International Journal of Advanced Engineering Research and Science (IJAERS) [Vol-4, Issue-5, May- 2017]
https://dx.doi.org/10.22161/ijaers.4.5.30 ISSN: 2349-6495(P) | 2456-1908(O)

Study of Broadside Linear Array Antenna with Different Spacing and Number of Elements

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***Abstract*— *A uniform linear antenna array has all its elements placed along a straight line with same spacing between them. This paper presents the comparative study of the consequences of different spacing and number of elements in terms of array factor, antenna directivity and half power beam-width (HPBW) for Broadside array. The results were obtained through the antenna parameters algorithm and simulations were done with MATLAB. The algorithm has been designed to operate with random number of elements with specific spacing. Output was studied with 2, 10, 40, 70 and 100 numbers of elements having specific spacing. The particular spacings are 0.1λ, 0.25λ, 0.5λ and 0.75λ. With the increase of number of elements and spacing between them, the directivity and array factor increases.*

Keywords*— *Algorithm, Array factor, linear antenna array, Directivity, Half power beamwidth

I. INTRODUCTION

Among the large variety of arrays of radiating elements, the simplest, type is the uniform linear array. An array is said to be Broadside array if the main beam is perpendicular to the axis of the array. This array is completely specified by the spacing and the phase progression constants [1]. Antenna exhibits a specific radiation pattern. Whenever the several antenna arrays are combined in an array, the overall radiation patters changes. This is due to the array factor which quantifies the effect of combining the radiating elements. The overall radiation pattern of an array is determined by this array factor combined with the array factor of the antenna element [2].

A uniformly spaced antenna array [3] consisting of number of elements with non-uniform amplitude distribution [4] spaced at a distance d from each other spaced along the x-axis in a horizontal manner. The elements in both cases are placed symmetrically along the x-axis about the origin and the amplitude excitation is also symmetrical about the origin. The topology for linear array is shown in Figure 1.

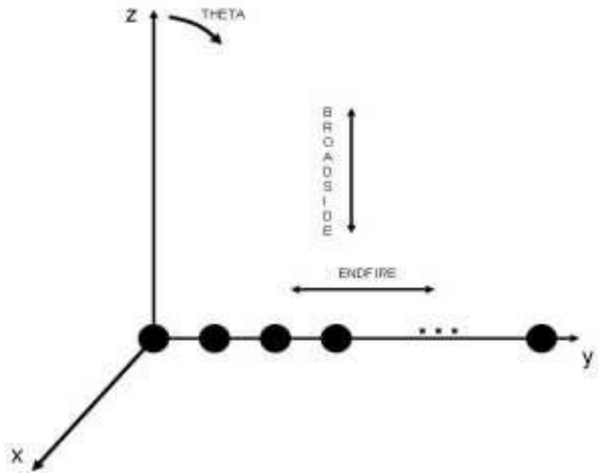

Fig.1. Topology of Linear Array

In a uniform array, the antennas are equi-spaced and are excited with uniform current with constant progressive phase shift (phase shift between adjacent antenna elements) as shown in Figure 2.

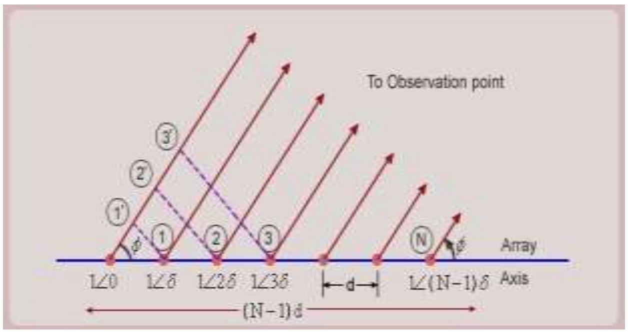

Fig.2. Uniform Antenna Array

II. ARRAY FACTOR AND DIRECTIVITY OF UNIFORM BROADSIDE ANTENNA ARRAY

The ability of an antenna to increase the quality of the performance depends on their parameters such as number of elements, spacing between elements, phase and amplitude excitation [5]. This accordingly changes the HPBW which in turn result in change in other parameters.

