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Side Lobe Reduction in Linear Array Antenna using Numerical Computation Approach

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ABSTRACT

Large amount of energy is saved when a transmitting antenna propagates its field radiations painstakingly in the required direction of propagation. For this reason, reduction in side lobe radiation is essential to avoid degrading the total power and efficiency of the radiating structure. In this paper, a numerical approach is adopted other than the well known stochastic approach to reduce side lobe radiations in linear array antennas. This choice is as a result of the short design cycle of the numerical solution for antenna field problems, full exploration of design space and provision of large physical insights on the design output. The parameters of the array antenna are deployed in the reduction of the side lobe radiations. These include; non-uniform inter-element spacing, non-uniform excitation amplitude and varying number of antenna elements. Radiation patterns for linear array antenna with non-uniform characteristics are generated from the simulation result. The patterns with the least side lobe and beam width are determined. This outcome ensures signals are not transmitted in undesirable directions and efficient communication process can be guaranteed.

Key words: Side lobe radiation, non-uniform spacing, non-uniform excitation amplitude, numerical computation

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1. INTRODUCTION

An Array Antenna is a collection of similar Antenna Elements in a defined geometrical configuration, for which the effect/impact of the entire elements is demonstrated in the radiation pattern so obtained. Array antennas find application in mobile, wireless communication systems, broadcast and point-to-point communication due to its signal quality and link coverage. But frequency spectrum is of great demand, although it is also very expensive. For these reasons, there is need to utilize system capacity without increasing spectrum demand. This can actually be achieved by adopting array antennas. This way, the performance of the antenna can be improved without increasing spectrum demand.

However, the array antenna is also implemented to overcome the limitations of a single element antenna, which include low directivity, low gain, and poor antenna efficiency. But the major drawback of the array antenna lies in the presence of side lobes in the radiation pattern so obtained. Side lobes are radiations in unwanted direction. They tend to waste signal power into other directions, which is meant to be minimized to enhance effective communication process.

2. LITERATURE REVIEW

In linear array antennas, side lobe can be reduced by applying stochastic or computational methods. The design of array antennas has a non linear and non convex dependence on elements parameters, for this reason, interest has been focused in recent times on stochastic search technique.

The stochastic approach is a synthesis method adopted for the solution of array antenna field problems. It utilizes optimization algorithms for which a fitness function is defined for the array factor of the radiation pattern so determined. The synthesis approach adopts biological, social, molecular and neurobiological characteristics to solve the array antenna problems. It is said to mimick the procedure of natural phenomenon to obtain optimum performance of the array antenna. This synthesis methods include; genetic Algorithm [1-3], particle swarm optimization [4,5], simulated Annealing [6-7], Invasive weed [8-9], Fire fly Algorithm [10], Tabu search [11] etc. A unique property of the stochastic approach lies in the conditions and criteria for determining the cost or fitness function of the radiation pattern. This implies that; the optimum fitness function can be described as the lowest value of the array factor expression when all necessary conditions for maximum operation has been applied. Generally, in stochastic solution to array antenna field problems, the optimum weight of the array elements are sought and implemented in the required radiation pattern.

In applying the stochastic approach each algorithmic method has a peculiar characteristics or short fall. For instance, in the genetic algorithm, it is required that premature convergence of solution need to be overcome and the manner in which the solution converges depends on the initial population, this makes it a time consuming process since the entire solution space is searched. However, the particle swarm optimization is easier to understand and implement but require little mathematical preprocessing. Although the Tabu search approach is not solely dependent on the objective function, it does not implore derivatives and initial guesses but finds near optimal solutions. It requires more CPU time and memory [11].The invasive weed optimization requires the presence of parent specie which ought to be forwarded to the next generation for completeness of the process. The Genetic Algorithm sometimes possesses poor fitness functions with no guarantee of global optimum solution. The Simulated Annealing (SA) approach may require time consuming algorithms to determine array antenna patterns [12]. However an interesting feature of the SA beckons on its ability to converge to the global minimum of its cost function while avoiding the local minima [13].

