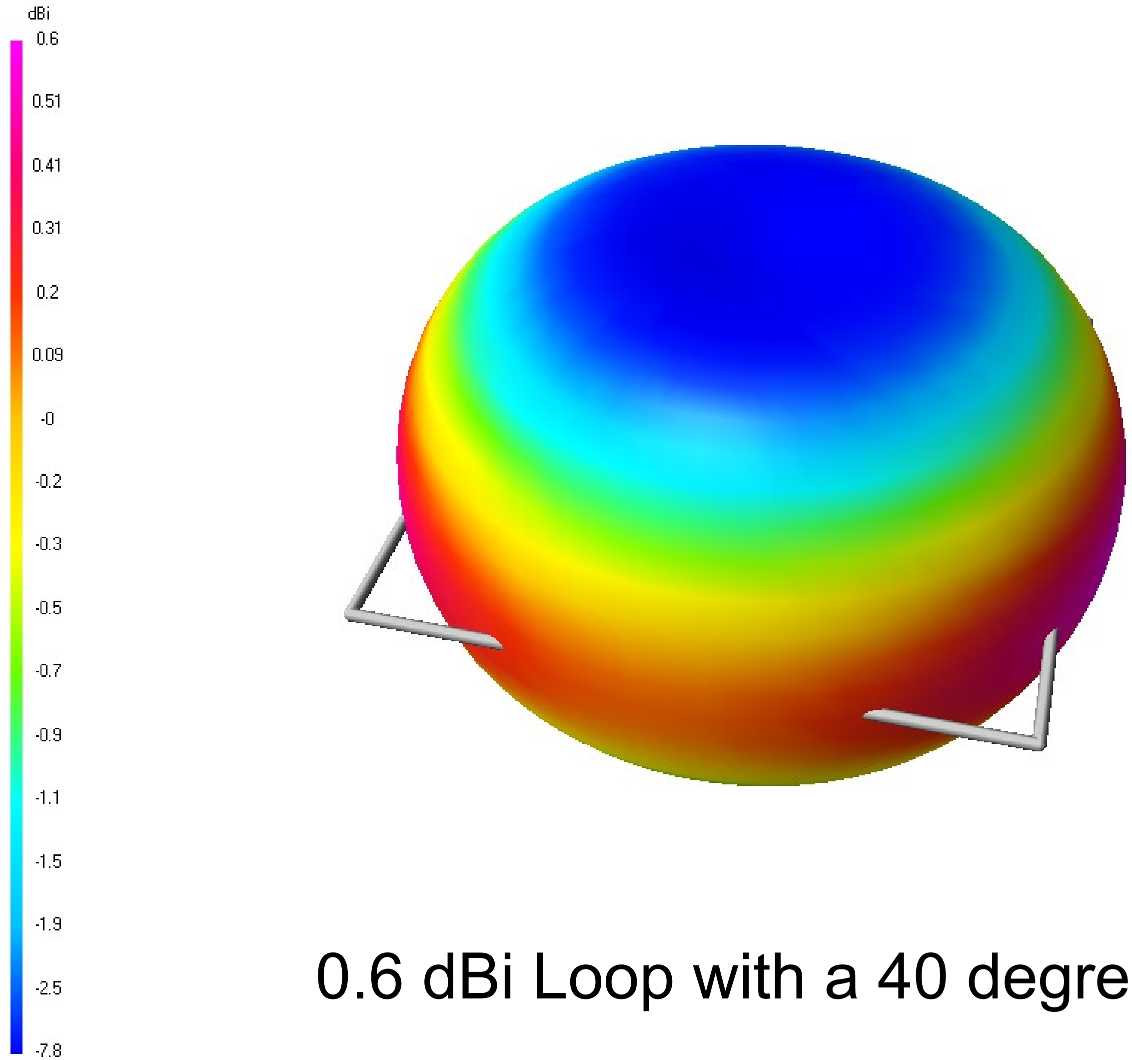
Magnetic Loop Antenna for 3.75MHz / 80m band, Design by Frank N4SPP
http://www.nonstopsystems.com/radio/frank_radio_antenna_magloop.htm

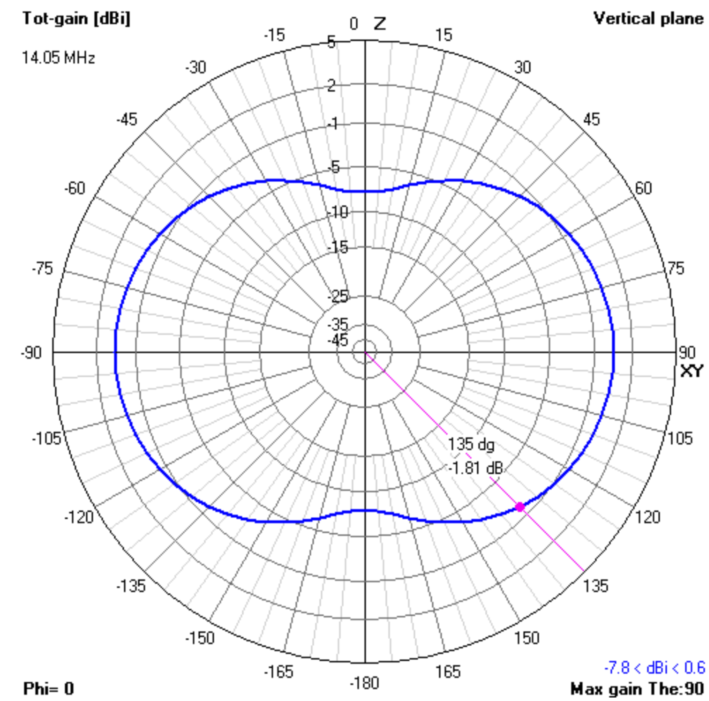


13.56 MHz Smartlabel photo by Wikimedia user Kalinko
https://commons.wikimedia.org/wiki/File:Transponder2.jpg

Loop Antennas: Dr. Michael Gebhart
rfid-systems.at/03_Loop_Antennas.pdf

Loop Antenna

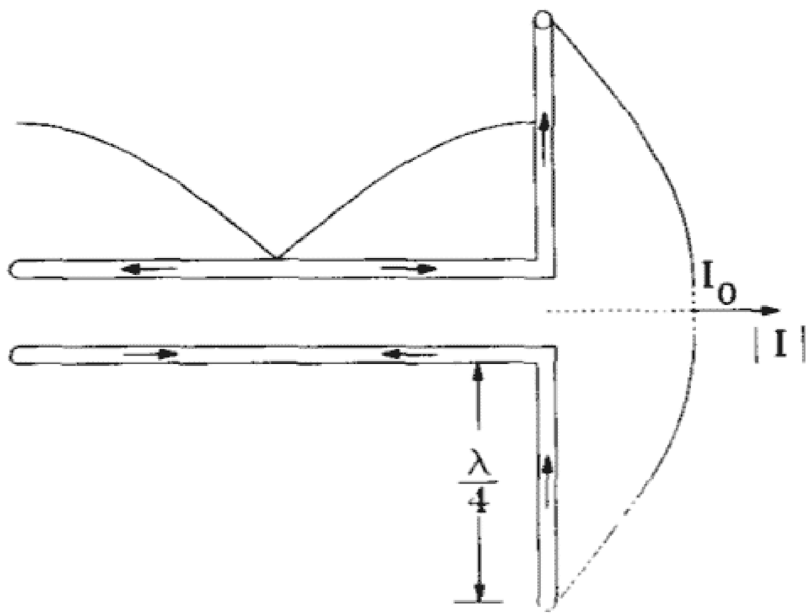


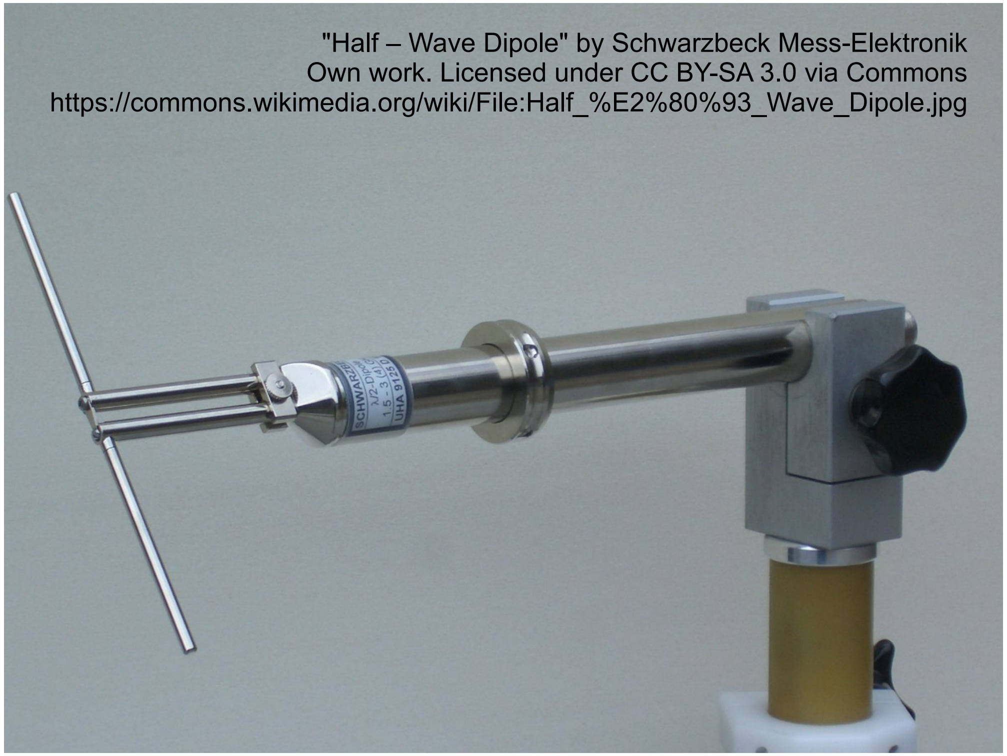


0.6 dBi Loop with a 40 degree omnidirectional beam

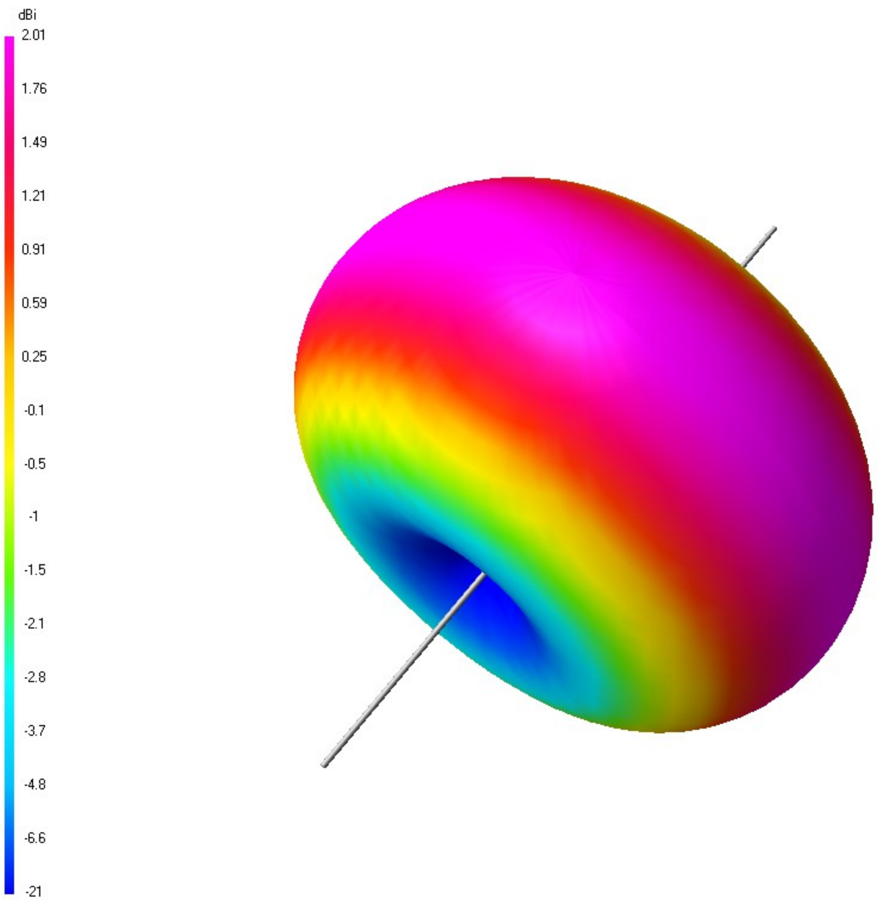
Dipole Antenna

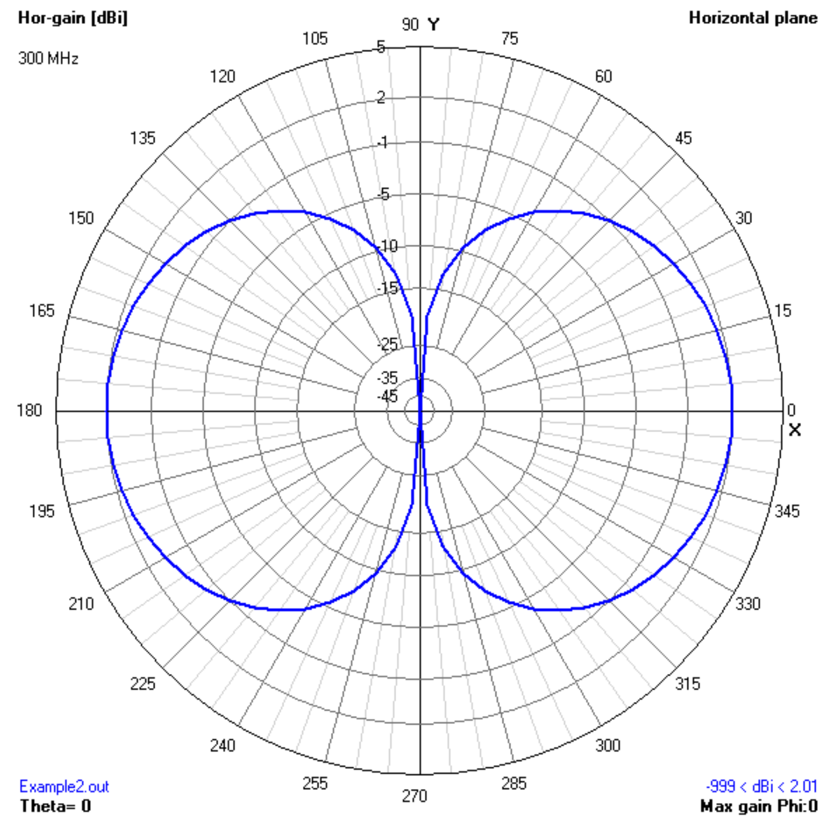
- Discovered in 1886 by Heinrich Hertz
- Typically has two ¼ λ elements & 2.1dBi gain





