Antenna Theory fundamentals

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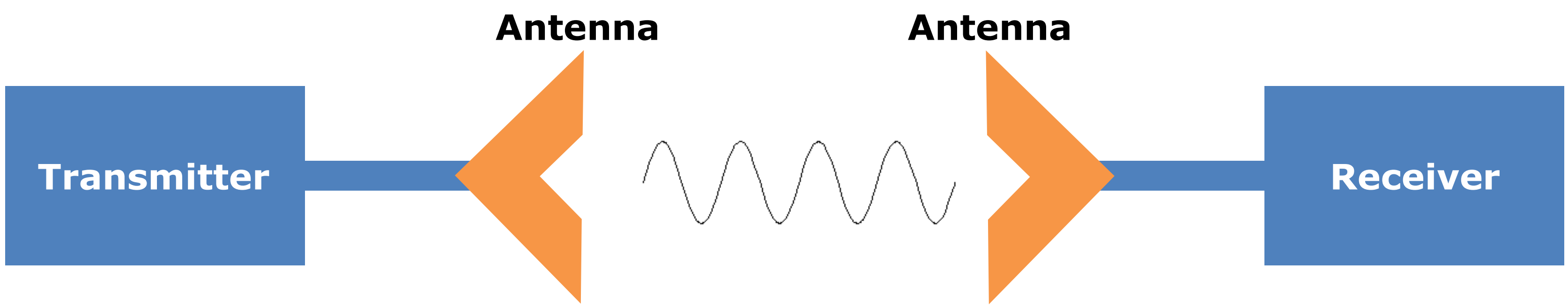
Outline

- **Antenna Fundamental**
- **Antenna Types**
- **Rules, Regulations, and Recommendations for Antenna Patterns**

Antenna Fundamentals

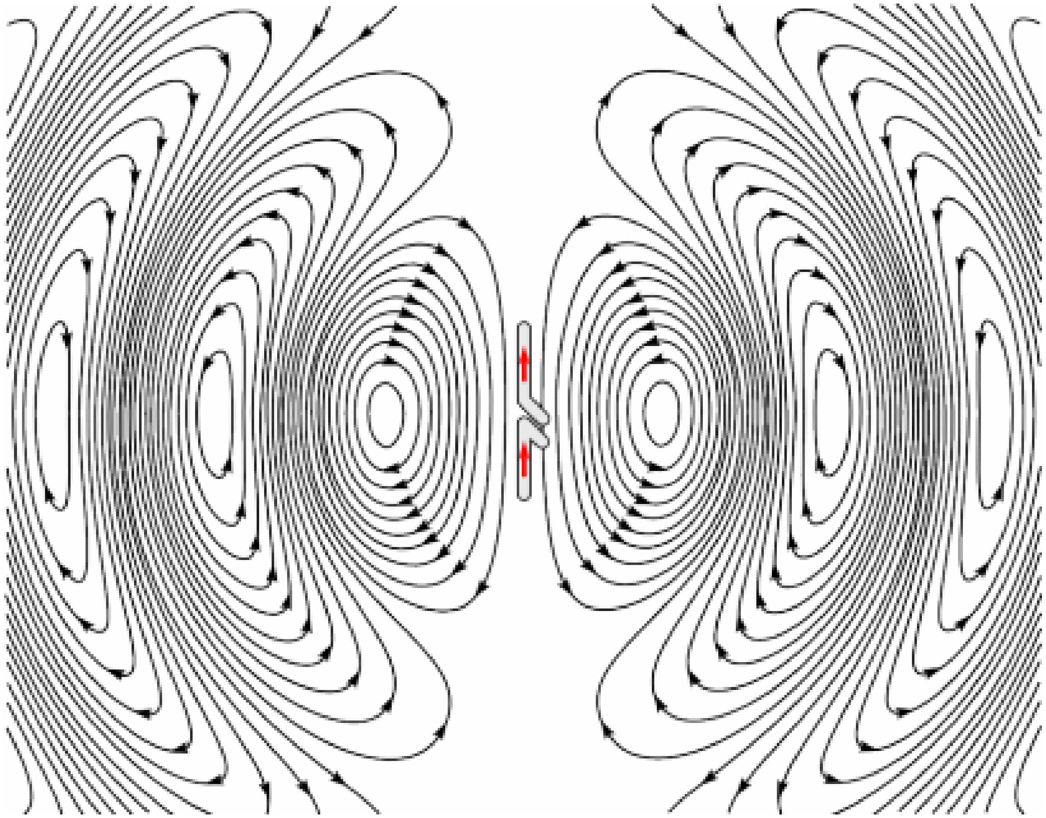
Antenna Definition

- “A means for radiating or receiving radio waves” (IEEE Std 145–1983)



- An antenna is a <u>passive structure</u> that provides a transition between a <u>guided wave</u> (in a transmission line or waveguide) and a <u>propagating wave</u> (usually in free-space), and focuses the electromagnetic energy into particular direction

Radiation



Two dimensional representation of the electric field radiated by a <u>wire antenna</u>

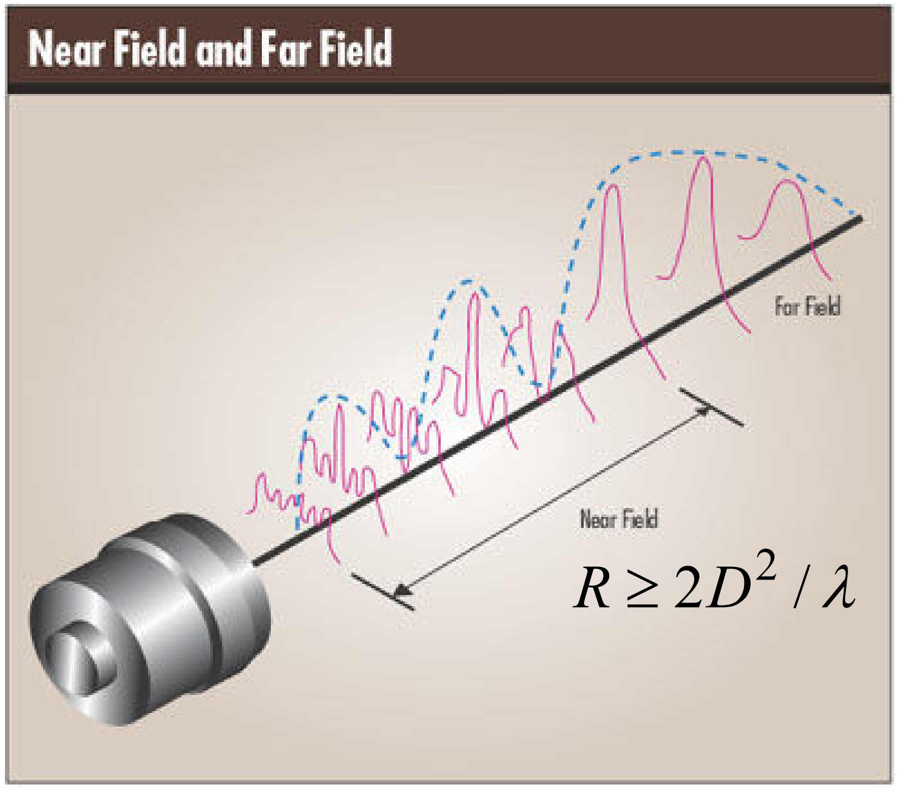
The fields are the result of solving the Maxwell equations

$$A = \frac{\mu}{4\pi} \int \frac{Ie^{-kR}}{R} dl'$$

$$H_A = \frac{\nabla \times A}{\mu}$$

$$E_A = -jwA - \frac{j}{w\varepsilon\mu} \nabla(\nabla.A)$$

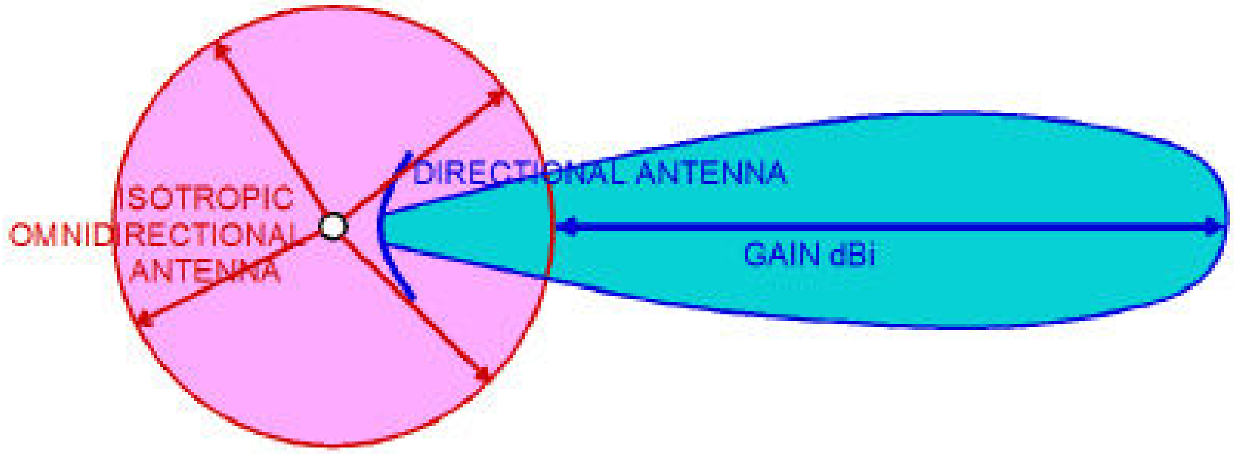
Near-Field vs Far-Field Region



D: Diameter or longest antenna dimension

λ = wavelength, meters;

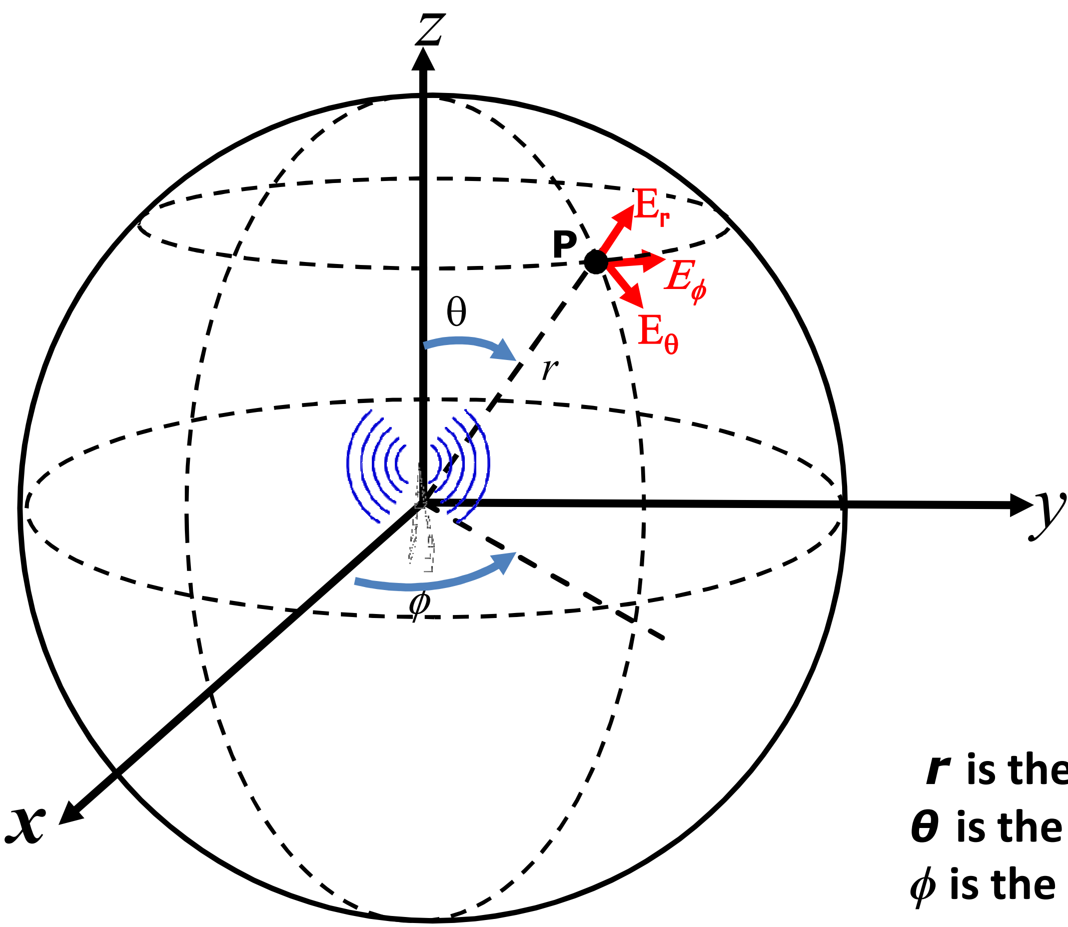
Types of Antennas



- An <u>isotropic antenna</u> is a fictitious antenna that radiate the power equally in all directions
- A <u>directional antenna</u> is a source of electromagnetic wave which transmits or receives more power in some directions than others
- <u>An omnidirectional antenna</u> is an directional antenna that can provide uniform radiation in a reference plane

