Antennas and Transmission Lines

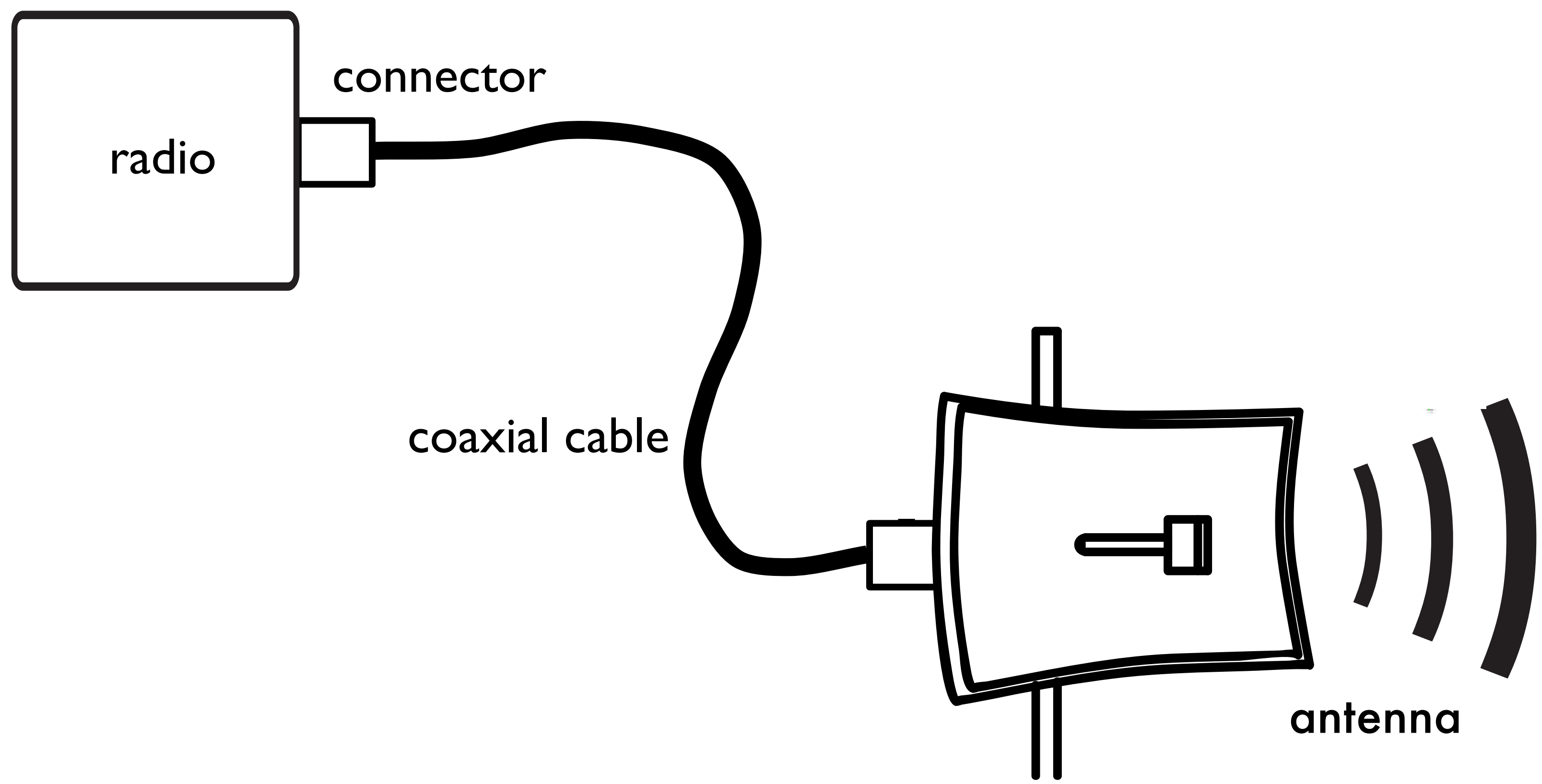
Training materials for wireless trainers

The Abdus Salam
International Centre
for Theoretical Physics

Goals

- To introduce the fundamentals concepts of transmission lines and antennas that are a fundamental part of a wireless system
- To guide in the choosing of the right kind of antenna for a given application

General scheme of a wireless station



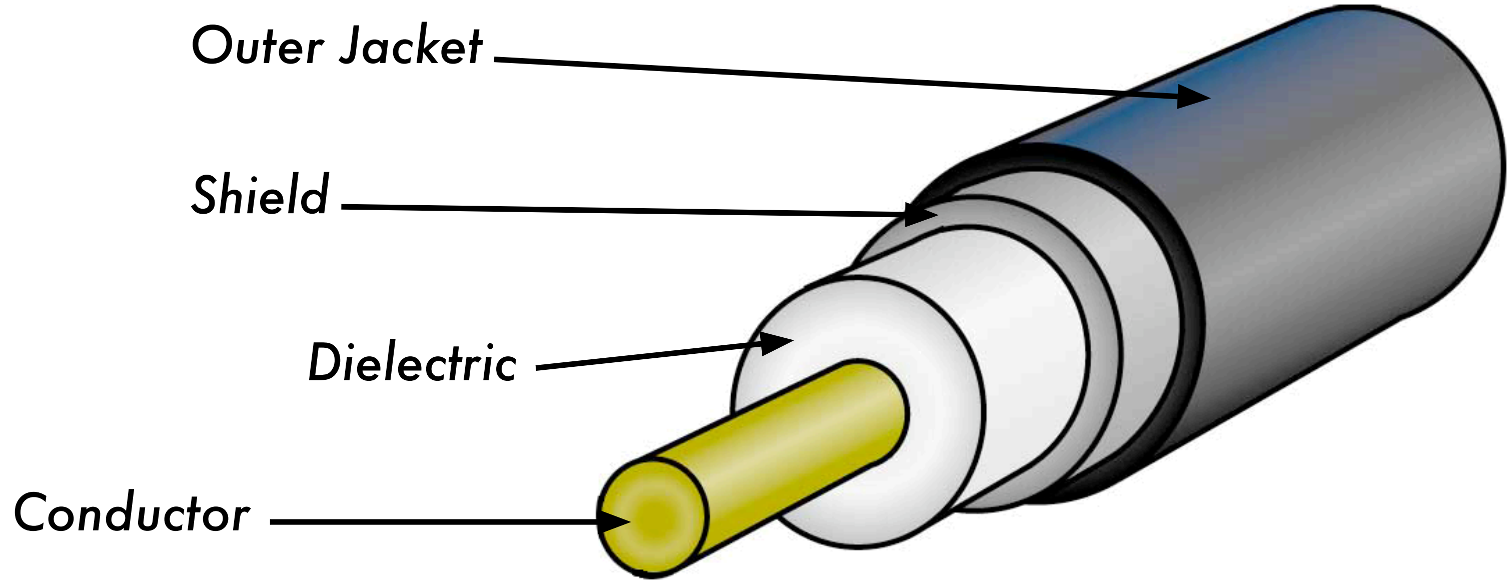
Transmission lines & antennas

- A ***transmission line*** is the device used to guide the RF energy from one point to another (e.g. a coaxial cable, a waveguide).

- An ***antenna*** is the structure associated with the region of transition from a guided wave to a free space wave, radiating RF energy.

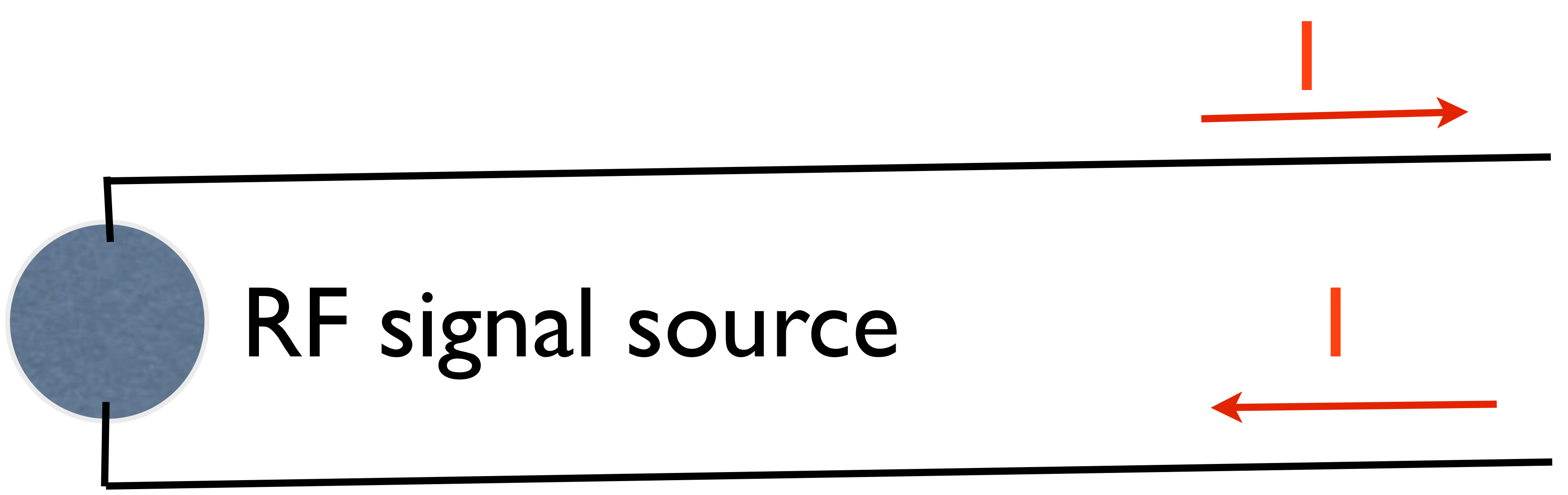
Coaxial transmission lines

- ***Coaxial transmission lines***



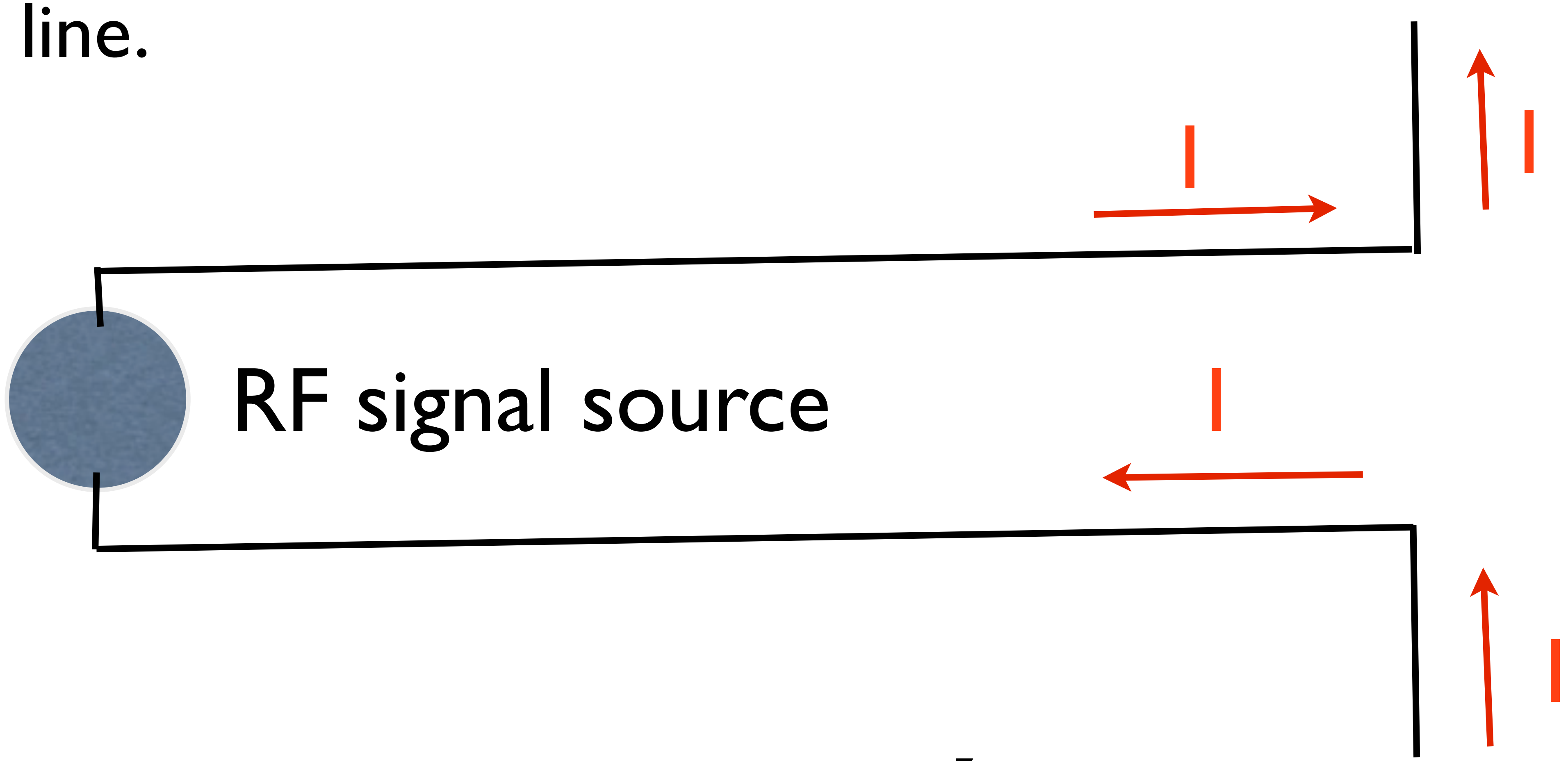
Bifilar transmission lines

- ***Bifilar transmission lines*** are formed by two conductor wires separated by a dielectric. There can be an alternating current even in an open ended transmission line.



Bifilar transmission lines

- If we now bend the open ends of the transmission line in opposite directions, the currents will now generate electric fields that are in phase and will reinforce each other and will therefore radiate and propagate at a distance.
- We now have a an antenna at the end of the transmission line.

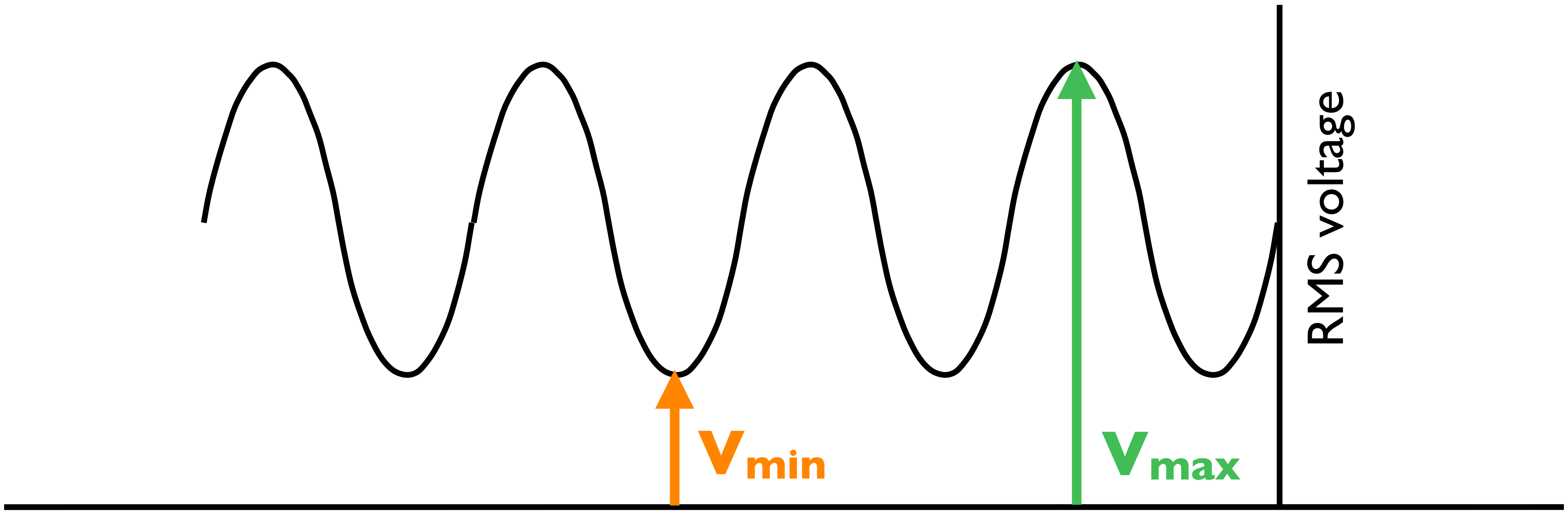


Impedance

All materials will oppose the flow of an alternating current to some extent. This opposition is called **impedance**, and is analogous to resistance in DC circuits.