Array Factor

The Array Factor (AF) of the uniform array [5, 6] can be obtained by considering the individual elements as point (isotropic) sources. Then, the total field pattern can be obtained by simply multiplying the AF by the normalized

https://dx.doi.org/10.22161/ijaers.4.5.30 *ISSN: 2349-6495(P) | 2456-1908(O)*

field pattern of the individual element (provided the elements are not coupled). The AF of an N-element linear array of isotropic sources is given by:

$AF=1+e^{j(kd\,\cos\theta+\beta)} + e^{j2(kd\,\cos\theta+\beta)} + .. + e^{j(N-1)(kd\,\cos\theta+\beta)}$ (1)

The above equation (1) may be written as

$$AF = \sum_{n=1}^{N} e^{j(n-1)(kd\cos\theta+\beta)},$$

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

Where β is the progressive phase lead and Ψ=kd Cosθ+β. From above equation, it is obvious that the AFs of uniform linear arrays can be controlled by the relative phase β between the elements. The AF in equation (2) may be expressed in a closed form, which is more convenient for pattern analysis:

$$AF \cdot e^{j\psi} = \sum_{n=1}^{N} e^{jn\psi},$$

$$AF \cdot e^{j\psi} - AF = e^{jN\psi} - 1,$$

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

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

Here, N shows the location of the last element with respect to the reference point in steps of the length d. The phase factor, exp.[(N-1) Ψ/2], is not important unless the array output signal is further combined with the output signal of another antenna. It represents the phase shift of the array's phase centre relative to the origin, and it would be equal to one if the origin were to coincide with the array centre.

B. Directivity

The directivity in case of broadside array [5,6,7] is defined as

$$G_{Dmax} = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}} = \frac{U_{max}}{U_{avg}} = \frac{U_{max}}{U_0}$$

where, U0 is average radiation intensity which is given by,

$$U_0 = \frac{P_{rad}}{4\pi} = \frac{1}{4\pi}\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} |E(\theta,\phi)|^2 \sin\theta \, d\theta \, d\phi \quad (4)$$

From the expression of ratio of magnitudes we can write,

$$\left|\frac{E_T}{E_0}\right| = n$$

or

$$|E_T| = n|E_0|$$

For the normalized condition let us assume $E_0 = 1$, then

$$|E_T| = n$$

The normalized field pattern is given by

$$E_{Normalized} = \left|\frac{E_T}{E_{Tmax}}\right| = \frac{|E_0|}{n|E_0|} = \frac{1}{n}$$

Hence the field is given by,

$$\therefore \quad E_{Normalized} = \frac{\sin n\frac{\psi}{2}}{n\left(\sin\frac{\psi}{2}\right)}$$

On further derivations, we deduce the following

$$U_0 = \frac{1}{2}\int_{+\frac{n}{2}\beta d}^{-\frac{n}{2}\beta d}\left[\frac{\sin z}{z}\right]^2 \cdot \frac{dz}{-\frac{n}{2}\beta d}$$

$$\therefore \quad U_0 = -\frac{1}{n\beta d}\int_{\frac{n}{2}\beta d}^{-\frac{n}{2}\beta d}\left[\frac{\sin z}{z}\right]^2 dz \quad (5)$$

For large array, n is large hence nßd is also very large.

C. The Half Power Beam Width

For a given array, the HPBW is a function of the direction of the main beam. The HPBW is minimum for a broadside direction [8]. For large arrays, the HPBW is approximately taken as half of the BWFN.

$$\varphi_{BS} = \frac{\lambda}{dN} = \frac{\lambda}{\text{Length of the array}}$$

III. SIMULATION OF N-ELEMENT FOR DIFFERENT SPACING ELEMENTS OF BROADSIDE LINEAR ARRAY ANTENNA

In this section, the simulation method using MATLAB tool has been described where the HPBW and directivity was compared with the increasing number of elements and their spacing. The MATLAB Codes were run in MATLAB version R2015b and presented in tabular form as shown in Table 1.

The simulations started with 2, 10, 40, 70 and 100 elements in linear array with a spacing of .01λ, 0.25λ, and 0.5λ. The graphical results obtained for the later four are illustrated in Figure 1(a)-4(f).

