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Impact of Element Spacing on the Radiation Pattern of Planar Array of Monopole Antenna

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Abstract

In recent years, several attempts have been made in designing planar array antennas with high directivity. This paper is aimed at investigating the impact of element spacing on the directivity of planar array of monopole antenna. The directivity of antenna with reduced grating lobes can be obtained by carefully varying the inter-element spacing of array antenna. Based on this conception, this paper presents the investigation carried out on the relationship between inter-element spacing and the directivity of planar array of monopole antenna. It went further to highlight the effect on the total fields radiated by the antenna. The inter-element spacing is one of the most important antenna parameters that determine the directivity of the antenna. For a planar array of monopole, the directivity can be improved by varying the inter-element spacing. Four elements uniform planar array antenna and Hadamard matrix method was used to determine element positioning in the array matrix. The simulated results obtained using Matlab, showed that good directivity was obtained by using element spacing between 0.1λ - 0.5λ. Increasing the spacing beyond 0.6λ - 1.0λ also improved the directivity, but generated many grating lobes. As inter-element spacing increased, the grating lobes increased in size, number and levels. The study, therefore, inferred that the best directivity (radiation pattern) can only be obtained when the element spacing is within 0.1 - 0.5λ.

Keywords

Grating Lobes, Array Antenna, Planar Array, Array Factor, Directivity, Element Spacing

1. Introduction

Planar array antennas are many antennas arranged and connected in a matrix format on a plane in order to reduce the inherent environmental pollution by reducing the grating lobes and levels [1] [2]. Directivity in the other hand as a fundamental antenna parameter is a measure of how "directional" an antenna's radiation pattern is [3]. It can also be seen as a 4π times the ratio of the far field power density to the total radiated power [4].

Many array antennas were developed, ranging from linear, circular, phased, conformal and planar array antennas. Planar array of monopole antenna method is chosen for this research [3]. The total field radiated as well as the directivity by this antenna depends largely on the elemental parameters, such as inter-element spacing.

Many researchers referenced in our research like [3] [4] [5] and [6] had researched on different ways and methods of improving the radiation pattern synthesis and attempts to enhance the directivity of the radiated field using different methods and have different aims. But this research, in which no researcher has done before, provides an in-depth study on the effect of varying inter-element spacing on the directivity of the total field radiated by planar array of monopole antenna.

2. Design of Planar Array Using Hadamard Matrix

The "on" and "off" states in the array arrangement correspond to "1" and "−1" of the Hadamard matrix [7]. The inter-element spacing in both directions of the array was varied. In determining the configuration of the planar array in a matrix form, a special matrix arrangement technique was adopted. This matrix technique or method is known as Hadamard matrix which was introduced by Jacques Hadamard in 1893.

An $n \times n$ matrix $F = f_{ij}$ is an *Hadamard matrix of order n* if the entries of F are either +1 or −1 and such that $FF^{\mathrm{T}} = nI$, where F^{T} is the transpose of F and I is the order n identity matrix.

$$FF^{\mathrm{T}} = nI \tag{1}$$

Hadamard matrix is one of the mathematical conjectures in nature. Although many associated ideas have been developed, the very existence of these matrices has extensive consequences in many fields of research, such as optimal design theory, information theory and graph theory. For instance, a Hadamard matrix can be interpreted directly as a weighing design. They can be used in forming optimal fractional factorial designs, orthogonal arrays (It consists of two conventionally summed linear sub-arrays that are oriented at right angle to each other, such that the outputs of the sub-arrays are cross-correlated to form an antenna pattern.) F-square designs [4].

From Hadamard *states that if* F_1 *is Hadamard matrix of order m and* F_2 *is a Hadamard matrix of n then* $F_1 \otimes F_2$ *is a hadamard matrix of order mn.*

The symbol $\otimes$ denotes direct product or convolution of matrices: if A is a matrix with typical entry a_{ij}, then

$$A \otimes B = \begin{bmatrix} a_{11}B & a_{12}B & \cdots \\ a_{21}B & a_{22}B & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix} \tag{2}$$

A $n \times n$ matrix $F = f_{ij}$ is a *Hadamard matrix of order n* if the entries of F are either +1 or −1 and such that

$$FF^{\mathrm{T}} = nI \tag{3}$$

That is let

$$F = \begin{bmatrix} + & + \\ + & - \end{bmatrix}$$

And

$$F^{\mathrm{T}} = \begin{bmatrix} - & - \\ - & + \end{bmatrix}$$

For a 4 × 4 matrix arrangement, that is using Equation (3) above, that product of FF^{T} gives [8]

$$FF^{\mathrm{T}} = F \otimes F^{\mathrm{T}} = \begin{bmatrix} + & + \\ + & - \end{bmatrix} \otimes \begin{bmatrix} - & - \\ - & + \end{bmatrix} = nI \tag{4}$$

Therefore,

$$FF^{\mathrm{T}} = \begin{bmatrix} + & + & + & + \\ + & - & + & - \\ + & + & - & - \\ + & - & - & + \end{bmatrix} \tag{5}$$

Equation (5) implies that F is nonsingular, and has an inverse $n^{-1}F^{\mathrm{T}}$; consequently

$$F^{\mathrm{T}}F = nI$$

But in this paper, we considered a uniform planar array antenna with all elements energised. From Hadamard, let $F_1 \otimes F_2 = A \otimes B$

$$A \otimes B \begin{bmatrix} a_{11}B & a_{12}B \\ a_{21}B & a_{22}B \end{bmatrix} \otimes \begin{bmatrix} a_{11}B & a_{12}B \\ a_{21}B & a_{22}B \end{bmatrix} = nI \tag{6}$$

Then

$$A \otimes B = \begin{bmatrix} a_{11}B & a_{12}B & a_{13}B & a_{14}B \\ a_{21}B & a_{22}B & a_{23}B & a_{24}B \\ a_{31}B & a_{32}B & a_{33}B & a_{34}B \\ a_{41}B & a_{42}B & a_{43}B & a_{44}B \end{bmatrix} = nI \tag{7}$$

According to Hadamard matrix, $F = f_{ij}$ is a *Hadamard matrix of order* $N \times M$ if the entries of F are either +1 or −1. In this paper we considered in Equation (7) where all the elements will to be +1, that is,

$$a_{11}B = a_{12}B = a_{13}B = a_{14}B = +1 \tag{8}$$

$$a_{21}B = a_{22}B = a_{23}B = a_{24}B = +1 \tag{9}$$

$$a_{31}B = a_{32}B = a_{33}B = a_{34}B = +1 \tag{10}$$

$$a_{41}B = a_{42}B = a_{43}B = a_{44}B = +1 \tag{11}$$

From the above Equations (8)-(11) it therefore implies that, in a uniform planar array antenna with all the elements in the array matrix energised and represented by "1" we have;

$$F = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \tag{12}$$

For clarity and easy placement of these elements in the planar array form, the nodal elements are numbered from 1 - 16 according the element's position in the matrix array as shown in **Figure 1**.

