Antennas and Transmission Lines

Training materials for wireless trainers

The Abdus Salam
International Centre
for Theoretical Physics

Goals

- To understand the various properties of antennas, so as to be able to choose the proper antenna for a particular application.
- Antennas are the interface between guided waves (from a cable) and unguided waves (in space).
- Realize that not all kinds of cable are appropriate for use with wireless systems.
- Identify different kinds of cable connectors and understand when each kind is needed.

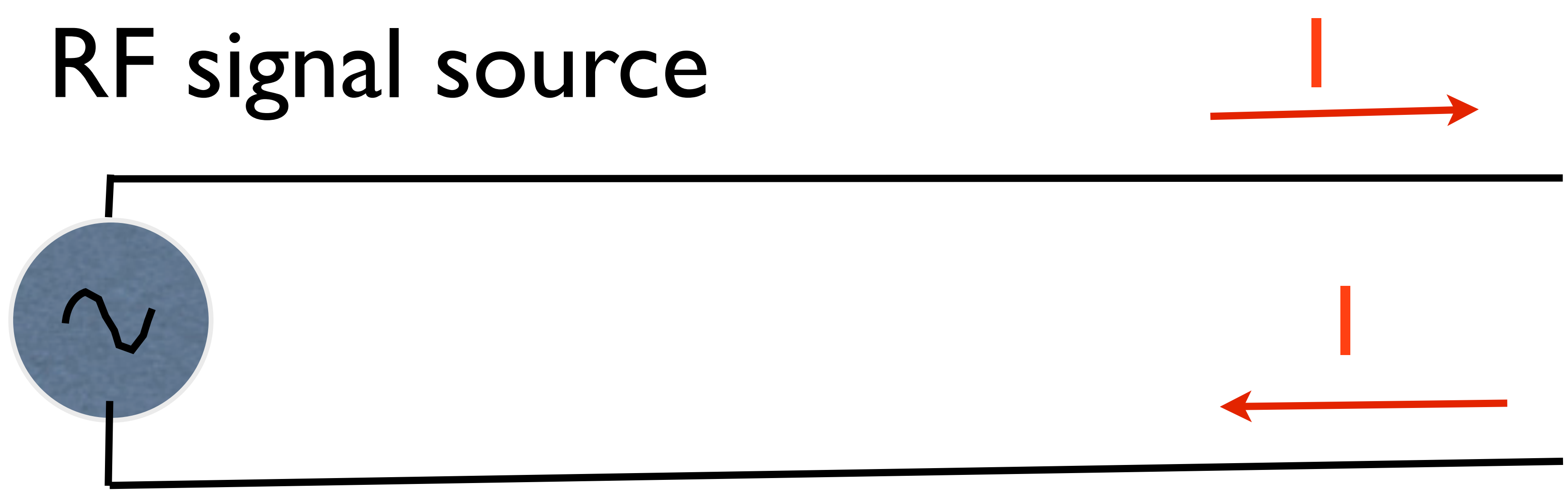
Transmission lines & antennas

- A ***transmission line*** is the device used to guide radio frequency (RF) energy from one point to another (for example a coaxial cable).

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

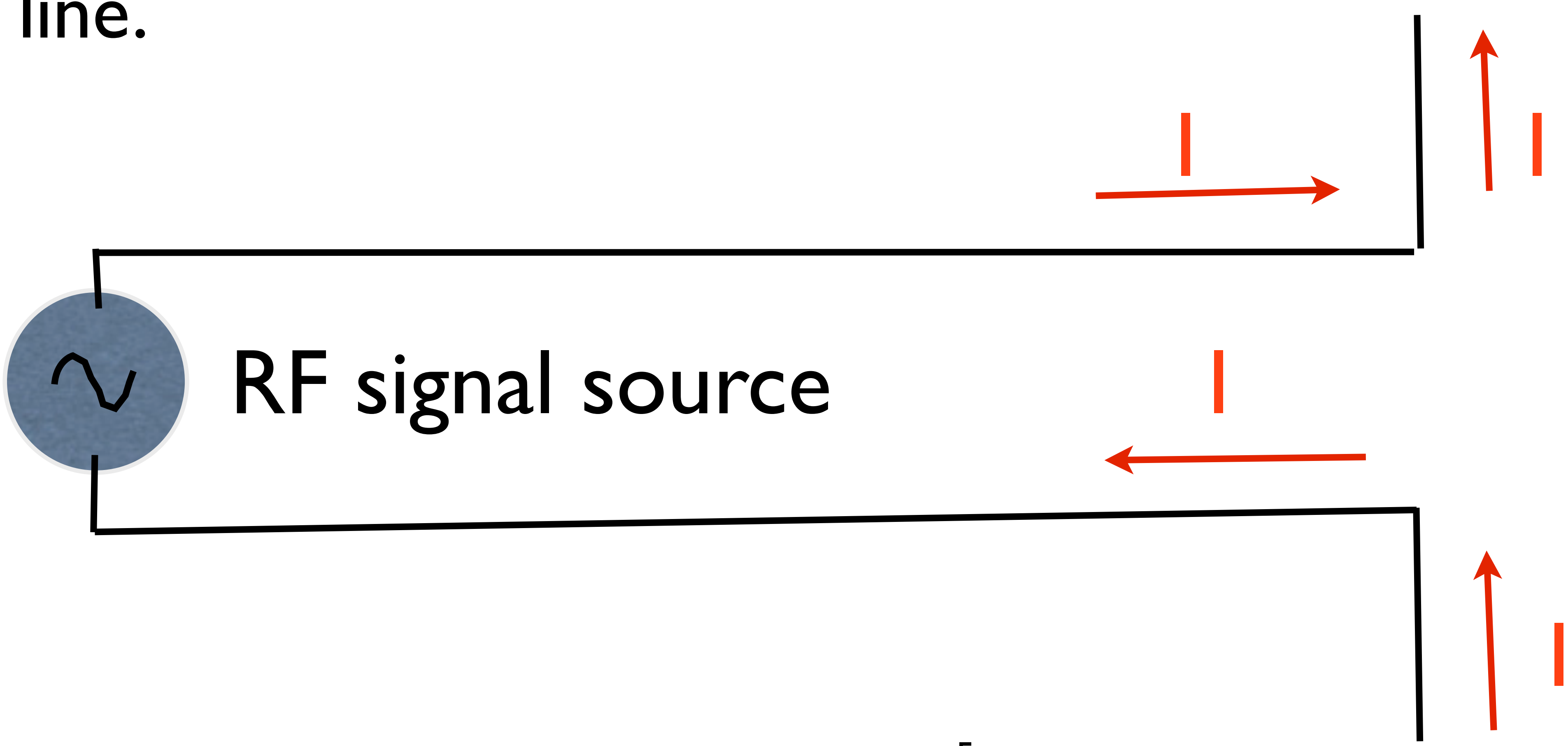
Bifilar transmission lines

- ***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.

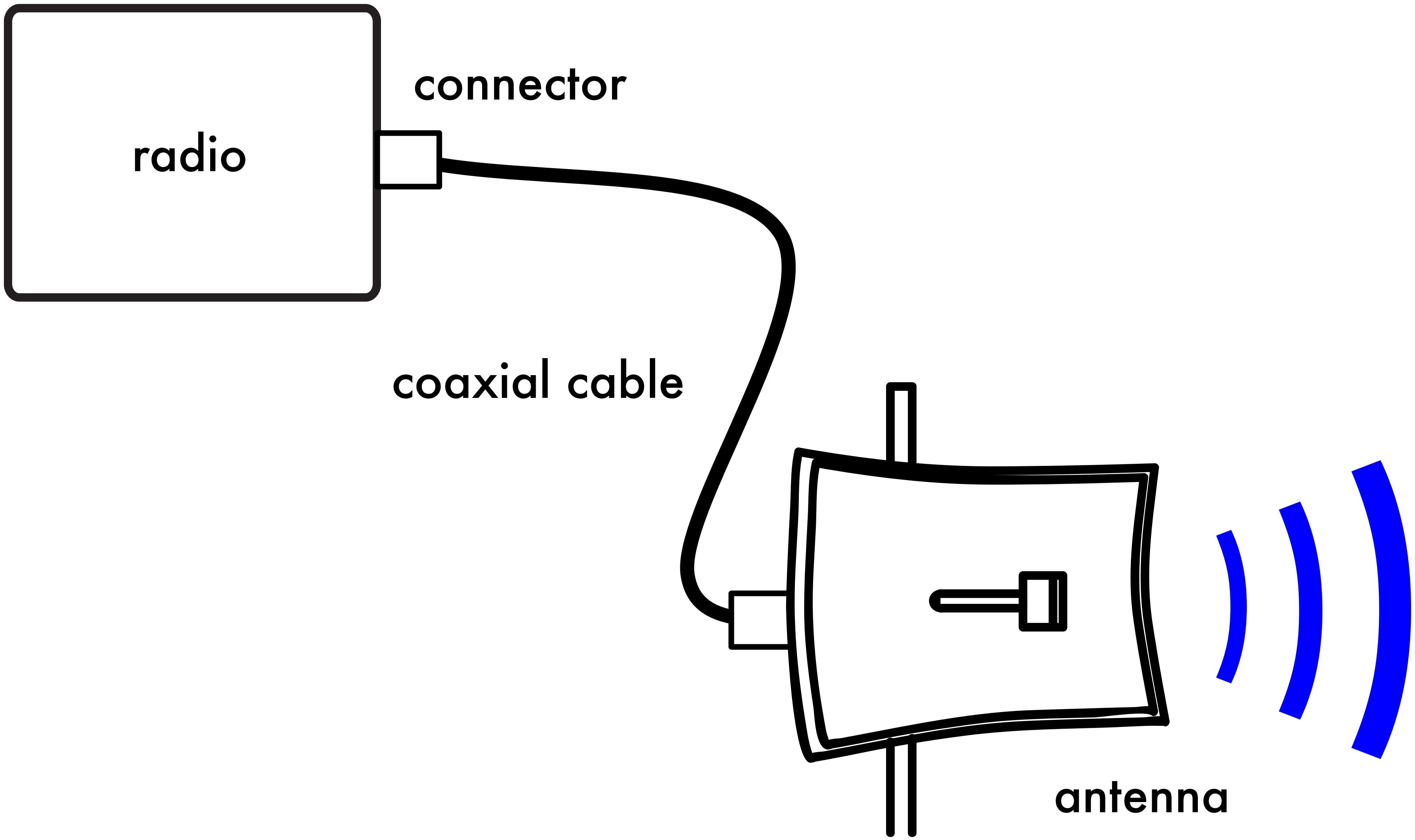


Bifilar transmission lines

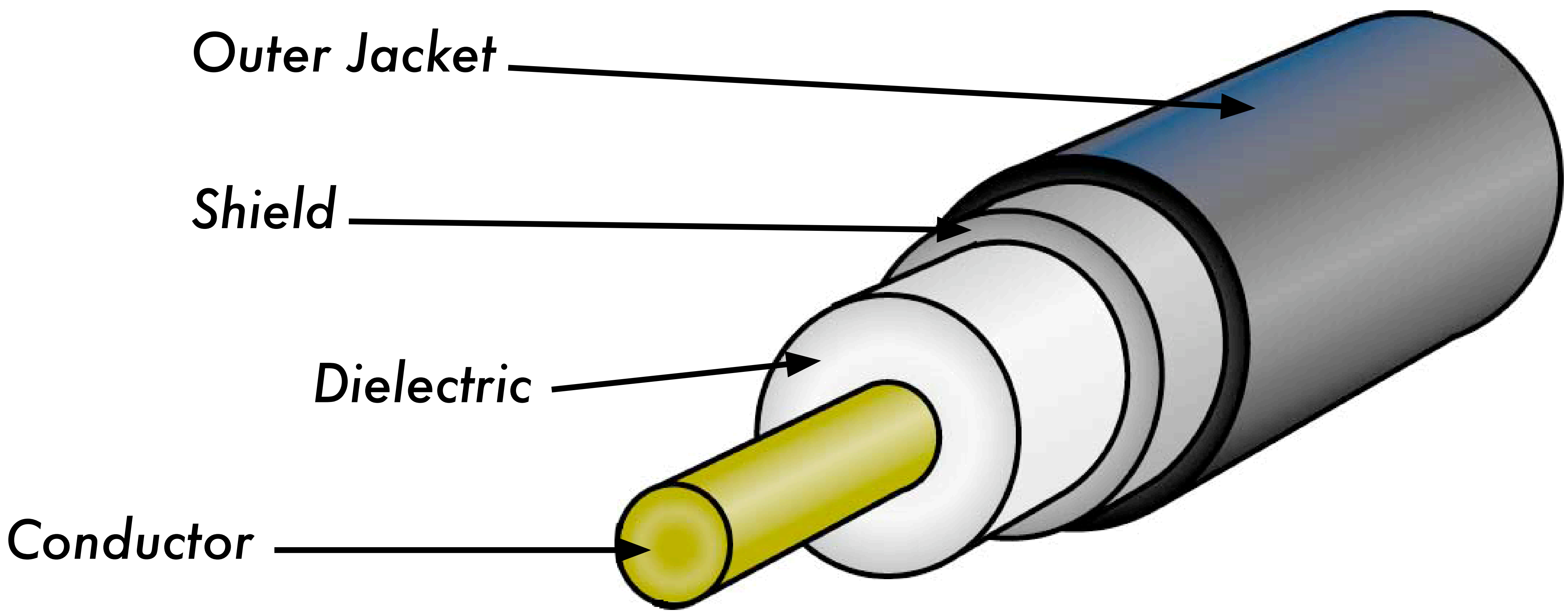
- If we now bend the open ends of the transmission line in opposite directions, the currents there will now generate electric fields that are in phase and will reinforce each other and will therefore radiate and propagate at a distance.
- We now have a an antenna at the end of the transmission line.



