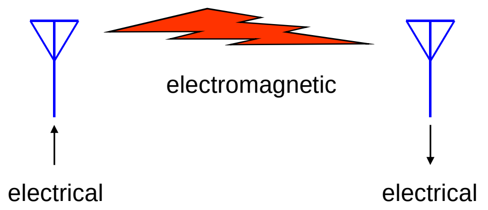
Basic Antenna Concepts

An antenna is a transducer of electrical and electromagnetic energy

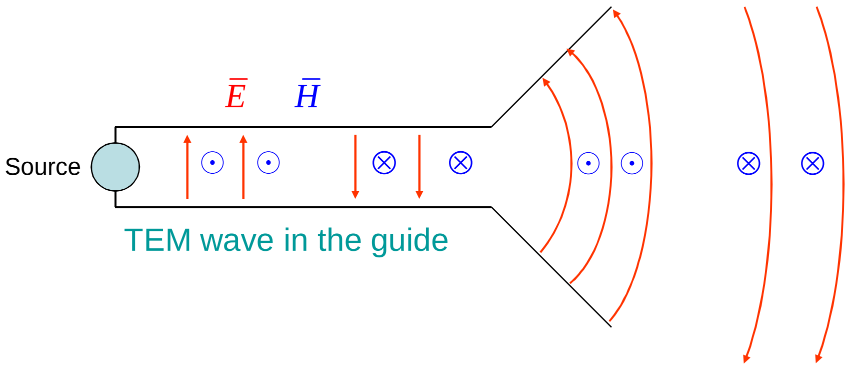


When We Design An Antenna, We Care About

- Operating frequency and bandwidth
  - Sometimes frequencies and bandwidths
- Input impedance (varies with frequency)
- Radiation pattern (Gain)
- Polarization
- Efficiency
- Power handling capacity
- Size and weight
  - Fits into component packaging (aesthetics)
- Vulnerability to weather and physical abuse
- Cost

Consider One Way To Launch A Wave

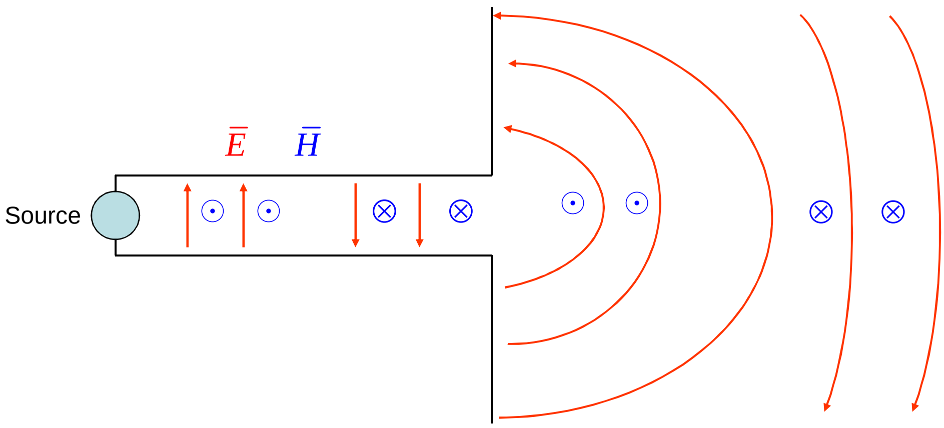
Start with a twin-lead or parallel-plate transmission line (they both look the same from the side)



By bending and terminating the guide the fields are forced to “leap” into free space

