ANTENNA AND WAVE PROPAGATION

WHY ANTENNAS ?

- Need of antenna arisen when two person wanted to communicate between them when separated by some distance and wired communication is not possible.
- Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field.
- Radio waves are electromagnetic waves which carry signals through the air (or through space) at the speed of light with almost no transmission loss.

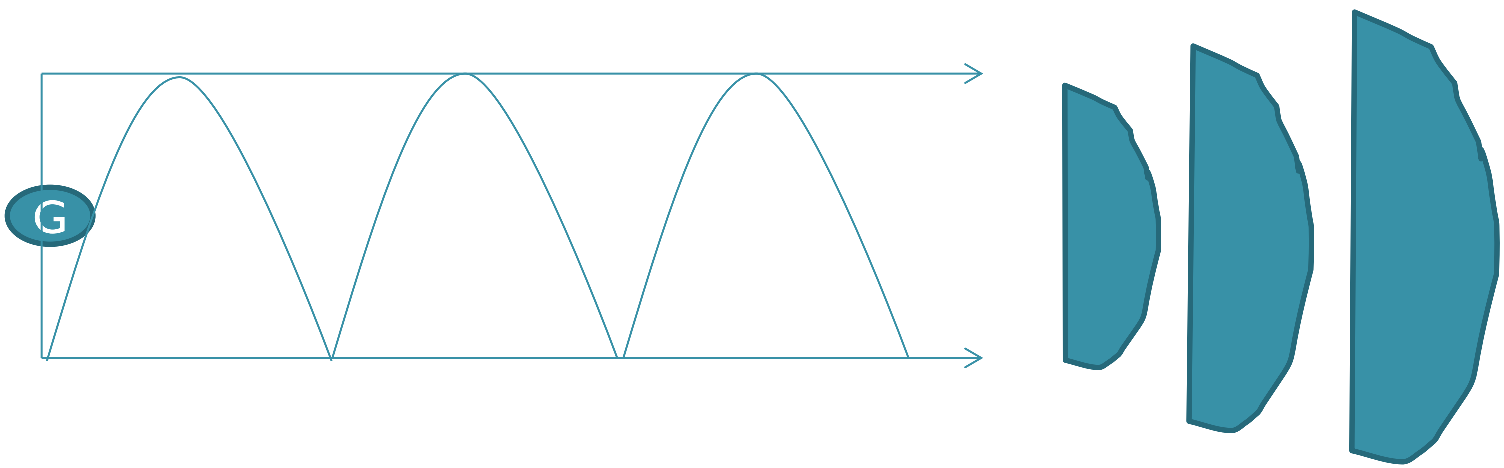
- Radio transmitters and receivers are used to convey signals (information) in systems including broadcast (audio) radio, television, mobile telephones , point-to-point communications links (telephone, data networks), satellite links.
- Radio waves are also used directly for measurements in technologies including Radar, GPS, and radio astronomy.
- In each and every case, the transmitters and receivers involved require antennas, although these are sometimes hidden (such as the antenna inside an AM radio or inside a laptop computer equipped with wi-fi).

WHERE USED?

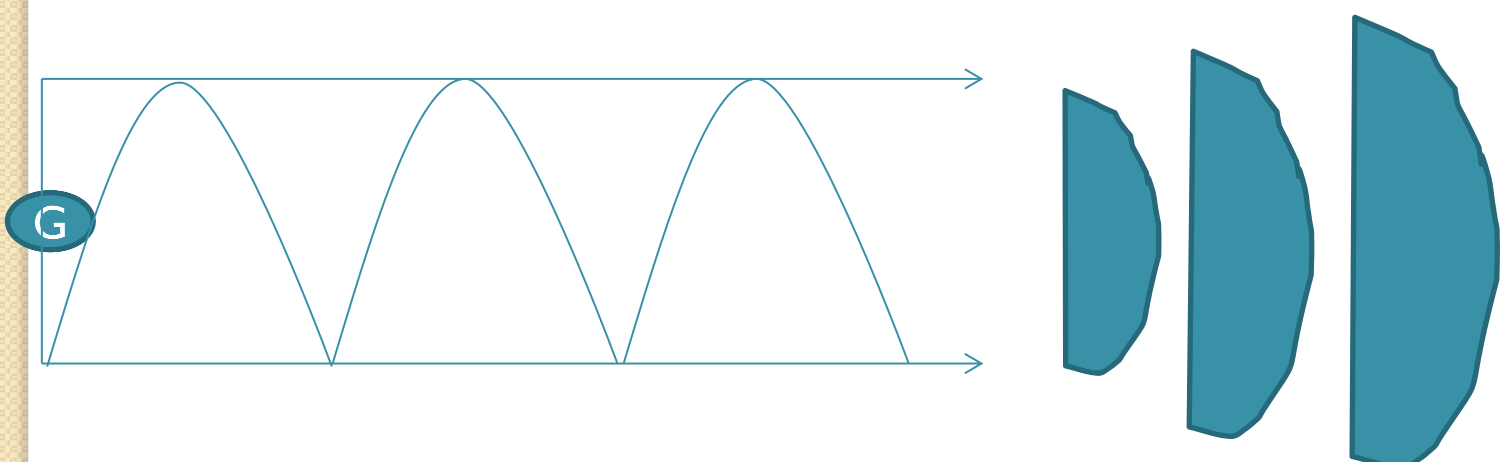
- Antennas are used in systems such as radio and television broadcasting, point to point radio communication, wireless LAN, radar and space exploration
- Antennas are most utilized in air or outer space
- But can also be operated under water or even through soil and rock at certain frequencies for short distances

RADIATION MECHANISM

- Ideally all incident energy must be reflected back when open circuit. But practically a small portion of electromagnetic energy escapes from the system that is it gets radiated.
- This occurs because the line of force don't undergo complete phase reversal and some of them escapes.