Dipole Antenna

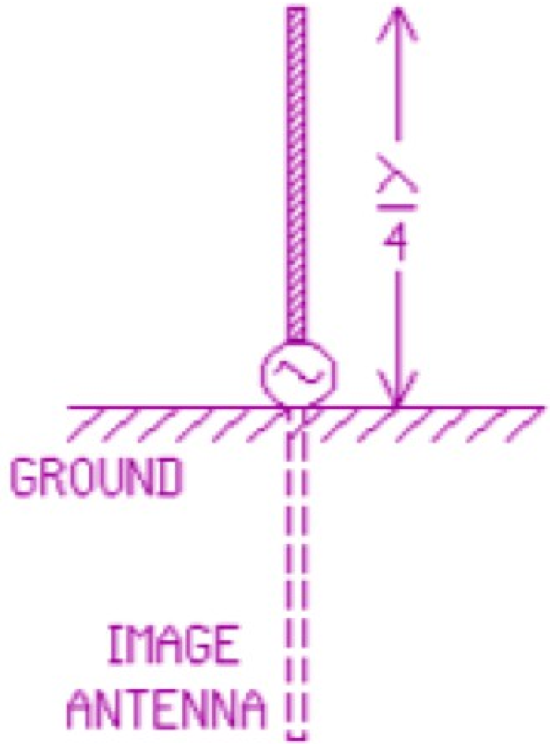


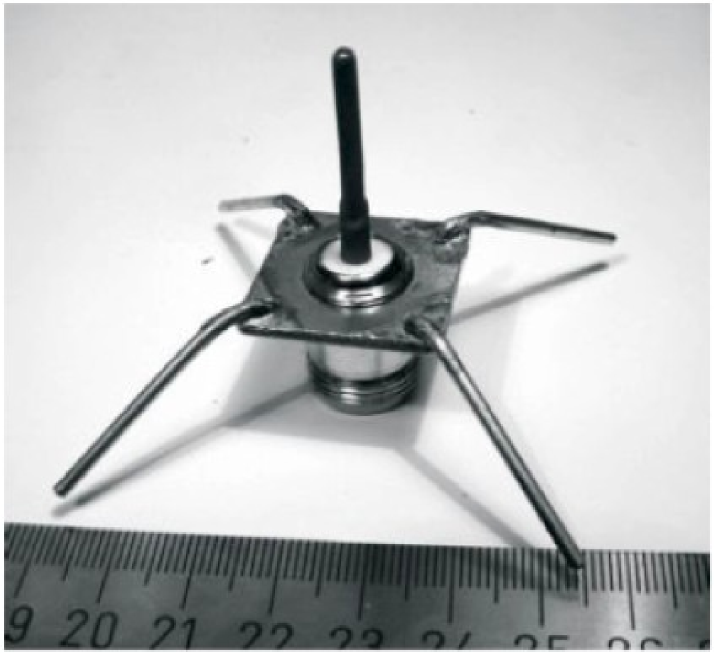


2 dBi Dipole with a 60 degree omnidirectional beam

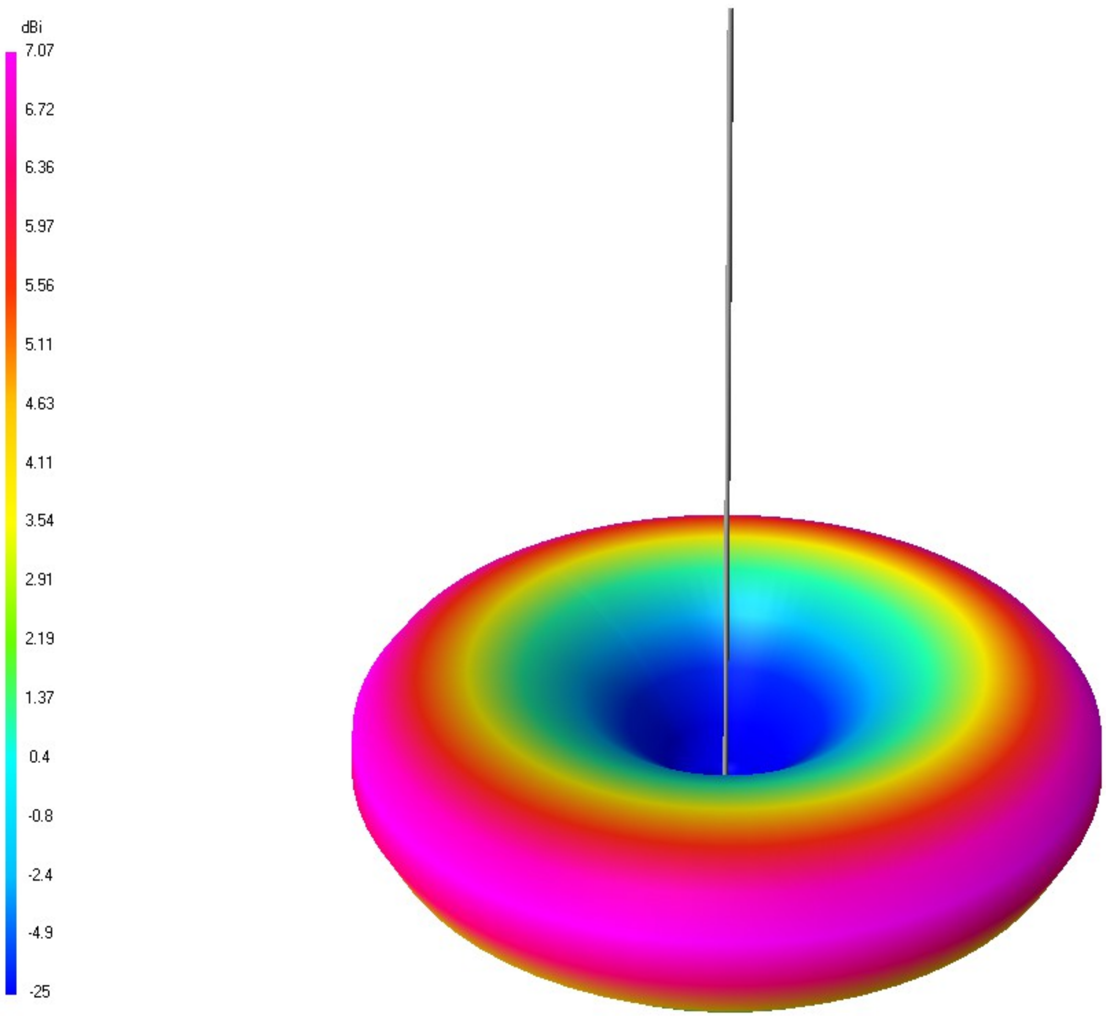
Monopole Antenna

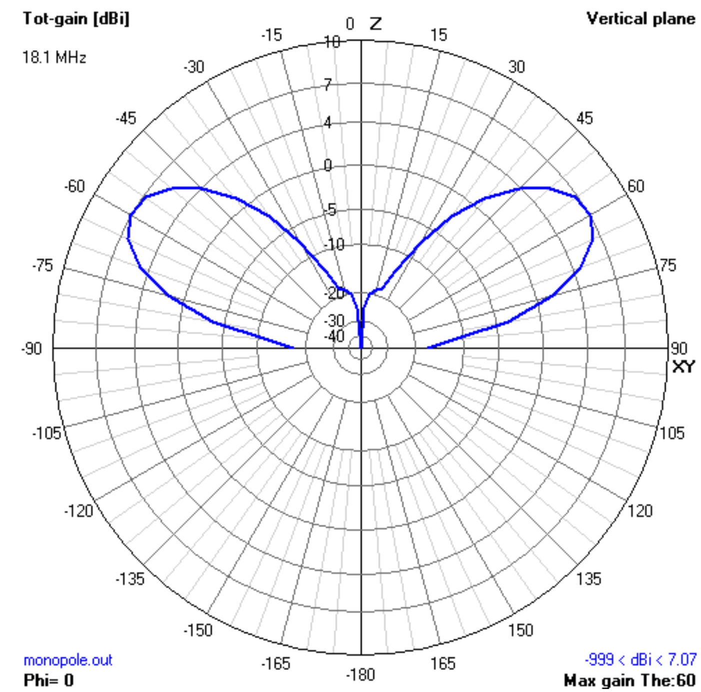
- Discovered in 1895 by Guglielmo Marconi
- ¼ λ vertical element over a ground plane
- Provides 5.14 dBi gain





Monopole Antenna

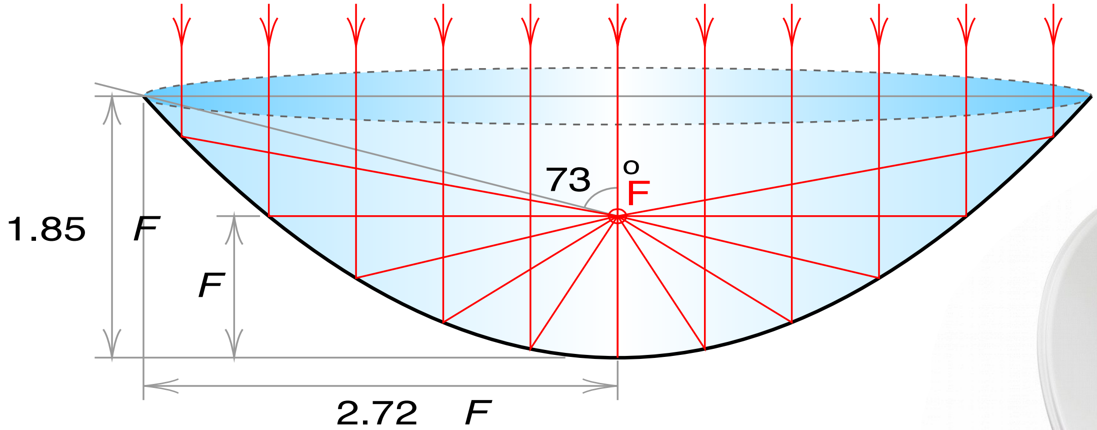




7 dBi Monopole with a tilted 30 degree omnidirectional beam

Parabolic Reflector

- Discovered around 200 BC by Diocles
- Used for Radio in 1887 by Heinrich Hertz



Parabola illustrated by Wikimedia Commons User CMGlee
https://commons.wikimedia.org/wiki/File:Focus-balanced_parabolic_reflector.svg

