Performance Evaluation of Equally Spaced Linear Array Antenna by Optimizing the Radiation Pattern using Two Optimization Techniques

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ABSTRACT
High side lobe levels in a radiation pattern often lead to unwanted patterns of radiation, energy wastage and reduction in the overall performance of the antenna. This research work aims to improve the performance of a smart antenna by optimizing the radiation pattern using various approaches. This was done by obtaining the optimum weights that give a radiation pattern with reduced side lobe level (SLL). Least Mean Squares (LMS) Algorithm and Genetic Algorithm (GA) were used to determine the optimal antenna parameters that would minimize side lobe level. Simulations were carried out to determine the effect of increase in inter-element spacing on array factor and beamwidth using the optimal antenna parameters. It was observed from the results, that for the same number of elements, LMS gave the better outcome in form of a more reduced beamwidth while GA performed better for the reduction of the side lobe level. This translates to the reduction of radiated power wasted in side lobes for linear arrays in antenna systems.

Keywords: *Least Mean Squares Algorithm, Genetic Algorithm, Equally Spaced Linear Arrays, Array Factor, Side Lobe Level, Beamwidth*
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I. INTRODUCTION

There has been great development in wireless communication systems and this is visible in the areas of signal processing, antenna theory, electronics and information theory. Over the years, an increase in the need for network bandwidth due to the use of various wireless and mobile communication devices has been evident. Solving such problem like this involves the design of improved antenna configurations to conform to such requirements. This design covers improvement in algorithms, signal processing techniques, error correction processes and enhanced hardware, including the developments of improved antenna arrays. Recent research and design attempts by engineers resulted in the development of smart antennas [1].

Smart antennas are employed to reduce interference, increase user function and data usage [2,3]. They can be used in several areas of communication. The arrival of adaptive antennas such as smart antennas has also enhanced the prospect for the introduction of new wireless communication services and better security [3]. A smart antenna has the ability to sense its environment and adjust its gain accordingly in different directions. A smart antenna consists of an antenna array which is assisted by a digital processing system that processes the signals transmitted and received by the array using array algorithms. It refers to a system of antenna arrays with smart signal processing algorithms. The functions of a smart antenna include estimation of direction of arrival (DOA) and beam forming [3].

Lower side lobe levels are becoming increasingly important in antenna arrays. It is therefore imperative to discover faster and more reliable methods at arriving at the optimum solution. The simulation of the antenna radiation pattern, which basically requires choosing the antenna parameters to obtain desired radiation characteristics such as reduced side lobe level and beamwidth of antenna pattern using two algorithms, is therefore carried out in this thesis.

The aim of this thesis is to improve the performance of a linear array antenna by optimizing the radiation pattern using two approaches. The following are the specific objectives that helped achieve this aim is to simulate and confirm the performance of linear array antenna using the Least Mean Square (LMS) algorithm already proposed in literature and to model and simulate the performance of linear array antenna using Genetic Algorithm (GA) with the aim of comparing it with the LMS method proposed in literature.

In this work, the scope is limited to linear arrays in antenna systems and particularly focused on the reduction of radiated power wasted in side lobes. Basically, two optimization techniques were used namely: Least Mean Square (LMS) Algorithm and Genetic Algorithm to calculate the weight coefficients, which would then be updated and assigned to each element in the forming of the radiation pattern.

II. RELATED WORKS

[4] demonstrated the different ways to apply Genetic Algorithm by varying the values of mutation, population size, and number of elements to optimize the array pattern. The designed array presented the largest directivity and a beamwidth approximating that of uniform arrays. Also, the side lobe level gotten was smaller than that of either uniform or Dolph-Chebyshev arrays.

[5] used Differential Evolution Algorithm employing Best of Random mutation strategy (DEBoR) for the analysis of linear arrays. This paper showed ways to overcome problems associated with sidelobes in large arrays using unequal current location.

[6] described the synthesis method of linear antenna array radiation pattern in adaptive beam forming using genetic algorithm. Genetic Algorithm Solver in Optimization toolbox of MATLAB was used to obtain maximum reduction in the side lobe level relative to the main beam on both sides of 0° and improve the directivity. The paper demonstrated the different ways to apply Genetic algorithm by varying number of elements to optimize the array pattern.

