Microwave Circuits and Antenna Design

Antenna Array
&
Beamforming

Dr. Cahit Karakuş

2019

Anten Dizisi

Bir anten dizisi, sinyalleri tek bir anteninkinden daha iyi hale getirmek için birleştirilen iki veya daha fazla antenden oluşan bir settir.

Bir anten dizisi,

- Toplam kazancı artırmak,
- Alış güzergah çeşitliliği sağlamak,
- Paraziti azaltmak,
- Anteni belirli bir yönde manevra ettirmek,
- Gelen sinyallerin varış yönünü değiştirmek ve
- Sinyal-Parazit artı Gürültü Oranını (SINR) en üst düzeye çıkarmak için kullanılır.

Normalde anten elemanları ayrı ayrı ışıma yaparken ve dizi antende tüm elemanların ışımaları toplanır, yüksek kazanç, yüksek yönlülük ve daha iyi performansa sahip radyasyon ışını minimum kayıplarla oluşturulur.

Dizi antenlerin uygulamaları arasında uydu iletişimi, kablosuz iletişim, radar iletişimi ve astronomik çalışma yer alır.

Advantages of using antenna arrays

- The signal strength increases
- High directivity is obtained
- Minor lobes are reduced much
- High Signal-to-noise ratio is achieved
- High gain is obtained
- Power wastage is reduced
- Better performance is obtained

- Sinyal gücü artar
- Yüksek yönlülük elde edilir
- Küçük loblar çok azalır
- Yüksek Sinyal-gürültü oranı elde edildi
- Yüksek kazanç elde edilir
- Güç israfı azalır
- Daha iyi performans elde edilir

Disadvantages of array antennas

- Resistive losses are increased
- Mounting and maintenance is difficult
- Huge external space is required

- Direnç kayıpları artar
- Montaj ve bakım zordur
- Büyük harici alan gerekli

Anten Dizisi

Anten dizisinde, ayrı antenler (elemanlar olarak adlandırılır) genellikle belirli bir faz (Dalga Boyu) ilişkisindeki elemanları besleyen besleme hatları ile tek bir alıcıya veya vericiye bağlanır. Her bir anten tarafından yayılan elektromanyetik dalgalar birleşir ve üst üste bindirilir, istenen yönlere yayılan gücü arttırmak için bir araya eklenir (yapısal olarak müdahale eder) ve diğer yönlere yayılan gücü azaltır (tahrip edici şekilde müdahale eder).

Anten Dizisi

- Bir anten dizisi, tek bir elemanın elde edebileceğinden daha dar bir elektromanyetik dalga hüzmesi demeti olan daha yüksek kazanç (yönlendirme) elde edebilir.
- Genel olarak, kullanılan anten elemanlarının sayısı arttıkça, kazanç artar ve ışın daralır. Bazı anten dizileri (askeri aşamalı dizi radarları gibi) binlerce ayrı antenden oluşur.
- Diziler daha yüksek kazanç elde etmek, iletişim güvenilirliğini artıran yol çeşitliliği (MIMO olarak da adlandırılır), belirli yönlerden paraziti iptal etmek, radyo ışınını farklı yönlere işaret etmek için elektronik olarak yönlendirmek ve elektromanyetik ışıma kaynağının yönünü bulmak için kullanılabilir .

Elektromanyetik dalgaları dar bir hüzmede yaymak

- Yarım dalga dipolleri ve çeyrek dalga boyundaki küçük antenlerin çok fazla yönlendiriciliği (kazancı) yoktur; elektromanyetik dalgaları uzak bir doğrultuya yayan çok yönlü antenlerdir.
- Elektromanyetik dalgalarını dar bir hüzmede yayan yönlü bir anten (yüksek kazançlı anten) oluşturmak için iki genel teknik kullanılabilir.
- Birinci teknik, horn antenler ve parabolik reflektörlerin metal yüzeyleri, elektromanyetik dalgaları yansıtır ya da yönünü değiştiriir. Parabolik çanak, bu tip antenin bir örneğidir. Ayrıca tek bir düşük kazançlı antenden bir ışıma odaklamak için dielektrik lenslerle kırılma da kullanılmaktır.

Elektromanyetik dalgaları dar bir hüzmede yaymak

- İkinci bir teknik, aynı verici veya alıcıdan beslenen çoklu antenler kullanmaktır; buna dizi anteni veya anten dizisi denir.
- Akımlar, uygun faz ile antenlere beslenirse, girişim olgusu nedeniyle, tek tek antenlerden gelen küresel dalgalar, dizinin önünde birleşerek (üst üste binerek) düzlem dalgaları, belirli bir yönde hareket eden bir elektromanyetik dalga demeti (hüzmesi) oluşturur .
- Tek tek antenlerden gelen dalgaların faza geldiği yönlerde, dalgalar yayılan gücü arttırmak için bir araya gelir (yapıcı girişim).
- Bireysel dalgaların fazdan çıktığı yönlerde, bir dalganın zirvesi bir diğerinin vadisiyle çakışır, dalgalar iptal eder (yıkıcı girişim), bu yönde yayılan gücü azaltır.
- Benzer şekilde, alınırken, istenen antenlerden alınan radyo dalgalarından ayrı antenler tarafından alınan salınım akımları fazdadır ve alıcıda birleştirildiğinde birbirini güçlendirirken, diğer yönlerden alınan radyo dalgalarından akımlar faz dışında ve birleştirildiğinde alıcı birbirini iptal eder.

Elektromanyetik dalgaları dar bir hüzmede yaymak

- Böyle bir antenin radyasyon paterni, bir yönde güçlü bir ışın, ana lob ve ayrıca yan loblar olarak adlandırılan farklı açılardaki, genellikle istenmeyen yönlerde artık radyasyonu temsil eden bir dizi zayıf ışından oluşur.
- Antenin genişliği büyüdükçe ve bileşen anten elemanlarının sayısı arttıkça, ana lob daha dar olur ve elde edilebilecek kazanç artar ve yan loblar küçülür.
- En büyük dizi antenleri, daha yüksek çözünürlük elde etmek için büyük parabolik antenlerden oluşan çoklu radyo teleskoplarının bir anten dizisine bağlandığı radyo astronomi alanında kullanılan radyo interferometrelerdir.

US Air Force PAVE PAWS phased array 420 - 450 MHz radar antenna for ballistic missile detection, Alaska. The two circular arrays are each composed of 2677 crossed dipole antennas.

HAARP, a phased array of 180 crossed dipoles in Alaska which can transmit a 3.6 MW beam of 3 - 10 MHz radio waves into the ionosphere for research purposes

Array of four helical antennas used as a satellite tracking antenna, Pleumeur-Bodou, France

Microstrip antenna arrays

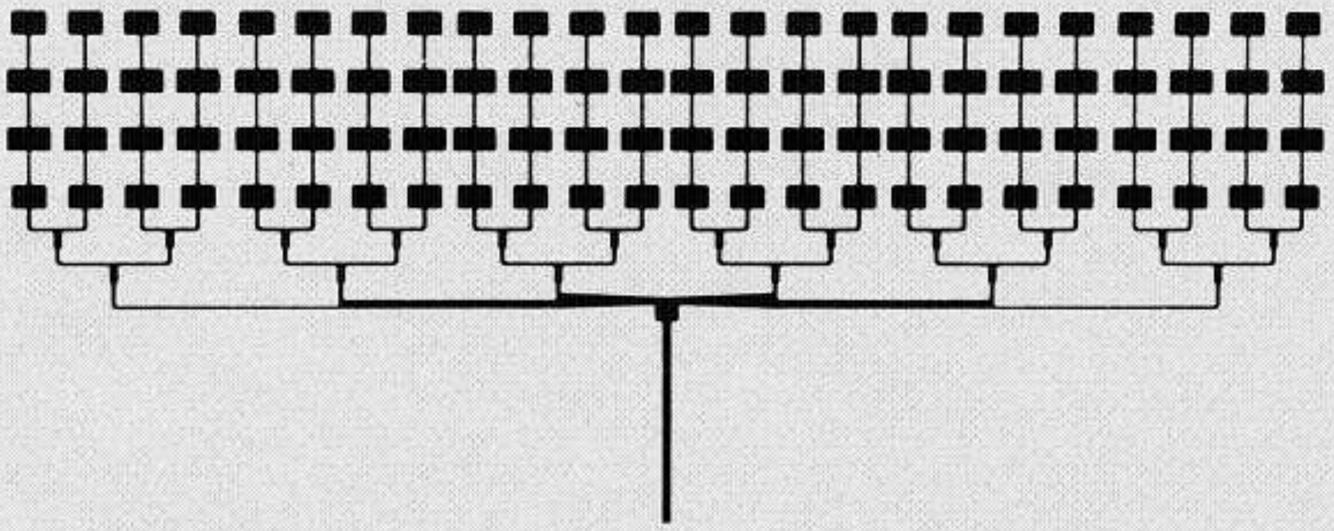
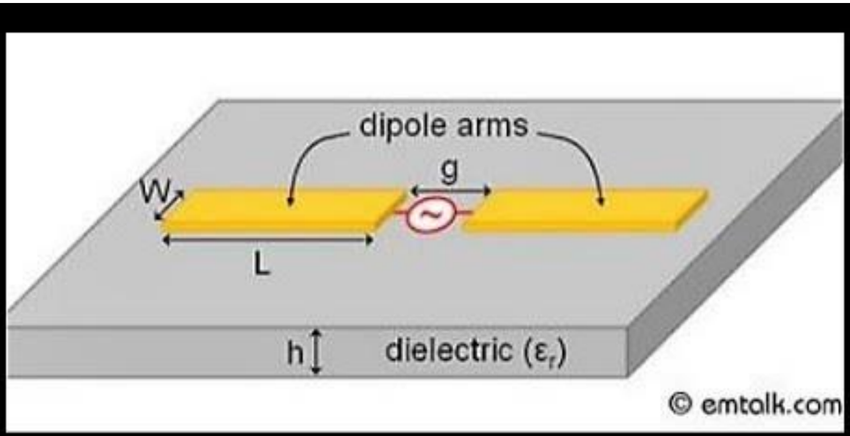
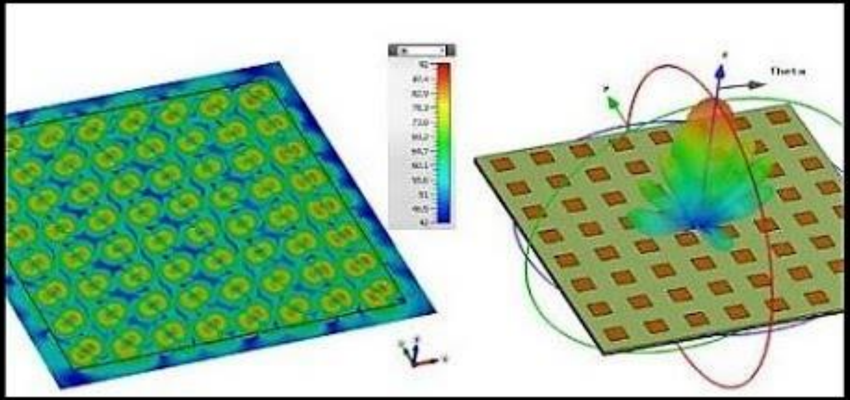
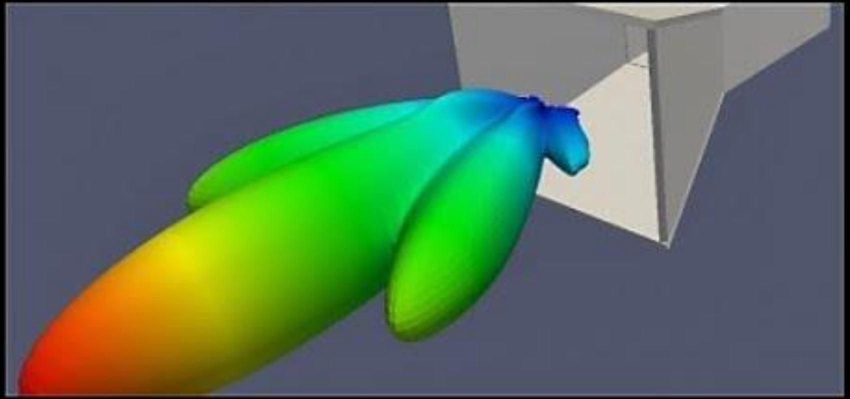
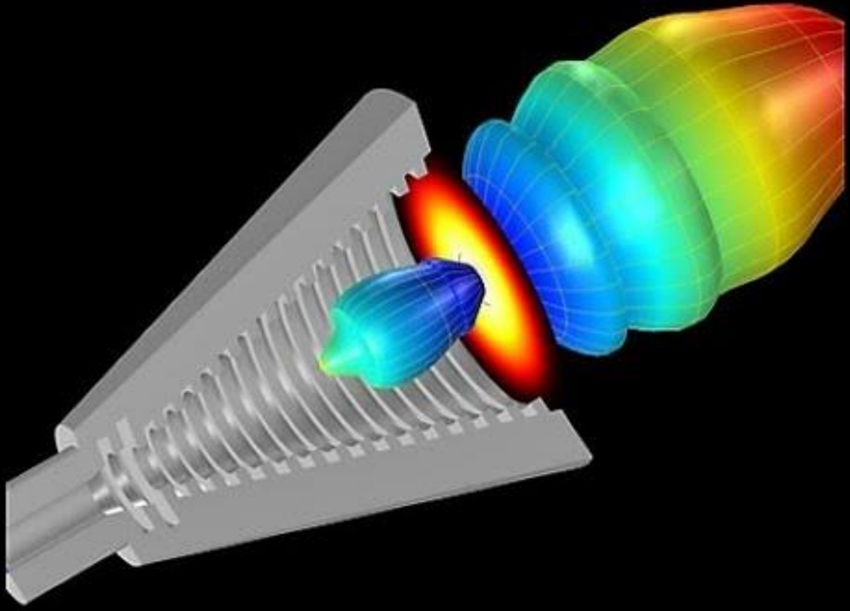


Plate 7.1/A 40 GHz Microstrip Array Antenna (Photo Courtesy of AEG-TELEFUNKEN, West Germany).