Ubiquiti Nanobeam Dishes: https://www.ubnt.com/

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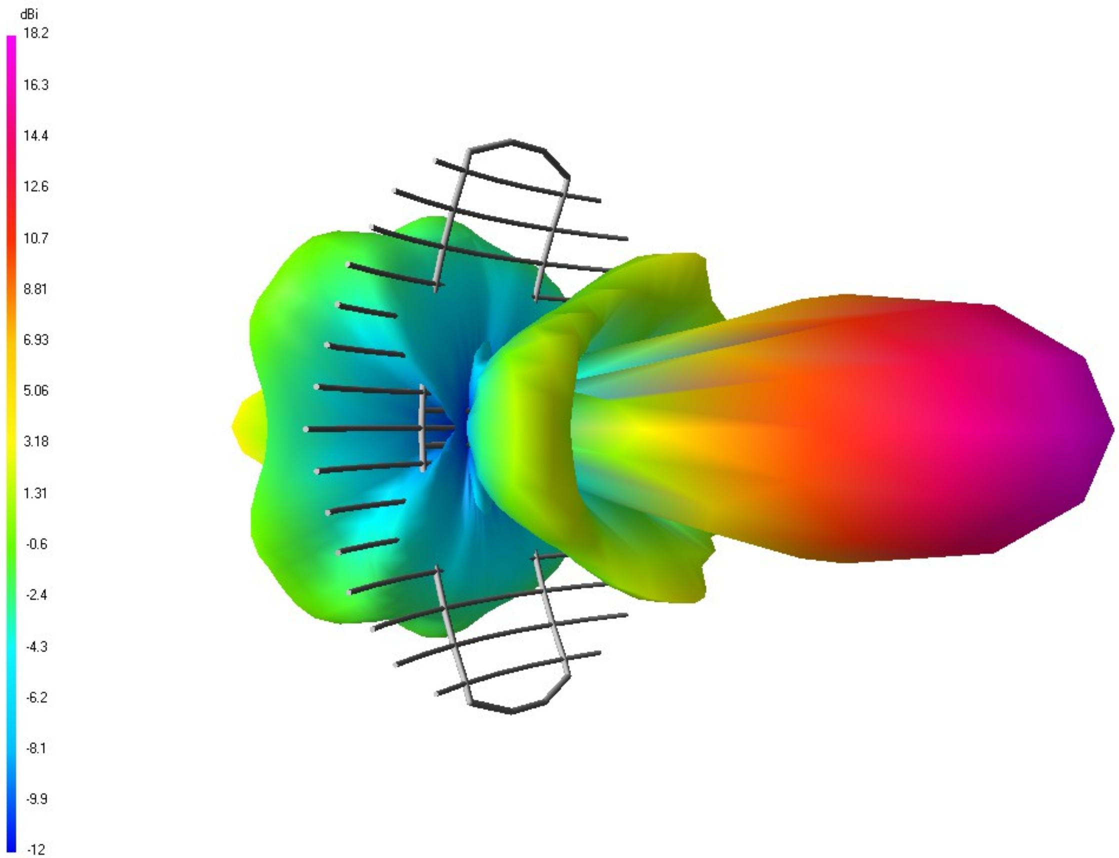
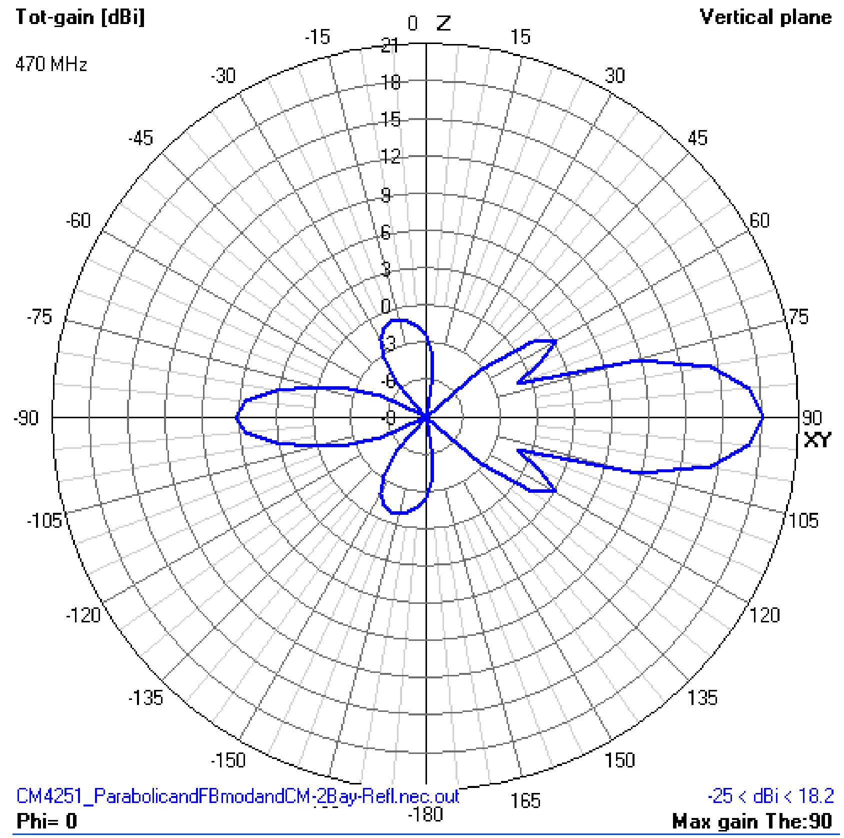
Parabolic Reflector



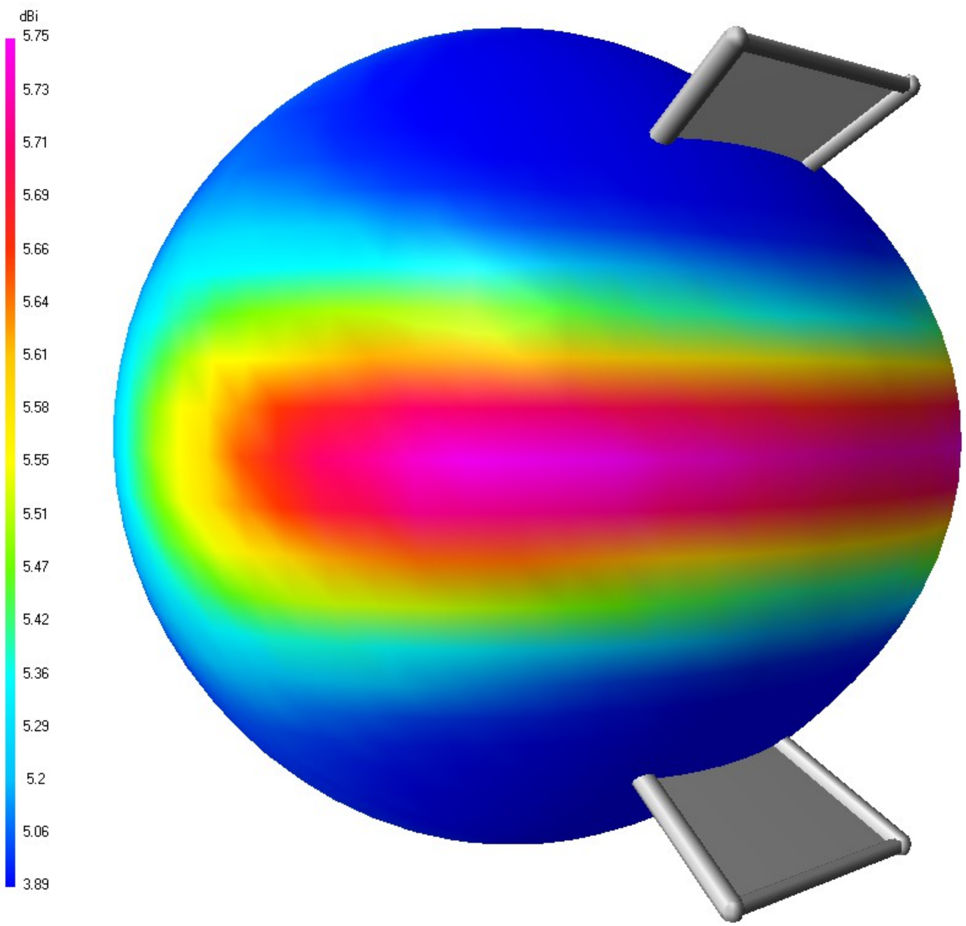


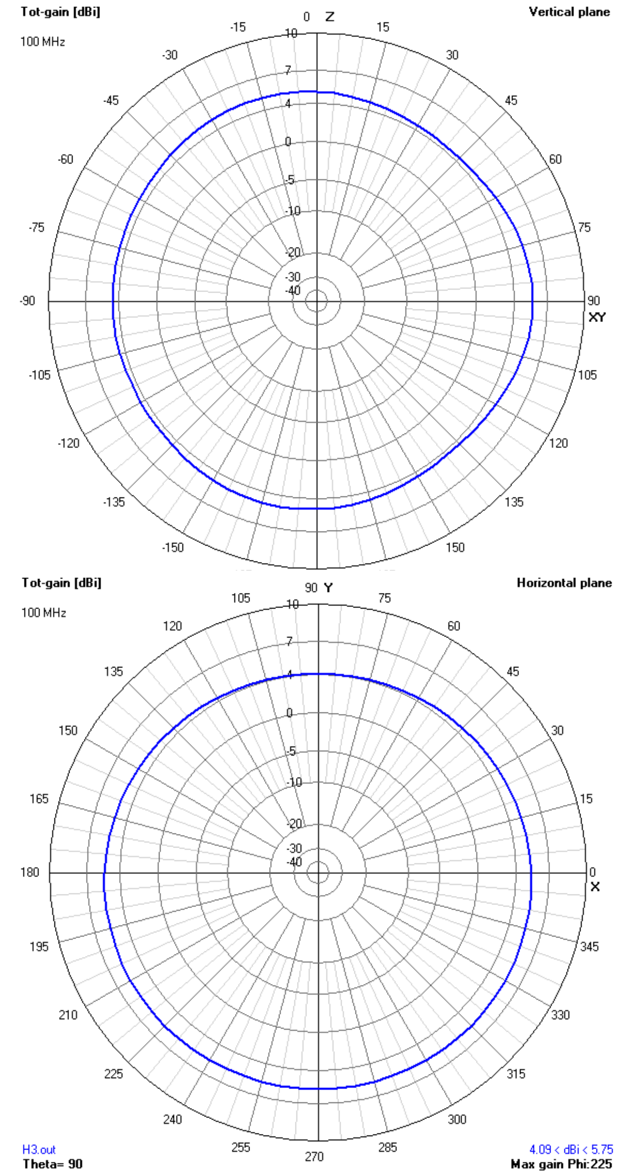
Antenna in front of a Parabolic Reflector yields 18dBi with a 40 degree H+E beamwidth

Horn Antennas

- Lens Discovered ~ 700 BC in Assyria
- Horns in use since Prehistoric times
- First used for radio in 1897 by Sir Jagadish Chandra Bose
- Often coupled with a lens to focus waves

Horn Antenna

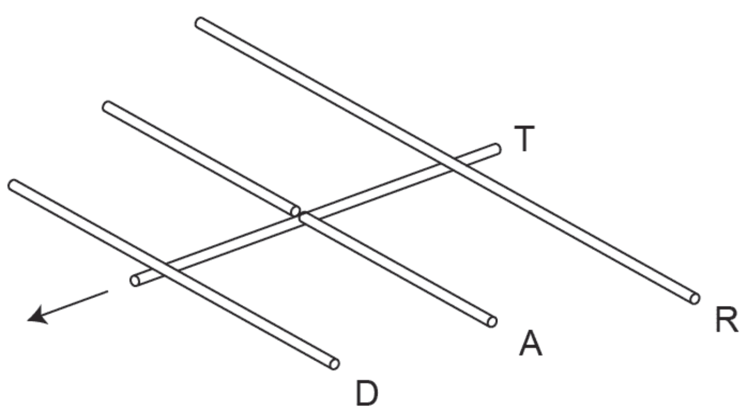




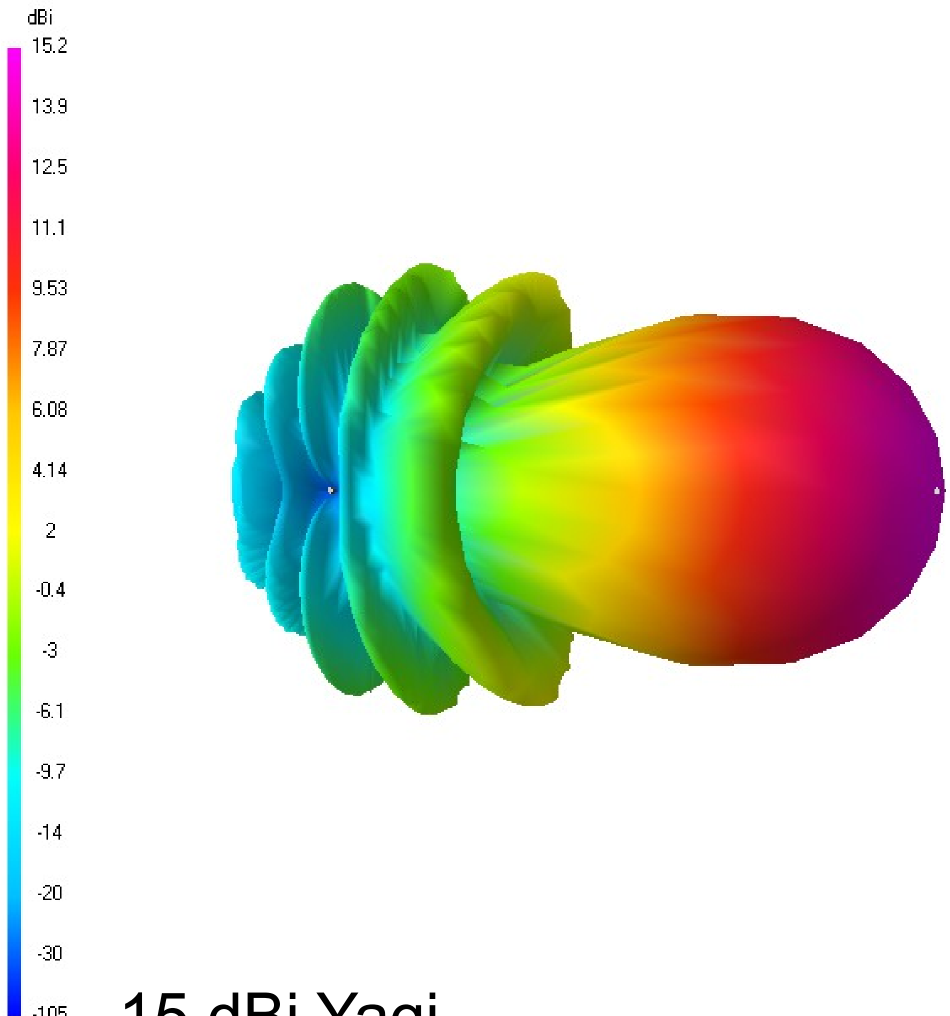
5.75 dBi Directional Horn
(approx) 60 degree E, 180 degree H

