SYNTHESIS OF NON-UNIFORM LINEAR ANTENNA ARRAY GEOMETRY WITH DEEPER NULLS USING REAL CODED GENETIC ALGORITHM

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Abstract*—In this article, the method of nullifying the radiation pattern of a symmetric linear antenna array in one or more particular directions is propounded using Real-Coded Genetic Algorithm. The method of genetic algorithms is used to determine an optimum set of antenna element separations that provide a radiation pattern with deeper nulls in one or two desired direction. The effectiveness of genetic algorithms for the design of non-uniform linear arrays is shown by means of experimental results. Element spacing d is taken to be between $\lambda/4$ and $\lambda/8$ thus enabling the design of compact multiple antenna terminals.*

Keywords*—Linear Antenna Array; Deeper Nulls; Real-coded Genetic Algorithm; Non-uniform spacing; Side lobe Level; First Null Beamwidth*

1. Introduction

Antennas play a vital role in the design and development of communication system. An array of antennas mounted on vehicles, ships, aircraft, satellites and base stations is expected to play an important role in fulfilling the increased demand of channel requirement for those services as well as for the realization of miniaturized communication devices at an affordable price [1]. An array of antennas may be used in a variety of ways to improve the performance of a communications system [2-4]. Perhaps most important is its capability to cancel co-channel interferences. An array works on the premise that the desired signal and unwanted co-channel interferences arrive from different directions. Different applications require antennas not to radiate to or receive from some particular directions thus radiated (or received) power in (or from) these directions should be negligible. Hence placing nulls in the radiation pattern of an antenna is essential to reject strong interferences. It is well known that multiple-input multiple-output (MIMO) systems with multi-element antennas both at the transmitter (Tx) and at the receiver (Rx) offer increased capacity, when the fading is independent in the links between different pairs of Tx and Rx antennas [5,6]. At the mobile terminal, space is limited and the fading might be correlated when antennas are closely spaced. Indoor measurements show that the capacity remains large, even if d is as small as $\lambda/5$ [5-6] or even less [7].

Increasing pollution of the electro-magnetic environment [8-9] has prompted the study of array pattern nulling techniques. The goal in antenna array geometry synthesis is to determine the physical layout of the array that produces the radiation pattern that is closest to the desired pattern. The shape of the desired pattern can vary widely depending on the application. Many synthesis methods are concerned with suppressing the side lobe level (SLL) while preserving the gain of the main beam. Other methods deal with the null control [10-14] to reduce the effects of interference and jamming. For the linear array geometry, this can be done by designing the spacings between the elements, while keeping a uniform excitation over the array aperture.

The goal of this paper is to optimize the inter-element spacing in order to introduce deeper nulls, hence working towards the improvement of antenna array pattern. Due to the great variety of parameters involved, optimization techniques such as genetic algorithms (GA) [15-17] are very appropriate tools to search for the best antenna models. GA techniques [11, 15, 18-20] are becoming widely used to solve electromagnetic problems due to their robustness, wide range of applications and readiness in their implementation.

The rest of the paper is organized as follows: In section 2 the general design equation for the linear array is stated. Section 3 gives a brief introduction of Real-Coded Genetic Algorithm. Computational results are presented in section 4 and finally the paper concludes with a summary of the work in section 5.

2. Design Equation

An array of an odd number of isotropic elements (2M+1) (where M is an integer) is positioned symmetrically along the z-axis, as shown in Fig. 1. M elements are placed on each side of the origin with one element at the origin itself.

Assuming that the amplitude excitation is symmetrical about origin, the Array Factor ($(AF)_{(2M+1)}$) for the given non-uniformly spaced broadside array is given by [1]:

$$(AF)_{(2M+1)} = I_n + 2\sum_{n=1}^{M} I_n \cos\left[\left(\frac{2n-1}{2}\right) k\, d_n \cos\theta + \beta\right] \quad (1)$$

