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LINEAR ANTENNA ARRAY DESIGN WITH USE OF GENETIC, MEMETIC AND TABU SEARCH OPTIMIZATION ALGORITHMS

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Abstract—Antenna array design techniques are focused on two main classes: uniformly spaced antenna arrays and the non-uniform spacing case. These include techniques based on mathematical programming, such as constrained programming and non-linear programming. More recently, meta-heuristics approaches have been successful at designing antenna arrays [5]. In this work, this paper presents efficient methods of genetic algorithm (GA), memetic algorithm (MA) and tabu search algorithm (TSA) for the synthesis of linear antenna design. We present three examples of antenna array design to compare the efficiency of the algorithms through simple design to complex design. The GA, TSA and MA has been used to optimize the spacings between the elements of the linear array to produce a radiation pattern with minimum SLL and null placement control.

1. INTRODUCTION

The usage performance of a single antenna is limited as gaining features in antenna patterns like high directivity, low side lobe level, narrow beam width and the pattern form being suppressed in certain angles. Because antenna arrays enable to provide the features desired in the pattern form with the arranging of one of the array element's amplitude and phase stimulation coefficient and the appropriate designing of the array geometry, they are commonly used in practical application [12]. Antenna array power is summation of the antenna elements, so we can get high power. Also shifting and rapid moving beam pattern can be supplied [14].

Side lobes have low gains and point in various directions. The increasing pollution of the electromagnetic environment has prompted the study of array pattern nulling techniques. These techniques are very important in radar, sonar and communication systems for minimizing degradation in signal-to-noise ratio performance due to undesired interference.

Most of the conventional nulling techniques proposed in the literature do not allow us to produce the radiation pattern with the prescribed nulls to the interference directions while at the same time controlling the side lobe level, and nulling [5]. For the linear array geometry, by designing the spacings between the elements while keeping the uniform excitation over the array aperature we can suppress side lobe level while preserving the gain of the main beam and can control nulling [4].

It is well known that the classical optimization techniques need a starting point that is reasonably close to the final solution, or they are likely to be stuck in a local minima. As the number of parameters and hence the size of the solution space increases, the quality of the solution strongly depends on the estimation of the initial values. If the initial values fall in a region of the solution space where all the local solutions are poor, a local search is limited to finding the best of these poor solutions. Because of these disadvantages of the classical optimization techniques, the heuristic optimization techniques were proposed to accurately solve antenna problems. These algorithms uses fitness function to optimize the side lobe level (SLL) and nulling [5].

A meta-heuristic method GA combines the of the fittest biological concepts of survival among string structures with a structured yet randomised information [10]. A basic GA consists of five components. These are a random number generator, a "fitness" evaluation unit and genetic operators for "reproduction", "crossover" and "mutation" operations.

At first the initial population is generated. A fitness value is a measure of the goodness of the solution that it represents. The aim of the genetic operators is to get a minimum fitness value. The reproduction operator performs a natural selection function. Individuals are copied from one set to the next according to their fitness value. The individuals which gives better result are being selected for the next generation. The crossover operator chooses pairs of individuals at random and produces new pairs. Crossover is the primary operator that increases the exploratory power of GAs. In order to successfully achieve the cross-fertilizing type of innovation, cross-over operator must ideally inter-mix good subsolutions without any disruption of the partitions [6]. The simplest crossover operation is to cut the original parents at a randomly selected point and exchange their tails. The number of crossover operations is governed by a crossover rate. The mutation operator randomly mutates or reverses the values of bits in a individual. The number of mutation operations is determined by a mutation rate [11]. To carry out the continual improvement type of innovation, the probability of applying mutation must be very low [6].

TSA as an optimization procedure to the electromagnetic and antenna are very newly problems and only a few compared to other heuristic optimization techniques such as the genetic and the simulated annealing algorithms [7].

TSA prevents cycles which are tested before by using memory. TSA generates an initial solution then finds the neighbors. By trying all of the neighbors with fitness function, TSA gets the one of neighbor as a new solution which gives better result. A neighbor is reached directly from the present solution by an operation called "move". Then TSA searchs around the new solution. Nextly updates the memory [7]. A tabu list is employed to store the characteristics of accepted neighbors so that these characteristics can be used to classify certain neighbours as tabu in later iterations. In other words, tabu list determines which neighbors may be reached by a move from the current solution.

