General Sir John Kotelawala Defence University

ET3122 Antennas and Propagation
Antenna Arrays

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Outline

Introduction

Motivation

- Single element antennas generally have low directivity
  - Directive antennas like very long dipoles or longwire antennas can have unusable radiation patterns with multiple major lobes
- Combining unusable radiation patterns can result in better radiation patterns
  - Discone antenna
  - V and rhombic antennas
- Can combining radiation patterns be put to better use?

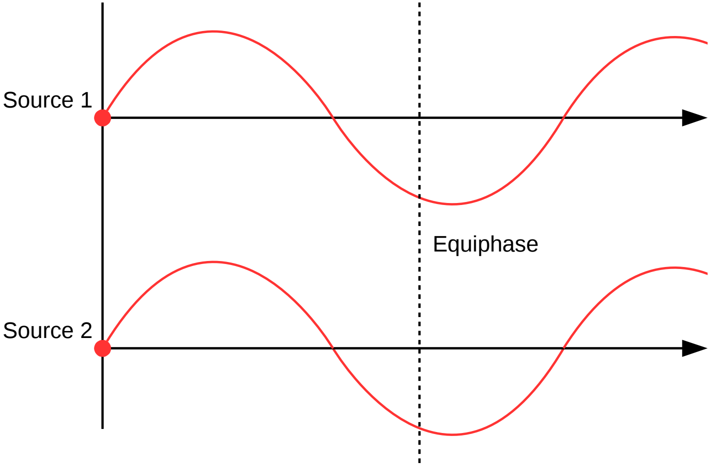
Antenna Arrays

- An antenna array is a system that consists of multiple (≥ 2) antennas operating at *the same frequency*
  - A log-periodic antenna is therefore not an array
- Each antenna is known as an element
  - An element can be active or passive (parasitic)
- Generally array elements are of the same type of radiator

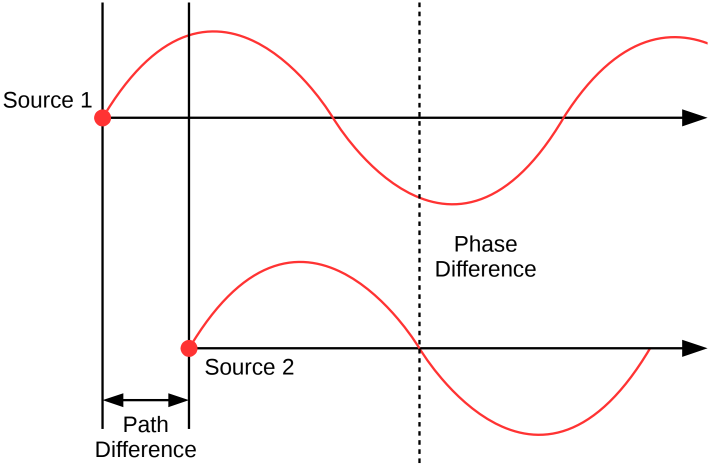
Operating Principle

- Interference
- Caused by the spatial path difference between the transmitted waves of multiple sources
  - Results in a *phase difference* between the sources

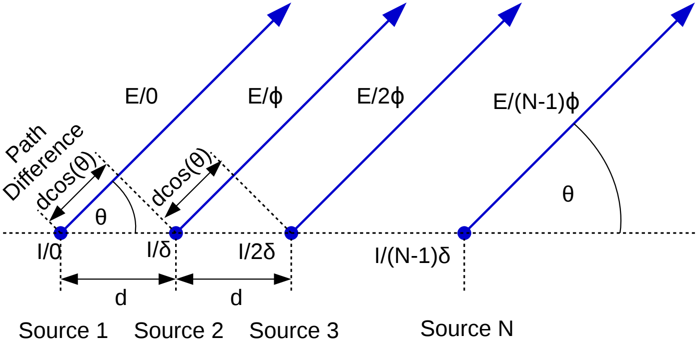
Identical Path Propagation



Propagation Path Difference



Uniform Linear Isotropic Array



Uniform Linear Isotropic Array (Contd..)