[7] reduced the first four side lobe levels of the linear and circular array antennas using gatool. The amplitude of the elements of the antennas was taken as the control variables. The design currents with the sum and difference pattern plots for different number of elements for linear and circular array antennas were considered. This paper showed how to apply gatool to find low side lobe levels that take into account antenna currents.

[8] used the Particle Swarm Optimization Gravitational Search Algorithm (PSOGSA) in the optimization of inter-element spacing in linear arrays. The results obtained showed an optimization in the locations of antenna elements and gave a radiation pattern with reduced side lobe level.

[9] used the particle swarm optimization (PSO) algorithm to achieve low sidelobes in linear arrays. The aim of the paper was to suppress SLL using PSO to obtain the optimum current excitations. Radiation patterns for small and large arrays were computed. The results obtained for a non-uniform excited linear array gave a significant sidelobe level without affecting the beam width negatively.

[10] in their paper showed the use of Unequally Spaced Arrays in the reduction of sidelobe level in linear arrays. An analytic method which transformed the array factor into a triangular system of equations was employed. This method was able to achieve increased speed and better accuracy when compared with other analytical methods. The results shown in this paper presented an improvement in the 3dB beamwidth when compared to an equally spaced array.

The authors of [11] used the Fourier series as a method for sidelobe reduction in equally spaced linear arrays. An array factor which comprised of a periodic function for the sidelobes of a uniformly excited array was created. The Fourier series was obtained was then used to achieve a great reduction in the sidelobe level. Analysis of other parameters such as directivity and half-power beam width were also carried out. It concluded that there were better improvements in their work when compared with other conventional array synthesis methods.

III. SYSTEM MODEL

Two optimization techniques were used: Least Mean Square (LMS) Algorithm and Genetic Algorithm to determine the optimal antenna parameters that minimize side lobe levels. Simulations were then carried out to determine the effect of increase in inter-element spacing on array factor and beamwidth using the optimal antenna parameters.

Linear arrays consist of radiating elements spaced in a straight line. The radiation pattern of the array is a weighted sum of radiating elements' patterns and its directivity is achieved by changing the weight coefficients that are calculated using an adaptive algorithm.

The array factor for a uniform linear array of N elements with an inter-element spacing d is given by:

$$AF(\theta) = \sum_{n=1}^{N} I_n e^{j(n-1)kd\cos\theta} = \sum_{n=1}^{N} I_n e^{j(n-1)\varphi} \quad (1)$$

where
I_n is the excitation of the element n.
k is the wave number.
d is the spacing between the elements.

Letting:

$$z = x + jy = e^{j\varphi} = e^{j(kd\cos\theta)} \quad (2)$$

Expanding and rearranging gives

$$AF(\theta) = \sum_{n=1}^{N} a_n z^{n-1} \quad (3)$$

The goal of the optimization process is to achieve a reduced side lobe level of the radiation pattern and a narrow main beamwidth. Hence, the problem formulated is aimed at obtaining the optimum weights that give a radiation pattern with reduced side lobe level (SLL). This objective is achieved by the following function:

$$min\ SLL = 20\ log\left(\frac{|AF_i|}{\sum_{j=1}^{N}|AF_j|}\right) \quad (4)$$

where AF_i = contribution of element i to array factor AF(θ)

Subject to:

$$a_n z^{n-1} \leq z^{n-1} \quad \forall\, 1 \leq n \leq N$$
$$0.5\lambda \leq d \leq \lambda$$
$$\theta \leq 90°$$
$$a_n \geq 0 \quad \forall\, 1 \leq n \leq N$$

In order to optimize energy utilization in the antenna configuration, the energy contents in the side lobe have to be minimized without reducing the efficiency of the antenna. The energy content of the side lobe in an of the array elements is defined as the ratio of the array factor of in that element to the sum of array factors in all the elements of the antenna. Hence, the decision variables in the objective function are the array factors of the elements of the antenna. The objective of the optimization problem therefore is to obtain the best combination of array factors for the elements of the antenna that will reduce the side lobe level to the barest minimum.

IV. SIMULATION AND RESULTS

For equal spacing between elements, the inter element spacing is in terms of lambda (λ). MATLAB simulations were performed to calculate the optimum weights for each antenna elements. The wavelength of 0.3m which corresponds to the frequency of 1GHz is used all through.