Most commercial communication antenna have an impedance of 50 ohms, while TV antennas and cables are usually 75 ohms.

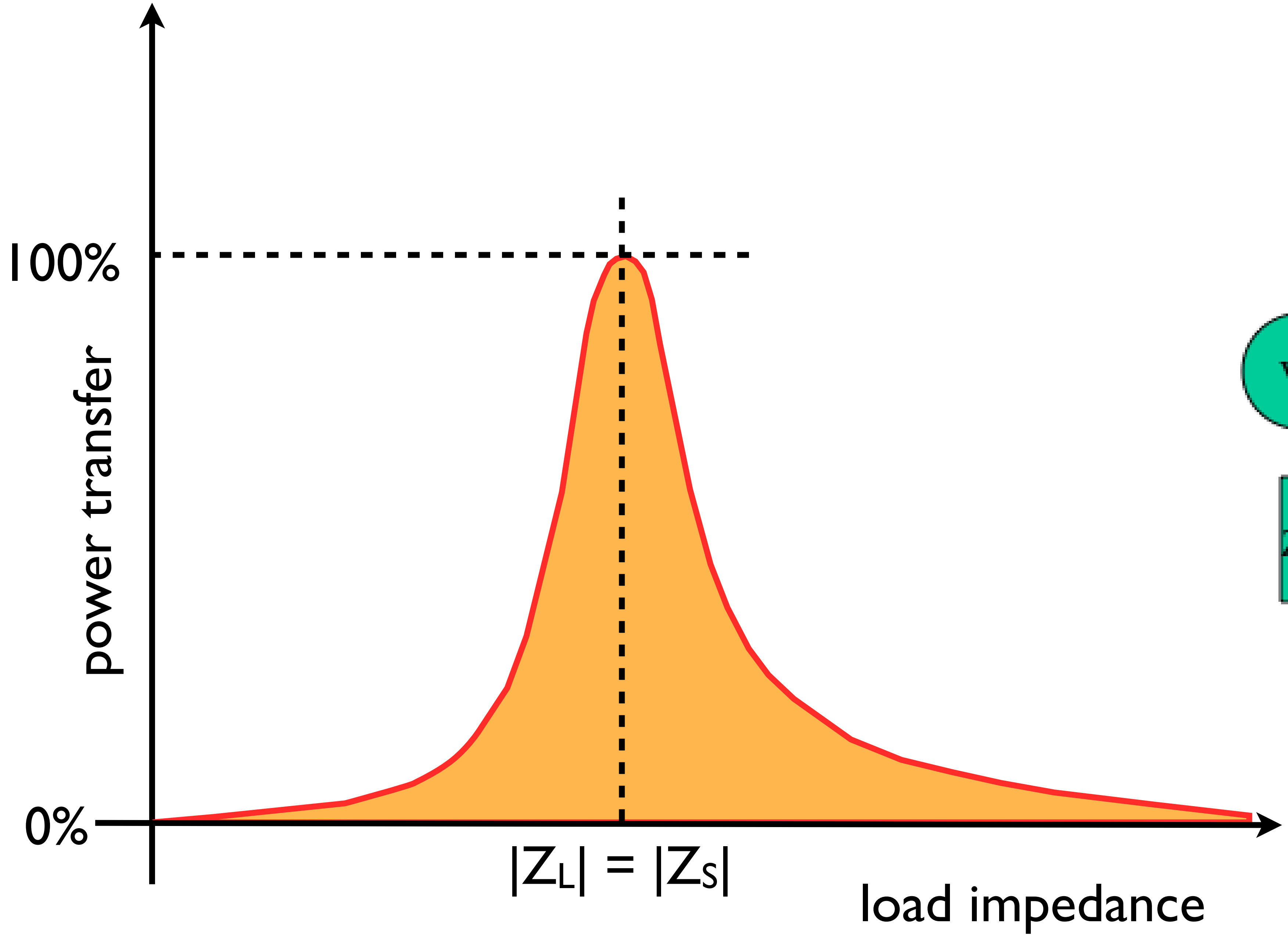
Reflections and VSWR

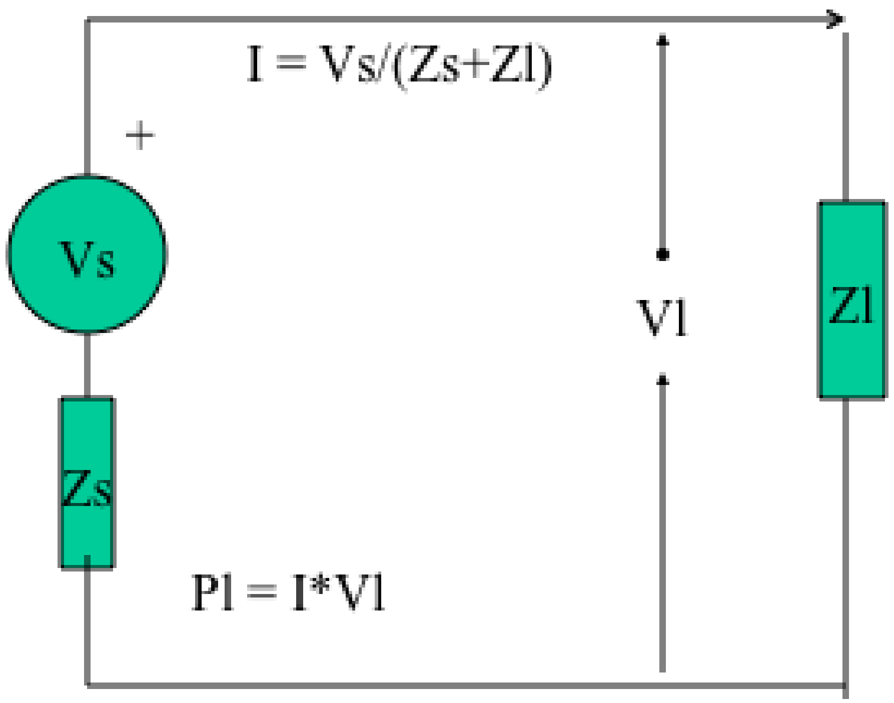


Voltage Standing Wave Ratio VSWR = $\frac{V_{max}}{V_{min}}$

Maximum Power Transfer

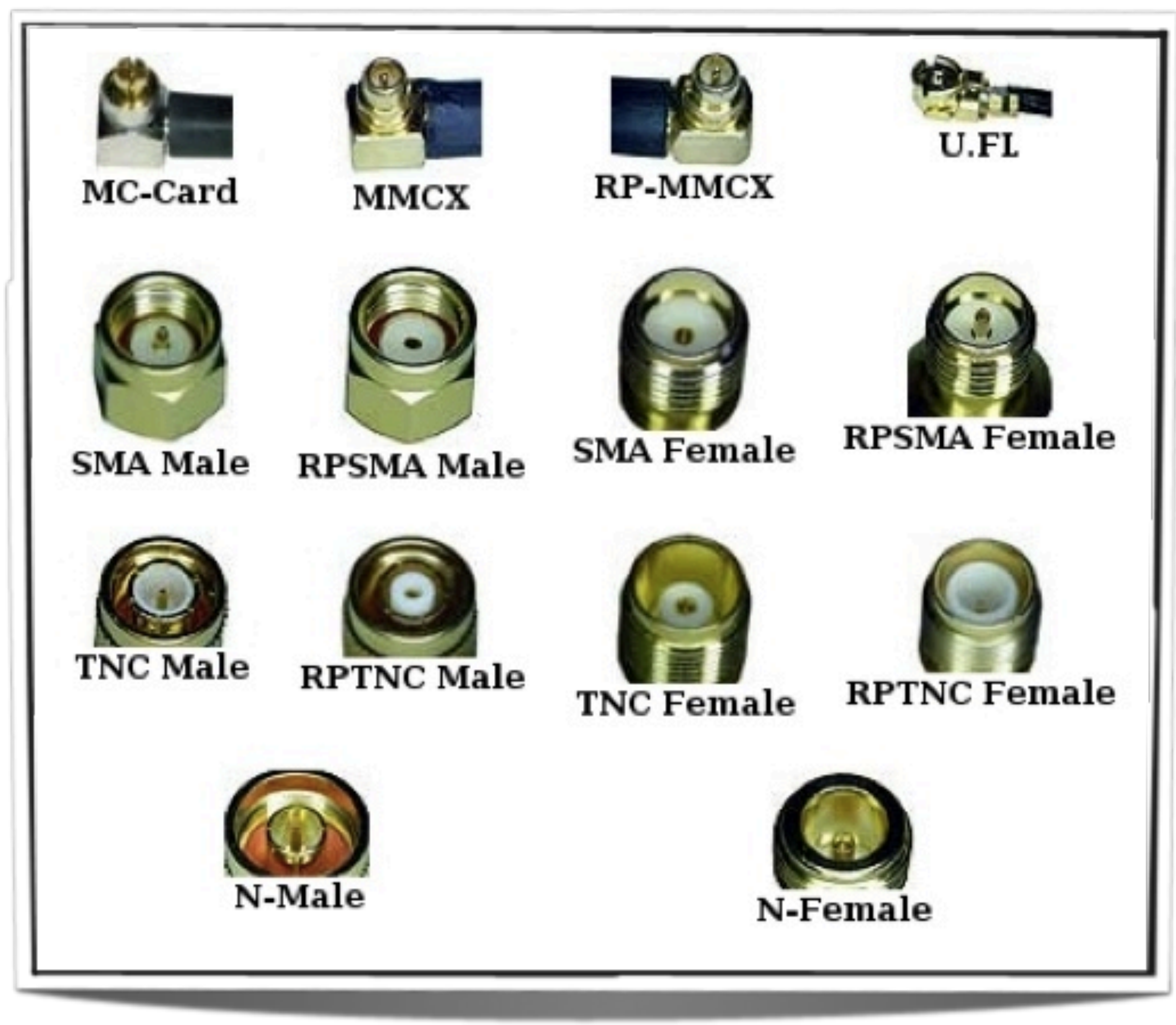
For maximum power transfer, the modulus of the load impedance $|Z_L|$ should equal the modulus of the source impedance $|Z_S|$.





Connectors

- Connectors allow a cable to be connected to another cable or to a component of the RF chain. There are a wide variety of fittings and connectors designed to go with various sizes and types of coaxial lines.



Adapters & Pigtails

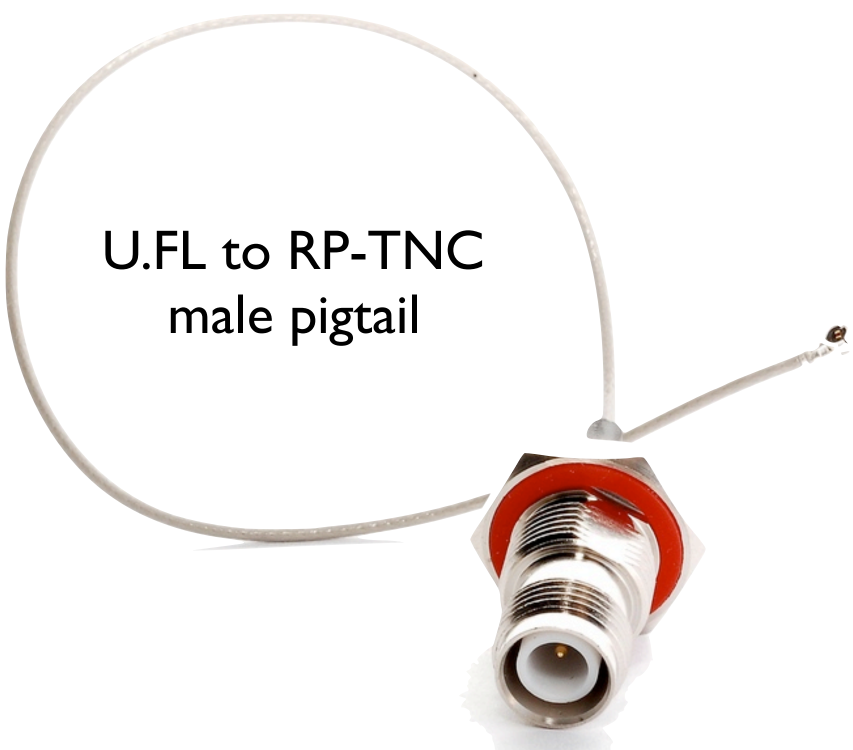
- Adapters and pigtails are used to interconnect different kinds of cable or devices.

SMA female to N male

N male to N male

N female to N female

SMA male to TNC male

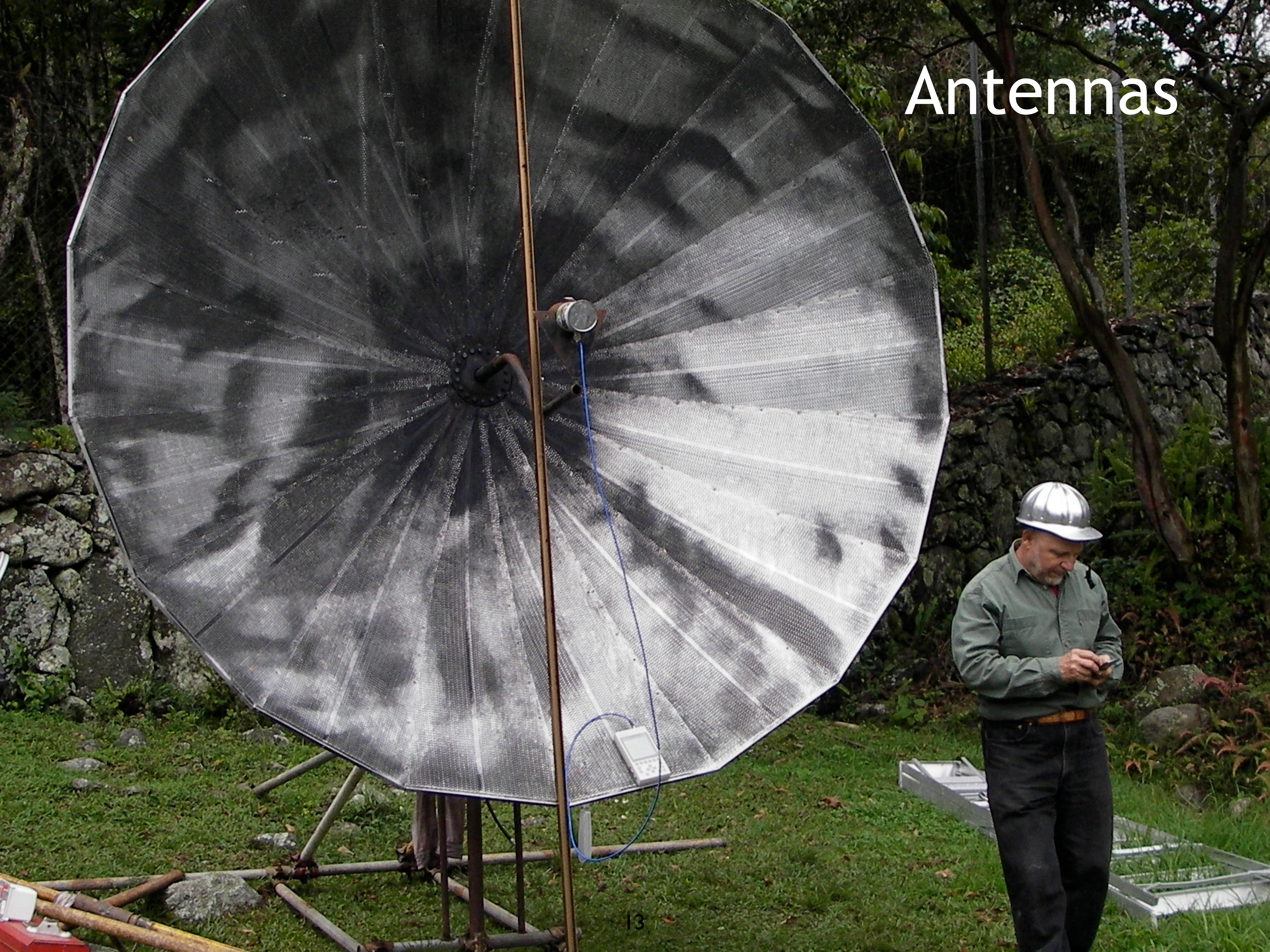


U.FL to RP-TNC male pigtail

U.FL to N male pigtail

SMA male to N female

Antennas



Reciprocity

Antenna characteristics like gain, beamwidth, efficiency, polarization, and impedance are independent of the antenna's use for either transmitting or receiving.