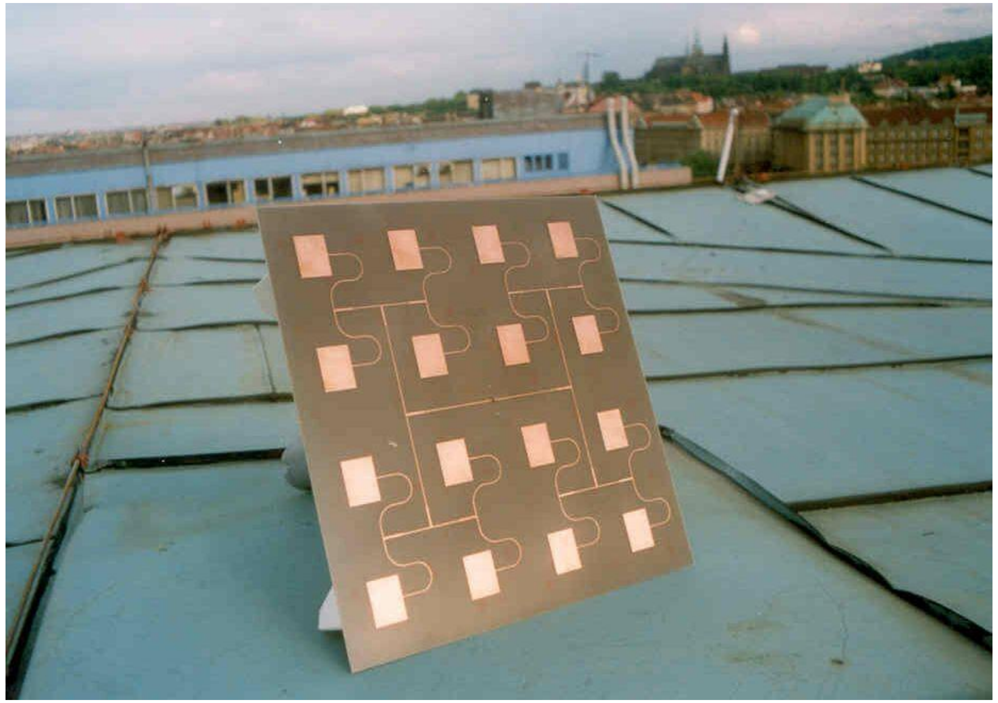

dipole arms
g
W
L
h
dielectric (ε_r)
© emtalk.com

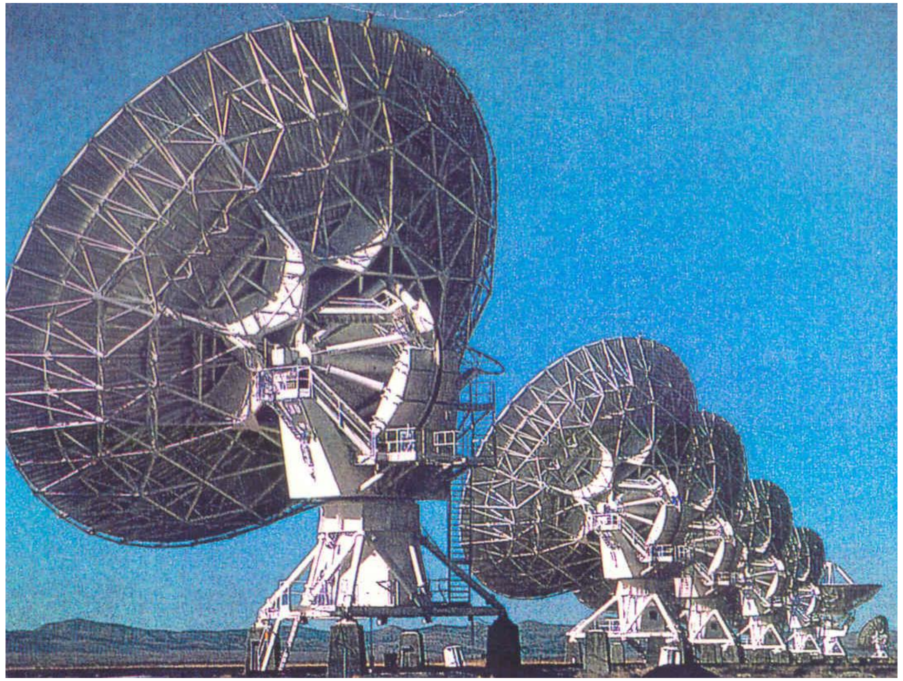

Theta





Antenna Arrays



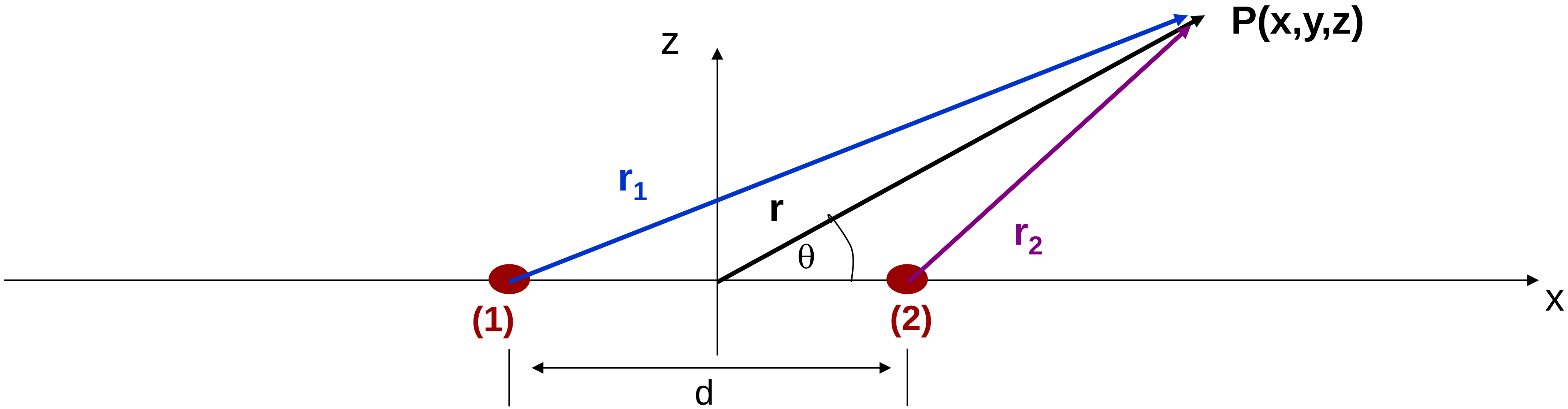


Dizi antende dalga boyu - faz ilişkisi

- İkili dizi antende, iki anten elemanı arasındaki boşluk=λ/4 dır. 3 dB artı kazanç sağlar.
- İki antenin besleme noktaları arasındaki uzaklık =λ/2 olmalıdır.
- Anten beslemelerinde mikroşerit hat kullanıldığında empedans dönüştürücü yapıları önemlidir.
- Dizi anten tasarlarken ayrık anten elemanları kullanıldığında kablo uzunluğu λ/2 nin katları olmalıdır.
- Empedans dönüştücülerde birim antenlerin giriş empedansı 50 ohm ise 50 ohmden 100 ohm dönüştürücü kullanılırken ışıma band genişliğine dikkat edilmelidir.
- Maksimumdan maksimuma uzaklık=λ/2
- Minumumdan minumuma uzaklık=λ/2
- Maksimumdan minumuma uzaklık=λ/4
- Acık devreden kısa devre ya da kısa devreden açık devre elde etmek için λ/4 hat uzunluğu kullanılır.

λ/2=360 derece
λ/4=180 derece

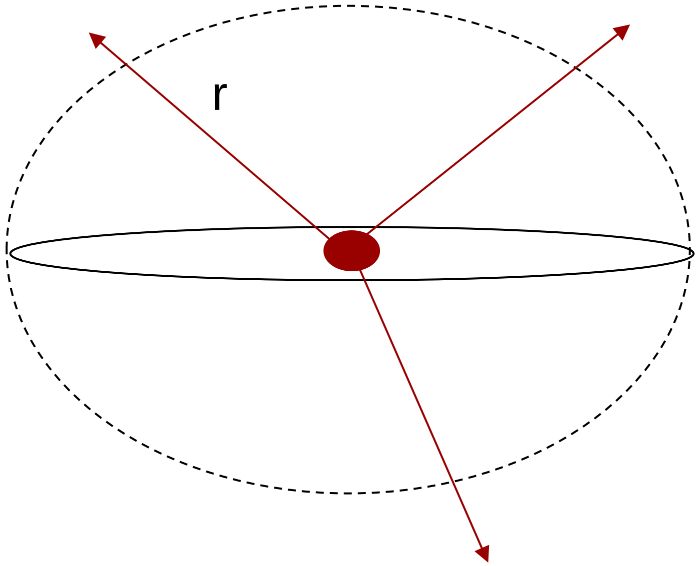
Array Factor for Two Isotropic Sources with Identical Amplitude and Phase (d = λ/2)



Isotropic sources are assumed for AF calculations. The radiated fields are uniform over a sphere surrounding the source.

Radiation from an Isotropic Source

$$E \propto \frac{e^{-jkr}}{r}$$



Total **E** Field

$$E(\theta,\varphi) = \left(I_o e^{j\varphi_o}\right)\frac{e^{-jkr_1}}{r_1} + \left(I_o e^{j\varphi_o}\right)\frac{e^{-jkr_2}}{r_2}$$

$$= I_o e^{j\varphi_o}\left[\frac{e^{-jkr_1}}{r_1} + \frac{e^{-jkr_2}}{r_2}\right]$$

where

$$r_1 = \left|\vec{r}_1\right|; \quad \vec{r}_1 = \vec{r} + \frac{d}{2}\hat{x}$$

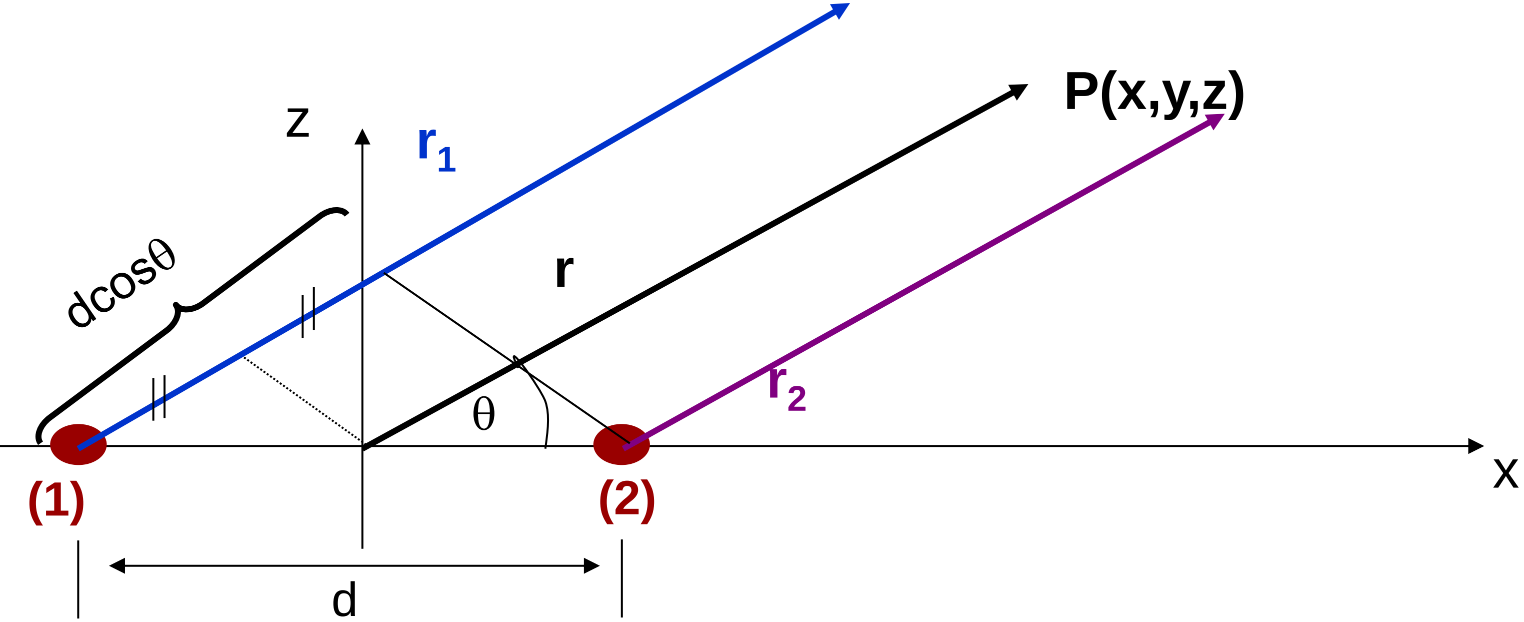
$$r_2 = \left|\vec{r}_2\right|; \quad \vec{r}_2 = \vec{r} - \frac{d}{2}\hat{x}$$

Far Field Geometry

In the far field, r>>d or (d/r) <<1

$$r_1 = r + \frac{d}{2}\cos\theta$$

$$r_2 = r - \frac{d}{2}\cos\theta$$



If the observation point **r** is much larger than the separation d, the vectors **r1**, **r** and **r2** can be assumed to be approximately parallel. The path lengths from the sources to the observation point are slightly different.

