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?

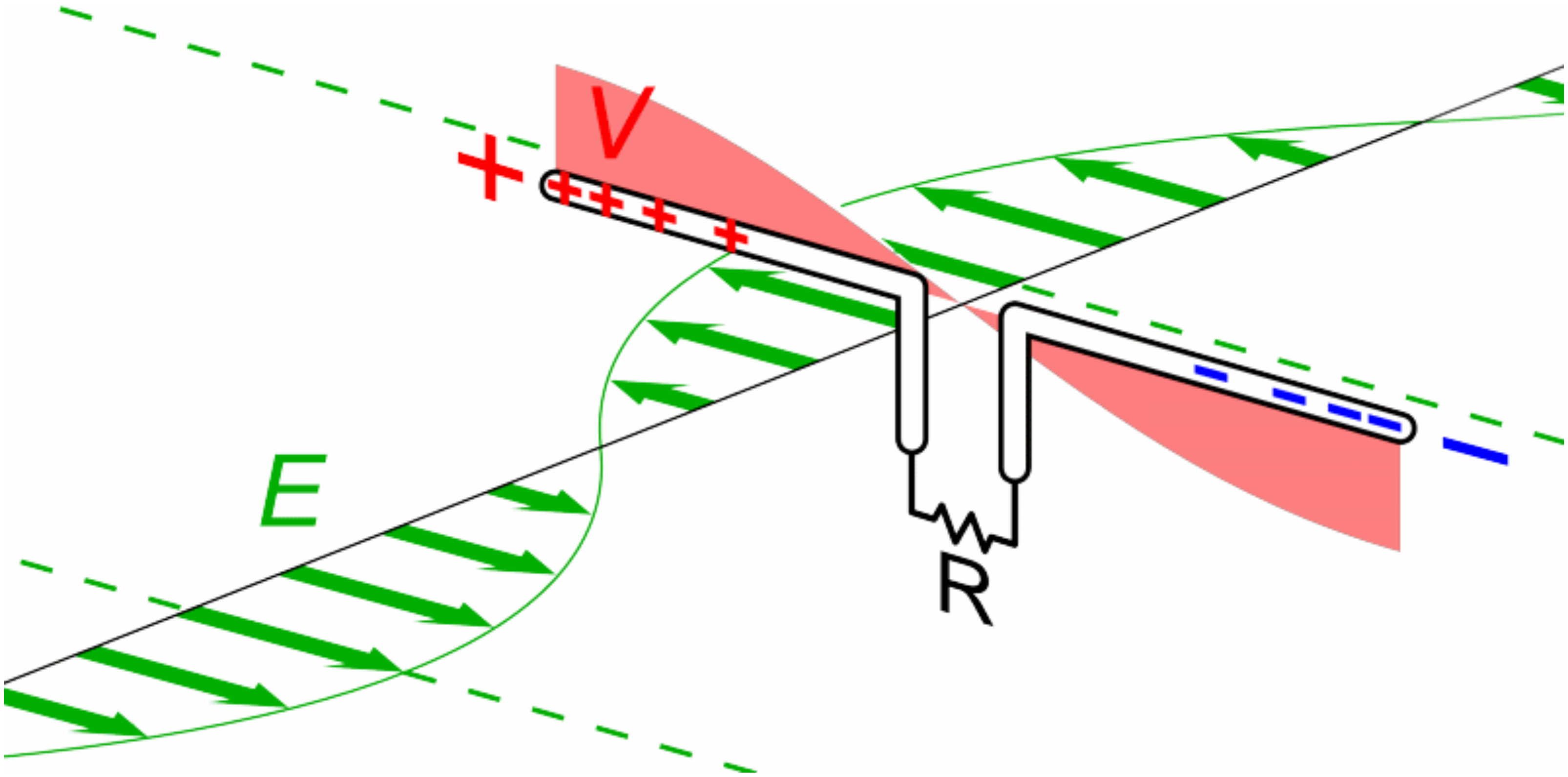
An antenna couples electrical current to radio waves

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

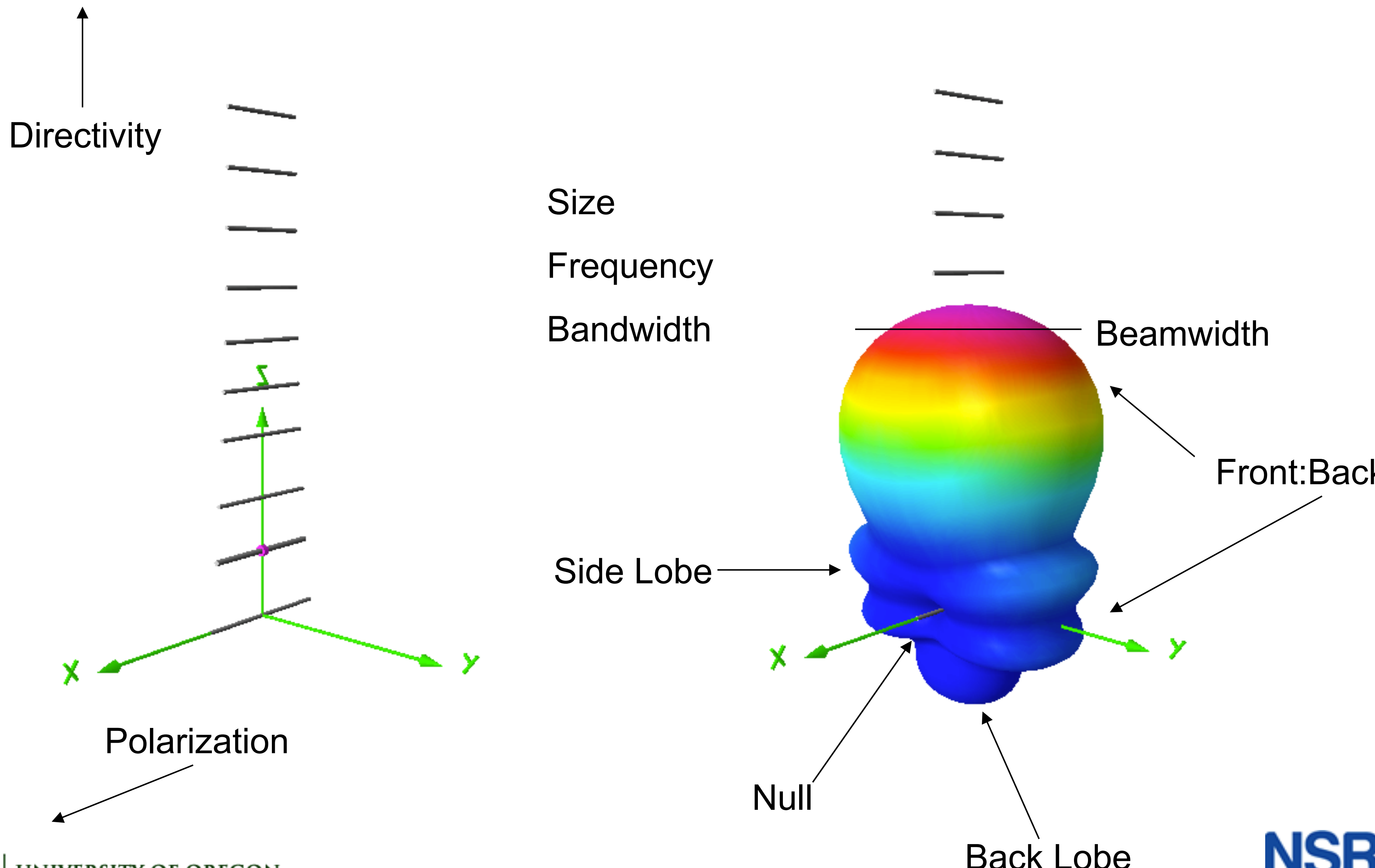
- Directivity
  - Gain, shown by radiation patterns
    - Beamwidth, lobes, sidelobes, nulls
    - Front to back ratios
- Polarization
- Center Frequency
- Bandwidth (How far ⬆ & ⬇ below center Frequency?)
- Physical Size
- Impedance & Return Loss

General Antenna Properties

Size

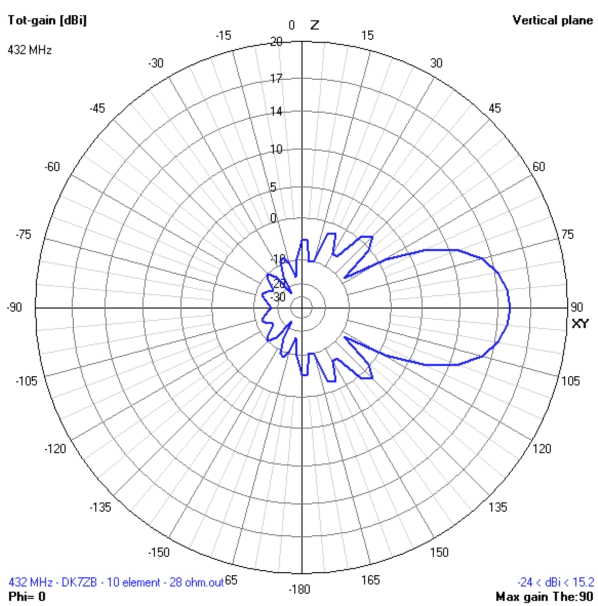
Frequency

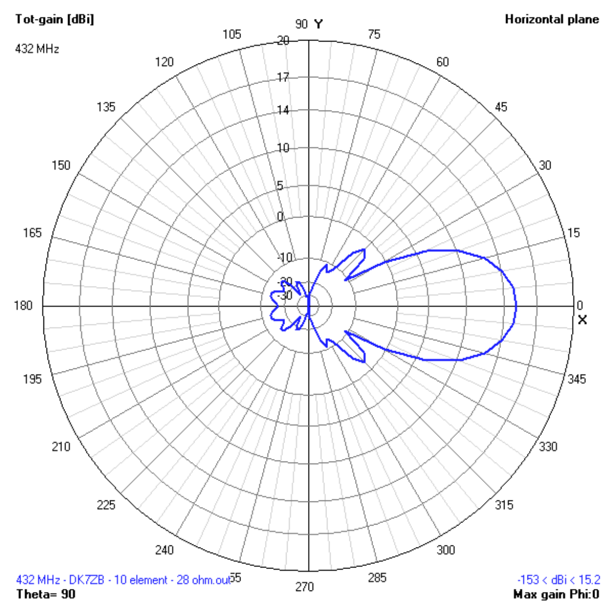
Bandwidth



Radiation Patterns

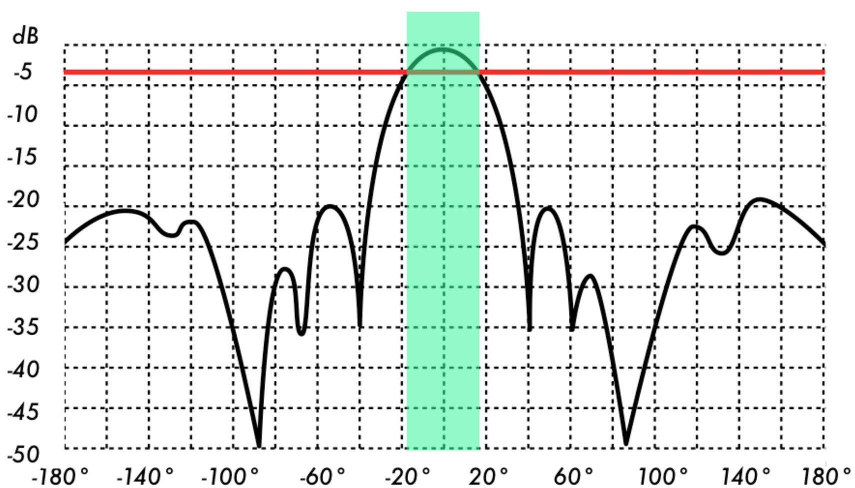
- Distribution of power radiated from or received by the antenna
- Shown as a function of direction angles from the antenna
- Patterns usually use a polar projection
- Directional antennas have differing Vertical & Horizontal gain

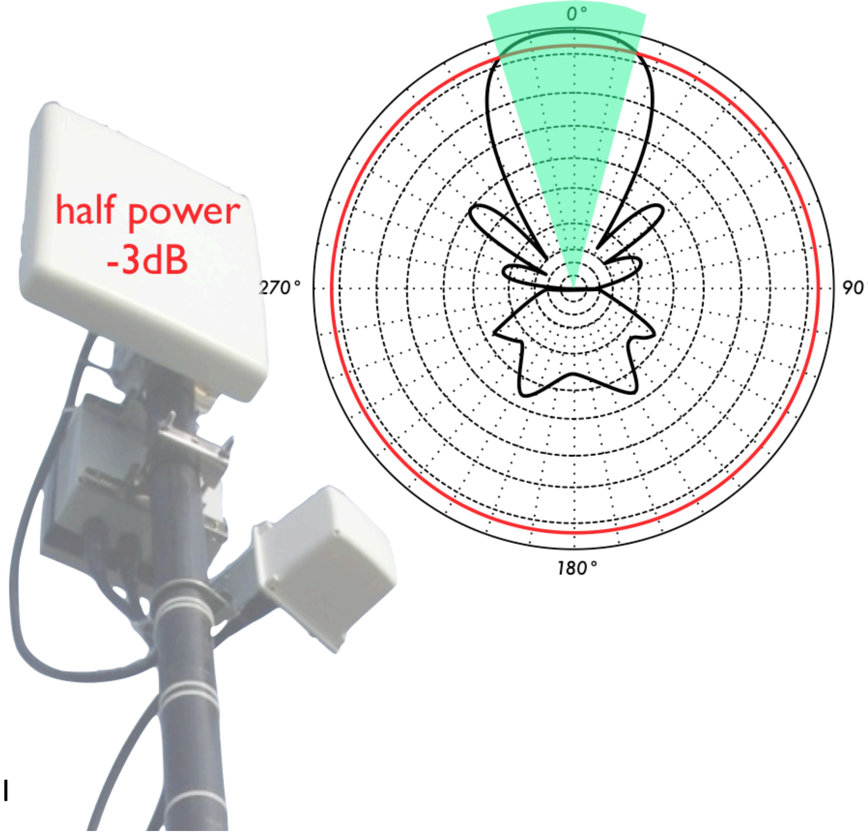




Beamwidth

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





Images: http://wndw.net/book.html

Polarization

- Electromagnetic waves are polarized
- Mismatched-polarization reduces gain
- Waves can be linear (H/V) or circular (RH/LH) polarized
- Many new antennas have multiple polarizations

