ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 5, Issue 4, April 2016

Investigations on the Behavior of Patterns of Uniformly Excited Array with Close and Wide Spacings.

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Abstract— **Array antennas are widely used to control, the radiations pattern characteristics as per the users requirements. The analysis and synthesis of arrays are common problems in communication and radar applications. The analysis of uniformly excited arrays with resonant spacing is common, however the behavior of radiation patterns for such arrays with other than resonant spacing is not available. In view of this intensive investigations are made to evaluate and consolidate the characteristics of radiation patterns for such arrays. The data is presented both for closely spaced arrays as well as widely spaced arrays. The variation of side lobe level and also the null to null beam width as a function of number of elements for a fixed array length is presented.**

Uniform arrays are economical although the side lobe level is relatively high. In the applications where the high side lobes are permitted uniform linear arrays are preferred.

I. Introduction

The study of a single antenna indicates that the radiation fields are uniformly distributed and it provides wide beamwidth but low directivity and gain. Such radiation characteristics may be preferred in broad cast applications where wide coverage is required. To meet the demands of point to point communication, it is necessary to design the narrow beam and high directive antennas. To improve the performance of an antenna without increasing the size of the antenna, it is required to arrange the antenna elements in a specific configuration so spaced and phased that their individual configurations are maximum in desired direction. This arrangement of multi antenna elements is referred to as an array. Among the large variety of arrays of radiating elements, the simplest type is uniform linear array. The array is specified by uniform spacing and fed with currents of equal magnitude and uniform progressive phase shift along the line. Equi -spaced elements will produce a desired space factor with reasonable accuracy. The space factor of an array of equi-spaced elements is a periodic function and can be expressed as a polynomial, where the coefficients are used to determine the excitation coefficients. Dolph [1] designed a theoretical optimum broad-side array with equi-spaced elements using the Tchebycheff polynomials. DuHamel [2] extended Dolph method for an end- fire array with equi spaced elements. To design a linear array of equi-spaced elements that will produce a space factor suitable to desire directions in space Woodward and Laswson [3] reported a method for an arbitrary pattern.

If the inter element spacing is not more than one half wave length, it avoids more than one period of the space factor. If the inter elements spacing is less than one of half wave length which is not practical, may cause the mutual coupling between the elements of the array and it is difficult to realize the excitation coefficients. If the spacing is large enough, the mutual coupling is not excessive and beam width is narrow, the spacing becomes electrically large and grating lobes appear at high frequencies.

In arrays of radiating elements, it is possible to have choice on the selection of input and spacing of elements. It is also possible to have array configuration depending on the direction of radiation beam and space availability. The individual radiating elements in the array also influence the pattern characteristics [4]. It is popularly known that an array, linear in character, results in lowest beam width but with relatively high first sidelobe level. Several studies are carried out in the past on the linear arrays with uniform excitation and half- wave spacings.

The results are reported in several text books and papers [5-11]. But it is unknown that what happens if the elements are clustered closely and widely. Several techniques are reported in the literature to reduce the sidelobes and beam width [12-16]. Yan et.al [17] designed an array to reduce sidelobes using genetic algorithm. In their work, Genetic algorithm technique avoids coding and directly works with real/complex numbers to simplify computer programming and to save computational time and cost. It is applied to linear and circular arrays.

Arrays with unequal spaced elements are designed by Kumar et.al [18]. In this paper, space distribution is designed for a given pattern characteristics. Whenever, spacing is changed the resultant phase is altered. It is so designed to avoid grating lobes. The spacing functions are several. They can be standard functions or they can be found using different algorithms. Each of them is complex and time consuming. In view of this, a simple clustering technique is used to improve pattern characteristics in terms of sidelobes and beamwidth.

II. FORMULATION

It is well known that pattern synthesis is carried out by several standard and conventional methods. Some of them are

1. Schelkunoff polynomial method.
2. Fourier Transform method.
3. Wood ward-Lawson method.
4. Dolph-Tchebyscheff or Chebyshev method.
5. Taylor's method.
6. Laplace Transform method.
7. Some standard amplitude distributions.

Fourier Transform method can be directly applied to the design and analysis of line source antennas. A line source becomes continuous, if large number of antennas are included with no spacing in a finite length of line source. It is purely a theoretical case and does not exist practically. This is due to finite size of radiating elements. A typical geometry of line source is prescribed in fig. (1).

