Transmission lines & antennas

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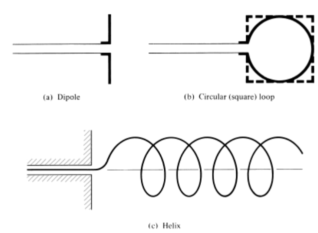
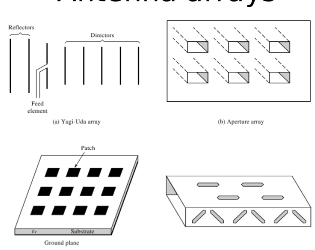
Introduction to antennas – some antenna types

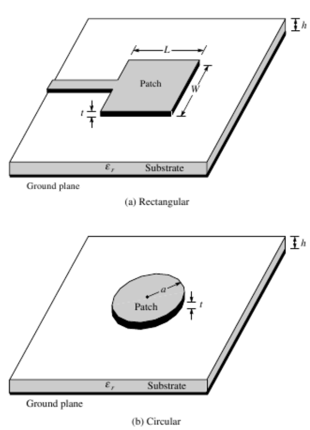
Wire antennas



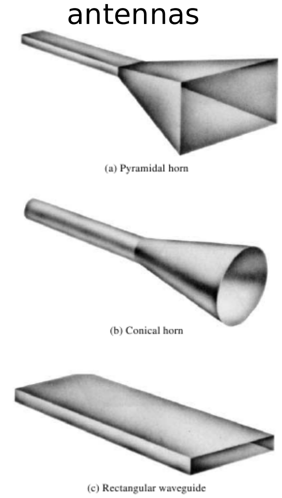
Antenna arrays



Printed antennas



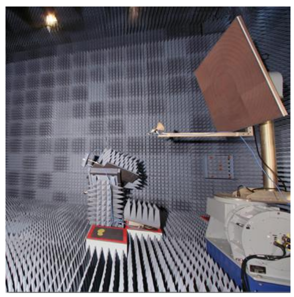
WG aperture antennas



Antenna examples

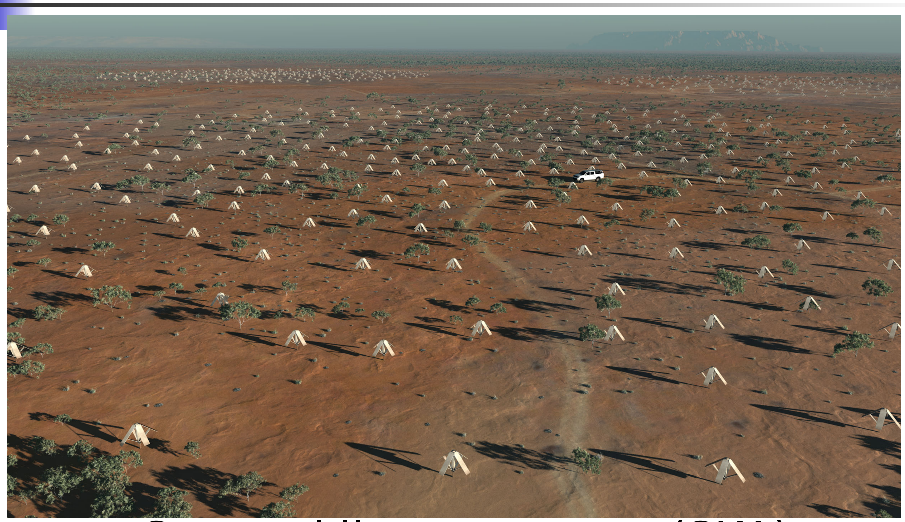
Direct radiation array for RADAR applications