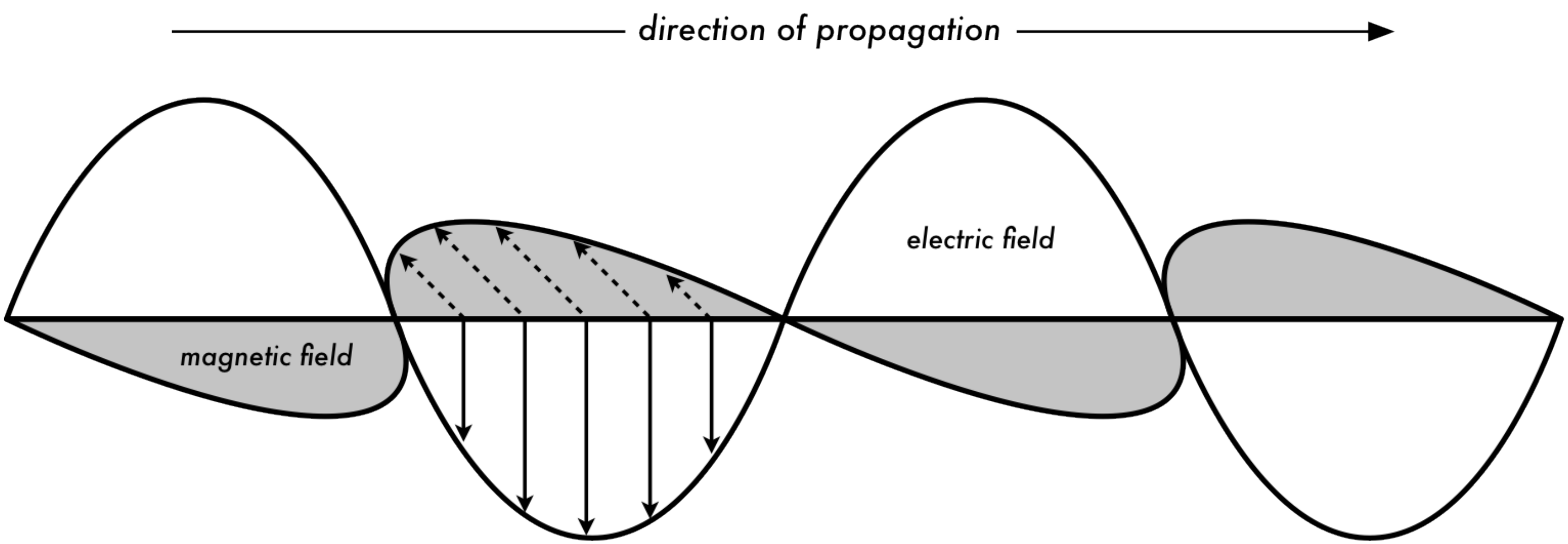
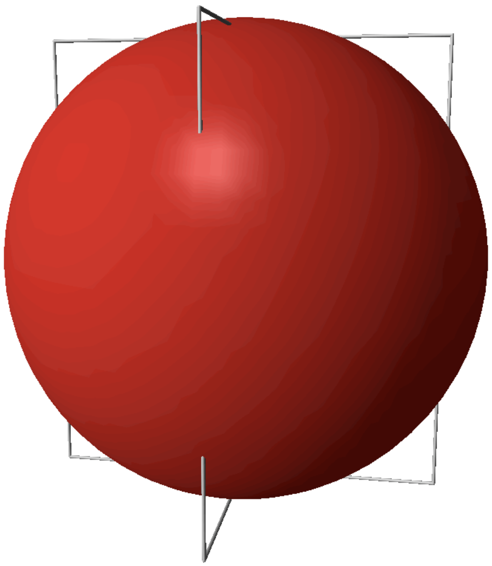


Image: http://wndw.net/book.html

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?

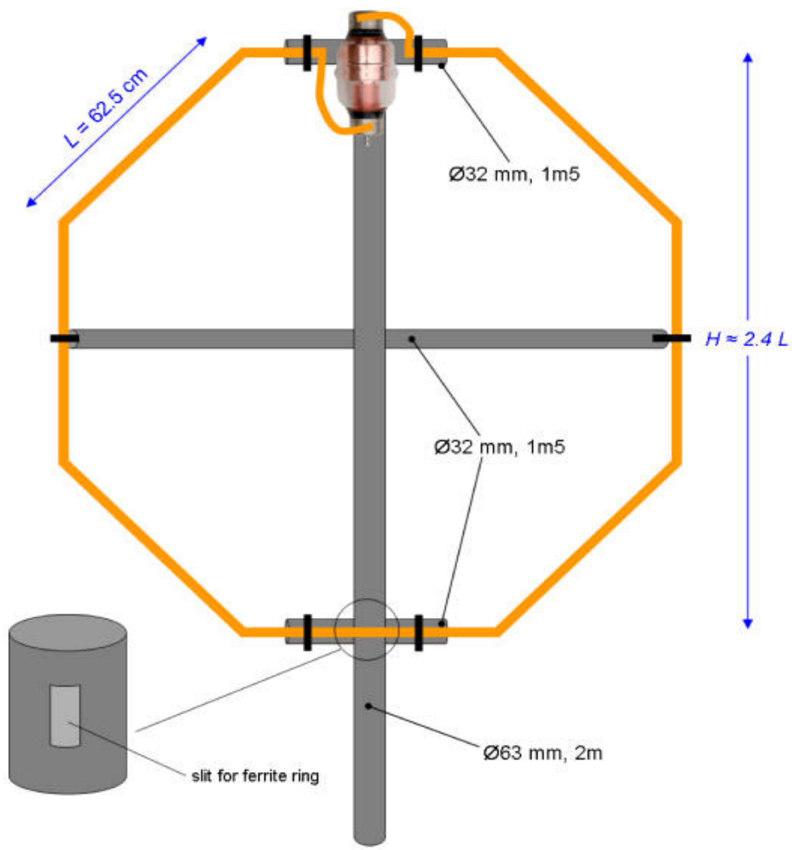


Directivity, Polarization, Lobes? No
Front to Back Ratio? 1:1

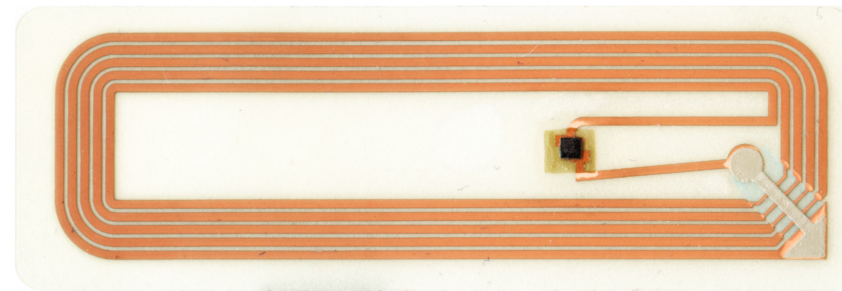
Loop Antenna

- 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



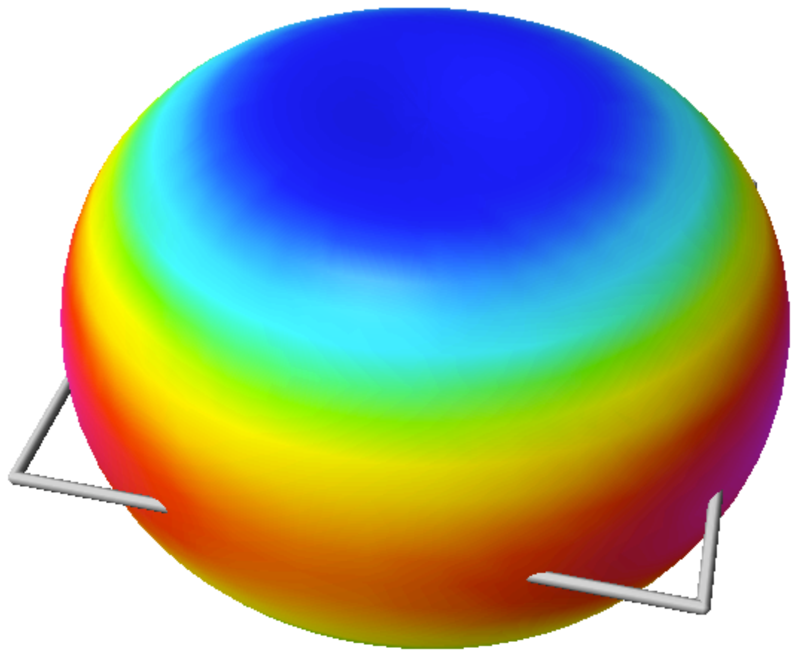
Magnetic Loop Antenna for 3.75MHz / 80m band, Design by Frank N4SPP
http://www.nonstopsystems.com/radio/frank_radio_antenna_magloop.htm

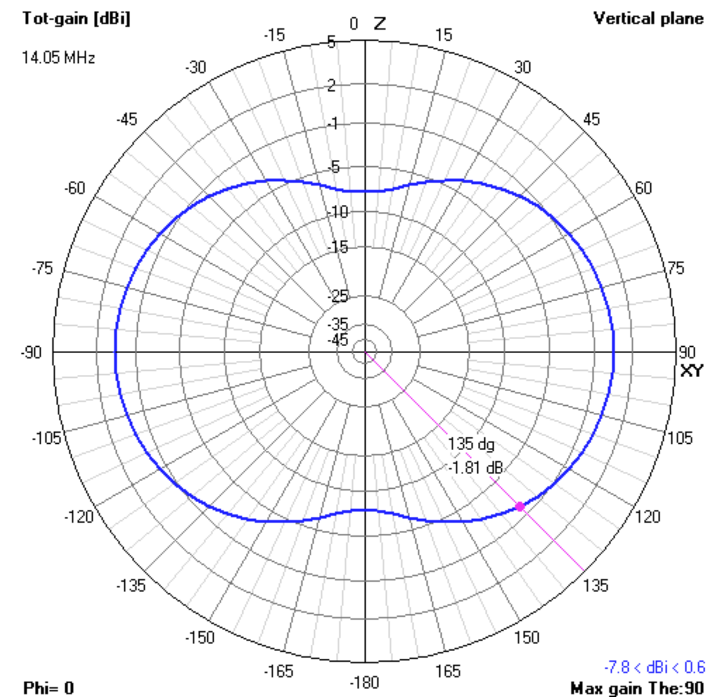


13.56 MHz Smartlabel photo by Wikimedia user Kalinko
https://commons.wikimedia.org/wiki/File:Transponder2.jpg

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

Loop Antenna





0.6 dBi Loop with a 40 degree omnidirectional beam

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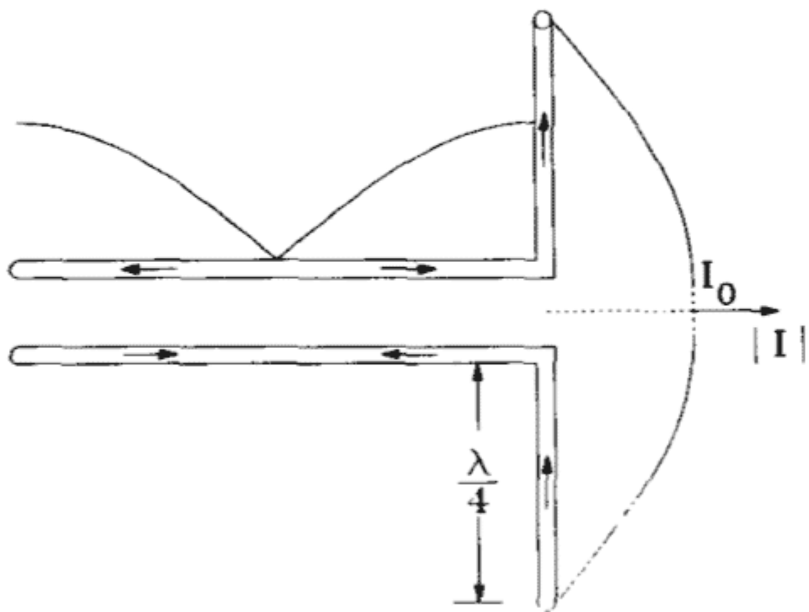
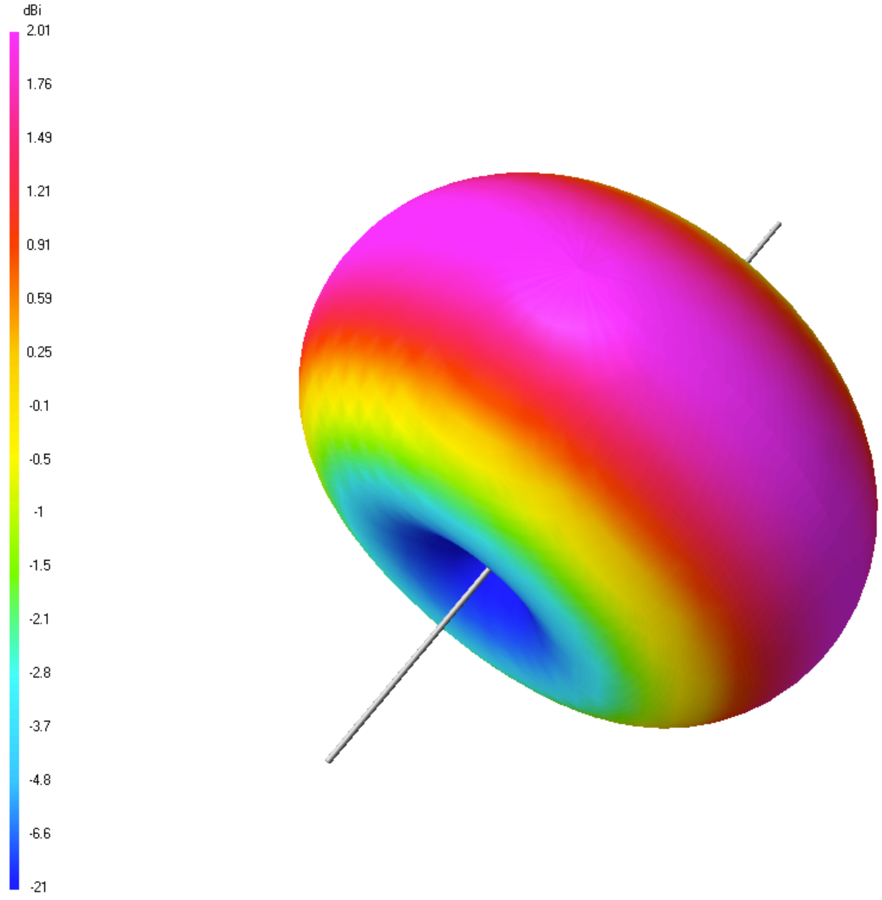
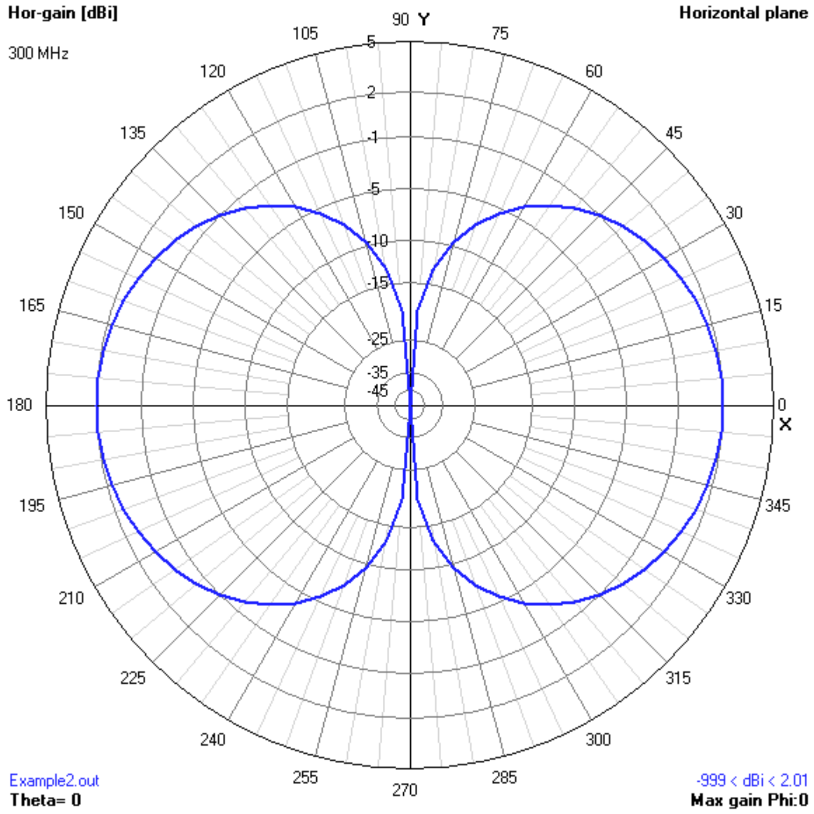
Dipole Antenna