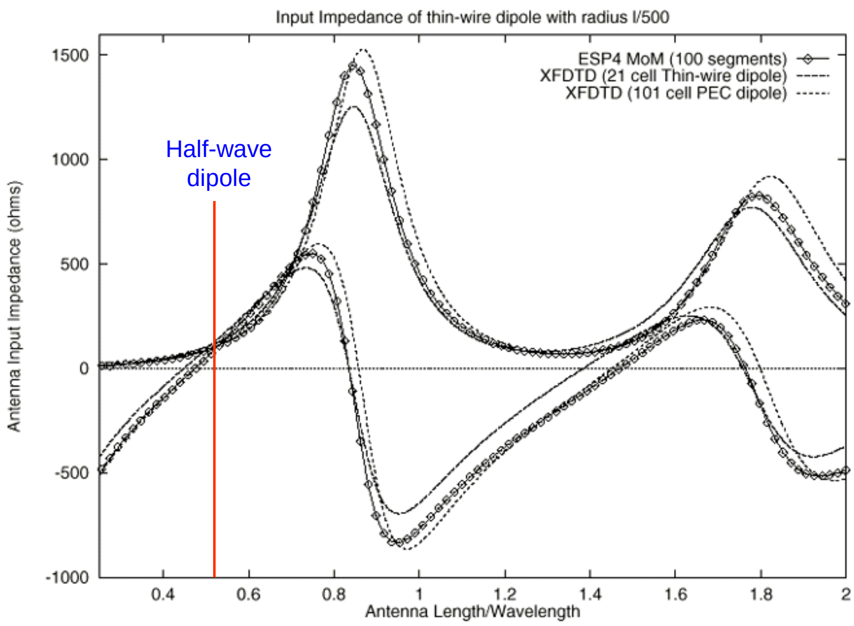
One Way To Launch A Wave (2)

By bending the transmission line so that it forms a 90º angle, you get the classic dipole antenna



If the total length of the dipole is $\lambda/2$, the input of the dipole (the gap between the two “legs”) will be $73+j42\Omega$

Dipole Impedance versus Length

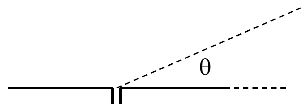


Network Analyzer Smith Chart Display

Antenna Patterns

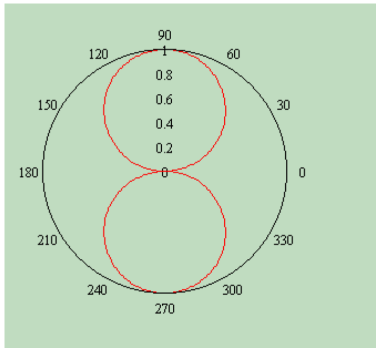
Antenna patterns indicate how the radiation intensity (*E*-field, *H*-field, or power) from an antenna varies in space (usually specified in spherical coordinates. The pattern is usually plotted against one spherical angle (θ or ϕ) at a time.

Example: The radiation pattern for a half-wave dipole



Physical antenna

The angle(s) at which maximum radiation occurs is called "boresight"

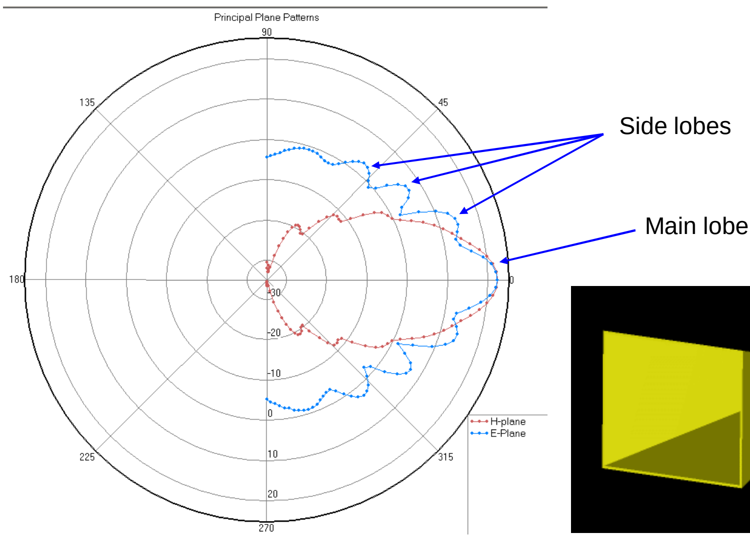


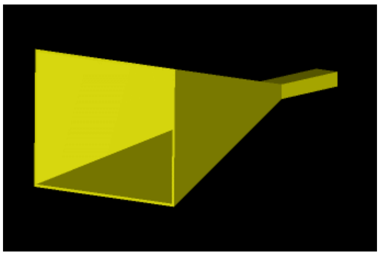
Normalized radiation pattern

Antenna Patterns (2)

