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Radiation Patterns of Different Tapered Excitations

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Abstract: *Several excitations are possible either for line sources or arrays of different radiating elements. However, in this work, different types are considered and radiation patterns are numerically computed. It has been possible, to generate low sidelobe, low beamwidth patterns. The patterns are extremely useful in high resolution radars, and EMC systems.*

I. Introduction:

Antenna array pattern synthesis has received much attention as antenna arrays and their application in different communication systems such as radar, sonar, satellite and wireless. The communication systems depend heavily on the antenna arrays for their performance. In many communication systems the main focus is on point to point communication and much more highly directive beam of radiation can be used to advantage [1 - 3].

The performance of a single antenna element is limited due to lack of high directivity; desired side lobe level is not always achieved, narrow beam width and uncontrollable null positions being the other problems. These problems can be addressed using suitable configuration of an array of antenna elements. Hence, by arranging elementary radiators into an array, a more directive beam of radiation can be obtained [4]. Synthesizing an array antenna depends on several matters, like requirements on the radiation pattern, directivity pattern etc.

The purpose of antenna array synthesis is to appropriate excitation vector and layout of the array that produces the radiation pattern which is closest to the desired pattern. Various techniques have been developed to array synthesis. Classic techniques such as the Dolph – Chebyshev and Taylor methods have many practical difficulties in the array design especially if there are some restricted conditions [5-6].

In antenna design technique, it is possible to use uniform and non-uniform distributions. The design of array antennas, the design of line source to produce a radiation pattern with prescribed properties like small beam width of the main lobe and low sidelobes is extremely useful. The design of such line sources have been considered by several authors [7-9]. The concept of line source can be applied to any antenna which consists of a long, narrow and straight geometry.

It is well known that narrow beams are produced for maximum directivity from a line source of specified length meeting desired sidelobe levels. However sidelobe suppression may not be required in all the directions for certain applications. In this connection it may be pointed out that the Taylor's pattern is not optimum in same applications [10].

The patterns generated in the present paper are from line source as well as discrete arrays of identical radiators and the patterns are controlled using amplitude and phase distributions. Both line source and discrete arrays radiation pattern results are almost the same.

In view of the above considerations, some studies are carried out to obtain some useful narrow radiation beams from an array of isotropic radiators. The proposed amplitude and phase distributions yield the desired radiation beams. The patterns computed in sinθ-domain, the overall directional characteristics are described in terms of different side lobe levels and null to null beam width. The results are obtained from isotropic arrays, which are excited from with the proposed amplitude and phase distributions.

Formulation:-

Line source is defined as a continuous distribution of current along a line segment. A typical line source is shown in Fig. 1

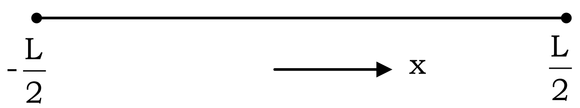

Fig. 1 Line source

Here, the aim is to design amplitude distribution for a specified radiation pattern. Let L be the length of the line source. Then the normalized space facto r is given by

$$E(\phi) = \int_{-L/2}^{L/2} A(x) e^{j(K\sin\phi + F(x)_e)x} dx$$

$$= \int_{-L/2}^{L/2} A(x) e^{jyx} dx \qquad (1)$$

Here, x is a point on the line source.

$$y = K\ \sin\phi + F(x) \qquad \text{or}$$

$$\phi = \sin^{-1}\left(\frac{y - F(x)}{K}\right) \qquad (2)$$

$F(x)$ = Excitation phase

$A(x)$= Desired amplitude distribution

$E(\phi)$ = Desired radiation pattern

Although the amplitude distribution extends from $-L/2$ to $L/2$ only, the limits can be extended to infinity in (3). Hence, using the concept of Fourier Transform, the field expression is written as

$$E(\phi) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} A(x) e^{jyx} dx \qquad (3)$$

Equation (3) represents Fourier Transform and it relates amplitude distribution $A(x)$ of a continuous source to its radiation pattern, $E(\phi)$. Therefore, its corresponding Transform pair is given by

$$A(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} E(y) e^{-jxy} dy \qquad \text{or}$$

$$A(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} E(\phi) e^{-jxy} dy \qquad (4)$$

Here $E(\phi)$ represents specified radiation pattern and $A(x)$ is the required amplitude distribution.
For a line source, the normalized amplitude distribution is given by

$$A(x) = \int_{-\infty}^{\infty} E(\phi) e^{-jxy} dy \text{ for } -L/2 \le x \ge L/2$$
$$= 0 \text{ elsewhere} \qquad (5)$$

When the amplitude distribution is uniform, it is well known that the radiation pattern contains one main lobe with a set of side lobes. The first side lobe level is found to be -13.5 dB. As such patterns are not useful in communications and radar applications because of the high side lobe levels, the amplitude distribution is redesigned to reduce the side lobe levels.

In the view of the above facts, an expression for amplitude distribution is derived using Taylor's approach. This approach has the advantage over the other distributions as it is possible to keep the desired number of side lobes at equal heights.

For the sake of completeness, the Taylor's distribution method is briefly presented. Taylor has reported a method of design of line source for narrow beam width and low side lobes. A continuous line source is considered to be an array of large number of elements placed along a line of finite length. It means that there is no spacing between the elements. It is purely theoretical case but does not exist practically. The patterns of continuous line source appear in the form of radiation integral. The amplitude distribution for a continuous line source is a function of only one coordinate. In pattern calculations the question of element pattern does not arise as the elements are considered to be point sources. A point source is in fact dimensionless one.