In order to analyze the effect caused by increase in number of elements on the array factor and beamwidth of an equally spaced linear antenna array, several experiments are performed. Number of elements was increased from 5 to 20 elements. An analysis on the effect of increase in inter-element spacing on the beamwidth and the overall radiation pattern was carried out. LMS algorithm and GA is used to obtain the weight coefficients which are then applied to the array. Inter-element spacing is altered from 0.5λ to 0.9λ for 18 to 20 elements.

The presence of side lobes in a normal radiation pattern usually causes unwanted radiation in undesired patterns as explained above in addition to the energy it wastes. Therefore, as part of the objectives of this research, effort was made to find out the effect of increase in number of elements on the side lobe level. Least Mean Squares (LMS) algorithm and Genetic Algorithm were employed to obtain the appropriate combination of weights that would give the optimal result. The number of elements was varied from 5 to 20 to observe the effect on the sidelobe level with the inter element spacing fixed at 0.5λ. But the lowest side lobes were observed between 18 and 20 elements. Thereafter, the side lobe level did not decrease further even though the beam width continued to decrease. The simulations were therefore halted at 20elements. The results are presented below using LMS and GA.

V. DISCUSSION

It was observed that the side lobe level reduced from -15dB to -30dB for 18 elements using LMS adaptive algorithm when compared to a setup without an algorithm. This value did not reduce even when the number of elements was increased to 19 and 20 elements. This therefore shows that the appropriate number of elements to give a minimum side lobe level is 18 so as not to waste the power that would be utilized in powering more elements since this would not result in reduced side lobe level. Results obtained through genetic algorithm were slightly different. The results are presented below:

The results of the simulations for equally spaced antenna elements using GA presented above show a further decrease in the side lobe level by about -0.29dB when the number of elements was increased to about 18. Further increase in the number of elements gave the same outcome as observed when LMS algorithm was used – the side lobe level did not decrease.

A graph showing the comparison of both adaptive algorithms with respect to the level of the side lobes is shown below. It is observed from the graph that GA initially had a higher side lobe level when 5 elements were used, but later produced a better result than the LMS when the number of elements was increased.

This result therefore shows that an optimum result with the lowest side lobe level can be obtained with equally spaced antenna elements when Genetic Algorithm is utilized as the adaptive algorithm compared to Least Mean Squares algorithm. This lowest value (-32.05dB) obtained through GA was gotten when the inter-elements spacing was fixed at 0.5λ.

Since the focus of this research is on both side lobe level and beamwidth, effects of the increase in number of elements on beamwidth are presented below.

The results to measure the effects of increase in number of elements on beamwidth can as well be inferred from the radiation patterns presented above. The vertical axis measures the Array Factor (in dB) while the horizontal axis measures the Angle of Arrival (AOA in degrees). The First Null Beamwidth (FNBW) reading can be extracted from the horizontal axis. Effects of increase in the number of elements on beamwidth are depicted in the result presented below using both LMS Algorithm and GA.

The result shows the number of elements increased from 5 to 20 elements. It can be observed from Figure 8 that the beamwidth is inversely related to the increase in the number of elements. As the elements increased from 5 to 20 elements, the First Null Beamwidth measured also decreased from 58^0 to about 14^0 when GA was used and 50^0 to 12^0 when LMS was used. This therefore depicts LMS having better results this time, compared to GA. Even though the beamwidth continued to decrease beyond 20 elements, it is not technically and economically recommended to continue to increase the number of elements particularly because the aim of energy decrease is in the side lobes whose decrease had already stalled at 18 elements. Increasing the number of elements therefore to 20 and beyond would amount to increase in the power and ultimately energy required to power the additional elements which the energy gain gotten through the reduced side lobes cannot compensate for. It is therefore technically and economically recommended especially in the case of linear array in smart antenna to halt the increase in the number of elements between 18 and 20 elements to get the optimal size of beamwidth that would still be effective while the appropriate side lobe level that would conserve energy optimally is been maintained at the minimum level.

