TriEmbed
Antennas

I wanna make contact ...
-- Joan Jett

DOUBLE PULSE TECHNOLOGIES

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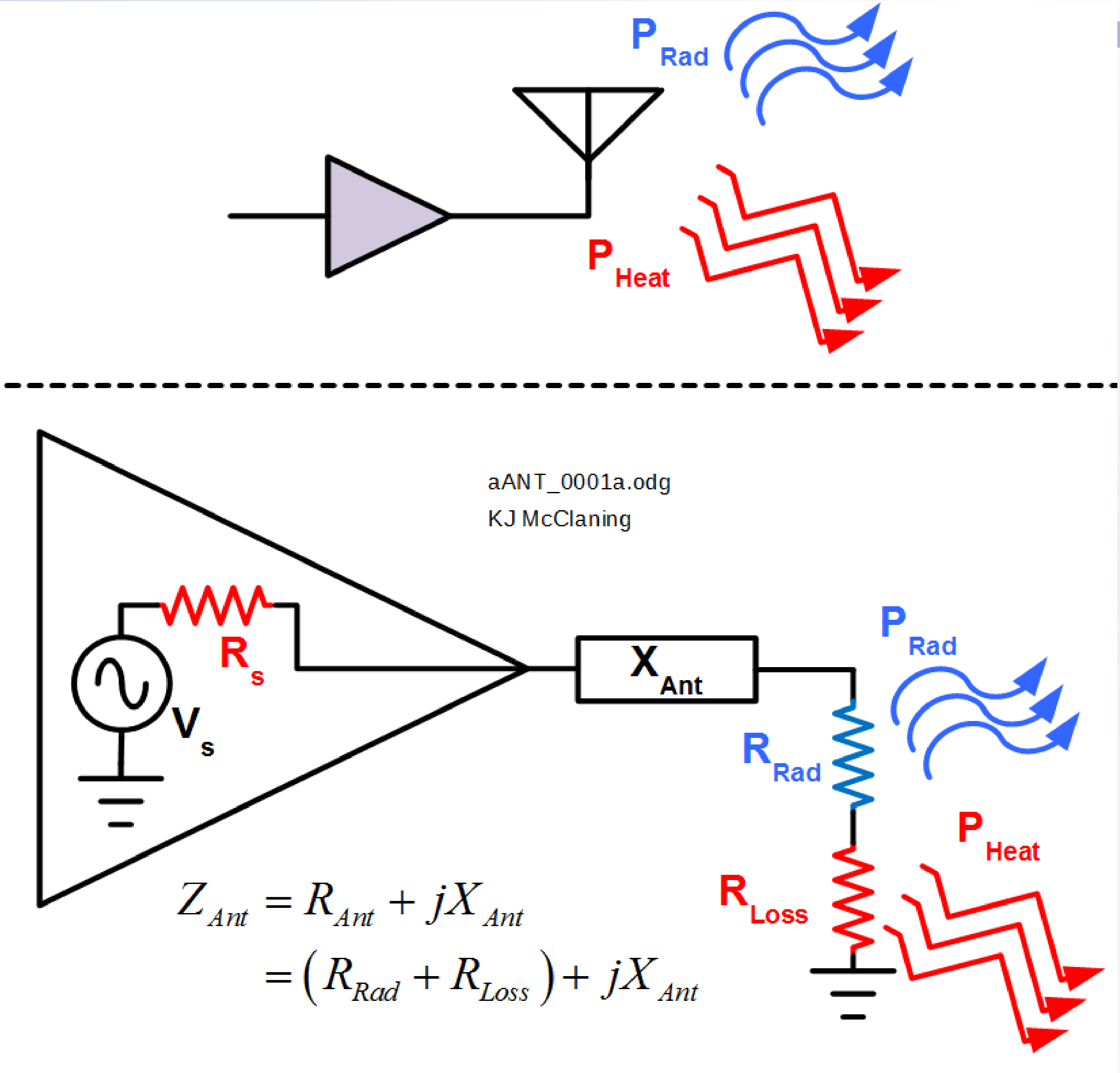
What’s an Antenna

- Interfaces between guided and unguided media
  - i.e. coax/waveguide and propagation through space
- Transmitting and receiving models
  - Both equally valid
  - Different ways of looking at the same thing
  - We’ll bounce freely between the receiving and transmitting models
- Exhibits “gain”
  - More sensitive to signals in certain directions
  - Throws more power in certain directions

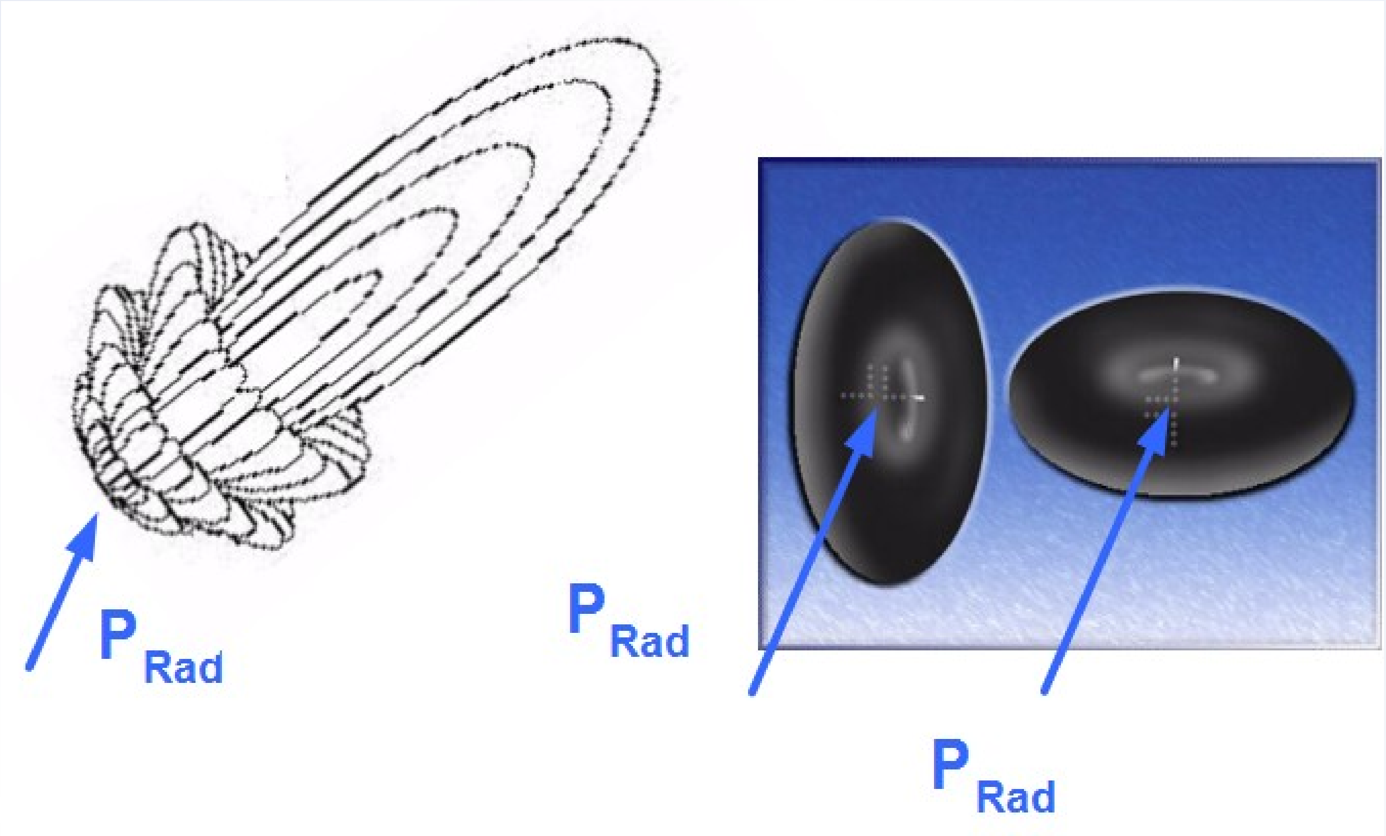
Transmitting Model



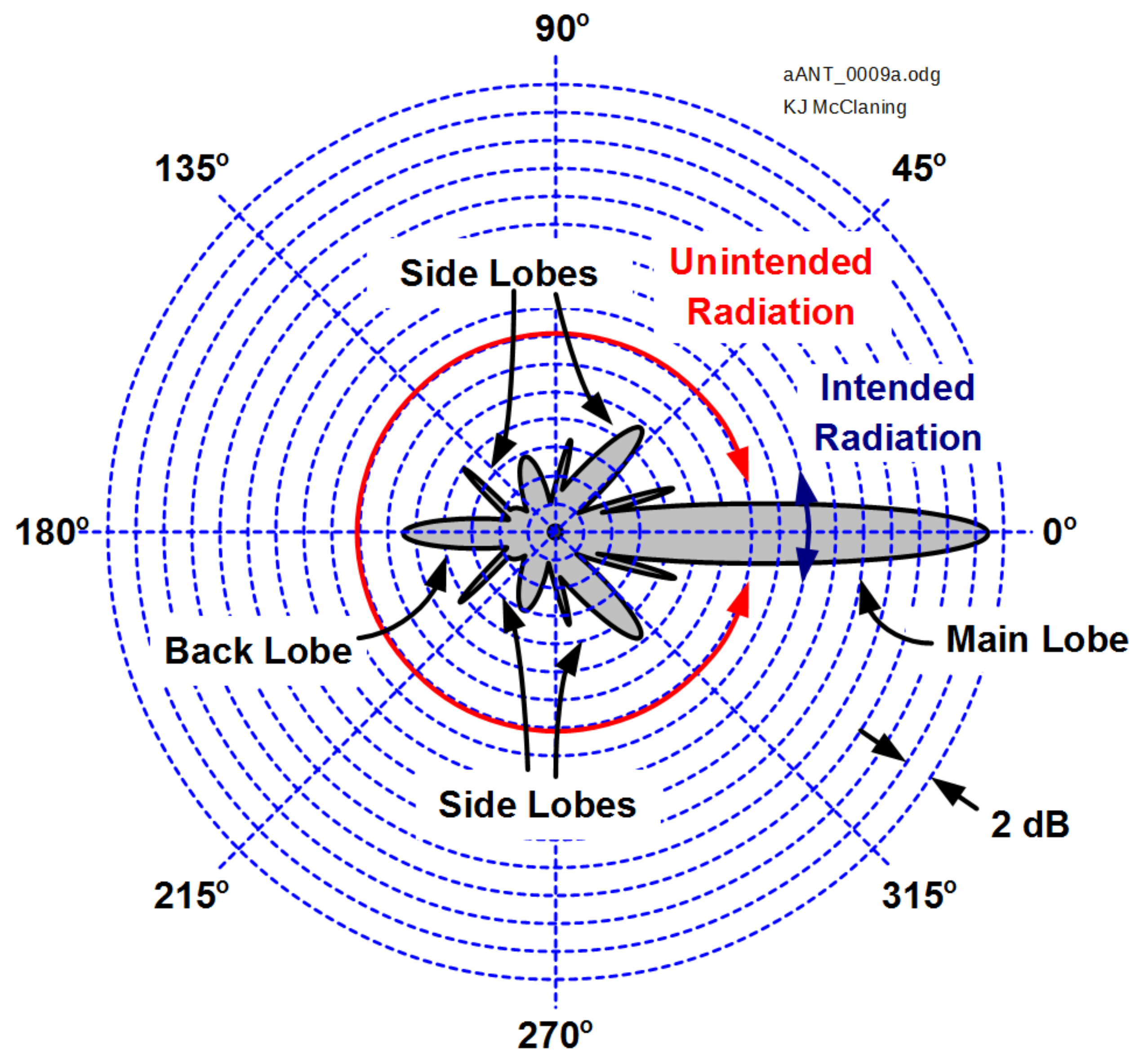
$$\begin{aligned} Z_{Ant} &= R_{Ant} + jX_{Ant} \\ &= \left(R_{Rad} + R_{Loss}\right) + jX_{Ant} \end{aligned}$$

Transmitting Model

- The power absorbed by the radiation resistance is distributed over 3D space and radiated away
- The pattern causes the energy to be stronger in some directions and weaker in others



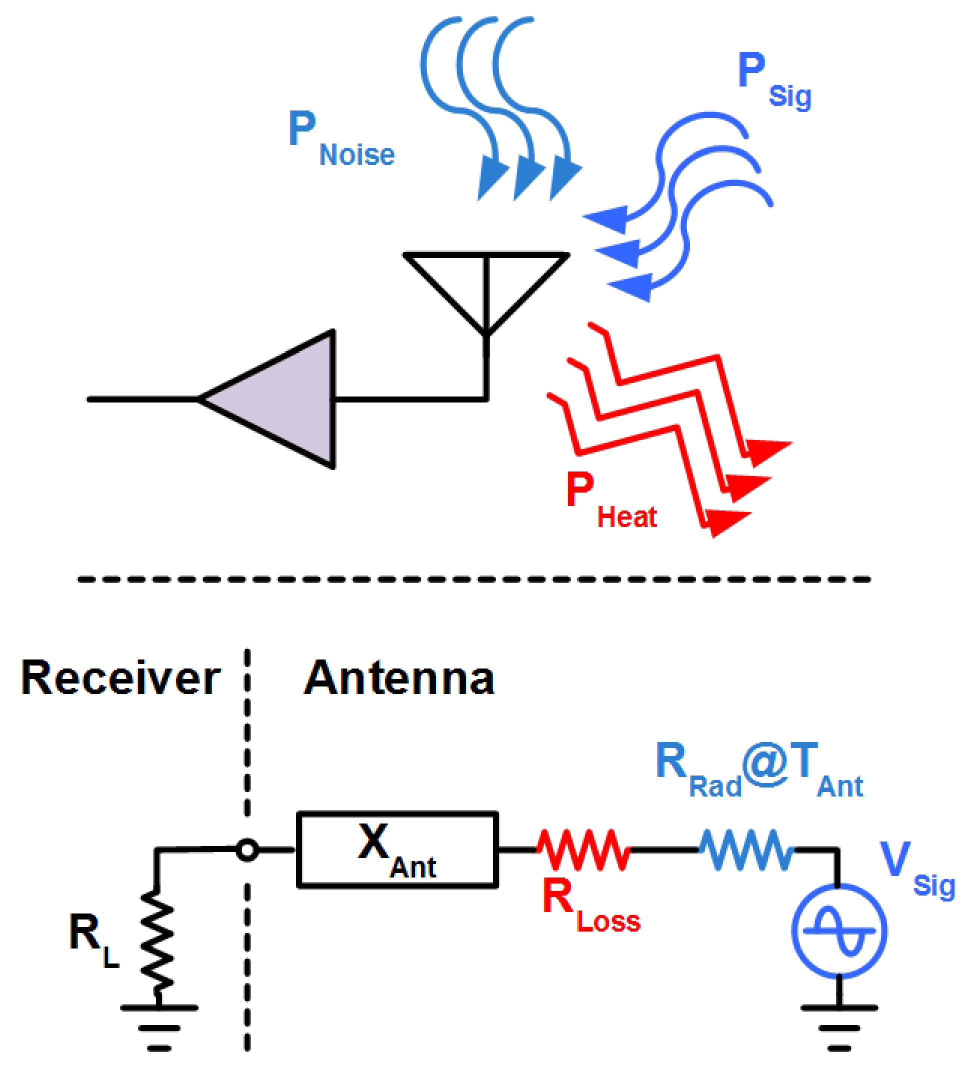
Transmitting Model



Receiving Model

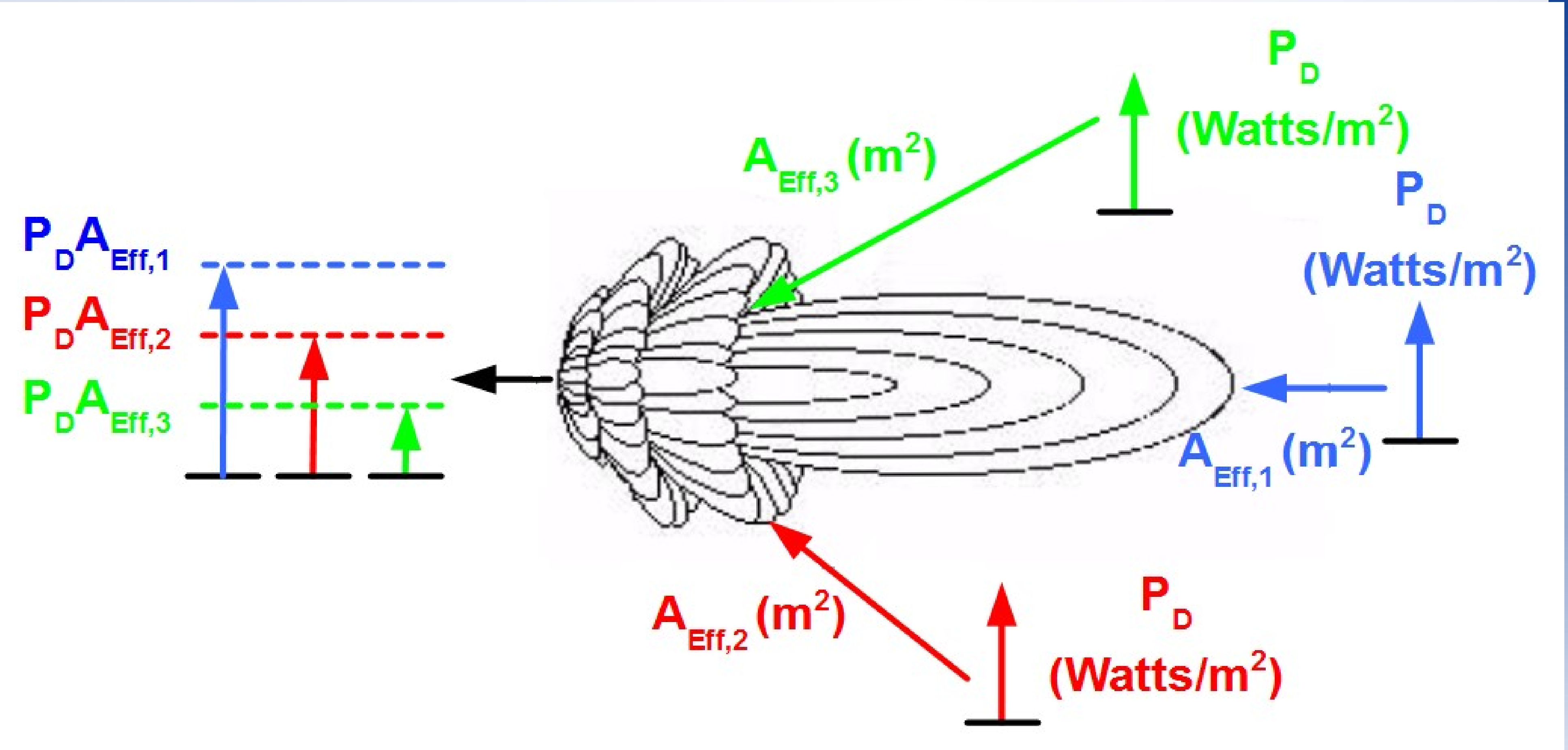
- Receives both signal and noise from the environment
- Presents an "effective area" A_E to the environment
- High gain => large A_E, low gain => small A_E