Total E in the Far Field

$$E(\theta,\varphi) = I_o e^{j\varphi_o} \frac{e^{-jk\left(r+\frac{d}{2}\cos\theta\right)}}{\left[r+\frac{d}{2}\cos\theta\right]} + I_o e^{j\varphi_o} \frac{e^{-jk\left(r-\frac{d}{2}\cos\theta\right)}}{\left[r-\frac{d}{2}\cos\theta\right]}$$

$$= I_o e^{j\varphi_o} e^{-jkr} \left[\frac{e^{-jk\frac{d}{2}\cos\theta}}{r} + \frac{e^{+jk\frac{d}{2}\cos\theta}}{r} \right]$$

$$= I_o e^{j\varphi_o} \frac{e^{-jkr}}{r} \left[e^{-jk\frac{d}{2}\cos\theta} + e^{+jk\frac{d}{2}\cos\theta} \right]$$

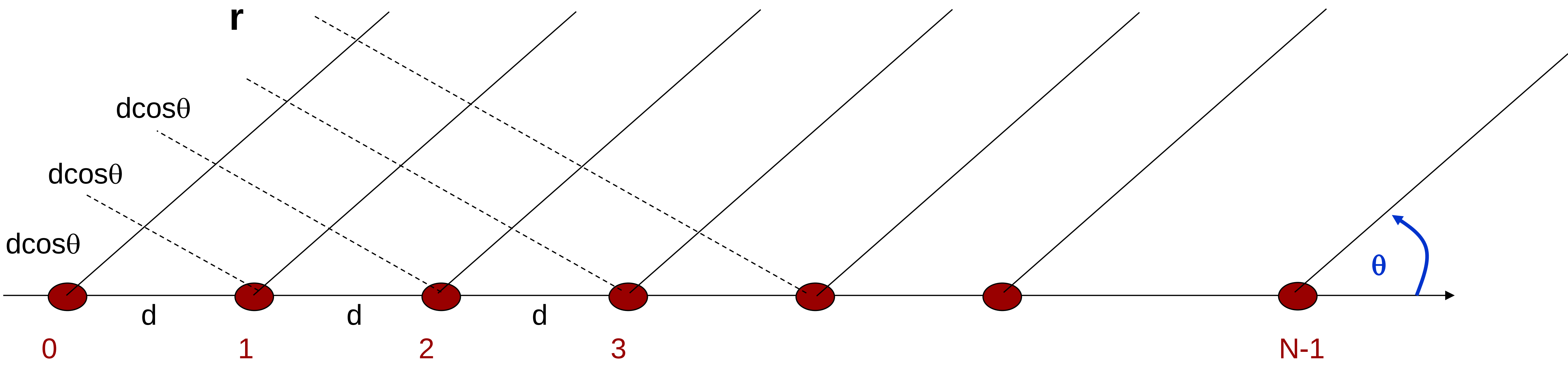
$$= 2 I_o e^{j\varphi_o} \frac{e^{-jkr}}{r} \cos\left(k\frac{d}{2}\cos\theta\right)$$

Total E for d=λ/2

Note that d=λ/2

$$
\begin{aligned}
E(\theta,\varphi) &= 2I_o e^{j\varphi_o}\,\frac{e^{-jkr}}{r}\cos\left(\frac{2\pi}{\lambda}\frac{\lambda}{4}\cos\theta\right) \\
&= 2I_o e^{j\varphi_o}\,\frac{e^{-jkr}}{r}\cos\left(\frac{\pi}{2}\cos\theta\right)
\end{aligned}
$$

Generalization to N Equally Spaced Elements



General Case for Linear Array

Total E field:

$$
\begin{aligned}
E(\theta,\varphi) &= I_o e^{j\varphi_o}\frac{e^{-jkr_1}}{r} + I_1 e^{j\varphi_1}\frac{e^{-jkr_2}}{r} + \ldots I_{N-1} e^{j\varphi_{N-1}}\frac{e^{-jkr_{N-1}}}{r} \\
&= \frac{e^{-jkr}}{r}\left[I_o e^{j\varphi_o} + I_1 e^{j\varphi_1} e^{+jkd\cos\theta} + \ldots I_{N-1} e^{j\varphi_{N-1}} e^{+j(N-1)kd\cos\theta} \right] \\
&= \frac{e^{-jkr}}{r}\sum_{n=0}^{N-1} I_n e^{j\varphi_n} e^{+jnkd\cos\theta}
\end{aligned}
$$

Array Factor:

$$
AF = r\left|E(\theta,\varphi)\right| = \left|\sum_{n=0}^{N-1} I_n e^{j\varphi_n} e^{+jnkd\cos\theta}\right|
$$

Equally Spaced Linear Array with Linear Phase Progression

$$\varphi_n = n\alpha$$

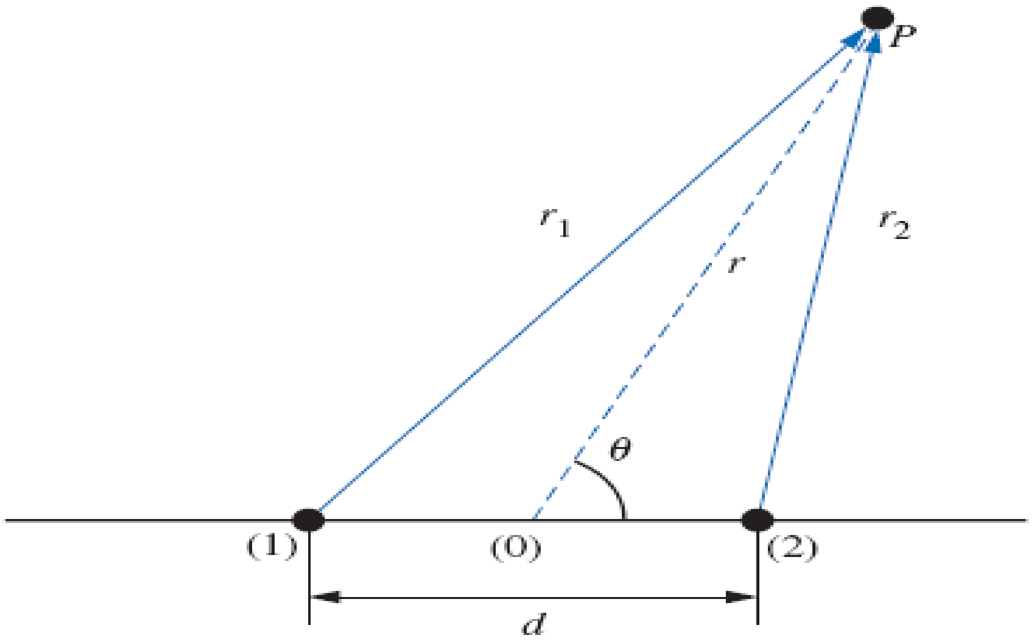
$$E(\theta,\varphi) = \sum_{n=0}^{N-1} I_n e^{+jn(kd\cos\theta+\alpha)} = \sum_{n=0}^{N-1} I_n e^{+jn\Psi}$$

where

$$\Psi = kd\cos\theta + \alpha$$

Fourier series

Antenna arrays



The individual elements are characterized by their element patterns $F_1(\theta,\phi)$.

At an arbitrary point P, taking into account the phase difference due to physical separation and difference in excitation, the total far zone electric field is:

$$E(r) = E_1(r)e^{j\psi/2} + E_2(r)e^{-j\psi/2} \qquad (10.39.1)$$

Field due to antenna 1 Field due to antenna 2

Here: $$\psi = kd\cos\theta + \delta \qquad (10.39.2)$$

The phase center is assumed at the array center. Since the elements are identical

$$E(r) = 2E_1(r)\frac{e^{j\psi/2} + e^{-j\psi/2}}{2} = 2E_1(r)\cos\frac{\psi}{2}$$

Relocating the phase center point only changes the phase of the result but not its amplitude.

Antenna arrays

The radiation pattern can be written as a product of the radiation pattern of an individual element and the radiation pattern of the array (array pattern):

$$F(\theta,\phi) = F_1(\theta,\phi)\cdot F_a(\theta,\phi)$$

where the array factor is:

$$F_a(\theta,\phi) = \cos\left(\frac{kd\cos\theta+\delta}{2}\right)$$

Here δ is the phase difference between two antennas. We notice that the array factor depends on the array geometry and amplitude and phase of the excitation of individual antennas.

Array Factor

$$\psi = kd\cos\theta,$$

array factor becomes

$$AF = \sum_{m=0}^{N-1} e^{jm\psi} = 1 + e^{j\psi} + e^{j2\psi} + \cdots + e^{j(N-1)\psi}$$

This function is a function of ψ and resembles a Fourier Series where the array factor is composed of a set of sinusoids at multiples of a 'fundamental frequency' ψ.

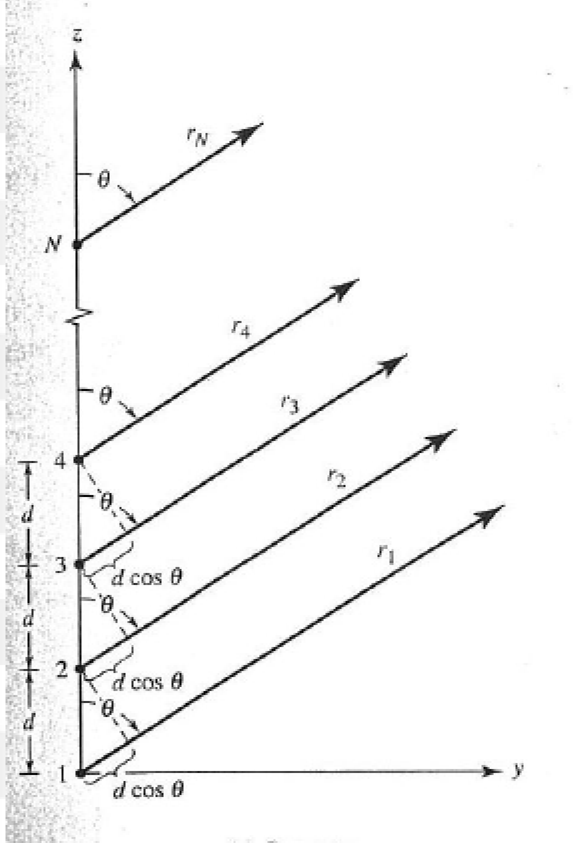
$$AF \cdot e^{j\psi} = e^{j\psi} + e^{j2\psi} + e^{j3\psi} + \cdots + e^{jN\psi}$$

$$AF(1 - e^{j\psi}) = 1 - e^{jN\psi}.$$

$$AF = \frac{1 - e^{jN\psi}}{1 - e^{j\psi}} = \frac{e^{jN\psi/2}}{e^{j\psi/2}} \frac{e^{jN\psi/2} - e^{-jN\psi/2}}{e^{j\psi/2} - e^{-j\psi/2}} = e^{j(N-1)\psi/2} \frac{\sin(N\psi/2)}{\sin(\psi/2)}$$

N-element Linear Array: Uniform amplitude & spacing

If the amplitude and spacing are both uniform, the array factor becomes



(a) Geometry

$$\begin{aligned} \mathrm{AF} &= 1 + e^{j(kd\cos\theta+\beta)} + e^{j2(kd\cos\theta+\beta)} \\ &\quad + \cdots + e^{j(N-1)(kd\cos\theta+\beta)} \\ &= \sum_{n=1}^{N} e^{j(n-1)\psi} \end{aligned}$$

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

N-element Linear Array: Uniform amplitude & spacing

thus

$$\mathrm{AF} = \frac{e^{jN\psi} - 1}{e^{j\psi} - 1} = e^{j\frac{N-1}{2}\psi} \frac{e^{j\frac{N}{2}\psi} - e^{-j\frac{N}{2}\psi}}{e^{j\frac{\psi}{2}} - e^{-j\frac{\psi}{2}}}$$

$$= e^{j\frac{N-1}{2}\psi} \frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\frac{\psi}{2}}$$

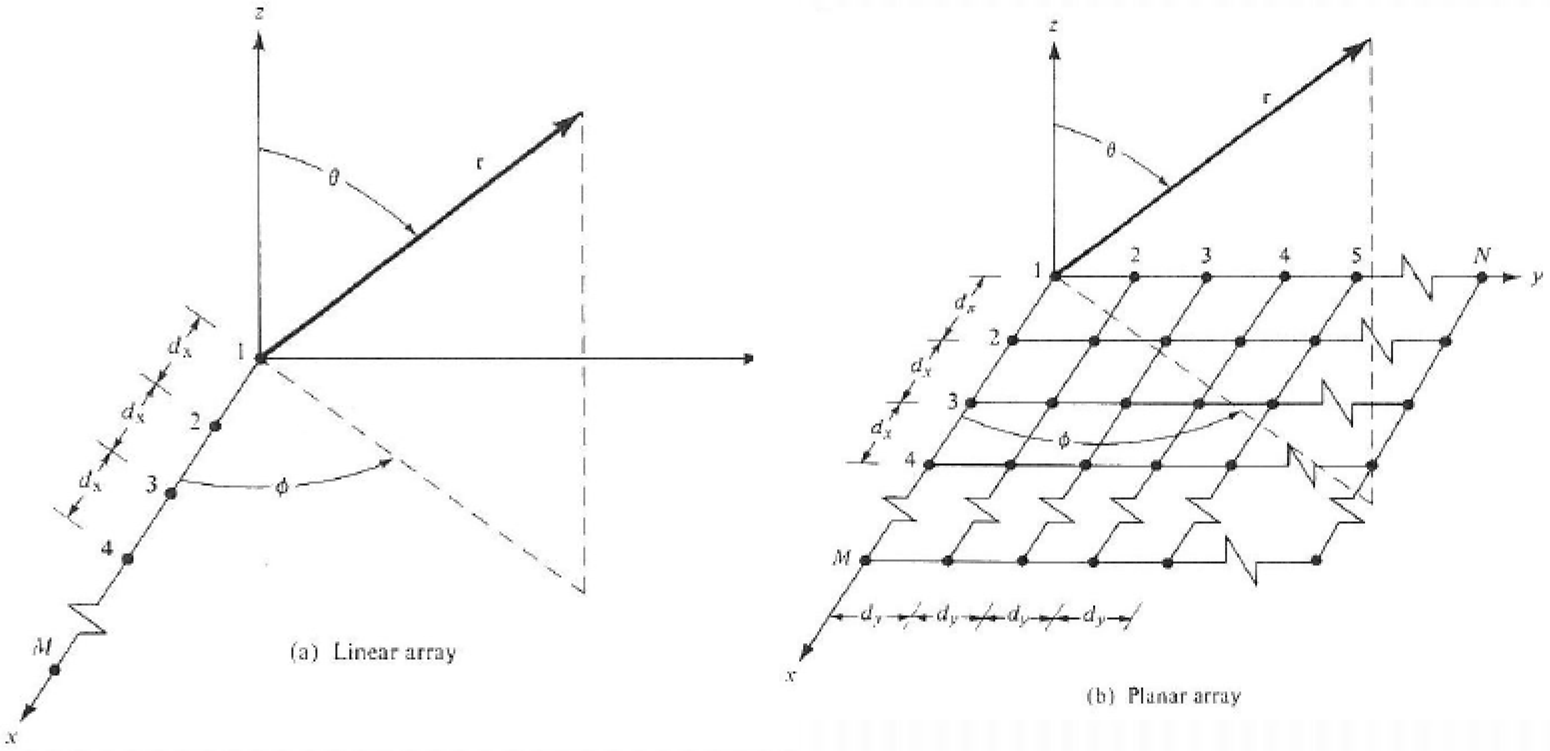
If the reference point is the physical center of the array

$$\mathrm{AF} = \frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\frac{\psi}{2}} \underset{\psi:\text{small}}{\cong} \frac{\sin\left(\frac{N}{2}\psi\right)}{\frac{\psi}{2}}$$

Planar Array

- Linear Array = one-dimensional array, i.e., can scan the beam only in one plane.
- In order to be able to scan the beam in any direction, two-dimensional arrays are needed. Geometries can be planar, circle, cylindrical, spherical and so on.