The initial simulations carried out for equally spaced antenna elements were done with the minimum inter element spacing which is 0.5λ. But further experiments were conducted to find out if better results could be obtained for the side lobe level and beamwidth when this value increased to 0.9λ. The increase was not extended to λ due to the appearance of grating lobes at that point. But it was observed that the radiation pattern produced no further decrease in the side lobes level except for the beamwidth which reduced much further. The effect of this increase in the inter element spacing on the beamwidth is depicted in the result presented in figure 9 below. Note that this was carried out with 20 elements, which is the optimal number recommended for proper balance with the stall already observed as regards the side lobe level reduction. The presented result in Figure 5.10 shows the beam width decreasing from 11.5^0 to about 6.8^0 when the inter element spacing was increased from 0.5λ to 0.8λ. All other results obtained after 0.8λ remained at the same width. It is therefore recommended to halt the increase at this point.

VI. CONCLUSION

It can be inferred from the results obtained that the aim of this research which was to improve the performance of a linear array antenna by optimizing the radiation pattern using various approaches has been achieved. This target was achieved with the LMS and Genetic Algorithms. The results for equally spaced linear array elements using LMS and Genetic Algorithms show that an increase in the number of elements produced a reduction in side lobe level and array factor which also helps to avoid interference.

Also, increasing in the number of elements resulted in a decrease in beamwidth which also has a positive effect on energy consumption. It was as well interesting to note that increase in the inter-element spacing from 0.5λ to 0.9λ caused a reduction in beamwidth without adverse effects on the radiation pattern. The result is a better capability of transmitting in the desired direction and avoiding unwanted signals.

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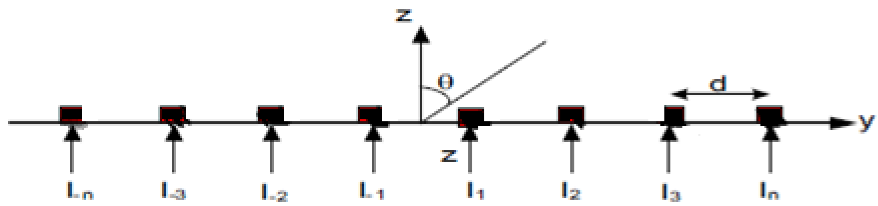

Figure 1: Equally Spaced Linear Array Arrangement [12]