A typical line source and its geometry is shown in fig. 2. Let L be the length of the line source. $A(x)$ be the amplitude distribution function. The pattern function is in the form of

$$E(u) = \frac{2\pi}{\lambda}\int_{-\infty}^{\infty} A(x)e^{j\frac{2\pi L}{\lambda}ux}dx \qquad (6)$$

Here, $u = \sin\theta$

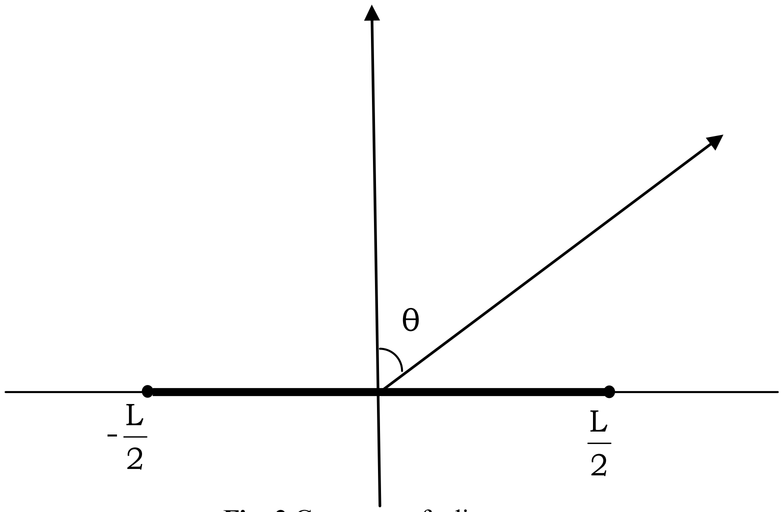

Fig. 2 Geometry of a line source

The above expression is obtained from Fourier Transform relationship. It is evident that the above integral can be disintegrated into three integrals

i.e. $$\int_{-\infty}^{\infty} = \int_{-\infty}^{-L} + \int_{-L}^{L} + \int_{L}^{\infty}$$

First and last integrals vanish, as amplitude distribution is zero in both cases.
Therefore the equation (6) now becomes

$$E(u) = \frac{2\pi}{\lambda}\int_{-L}^{L} A(x)e^{j\frac{2\pi L}{\lambda}ux}dx \qquad (7)$$

For the design of a practical line source, let the practical space factor be

$$E_1(Z, A) = \cos\pi\sqrt{\left(\frac{Z}{\sigma}\right)^2 - A^2} \qquad (8)$$

Here, $$\sigma = \frac{\overline{n}}{\sqrt{A^2 + \left(\overline{n} - \frac{1}{2}\right)^2}}$$

$\overline{n}$ is an integer which divides the relation pattern into uniform side lobe region surrounding the main beam and the region of decaying side lobes. The entire function can be constructed using the zeros

$$Z_n = \pm\sigma\sqrt{A^2 - \left(\overline{n} - \frac{1}{2}\right)^2} \text{ for } 1 \le n \le \overline{n}$$

$$(9)$$

$$= \pm n \text{ for } \overline{n} \le n \le \infty$$

The entire function with above zeros using canonical product is

$$E(Z, A, \overline{n}) = C \prod_{n-1}^{\overline{n}-1}\left\{1 - \frac{Z^2}{\sigma^2\left[A^2 + \left(n - \frac{1}{2}\right)^2\right]}\right\} \qquad (10)$$

Here, C is an arbitrary constant and is equal to $\cosh \pi A$.
Finally, the expression for desired pattern is given by

$$E(u) = \cosh(\pi A)\frac{\sin(u)}{u} \prod_{n-1}^{\bar{n}-1} \left[\frac{1 - \dfrac{(u)^2}{\sigma^2 \pi^2 \left\{ A^2 + \left(n - \dfrac{1}{2} \right)^2 \right\}}}{\left\{ 1 - \dfrac{(u)^2}{(\pi n)^2} \right\}} \right] \tag{11}$$

Using (11), the amplitude distribution of the array is found. Applying Woodward's method, the aperture distribution $A(x)$ is given by

$$A(x) = \sum_{n=-\infty}^{\infty} a_n e^{-jn\pi x} \tag{12}$$

Here, $x = X/(L/2)$, x is being the variable point on the array.
The pattern $E(u)$ related to $A(x)$ is given by

$$E(u) = \int_{-1}^{1} A(x) e^{jux} dx \tag{13}$$

From (12) and (13) we get,

$$E(u) = \sum_{n=1}^{\infty} a_n \frac{\sin(u - n\pi)}{u - n\pi} \tag{14}$$

This gives

$$a_n = E(u) \big/ u - n\pi \tag{15}$$

Therefore, the expression for $E(u)$ reduces to

$$E(u) = \sum_{n=1}^{\infty} E(n\pi) \frac{\sin(u - n\pi)}{(u - n\pi)} \tag{16}$$

The aperture distribution is obtained in the form of

$$A(x) = a_0 + \sum_{n=1}^{\infty} 2a_n \cos(n\pi x) \tag{17}$$

i.e

$$A(x) = E(0) + 2\sum_{n=1}^{\infty} \left[E(n\pi) \cos(n\pi x) \right] \tag{18}$$

and $E(n\pi) = 0$ for $n \geq \bar{n}$

In this work the proposed amplitude and phase distributions are obtained for specified sidelobe level of -35dB. The variation excitation levels of line source and discrete array are shown in Figs (4 – 13 & 18 -27).

Proposed amplitude and phase distributions: - The radiation pattern depends on amplitude, phase and space distribution functions. However in the present work sum pattern is produced from suitable proposed amplitude and phase distributions.