TSA has a memory to prevent searching at the same places, so uses tabu list. Tabu list determines which neighbors can not be used as a new solution. If tabu list restricts much of the solutions, we can not go out from the seaching environment so, tabu list must have flexible memory. In this work we used recency and frequency memory to gether to control tabu list.

The recency-based memory prevents cycles of lengthless than or equal to a predetermined number of iterations from occurring in the trajectory. The frequency-based memory keeps the number of changes of solution vector elements. If an element of the solution vector does not satisfy the following tabu restrictions, then it is accepted as tabu [7].

$$\text{Tabu Restrictions}=\begin{cases}\text{recency}(k) > \text{recency limit}\\ \text{frequency}(k) < \text{frequency limit}\end{cases} \tag{1}$$

MA is a kind of an improved type of the traditional genetic algorithm. By using local search procedure, it can avoid the shortcoming of the traditional genetic algorithm, whose termination criteria are set up by using the trial and error method. For many problems, there exists a well-developed, efficient search strategy for

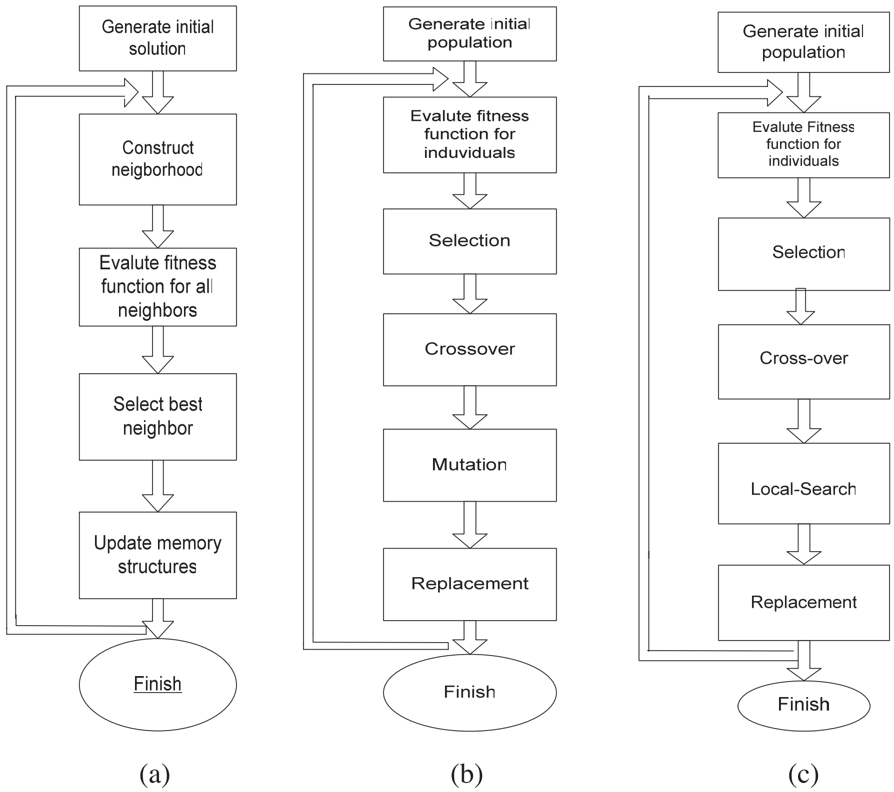

Figure 1. Evolutionary algorithms, (a) Genetic algorithm (b) Tabu search algorithm (c) Memetic algorithm.

local improvement [15]. Memetic algorithm combines the advantages of genetic algorithms and local search for optimization problems.

2. FORMULATION

When the elements are symmetrical at the center of the linear array along x-axis with unequal interelement spacing, the $2N$ isotropic elements' far field array factor can be written as:

$$AF(\phi) = 2\sum_{n=1}^{N} a_n \cos\left[\frac{2\pi}{\lambda} x_n \cos(\phi) + \varphi_n\right] \qquad (2)$$

where a_n is the excitation amplitude, x_n is the the location of the xth element. φ_n represents phase and ϕ is the angle measured from the

