OPTIMIZING ENERGY UTILIZATION IN UNEQUALLY SPACED LINEAR ARRAY FOR SMART ANTENNA

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Abstract
Radiation in unwanted patterns, energy wastage and reduction are caused by high side lobe levels in a radiation pattern. This in turn affects the overall performance of the antenna. The purpose of this work is to improve the performance of a smart antenna by optimizing the radiation pattern using genetic algorithm. Optimal antenna parameters that would minimize side lobe level were obtained using genetic algorithm. Simulations were carried out to determine the impact of the increase in inter-element spacing on array factor and beamwidth using the optimal antenna parameters. The optimal arrangement of inter-element spacing and number of elements in unequally spaced antenna elements were then considered. The array factor model for a uniform linear array of elements was used with the aim of obtaining the optimum weights that would give a radiation pattern with reduced side lobe level. It was observed from the results for unequally spaced linear arrays, using all the possible configurations, that non-tapered arrangement gave the best improvement in the side lobe level. The outcome of this improvement is an optimized radiation pattern which is expected to aid the reduction of radiated power wasted in the side lobes of linear arrays in antenna systems.

Keywords: Array Factor, Genetic Algorithm, Side Lobe Level, Unequally Spaced Linear Arrays

1.0 INTRODUCTION

Antenna arrays are widely used in wireless communications. An antenna with higher directivity and lower Side Lobe Level (SLL) is usually preferred. In an antenna radiation pattern, nulls are directed towards interfering signals while the main beam is pointed towards signals-of-interest. A single element antenna has limited performance. Thus, antenna arrays are used to achieve low side lobes, narrower beamwidth, gain and higher directivity (Balanis, 2005). An antenna array consists of radiating elements of an antenna connected electrically and geometrically. The radiation pattern of an antenna array is formed by the contribution of the pattern of each individual element. Several variables could be used to determine the general radiation pattern of an antenna array. These include the geometrical configuration of the array, relative displacement between elements, excitation amplitude of individual elements, excitation phase of individual elements, and relative pattern of the individual elements (Lakshmi and Raju, 2011). In the wireless communication systems, the purpose of using array antennas is to separate the desired signal from unwanted interferences.

It is usually desired in the antenna arrays that the height of side lobes be kept low to optimize energy utilized. But the level of the side lobes in a normal radiation pattern is usually high thereby causing: unwanted radiation in undesired patterns, energy wastage and reduction in the overall performance of the antenna. Since lower side lobe antenna arrays are becoming increasingly important, components of high performance electronic systems, particularly those operating in technically demanding environments, it is therefore necessary to discover faster and more reliable methods at arriving at the optimum solution. The simulation of the antenna radiation pattern is therefore carried out in this research work using unequally spaced linear array elements to optimize the performance of smart antennas.

The aim of this research is to improve the performance of an unequally spaced linear array antenna by optimizing the energy utilized in the radiation pattern.The following are the specific objectives that helped achieve this aim: determiningthe optimal inter-element spacing, arrangements and the number of elements in unequally spaced linear antenna array.

In this work, the scope is limited to unequally spaced linear arrays in antenna systems and particularly focused on the reduction of radiated power wasted in side lobes. Basically, the optimization technique used is the Genetic Algorithm to calculate the weight coefficients, which would then be updated and assigned to each element in the forming of the radiation pattern.

2.0 RELATED WORKS

Sanchez-Gomez et al. (2009) used Legendre functions for the optimization of linear and planar arrays. They showed a reduction in the side lobe level, half power beamwidth as well as a better directivity for non-uniform linear and planar arrays than in the uniform ones. Kumar and Branner (1999) used a simple inversion algorithm to determine the inter-element spacing in linear arrays. It is shown from this work that an improvement was achieved in unequally spaced linear array than in an equally spaced array with the same number of elements. In Hussein et al (2012), a combination of Method of Moments (MoM) and Genetic Algorithm (GA) was used for linear antenna arrays to obtain a maximum side lobe level reduction. Side lobe level reduction was achieved with a reduced number of antenna elements using this method while keeping the main lobe beamwidth intact. Maharimi et al. (2012) showed the effect of spacing and number of elements on gain and half power beamwidth (HPBW). It showed an increase in the HPBW and number of side lobes as the inter-element spacing increased while the gain remained the same. However, there was an increase in gain with increasing number of elements. Tan et al. (2010) used unequal spacing technique to reduce the side lobe level and the number of element of a linear antenna array. The paper showed that an unequally spaced antenna with lower number of elements produced better side lobe level, same half power beamwidth and similar antenna gain when compared with an equally spaced antenna with little more elements than it.