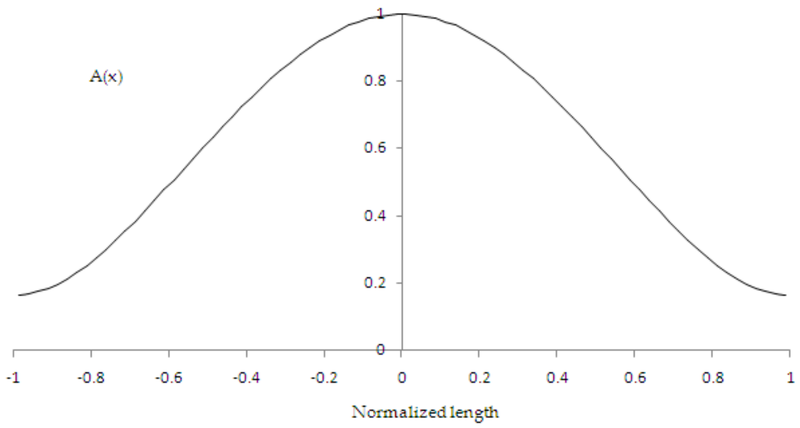

Fig. 3 amplitude distribution for $\overline{n}$ = 6 and SLL = -35 dB

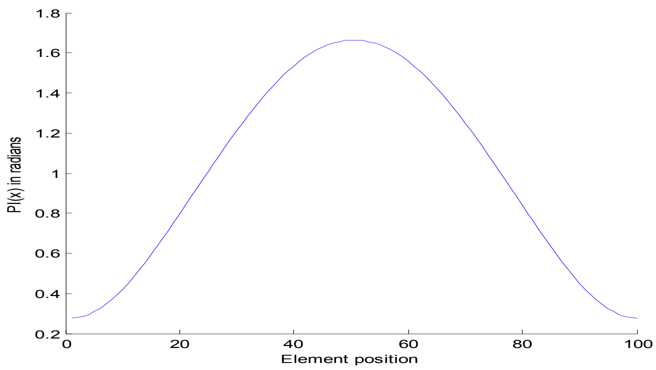

Fig. 4 phase distribution

II. Results:

Expression (18) is evaluated numerically and appears in the following form.
a(x)=1.0+2.0*(0.3432984*cos(pi*x)- 0.01510711*cos(2.0*pi*x)+0.004048508*cos(3.0*pi*x)- 0.0004369425*cos(4.0*pi*x)- 0.000344895*cos(5.0*pi*x)).

The amplitude and phase distributions are presented in fig. 3 - 4. The radiation patterns are numerically computed for line source and discrete arrays and they are presented in fig. 5-14 & fig. 19-28. The variation of first, second, last sidelobe levels and null to null beam width for different line sources and discrete arrays are presented in fig.14-17 & fig. 28-31.