The parameters of the antenna, determines the radiation pattern of the resulting field. Optimizing array antenna for side lobe reduction can be considered by varying the inter element spacing while maintaining a uniform excitation amplitude [14]. Other approach may also require varying excitation amplitude rather than the inter-element spacing [15].

In this work, the numerical method of solution was adopted. Generally, Numerical method involves the use of side lobe nulling [16], imposing nulls at the grating lobe points of the radiation pattern and applying non uniform parameters in the array analysis [17]. In this work therefore, the radiation pattern of the array antenna with non uniform elements and non-uniform inter element spacing are generated for different possibilities of the array spacing combination. The solution process can generate a maximum of hundred radiation patterns for the same number of antenna element based on the different possible position of the antenna element. A maximum of thirty antenna elements can be simulated based on design specification of interest. At the long run, the radiation pattern with the least side lobe and beam width can be determined. A reduced beam width in the main radiation indicates a higher directivity of the propagated signal. This outcome is robust since the entire solution space of the radiated fields are explored. It is an economical process since the best radiation pattern can be determined from a large sample of the solution domain.

3. FORMULATION

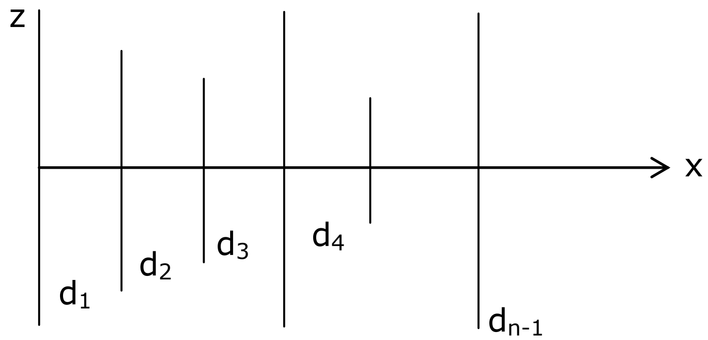

Fig. 1 Linear array of Non-uniform Antenna Elements with Non-uniform Inter-element Spacing

Consider a linear array of cylindrical wire antennas of N unequal elements (with non uniform spacing (d_n)) parallel to the z-axis and aligned along the x-axis of a co-ordinate system.

The elements are non isotropic radiators but due to the far field consideration of array antennas in the radiation pattern, each element is weighted by their respective excitation amplitude. The total field is given by the product of the element pattern and the array factor. The element pattern captures the element directional radiation, polarization and the mutual coupling characteristics. The array factor gives the effective impact of the individual elements constituting the array, and is therefore considered for the side lobe reduction process [18]. This implies that, the radiation pattern of the array antenna is dependent on the array factor for far field consideration hence the element pattern is negligible [19]. The expression for the array factor (AF) for N array elements is given by;

The electric field for the first antenna as seen in figure 1 is given by;

$$\bar{E}\theta_1 = \frac{j\omega\mu Sin\theta}{4\pi}\int_{-l_1/2}^{l_1/2} I_{z_1}(z')\frac{e^{-jkr}}{r}dz' = \frac{j\omega\mu \sin\theta}{4\pi} a_{n_1}\frac{e^{-jkr}}{r} \qquad (1)$$

For the second antenna,

$$\bar{E}\theta_2 = \frac{j\omega\mu Sin\theta}{4\pi}\int_{-l_2/2}^{l_2/2} I_{z_2}(z')e^{-jk(r-d_1\sin\theta)+\phi_1}\,dz'$$

$$\bar{E}\theta_2 = \frac{j\omega\mu Sin\theta}{4\pi} a_{n_2} \frac{e^{-jkr}}{r} \times e^{jkd_1 \sin\theta + \phi_1} \tag{2}$$