Antenna coordinate systems

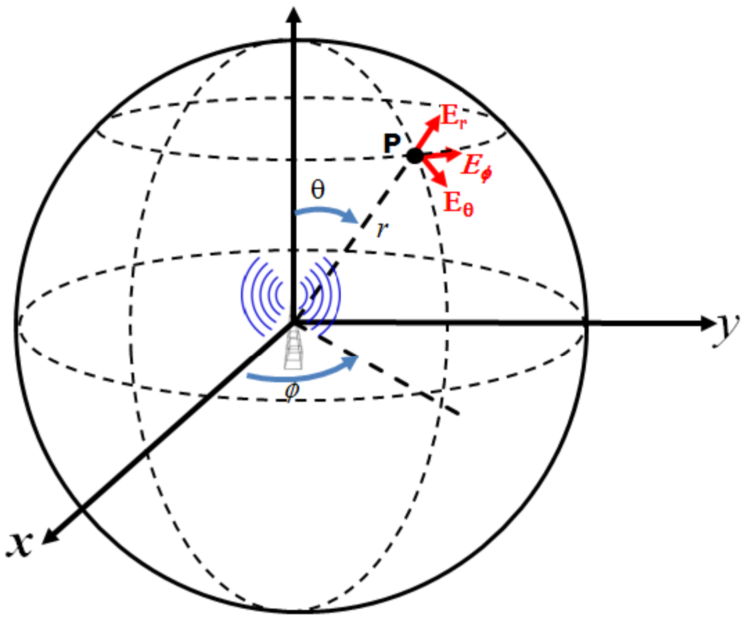
- Real antennas radiate in all directions
- They characteristics are explained better in spherical coordinate system



r **is the radius distance**
θ **is the elevation angle**
ϕ **is the azimuth angle**

Communication Link

- The signal power received by a radio system in the at point P is given by



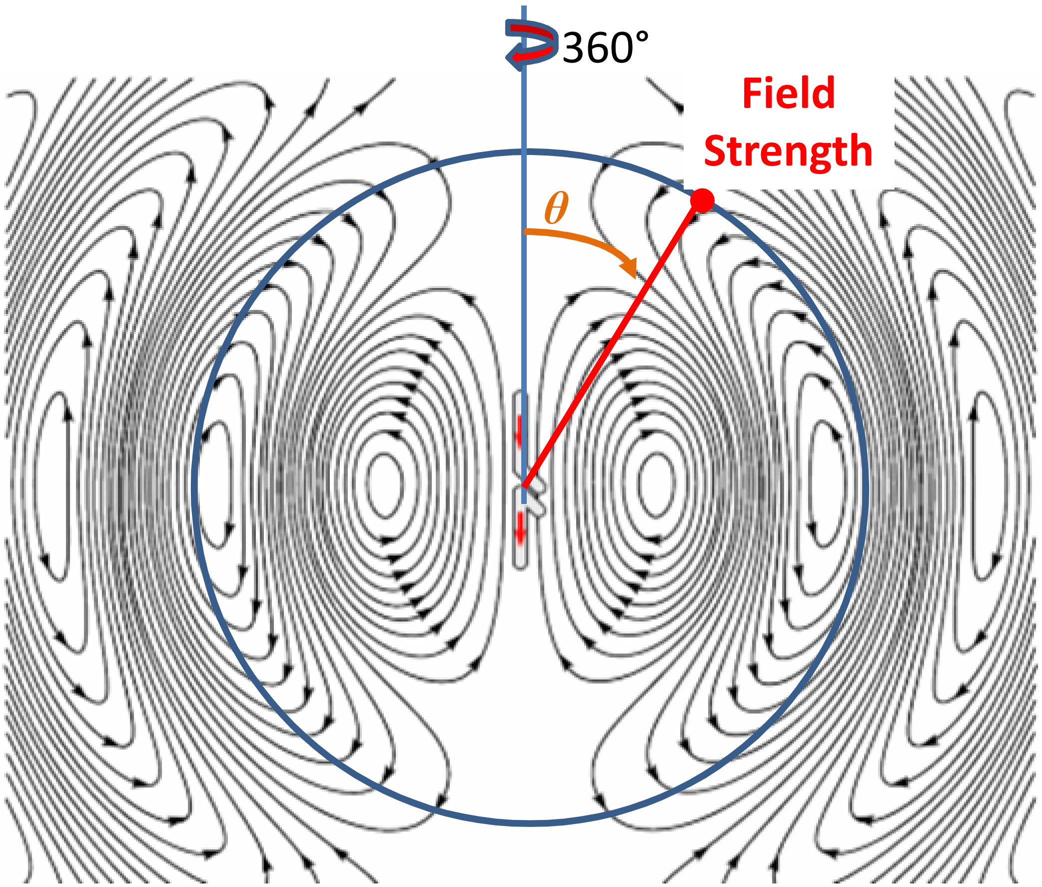
$$P_r(r,\theta,\phi) = \frac{G_t(\theta_t,\phi_t)G_r(\theta_r,\phi_r)\lambda^2 L_p P_t}{(4\pi r)^2}$$

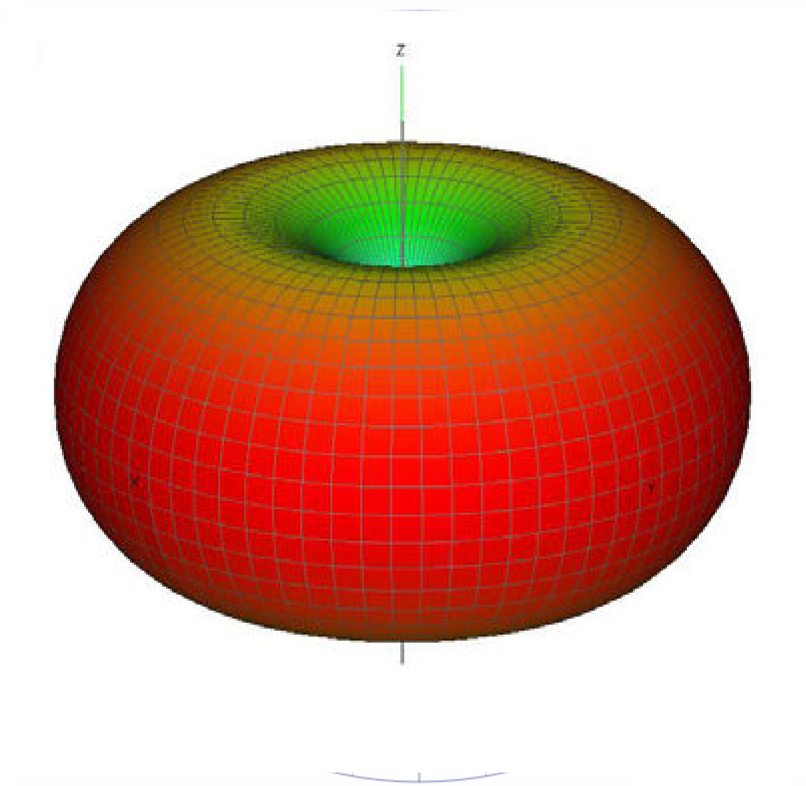
P_r: received power, watts;
$G_t(\theta_t,\phi_t)$: transmitting antenna power gain;
$G_r(\theta_r,\phi_r)$: receiving antenna power gain;
λ = wavelength, meters;
L_p: propagation loss
P_t: transmitter power, watts;
r = range, meters

- The received power not only depend on the system characteristics, but also of the direction of the antenna observation point

Radiation Pattern

- The radiation pattern is a graphical representation of the geometrical distribution of the radiated power over all space



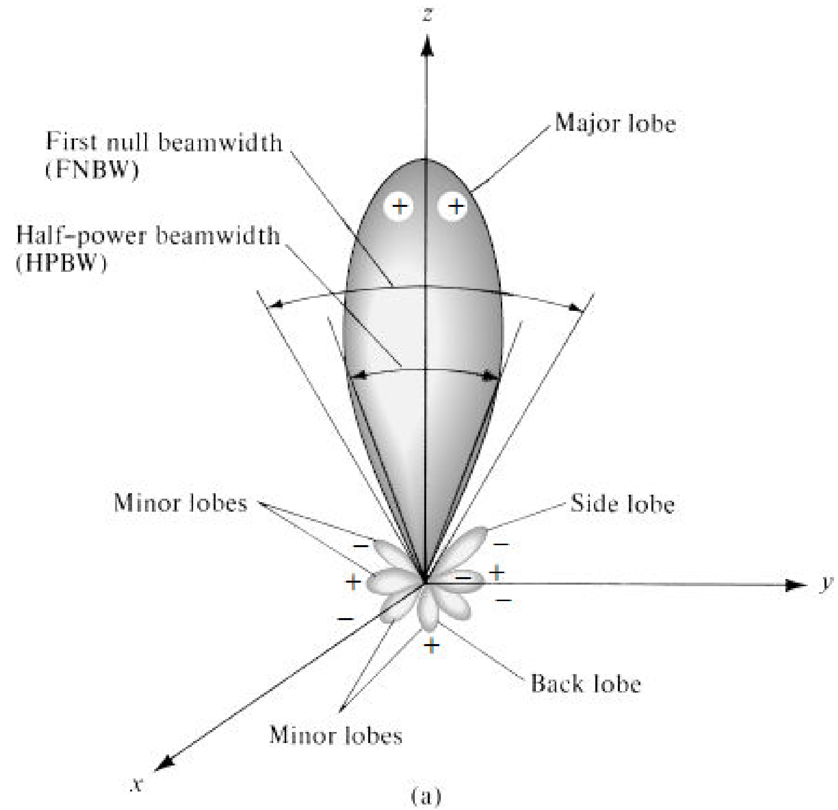


- **Directional antennas may present radiation patterns with several lobes**

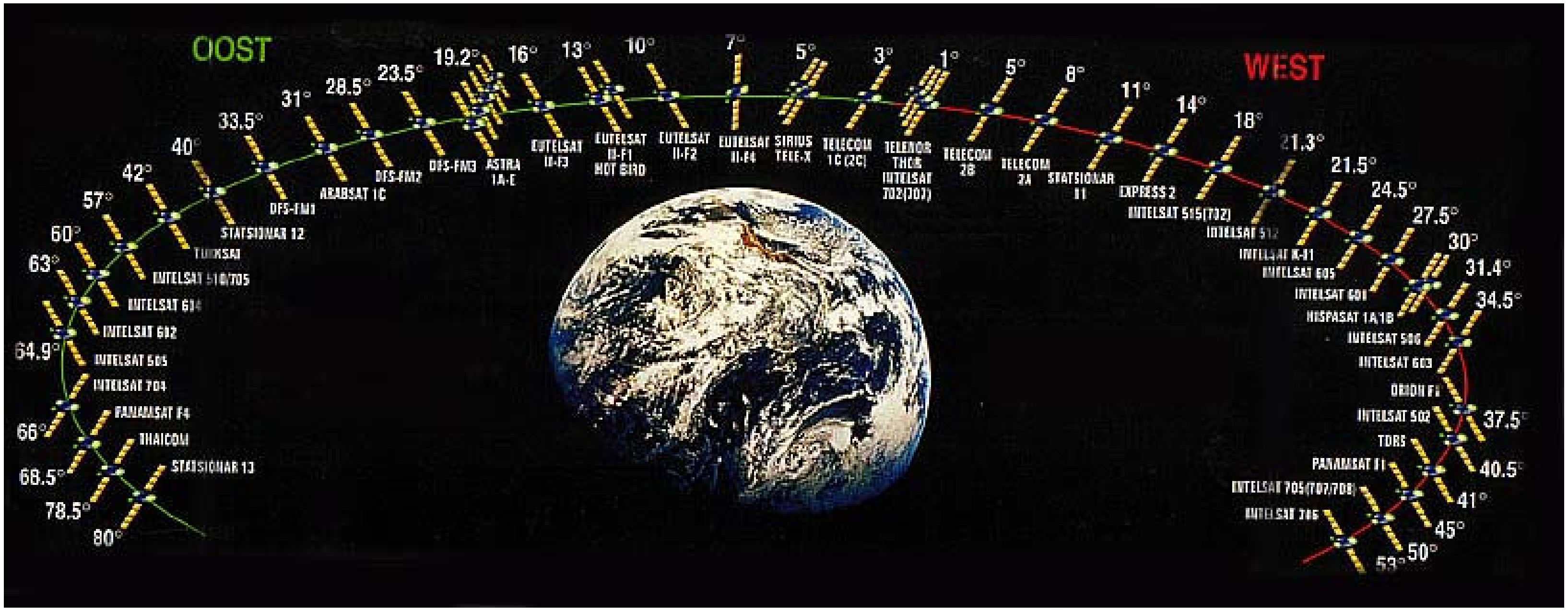
- **Main lobe represents the desired radiation**

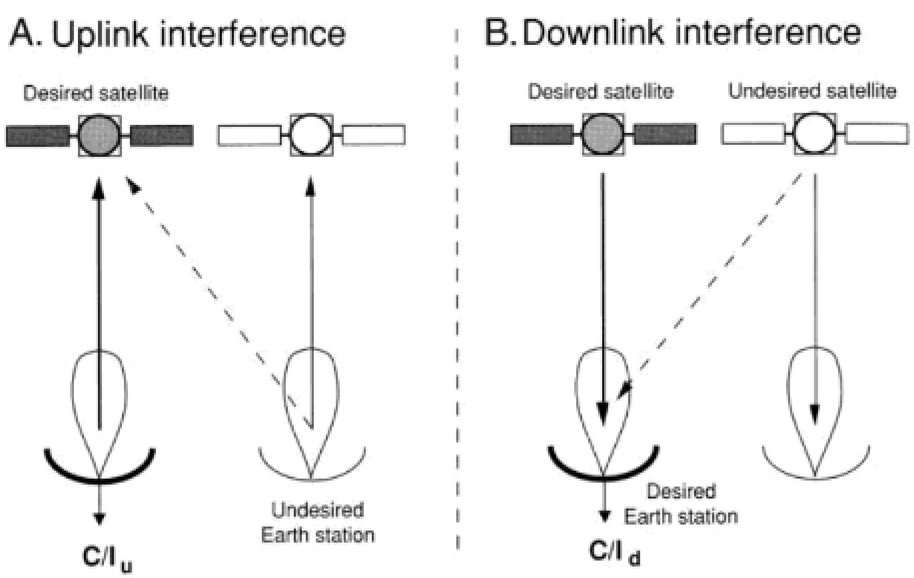
- **Minor lobes represents the undesired radiation**

