

# Lecture-4

## 6.3.2 Broadside and End-fire Arrays

The phasing of uniform linear array elements may be chosen such that the main lobe of the array pattern lies along the array axis (end-fire array) or normal to the array axis (broad side array).

### Broadside Arrays:

An array is referred to as a broadside array when it has its maximum radiation in the direction perpendicular to that of axis of the array i.e.  $\theta = 90^\circ$ . For optimum performance, both the element factor and the AF, should have their maxima at  $\theta = 90^\circ$ .

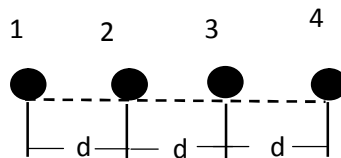
The maximum of the array factor occurs when the array phase function is zero i.e.

$$\begin{aligned} \mathcal{E} = s + kd \cos \theta \Big|_{\theta=90^\circ} &= 0 \\ \Rightarrow s &= 0 \end{aligned} \tag{6.22}$$

For a broadside array, in order for the above equation to be satisfied with  $\theta = 90^\circ$ , the phase angle  $s$  must be zero i.e. all elements of the array must be driven with the same phase.

### Example-5

Find the pattern of a broadside array of 4 isotropic point sources of the same amplitude and phase. Spacing between the sources is  $\lambda/2$ .



$$\mathcal{E} = (kd \cos \theta + s)$$

For broadside array and  $s = 0^\circ$ , the given spacing between the source is  $\lambda/2$ .

$$\text{Then } \mathcal{E} = \left( \frac{2\pi}{\lambda} d \cos \theta \right) = \pi \cos \theta$$

$$(AF)_n = \frac{1}{N} \left[ \frac{\sin\left(\frac{N}{2}\mathcal{E}\right)}{\sin\left(\frac{\mathcal{E}}{2}\right)} \right]$$

		AF
0		0
$\lambda/3$	$\lambda/2$	0
$\lambda/2$	0	1

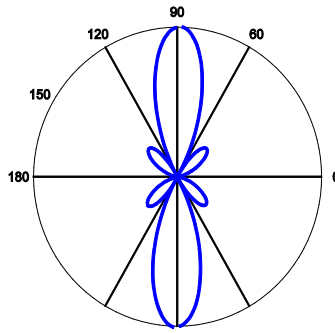


Fig 6.10 Polar plot a broadside array of 4 isotropic point sources

**Note:**

To ensure that there are no maximas in other directions (grating lobes), the separation between the elements should not be equal to multiples of a wavelength:

$$d < n \lambda, n = 1, 2, 3, \dots$$

Otherwise additional maxima will appear.

Assume that  $d = n \lambda$ , then

$$E = E_0 \sum_{n=0}^{N-1} e^{jkd \cos \theta_n} \Big|_{d=n\lambda, s=0} = 2nf \cos \theta_n \quad (6.23)$$

If equation (6.23) is true, then the maximum condition of  $AF \cos \theta_m = 2f \cdot m$  is satisfied not only for  $\theta = f / 2$ , but also for

$$\theta_g = \cos^{-1} \left( \frac{m}{n} \right), m = \pm 1, \pm 2, \dots \quad (6.24)$$

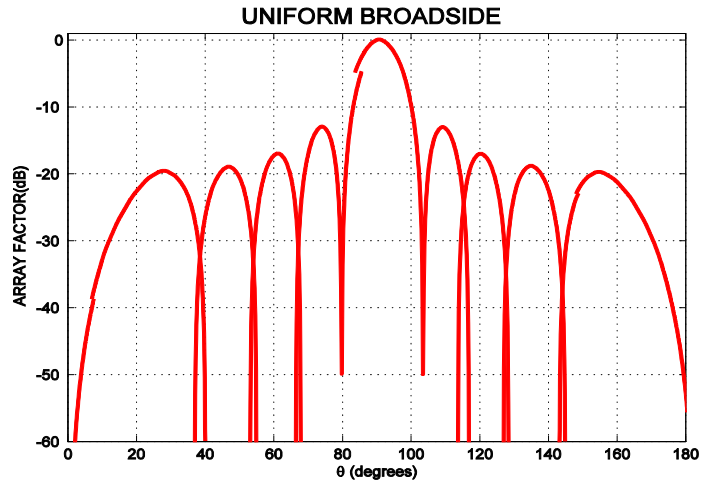
e.g.  $d = \lambda$  ( $n = 1$ ), then equation (6.24) gives two additional major lobes at

$$\theta_g = \cos^{-1}(\pm 1) \Rightarrow \theta_g = 0^\circ \text{ or } 180^\circ$$