Reflect arrays for communications



Large reflector for radio-astronomy applications

Antenna examples: c'ed



Square kilometer array (SKA)

http://www.skatelescope.org/

Antenna parameters – radiation pattern

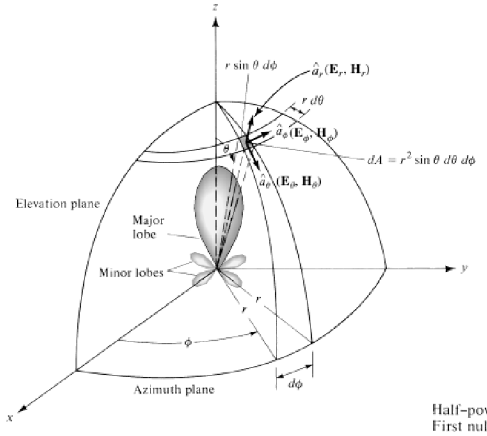
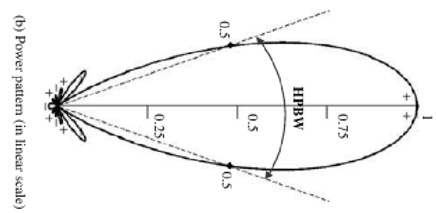
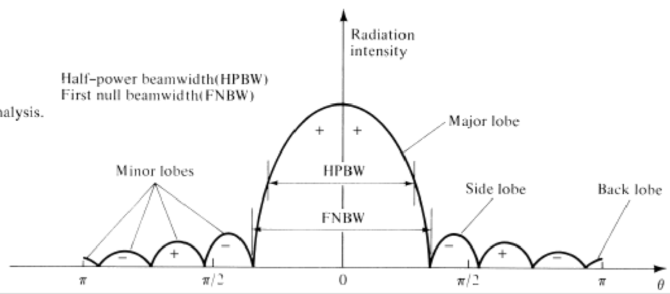


Figure 2.1 Coordinate system for antenna analysis.



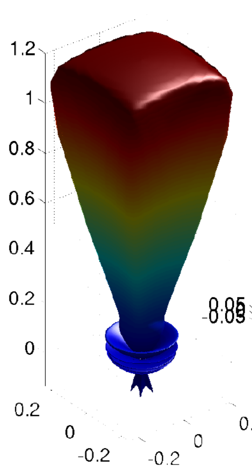


- Antenna principal planes
- Antenna lobes
- Beamwidth

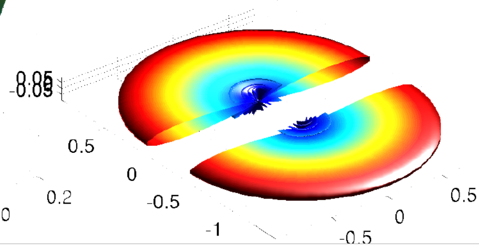
Antenna Pattern types

- Isotropic: equal radiation in all directions (not physically realizable)
- Directional: power is radiated more effectively in some directions than others.
  - Omnidirectional: non-directional in one plane and directional in any perpendicular plane.
  - pencil beam: considerable radiation only in a small neigborhood of a unique direction.
  - contoured beam: considerable radiation only in a shaped portion of solid angle.

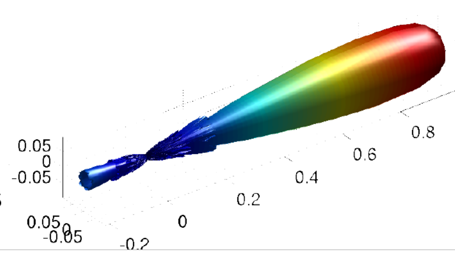
Contoured beam pattern



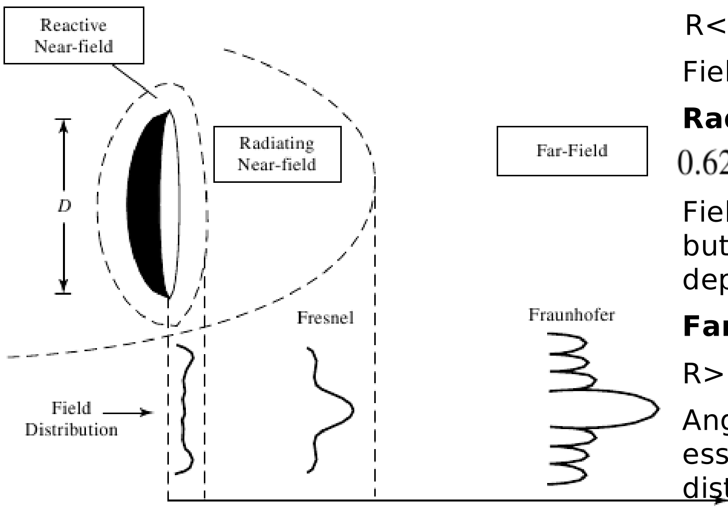
Omnidirectional pattern



Pencil beam pattern



Field regions



Reactive near-field:

R< $0.62\sqrt{D^3/\lambda}$

Fields are mostly reactive.