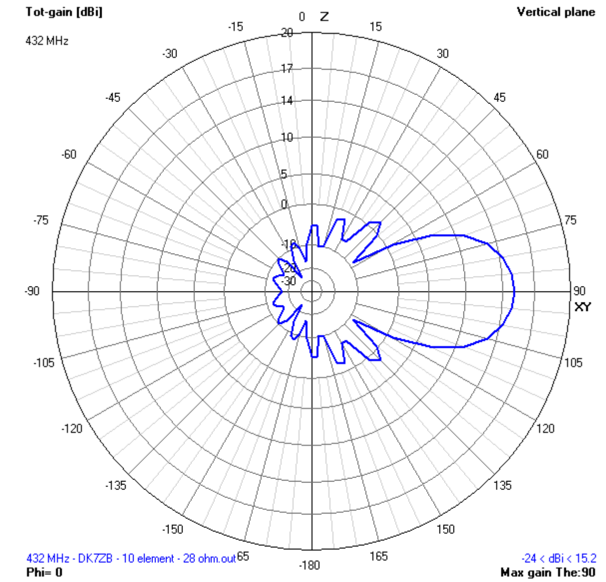
Yagi-Uda (Yagi) Antenna

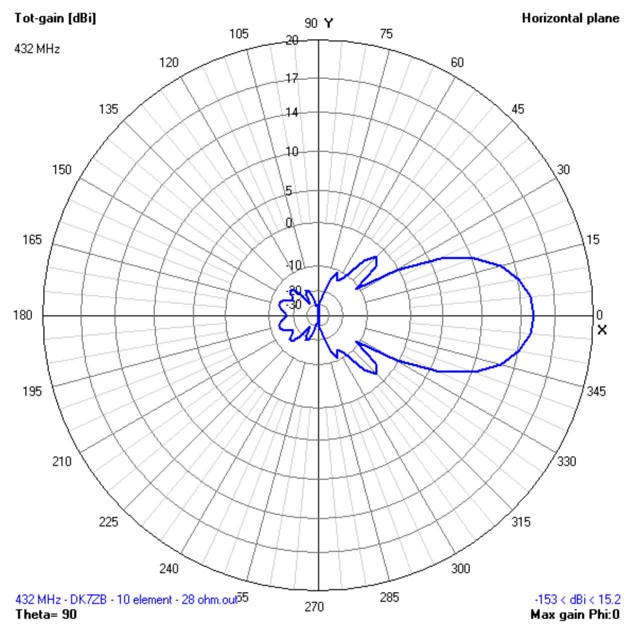
- Invented 1926 by Shintaro Uda & Hidetsugu Yagi
- Common from VHF up to 3 GHz
- Low cost, light weight, durable, and high gain



Yagi Antenna



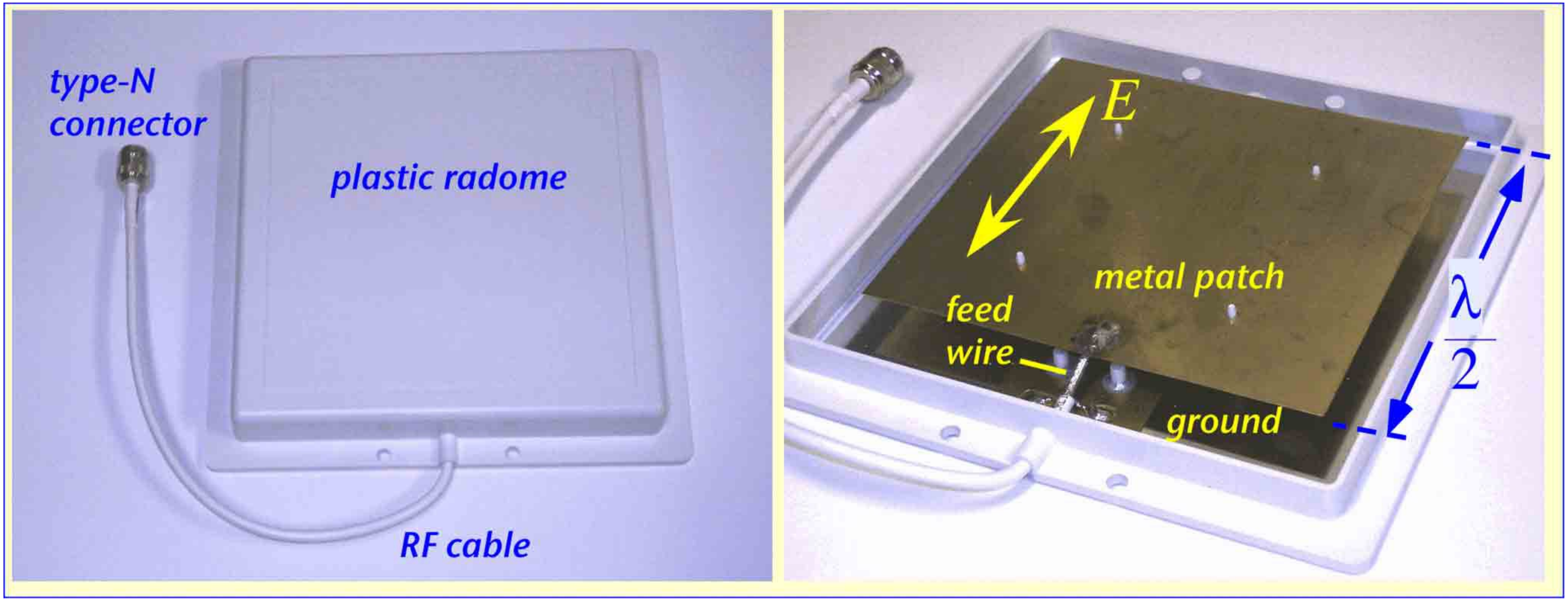




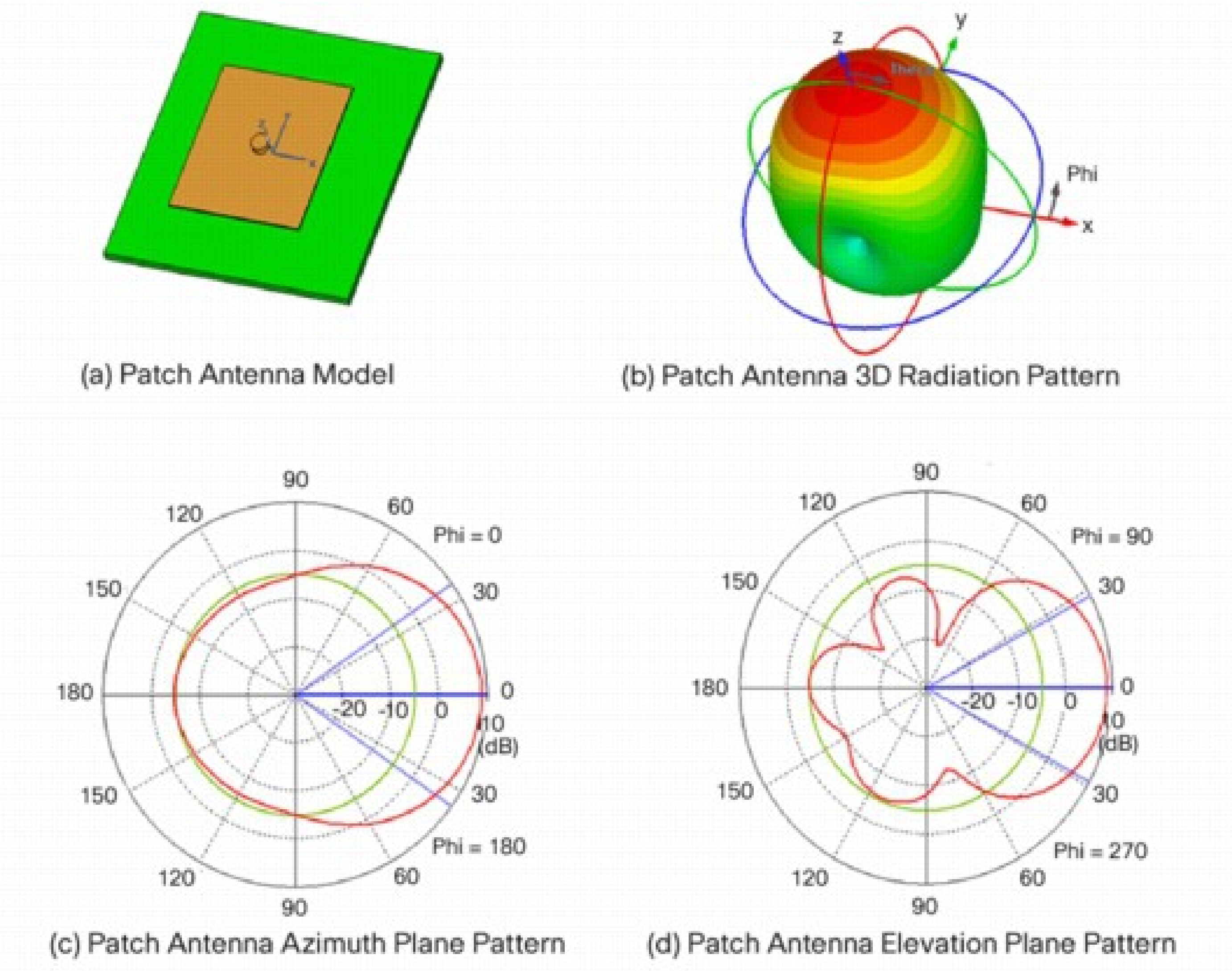
15 dBi Yagi
(approx) 30 degree E, 30 degree H

Microstrip (Patch) Antennas

- Invented in 1972 by J.Q. Howell at NASA
- Very common in electronics and Wi-Fi



Microstrip (Patch) Antennas



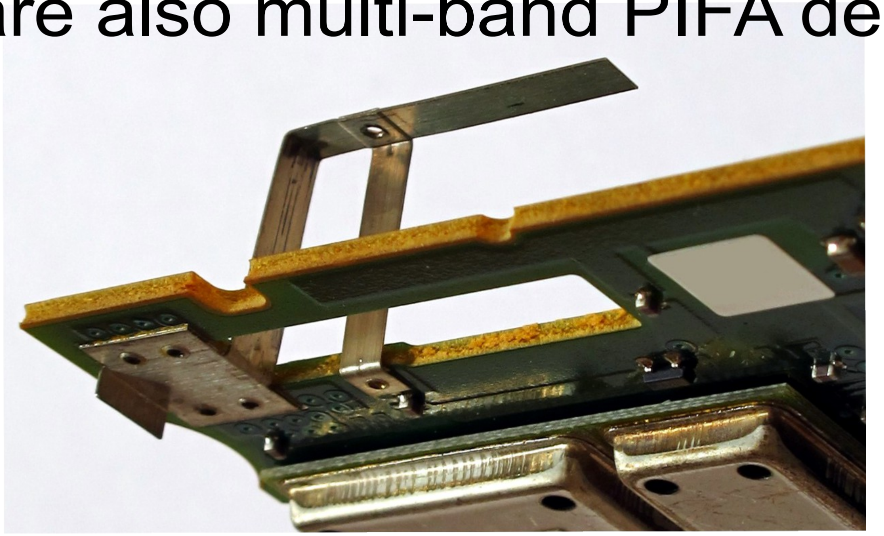
(a) Patch Antenna Model (b) Patch Antenna 3D Radiation Pattern

(c) Patch Antenna Azimuth Plane Pattern (d) Patch Antenna Elevation Plane Pattern

http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-antennas-accessories/prod_white_paper0900aecd806a1a3e.html