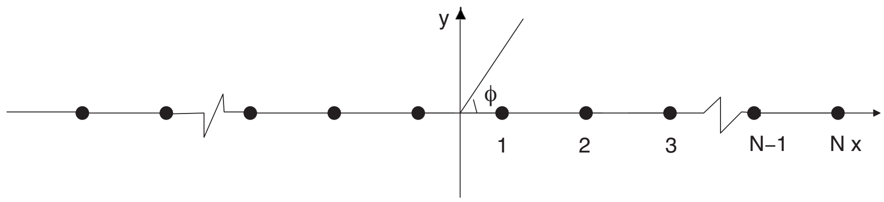

Figure 2. Symmetrically placed linear array.

array line. If we assume a uniform excitation of amplitude and phase as $a_n = 1$, $\varphi_n = 0$; the array factor is can be written in a simple form as follows.

$$AF(\phi) = 2\sum_{n=1}^{N} \cos\left[\frac{2\pi}{\lambda} x_n \cos(\phi)\right] \tag{3}$$

For side lobe reduction, the fitness function is:

$$\text{Fitness} = \sum_i \frac{1}{\Delta\phi_i} \int_{\phi_{li}}^{\phi_{ui}} \left| AF(\phi)^2 \right| d\phi \tag{4}$$

And for null control:

$$\text{Fitness} = \sum_k |AF(\phi_k)|^2 d\phi \tag{5}$$

To control both of them we used summation of (4) and (5) as a fitness function of the algorithms. Where $\Delta\phi_i$ represents the bandwidth to suppress as $\phi_{ui} - \phi_{li}$, ϕ_k is the direction of the nulls. The problem is then reduces to find the x_n replacement for minimum side lobe level if desired nulls at specific directions.

3. DESIGN EXAMPLES

In this section, the capabilities of the GA, MA and TSA algorithms are implemented and simulated, for the $2N$ isotropic elements. If the array elements located even symmetry, the computational time are halved.

In the first example GA, MA and TSA was used to design 12 element array for minimum SLL in bands [0°, 82°] and [98°, 180°] with no prescribed nulls. Just to suppress side lobes we used the Equation (3). The results are shown in Fig. 3.

In the second example 22 element array has been designed for minimum SLL in bands [0°, 82°] and [98°, 180°] and has nulls at 81°

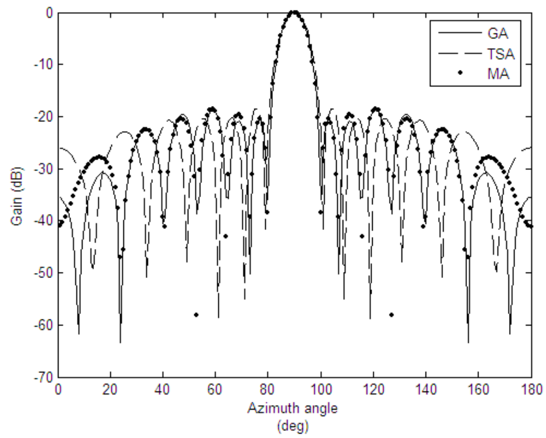

Figure 3. 12 element array for minimum SLL in bands [0°, 82°] and [98°, 180°] with no prescribed nulls.

Table 1. Geometry of the 12 element linear array, normalized numbers with respect to $\lambda/2$.

GA	±0.507	±1.262	±2.289	±3.19	±4.56	±5.99
TSA	±0.388	±1.259	±2.107	±3.053	±4.189	±5.451
MA	±0.482	±1.28	±2.289	±3.236	±4.603	±5.999

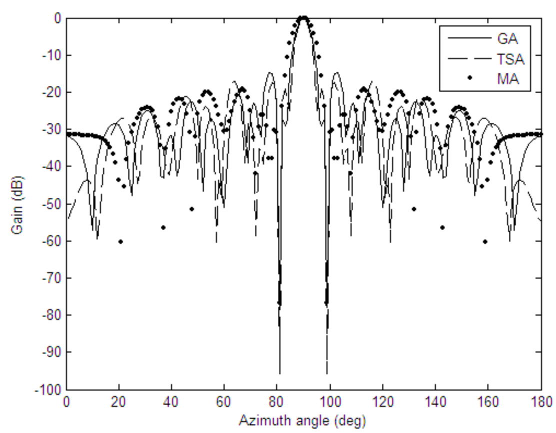

Figure 4. 22 element array for minimum SLL in bands [0°, 82°] and [98°, 180°] with nulls at 81° and 99°.

Table 2. Geometry of the 22 element linear array, normalized numbers with respect to $\lambda/2$.

