

INVESTIGATION OF THE IMPACT OF NUMBER OF ELEMENTS ON THE DIRECTIVITY OF PLANAR ARRAY OF MONOPOLE ANTENNA

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Abstract:

This paper is an investigative study of the impact of the number of elements on the directivity and array factor of planar array of monopole antenna. Also, the impact on the total field radiated by the antenna is considered in this research. The main aim of this research is to study the effect of varying matrix size of a planar array of monopole antenna on its directivity and the array factor. Hadamard matrix method is used to position all the elements (monopole antennas) in their places in a planar form. The directivities of the planar array of monopole antenna with an incremental element of 5 X 5 was computed and also, radiation pattern of each incremental step was simulated and recorded using MATLAB tool. The research was done considering a set of elements from 5 X 5 to 50 X 50 planar arrangements. It was observed from the results obtained that the directivity of the antenna improved as the number of elements is increased. These results show an excellent improvement in the directivity obtained by increasing the number of elements in the planar array and a corresponding increase in the antenna array factor. Therefore, the result show that an increase in the number of elements (matrix size) affects the total field radiated by improving on the directivity of the planar array antenna and its array factor.

Keywords: Grating lobes, Array Antenna, Array factor, Directivity and Element,

1. Introduction

Planar array antennas are many antennas arranged and connected in a matrix format on a plane in order to reduce the inherent grating lobes and lobe 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 [1, 3, and 4]. In recent years, many antennas synthesis methods have been formed for planar arrays and also in recent times, there exist a burning desire in the communication industry to transmit signals over long distances at the same time keeping the gain and quality of the signal very high.

The use of single antenna like (monopole, dipole and others) [5] lacks the ability to deliver this signal at such distance with the desired signal quality, hence the development of array antenna technology [1, 6]. Planar array of monopole antenna is chosen for this research, because of its ability to transmit signal to long distances retaining the quality of the signal in terms its power and content [7]. The total field radiated as well as the directivity by this planar array of monopole antenna depends largely on the elemental parameters (inter-element spacing, number of elements and progressive phase of the array elements)

[7, 8]. But number of elements has a crucial impact on improving and enhancing the directivity of the radiated field [10].

2. Methodology

The design principles for planar arrays antennas are similar to those elements placed in two dimensions [9, 10] as shown in the antenna geometry of Figure 1. In this research, the $N=M$ and all the elements are monopole antenna with the same parameters.

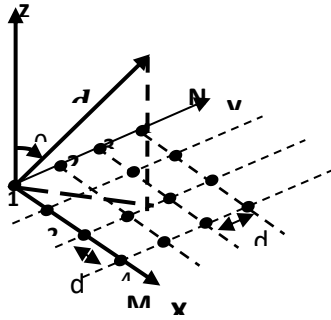


Figure 1. The geometry of $N \times M$ planar

The incremental number of elements for each step is five (5) through an incremental steps of nine (9). The last increment was 50 X 50 matrix size. For each increment, the directivity obtained was recorded as shown in Table 1. The array factor of a planar array is the multiplication of the array factors of two linear arrays, one along the x-axis and the other one along the y-axis. Therefore, planar array factor AF_{planar} is simply expressed as:

$$AF_{planar} = \left\{ \frac{1}{M} \frac{\sin\left(\frac{M}{2}\ell_x\right)}{\sin\left(\frac{\ell_x}{2}\right)} \right\} \left\{ \frac{1}{N} \frac{\sin\left(\frac{N}{2}\ell_y\right)}{\sin\left(\frac{\ell_y}{2}\right)} \right\} \quad (1)$$

Where,

$$\ell_x = ka_x \sin\theta \cos\phi + \omega_x \quad (2)$$

$$\ell_y = ka_y \sin\theta \cos\phi + \omega_y \quad (3)$$

Where ℓ_x and ℓ_y are the array phase functions along x and y axis, respectively. 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 along x and y axis respectively. Given that the phase factor ℓ_x and $\ell_y = 0$, then,:

$$\omega_x = -ka_x \sin\theta \cos\phi \quad (4)$$

$$\omega_y = -ka_y \sin\theta \cos\phi \quad (5)$$

And

$$k = 2\frac{\pi}{\lambda} \quad (6)$$

Equation(6), is the free space wave constant. The nulls of the array function are found by determining the zeros of the numerator term where the denominator is not simultaneously zero [2, 10].