The radiation pattern of a continuous line source is given by

$$E(u) = \int_{-1}^{1} A(x)\, e^{j\frac{2\pi L}{\lambda}[ux+\phi(x)]} \quad (1)$$

Here

E(u) = Electric field intensity with respect to u
u = Sin θ, θ : -1 to 1
A(x) = Amplitude distribution
2 L/λ = Array length
ϕ(x) = Phase function

On the other hand, a discrete linear array is a group of elements arranged along a line with finite spacing between them. As the elements are discrete in nature, the radiation pattern becomes a summation instead of integration. The location of elements is determined on the basis of resonance or non-resonance requirements. One continuous amplitude distribution is evaluated for a continuous line source, the amplitude levels are determined at the sampled locations of the individual elements.

In a linear array of discrete radiating elements, individual and distinguishable elements are separated by a well defined spacing along a straight line. The variable parameters in the design of array are type of elements, total number of elements, the spatial distribution, amplitude and phase excitation functions. They can be varied simultaneously or some of them kept constant, and one or two can be made variable. If a large number of them are made to vary the design of arrays become complex and involved. In view of these facts, most of the designers prefer to choose only one as a variable quality while other design parameters are kept at predetermined values or functions.

In the present work, spatial distribution is chosen as variable quantity as it does not involve additional cost. It is also possible to save space that is available to the designer.

If nth element is assumed to be at (rn, θ_n, ϕ_n), its radiation field is given by fig. (2).

$$E_n(\theta,\phi) = f(\theta,\phi)A(x_n)e^{[j(Kr_n\cos\varphi_n+\alpha_n)]} \quad (2)$$

Here

K = 2π/λ
$A(x_n)$ = Amplitude of input
α_n = Phase of input

$$\cos\psi_n = \cos\theta\cos\theta_n + \sin\theta\sin\theta_n\cos(\phi-\phi_n) \quad (3)$$

(rn, θ_n, ϕ_n) represent the position of nth radiating element

If n elements are along with z-axis,

$$\theta_n=0,\ rn=z_n,\ n=1,2\ldots N \quad (4)$$

The resultant field of the array

$$E(\theta,\Phi) = \sum_{n=1}^{N} E_n(\theta,\Phi) = f(\theta,\Phi)A(x_n)e^{[j(kz_n\cos\theta+\Phi(x_n))]} \quad (5)$$

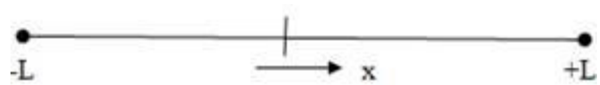

Fig.(1) Line source of length

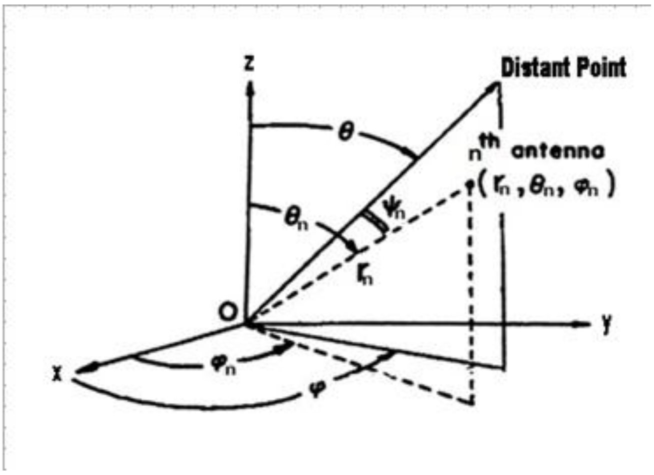

Fig.(2)

If θ is measured from broadside, Cos θ become Sin θ. The array factor of linear array of radiators

$$E(\theta) = f(\theta)\sum_{n=1}^{N} A(x_n)\, e^{j\frac{2\pi L}{\lambda}[u(x_n)+\phi(x_n)]} \quad (6)$$

E(θ) : Electric Field Intensity with respect to θ
$A(x_n)$: Amplitude Distribution
2L/λ : Array Length
N : number of elements
$\phi(x_n)$: Phase function

For an array of an isotropic radiators it becomes

$$E(\theta) = \sum_{n=1}^{N} A(x_n)\, e^{j\frac{2\pi L}{\lambda}[u(x_n)+\phi(x_n)]} \qquad (7)$$

III. Results and Conclusion

For uniform excitation of the array for both closed and wide spaced elements, radiation patterns are computed. For N=100, the spacing is varied from 0.1λ to 1.0λ in steps and the radiation patterns are presented in figures3-8 .Keeping the array length fixed at 10λ and the inter-element spacing is made closer and the corresponding patterns are plotted in figures 9-14. The variation of first side lobe level and the Null to Null Beam width are presented in tables 1 and 2.

