

# Radiation Pattern Determination of a Broad Side Array

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**Abstract**— Antenna arrays are becoming increasingly important in wireless communications. Advantages of using antenna arrays are providing the capability of beam steering (radiation direction change) as in smart antennas, providing a high gain (array gain) by using simple antenna elements, providing a diversity gain in multipath signal reception and they enable array signal processing, which can be done by array antennas. These are mainly classified in to two type's Broad side and End fire. In many applications we have the maximum radiation of an array directed normal to the axis of the array, which is known as Broad side Array. In this paper we will discuss the radiation analysis of Broad side array.

**Keywords**- Array, Broad Side, End Fire, Pattern Multiplication, Array Factor (AF)

## I. INTRODUCTION

The maximum radiation of a short dipole is along the direction perpendicular to the axis of the dipole, but when polar angle decreases the radiation also decreases. This type of radiation characteristics may be used for broadcast services. In point to point communication the most of the energy is desired to be radiated in one particular direction which means that to have greater directivity in a desired direction [3]. This can be accomplished by making group of antennas excited simultaneously which is not possible by a single dipole antenna. Such a group of antennas is called an antenna array. Generally antenna array is the radiating system in which several identical or non-identical and/or either similarly oriented or differently oriented antennas are placed properly so as to get field strength at a far distance from the radiating system by combining radiations at point from all the antennas in the system [2].

It is difficult for a single antenna like motor connected parabolic dish to scan a radiation pattern or beam because the entire antenna system has to rotate to change the direction of the beam which leads to a considerable amount of aerodynamic drag when the antenna is airborne. Even when the

antenna is on the ground plane and directs its beam in a direction to catch the target, the target will be in different direction due to its velocity being high and it will always be out of sight. It is possible to scan the beam from the array antenna electronically and it can be with either phase control or frequency control [1]. Array antennas are extremely useful in both airborne as well as ground based applications. Since there is no movement of the antenna there will be no aerodynamic drag with antenna array. Moreover, arrays provide a greater number of parameters and offer better flexibility for the designer [2]. Using antenna array gain and directivity can be increased and beam width can be reduced [3]. Broad side array, end fire array, collinear array and parasitic array are some of the practically used forms of antenna array. Circular Array is one of the most widely used antenna array designs. Its applications include radio direction finding, air and space navigation, underground propagation, radar, sonar, and many other applications [1]. A broadside uniform circular array radiates (receives) not only in the broadside direction, but, in the other directions as well. Such an array has a significant power loss due to along resting plane scanning property. The power radiation or reception pattern of a circular array is dependent on the linear distance between two consecutive elements, the radius, and the number of elements. Broadside arrays are used for a wide range of radio waves. At decameter (short) wavelengths, they are used chiefly for radio broadcasting over long distances [4]. It has great potential for applications in wireless communications. BORO array is a new class of broadside antenna arrays with passive elements [5]. In this paper we discuss the design analysis of broad side array.

## II. BROAD SIDE ARRAY

Broad side array is a stacked collinear antenna consisting of half-wave dipoles spaced from one another by one half ( $\lambda/2$ ) wavelengths which

produces a highly directional radiation pattern that is broadside or normal to the plane of the array [6]. Its radiation pattern is bidirectional but pattern has a very narrow beam width and high gain. Broad side array may also be formed from other elements such as horns, slots, helixes and polyrods. The elements should be arranged in parallel and in the same phase when more than two elements are used in a broadside array. The direction of maximum radiation is always perpendicular to the line or the plane of the array according to the elements that lie on a line or a plane. A broadside array looks like a ladder. A uniform broadside array is a linear array. The elements of a uniform broadside array contribute EM fields of equal amplitude and phase [5]. A typical arrangement of a broadside array is as shown in the Fig. 1.

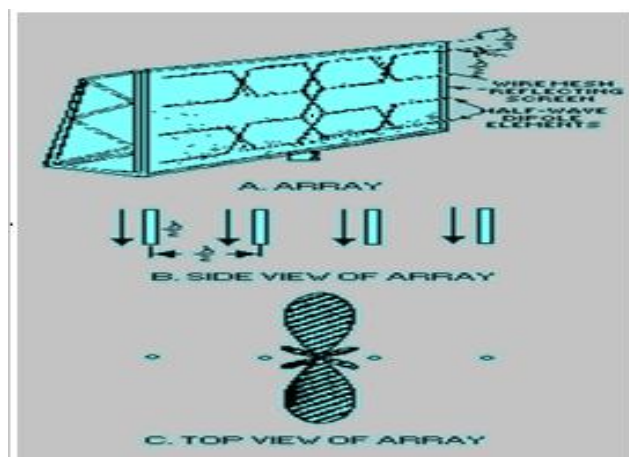


Fig. 1. A typical arrangement of a broadside array, illustrating wire mesh, reflecting screen and half wave dipole elements(a), side view of array(b) and top view of array showing radiation pattern(c).

The directional pattern of a broadside array (Figure 1(c)) in any plane perpendicular to the plane of the array consists of a main lobe and many side lobes with widths that depend on the linear dimensions of the array. In order to obtain unidirectional radiation from a broadside array, the array is supplemented with a tuned or a periodic reflector. In cases where it is necessary to simplify the feed system of a broadside array, a unidirectional traveling-wave antenna having a small gain is used as a radiator, a director antenna, helical antenna, or log-periodic antenna may be used in such cases, obviating the need for a reflector [4].