From **Figure 1** below, the element of each node $E(a_x, a_y)$ is the element's position number in the uniform planar array matrix. The inter-element spacings $a_x\lambda$ and $a_y\lambda$ are spacings along x and y-axis respectively.

10 elements with (+) sign before them, that is, elements 1, 2, 3, 4, 5, 9, 11, 13 are "on" while 6 elements with (−) sign before them, that is, elements 7, 8, 10, 12, 14, and 15 are "off" of the 4 × 4 array. The total elements involved in this planar array evaluation were 16 elements.

3. Derivation of the Formula for Planar Array Factor AF_{planar} from Linear Array Antenna

Linear antenna array provides a good background in array theory because of the insights that leads into formation of beam and it relates to the array excitation functions and the radiation pattern obtained [6].

Consider an isotropic radiator located at the origin of the linear array, the E-field may be written as (assuming θ-polarization)

$$E_\theta = I_0 \frac{e^{-jkd}}{4\pi d} \tag{13}$$

where,

I_0 is the complex excitation of the isotropic radiator, k is the free space wave number and d is distance of the observation point from the origin.

Assume that the N elements of the array are uniformly spaced with a separation

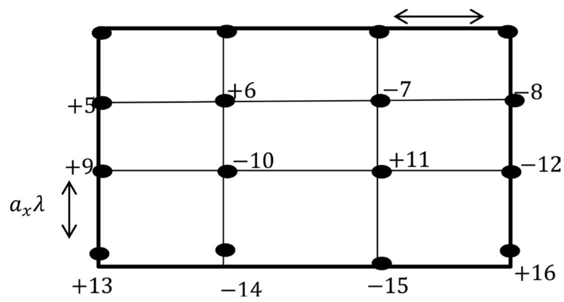


Figure 1. Placement of element in planar array form [1].

distance d. The uniformly spaced linear array antenna is presented in **Figure 2** below [6].

This arrangement is necessary showing that the configuration of a planar array antenna is made up of two linear antennas placed at orthogonally to each other. The nodes, 1 - 4 represent the four elements of the linear array and *a*, is the inter-element spacing. While d_1 - d_4 is the far field approximation.

From **Figure 2** below, the far field approximations of the array is

$$d_1 = d \tag{14}$$

$$d_2 \approx d - a\cos\theta \tag{15}$$

$$d_3 \approx d - 2a\cos\theta \tag{16}$$

$$r_N \approx d - (N-1)a\cos\theta \tag{17}$$

The magnitudes of current of the array elements was assumed to be equal and the current on the array element located at the origin was used as the phase reference (zero phase) [3] see **Figure 1**.

Therefore, the currents $I_1 = I_0 I_2 = I_0 e^{j\phi_2} \cdots I_N e^{j\phi_N}$.

The far *E*-field of the individual elements is:

$$E_{\theta_1} = I_0 \frac{\mathrm{e}^{-jkd}}{4\pi d} = E_0 \tag{18}$$

$$\begin{aligned} E_{\theta_2} &= I_0 \mathrm{e}^{j\phi_2} \frac{\mathrm{e}^{-jk(r-a\cos\theta)}}{4\pi d} = E_0 \mathrm{e}^{-jk(r+kac\cos\theta)} \\ E_{\theta_3} &= I_0 \mathrm{e}^{j\phi_3} \frac{\mathrm{e}^{-jk(d-2ac\cos\theta)}}{4\pi d} = E_0 \mathrm{e}^{-jk(d+2kac\cos\theta)} \\ E_{\theta_N} &= I_0 \mathrm{e}^{j\phi_N} \frac{\mathrm{e}^{-jk(d-(N-1)a\cos\theta)}}{4\pi d} = E_0 \mathrm{e}^{j[\phi_N+(N-1)ka\cos\theta]} \end{aligned} \tag{19}$$

The total array far field could be found by using superposition:

$$E_0 = E_{\theta_1} + E_{\theta_2} + E_{\theta_3} + \cdots + E_{\theta_N} \tag{20}$$

$$= E_0 \left[1 + \mathrm{e}^{j(\phi_2 + ka\cos\theta)} + \cdots + \mathrm{e}^{j[\phi_N + (N-1)ka\cos\theta]} \right] = E_0 [AF] \tag{21}$$

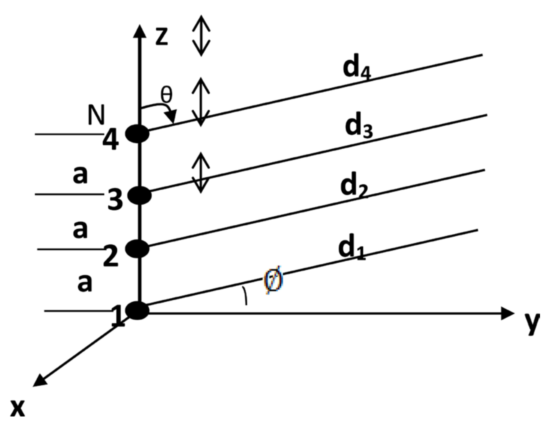


Figure 2. Uniform linear array antenna [1].

Note that the array factor (*AF*) is independent of the antenna type, assuming all of the elements are identical. The array factor for a uniformly-spaced *N*-element linear array is [3]:

$$AF = \left[1 + e^{j(\phi_2 + ka\cos\theta)} + \cdots + e^{j\left[\phi_N + (N-1)ka\cos\theta\right]}\right] \tag{22}$$

We consider a uniform array defined by uniformly-spaced identical elements of equal magnitude with a linearly progressive phase from element to element:

$$\phi_1 = 0, \phi_2 = \rho, \phi_3 = 2\rho, \cdots, \phi_N = (N-1)\rho \tag{23}$$

Inserting this linear phase progression into the formula for the general *N*-element array gives

$$AF = \left[1 + e^{j(\phi_2 + ka\cos\theta)} + \cdots + e^{j\left[\phi_N + (N-1)ka\cos\theta\right]}\right]$$

$$AF = \left[1 + e^{j\rho} + e^{j2\rho} + e^{j3\rho} + e^{j4\rho} + e^{j5\rho} + \cdots + e^{j\rho(N-1)}\right] \tag{24}$$

where,

$$\rho = \phi_N + ka\cos\theta$$

And thus,

$$AF = \sum_{n=1}^{N} e^{j\rho(N-1)} \tag{25}$$

where ρ is a function which defined as the *array phase function* and is a function of [6] the element spacing, phase shift, frequency and elevation angle. If the array factor of Equation (25) is multiplied by $e^{j\rho}$ the result is

$$AFe^{j\rho} = \left[e^{j\rho}e^{j\rho} + e^{j2\rho} + e^{j3\rho} + e^{j4\rho} + e^{j5\rho} + \cdots + e^{jN\rho}\right] \tag{26}$$