Radiating near-field

$0.62\sqrt{D^3/\lambda}$ <R< $2D^2/\lambda$

Fields are mostly radiating but angular distribution depends on distance.

Far field (Fraunhofer)

R> $2D^2/\lambda$

Angular distribution is essentially independent on distance, fields are transverse.

Far field

In the far field, dependence on r and spherical angles theta, phi are separable, the wavefront is spherical and fields are transverse:

$$\underline{E}(\underline{P}) = \frac{e^{-jk_0 r}}{4\pi r}\underline{e}(\theta,\phi)$$

Antenna-specific pattern, vector with negligible radial component

Universal spherical wave

In far-field, E and H are transverse and are related by the usual impedance relations. P is a unit vector along the observation direction.

$$\underline{H}(\underline{P}) = -\frac{1}{Z_0}\hat{r}\times\underline{E}(\underline{P})$$

$$\underline{E}(\underline{P}) = Z_0\hat{r}\times\underline{H}(\underline{P})$$

Radiated power and radiation intensity

Power radiated by antennas can be computed by the surface integral of the poynting vector on any enclosing surface:

$$\text{Prad} = \frac{1}{2} \oiint_S \mathrm{Re}(\mathbf{E} \times \mathbf{H}^*) \cdot d\mathbf{s}$$

Radiation intensity is defined as the power radiated per unit solid angle (for large r it becomes independent from distance):

$$U(\theta, \phi) = \frac{r^2}{2\eta} |\mathbf{E}(r, \theta, \phi)|^2$$

Antenna Directivity

Ratio between the radiation intensity in a given direction and the average radiation intensity. If direction is not specified, the maximum value is implied.

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}}$$

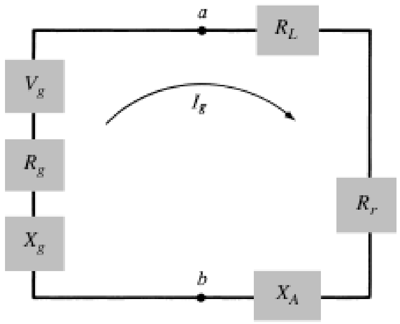
Directivity can be specified separately for individual field components:

$$D_\theta = \frac{4\pi U_\theta}{(P_{\text{rad}})_\theta + (P_{\text{rad}})_\phi}$$

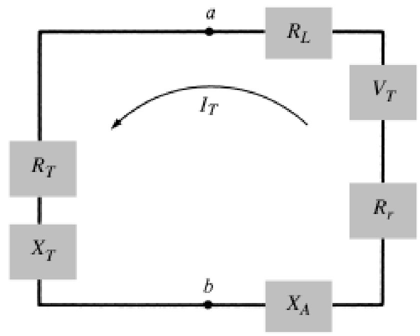
$$D_\phi = \frac{4\pi U_\phi}{(P_{\text{rad}})_\theta + (P_{\text{rad}})_\phi}$$

Max directivity is always >= 1

Antenna parameters – impedance



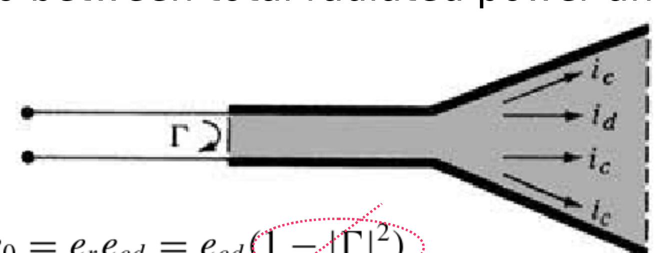
TX



RX

Antenna Efficiency

Not all the power delivered in input to the antenna is radiated: reflections, conduction and dielectric losses reduce antenna efficiency, i.e. the ratio between total radiated power and input power.



