Communication Systems.

Lecture 3, part 1

Antenna Arrays and Microstrip antennas

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Antenna Arrays

In an array of identical elements, there are 6 controls for Shaping the overall radiation pattern of the array:

1 The Geometrical configuration of the array (linear, circular, rectangular etc.)

2 The relative displacement of the individual elements

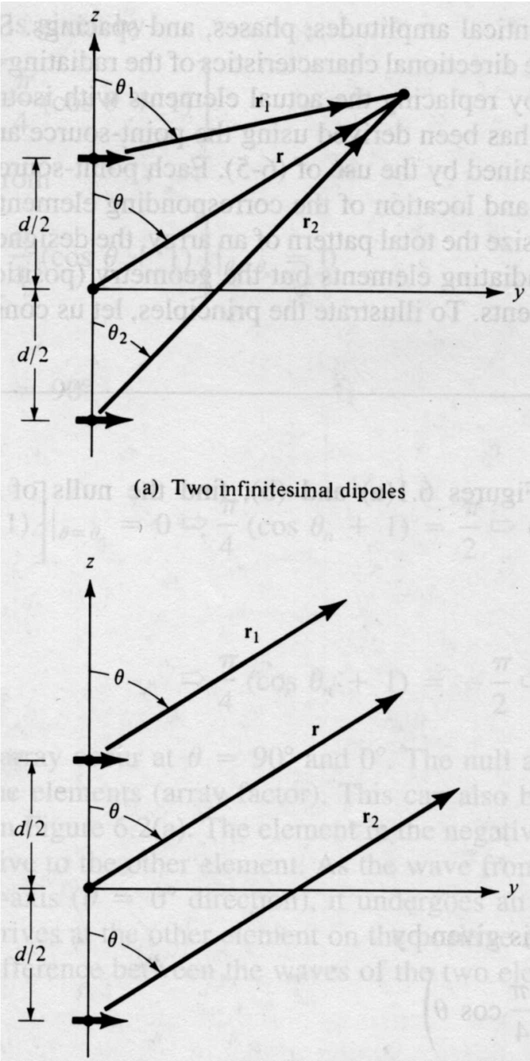
3 The excitation amplitude of the elements

4 The excitation phase of the elements

5 The radiation pattern of the elements

6 Number of elements

Two-element Array



(a) Two infinitesimal dipoles

(b) Far-field observations

$$\vec{E}_t = \vec{E}_1 + \vec{E}_2 =$$

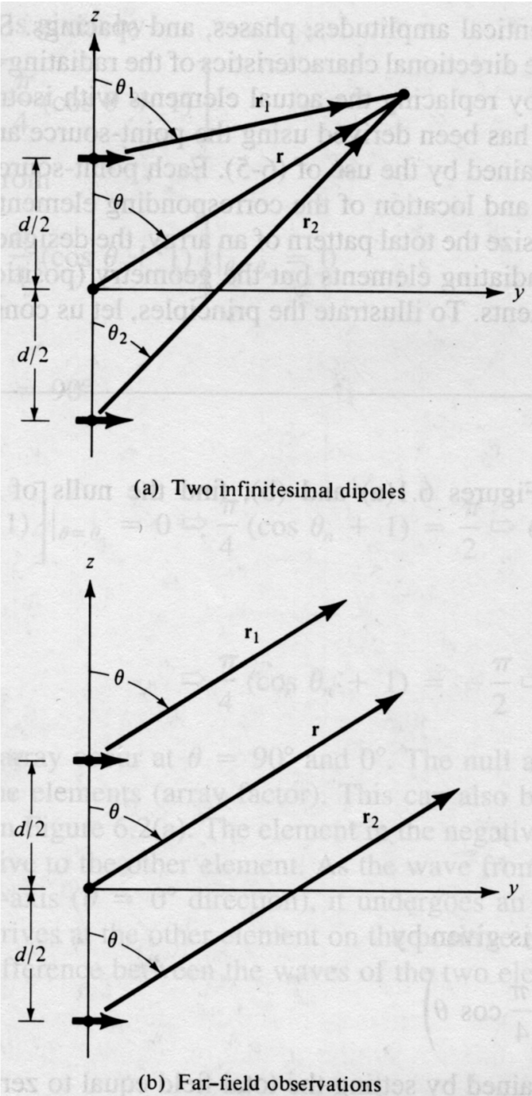
$$\hat{a}_\theta j\eta \frac{kI_0 l}{4\pi}\left\{ \frac{e^{-j(kr_1 - \frac{\beta}{2})}}{r_1}\cos(\theta_1) + \frac{e^{-j(kr_2 - \frac{\beta}{2})}}{r_2}\cos(\theta_2) \right\}$$

$$\theta_1 \cong \theta_2 \cong \theta$$

$$\left. \begin{aligned} r_1 &\cong r - \frac{d}{2}\cos(\theta) \\ r_2 &\cong r + \frac{d}{2}\cos(\theta) \end{aligned} \right\} for \quad Phase$$

$$r_1 \cong r_2 \cong r \} for \quad Amplitude$$

Two-element Array



(a) Two infinitesimal dipoles

(b) Far-field observations

$$\vec{E}_t = \vec{E}_1 + \vec{E}_2 =$$

$$\hat{a}_\theta j\eta \frac{kI_0 l}{4\pi}\left\{ \frac{e^{-j(kr_1-\frac{\beta}{2})}}{r_1}\cos(\theta_1) + \frac{e^{-j(kr_2-\frac{\beta}{2})}}{r_2}\cos(\theta_2) \right\}$$

Assuming Farfield observations =>

$$\vec{E}_t = \hat{a}_\theta j\eta \frac{kI_0 l e^{-jkr}}{4\pi r}\cos(\theta)2\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

or

$$\vec{E}_t = \vec{E}_{SingleElement} \quad x \quad ArrayFactor$$

Two-element Array

$$\vec{E}_t = \vec{E}_{SingleElement} \quad x \quad ArrayFactor$$

The array factor (AF) is a function of the geometry of the array and the excitation phase (uniform array). =>
By varying the separation *d*, and/or the the phase, β, between the elements the characteristic of the array antenna can be controlled!

Array general

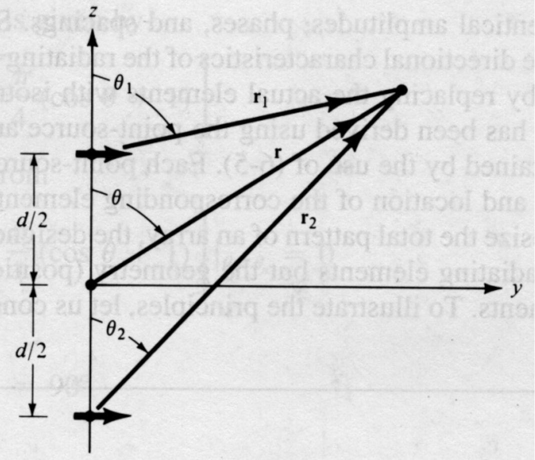
$$\vec{E}_t = \vec{E}_{SingleElement} \quad x \quad ArrayFactor$$

Each array has its own array factor.

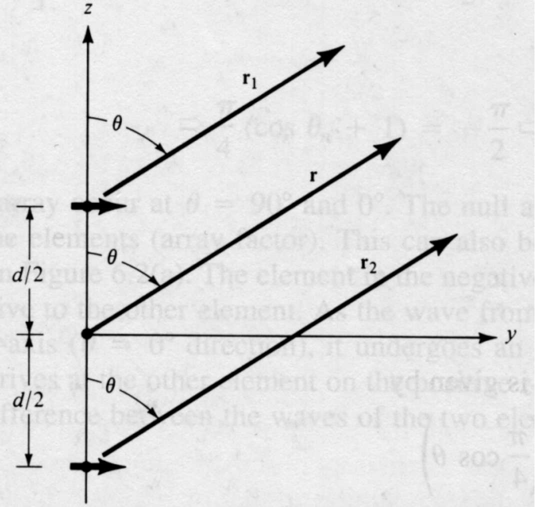
The AF is determinate by N, number of elements, their location, their relative magnitude and phase and the spacing.