The subtraction of the array factor from Equation (26) above gives

$$AF\left(e^{j\rho} - 1\right) = \left(e^{jN\rho} - 1\right) \tag{27}$$

Therefore, according to [2] and [6]

$$AF = \frac{e^{jN\varphi} - 1}{e^{j\varphi} - 1} = \frac{e^{jN\frac{\rho}{2}}}{e^{j\frac{\rho}{2}}} \frac{e^{jN\frac{\rho}{2}} - e^{-jN\frac{\rho}{2}}}{e^{j\frac{\rho}{2}} - e^{-j\frac{\rho}{2}}} = e^{j(N-1)\frac{\rho}{2}} \frac{\sin\left(N\frac{\rho}{2}\right)}{\sin\left(\frac{\rho}{2}\right)} \tag{28}$$

The complex exponential term $e^{j(N-1)\frac{\rho}{2}}$ in Equation (28) is the phase shift (array phase factor) of the array phase center relative to the origin. If the position of the array is shifted so that the center of the array is located at the origin, this phase term goes to zero. That is if $(N-1)\frac{\rho}{2} = 0$,

then Equation (23) becomes;

$$AF = \frac{\sin\left(\frac{N\rho}{2}\right)}{\sin\left(\frac{\rho}{2}\right)} \tag{29}$$

The array factor is normalized so that the maximum value for any value of N is unity [6]. The normalized array factor therefore is given as

$$AF = \frac{1}{N}\frac{\sin\left(\frac{N\rho}{2}\right)}{\sin\left(\frac{\rho}{2}\right)} \tag{30}$$

The antenna is rectangular array antenna as shown in **Figure 3**. The interest is the arrangement of a linear array which is of $N \times N$ matrix with M number of element in x equals N number elements in y [4].

The designed principles for planar arrays are similar to those elements placed in two dimensions (**Figure 3**), the array factor of a planar array can be expressed as the multiplication of the array factors of two linear arrays of Equation (30) above, one along the x-axis and the other one along the y-axis. Therefore, planar array factor AF_{planar} can be simply expressed as:

$$AF_{planar} = \left\{\frac{1}{M}\frac{\sin\left(\frac{M}{2}\rho_x\right)}{\sin\left(\frac{\rho_x}{2}\right)}\right\}\left\{\frac{1}{N}\frac{\sin\left(\frac{N}{2}\rho_y\right)}{\sin\left(\frac{\rho_y}{2}\right)}\right\} \tag{31}$$

where,

$$\rho_x = ka_x \sin\theta\cos\phi + \omega_x \tag{32}$$

$$\rho_y = ka_y \sin\theta\cos\phi + \omega_y \tag{33}$$

where, ρ_x and ρ_y is the array phase function along x-and-y axis while ω_x and ω_y is the progressive phase shift along x-and-y axis respectively. a_x and a_y, is the inter-element spacing x-and-y axis respectively when ρ_x and $\rho_y = 0$ can be obtained as

$$\omega_x = -ka_x \sin\theta\cos\phi \tag{34}$$

$$\omega_y = -ka_y \sin\theta\cos\phi \tag{35}$$

And

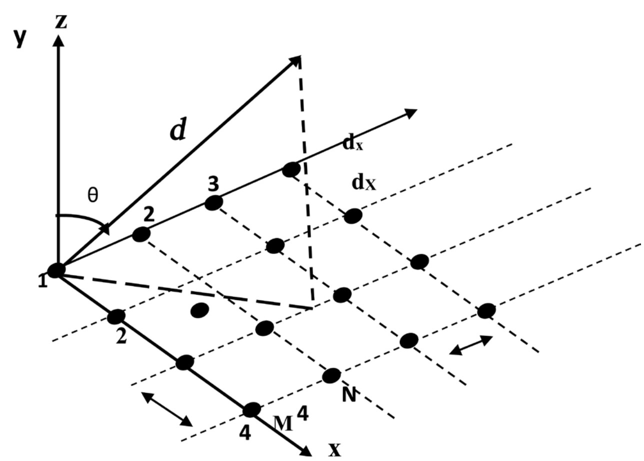


Figure 3. Geometry of the $N \times M$ planar array antenna [1].

$$k = 2\frac{\pi}{\lambda} \tag{36}$$

The nulls of the array function are found by determining the zeros of the numerator term where the denominator is not simultaneously zero [2]. That is:

$$\sin\left(\frac{N\rho}{2}\right) = 0 \Rightarrow \frac{N\rho}{2} = \pm n\pi \Rightarrow \phi + ka\cos\theta_n = \pm\frac{2n\pi}{N} \tag{37}$$

$$\theta_n = \cos^{-1}\left[\frac{\lambda}{2\pi a}\left(-\alpha \pm \frac{2n\pi}{N}\right)\right] \tag{38}$$

$$n = 1, 2, 3, \cdots$$

$$n \neq 0, N, 2N, 3N, \cdots$$

The peaks of the array function can be found by determining the zeros of the numerator term where the denominator is simultaneously zero.

$$\theta_m = \cos^{-1}\left[\frac{\lambda}{2\pi a}\left(-\alpha \pm 2m\pi\right)\right], \quad m = 1, 2, 3, \cdots \tag{39}$$

When $m = 0$ term,

$$\theta_m = \cos^{-1}\left(\frac{\lambda}{2\pi a}\right) \tag{40}$$

4. The Wavelength (Lambda, λ)

It has been established that the speed of electromagnetic wave on air is 3×10^8 m/s, and can be obtained from the formula,

$$V = f\lambda \tag{41}$$

where,

f= the frequency of the electromagnetic wave.

λ = Lambda, the wavelength.

For the purpose of this investigation, the frequency is 2.5 GHz, therefore, the wavelength, λ can be obtained as follows;

$$\lambda = \frac{v}{f} = \frac{3\times10^8}{2.5\times10^9} = \frac{3\times10^{-1}}{2.5} = 0.12\ \text{m}$$

The (AF) in this research is calculated using the normalized (AF) obtained in Equation (28)

$$AF_n(\theta,\phi) = \left\{\frac{1}{M}\frac{\sin\left(\frac{M}{2}\rho_x\right)}{\sin\left(\frac{\rho_x}{2}\right)}\right\}\left\{\frac{1}{N}\frac{\sin\left(\frac{N}{2}\rho_y\right)}{\sin\left(\frac{\rho_y}{2}\right)}\right\}$$

where,

$$\rho_x = ka_x\sin\theta\cos\phi + \omega_x$$

$$\rho_y = ka_y\sin\theta\cos\phi + \omega_y$$

For a beam pattern broadside

$$d_x = d_y = \frac{\lambda}{2}, \quad \omega_x = \omega_y = 0 \quad \text{and} \quad M = N = 4$$

Let $\rho_x = kd\cos\theta + \omega = \rho_y$ for a uniform array and $M = N = 4$. $\omega_x = \omega_y = 0$, $\theta = 45^\circ$.

5. Determination of the Directivity D_x and D_y of a Linear Array

The directivity of linear array antenna *D*, is determined by the formula,

$$D = \frac{2R_0^2}{1 + \left(R_0^2 - 1\right) f \frac{\lambda}{L + a}} \tag{42}$$

where, R_0 is the voltage ratio, *L* is the length of the linear array, *f* is the broadening factor of broad array and *a* is the distance between elements in the linear array [2]. Let $R_0 = 20$ voltage ratio, $L = 4, a = 0.47, f$.