At the far field, the path difference between two adjacent sources,

$$\Delta d = dcos(\theta)$$

Therefore, the resulting phase difference,

$$\Delta\phi = \frac{2\pi\Delta d}{\lambda} = \frac{2\pi dcos(\theta)}{\lambda}$$

The total phase difference due to both the path difference and the phase difference between feed currents thus becomes,

$$\phi = \delta + \Delta\phi = \delta + \frac{2\pi dcos(\theta)}{\lambda}$$

Uniform Linear Isotropic Array (Contd..)

From superposition, the resultant E field is given by,

$$\begin{aligned} E_N &= E + Ee^{j\phi} + Ee^{j2\phi} + \cdots + Ee^{j(N-1)\phi} \\ &= E\left[1 + e^{j\phi} + e^{j2\phi} + \cdots + e^{j(N-1)\phi}\right] \\ &= E\left[\frac{1 - e^{jN\phi}}{1 - e^{j\phi}}\right] = E\left(\frac{sin\left(\frac{N\phi}{2}\right)}{sin\left(\frac{\phi}{2}\right)}\right) e^{j\frac{(N-1)\phi}{2}} \end{aligned}$$

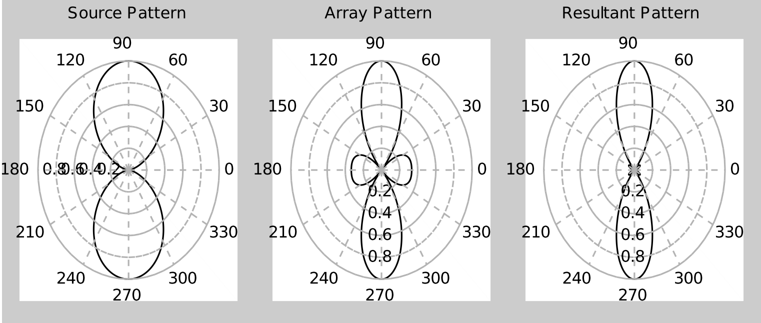
Therefore the amplitude variation of the array is given by,

$$|E_N| = E\left(\frac{sin\left(\frac{N\phi}{2}\right)}{sin\left(\frac{\phi}{2}\right)}\right)$$

- $|E_N|$ is also known as the *array factor*

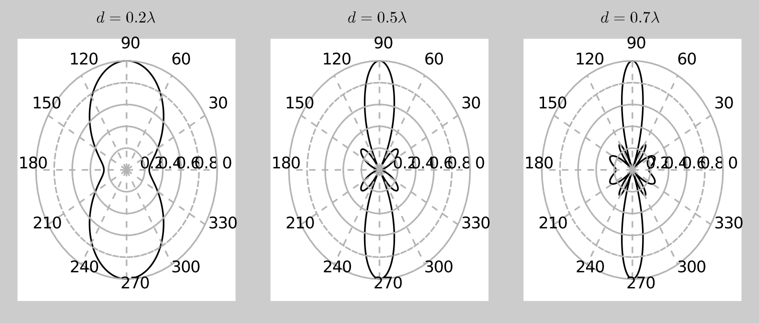
Uniform Arrays of Anisotropic Sources

- For an anisotropic source $(E_S(\theta))$, the *approximate* radiation pattern is given by $E_R(\theta) = E_S(\theta) \times |E_N(\theta)|$ where $E_N(\theta)$ is the pattern of the isotropic array with N elements.
- This is known as *pattern multiplication*



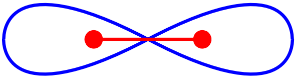
Special Array Formulations

Variation of Distance (N=4)

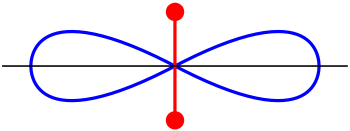


- Increased distance results in better directivity
  - Sidelobe energy increases with distance
  - Antenna also gets physically larger
- Usually $d = \lambda/2$