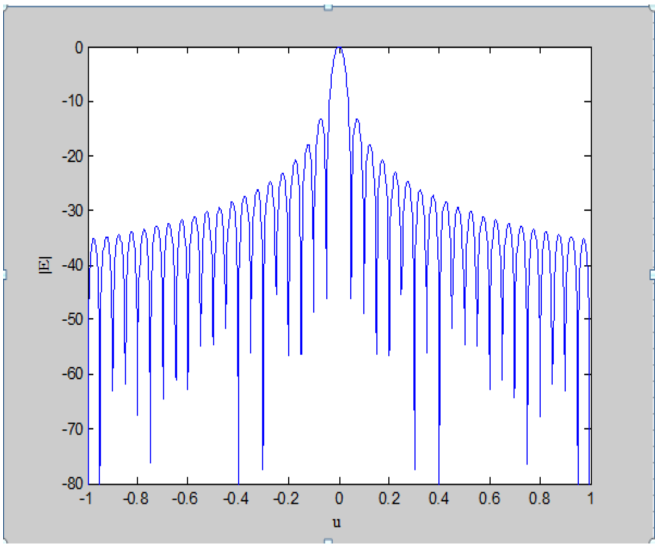

Fig. (3) N=100, $A(x_n)$ =1, d=0.2 λ

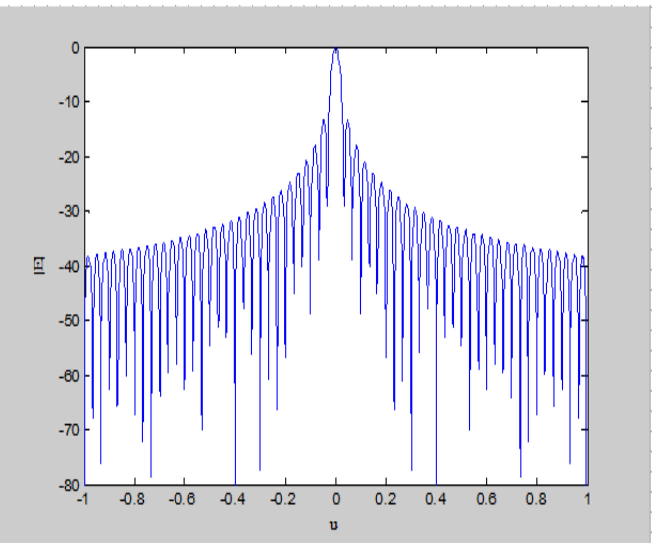

Fig. (4) N=100, $A(x_n)$ =1, d=0.3 λ

It is found from the results, the side lobe levels remain constant with varied spacing, and the beam width is effected with space distribution. It is possible to use the data presented in this paper by the array designer and in corporate a particular spacing for chosen application. It is also possible to design the arrays economically.