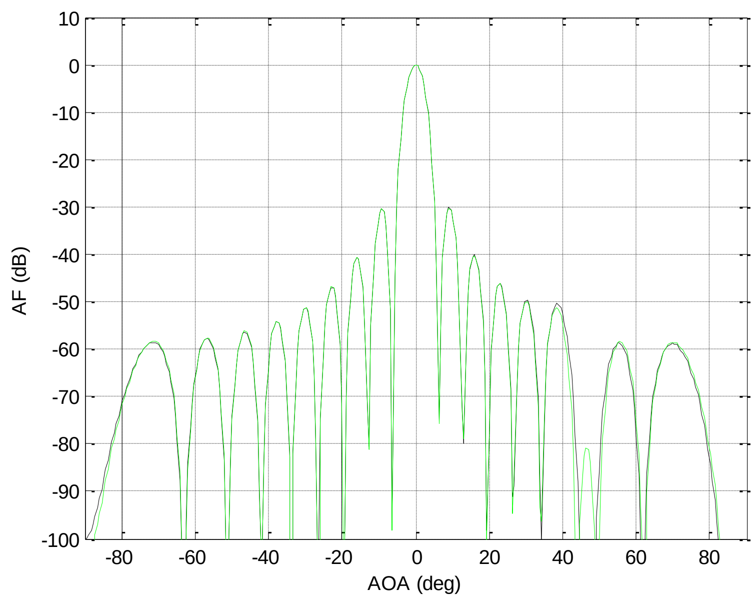

Figure 2: Radiation pattern for 18 Elements using LMS Algorithm

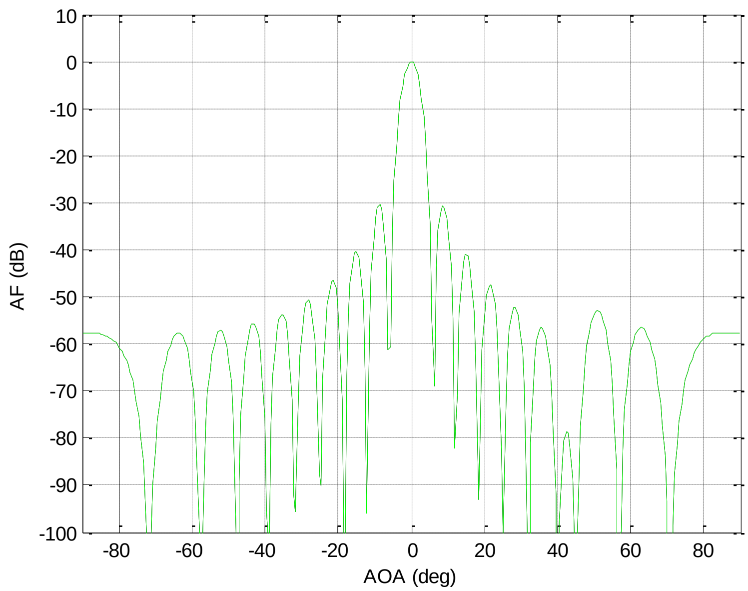

Figure 3: Radiation pattern for 19 Elements using LMS Algorithm

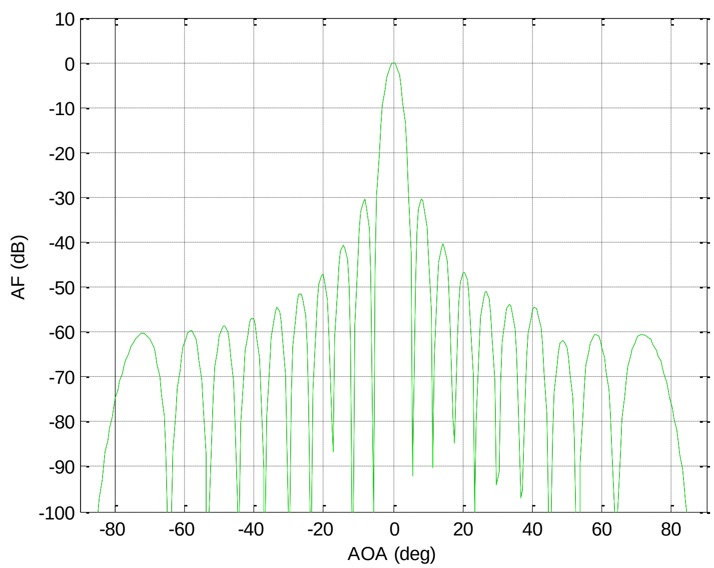

Figure 4: Radiation pattern for 20 Elements using LMS Algorithm

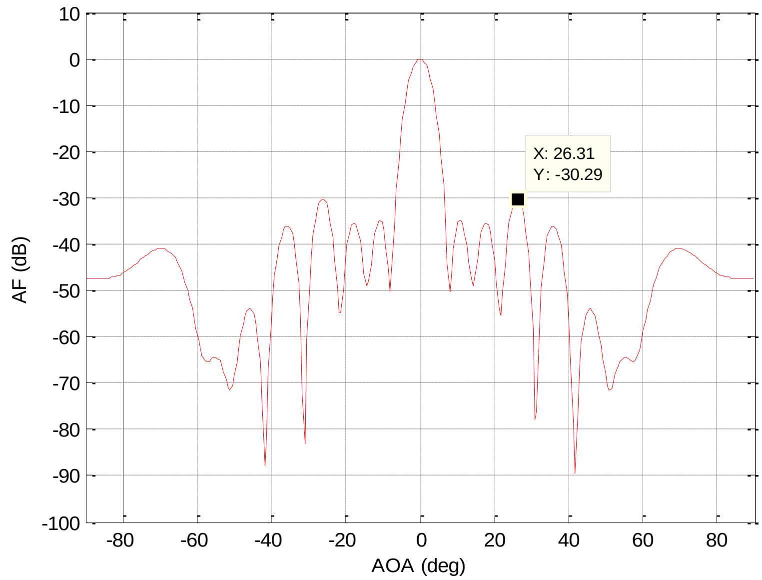

Figure 5: Radiation pattern for 18 Elements using GA

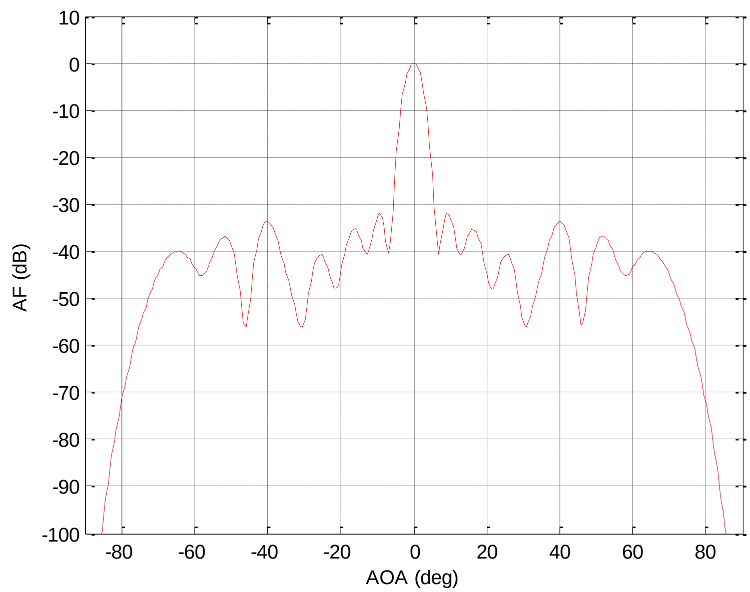

Figure 6: Radiation pattern for 20 Elements using GA

Table 1: Measured side lobe level and beamwidth for 0.5λ inter-element spacing for LMS and GA