Broadside and Endfire Arrays



Endfire Array

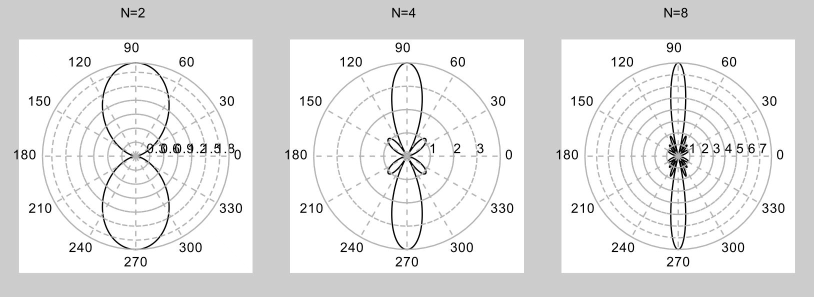


Broadside Array

When $d = \lambda/2$,

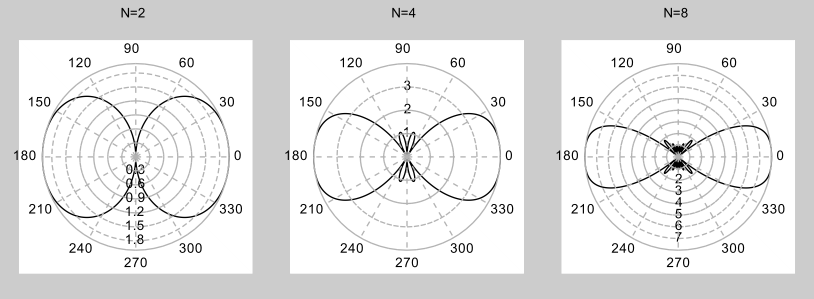
- Taking $\delta = \pi$ results in an *endfire array* where the major lobes are along the array elements
- When $\delta = 0$, the array is *broadside* and the major lobes are perpendicular to the array elements

Broadside Arrays



- Increased sidelobes and directivity with N

Endfire Arrays

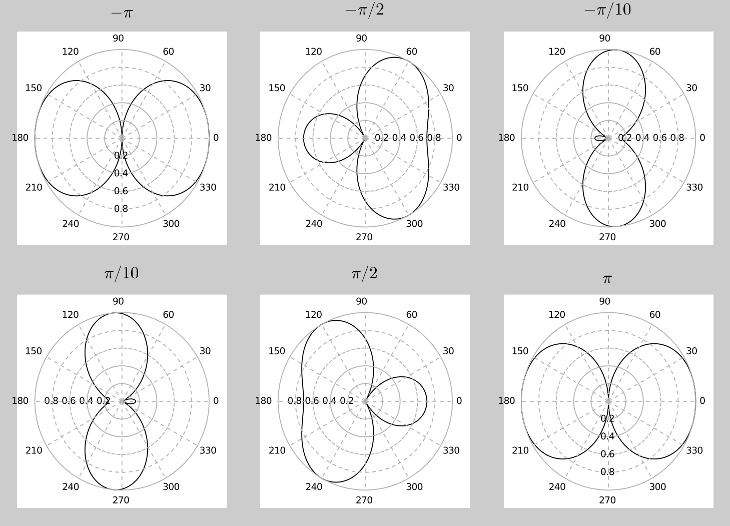


- Increased sidelobes and directivity with N
- Lesser directivity than broadside arrays

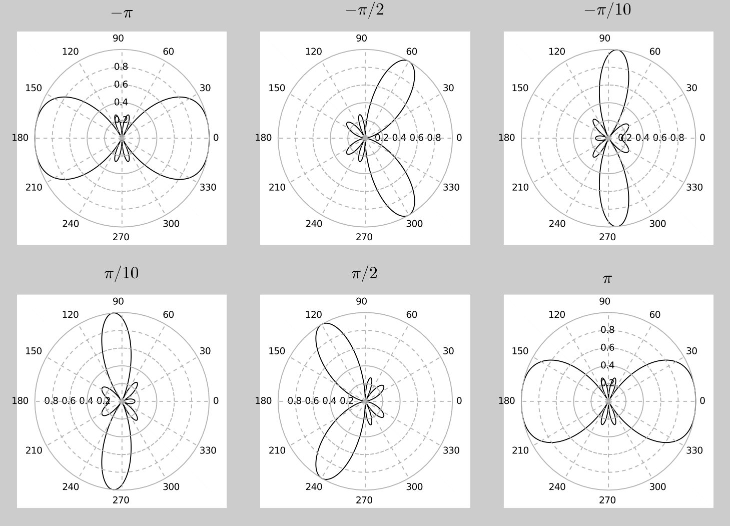
Beam Steering

- Broadside ($\delta = 0$) and endfire ($\delta = \pi$) configurations are the two *extremes*
  - When $\theta \in (0, \pi)$ the radiation pattern can be modified so that the major lobes are steered between the two extreme patterns
  - For large N, versatile steering can be achieved
- Enables the major lobes to be steered without physically rotating the antenna