Another way to state this is that an antenna's transmitting and receiving characteristics are ***reciprocal***.

Theory: *isotropic* antennas

An ***isotropic antenna*** radiates the energy fed into it equally in every direction in space. It is only an ideal and cannot be built.

Any ***real world antenna*** will favor some regions of the space, thus showing directivity.

Directional Versus Omnidirectional

Antenna features

These features depend on the design of the antenna:

- Input Impedance
- Directivity, Efficiency, and Gain
- Radiation Pattern (Vertical and Horizontal)
- Beamwidth (Vertical and Horizontal)
- Front-to-Back Ratio and Sidelobes
- Polarization
- Bandwidth
- Aperture
- Wind Load

Antenna directivity

Real-world antennas are characterized by their ability to radiate more strongly in some directions than in others; this is called ***directivity***.

The ratio of the maximum power density to the average power density over the entire space is the numerical measure of directivity that is:

$$D = P_{max} / P_{av}$$

$$D[dBi] = 10\log_{10} (P_{max} / P_{av})$$

Efficiency and gain

The gain is closely related to directivity: in this case you have to take into account the efficiency **η** of the antenna:

$$G = \eta(P_{max} / P_{av})$$

$$G[dBi] = 10\log_{10} \eta(P_{max} / P_{av})$$

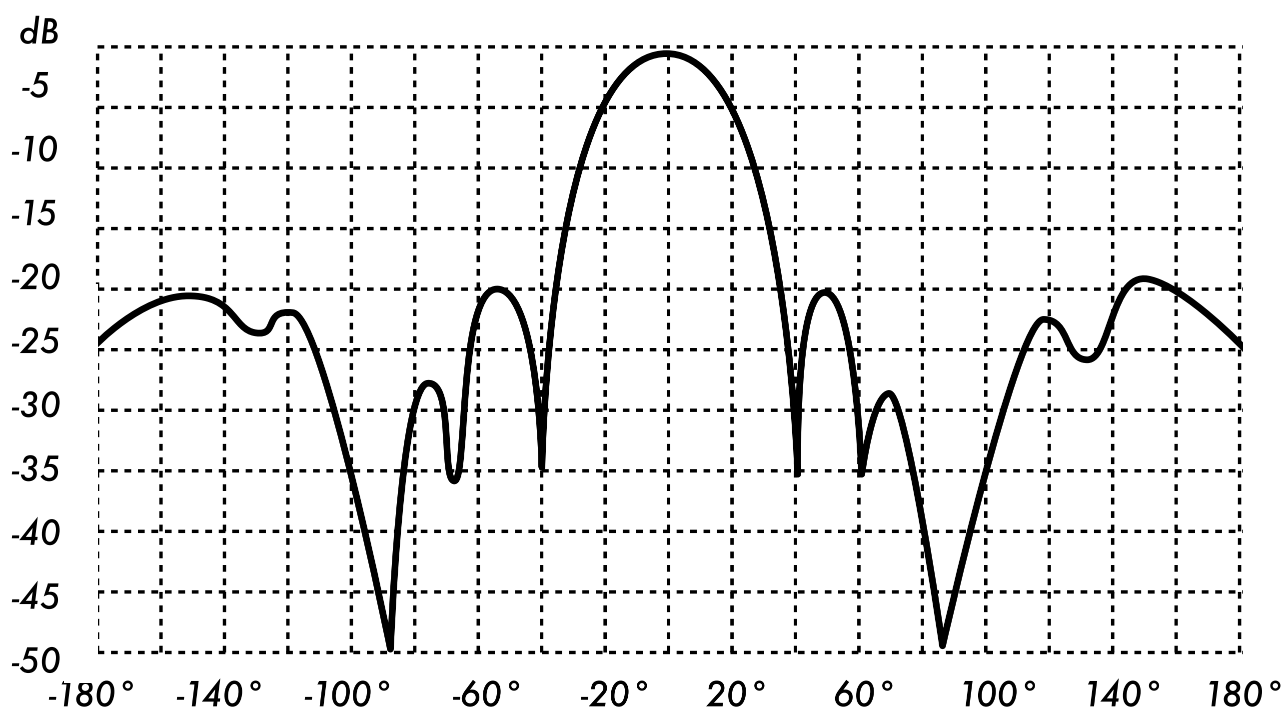
Typical efficiency is between 0.5 and 0.9, depending on the quality of the construction and the conductivity of the metal used.

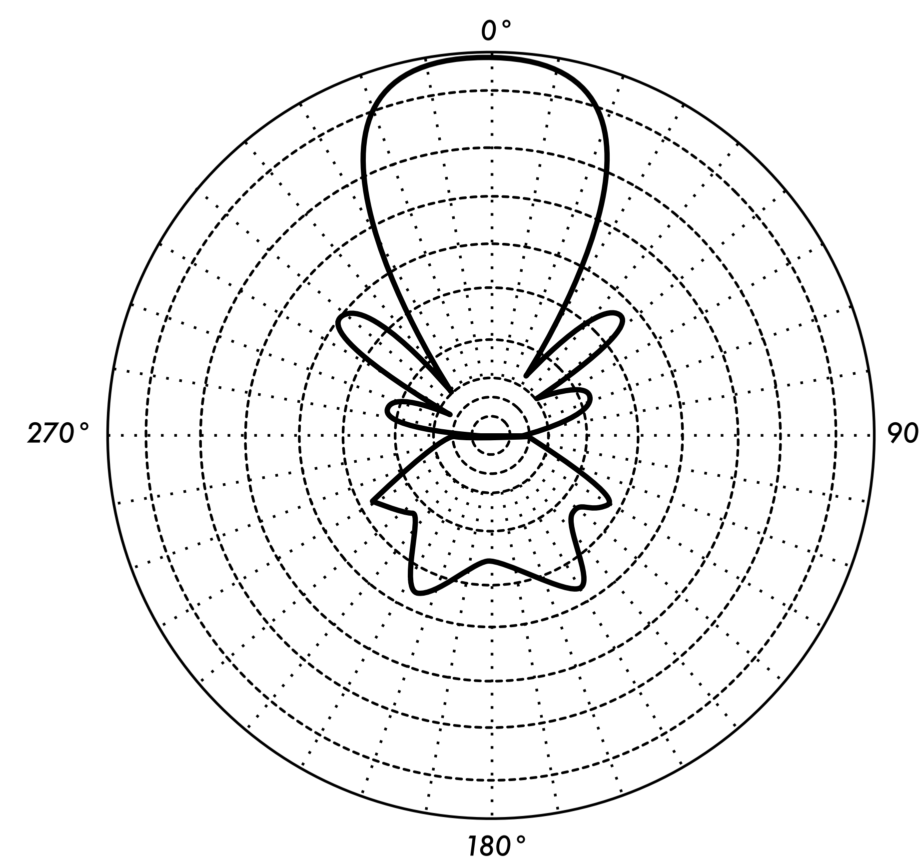
An antenna is a passive element and cannot amplify the signal, what it does is concentrate it in a given direction, while reducing it in other directions.

Radiation pattern

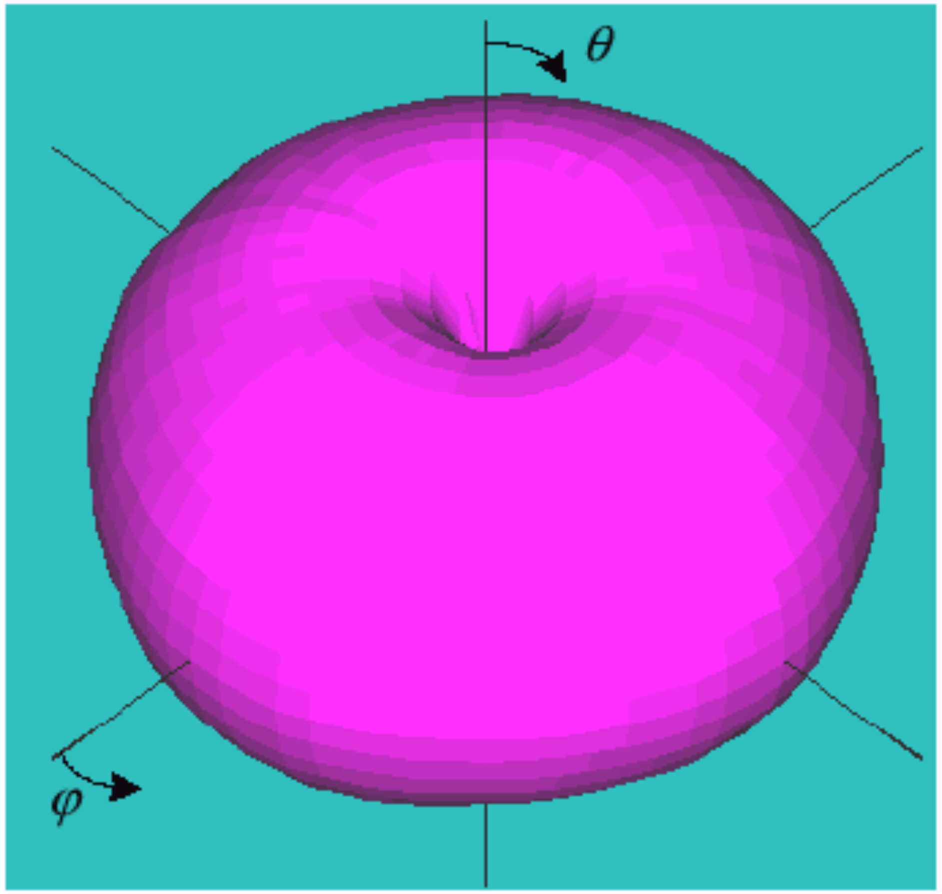
The ***radiation pattern*** of antenna is a pictorial representation of the distribution of the power radiated from, or received by, the antenna. This is presented as a function of direction angles centered on the antenna.

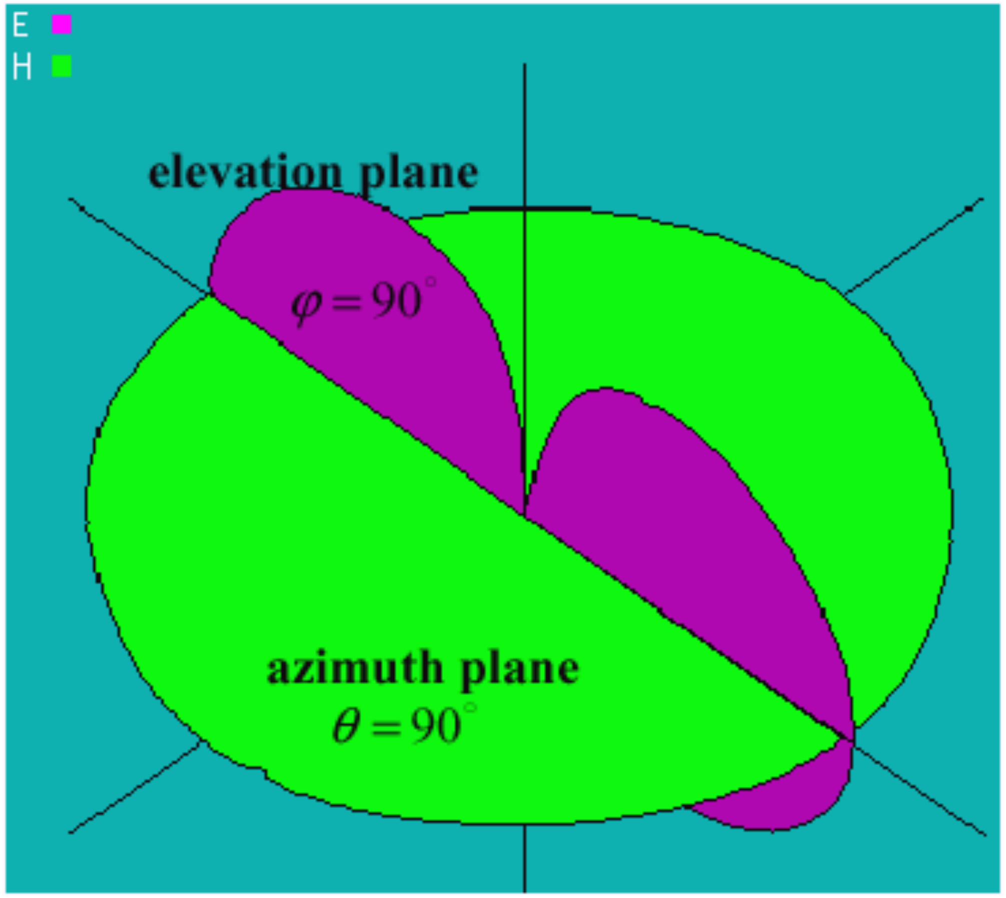
Since antenna gain is reciprocal, the transmitting and receiving patterns of a given antenna are identical.