Wireless system connections



Coaxial transmission lines



Coaxial transmission lines

The loss (or ***attenuation***) of a coaxial cable depends on the construction of the cable and the operating frequency. The total amount of loss is proportional to the length of the cable.

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	0.341 dB/m
LDF4-50A	16 mm	0.118 dB/m	0.187 dB/m

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

Impedance

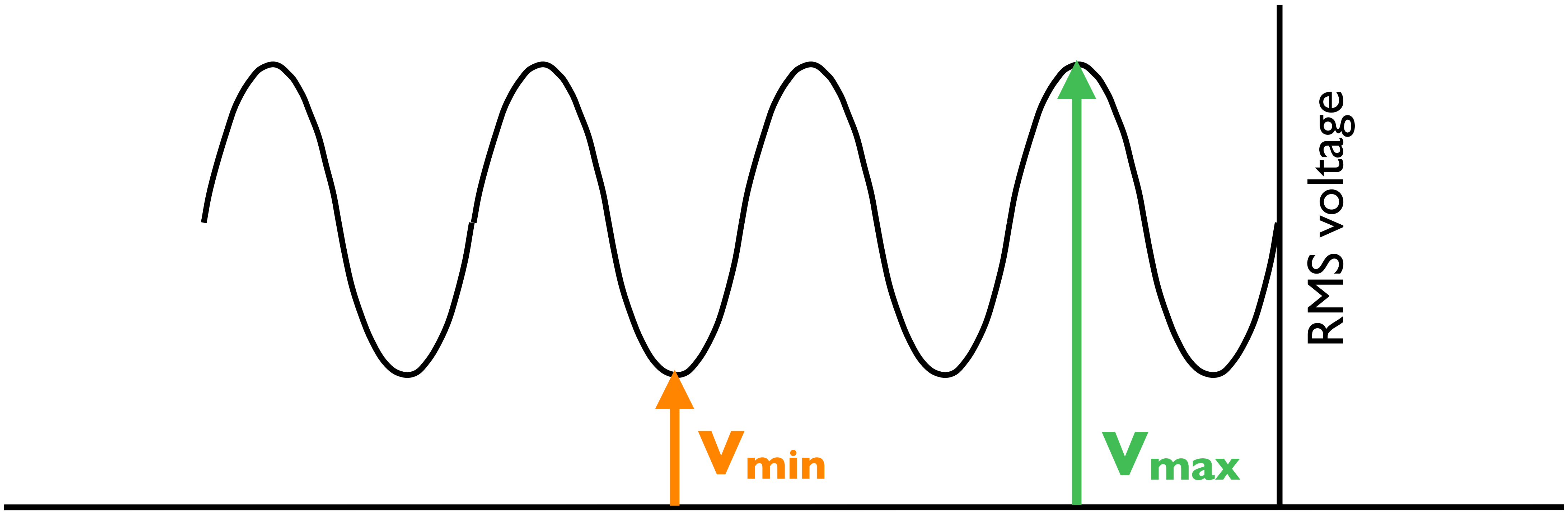
All materials will oppose the flow of an alternating current to some extent. This opposition is called ***impedance***, and is analogous to resistance in DC circuits.

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

Make sure that the characteristic impedance of the cable between the radio and the antenna is 50 ohms. Any mismatch will cause undesired reflections and power loss.

Reflections and VSWR

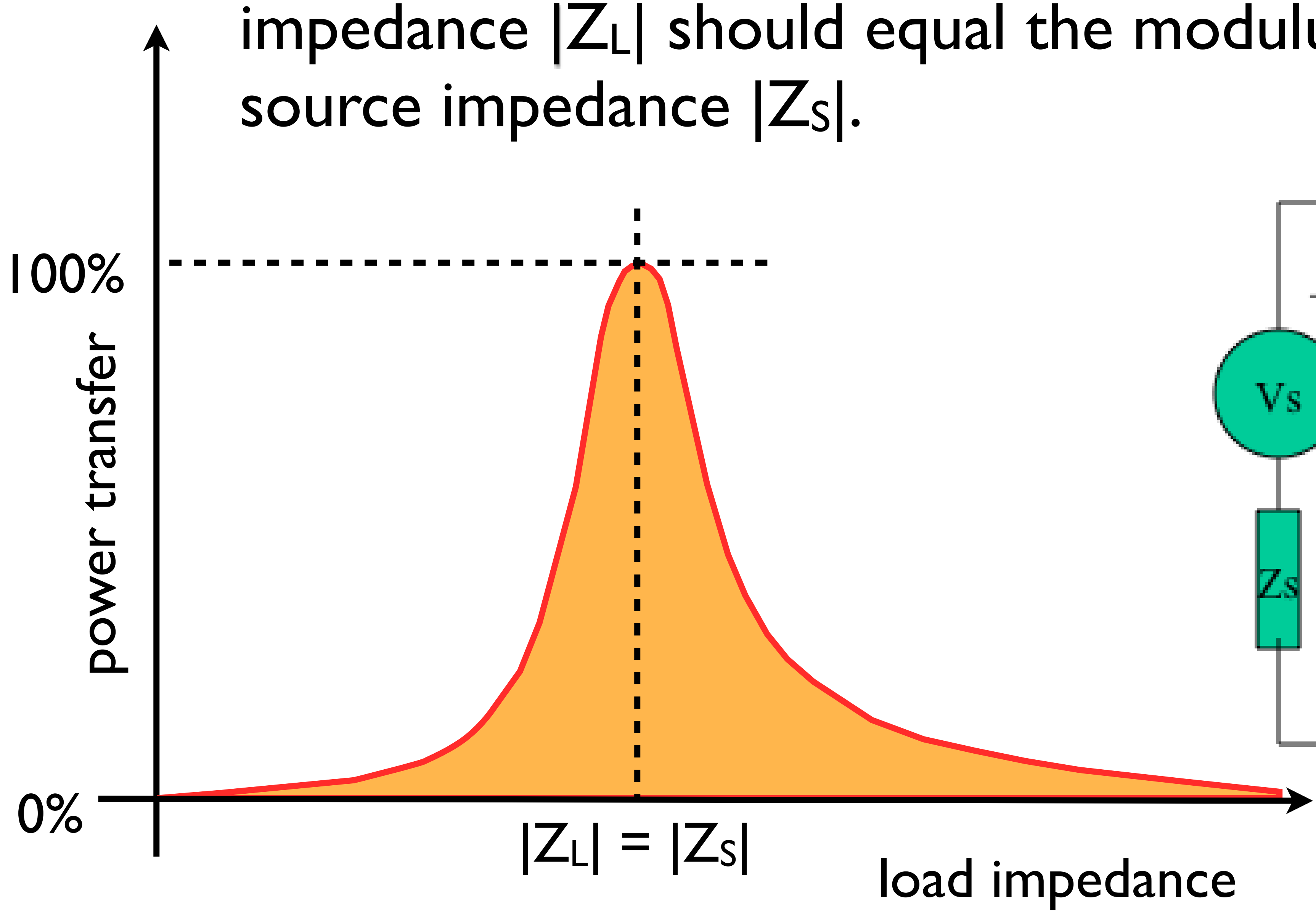
Impedance mismatch causes reflections and increased VSWR.