$$P_{RX} = A_E \left(PD_{W/M2} \right)$$



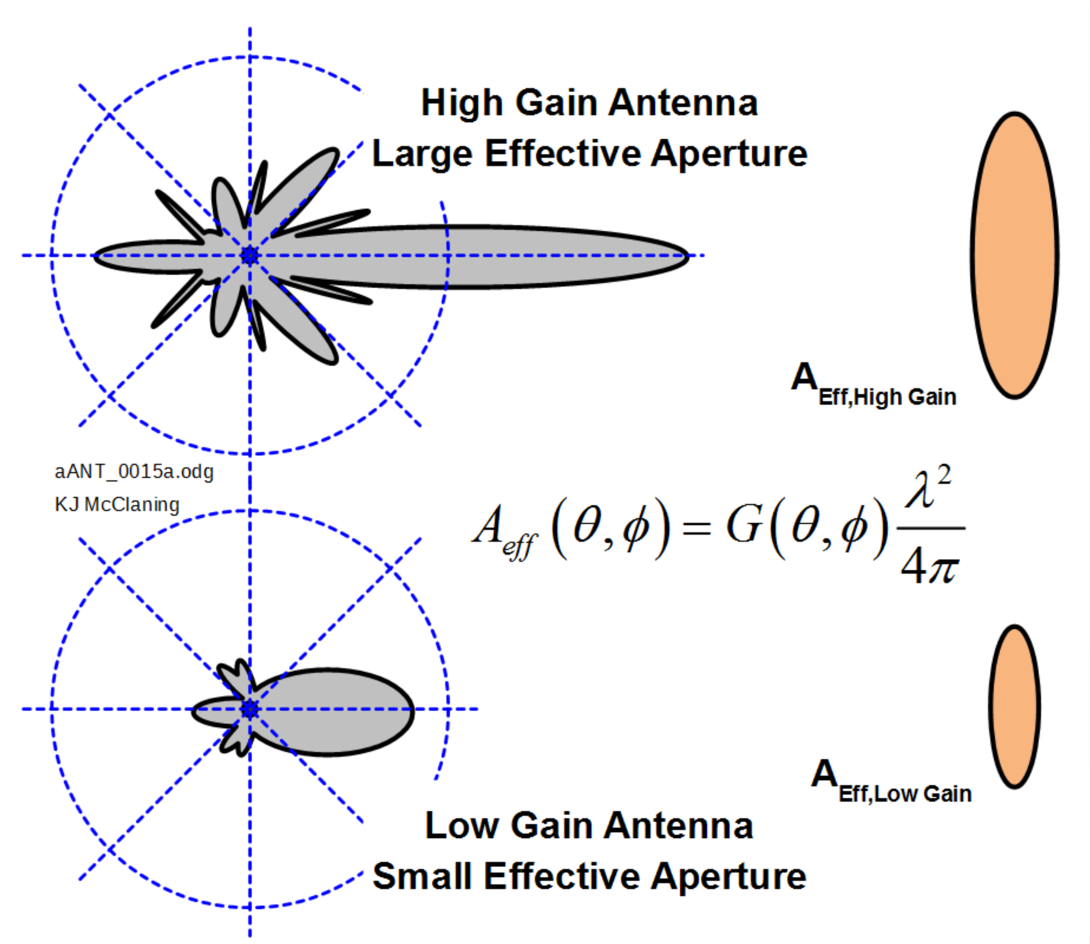
Receiving Model

- The power seen at the receiver is a function of effective area in a direction times the power density from that direction



Receiving Model – Aperture

- Aperture is the amount of electrical "area" an antenna presents to its environment
- Numerically related to antenna gain



$$A_{eff}(\theta,\phi) = G(\theta,\phi)\frac{\lambda^2}{4\pi}$$

Receiving Model – Aperture

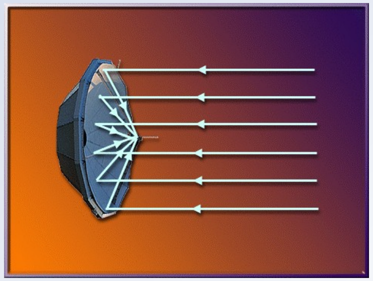
- The relationship between gain and effective area is

$$A_{eff}\left(\theta,\phi\right)=G\left(\theta,\phi\right)\frac{\lambda^2}{4\pi}$$

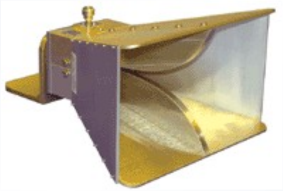
- Some antennas, like parabolic dishes, present a physical area to the oncoming wave front. The aperture efficiency of such antennas is

$$\eta_{aperture}=\frac{A_{eff}}{A_{physical}}$$

Receiving Model – Aperture Antennas



Parabolic Dish Antenna



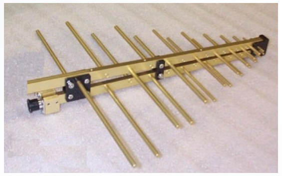
Horn Antenna

Aperature Antennas
Obvious Physical Aperture

Yagi-Uda Antenna

Dipole Antenna

BiConical Antenna



LPA Antenna

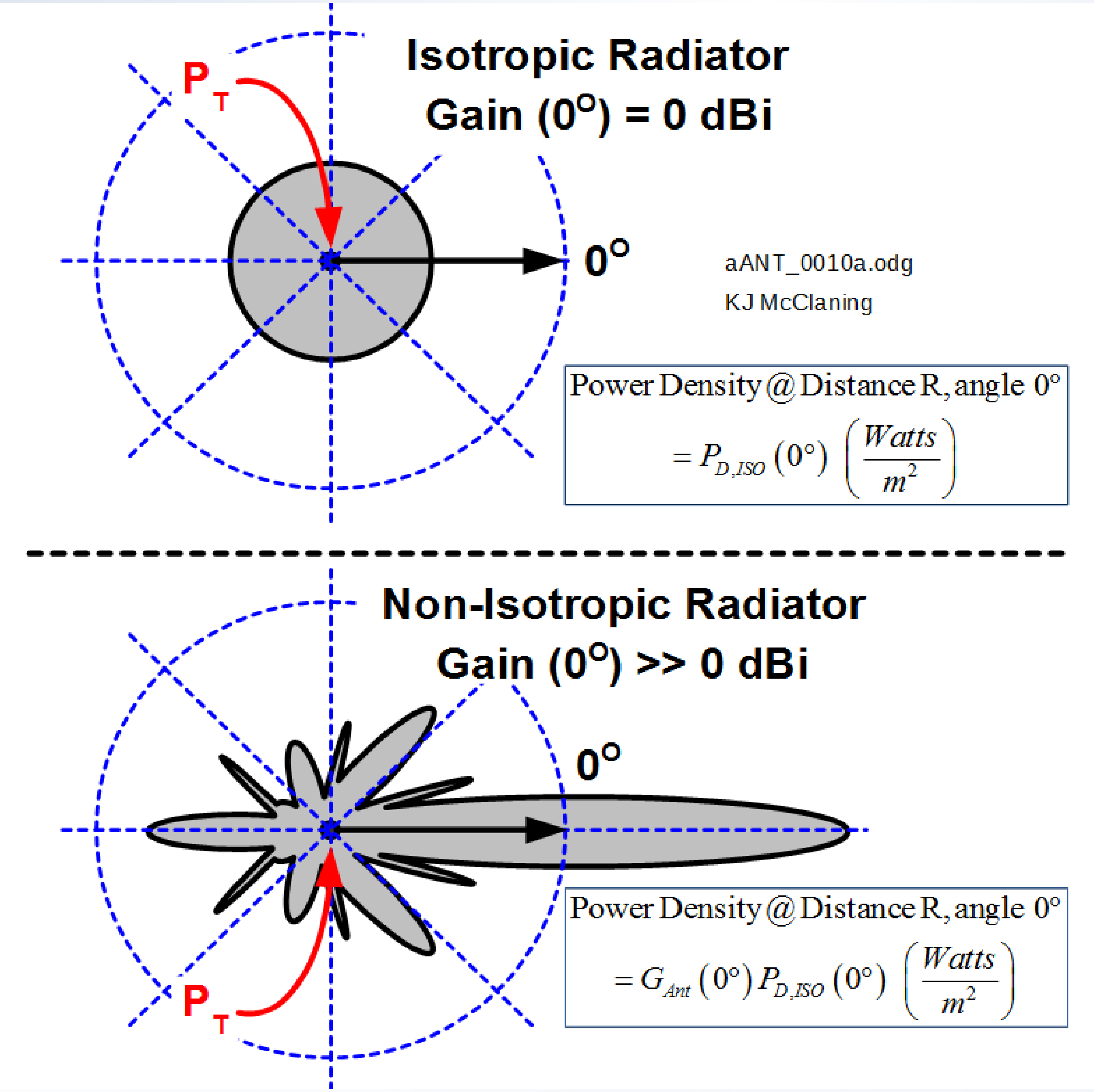
Non-Aperature Antennas
No Obvious Physical Aperture

Gain and Beamwidth

- Gain and beamwidth are inversely related
- Antennas achieve gain by focusing energy in one direction at the expense of other directions
- Empirical relationships

$$G = \frac{30,000}{\theta^2} \quad (\theta \text{ in degrees})$$

Antenna Gain (dBi)	Beamwidth (°)
10	55°
20	17°
30	5.4°
40	1.7°



Isotropic Radiator
Gain (0°) = 0 dBi

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Power Density @ Distance R, angle 0°

$$= P_{D,ISO}(0^\circ) \left(\frac{Watts}{m^2}\right)$$

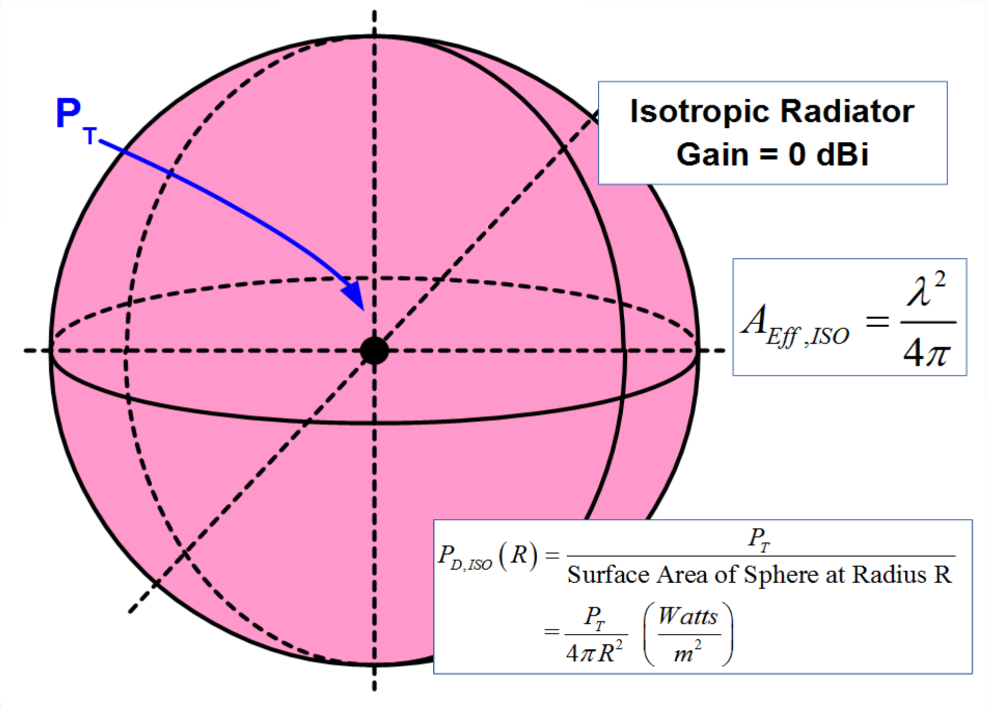
Non-Isotropic Radiator
Gain (0°) >> 0 dBi

Power Density @ Distance R, angle 0°

$$= G_{Ant}(0^\circ) P_{D,ISO}(0^\circ) \left(\frac{Watts}{m^2}\right)$$

Isotropic Radiator

- Imaginary antenna that represents a lossless geometric point in free space
- Radiates a perfect equally signal in all directions
  - A perfect spherical pattern
- Is equally sensitive to signals arriving from all directions
- Standard gain => dBi (dB relative to an isotropic antenna)



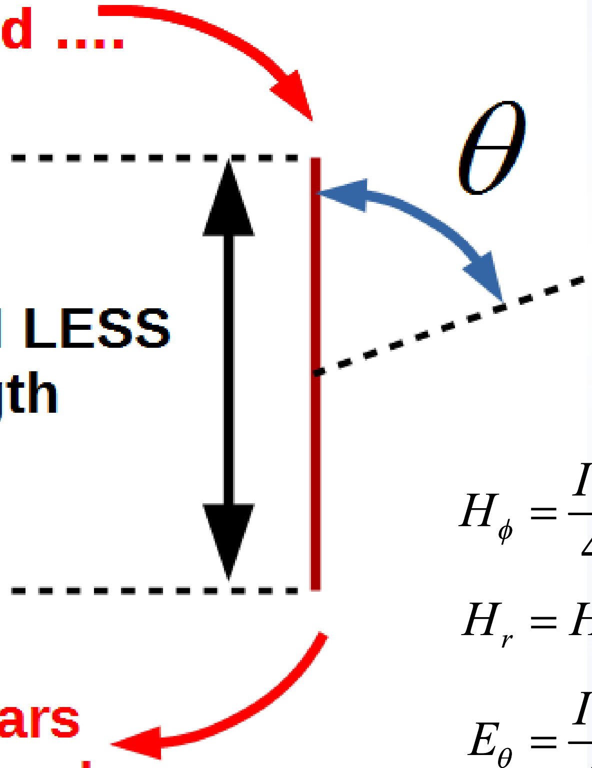
$$A_{Eff,ISO} = \frac{\lambda^2}{4\pi}$$

$$P_{D,ISO}(R) = \frac{P_T}{\text{Surface Area of Sphere at Radius R}} = \frac{P_T}{4\pi R^2}\left(\frac{Watts}{m^2}\right)$$

Ideal Antenna Types

- Let’s look at some almost real antennas
- The isotropic radiator
    - Gain standard
    - Not easy to build
- The short dipole or doublet
    - The basic for almost all of our antenna analysis
    - Math isn’t too bad

The Ideal or Short Dipole



Current magically arrives at one end ….