To understand the radiation characteristics of the broadside array more clearly the following example can be considered. Figure.2 shows an end view of two parallel half-wave array antenna (A and B) operating in the same phase and located ( $\lambda/2$ ) apart. At a point P far distance from the antennas, the antennas appear as a single point. Energy radiating toward P from antenna A starts out in phase with the energy radiating from antenna B in the same direction. Propagation from each antenna travels over the same distance to point P,

arriving there in phase. The antennas reinforce each other in this direction, making a strong signal available at P. Field strength measured at P is greater than it would be if the total power supplied to both the antennas had been fed to a single dipole. Radiation toward point P1 is built up in the same manner.

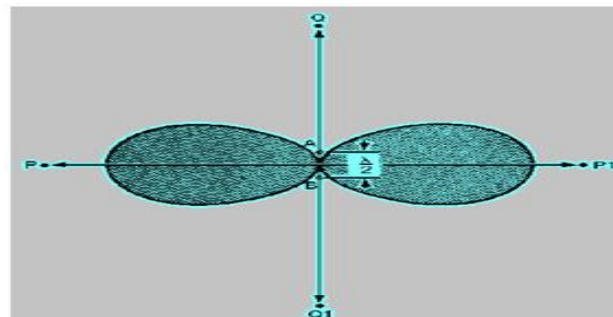


Fig. 2. Radiation pattern of two in phase parallel elements (two element array).

Now consider a wave front traveling toward point Q from antenna B. By the time it reaches antenna A,  $\lambda/2$  away,  $1/2$  cycle has elapsed. Therefore energy from antenna B meets the energy from antenna A 180 degrees out of phase. As a result, the energy moving toward point Q from the two sources cancels. In a like manner, radiation from antenna A traveling toward point Q1 meets and cancels the radiation in the same direction from antenna B. As a result, little propagation takes place in either direction along the QQ1 axis. Most of the energy is concentrated in both directions along the PP1 axis. When both antenna elements are fed from the same source, the result is the basic broadside array. When more than two elements are used in a broadside arrangement, they are all parallel and in the same plane, as shown in figure 1(b). Current phase, indicated by the arrows, must be the same for all elements. The radiation pattern shown in figure 1(C) is always bidirectional. This pattern is sharper than the one shown in figure 2 because of the additional two elements.

#### A. Pattern multiplication and Array factor (AF)

Pattern multiplication states that the radiation pattern of an array is the product of the pattern of the individual antenna with the array pattern [2]. The array pattern is a function of the location of the antennas in the array and their relative complex excitation amplitudes. Advantage of this method of multiplication is to sketch the radiation pattern of array antennas rapidly from the simple product of element pattern and array pattern. But this principle is applicable only for arrays containing identical elements [2]. Hence the total radiation pattern of an array is given by

$$E(\text{total}) = [E(\text{single element at reference point})] \times [\text{AF}] \quad (1)$$

Equation (1) is referred to as pattern multiplication for arrays of identical elements. The AF is a function of the geometry of the array and the excitation phase. By varying the spacing and/or the phase between the elements, the characteristics of the AF and the total field E (total) of the array can be controlled [1]. The AF can be obtained by considering the elements to be point sources. If the actual elements are not isotropic sources, the total field can be formed by multiplying the array factor of isotropic sources by the field of a single element which is according to the pattern multiplication rule (1). The AF for an n-element linear array of uniform amplitude and spacing can be written as

$$AF = \sum_{n=1}^N e^{j(n-1)\psi} \quad (2)$$

$$\text{where } \psi = kd \cos \theta + \beta \quad (2a)$$

Here  $\psi$  is the relative phase,  $\beta$  is the path difference,  $d$  is the spacing between the elements,  $\theta$  is the angle measured from the z-axis and  $k$  is a constant.

Since the total AF for the uniform array is summation of exponentials, it can be represented by the vector sum of  $N$  phasors each of unit amplitude and progressive phase  $\psi$  which is illustrated

graphically in figure 3(b). It is apparent from the phasor diagram that the amplitude and phase of the AF can be controlled in uniform arrays by properly selecting the relative phase  $\psi$  between the elements.

The AF of (2) can also be expressed in an alternate, compact and closed form whose functions and their distributions are more recognizable.

$$AF = e^{j\left[\frac{N-1}{2}\right]\psi} \left[ \frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{\psi}{2}\right)} \right] \quad (3)$$

If the reference point is the physical center of the array, the AF of (3) reduces to

$$AF = \left[ \frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{\psi}{2}\right)} \right] \quad (3a)$$

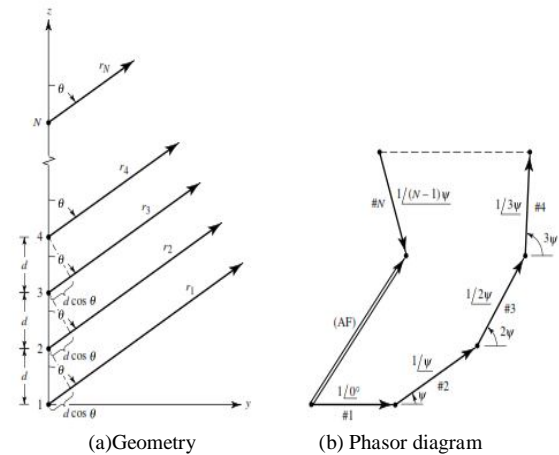


Fig. 3. Far-field geometry and phasor diagram of N-element array of isotropic sources positioned along z-axis.