Planar Array



(a) Linear array

(b) Planar array

Array Factor

AF for each linear array along x-axis:

$$\mathrm{AF} = \sum_{m=1}^{M} I_{m1} e^{j(m-1)(kd_x \sin\theta\cos\phi + \beta_x)}$$

AF for the entire planar array:

$$\mathrm{AF} = \sum_{n=1}^{N} I_{1n} \left[\sum_{m=1}^{M} I_{m1} e^{j(m-1)(kd_x \sin\theta\cos\phi + \beta_x)} \right] e^{j(n-1)(kd_y \sin\theta\sin\phi + \beta_y)}$$

$$= S_{xm} S_{yn}$$

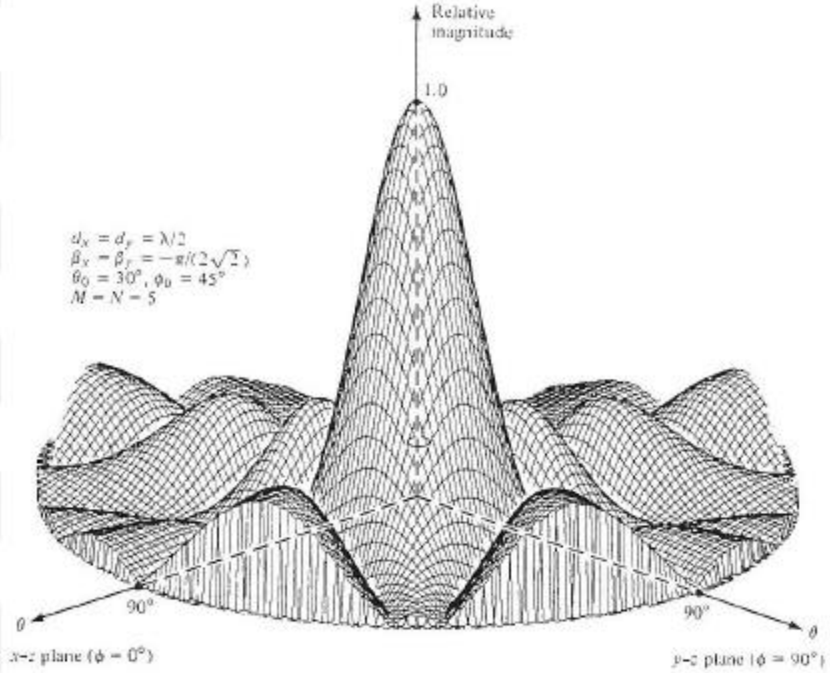
For uniform excitation,
i.e., $|I_{m1} I_{1n}| = I_0$,

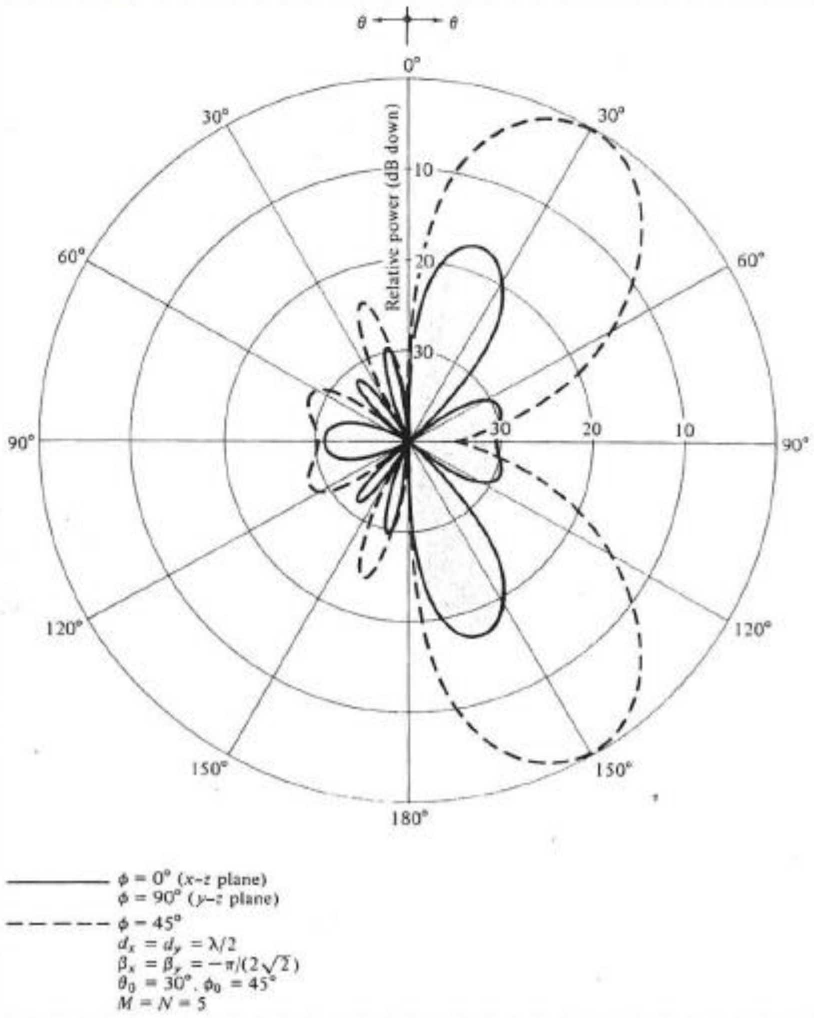
$$(\mathrm{AF})_n = \frac{\sin\left(\frac{M}{2}\psi_x\right)}{M \sin\frac{\psi_x}{2}} \frac{\sin\left(\frac{N}{2}\psi_y\right)}{N \sin\frac{\psi_y}{2}};$$

$$\psi_x = kd_x \sin\theta\cos\phi + \beta_x;$$

$$\psi_y = kd_y \sin\theta\sin\phi + \beta_y$$

Planar Array Example





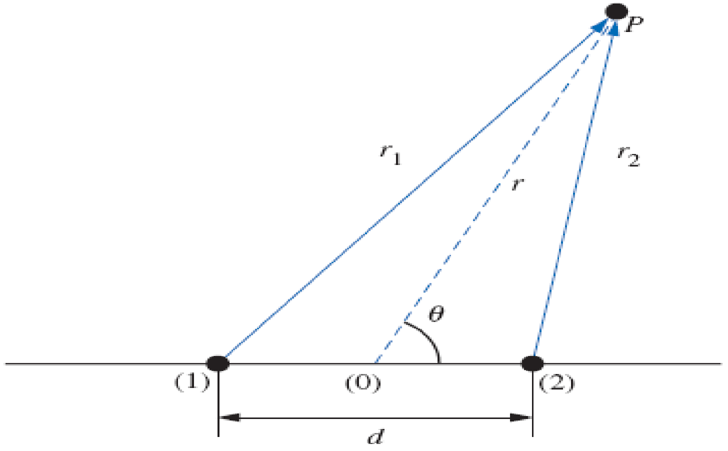
$$d_x = d_y = \lambda/2; \beta_x = \beta_y = -\pi/(2\sqrt{2});$$
$$\theta_0 = \pi/6, \phi_0 = \pi/4; M = N = 5$$

Antenna arrays

It is not always possible to design a single antenna with the radiation pattern needed. However, a proper combination of various types of antennas might yield the required pattern.

An antenna array is a cluster of antennas arranged in a specific physical configuration (line, grid, etc.). Each individual antenna is called an element of the array. We initially assume that all array elements (individual antennas) are identical. However, the excitation (both amplitude and phase) applied to each individual element may differ. The far field radiation from the array in a linear medium can be computed by the superposition of the EM fields generated by the array elements.

We start our discussion from considering a linear array (elements are located in a straight line) consisting of two elements excited by the signals with the same amplitude but with phases shifted by δ.



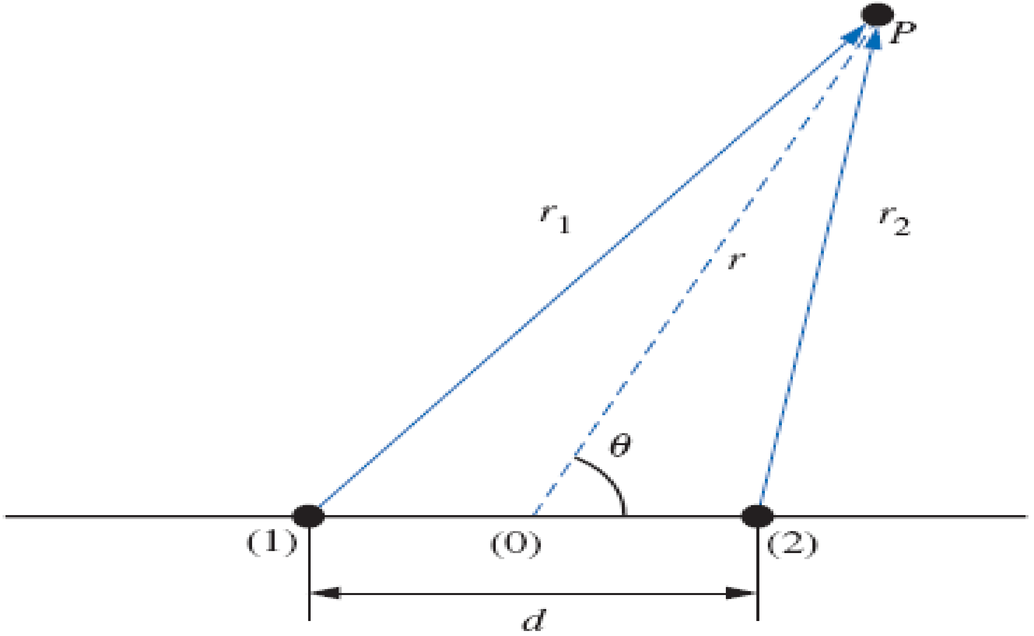
Antenna arrays

The individual elements are characterized by their element patterns $F_1(\theta,\phi)$.

At an arbitrary point P, taking into account the phase difference due to physical separation and difference in excitation, the total far zone electric field is:

$$\underbrace{E(r) = E_1(r)e^{j\psi/2}}_{\text{Field due to antenna 1}} + \underbrace{E_2(r)e^{-j\psi/2}}_{\text{Field due to antenna 2}} \tag{10.39.1}$$

Here: $$\psi = kd\cos\theta + \delta \tag{10.39.2}$$



The phase center is assumed at the array center. Since the elements are identical

$$E(r) = 2E_1(r)\frac{e^{j\psi/2}+e^{-j\psi/2}}{2} = 2E_1(r)\cos\frac{\psi}{2} \tag{10.39.3}$$

Relocating the phase center point only changes the phase of the result but not its amplitude.

Antenna arrays

The radiation pattern can be written as a product of the radiation pattern of an individual element and the radiation pattern of the array (array pattern):

$$F(\theta,\phi) = F_1(\theta,\phi) \cdot F_a(\theta,\phi) \tag{10.40.1}$$

where the array factor is:

$$F_a(\theta,\phi) = \cos\left(\frac{kd\cos\theta + \delta}{2}\right) \tag{10.40.2}$$

Here δ is the phase difference between two antennas. We notice that the array factor depends on the array geometry and amplitude and phase of the excitation of individual antennas.

Antenna arrays: Example

Example 10.7: Find and plot the array factor for 3 two-element antenna arrays, that differ only by the separation difference between the elements, which are isotropic radiators. Antennas are separated by 5, 10, and 20 cm and each antenna is excited in phase. The signal’s frequency is 1.5 GHz.

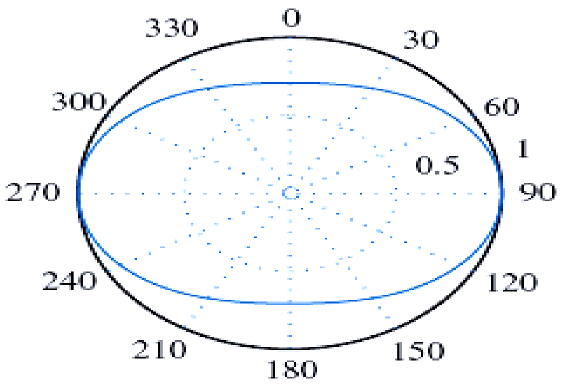
The separation between elements is normalized by the wavelength via

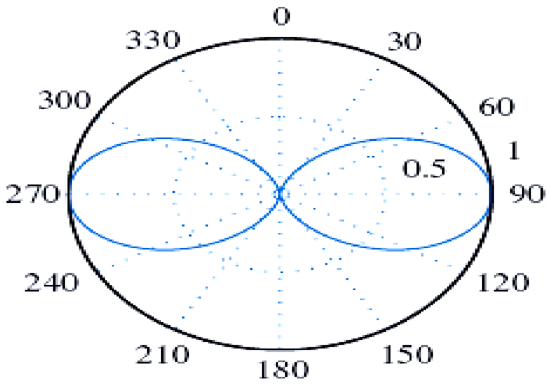
$$\xi = kd/2 = \pi d/\lambda$$

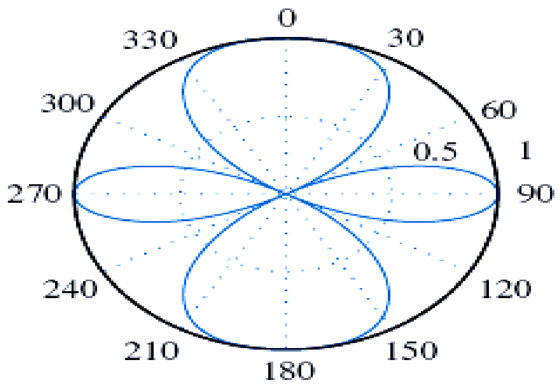
The free space wavelength:

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{1.5 \cdot 10^9} = 20\,cm$$

Normalized separations are λ/4, λ/2, and λ. Since phase difference is zero (δ = 0) and the element patterns are uniform (isotropic radiators), the total radiation pattern $F(\theta) = F_a(\theta)$.







Antenna arrays

Another method of modifying the radiation pattern of the array is to change electronically the phase parameter δ of the excitation. In this situation, it is possible to change direction of the main lobe in a wide range: the antenna is scanning through certain region of space. Such structure is called a phased-array antenna.

We consider next an antenna array with more identical elements.