3.0 SYSTEM MODEL

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 unequally spaced symmetrical arrangement can be classified into space-tapered (ST) arrays and non-tapered (NT) arrays. The inter-element spacing increases from the centre of the array towards the end for the space-tapered arrangement. However, the inter-element spacing decreases from the centre of the array towards the end for non-tapered arrangement [23].

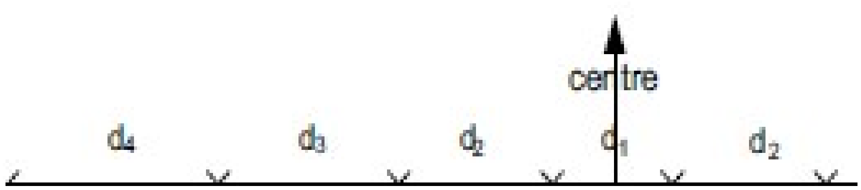

Figure 1: Symmetric Unequal Spacing Arrangement (Tan et al., 2010)

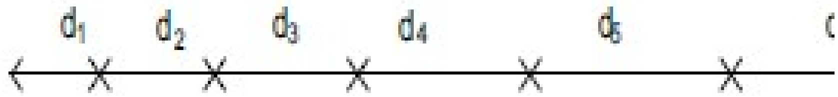

Figure 2: Asymmetric Unequal Spacing Arrangement (Tan et al., 2010)

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

$$AF(\theta) = \sum_{n=1}^{N} I_n e^{j(n-1)kd\,c} \qquad = \sum_{n=1}^{N} I_n \, e^{j(n-1)\varphi} \tag{1}$$

Where:

I_n is the excitation of the element n.

k is the wave number.

d is the spacing between the elements.

Letting:

$$z = x + jy = e^{j\varphi} = e^{j(kd\,c \quad)} \tag{2}$$

Expanding and rearranging (1) gives

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

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

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

Given that:

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

Where AF_i = contribution of element i to array factor $AF(\theta)$

Subject to:

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

4.0 SIMULATION AND RESULTS

The distances for unequal spaced linear array of an antenna with *N*-element are non-uniform in arrangement. Their configuration can be rearranged either in symmetrical or asymmetrical arrangement. Experiments were performed to demonstrate the effect of different unequal inter-element spacing on the sidelobe level and beamwidth. The symmetric and asymmetric arrangements were considered. Genetic Algorithm was used to obtain weights for 18 to 20 elements. It was also used to obtain the best combination of inter elements which would produce a lower array factor thereby producing a much lower level in the side lobes. Having obtained the optimal inter element distances which indicated an interval of about 0.04λ, the arrangement of these distances were then put into consideration. The results for the various spacing arrangements are presented as shown in Figure 3 through Figure 8.

4.1 Result using Asymmetric Spacing Arrangement

This arrangement is as explained earlier where the inter elements spacing are arranged in ascending or descending order. The radiation pattern using asymmetric arrangement for 18 and 20 elements is as shown in Figure 3 and Figure 4 respectively.