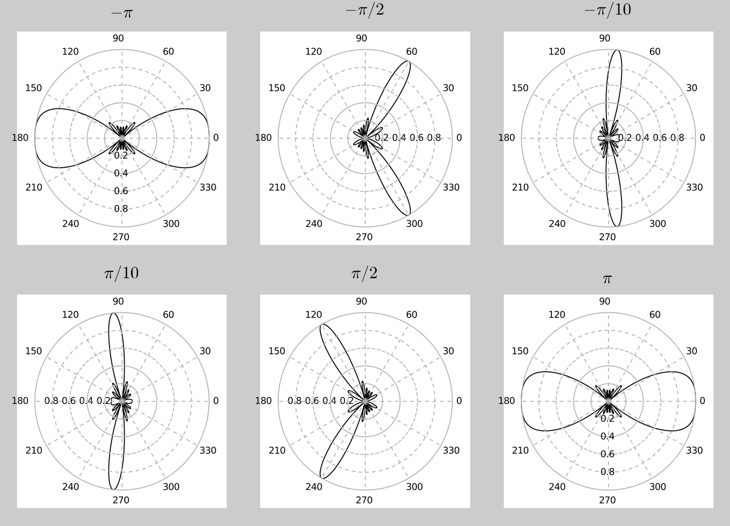
Beam Steering $N = 2$



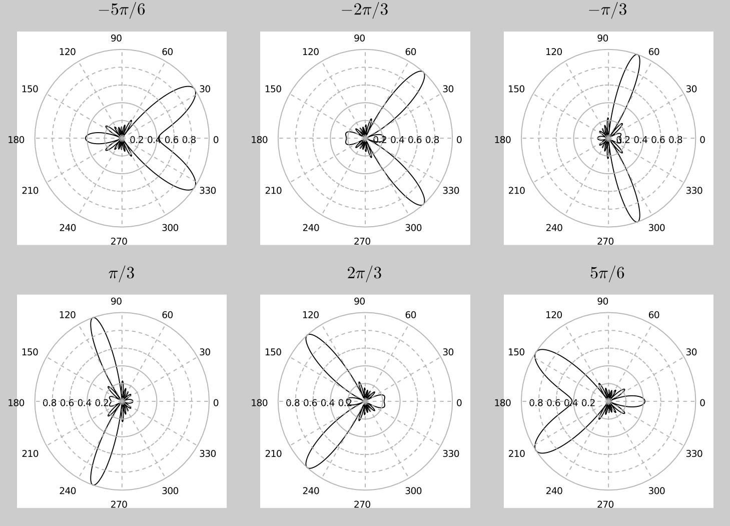
Beam Steering $N = 4$



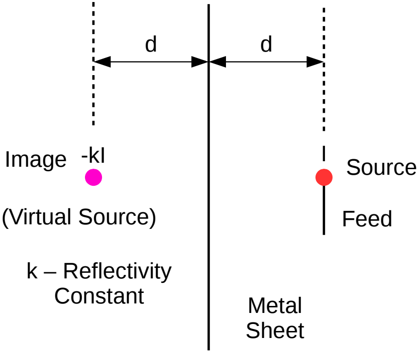
Beam Steering $N = 8$



Beam Steering $N = 8$ (Contd..)