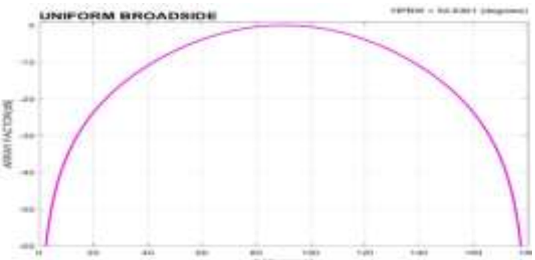

Fig. 1(a): HPBW with 10 elements, 0.1λ spacing

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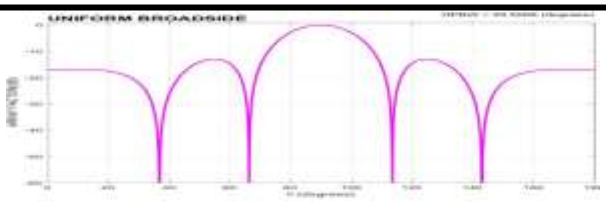

Fig. 1(b): HPBW with 10 elements, 0.25λ spacing

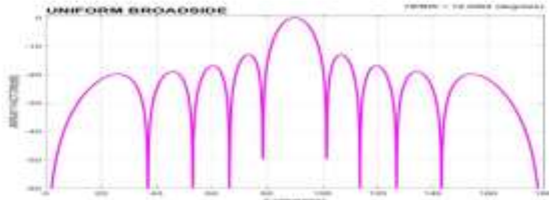

Fig. 1(c): HPBW with 10 elements, 0.5λ spacing

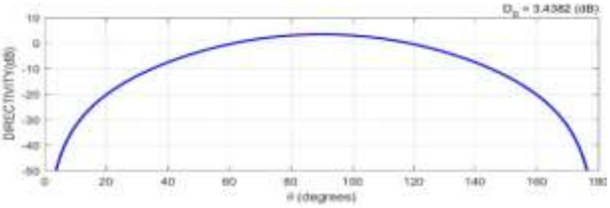

Fig. 1(d): Directivity(dB) with 10 elements, 0.1λ spacing

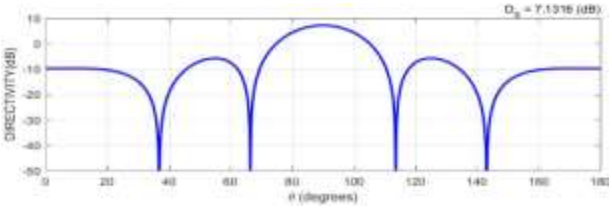

Fig. 1(e): Directivity(dB) with 10 elements, 0.25λ spacing

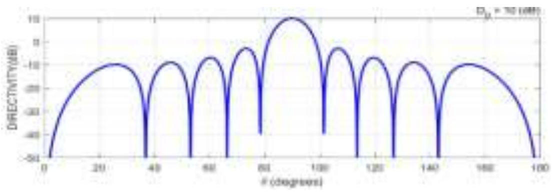

Fig. 1(f): Directivity (dB) with 10 elements, 0.5λ spacing

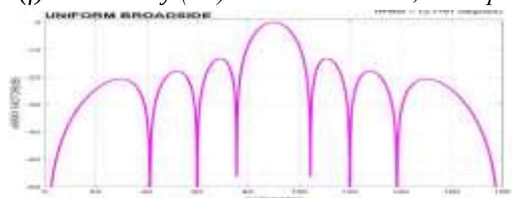

Fig. 2(a): HPBW with 40 elements, 0.1λ spacing

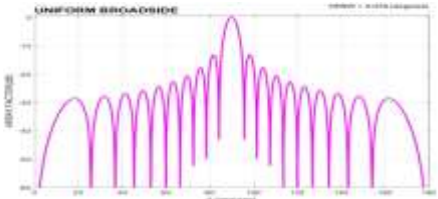

Fig. 2(b): HPBW with 40 elements, 0.25λ spacing

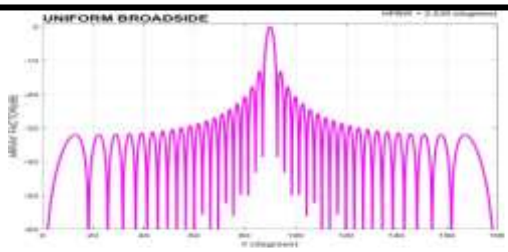