3. Array Factor Determination

The array factor of a planar array antenna is obtained using equation (1). Using the progressive phase shift as $\rho_x = k a \cos\theta = 2.088134956$ and when the array is 5 X 5 elements array, the array factor is obtained as:

$$\begin{aligned} AF_n(\theta)_2 &= \left\{ \frac{1}{5} \frac{\sin\left(\frac{5}{2} \times 2.088134956\right)}{\sin\left(\frac{2.088134956}{2}\right)} \right\} \\ &= \frac{\sin(5.22033739)}{5 \sin(1.044067478)} \\ &= \frac{0.090986068}{0.091107035} \\ &= 0.997978707 \end{aligned}$$

This process was repeated to obtain the array factor as shown in Table 1.

4. The Wavelength (Lambda, λ)

The speed of electromagnetic wave on air is given by $3 \times 10^8 \text{ m/s}$, and can be obtained [1, 9] from the formula,

$$V = f\lambda \quad (7)$$

Where,

f = the frequency of the electromagnetic wave

λ = Lambda, the wavelength

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

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{2.5 \times 10^9} = \frac{3 \times 10^{-1}}{2.5} = 0.12 \text{ m}$$

5. Determination of the Directivity D of a Linear Array, N is varied.

The directivity of linear array antenna D , can be determined by the formula, of equation (8) as

$$D = \frac{2V_0^2}{1 + (V_0^2 - 1)f \frac{\lambda}{(L + a)}} \quad (8)$$

Where, V_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 [1, 2]. Let $V_0 = 20$ voltage ratio, $L = 4$, $a = 0.47$, f

Find directivity of a linear array antenna, D_1 when $N = 5$ and a_x remain constant.

$$D_1 = \frac{2V_0^2}{1 + (V_0^2 - 1)f \frac{\lambda}{(L + a)}}$$

When $N = 5$

$$D_1 = \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(5 + 0.47)}}$$

$$= \frac{2 \times 400}{1 + (400 - 1) \times 2.207732865}$$

$$= \frac{2 \times 400}{881.885413135} = \tan^{-1} 0.907147332 = 42.21 \text{ dB}$$

When $N = 10$

$$D_2 = \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(10 + 0.47)}} = \frac{2 \times 400}{1 + (400 - 1) \times 1.153419176} = \frac{2 \times 400}{461.214251224} = \tan^{-1} 1.734551779 = 60.04 \text{ dB}$$

When $N = 15$

$$D_3 = \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(15 + 0.47)}} = \frac{2 \times 400}{1 + (400 - 1) \times 0.78062694} = \frac{2 \times 400}{312.47014906} = \tan^{-1} 2.560244562 = 68.66 \text{ dB}$$

When $N = 20$

$$D_4 = \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(20 + 0.47)}} = \frac{2 \times 400}{1 + (400 - 1) \times 0.589951088} = \frac{2 \times 400}{236.390484112} = \tan^{-1} 3.384230981 = 73.54 \text{ dB}$$

When $N = 25$

$$\begin{aligned}
 D_5 &= \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(25 + 0.47)}} \\
 &= \frac{2 \times 400}{1 + (400 - 1) \times 0.78062694} \\
 &= \frac{2 \times 400}{190.181123446} = \tan^{-1}4.206516322 \\
 &= 76.63\text{dB}
 \end{aligned}$$

When $N = 30$

$$\begin{aligned}
 D_6 &= \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(30 + 0.47)}} \\
 &= \frac{2 \times 400}{1 + (400 - 1) \times 0.396334059} \\
 &= \frac{2 \times 400}{159.137289541} = \tan^{-1}5.027105855 \\
 &= 78.75\text{dB}
 \end{aligned}$$

When $N = 35$

$$\begin{aligned}
 D_7 &= \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(35 + 0.47)}} \\
 &= \frac{2 \times 400}{1 + (400 - 1) \times 0.340465147} \\
 &= \frac{2 \times 400}{136.845593653} = \tan^{-1}5.846004819 \\
 &= 80.39\text{dB}
 \end{aligned}$$

When $N = 40$

$$\begin{aligned}
 D_8 &= \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(40 + 0.47)}} \\
 &= \frac{2 \times 400}{1 + (400 - 1) \times 0.298401255} \\
 &= \frac{2 \times 400}{120.062100745} = \tan^{-1}6.66321841 \\
 &= 81.46\text{dB}
 \end{aligned}$$

When $N = 45$

$$\begin{aligned}
 D_9 &= \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(45 + 0.47)}} \\
 &= \frac{2 \times 400}{1 + (400 - 1) \times 0.265588273} \\
 &= \frac{2 \times 400}{106.969720927} = \tan^{-1}7.478751866 \\
 &= 82.38\text{dB}
 \end{aligned}$$