The AF is simpler for identical amplitudes, phase and spacing.

Two Element array example



(a) Two infinitesimal dipoles



(b) Far-field observations

$$\vec{E}_t = \hat{a}_\theta j\eta \frac{kI_0 l e^{-jkr}}{4\pi r}\cos(\theta)2\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

$$\beta = 0,\;\; d = \tfrac{\lambda}{4} \Rightarrow$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}\cos\theta)$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90^\circ$$

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Two Element array example

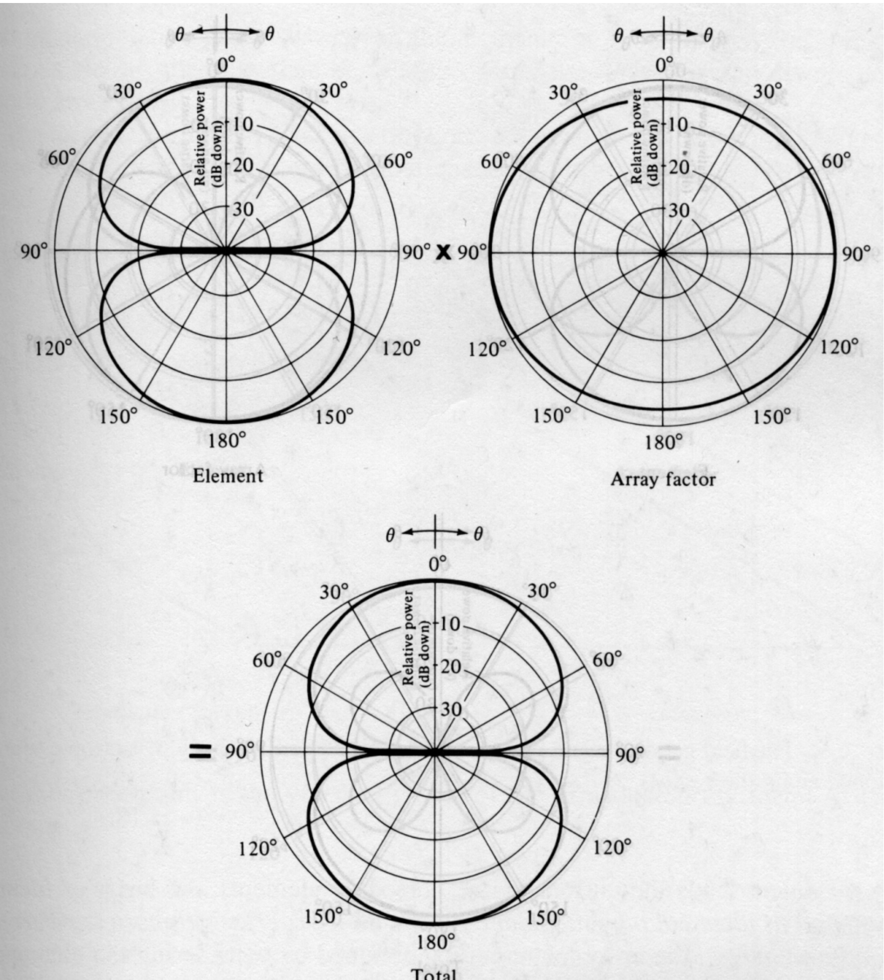


Figure 6.3 Element, array factor, and total field patterns of a two-element array of infinitesimal horizontal dipoles with identical phase excitation ($\beta = 0°$, $d = \lambda/4$).

$$E_{tn} = \cos(\theta)\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

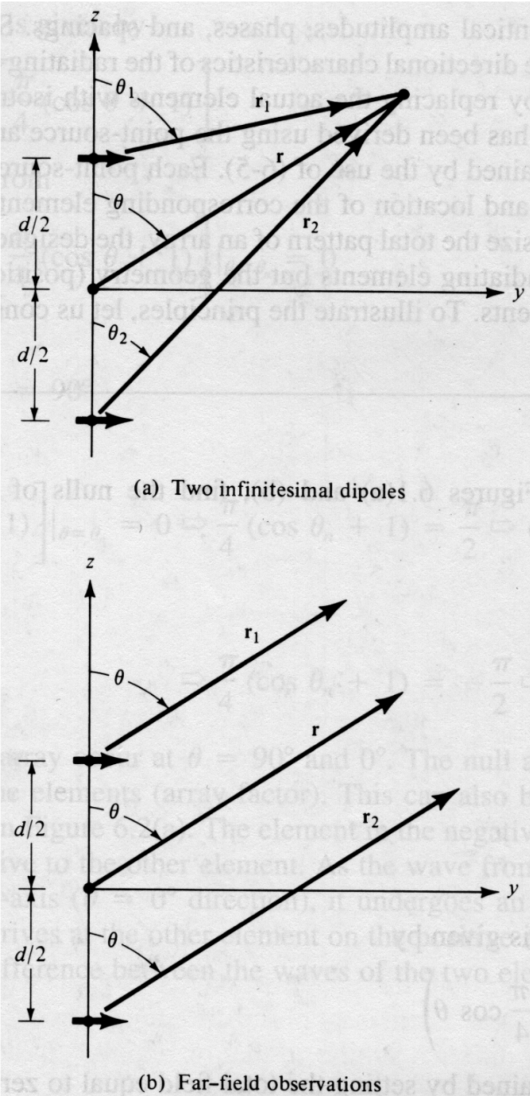
$$\beta = 0, \quad d = \tfrac{\lambda}{4} \Rightarrow$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}\cos\theta)$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90°$$

Two Element array example



(a) Two infinitesimal dipoles

(b) Far-field observations

$$\vec{E}_t = \hat{a}_\theta j\eta \frac{kI_0 l e^{-jkr}}{4\pi r}\cos(\theta) 2\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

$$\beta = \tfrac{\pi}{2}, \quad d = \tfrac{\lambda}{4} \Rightarrow$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}(\cos\theta + 1))$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90°, and \quad \theta_n = 0°$$