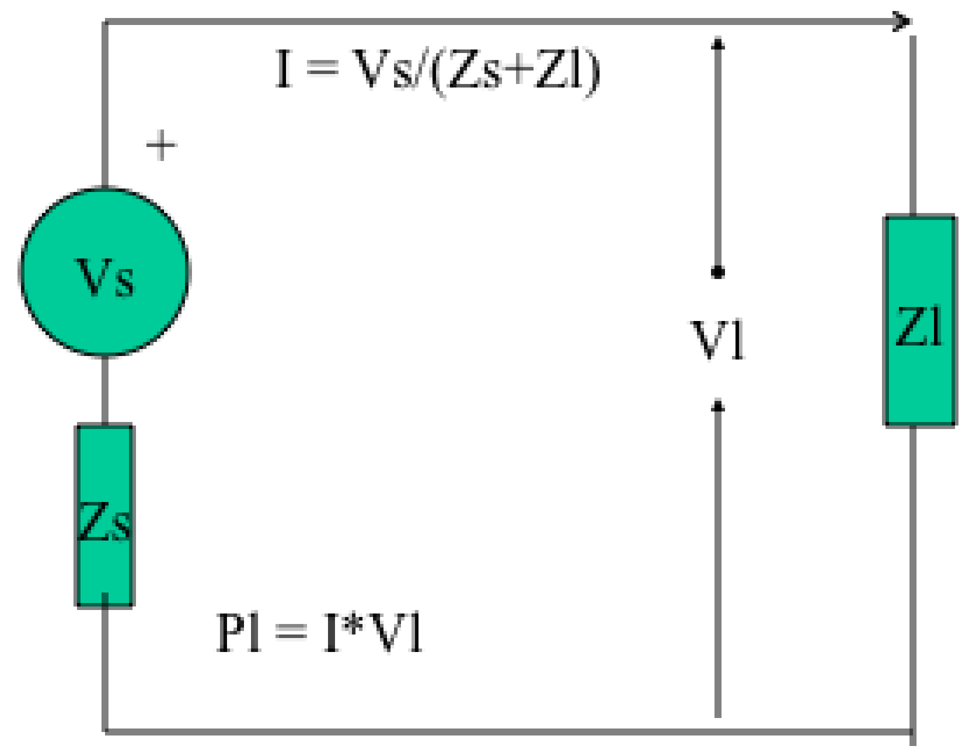


$$\text{Voltage Standing Wave Ratio VSWR} = \frac{V_{max}}{V_{min}}$$

Matched impedance = maximum power transfer

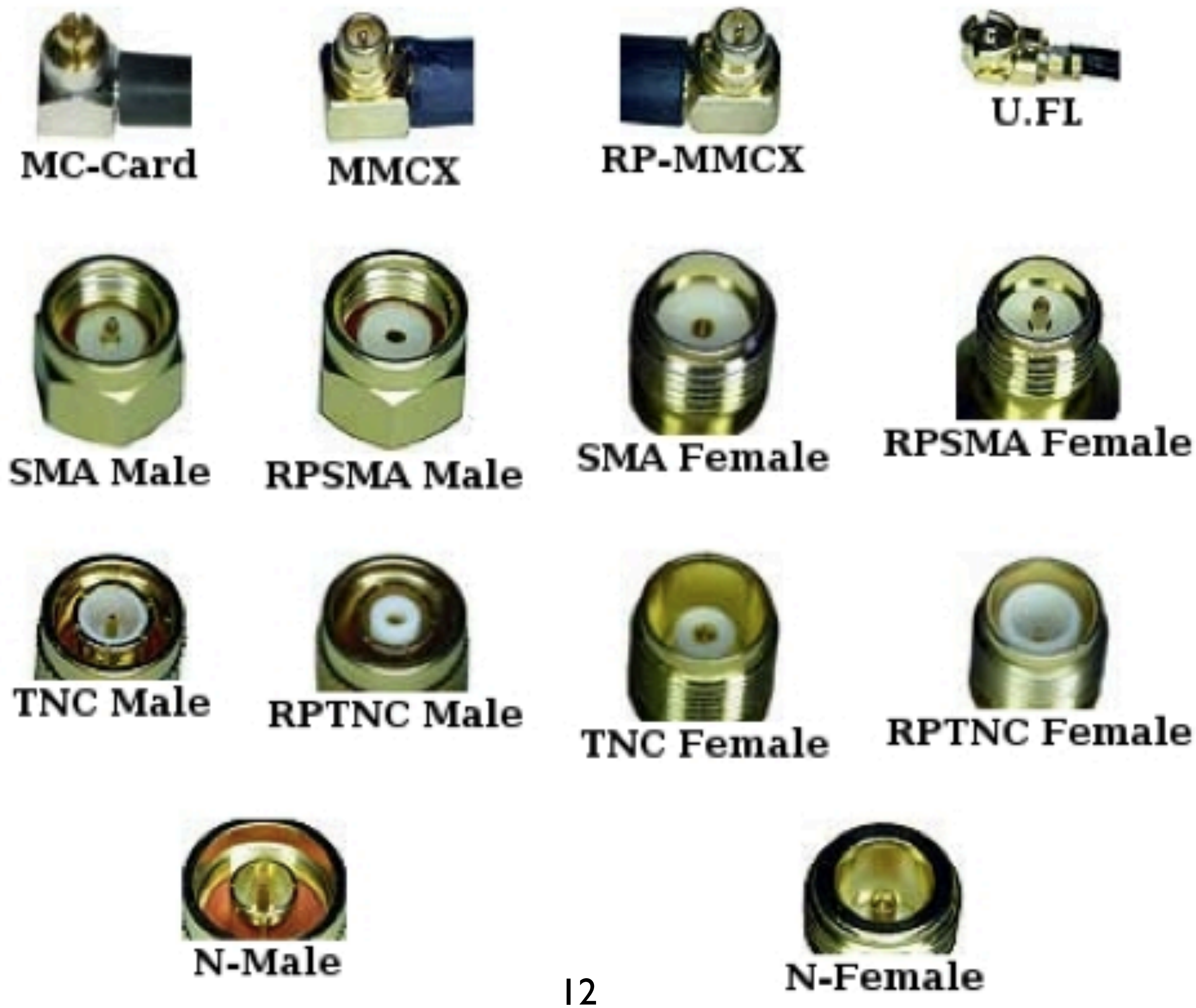
For maximum power transfer, the load impedance must be the complex conjugate of the source impedance. This implies that the modulus of the load impedance $|Z_L|$ should equal the modulus of the source impedance $|Z_S|$.





Connectors

Connectors come in a huge variety of shapes and sizes. In addition to standard types, connectors may be ***reverse polarity*** (genders swapped) or ***reverse threaded***.



Adapters & Pigtails

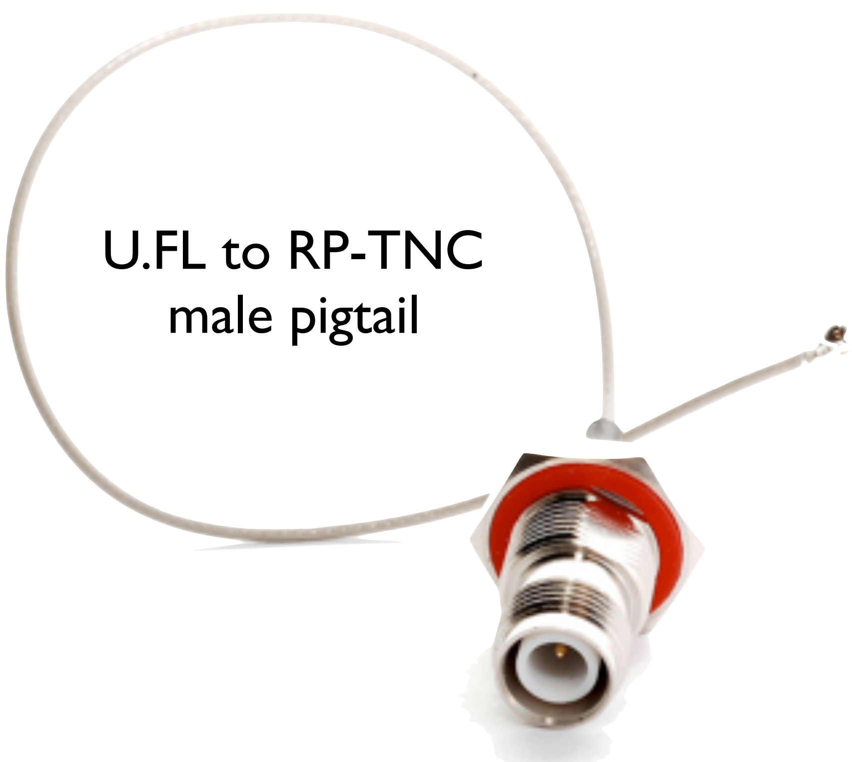
Adapters and pigtails are used to interconnect different kinds of cable or devices.

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

Theory: isotropic antennas

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

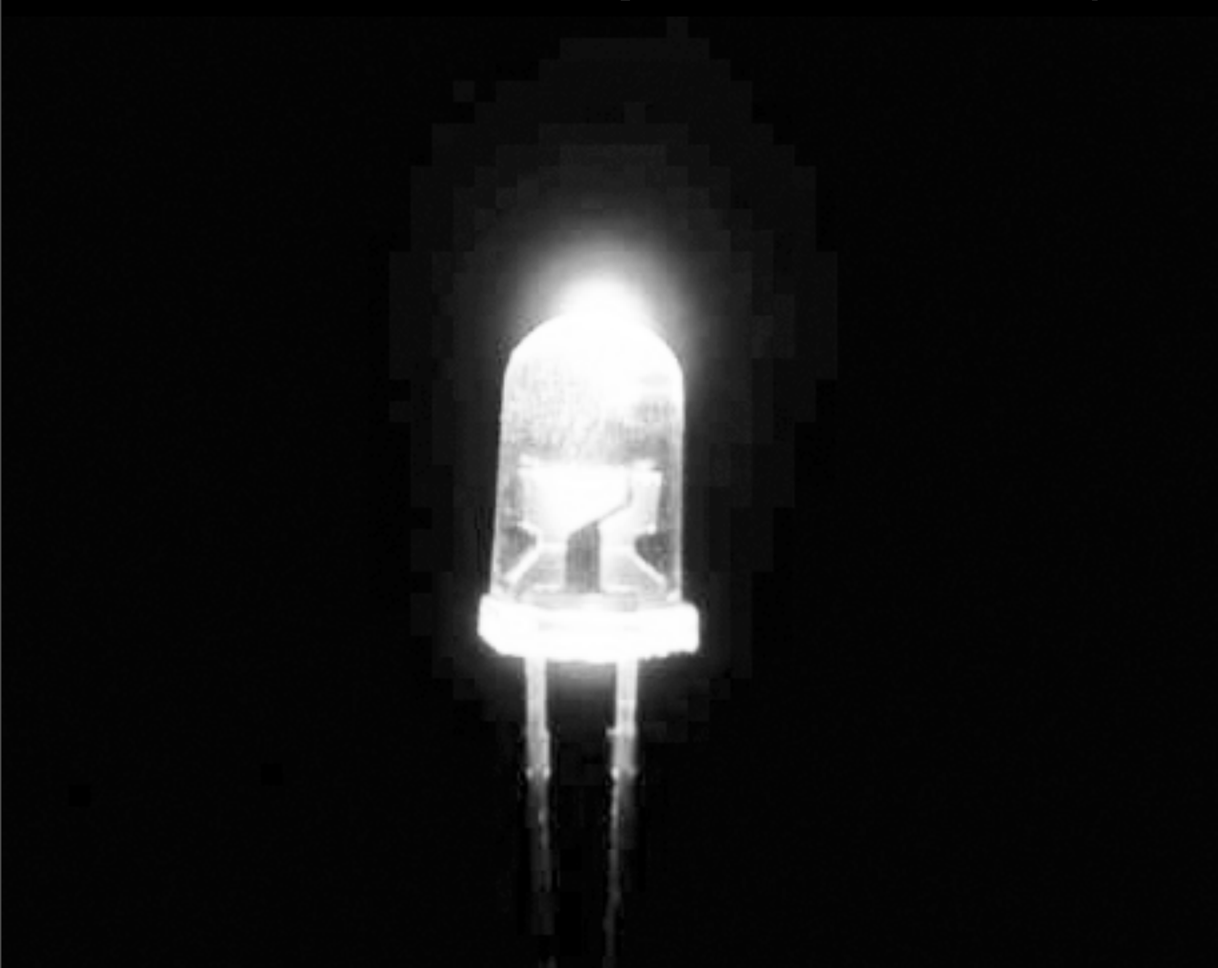
Real-world antennas are characterized by their ability to radiate more strongly in some directions than in others; this is called ***directivity***.

When taking the efficiency of the antenna into account, this preference for a direction of radiation is referred to as ***gain***.