When $N = 50$

$$\begin{aligned}
 D_{10} &= \frac{2 \times 20^2}{1 + (20^2 - 1)1.006358231 \times \frac{12}{(40 + 0.47)}} \\
 &= \frac{2 \times 400}{1 + (400 - 1) \times 0.239276774} \\
 &= \frac{2 \times 400}{96.471432826} = \tan^{-1}8.2922610326 \\
 &= 83.12\text{dB}
 \end{aligned}$$

6. Determination of the Directivity D_0 of the Array Antenna

The directivity of an array antenna is obtained using the formula in equation (8), since the configuration of a planar array antenna consists of two linear antennas placed orthogonally to each other, the

directivity of a planar array antenna, D_0 can be obtained as [2];

$$D_0 = d_x d_y \cos \theta \quad (8)$$

Where,

d_x = The directivity of a linear array along x – axis

d_y = The directivity of a linear array along y – axis

From Table 1, the best directivity was obtained the number of elements is 50. Therefore, and $\theta = 45^\circ$

$$D_0 = d_x d_y \cos \theta$$

No. of Element	5	10	15	20	25	30	35	40	45	50
Directivity	42.	60	69	74	77	79	80	81	82	83
AF(mdB)	0.2	0.4	1.1	1.9	3.0	3.4	6	7.8	9.9	12.4

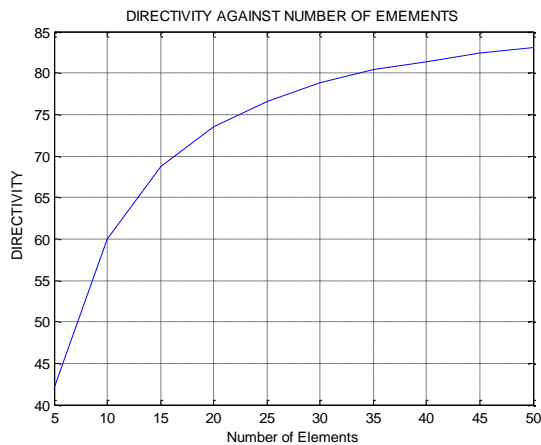


Figure 2. Graph of Number of Element and Directivity

Figure 2 is obtained from plotting number of element against Directivity. The two graphs obtained shows that as the Number of elements of the matrix array is increased, the Array Factor is decreases as well as the Directivity.

$$D_0 = 83.1 \times 83.1 \times \cos 45^\circ = 4,883dB$$

7. Result

The results presented were obtained from the computational variation of the number of elements of the planar array antenna configuration. These is presented both in Table 1 and Figures 2 and three respectively.

Table 1 Result of Varying Number of Elements on the Directivity of a Planar Array Antenna

Table 1 is constructed by the computation of varying the number of elements of the Planar Array of Monopole Antenna in both x and y -directions keeping progressive phase shift, $\theta/\phi = 45$ and inter-elements spacing = 0.47λ constant throughout the variation. The table contain the values of number of elements along both x and y -direction

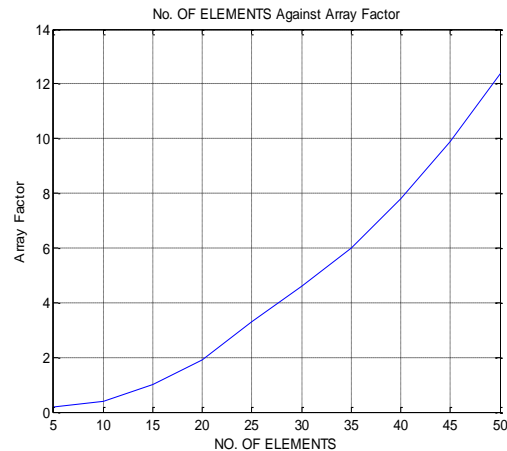


Figure 3 Graph of Array Factor and Number Element

Figure 3 is a graph of number of elements and the array factor. It shows that the array factor of the planar array antenna increases as the matrix size increases.

8. Radiation Patterns of Varying Number of Elements

This section shows the various radiation patterns obtained by varying the number of elements in the matrix array as shown in Table 1. While the values of

angles theta and phi is 45° and the inter-element spacing for both x and y axis is 0.47λ .