- The amount of escaped energy is very small due to mismatch between transmission line and surrounding space.
- Also because two wires are too close to each other, radiation from one tip will cancel radiation from other tip.(as they are of opposite polarities and distance between them is too small as compared to wavelength)

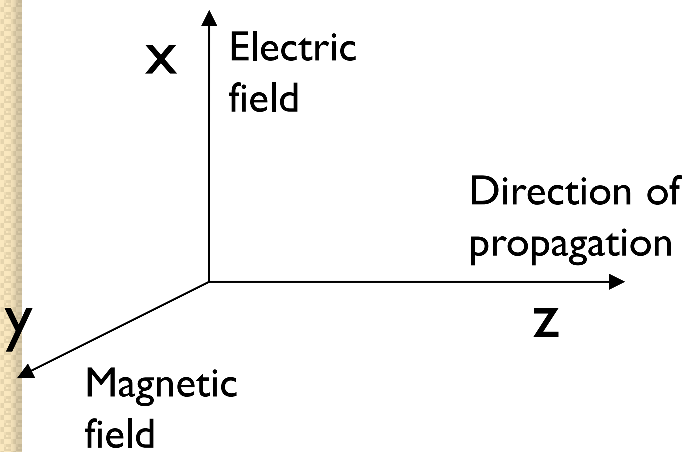


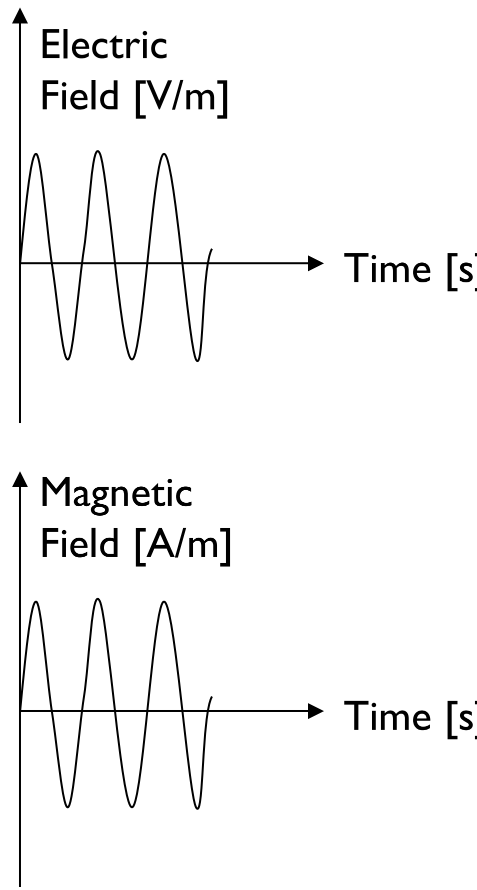
- To increase amount of radiated power open circuit must be enlarged , by spreading the two wires.
- Due to this arrangement, coupling between transmission line and free space is improved.
- Also amount of cancellation has reduced.
- The radiation efficiency will increase further if two conductors of transmission line are bent so as to bring them in same line.

What is an antenna?

- Region of transition between guided and free space propagation
- Concentrates incoming wave onto a sensor (receiving case)
- Launches waves from a guiding structure into space or air (transmitting case)
- Often part of a signal transmitting system over some distance
- Not limited to electromagnetic waves (e.g. acoustic waves)

Free space electromagnetic wave





- Disturbance of EM field
- Velocity of light (~300 000 000 m/s)
- E and H fields are orthogonal
- E and H fields are in phase
- Impedance, Z_0: 377 ohms

EM wave in free space

$$\frac{\partial^2 E_x}{\partial t^2} = \frac{1}{\mu_0 \varepsilon_0} \frac{\partial^2 E_x}{\partial z^2}$$

$$\frac{\partial^2 H_y}{\partial t^2} = \frac{1}{\mu_0 \varepsilon_0} \frac{\partial^2 H_y}{\partial z^2}$$

$$E_x = E_0 e^{j(\omega t \pm \beta z)}$$

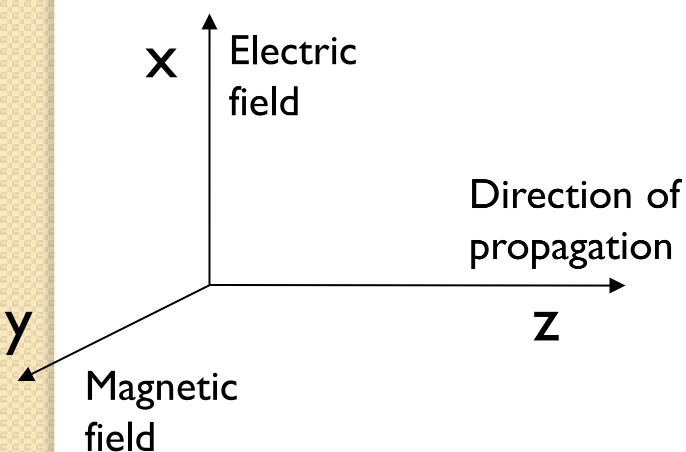
$$H_y = H_0 e^{j(\omega t \pm \beta z)}$$

frequency $f = \frac{\omega}{2\pi}$

wavelength $\lambda = \frac{1}{\sqrt{\mu_0 \varepsilon_0} f}$

Phase constant $\beta = \frac{2\pi}{\lambda}$

$$Z_0 = \frac{E_0}{H_0} \qquad Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$$