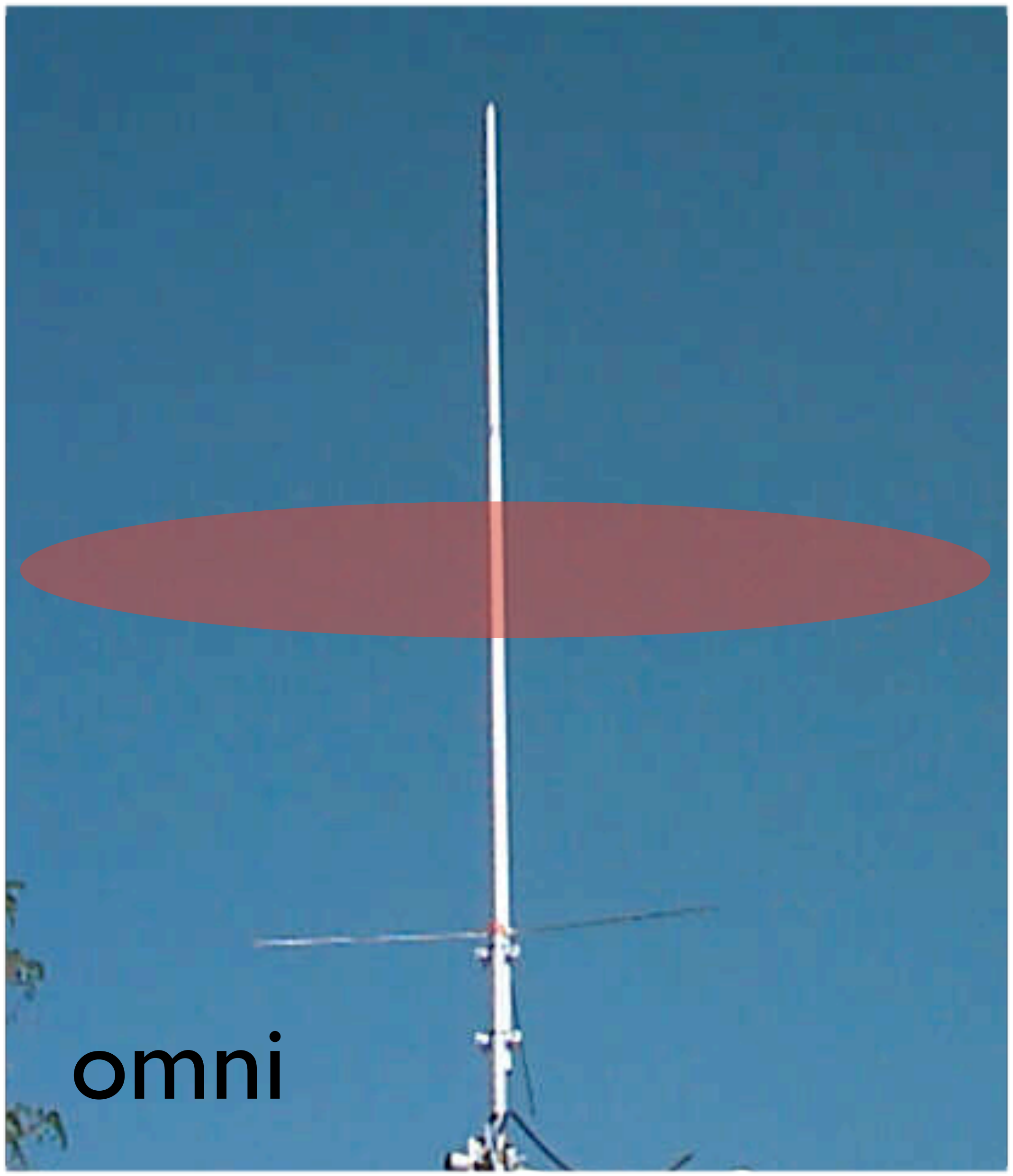
dBi

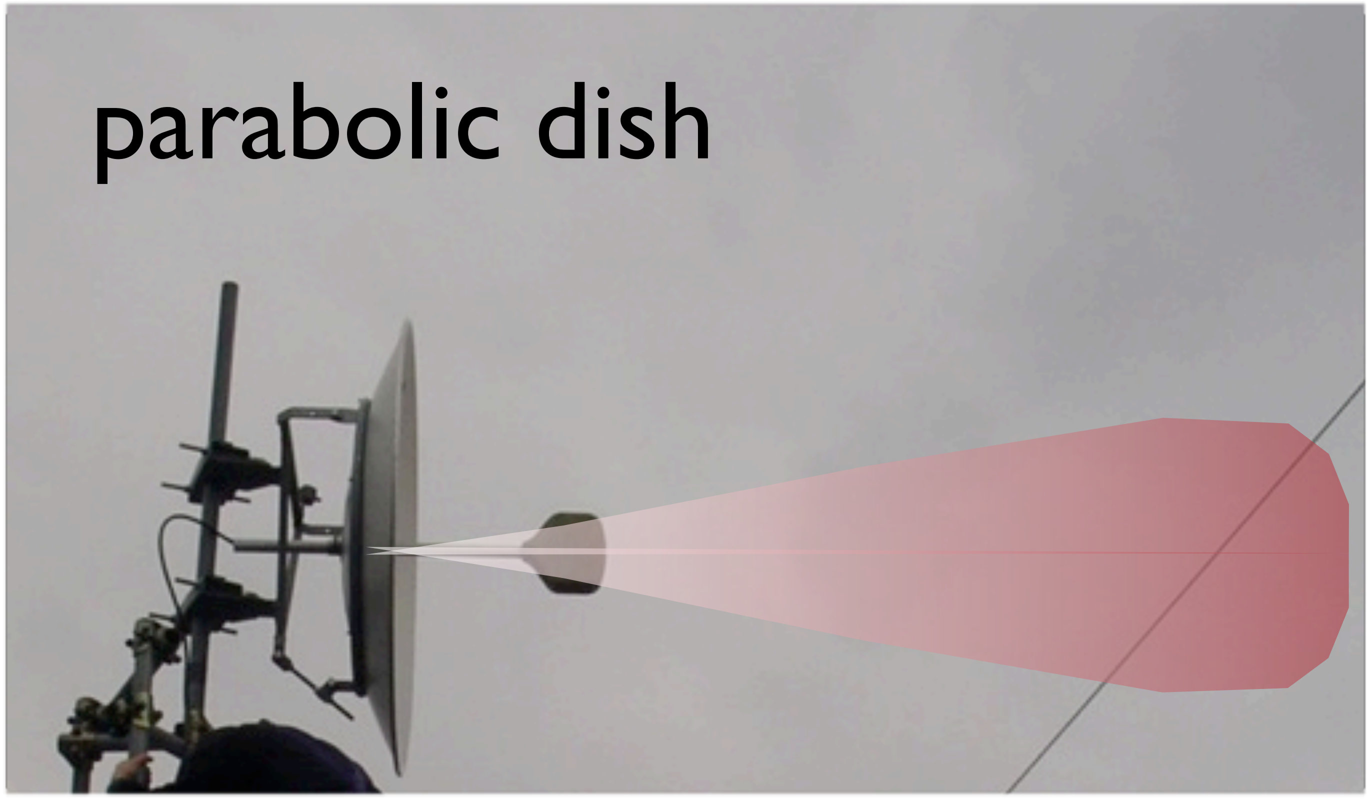
Antennas do not add power. They direct available power in a particular direction.

The gain of an antenna is measured in ***dBi*** (decibels relative to an isotropic radiator).



Directional vs. Omnidirectional





Antenna features

When buying an antenna, what features are important to consider?

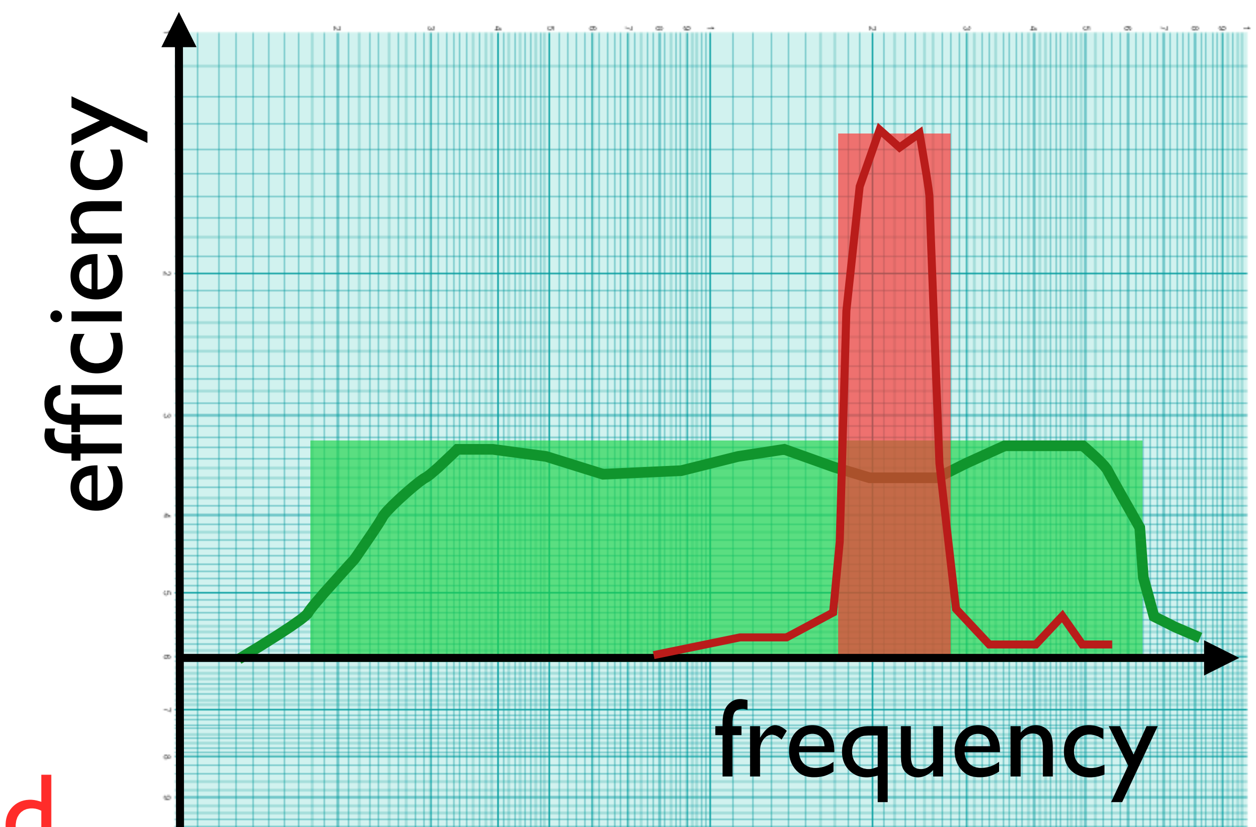
- Usable frequency range (bandwidth)
- Radiation pattern (beamwidth, sidelobes, backlobe, front-to-back ratio, location of nulls)
- Maximum gain
- Input impedance
- Physical size and wind resistance
- Cost

Bandwidth

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

You must choose an antenna that works well for the frequencies you intend to use (for example, use a 2.4 GHz antenna for 802.11 b/g, and a 5 GHz antenna for 802.11a).