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Two Element array example

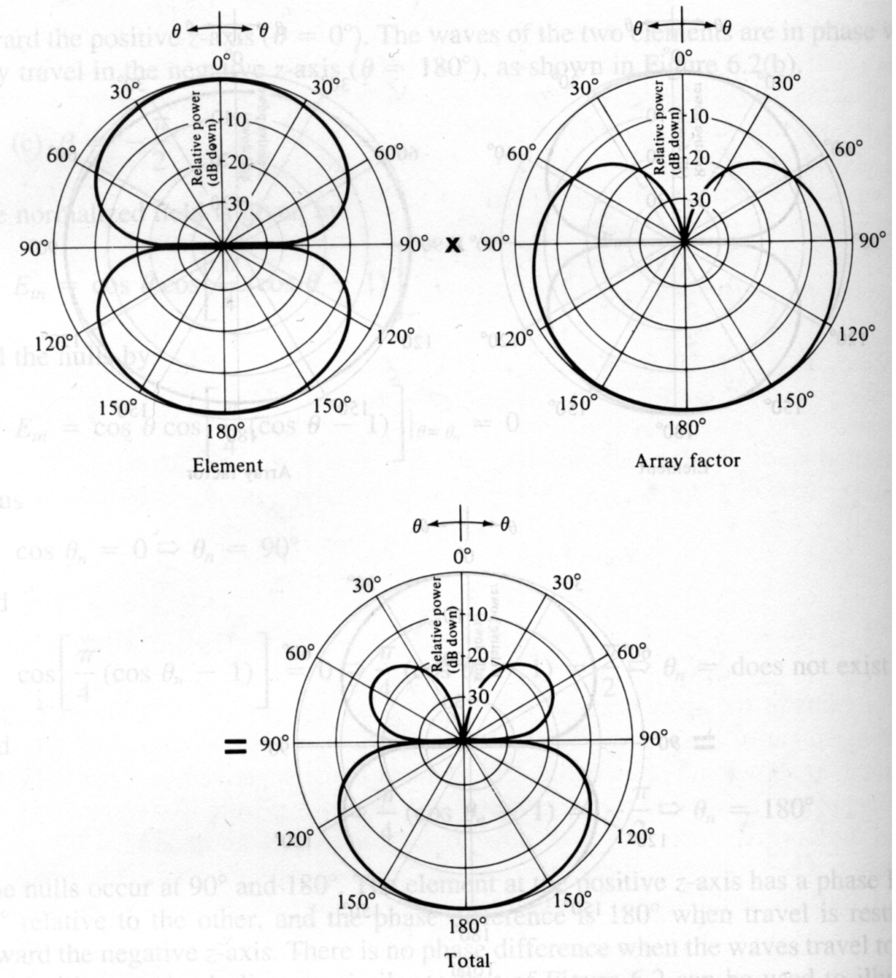


Figure 6.4 Pattern multiplication of element, array factor, and total array patterns of a two-element array of infinitesimal horizontal dipoles with (a) $\beta = +90°$, $d = \lambda/4$.

$$E_{tn} = \cos(\theta)\cos(\tfrac{1}{2}(kd\cos(\theta+\beta))$$

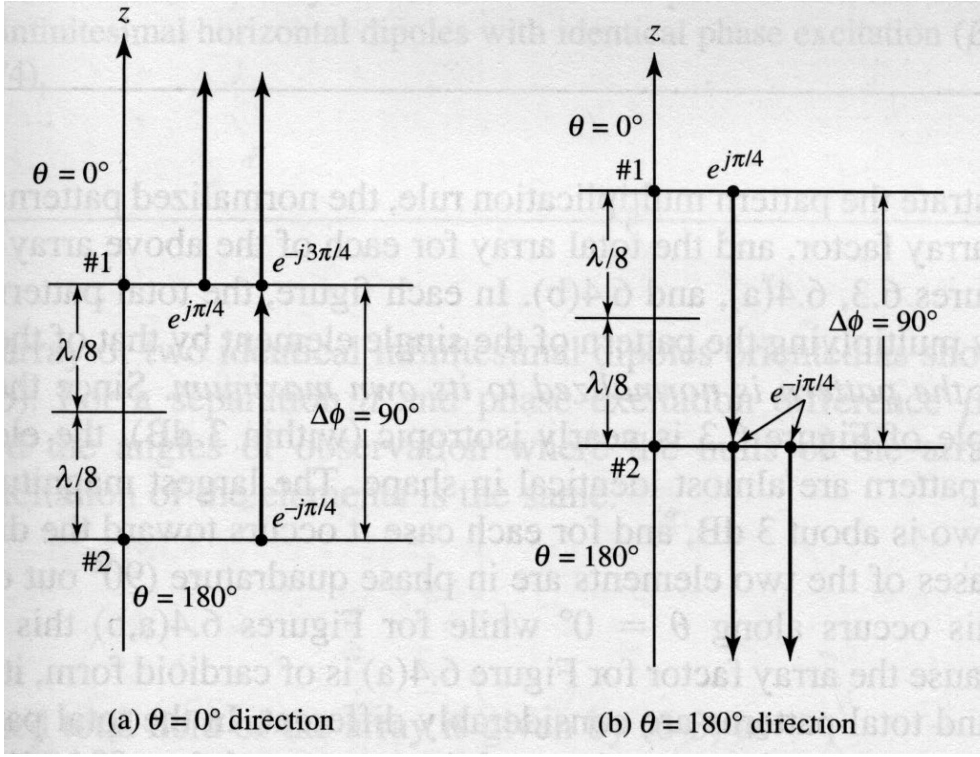
$$\beta = \tfrac{\pi}{2},\ \ d = \tfrac{\lambda}{4} \Rightarrow$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}(\cos\theta + 1))$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90°, and \quad \theta_n = 0°$$

Two Element array example



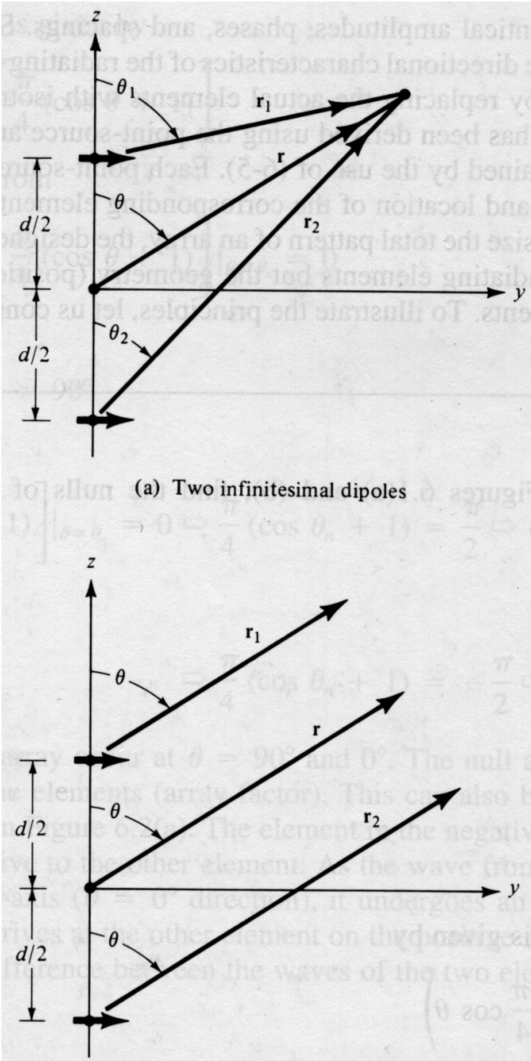
$$\beta = \tfrac{\pi}{2}, \quad d = \tfrac{\lambda}{4} \Rightarrow$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}(\cos\theta + 1))$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90°, and \quad \theta_n = 0°$$

Two Element array example



(a) Two infinitesimal dipoles

(b) Far-field observations

$$\vec{E}_t = \hat{a}_\theta j\eta \frac{kI_0 l e^{-jkr}}{4\pi r} \cos(\theta) 2\cos(\tfrac{1}{2}(kd\cos(\theta + \beta))$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{1}{2}(kd\cos(\theta + \beta))$$

$$\beta = -\tfrac{\pi}{2}, \quad d = \tfrac{\lambda}{4} \Rightarrow$$

$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}(\cos\theta + 1))$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90°, and \quad \theta_n = 180°$$