Wave in lossy medium

$$E_x = E_0 e^{-\gamma z} e^{j\omega t} = E_0 \cdot e^{-\alpha z} \cdot e^{-j\beta z} \cdot e^{j\omega t}$$

Attenuation increases with z

Phase varies with z

Periodic time variation

$\gamma = \alpha + j\beta$ Propagation constant

α Attenuation constant

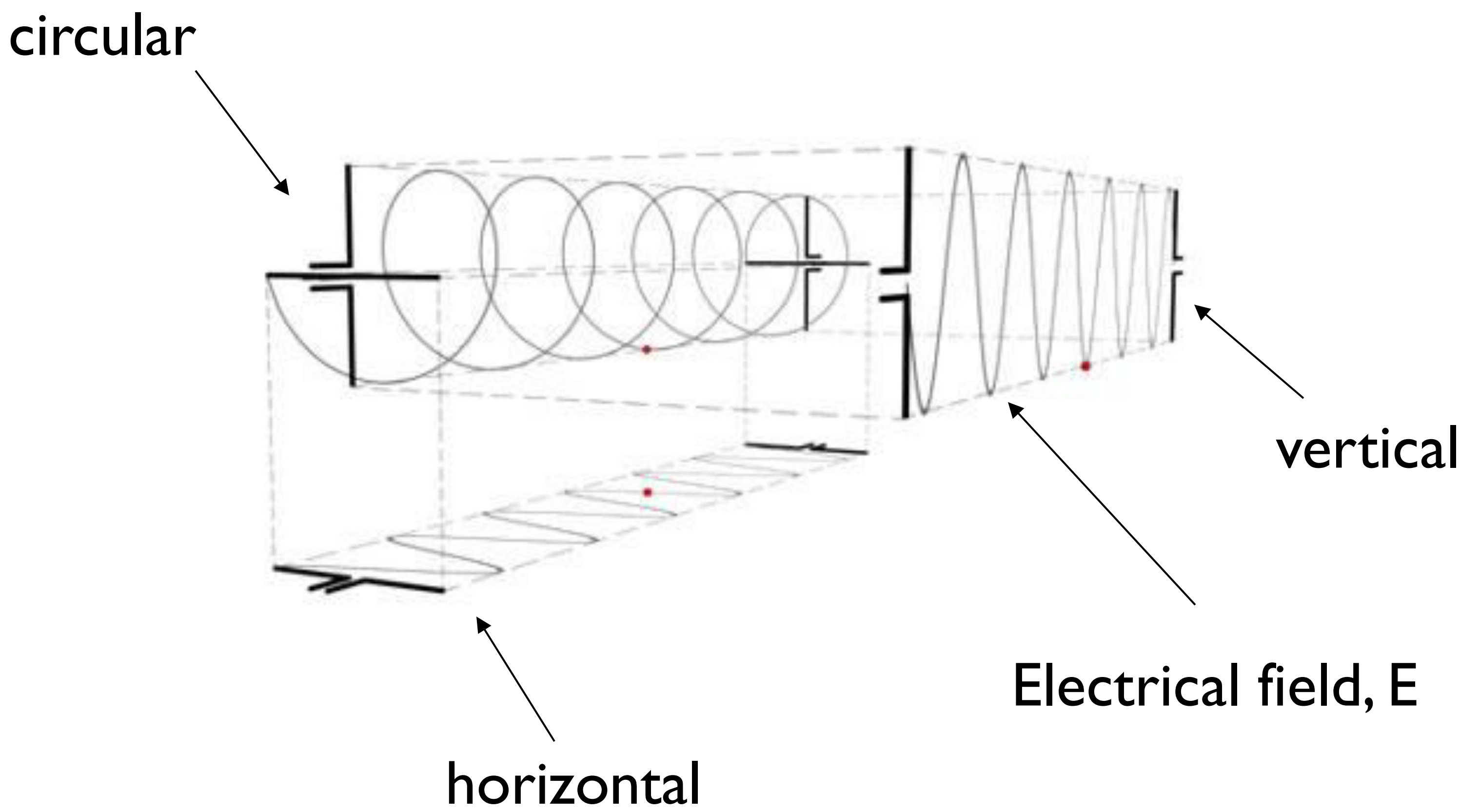
β Phase constant

Power flow

Poynting vector $\vec{S} = \vec{E} \times \vec{H}$

Average power density $$S_{av} = \frac{1}{2}\left|E_x\right|^2 \frac{1}{Z_0} = \frac{1}{2}\left|H_y\right|^2 Z_0$$