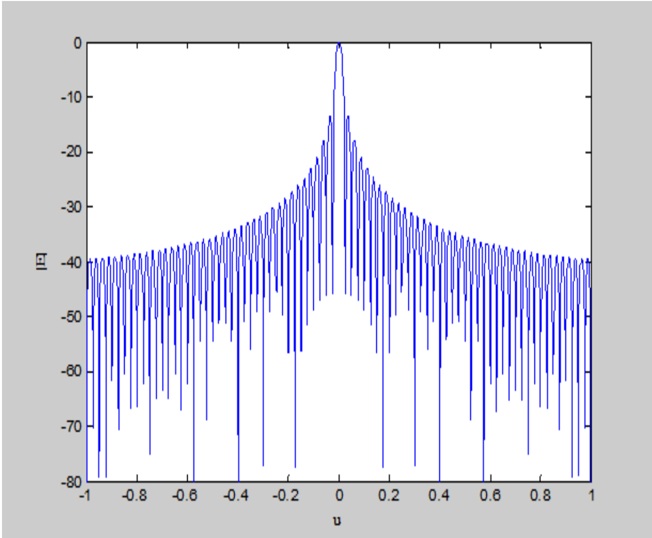

Fig. (5) N=100, $A(x_n)$ =1, d=0.4 λ

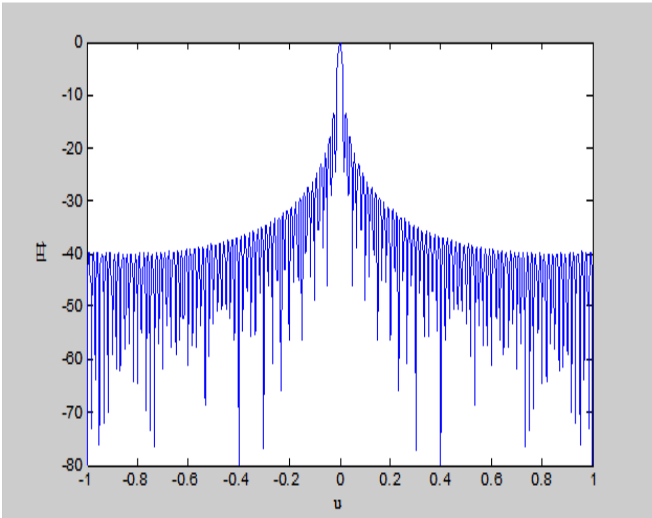

Fig. (6) N=100, $A(x_n)$ =1, d=0.6 λ

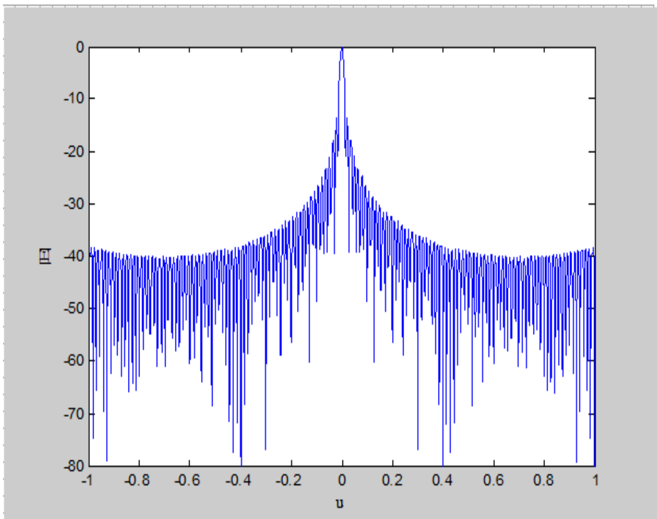

Fig. (7) N=100, $A(x_n)$ =1, d=0.7 λ

ISSN: 2278 – 909X
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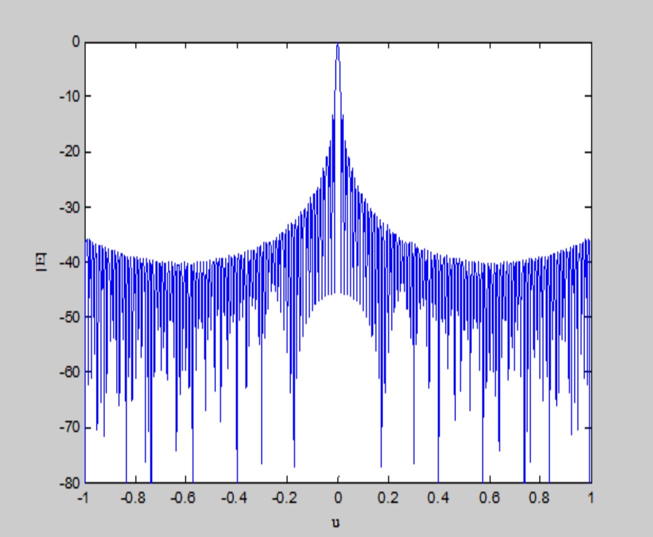