where

β = phase weight at element n

I_n = Excitation Amplitude for n^{th} array element

$(2M+1)$ = total number of elements in the array

k = propagation constant

d_n = spacing between n^{th} and $(n-1)^{th}$ element

θ = angle of radiation of electromagnetic plane wave

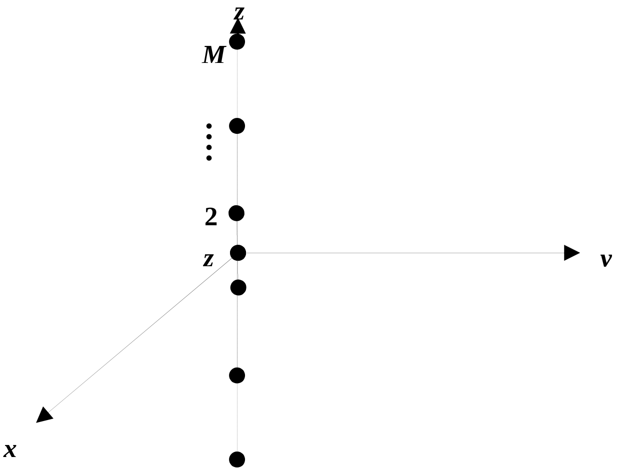

Fig. 1. Schematic architecture of a symmetric Linear Array Antenna structure of *(2M+1)* elements placed along z-axis.

All the antenna elements are assumed isotropic. Only the inter-element spacing of each antenna is used to change the antenna pattern. So, this is an optimization problem and the Cost Function (*CF*) for imposing nulls at a desired direction, is given by (2):

$$CF = \frac{\left|\prod_{i=1}^{m} AF_{null}(\theta_i)\right|}{\left|AF_{\max}\right|} \quad (2)$$

'm' is the maximum number of positions where nulls can be imposed. In this paper, one and two has been considered as the value of 'm'. $AF_{null}(\theta_i)$ is the Array factor value at the particular null. AF_{max} is the maximum of the array factor. In cost function, both the numerator and denominator are absolute values. Smaller value of the cost function means that array factor values at predefined positions are less. Consequently, GA controls the inter-element spacing in order to minimize the cost function.

3. Evolutionary Technique Employed

Real Coded Genetic Algorithm (RGA)

A Genetic algorithm is mainly a probabilistic search algorithm based on the principles and concept of natural selection and evolution [15-17]. At each generation it maintains a population of individuals where each individual is a coded form of a possible solution of the problem at hand and called chromosome. Each chromosome is evaluated by a function known as fitness function, which is usually the cost function or the objective function of the corresponding optimization problem. Next, new population is generated from the present one through selection, crossover and mutation operations. Purpose of selection mechanism is to select more fit individuals (parents) for crossover and mutation. Crossover causes the exchange of genetic materials between the parents to form offspring, whereas mutation incorporates new genetic material in the offspring.

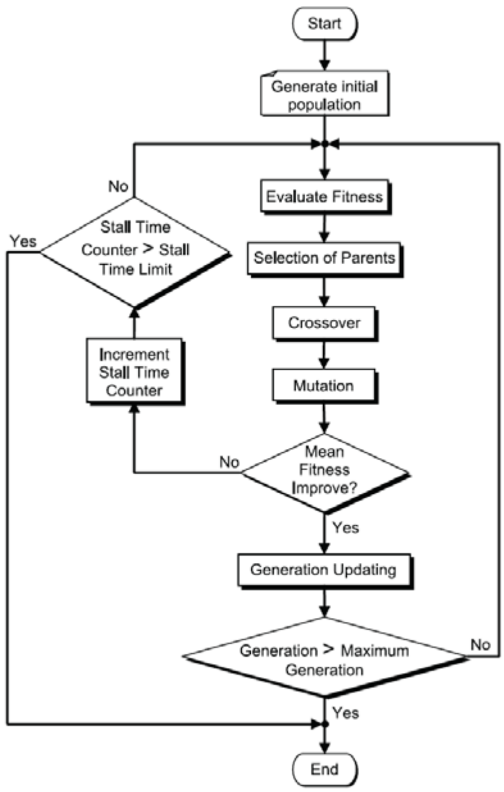

Fig. 2. Flow chart for the optimization algorithm RGA

Implementations of above-mentioned components for the Genetic Algorithms given in Fig. 2 are as follows [19]:

- *Population*: Initial population is generated randomly and uniformly. The different sets of inter-element spacings $d_1, d_2, \ldots, d_i, \ldots, d_M$ constitute the chromosomes of each generation. With i varying from 1 to M d_i represents the gene of each chromosome.
- *Evaluation of Fitness Function:* With the help of (1) and (2) Array Factor (AF) and the Cost Function (CF) are evaluated for each set of chromosomes in each generation. Based on the cost function value the sets of inter-element spacing are sorted and finally the set of chromosome which gives the best improved solution for the radiation pattern is obtained.
- *Crossover*: Here, single point crossover is used.
- *Mutation*: Mutation rate was set to 0.01.
- *Stopping Criteria*: The operation will stop once the maximum number of iterations is reached.

4. Computational results

4. A. Analysis of radiation pattern

This section gives simulated results of the performance of the imposed nulls at various positions of the radiation pattern. The linear antenna array structure having 41 elements is assumed, every element being excited equally. For predefined null positions of the radiation pattern, the nulling performances are improved. Similarly at predefined peak positions, the nulls are imposed. Every time GA is executed with 100 iterations. The population size was fixed at 120. For the real coded GA, the mutation rate was set to 0.01 and uniform crossover was taken with crossover probability 1. GA algorithm is initialized using random values.

For the existing radiation pattern the initial parameters are enlisted in Table 1.

Table 1
Initial parameters for 41 element linear array

Positions	Positions value (In degree)	Null/Peak level (in dB)
1st Null	78.1, 101.9	-49.41
2nd Null	66.9, 113.1	-50.85
1st Peak	73.4, 106.6	-14.52
2nd Peak	60.5, 119.5	-16.45

Introduction of deeper nulls is considered for four different cases. The different positions considered are 1st null, 2nd null, 1st peak and 2nd peak. 1st null is positioned at $\theta = 78.1$ deg. Due to the symmetricity of the radiation pattern; null is also obtained at $\theta = 101.9$ deg. Similarly 2nd null is positioned at $\theta = 66.9$ deg and $\theta = 113.1$ deg. 1st peak is located at $\theta = 73.4$ deg .When null is imposed at 1st peak; due to symmetricity of pattern deeper null is obtained at $\theta = 106.6$ deg. Similarly imposing null at 2nd peak gives deeper null at $\theta = 60.5$ deg and $\theta = 119.5$ deg.

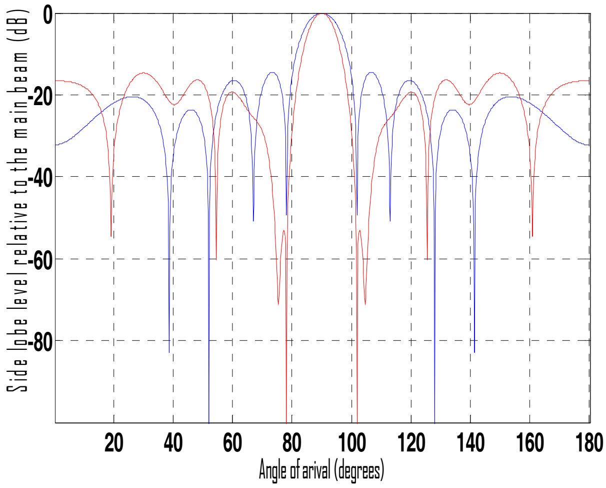

Fig. 3. Best array pattern found by GA for the 41-element array case with an improved null at 1st null i.e. θ=78.10 and $\theta = 101.9$.

Figs. 3-6 show the imposition of deeper nulls over single null, two nulls, single peak and two peaks respectively. As shown in Fig. 3 for the existing radiation pattern, the null has improved up to -127 dB for the case of imposition of deeper nulls over the 1st null. The peak SLL has improved to -14.7dB. The mean SLL has improved to -24.02dB in the radiation pattern with deeper first null. The 3-dB bandwidth reduces to 7.35 deg from 10.3 deg in the original radiation pattern. The final null value, the improved 3-dB bandwidth and the optimized inter-element spacings obtained using RGA corresponding to this case are enlisted in Table 2. Fig.4 shows the improvement in radiation pattern for the case of imposing deeper nulls at the existing 1st and 2nd null. The 1st null has been modified to -103.8dB while the 2nd null has been brought down to -61.99dB. Simultaneously there is an improvement in 3-dB bandwidth which is reduced to 7.34deg. The peak SLL has been reduced to -18.18dB and the mean SLL is reduced to -22.92dB. Table 3 shows the optimized spacing values, the final null values and improved 3-dB bandwidth corresponding to fig. 4.