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Two Element array example

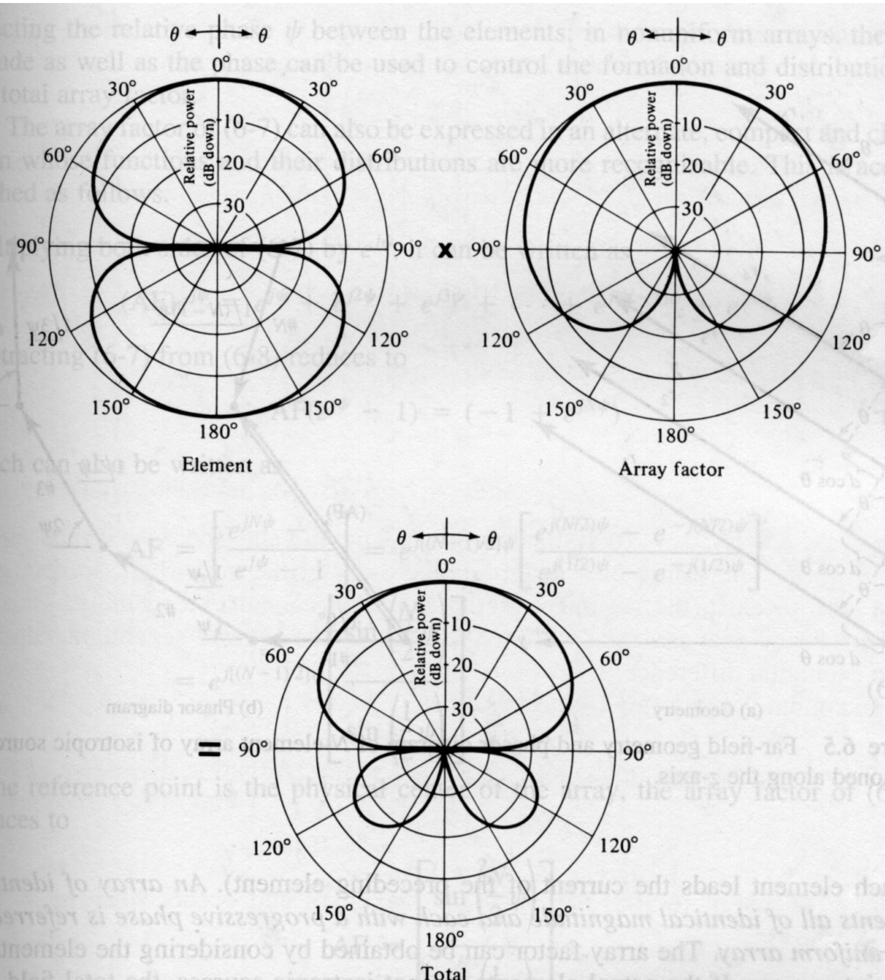


Figure 6.4 (b) Continued ($\beta = -90°$, $d = \lambda/4$).

$$E_{tn} = \cos(\theta)\cos(\tfrac{1}{2}(kd\cos(\theta + \beta))$$

$$\beta = -\tfrac{\pi}{2}, \quad d = \tfrac{\lambda}{4} \Rightarrow$$

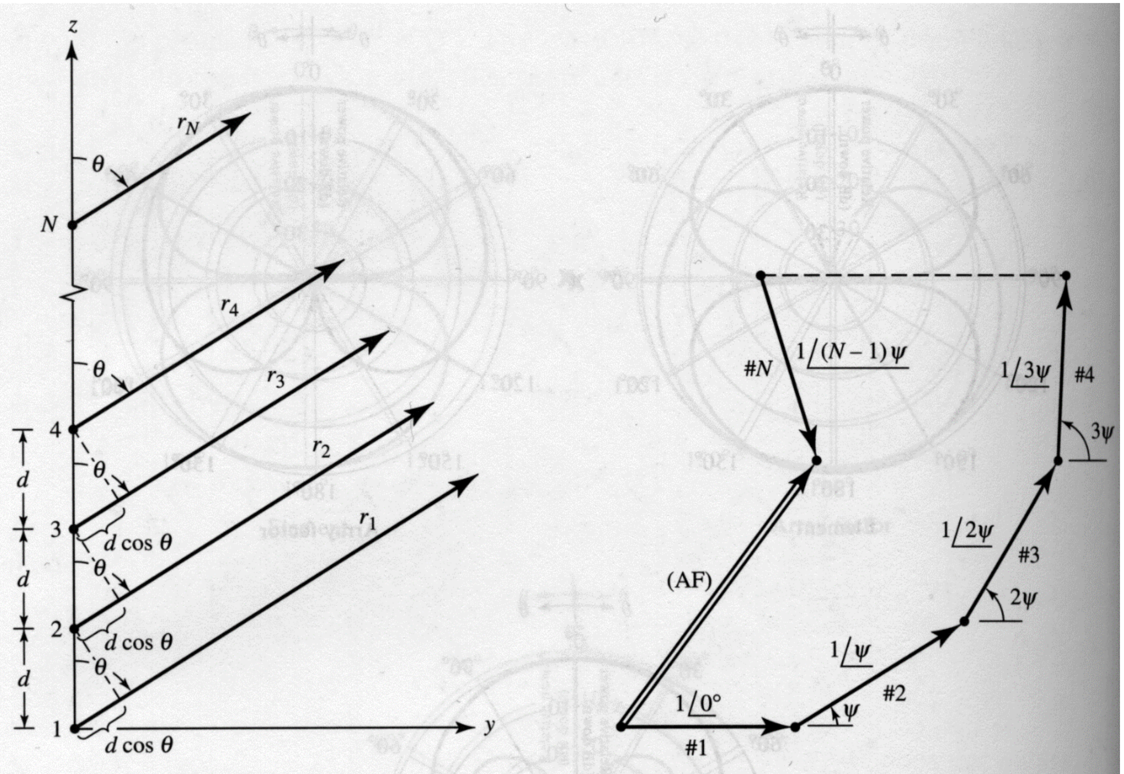
$$E_{tn} = \cos(\theta)\cos(\tfrac{\pi}{4}(\cos\theta + 1))$$

$$E_{tn} = 0 \Rightarrow$$

$$\theta_n = 90°, and \quad \theta_n = 180°$$

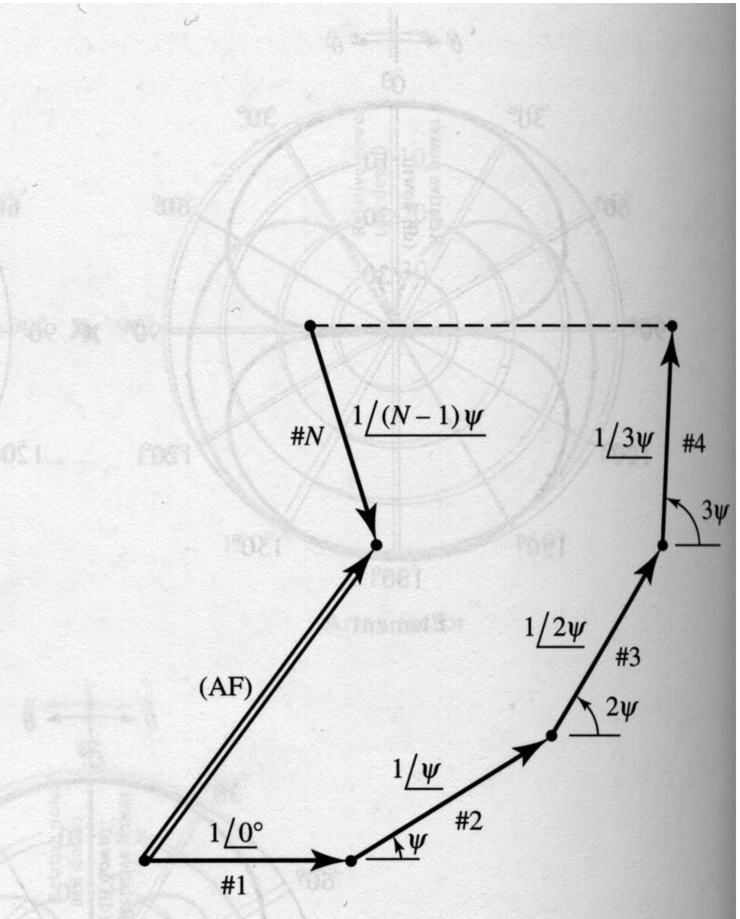
Uniform Array

An array of identical elements all of identical magnitude and each with a progressive phase is referred to as a uniform array