Polarisation of EM wave

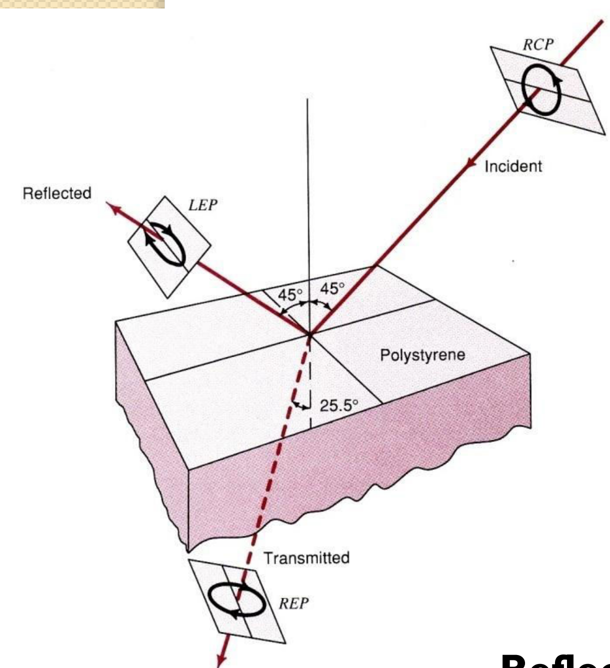


Reflection, refraction

Reflection $\theta_r = \theta_i$

Reflection coefficient: $\rho = \frac{E_r}{E_i}$

Depends on media, polarisation of incident wave and angle of incidence.



Refraction $\sin(\theta_t) = \frac{\eta_1}{\eta_2} \sin(\theta_i)$

if both media are lossless $\sin(\theta_t) = \sqrt{\frac{\mu_1 \varepsilon_1}{\mu_2 \varepsilon_2}} \sin(\theta_i)$

Reflection and refraction affect polarisation

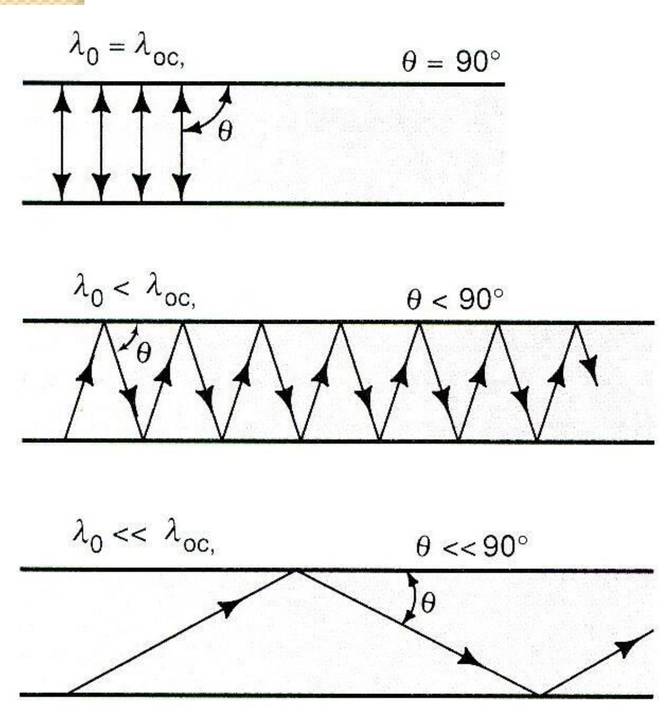
Guided electromagnetic wave

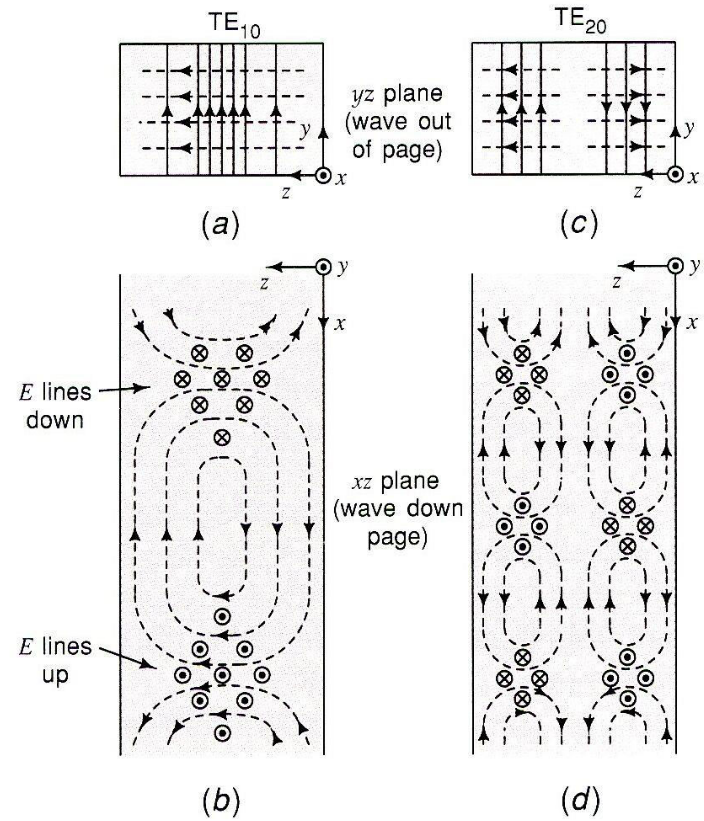
- Cables
  - Used at frequencies below 35 GHz
- Waveguides
  - Used between 0.4 GHz to 350 GHz
- Quasi-optical system
  - Used above 30 GHz