Table 2
Single null imposed in the 1st null position using RGA

Inter-element Spacing $(d_1, d_2, \ldots\ldots, d_M)$ in λ	Null Value (dB)	3-dB Band width (deg)
5.8376, 3.2056, 5.0253, 4.6218, 5.4253, 5.1034, 4.1955, 3.5098, 4.5054, 3.4800, 3.4918, 5.8276, 4.5203, 3.1398, 4.5379, 5.3203, 3.2324, 4.5780, 0.6155 , 5.5366	-127	7.35

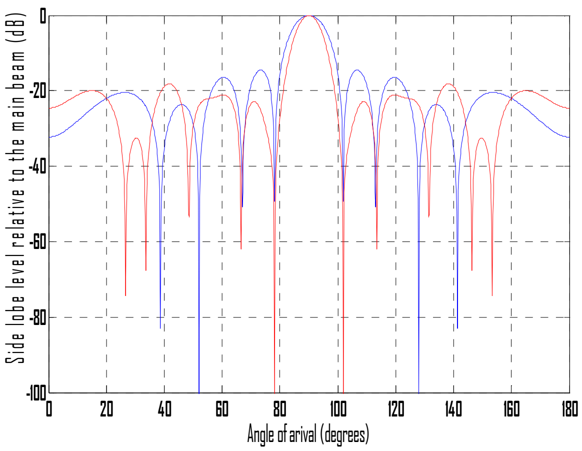

Fig. 4. Best array pattern found by GA for the 41-element array case with an improved null at 1st null i.e. θ=78.1, $\theta = 101.9$ and 2nd null $\theta = 66.9$, $\theta = 113.1$.

Table 3
Final Parameters with nulls imposed in the 1st And 2nd null position using RGA

Inter-element Spacing $(d_1, d_2, \ldots, d_M)$ in λ	Null Value (dB) 1st Null,2nd Null	3-dB Band width (deg)
4.5940, 5.2332, 5.9738, 4.7843, 3.5183, 4.8918, 4.2407, 3.6931, 5.3904, 3.8647, 4.0415, 5.4563, 5.0527, 3.0750, 3.2966, 5.1855, 3.0877, 5.0367, 5.9212 , 0 .4192	-103.8, -61.99	7.34

Fig.5 depicts the improved radiation pattern when null is imposed at the first peak. The final value of null obtained is -116.2dB over the initial value of -14.52dB. The resultant 3-dB bandwidth obtained in this case is 7.35deg.The mean SLL has improved to-33.24dB while the peak SLL goes down to -22.07dB. The final parameters with one null imposed in 1st peak position are enlisted in Table 4. For the case of nulling at 1st peak and 2nd peak as shown in fig. 6 the final values of nulls obtained are -108.3dB and -82.62dB respectively. The 3-dB bandwidth obtained is 7.35deg.

The peak SLL in the final radiation pattern is -14.19dB while the mean SLL is -25.48dB. Table 5 gives the optimized inter-element spacing values, the final peak values and 3-dB bandwidth values for the radiation pattern corresponding to fig. 6.

Table 6 gives the mean, variance and standard deviation of SLL in the original radiation pattern. Table 7 enlists the corresponding parameters in the improved radiation patterns after nulls being imposed in different positions as considered in the four cases above.