- **The proper design or selection of the radiation pattern of an antenna helps to reduce RF interference problems**

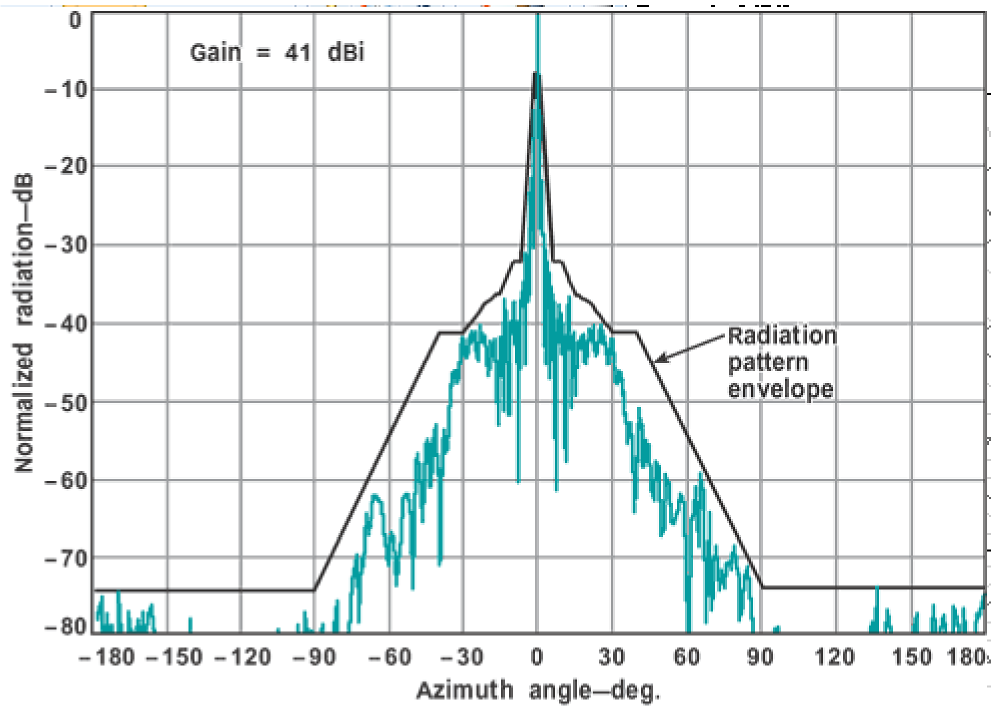


Example 1: Satellite communication

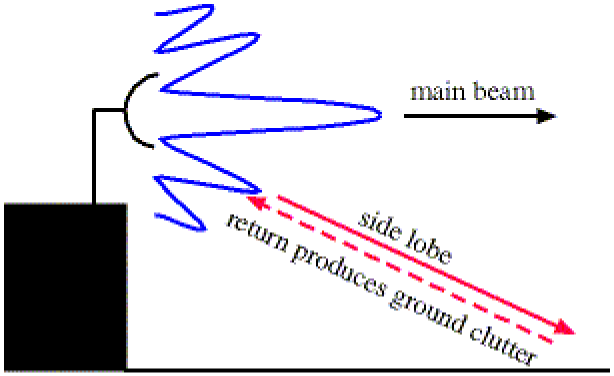


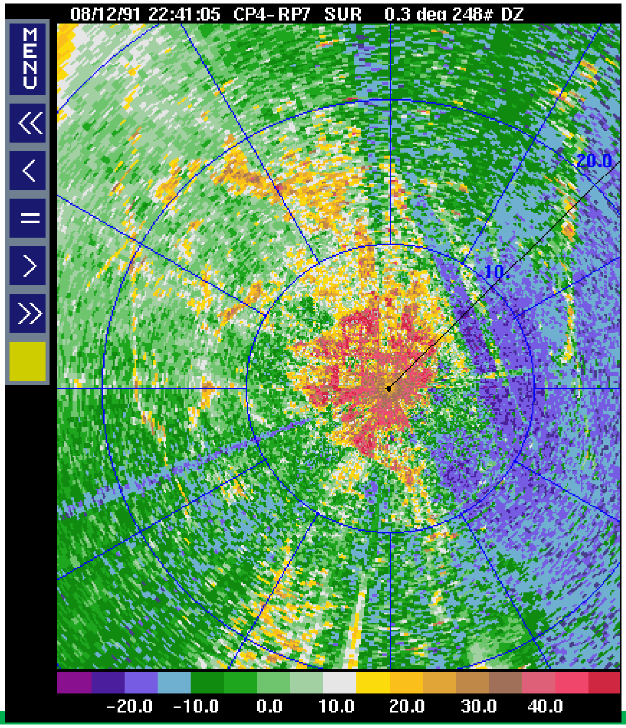


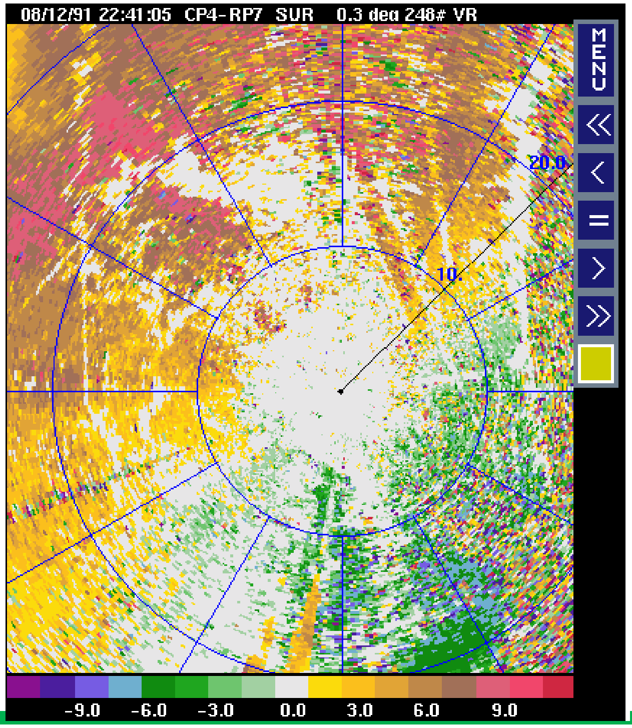
- To prevent RF interference between adjacent satellite:
  - Narrow beamwidth
  - Low sidelobes
  - Adequate Gain


Gain = 41 dBi
Normalized radiation—dB
0
−10
−20
−30
−40
−50
−60
−70
−80
−180 −150 −120 −90 −60 −30 0 30 60 90 120 150 180
Azimuth angle—deg.
Radiation pattern envelope

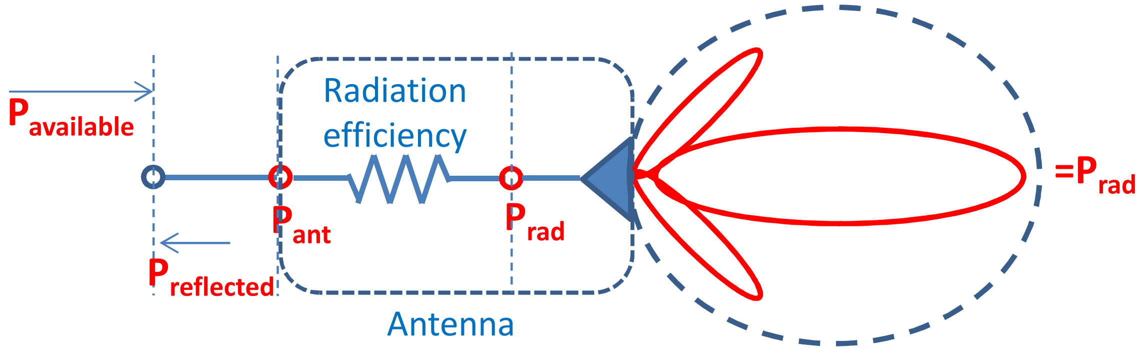
Example 2: Meteorological Radar







Power



- The available power, $P_{available}$, is the total power supplied by the transmitter

- The antenna power, P_{ant}, is the total power input to the antenna system. It generates the far-field radiating EM wave, the non-radiating EM field that stores energy in the near field, and joule heat.

- The far-field radiated power, P_{rad}, is the total radiated power carried by the far-field EM wave. P_{rad} is independent of the propagation distance r and is a constant.

Radiated Power Density

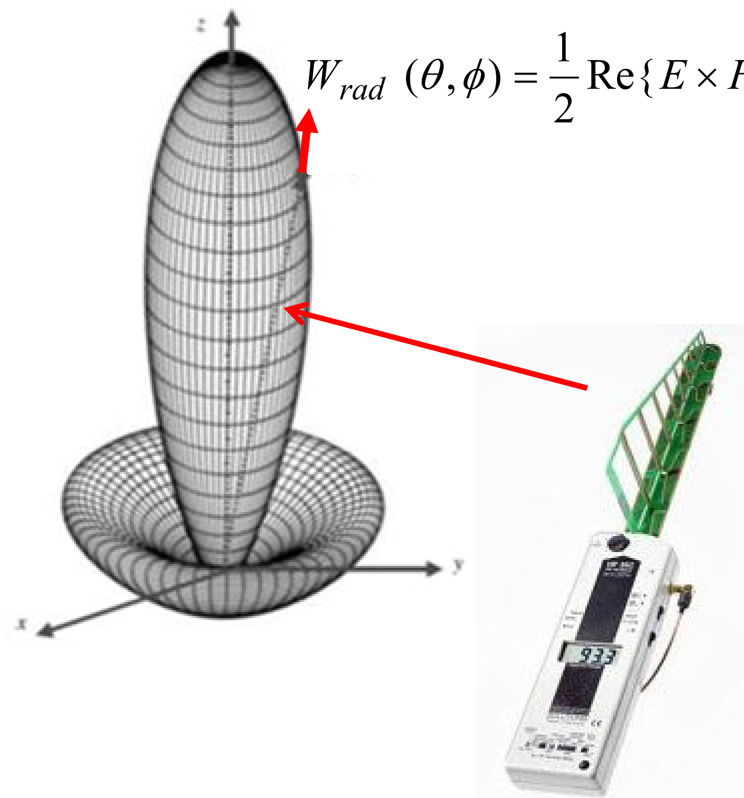
- The power density, $\mathbf{W_{rad}}$, is the product of the electric and magnetic fields at a particular location (θ, ϕ) in space.

- $\mathbf{W_{rad}}$ is given in watts/meters^2

- We can be measured with power meters

- When regulating radio interference between radio systems, one of the specifications is maximum allowable W_{rad} at the front end of a receiving antenna

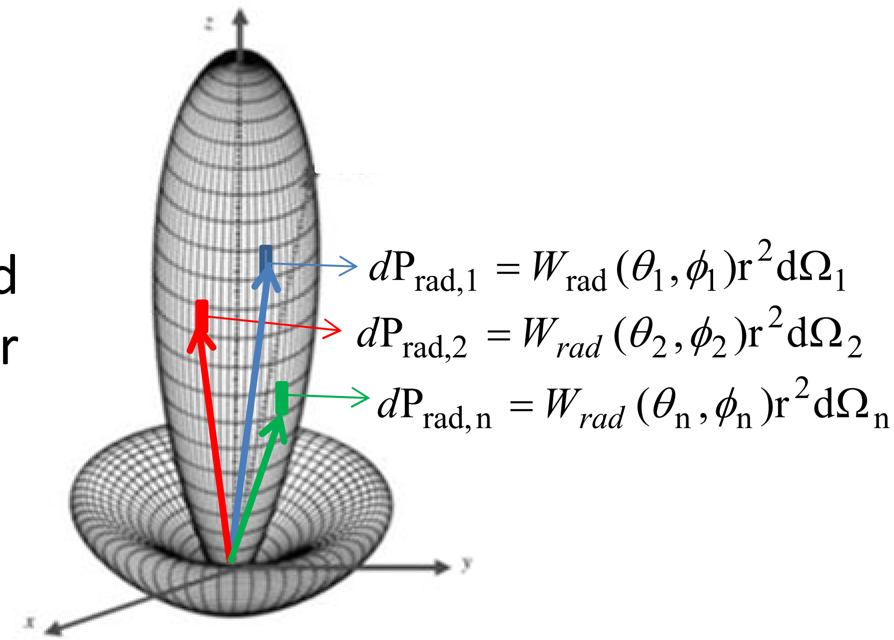
$$W_{rad}\ (\theta,\phi) = \frac{1}{2}\mathrm{Re}\{E \times H^*\}$$



Radiated Power

- The far-field radiated power, P_{rad}, is the total radiated power carried by the far-field EM wave.