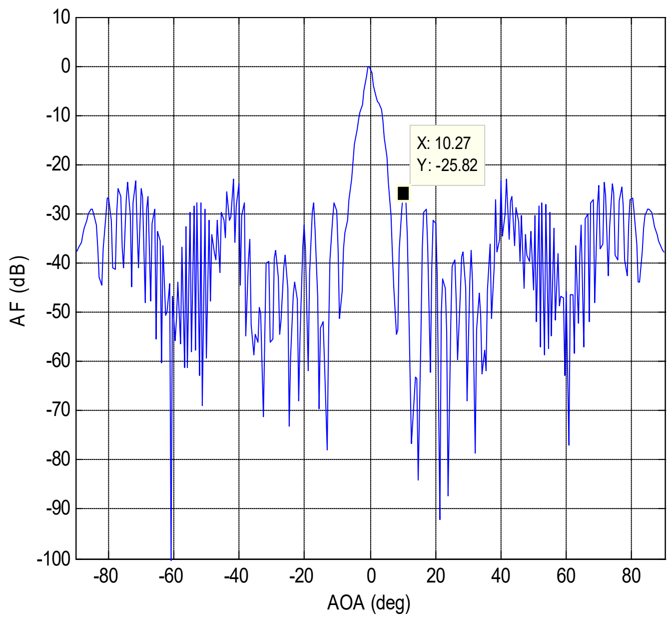

Figure 3: Radiation Pattern for 18 elements using asymmetric arrangement

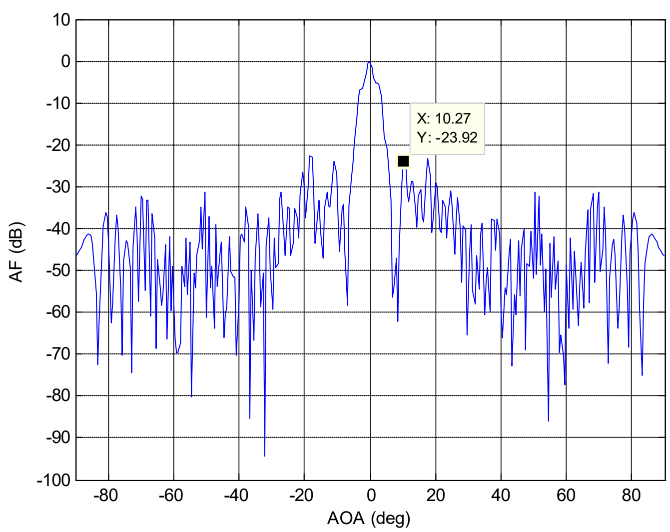

Figure 4: Radiation Pattern for 20 elements using asymmetric arrangement

4.2 Result using Space-Tapered Arrangement

Space-Tapered is a symmetric arrangement where the unequal distances spread out from the centre. The results obtained especially for the 18 and 20 elements were different from the asymmetric results as clearly seen and presented as shown in Figures 5 and 6 respectively.

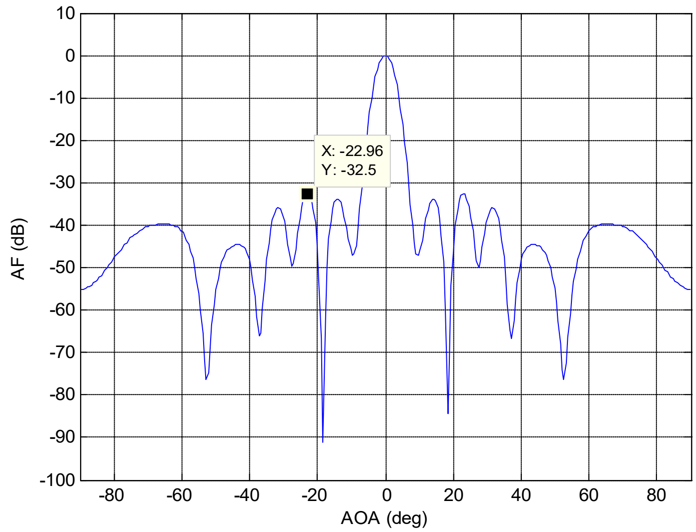

Figure 5: Radiation Pattern for 18 elements using space-tapered arrangement

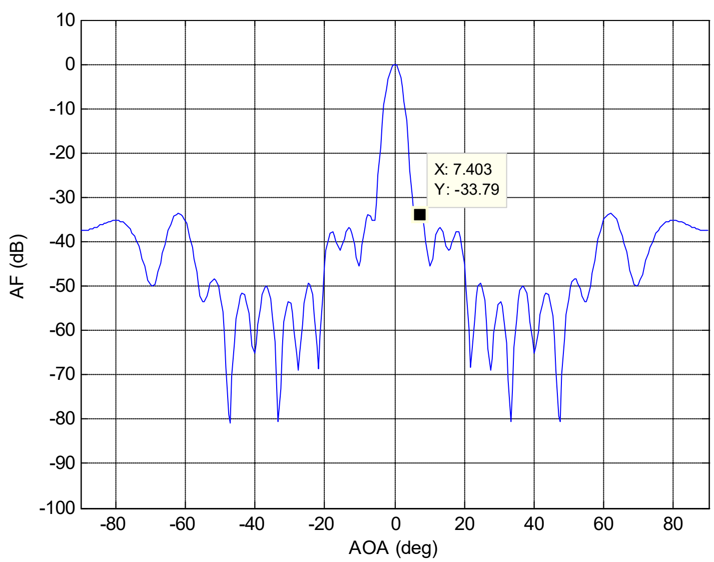

Figure 6: Radiation Pattern for 20 elements using space-tapered arrangement

4.3 Result using Non-Tapered Arrangement

This is another form of symmetric arrangement where the inter element spacing decreases outwards from the centre. The parameters used in the simulation carried out to produce this result were similar to that used to produce the other results except for the arrangement pattern. The significant changes as before occurred when the elements were increased to about 18 elements. The results presented therefore are just for 18 and 20 elements. This form of arrangement gave very interesting results as shown in Figures 7 and 8 respectively.