(a) Geometry (b) Phasor diagram

Uniform Array



(b) Phasor diagram

$$AF = \sum_{1}^{N} e^{j(n-1)(kd\cos\theta+\beta)}, or$$

$$AF = \sum_{1}^{N} e^{j(n-1)\Psi}$$

$$\psi = kd\cos\theta + \beta$$

Uniform Array

$$\left.\begin{aligned} AF &= \sum_{1}^{N} e^{j(n-1)\Psi} \\ \psi &= kd\cos\theta + \beta \end{aligned}\right\} =>$$

$$AF = \frac{\sin(\frac{N}{2}\psi)}{\sin(\frac{1}{2}\psi)}, or$$

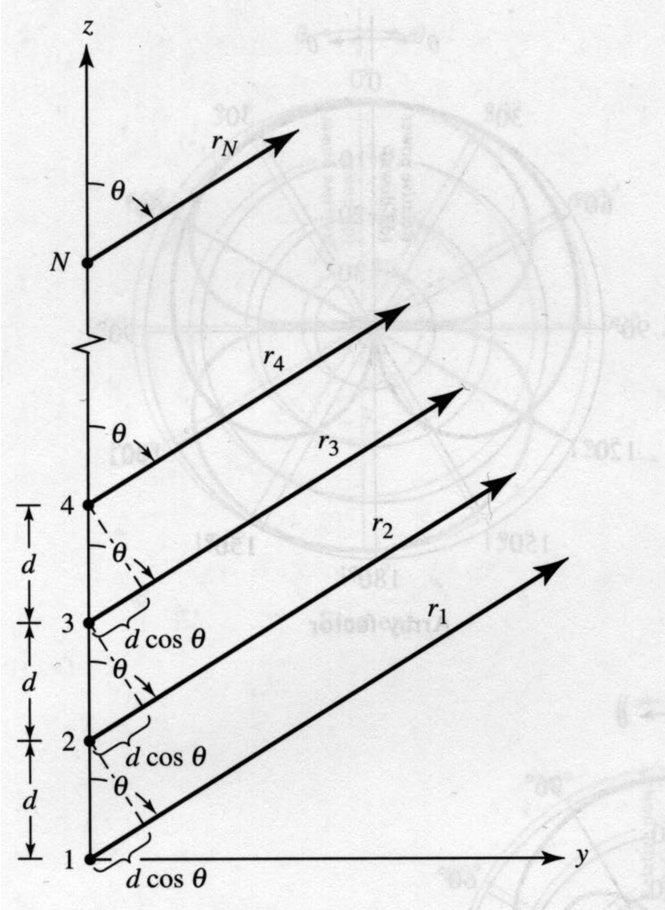
$$AF_n = \frac{1}{N}\frac{\sin(\frac{N}{2}\psi)}{\sin(\frac{1}{2}\psi)}$$

Broadside Array

Maximum at θ=90: Maximum when ψ=0

$$\psi = kd\cos\theta + \beta = 0 \Rightarrow$$

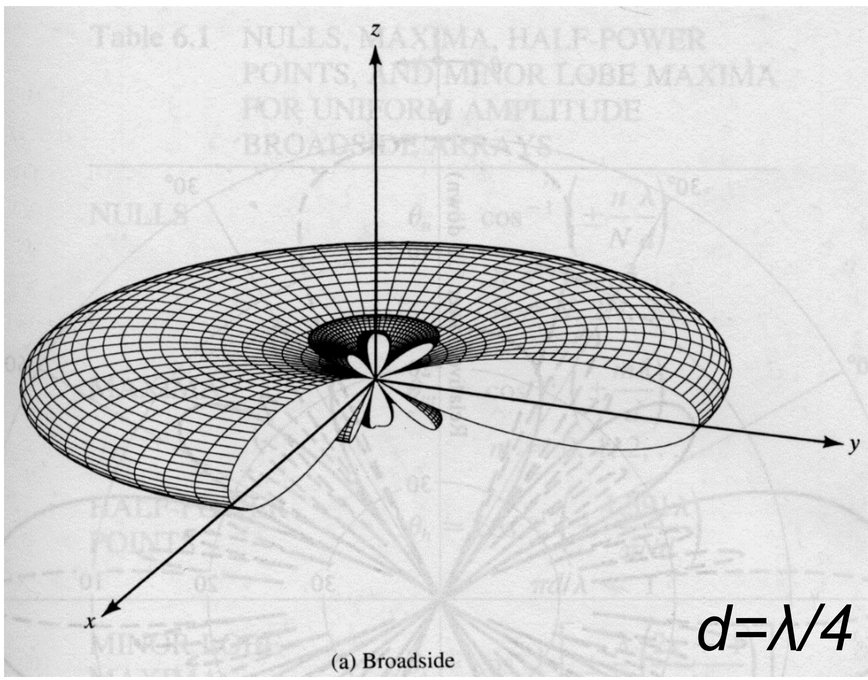
$$\beta = 0$$

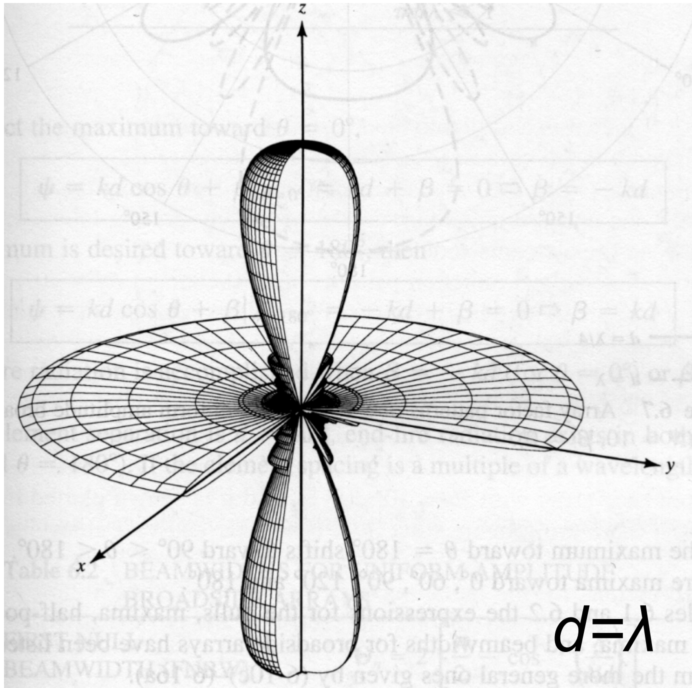


(a) Geometry

Broadside Array

To ensure no principal maxima in other directions => separation must be $d<\lambda$ when $\beta=0$





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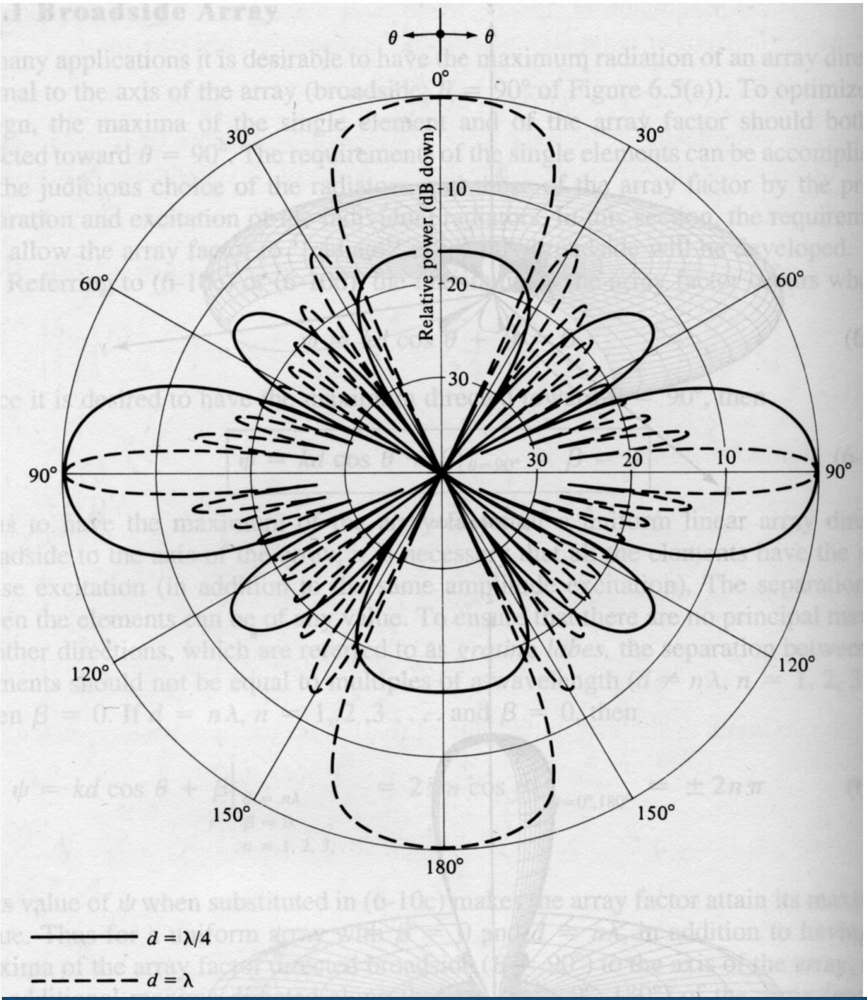
Broadside Array



Note that the larger the overall length of the antenna the narrower the beamwidth – but other problems arises if the spacing is larger than one wavelength!