narrow band

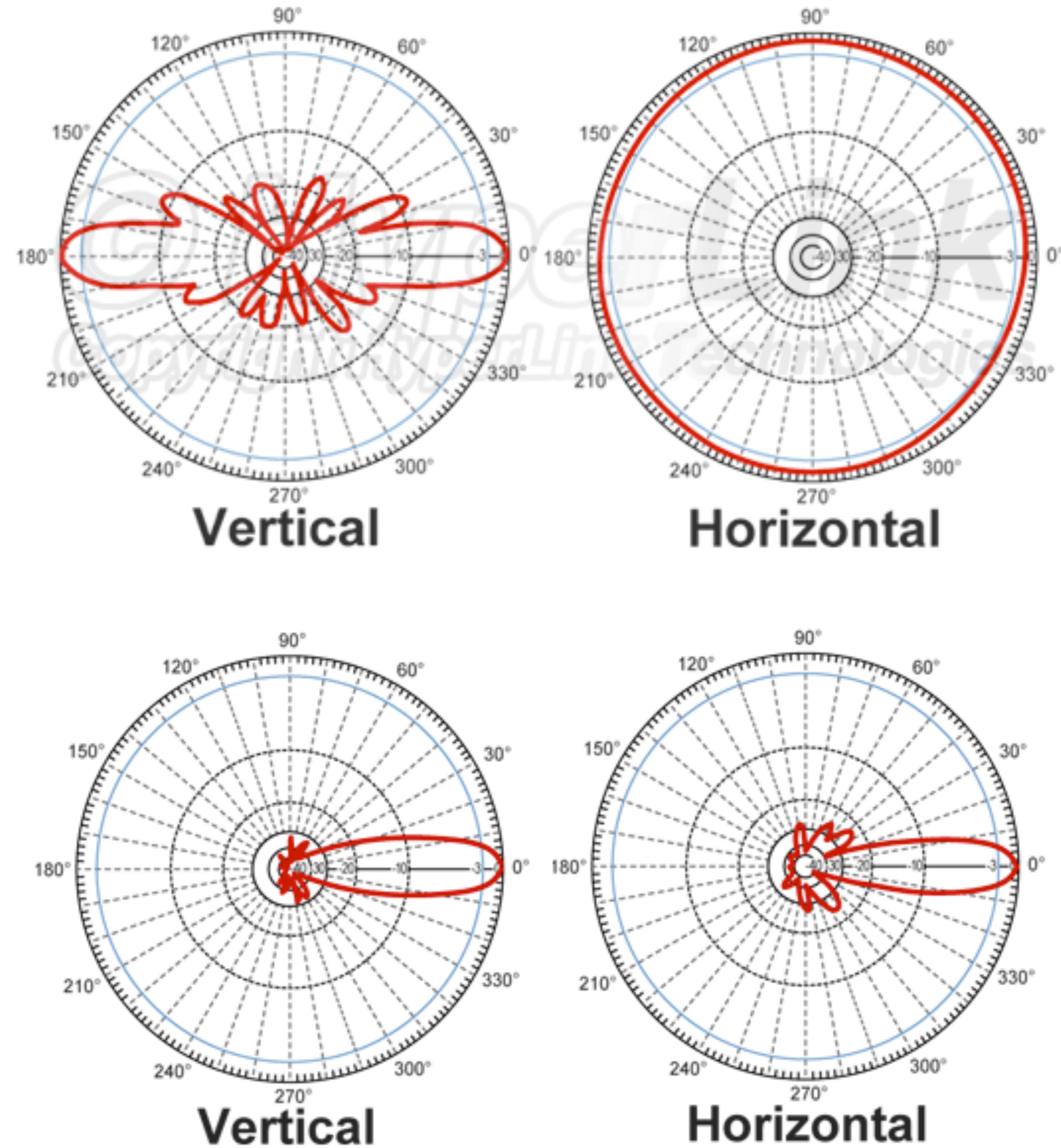


wide band

Radiation pattern

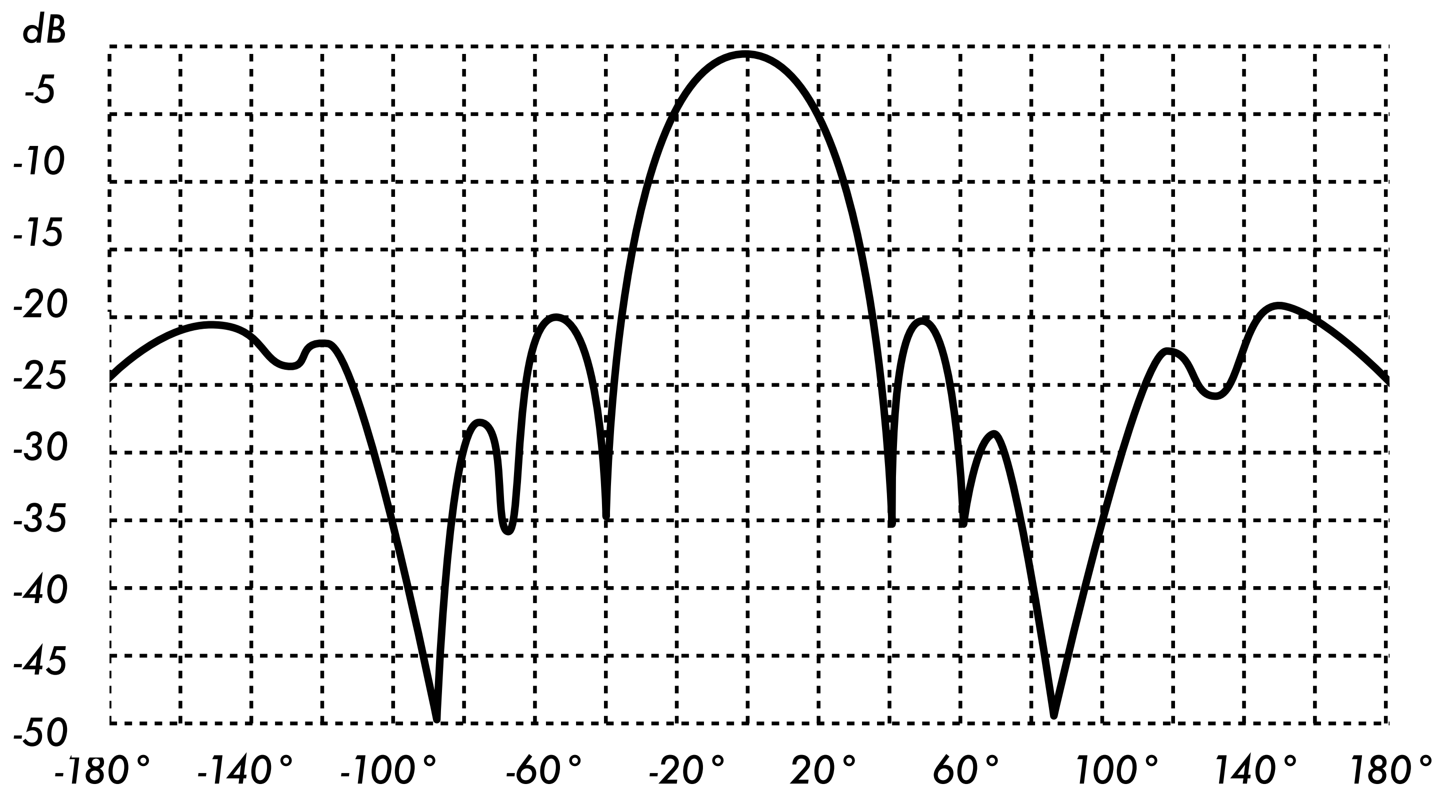
The ***radiation pattern*** of an antenna is a pictorial representation of the distribution of the power radiated from, or received by, the antenna. This is presented as a function of direction angles centered on the antenna.

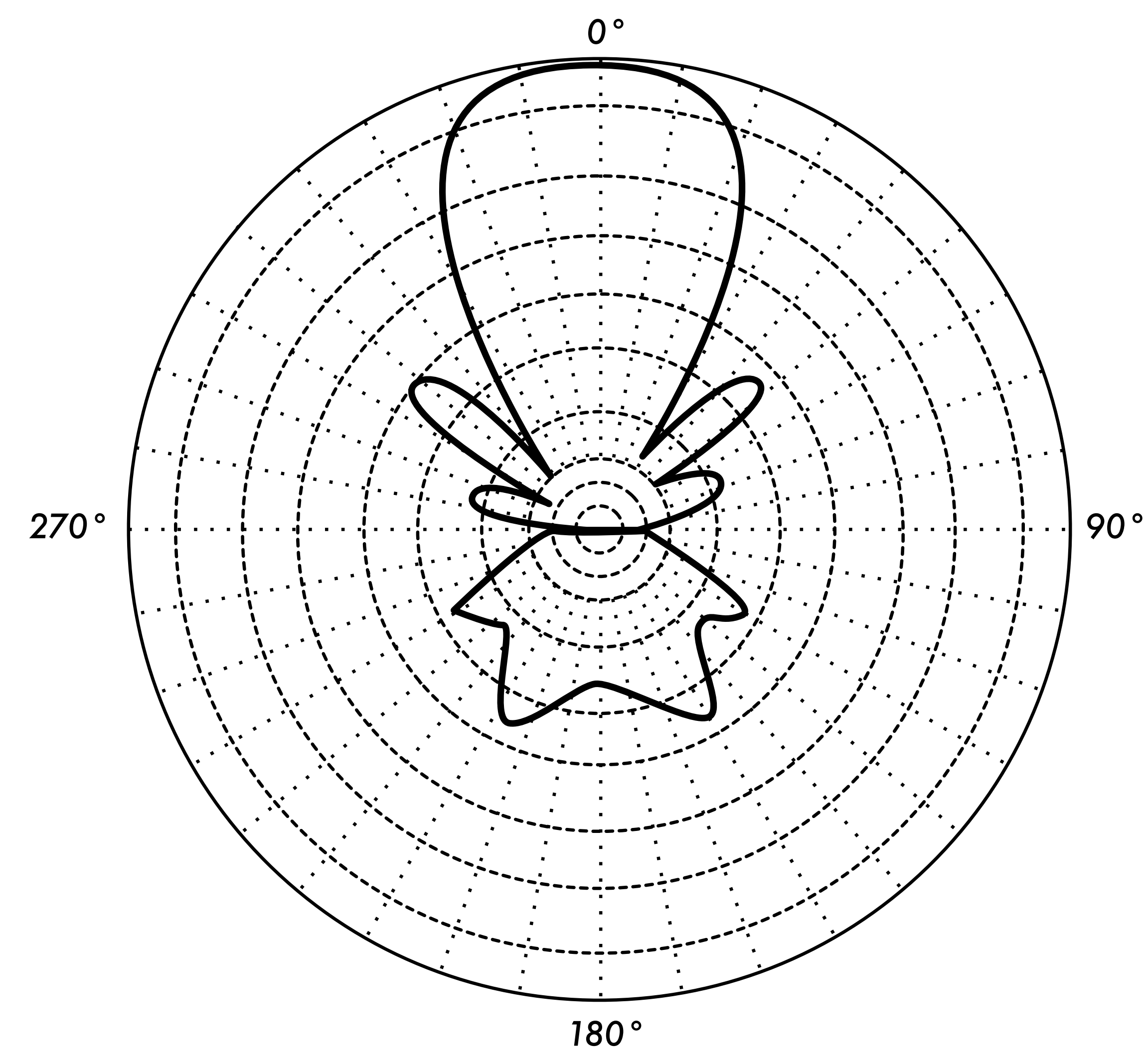
Radiation patterns usually use a polar projection.



Radiation pattern

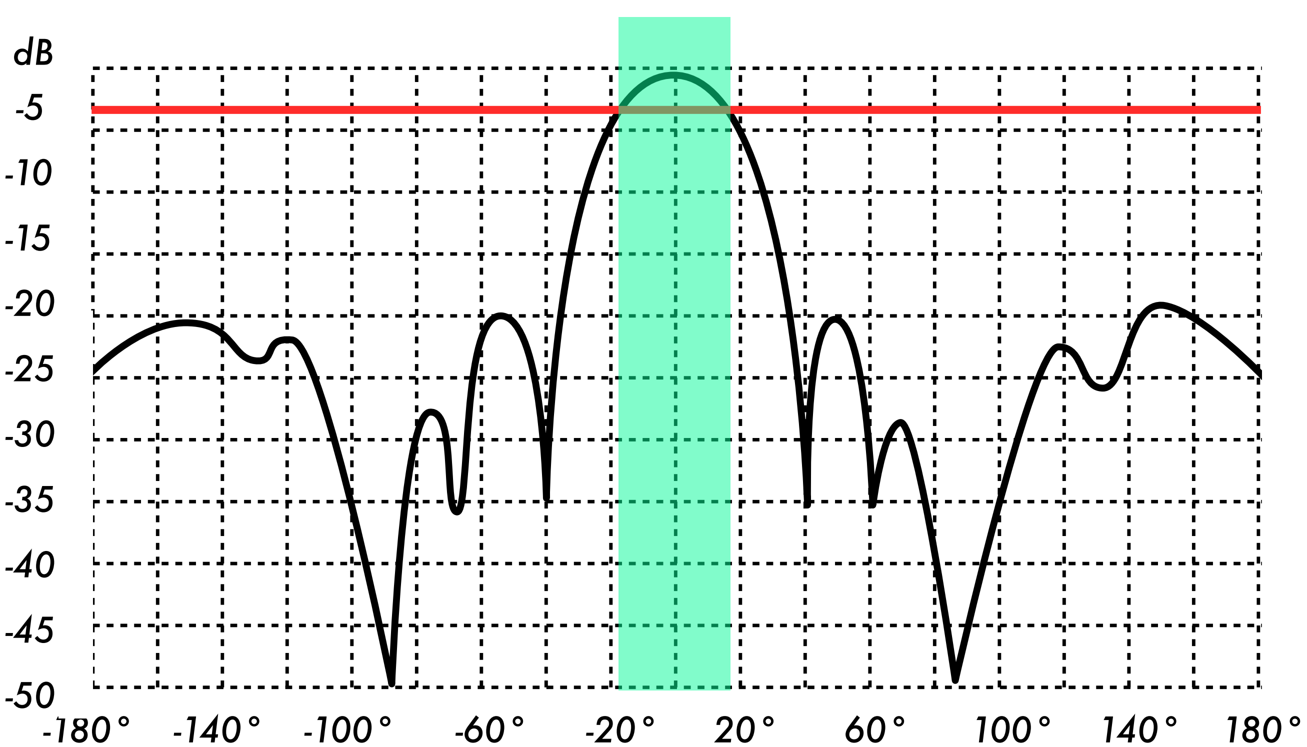
This is a ***rectangular plot*** and a ***polar plot*** of the same antenna (in a single plane). Polar coordinate systems are far more common than rectangular plots, since they give a better visual representation of antenna performance in every direction.