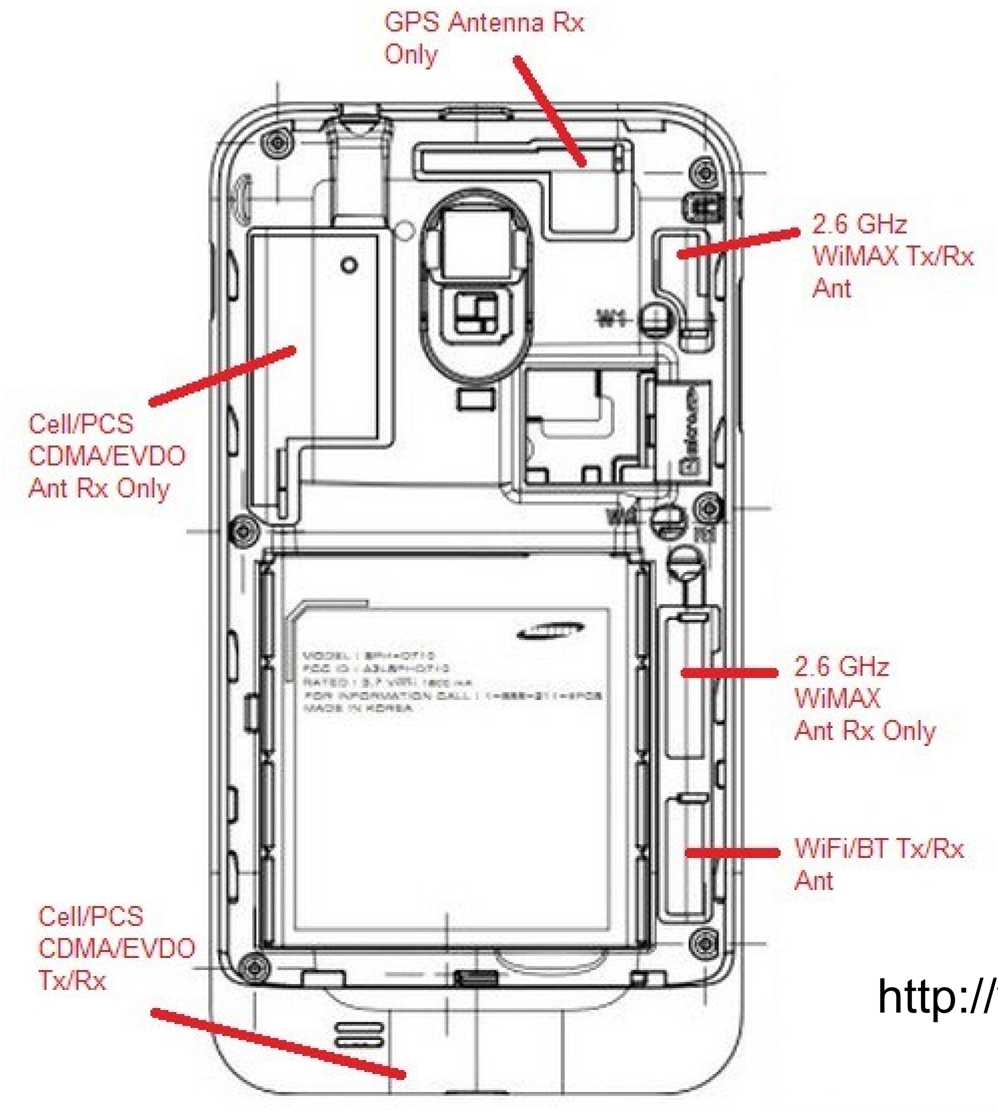
Planar Inverted F-Antenna (PIFA)

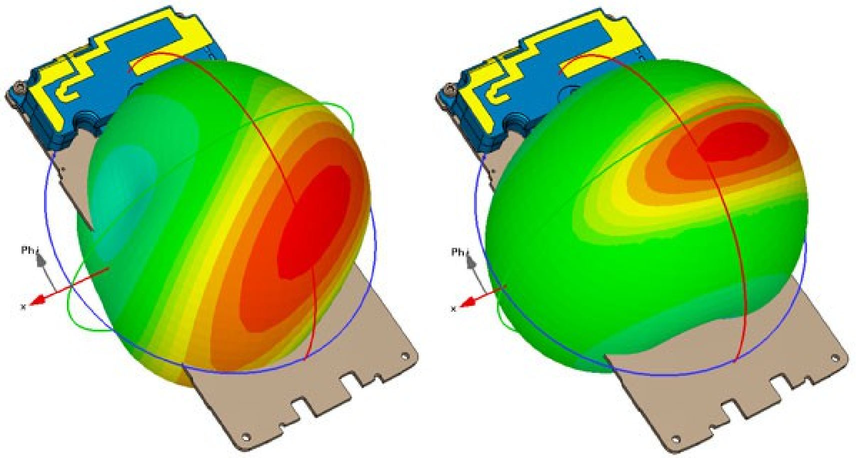
- Invented in 1987 by Taga & Tsunekawa at NTT
- Allows for a very small antenna
  - Width + Height can be around ¼ λ
  - A ¼ λ dipole at 750 MHz is 100mm: Phone size!
  - PIFA allows for good antennas less than ¼ λ long
  - There are also multi-band PIFA designs



https://commons.wikimedia.org/wiki/File:
Planar_Inverted_F-Shaped_DECT_Antenna.jpg

Planar Inverted F-Antenna (PIFA)



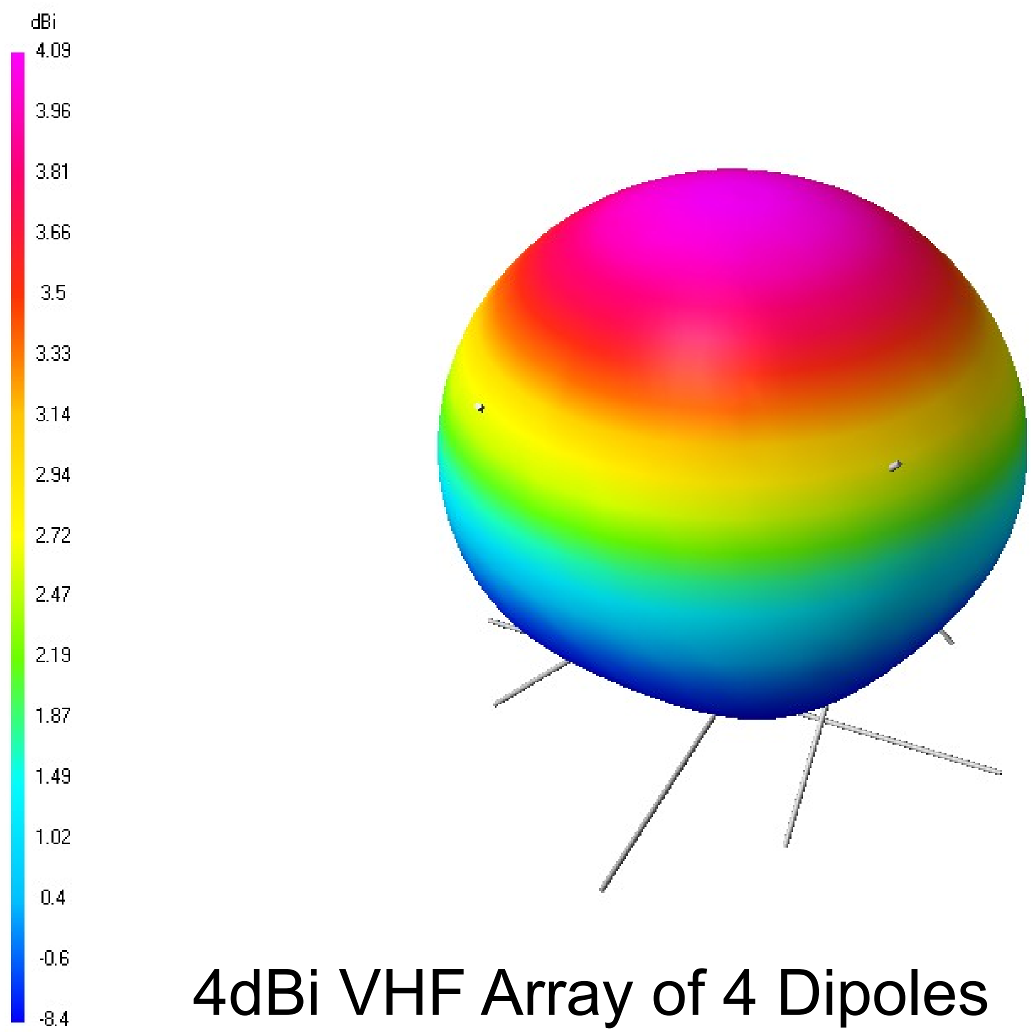


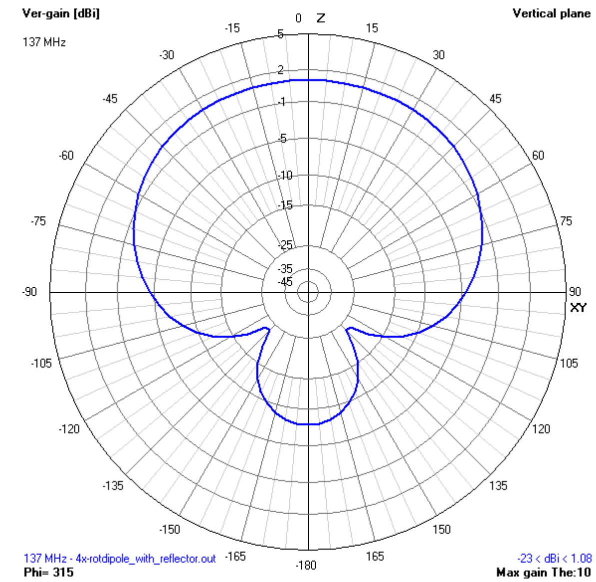
http://www.raymaps.com/index.php/tag/antenna/

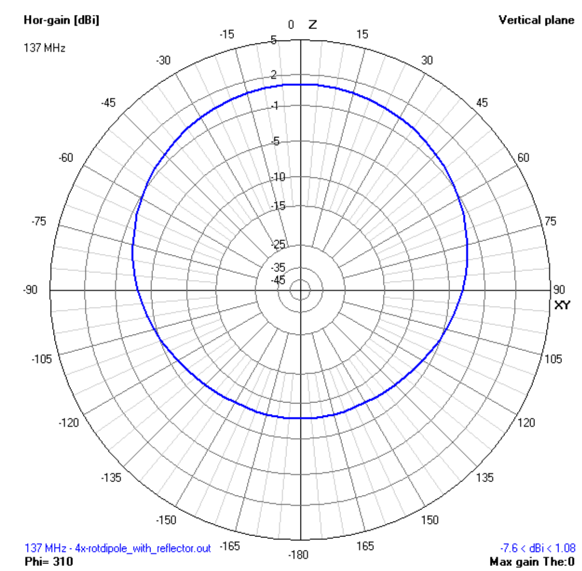
Antenna Arrays

- Two or more antennas
- Signals combined for multiple purposes
  - increase gain
  - provide diversity receive
  - cancel interference
  - steer the direction of highest gain
  - locate the direction of received signals
- Most WiFi Sector Antennas are Arrays

Antenna Arrays







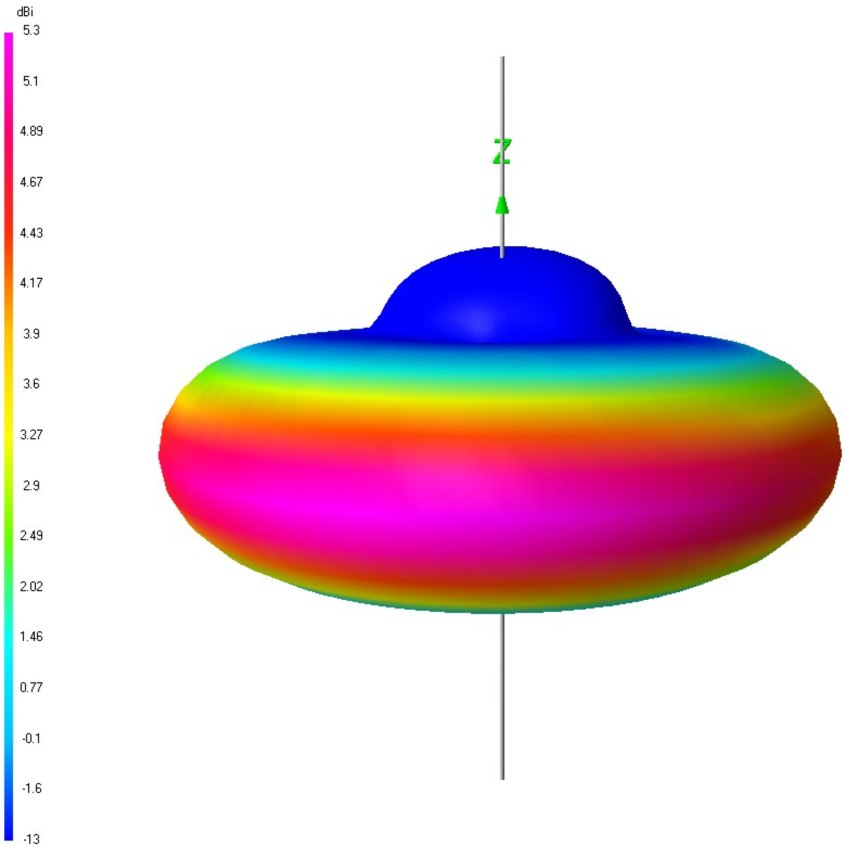
4dBi VHF Array of 4 Dipoles
(approx) 120 degree E, 90 degree H