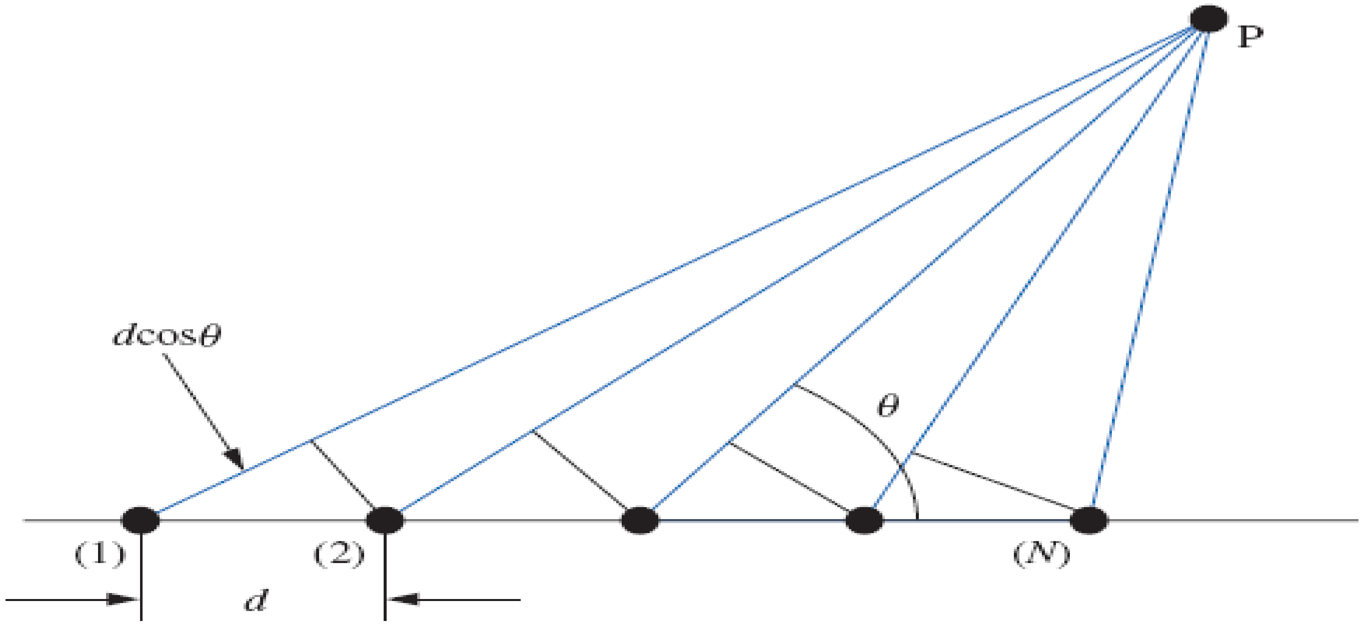
There is a linearly progressive phase shift in the excitation signal that feeds *N* elements.

The total field is:

$$E(r) = E_0(r)\left[1 + e^{j\psi} + \ldots + e^{j(N-1)\psi}\right] \tag{10.42.1}$$

Utilizing the following relation:

$$\sum_{n=0}^{N-1} q^n = \frac{1-q^N}{1-q} \tag{10.42.2}$$



Antenna arrays

the total radiated electric field is

$$E = E_0 \frac{1 - e^{jN\psi}}{1 - e^{j\psi}} \tag{10.43.1}$$

Considering the magnitude of the electric field only and using

$$\left|1 - e^{j\xi}\right| = \left|2\,je^{j\xi/2} \sin\frac{\xi}{2}\right| = 2\sin\frac{\xi}{2} \tag{10.43.2}$$

we arrive at

$$E(\theta) = E_0 \sin\left(\frac{N\psi}{2}\right) \Big/ \sin\left(\frac{\psi}{2}\right) \tag{10.43.3}$$

where

$$\psi = kd\cos\theta + \delta \tag{10.43.4}$$

δ is the progressive phase difference between the elements. When $\psi = 0$:

$$E(\theta) = E_{\max} = NE_0 \tag{10.43.5}$$

Antenna arrays

The normalized array factor:

$$F_a(\theta) = \frac{\sin\left(\frac{N\psi}{2}\right)}{N\sin\left(\frac{\psi}{2}\right)} \qquad (10.44.1)$$

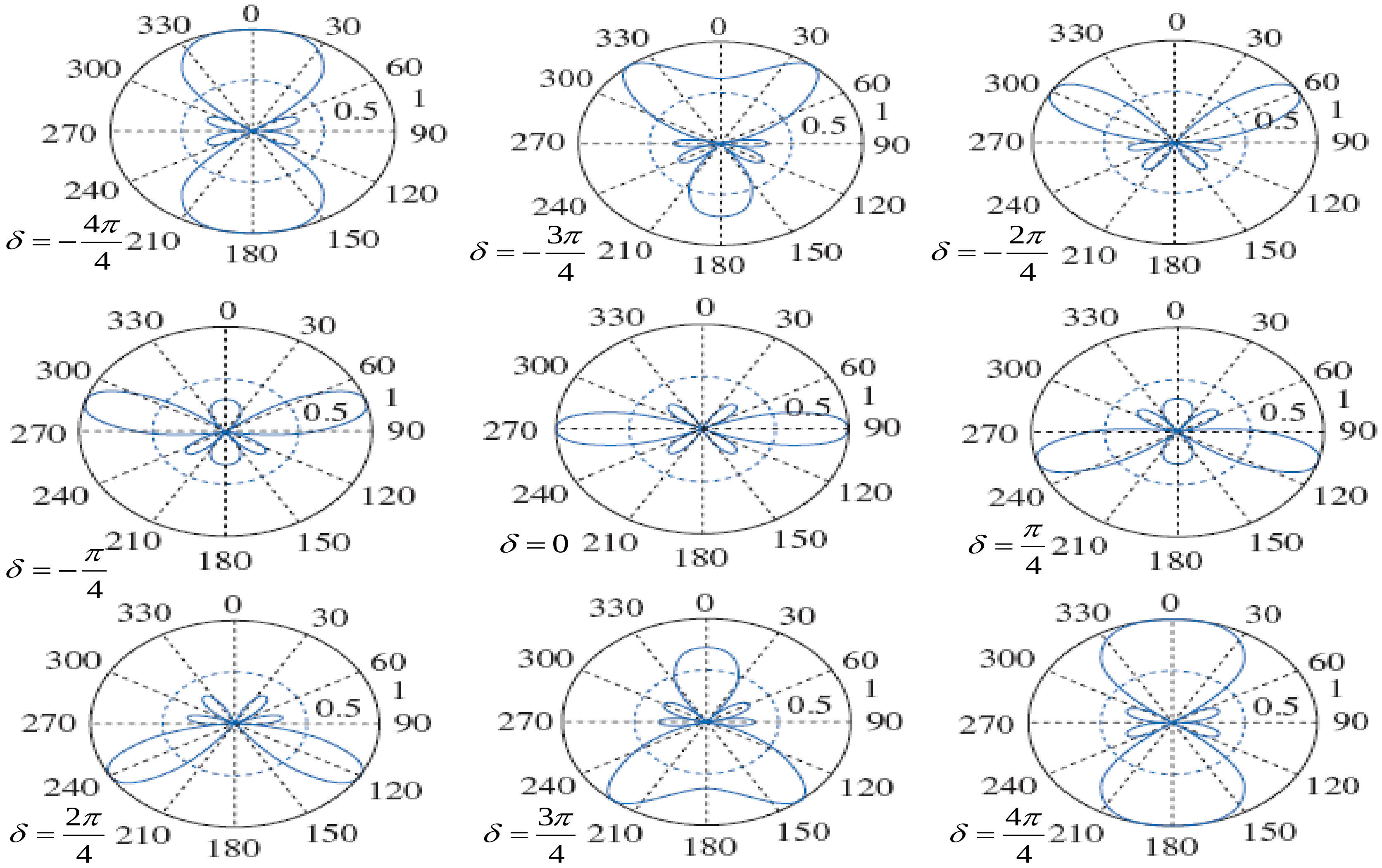
The angles where the first null occur in the numerator of (10.43.1) define the beamwidth of the main lobe. This happens when

$$\psi = \pm k2\pi/N, \qquad k \; is \; integer \qquad (10.44.2)$$

Similarly, zeros in the denominator will yield maxima in the pattern.

Antenna arrays

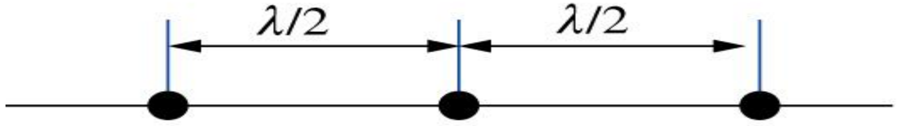
Field patterns of a four-element ($N = 4$) phased-array with the physical separation of the isotropic elements $d = \lambda/2$ and various phase shift.

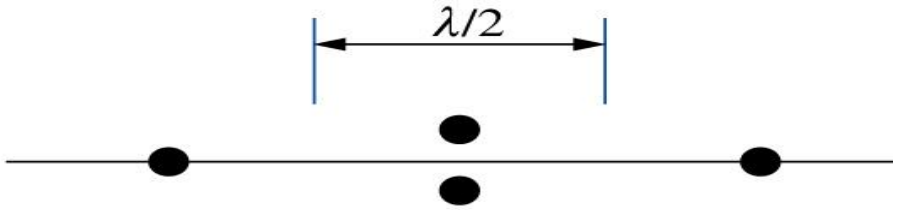


Antenna arrays

Another method to analyze behavior of a phase-array is by considering a non-uniform excitation of its elements.

Let us consider a three-element array shown. The elements are excited in phase ($\delta = 0$) but the excitation amplitude for the center element is twice the amplitude of the other elements. This system is called a binomial array.





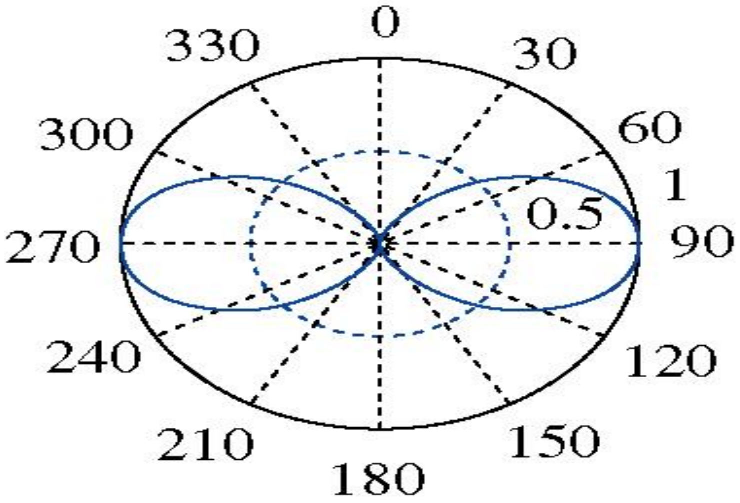
Because of this type of excitation, we can assume that this three-element array is equivalent to 2 two-element arrays (both with uniform excitation of their elements) displaced by λ/2 from each other. Each two-element array will have a radiation pattern:

$$\boxed{F_1(\theta) = \cos\left(\frac{\pi}{2}\cos\theta\right)} \qquad (10.46.1)$$

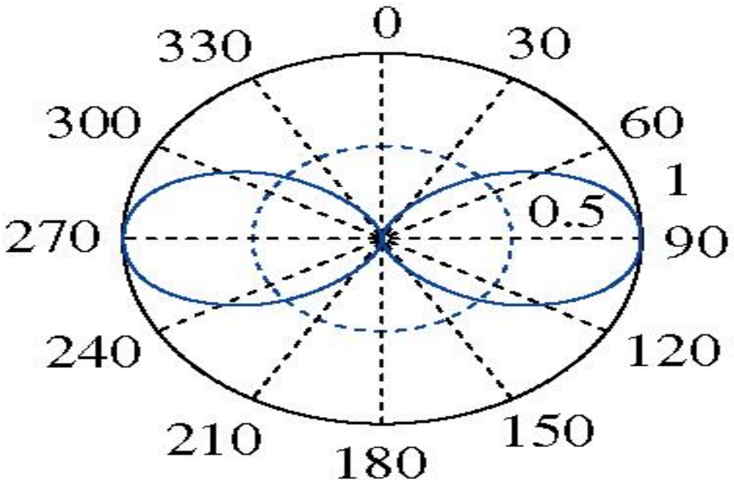
Antenna arrays

Next, we consider the initial three-element binomial array as an equivalent two-element array consisting of elements displaced by $\lambda/2$ with radiation patterns (10.46.1). The array factor for the new equivalent array is also represented by (10.46.1). Therefore, the magnitude of the radiated field in the far-zone for the considered structure is:

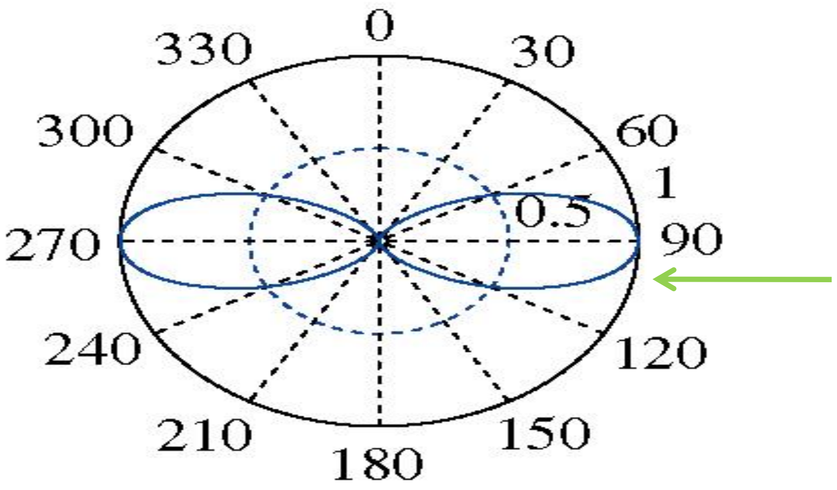
$$F(\theta) = F_1(\theta)F_A(\theta) = \cos^2\left(\frac{\pi}{2}\cos\theta\right) \tag{10.47.1}$$



Element pattern $F_1(\theta)$



Array factor $F_A(\theta)$

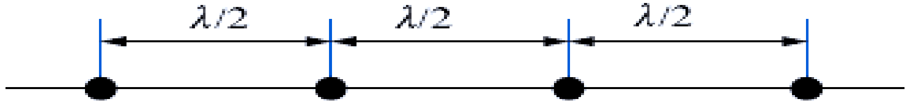


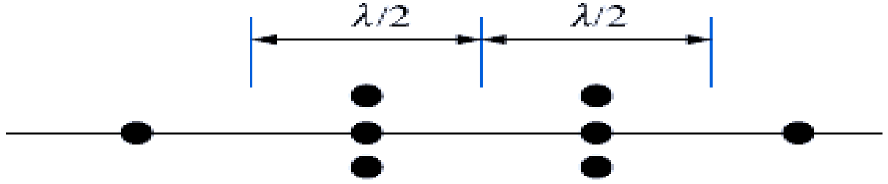
No sidelobes!!

Antenna pattern $F(\theta)$

Antenna arrays (Example)

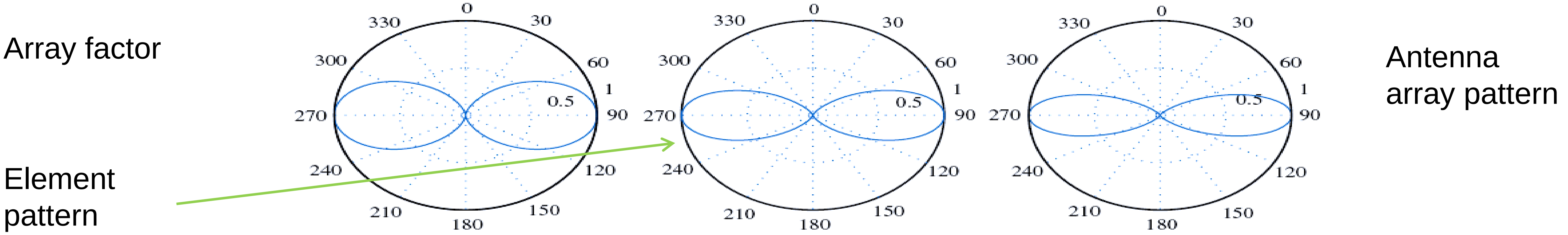
Example 10.8: Using the concept of multiplication of patterns (the one we just used), find the radiation pattern of the array of four elements shown below.