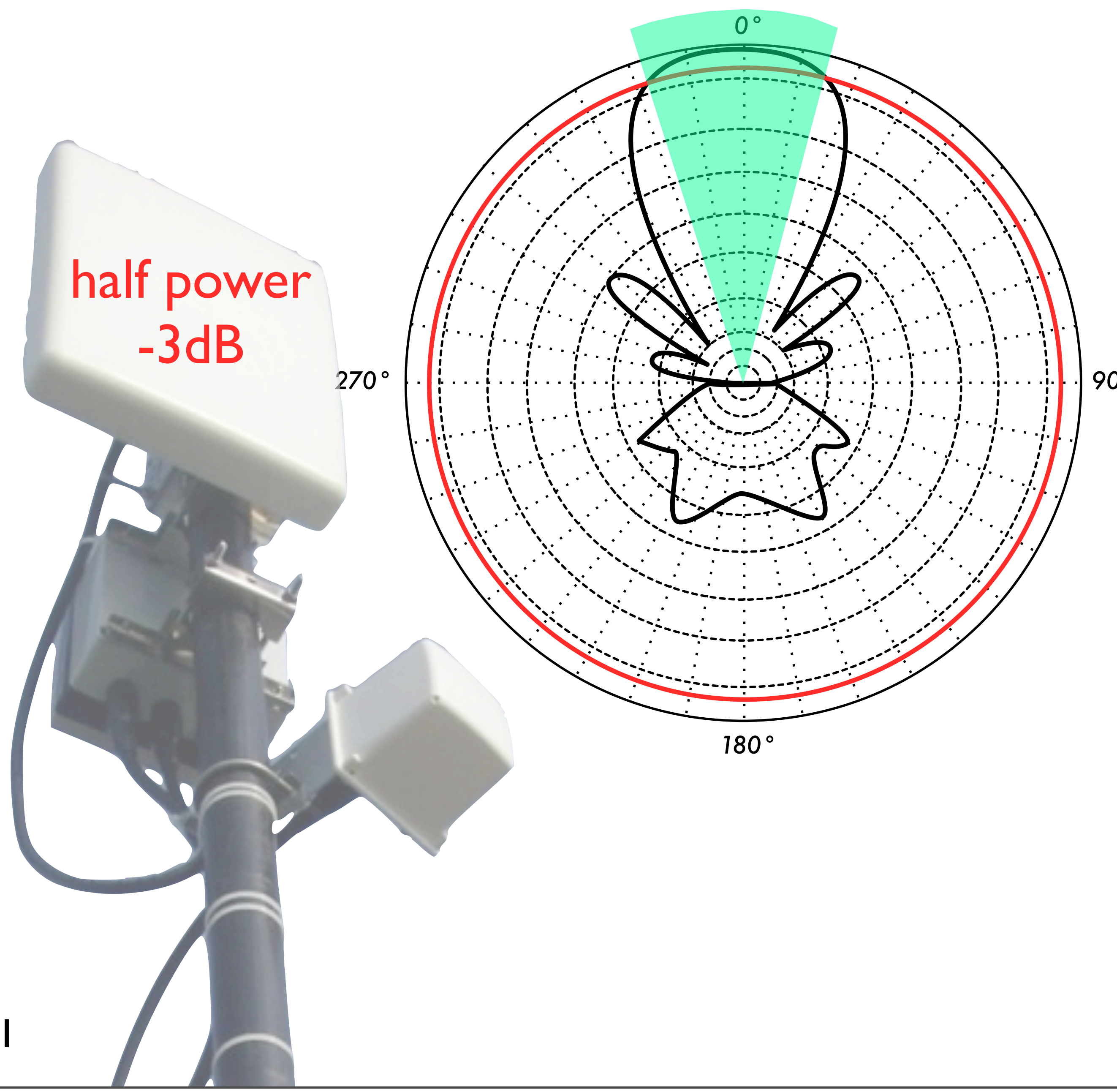




Beamwidth

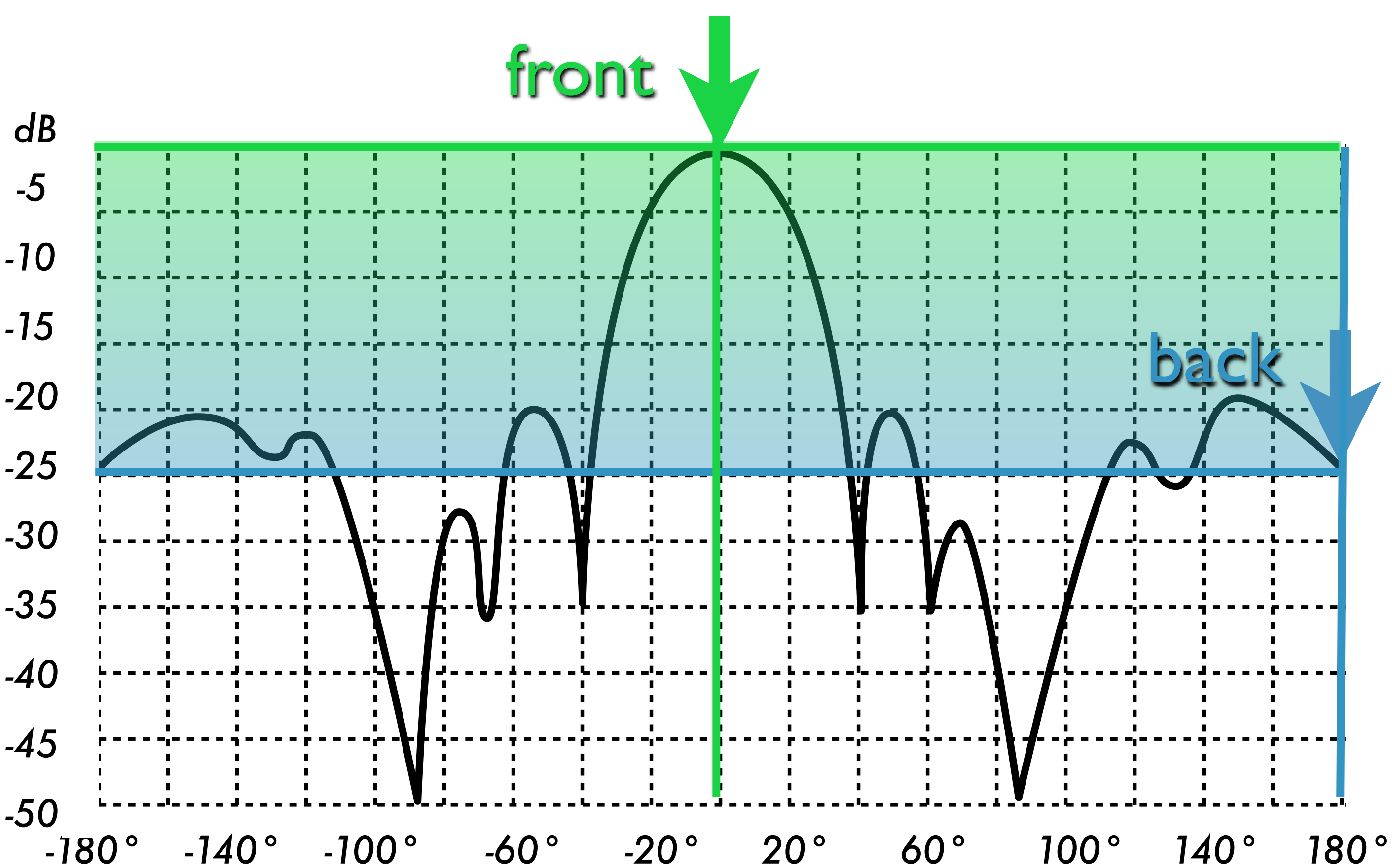
The ***beamwidth*** of an antenna is the angular measure of that part of the space where the radiated power is greater than or equal to the half of its maximum value.

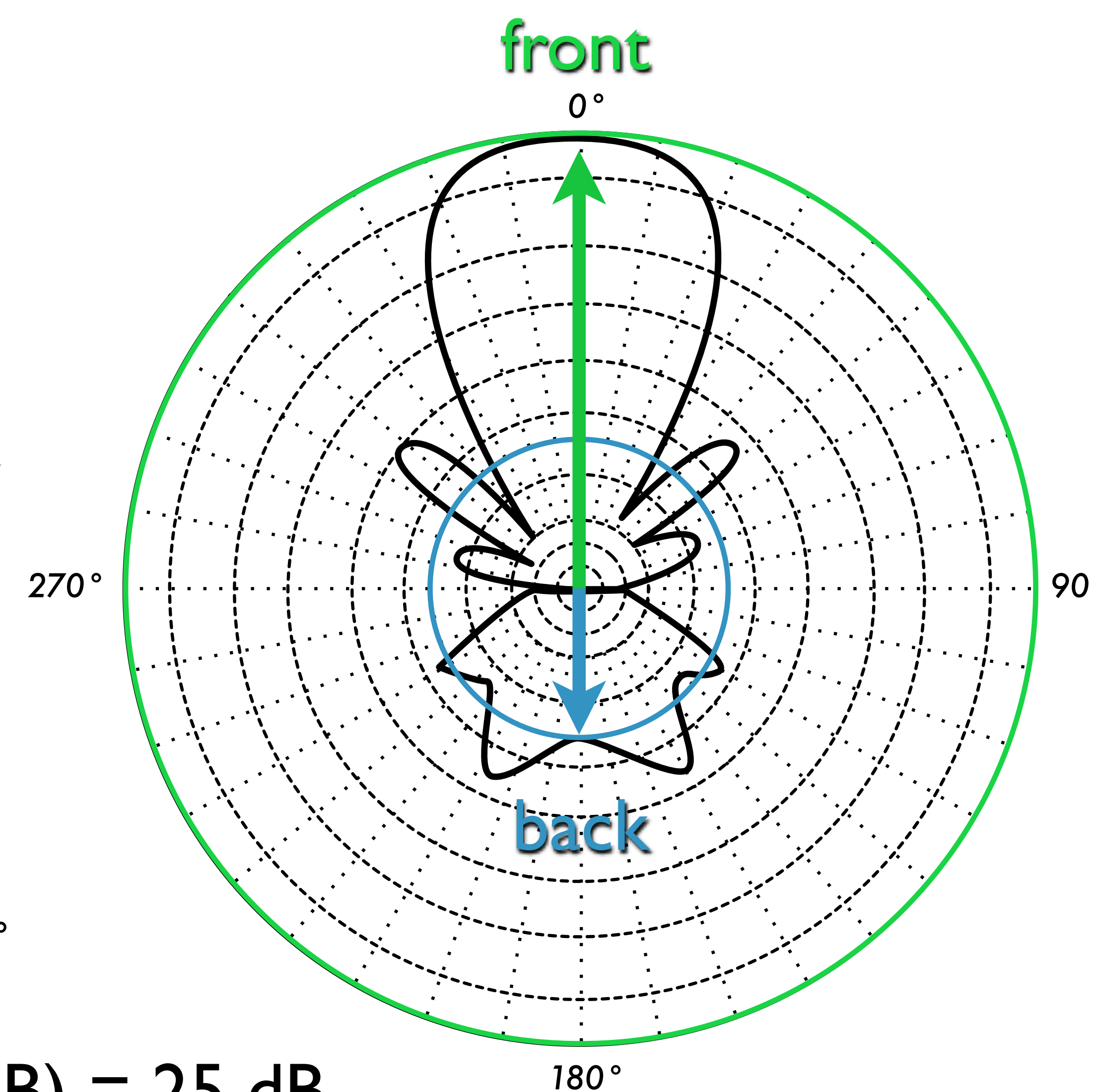




Front-to-back ratio

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.