6. Determination of the Directivity D_0 of Planar Array

Since the configuration of a planar array antenna is consists of two linear antennas placed orthogonally to each other, the directivity of a planar array antenna, D_0 can be obtained as [2]:

$$D_0 = D_x D_y \cos\theta \tag{43}$$

where, D_x = The directivity of a linear array along *x*-axis.

D_y = The directivity of a linear array along *y*-axis.

Table 1 is the result of the computation of varying the Inter-Element spacing

Table 1. Result of varying the inter-element spacing.

S/N	$a_x = a_y$	ρ_x	$AF_n(\theta)_X$	$AF_n(\theta)_{dB}$	$AF_n(\theta,\phi)_{xy}$	D_0 (dB)
1	0.47λ	2.8813	0.9992	−0.0072	0.9984	36.56
2	0.50λ	2.2214	0.9991	−0.0082	0.9982	36.74
3	0.52λ	2.3102	0.9990	−0.0088	0.9980	36.86
4	0.55λ	2.4436	0.9989	−0.0099	0.9978	37.22
5	0.57λ	2.5324	0.9988	−0.0106	0.9976	37.16
6	0.60λ	2.2666	0.9986	−0.0118	0.9972	37.34
7	0.65λ	2.8878	0.9984	−0.0138	0.9968	37.64
8	0.67λ	2.9767	0.9983	−0.0147	0.9966	37.76
9	0.70λ	3.1100	0.9981	−0.0161	0.9962	37.94
10	0.75λ	3.3321	0.9979	−0.0184	0.9958	38.23
11	0.78λ	3.4654	0.9977	−0.0199	0.9954	38.41
12	0.80λ	3.5548	0.9976	−0.0352	0.9952	38.52
13	0.90λ	3.9986	0.9970	−0.0265	0.9940	39.10
14	0.95λ	4.2207	0.9966	−0.0296	0.9932	39.39
15	1.0λ	4.4424	0.9962	0.0327	0.9924	39.67

of the Planar Array of Monopole Antenna in both x and y-directions keeping progressive phase shift, theta/phi = 45, number of elements $N = M = 4$ constant throughout the variation. The table contain the values of number elements along both x and y-directions, progressive phase-shift and directivity of fields.

It also shows a decrement on the array factor, $AF_n(\theta,\phi)_{xy}$ as the inter-element spacing was increased, for instance, when the element spacing of 0.47λ was mathematically evaluated, the correspondent value of array factor is 0.9984 as the value of the list spacing considered in this evaluation. While 0.9924 is obtained as the array factor, $AF_n(\theta,\phi)_{xy}$ when 1.0λ spacing is considered as the widest distance between the elements. On the other hand, the numerical value of directivity increases as the inter-element spacing increases.

The below Figure 4(a) and Figure 4(b) are obtained from plotting Array

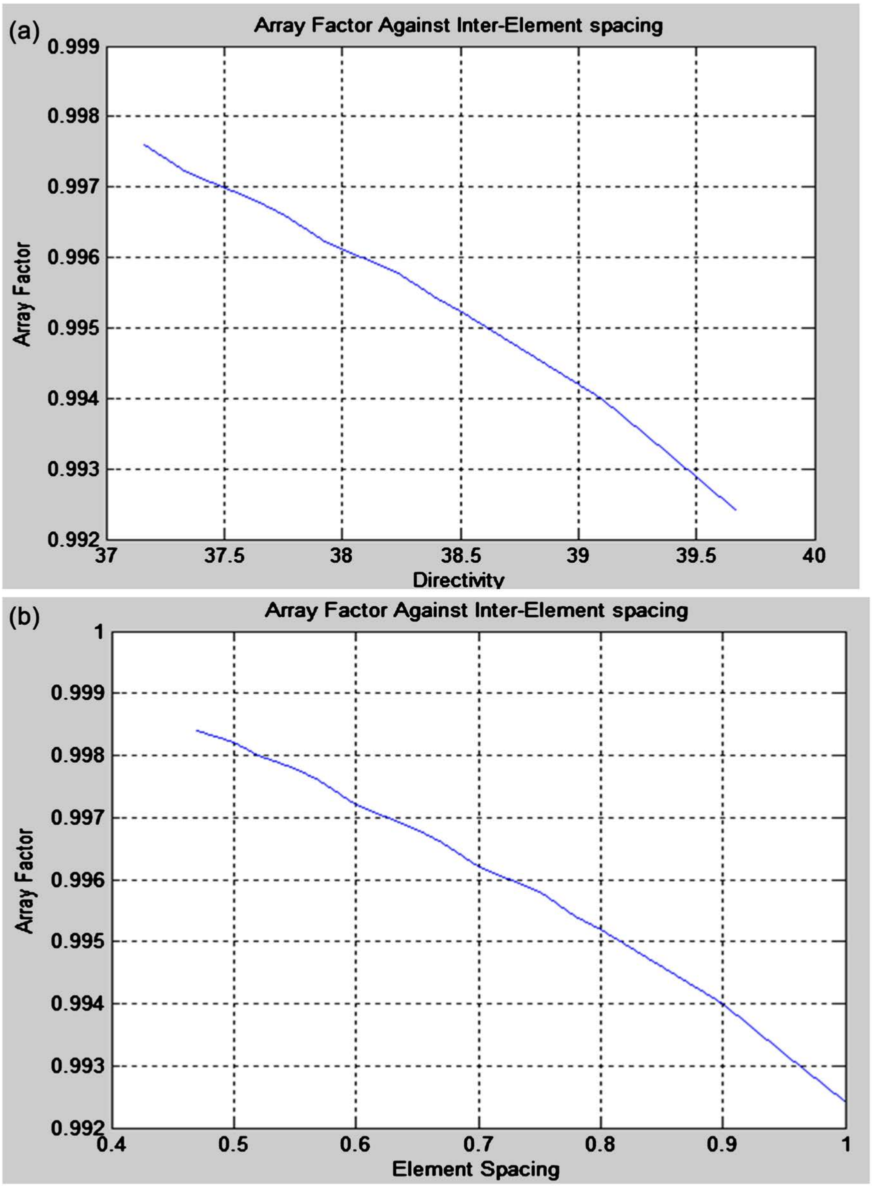
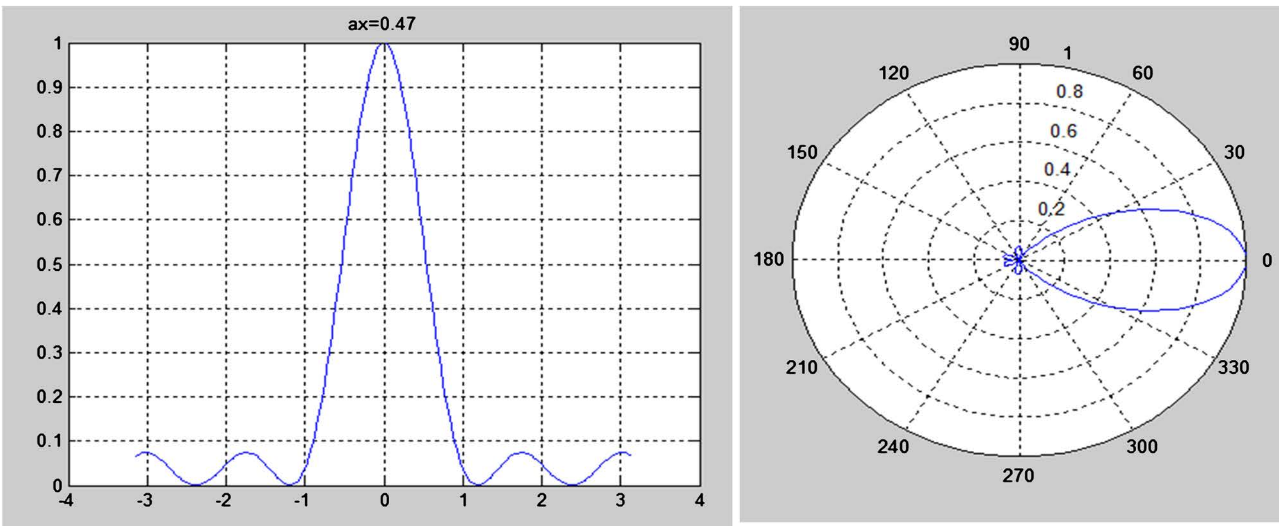