For the third antenna,

$$\bar{E}\theta_3 = \frac{j\omega\mu Sin\theta}{4\pi} \int_{-l_3/2}^{l_3/2} I_{z_3}(z') \frac{e^{jkr_3}}{r} dz'$$

$$= \frac{j\omega\mu Sin\theta}{4\pi} \int_{-l_3/2}^{l_3/2} I_{z_3}(z') e^{-jk((d_1+d_2)Sin\theta)+\phi_2} dz'$$

$$\bar{E}\theta_3 = \frac{j\omega\mu Sin\theta}{4\pi} \frac{e^{-jkr}}{r} a_{n_3} \times e^{jk(d_1+d_2)Sin\theta+\phi_2} \tag{3}$$

$$\bar{E}\theta_4 = \frac{j\omega\mu Sin\theta}{4\pi} \int_{-l_4/2}^{l_4/2} I_{z_4}(z') \frac{e^{-jkr}}{r} \times e^{jk((d_1+d_2+d_3)Sin\theta)+\theta_3} dz' \tag{4}$$

$$\bar{E}\theta_N = \frac{j\omega\mu Sin\theta}{4\pi} \int_{-l_N/2}^{l_N/2} I_{z_N}(z') \frac{e^{jk\left(\sum_{n=1}^{N-1} dn\right)Sin\theta + \phi_{N-1}}}{r} dz' \tag{5}$$

$$\bar{E}\theta_N = \frac{j\omega\mu Sin\theta}{4\pi} \frac{e^{-jkr}}{r} a_{n_N} \times e^{jk\left(\sum_{n=1}^{N-1} dn\right)Sin\theta + \phi_{N-1}}$$

Adding the field contributions from the antennas in the array, the total Electric field becomes

$$\bar{E}\theta_{Total} = \frac{j\omega\mu \sin\theta}{4\pi} \frac{e^{jkr}}{r} \left[a_{n_1} + a_{n_2} \ell^{jkd_1 Sin\theta + \phi_1} + a_{n_3} \ell^{jk(d_1+d_2)Sin\theta+\phi_2} + a_{n_4} \ell^{jk(d_1+d_2+d_3)Sin\theta+\phi_3} + \ldots + \ell^{jk\left(\sum_{N=1}^{N-1} dn\right)Sin\theta + \phi_{N-1}} \right] \tag{6}$$

The above equation can be represented by:

$$\bar{E}\theta_{Total} = \bar{E}\theta \text{ single antenna x Array Factor}$$

The array (AF) is given by;

$$AF = \sum_{n=1}^{N} a_n \left[K \left(\sum_{n-1}^{dN-1} dn \right) Sin\theta \right] \tag{7}$$

$$AF_{norm} = \frac{|AF|}{|AF|_{\max}} \tag{8}$$

Where:

θ = Elevation angle

d_n = Varying inter-element spacing

K = wave number = $\frac{2\pi}{\lambda}$

λ = wavelength

a_n = excitation amplitude

n = 1, 2, 3…N =number of antenna elements.

AF_{nom} = Normalized array factor.

Low side lobe is necessary in array antennas to reduce interference radiation in communication system, strengthen the radiated signal power and avoid misinterpretation of signals as seen in radiations with grating lobes. The excitation amplitude of each array element is determined by applying the method of moment analysis for linear array antennas [20]. This method requires that the exact peak values are to be deployed in the array factor formulation rather than optimizing an assumed range of values as proposed in the synthesis approach. The normalized array factor is expressed as 20log AF, presenting its values in decibels.