- Since the antenna radiates EM fields in all directions, the total power delivered by the antenna is obtained by summing all differentials of power ***dP_{rad}*** that intercepted into an infinitesimal solid angle $d\Omega$

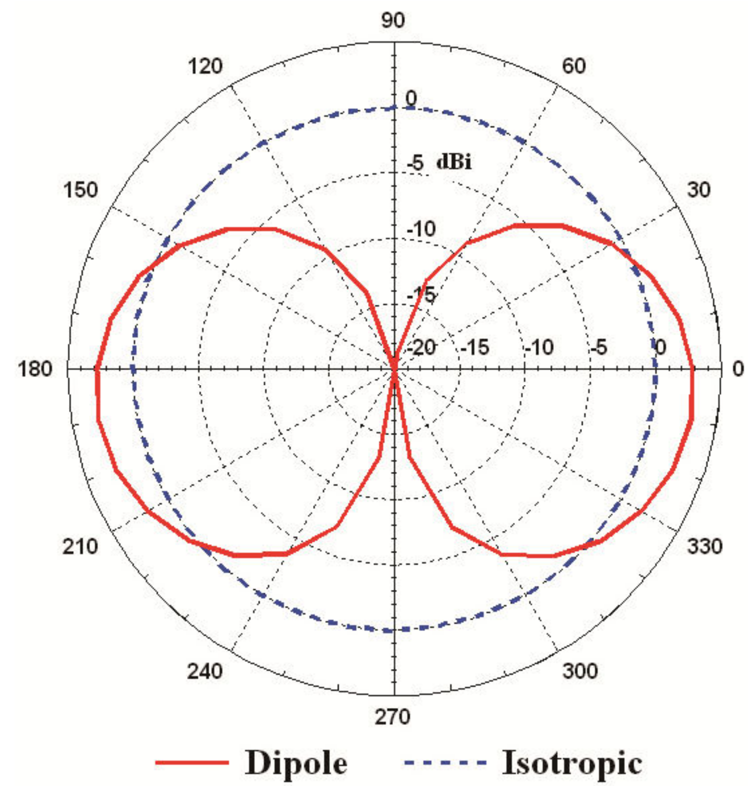


$$P_{rad} = dP_{rad,1} + dP_{rad,2} + .. + dP_{rad,N}$$
$$= \sum W_{rad}(\theta_n, \phi_n) r^2 d\Omega_n$$
$$= \int_0^{2\pi} \int_0^{\pi} W_{rad} R^2 \sin\theta \, d\theta \, d\phi$$

Directivity and Gain

- The directive gain of Directivity is given by

$$D(\theta,\phi) = \frac{\text{DUT radiation intensity}}{\text{isotropic radiation intensity}}$$

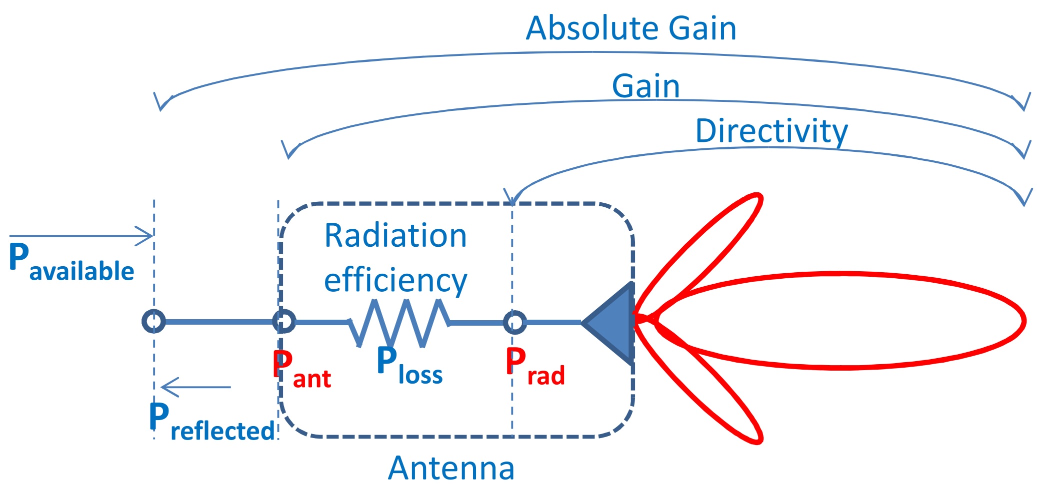


Gain

- <u>Gain</u> is the directive gain affected the antenna efficiency

$$G(\theta,\phi) = \varepsilon_a D(\theta,\phi)$$

$$\varepsilon_a = \frac{P_{rad}}{P_{ant}} = \frac{P_{rad}}{P_{rad} + P_{ant}} = \text{antenna efficiency} < 1$$



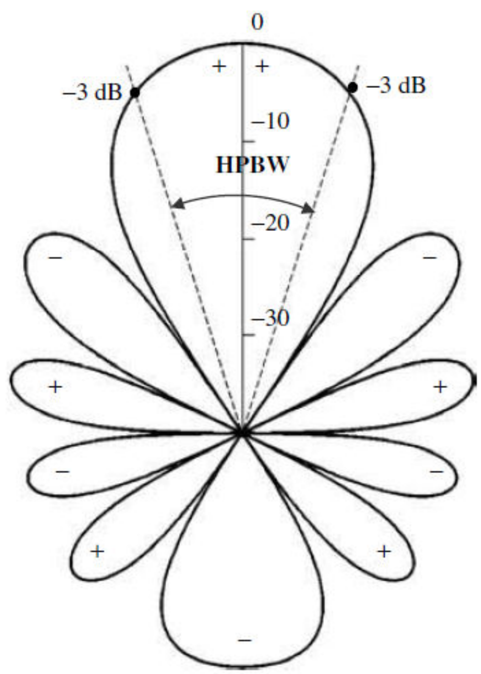
- Usually, it is practical for antenna engineer expresses the directive and gain in decibels

$$D_{\mathrm{dB}}(\theta,\phi) = 10\log_{10} D(\theta,\phi)$$

$$G_{\mathrm{d}B}(\theta,\phi) = 10\log_{10} G_{\mathrm{d}B}(\theta,\phi)$$

Beamwidth

- The beamwidth or High Power Beamwidth (HPBW) is the angle at which the power gains are one-half of the peak gain (-3dB) relative to the maximum, separated by the maximum.

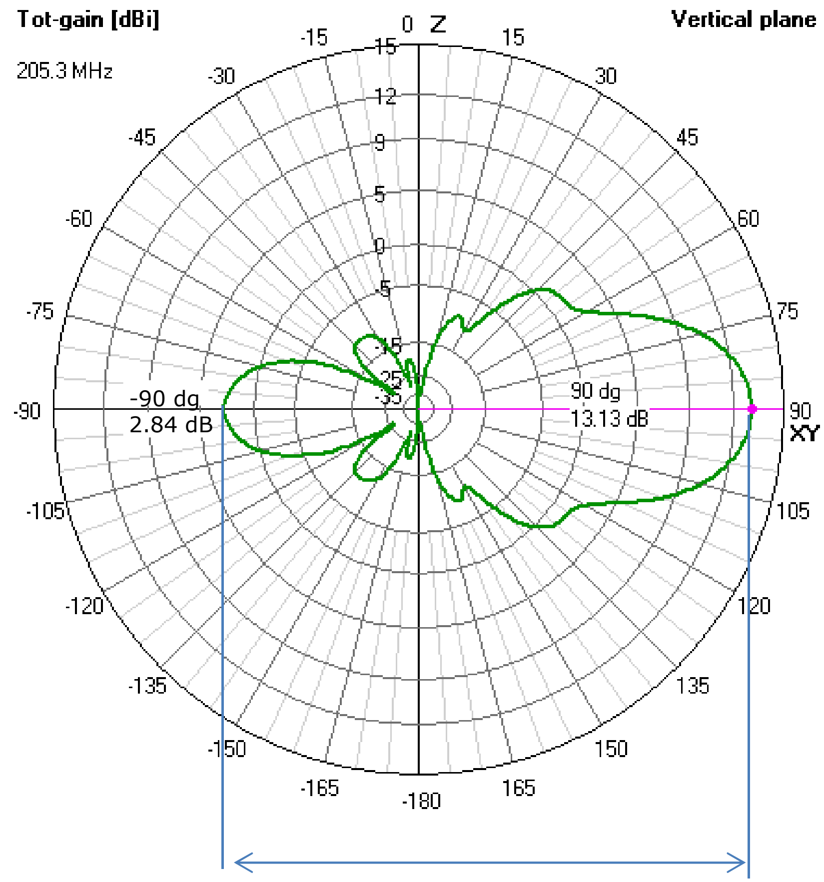


$$\mathrm{H}PBW = \theta_{\mathrm{3dB,left}} - \theta_{\mathrm{3dB,rigth}}$$

Front-to-Back Ratio

- Front to Back Ratio (F/B Ratio) is a parameter that describe the extent of backward radiation.

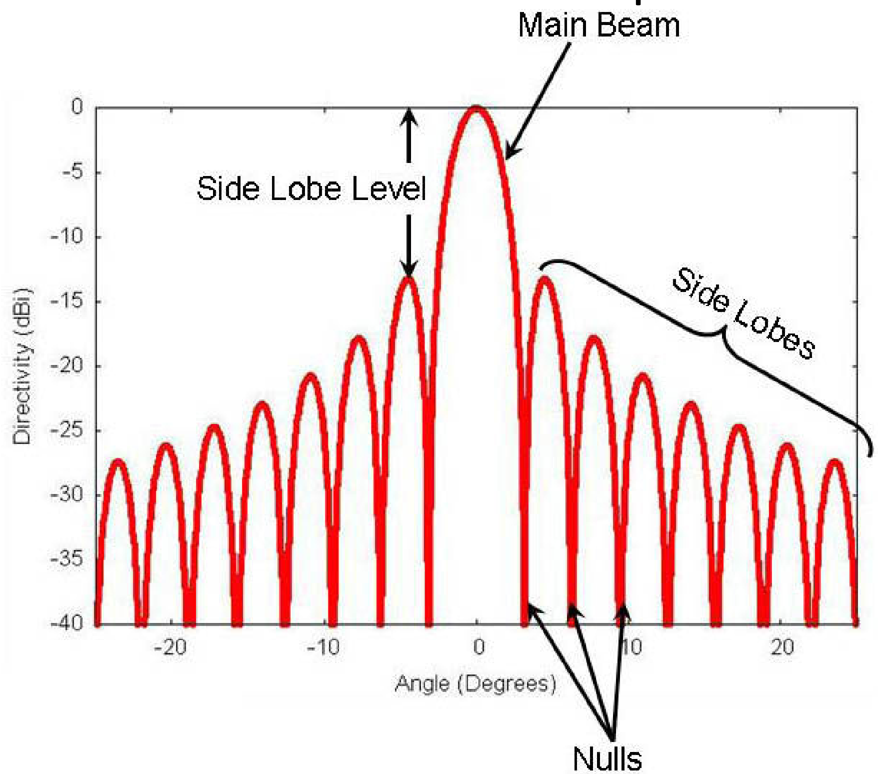
- The F/B ratio is defined as the difference in decibels between the value of gain in the direction of maximum radiation (front) and the value of the radiation pattern in the opposite direction (back).



$$FBR_{dB} = 13.13 - 2.84 = 10.29 \text{ dB}$$

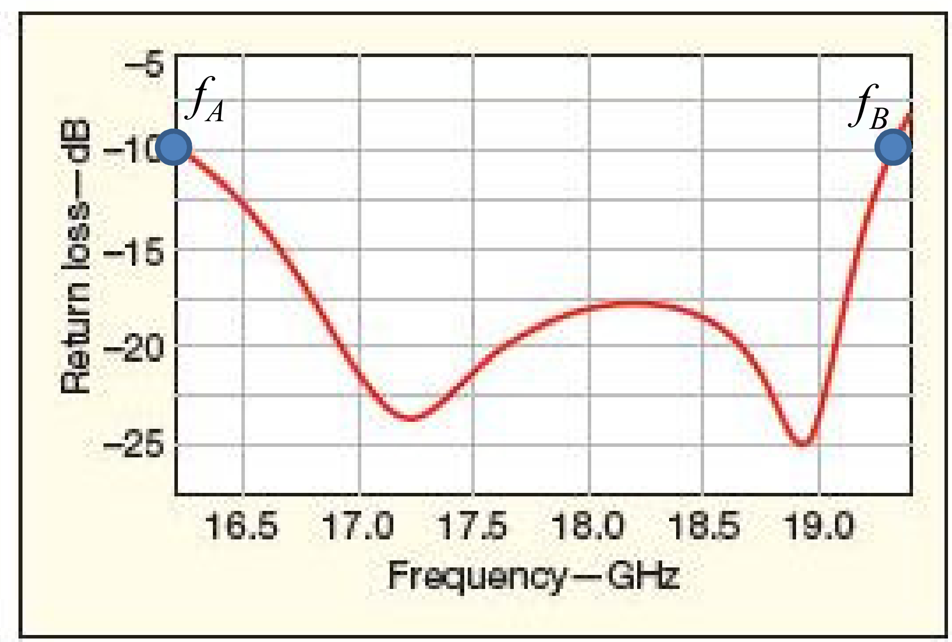
Sidelobe level

- Side Lobe Level (SLL) is a parameter used to describe the level of side lobe suppression.
- High side lobes are often not desired
- The side lobe level is defined as the difference in decibels between the main beam peak value and the side lobe peak value.