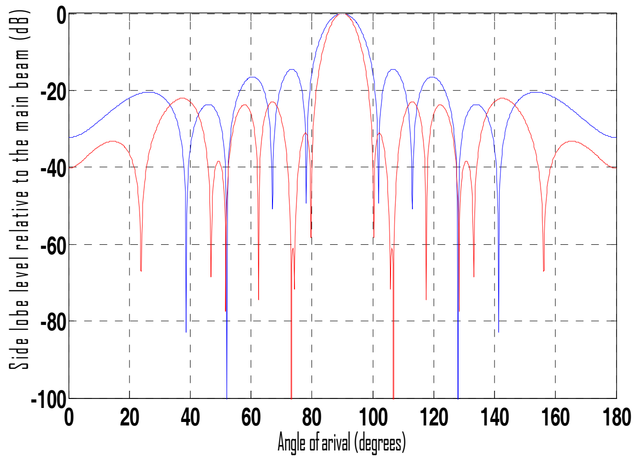

Fig. 5. Best array pattern found by GA for the 41-element array case with an improved null at 1st peak i.e. θ=73.4 and $\theta = 106.6$.

Table 4
Final parameter with one null imposed in the 1st peak position using RGA

Inter-element Spacing $(d_1, d_2, \ldots\ldots, d_M)$ in λ	Peak Value (dB)	3-dB Band width (deg)
4.4750 , 3.9370, 5.1204, 5.5202 , 5.1399, 4.4628, 4.7566, 3.0590, 3.9753, 4.7035, 5.6995, 3.5832, 3.2904, 0.6384, 3.1679, 5.4286, 4.8698, 5.5566, 3.2489 , 3.2635	-116.2	7.35

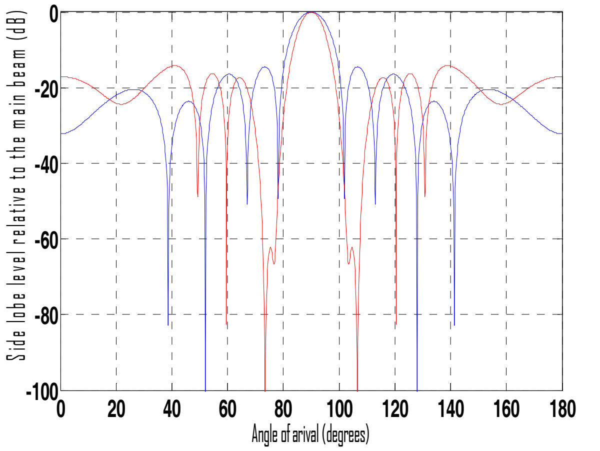

Fig. 6. Best array pattern found by GA for the 41-element array case with improved nulls at 1st peak i.e. θ =73.4 and θ = 106.6 and 2nd peak i.e. θ =60.5 and θ = 119.5.

Table 5
Final parameters with two nulls imposed in the 1st & 2nd peak position

Inter-element Spacing $(d_1, d_2, \ldots, d_M)$ in λ	Peak Value (dB)		3-dB Band width (deg)
	1st Peak	2nd Peak	
4.7101, 4.1833, 4.4127, 5.6448, 5.0405, 3.2232, 4.0529, 4.0922, 3.5417, 5.2732, 4.7483, 3.1641, 3.6666, 4.4186, 4.4608, 5.9834, 4.0425, 3.7368, 5.7866, 0.1556	-108.3	-82.62	7.35

Table 6
Mean, variance, standard deviation of SLL in the existing radiation pattern

Mean (in dB)	Variance (in dB)	Standard Deviation (in dB)
-18.76	12.46	3.5298

Table 7
Mean, variance, standard deviation of SLL in the final radiation pattern after imposition of null

Cases	Positions of null imposition	Mean (in dB)	Variance	Standard Deviation
I.	1st null	-24.02	215.09	14.6659
II.	1st and 2nd Null	-22.92	25.15	5.015
III.	1st Peak	-33.24	161.56	12.7
I V.	1st and 2nd Peak	-25.48	340.38	18.45

4. B. Convergence profile of RGA

The minimum *CF* values are plotted against the number of iteration cycles to get the convergence profiles for the optimization techniques. All optimization programs are written in MATLAB 7.5 version on core (TM) 2 duo processor, 3.00 GHz with 2 GB RAM. Figs. 7-10 show the convergence profiles for the cases of deeper null imposition at single null, two nulls, single peak and two peaks respectively.