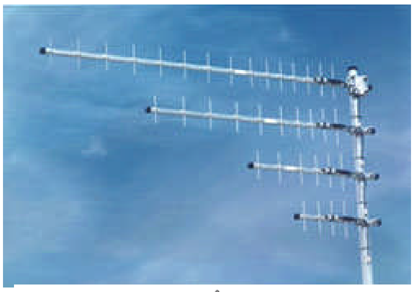
- Patterns usually represent far-field radiation
  - Far enough away from the antenna so that the $1/R^2$ & $1/R^3$ field terms have dropped out
  - Rule of thumb: the far field begins at $2d^2/\lambda$, where d is the maximum dimension of the antenna (or antenna array)
- Antennas are generally categorized as isotropic (equal radiation in all directions) or directional
  - There is no such thing as an isotropic antenna (i.e., one that is isotropic in θ and ϕ
- In some cases we are only interested in particular components (e.g., $E_\theta(\theta,\phi)$, $H_\phi(\theta,\phi)$, etc.)

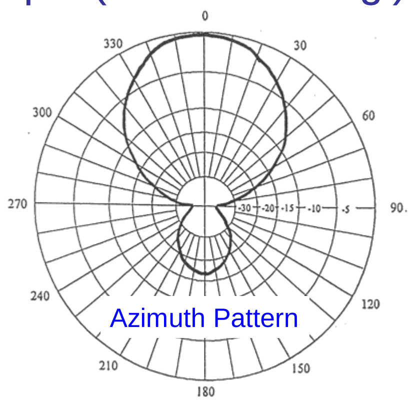
Antenna Pattern Example (horn antenna)

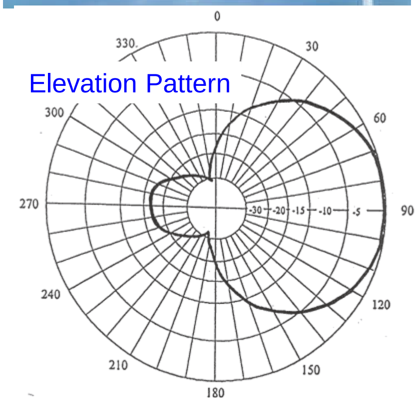




Antenna Pattern Example (4-element Yagi)







Definition: Front-to-back ratio is the ratio of maximum signal out of the front of the antenna to the maximum signal coming out of the back of the antenna, expressed in dB. This antenna has a front-to-back ratio of about 17 dB.

Reasons For Wanting Directive Antennas

- Lower noise when "looking" only at a small section of space
- Stronger signal when "looking" in the direction of the source
- Remote sensing (radar)- when interested in properties of a small section of space
- Can be used to spatially filter out signals that are not of interest
- Can provide coverage to only desired region

Antenna directional characteristics are sometimes expressed as a single scalar variable: beam width, beam area, main-lobe beam area, beam efficiency, directivity, gain, effective aperture, scattering aperture, aperture efficiency, effective height.

Calculating Antenna Patterns

The normalized field pattern (dimensionless) is given by:

$$E_\theta(\theta,\phi)_n = \frac{E_\theta(\theta,\phi)}{E_\theta(\theta,\phi)_{\max}}$$

And the normalized power pattern (dimensionless) is given by:

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

where $S(\theta,\phi)$ is the Poynting vector $= \dfrac{E_\theta^2(\theta,\phi)+E_\phi^2(\theta,\phi)}{Z_0}\left(W/m^2\right)$