Bandwidth

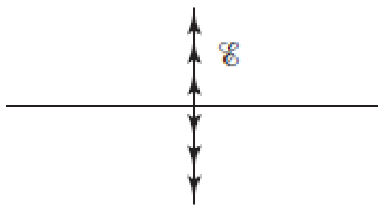
- The bandwidth of an antenna is the range of frequencies over which the antenna can operate correctly
- We measured it from the plot of return loss versus frequencies .
- Usually defined as the range of frequencies over which the antenna has a return loss below -10 dB



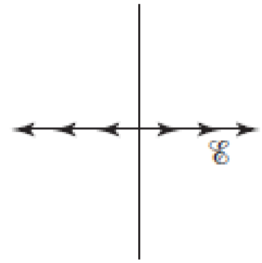
$$BW = f_B - f_A$$

Polarization

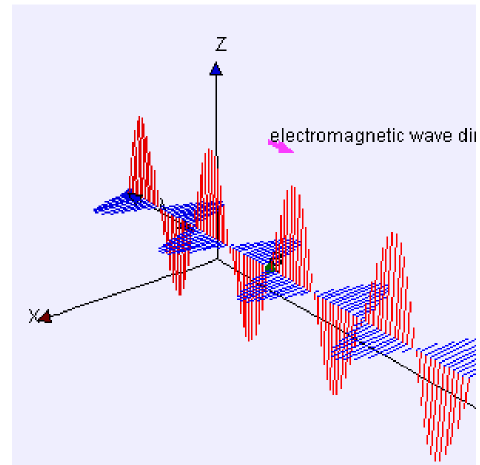
The polarization of an antenna is the polarization of the wave radiated in a given direction by the antenna when transmitting



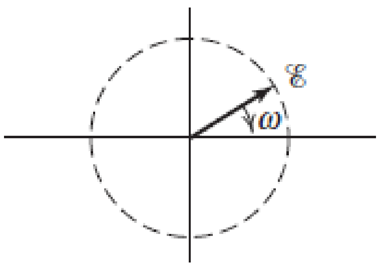
(a) Vertical linear polarization.



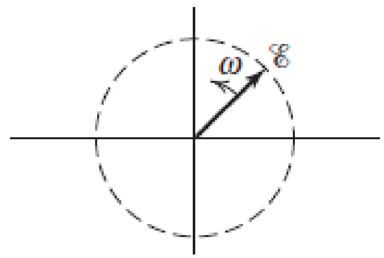
(b) Horizontal linear polarization.



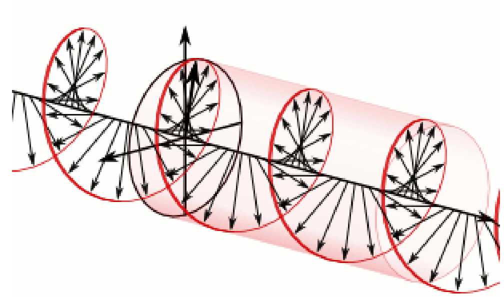
Vertical polarization



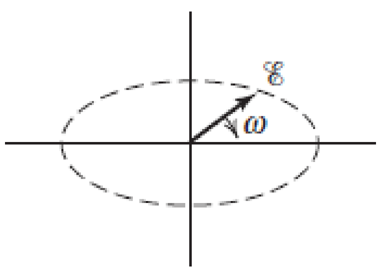
(c) Left-hand circular polarization.



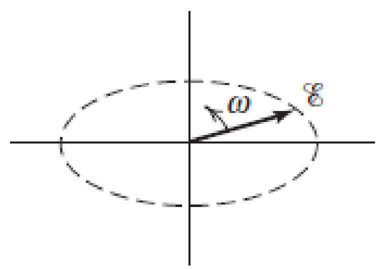
(d) Right-hand circular polarization.



Left-hand circular polarization



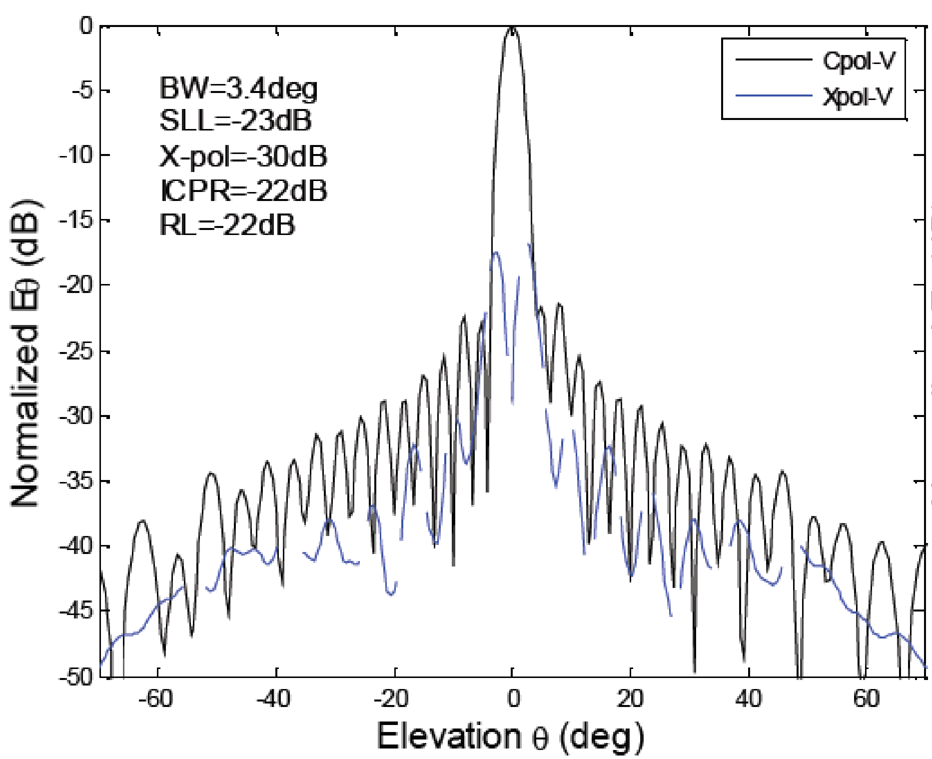
(e) Left-hand elliptical polarization.



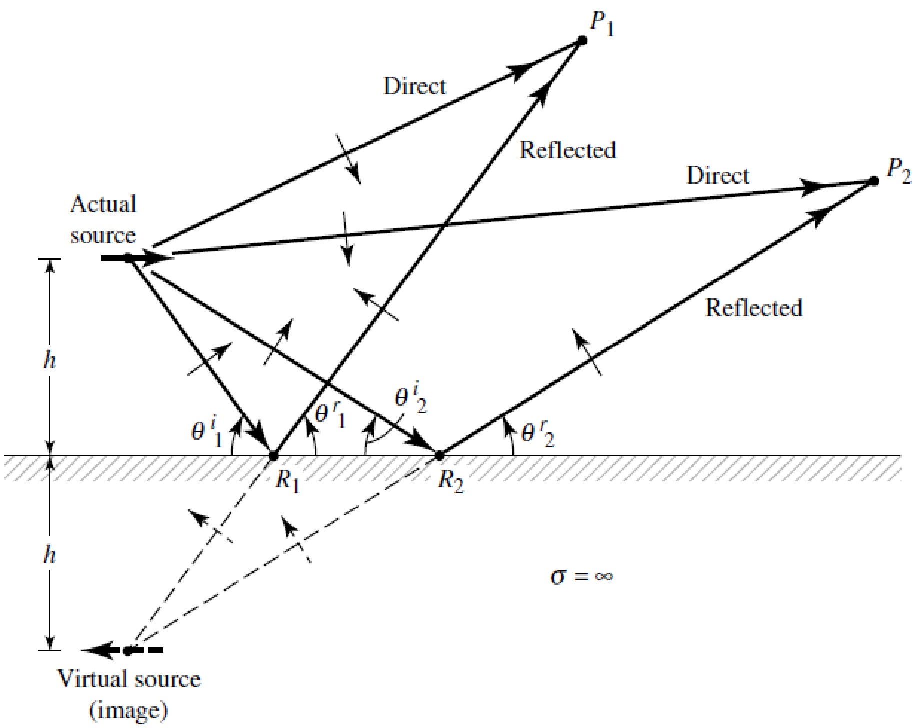
(f) Right-hand elliptical polarization.

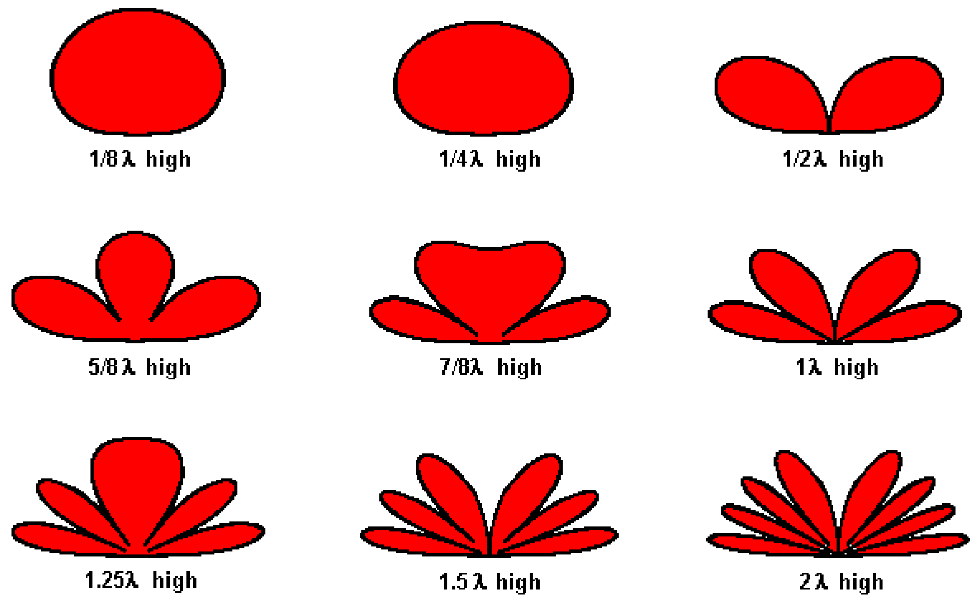
Co-polarization and Cross-Polarization

- Most of the antennas are designed for one polarization, but the unavoidable imperfection of the antenna design can cause the antenna to have cross-polarization characteristics in its operations.
- When a radiation pattern is measured as the same polarization as the antenna's designated polarization, we called **Co-Polarization pattern**
- while its orthogonal pair, it called **Cross-Polarization pattern**



Ground Effect

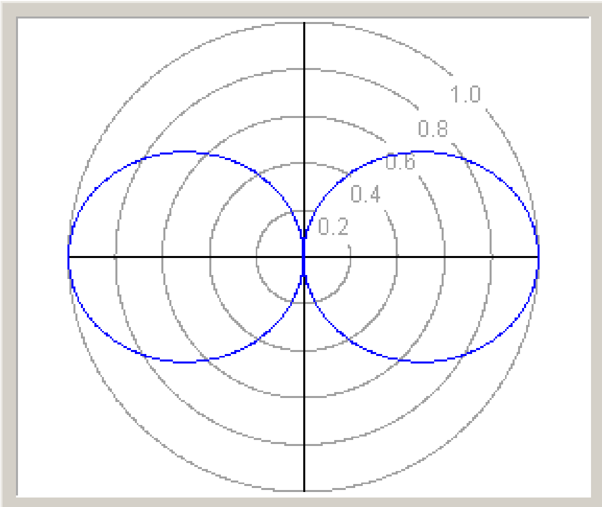




Radiation pattern for an horizontal dipoles placed at various height above a flat ground off the ends of the antenna wire