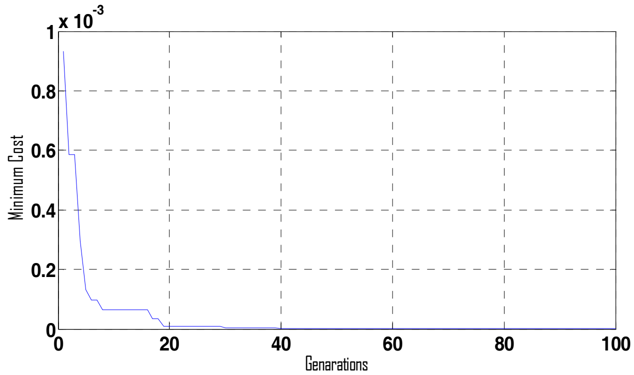

Fig. 7. Convergence curve for GA for the case of single null

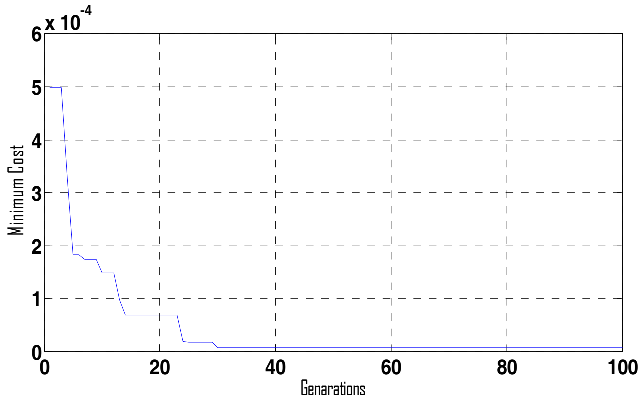

Fig. 8. Convergence curve for GA for the case of 2 nulls

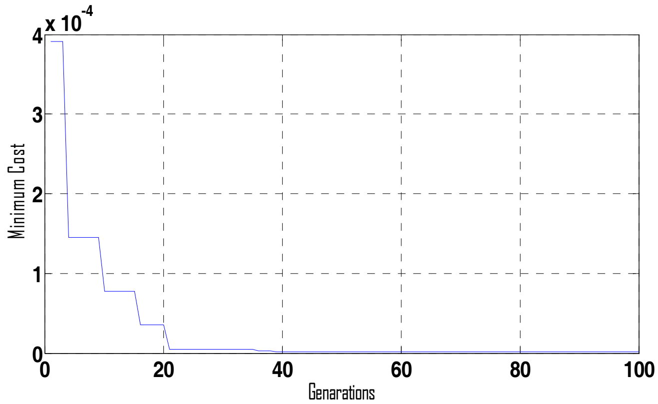

Fig. 9. Convergence curve for GA for the case of null imposition at single peak.

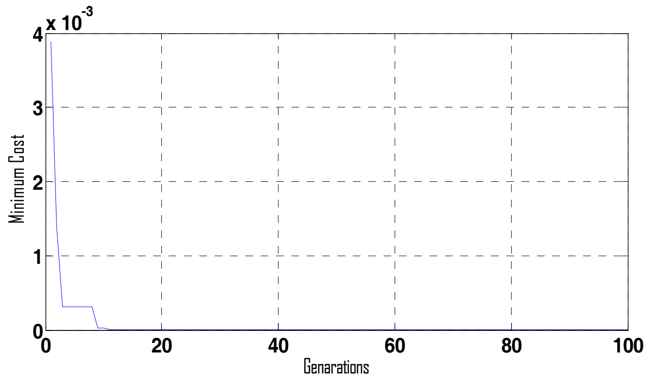

Fig. 10. Convergence curve for GA for the case of null imposition at 2 peaks

5. Conclusion

Data transmission needs to be less effected by the losses, noises so antenna array systems must be designed to avoid from these negative effects. This paper illustrates the design of non-uniform linear antenna arrays for imposing deeper nulls. The well-known method of genetic algorithms is proposed as the solution for this problem design. The genetic algorithm can efficiently handle the design of non-uniformly spaced symmetric linear antenna array by generating radiation patterns with maximum deeper nulls at a desired direction with respect to corresponding uniformly spaced linear array with interelement spacing of $\lambda/2$, for a given number of the array elements. Simultaneously there has been appreciable improvement in the SLL in the generated radiation pattern over the existing pattern.

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