Fig. 2(c): HPBW with 40 elements, 0.5λ spacing

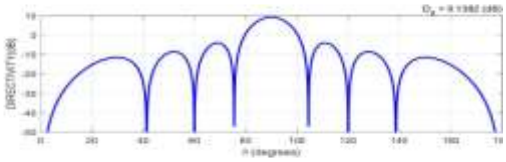

Fig. 2(d): Directivity (dB) with 40 elements, 0.1λ spacing

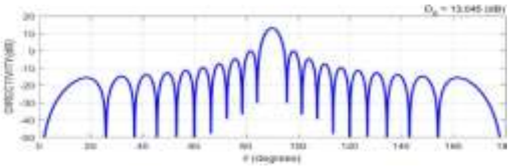

Fig. 2(e): Directivity (dB) with 40 elements, 0.25λ spacing

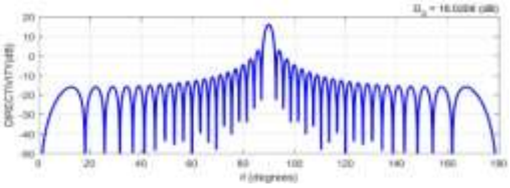

Fig. 2(f): Directivity (dB) with 40 elements, 0.5λ spacing

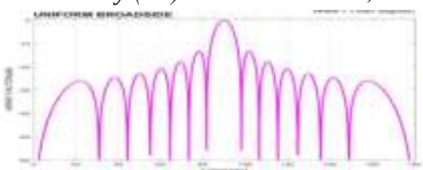

Fig. 3(a): HPBW with 70 elements, 0.1λ spacing

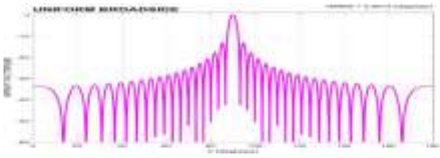

Fig. 3(b): HPBW with 70 elements, 0.25λ spacing

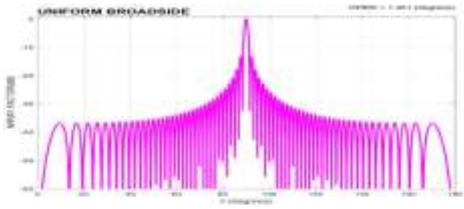

Fig. 3(c): HPBW with 70 elements, 0.5λ spacing

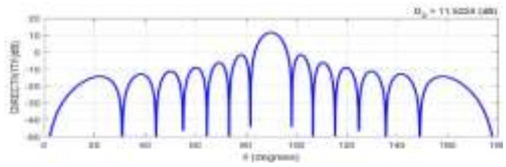

Fig. 3(d): Directivity (dB) with 70 elements, 0.1λ spacing

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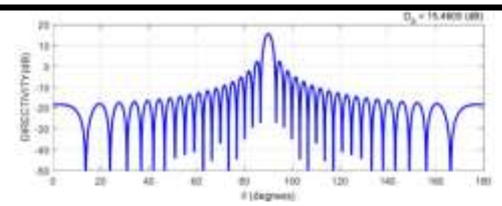