Antenna Types

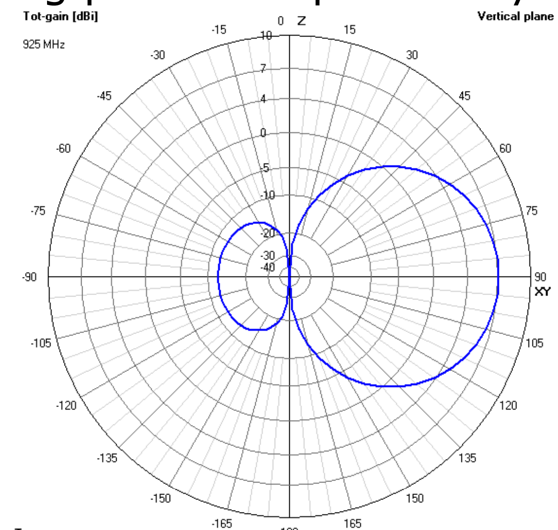
Wire antennas

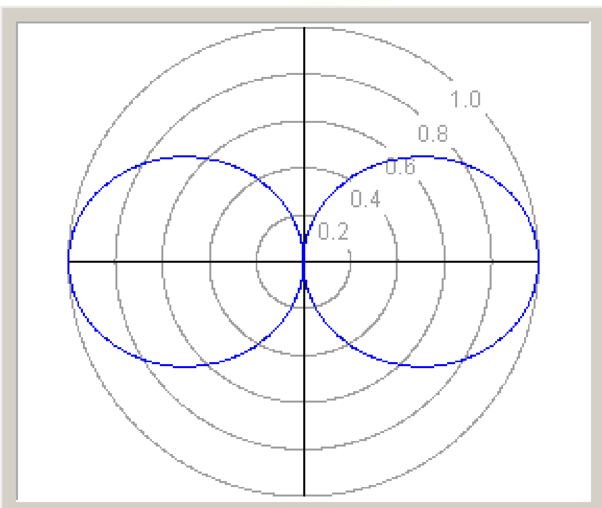


Dipole

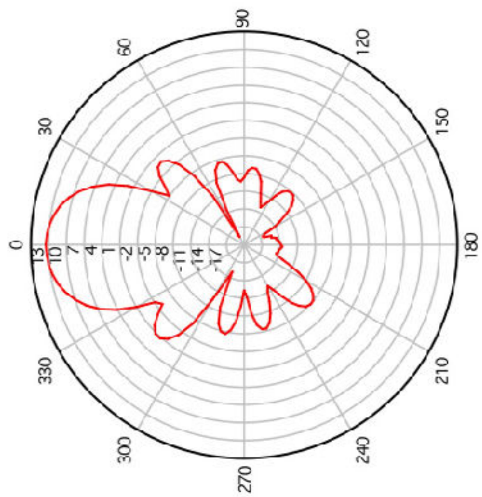
Biconical

Log periodic Dipole Array

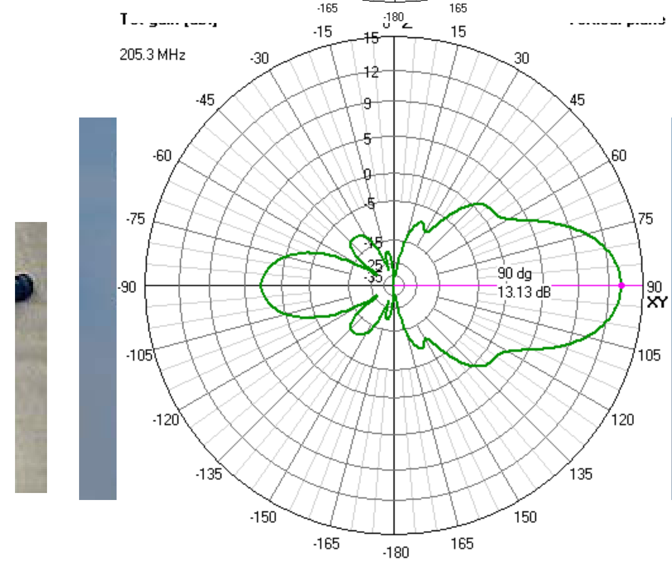




Loop

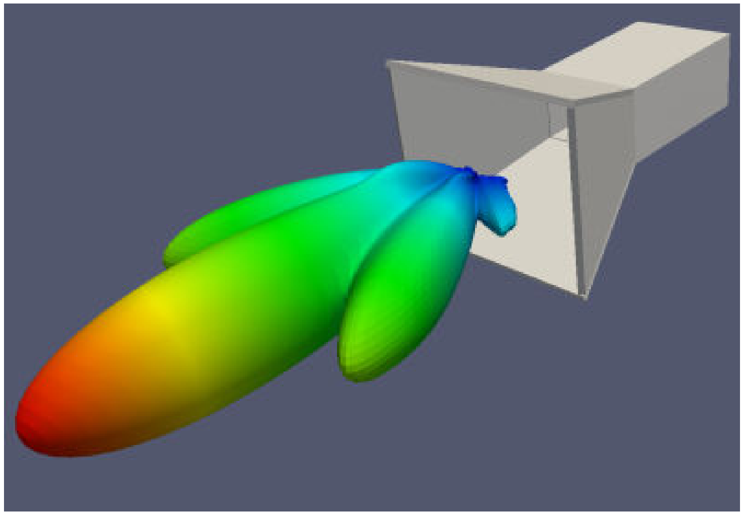


Helix

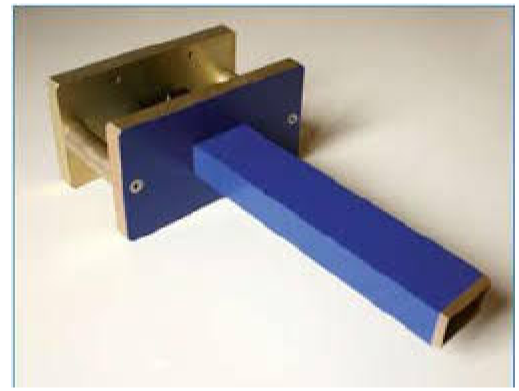


Yagi-Uda

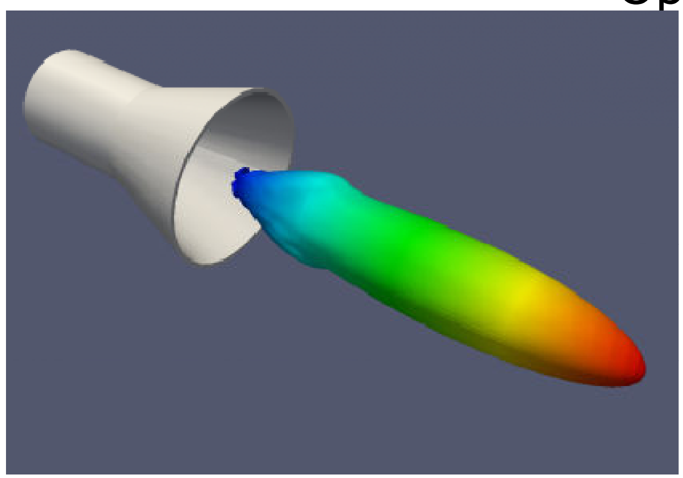
Aperture antennas



Horn antenna



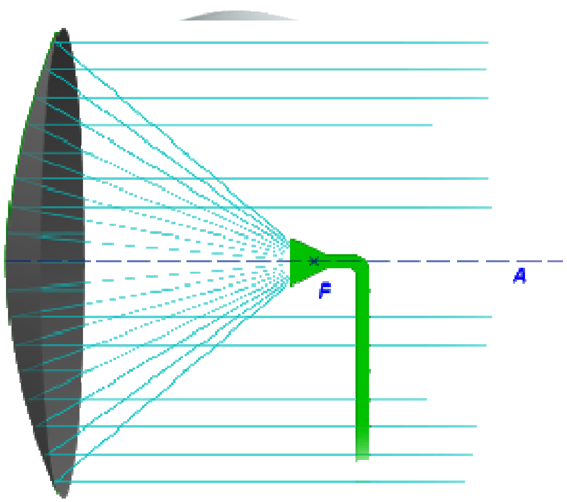
Open waveguide antenna



Conical antenna

Reflector Antenna

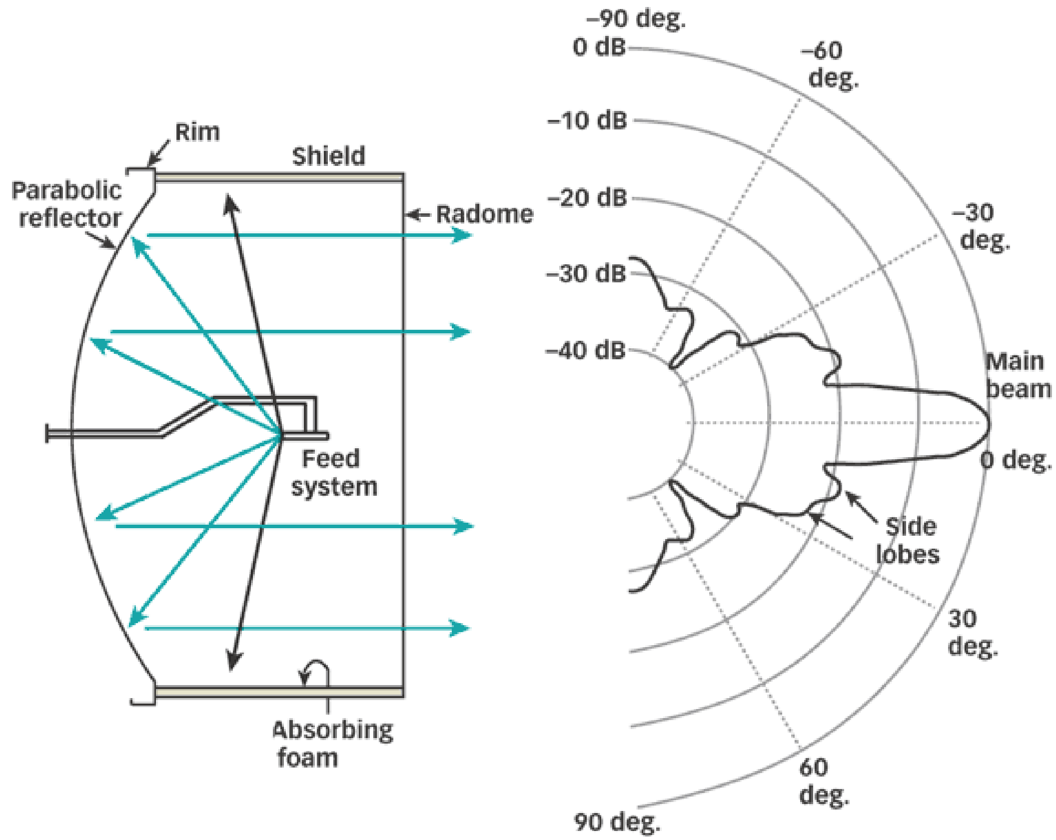
Corner reflectors



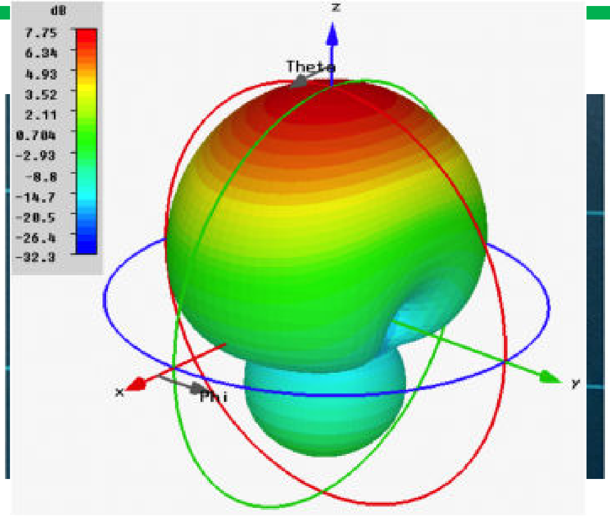
Parabolic reflector

Cassegrain reflector

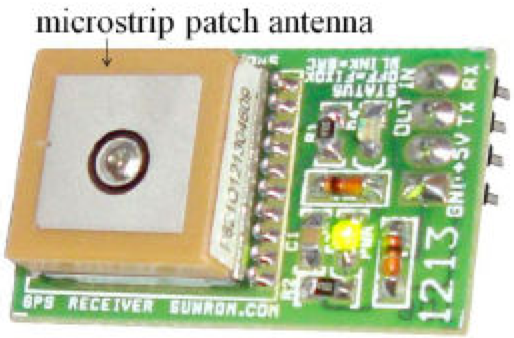
Gregorian reflectors


Rim
Shield
Parabolic reflector
Radome
Feed system
Absorbing foam
–90 deg.
0 dB
–10 dB
–20 dB
–30 dB
–40 dB
–60 deg.
–30 deg.
Main beam
0 deg.
Side lobes
30 deg.
60 deg.
90 deg.