Figure 4. Graph of array factor against (a) directivity (b).

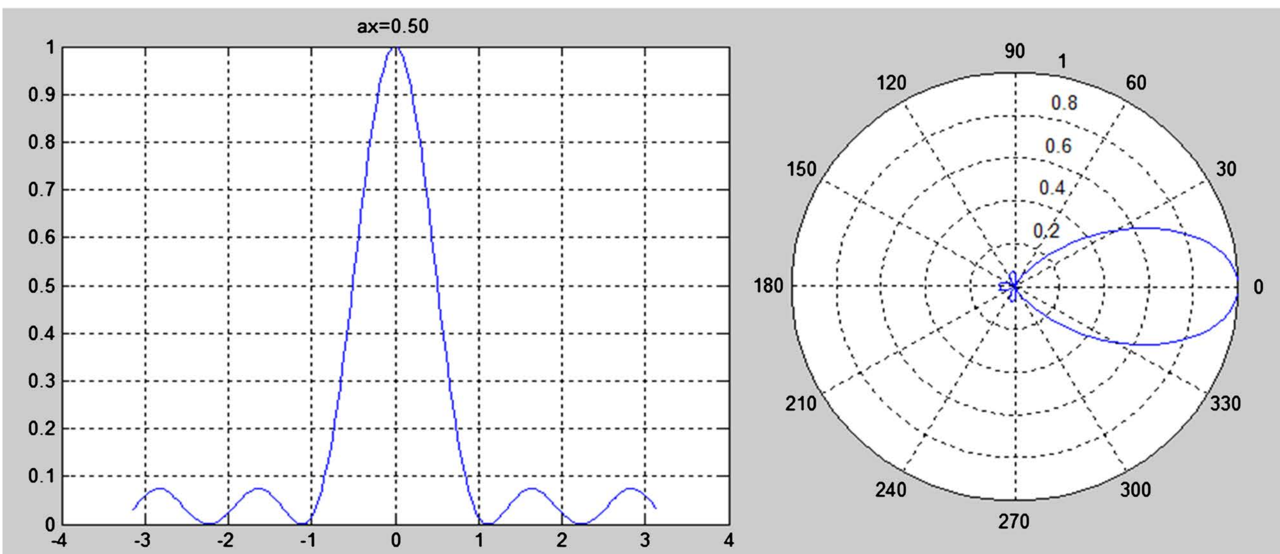
Factor against Directivity and inter-element spacing of the **Table 1** above. The two graphs obtained show that as the inter-element spacing of the matrix array is increased, the Array Factor decreases and the Directivity of the radiated pattern of the field increases.

7. Radiation Patterns of Varying Element Spacing

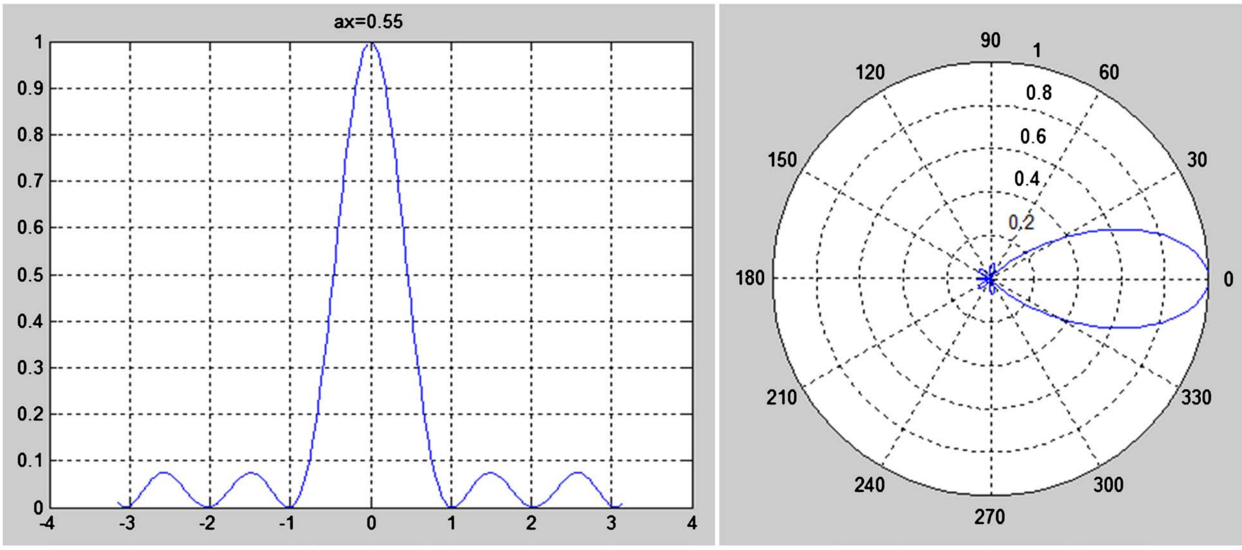
Figure 5 below are the simulation results obtained both in 2D plots and polar plots of Array Factor against the elevation (azimuthal). It is the various radiation patterns obtained by varying the inter-element spacing along a_x and a_y axis of the matrix array as a_x and a_y are varied, while the number of elements, N and progressive phase shift, theta/phi = 45, number of elements $N = M = 4$ are kept constant.



