Comparative Study of Symmetrical Linear Antenna Array Optimization Techniques

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Abstract: As in the radiation of signal from antenna array, the side lobes radiated plays an adverse role in communication of signal in the desired direction. So, for better radiation pattern the Side Lobe Level must be reduced. In this paper comparison of reduction of Side Lobe Level (SLL) of uniformly excited symmetrical linear antenna array is done using Genetic Algorithm (GA), Simulated Annealing (SA), and Artificial Bee Colony (ABC). The method of Genetic Algorithm, Simulated Annealing and Artificial Bee Colony is used to determine a set of inter-element spacing that is required for reducing the side lobe level. The performance of above mentioned optimization techniques are analyzed and compared based on the results presented in this paper in graphical and tabular form.

Keywords: Symmetrical Linear Antenna Array, Genetic Algorithm, Simulated Annealing, Artificial Bee Colony, Side lobe level.

I. INTRODUCTION

Antenna Array consists of a number of radiating elements. The individual elements in array are fed with individual currents. The amplitude and phase of the applied current may be same or different. In this paper amplitude and phase are same for all the elements. Total field of the antenna array is found by vector addition of the fields radiated by each individual elements. The radiation pattern of antenna array can be controlled by geometrical configuration (linear, circular, rectangular, spherical etc.), inter-element spacing, current excitation amplitude and phase of excitation [1]. A linear antenna array has all its elements placed along a straight line. In this paper inter element spacing has been optimized to reduce of Side Lobe Level.

A number of optimization techniques have been developed, a few of them include Monte Carlo Simulations, Simulated Annealing, Iterative Least Squares, Projection Methods, Artificial Bee Colony, Genetic Algorithm. Monte Carlo simulation is generally attributed to von Neumann and Ulam, who around 1946–47 developed the idea that random sampling can be used to solve deterministic mathematical problems [2]. They recognized that development of digital computers would enable Monte Carlo methods for many applications. In 1983, Kirkpatrick et al. proposed a method known as Simulated Annealing for using Monte Carlo simulations at a controlled temperature [3]. Simulated annealing, introduced by Kirkpatrick et al. may be thought of as the computational analogue of slowly cooling a metal so that it adopts a low-energy, crystalline state. In physical annealing, at high temperatures particles are free to move around, but as the temperature is lowered they are confined to the crystal lattice. When the temperature is cooled sufficiently slowly, the system can settle into the crystalline lattice, but if cooled too rapidly the atoms may freeze into misaligned irregular domains, which have a higher energy. The act of annealing a metal such that it adopts the state of minimum energy can be thought of as a minimizing optimization problem [4]. Iterative Least Squares was discovered by Gauss in 1795. Essentially the method performs a least squares fit to a required function then iteratively improves the fit by calculating the difference between the required function and the problem. Projection methods attempt to obtain a ‘mini-max’ fit to the required far field power pattern. The term Genetic Algorithm, universally abbreviated as GA, was first developed by John Holland [5], his colleagues and his students at the University of Michigan in the 1960s and 1970s. Holland's goal was to understand the phenomenon of adaptation as it occurs in nature and to develop ways in which the mechanisms of natural adaptation might be imported into computer systems. Genetic algorithms are based upon genetic processes of biological organisms. Karaboga proposed algorithm for solving multi-dimensional and multi-modal optimization problems, called Artificial Bee Colony (ABC) [6].

The rest of the paper is arranged as follows: In section II, Array factor equation and fitness function is described. Section III describes Genetic Algorithm, Artificial Bee Colony Optimization and Simulated Annealing. Numerical results are presented in section IV. The paper concludes comparison of results of algorithms in section V.
II. DESCRIBING ARRAY FACTOR AND FITNESS FUNCTION

Figure 1 shows a 2N element Symmetrical Linear Antenna Array. The elements are along the x-direction, signal is transmitted along y-direction. The equation for far field radiation pattern is given as under:

\[ F(\theta) = 2 \sum_{n=1}^{N} \cos(\phi m_0 a_n \cos(\theta) + \phi) \ldots (1) \]

where \( a_n \) is the current amplitude to the \( n^{th} \) antenna elements, \( d = \lambda/2 \), \( \theta \) is the angle where signal is measured and \( \phi \) is the current phase difference between antenna elements. \( N \) is number of elements in antenna array. \( k_0 = 2 \pi/\lambda \) is wave number, \( \lambda \) being the signal wavelength, \( x_n \) is the location of \( n^{th} \) element.[4]

For fitness function calculation the above mentioned \( F(\theta) \) is used. Fitness function is also known as cost function. Now the fitness function that is to be minimized using Genetic Algorithm, Simulated Annealing and Artificial Bee Colony optimization is given as under:

\[ Fitfun = \frac{1}{\phi_2 - \phi_1} \sum_{\phi_1}^{\phi_2} F(\phi) + \frac{1}{\phi_4 - \phi_3} \sum_{\phi_3}^{\phi_4} F(\phi) + \sum_{i=1}^{m} F(\psi_i) \ldots (2) \]

where \( \phi_1 \) to \( \phi_2 \) and \( \phi_3 \) to \( \phi_4 \) are the regions were side lobe level is reduced, \( \psi \) is angle where null to be imposed, \( m \) is the no of nulls to be imposed and \( F(\theta) \) is the function described above in equation 1.