For small values of  $\psi$ , the expression (3a) can be approximated by

$$AF \approx \left[ \frac{\sin\left(\frac{N}{2}\psi\right)}{(\psi/2)} \right] \quad (3b)$$

The maximum values of (3a) and (3b) is equal to  $N$ . To normalize the AF so that the maximum value of each is equal to unity, (3a) and (3b) are written in normalized form as

$$(AF)_n = \frac{1}{N} \left[ \frac{\sin\left(\frac{N}{2}\psi\right)}{\sin\left(\frac{\psi}{2}\right)} \right] \quad (3c)$$

$$(AF)_n \approx \frac{1}{N} \left[ \frac{\sin\left(\frac{N}{2}\psi\right)}{(\psi/2)} \right] \quad (3d)$$

#### B. Nulls and beam width

To find the nulls of the array, (3c) or (3d) is set equal to zero that is

$$\begin{aligned} \sin\left(\frac{N}{2}\psi\right) &= 0 \\ \Rightarrow \frac{N}{2}\psi|_{\theta=\theta_n} &= \pm n\pi \Rightarrow \theta_n = \cos^{-1}\left[\frac{\lambda}{2\pi d}\left(-\beta \pm \frac{2n}{N}\pi\right)\right] \end{aligned} \quad (4)$$

where  $n=1, 2, 3, \dots$  and  $n \neq N, 2N, 3N, \dots$  with

(3c). For  $n = N, 2N, 3N, \dots$ , (3c) attains its

maximum value (due to  $\sin(0)/0$  form)). The value of  $n$  determines the order of the nulls. The number of nulls that can exist will be a function of the element spacing  $d$  and the phase excitation difference  $\beta$ . The maximum values of (3c) occur

when

$$\frac{\psi}{2} = \frac{1}{2} (kd \cos \theta + \beta) \big|_{\theta=\theta_m} = \pm m\pi$$

$$\Rightarrow \theta_m = \cos^{-1} \left[ \frac{\lambda}{2\pi d} (-\beta \pm 2m\pi) \right] \quad (5)$$

where  $m = 0, 1, 2, \dots$

The AF of (3d) has only one maximum and occurs when  $m = 0$  in (5) that is

$$\theta_m = \cos^{-1} \left( \frac{\lambda \beta}{2\pi d} \right)$$

(6)

which is the observation angle that makes  $\psi =$

0. The 3-dB point for the AF of (3d) occurs when

$$\frac{N\psi}{2} = \frac{N}{2} (kd \cos \theta + \beta) \big|_{\theta=\theta_h} = \pm 1.391$$

$$\Rightarrow \theta_h = \cos^{-1} \left[ \frac{\lambda}{2\pi d} \left( -\beta \pm \frac{2.782}{N} \right) \right]$$

(7)

which can also be written as

$$\theta_h = \frac{\pi}{2} - \sin^{-1} \left[ \frac{\lambda}{2\pi d} \left( -\beta \pm \frac{2.782}{N} \right) \right]$$

(7a)

for large values of  $d (d \gg \lambda)$ , it reduces to

$$\theta_h \approx \left[ \frac{\pi}{2} - \frac{\lambda}{2\pi d} \left( -\beta \pm \frac{2.782}{N} \right) \right]$$

(7b)

The half-power beam width  $\theta_{HP}$  can be found

once the angles of the first maximum ( $\theta_m$ ) and half-power point ( $\theta_h$ ) are determined. For a symmetrical pattern

$$\theta_{HP} = 2 | \theta_m - \theta_h |$$

(7c)

For the AF of (3d), there are secondary maxima (maxima of minor lobe which occur approximately when the numerator of (3d) attains its maximum value. That is

$$\sin \left( \frac{N}{2} \psi \right) = \sin \left[ \frac{N}{2} (kd \cos \theta + \beta) \right] \big|_{\theta=\theta_s} \approx \pm 1$$

$$\Rightarrow \frac{N}{2} (kd \cos \theta + \beta) \big|_{\theta=\theta_s} =$$

$$\approx \pm \left( \frac{2s+1}{2} \right) \pi$$

$$\Rightarrow \theta_s \approx \cos^{-1} \left\{ \frac{\lambda}{2\pi d} \left[ -\beta \pm \left( \frac{2s+1}{N} \right) \pi \right] \right\}$$

(8)

$s = 1, 2, 3 \dots$

which can also be written as

$$\theta_s \approx \frac{\pi}{2} - \sin^{-1} \left\{ \frac{\lambda}{2\pi d} \left[ -\beta \pm \left( \frac{2s+1}{N} \right) \pi \right] \right\}$$

(8a)

$s = 1, 2, 3 \dots$

For large values of  $d (d \gg \lambda)$ , it reduces to

$$\theta_s \approx \frac{\pi}{2} - \frac{\lambda}{2\pi d} \left[ -\beta \pm \left( \frac{2s+1}{N} \right) \pi \right]$$

(8b)

$s = 1, 2, 3 \dots$

The maximum of the first minor lobe of (3c) occurs approximately when

$$\frac{N\psi}{2} = \frac{N}{2} (kd \cos \theta + \beta) \big|_{\theta=\theta_s} \approx \pm \frac{3\pi}{2}$$

(9)

or when

$$\theta_s = \cos^{-1} \left\{ \frac{\lambda}{2\pi d} \left[ -\beta \pm \left( \frac{3\pi}{N} \right) \right] \right\}$$

(9a)

At that point, the magnitude of (3d) reduces to

$$(AF)_n \approx \left[ \frac{\sin \left( \frac{N\psi}{2} \right)}{\left( \frac{N\psi}{2} \right)} \right] \bigg|_{\theta=\theta_s, s=1} = \frac{2}{3\pi} = 0.212$$

(10)

In decibels it is equal to

$$(AF)_n = 20 \log_{10} (0.212) = -13.46 \text{ dB}$$

(10a)

Thus the maximum of the first minor lobe of the AF of (3d) is 13.46 dB down from the maximum at the major lobe.