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Length is MUCH LESS than a wavelength

… and disappears from the other end

$$H_\phi = \frac{I\Delta z}{4\pi}\left[j\frac{\beta}{r}+\frac{1}{r^2}\right]e^{-j\beta r}\sin(\theta)$$

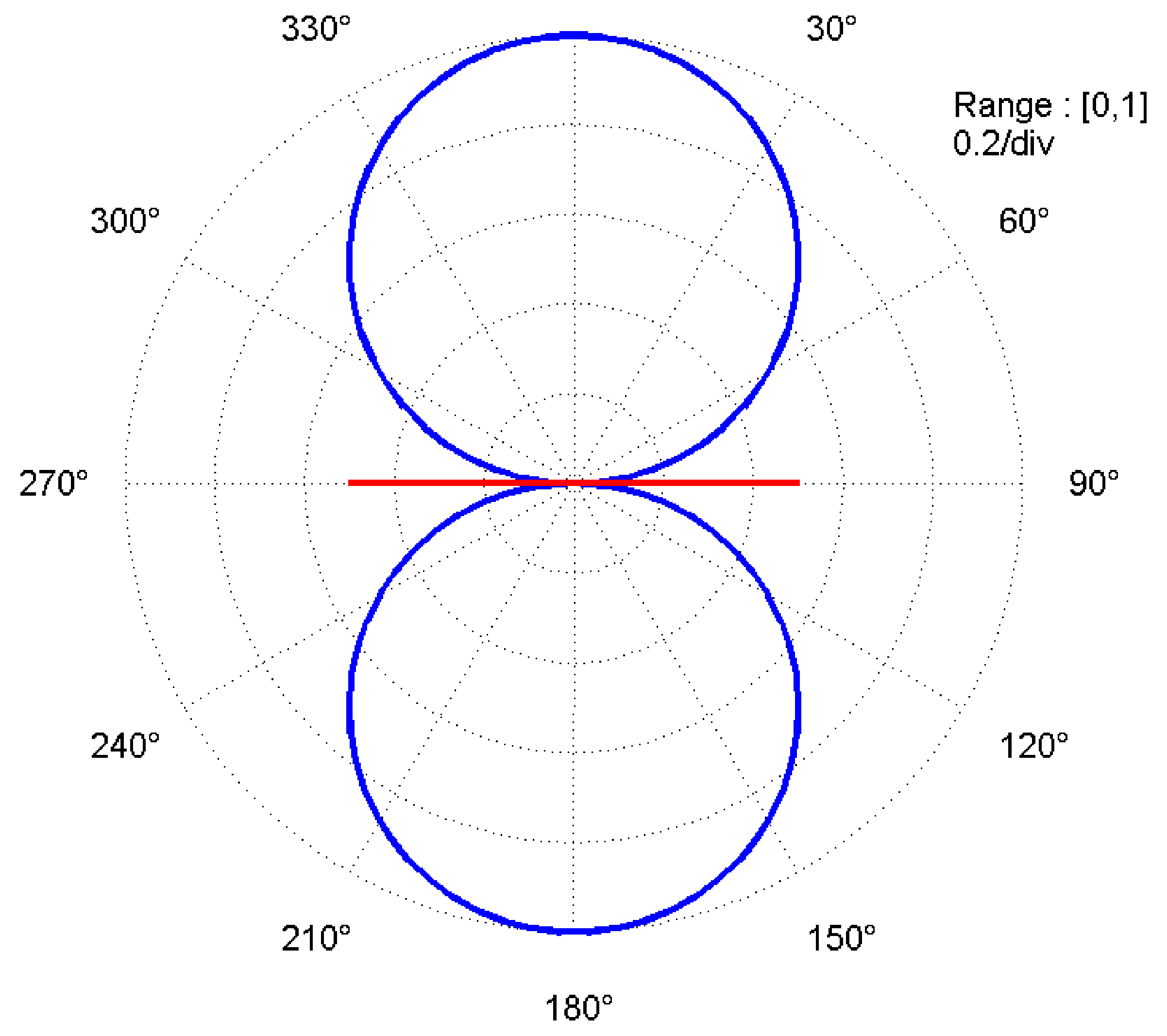
$$H_r = H_\theta = 0$$

$$E_\theta = \frac{I\Delta z}{4\pi}\left[j\frac{\omega\mu}{r}+\sqrt{\frac{\mu}{\varepsilon}}\frac{1}{r^2}+\frac{1}{j\omega\varepsilon r^3}\right]e^{-j\beta r}\sin(\theta)$$

$$E_r = \frac{I\Delta z}{2\pi}\left[\sqrt{\frac{\mu}{\varepsilon}}\frac{1}{r^2}+\frac{1}{j\omega\varepsilon r^3}\right]e^{-j\beta r}\cos(\theta)$$

$$E_\phi = 0$$

The Ideal or Short Dipole



The Ideal or Short Dipole

Far Field

- All $1/r^2$ and $1/r^3$ terms assumed = 0

Near field

- r is very small
- The $1/r^2$ and $1/r_3$ terms dominate

$$H_\phi = \frac{I\Delta z}{4\pi}\left[j\frac{\beta}{r} + \frac{1}{r^2}\right]e^{-j\beta r}\sin(\theta)$$

$$H_r = H_\theta = 0$$

$$E_\theta = \frac{I\Delta z}{4\pi}\left[j\frac{\omega\mu}{r} + \sqrt{\frac{\mu}{\varepsilon}}\frac{1}{r^2} + \frac{1}{j\omega\varepsilon r^3}\right]e^{-j\beta r}\sin(\theta)$$

$$E_r = \frac{I\Delta z}{2\pi}\left[\sqrt{\frac{\mu}{\varepsilon}}\frac{1}{r^2} + \frac{1}{j\omega\varepsilon r^3}\right]e^{-j\beta r}\cos(\theta)$$

$$E_\phi = 0$$

The Ideal or Short Dipole

- Far Field Equations

$$H_\phi = j\frac{\beta I\Delta z}{4\pi r}e^{-j\beta r}\sin(\theta)$$

$$H_r = H_\theta = 0$$

$$E_\theta = j\frac{\omega\mu I\Delta z}{4\pi r}e^{-j\beta r}\sin(\theta)$$

$$E_r = 0$$

$$E_\phi = 0$$

- Near Field Equations

$$H_\phi = \frac{I\Delta z}{4\pi r^2}e^{-j\beta r}\sin(\theta)$$

$$H_r = H_\theta = 0$$

$$E_\theta = -j\frac{I\Delta z}{\omega\varepsilon 4\pi r^3}e^{-j\beta r}\sin(\theta)$$

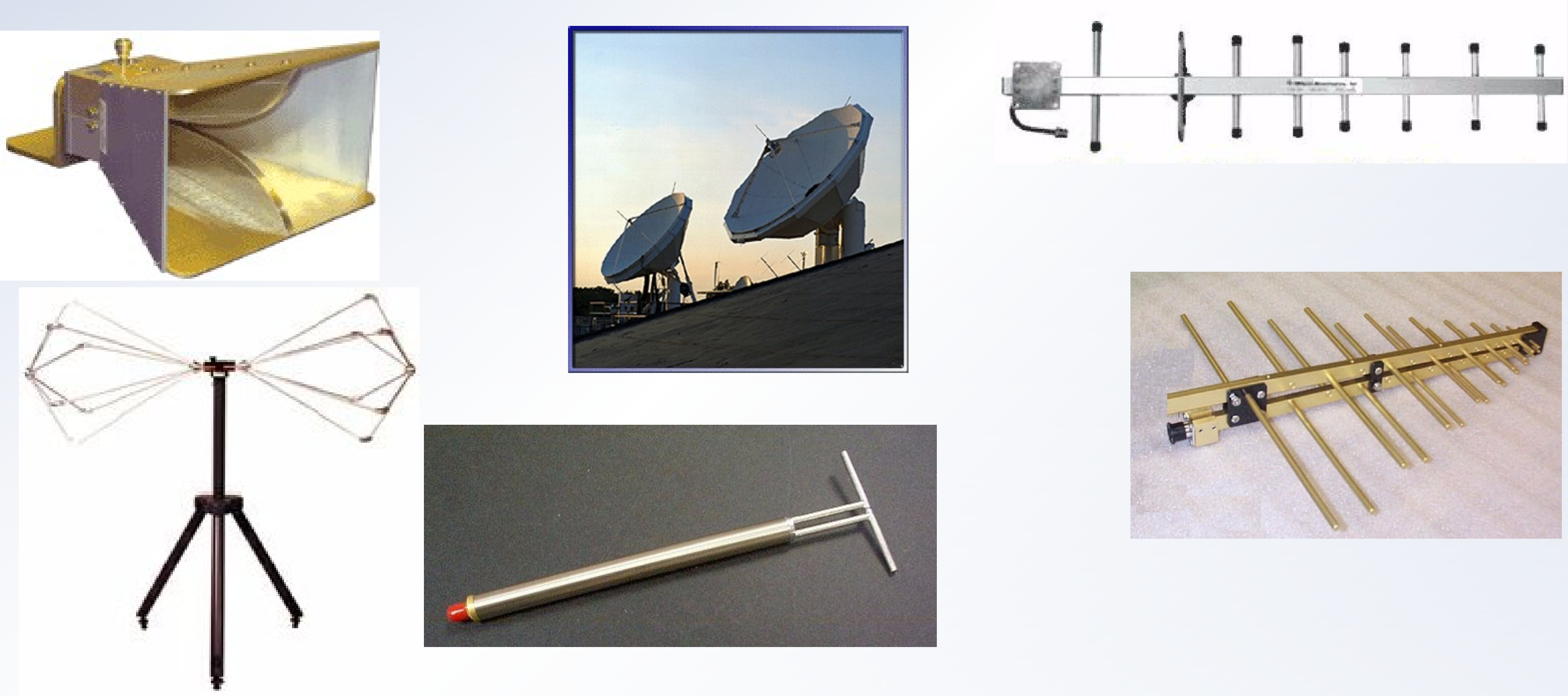
$$E_r = -j\frac{I\Delta z}{\omega\varepsilon 2\pi r^3}e^{-j\beta r}\cos(\theta)$$

$$E_\phi = 0$$

- Near Field => High E-field coming off the tips of the dipole
- Far Field => Null coming off the tip

Realized Antennas

- Let's look at some real antennas

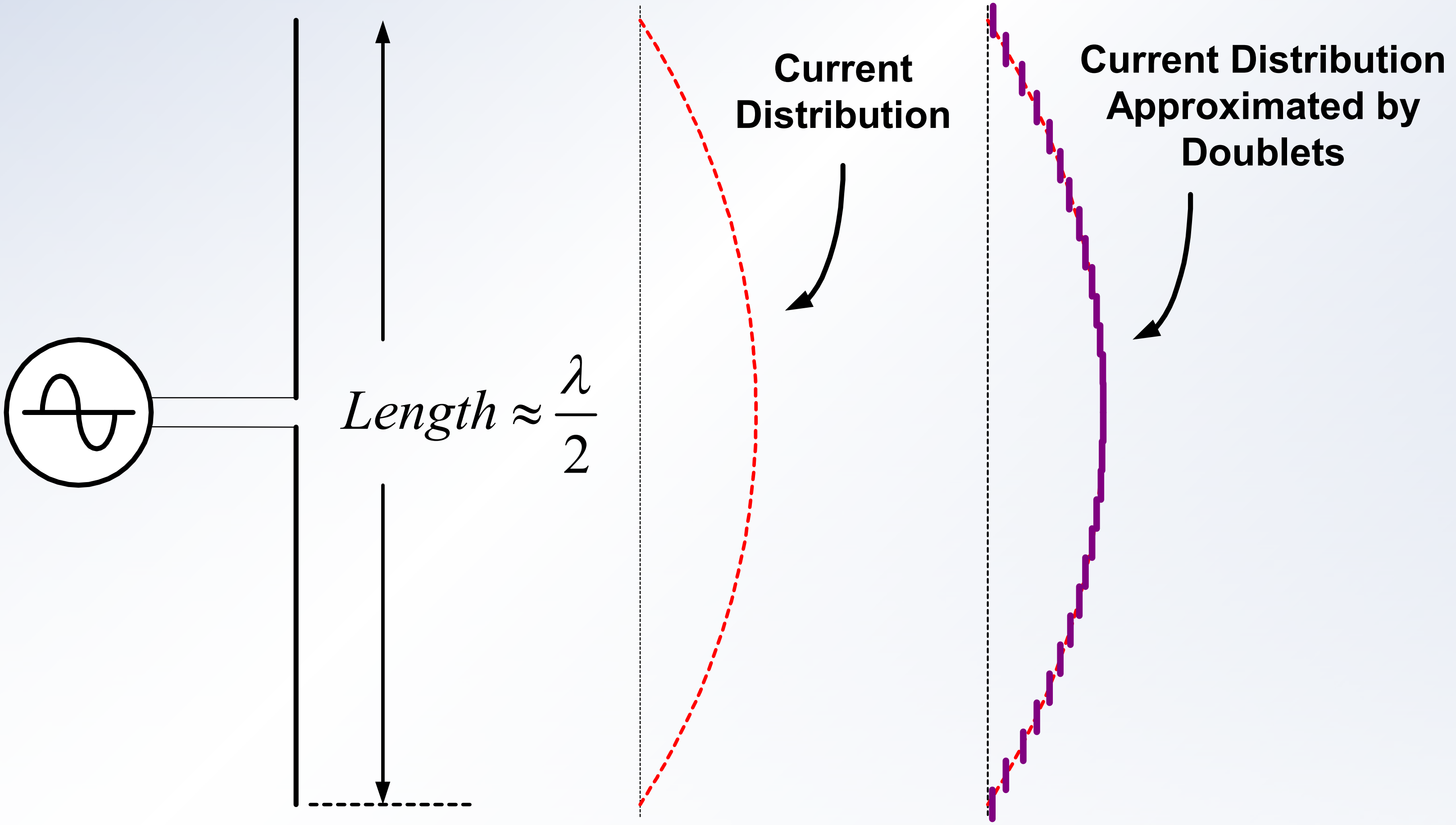


Realized Antennas – Mechanical Precision

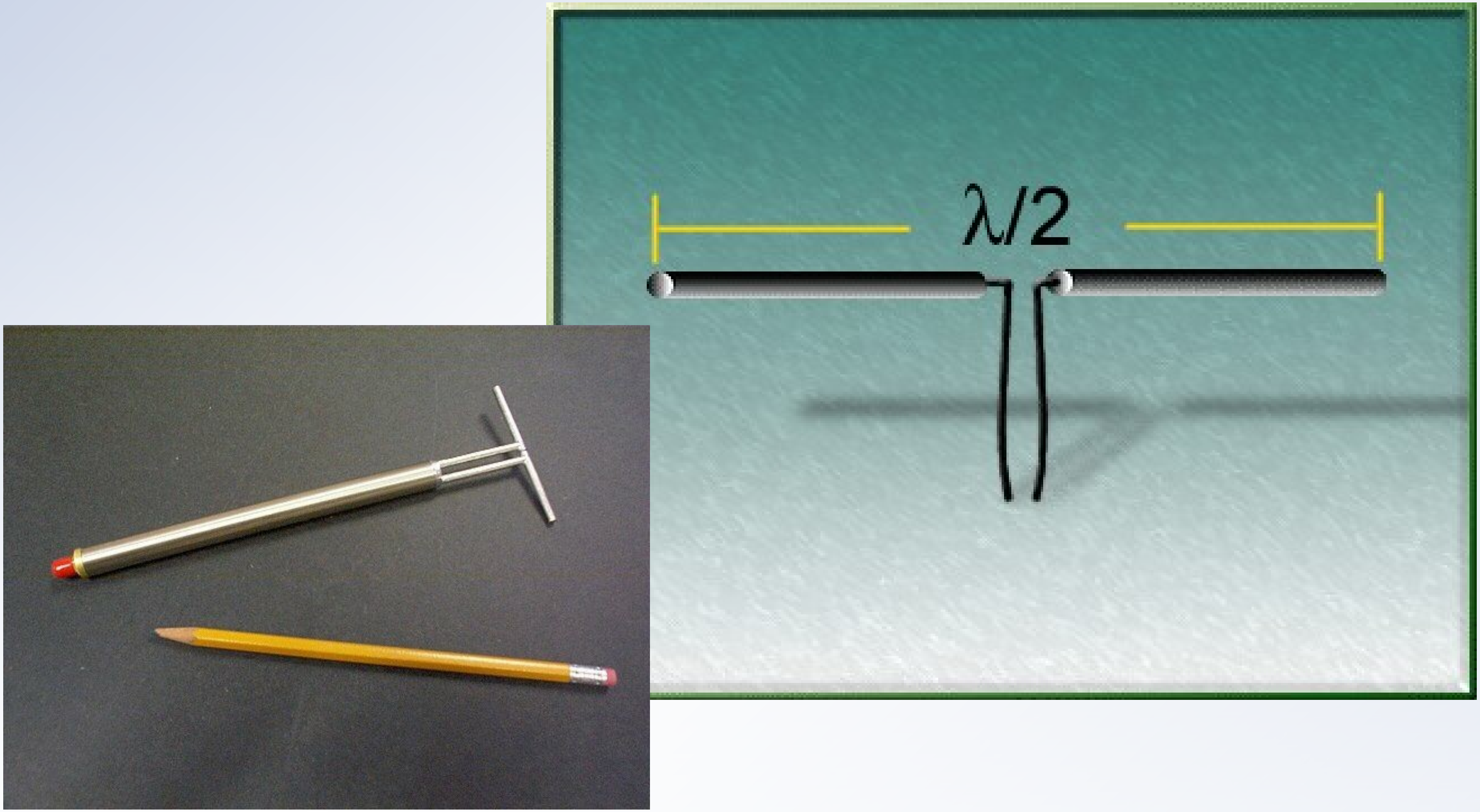
- Building an antenna is all about positioning electrical conductors in 3-space
- In general, features smaller than λ/20 will not affect the performance of a structure
    - The lower limit is about λ/15 (some use λ/10)
- Antennas with very high gain or very low side lobes will require tighter tolerances
- At 30 GHz, the wavelength is 1cm => tolerances need to be good to 0.5mm
    - Building a 4-foot parabolic reflector to an accuracy of 0.5mm is a tough job
- At 3 GHz, λ = 10 cm so it's an easier job because the tolerance is around 5mm