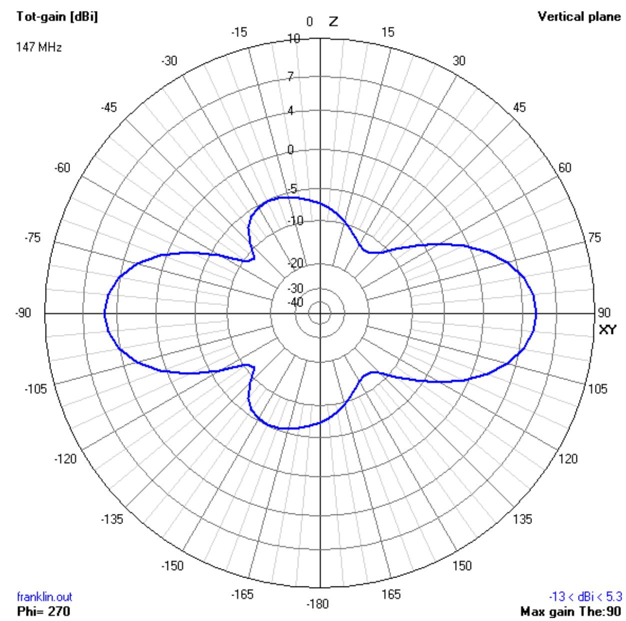
Collinear (Omni) Antenna

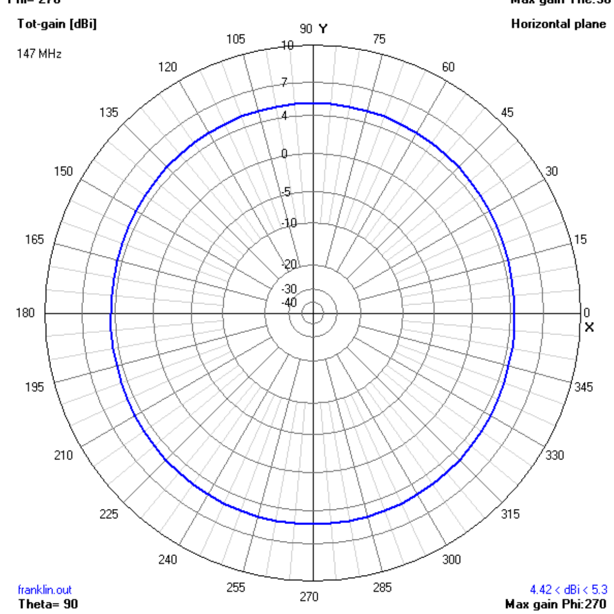
- Invented 1925 by Charles Franklin
- Made of an array of stacked dipoles
- Common from VHF up to 6 GHz
- Low cost, light weight, durable, and high gain

https://commons.wikimedia.org/wiki/File:
Antennes_VHF_UHF_01.JPG

Collinear (Omni) Antenna



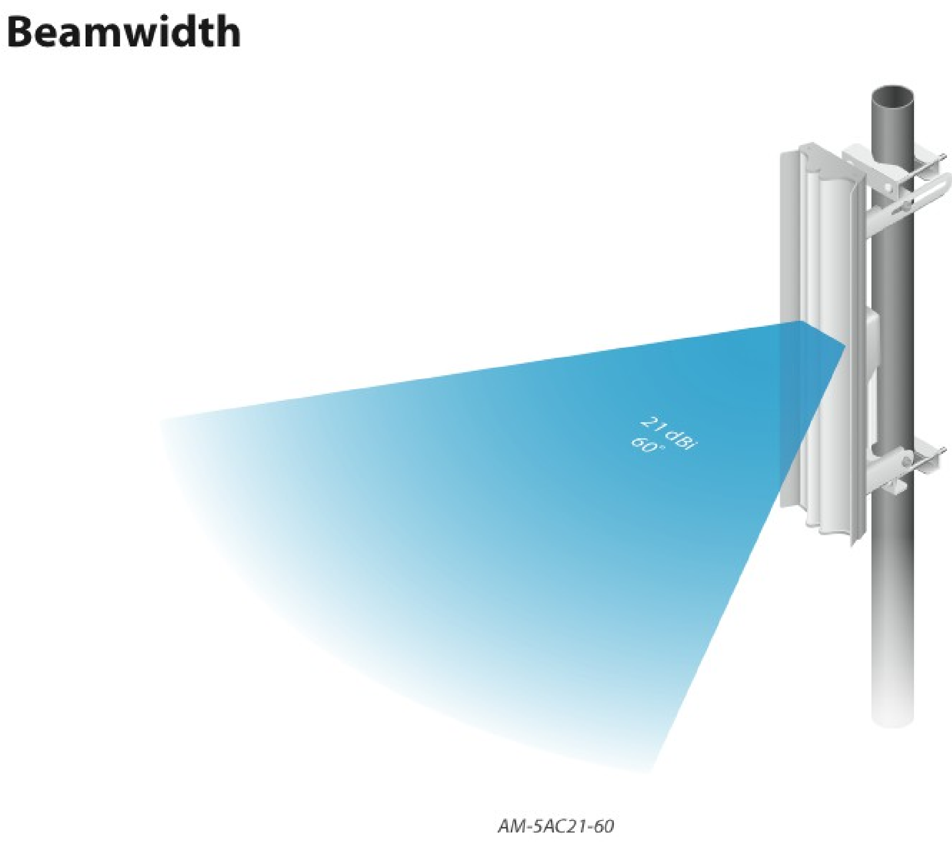




Choosing an Antenna

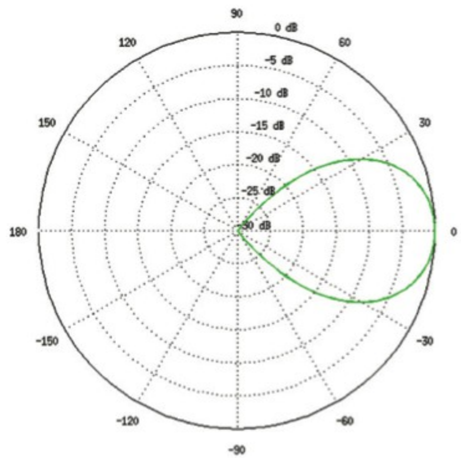
- What frequency and bandwidth?
- What coverage do you need?
- Does physical size matter?
  - Is your mast strong enough for a big antenna?
  - Are aesthetics important?
- Is the environment windy?
  - Maybe use a grid antenna with low surface area
- Is there ice?
  - Use a dish with a plastic cover to keep the ice off

A Commercial Sector (Array of Patches)

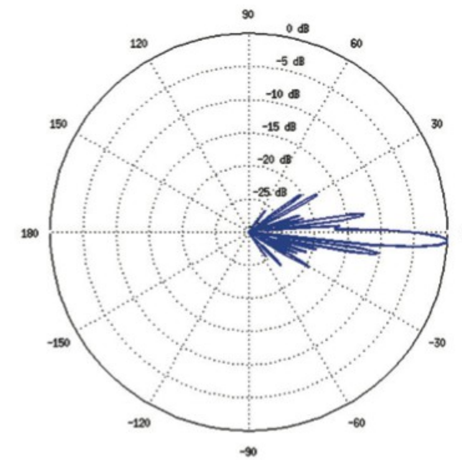


A Commercial Sector Antenna

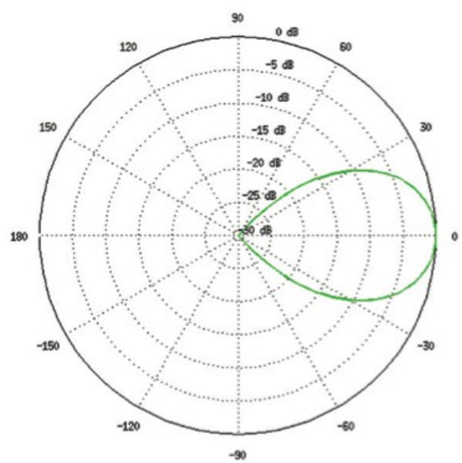
Vertical Azimuth



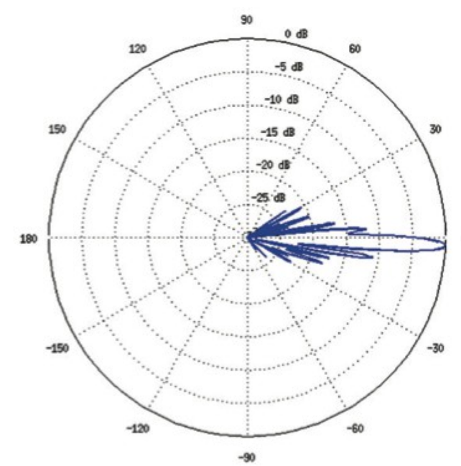
Vertical Elevation



Horizontal Azimuth



Horizontal Elevation

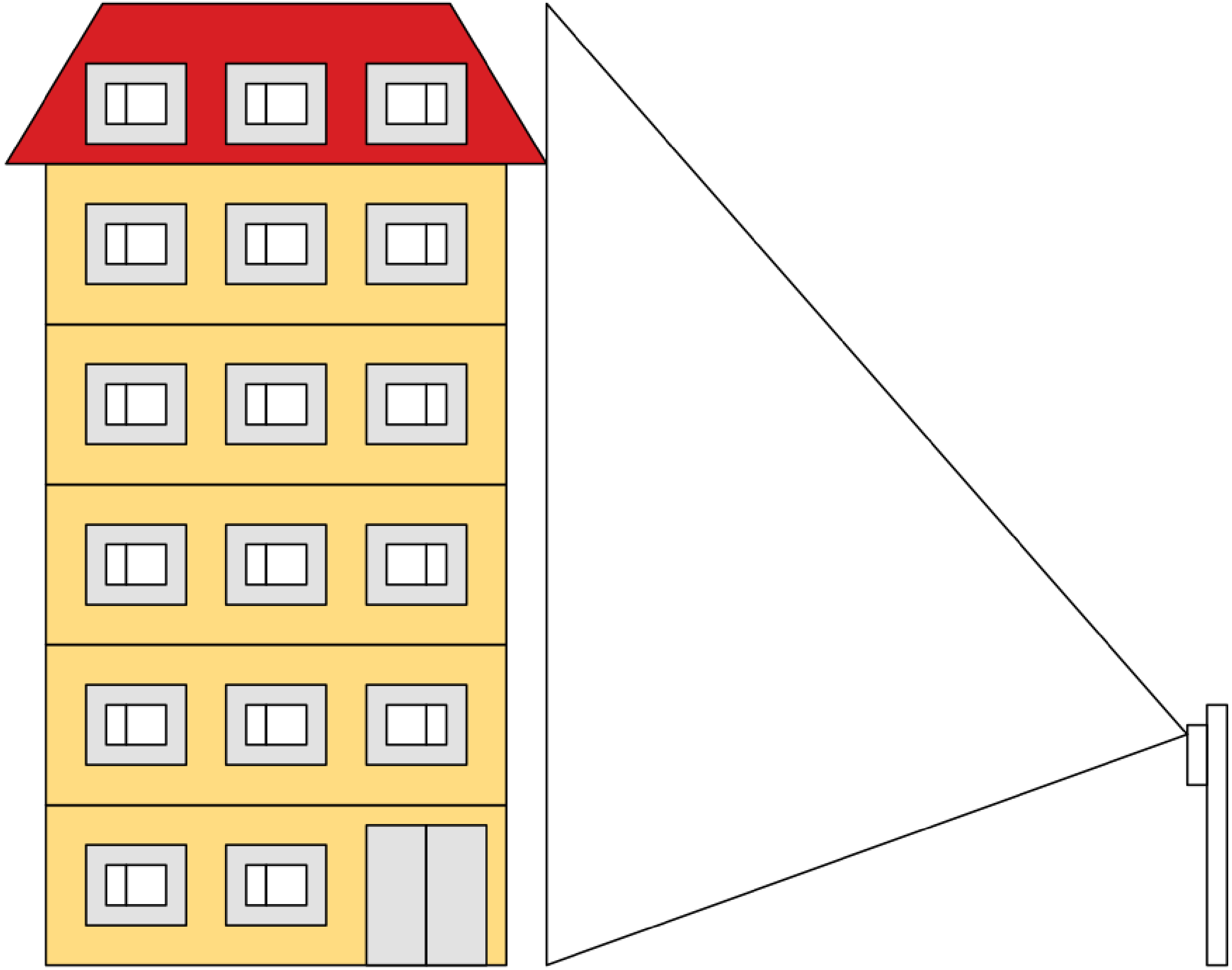


A Commercial Sector Antenna

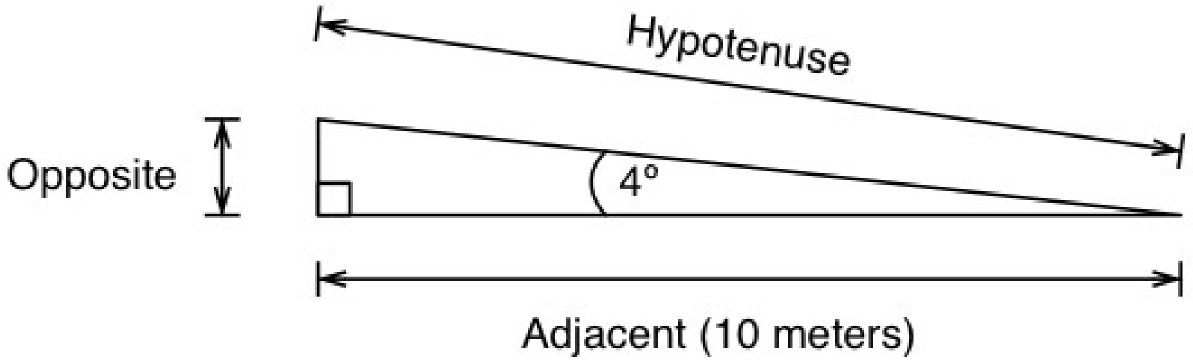
60 degree H, 4 degree E, 10m from a 18m Building

Is this going to work?