This array can be replaced with an array of two elements containing three sub-elements (with excitation 1:2:1). The initial array will have an excitation 1:3:3:1 and will have a radiation pattern, according to (10.40.1), as:

$$F(\theta) = \cos\left(\frac{\pi}{2}\cos\theta\right)\cos^2\left(\frac{\pi}{2}\cos\theta\right) = \cos^3\left(\frac{\pi}{2}\cos\theta\right)$$



Antenna arrays

Continuing the process of adding elements, it is possible to synthesize a radiation pattern with arbitrary high directivity and no sidelobes if the excitation amplitudes of array elements correspond to the coefficients of binomial series. This implies that the amplitude of the *k*th source in the *N*-element binomial array is calculated as

$$I_k = \frac{N!}{k!(N-k)!}, \qquad k = 0, 1, \ldots, N \tag{10.49.1}$$

It can be seen that this array will be symmetrically excited:

$$I_{N-k} = I_k \tag{10.49.2}$$

Therefore, the resulting radiation pattern of the binomial array of *N* elements separated by a half wavelength is

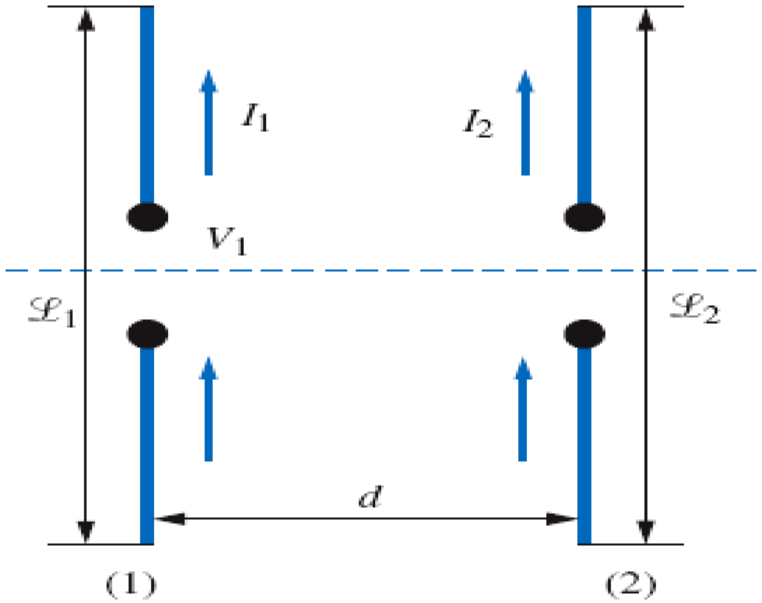
$$F(\theta) = \cos^{N-1}\left(\frac{\pi}{2}\cos\theta\right) \tag{10.49.3}$$

Antenna arrays

During the analysis considered so far, the effect of mutual coupling between the elements of the antenna array was ignored. In the reality, however, fields generated by one antenna element will affect currents and, therefore, radiation of other elements.

Let us consider an array of two dipoles with lengths L_1 and L_2. The first dipole is driven by a voltage V_1 while the second dipole is passive. We assume that the currents in both terminals are I_1 and I_2 and the following circuit relations hold:

$$\begin{aligned} Z_{11}I_1 + Z_{12}I_2 &= V_1 \\ Z_{21}I_1 + Z_{22}I_2 &= 0 \end{aligned} \qquad (10.50.1)$$



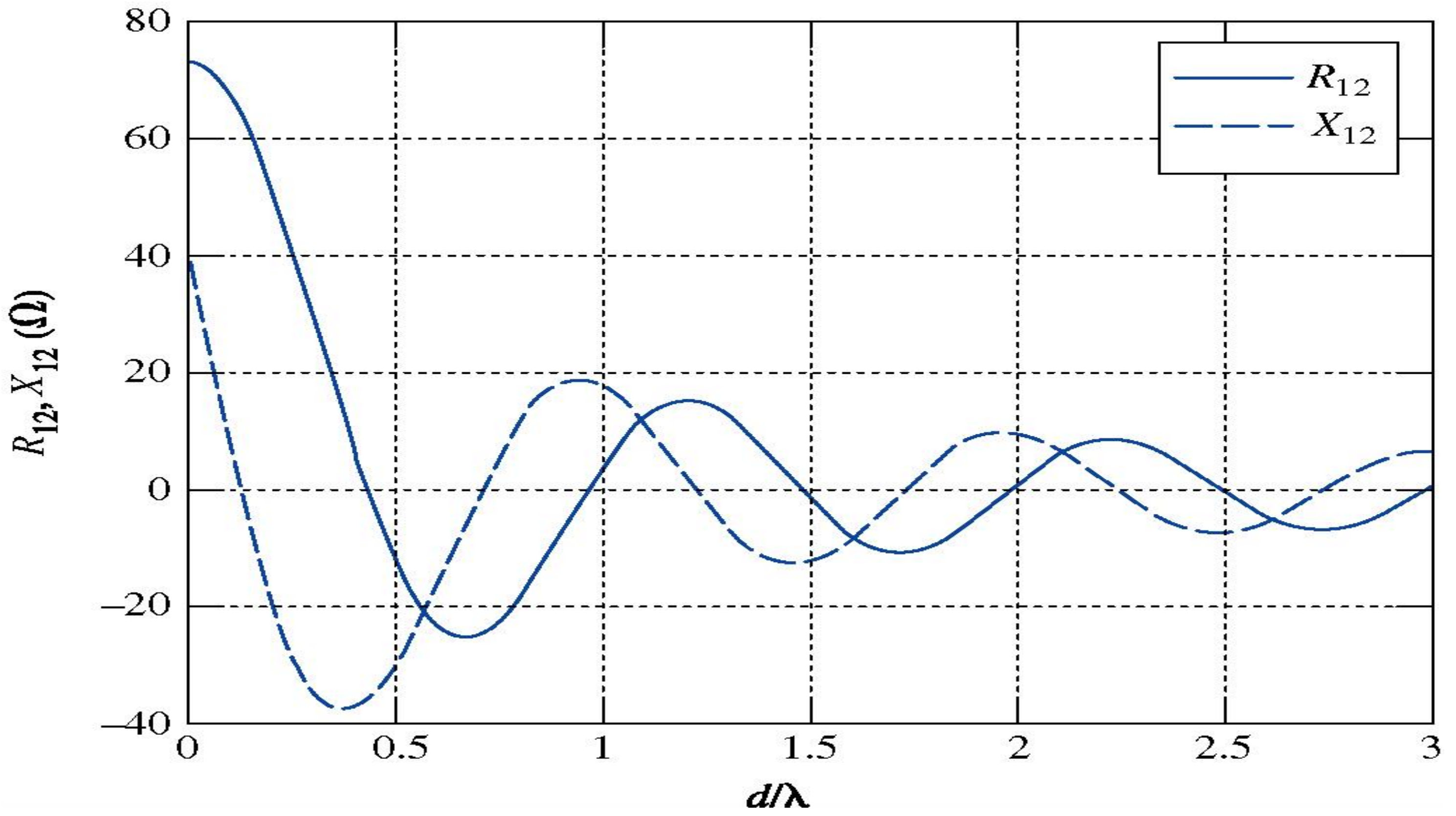
where Z_{11} and Z_{22} are the self-impedances of antennas (1) and (2) and $Z_{12} = Z_{21}$ are the mutual impedances between the elements. If we further assume that the dipoles are equal, the self-impedances will be equal too.

Antenna arrays

In the case of thin half-wavelength dipoles, the self-impedance is

$$Z_{11} = 73.1 + j\,42.5\ \Omega$$

The dependence of the mutual impedance between two identical thin half-wavelength dipoles is shown. When separation between antennas *d* → 0, mutual impedance approaches the self-impedance.



For the 2*M*+1 identical array elements separated by λ/2, the directivity is:

$$D = \left(\sum_{n=-M}^{M} I_n\right)^2 \Bigg/ \sum_{n=-M}^{M} I_n^2 \qquad (10.51.1)$$

Antenna arrays: Example

Example 10.9: Compare the directivities of two arrays consisting of three identical elements separated by a half wavelength for the:

a) Uniform array: $I_{-1} = I_0 = I_1 = 1\text{A}$;
b) Binomial array: $I_{-1} = I_1 = 1\text{A}$; $I_0 = 2\text{A}$.

We compute from (10.51.1):

Uniform array:

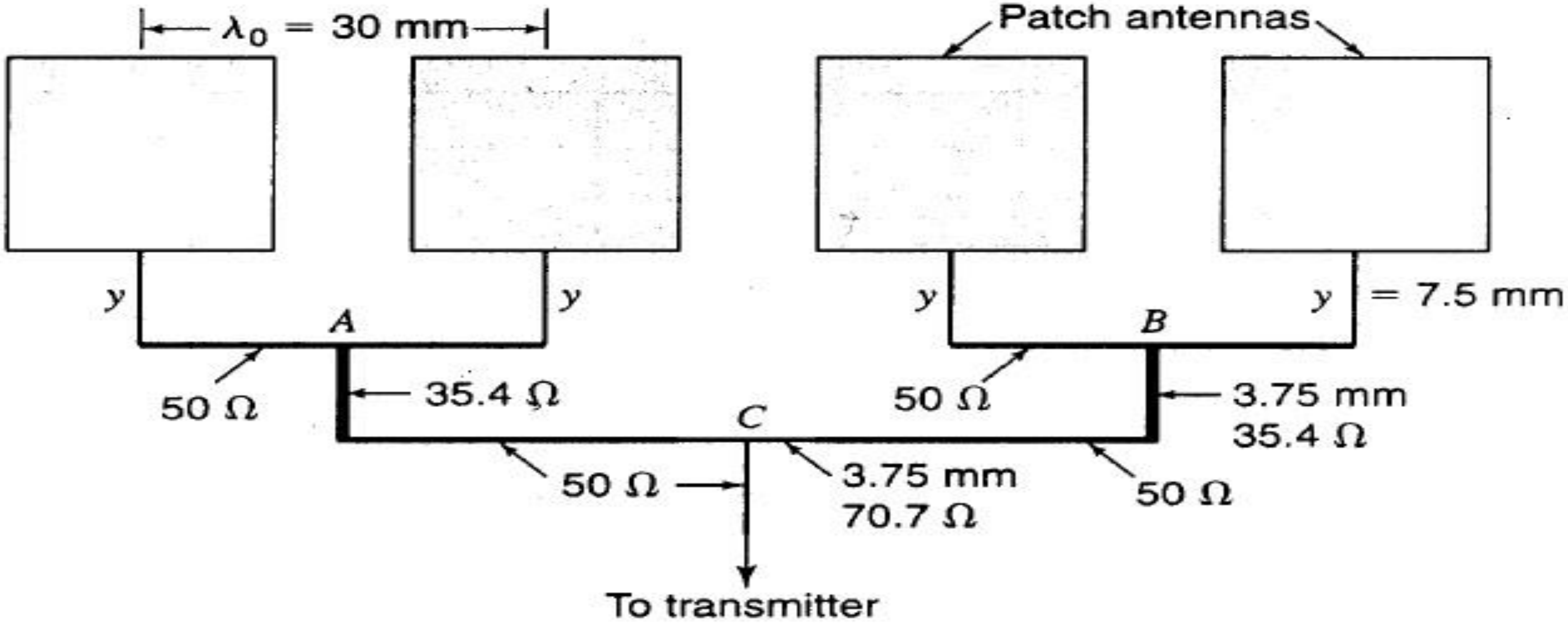
$$D = \frac{(1+1+1)^2}{1+1+1} = 3 \approx 4.77\ dB$$

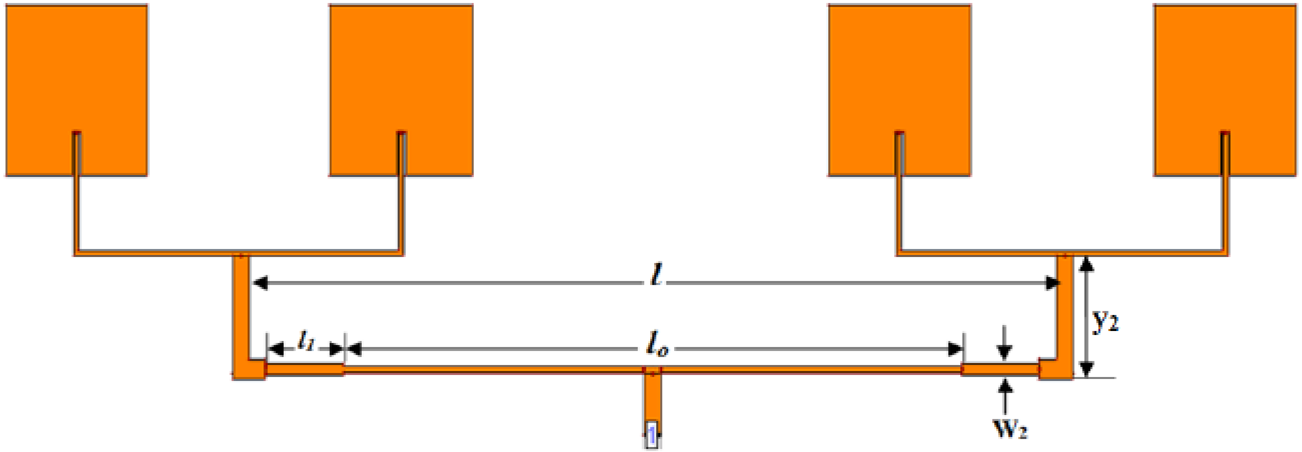
Binomial array:

$$D = \frac{(1+2+1)^2}{1+4+1} = \frac{16}{6} \approx 4.26\ dB$$

The directivity of a uniform array is higher than of a binomial array.