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

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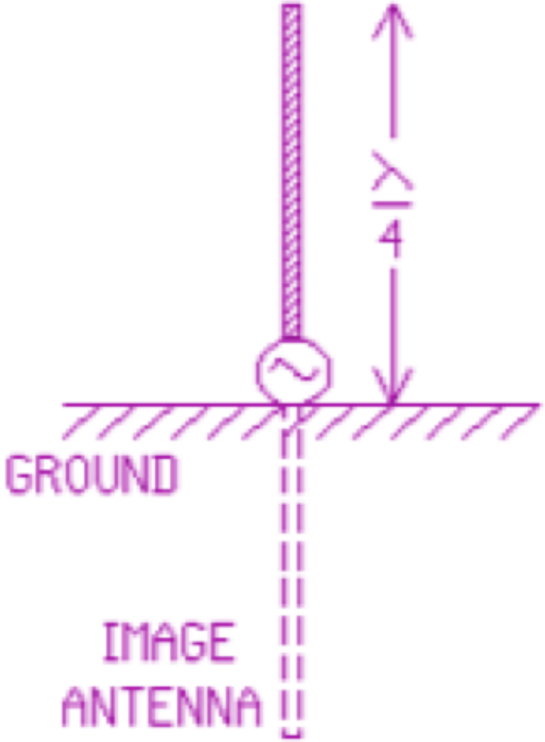
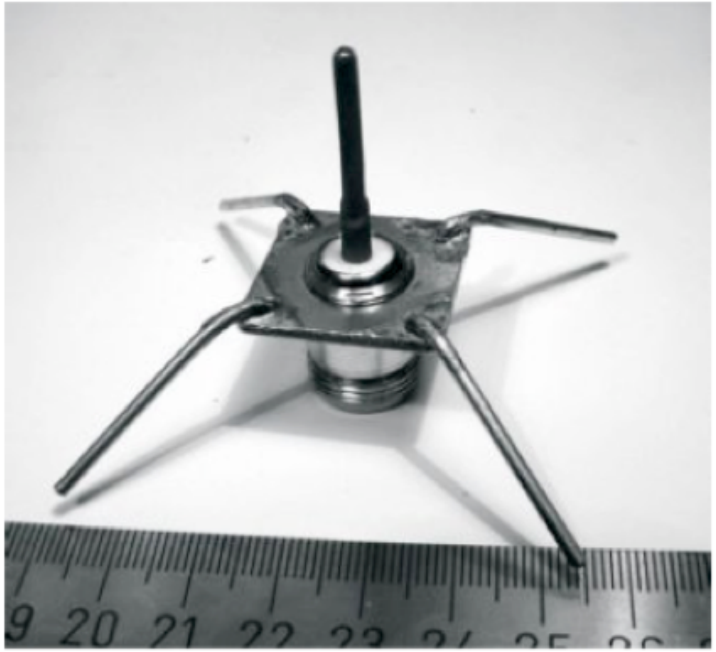
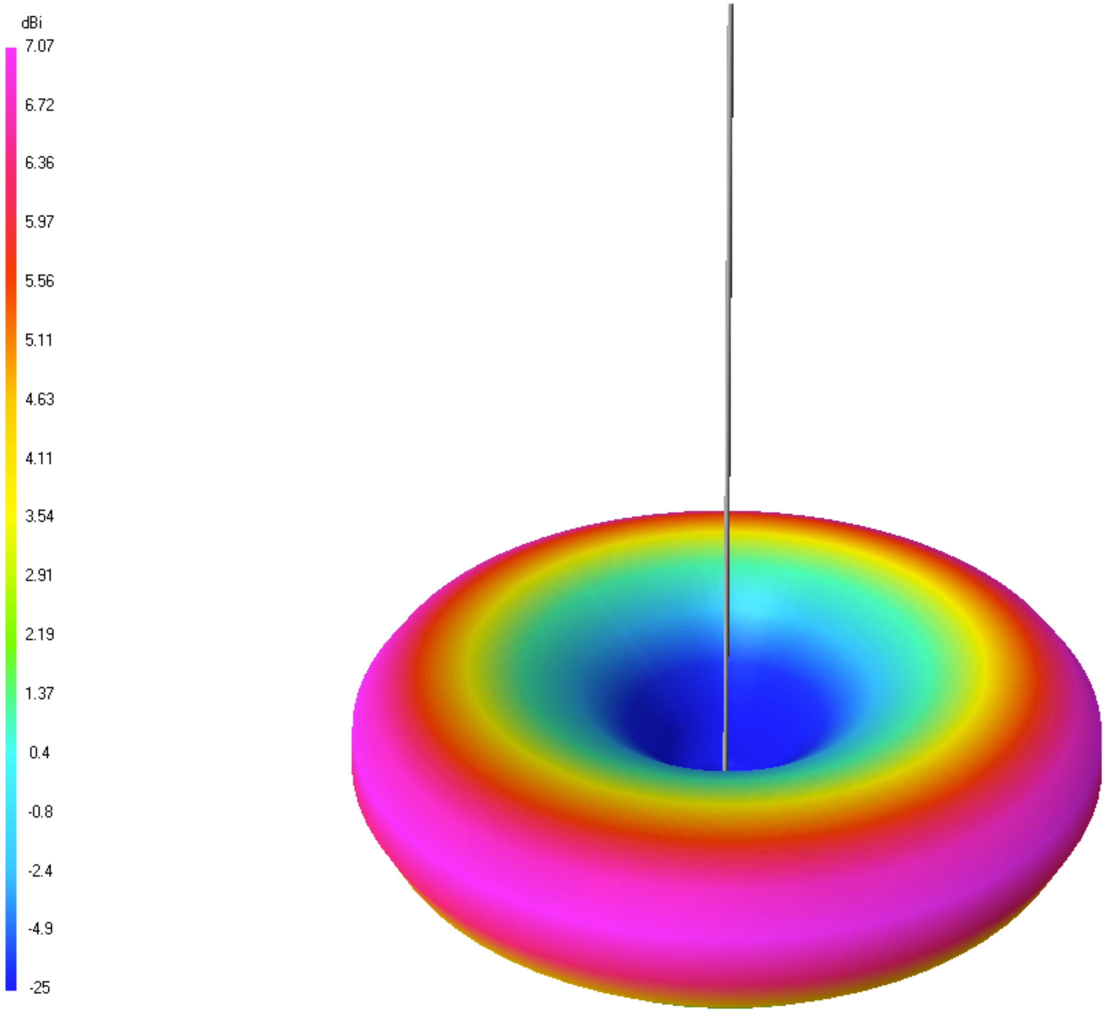
Monopole Antenna

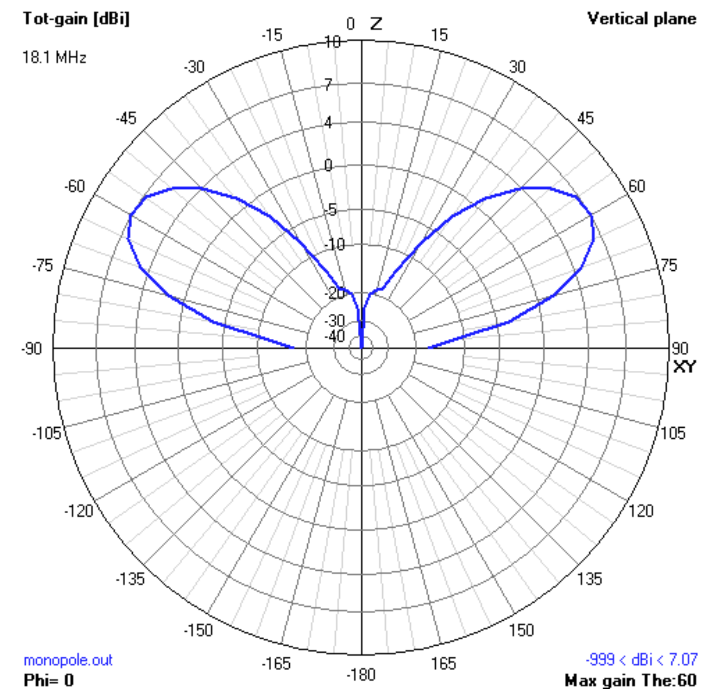
Discovered in 1895 by Guglielmo Marconi
¼ λ vertical element over a ground plane
Provides 5.14 dBi gain





Monopole Antenna

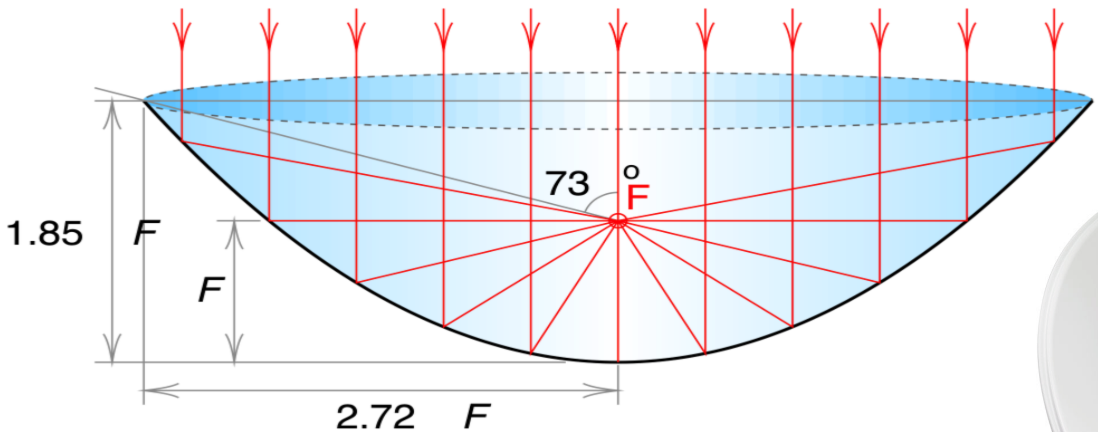




7 dBi Monopole with a tilted 30 degree omnidirectional beam

Parabolic Reflector

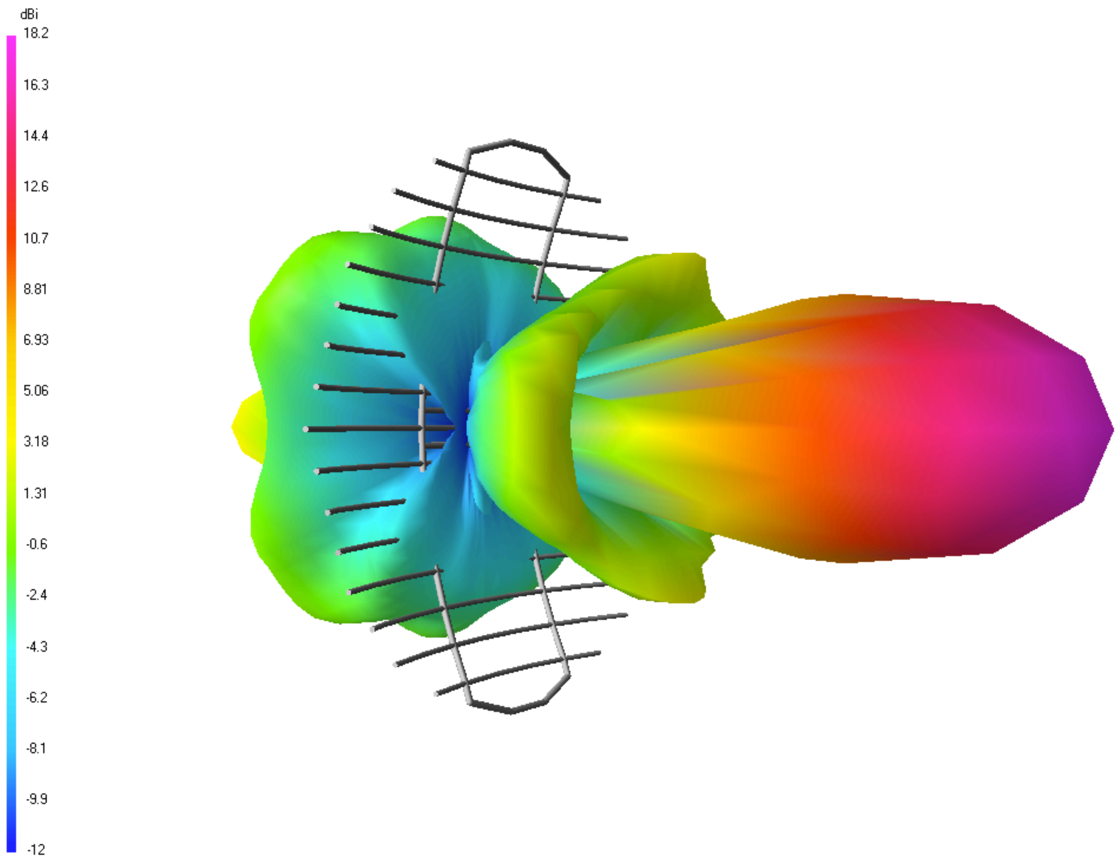
Discovered around 200 BC by Diocles
Used for Radio in 1887 by Heinrich Hertz

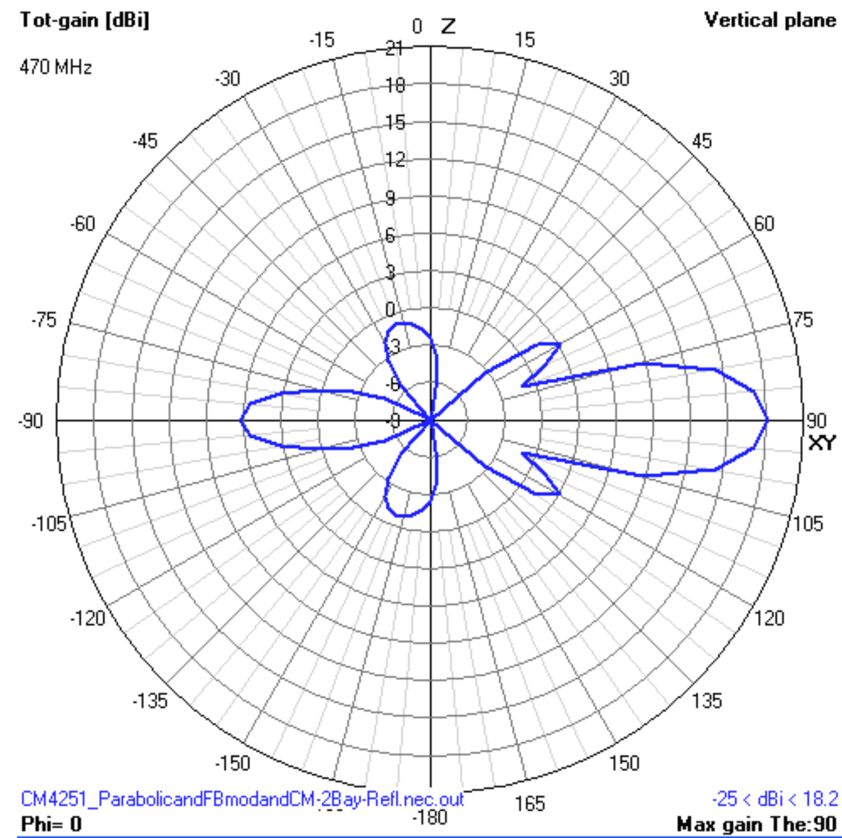


Parabola illustrated by Wikimedia Commons User CMGlee
https://commons.wikimedia.org/wiki/File:Focus-balanced_parabolic_reflector.svg