Half-Wave Dipole

- Most antennas are variations on a dipole or made from arrays of dipoles

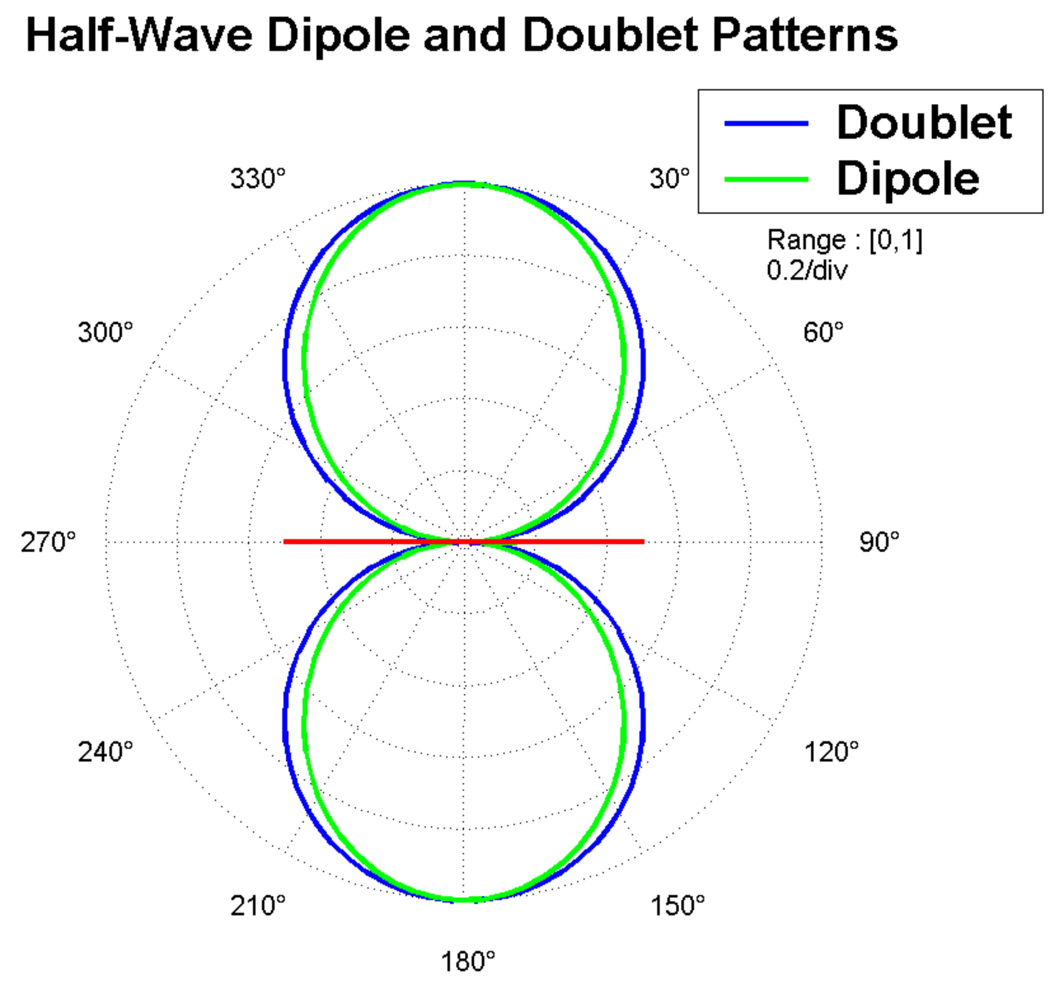


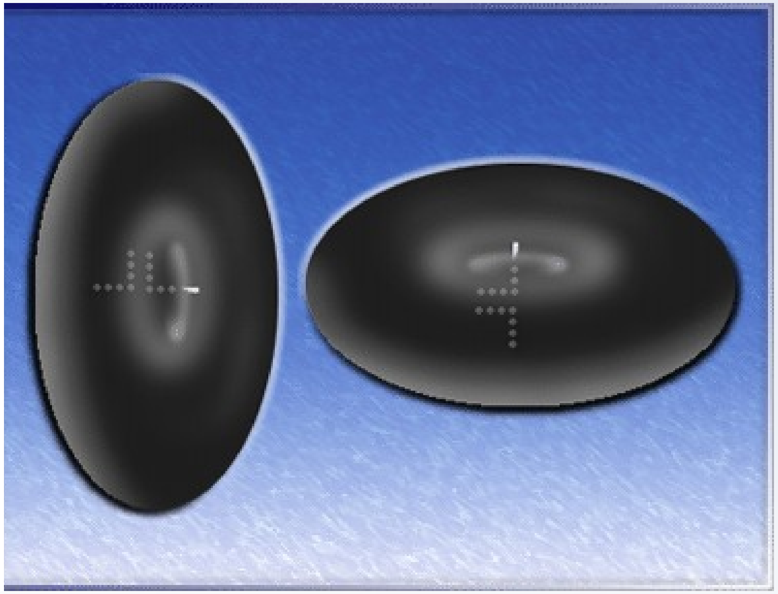
Half-Wave Dipole



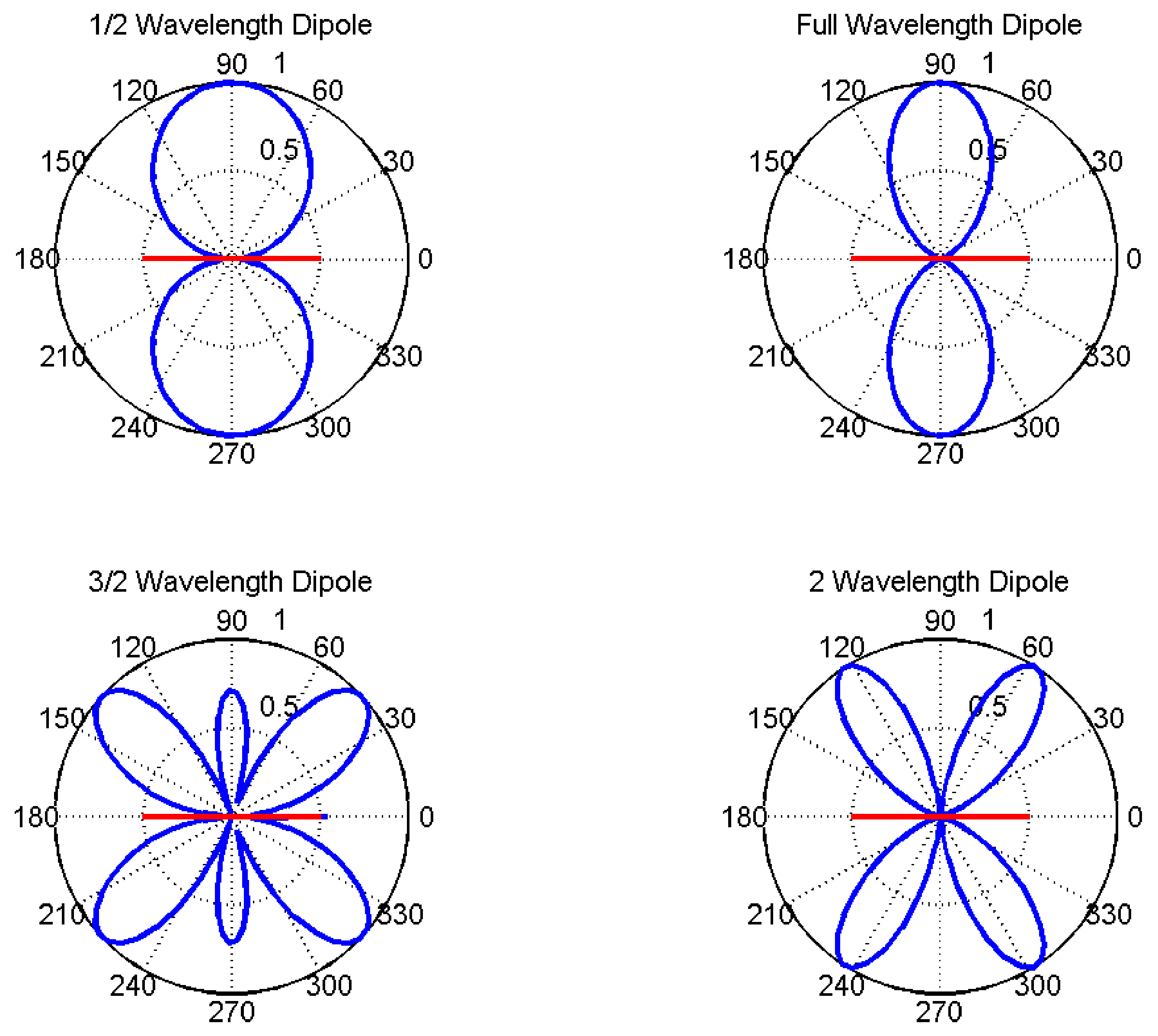
Half-Wave Dipole - Pattern

- The familiar doughnut pattern





Longer Dipoles

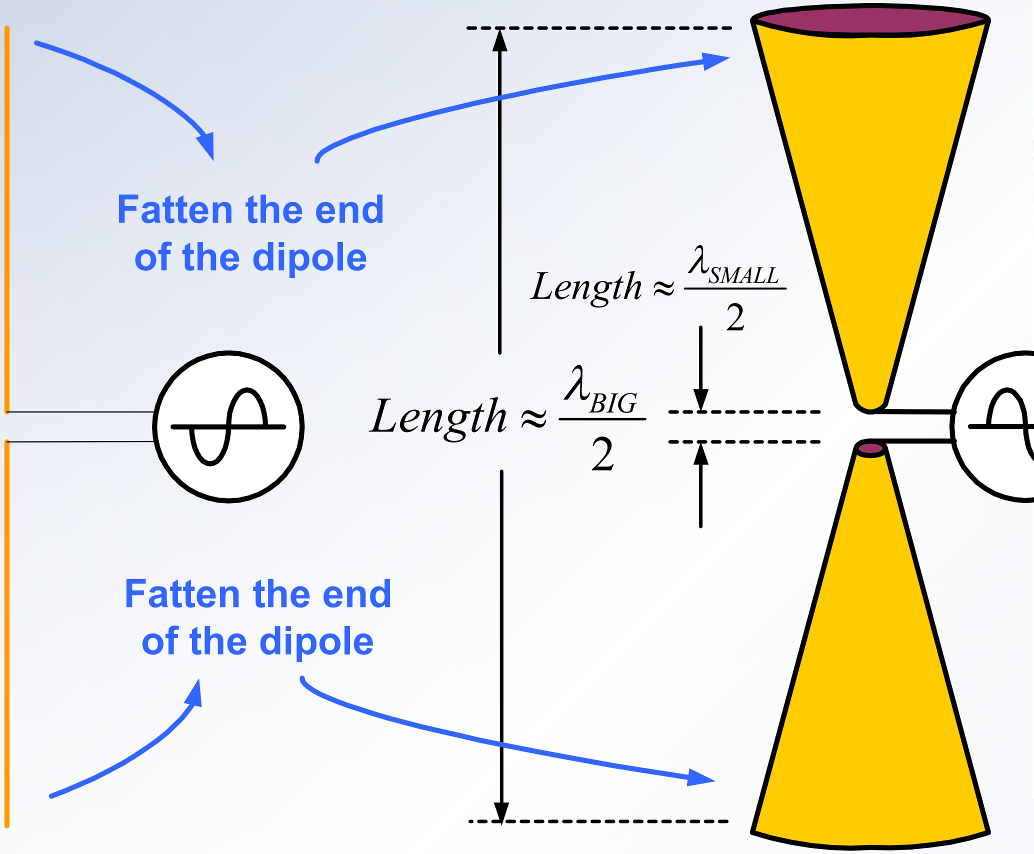

1/2 Wavelength Dipole

Full Wavelength Dipole

3/2 Wavelength Dipole

2 Wavelength Dipole

Bi-conical Antennas



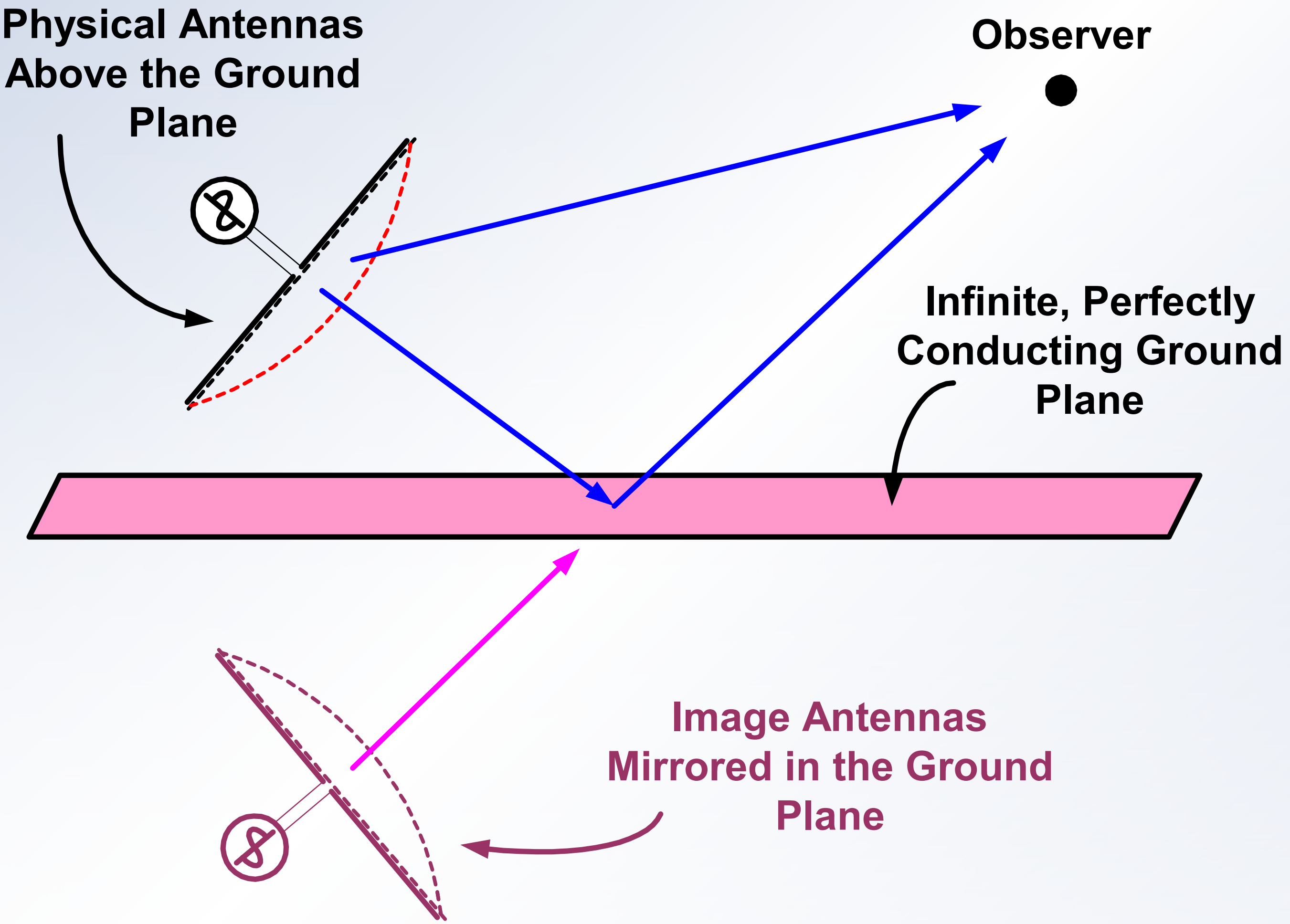
Fatten the end of the dipole

$Length \approx \frac{\lambda_{SMALL}}{2}$

$Length \approx \frac{\lambda_{BIG}}{2}$

Fatten the end of the dipole

Reflectors



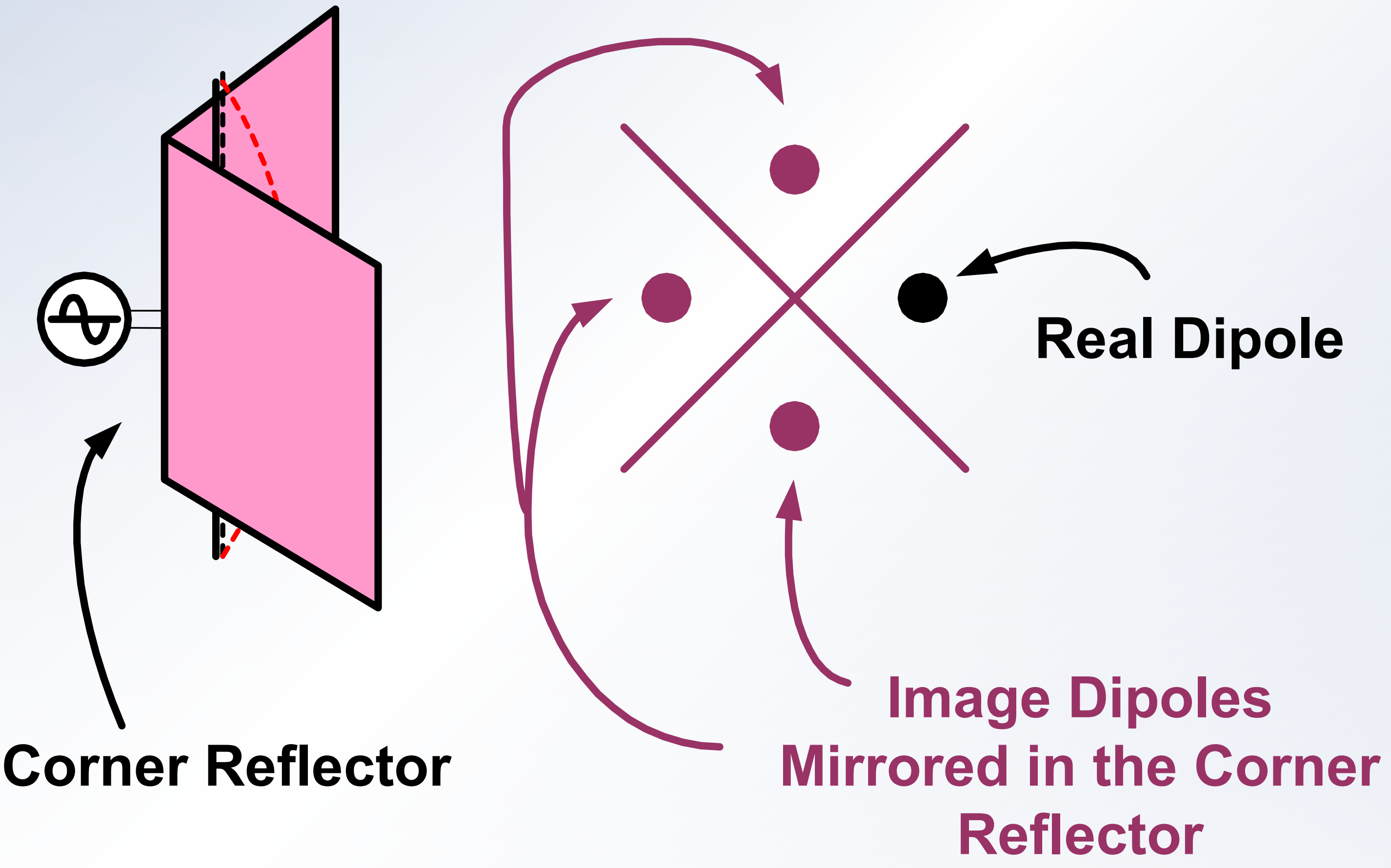
Physical Antennas Above the Ground Plane