Guided electromagnetic wave (2)

- TEM wave in cables and quasi-optical systems (same as free space)
- TH,TE and combinations in waveguides
  - E or H field component in the direction of propagation
  - Wave bounces on the inner walls of the guide
  - Lower and upper frequency limits
  - Cross section dimensions proportional to wavelength

Rectangular waveguide





Launching of EM wave

Open up the cable and separate wires

↓

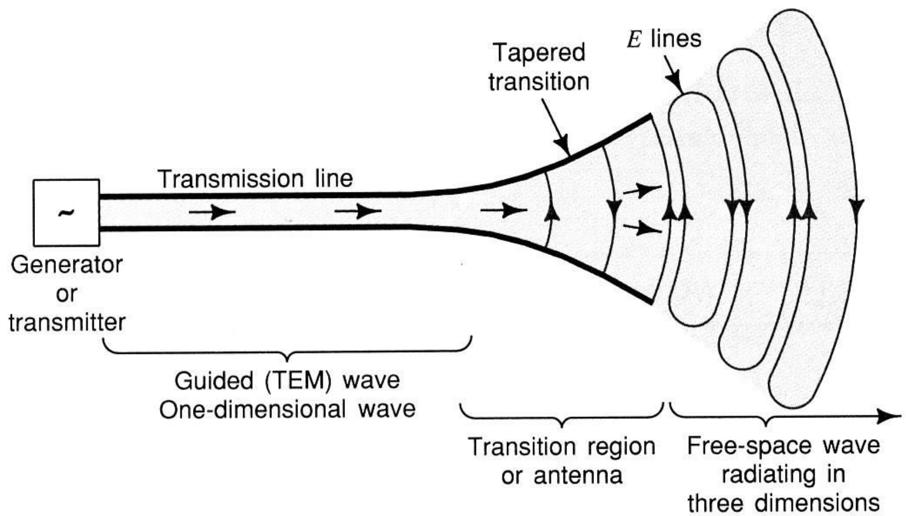
Dipole antenna

Open and flare up wave guide

↓

Horn antenna

Transition from guided wave to free space wave



Reciprocity

- Transmission and reception antennas can be used interchangeably
- Medium must be linear, passive and isotropic
- Caveat: Antennas are usually optimised for reception or transmission not both !

BASIC ANTENNA PARAMETERS

- Radiation pattern
- Beam area and beam efficiency
- Effective aperture and aperture efficiency
- Directivity and gain
- Radiation resistance

PATTERNS

Radiation pattern

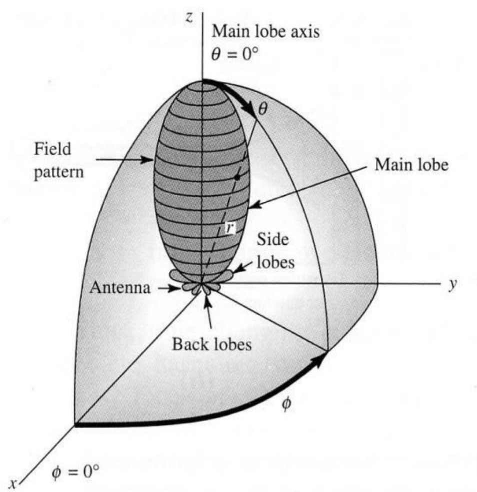
- Far field patterns
- Field intensity decreases with increasing distance, as 1/r
- Radiated power density decreases as $1/r^2$
- Pattern (shape) independent on distance
- Usually shown only in principal planes

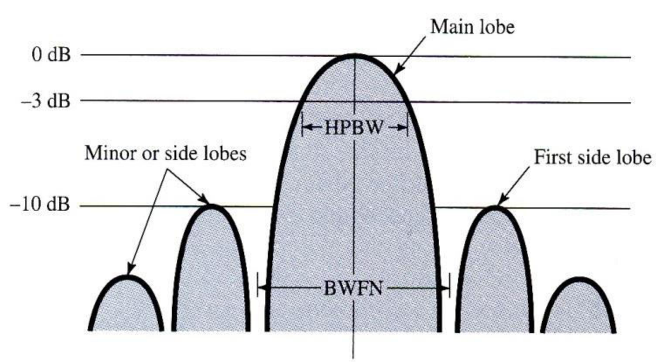
$$\text{Far field}: \; r > 2\frac{D^2}{\lambda}$$

D : largest dimension of the antenna

e.g. r > 220 km for APEX at 1.3 mm !

Radiation pattern (2)





HPBW: half power beam width

Field patterns

$$E_\theta(\theta,\phi) \qquad E_\phi(\theta,\phi)$$

+ phase patterns

$$\varphi_\theta(\theta,\phi) \qquad \varphi_\phi(\theta,\phi)$$

$$P(\theta,\phi)=\frac{E_\theta^2(\theta,\phi)+E_\phi^2(\theta,\phi)}{Z_0}r^2$$

$$P_n(\theta,\phi)=\frac{P(\theta,\phi)}{P(\theta,\phi)_{\max}}$$

Beam area and beam efficiency

Beam area $$\Omega_A = \int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)\cdot\sin(\theta)\,d\theta\,d\phi = \iint_{4\pi} P_n(\theta,\phi)\,d\Omega$$

Main beam area $$\Omega_M = \iint_{\substack{Main\\beam}} P_n(\theta,\phi)\,d\Omega$$