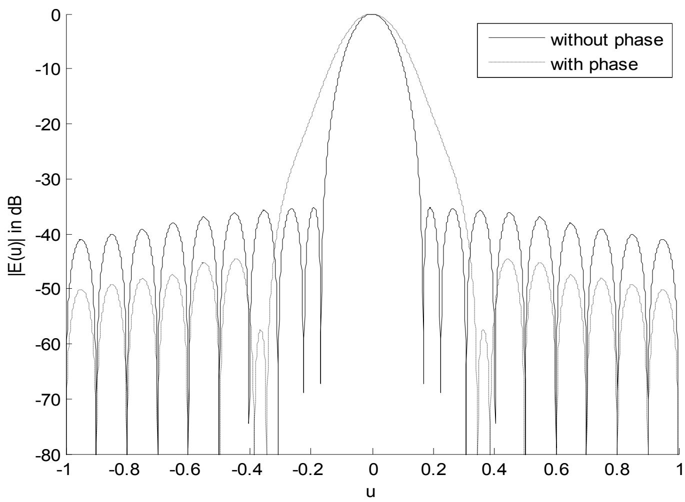

Fig. 5 2L/λ=10

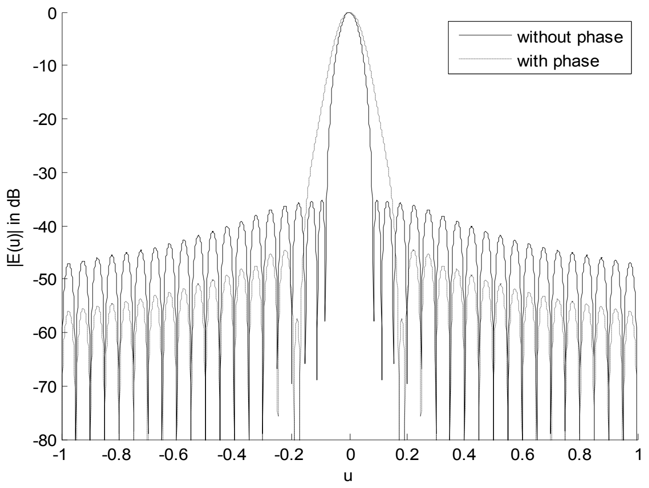

Fig. 6 2L/λ=20

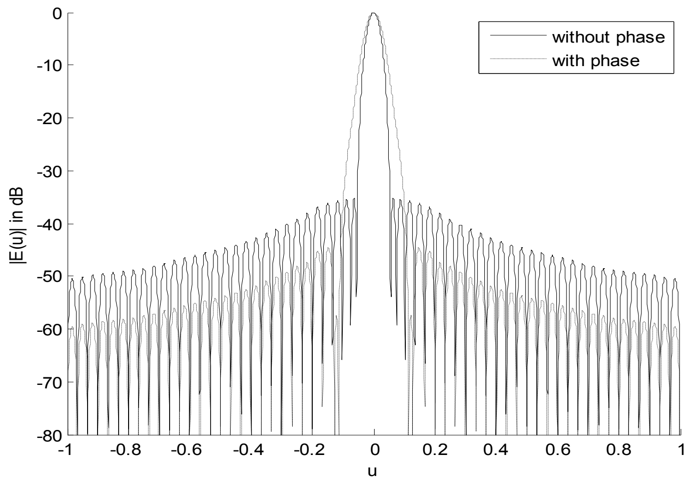

Fig. 7 2L/λ=30

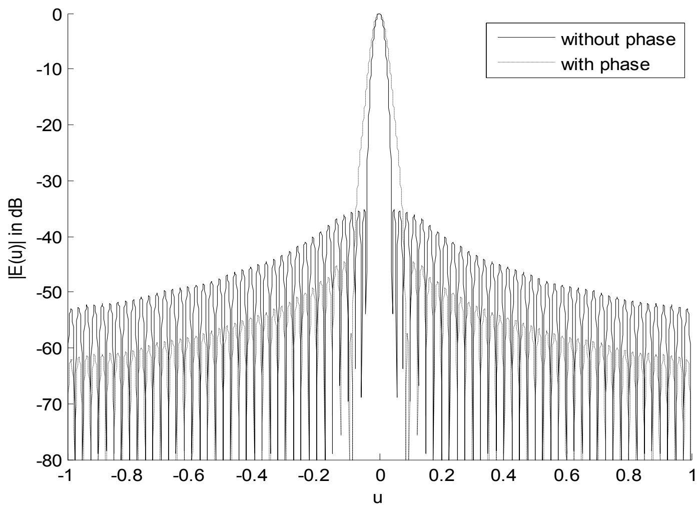

Fig. 8 2L/λ=40

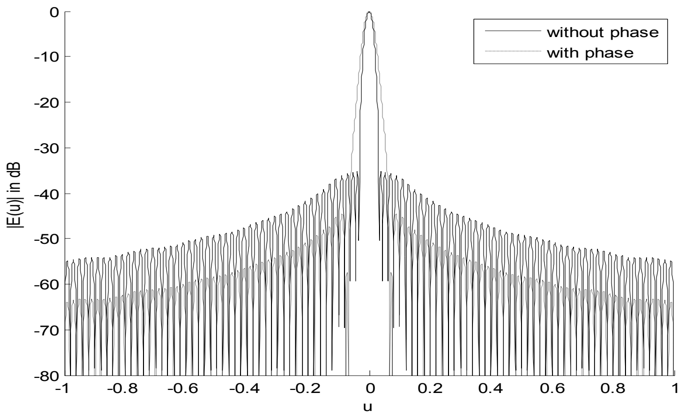

Fig. 9 2L/λ=50

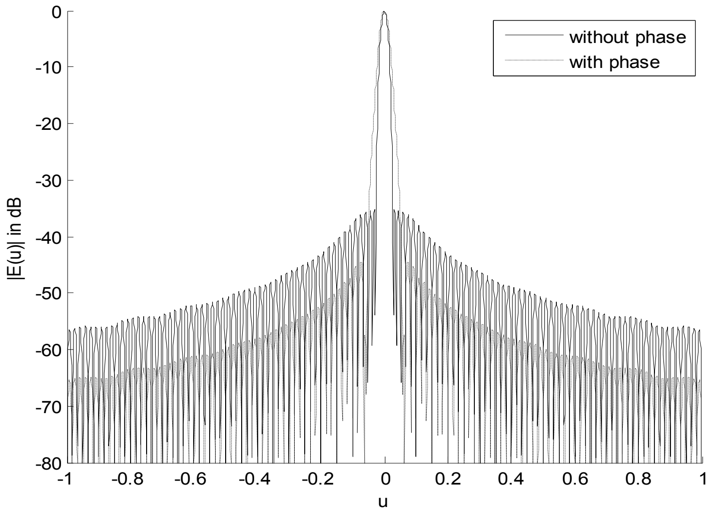

Fig. 10 2L/λ=60

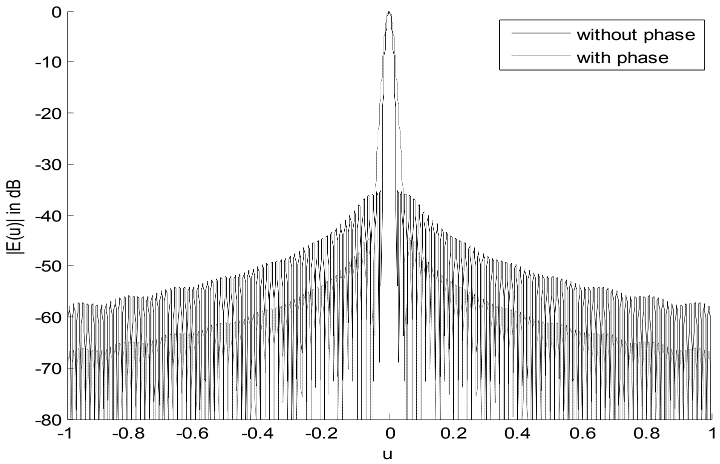

Fig. 11 2L/λ=70

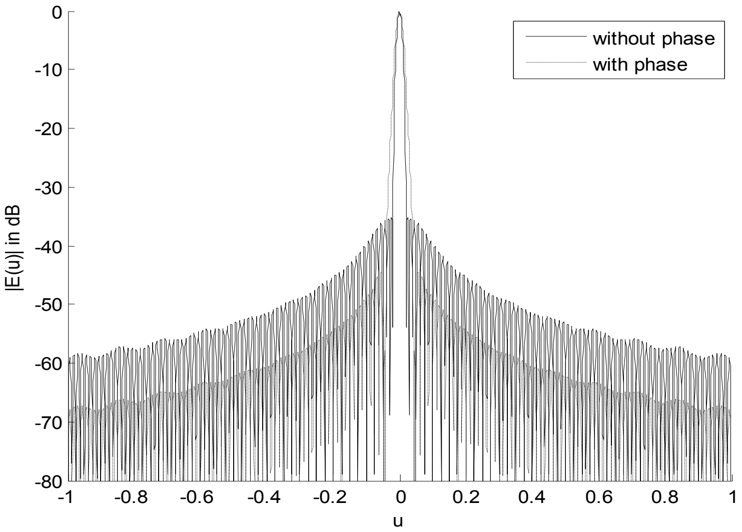

Fig. 12 2L/λ=80

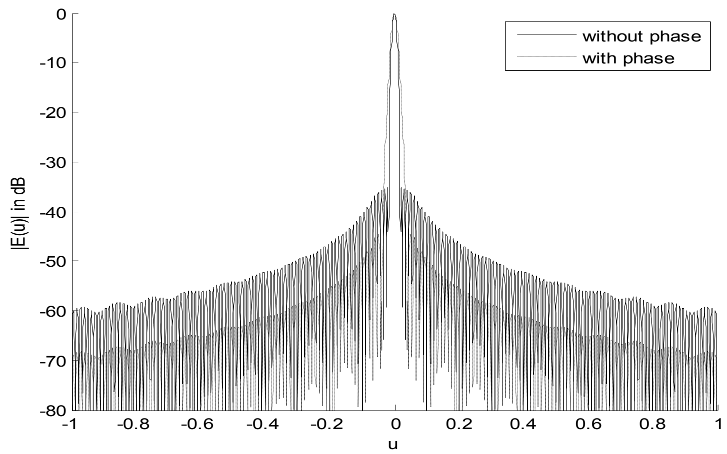

Fig. 13 2L/λ=90

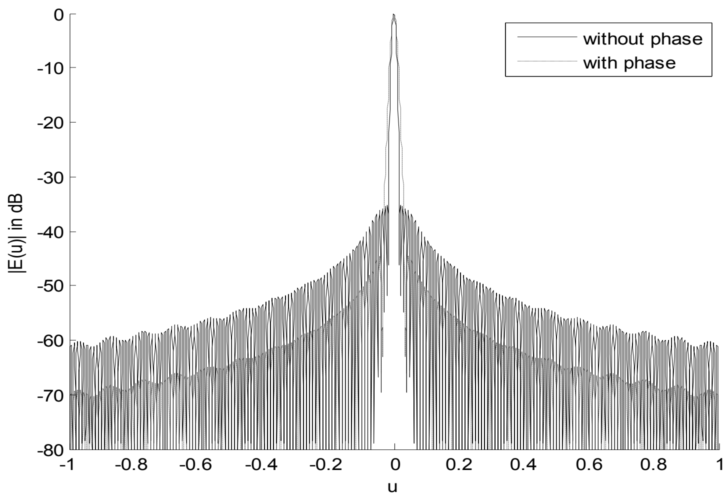

Fig. 14 2L/λ=100

		A(X)				A(X) + ϕ(X)			
S.NO	N	B.W	1ST SLL	2nd SLL	LAST SLL	B.W	1ST SLL	2nd SLL	LAST SLL
1.	10	0.3384	35.22	35.44	41.01	0.7423	57.32	44.53	50.07
2.	20	0.1168	35.22	35.44	46.99	0.3447	57.33	44.53	56
3.	30	0.1122	35.23	35.44	50.52	0.2259	57.32	44.53	59.51
4.	40	0.0840	35.27	35.44	53.02	0.1708	57.33	44.53	62.01