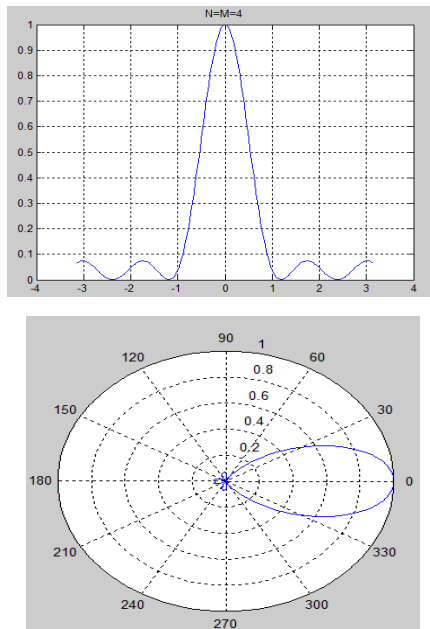


Figure 4. Directivity at 5 X 5 Matrix Elements

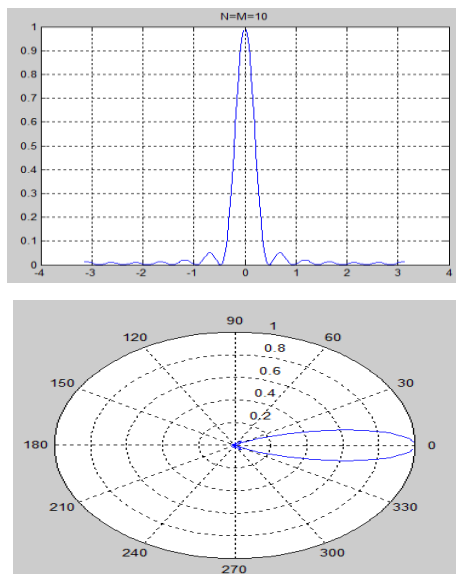


Figure 5. Directivity at 10 X 10 Matrix Elements

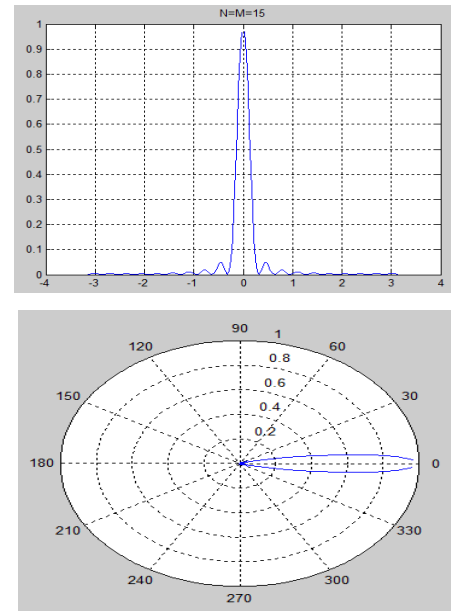


Figure 5 Directivity at 15 X 15 Matirx Eelements

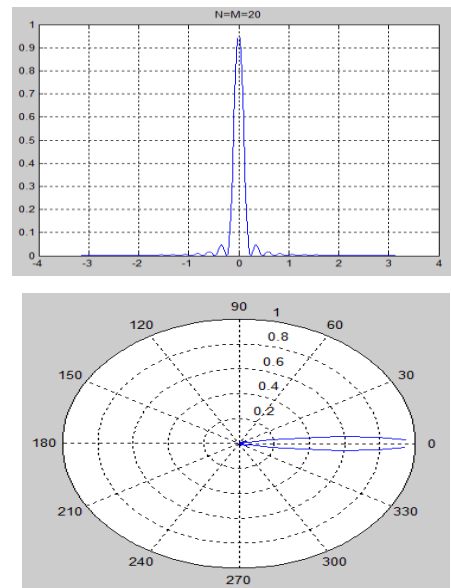


Figure 6. Directivity at 20 X 20 Matrix Elements

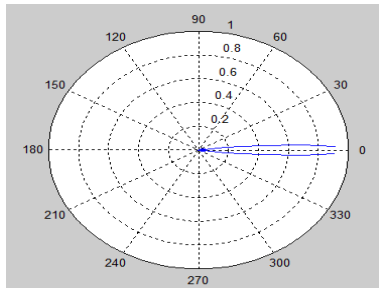
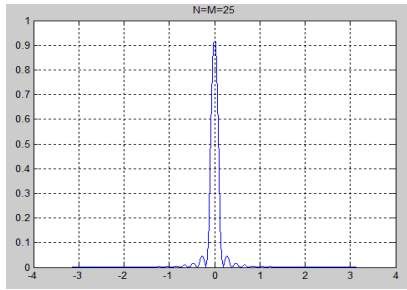