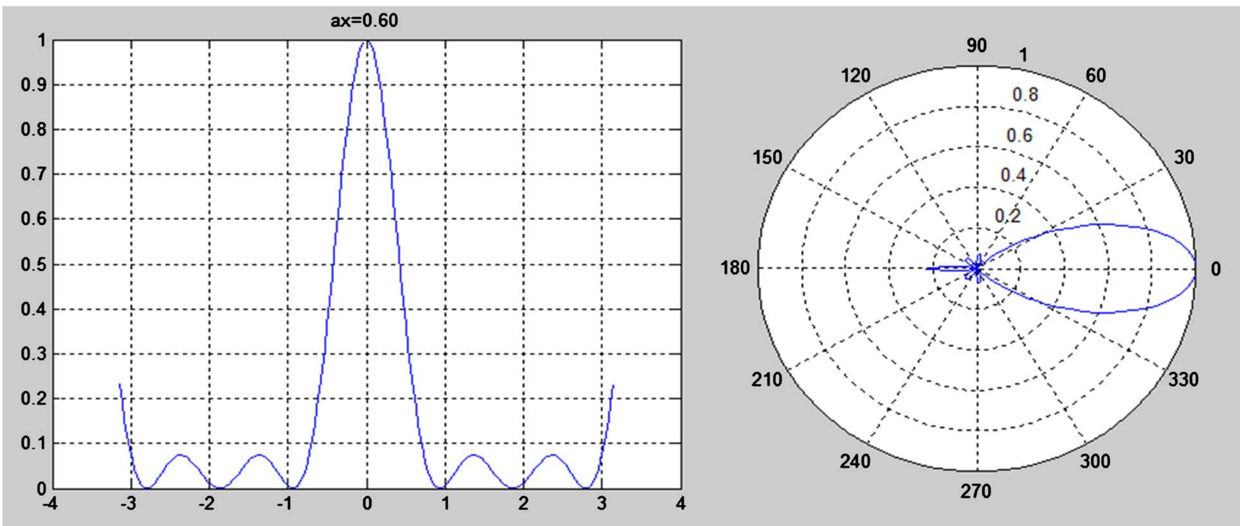
$a_x = a_y = 0.47\lambda$



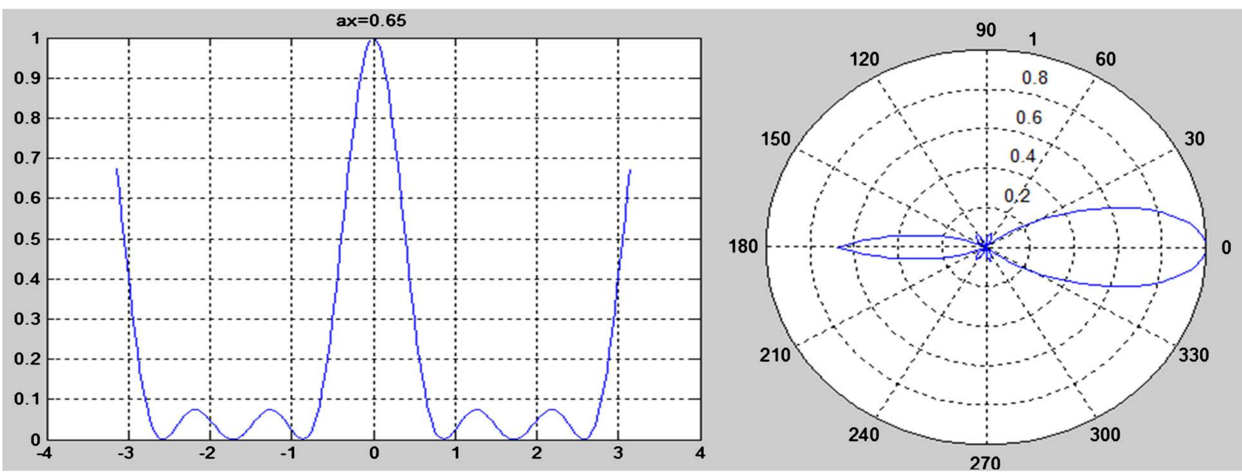
$a_x = a_y = 0.50\lambda$



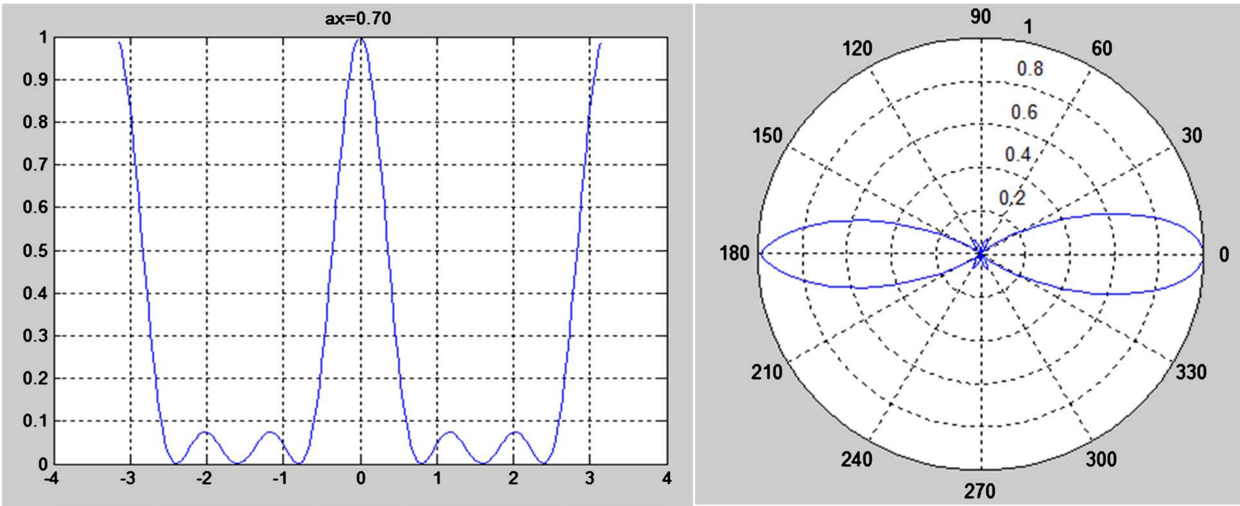
$a_x = a_y = 0.55\lambda$



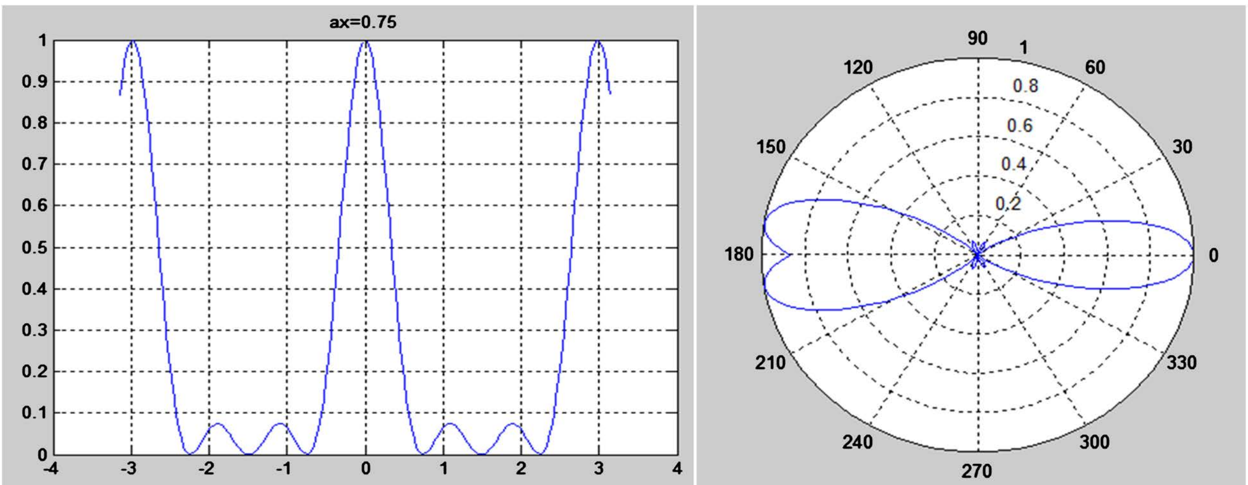
$a_x = a_y = 0.60\lambda$



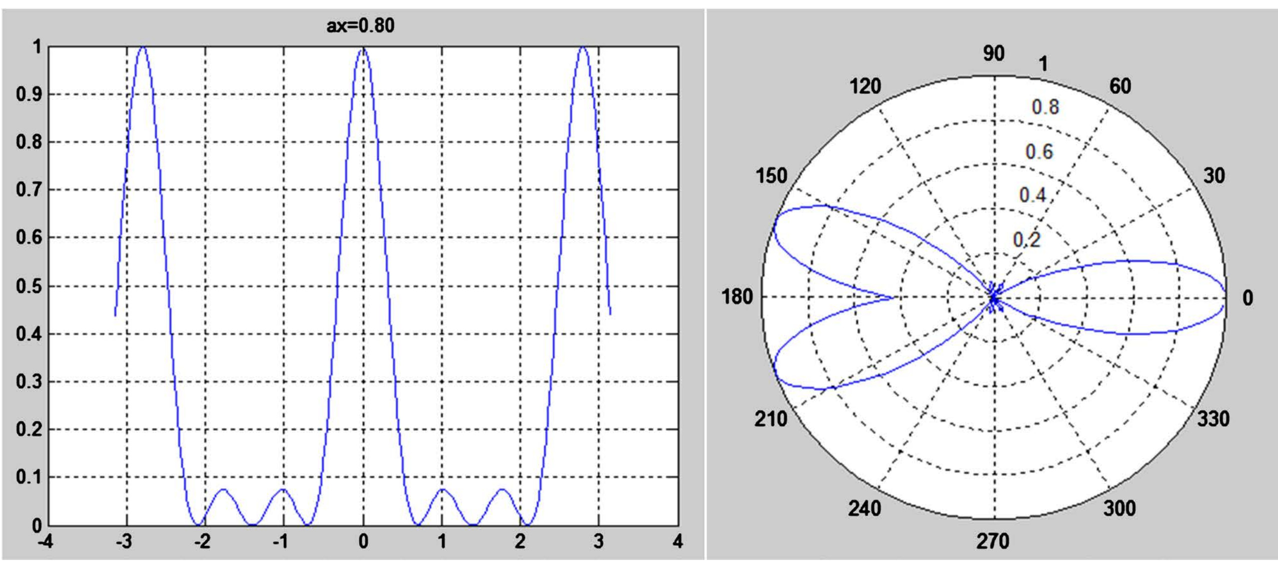
$a_x = a_y = 0.65\lambda$



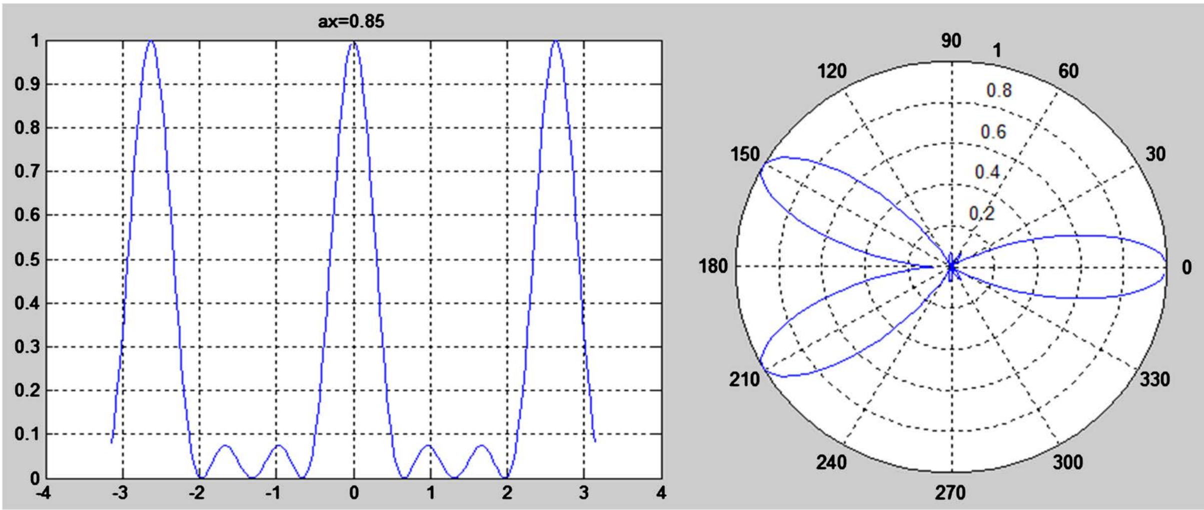
$a_x = a_y = 0.70\lambda$



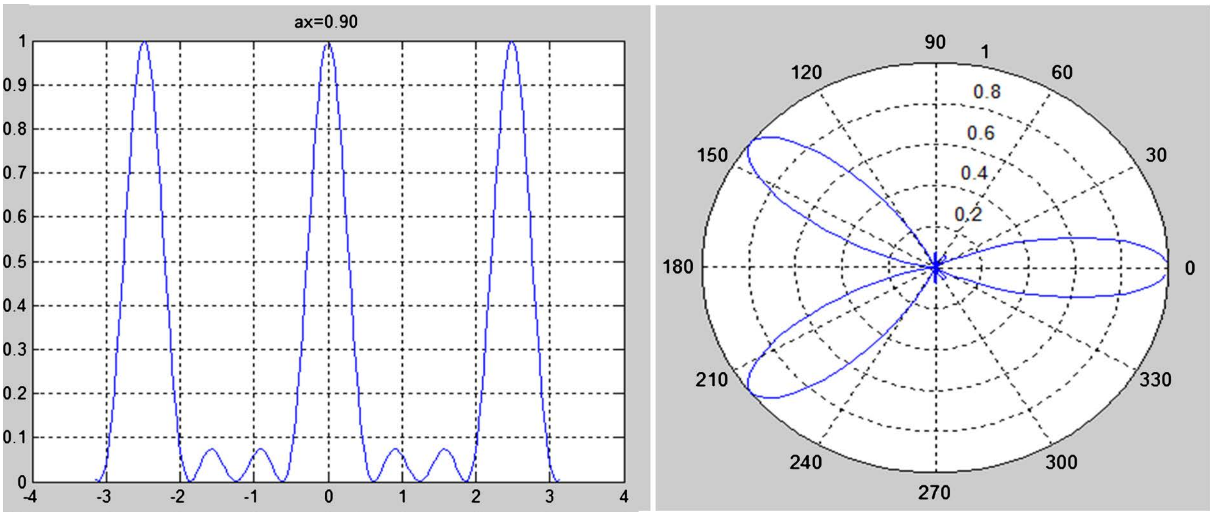
$a_x = a_y = 0.75\lambda$



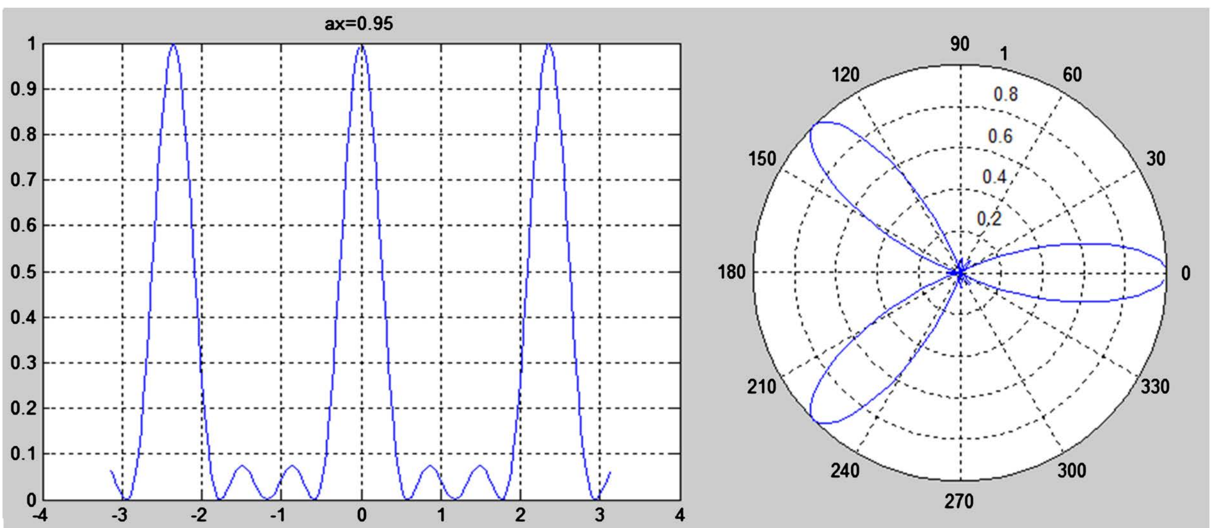
$a_x = a_y = 0.80\lambda$



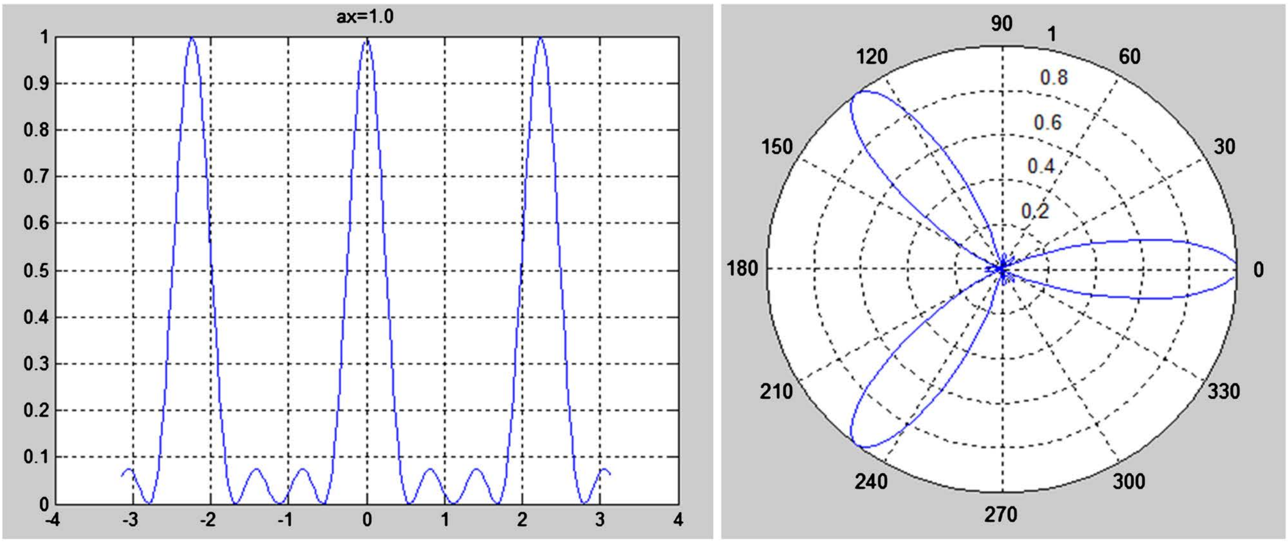
$a_x = a_y = 0.85\lambda$



$a_x = a_y = 0.90\lambda$



$a_x = a_y = 0.95\lambda$



$a_x = a_y = 1.0\lambda$

Figure 5. Radiation patterns of varying element spacing.

8. Discussion of Results

Figure 2 above shows the various simulated radiation patterns obtained by varying the inter-element spacing of the 4 × 4 matrix array. While the values of progressive phase shift and the number of elements *N*, is kept constant throughout the variation.