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

Parabolic Reflector



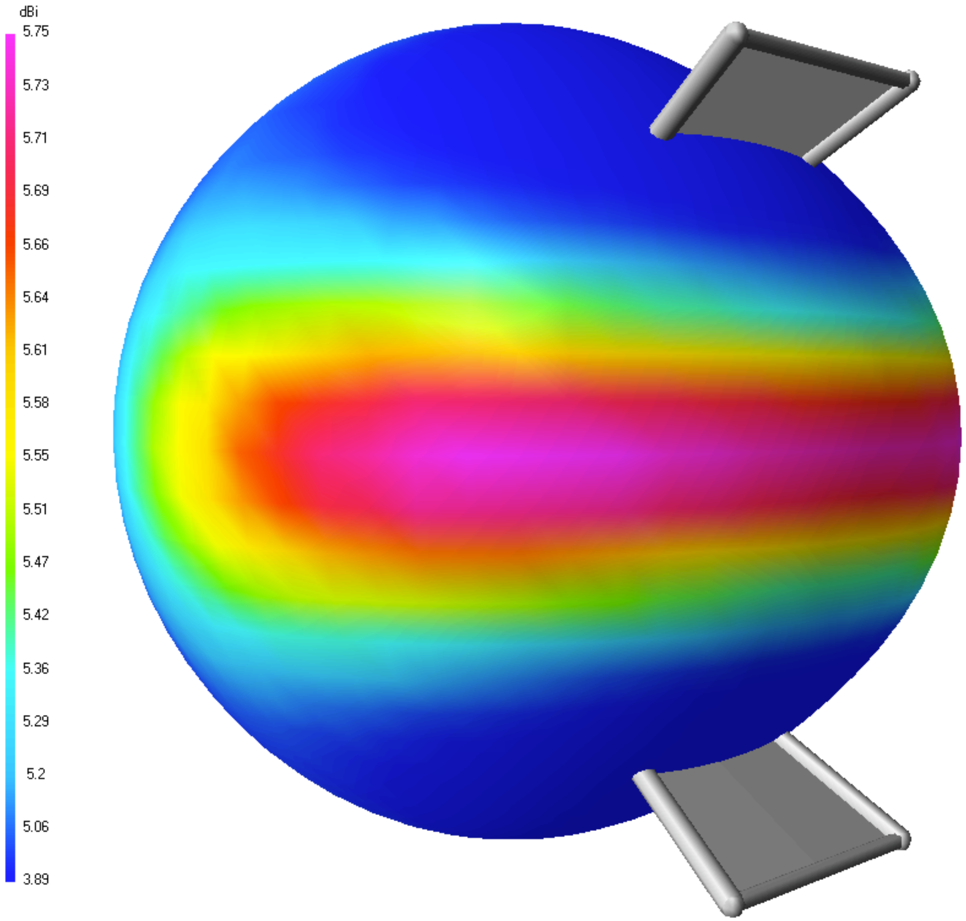


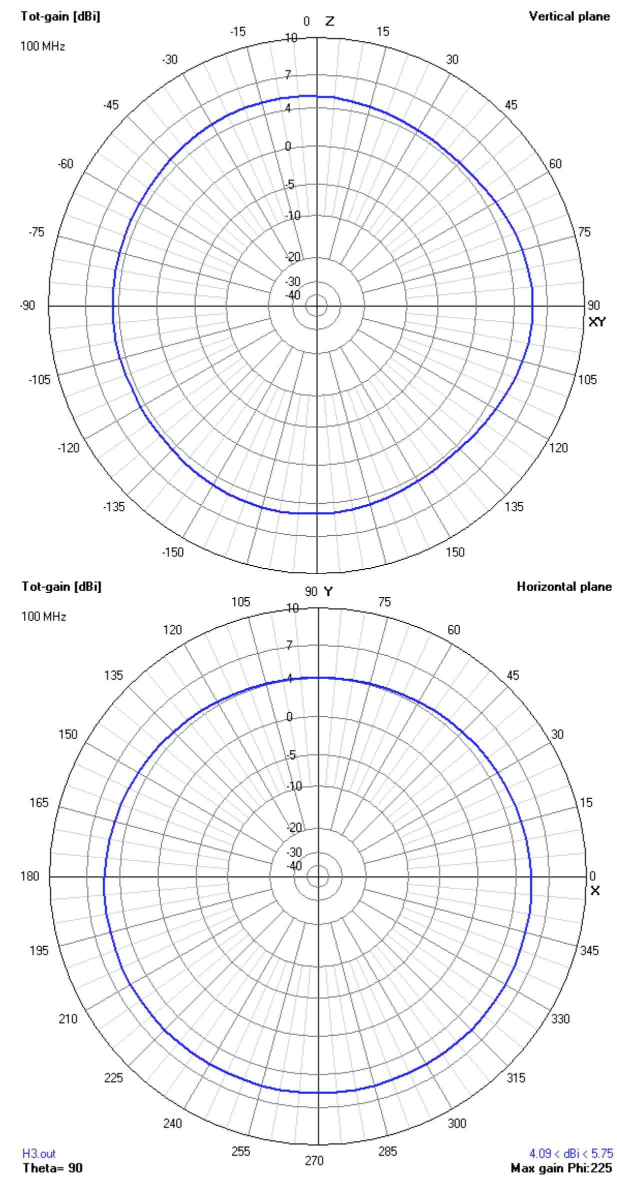
Antenna in front of a Parabolic Reflector
yields 18dBi with a 40 degree H+E beamwidth

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

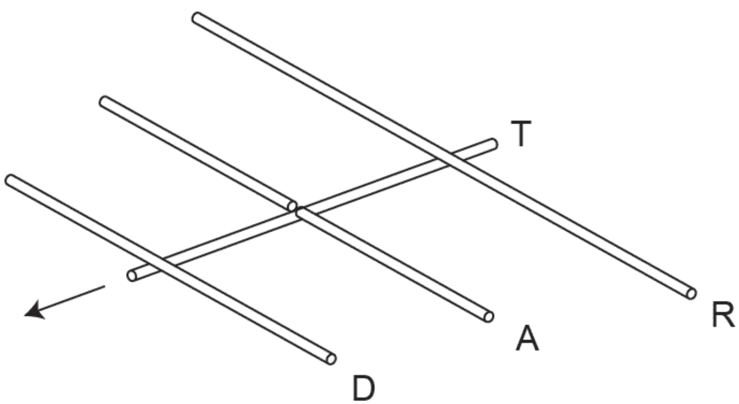


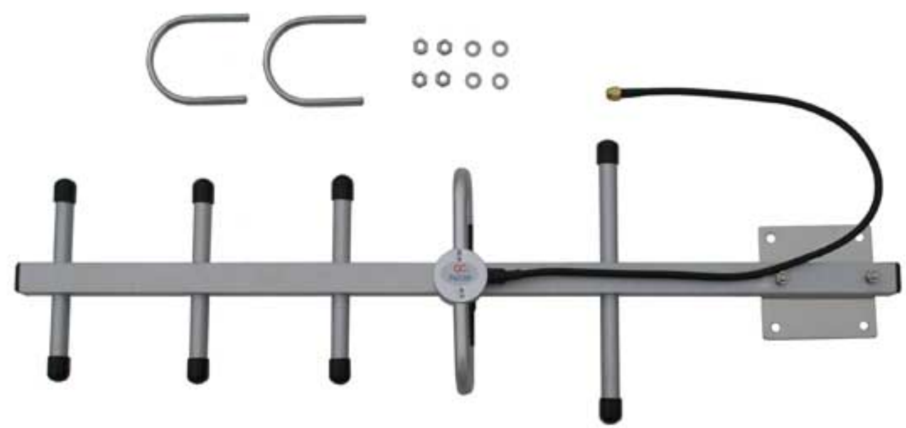


5.75 dBi Directional Horn
(approx) 60 degree E, 180 degree H

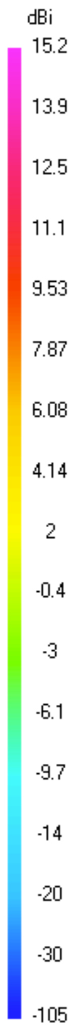
Yagi-Uda (Yagi) Antenna

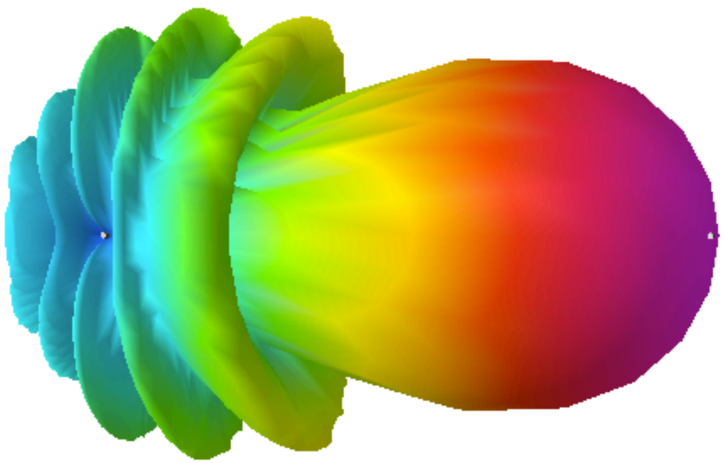
Invented 1926 by Shintaro Uda & Hidetsugu Yagi
Common from VHF up to 3 GHz
Low cost, light weight, durable, and high gain

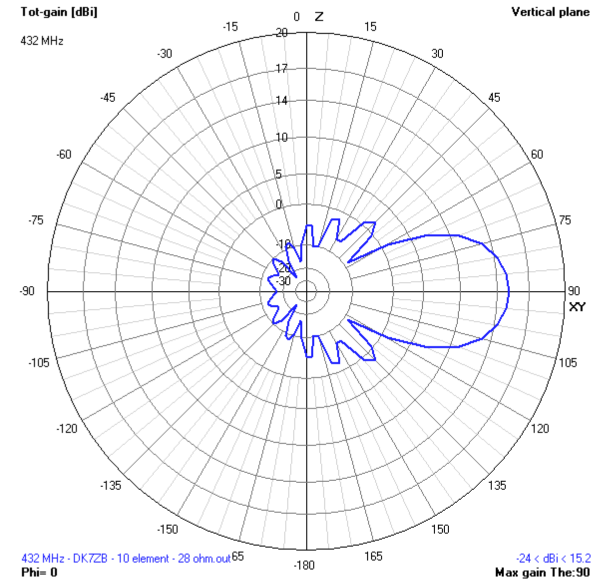


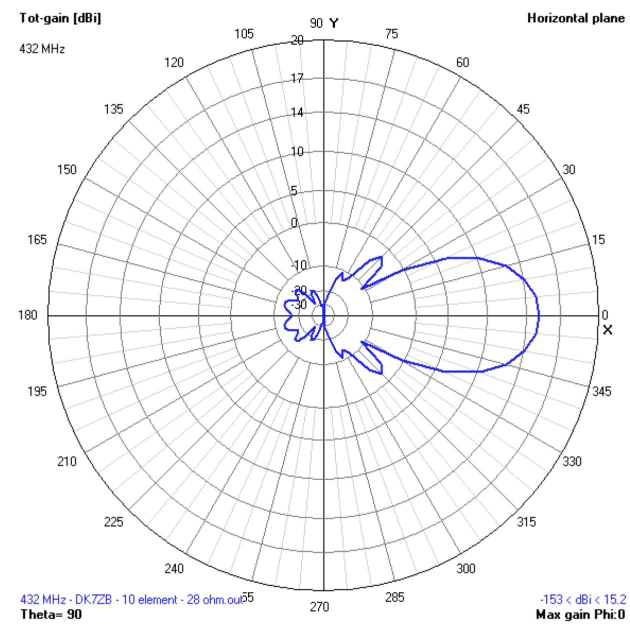


Yagi Antenna







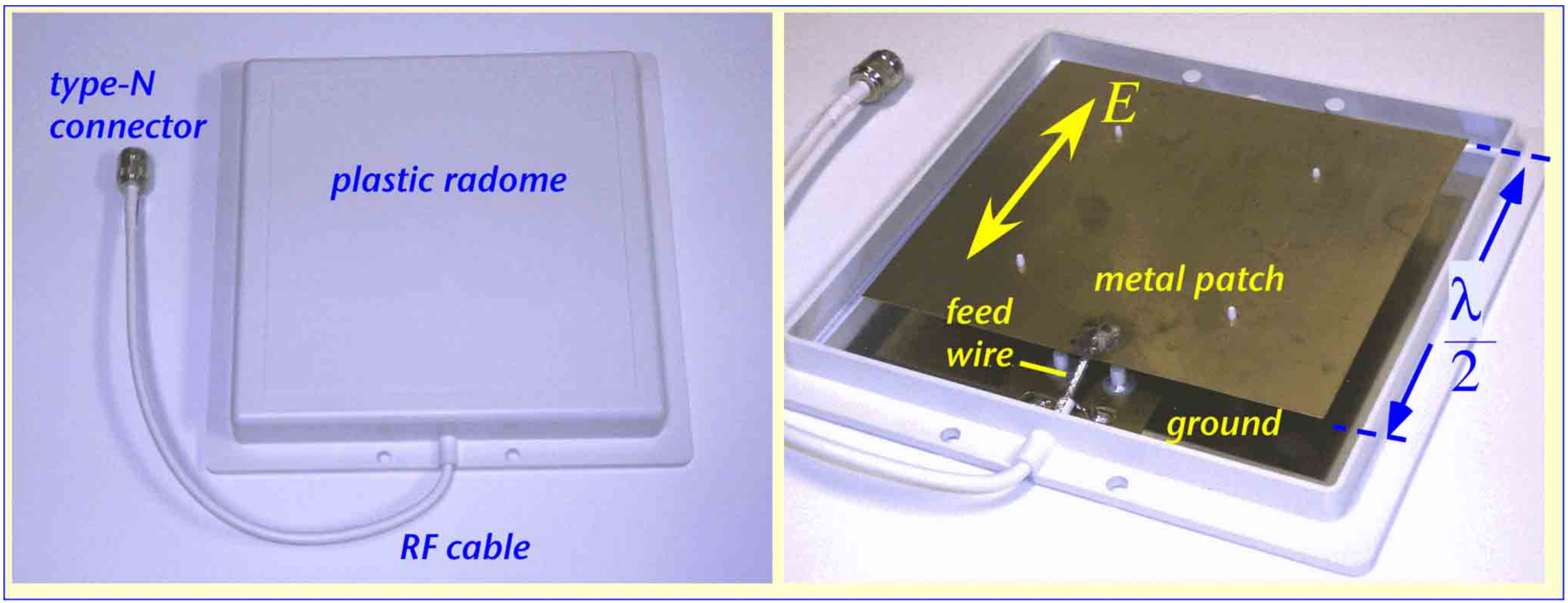


15 dBi Yagi

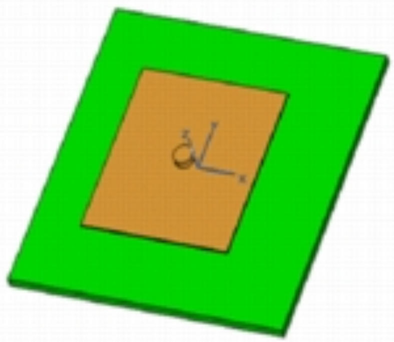
(approx) 30 degree E, 30 degree H

Microstrip (Patch) Antennas

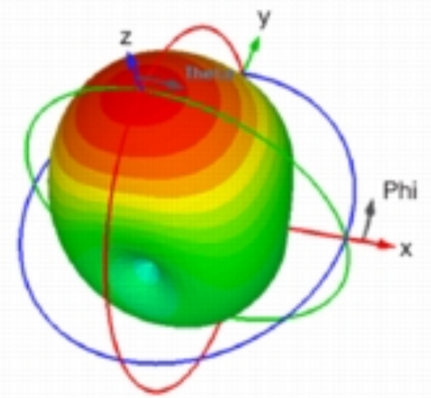
Invented in 1972 by J.Q. Howell at NASA
Very common in electronics and Wi-Fi