### III. OPTIMUM DESIGN OF BROAD SIDE ARRAY

To optimize the design, the maxima of the single element and the AF should both be directed towards  $\theta_0 = 90^\circ$ . Referring to (3c) or (3d), the first maximum of the AF occurs when

$$kd \cos\theta + \beta = 0 \quad (11)$$

Since it is desired to have the first maximum directed toward  $\theta_0 = 90^\circ$ , then

$$kd \cos\theta + \beta|_{\theta = 90^\circ} = \beta = 0 \quad (11a)$$

Thus to have the maximum of the AF of a uniform linear array directed broadside to the axis of the array, it is necessary that all the elements have the same phase excitation. The spacing between the elements can be of any value. In order to avoid having grating lobes which are the principal maxima occurs in other directions, the spacing between the elements should not be equal to multiples of a wavelength that is  $d \neq n\lambda$ ,  $n = 1, 2, 3, \dots$  when  $\beta = 0$ . If  $d = n\lambda$ , for  $n = 1, 2, 3, \dots$  and  $\beta = 0$ , then

$$\begin{aligned} &= kd \cos\theta + \beta|_{(d = n\lambda, n = 1, 2, 3, \dots \text{ and } \beta = 0)} \\ &= 2\pi n \cos\theta|_{\theta = 0^\circ, 180^\circ} = 2n\pi \end{aligned} \quad (12)$$

When this value of  $d$  is substituted in (3c), then the AF attains its maximum value. Thus for an uniform array with  $\beta = 0$  and  $d = n\lambda$ , in addition to having the maxima of the AF directed broadside to the axis of the array, there are additional maxima directed along the axis ( $\theta_0 = 0^\circ, 180^\circ$ ) of the array (end-fire radiation). One of the main objectives for many designs is to avoid multiple maxima (grating lobes). To avoid any grating lobe, the largest spacing between the elements should be less than one wavelength that is ( $d_{\max} = \lambda$ ). Figure 4(a) shows the plot of the three-dimensional AF of a 10-element uniform linear array ( $N=10$ ) with  $\beta = 0$  and  $d = \lambda/4$ .

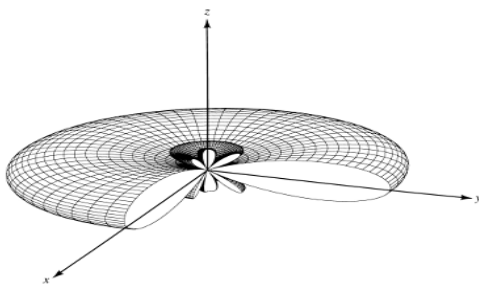


Fig. 4(a). Broad side ( $\beta = 0$  and  $d = \lambda/4$ ).

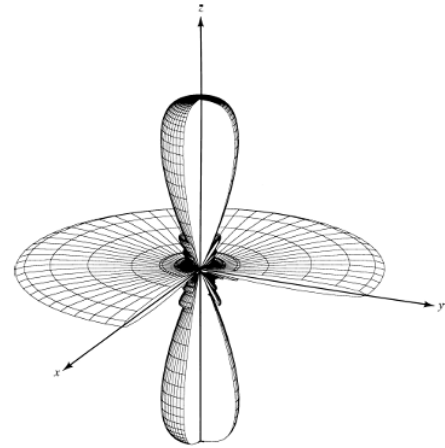


Fig. 4(b). Broad side/end-fire ( $\beta = 0$  and  $d = \lambda/2$ ).

Figure 4(b) shows the plot of the three-dimensional pattern of the same array but with  $d = \lambda/2$ . For this pattern, in addition to the maximum at  $\theta_0 = 90^\circ$  (for  $d = \lambda/4$ ), there are additional maxima in the direction toward  $\theta_0 = 0^\circ, 180^\circ$ . The corresponding two-dimensional patterns of figures 4(a, b) are shown in fig. 5. If the spacing between the elements is chosen between  $d = \lambda/2$ , then the maximum of figure 4 toward  $\theta_0 = 0^\circ$  shifts toward the angular region  $0^\circ < \theta_0 < 90^\circ$  while the maximum toward  $\theta_0 = 180^\circ$  shifts toward  $90^\circ < \theta_0 < 180^\circ$ . When  $d = \lambda$ , there are maxima toward  $0^\circ, 60^\circ, 90^\circ, 120^\circ$  and  $180^\circ$ .

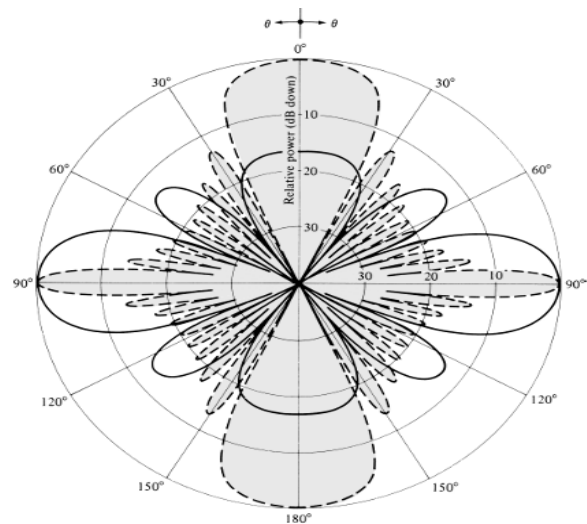


Fig. 5. Patterns of AF of a 10-element uniform amplitude broadside array ( $N=10, \beta = 0$ ).