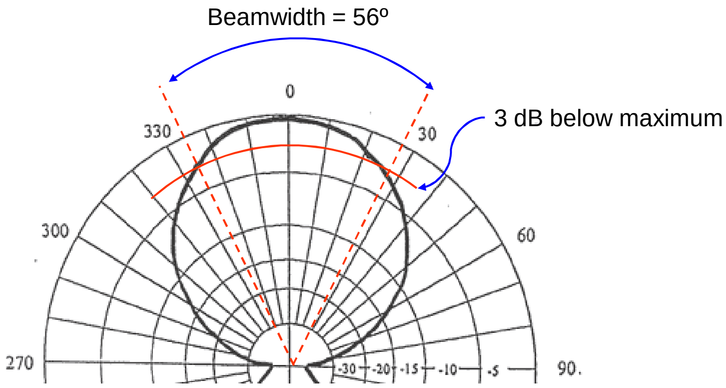
which can be put in terms of decibels: $P(\theta,\phi)_{dB} = 10\log_{10} P(\theta,\phi)_n$

3 dB, or Half-Power, Beamwidth

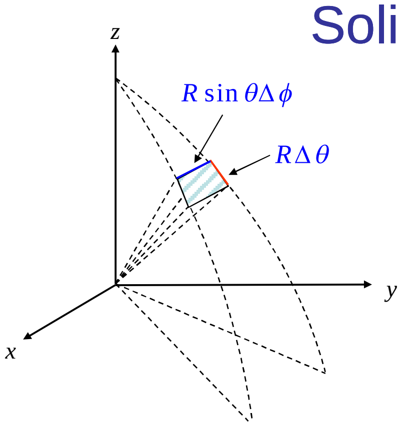
(analogous to the 3 dB bandwidth)

The beamwidth is the range of angles for which the radiation pattern is greater than 3 dB below its maximum value

Example: what is the beamwidth for the radiation pattern below?



Solid Angle (Ω)



The actual area traced out by $\Delta\theta$ and $\Delta\phi$ is $R^2 \sin\theta\Delta\theta\Delta\phi$

The solid angle represented by $\Delta\theta$ and $\Delta\phi$ is $\Omega = \sin\theta\left(\Delta\theta\Delta\phi\right)$

The solid angle is range independent

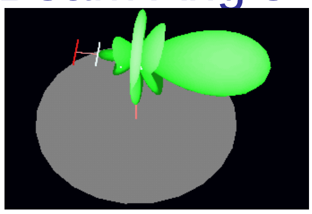
The actual area is equal to $R^2\Omega$

The solid angle of a sphere is 4π steradians, or sr. Solid angle is sometimes expressed in degrees:

$$1 \text{ radian } = \frac{180}{\pi} = 57.3° \Rightarrow (1 \text{ radian})^2 = \left(\frac{180}{\pi}\right)^2 = 3282.8 \text{ deg}^2/\text{radian}^2$$

Thus there are $3282.8 \times 4\pi = 41,253$ square degrees in a sphere

Beam Area (Ω_A), or Solid Beam Angle



This parameter provides a means for specifying directivity when the antenna is directive in both θ and ϕ. Provides an alternative to specifying beamwidth in both θ and ϕ separately.

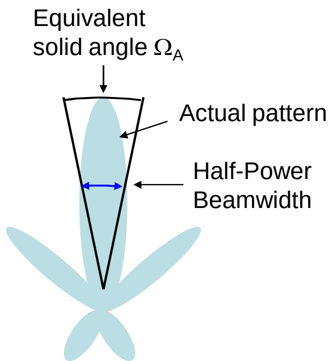
Beam Area is given by the integral of the normalized power pattern:

$$\Omega_A = \int\int P_n(\theta,\phi)d\Omega$$

$$= \int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)\sin\theta d\theta d\phi \quad \text{(sr)}$$

Ω_A can often be approximated by the half-power beamwidths in θ and ϕ

$$\Omega_A \approx \theta_{HP}\phi_{HP} \quad \text{(sr)}$$



Polar Plot of $P(\theta)$

Radiation Intensity ($U(\theta,\phi)$) and Directivity (D)

Radiation Intensity is the power radiated per solid angle, and unlike the Poynting vector, it will be independent of range. Its units are (Watts/steradian), and it is related to the Poynting vector magnitude and normalized power by:

$$P(\theta,\phi)_n = \frac{U(\theta,\phi)}{U(\theta,\phi)_{\max}} = \frac{S(\theta,\phi)}{S(\theta,\phi)_{\max}}$$