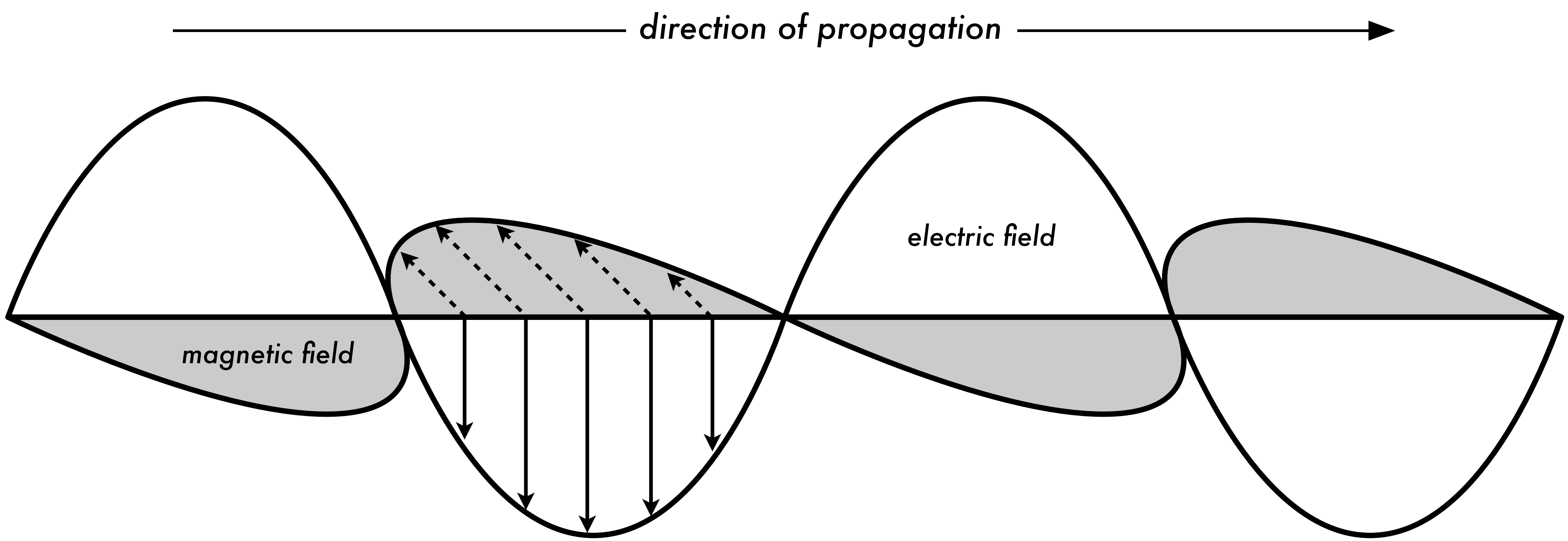




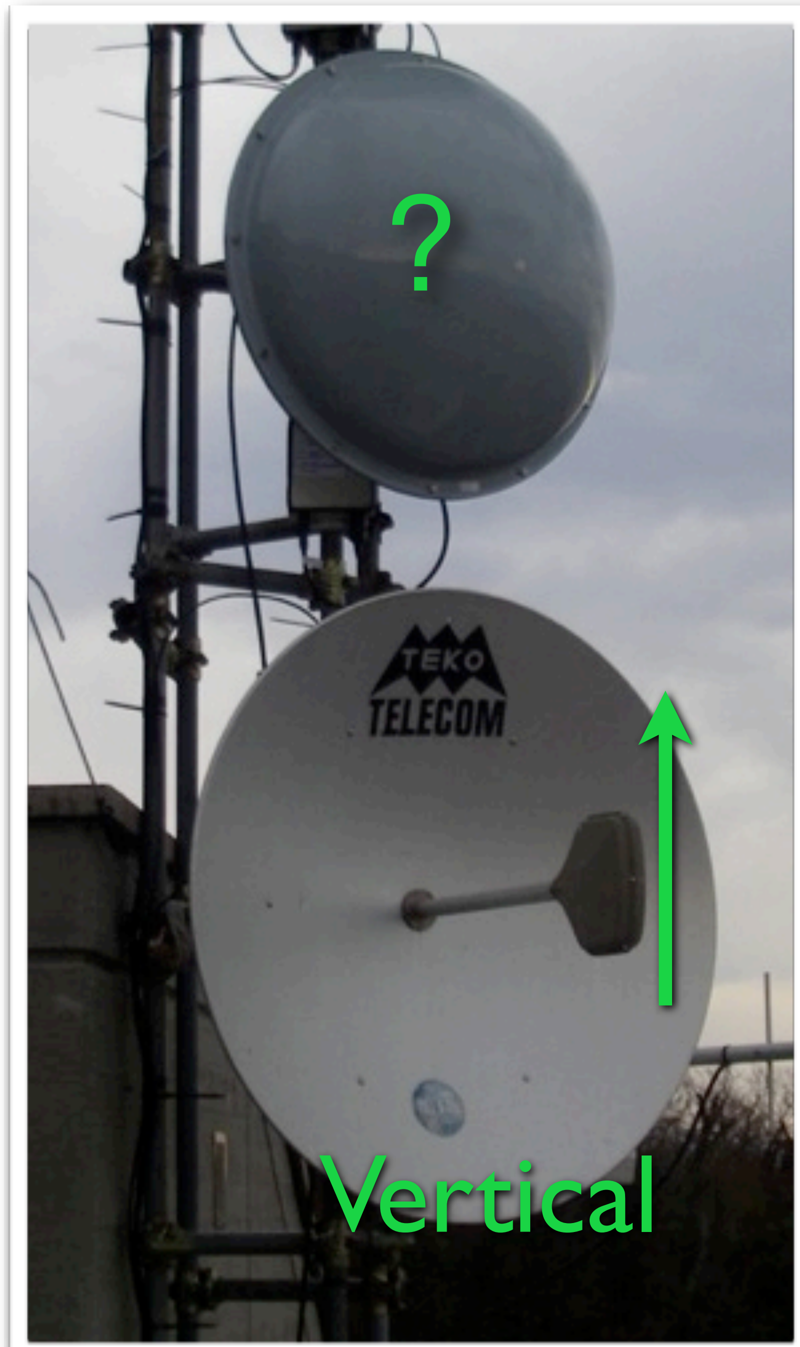
In this example the f/b ratio is: 0 dB - (-25 dB) = 25 dB

Polarization

- Electromagnetic waves have electrical and magnetic components.
- The polarization of transmitting and receiving antennas **MUST MATCH** for optimum communications.



Antenna polarization



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***.

Wind load

Sector Antenna

Parabolic Antenna with Radome

Parabolic Grid Antenna

Weather effects

parabolic grid

parabolic grid
(covered by snow)

Weatherproofing antennas

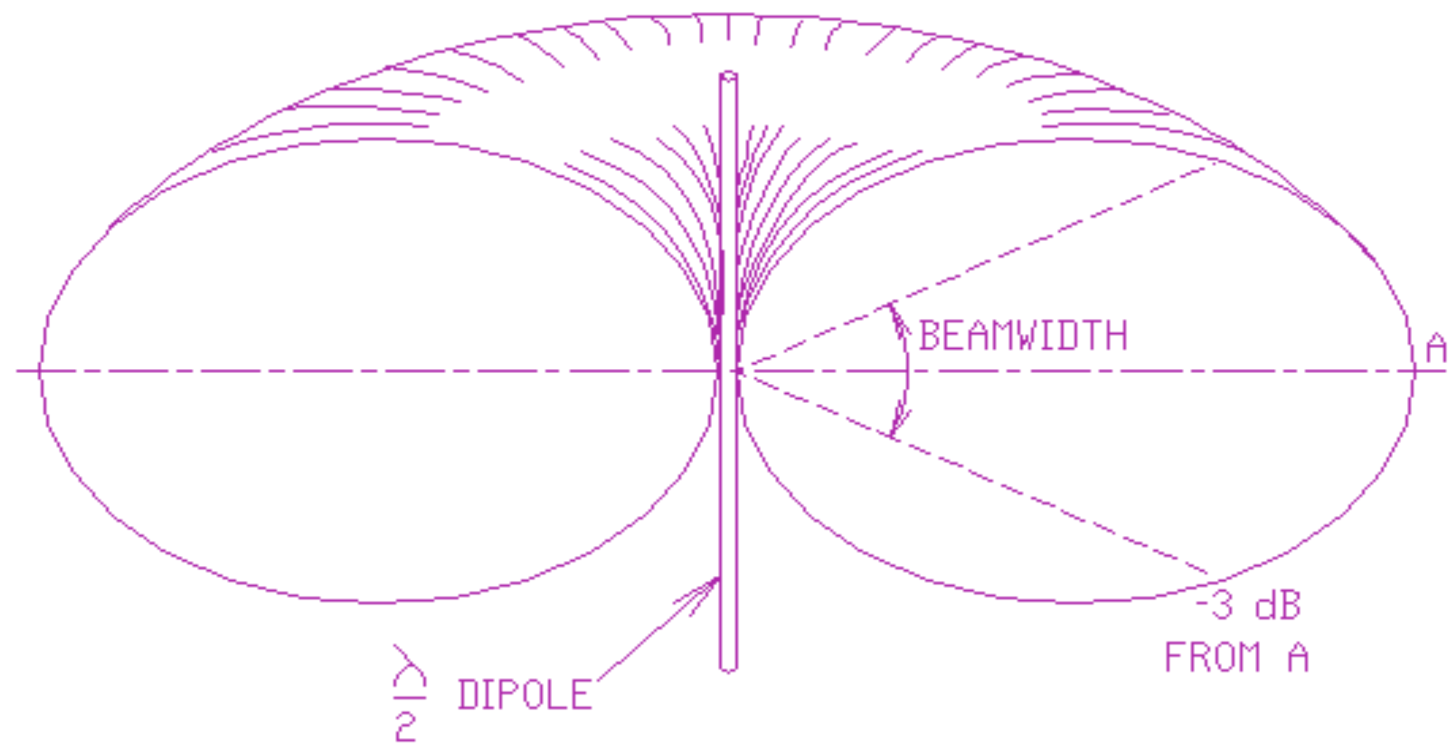
Most antenna problems are caused by coaxial cable connections that loosen due to vibration, allowing moisture to penetrate the connector interface.

Weatherproof all outdoor connections.

Antenna types

- Omnidirectional
  - Dipole
  - Monopole
  - Collinear
  - Slotted Waveguide
- Directional
  - Sectorial
  - Patch
  - Cantenna
  - Yagi
  - Biquad
  - Dish

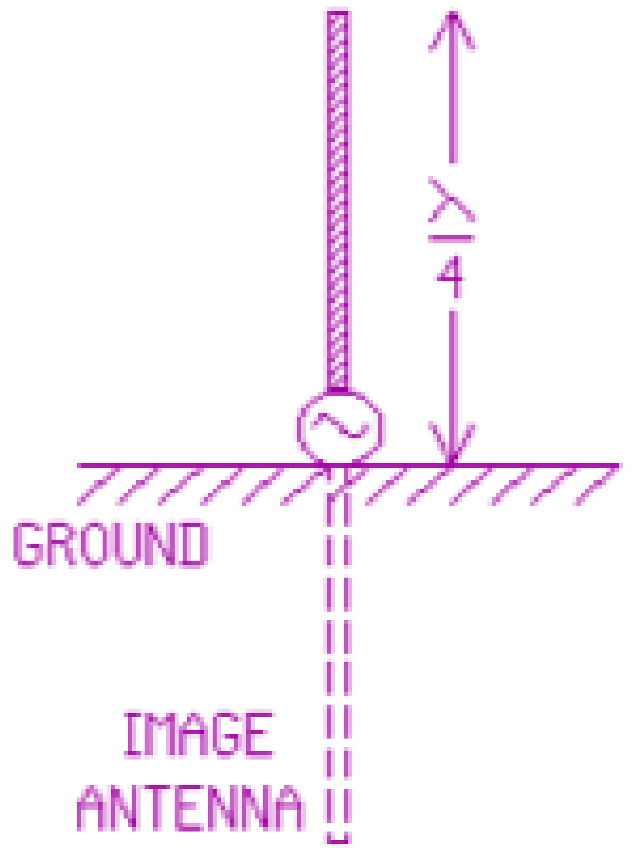
Half Wavelength Dipole



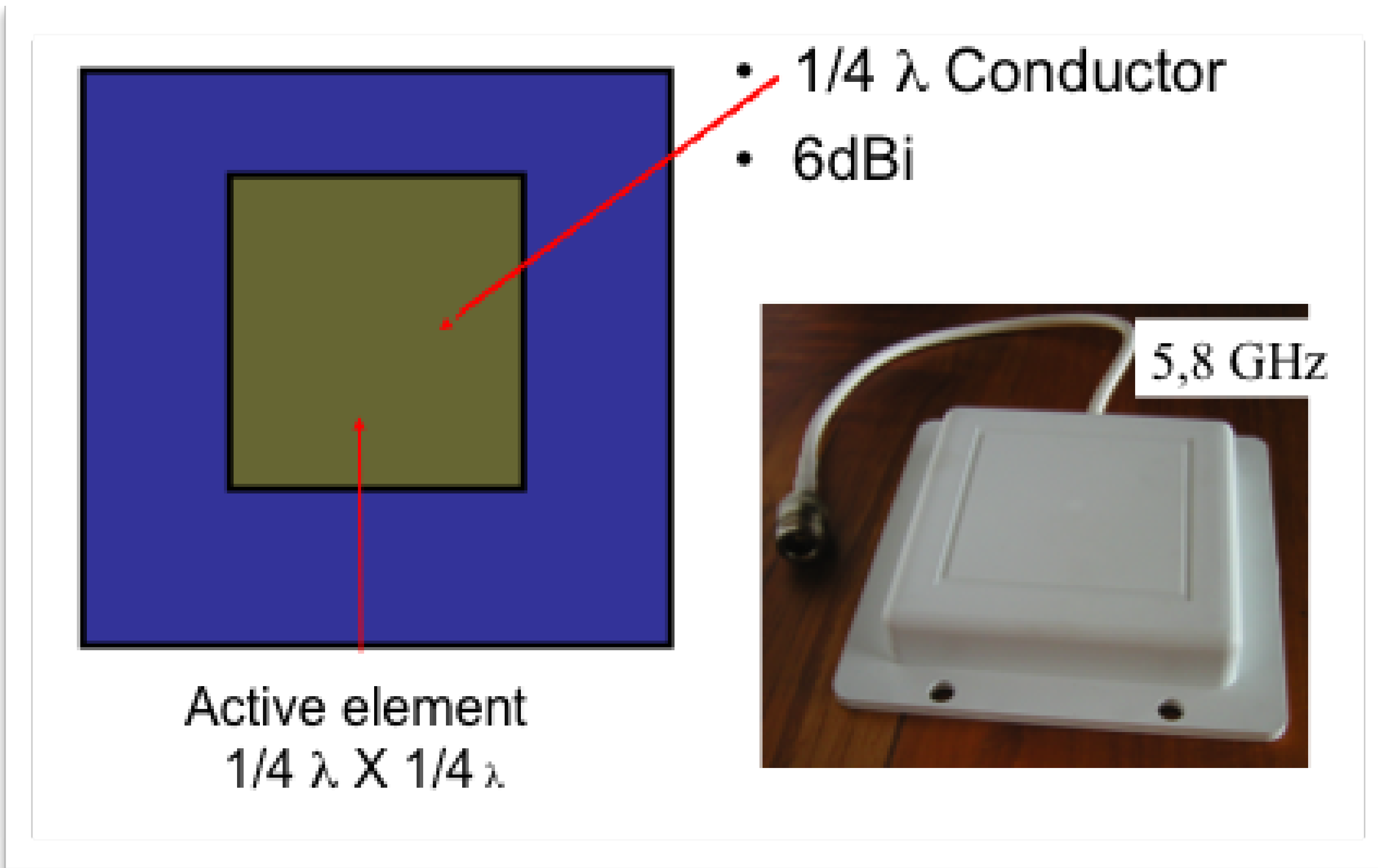
- Two 1/4 λ elements
- Very easy to build over a wide frequency range
- Omnidirectional in the plane perpendicular to the elements
- 2.15 dBi gain
- 72 ohm input impedance nearly matches the 50 ohm coax