A Commercial Sector Antenna



A Commercial Sector Antenna



tan(θ) = Opposite / Adjacent

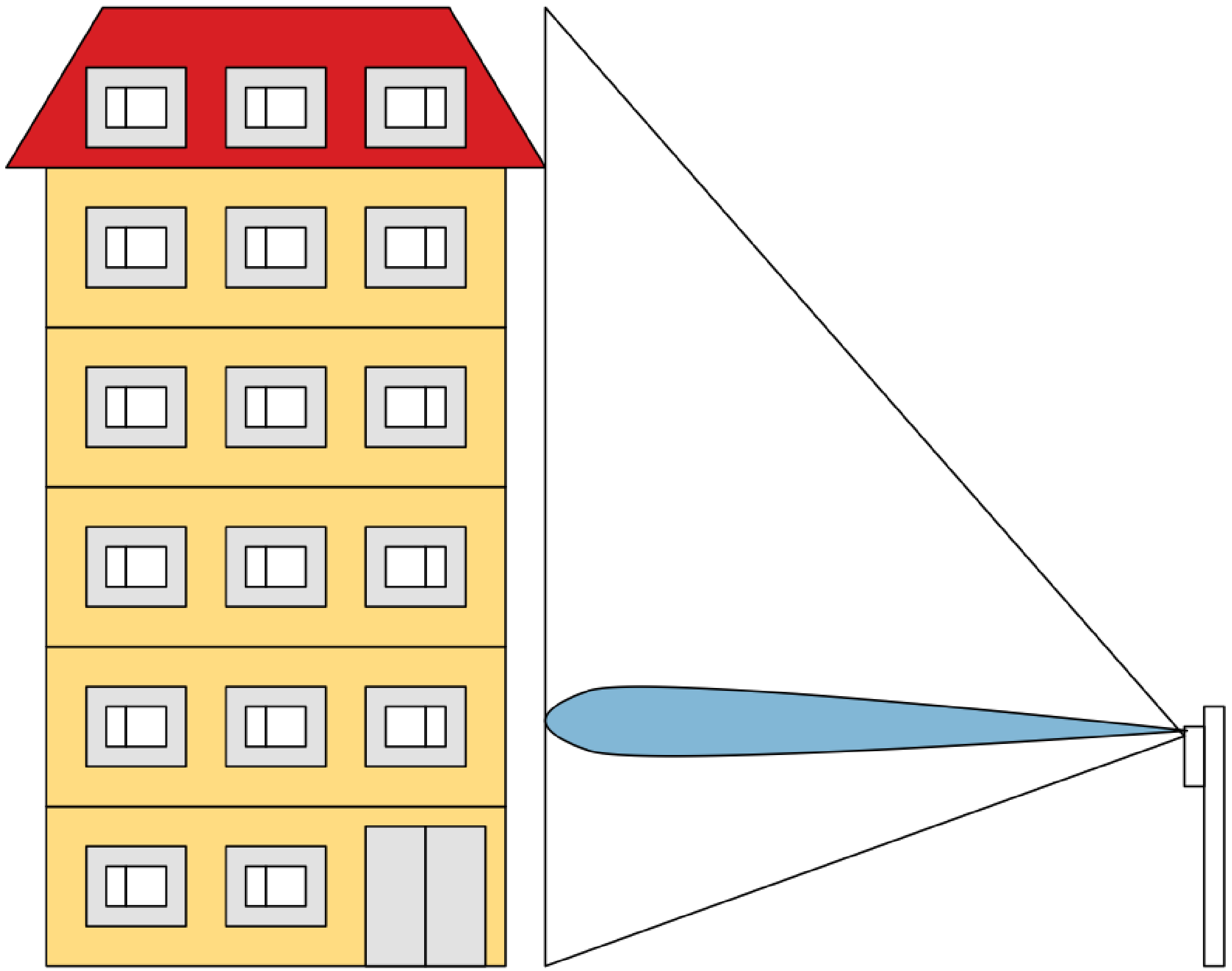
tan(4) = 0.07

0.07 = Opposite / 10

Opposite = 0.07 * 10

Opposite = 0.7 meters

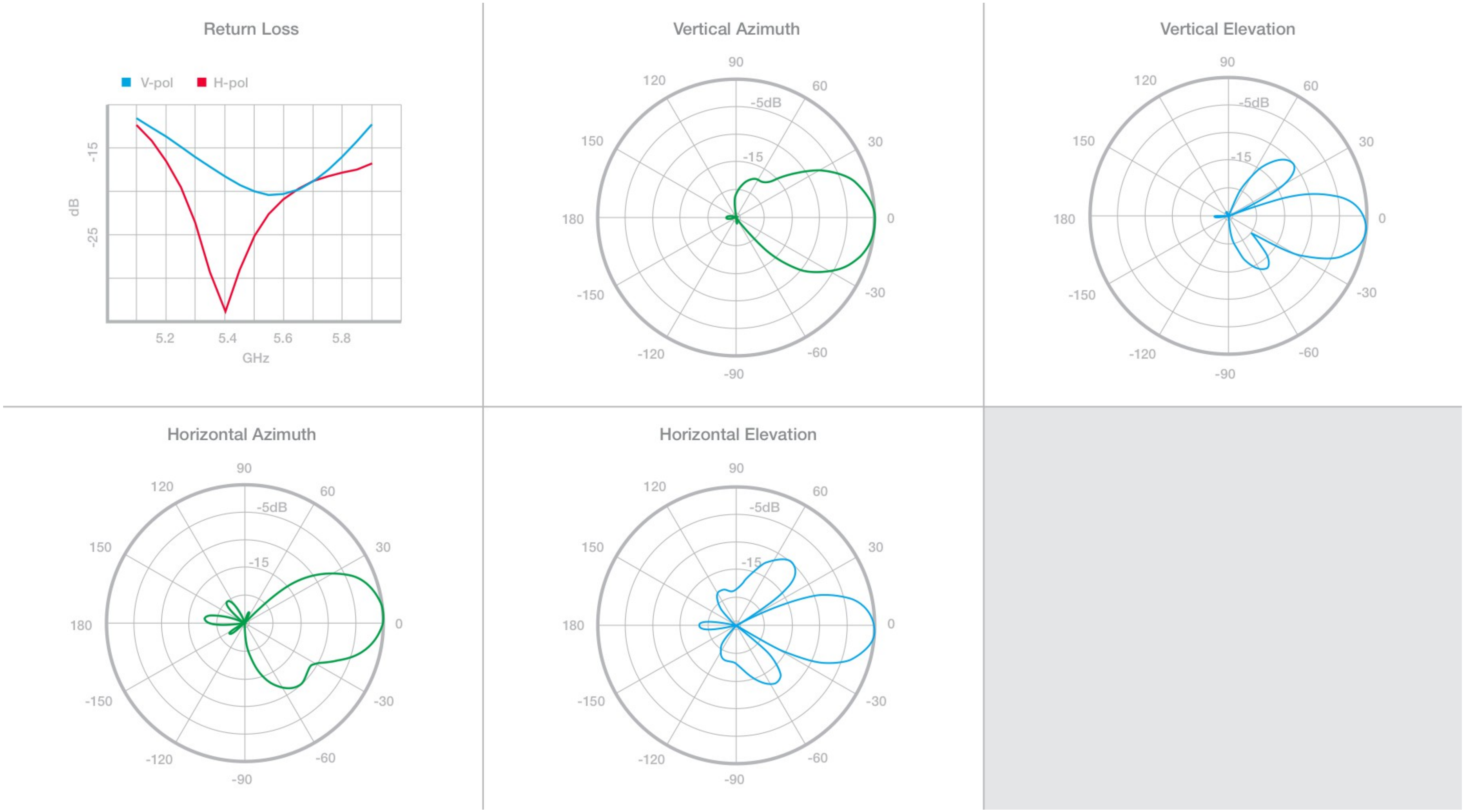
A Commercial Sector Antenna



A Commercial Sector Antenna

This array of patch antennas has an access point built-in!

A Commercial Sector Antenna



A Commercial Sector Antenna

45 degree H, 45 degree E, 10m from a 18m Building

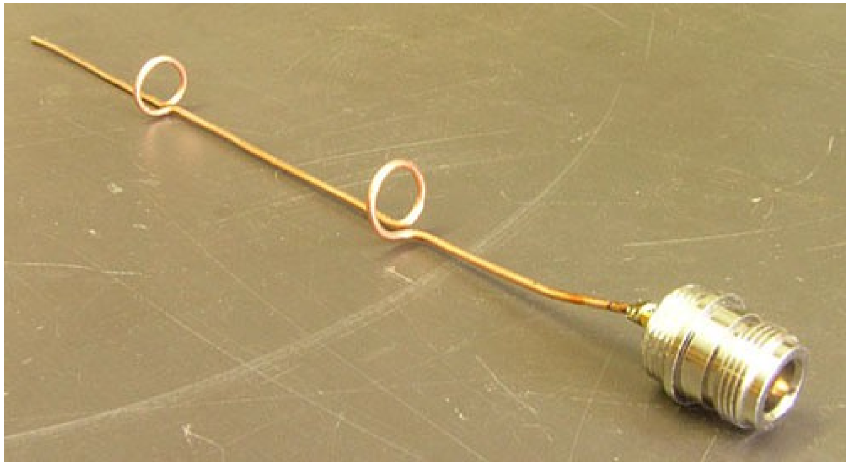
Is this going to work?

Making Your Own Antennas

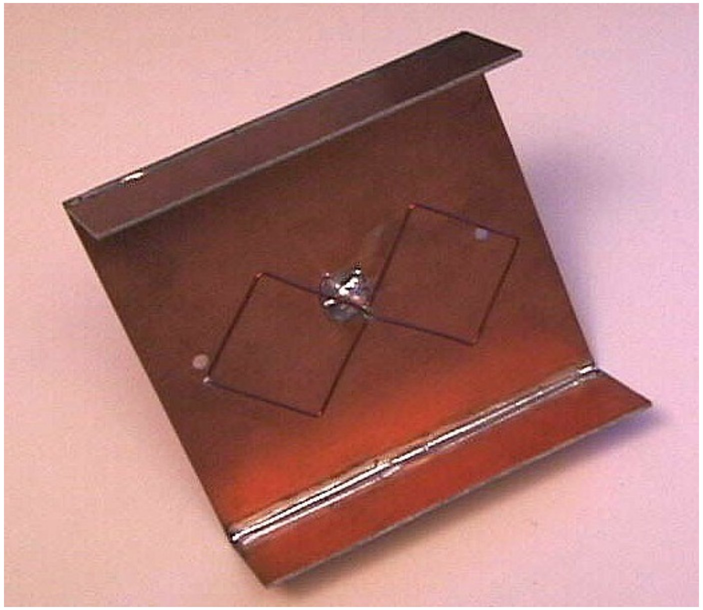
- Free, Open Source Designs Available
- Combine with Reflectors (Satellite Dishes) for high gain
- Learn Collinear & Cantenna with WNDW (multiple languages)
  - http://wndw.net/book.html
- Make a BiQuad with Trevor Marshall (English)
  - http://www.trevormarshall.com/biquad.htm
- Make a Parabolic Reflector & More with M. Erskine (English)
  - http://www.freeantennas.com/projects/template/index.html
- Make a Collinear with Marty Bugs (English)
  - http://martybugs.net/wireless/collinear.cgi

Making Your Own Antennas

http://www.dslreports.com/forum/remark,5605782~root=wlan~mode=flat



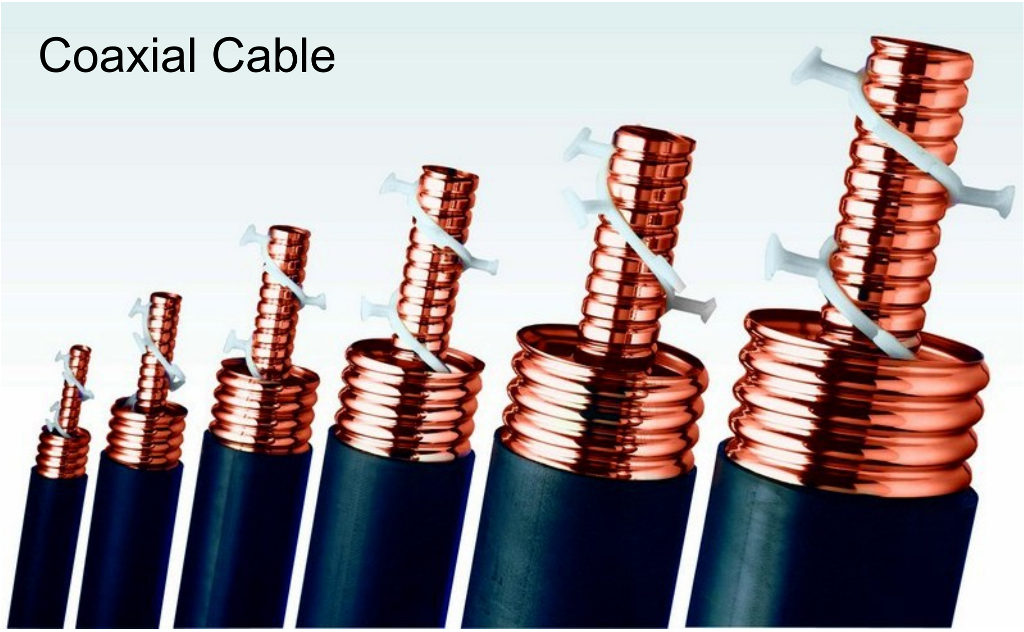
http://martybugs.net/wireless/collinear.cgi