Observer

Infinite, Perfectly Conducting Ground Plane

Image Antennas Mirrored in the Ground Plane

Corner Reflectors

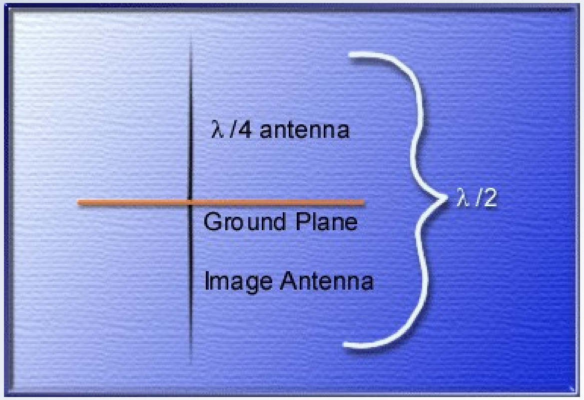


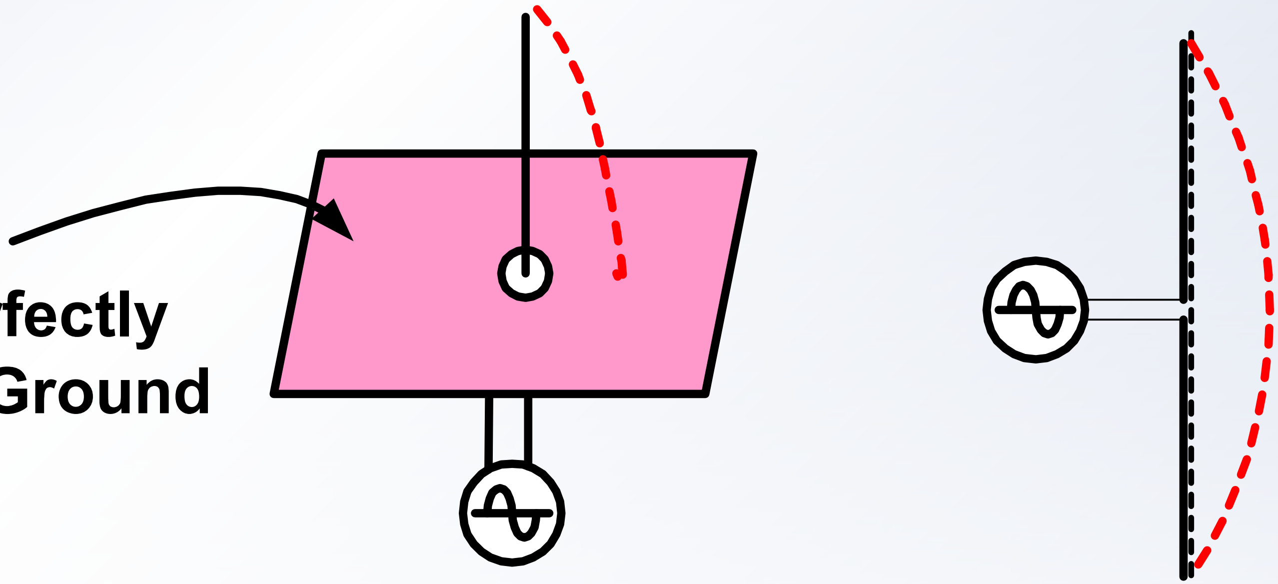
Real Dipole

Corner Reflector

Image Dipoles Mirrored in the Corner Reflector

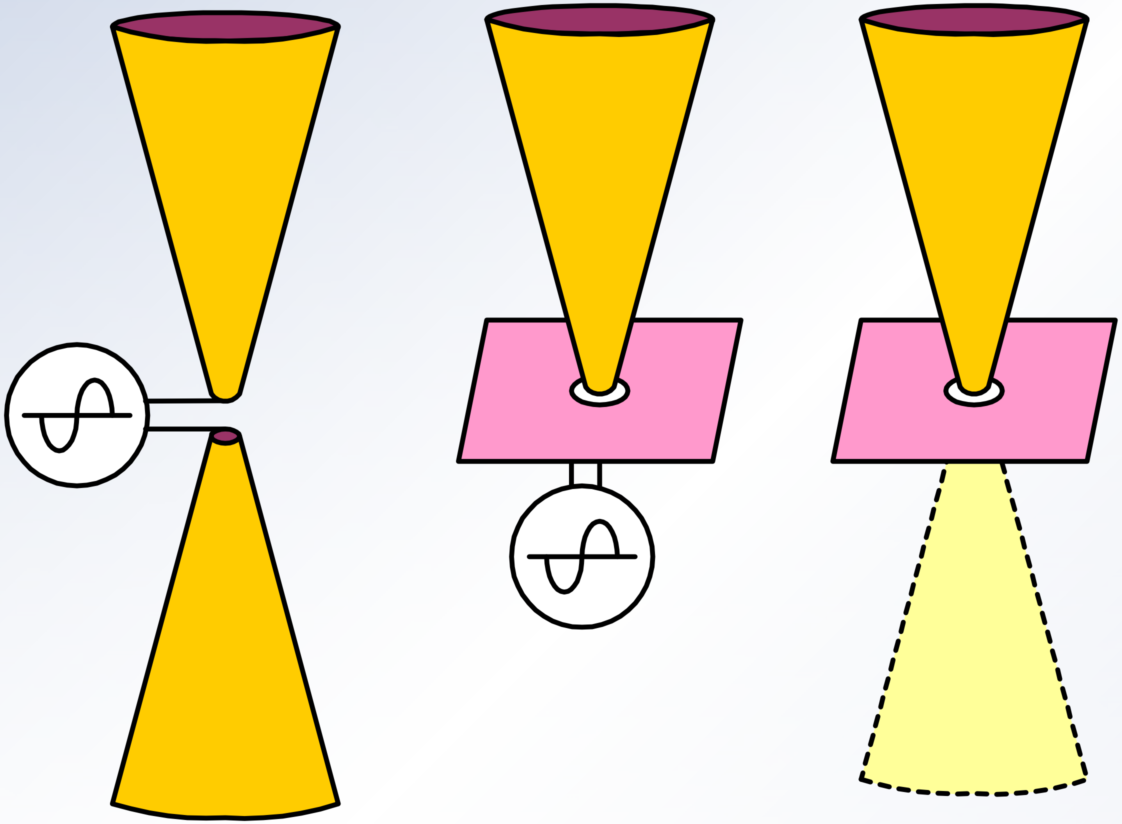
Monopoles

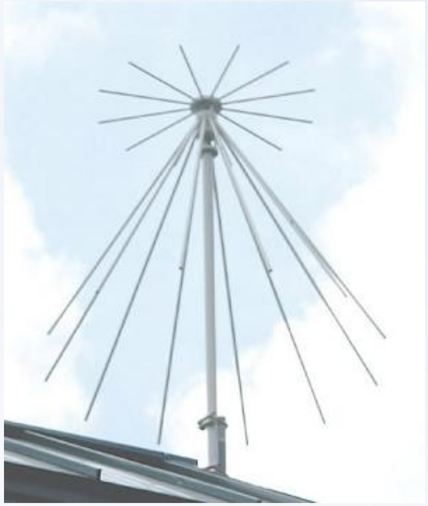




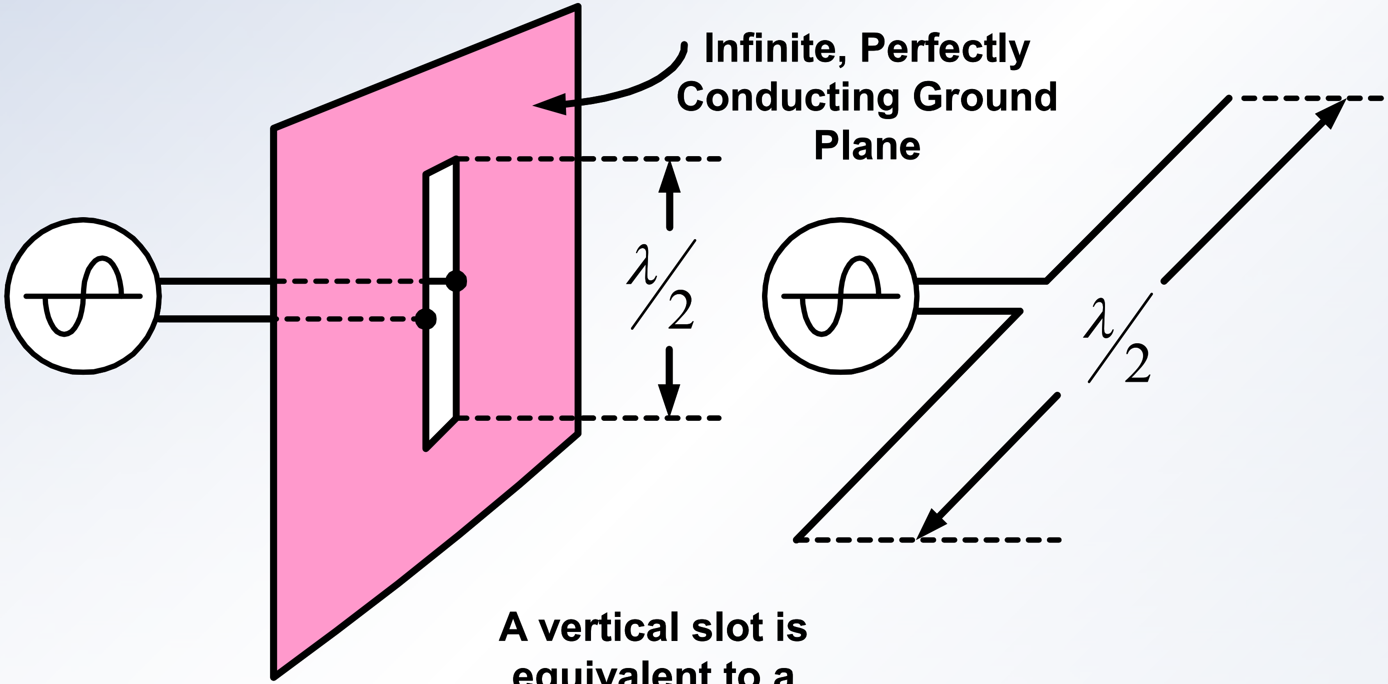
Infinite, Perfectly Conducting Ground Plane