GA	±0.002	±1.061	±1.486	±2.419	±3.386	±4.285	±5.407	±6.846	±8.0426	±9.136	±10.398
TSA	±0.698	±1.072	±2.500	±2.543	±4.148	±5.479	±6.480	±7.573	±8.714	±10.211	±11.641
MA	±0.811	±2.273	±3.157	±3.948	±4.770	±5.411	±6.432	±6.934	±7.896	±8.712	±10.1243

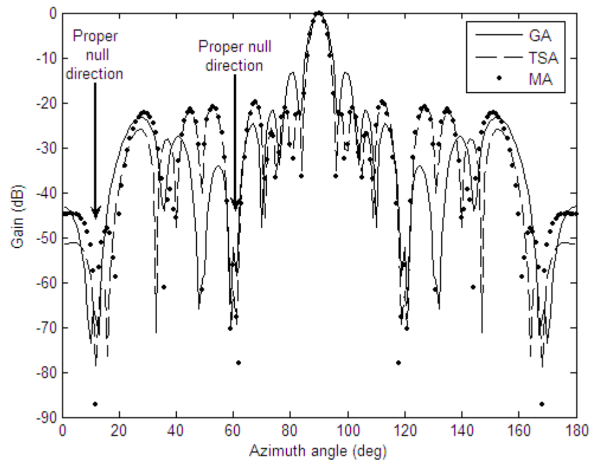

Figure 5. 26 element array for minimum SLL in bands [0°, 80°] and [100°, 180°] with nulls at 12°, 60°, 120° and 168°.

Table 3. Geometry of the 26 element linear array, Normalized numbers with respect to $\lambda/2$.

GA	±0.424	±0.847	±1.579	±2.471	±2.993	±4.391	±4.624	±5.660	±6.399	±7.791	±8.796	±9.973	±11.379
TSA	±0.529	±1.491	±2.5	±3.445	±4.524	±5.500	±6.492	±7.268	±8.498	±9.514	±10.277	±11.440	±12.418
MA	±0.452	±0.85	±1.606	±2.497	±3.019	±4.397	±4.629	±5.687	±6.399	±7.792	±8.796	±9.976	±11.403

and 99°. We used sum of the Equations (3) and (4) as a fitness function, to suppress side lobes and to get nulls where it is needed.

In the last example the fitness function used same as the second example as they both designed for suppressing side lobe with nulls. The null number, has been increased, and designed for 26 element array for minimum SLL in bands [0°, 80°] and [100°, 180°] with nulls at 12°, 60°, 120° and 168°.

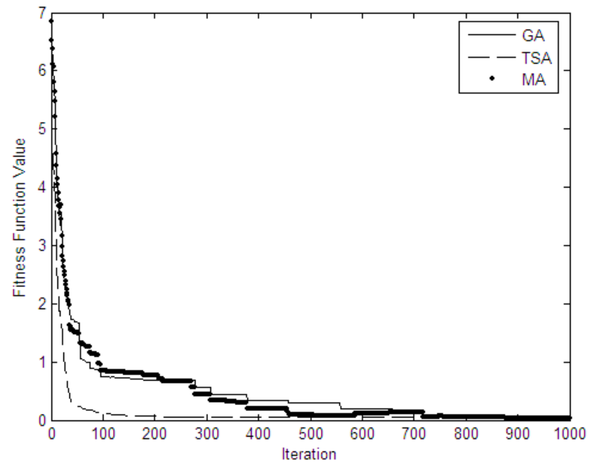

Figure 6. Convergence curve of the fitness value of the 26 element linear array versus the number of iterations. The GA, TSA and MA are attempting to reach the minimum value of the fitness function.

4. CONCLUSIONS

By technology improvement, data transmission is increasing. Nowadays, antenna system design with a arbitrary performance is the one of the most studied subjects. Especially data transmission needs to be less effected by the losses, noises so antenna array systems must be designed to avoid from these negative effects.

At this work with a good performance we designed arrays with minimum side lobe level and nulls where it is wanted with the algorithms GA, TSA and MA. GA and MA uses a population-based directed random search technique, The GA has good performance for finding results, but it is not so successful at local search, because of the probabilistic rules used. MA's efficiency attracts attention that the algorithm finds the most convenient results at all. The difference of the MA and GA is local search so it can be emphasized that local search gives weight to algorithm. But conversely, local search increases the time of an iteration. TSA gets ahead with the speed of the algorithm, but couldn't find better results than MA and GA.

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