Directivity is the ratio of the maximum radiation intensity to the average radiation intensity:

$$D = \frac{U(\theta,\phi)_{\max}}{U_{Average}} = \frac{S(\theta,\phi)_{\max}}{S_{Average}} \quad \text{(dimensionless)}$$

The average value of the Poynting vector is given by:

$$S_{Average} = \frac{1}{4\pi}\int\int S(\theta,\phi)d\Omega = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} S(\theta,\phi)\sin\theta d\theta d\phi \quad \text{(Watts/m}^2\text{)}$$

Directivity (D)

Substituting our expression for $S_{average}$ into our equation for D:

$$D = \frac{S(\theta,\phi)_{\max}}{S_{Average}} = \frac{S(\theta,\phi)_{\max}}{\frac{1}{4\pi}\iint S(\theta,\phi)\,d\Omega} = \frac{1}{\frac{1}{4\pi}\iint \frac{S(\theta,\phi)}{S(\theta,\phi)_{\max}}\,d\Omega}$$

$$= \frac{1}{\frac{1}{4\pi}\iint P_n(\theta,\phi)\,d\Omega} = \frac{4\pi}{\Omega_A}$$

This gives us the expected result that as the beam area decreases, the antenna becomes more directive.

Example: what is the beam area and directivity of an isotropic antenna (assuming one existed)?

Isotropic $\Rightarrow P_n(\theta,\phi) = 1 \Rightarrow \Omega_A = \int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)\sin\theta\,d\theta\,d\phi = 4\pi$ (Sr)

A beam area of 4π implies that the main beam subtends the entire spherical surface, as would be expected

$D = \frac{4\pi}{\Omega_A} = 1$ Which is the smallest directivity that an antenna can have

Directivity (D) and Gain (G)

Recalling our approximation $\Omega_A \approx \theta_{HP}\phi_{HP}$ (sr), we can write D as:

$$D = \frac{4\pi}{\Omega_A} \approx \frac{4\pi \text{ (Sr)}}{\theta_{HP}\phi_{HP}} \approx \frac{41000 \text{ (deg}^2\text{)}}{\theta^{\circ}_{HP}\phi^{\circ}_{HP}}$$

Note that the number of square degrees in a sphere is rounded off

The Gain of an antenna, G, depends upon its directivity and its efficiency. That efficiency has to do with ohmic losses (the heating up of the antenna). For high-frequency, low-power applications we generally assume efficiency to be high. G is related to D by $G = kD$, where k is efficiency ($0 \le k \le 1$)

Gain is often expressed in decibels, referenced to an isotropic antenna.

$$G_{dBi} = 10\log_{10}\left(\frac{G}{G_{isotropic}}\right) = 10\log_{10} G$$

10 log is used, rather than *20 log*, since G is based on power

Example: Apply Our Equations On Some Published Antenna Specifications

Since the gain is less than the directivity, the antenna is not 100% efficient. The one dB difference can be put into linear units.

TYPE NO.	**201164**
FREQ. RANGE	225-400-MHz
VSWR	2.0:1 MAX.
INPUT IMPEDANCE	50 OHMS
DIRECTIVITY	11 dBi
GAIN	10 dBi NOM.
BEAMWIDTH H PLANE	60° NOM.
BEAMWIDTH E PLANE	60° NOM.
SIDE AND BACK LOBE LEVEL.	-15 dB MIN.
CROSS POLARIZATION	20 dB NOM.
POWER HANDLING	100 WATTS CW

$$10\log_{10}\left(\frac{G}{D}\right) = 10\log_{10}\left(\frac{kD}{D}\right) = -1 \Rightarrow k = 10^{-0.1} = 0.79$$

or the antenna is 79% efficient

Let's see if directivity agrees with beamwidths

$$D \approx \frac{41000\ (\text{deg}^2)}{\theta^{\circ}_{HP}\phi^{\circ}_{HP}} = \frac{41000}{(60)(60)} = 11.4$$

$$D_{dBi} = 10\log_{10}\left(\frac{D}{D_{isotropic}}\right) = 10\log_{10} 11.4 = 10.6$$