Discones





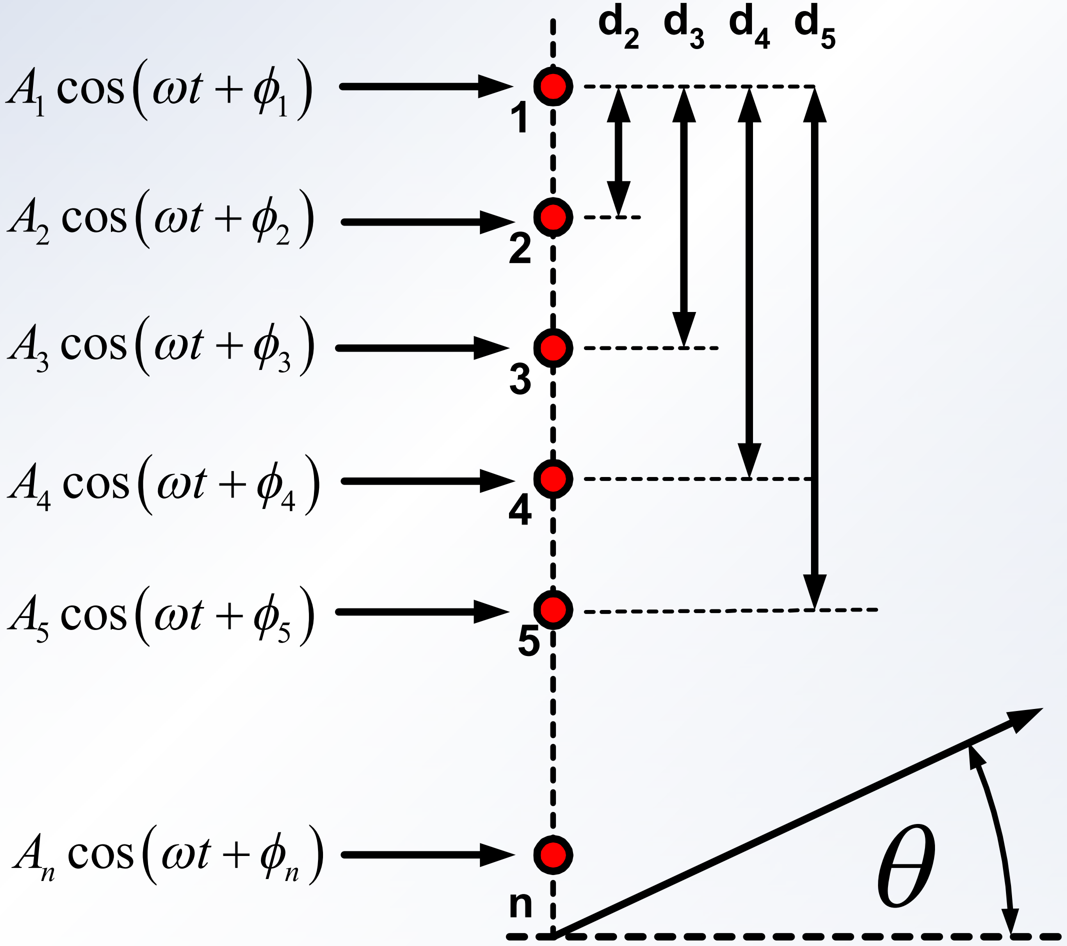
Slot Antennas



Infinite, Perfectly Conducting Ground Plane

A vertical slot is equivalent to a horizontal dipole

Array Factor



$A_1 \cos(\omega t + \phi_1)$

$A_2 \cos(\omega t + \phi_2)$

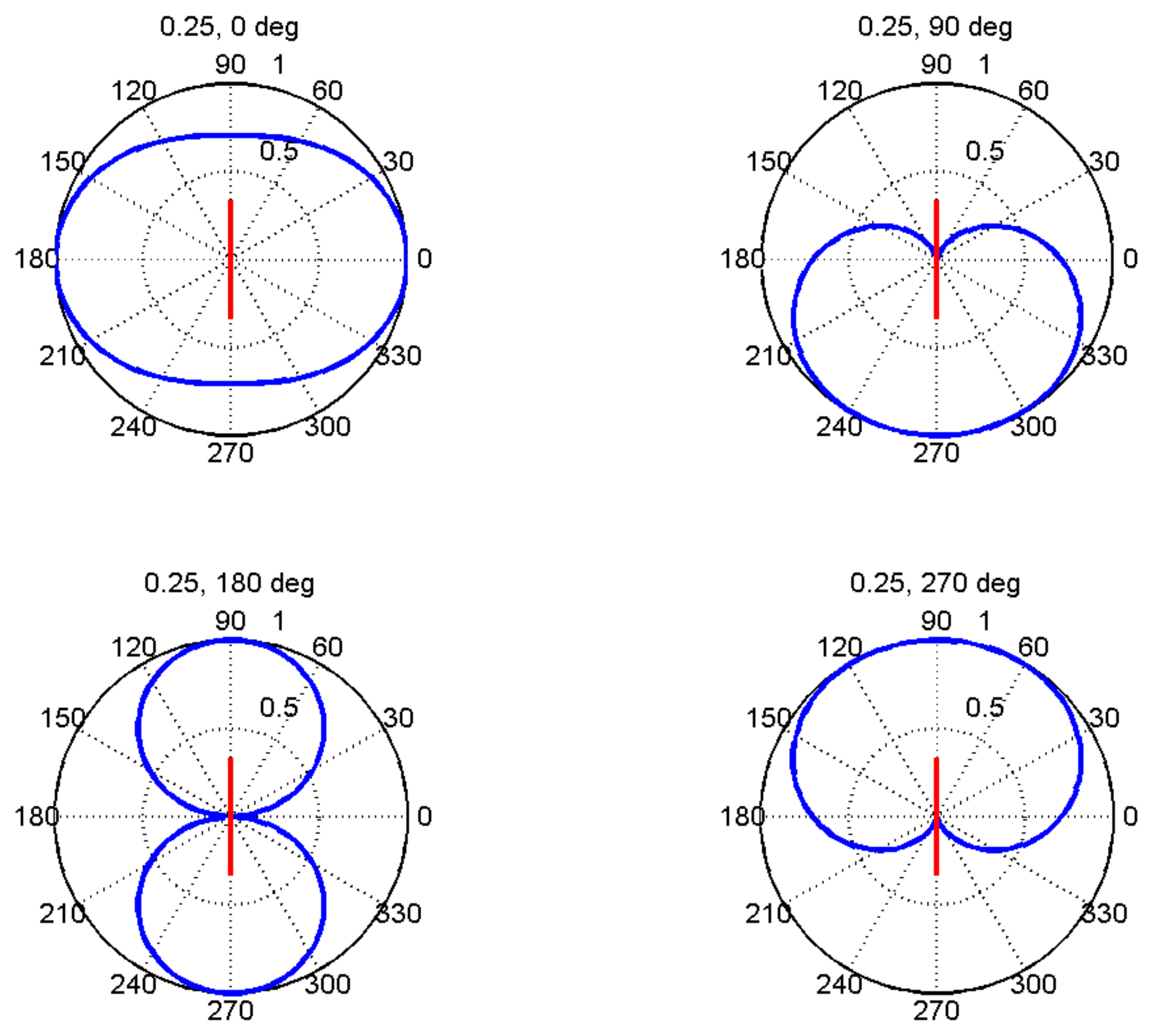
$A_3 \cos(\omega t + \phi_3)$

$A_4 \cos(\omega t + \phi_4)$

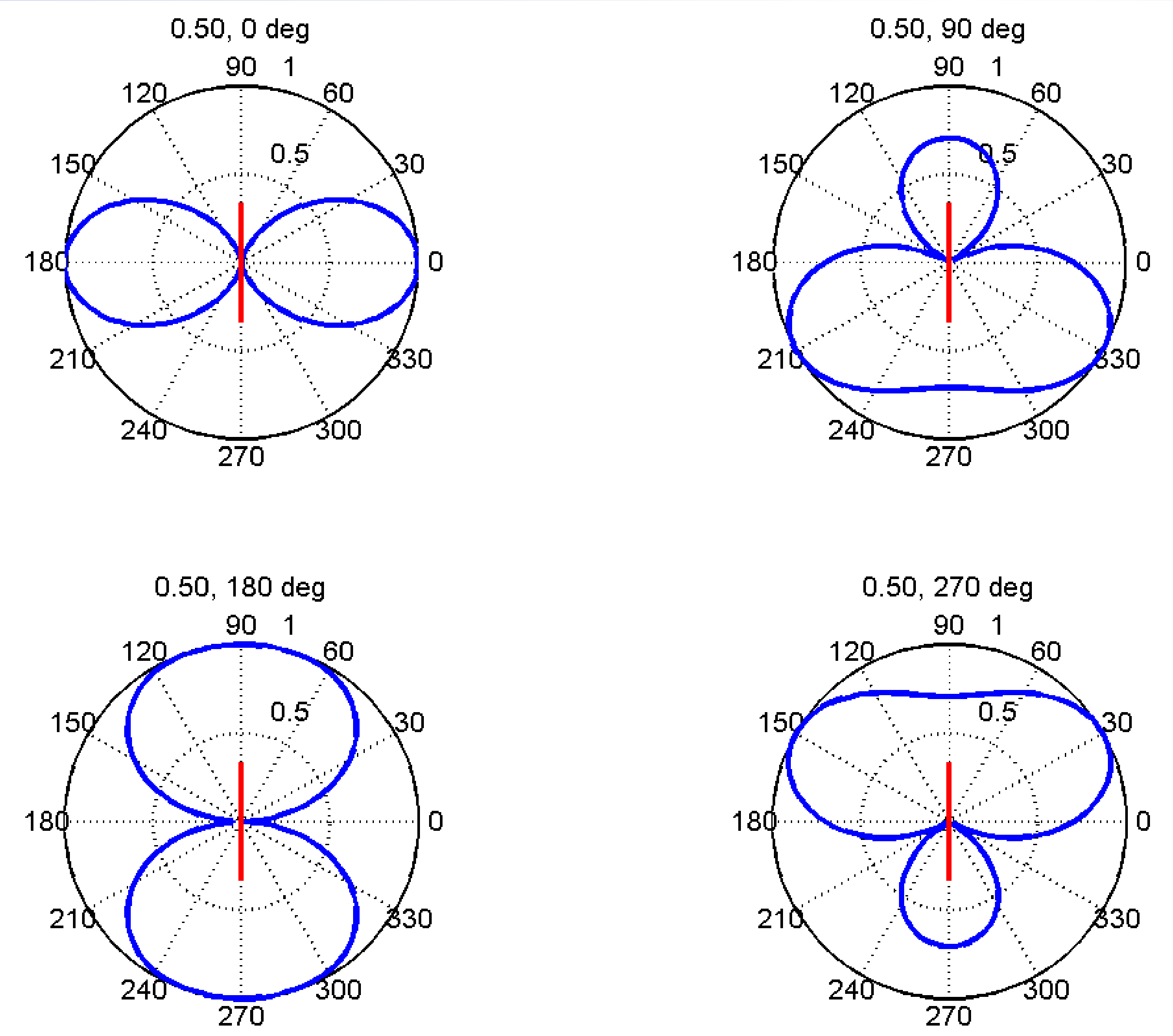
$A_5 \cos(\omega t + \phi_5)$

$A_n \cos(\omega t + \phi_n)$

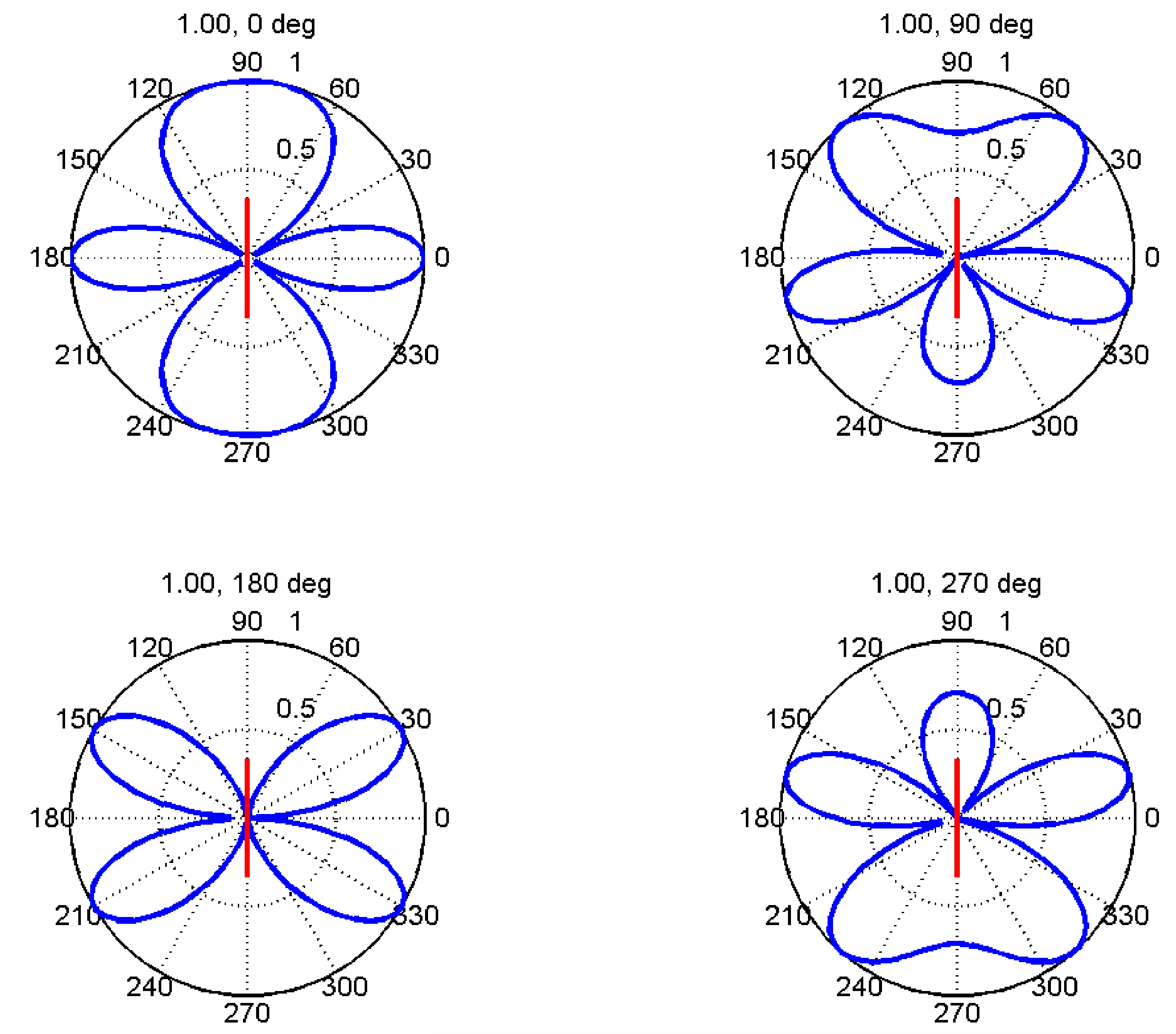
Array Factor – Isotropic Radiators, λ/4 Apart



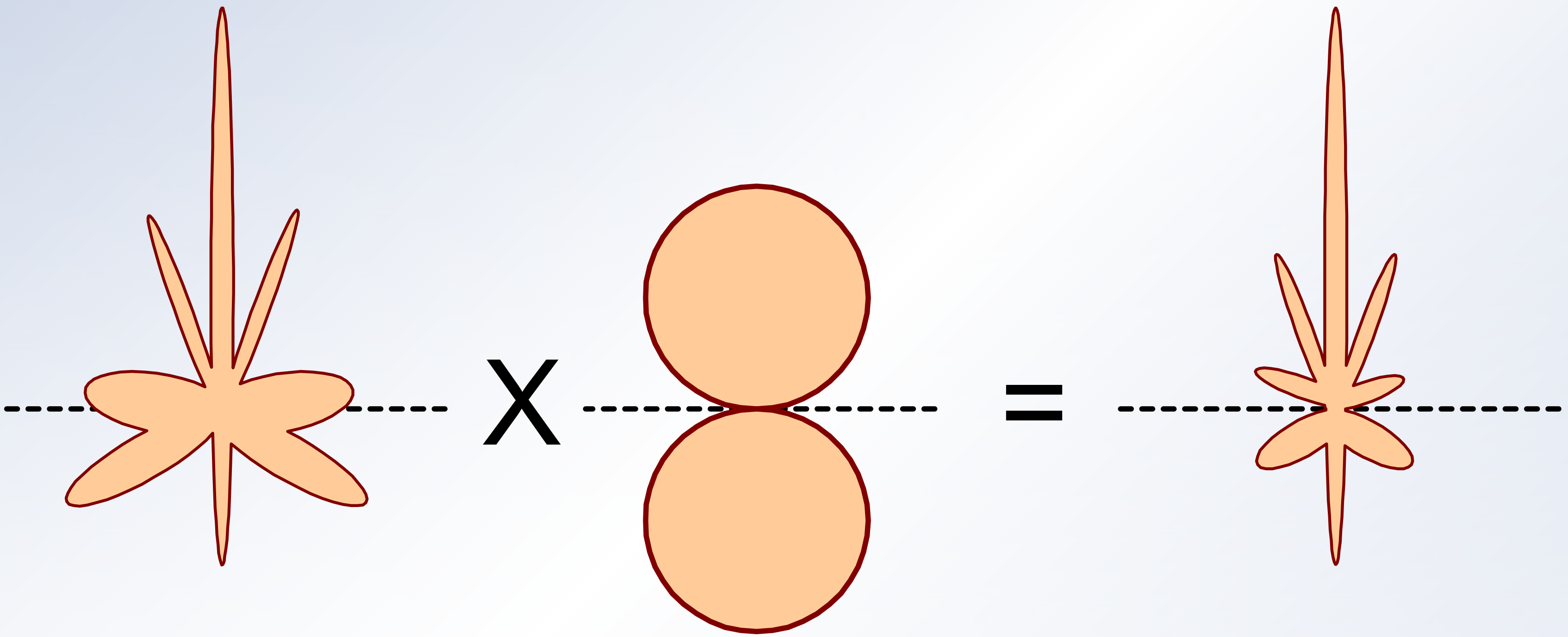
Array Factor – Isotropic Radiators, λ/2 Apart



Array Factor – Isotropic Radiators, λ Apart



Array Factor and the Radiation Pattern of the Individual Elements



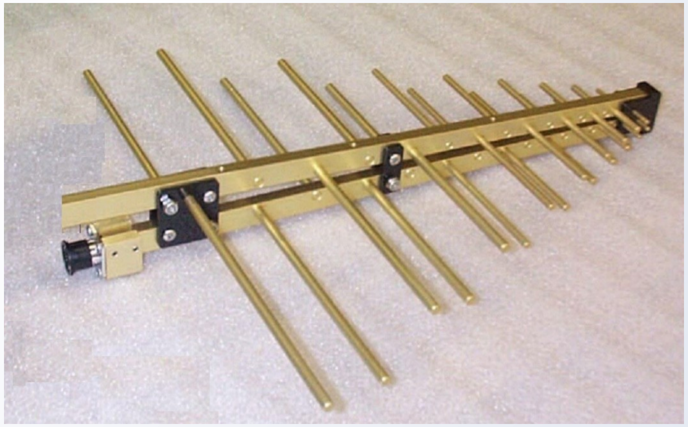
Pattern of the Individual Radiators

Pattern of the Array with Isotropic Radiators

Pattern of the Array

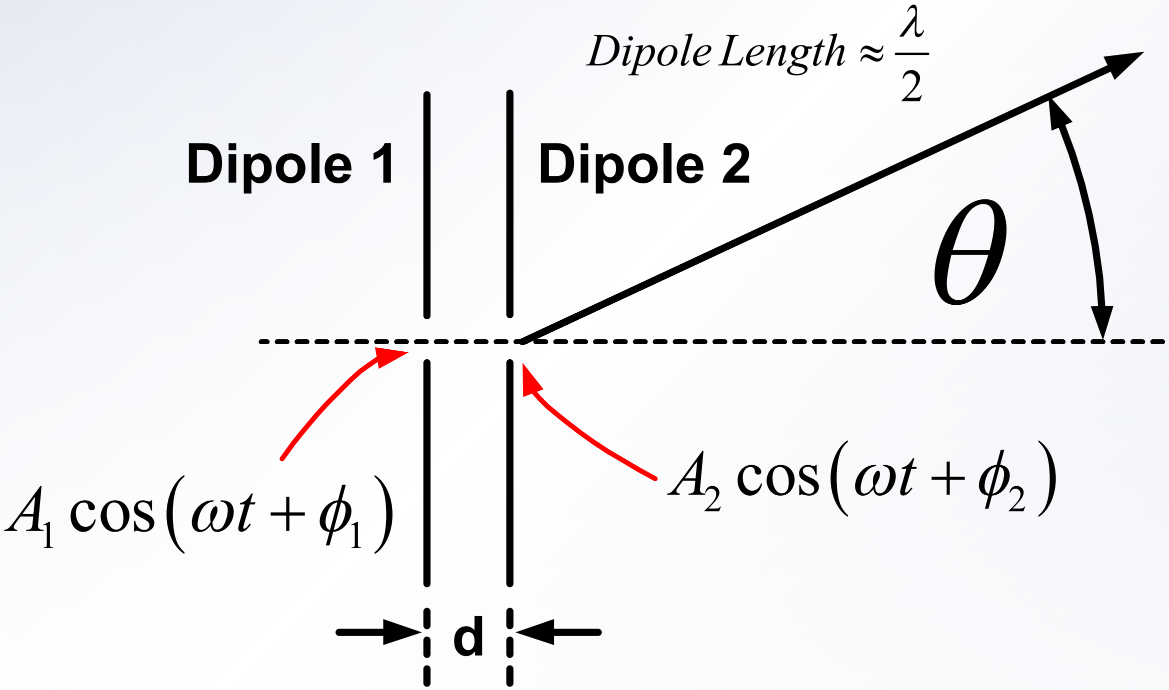
Array Antennas

- Antennas made up of arrays of simpler antennas
  - Usually dipole arrays
  - Yagi-Uda
  - Log Periodic Arrays (LPAs)
  - Slotted Arrays

