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Study of Optimization Techniques in Generation of Low Side Lobe Patterns

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Abstract : *Generation of ultra low side lobes is one of most challenging in design of antenna arrays for EMI suppression problems. Using conventional methods like binomial and chebyshev techniques, side lobe levels are reduced to some extent but not adequate. In this paper generation of very low side lobes beyond -40dB is presented using different evolutionary techniques like genetic algorithm, particle swarm optimization and simulated annealing. Very narrow beam patterns are obtained which can be used for point to point communication with less electromagnetic interference.*

Keywords: *EMI, GA, PSO, SA and Side lobe level.*

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I. Introduction

Array antennas can provide desired radiation pattern by changing the amplitude, distance between the elements, phase and the geometry of the array [1]. Using single antenna it is not possible to generate desired gain, beam width and reduced side lobe levels. With the increase of users and aerials, the problems of electromagnetic interference have been increasing day by day. There is a need to control this electromagnetic interference. The Radar antennas which are used for search and tracking applications are to be designed with ultra side lobes to mitigate the EMI. Not only in radars but where ever multiple antennas are present onboard [2], it is very much essential to have ultra side lobes to avoid interference.

There exist several methods for antenna pattern synthesis. By choosing proper amplitude distribution sum patterns are generated. Conventional optimization techniques work on gradient calculations and have the disadvantage of quickly converging to local minima [3]. Moreover they have the ability to work on few parameters. On the other hand the evolutionary techniques like Genetic algorithm (GA), particle swarm optimization(PSO) and simulated annealing(SA) techniques are robust in nature and search space is not limited. They have the ability to solve multi objective functions. These optimization techniques are superior to Dolph-chebyshev [4] and other conventional methods in reducing relative side lobe level (RSSL) and half power beam width. In this paper a comparison of three optimization techniques GA, PSO and SA is presented in reducing side lobe level by taking N point source array.

II. Optimization Methods Used

II.1 Genetic algorithm

Genetic algorithms (GA) are global optimization techniques that are based on the Darwinian theory of natural selection and evolution. Genetic algorithms offer many advantages over traditional numerical optimization techniques including the ability to use both continuous and discrete parameters, search across a wide sampling of the solution space, and handle a large number of variables [5]. Derivative information of the performance surface is not needed by the GA, which eliminates many of the difficulties associated with traditional gradient-based algorithms. For these reasons, and the overall simplicity to both understand and implement, genetic algorithms have become a popular and powerful optimization technique [6]. The genetic algorithm mimics the evolutionary notion of survival of the fittest. The flow chart steps for GA technique are shown in Fig.1 [5&7].