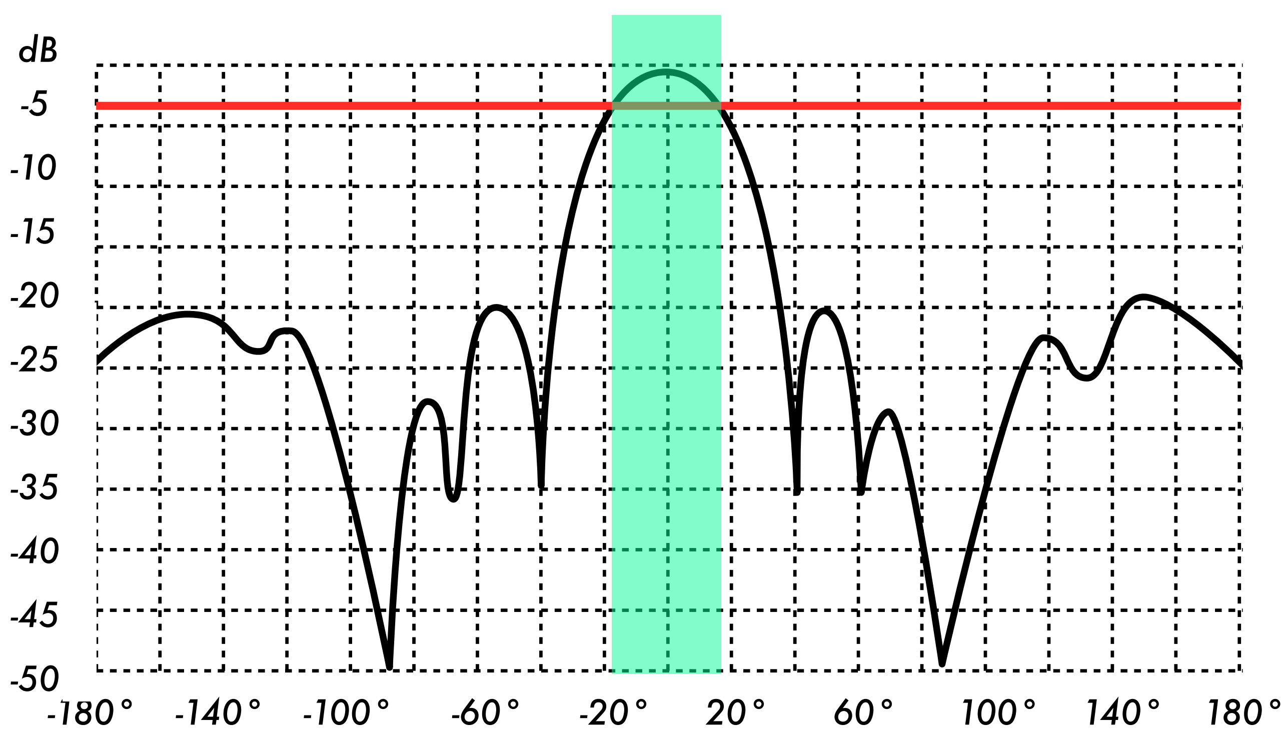
Dipole omnidirectional antenna

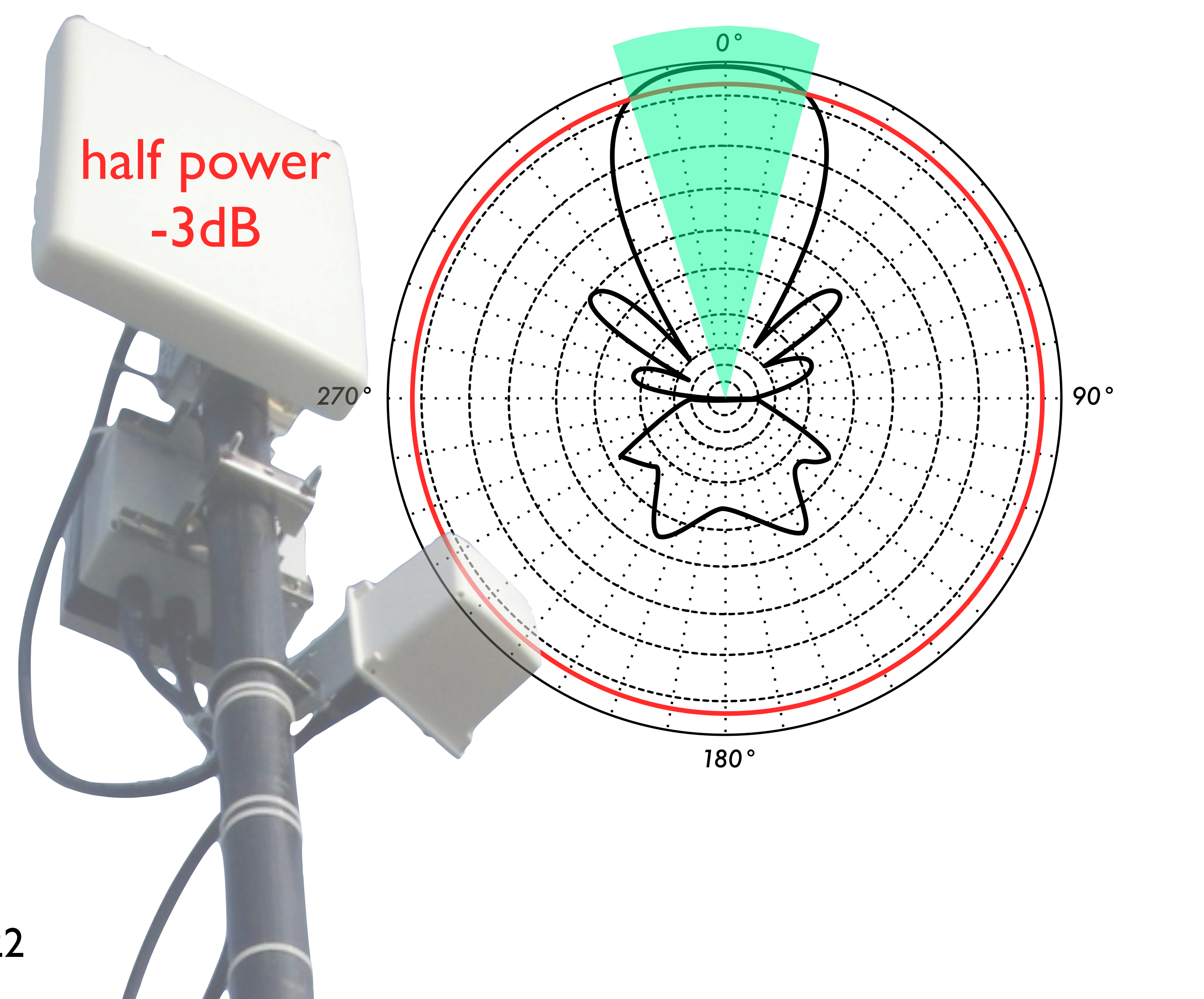




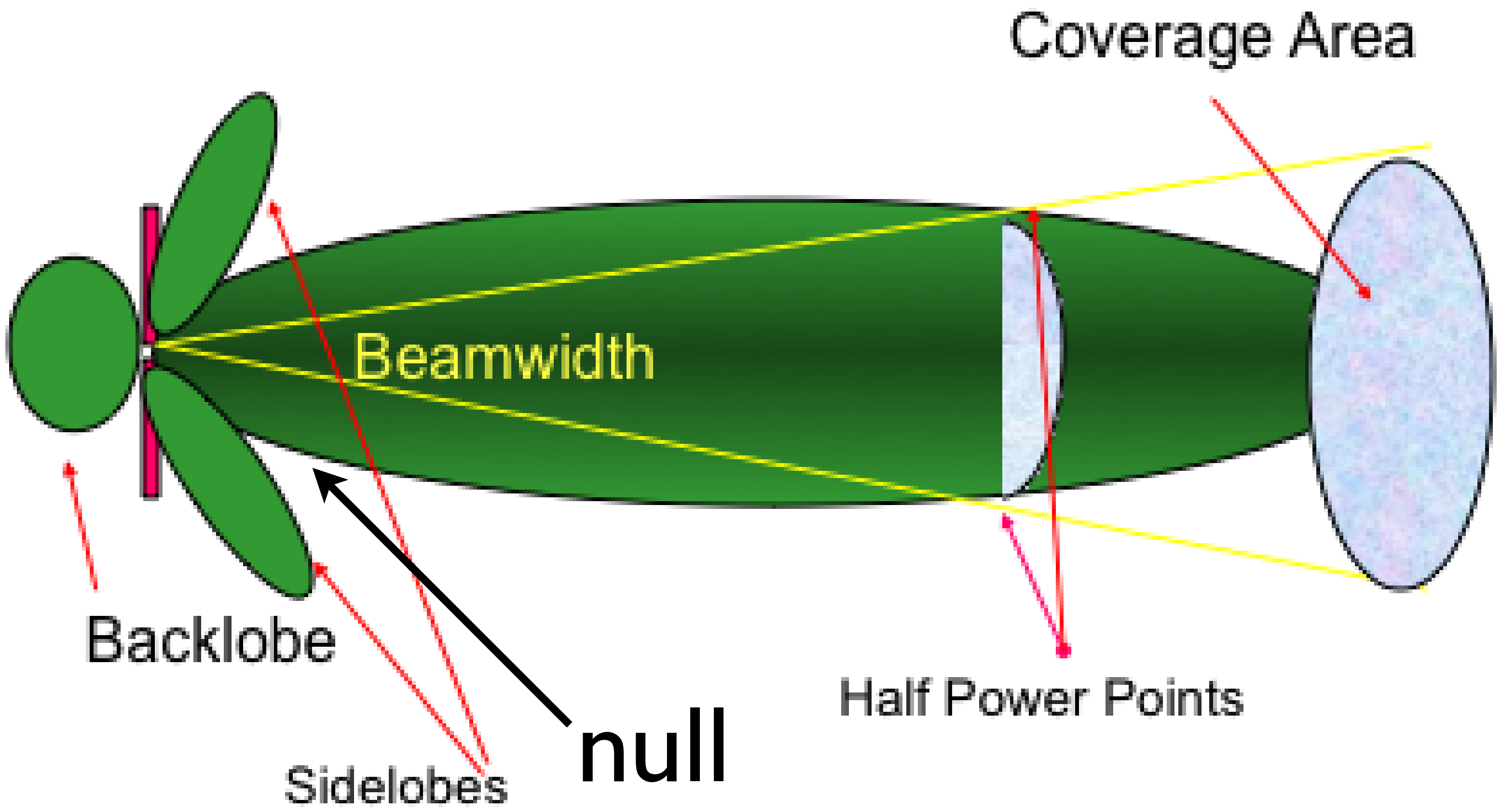
Beamwidth

- The ***beamwidth*** of an antenna is the angular measure of that part of the space where the radiated power is greater than or equal to the half of its maximum value.



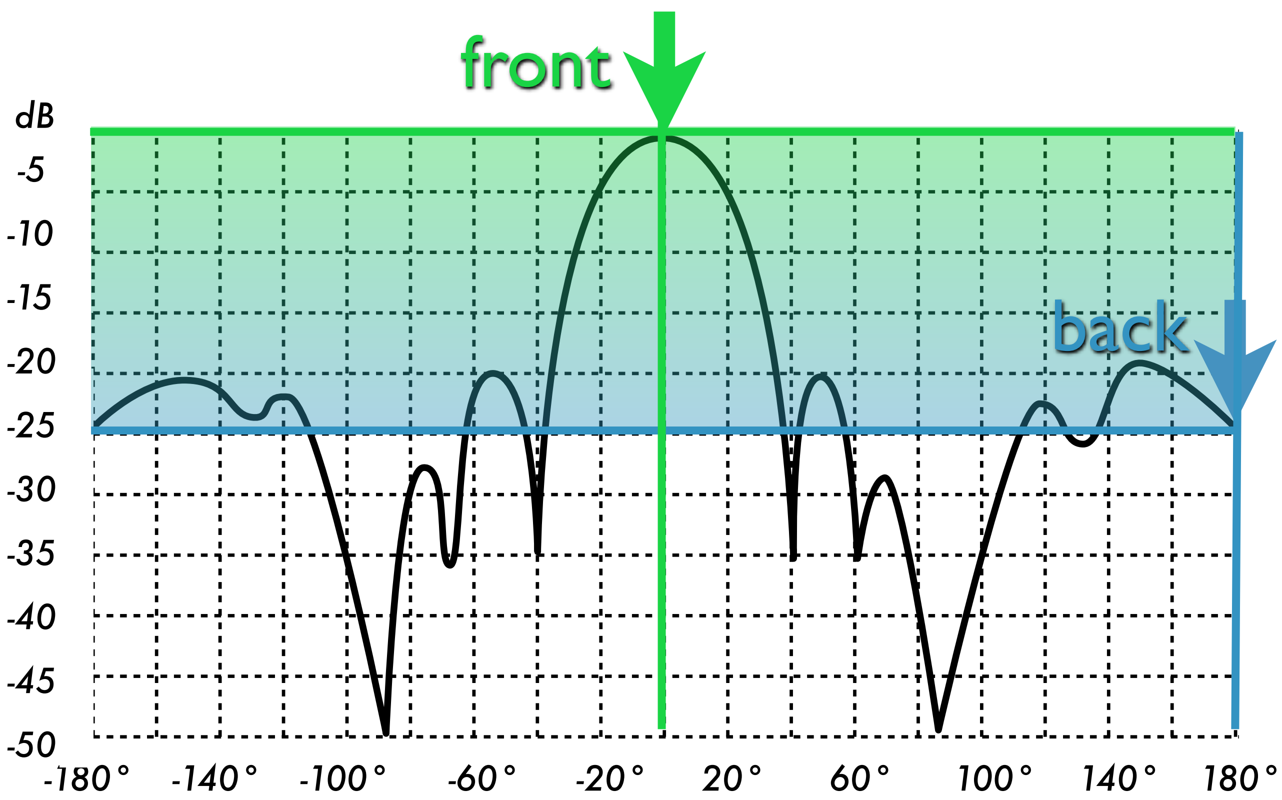


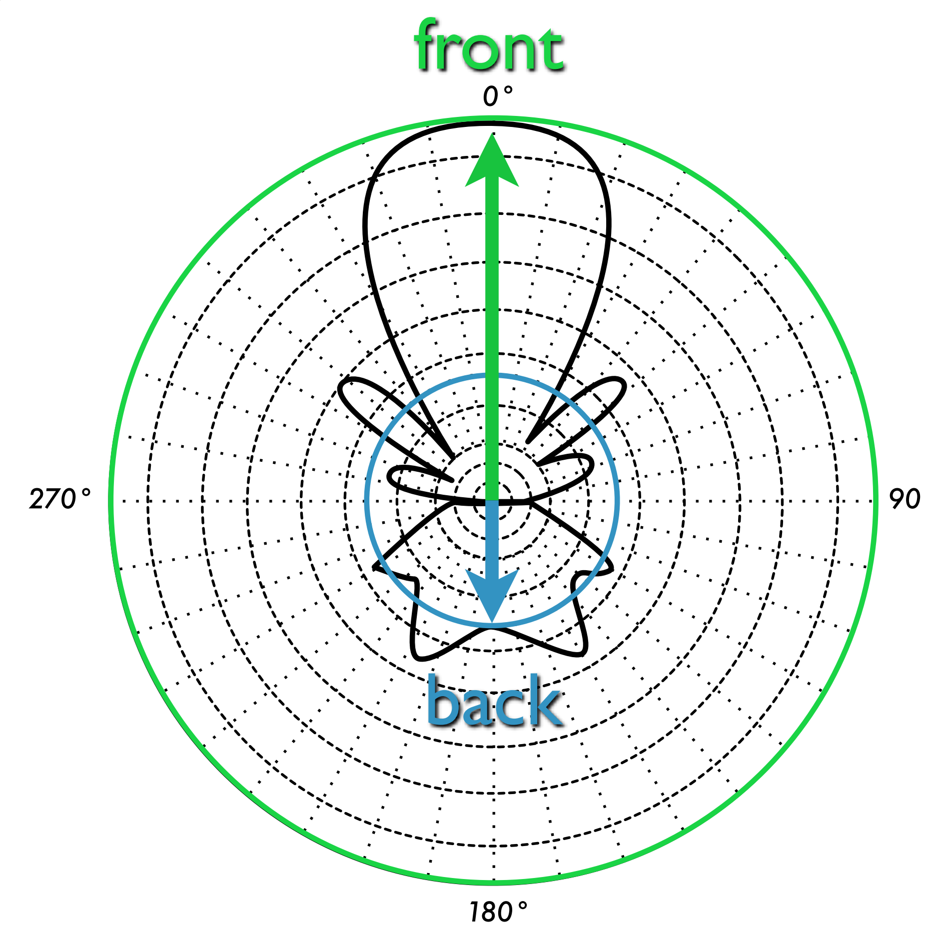
Beamwidth and coverage



Front-to-back ratio

- The ***front-to-back ratio*** of a directional antenna is the ratio of the maximum directivity of the antenna to its directivity in the opposite direction.

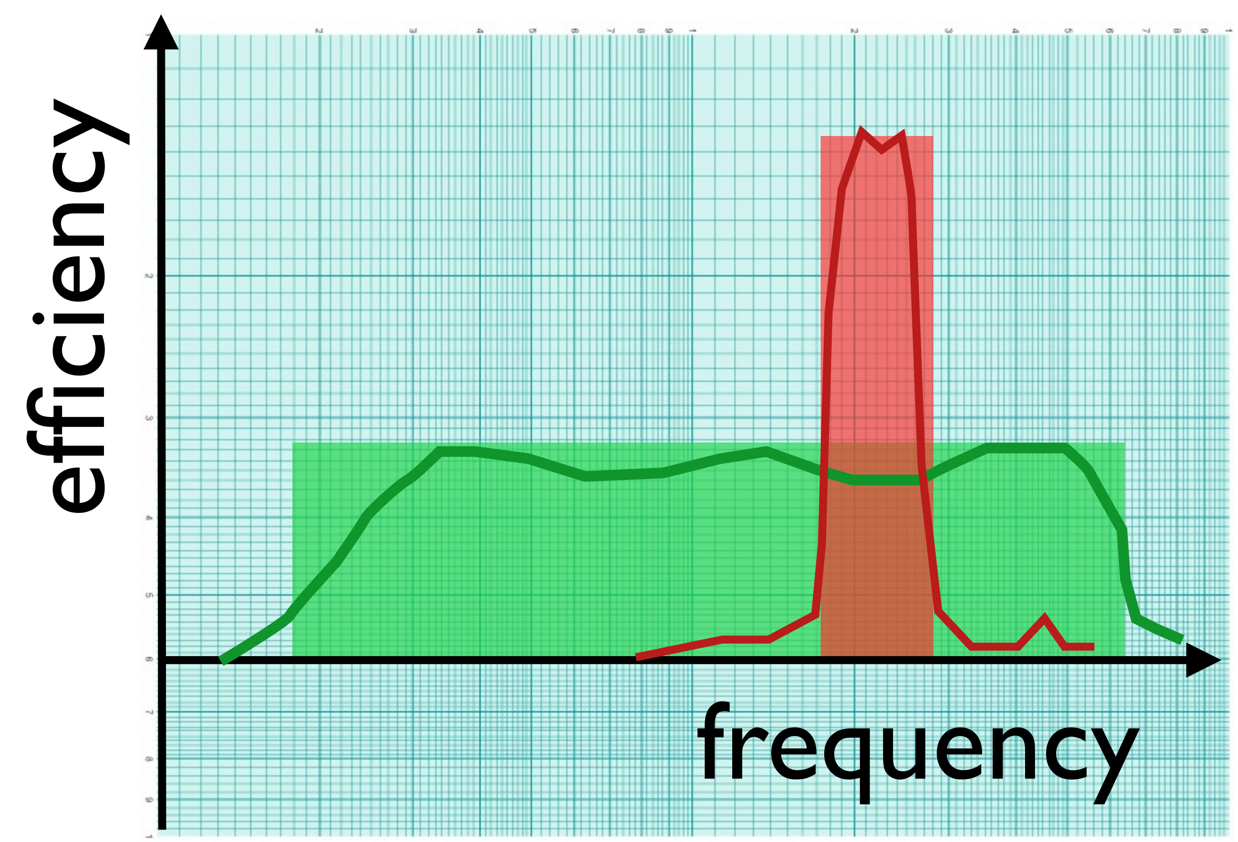




In this example the f/b ratio is: 0 dB - (-25 dB) = 25 dB

Bandwidth

- The ***bandwidth*** refers to the range of frequencies over which the antenna can operate correctly.