Minor lobes area $$\Omega_m = \iint_{\substack{\min or\\lobes}} P_n(\theta,\phi)\,d\Omega$$

$$\Omega_A = \Omega_M + \Omega_m$$

Main beam efficiency $$\varepsilon_M = \frac{\Omega_M}{\Omega_A}$$

Effective aperture and aperture efficiency

Receiving antenna extracts power from incident wave

$$P_{rec} = S_{in} \cdot A_e$$

Aperture and beam area are linked:

$$A_e = \frac{\lambda^2}{\Omega_A}$$

For some antennas, there is a clear physical aperture and an aperture efficiency can be defined

$$\varepsilon_{ap} = \frac{A_e}{A_p}$$

Directivity and gain

Directivity $$D = \frac{P(\theta,\phi)_{\max}}{P(\theta,\phi)_{average}}$$

From pattern $$D = \frac{4\pi}{\iint_{4\pi} P_n(\theta,\phi)\,d\Omega} = \frac{4\pi}{\Omega_A}$$

From aperture $$D = 4\pi \frac{A_e}{\lambda^2}$$

Isotropic antenna: $\Omega_A = 4\pi \quad D = 1$

Gain $G = k_g\ D$

k_g = efficiency factor $(0 < k_g < 1)$

G is lower than D due to ohmic losses only

Radiation resistance

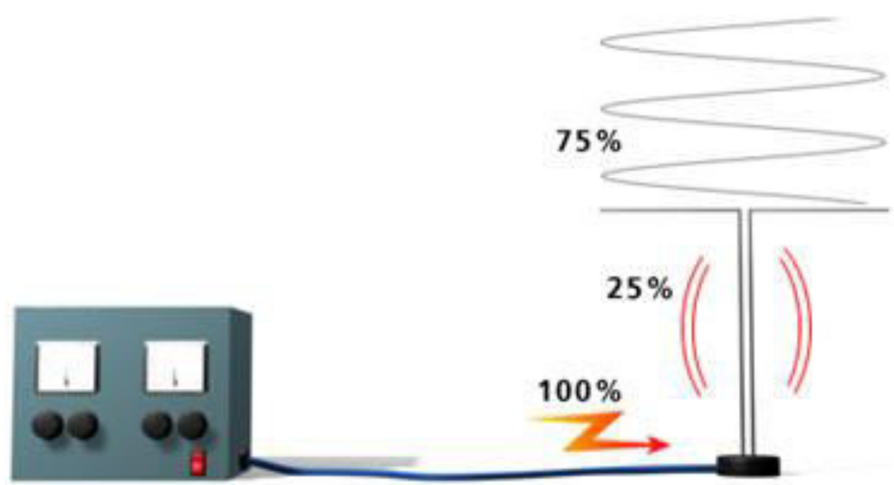
- Antenna presents an impedance at its terminals

$$Z_A = R_A + jX_A$$

- Resistive part is radiation resistance plus loss resistance

$$R_A = R_R + R_L$$

The radiation resistance does not correspond to a real resistor present in the antenna but to the resistance of space coupled via the beam to the antenna terminals.