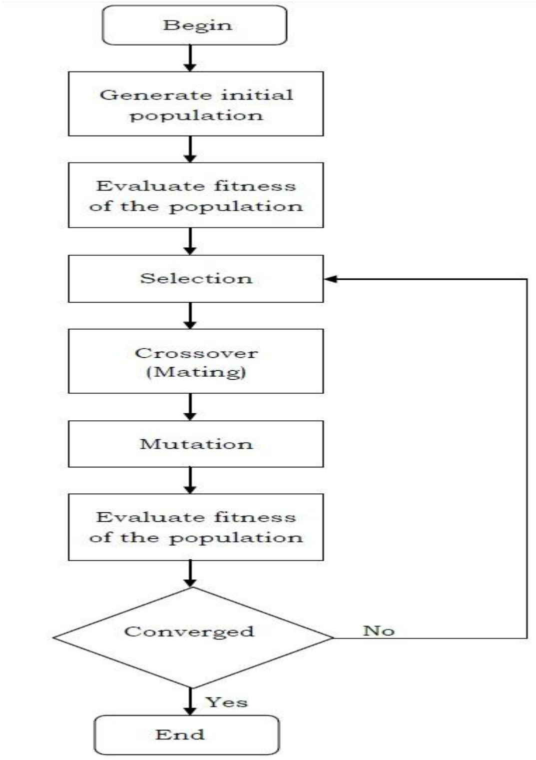

Fig.1 Genetic Algorithm Flowchart

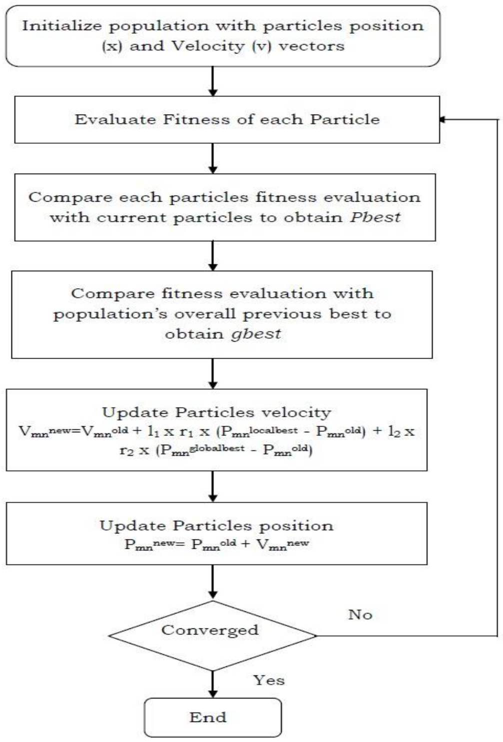

Fig.2 PSO Algorithm Flowchart

The process of genetic optimisation is carried on in several phases. The process that involves in genetic optimisation starts from generation of random population called chromosomes. For every chromosome the fitness value is calculated and then best fitness chromosomes are retained as new population. Then crossover operation is performed on every pair of chromosomes where some portions of chromosomes are interchanged. There after some bits may modified based on mute rate. Again fitness value of each chromosome is calculated. This process will continue till fitness value reaches minimum/maximum value based on minimization problem or maximization problem.

II.2 Particle **Swarm optimization**

Particle swarm optimization (PSO) algorithm, one of the evolutionary computation methods, has come to existence from the interests to replicate the collective foraging behaviour of a group of simple agents, like a school of fish, a flock of birds, and similar. PSO is simple in concept, few in parameters, and easy in implementation. It has been used in many application areas. Generally, PSO is found good at all application areas where the other evolutionary optimization techniques are being applied [8]. The PSO has been shown to be effective in optimizing difficult multidimensional discontinuous problems in a variety of fields [9]. In recent times this technique was successfully used in the antenna design. The flow chart for PSO is given in Fig.2. Here I_1 and I_2 are called learning factors, r_1 and r_2 are uniform random numbers. P_{mn} refers to best local and global solution corresponding to superscript localbest and globalbest respectively. The global solution will get updated from local solution if the cost of local solution is less than the cost of global solution. Each particle of the swarm will undergo this process.

II.3 Simulated annealing

Simulated annealing (SA) is a random search technique which exploits an analogy between the way in which a metal cools and freezes into a minimum energy crystalline structure (the annealing process) and the search for a minimum in a more general system; it forms the basis of an optimization technique for combinatorial and other problems. The idea of Simulated annealing developed from the base paper published by Metropolis and Rosenbluth in 1953 [10]. Their proposed algorithm simulated the material as a system of particles. The algorithm simulates the cooling process by gradually lowering the temperature of the system until it converges to a steady, frozen state. Simulated annealing major advantage compared to other techniques is its ability to not trap in local minima.