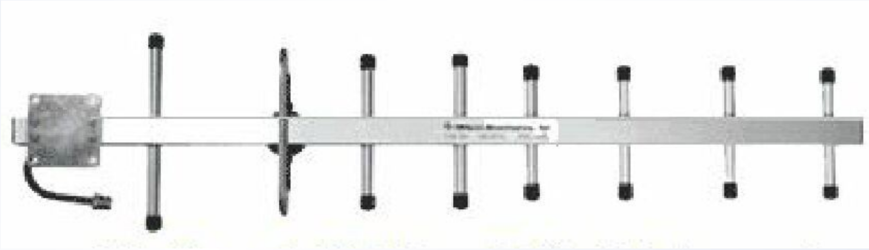


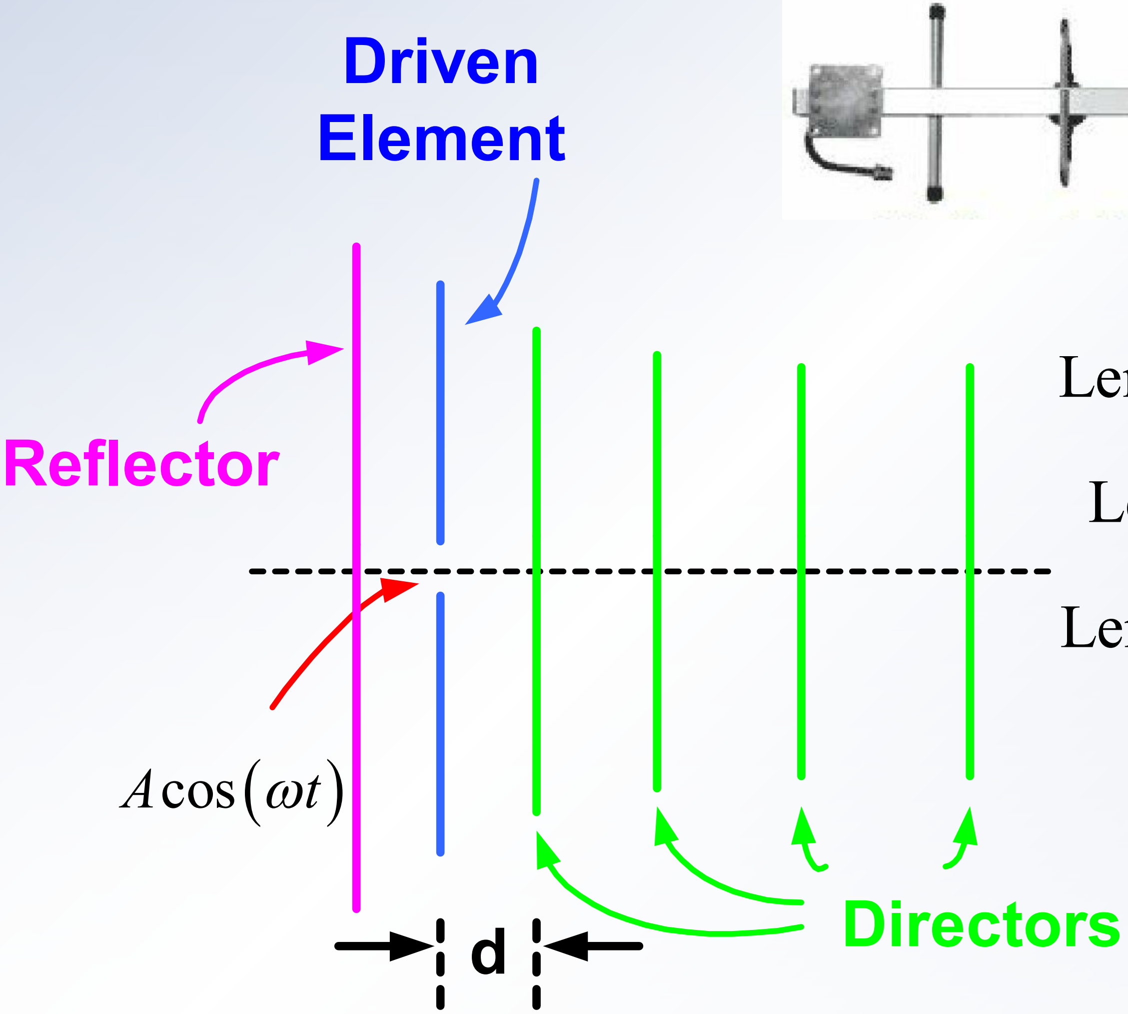
Yagi-Uda Antennas

- An narrow band, medium- or high-gain antenna made up of dipoles



Yagi-Uda Antennas





Driven Element

Reflector

$A\cos(\omega t)$

Directors

d

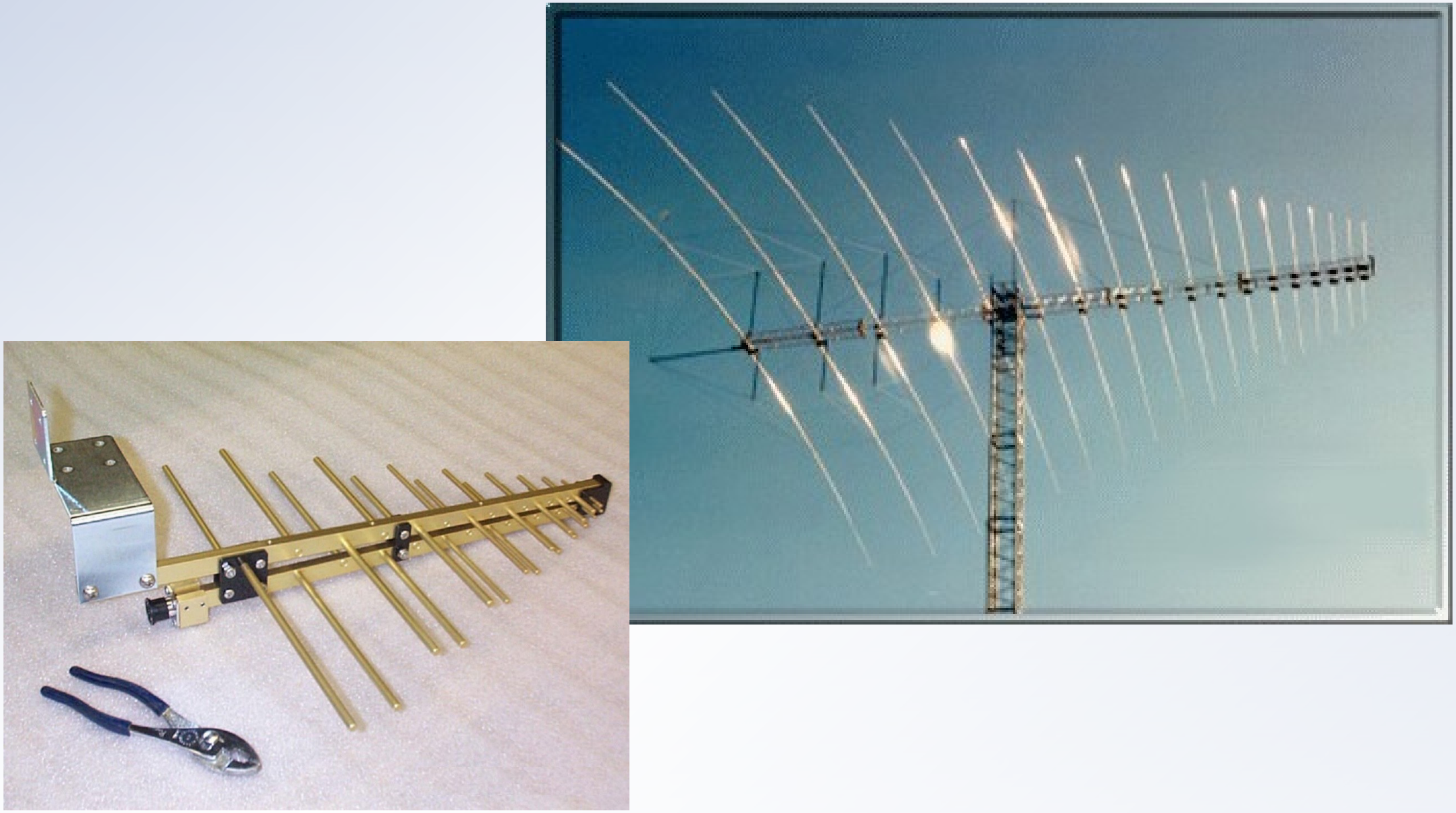
$$\text{Length Reflector} > \lambda/2$$

$$\text{Length Driven} \approx \lambda/2$$

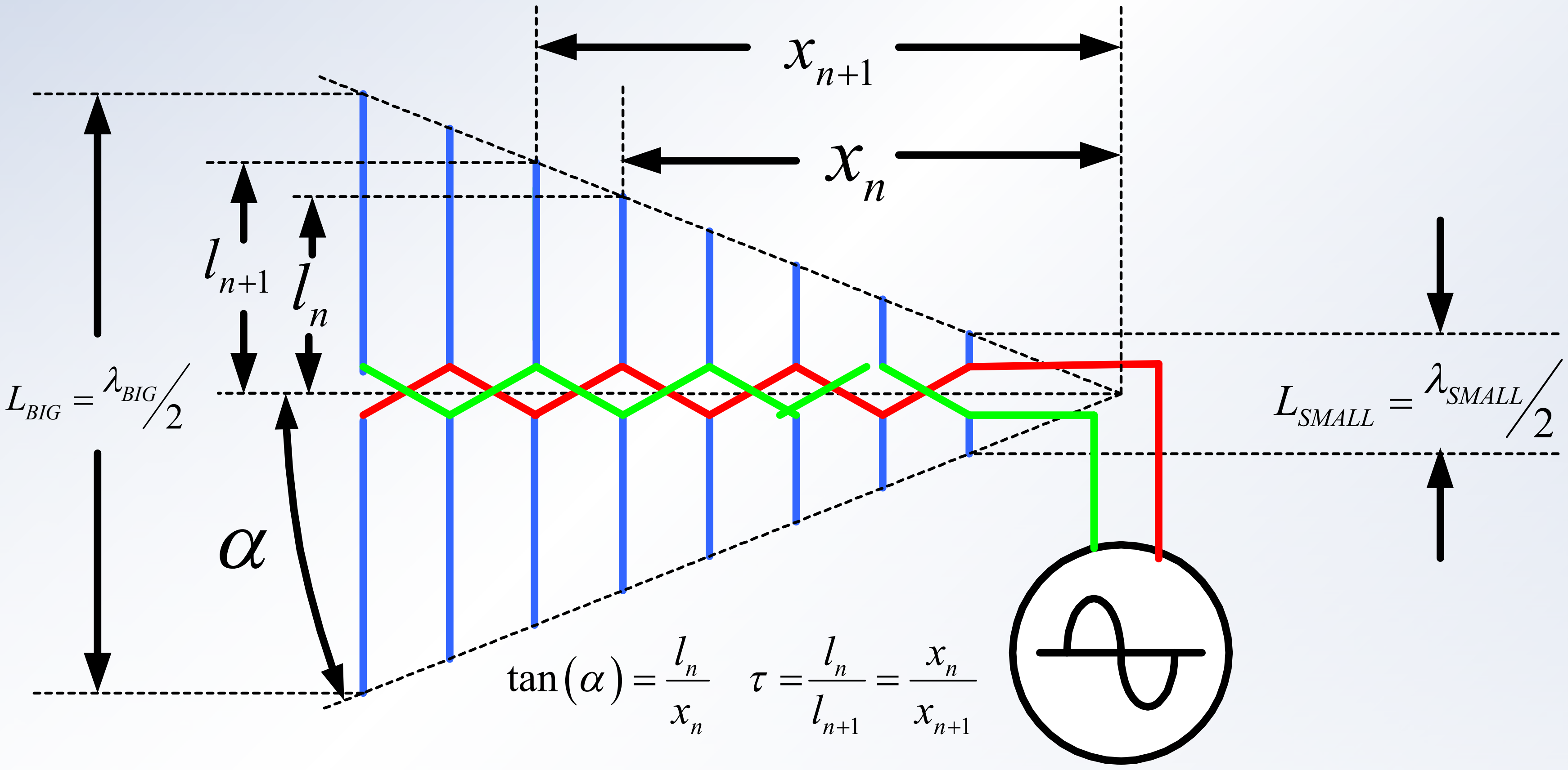
$$\text{Length Directors} < \lambda/2$$

$$d \approx \lambda/5$$

Log Periodic Array (LPA) Antenna



Log Periodic Array (LPA) Antenna

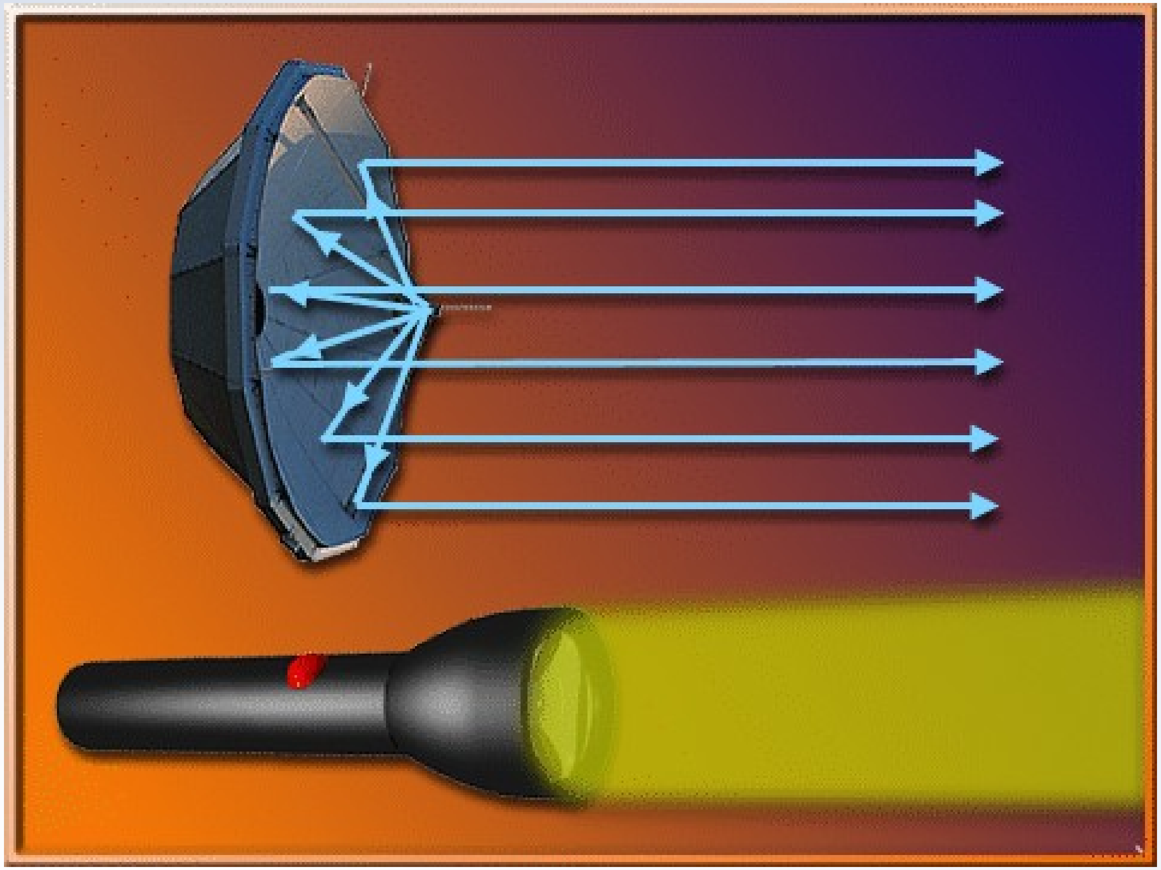


$$\tan(\alpha) = \frac{l_n}{x_n} \qquad \tau = \frac{l_n}{l_{n+1}} = \frac{x_n}{x_{n+1}}$$

Slotted Array Antenna

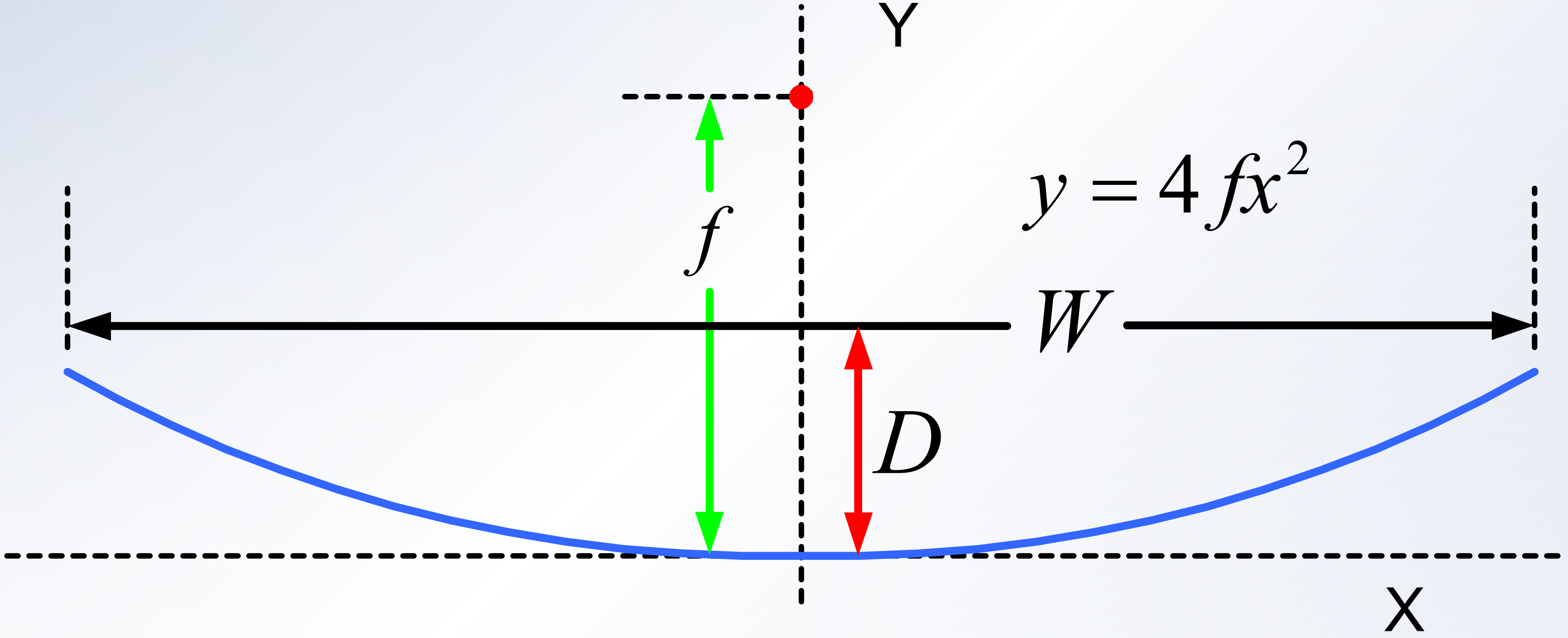
- Usually a waveguide with slots (slot antennas) cut into one surface
- Array of dipoles