Source Images



The Corner Reflector

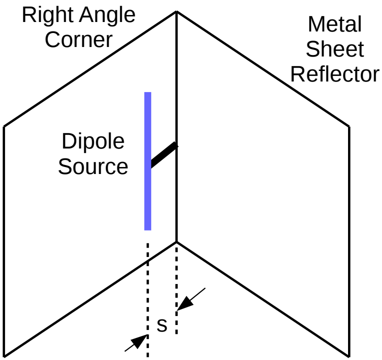
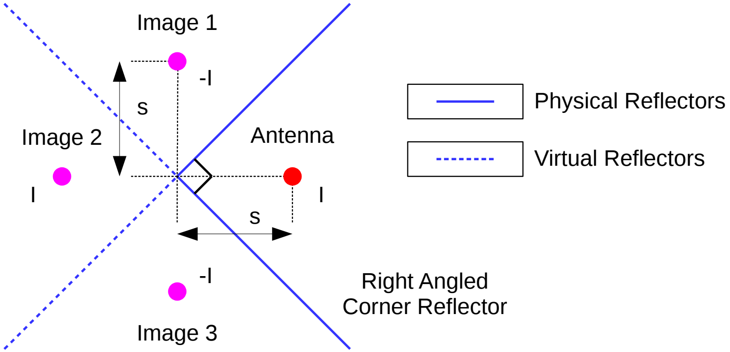


Image Arrays (Corner Reflector)



- The antenna along with the images form two broadside arrays
  - Antenna and Image 2
  - Images 1 and 3

Corner Reflector

Taking the Antenna and Image 2,

$$
\begin{aligned}
\phi_1 &= \frac{4\pi s cos(\theta)}{\lambda} \\
E_1(\theta) &= E_0 cos\left(\frac{\phi_1}{2}\right) = E_0 cos\left(\frac{2\pi s cos(\theta)}{\lambda}\right)
\end{aligned}
$$

Taking Image 1 and Image 3 as a broadside array,

$$
\phi_2 = \frac{4\pi s sin(\theta)}{\lambda}
$$

Since both contain negative currents,

$$
E_2(\theta) = -E_0 cos\left(\frac{\phi_2}{2}\right) = -E_0 cos\left(\frac{2\pi s sin(\theta)}{\lambda}\right)
$$

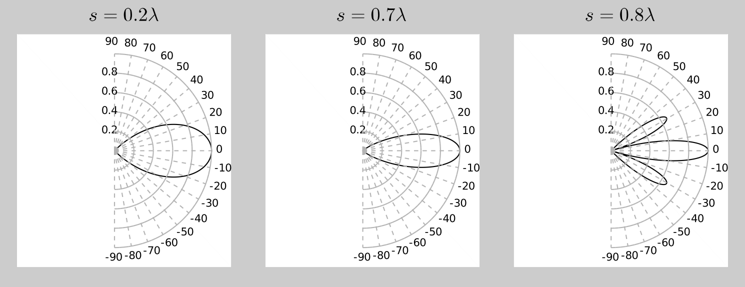
Corner Reflector (Contd..)

Therefore the resultant pattern is given by,

$$\begin{aligned} E(\theta) &= E_1(\theta) + E_2(\theta) \\ &= E_0 \left[cos\left(\frac{2\pi s cos(\theta)}{\lambda}\right) - cos\left(\frac{2\pi s sin(\theta)}{\lambda}\right)\right] \end{aligned}$$

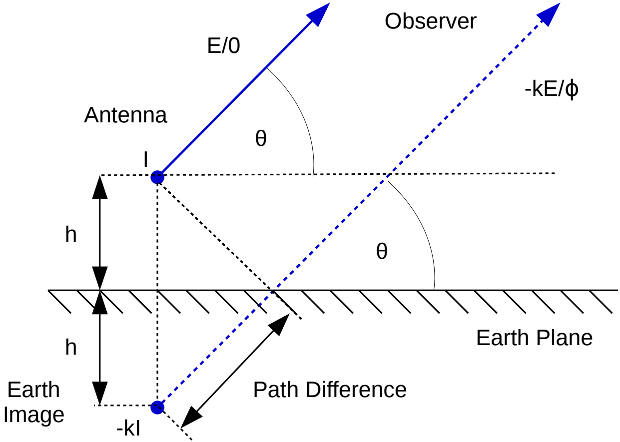
- Can make an omnidirectional antenna directive
- Dimensions will only be practical at high frequencies

Corner Reflector Radiation Patterns



- Directive radiation pattern
- Significant sidelobes emerge when s increases compared to λ

Earth Reflection



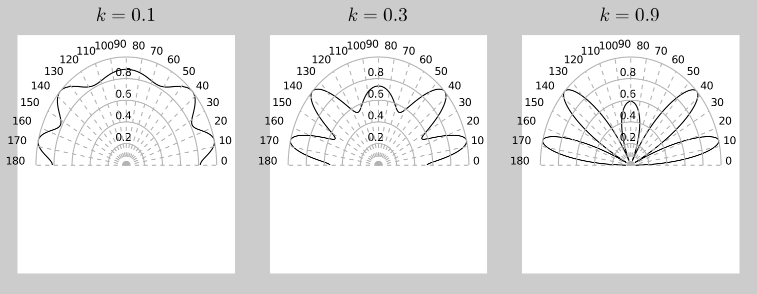
Earth Reflection (Contd..)