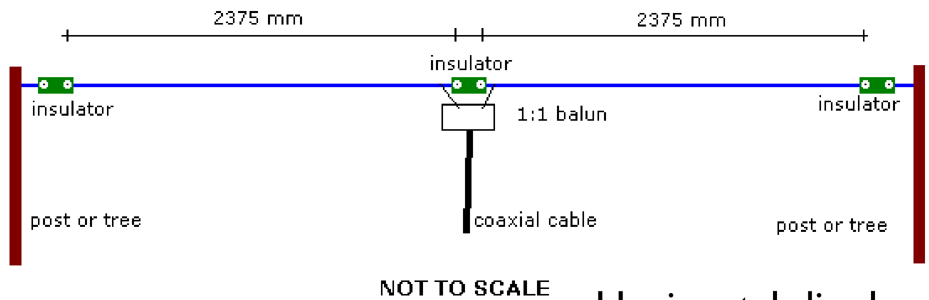


Types of Antenna

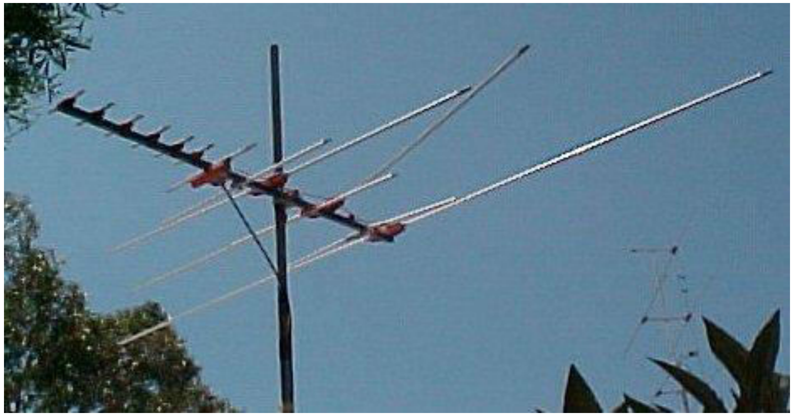
- Wire
- Aperture
- Arrays

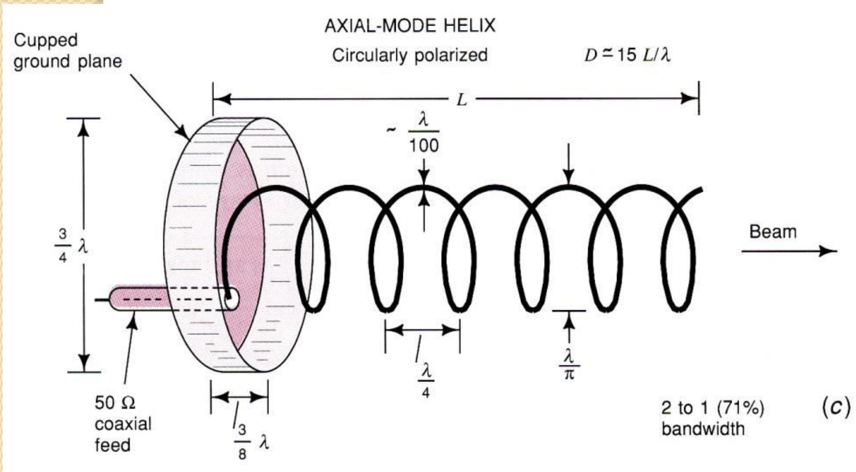
Wire antenna

- Dipole
- Loop
- Folded dipoles
- Helical antenna
- Yagi (array of dipoles)
- Corner reflector
- Many more types



Horizontal dipole

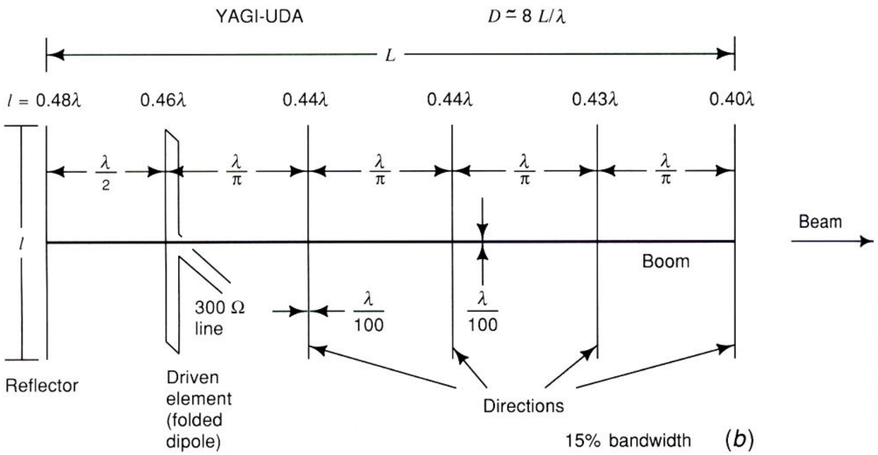


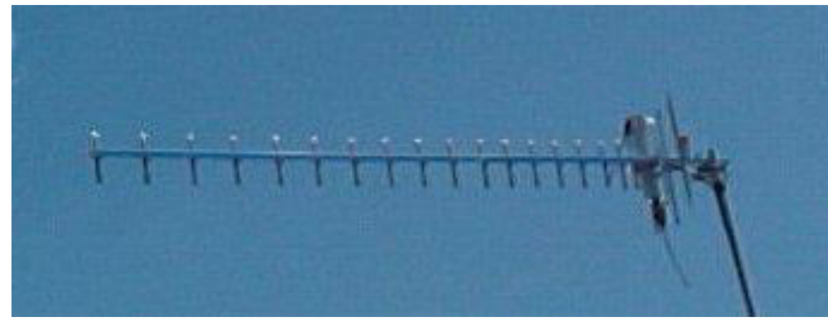


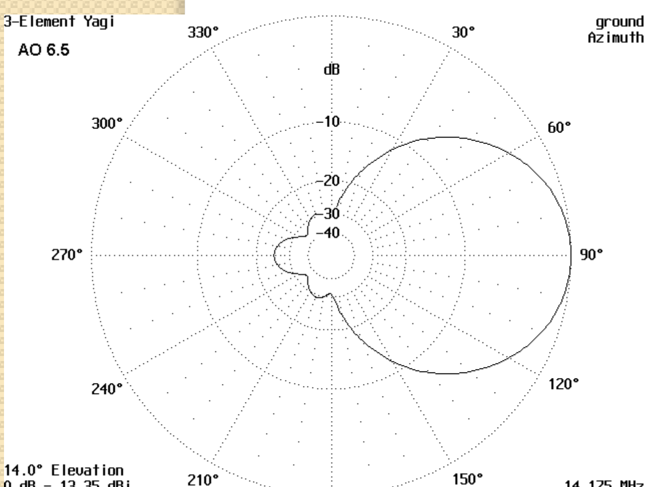
Wire antenna - resonance

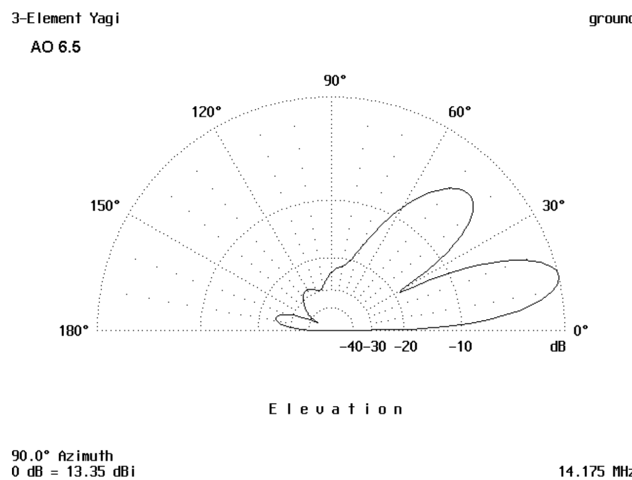
- Many wire antennas (but not all) are used at or near resonance
- Some times it is not practical to built the whole resonant length
- The physical length can be shortened using loading techniques
  - Inductive load: e.g. center, base or top coil (usually adjustable)
  - Capacitive load: e.g. capacitance "hats" (flat top at one or both ends)