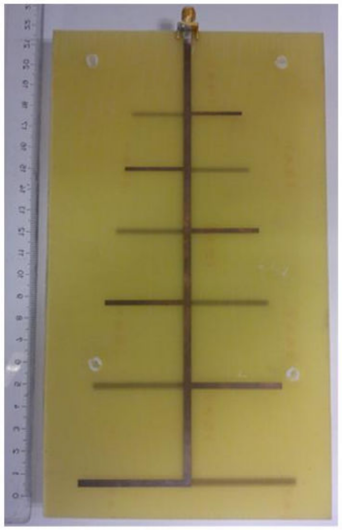
Microstrip



Patch

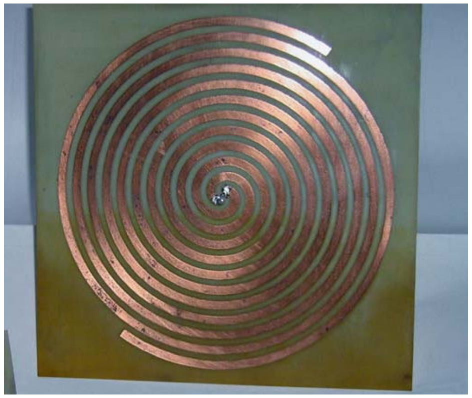


Microstrip Patch Antenna in
GPS Receiver Circuit Board



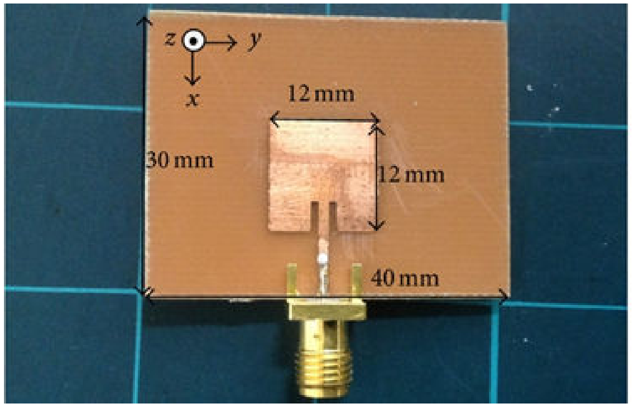
Log periodic

Dipole

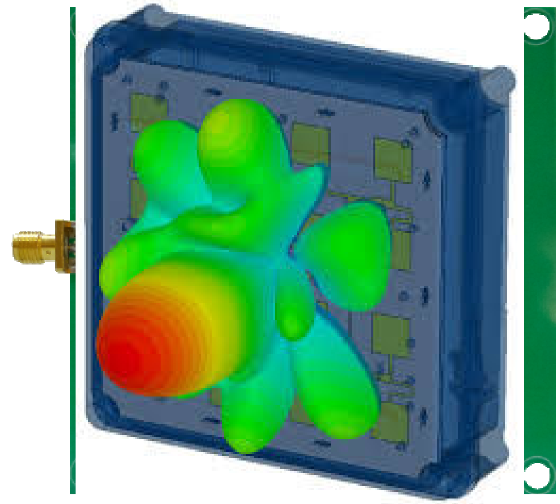


Spiral

Array antennas

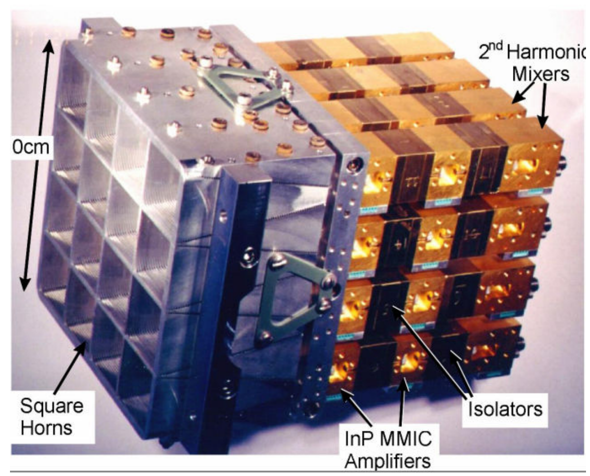


Patch

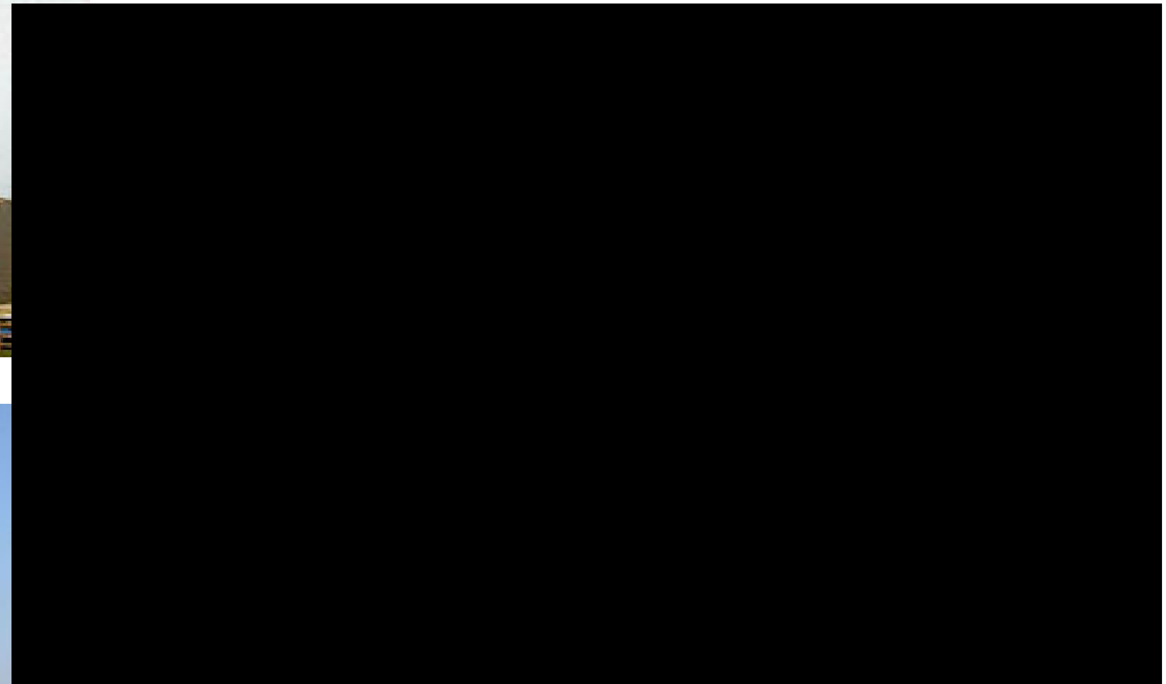


Array of patch antennas

Horn antenna

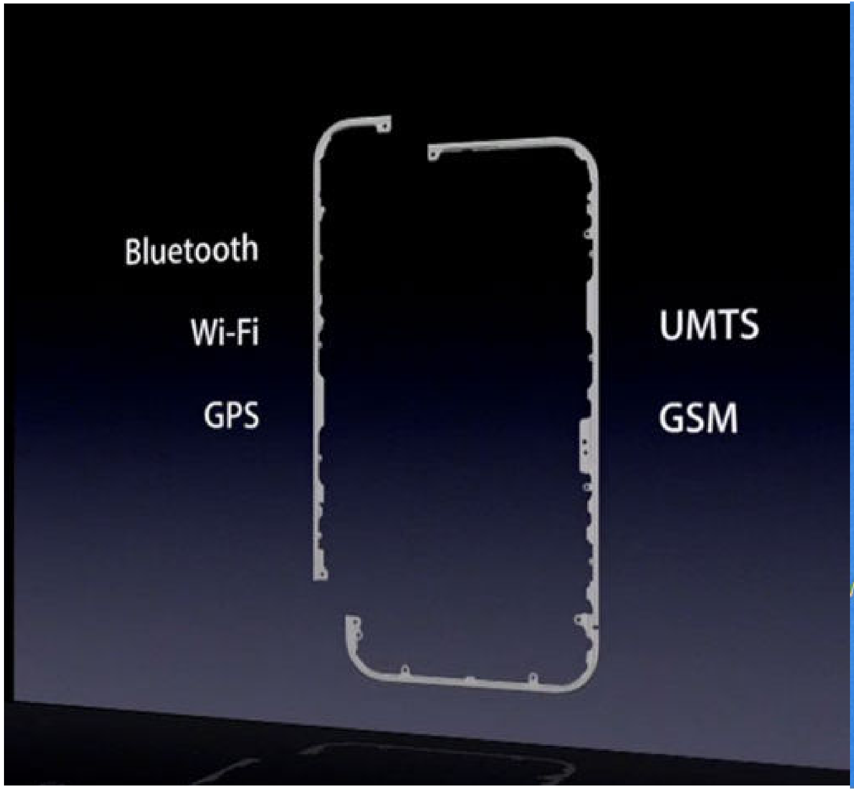


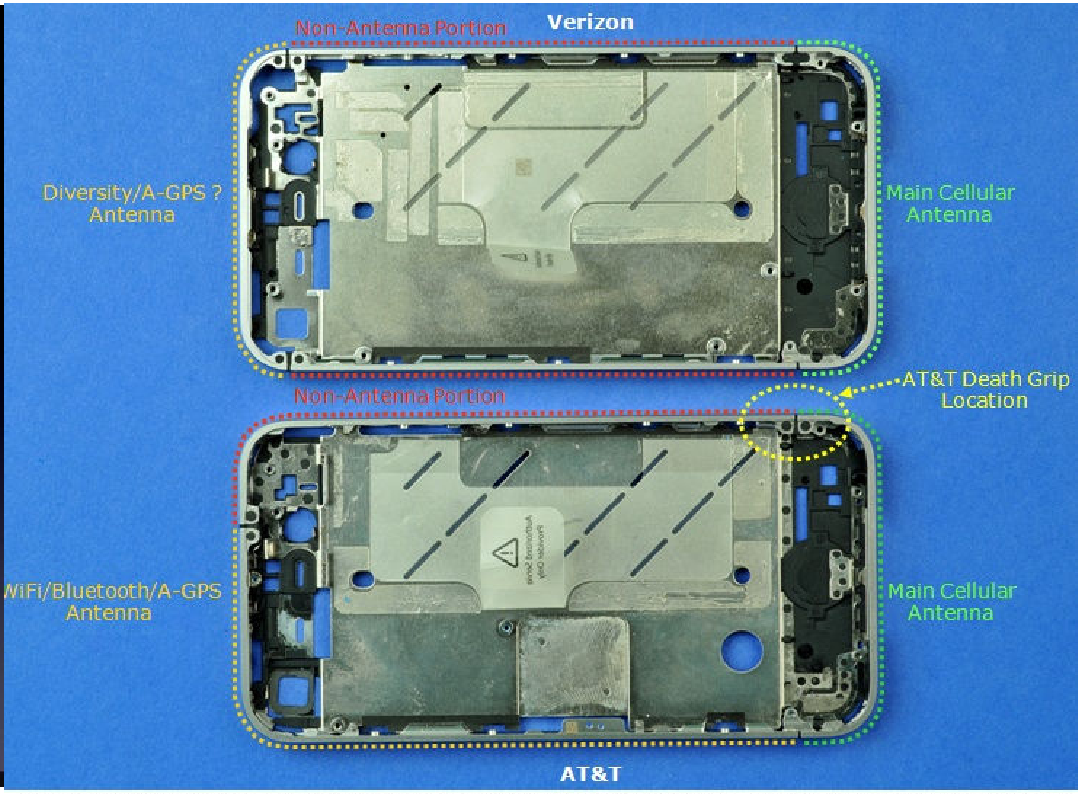
Array of horn antennas



Phased array antennas

- Iphone 4



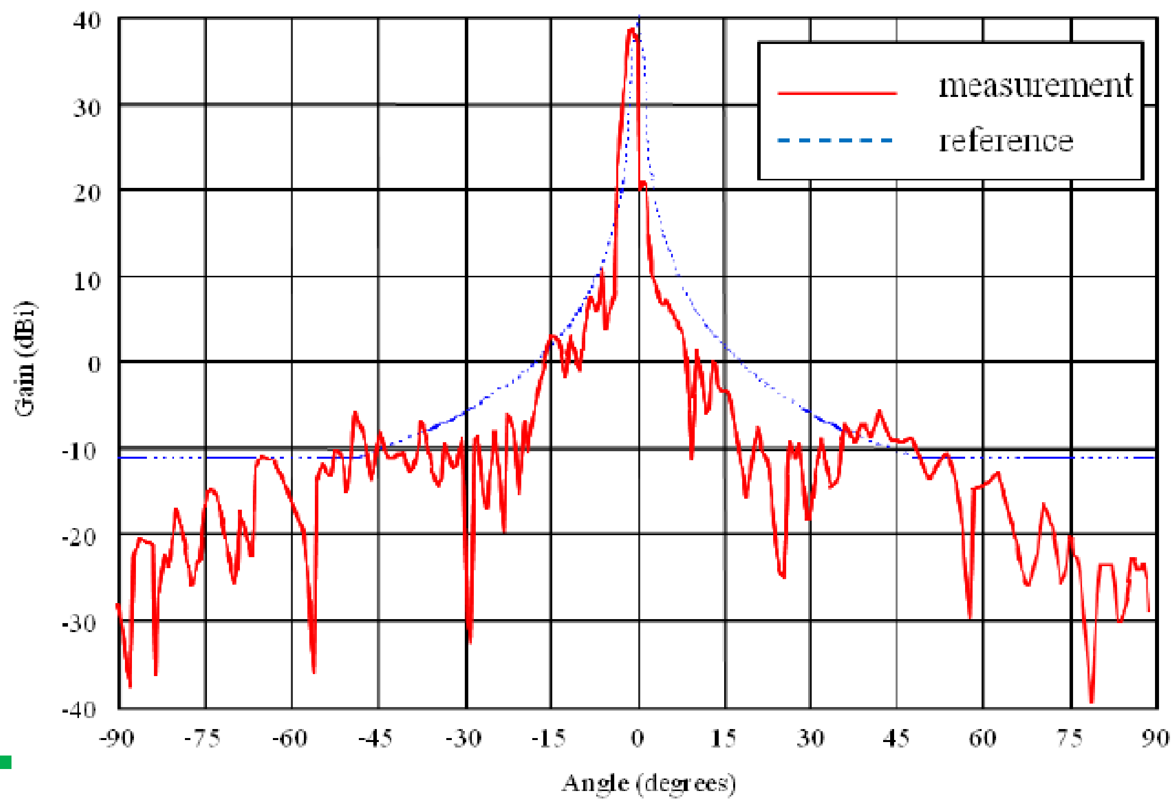


Comparison of the iPhone 4 antenna for the Verizon version (above) and AT&T version. Source: Chad Davis/UBM TechInsights

Rules, Regulations, and Recommendations for Antenna Patterns

Reference Radiation Pattern

- Considering that there is a need to control the levels of interference which may occur at difference radio services, due to various sources of interference, <u>a reference antenna pattern</u> is typically defined
- A reference radiation pattern is the envelope of the actual radiation pattern, and is usually artificially shaped to be symmetric to the mainbeam axis.



Antenna radiation performance standards

- Some sources for rules, regulations, and recommendations about antennas are:
  - NTIA Manual
  - Title 47 of the Code of Federal Regulations (47 CFR) for FCC
  - The ITU-R Radio Regulations (RR)
  - The ITU-R Recommendations

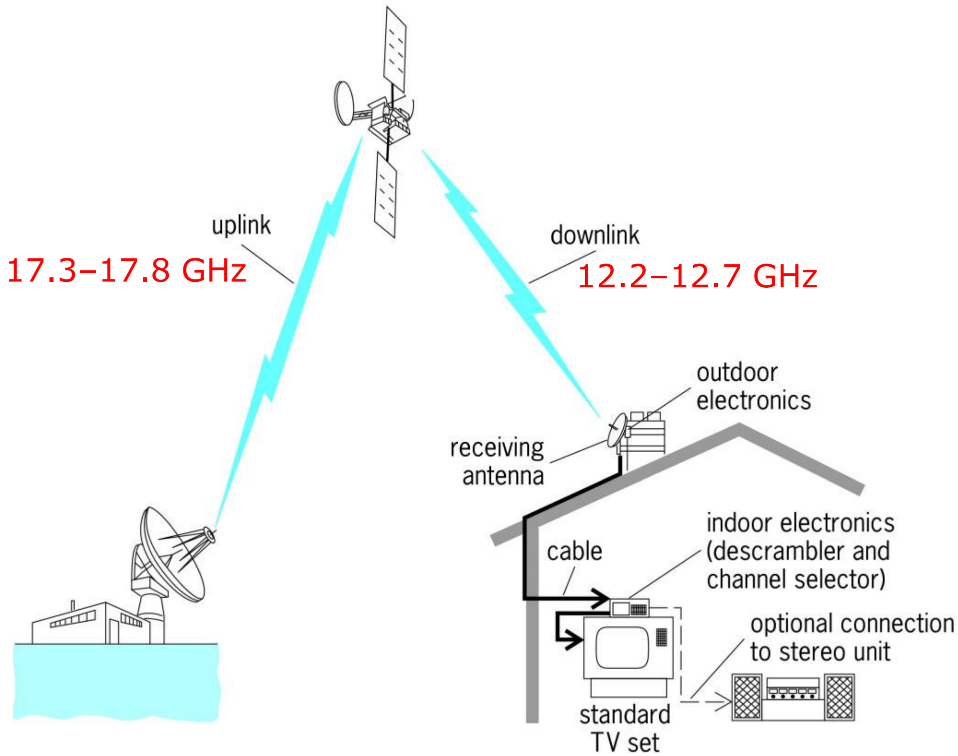
- Antenna radiation performance standards and reference radiation patterns are developed from measured radiation patterns,
- and then established as reference with consensus from radio spectrum regulators and antenna engineers.
- Regulators use them as reference in EMC analyses,
- and engineers use them as compliance guidelines in antenna design and production.