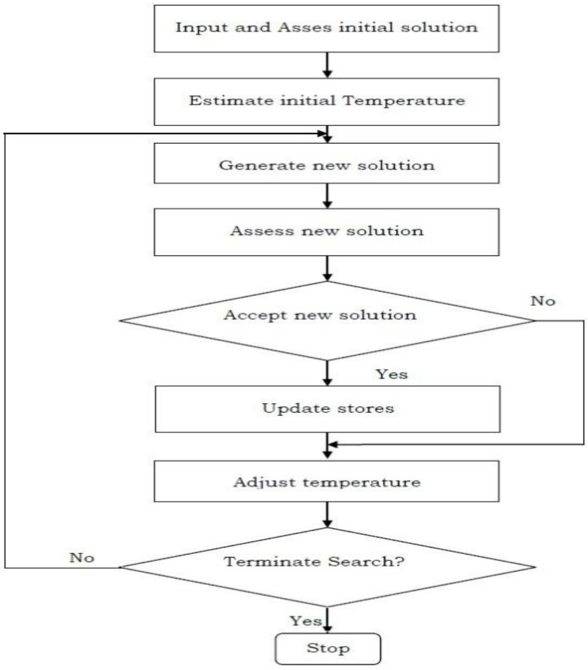

Fig.3 Simulated Annealing Flowchart

The technique uses a random search which not only accepts changes that decrease the objective function f (considering a minimization problem), but also some changes that would increase it. The latter are p = exp (-Δf / T) accepted with a probability. Here Δf is the increased change in f and T is the controlling parameter, which by analogy with the original application is known as the system "Temperature" irrespective of the objective function involved. The flow chart of the basic SA algorithm is straight forward as shown in Fig.3 [11&12].

III. Formulations

Consider a continuous line source of length 2L. Its far field radiation equation is given by :

$$E(u) = \int_{-L}^{L} A(x) e^{j\frac{2\pi L[ux+\varphi(x)]}{\lambda}} dx \qquad \text{-- (1)}$$

Where A(x) is the amplitude distribution

u=sin (θ) and 2L/λ represents normalized array length. x is the position on the line source. φ(x) is the excitation phase.

This equation (1) turns into summation for n element discrete array. For N discrete point sources the far field radiation equation is given by:

$$E(u) = \sum_{n=1}^{N} A(x_n) e^{\frac{j2\pi l[u\,x_n+\varphi(x_n)]}{\lambda}} \qquad \text{-- (2)}$$

Here in equation (2) Ishimaru spacing is used for element location [13] and is given by:

$$x_n = \frac{2n-1-N}{N} \qquad \text{-- (3)}$$

The fitness function is chosen as the side lobe level (SLL) and is given by:

$$F = SLL = \max[20\log(E(u))] \qquad \text{-- (4)}$$

This is computed in the side lobe regions other than main lobe. In this paper the optimization is done using GA, PSO and SA for getting best amplitude distributions which results in ultra low side lobes.

IV. Results

The three optimization techniques are applied on N=8, 16, 32, 64 and 128 elements respectively and their amplitude distributions and 2D radiation field patterns in sin (θ) domain are plotted.