- The current in the antenna I and the image due to earth reflection $-kI$ form an array
- Using first principles to obtain the radiation pattern

$$
\begin{aligned}
E_{ER} &= E\left(1 - ke^{j\phi}\right) = E\left(1 - kcos(\phi) - jksin(\phi)\right) \\
&= E\sqrt{[1 + k^2 - 2kcos(\phi)]} \\
&= E\sqrt{\left[1 + k^2 - 2kcos\left(\frac{4\pi hsin(\theta)}{\lambda}\right)\right]}
\end{aligned}
$$

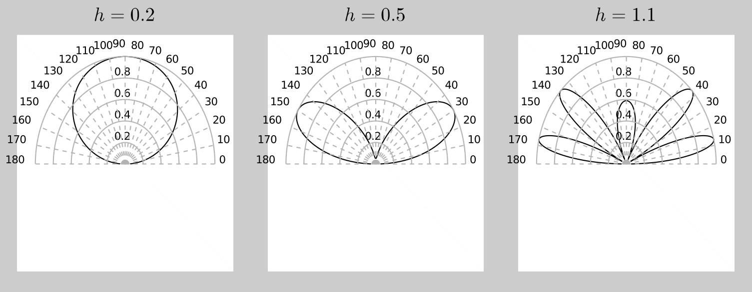
- For perfectly reflective earth $k = 1$

Radiation Patterns for Different k ($h = 1.1\lambda$)



- The omnidirectional radiation pattern deteriorates into a heavily lobed pattern with increased k

Radiation Patterns for Different h ($k = 0.9$)



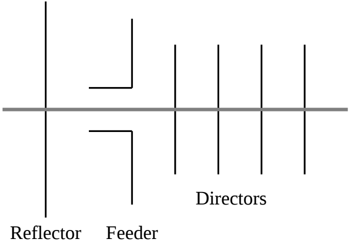
- The number of lobes increases with h

The Yagi-Uda Array

Yagi-Uda Array

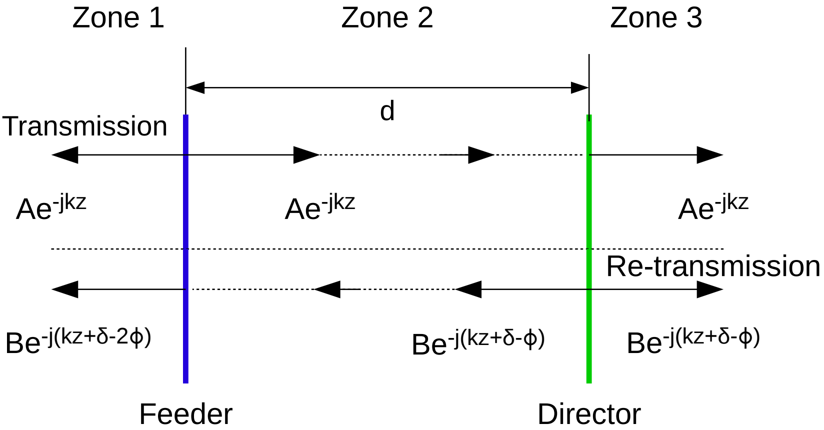
Overview

- Single feeding (active) element
- Multiple parasitic (passive) elements
  - Directors and reflector (increase directivity)
  - Parasitic elements help modify the feed impedance
  - The end result is a highly directive antenna



- Feeding element ($\approx 0.99\lambda$)
  - Capacitive
- Directors ($\approx 0.9\lambda - 0.95\lambda$)
  - Capacitive
- Reflector ($\approx 1.1\lambda$)
  - Inductive

Yagi-Uda Array Operation



Yagi-Uda Array Operation (Contd..)