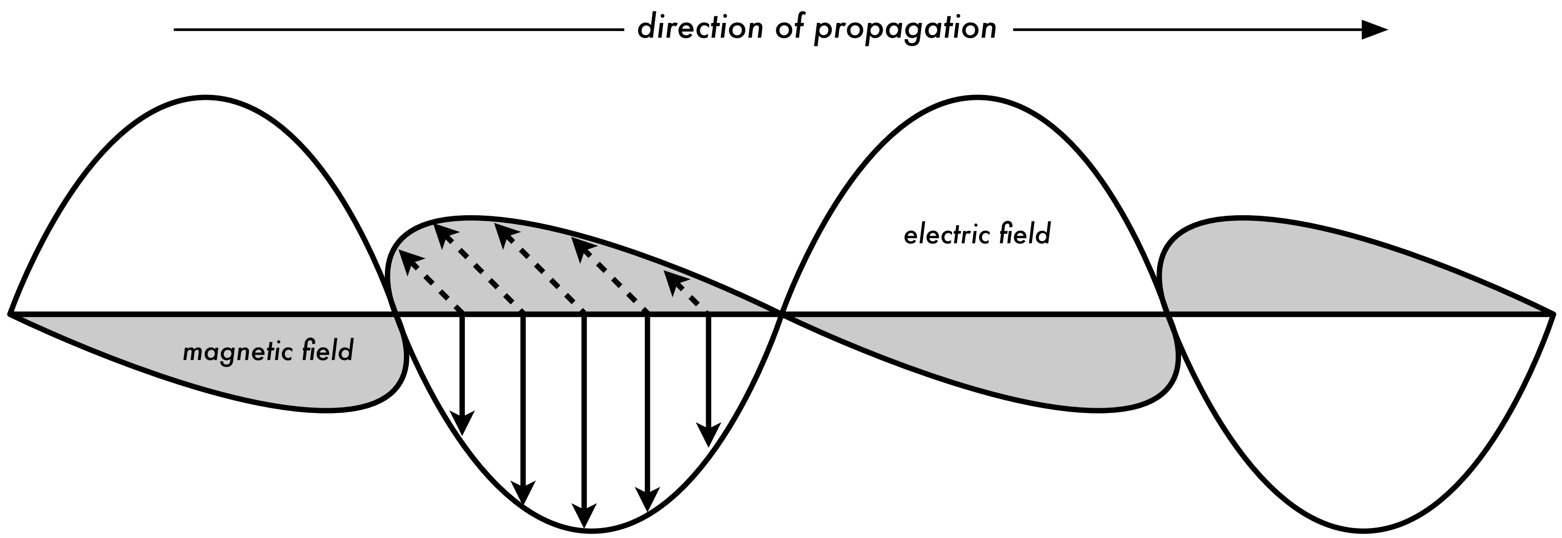


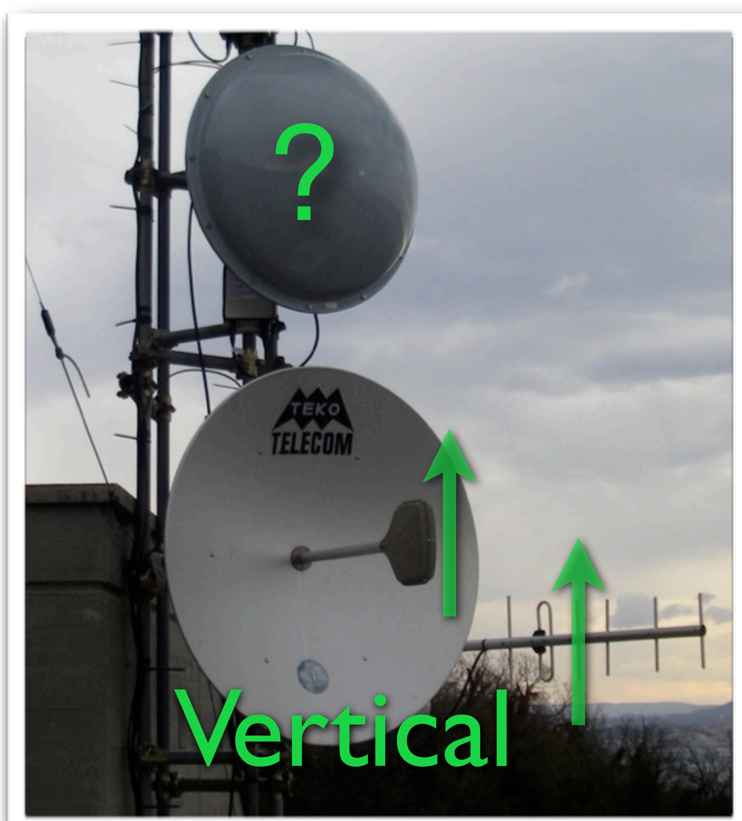
narrow band

wide band

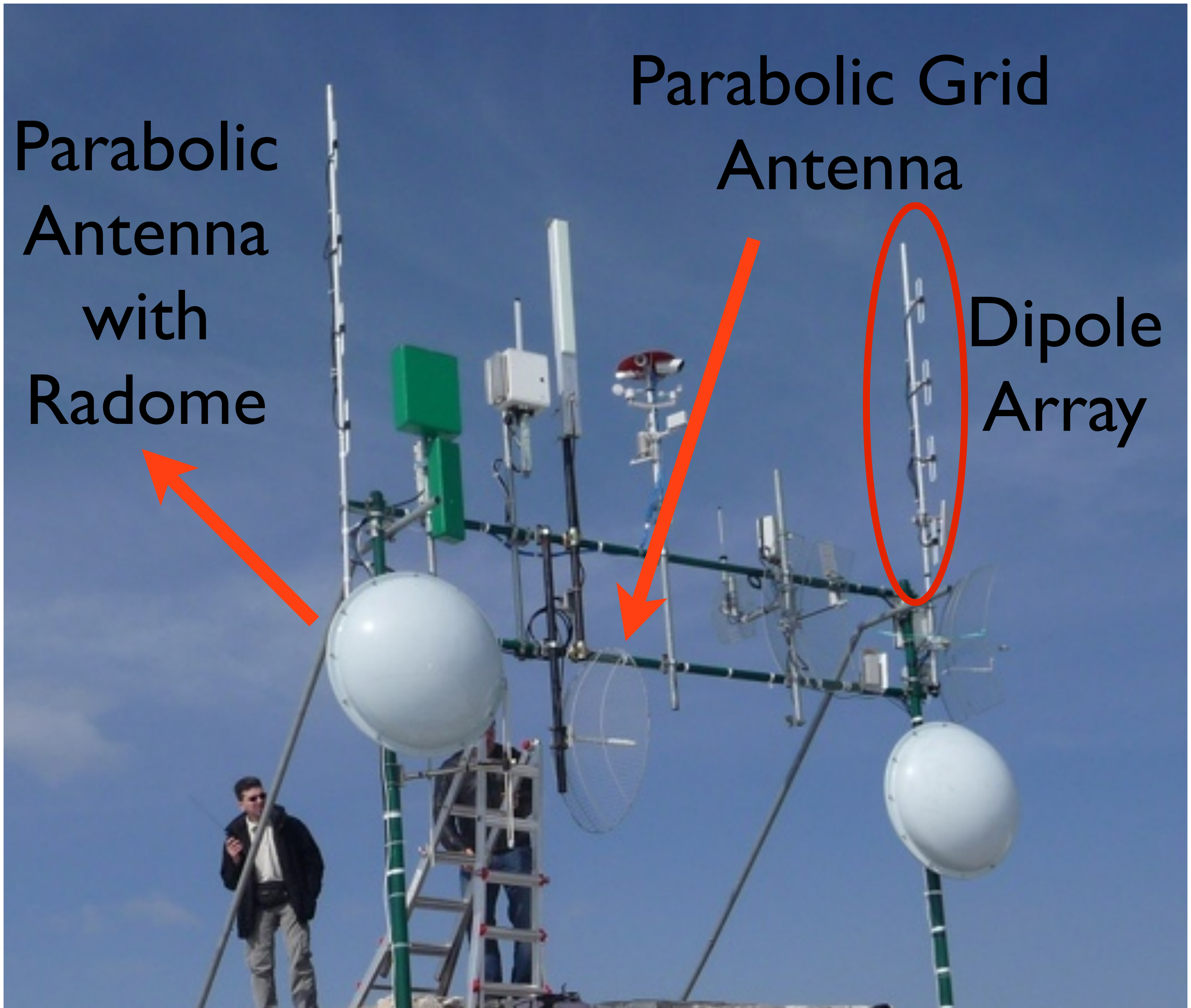
Polarization

- Antenna ***polarization*** is defined as the orientation of the electric field radiated or received by the antenna.





Wind load


Parabolic Antenna with Radome
Parabolic Grid Antenna
Dipole Array

Wind speed at different heigths

Wind Power Classes	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Average Wind Speed m/s (mph)	Wind Power Density (W/m2)	Average Wind Speed m/s (mph)
1	0-100	0-4.4 (0-9.8)	0-200	0-5.6 (0-12.5)
2	100-150	4.4-5.1 (9.8-11.5)	200-300	5.6-6.4 (12.5-14.3)
3	150-200	5.1-5.6 (11.5-12.5)	300-400	6.4-7.0 (14.3-15.7)
4	200-250	5.6-6.0 (12.5-13.4)	400-500	7.0-7.5 (15.7-16.8)
5	250-300	6.0-6.4 (13.4-14.3)	500-600	7.5-8.0 (6.8-17.9)
6	300-400	6.4-7.0 (14.3-15.7)	600-800	8.0-8.8 (17.9-19.7)
7	400-1,000	7.0-9.4 (15.7-21.1)	800-2,000	8.8-11.9 (19.7-26.6)

Antenna Aperture

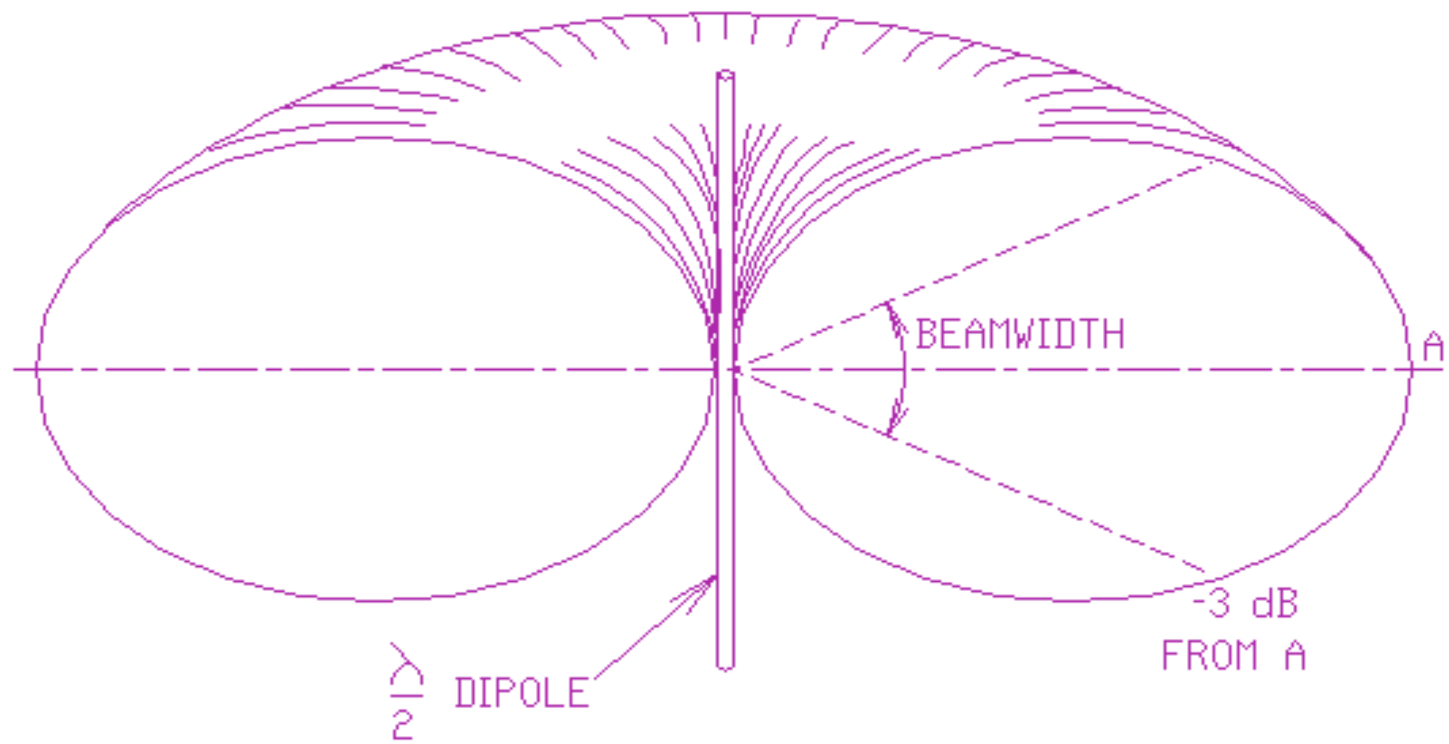
The electrical "aperture" of a receiving antenna is defined as the cross section of a parabolic antenna that would deliver the same power to a matched load. It is easy to see that a parabolic grid has an aperture very similar to a solid paraboloid.

Antenna gain is directly proportional to aperture.