Yagi-Uda









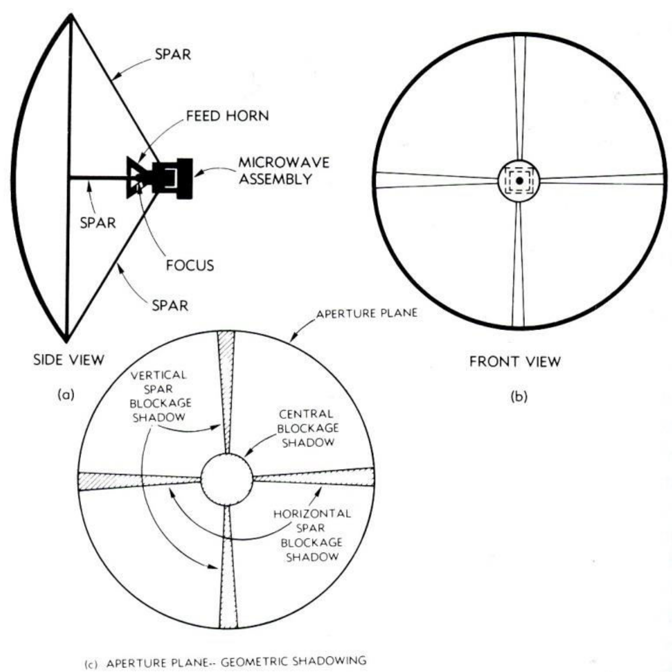
Elements	Gain dBi	Gain dBd
3	7.5	5.5
4	8.5	6.5
5	10	8
6	11.5	9.5
7	12.5	10.5
8	13.5	11.5

Aperture antenna

- Collect power over a well defined aperture
- Large compared to wavelength
- Various types:
  - Reflector antenna
  - Horn antenna
  - Lens

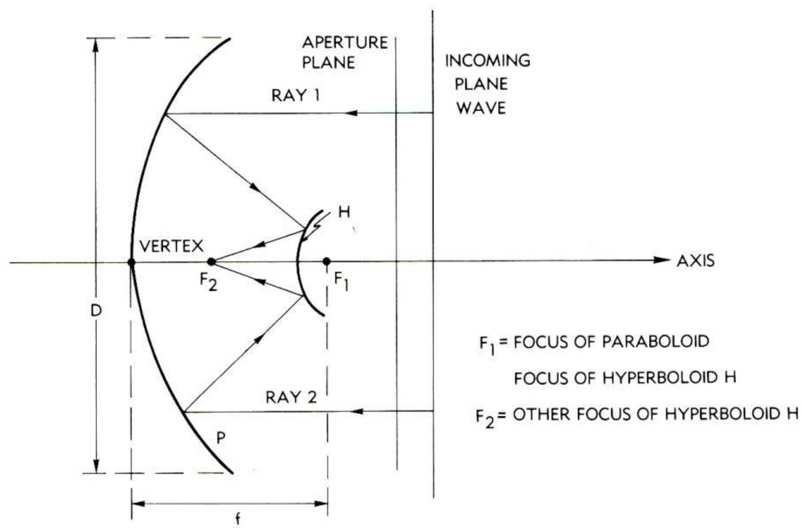
Reflector antenna

- Shaped reflector: parabolic dish, cylindrical antenna …
  - Reflector acts as a large collecting area and concentrates power onto a focal region where the feed is located
- Combined optical systems: Cassegrain, Nasmyth …
  - Two (Cassegrain) or three (Nasmyth) mirrors are used to bring the focus to a location where the feed including the transmitter/receiver can be installed more easily.



Cassegrain antenna

- Less prone to back scatter than simple parabolic antenna
- Greater beam steering possibility: secondary mirror motion amplified by optical system
- Much more compact for a given f/D ratio



Cassegrain antenna (2)

- Gain depends on diameter, wavelength, illumination
- Effective aperture is limited by surface accuracy, blockage
- Scale plate depends on equivalent focal length
- Loss in aperture efficiency due to:
  - Tapered illumination
  - Spillover (illumination does not stop at the edge of the dish)
  - Blockage of secondary mirror, support legs
  - Surface irregularities (effect depends on wavelength)

$$K_g = \cos\left(4\pi \frac{\delta}{\lambda}\right)^2 \qquad \delta = \text{rms of surface deviation}$$

At the SEST:

$$\text{taper efficiency}: \ \varepsilon_t = 0.87$$

$$\text{spillover efficiency}: \ \varepsilon_s = 0.94$$

$$\text{blockage efficiency}: \ \varepsilon_b = 0.96$$