4. RESULT

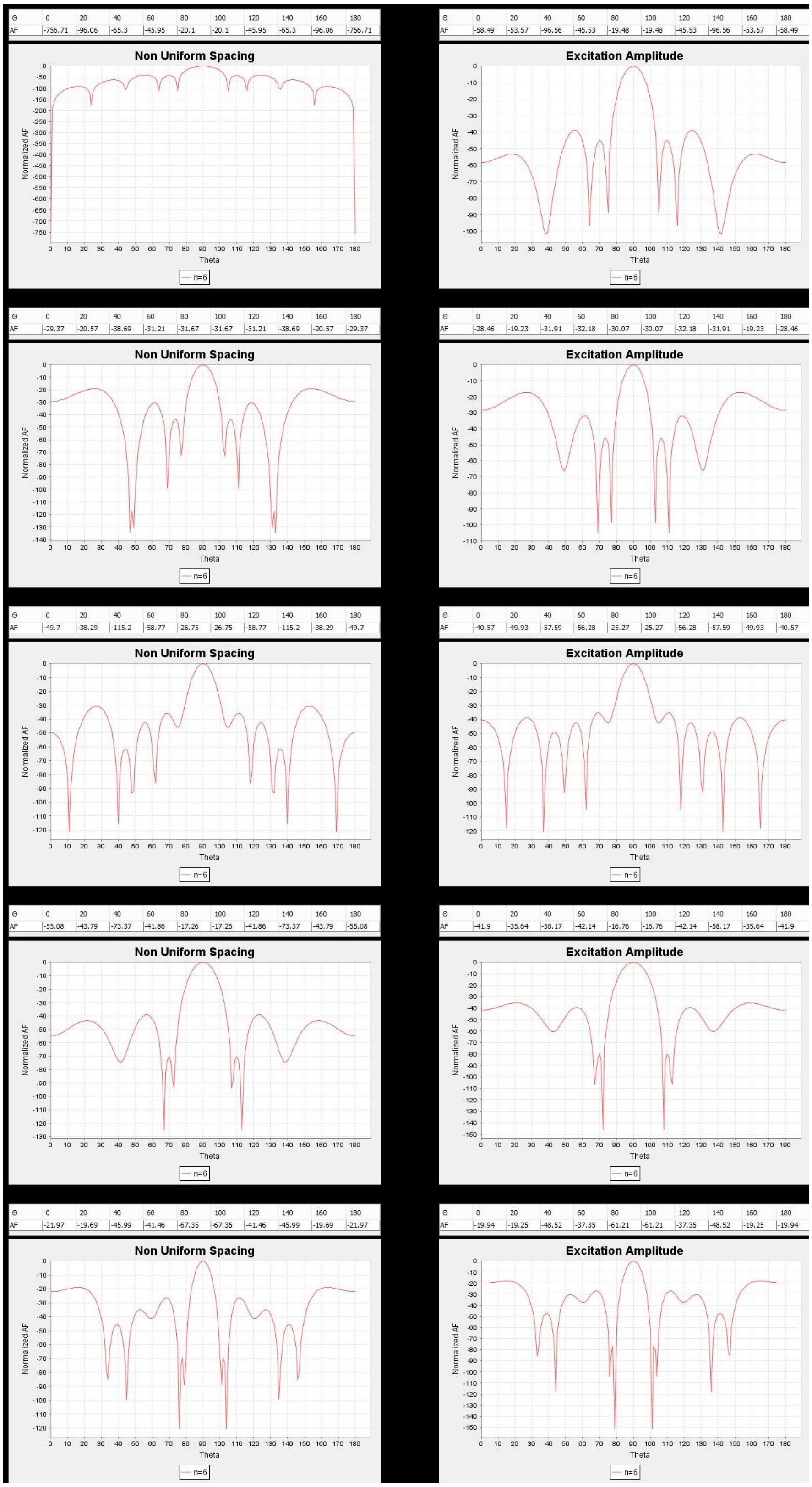

Fig. 2a Radiation pattern for 6 element array antenna

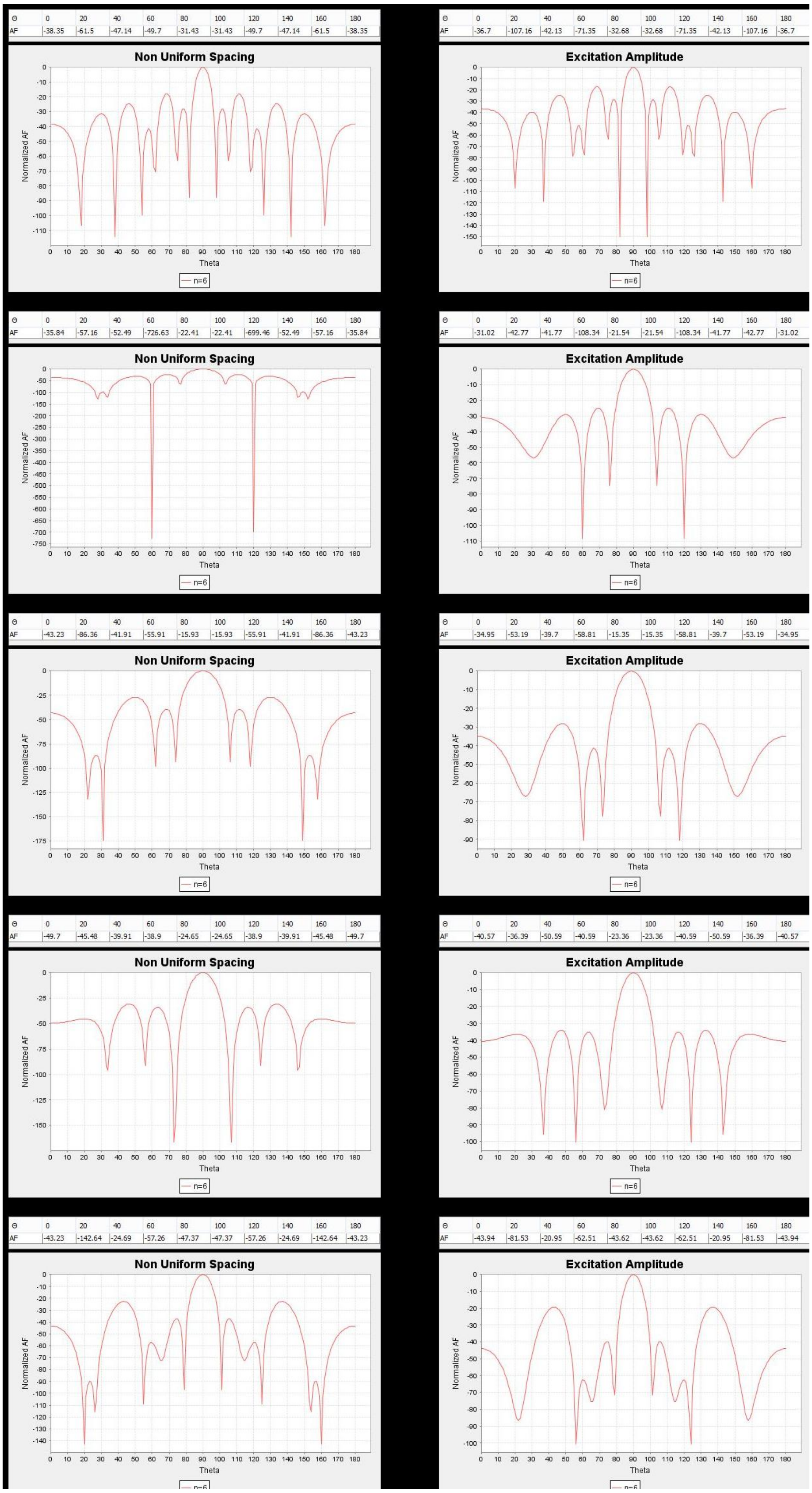

Fig. 2b Radiation pattern for 6 element array antenna

The simulation process requires the parameters to be provided on the application interface. These parameters include the excitation amplitude, antenna spacing and number of antenna elements. Because the computational analysis is considered at the far field region, the antenna element does not experience any phase difference. From the results seen in figures 2a and 2b, a total of 20 radiation patterns are generated in a 10 by 2 matrix arrangement. This amounts to 10 plots on each column of the array, with the first column varying only inter element spacing and the second column varying both inter element spacing as well as excitation amplitude. This is achievable because of the different possible ways in which the element position/spacing can be aligned. This approach is robust because, when the total number of graphs generated is considered, the one with the least side lobe and maximum directivity can be determined. The directivity in this case is informed by the width of the main lobe of the radiation pattern. A major advantage of this method lies in its ability to produce variety of radiation patterns with a click of the button, since large amount of spacing consideration is possible.