#### A. Gain and directivity

Gain: Directivity and gain depend on the number of elements and the spacing between them. The physical disposition of dipoles operated broadside to each other allows for much greater coupling between them than can occur between collinear elements. Moving the parallel antenna elements closer together or farther apart affects the actual impedance of the entire array and the overall



radiation resistance as well. As the spacing between broadside elements increases, the effect on the radiation pattern is a sharpening of the major lobes. When the array consists of only two dipoles spaced exactly  $\lambda/2$  apart, no minor lobes are generated at all. Increasing the distance between the elements beyond that point, however, tends to throw off the phase relationship between the original current in one element and the current induced in it by the other element. The result is that, although the major lobes are sharpened, minor lobes are introduced, even with two elements. These, however, are not large enough to be of concern. If you add the same number of elements to both a broadside array and a collinear array, the gain of the broadside array will be greater. Reduced radiation resistance resulting from the efficient coupling between dipoles accounts for most of this gain. However, certain practical factors limit the number of elements that may be used. The construction problem increases with the number of elements, especially when they are polarized horizontally. The directivity of each of the array represents figure of merit on the operation of the system.

The directivity of the AF can be evaluated using the following equation

$$D_0 = \frac{4\pi U_{max}}{P_{rad}} = \frac{U_{max}}{U_0} \quad (13)$$

$$\text{Since } U_0 = \frac{P_{rad}}{4\pi}$$

Where  $U_{max}$  and  $U_0$  are the maximum and average radiation intensity respectively.

Consider N-element linear uniform broadside array. As a result of the criteria for broadside radiation given by (11a), the AF for this form of the array reduces to

$$(AF)_n = \frac{1}{N} \left[ \frac{\sin\left(\frac{N}{2}Kd \cos\theta\right)}{\sin\left(\frac{1}{2}Kd \cos\theta\right)} \right] \quad (14)$$

Which for a small spacing between the elements ( $d \ll \lambda$ ) can be approximated by

$$(AF)_n \approx \left[ \frac{\sin\left(\frac{N}{2}Kd \cos\theta\right)}{\left(\frac{N}{2}Kd \cos\theta\right)} \right] \quad (14a)$$

The radiation intensity can be written as

$$U(\theta) = [(AF)_n]^2 = \left[ \frac{\sin\left(\frac{N}{2}Kd \cos\theta\right)}{\left(\frac{N}{2}Kd \cos\theta\right)} \right]^2 = \left[ \frac{\sin(z)}{z} \right]^2$$

(15)

$$z = \frac{N}{2}Kd \cos\theta$$

(15a)

After taking certain assumptions the directivity can be expressed as

$$D_0 \approx \frac{Nkd}{\pi} = 2N \left( \frac{d}{\lambda} \right)$$

(16)

Let L be the overall length of the array which can be written as

$$L = (N-1)d \quad (17)$$

Using (17), the directivity of (16) in terms of overall length of the array can be expressed as

$$D_0 \approx 2N \left( \frac{d}{\lambda} \right) \approx 2 \left( 1 + \frac{L}{d} \right) \left( \frac{d}{\lambda} \right)$$

(18)

which for a large array ( $L \gg d$ ) reduces to

$$D_0 \approx 2 \left( \frac{L}{\lambda} \right)$$

(18a)

The radiation pattern of any general antenna is bi-directional or multi-directional. It contains a main lobe and adjacent minor or side lobes. The presence of side lobes is undesirable and they create electromagnetic interference (EMI) in the radar receivers. The EMI creates false targets in the radar display. The presence of EMI is also prone to jamming. The width of the main lobe is required to be small. But the general tendency is that if the side lobe levels are reduced, the beam width increases and vice-versa. Ideally, there should be no side lobes as there will be waste of power in undesired directions of radiation and reduced gain in the desired directions. It is possible to reduce the side lobes by appropriate tapered amplitude excitations to the array elements

#### IV. RESULTS AND DISCUSSION

**Antenna analysis** determines the radiation pattern for a given input distribution. **Antenna synthesis** is the inverse process in which, input or source distribution is determined for a specified radiation pattern [2]. This synthesis algorithm will design a linear array for a specified directivity or beam width and excitation taper. The specification of the excitation taper allows the side lobes to be

controlled. This array can be designed with the elements arranged along any of the 3 major axes, resulting in a beam that is rotationally symmetric around the chosen axis, with the peak directivity normal (broad side) to the array. In this design the chosen inter element spacing is  $\lambda/2$ . The excitation taper can be selected between equal excitation [Uniform], uniform side lobe level [Dolph-Chebychev] and first few side lobes uniform [Villeneuve]. The side lobe level and number of side lobes (where applicable) can then be set. For synthesis environment the following assumptions are made for simulation.

Reflective plane orientation taken is none, Array shape is linear with specific excitation taper, Orientation along X axis, Frequency chosen is 300M Hz, Main beam Directivity 25dBi and equal excitation Isotropic array pattern. Figures 6-18 illustrates simulated results.