III VARIOUS OPTIMIZATION TECHNIQUES

A. GENETIC ALGORITHM

The genetic algorithm was first introduced in 1975 by Holland. Genetic Algorithms are a family of computational models inspired by evolution [5]. GA is a procedure used to find approximate solutions to search problems through application of the principles of evolutionary biology. GA uses biologically inspired techniques such as genetic inheritance, natural selection, mutation, and sexual reproduction (recombination, or crossover). Genetic Algorithm consists of following steps:-

1. Generate an initial population within the variable constraint range, randomly or heuristically.
2. Compute and save the fitness for each individual in the current population.
3. Define selection probability for each individual so that it is proportional to its fitness.
4. Generate the next current population by probabilistically selecting the individuals from the previous current population, in order to produce offspring via genetic operators.
5. Repeat step 2 until a satisfactory solution is obtained.

B. Artificial Bee Colony Optimization

The Artificial Bee Colony (ABC) algorithm is an evolutionary computational technique, first developed by Karaboga in 2005 [6]. The algorithm is based on the foraging behavior of honey bees. In ABC algorithm, the colony of the artificial honey bees contains three groups of bees, e.g. employed bees, onlookers and scouts. The first half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source has been abandoned becomes a scout.

In this algorithm, the position of a food source represents a possible solution to the considered optimization problem and the nectar amount of the food source corresponds to the quality or fitness of the associated solution. The number of the employed bees or onlooker bees is equal to the number of solutions in the population[8]. An employed bee produces a modification on the position (solution) in its memory depending on the local information (visual information) and tests the nectar amount (fitness value) of the new food source (new solution). Provided that the nectar amount of the new source is higher than that of the previous one, the bee memorizes the new position and forgets the old one. Otherwise, it keeps the position of the previous source in its memory. When all the employed bees complete the search
process, they share the nectar information of the food sources and their position information with the onlooker bees in the dance area. An onlooker bee evaluates the nectar information taken from all the employed bees and selects a food source with a probability related to its nectar amount. As in the case of an employed bee, the onlooker bee produces a modification on the position in its memory and checks the nectar amount of the candidate source. If its nectar amount is higher than that of the previous one, the onlooker bee memorizes the new position and forgets the old one[9].

**C. Simulated Annealing Optimization**

Simulated Annealing (SA), originally published by Kirkpatrick (Kirkpatrick et al., 1983) and independently achieved by (Cemy, 1985) [3], is an optimization method that takes its inspiration from annealing in metallurgy. Materials are heated and then cooled on a specified temperature schedule, allow atoms to find lower energy states, which at the macroscopic level means that the material can be formed into larger crystals with fewer defects. In the natural situation, the energy of the system is reduced. The process is sensitive to the temperature schedule used, fast schedules cause poor energy minimization within the material, while slow schedules result in better energy minimization. Simulated Annealing algorithms have two characteristic features: firstly, the search operator is confined to points in the search space that are close to the current position of the algorithm. This is analogous to atoms moving within a material. Secondly: the probability of accepting a newly searched point that has a higher energy than the current one[10].

**IV. NUMRICAL RESULTS**

A 32 element symmetrical linear antenna array of isotropic radiating elements, with $d = \lambda/2$, $k_0 = 2\pi/\lambda$ is used. The current excitation is constant($I_n=1$) and the current applied with zero phase difference to the elements ($\phi=0$). $X_n$ is the inter element spacing that is optimized using GA, ABC and SA. The numbers of iterations taken for GA are 100 whereas for SA and ABC are 1500.

For optimization $\phi_1$ to $\phi_2$ are taken as $0^0$ to $87^0$ [ $0^0$ - $87^0$] and $\phi_3$ to $\phi_4$ are taken as $93^0$ to $180^0$ [ $93^0$ - $180^0$]. The number of nulls i.e. $m$ is taken as 2 at $80^0$ and $100^0$.

From figure 2(a),(b),(c) it can be seen that SLL reduction has been achieved best using GA for far away side lobes. The value of SLL at far away is -302.327db for GA at $0^0$ and $180^0$ whereas it is -36.75db for ABC and for SA it is -42.89db. The value of SLL at the nulls is -20.22db,-43.14db and -20.99db for GA, ABC and SA respectively. For close in side lobes SLL is more reduced using ABC. It is -13.67db,-19.65db and -12.89db for GA, ABC and SA respectively. It is also seen in the figure that in the region [ $0^0$ - $50^0$ ] and in [ $130^0$ - $180^0$ ] GA optimization technique shows the better reduction of side lobe level as compared to ABC and SA. In the region [ $50^0$ - $80^0$ ] and [ $100^0$ - $130^0$ ] ABC optimization technique shows better reduction of side lobe level as compared to GA and SA. It is also seen that as the azimuthal angle decreases from $90^0$ to $0^0$ and increases from $90^0$ to $180^0$, the side lobe level for GA goes on decreasing but it is not the same in the case of ABC and SA.

Plot for side lobe level (db.) vs. Azimuthal angle (degrees) is plotted for GA, ABC and SA.
In table I side lobe level at various azimuthal angle using above mentioned techniques has been shown. In table II optimized inter element spacing has been shown for 32 element antenna array.

<table>
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<th>Angle of Arrival</th>
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<th>Using ABC</th>
<th>Using SA</th>
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<td>6.05</td>
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V. CONCLUSION

The Optimization techniques GA ,ABC and SA have been used for SLL reduction. The value of SLL at various azimuthal angle for these techniques has been compared. It can be seen that lowest value of SLL has been achieved using GA for the far side lobes whereas the close in side lobes are almost same for three methods. It is also seen that as the azimuthal angle decreases from 90° to 0° and increases from 90° to 180°, the side lobe level for GA goes on decreasing but it is not the same case in ABC and SA.

REFERENCES