- Phase difference between feeder and director $\phi = 2\pi d/\lambda$
- Phase difference due to director $\pi + \delta$
- Resultant wave in **Zone 1**

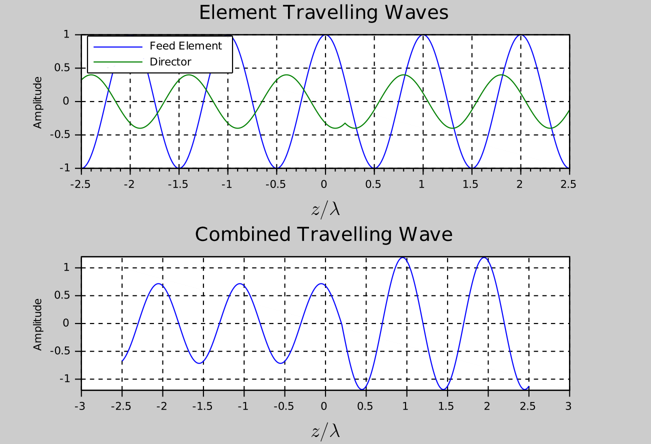
$$F_1(z) = Ae^{-jkz} + Be^{-j(kz+\psi_1)} = Ae^{-jkz} + Be^{-j(kz+\delta-2\phi)}$$

- Resultant wave in **Zone 3**

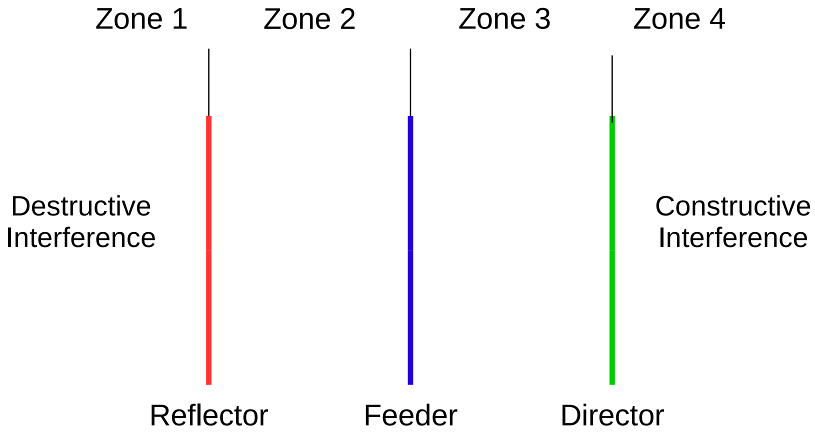
$$F_3(z) = Ae^{-jkz} + Be^{-j(kz+\psi_2)} = Ae^{-jkz} + Be^{-j(kz+\delta-\phi)}$$

- Select d such that ψ_1 results in *destructive* interference in **Zone 1** and ψ_3 results in *constructive* interference in **Zone 3**.

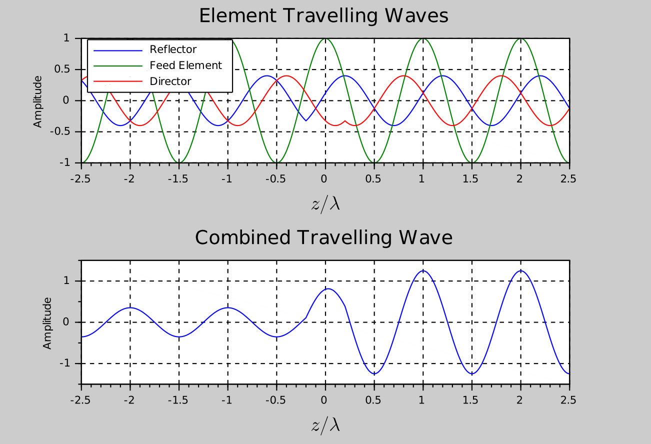
Yagi-Uda Array Operation (Contd..)



Yagi-Uda Array Operation (Contd..)



Yagi-Uda Array Operation (Contd..)



Conclusion

Summary

- An array consists of multiple antenna elements
- Directivity improves with number of elements
  - Most effective at high frequencies due to smaller dimensions