Array Antennas





l
l_1
l_o
y_2
W_2
1

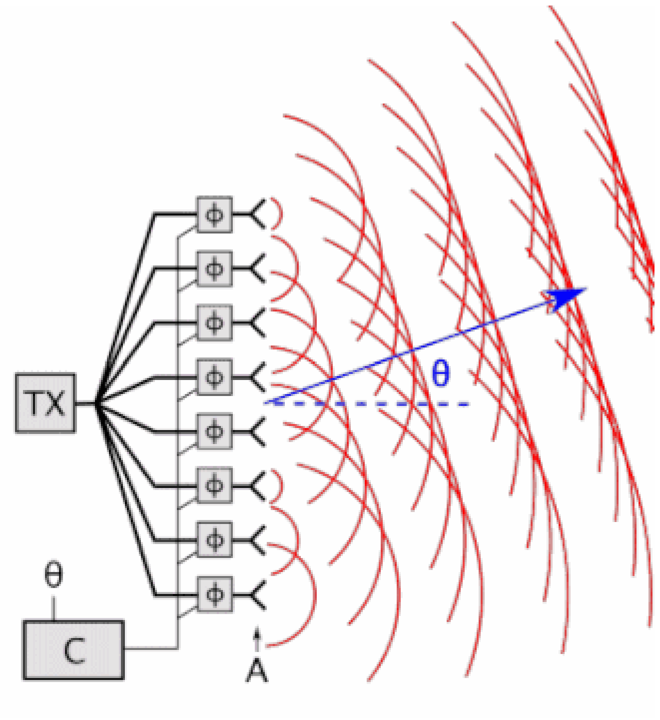
Types of Arrays

- Collinear array
- Broad side array
- End fire array
- Parasitic array
- Yagi-Uda array
- Log-peroidic array
- Turnstile array
- Super-turnstile array

Dizi anten sınıflandırılması

- Çoğu dizi anten, bileşen antenlerin ekseninin radyasyon yönüyle nasıl ilişkili olduğuna bağlı olarak iki sınıfa ayrılabilir.
- Bir geniş taraf dizisi, radyo dalgalarının radyasyon yönünün (ana lob) antenlerin düzlemine dik olduğu bir veya iki boyutlu dizidir. Dikey yaymak için antenler fazda beslenmelidir.
- Bir son ateş dizisi, radyasyon yönünün anten hattı boyunca olduğu doğrusal bir dizidir. Antenler, bitişik antenlerin ayrılmasına eşit bir faz farkı ile beslenmelidir.
- Ayrıca, radyasyon yönünün anten eksenine başka bir açıda olduğu bu kategorilerden birine ait olmayan diziler (aşamalı diziler gibi) vardır.

Phased array



- Faz dizi veya elektronik olarak taranan dizi (Phased array or electronically scanned array): Anteni fiziksel olarak hareket ettirmeden dizinin önündeki geniş bir açı üzerinde herhangi bir yöne ışıma yaptırmak üzere elektronik olarak yönlendirilebildiği düzlemsel bir dizi.
- Vericiden gelen akım, bir bilgisayar tarafından kontrol edilen bir faz kaydırıcı vasıtasıyla her bileşen anteni farklı besler.
- Besleme akımlarının nispi fazı değiştirilerek, ışıma anında farklı yönlere yönlendirilebilir. Askeri radarlarda yaygın olarak kullanılan bu teknik, sivil uygulamalara hızla yayılmaktadır.
- Pasif Elektronik Olarak Taranan Dizi (PESA-Passive Electronically Scanned Array) - Anten elemanlarının tek bir verici veya alıcıdan faz kaydırıcılar aracılığıyla beslendiği, yukarıda tarif edildiği gibi bir fazlı dizi.
- Aktif Elektronik Taranan Dizi (AESA-Active Electronically Scanned Array) - Her anten elemanının merkezi bir bilgisayar tarafından kontrol edilen kendi verici ve / veya alıcı modülüne sahip olduğu aşamalı bir dizi. Bu ikinci nesil aşamalı dizi teknolojisi, aynı anda birden fazla frekansta çoklu ışınlar yayabilir ve çoğunlukla sofistike askeri radarlarda kullanılır.

Planar Array

- Düzlemsel dizi - düz iki boyutlu bir anten dizisi. Çok yönlü anten dizisi, antenin her iki yanından 180 ° aralıklarla iki ışın yaydığı için, genellikle bir reflektörün önüne monte edilir veya tek yönlü bir ışın vermek için Yagi veya sarmal antenler gibi yönlendirici antenlerden oluşur.

Reflective array

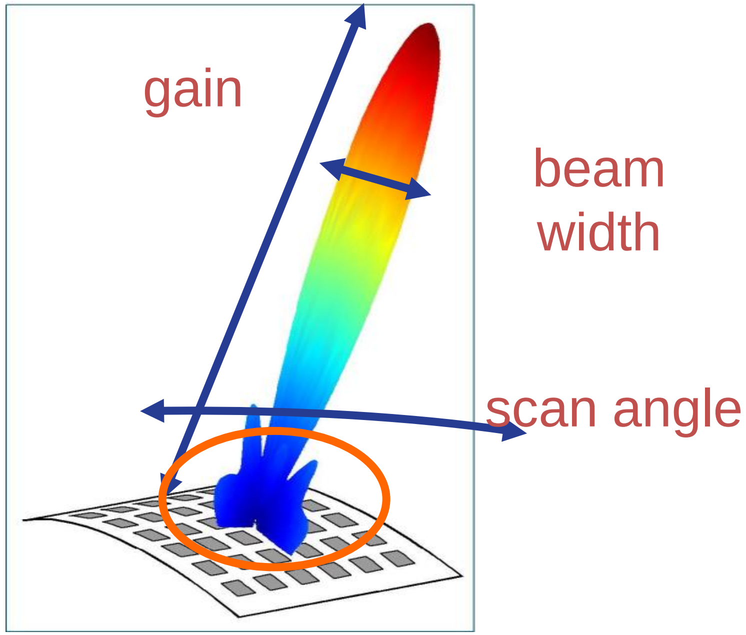
- Yansıtıcı dizi - metal bir plaka veya tel ekran gibi düz bir reflektörün önünde, genellikle fazda beslenen yarım dalga dipoller olan düzlemsel bir dizi anten. Bu, diziye dik (geniş taraf) tek bir elektromanyetik dalga demeti (hüzmesi)yayar. UHF televizyon antenleri ve radar antenleri olarak kullanılır.

BEAMFORMING

Beamforming

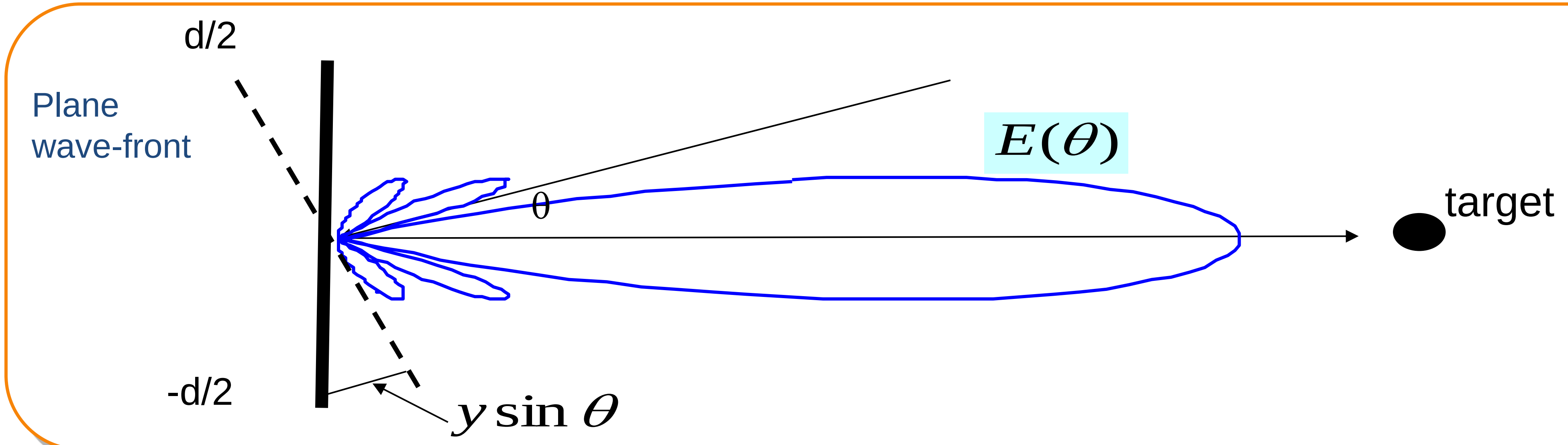
Smart Antenna systems: Switched beam: finite number of fixed predefined patterns
Adaptive array: Infinite number of (real time) adjustable patterns
Passive Beamforming - Adaptive Beamforming

- Adjusting signal amplitudes and phases to form a desired beam
- Estimation of signal arriving from a desired direction in the presence of noise by exploiting the spatial separation of the source of the signals.
- Applicable to radiation and reception of energy.
- May be classified as:
  - Data Independent
  - Statistically optimum
  - Adaptive
  - Partially Adaptive



Beampattern of Antennas

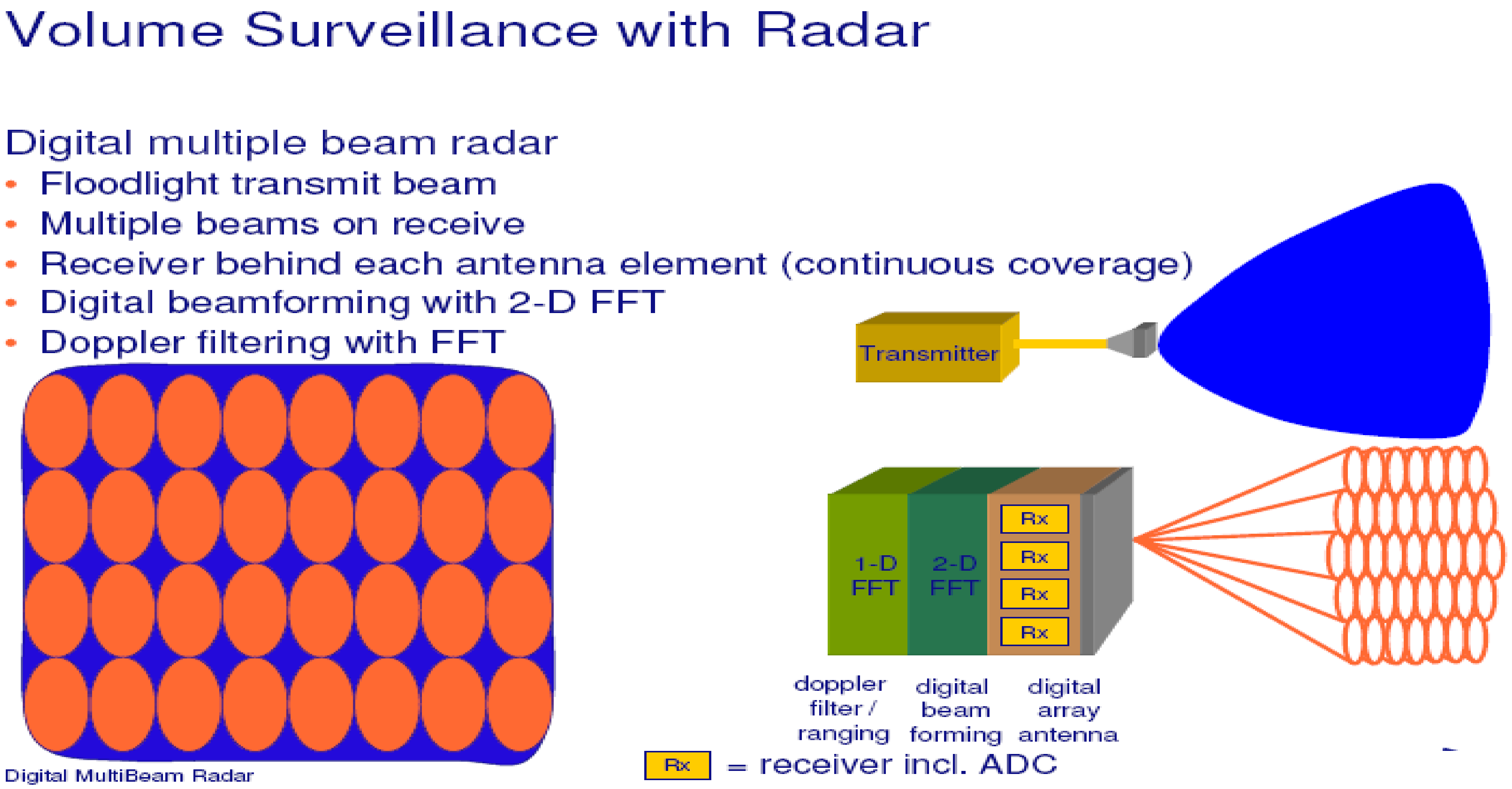
Beampattern is the **antenna gain** as a function of **angle of arrival**.



Fourier transform

$$E(\theta) \propto \int_{-d/2}^{d/2} A_0 e^{j\frac{2\pi y}{\lambda}\sin\theta} dy = \int_{-d/2}^{d/2} A_0 e^{j\omega} dy \Big|_{\omega=\frac{2\pi y}{\lambda}\sin\theta} = \mathrm{sinc}\left(\frac{d\sin\theta}{\lambda}\right)$$

Volume Surveillance with Radar



Volume Surveillance with Radar

Digital multiple beam radar

- Floodlight transmit beam
- Multiple beams on receive
- Receiver behind each antenna element (continuous coverage)
- Digital beamforming with 2-D FFT
- Doppler filtering with FFT

Digital MultiBeam Radar

Rx = receiver incl. ADC

Direction of Arrival Estimation(DOA)

- DOA involves computing the spatial spectrum and determining the maximas.
  - Maximas correspond to DOAs
- Typical DOA algorithms include:
  - Multiple SIgnal Classification(MUSIC)
  - Estimation of Signal Parameters via Rotational Invariance Techniques(ESPRIT)
  - Spectral Estimation
  - Minimum Variance Distortionless Response(MVDR)
  - Linear Prediction
  - Maximum Likelihood Method(MLM)
- MUSIC is explored in this presentation

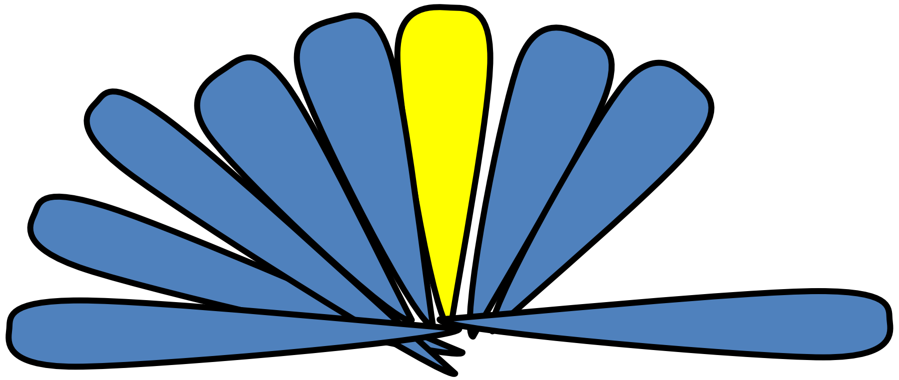
MUSIC Algorithm

- MUSIC algorithm is a high resolution **MU**ltiple **SI**gnal **C**lassification technique based on exploiting the eigenstructure of the input covariance matrix.