Figure 7 Directivity at 25 X 25 Matrix Elements

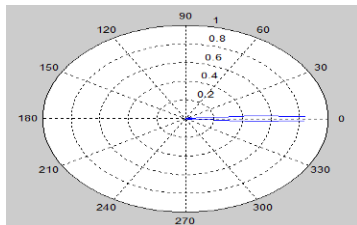
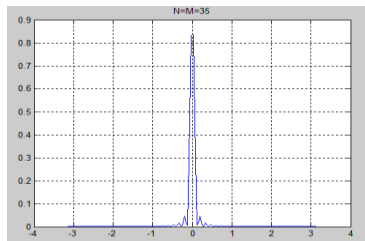


Figure 8. Directivity at 35 X 35 Matrix Element

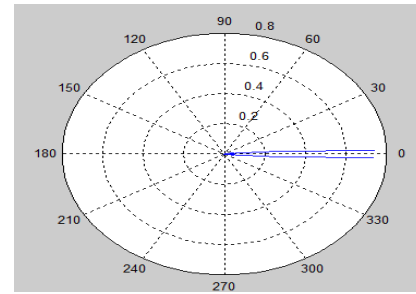
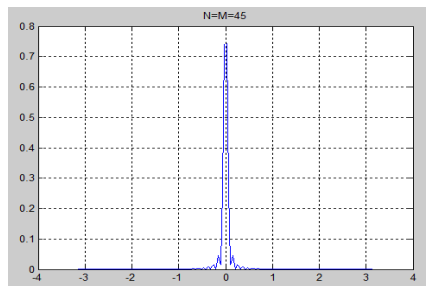


Figure 9. Directivity at 45 X 45 Matrix elements

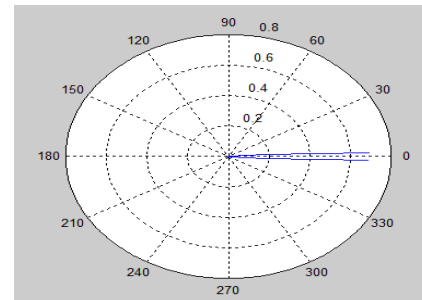
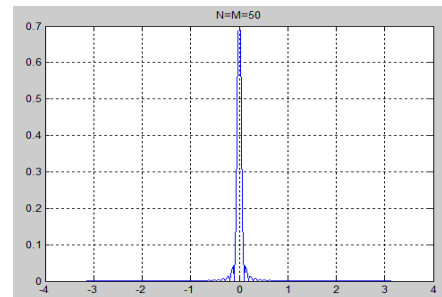


Figure 10. Directivity at 50 X 50 Matrix Element

Fig. 4 Results of Varying the number of elements on the Directivity

9. Discussion of Results

From Table 1, is made up of number of element and the corresponding values of directivity in (dB). The directivity shows a continuous increment as the number of elements is increased. For instance, for flive elements matrix, of Figure 4, the corresponding valued of the directivity of the antenna is 42.21dB. When the number element was increased to 15 X 15 matrix element of Figure 5, the value the directivity obtain is 60.66dB. And the directivity became 80dB when the number of elements was 35.X 35matrix elements of Figure 8.

The best and highest directivity is obtained when the number of elements were increased to 50 X 50 at 83.12dB. The development of side lobes main lobes reduces and shrinks drastically as the number elements are increased. In this paper, the best directivity is obtained in Figure 10. Table 1 also show that the array factor of a planar array antenna increases as the matrix size increases as shown in Figure 5 X 5 to 50 X 50 matrix size respectively. The best directivity is achieved when matrix size is increased to 50 X 50 matrix size.

10. Conclusion

The impact of number of elements on the directivity and the array factor of planar array of monopole antenna has been investigated in this paper. The purpose was to investigate the impact of varying the number of elements on the directivity of the antenna, using monopole antenna. The results of Table 1 and figure 1 shows that directivity of the radiated field increases as the matrix size is increased. It is also found that there is no development of sidelobes as the elements are increased, instead, the sidelobes shrinks as the number of elements increases. Also, the size of the main lobe shrinks as the number of elements increase from 5 X 5 to 50 X 50 elements array, the main lobe becomes more directed. Therefore, increase in the matrix size of the planar array affects the total field radiated by the antenna by improving the directivity of the main lobe of the radiation pattern and its array factor. This category of antenna find its application mostly in satellite and other line of sight communication usages.

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