5.	50	0.0660	35.22	35.46	54.93	0.1364	57.39	44.53	63.90
6.	60	0.0560	35.27	35.44	56.52	0.1142	57.57	44.53	65.48
7.	70	0.0480	35.23	35.49	57.82	0.0981	57.33	44.56	66.78
8.	80	0.0420	35.27	35.44	58.96	0.0840	57.57	44.58	67.92
9.	90	0.0380	35.23	35.46	60.02	0.0760	57.57	44.56	68.68
10.	100	0.0340	35.22	35.49	60.83	0.0700	57.57	44.58	69.77

Table. 1 For line source

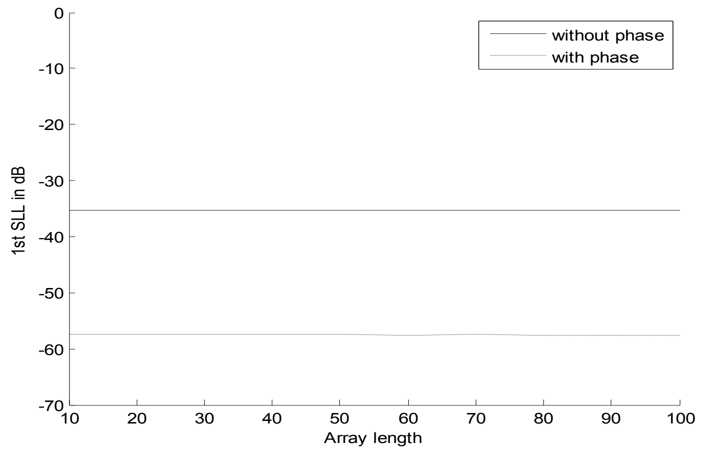

Fig.15 Variation of first side lobe level as a function of array length for with and without phase.

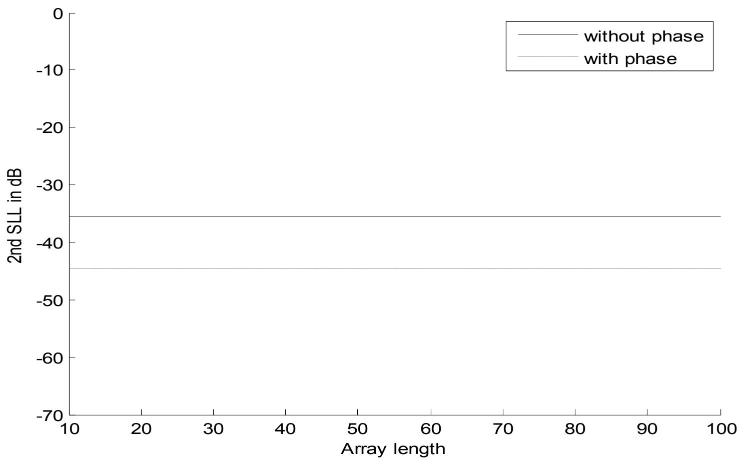

Fig.16 Variation of 2nd side lobe level as a function of array length for with and without phase.

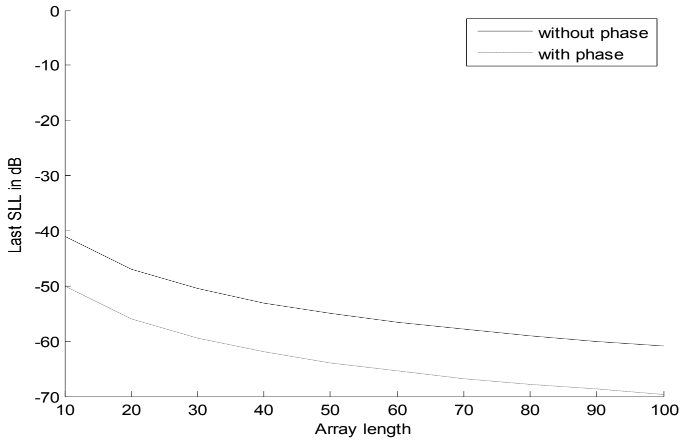

Fig.17 Variation of last Side lobe level as a function of array length for with and without phase.

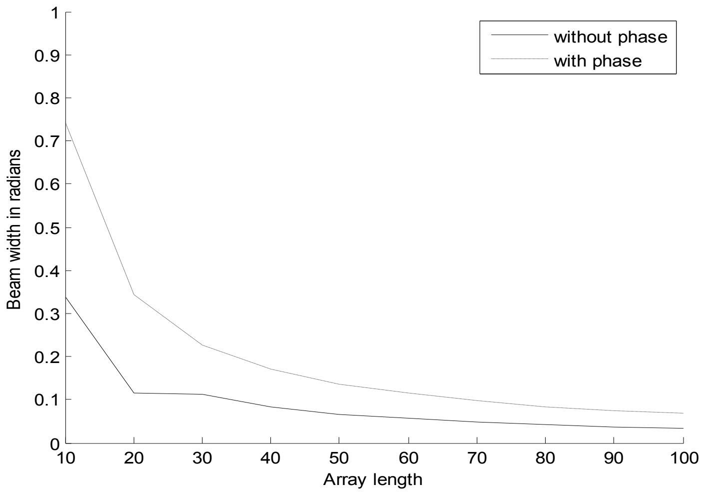

Fig.18 Variation of beam width as a function of array length for with and without phase.