The results (figures 2a and 2b) strongly portray the numerical approach for side lobe reduction in linear array antennas with non uniform parameters viz-a-viz excitation amplitude and inter element spacing. The inter element spacing ranges between 0 and one wavelength (1λ) as applied in uniform linear arrays. This spacing can be categorized as closely, moderately or largely spaced. For instance, considering an array of 6 elements, 5 inter element spacing should be specified since the first element is placed at the origin of the axis on which the antenna is aligned. This implies that there is zero spacing between the first antenna element with respect to the origin. The spacing is categorized as moderately spaced antennas with spacing difference of 0.3**λ** and 0.4**λ**. This spacing can be randomly chosen to generate the corresponding number of graphs for the radiation patterns. The two model consideration includes; 1 graphs generated by varying the excitation amplitude alone with uniform spacing and 2. graphs generated by varying both excitation amplitude and inter element spacing for the same number of antennas. The graph was analyzed and the following results were obtained. I) the entire graphs for the model consideration are obtained (figures 2a and 2b). (II) The graphs are specified in two columns. The first column produces radiation pattern obtained by varying only inter element spacing while the second column produces radiation pattern obtained by varying both element spacing and excitation amplitude. (III) The graph with the least side lobe is determined and presented in figure 3a. This choice is obtained from the entire patterns generated in figures 2a and 2b. (IV) The graph with the smallest beam width is also determined and presented in figure 3b. The above listed information is important for predicting the performance of array antenna through simulation process, for directional propagation prior to the antenna fabrication.

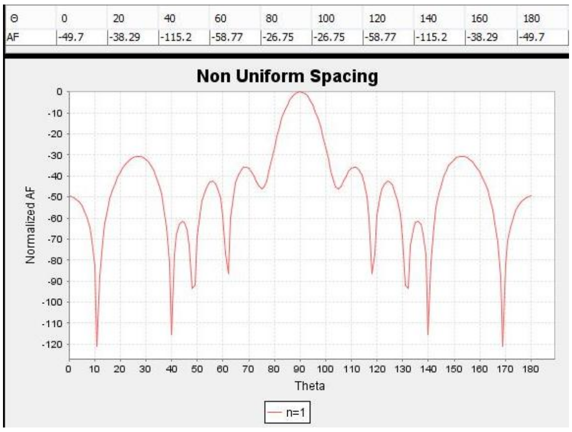

Fig. 3a Radiation pattern with the least side lobe

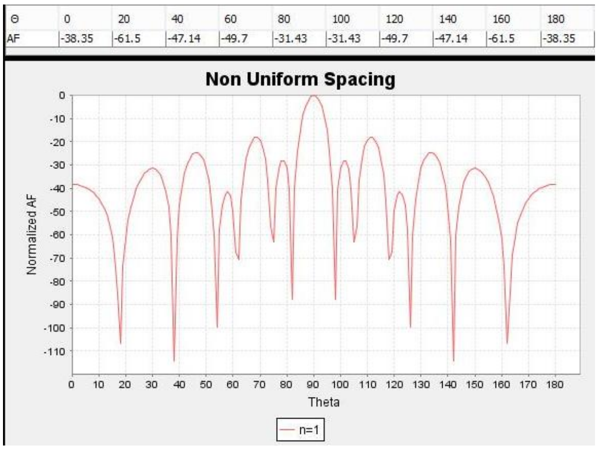

Fig. 3b Radiation pattern with the smallest beam width

5. CONCLUSION

A numerical technique is presented for the reduction of side lobe level in linear array antenna analysis. It is evident that using unequal element spacing brings about large application of array antennas. This is because; every spacing consideration produces a resulting radiation pattern. This implies that it is possible to obtain patterns with the least side lobe and beam width for the same number of antenna element. This will help to save cost by implementing the best array configuration with the least side lobe level. However the radiation pattern with the least beam width of the main lobe can be obtained from the radiation patterns generated using the same number of antenna elements.

The results shows that side lobe reduction cannot be achieved with synthesis method alone, but numerical method in array analysis can be adopted to obtain enhanced radiation pattern with low side lobes and reduced beam width. Numerical method is thus recommended for array considerations of other geometrical configuration.

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