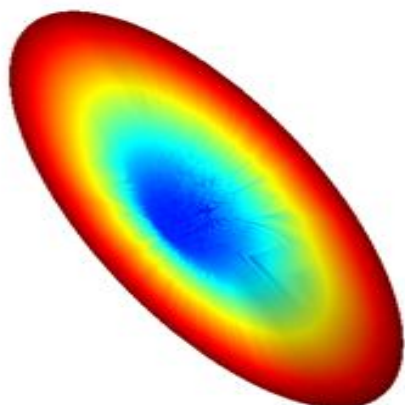


Fig. 6. Isotropic array pattern

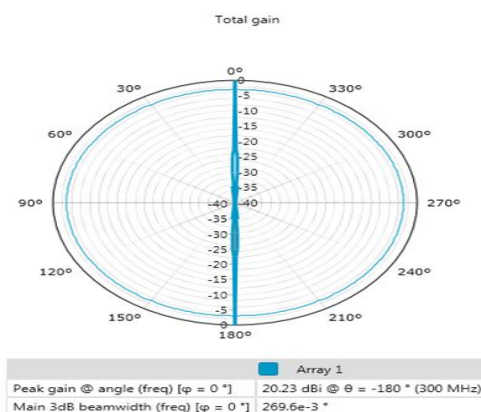
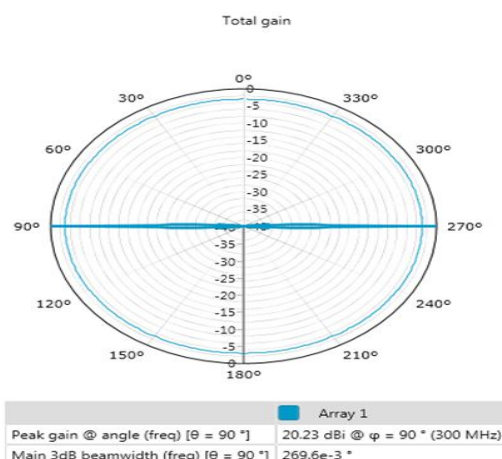