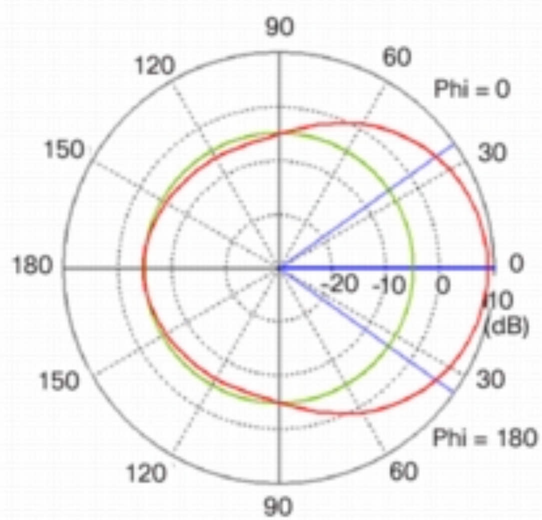
Microstrip (Patch) Antennas



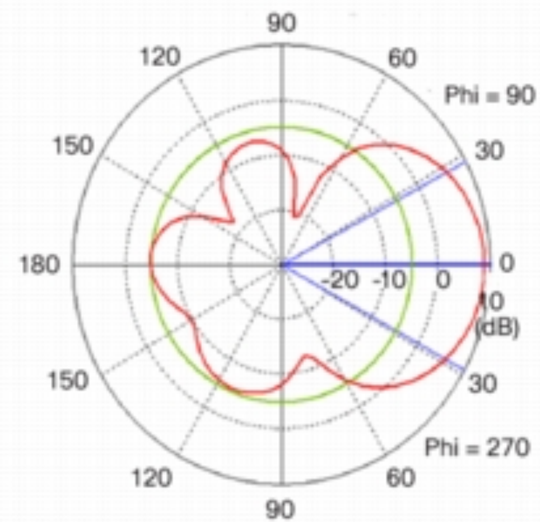
(a) Patch Antenna Model



(b) Patch Antenna 3D Radiation Pattern



(c) Patch Antenna Azimuth Plane Pattern

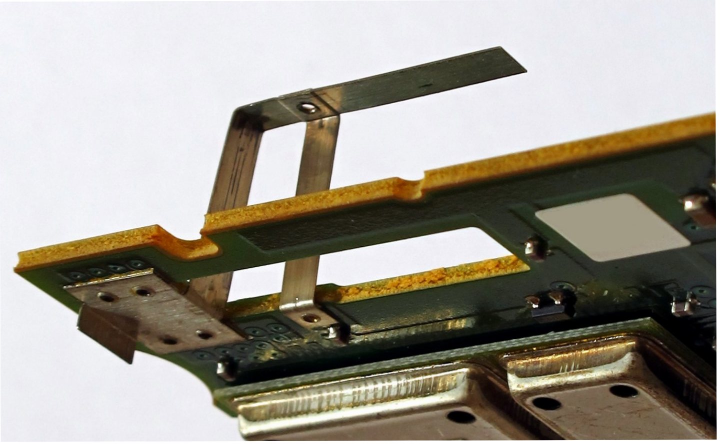


(d) Patch Antenna Elevation Plane Pattern

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

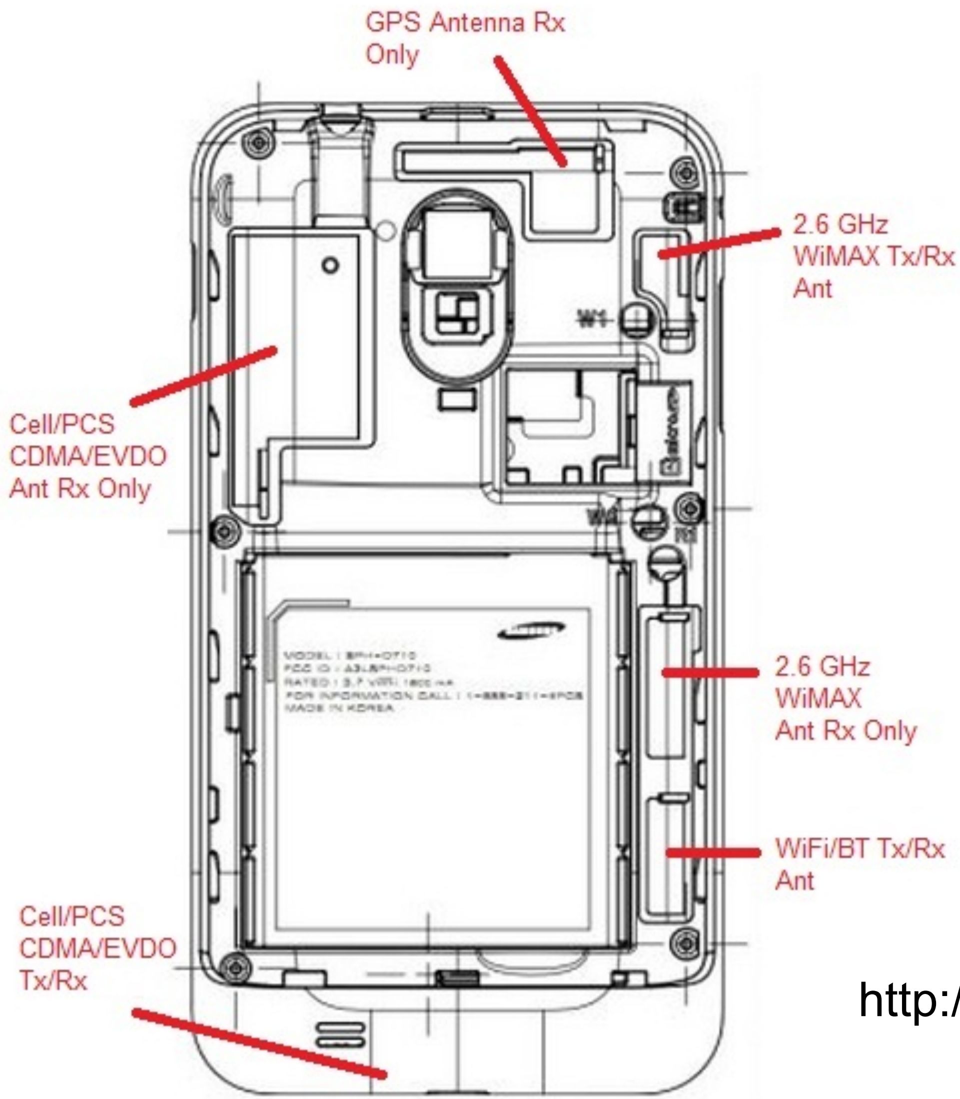
Planar Inverted F-Antenna (PIFA)

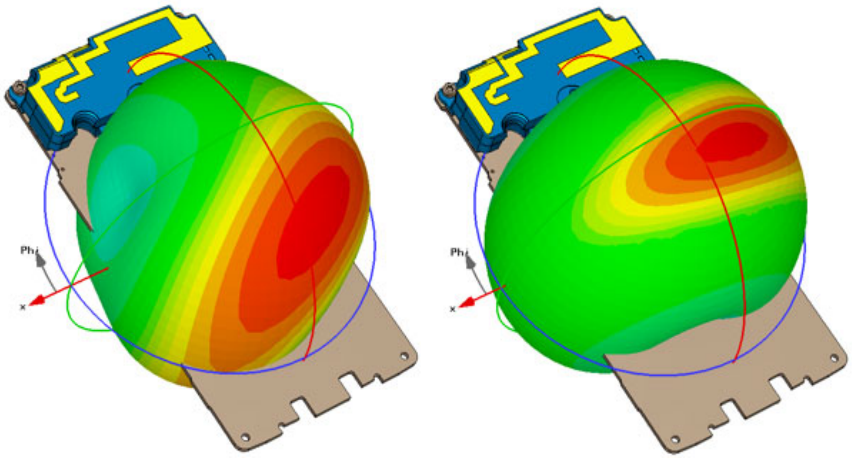
- Invented in 1987 by Taga & Tsunekawa at NTT
- Allows for a very small antenna
- Width + Height can be around ¼ λ
- A ¼ λ dipole at 750 MHz is 100mm: Phone size!
- PIFA allows for good antennas less than ¼ λ long
- There are also multi-band PIFA designs



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

Planar Inverted F-Antenna (PIFA)



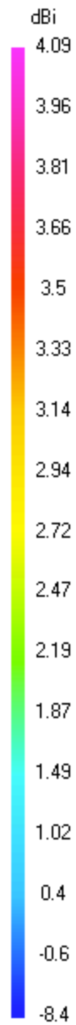


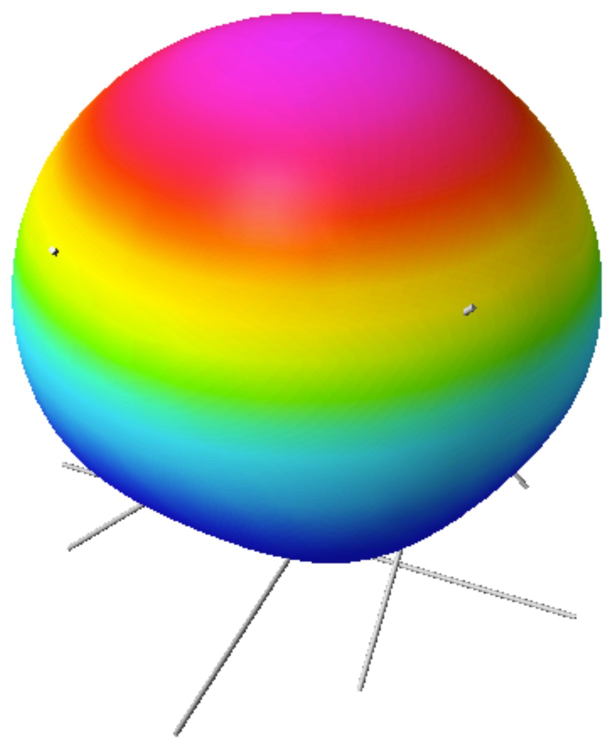
http://www.raymaps.com/index.php/tag/antenna/

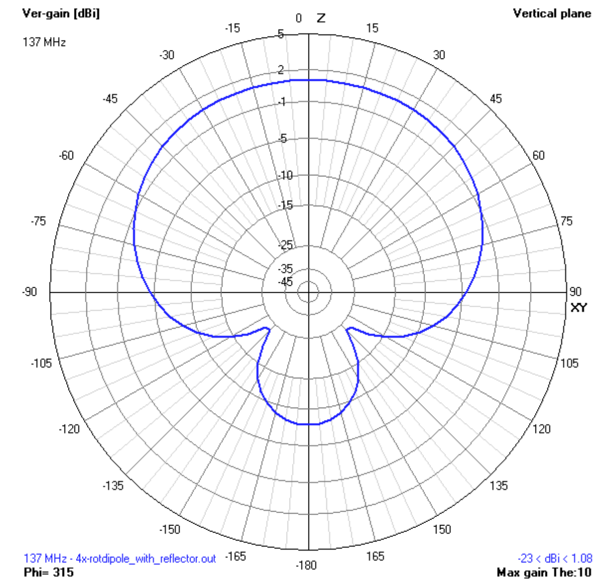
Antenna Arrays

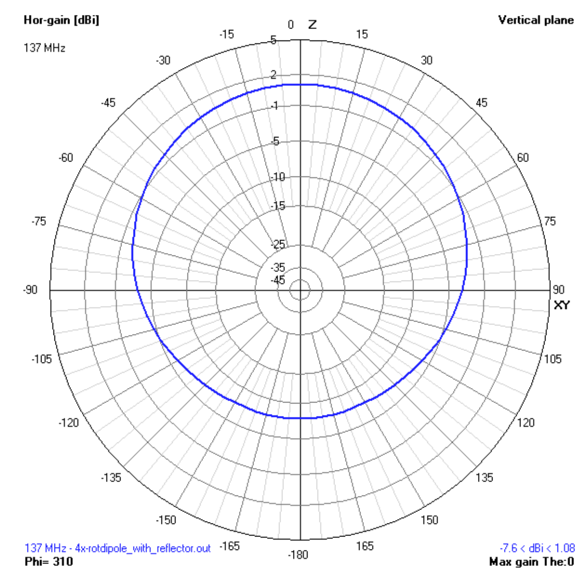
- Two or more antennas
- Signals combined for multiple purposes
  - increase gain
  - provide diversity receive
  - cancel interference
  - steer the direction of highest gain
  - locate the direction of received signals
- Most WiFi Sector Antennas are Arrays