Monopole or Marconi antenna

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



Patch antenna



Antenna types

parabolic reflector

panel antennas

Do-it-yourself reflector

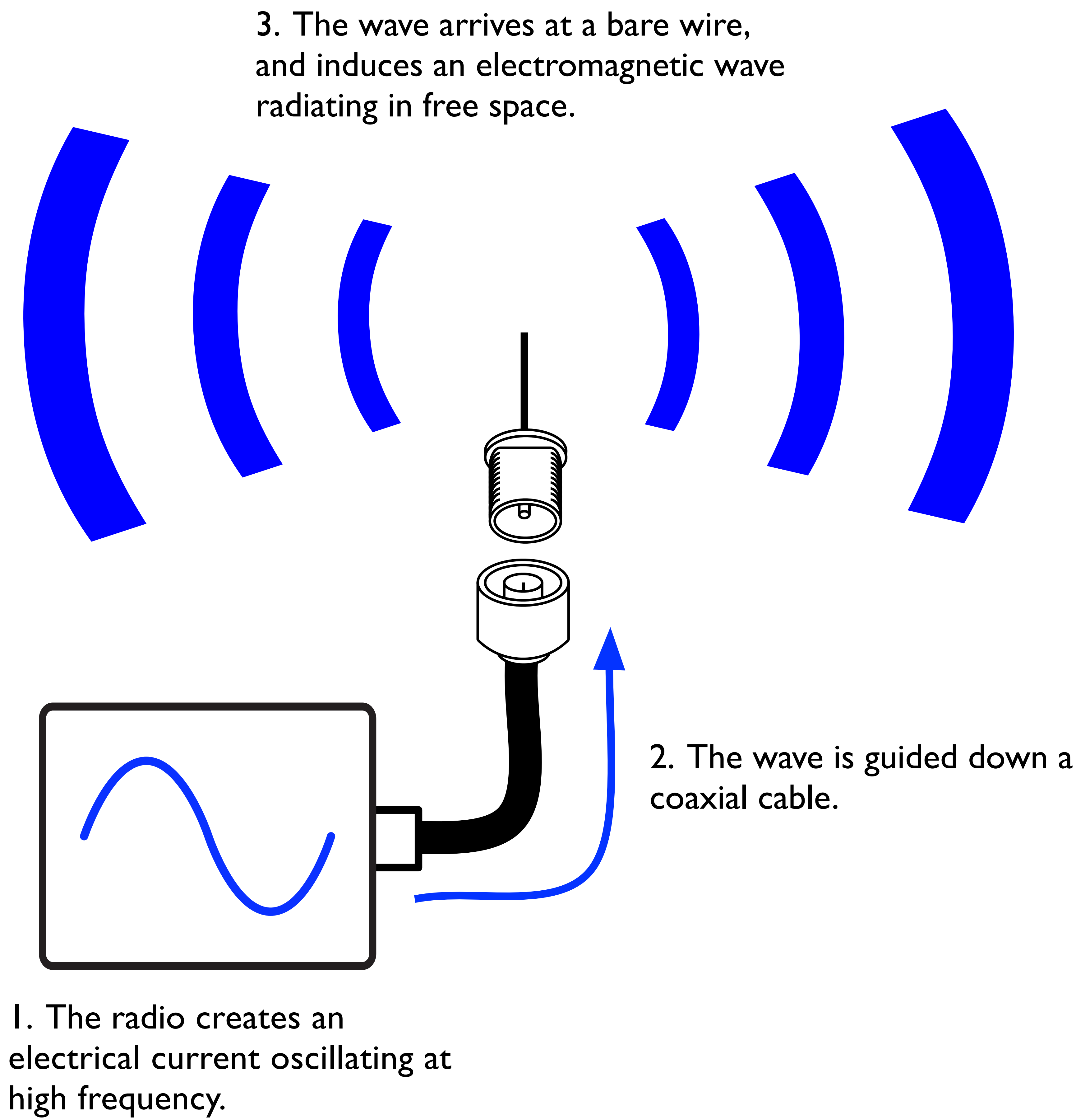
You can make your own reflector using an aluminum sheet, cardboard or thick paper, scissors and glue.

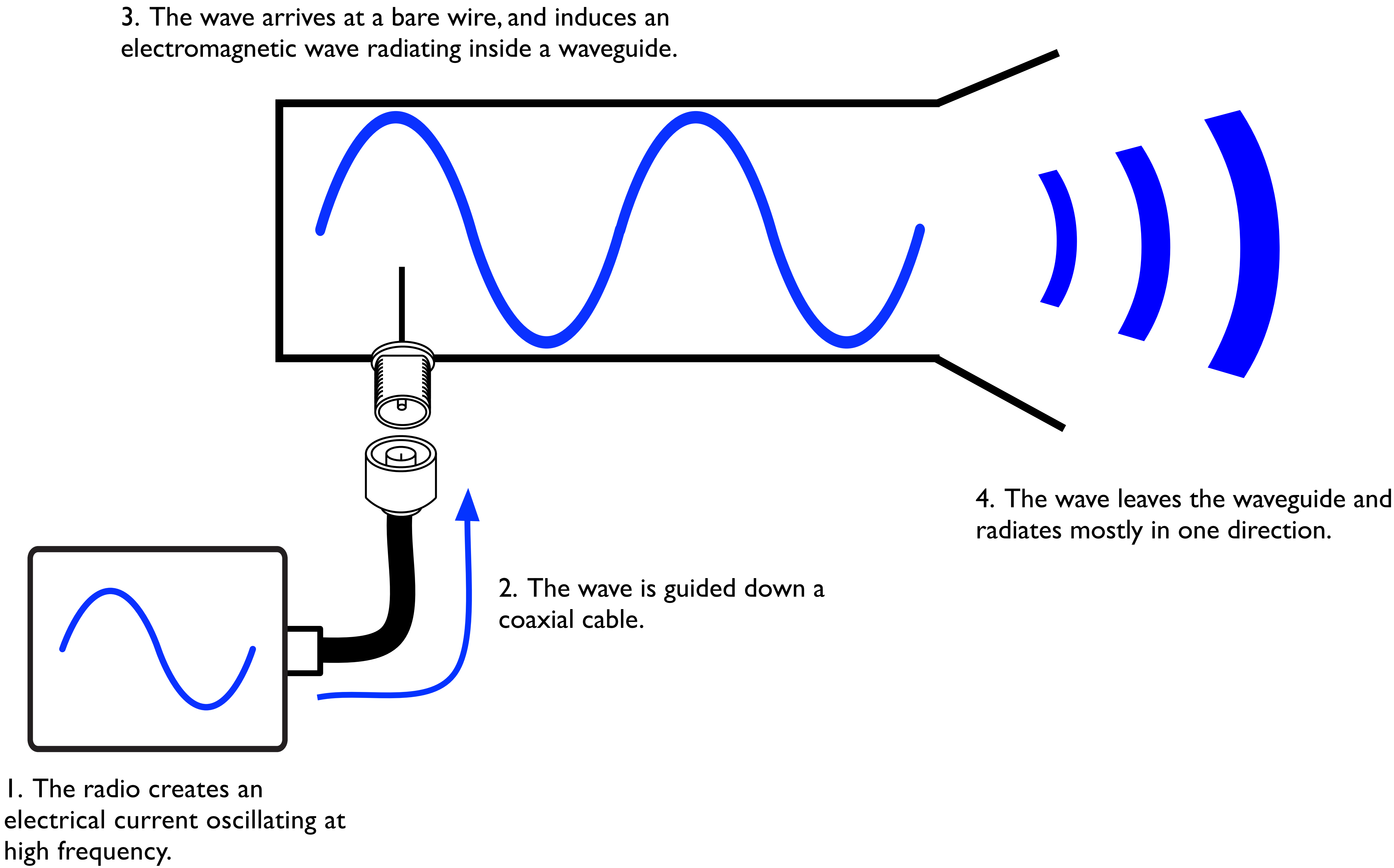
Parabolic reflectors

- 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

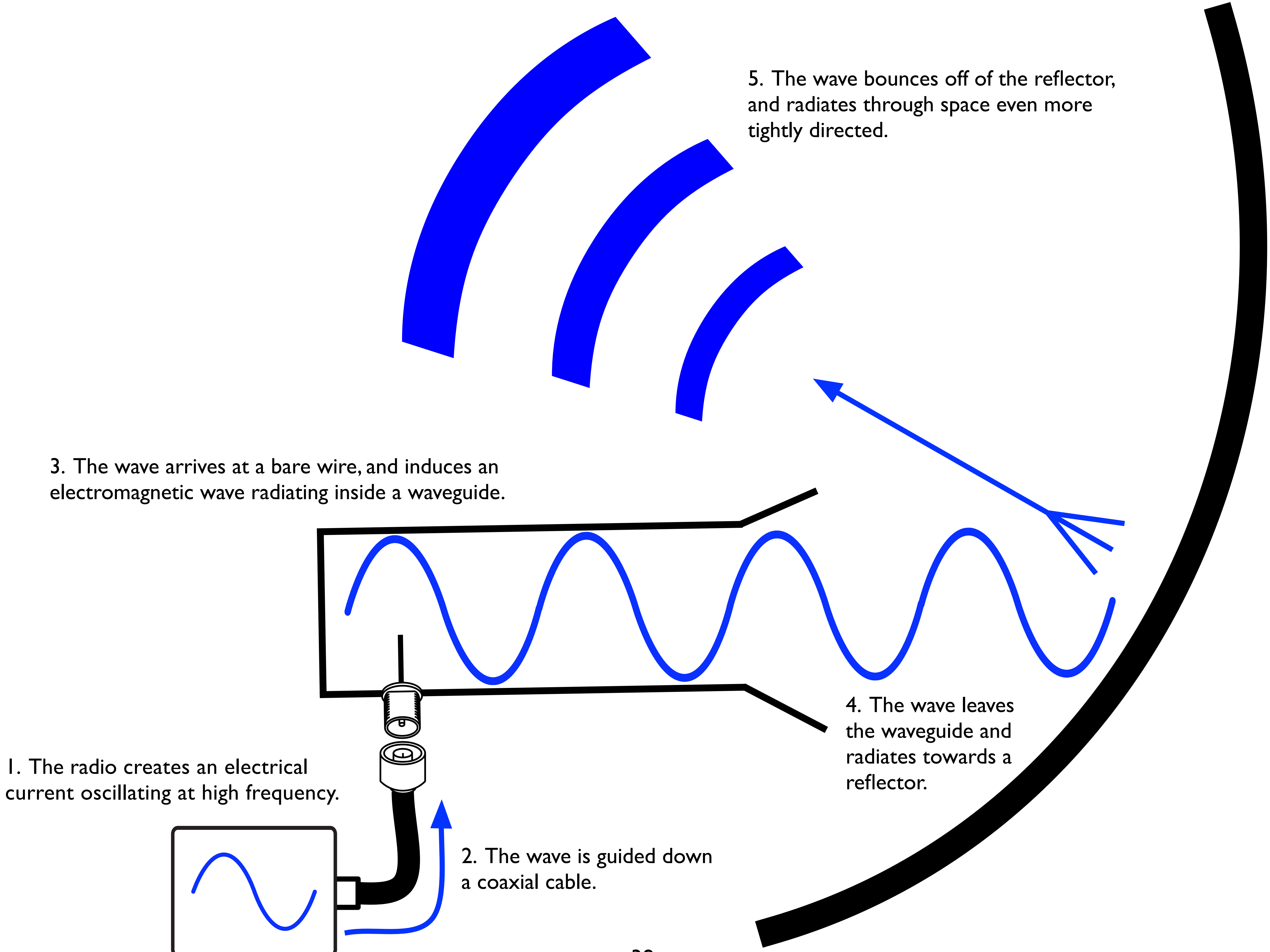
Do-it-yourself cantenna

Cheap and effective antennas can be made from food cans.


3. The wave arrives at a bare wire, and induces an electromagnetic wave radiating in free space.
2. The wave is guided down a coaxial cable.
1. The radio creates an electrical current oscillating at high frequency.



3. The wave arrives at a bare wire, and induces an electromagnetic wave radiating inside a waveguide.
4. The wave leaves the waveguide and radiates mostly in one direction.
2. The wave is guided down a coaxial cable.
1. The radio creates an electrical current oscillating at high frequency.


5. The wave bounces off of the reflector, and radiates through space even more tightly directed.
3. The wave arrives at a bare wire, and induces an electromagnetic wave radiating inside a waveguide.
4. The wave leaves the waveguide and radiates towards a reflector.
1. The radio creates an electrical current oscillating at high frequency.
2. The wave is guided down a coaxial cable.

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 a fraction of the wavelength it handles.
- Antenna impedance must match the transmission line.
- There is no “best antenna” for every application; the choice is always a trade-off between reaching long distances and covering a wide area.
- 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/