Fig. 8. XZ - plane cut

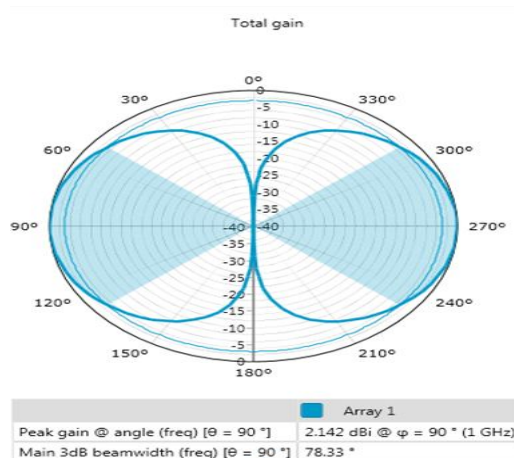


Fig. 9. XY - plane cut

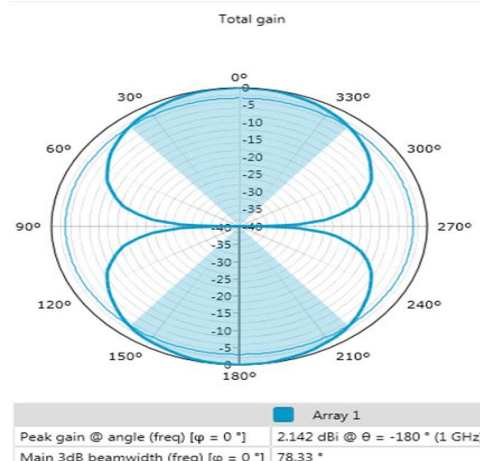


Fig. 10. XZ - plane cut

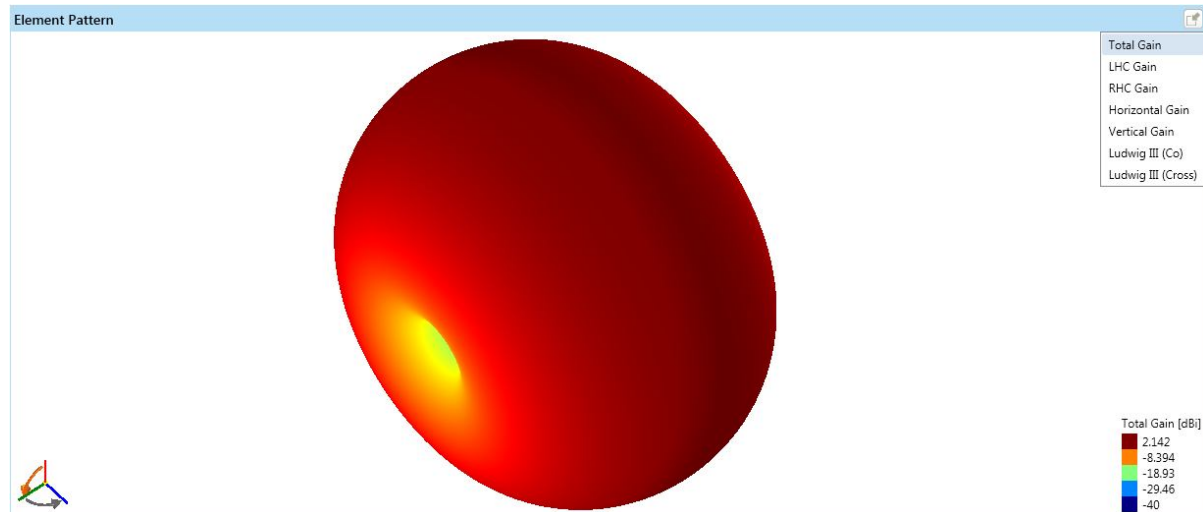


Fig. 11. Element Pattern

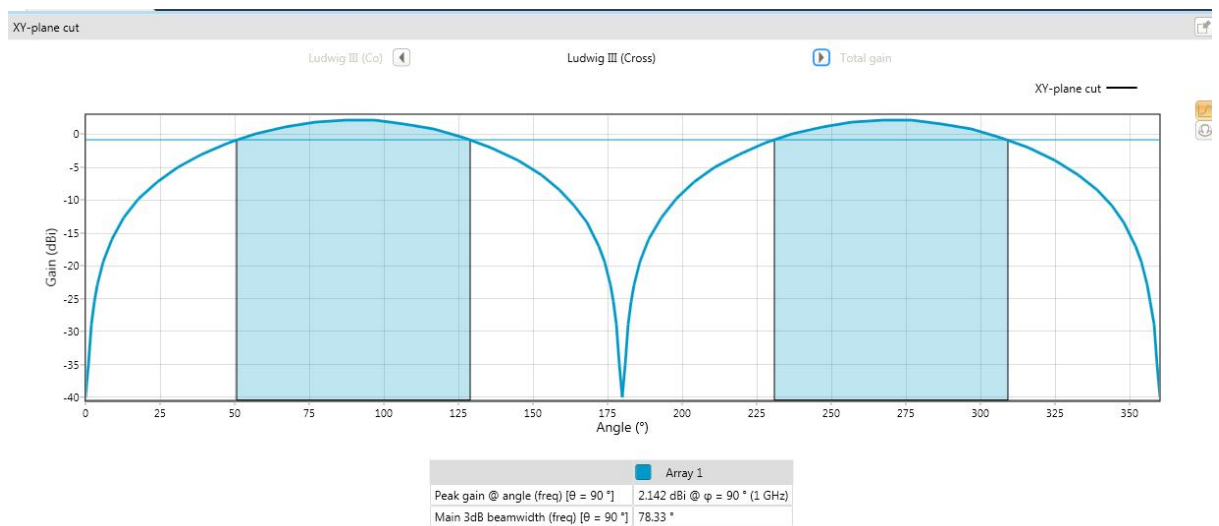


Fig. 12. Element Pattern XY Plane cut

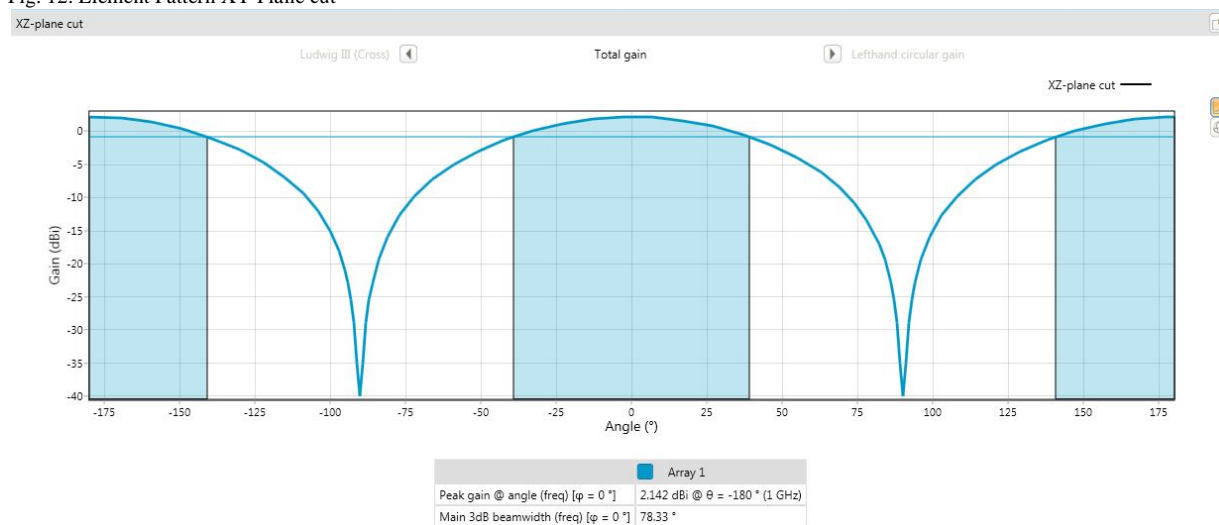


Fig. 13. Element Pattern XZ Plane cut



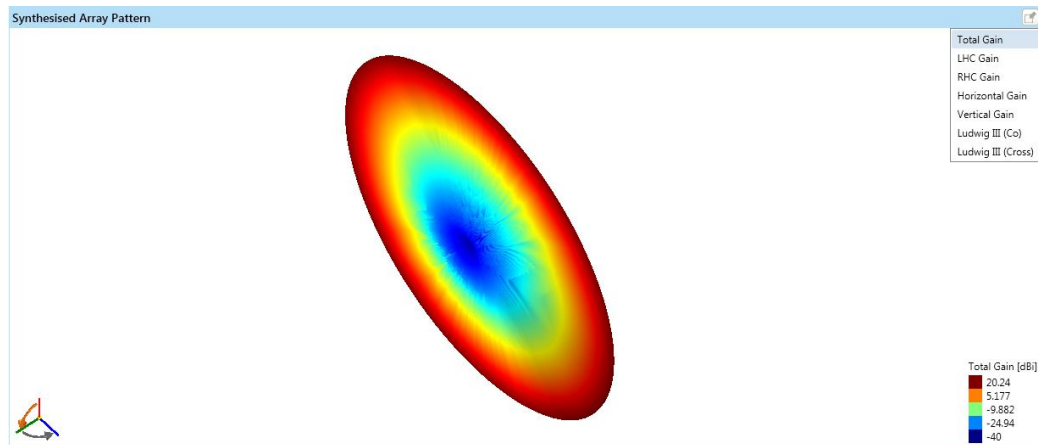


Fig. 14. Synthesised Array Pattern