Antenna Arrays





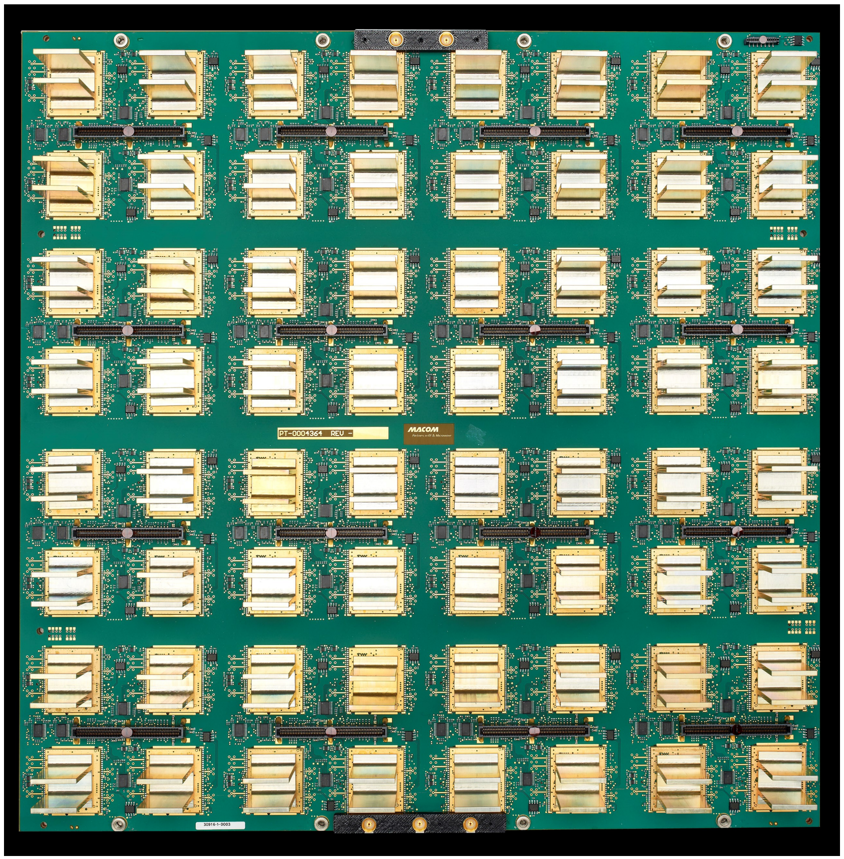


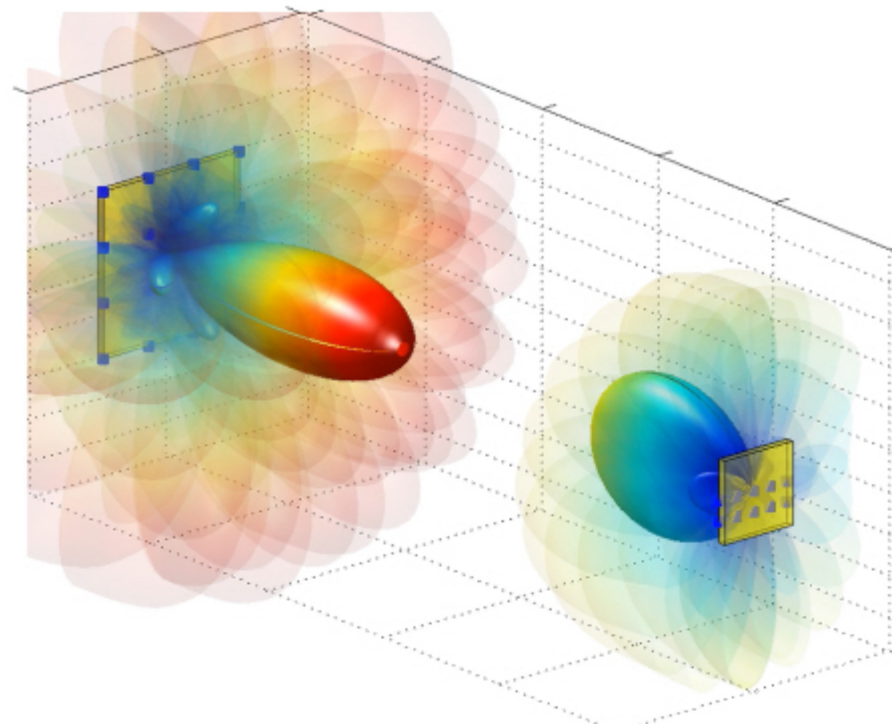


4dBi VHF Array of 4 Dipoles
(approx) 120 degree E, 90 degree H

Antenna Arrays For Beam Forming

https://www.macom.com/blog/phased-array-antennas--the-roadm





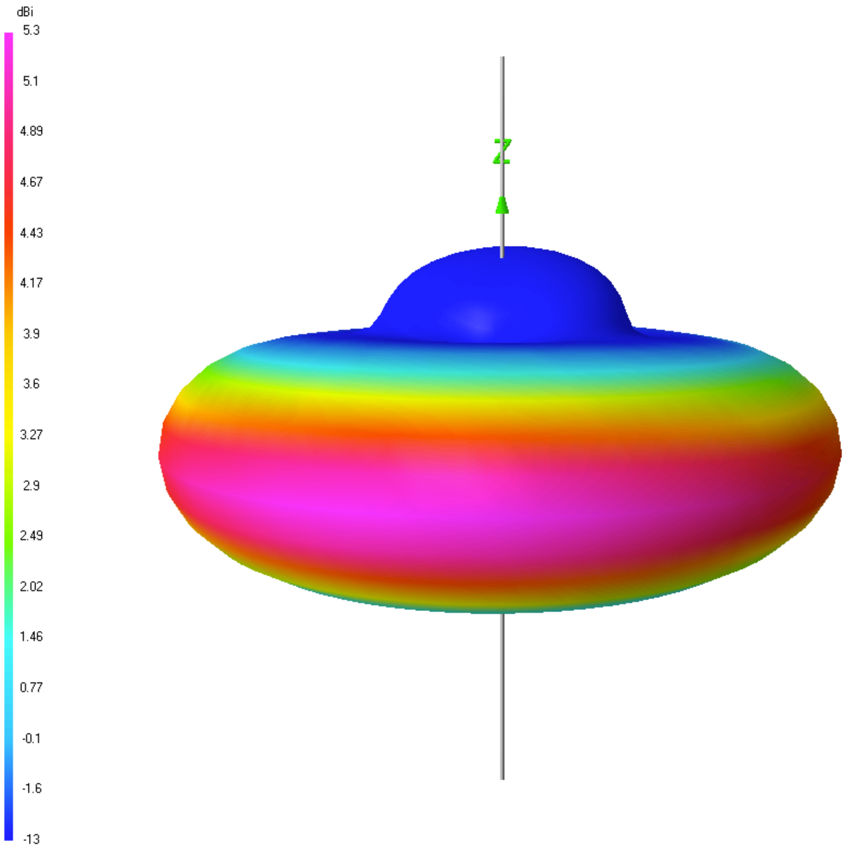
https://www.electronicsweekly.com/news/design/communications/5g-millimetre-comms-bristol-university-2014-06/

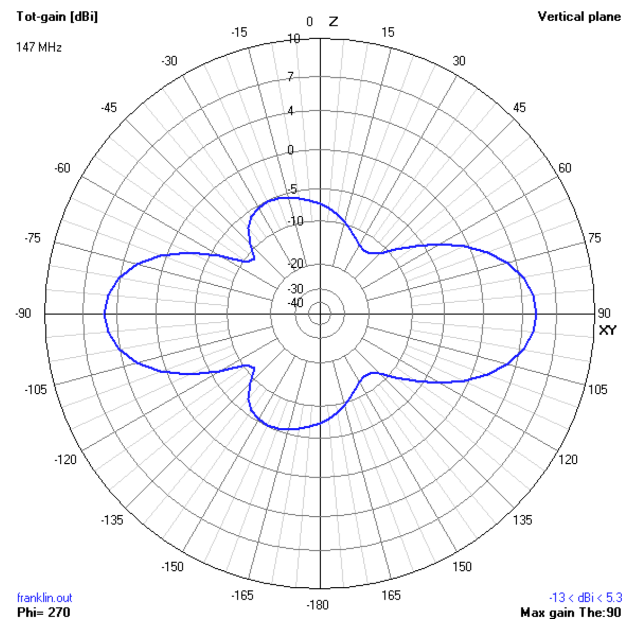
Collinear (Omni) Antenna

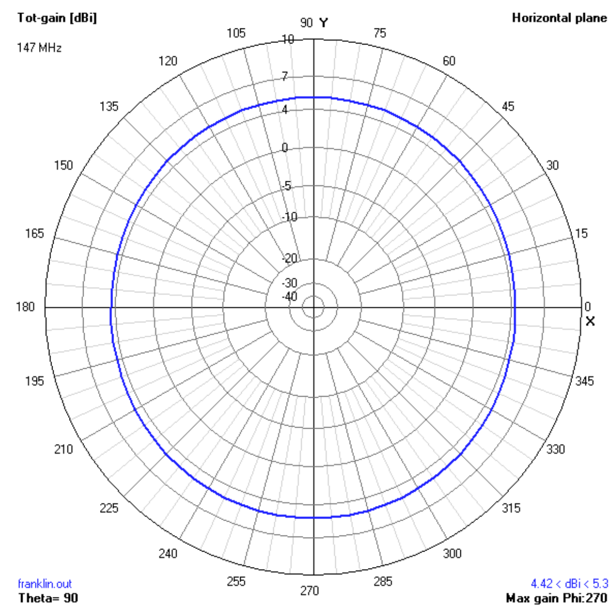
- Invented 1925 by Charles Franklin
- Made of an array of stacked dipoles
- Common from VHF up to 6 GHz
- Low cost, light weight, durable, and high gain

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

Collinear (Omni) Antenna





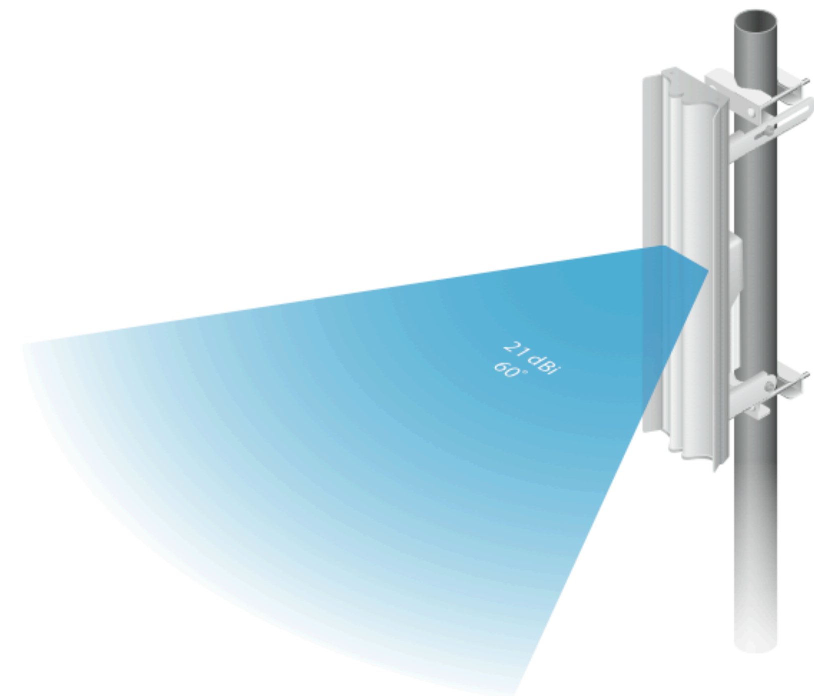


Choosing an Antenna

- 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)