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Ordinary End-fire Array

Maximum at θ=0 or 180:

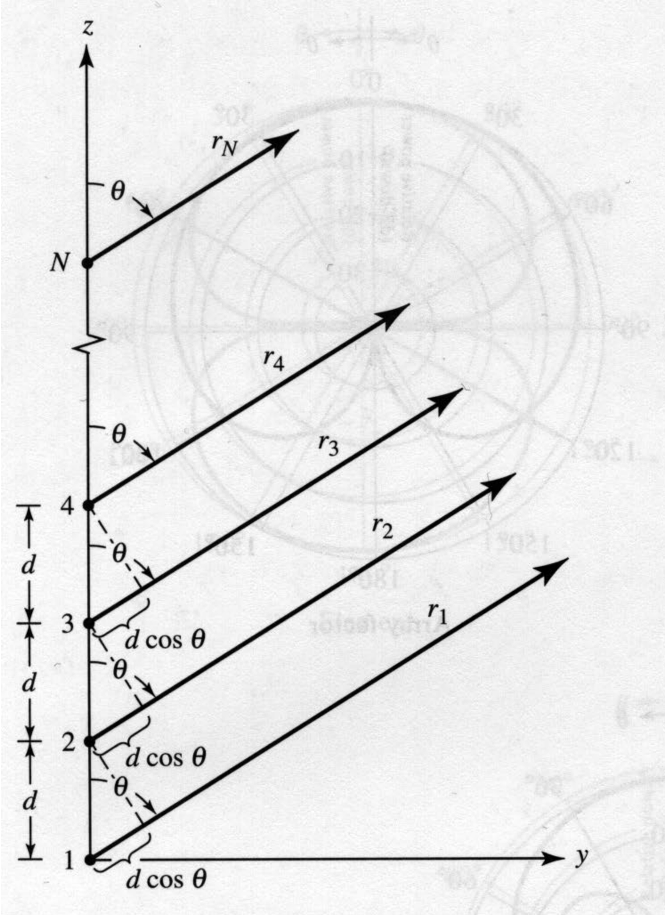
Maximum when ψ=0

$$\psi = kd\cos\theta + \beta = 0 \Rightarrow$$

$$\beta = kd$$

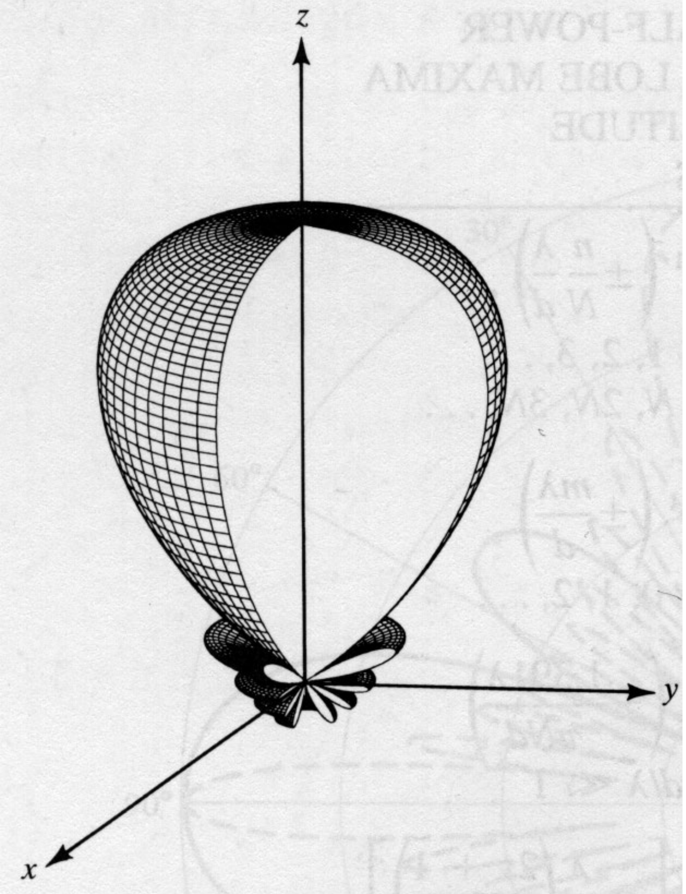
$$\psi = kd\cos(180°) + \beta = 0 \Rightarrow$$