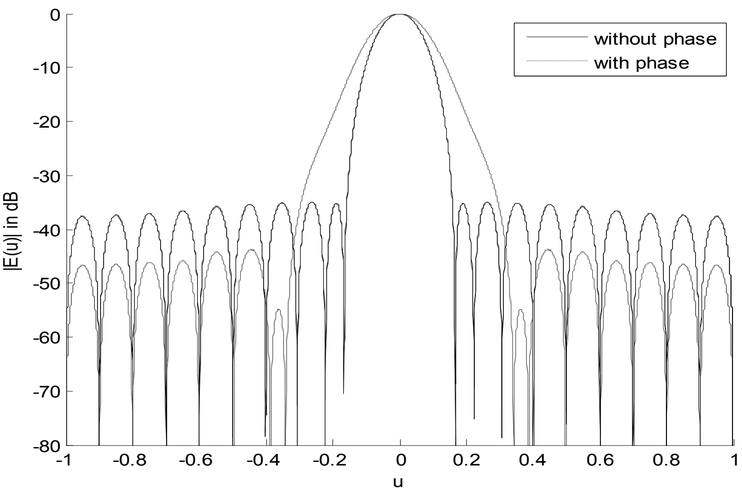

Fig.19 N=20

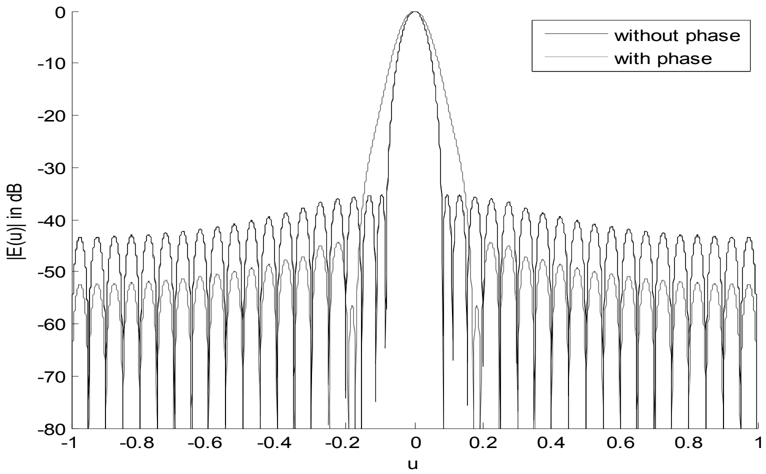

Fig. 20 N=40

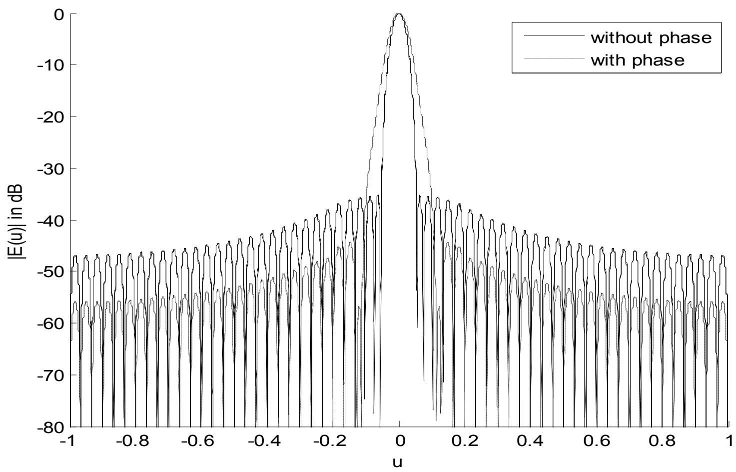

Fig.21 N=60

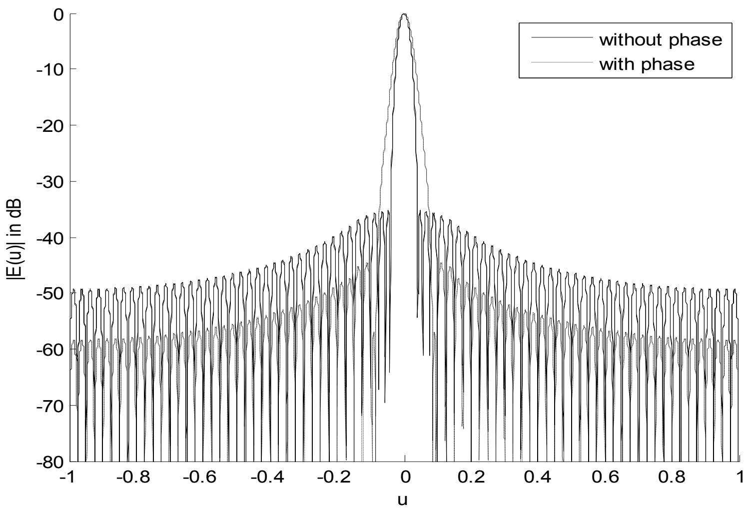

Fig.22 N=80

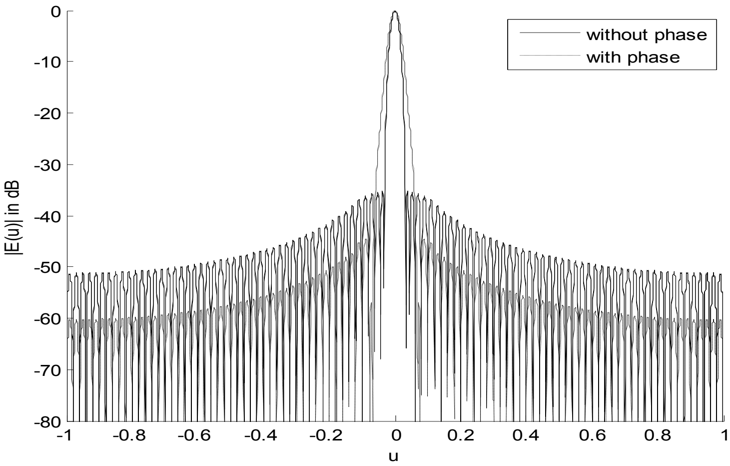

Fig.23 N=100

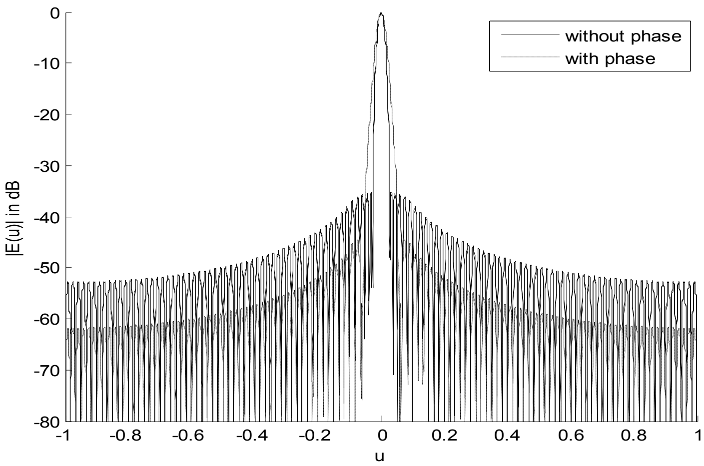

Fig.24 N=120

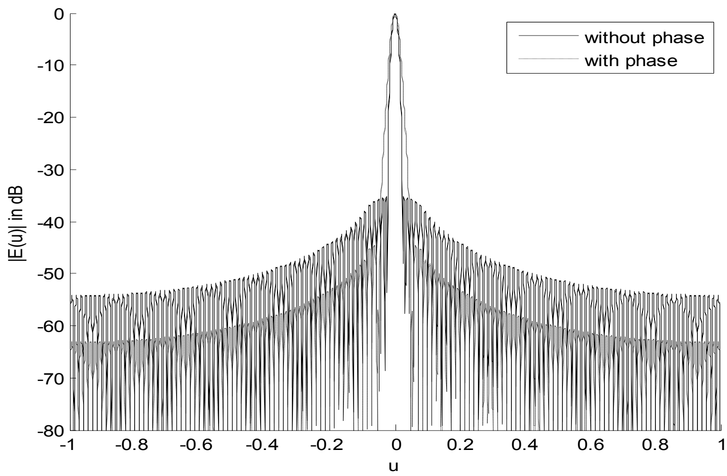

Fig.25 N=140

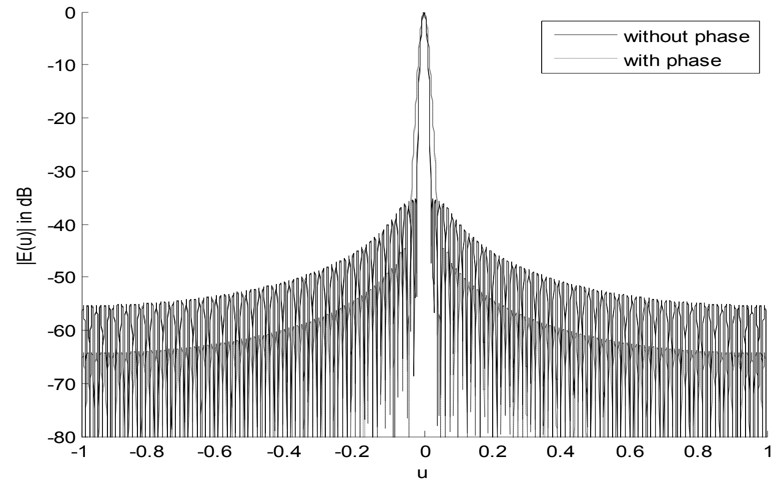

Fig.26 N=160

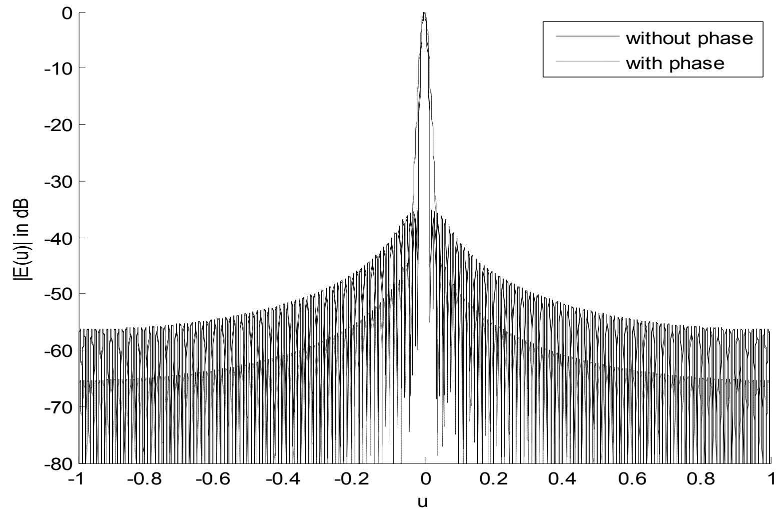

Fig.27 N=180

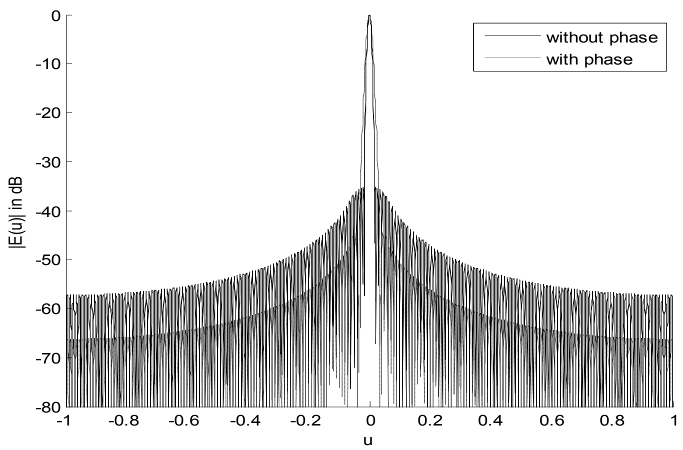

Fig.28 N=200

		A(X)				A(X) + ϕ(X)			
S.NO	N	B.W	1ST SLL	2nd SLL	LAST SLL	B.W	1ST SLL	2nd SLL	LAST SLL
1.	20	0.3365	-35.10	-34.96	-37.57	0.7504	54.79	43.73	46.65
2.	40	0.1659	-35.18	-35.28	-43.34	0.3486	56.47	44.32	52.37
3.	60	0.1099	-35.19	-35.35	-46.81	0.2324	56.82	44.44	55.82
4.	80	0.08415	-35.21	-35.38	-49.30	0.1734	56.94	44.48	58.30
5.	100	0.06543	-35.25	-35.38	-51.23	0.1375	57.00	44.50	60.23
6.	120	0.0562	-35.23	-35.42	-52.81	0.1145	57.15	44.50	61.81
7.	140	0.0474	-35.25	-35.39	-54.15	0.0993	57.17	44.55	63.15
8.	160	0.04178	-35.25	-35.39	-55.30	0.0864	57.14	44.56	64.30
9.	180	0.0371	-35.21	-35.45	-56.34	0.0758	57.33	44.55	65.33
10.	200	0.03300	-35.21	-35.44	-57.24	0.0668	57.21	44.58	66.24