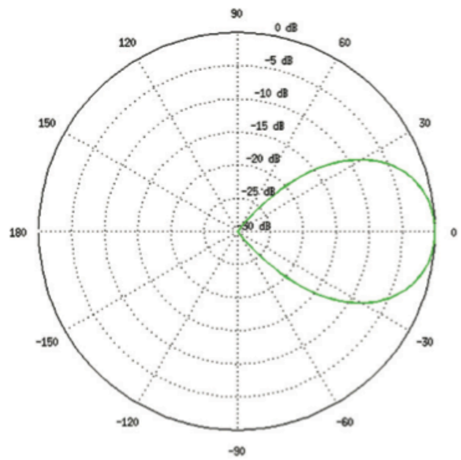
Beamwidth



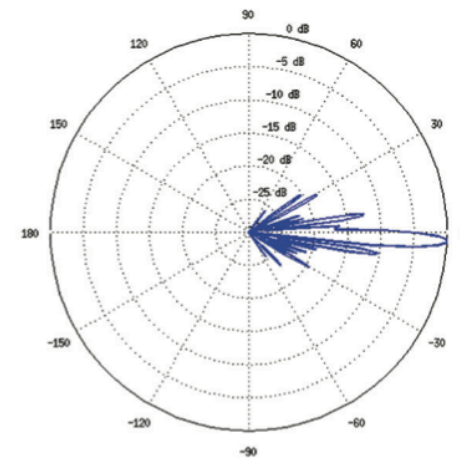
AM-5AC21-60

A Commercial Sector Antenna

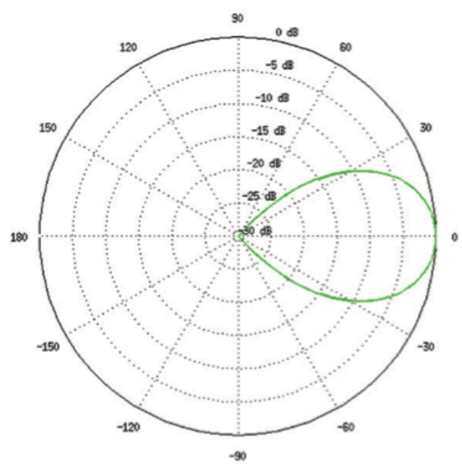
Vertical Azimuth



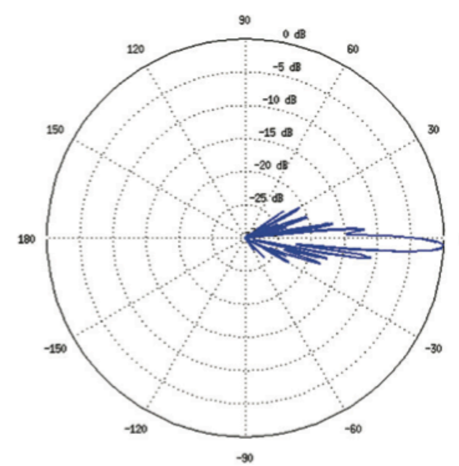
Vertical Elevation



Horizontal Azimuth



Horizontal Elevation

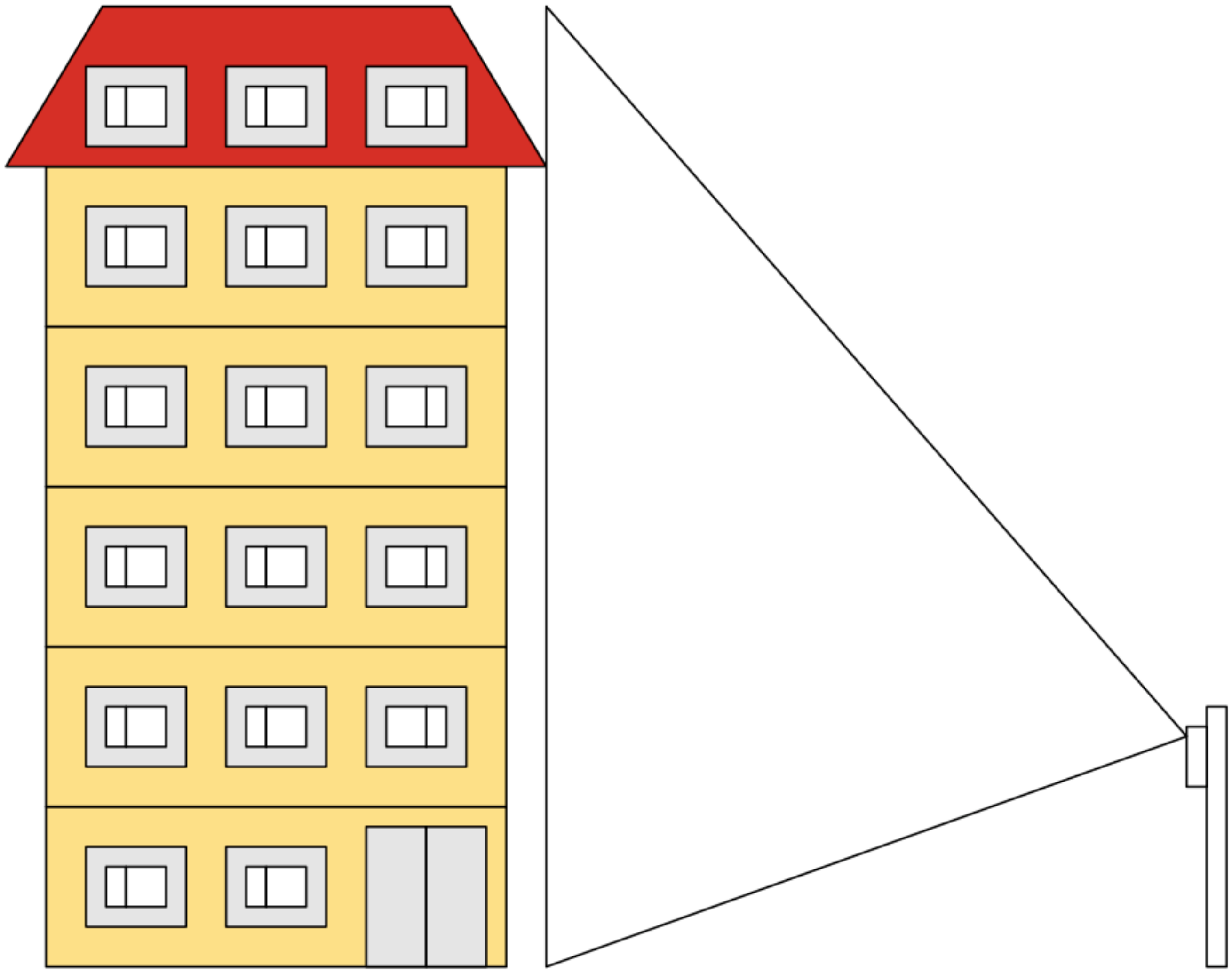


A Commercial Sector Antenna

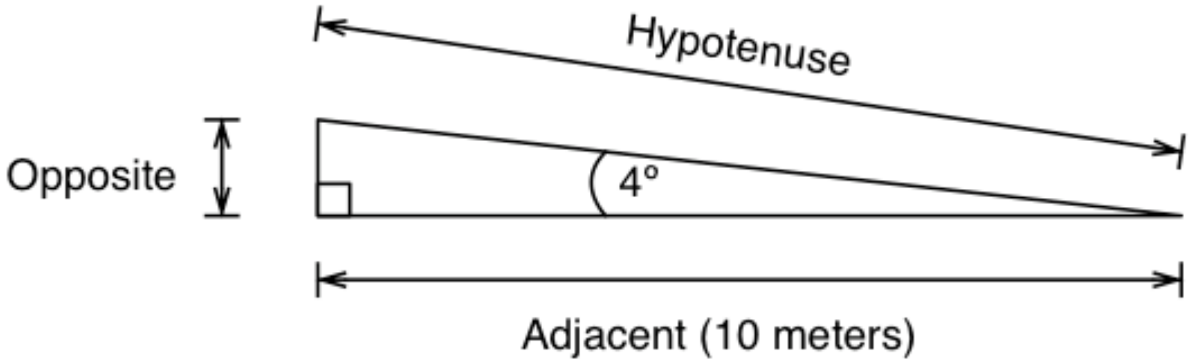
60 degree H, 4 degree E, 10m from a 18m Building

Is this going to work?

A Commercial Sector Antenna



A Commercial Sector Antenna



tan(θ) = Opposite / Adjacent

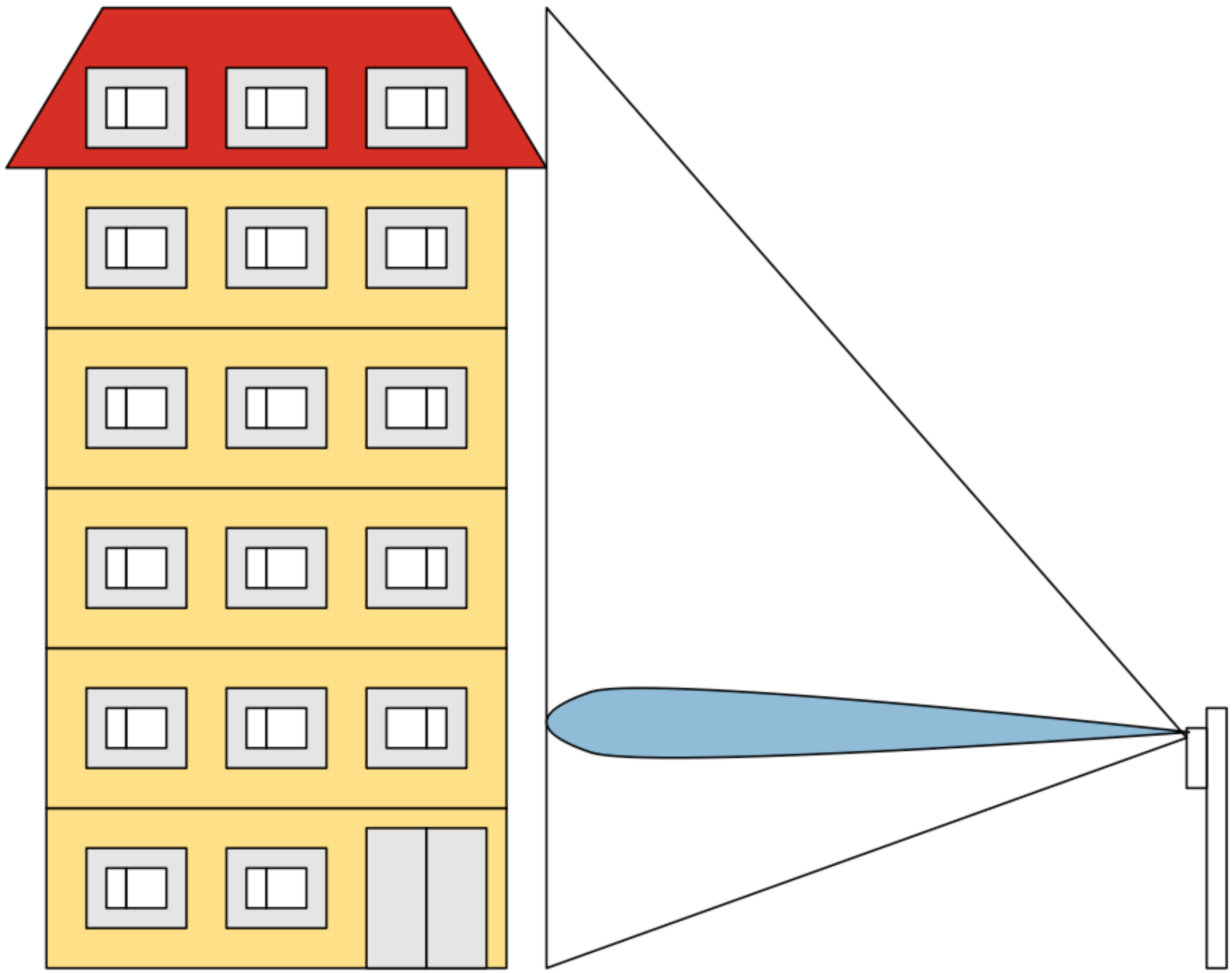
tan(4) = 0.07

0.07 = Opposite / 10

Opposite = 0.07 * 10

Opposite = 0.7 meters

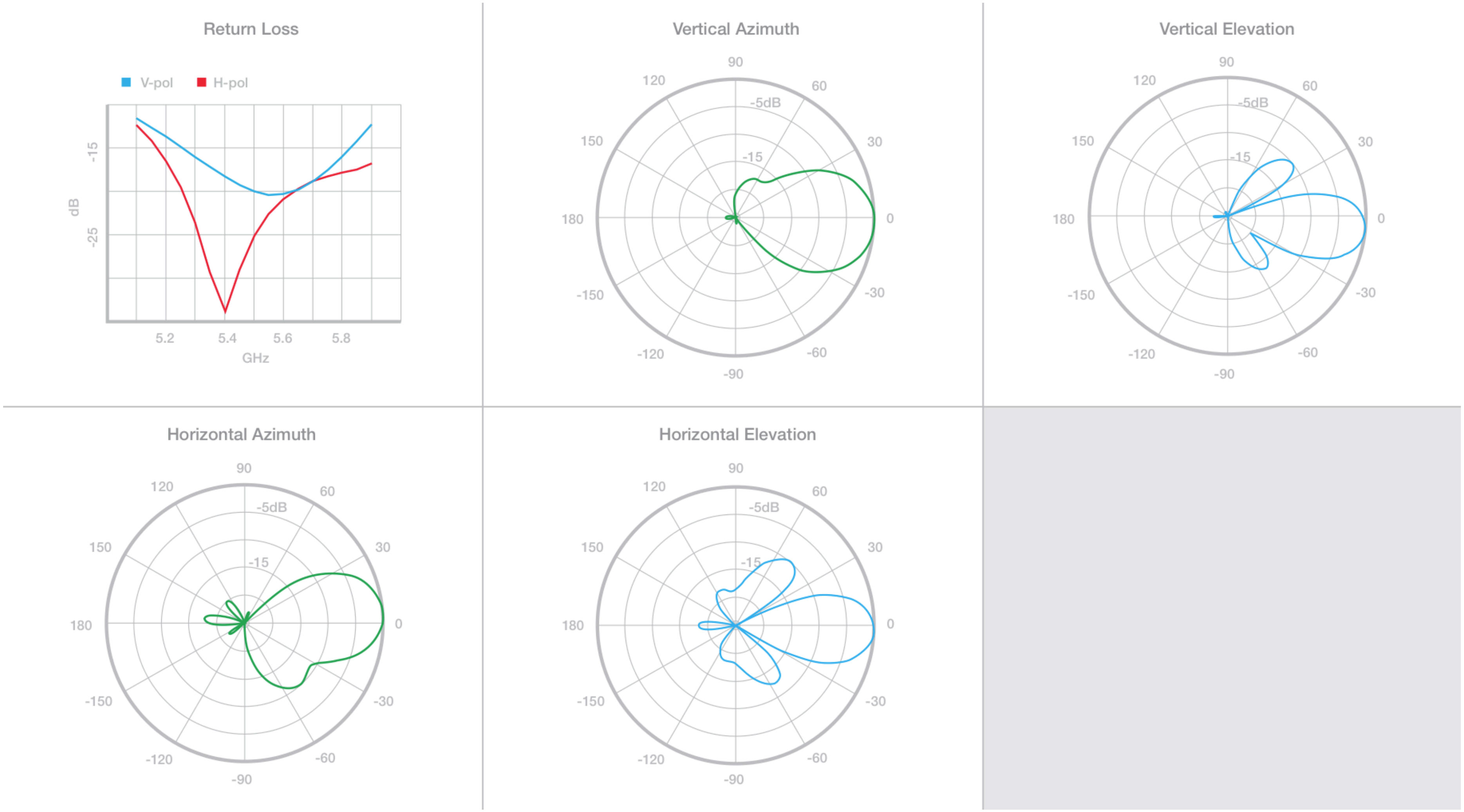
A Commercial Sector Antenna



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

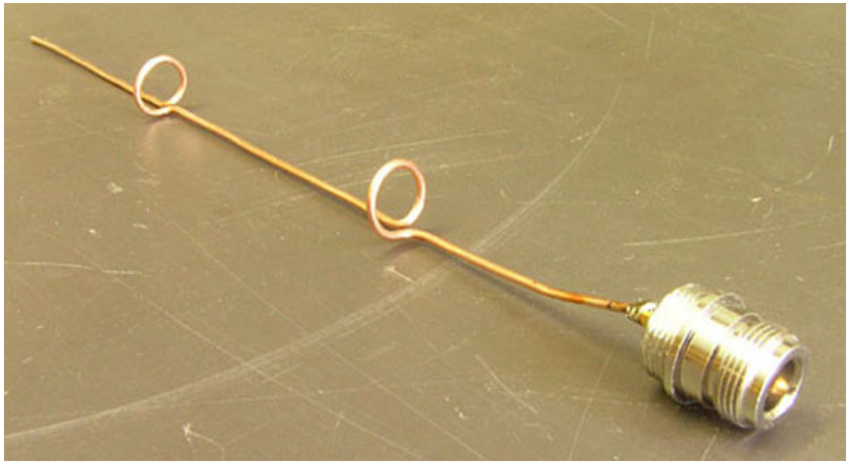
Is this going to work?

Making Your Own Antennas

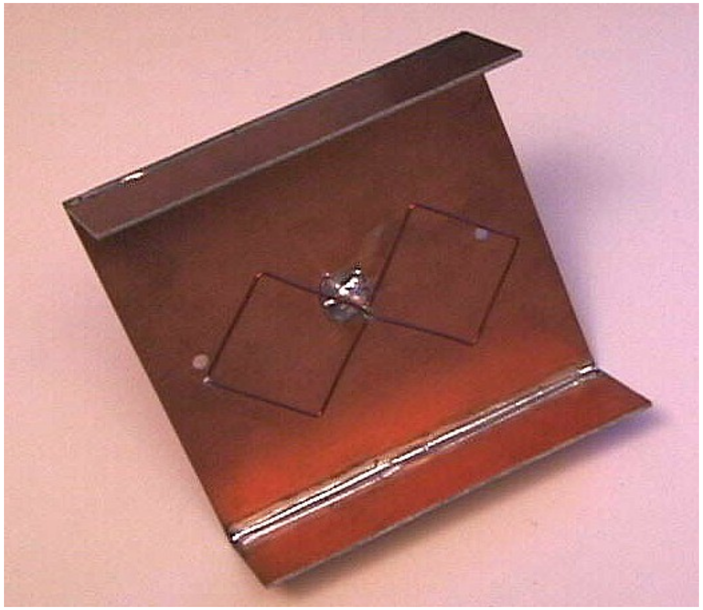
- Free, Open Source Designs Available
- Combine with Reflectors (Satellite Dishes) for high gain
- Learn Collinear & Cantenna with WNDW (multiple languages)
    - http://wndw.net/book.html
- Make a BiQuad with Trevor Marshall (English)
    - http://www.trevormarshall.com/biquad.htm
- Make a Parabolic 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



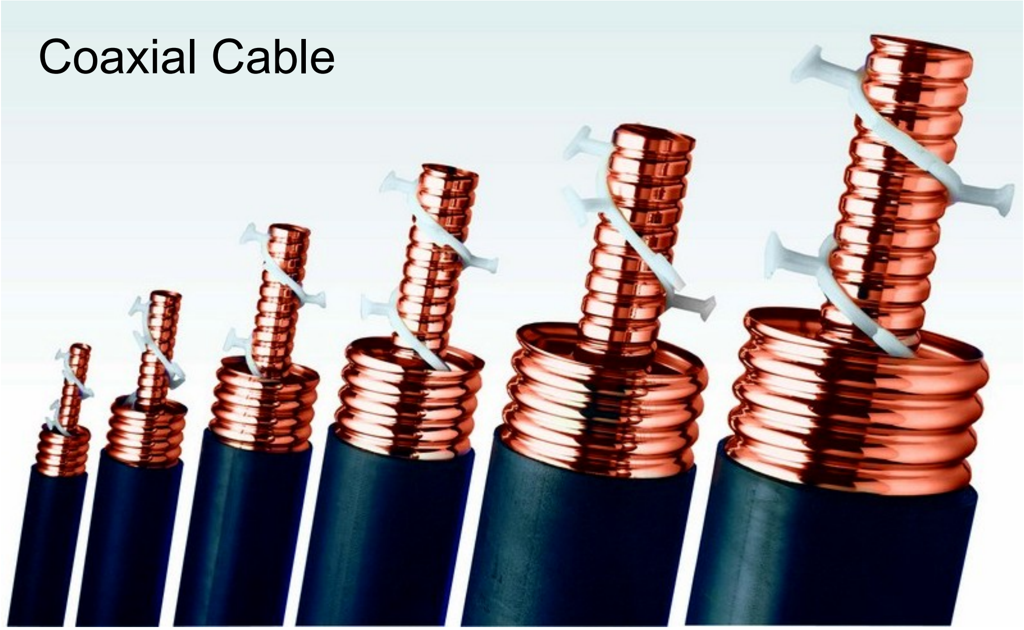
http://martybugs.net/wireless/collinear.cgi