Number of Elements	0.5λ SLL LMS (dB)	0.5λ FNBW LMS (Deg)	0.5λ SLL GA (dB)	0.5λ FNBW LMS (Deg)
5	-25.58	50.32	-25.1	58.36
6	-26.13	38.86	-27.71	49.18
7	-28.65	35.44	-28.69	40.24
8	-28.79	28.56	-29.22	29.7
9	-28.7	26.26	-29.54	27.88
10	-29.7	22.82	-29.75	26.44
11	-29.75	20.54	-29.84	24.28
12	-29.62	19.58	-30.12	23.94
13	-30.13	18.24	-30.24	22.86
14	-30.34	15.96	-30.52	20.46
15	-30.04	14.8	-31.23	18.48
16	-30.52	14.8	-31.59	17.52
17	-30.29	13.66	-31.62	14.9
18	-30.42	12.52	-31.73	14.44
19	-30.58	12.52	-32	14.2
20	-30.58	11.16	-32.05	13.66

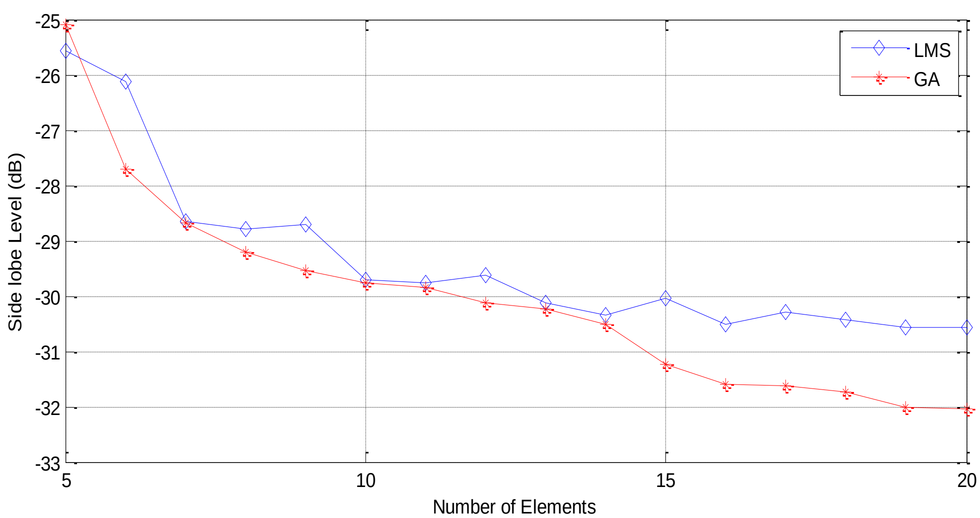

Figure 7: Comparison of LMS and GA Side Lobe level Results Obtained for Equally Spaced Antenna Elements