Categories of Radio Services

- Classes of radio services categorized by ITU-R
  - Antenna data for the Fixed Service (FS),
  - Fixed-Satellite Service (FSS),
  - Broadcasting Service (BS),
  - Broadcasting-Satellite Service (BSS), Mobile Service (MS),
  - Mobile-Satellite Service (MSS),
  - Radiodetermination Service (RDS),
  - Radiodetermination-Satellite Service (RDSS),
  - Radio Astronomy Service (RAS),
  - Remote Sensing Service (RSS),
  - and Space Application Service (SA)

Example: Broadcasting-Satellite Service

- Consists of an uplink that feeds the program to the satellite for downlink broadcasting,
- and many receive-only earth stations to receive the program.
- Ground antennas:
  - Feeder Link Transmitting Antenna
  - Downlink Receive-Only Antenna
- Satellite antenna
  - Feeder Link Receiving Antenna
  - Downlink Receive-Only Antenna



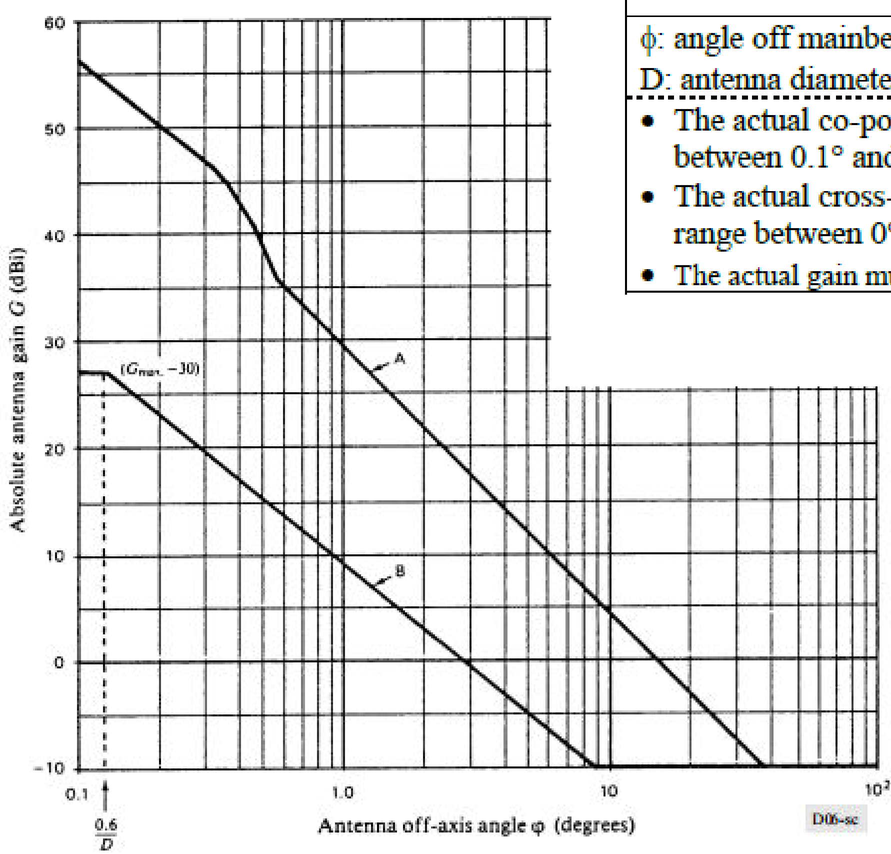
1. Ground antennas: Feeder Link Transmitting Antenna

Allotment Plan in Region 2 in 17.3–17.8 GHz

Category	Gain Function (dBi)	Angular Range
Co-Polarization	G_{max}	$0° \le \phi < 0.1°$
	$36 - 20 \times \log(\phi)$	$0.1° \le \phi < 0.32°$
	$51.3 - 53.2 \times \phi^2$	$0.32° \le \phi < 0.54°$
	$\max[29 - 25 \times \log(\phi), -10]$	$0.54° \le \phi \le 180°$
Cross-Polarization	$G_{max} - 30$	$0° \le \phi < (0.6/D)°$
	$\max[9 - 20 \times \log(\phi), -10]$	$(0.6/D)° \le \phi \le 180°$

ϕ: angle off mainbeam axis, deg.
D: antenna diameter, meters, $D \ge 2.5$

- The actual co-polarization gain must not exceed the reference pattern in the angular range between 0.1° and 0.54°.
- The actual cross-polarization gain must not exceed the reference pattern in the angular range between 0° and (0.6/D)°.
- The actual gain must not exceed the reference pattern for 90% of all sidelobe peaks for $\phi > 0.54°$.



4. Satellite antennas: Feeder Link Transmitting Antenna

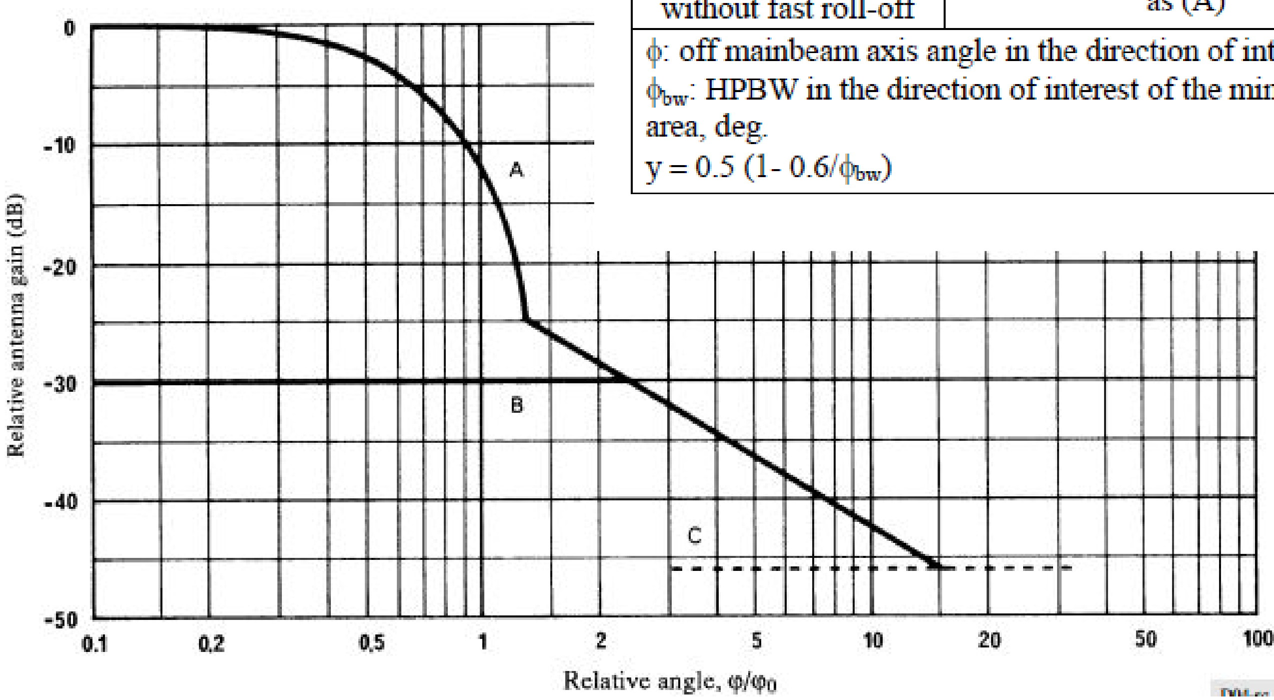
Allotment Plan in Region 2 in 17.3–17.8 GHz

Polarization	Gain Function Relative to G_{max} (dB)	Angular Range
Co-polarization, mainbeam without fast roll-off (A)	$-12\,(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} \leq 1.45$
	$\max[-22 - 20\times\log(\phi/\phi_{bw}), -G_{max}]$	$1.45 < \phi/\phi_{bw}$
Co-polarization, mainbeam with fast roll-off	$-12\,(\phi/\phi_{bw})^2$	$0 \leq \phi/\phi_{bw} \leq 0.5$
	$-33.33\,\phi_{bw}^2\,(\phi/\phi_{bw} - y)^2$	$0.5 < \phi/\phi_{bw} \leq 0.87/\phi_{bw} + y$
	-25.23	$0.87/\phi_{bw} + y < \phi/\phi_{bw} \leq 1.45$
	$\max[-22 - 20\times\log(\phi/\phi_{bw}), -G_{max}]$	$1.45 < \phi/\phi_{bw}$
Cross-polarization, mainbeam with or without fast roll-off	-30	$0 \leq \phi/\phi_{bw} \leq 2.51$
	as (A)	after intersection with (A)

ϕ: off mainbeam axis angle in the direction of interest, deg.

ϕ_{bw}: HPBW in the direction of interest of the minimum elliptical beam fitted to the service area, deg.

$y = 0.5\,(1 - 0.6/\phi_{bw})$

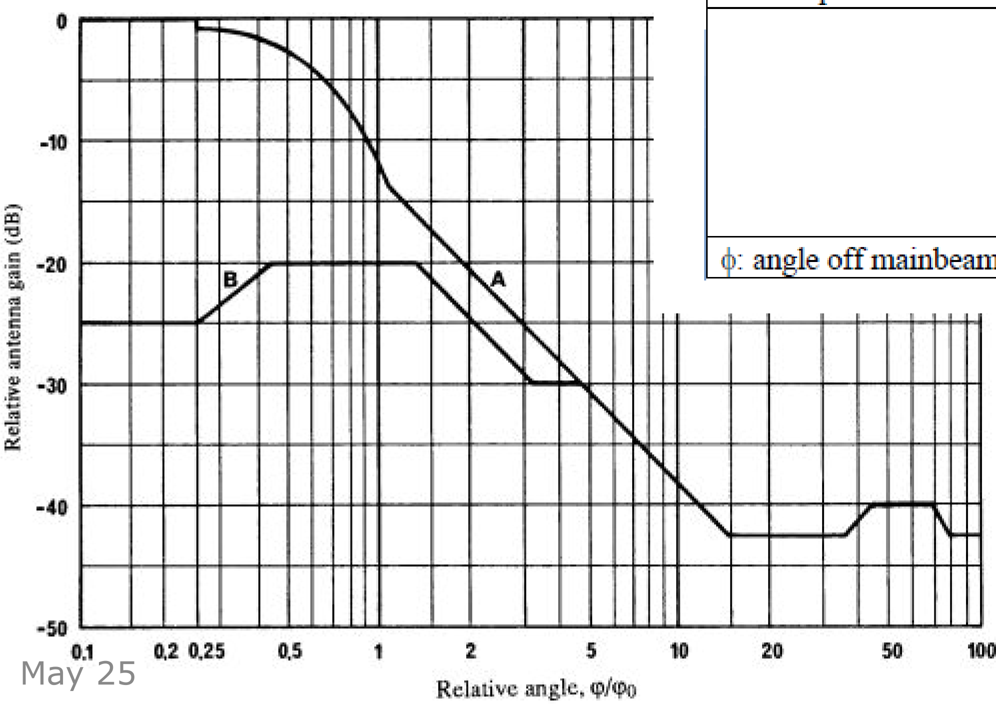


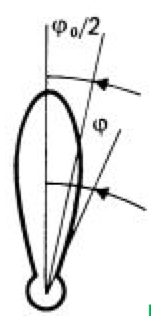
2. Ground antennas: Downlink Receive-Only Antenna

Allotment Plan in Region 2 in 12.2–12.7 GHz

Category	Gain Function Relative to G_{max} (dB)	Angular Range
Co-polarization, no sidelobe suppression	0	$0 \le \phi/\phi_{bw} < 0.25$
	$-12(\phi/\phi_{bw})^2$	$0.25 \le \phi/\phi_{bw} < 1.13$
	$-14 - 25 \times \log(\phi/\phi_{bw})$	$1.13 \le \phi/\phi_{bw} < 14.7$
	-43.2	$14.7 \le \phi/\phi_{bw} < 35$
	$-85.2 + 27.2 \times \log(\phi/\phi_{bw})$	$35 \le \phi/\phi_{bw} < 45.1$
	-40.2	$45.1 \le \phi/\phi_{bw} < 70$
	$55.2 - 51.7 \times \log(\phi/\phi_{bw})$	$70 \le \phi/\phi_{bw} < 80$
	-43.2	$80 \le \phi/\phi_{bw} \le 180/\phi_{bw}$
Cross-polarization	-25	$0 \le \phi/\phi_{bw} < 0.25$
	$-30 - 40 \times \log(1 - \phi/\phi_{bw})$	$0.25 \le \phi/\phi_{bw} < 0.44$
	-20	$0.44 \le \phi/\phi_{bw} < 1.28$
	$-17.3 - 25 \times \log(\phi/\phi_{bw})$	$1.28 \le \phi/\phi_{bw} < 3.22$
	-30	$3.22 \le \phi/\phi_{bw}$
	as co-polarization pattern	after intersection with co-polarization pattern

ϕ: angle off mainbeam axis, deg.





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