- Provides information about the number of incident signals, DOA – direction of arrival of each signal, strengths and cross correlations between incident signals, noise power, etc.

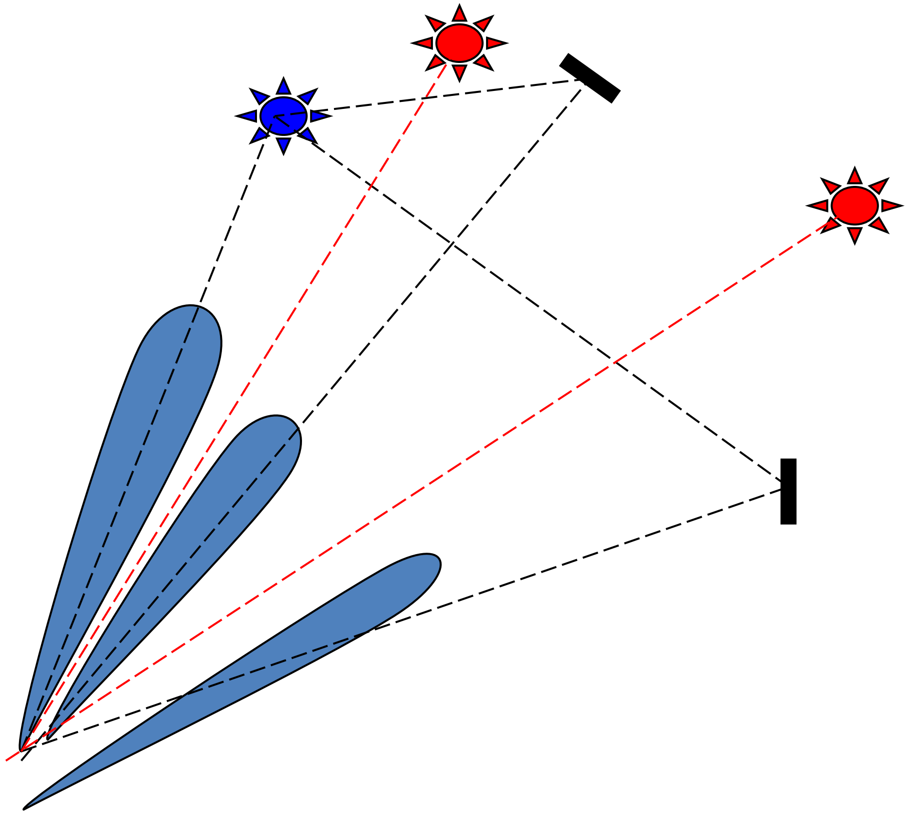
- Useful for estimating
  - Number of sources
  - Strength of cross-correlation between source signals
  - Directions of Arrival
  - Strength of noise
- Assumes number of sources < Number of antenna elements.
  - else signals may be poorly resolved
- Estimates noise subspace from available samples

Switched Beam Antennas



- *Switched beam antennas*
  - Based on switching function between separate directive antennas or predefined beams of an array
- *Space Division Multiple Access* (SDMA) = allocating an angle direction sector to each user
  - In a TDMA system, two users will be allocated to the same time slot and the same carrier frequency
  - They will be differentiated by different direction angles

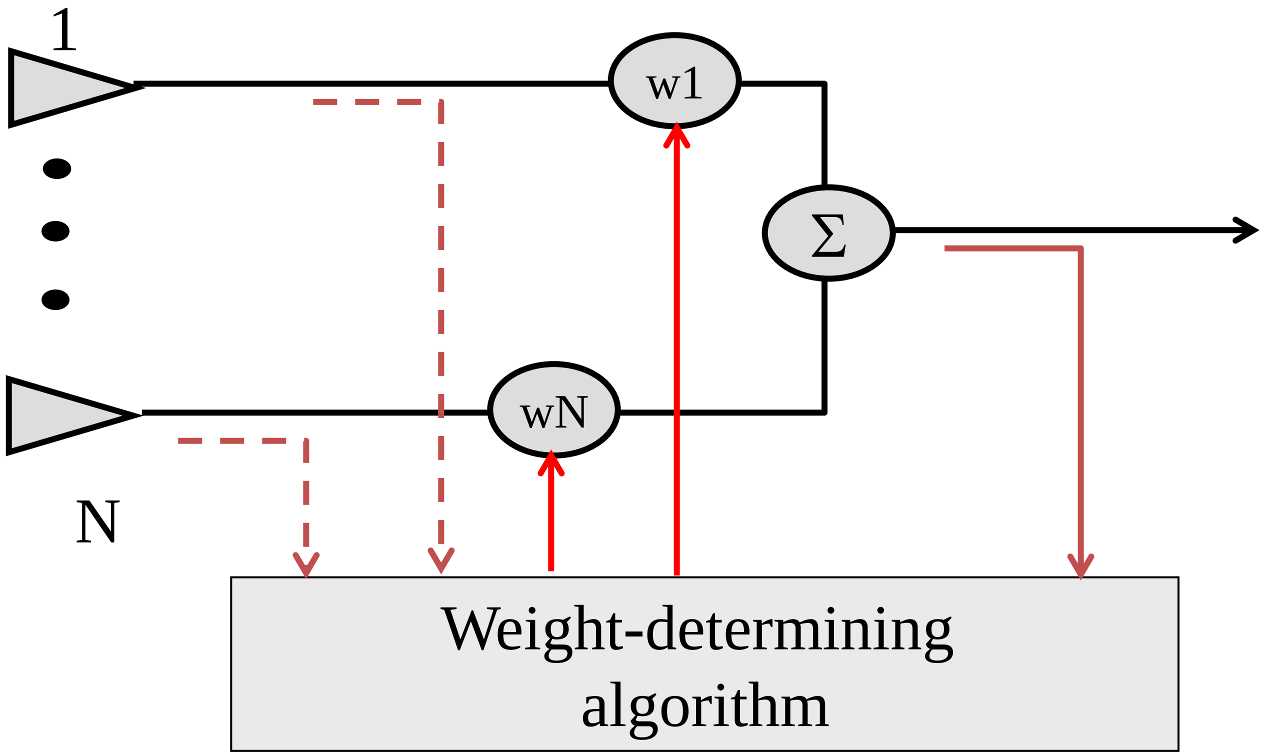
Adaptive (“Intelligent”)Antennas



- Array of N antennas in a linear, circular, or planar configuration
- Used for selection signals from desired sources and suppress incident signals from undesired sources
- The antenna pattern track the sources
- It is then adjusted to null out the interferers and to maximize the signal to interference ratio (SIR)
- Able to receive and combine constructively multipath signals

Adaptive (“Intelligent”)Antennas

- The amplitude/ phase excitation of each antenna controlled electronically (“software-defined”)
- The weight-determining algorithm uses a-priori and/ or measured information to adapt antenna to changing environment
- The weight and summing circuits can operate at the RF and/ or at an intermediate frequency



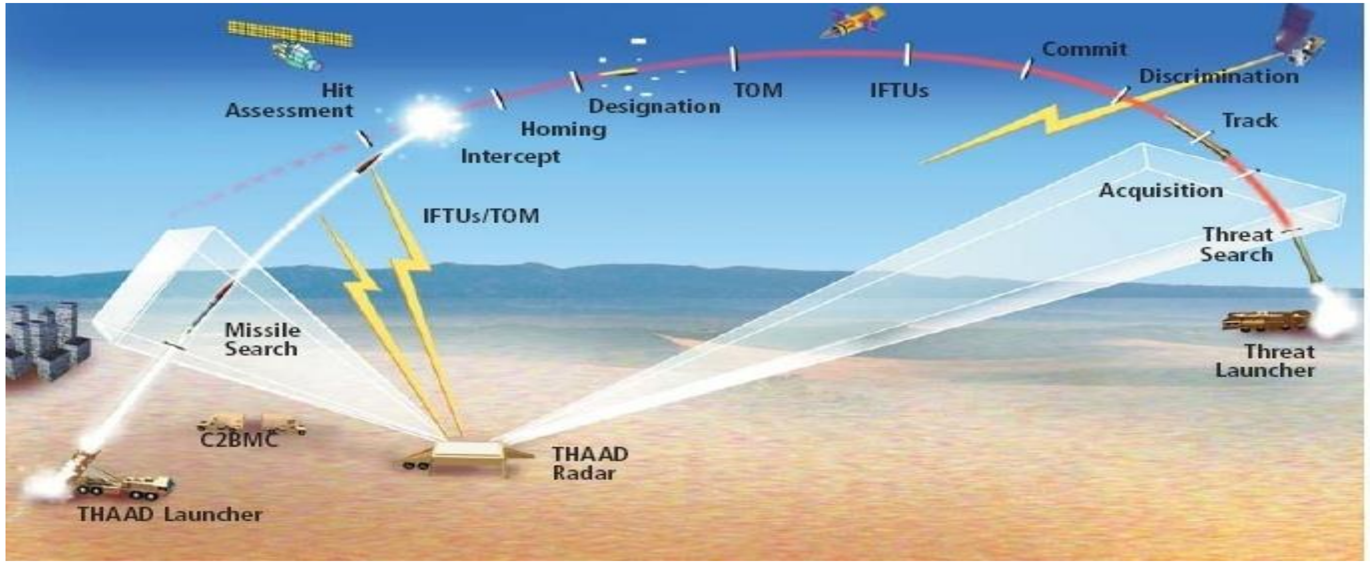
Erken Uyarı Radarı

Erken uyarı radarı yer yüzeyinin üstündeki tüm uzayı belirli bir ışıma açıklığında gözlem yapar. Füze erken uyarısında bulunduğunda füze savunma sistemi devreye girer.

Füze algılama, doğrulama ve tehdit olup olmadığı sınıflandırır.

Erken uyarı radarı balistik füze savunma sisteminin bir parçası olarak görev yapar.

Patriot ve denizden fırlatmalı füze savunma sistemleri ile yüksek mertebelerde tehdit olarak algılanan ve doğrulanan füzelere müdahale eder.

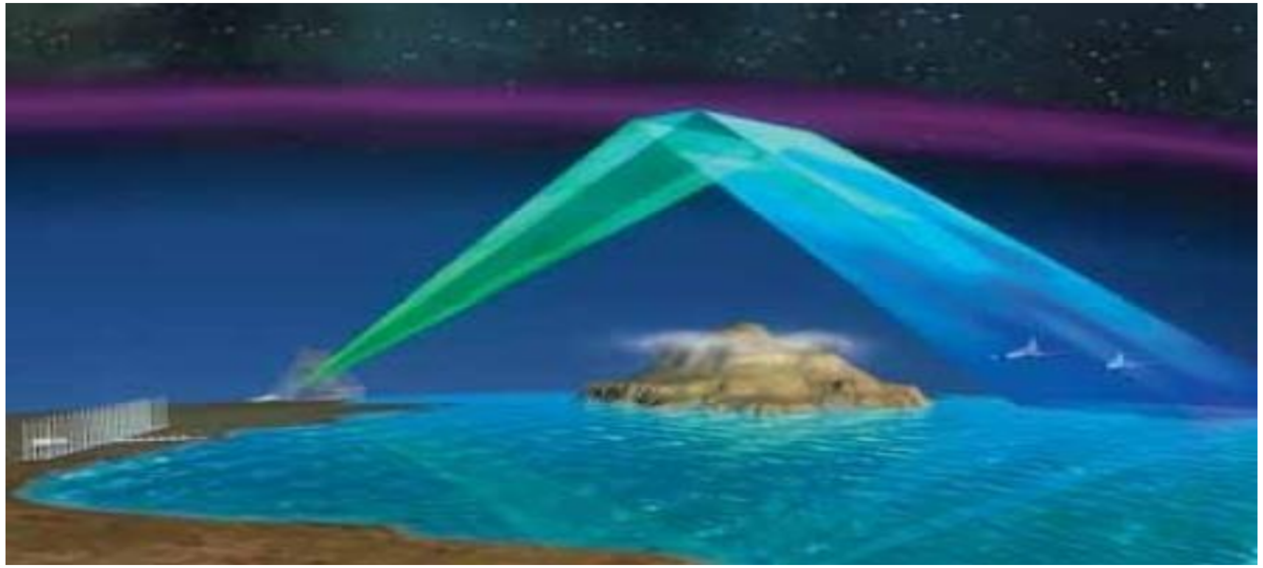


İyonosferden Takip

- İyonosferden yansıyan dalgalar kullanılarak 2.000 km gibi geniş kıyı şeridinde gemileri ve uçakların konumlarını, rotalarını ve hızlarını belirleyecek.

- Tüm hava koşullarında ve tüm yüksekliklerdeki uçaklar izlenecektir.

- Uzunlukları 30m den büyük olan gemiler muntazaman izlenecektir.



Terminology

Antenna – structure or device used to collect or radiate electromagnetic waves

Array – assembly of antenna elements with dimensions, spacing, and illumination sequency such that the fields of the individual elements combine to produce a maximum intensity in a particular direction and minimum intensities in other directions

Beamwidth – the angle between the half-power (3-dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe

Directivity – the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions

Effective area – the functional equivalent area from which an antenna directed toward the source of the received signal gathers or absorbs the energy of an incident electromagnetic wave

Efficiency – ratio of the total radiated power to the total input power

Far field – region where wavefront is considered planar

Gain – ratio of the power at the input of a loss-free isotropic antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength at the same distance

Isotropic – radiates equally in all directions

Main lobe – the lobe containing the maximum power

Null – a zone in which the effective radiated power is at a minimum relative to the maximum effective radiation power of the main lobe

Radiation pattern – variation of the field intensity of an antenna as an angular function with respect to the axis

Radiation resistance – resistance that, if inserted in place of the antenna, would consume that same amount of power that is radiated by the antenna

Side lobe – a lobe in any direction other than the main lobe

Kaynaklar

- https://www.ece.ucsb.edu/~long/ece145a/ampdesign.pdf
- Amplifiers, Prof. Tzong-Lin Wu. EMC Laboratory. Department of Electrical Engineering. National Taiwan University

Usage Notes

- These slides were gathered from the presentations published on the internet. I would like to thank who prepared slides and documents.
- Also, these slides are made publicly available on the web for anyone to use
- If you choose to use them, I ask that you alert me of any mistakes which were made and allow me the option of incorporating such changes (with an acknowledgment) in my set of slides.

Sincerely,

Dr. Cahit Karakuş

cahitkarakus@gmail.com