Antenna types

- Omnidirectional
  - Dipole
  - Monopole
  - Collinear
- Directional
  - Point to Point
  - Sectorial

Half Wavelength Dipole

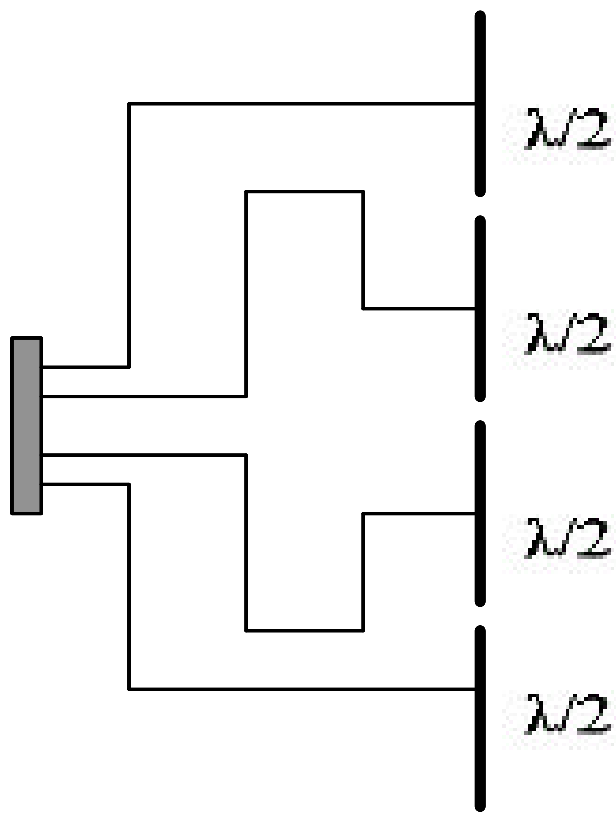


- Two 1/4 λ elements
- Very easy to build over a wide frequency range
- Omnidirectional in the plane perpendicular to the elements
- 2.15 dBi gain
- 72 ohm input impedance nearly matches the 50 ohm coax
- ~ 36 Ω impedance

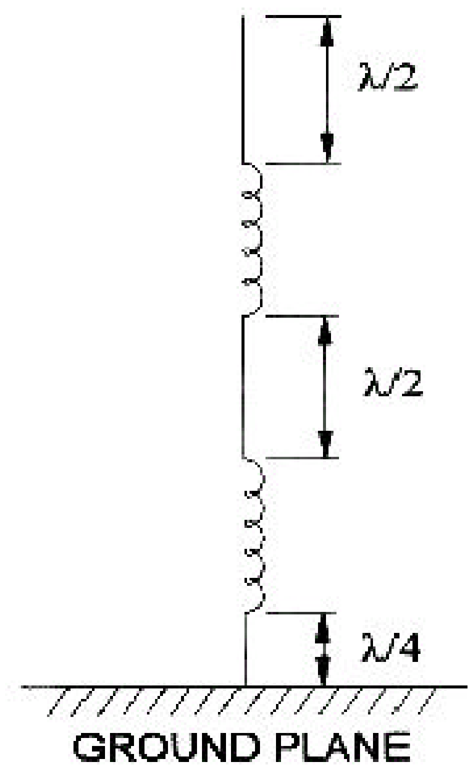
Collinear Antenna

Vertically Polarized Omnidirectional Antenna

Parallel or Corporate Feed

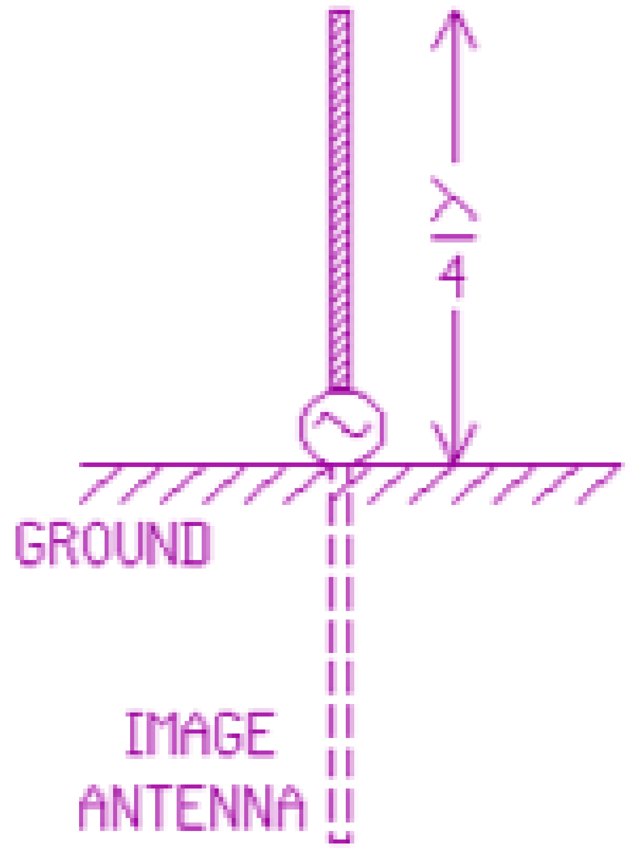


Series Feed

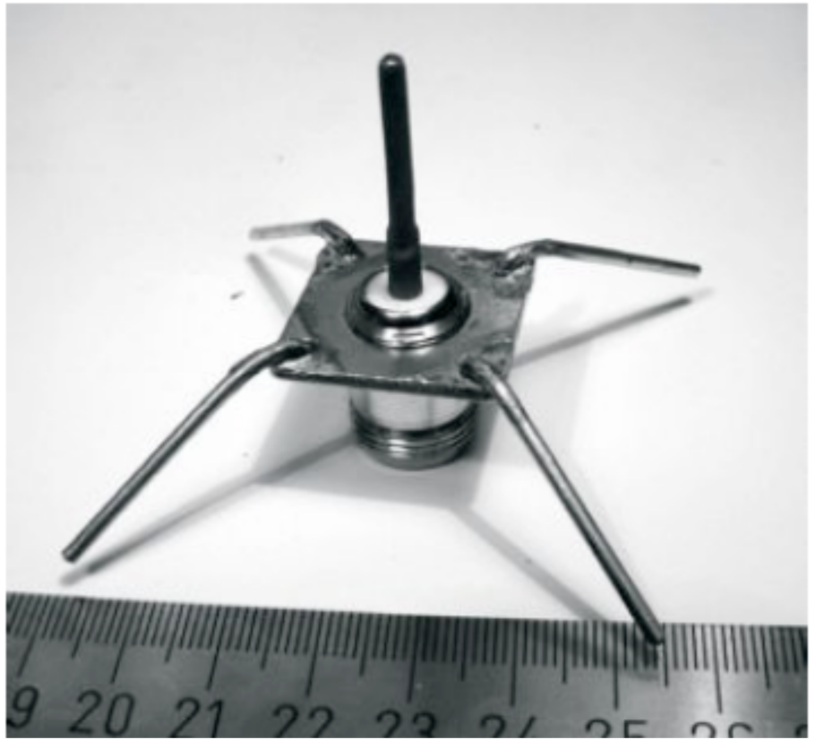


Series and Parallel Feeds

Monopole or Marconi antenna

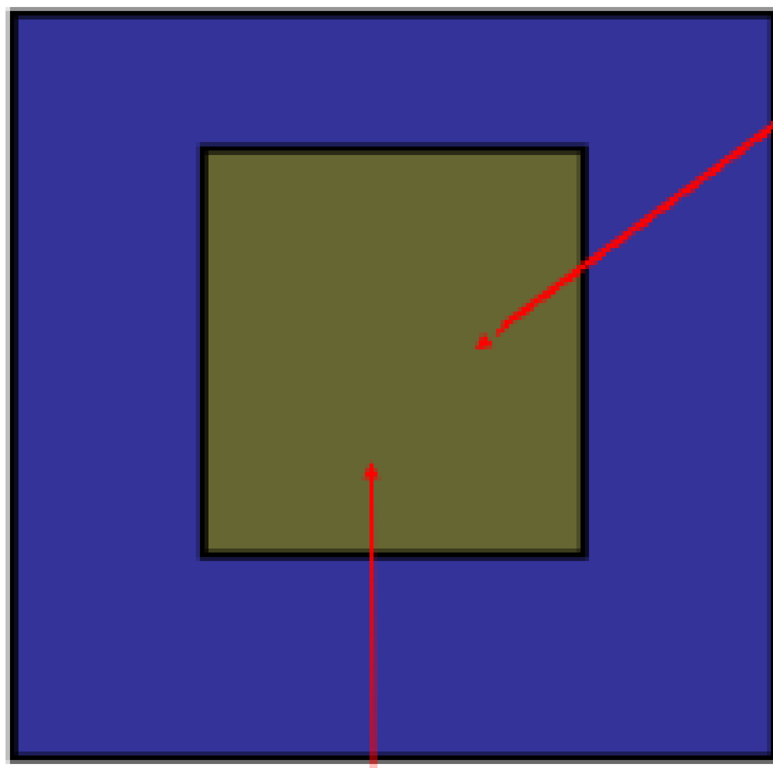


- Vertical element 1/4 λ
- A good ground plane is required
- omnidirectional in the horizontal plane
- 5.14 dBi
- ~ 36 Ω impedance