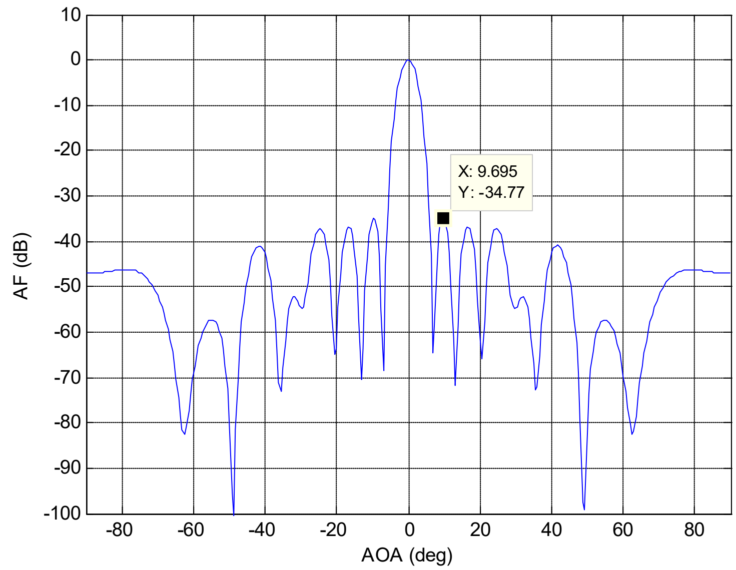

Figure 7: Radiation Pattern for 18 elements using non-tapered arrangement

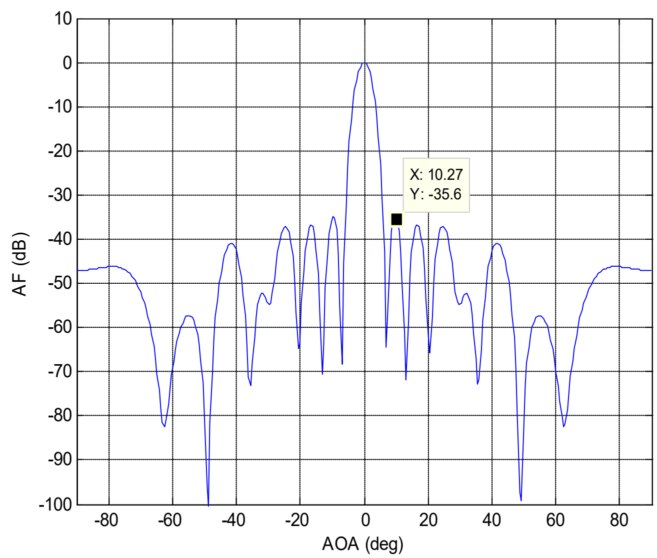

Figure 8: Radiation Pattern for 20 elements using non-tapered arrangement

5.0 DISCUSSION

The results shown in Figures 3 and 4 are the radiation patterns obtained for 18 and 20 elements respectively using asymmetric spacing arrangement. It can be observed from the results that the side lobes level is about 25.8dB which is not as low as the results obtained when experiments were conducted with equally spaced antenna elements. Also the side lobes are not well spread as compared to the pattern obtained with equally spaced antenna elements. This arrangement is therefore not recommended

The result presented in Figures 5 and 6 depicts the observations made when the inter element spacing were arrangement in space-tapered order for 18 and 20 elements respectively. It is noted that the side lobe level reduced significantly beyond the level where the equally spaced antenna elements reached. This value (-33.79dB) indicated a significant improvement compared to the value obtained when equal inter element spacing was used. The beamwidth is also reduced to about 12^0 which is lower than that of equally spaced observed in literature.

Another significant observation made was the fact the side lobes were well laid out contrary to the irregular lay out observed when asymmetric arrangement was utilized.