$$\beta = -kd$$

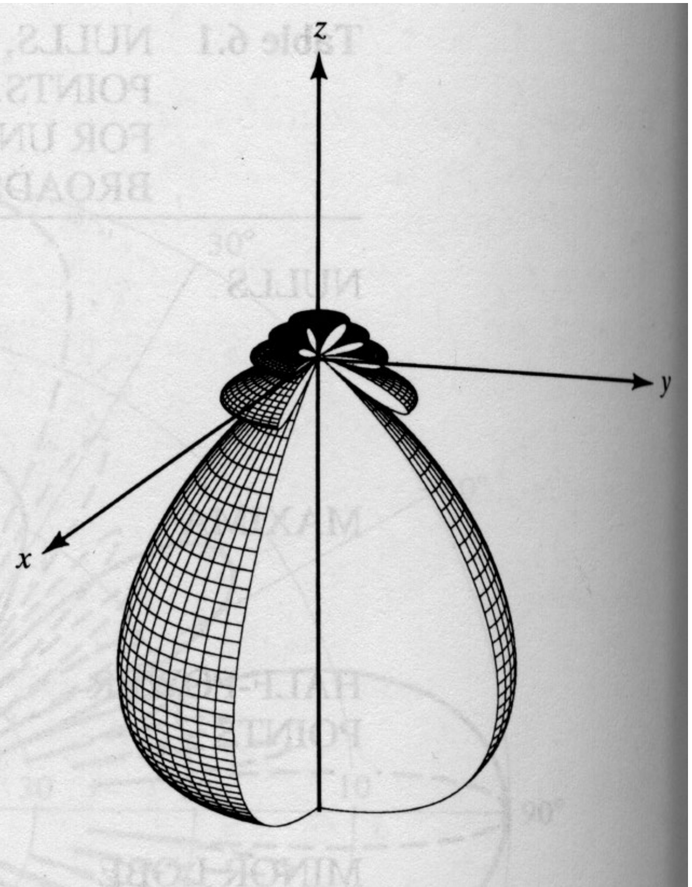


(a) Geometry

Ordinary End-fire Array



(a) $\theta = 0°$



(b) $\theta = 180°$

Note, end-fire

Radiate only in one direction IF

$$d < \frac{\lambda}{2}$$

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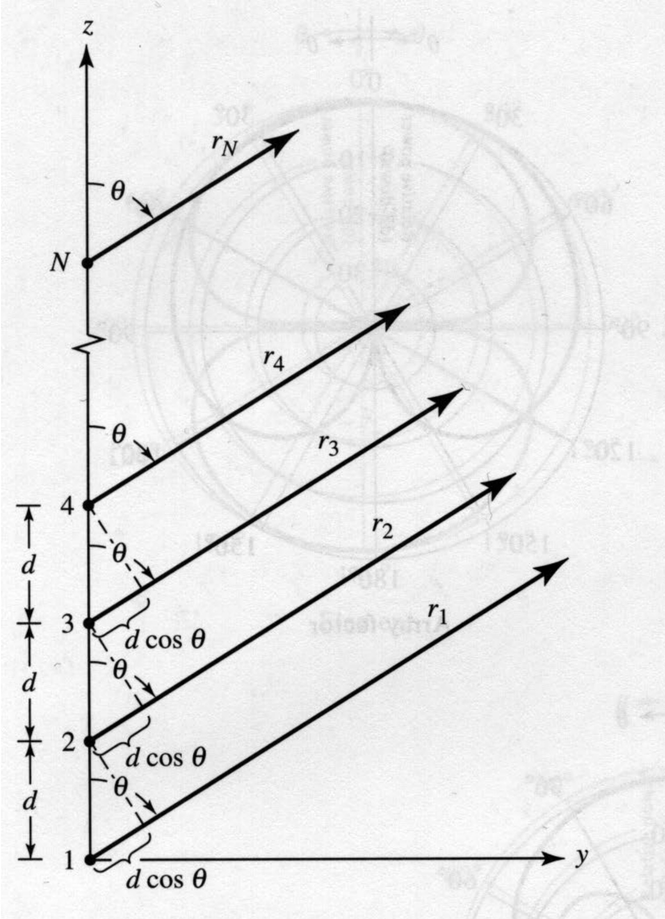
Phase (or Scanning) Array

Maximum at θ: Maximum when ψ=0

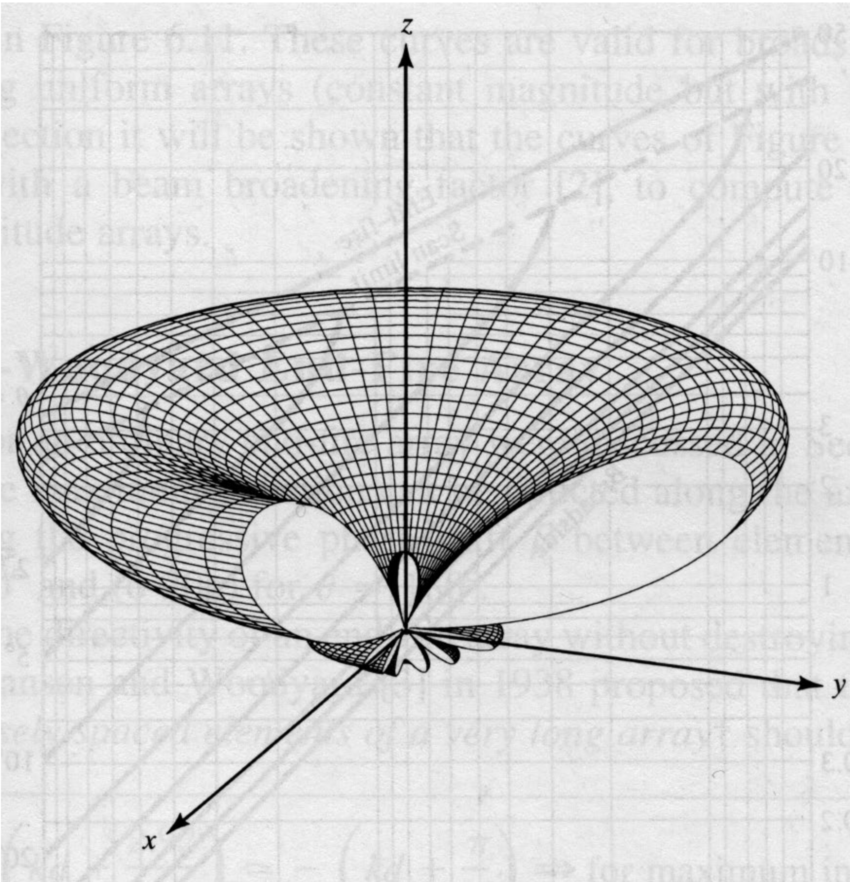
$$\psi = kd\cos\theta + \beta \Big|_{\theta=\theta_0} = 0 \Rightarrow$$