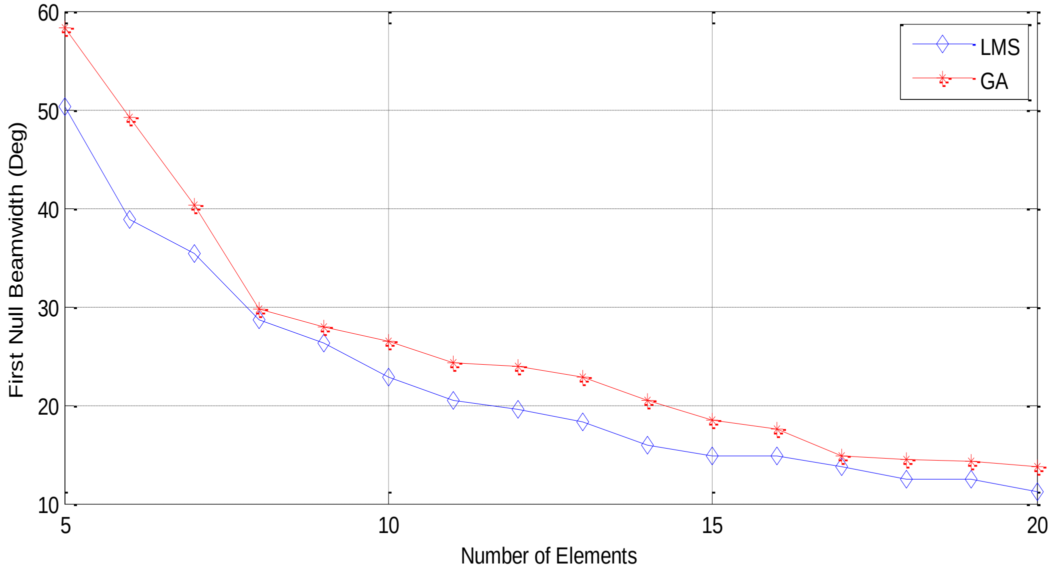

Figure 8: Comparison of LMS and GA Beamwidth Results Obtained for Equally Spaced Antenna Elements

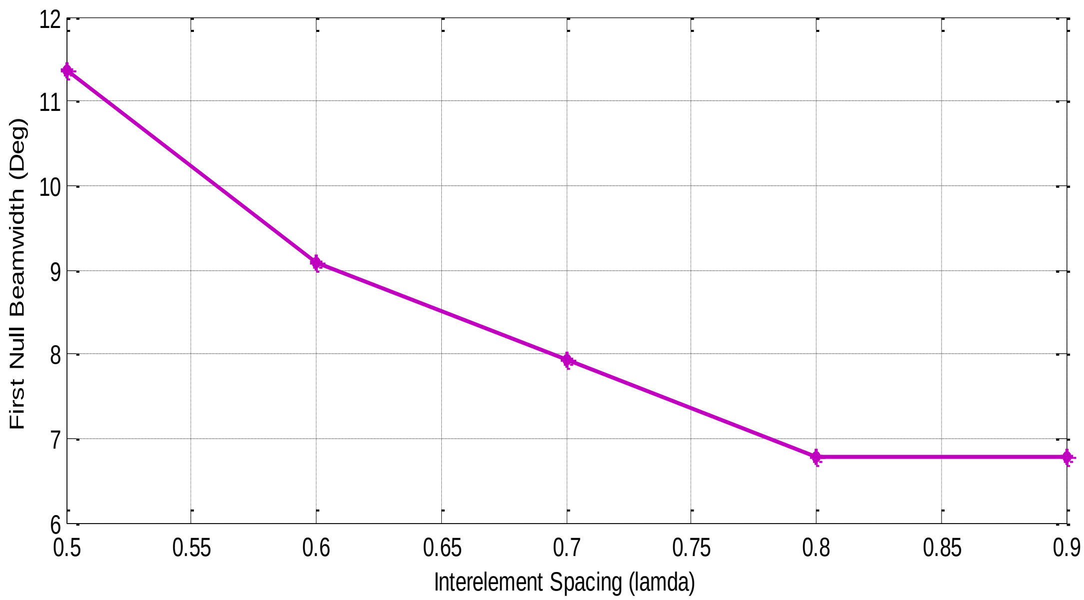

Figure 9: Result showing the effect of increase in Inter Element Spacing on Beamwidth