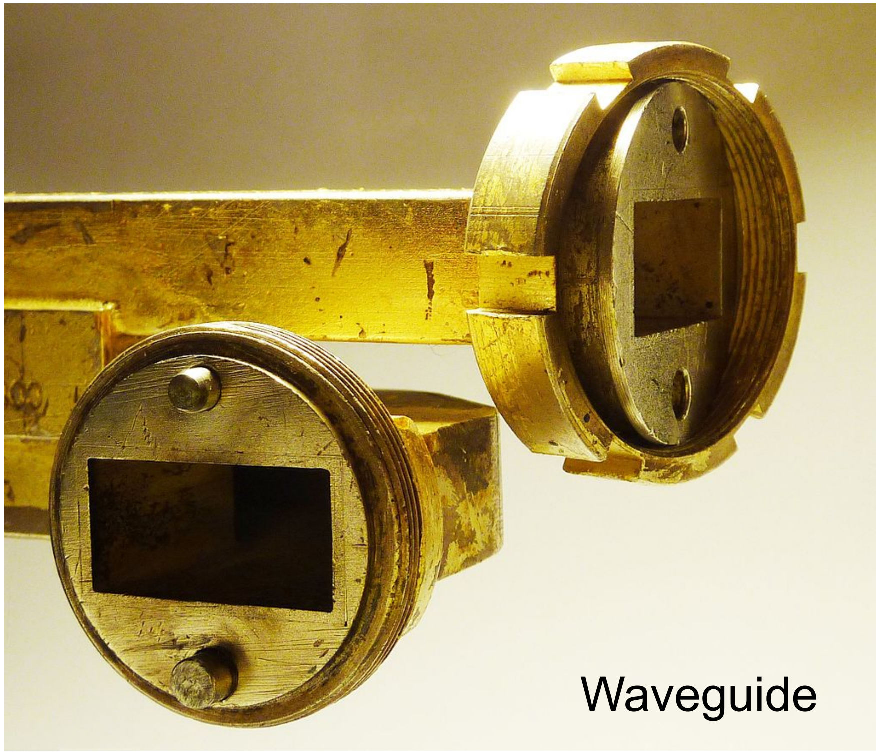
http://www.trevormarshall.com/biquad.htm

What's A Transmission Line?

A device to guide waves that are not in free space



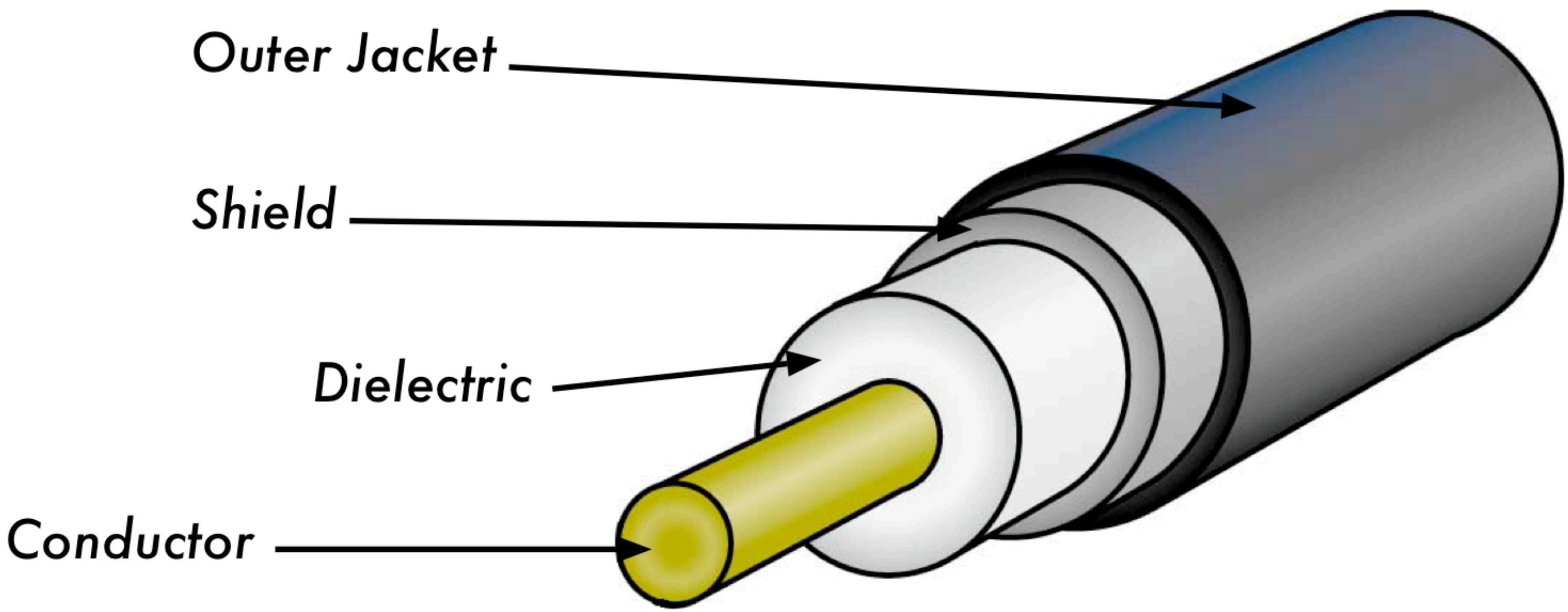
https://commons.wikimedia.org/wiki/File:Air_Cables.jpg



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

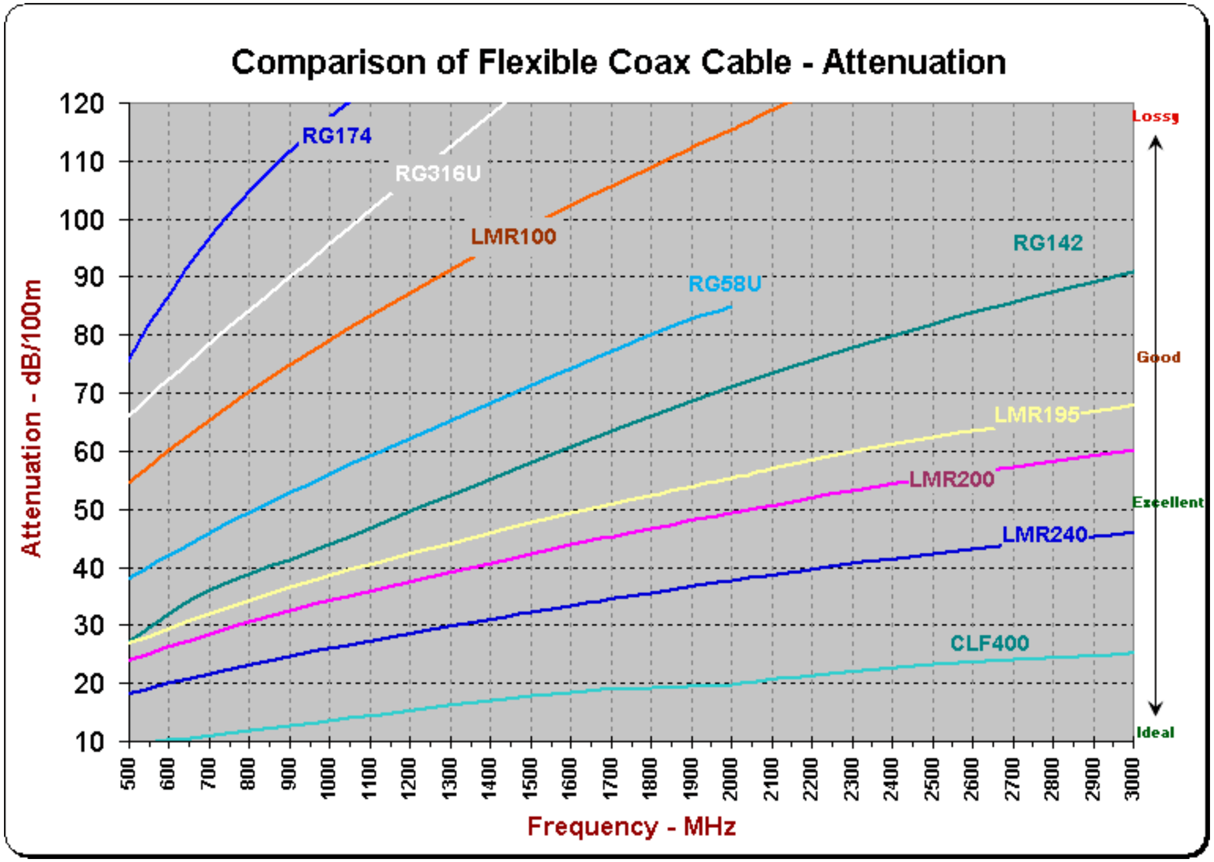
Thicker cable = less loss, harder to work with

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

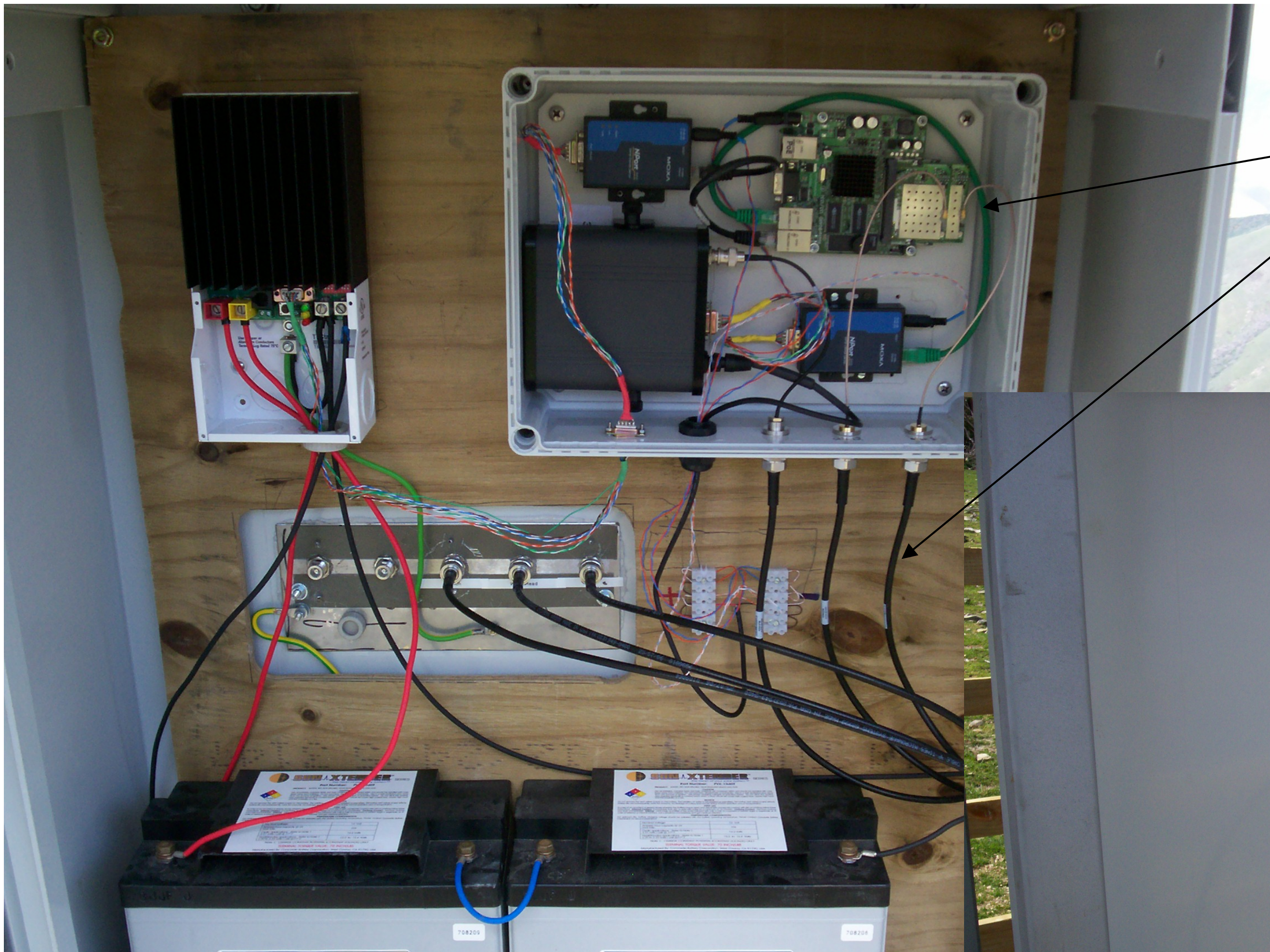
http://www.ocarc.ca/coax.htm

Cable Loss Chart

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



Why Use Different Cables? Flexibility



1.3mm Pigtails: tiny, high loss

LMR240 Jumpers: thin, medium loss

LMR 400 Cables: thick, low loss

Choosing Transmission Line

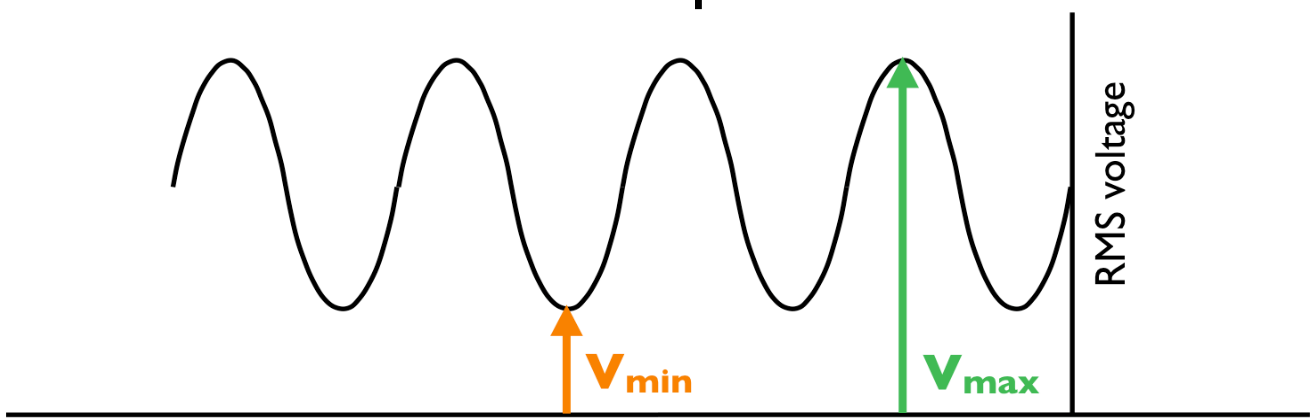
- What frequencies do you need?
- How much loss can your system tolerate?
- Does size matter? Flexibility?
- Using multiple types of line is ok!

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 VSWR = less power from tx to antenna
- Lower VSWR = more power from tx to antenna



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

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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?