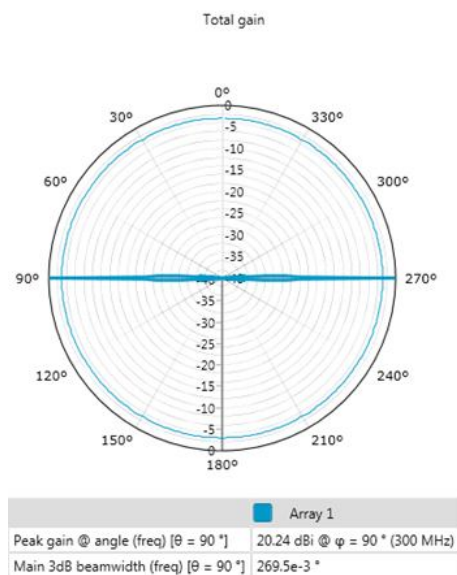


Fig. 15. Synthesised Array Pattern XY Plane cut

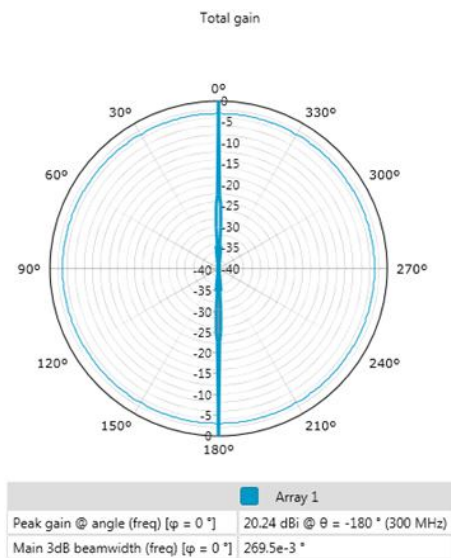


Fig. 16. Synthesised Array Pattern XZ Plane cut

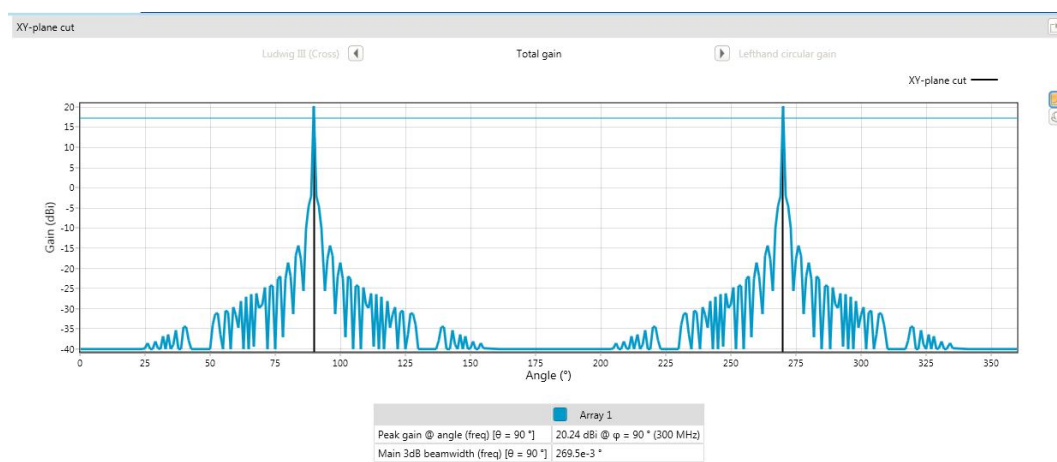


Fig17.Synthesised Array Pattern XY plane cut (Rectangular Coordinates)

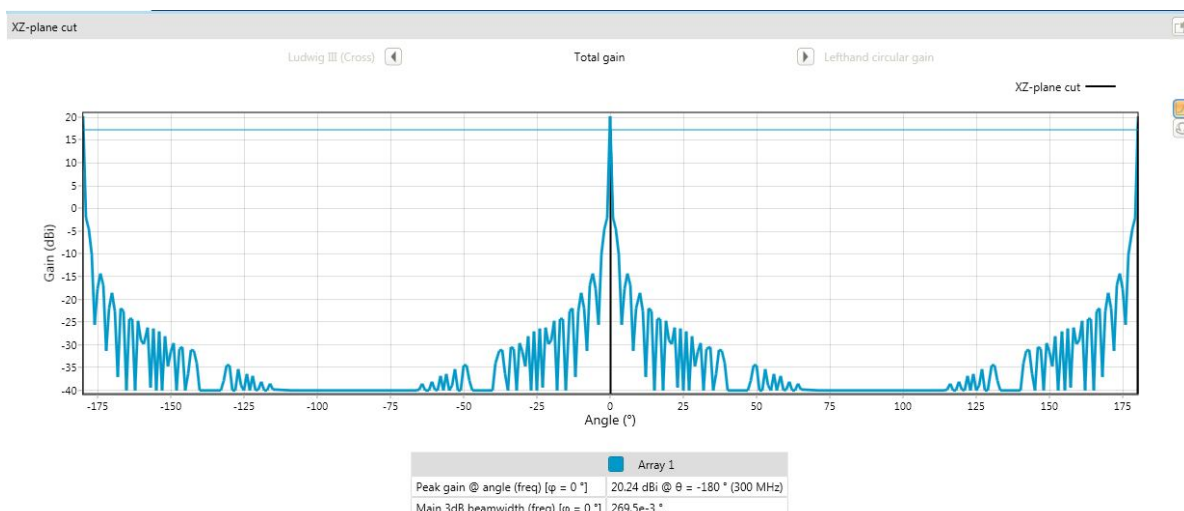


Fig. 18. Synthesised Array Pattern XZ Plane cut (Rectangular Coordinates)

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