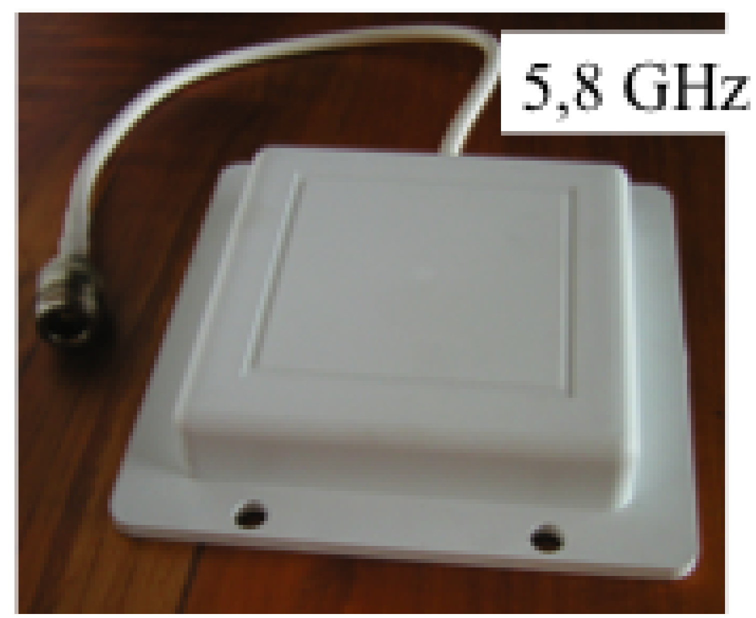


Patch antenna

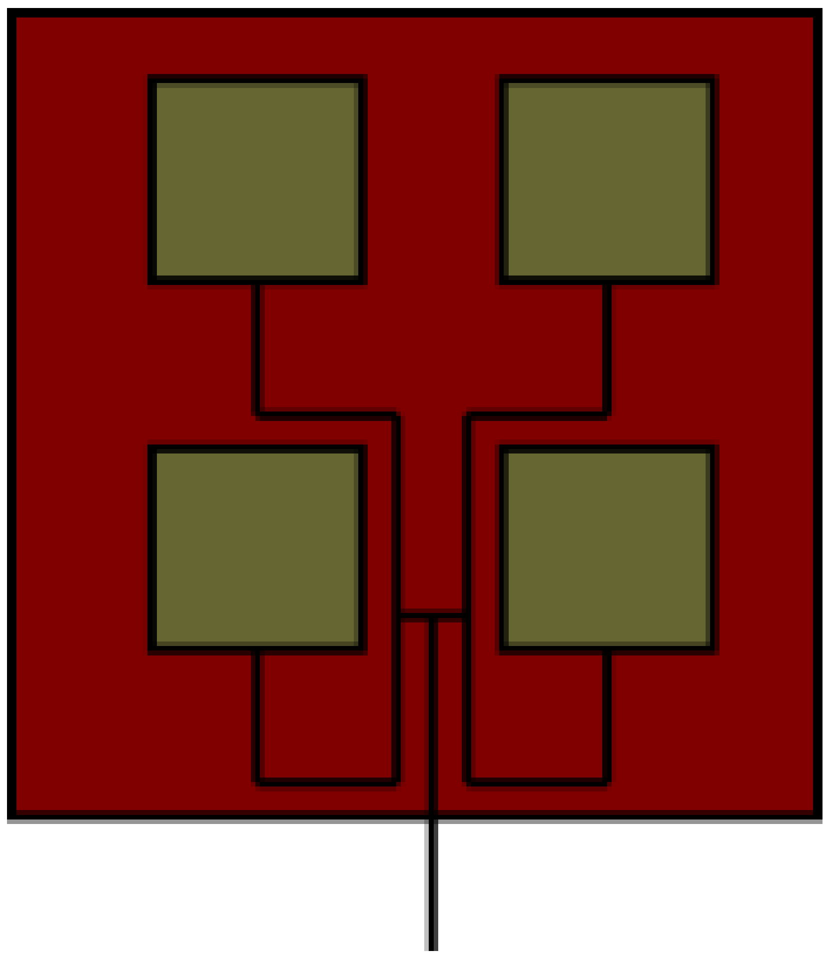
- 1/4 λ Conductor
- 6dBi



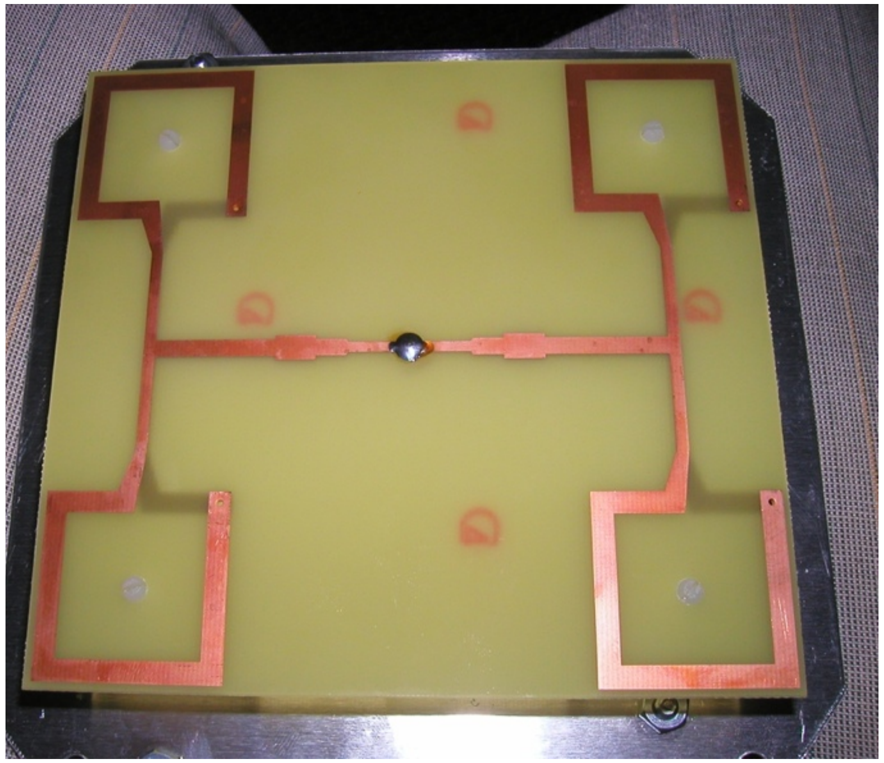
Active element
1/4 λ X 1/4 λ



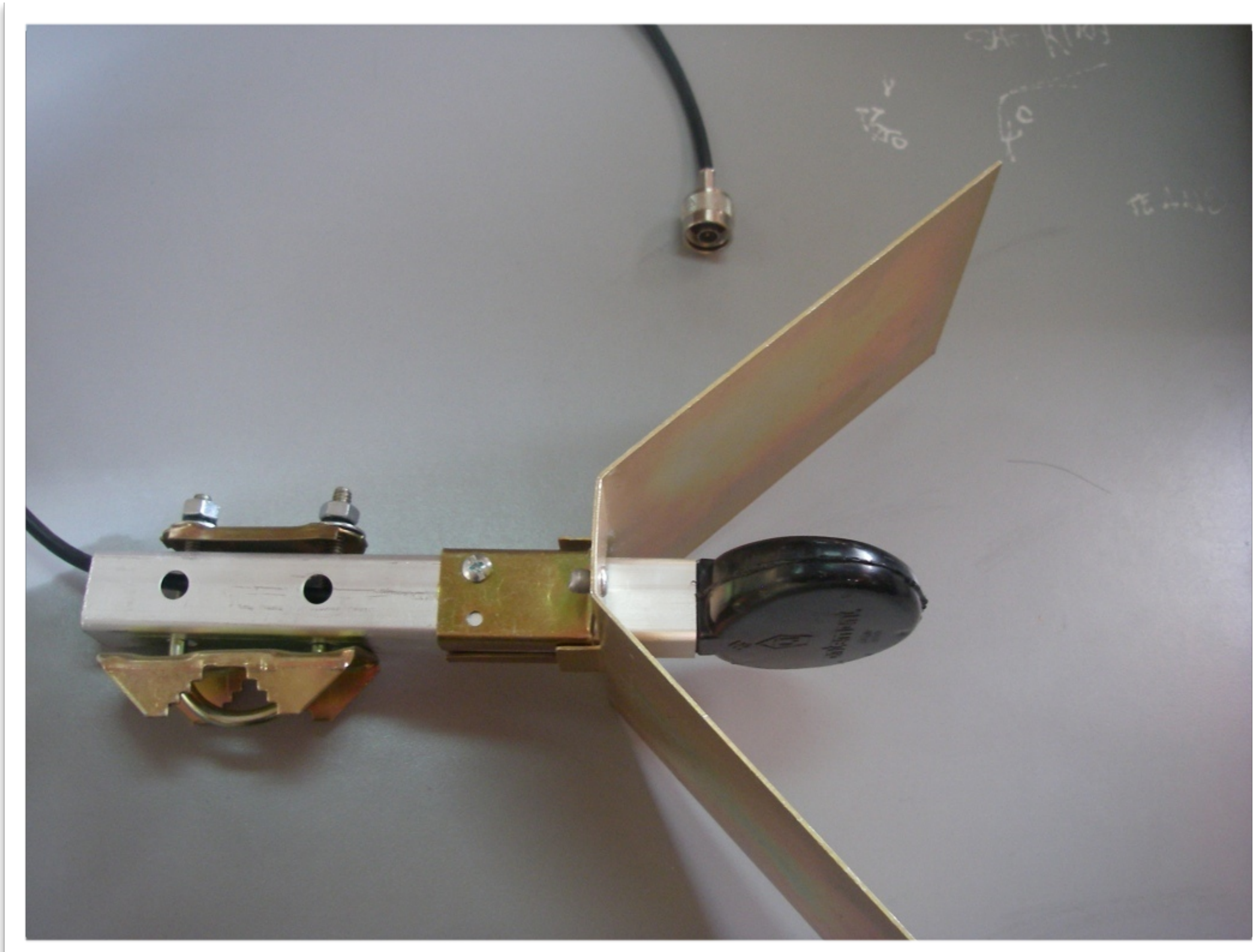
Multi-element patch antenna



- 4 elements
  - 12 dBi
- 12 elements
  - 17 dB



A 5 GHz corner (trough) reflector

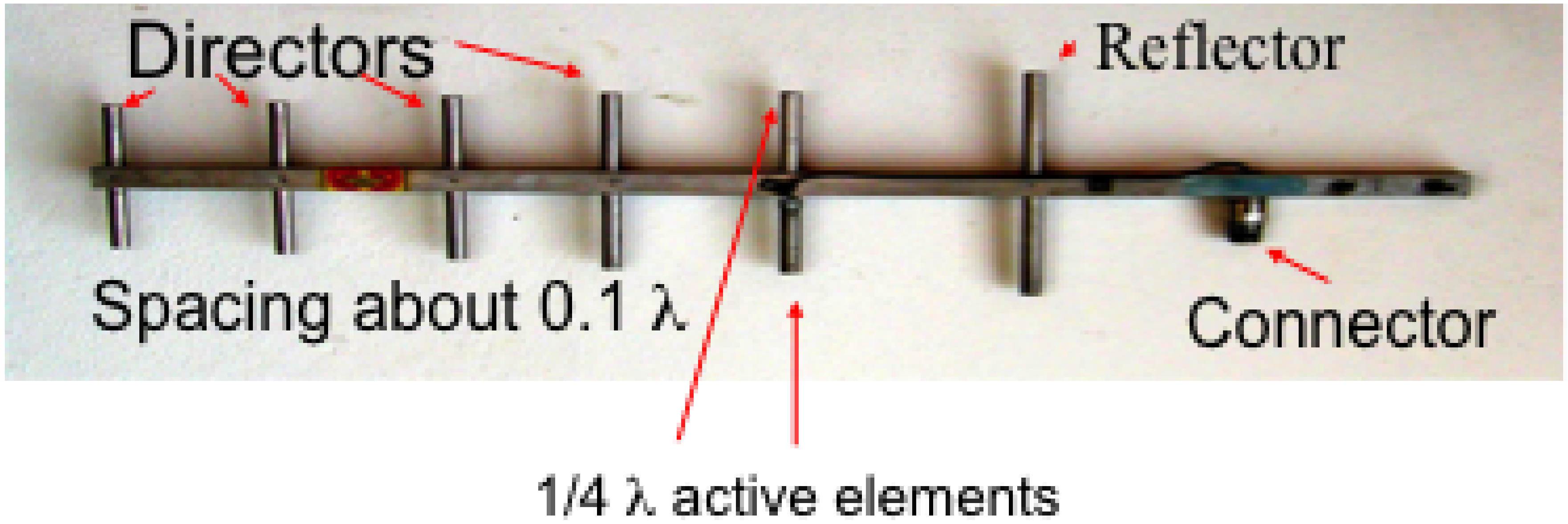


Antenna types

parabolic reflector

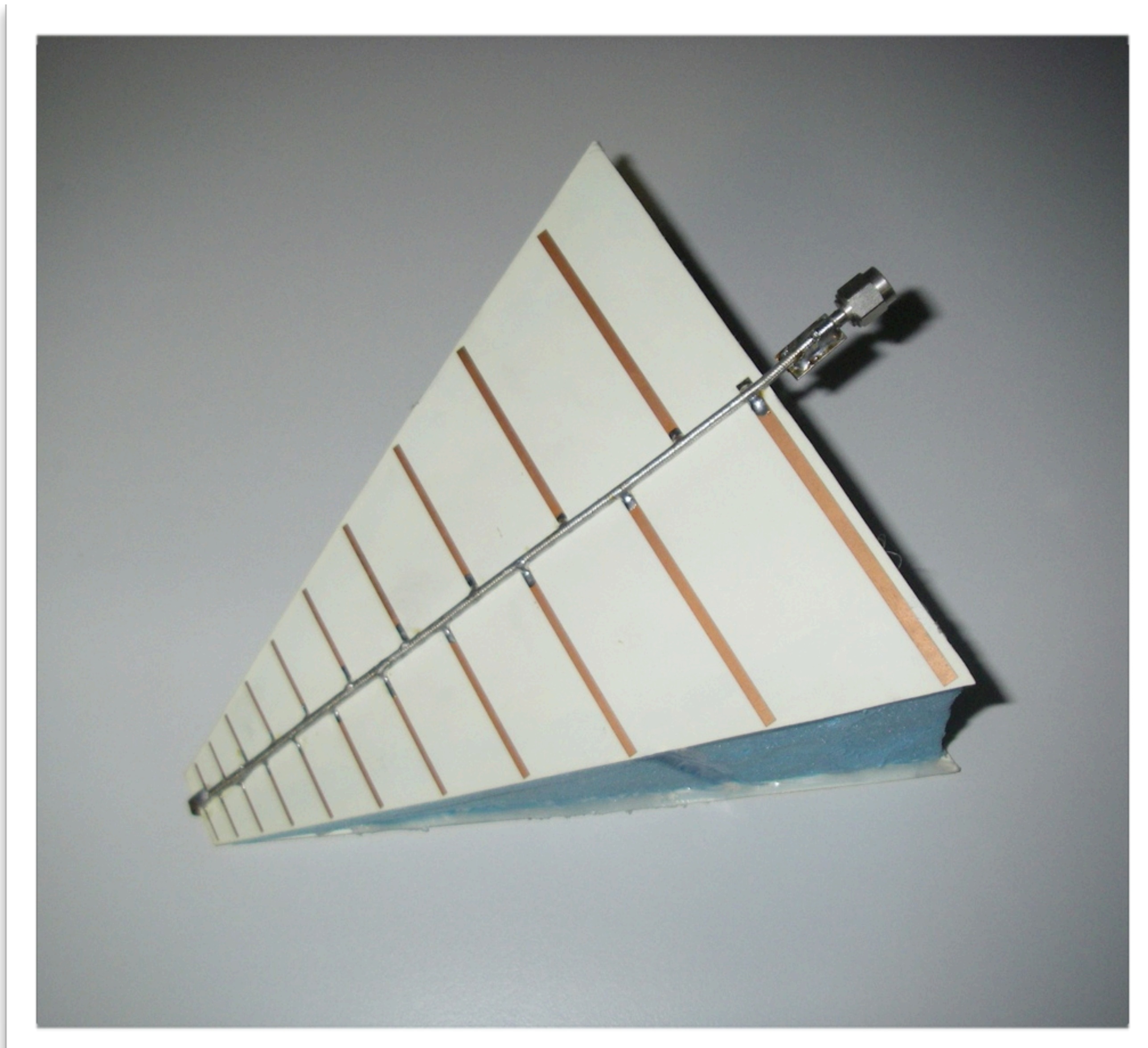
panel antennas

Yagi-Uda antenna



- 1 director = 8dBi
- 15 directors = 14 dBi
- Often inclosed in a “*Radome*” that provides protection