Fig. (8) N=100, A(x_n) =1, d=0.8 λ

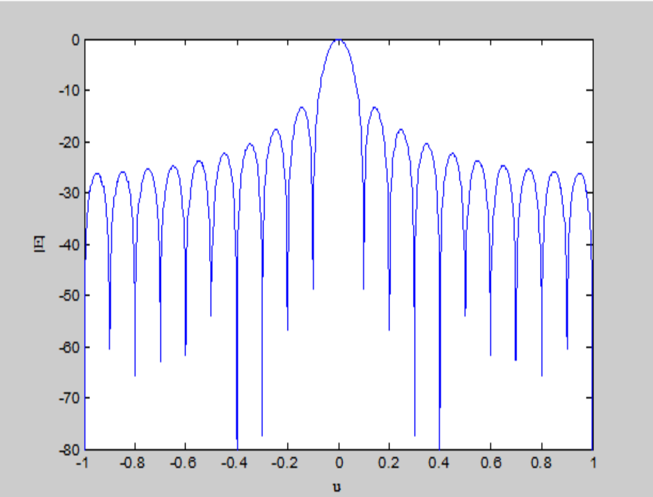

Fig. (9) N=20, A(x_n) =1, (2L/λ) =10, d=0.5 λ

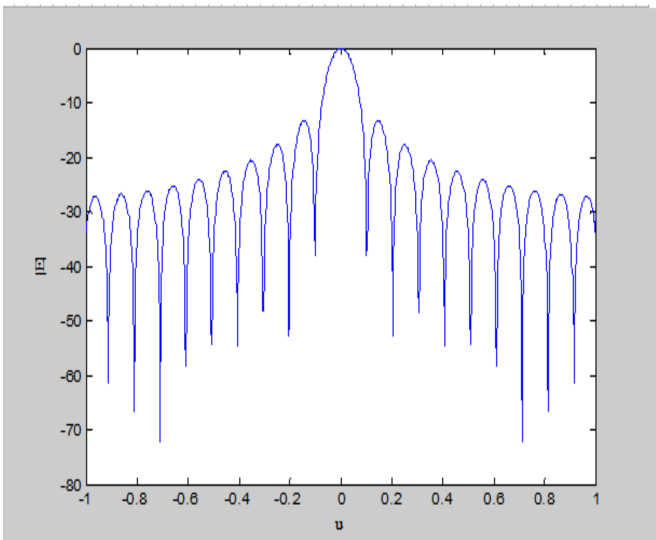

Fig. (10) N=24, A(x_n) =1, (2L/λ) =10, d=0.41 λ

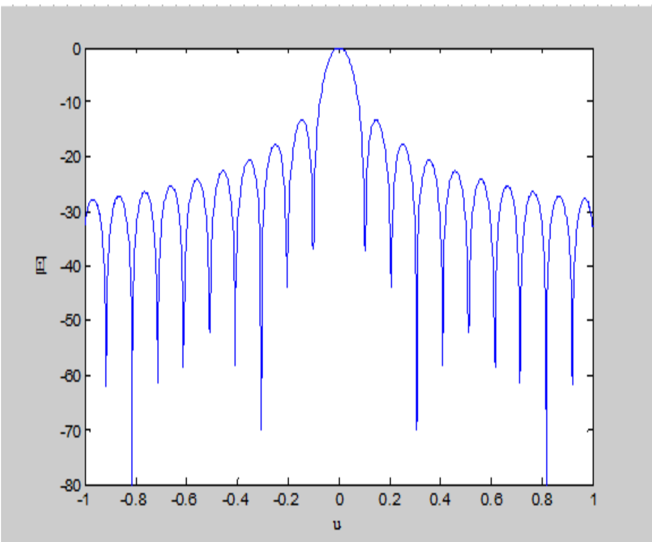

Fig. (11) N=28, A(x_n)=1, (2L/λ) =10, d=0.35 λ

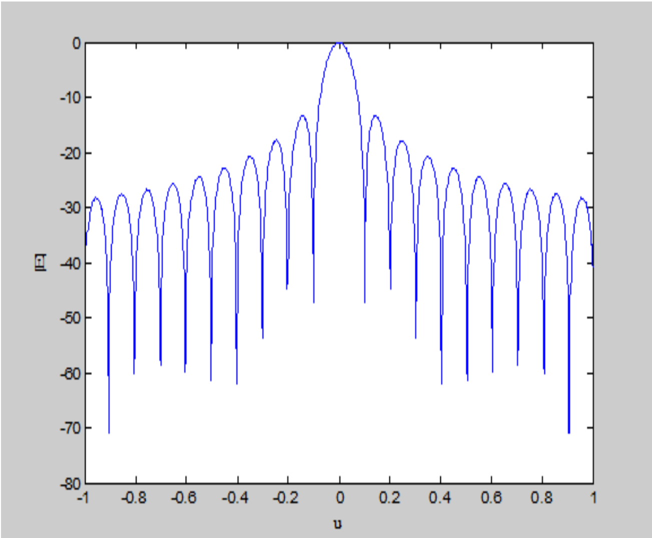

Fig. (12) N=32, A(x_n)=1, (2L/λ) =10, d=0.31 λ

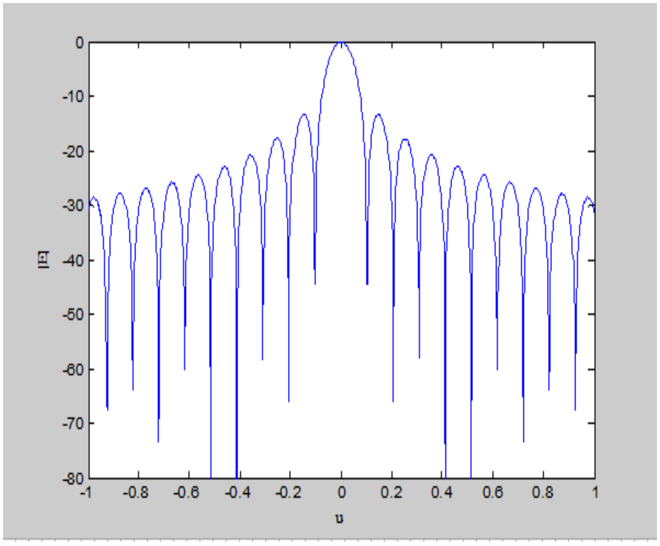

Fig. (13) N=36, A(x_n)=1, (2L/λ) =10, d=0.27 λ

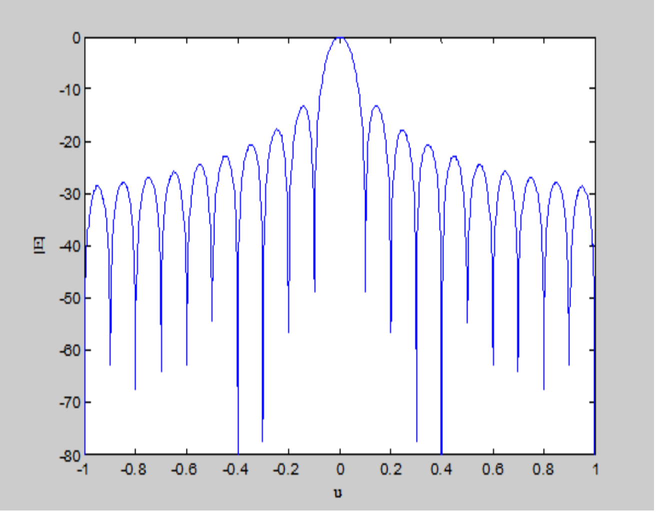

Fig. (14) N=40, A(x_n)=1, (2L/λ) =10, d=0.25 λ

Table 1. Side lobe Levels and Beam width with space distribution for large arrays

Sl.No.	Number of Elements (N)	d(λ)	FSLL (dB)	NNBW (radians)
1.	100	0.1	-13.26	0.128
2.	100	0.2	-13.27	0.064
3.	100	0.3	-13.27	0.042
4.	100	0.4	-13.27	0.032
5.	100	0.5	-13.27	0.026
6.	100	0.6	-13.27	0.022
7.	100	0.7	-13.26	0.018
8.	100	0.8	-13.36	0.016
9.	100	0.9	-13.27	0.014
10.	100	1.0	-13.27	0.038

Table 2. Side lobe levels and Beamwidth with space distribution for medium arrays

Sl.No	Number of Elements (N)	d(λ)	FSLL (dB)	NNBW (radians)
1.	20	0.50	-13.19	0.128
2.	22	0.45	-13.20	0.128
3.	24	0.41	-13.22	0.126
4.	26	0.38	-13.22	0.130
5.	28	0.35	-13.23	0.126
6.	30	0.33	-13.23	0.128
7.	32	0.31	-13.23	0.128
8.	34	0.29	-13.24	0.130
9.	36	0.27	-13.24	0.126
10.	38	0.26	-13.24	0.130
11.	40	0.25	-13.24	0.128

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