Table. 2 Discrete Array elements

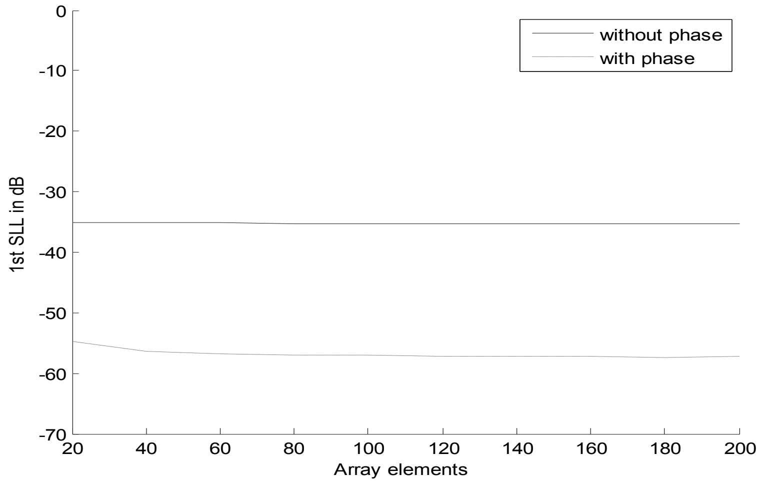

Fig.29 Variation of first side lobe level as a function of No of elements for with and without phase

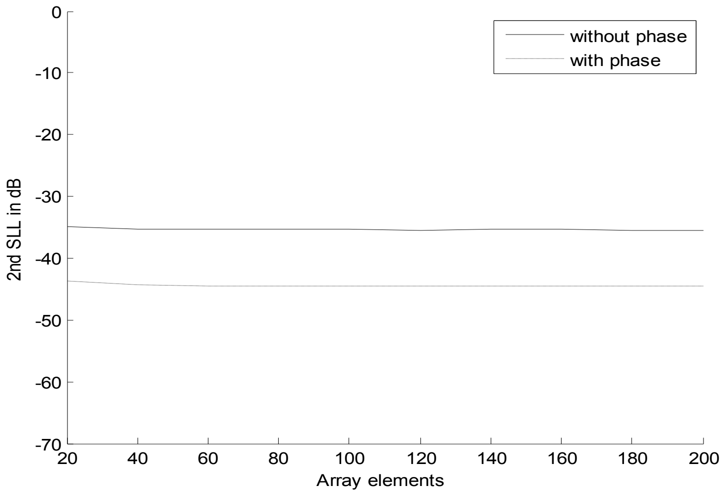

Fig.30 Variation of 2nd side lobe level as a function of No of elements for with and without phase

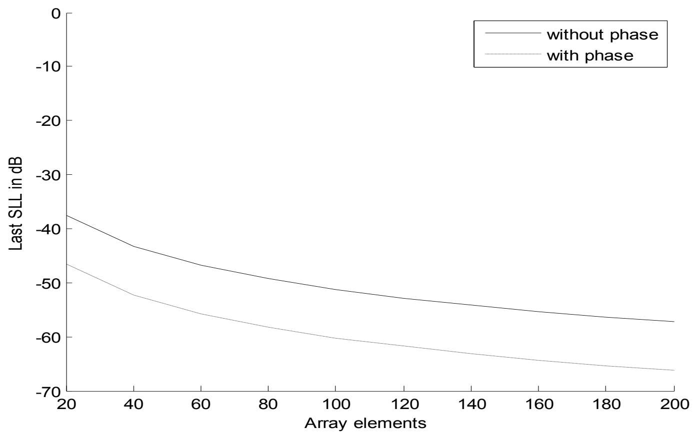

Fig.31 Variation of last side lobe level as a function of No of elements for with and without phase

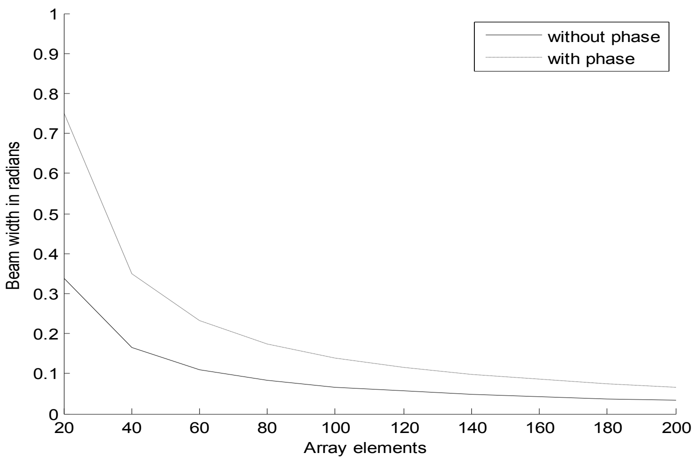

Fig.32 Variation of beam width as a function of No of elements for with and without phase

III. Conclusion:

The Computed amplitude and phase distributions are introduced for continuous line sources and discrete arrays. The prescribed radiation pattern with uniform sidelobe region surrounding the main beam and the region of decaying sidelobes at the far-end are achieved. The radiation pattern is numerically computed for sidelobe level SLL=-35dB. It is evident from the results that the radiation patterns have the sidelobe levels which are more or less constant at the near or main lobe and the decay of side lobes is more with the far-out side lobes. This behavior remains same even when the array length is altered. On the other hand null to null beam width is reduced with increase in array length. The variation of first, second and last sidelobe levels are computed for with and without phase distributions. They are at the same level for various arrays. In order to give more information on first, second, last sidelobe levels and also null to null beam width, the pattern characteristics are presented in tables 1-2. This is mainly used in radar applications to avoid EMI problems.

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