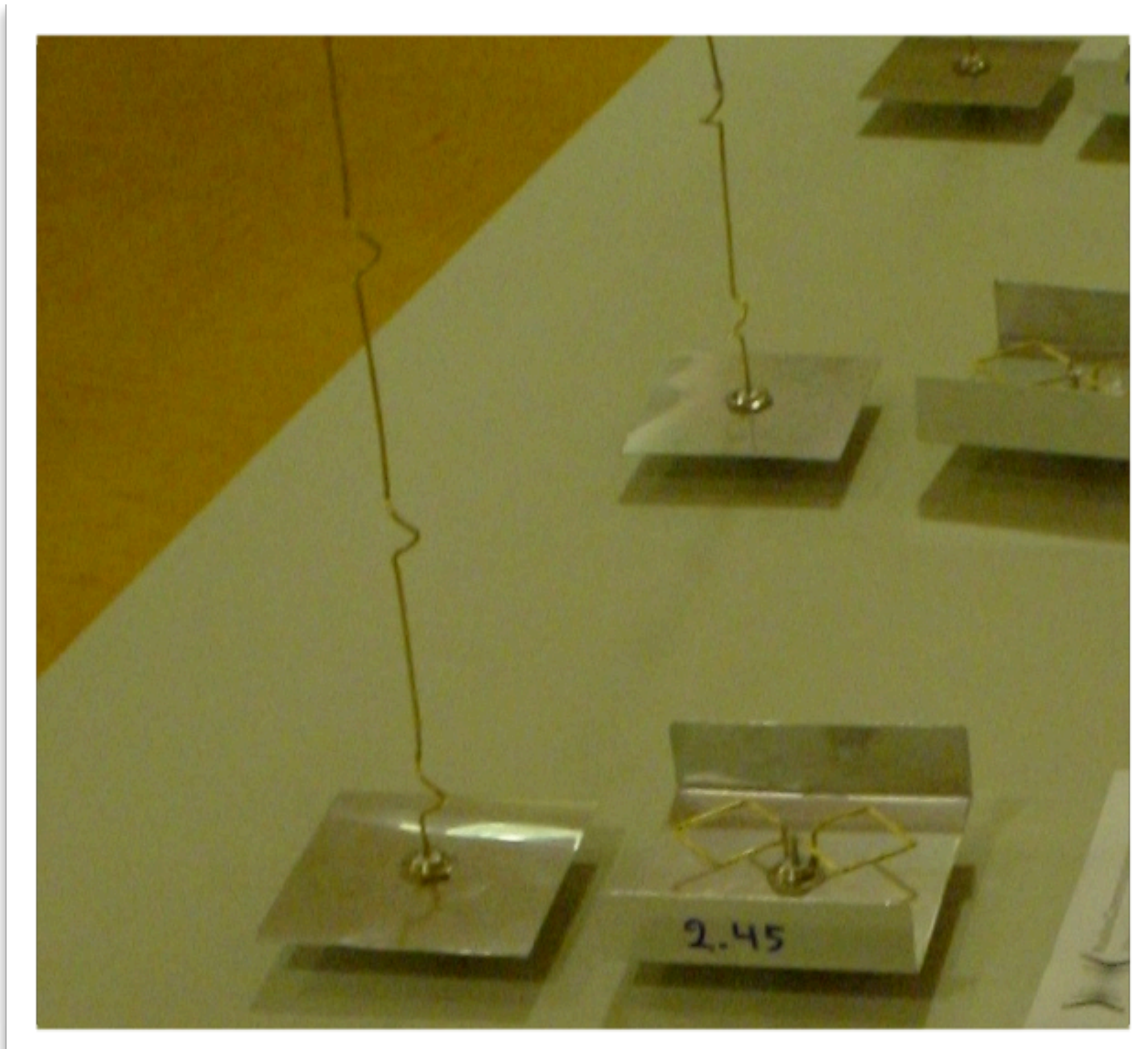
Antenna types



log-periodic antenna

panel (patch) antenna

Antenna types



collinear and biquad antenna

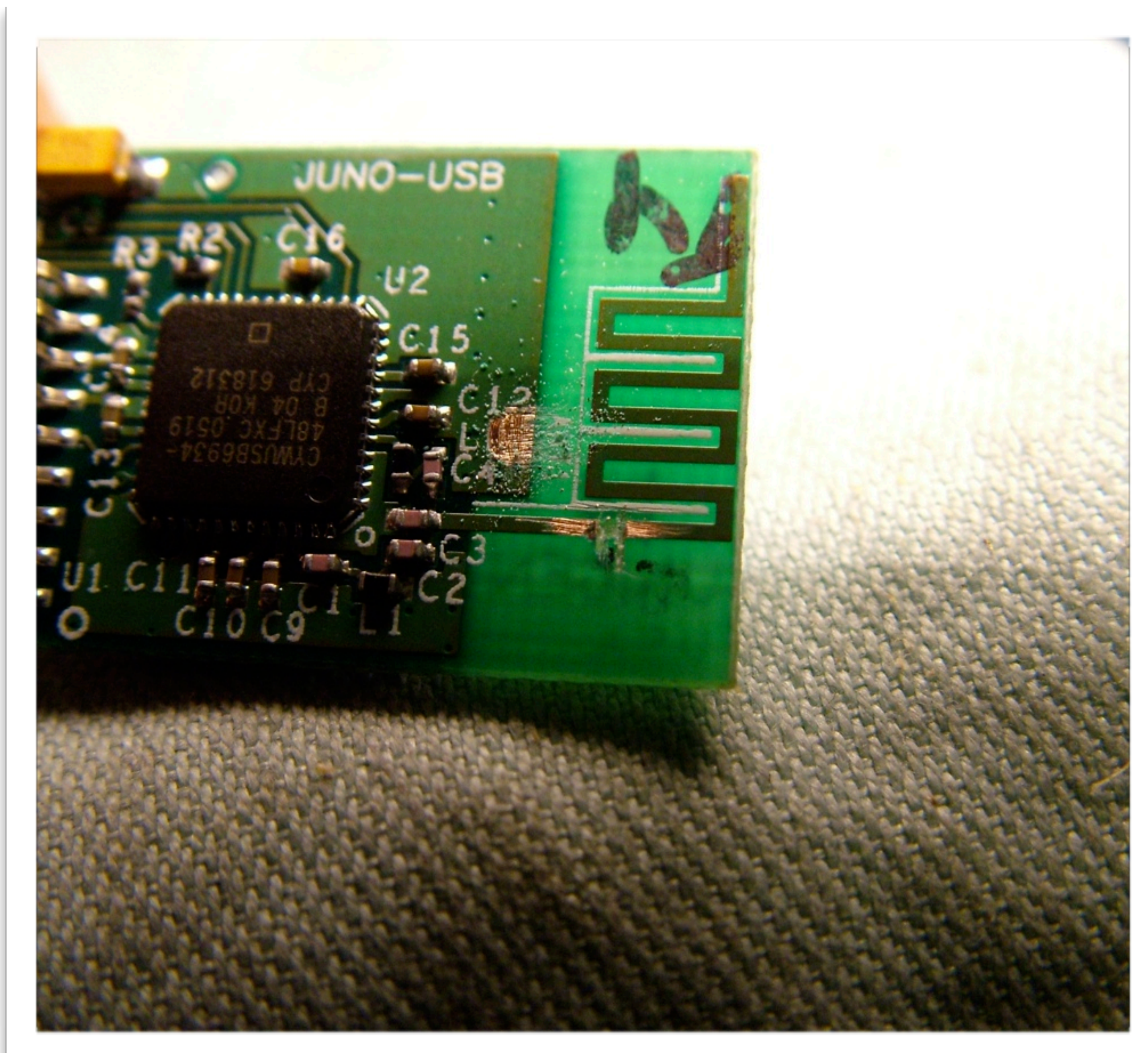
offset parabolic dish

Antenna types

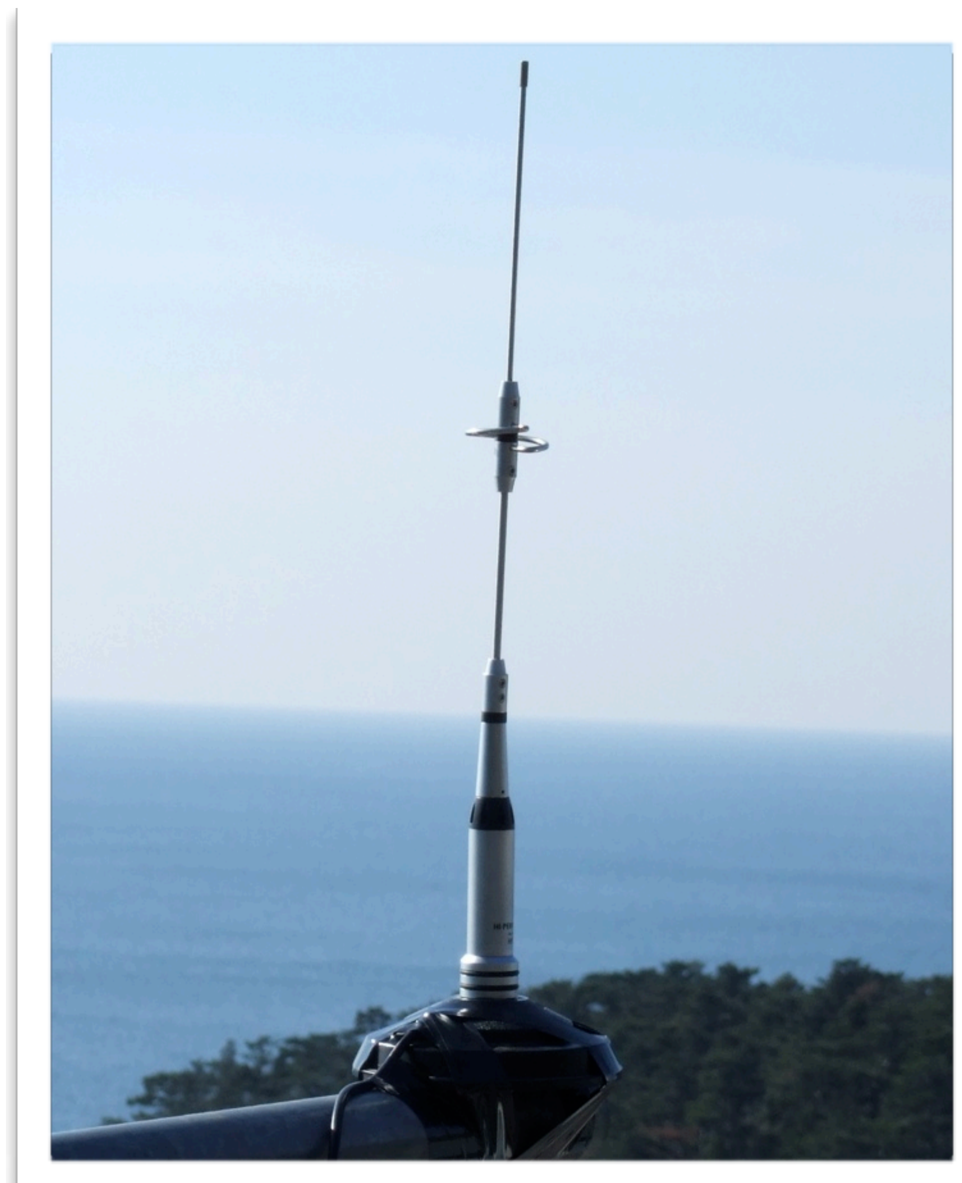
parabolic grid

parabolic grid
(covered by snow)

Antenna types



printed circuit (stripline) antenna



omni (collinear) antenna

Do-it-yourself reflector

- Make your own reflector using an aluminum sheet, cardboard or thick paper, scissors and glue.

Antenna types

offset parabolic dish (big)

center-fed parabolic dish (big)

Parabolic reflectors

- Parabolic dish/grid shape. Corner reflectors also work well.
- Gain =~ $(D / \lambda)^2$
- Beamwidth =~ λ / D
- It must have the right feed, positioned at the focal point of the reflector
- Off-center feeds (e.g. for satellite TV) are difficult to align

Dish illumination

- The illumination of the dish is crucial to performance
- You should illuminated the reflecting surface of the dish as much as possible while avoiding spillover
- The position of the feed with respect to the reflector is also critical.

Do-it-yourself cantenna

- Cheap and effective antennas can be made from food cans.

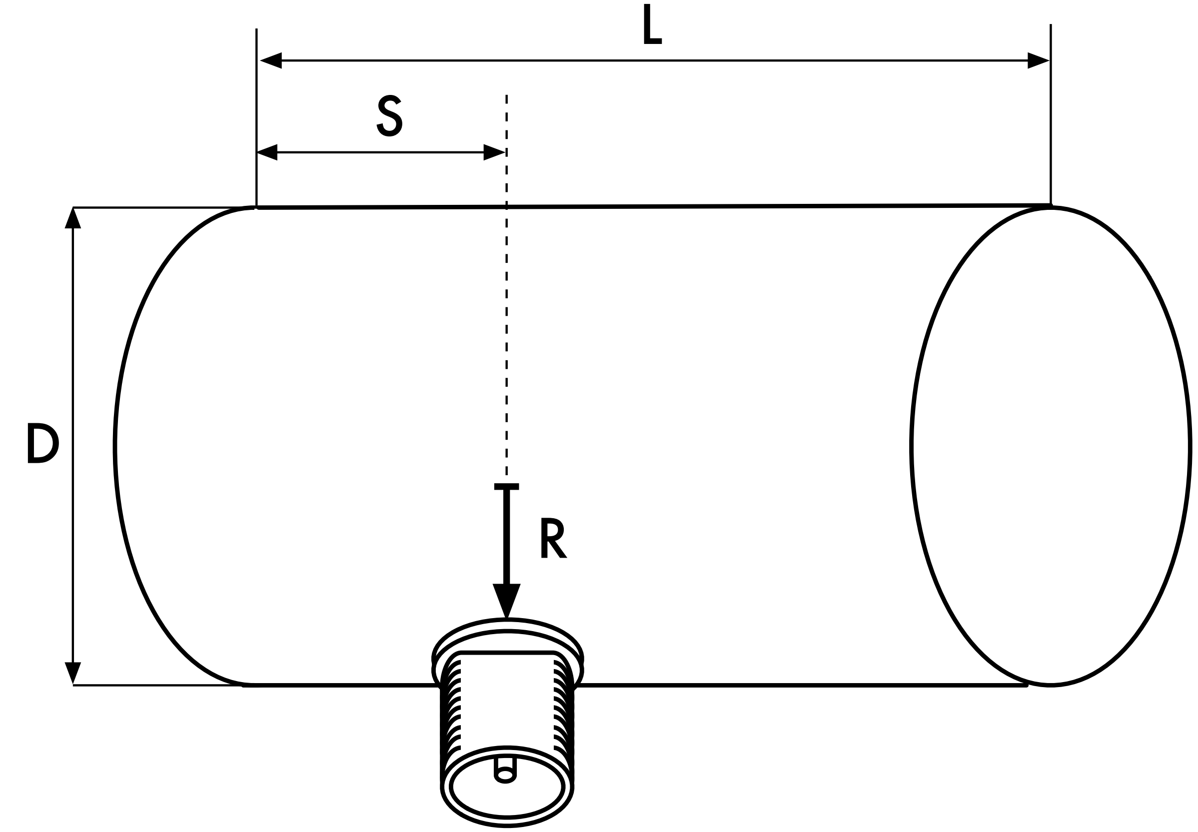
Do-it-yourself cantenna

A number of different sized cans will work as 2.4 GHz antennas.

- The can's diameter (D) should be 8 to 12 cm.
- The can's length (L) should be at least 20 cm.
- The distance from the back of the can to the center of the connector (S) is given by:

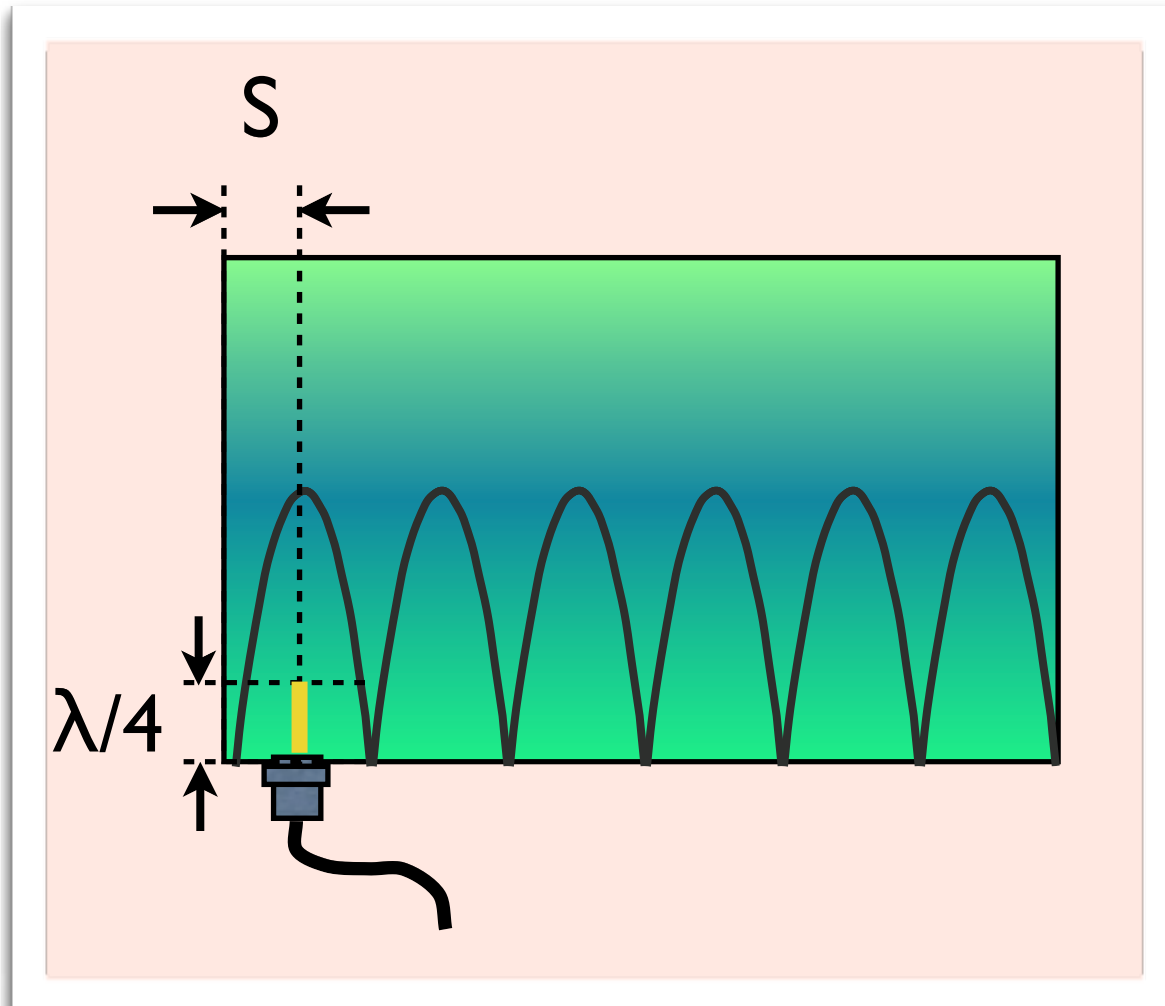
$$S = \frac{\lambda / 4}{\mathrm{sqrt}(1 - (\lambda / 1.706D)^2)}$$

- The length of the probe at the center of the connector (R) should be $\lambda / 4$

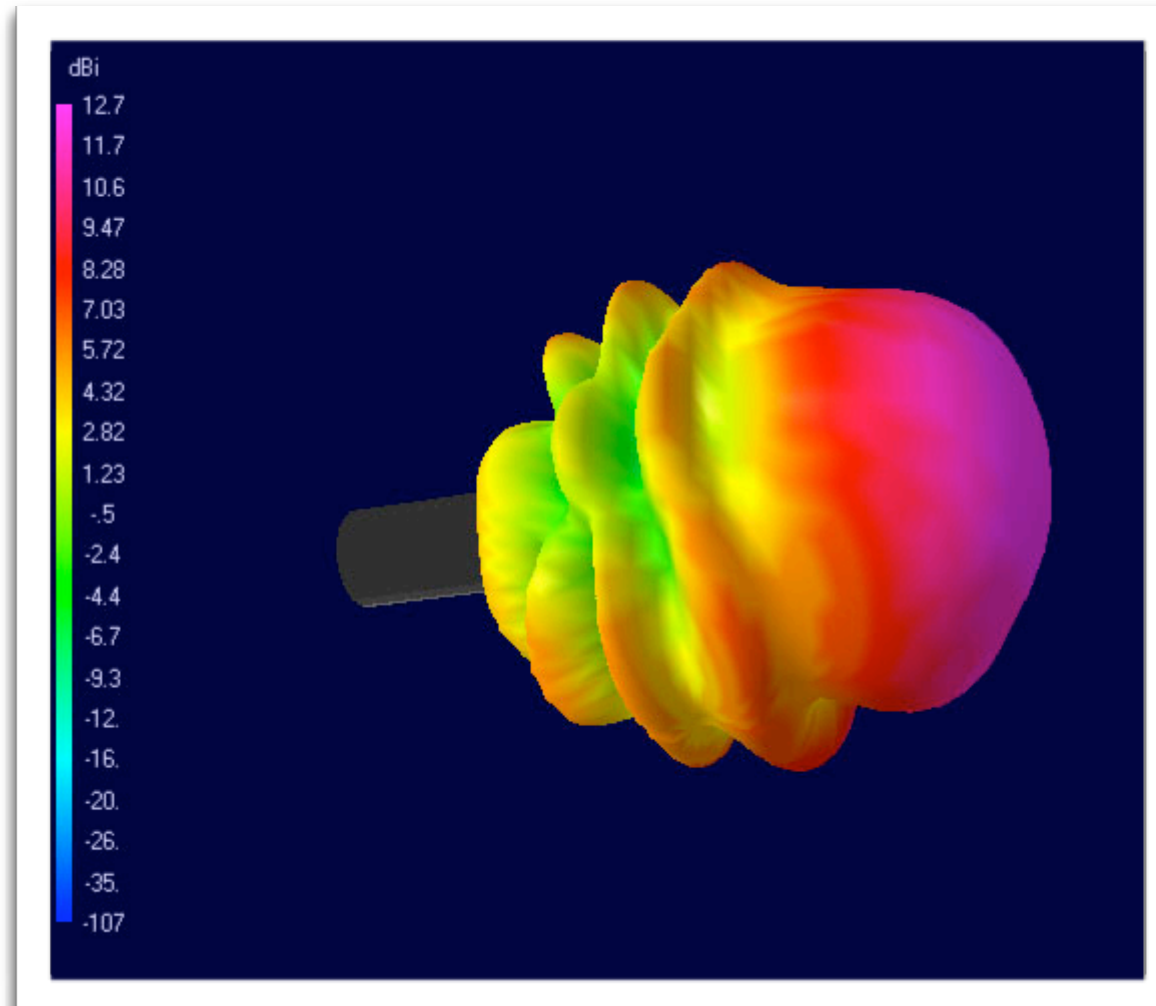


This will make a directional antenna of about 10 to 14 dBi with about a 60 degree beamwidth.

Cantenna and its radiation pattern



at 2.4GHz, λ/4 = 31mm
while S is a function of λ
and D (diameter of the can)



tridimensional radiation pattern
obtained with the NEC antenna
simulator software

Antenna Measurements

Conclusions

- Antennas are the interface between guided and unguided waves.
- Antenna come in all shapes and sizes.
- The size of the antenna must be at least of the order of magnitude of the wavelength it handles.
- Antenna impedance must match the transmission line.
- There is no “best antenna” for every network.
- Use high gain antennas to reach long distances, and omni or sectorial antennas to cover wide areas.

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as free download in many languages at:

http://wndw.net