Fig. 3(e): Directivity (dB) with 70 elements, 0.25λ spacing

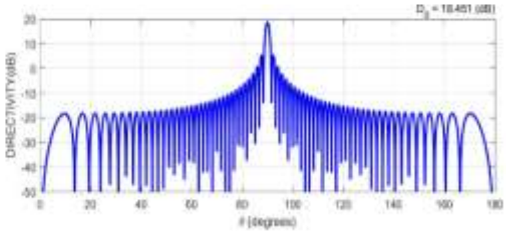

Fig. 3(f): Directivity (dB) with 70 elements, 0.5λ spacing

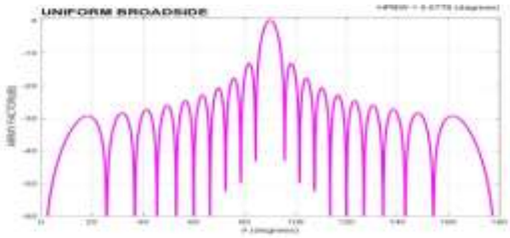

Fig. 4(a): HPBW with 100 elements, 0.1λ spacing

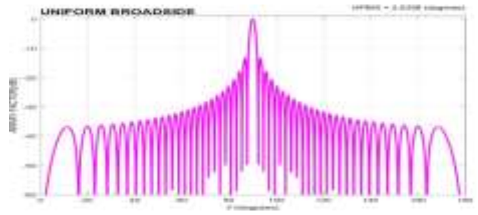

Fig. 4(b): HPBW with 100 elements, 0.25λ spacing

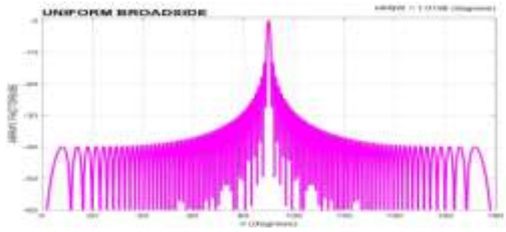

Fig. 4(c): HPBW with 100 elements, 0.5λ spacing

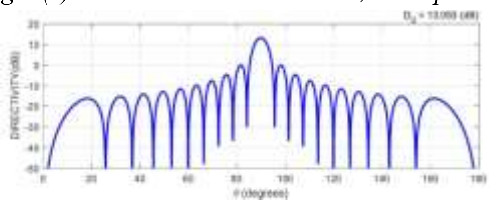

Fig. 4(d): Directivity (dB) with 100 elements, 0.1λ spacing

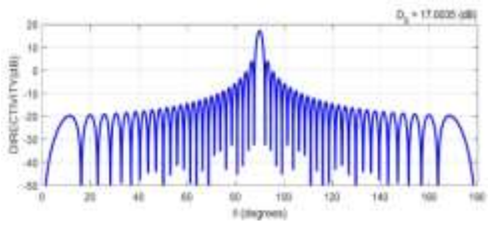

Fig. 4(e): Directivity (dB) with 100 elements, 0.25λ spacing

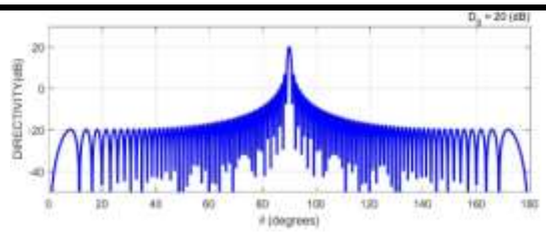

Fig. 4(f): Directivity (dB) with 100 elements, 0.5λ spacing

The above simulations is presented in tabular form in table 1

Table 1: HPBW and Directivity (D, dB) for elements N = 2, 10, 40, 70 and 100 at 0.1λ, 0.25λ and0.5λ spacing elements.

	0.1λ		0.25λ		0.5λ	
N	HPBW	D(dB)	HPBW	D(dB)	HPBW	D(dB)
2	91.83◦	0.1424	75.09◦	0.878	60.000◦	3.010
10	52.83◦	3.438	20.50◦	7.132	10.209◦	10.000
40	12.72◦	9.138	5.079◦	13.045	2.539◦	16.021
70	7.25◦	11.522	2.901◦	15.460	1.451◦	18.451
100	5.008◦	13.198	2.031	17.003	1.015◦	20.000

The HPBW is decreasing with the increasing of number of elements with specific Spacing in between them. However, if we carry out the study according to the same number of elements with varying spacing, the HPBW decreases and the Directivity increases with the increment in element spacing. For example When N=10 with element spacing of 0.1λ to 0.5λ, the half power beam width goes on decreasing from 52.8◦ for 0.1λ, 20.50◦ for 0.25λ and 10.209 for 0.5λ .In this condition, the directivity goes on increasing from 3.4383 dB for 0.1λ to 10 dB for 0.5λ.

IV. FUTURE SCOPE

Better results may be obtained in terms of directivity and HPBW with the application of Evolutionary Algorithms like Genetic Algorithm, Particle Swarm Optimization technique, QPSO technique etc. The performance of the antenna due to larger number of array elements may cause formation of grating and unwanted lobes which may be improved further.

V. CONCLUSION

This paper focuses on the investigations that are carried out with respect to the number of antenna elements used in a broadside linear antenna array for different spacing and number of elements. A thorough examination has been made with respect to the array factor, HPBW and directivity of the arrays. It has been observed that more the number of elements, better is the directivity. Also, lesser the spacing between antenna elements, more is the HPBW. This paper presents the practical consequences of the number of elements present in the array and their spacing on Directivity ad HPBW. These results are directly applicable for planar array of the Broadside Uniform Planar Linear Array.

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