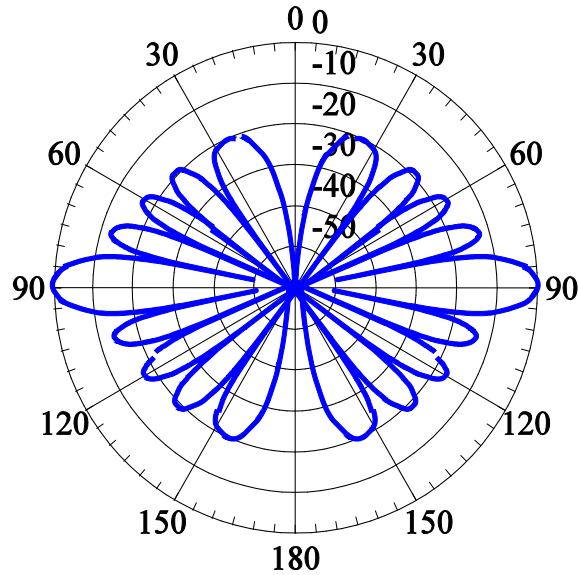
If  $d = 2\lambda$  ( $n = 2$ ), equation (6.24) gives four additional major lobes at

$$\theta_g = \cos^{-1} \left( \pm \frac{1}{2}, \pm 1 \right) \Rightarrow \theta_g = 0^\circ, 60^\circ, 120^\circ \text{ or } 180^\circ$$

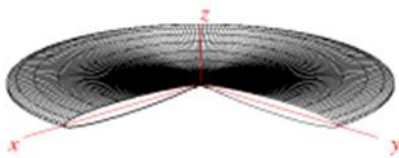
A 10-element uniform broadside array was considered to verify the above discussion. It was observed that, when  $d = \lambda$ , multiple major lobes are present in the radiation pattern.



(a) Linear Scale

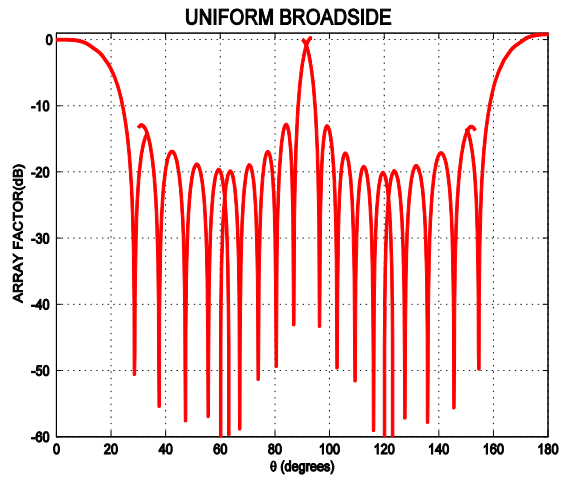


(b) 2D-Pattern

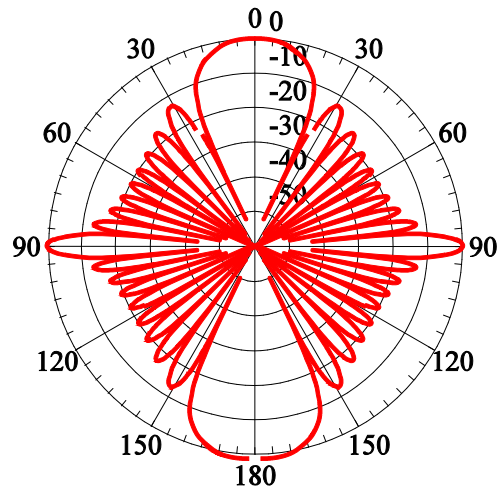


(c) 3D Pattern

Fig.6.11: Array factor pattern of a 10 element uniform amplitude broadside array ( $d = \lambda/2$ )



(a) Linear Scale



(b) 2D-Pattern



(c) 3D Pattern

Fig. 6.12: Array factor pattern of a 10-element uniform amplitude broadside array ( $d = \lambda/2$ ) with multiple major lobes.

**End-fire Arrays:**

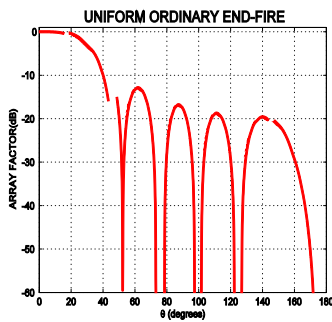
End-fire arrays may be designed to focus the main beam of the array factor along the axis of the array. It may be required that the array radiates only in one direction – either  $\theta = 0^\circ$  or  $\theta = 180^\circ$ . The maximum of the array factor occurs when the array phase function is zero i.e.

$$\Psi = \beta + kd \cos \theta \Big|_{\theta = 0^\circ \text{ or } \theta = 180^\circ} = 0$$