$$\beta = -kd\cos\theta_0$$

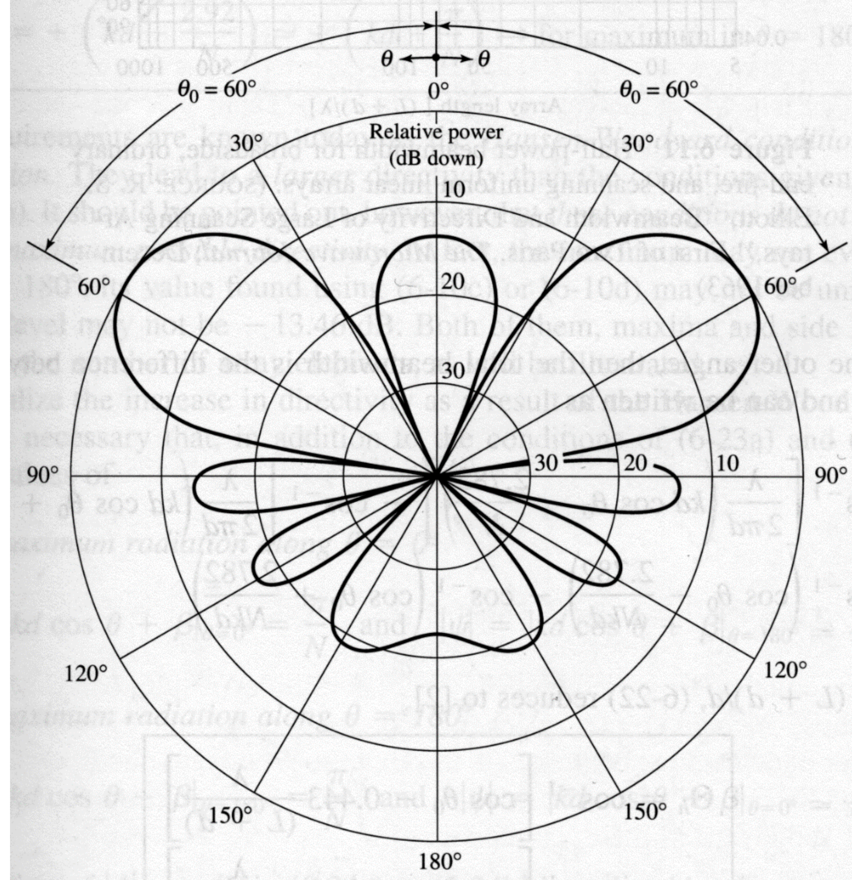


(a) Geometry

Phase (or Scanning) Array

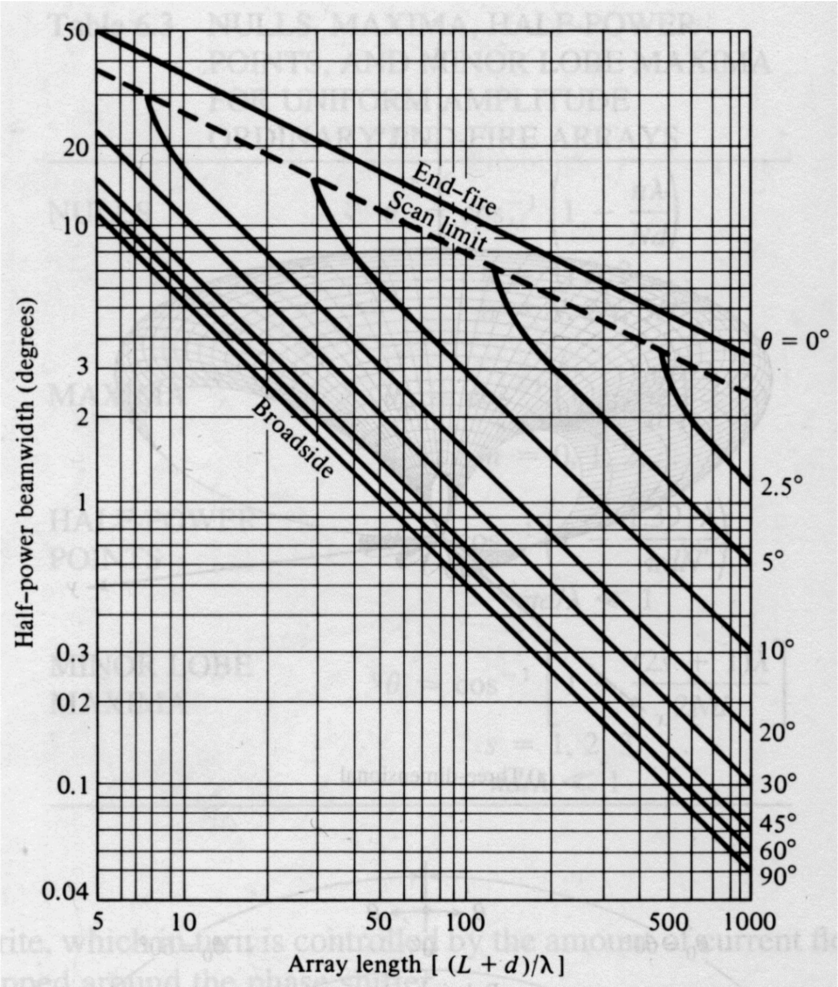


(a) Three-dimensional



(b) Two-dimensional

Directivity of uniform linear Arrays



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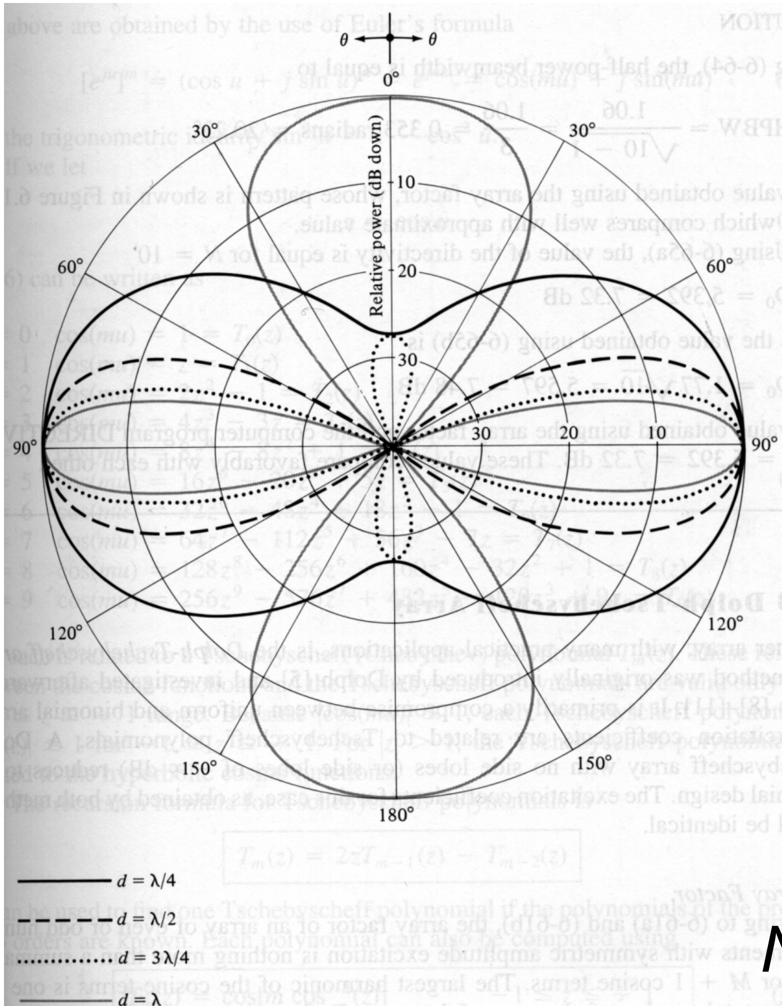
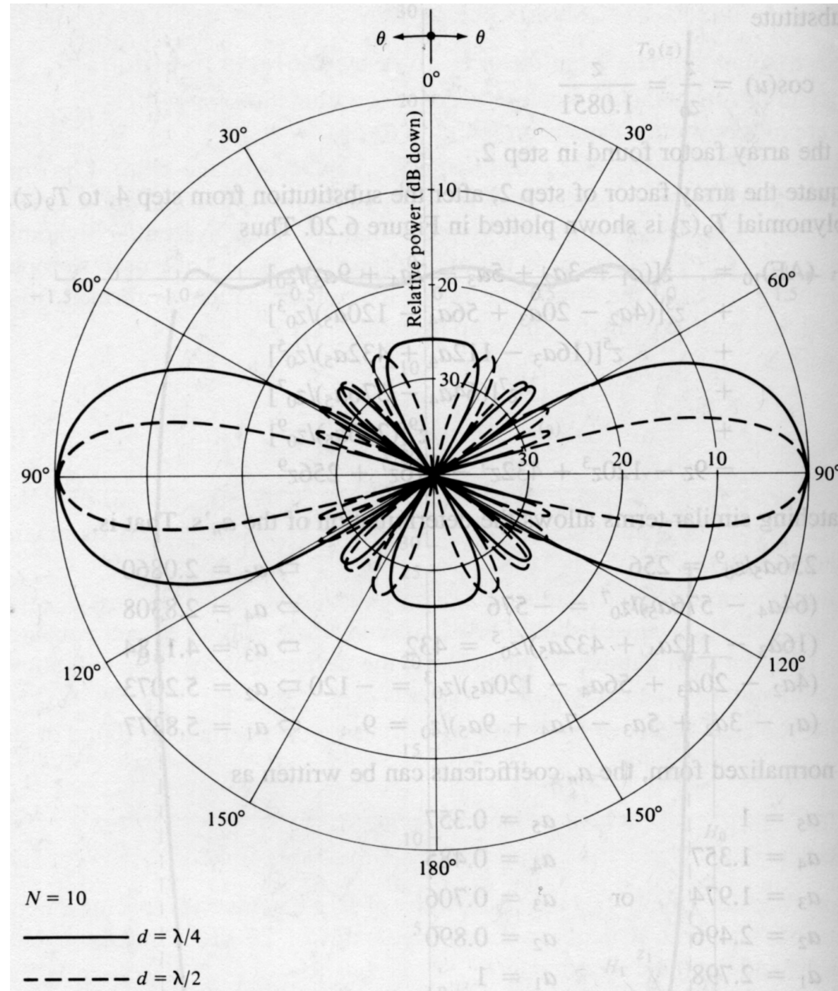
Binomial and Tschebyscheff linear Arrays



N=10



Problem 3.1

Design an ordinary end-fire uniform linear array with only maximum so that its directivity is 20 dBi. The spacing between the elements is $\lambda/4$, and its length is much greater that the spacing. Dertermine the:

a) Number of elements
b) Overall lenght of the array (in wavelengths)

Problem 3.1

c) Approximate half-power beamwith (in degrees)

d) Amplitude level (compered to the maximum of the major lobe) of the first minor lobe in dB.

e) Progressive phase shift between the elements in degrees.

Problem 3.2

Design a patch antenna for Bluetooth,(frequency 2.402 to 2.480 GHz).Use PP material with Er=2.2 and a thickness of 3 mm.

The impedance at the edge is 240 Ω, calculatethe position for 50 Ohm impedance.

Find the W for a 50 Ohm microstrip.

Make the antenna.