The results have a great effect on the array factor as it is clearly shown by radiation patterns of **Figure 2** above. Element spacing of 0.47*λ* to 0.55*λ* has broad radiation pattern and occupied large bandwidth, which decrease with increase in the spacing. But from element spacing of 0.60*λ*, the radiation patterns shows an emergence of grating lobe whose size and level increases with the increase in a_x and a_y respectively. When element spacing equals 0.70*λ*, the size of the grating lobe equals that of the main lobe in opposite direction. Further increase to 0.75*λ* shows a beginning in the split of the grating lobe. Complete splitting in the grating lobe is eminence when a_x is increased to 0.85*λ*, 0.90*λ*, 0.95*λ* and 1.0*λ*. Increasing the element spacing towards l results in an increased directivity and grating lobe effect with a maximum grating lobe amplitude equal to the main lobe magnitude at an element spacing of 1.0*λ*, see **Figure 2**.

9. Findings

After a thorough research and simulation of results as can be seen in **Table 1** and in **Figure 2** above, the following are my findings:

1) As inter-element spacing increases, the grating lobes increase in size, number and levels.

2) Increase in inter-element spacing also increases the directivity of the main lobe.

3) Increasing the spacing to 1.0*λ*, is a bad element spacing as more grating

lobes are developed equal in size and level with the main lobe.

4) Therefore, the best directivity (radiation pattern) can only be obtained when the element spacing is within 0.1 - 0.5λ.

10. Conclusion

In this paper, a low profile planar array of monopole antenna has been presented. The purpose was to design a low level grating lobe with high directivity using planar array of monopole antenna by varying the inter-element spacing within the array matrix. A 4 × 4 matrix array of monopole antennas has been used in order to enhance the directivity and directivity as high as 39.67 dB has been achieved. The results of **Table 1** and **Figure 1** above show that directivity of the radiated field decreases as the inter-elements spacing is increased.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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