The results shown in Figures 7 and 8 indicate even much better improvement in the side lobe level as well as the beamwidth. The side lobe level is now further reduced to -35.6dB while the beamwidth obtained was 13.26^0.

The non-tapered arrangement therefore gave the best result in terms of side lobe level while the space-tapered gave the best result in terms of beamwidth.The three arrangements were then compared in terms of their side lobe level and beamwidth. The results obtained are presented in Figures 9 and 10 respectively.

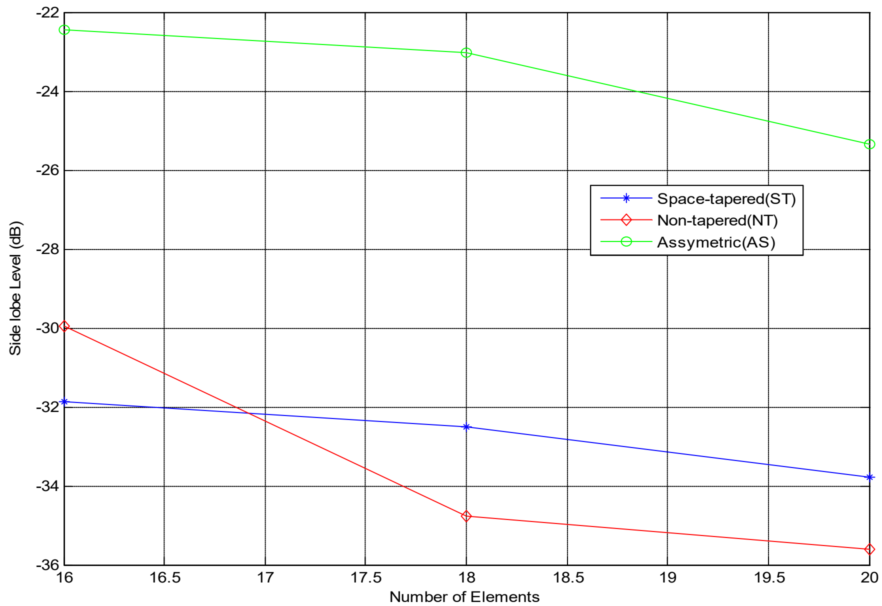

Figure 9: Comparison of arrangement on side lobe level

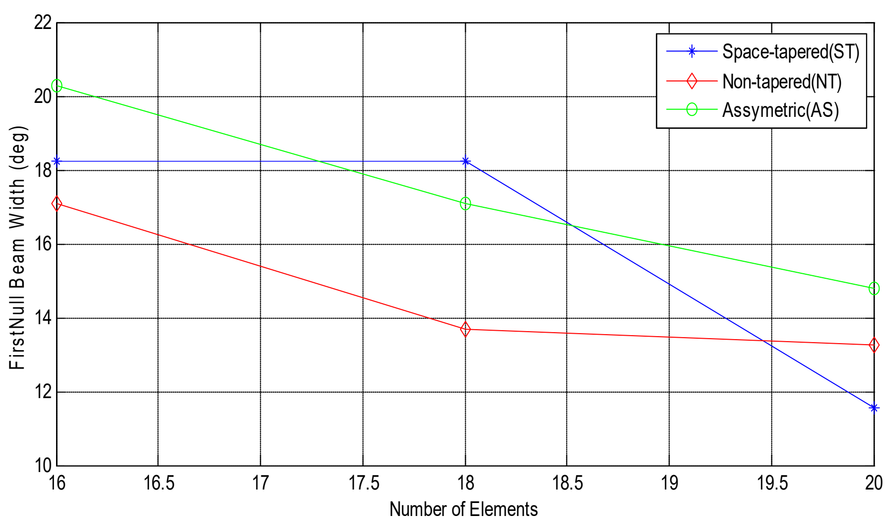

Figure 10: Comparison of arrangement on beamwidth

It can be observed from the results presented in Figures 9 and 10 that the non-tapered arrangement gave the best result while the asymmetric gave the worst result in terms of side lobe level. But space-tapered arrangement gave the best result in terms of beamwidth.

6.0 CONCLUSION

For unequally spaced linear arrays, using all the possible configurations, there is improvement in the sidelobe level (SLL) by approx. 3.5dB for 20 elements with Non-Tapered arrangement as the best configuration when compared to that of the equally spaced linear array. This therefore means that with less number of antenna elements using non uniform inter-element spacing, energy wasted through the side lobes can be significantly reduced.

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