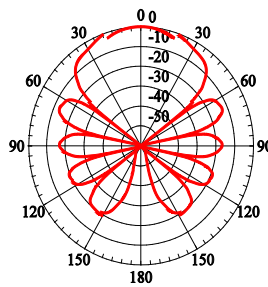
$$\beta = -kd \text{ for } \theta = 0^\circ \tag{6.25}$$

$$\beta = kd \text{ for } \theta = 180^\circ \tag{6.26}$$

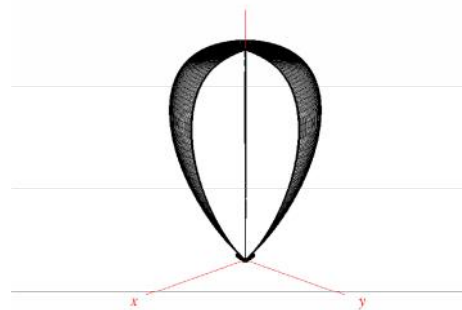
If the element separation is multiple of a wavelength,  $d = n\lambda$ , then in addition to the end-fire maxima there also exist maxima in the broadside directions. As with the broadside array, in order to avoid grating lobes, the maximum spacing between the element should be less than  $\lambda/2$ , i.e.  $d_{max} < \lambda/2$ .



(a) Linear Scale

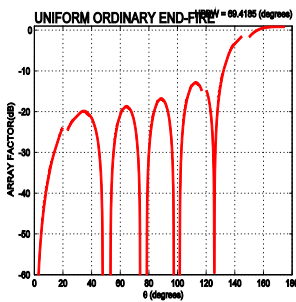


(b) 2D-Pattern

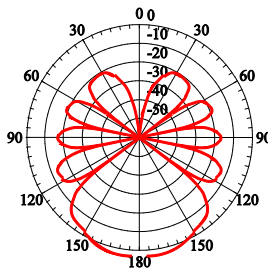


(c) 3D Pattern

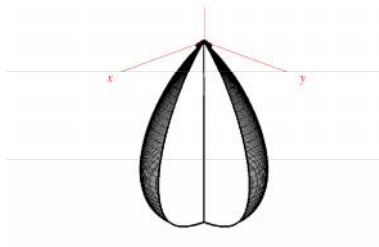
Fig6.13. Array factor pattern of a 10 element uniform amplitude ordinary end-fire array ( $d = \lambda/4$ ,  $\theta = 0^\circ$ )



(a) Linear Scale



(b) 2D-Pattern



(c) 3D Pattern

Fig6.14. Array factor pattern of a 10 element uniform amplitude ordinary end-fire array ( $d = \lambda/4$ ,  $\beta = 180^\circ$ )

### 6.3.3 Phased (Scanning) Array:

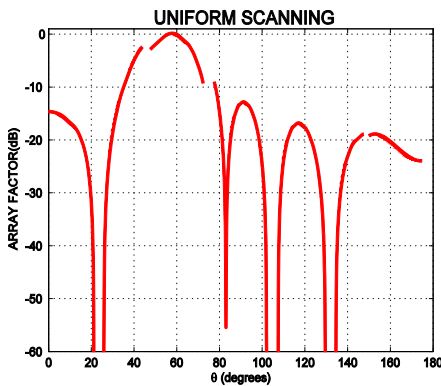
In some applications the goal is to direct the main lobe of the radiation pattern at an angle other than the broadside or end-fire direction. The scan angle of the pattern dictates this steered angular location. The scan pattern can be obtained by introducing a phase difference to elements of the antenna array. This is the basic principle of electronic scanning for phased arrays. When the scanning is required to be continuous, the feeding system must be capable of continuously varying the progressive phase  $\beta$  between the elements. This is accomplished by ferrite or diode shifters (varactors).

Let us assume that the maximum radiation of the array is required to be oriented at angle  $\theta_0$ . To accomplish this, the progressive phase excitation  $S$  between the elements must be adjusted so that

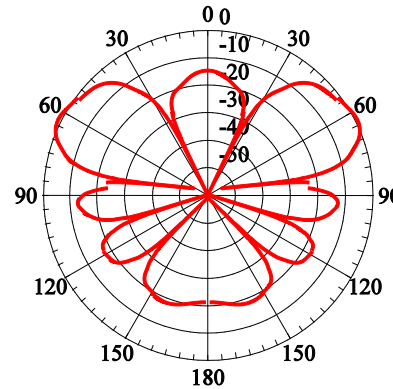
$$\beta = S + kd \cos \theta_0 = 0$$

$$S = -kd \cos \theta_0 \tag{6.27}$$

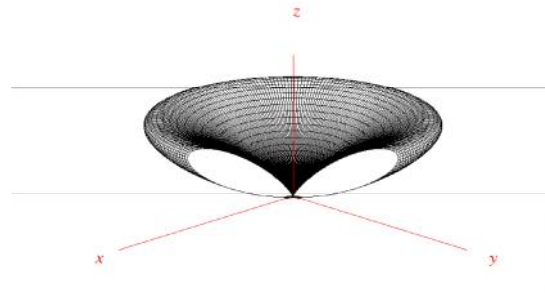
Thus by controlling the progressive phase difference between the elements, the maximum radiation can be squinted in any desired direction to form a scanning array. This is the basic principle of scanning array operation.



(a) Linear Scale



(b) 2D-Pattern



(c) 3D Pattern

Fig6.15. Uniform Scanning array for 10-element array with main beam directed at  $60^\circ$  and  $d = \lambda/4$ .