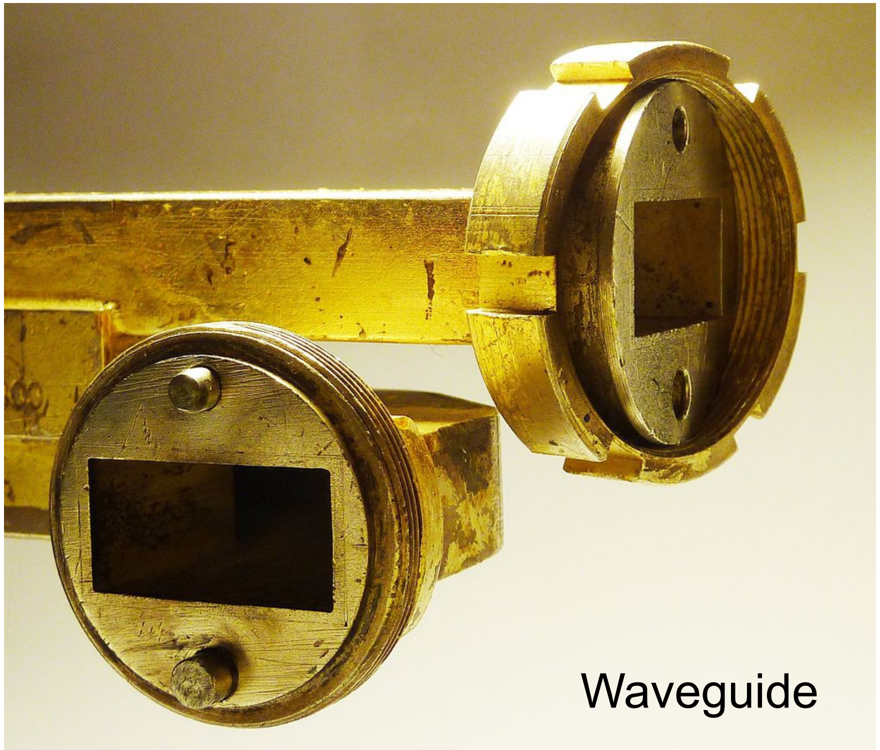
http://www.trevormarshall.com/biquad.htm

What's A Transmission Line?

- A device to guide waves that are not in free space



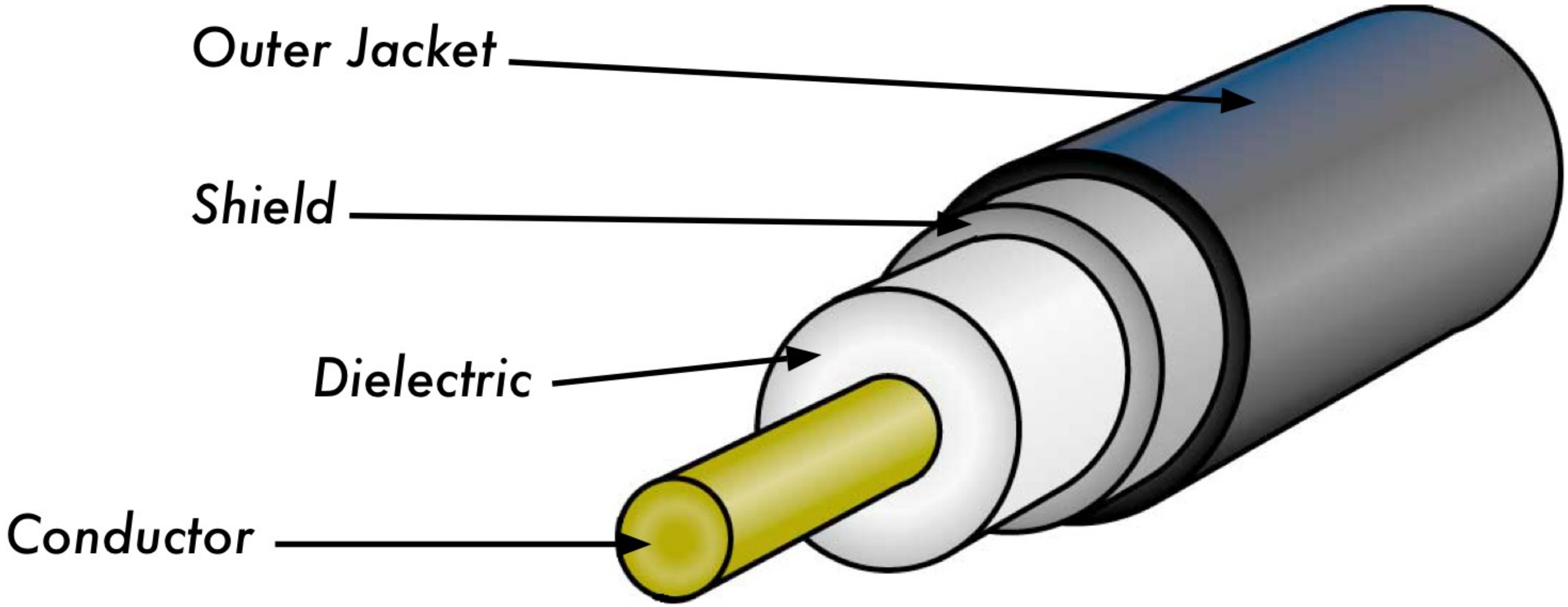
https://commons.wikimedia.org/wiki/File:Air_Cables.jpg



https://commons.wikimedia.org/wiki/File:
Waveguide-flange-with-threaded-collar.jpg

Coaxial Transmission Lines

- The most common cables for use with Wi-Fi



Coaxial Transmission Lines

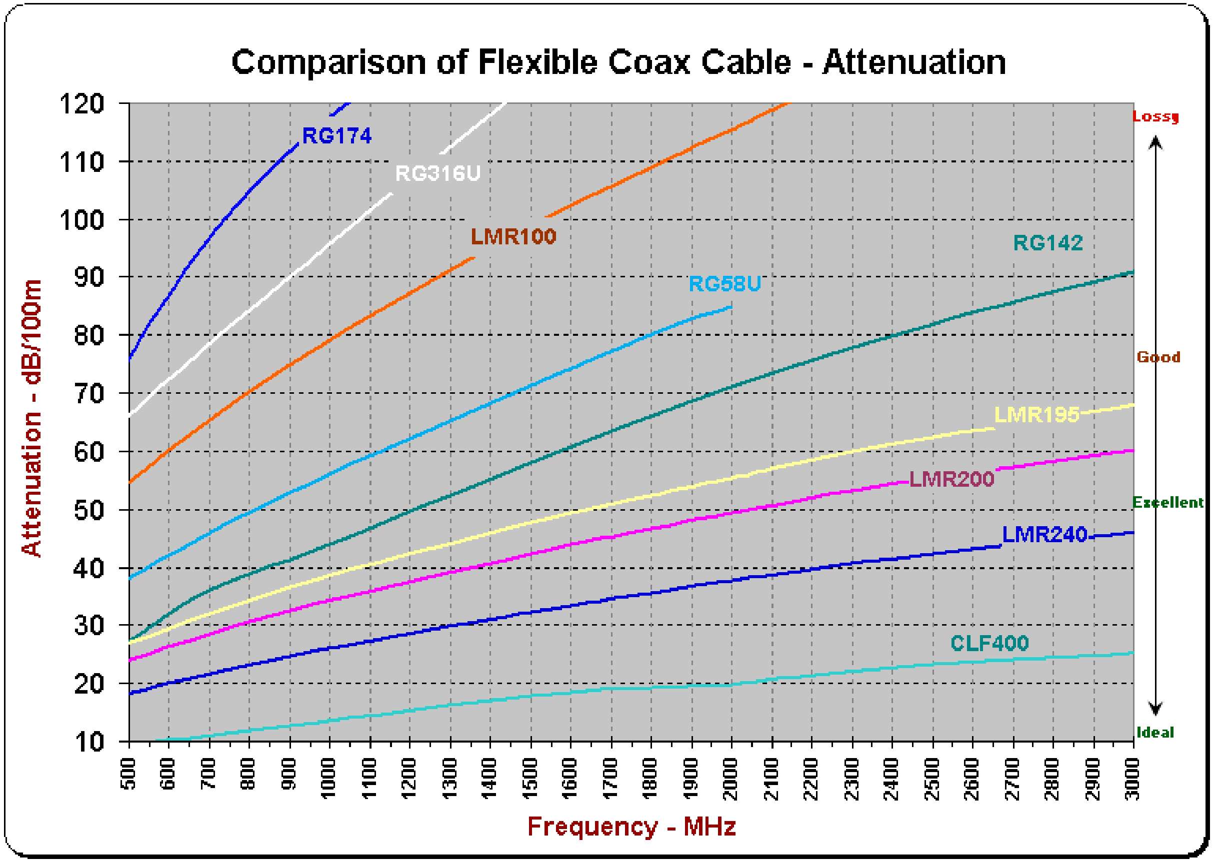
- The loss (or attenuation) of a coaxial cable depends on cable construction and operating frequency
- Loss is proportional to cable length
- Thicker cable = less loss, harder to work with

Cable Type	Diameter	Attenuation @ 2.4 GHz	Attenuation @ 5.3 GHz
RG-58	4.95 mm	0.846 dB/m	1.472 dB/m
RG-213	10.29 mm	0.475 dB/m	0.829 dB/m
LMR-400	10.29 mm	0.217 dB/m	0.314 dB/m
LDF4-50A	16 mm	0.118 dB/m	0.187 dB/m

http://www.ocarc.ca/coax.htm

Cable Loss Chart

- Cable manufacturers publish charts per product
- Always understand: frequency, distance, loss



Why Use Different Cables? Flexibility

Choosing Transmission Line

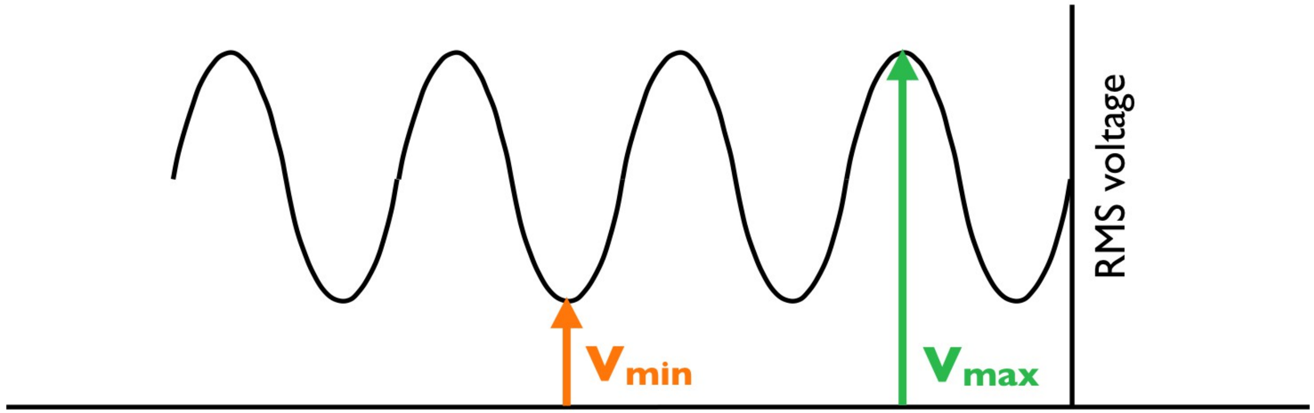
- What frequencies do you need?
- How much loss can your system tolerate?
- Does size matter? Flexibility?
- Using multiple types of line is ok!

Impedance

- All materials oppose the flow of current
- This opposition is called impedance
- It's analogous to resistance in DC circuits
- Comms cable & antennas are usually 50 Ohms
- TV cable & antennas are usually 75 Ohms
- Always match impedance of cable & antennas
  - Mis-match will cause reflections & high VSWR

Voltage Standing Wave Ratio

- Impedance mismatch will result reflections
- VSWR is a function of the reflection coefficient
- Higher VWSR = less power from tx to antenna
- Lower VWSR = more power from tx to antenna



$$\text{Voltage Standing Wave Ratio VSWR} = \frac{V_{max}}{V_{min}}$$

How could you Mismatch Impedance?

- UHF Television antennas are 75 Ohm
- UHF Television antennas cover 500-800 MHz
- RG-6 Cable is ideal for 500-800MHz. It's 75 Ohm
- All these things are inexpensive & available
- New LTE services use 700-800 MHz
- LTE radios are 50 Ohm
- Use TV equipment for LTE? Impedance Mismatch

Review

- How does an antenna work?
- What's a radiation pattern?
- How do you choose the right antenna?
- What does a transmission line do?
- How do you choose a transmission line?