$$e_0 = e_r e_{cd} = e_{cd} \cancel{(1 - |\Gamma|^2)}$$

In this course we will not include the impedance mismatch factor in the total efficiency, i.e. e0 = ecd

Antenna Gain

Gain is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically.

$$\text{Gain} = 4\pi \frac{\text{radiation intensity}}{\text{total input (accepted) power}} = 4\pi \frac{U(\theta, \phi)}{P_{in}}$$

With this definition, gain is simply the antenna efficiency times antenna directivity

$$G(\theta, \phi) = e_{cd} D(\theta, \phi)$$

Per-component Gain definitions are possible as with Directivity

Antenna polarization and polarization mismatch

Antenna polarization is defined as the polarization of the wave it radiates in a given direction. When direction is not specified, the maximum radiation direction is implied. It can be linear, circular or elliptical. It is a unit vector.

By reciprocity, it is possible to compute the fraction of the incident energy that is captured by a an antenna from an incident wave when it has a different polarization:

$$\text{PLF} = |\hat{\boldsymbol{\rho}}_w \cdot \hat{\boldsymbol{\rho}}_a|^2$$

For ellyptical polarization, the “axial ratio” is defined as the ratio of the largest to the smallest ellypse semiaxis, and is thus >=1, with 1 corresponding to circular polarization.

Antenna vector effective length

The vector effective length is a complex vector relating an incident field with the open-circuit voltage at the antenna terminals. It relates also the current in the antenna terminals with the field radiated in a given direction (in far field).

$$V_{oc} = \mathbf{E}^i \cdot \boldsymbol{\ell}_e$$

$$\mathbf{E}_a = \hat{\mathbf{a}}_\theta E_\theta + \hat{\mathbf{a}}_\phi E_\phi = -j\eta \frac{k I_{in}}{4\pi r} \boldsymbol{\ell}_e e^{-jkr}$$

Antenna effective area

The effective area (effective aperture) is the ratio between the incident power density and the power available at the antenna terminals considering polarization matching:

$$A_e = \frac{P_T}{W_i} = \frac{|I_T|^2 R_T/2}{W_i}$$

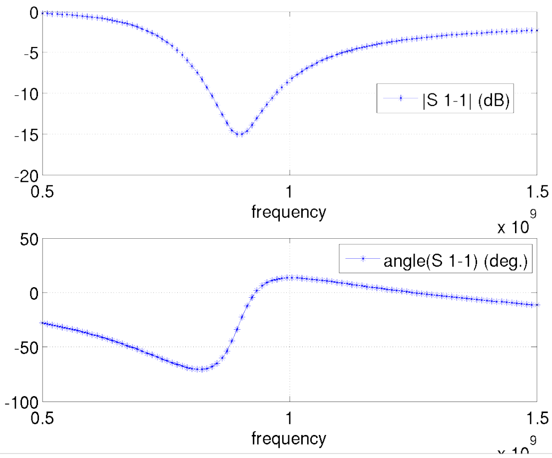
One may define other equivalent areas considering the scattered and lost power.

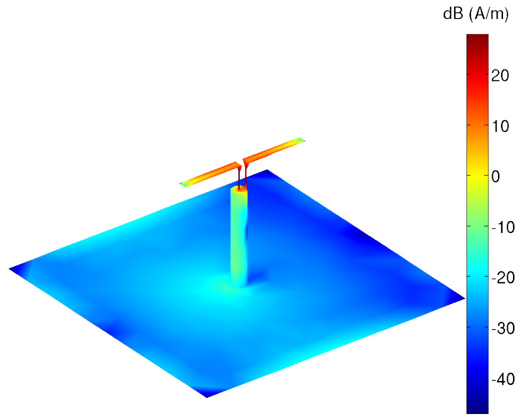
It can be shown that the maximum effective area is related to the maximum antenna directivity:

$$A_{em} = e_{cd}\left(\frac{\lambda^2}{4\pi}\right) D_0$$

Antenna Bandwidth

The range of frequencies over which antenna performance conforms to a given standard. It can be stated in terms of polarization purity, directivity, input impedance, etc.





Friis equation