Parabolic Reflector Antennas

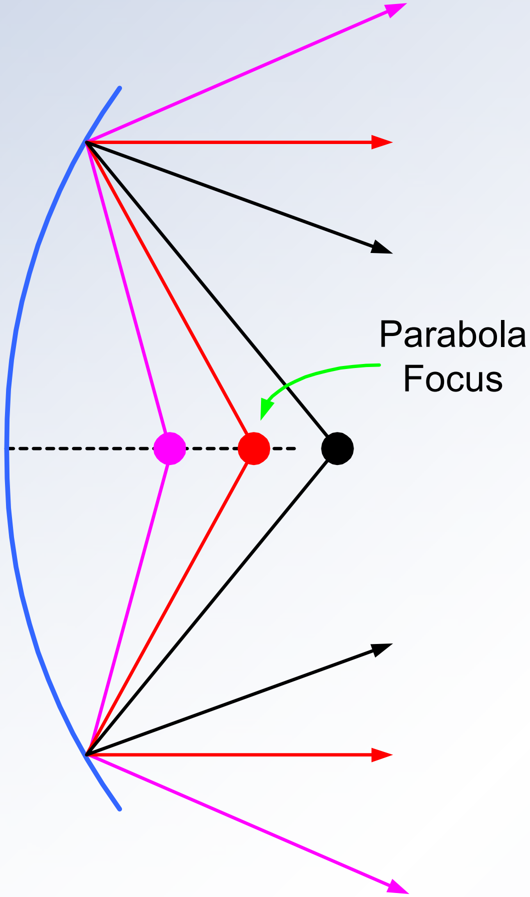


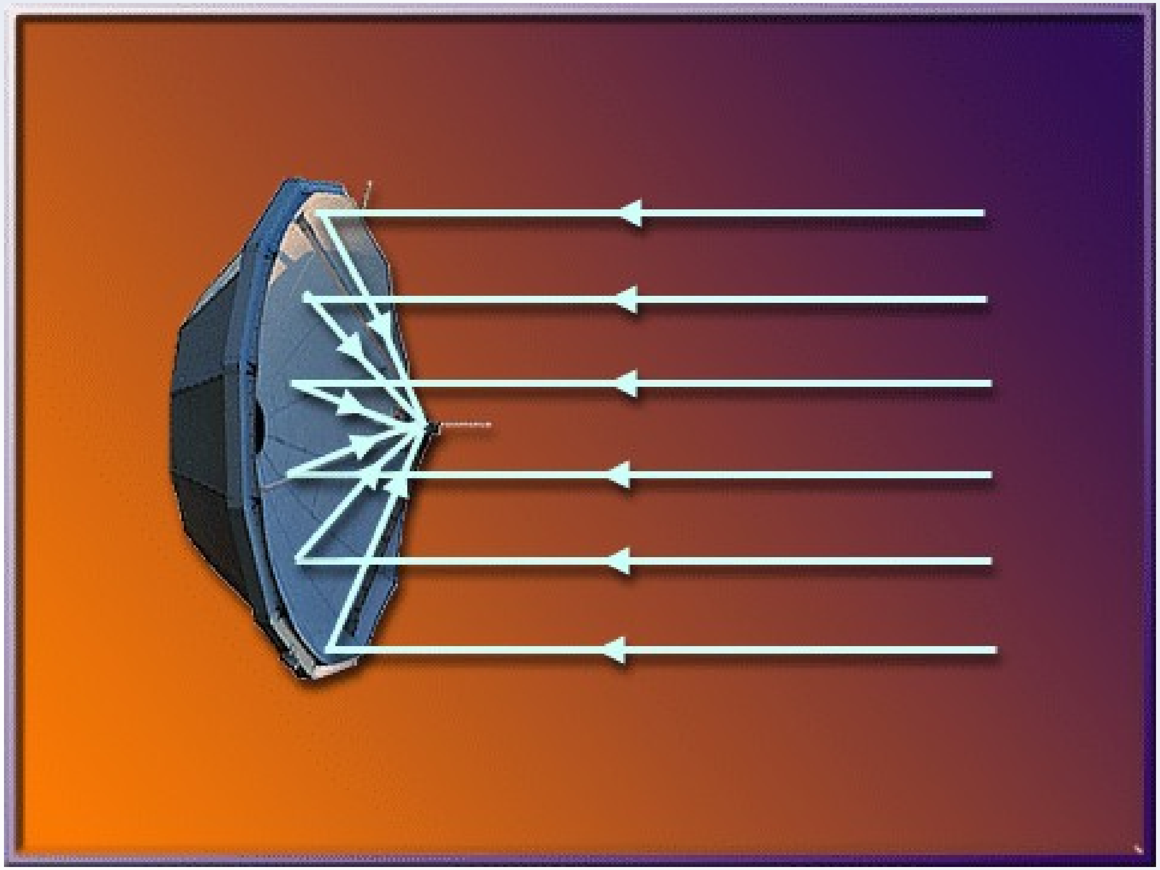
Parabolic Reflector Antennas

Parabolic Reflector Antennas

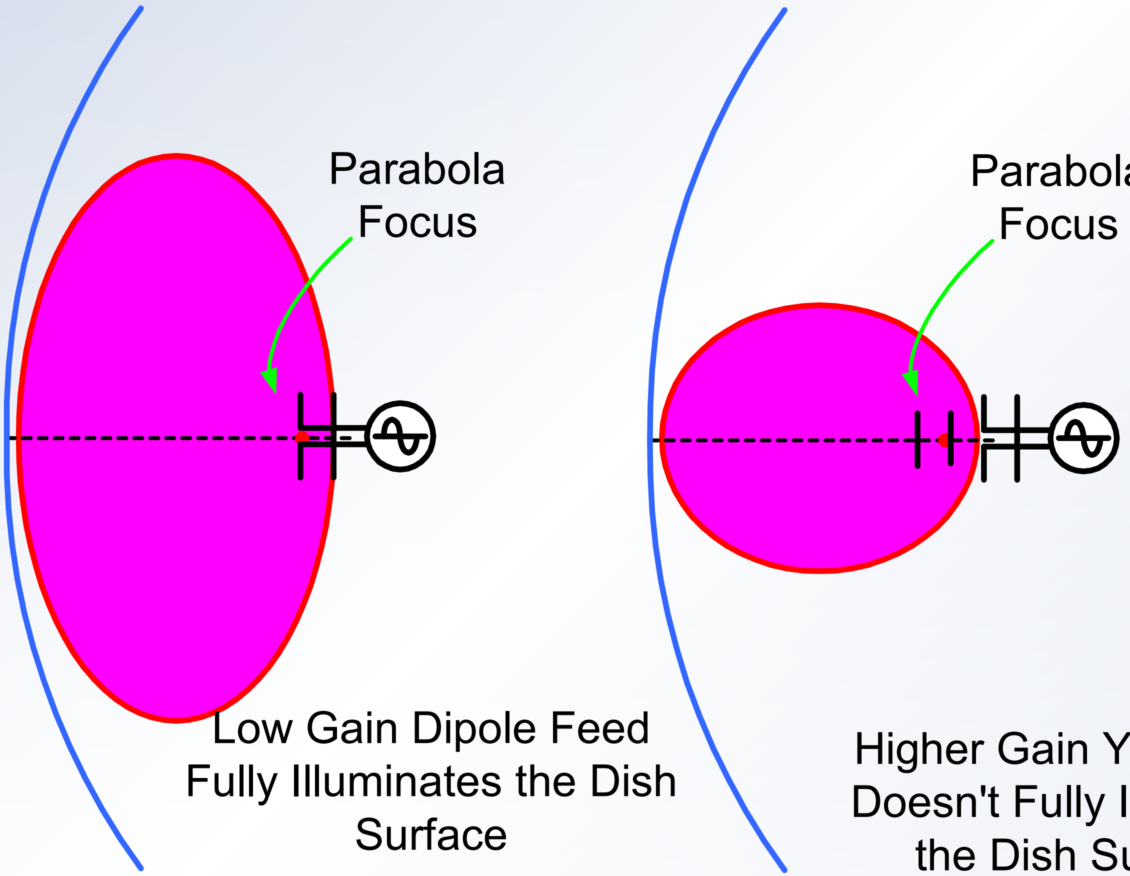


Parabolic Reflector Antennas





Parabolic Reflector Antennas – Aperture Illumination



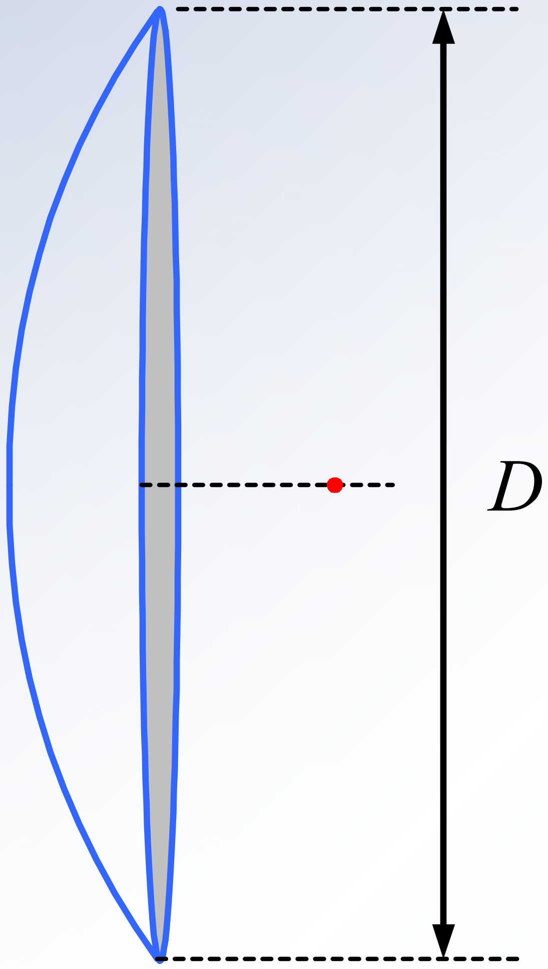
Parabola Focus

Low Gain Dipole Feed Fully Illuminates the Dish Surface

Parabola Focus

Higher Gain Yagi Feed Doesn't Fully Illuminate the Dish Surface

Parabolic Reflector Antennas – Gain and Beamwidth

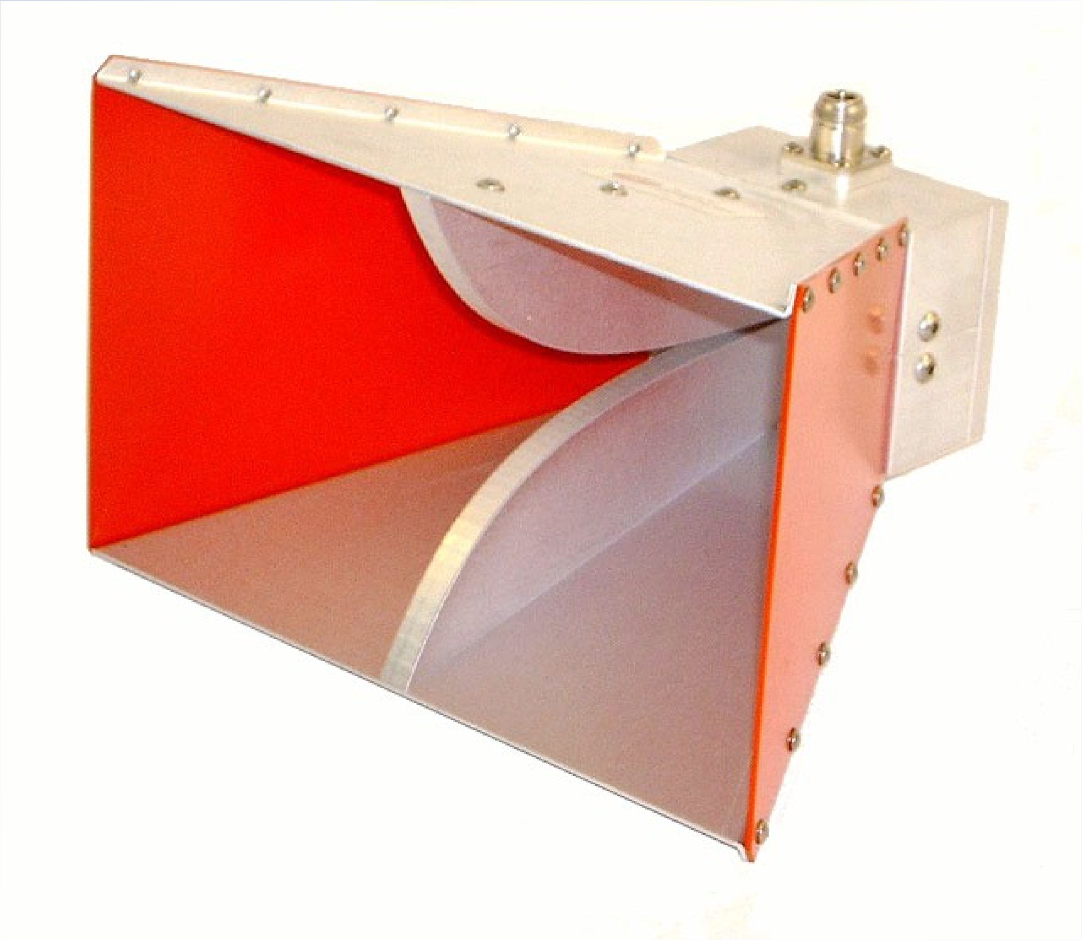


$$G_{\max} = \eta_{aperature}\left(\pi \frac{D}{\lambda}\right)^2 = \eta_{aperature}\left(\pi \frac{fD_{meter}}{c}\right)^2$$

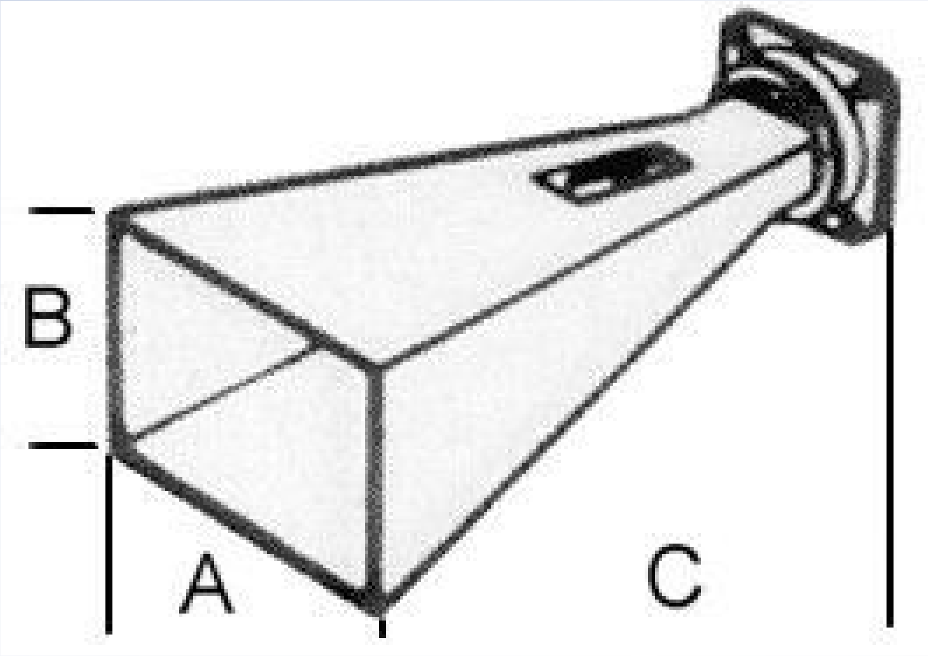
$$BW°_{3dB} \approx 70° \frac{\lambda}{D_{meters}} \approx 70° \frac{c}{fD_{meters}} \approx \frac{70°}{f_{GHz} D_{ft}}$$

$$G_{\max,dB} = 10\log\left(\eta_{aperature}\right) + 20\log\left(\pi \frac{d}{\lambda}\right) = 10\log\left(\eta_{aperature}\right) + 20\log\left(f \bullet d_{meter}\right) - 159.6$$

Horn Antennas



Horn Antennas



$$G = \eta_{aperature} A_{physical} \frac{4\pi}{\lambda^2}$$

$$= \eta_{aperature} A_{physical} \left(\frac{f}{c}\right)^2$$

$$G = \eta_{aperature} \left(\pi \frac{d^2}{4}\right) \frac{4\pi}{\lambda^2}$$

$$= \eta_{aperature} \left(\pi \frac{d}{\lambda}\right)^2$$

$$= \eta_{aperature} \left(\pi \frac{df}{c}\right)^2$$

$$G = \eta_{aperature} (ab) \frac{4\pi}{\lambda^2}$$

$$= \eta_{aperature} (ab) \left(\frac{f}{c}\right)^2$$

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