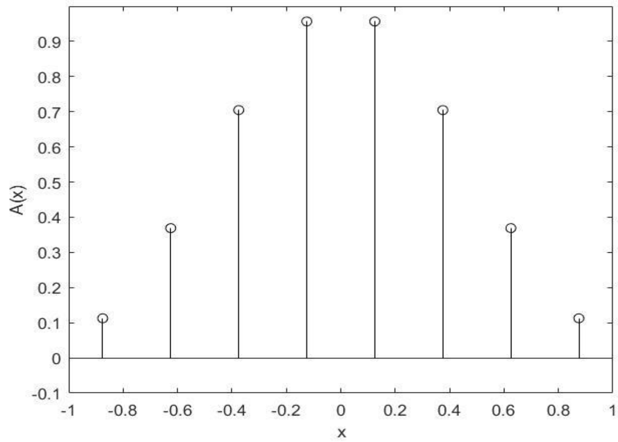

Fig.4 Amplitude distribution obtained by GA for N=8 element array

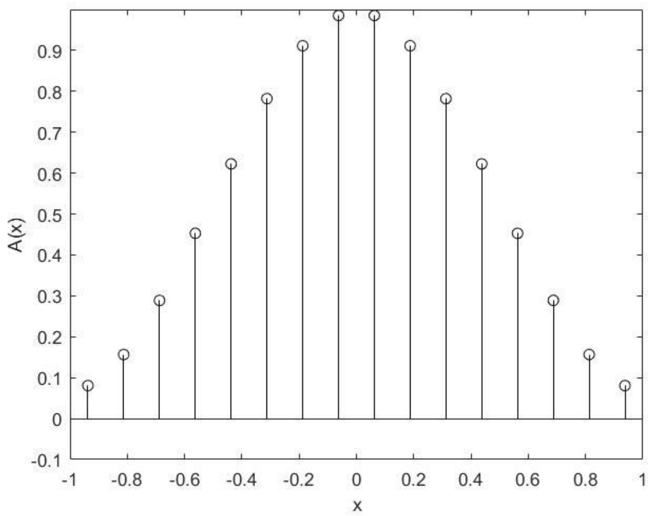

Fig.5 Amplitude distribution obtained by GA for N=16 element array

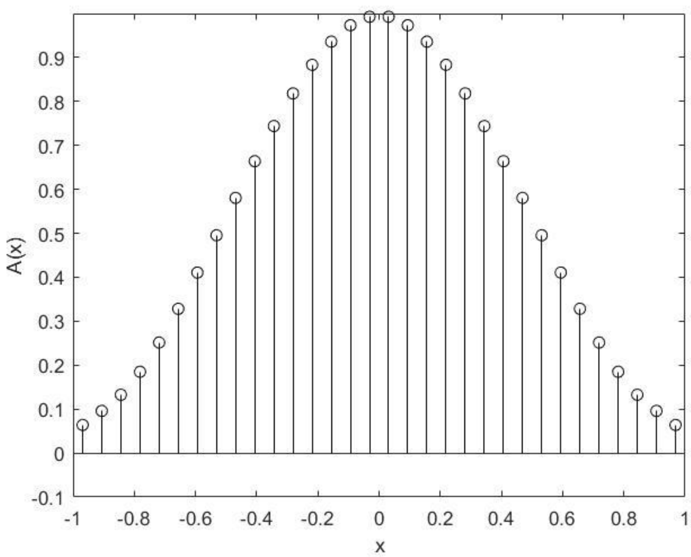

Fig. 6 Amplitude distribution obtained by GA for N=32 element array

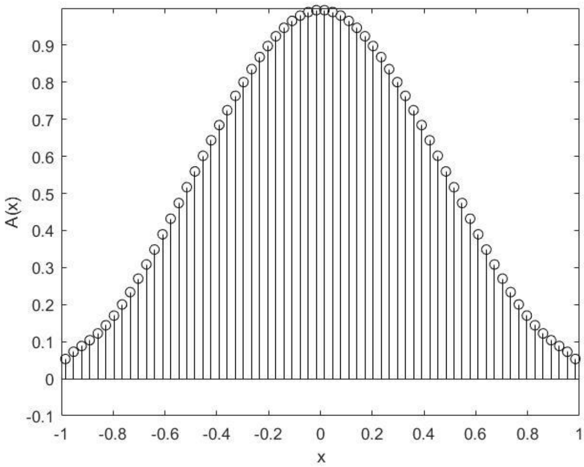

Fig. 7 Amplitude distribution obtained by GA for N=64 element array

TABLE.1 Amplitude coefficients for N=16 element array using GA, PSO and SA

S.NO	Spacing x(n)	$A(x_n)$ *Genetic Algorithm*	$A(x_n)$ *Particle Swarm Optimization*	$A(x_n)$ *Simulated Annealing*
1	-0.9375	0.080683	0.075936	0.073714
2	-0.8125	0.156734	0.149966	0.142315
3	-0.6875	0.288916	0.276363	0.260689
4	-0.5625	0.452898	0.436598	0.433884
5	-0.4375	0.622583	0.613075	0.618548
6	-0.3125	0.782075	0.781316	0.785375
7	-0.1875	0.911395	0.914634	0.913954
8	-0.0625	0.985263	0.990266	0.984236
9	0.0625	0.985263	0.994096	0.980792
10	0.1875	0.911395	0.924037	0.902962
11	0.3125	0.782075	0.791831	0.769003
12	0.4375	0.622583	0.621695	0.608495
13	0.5625	0.452898	0.443811	0.447683
14	0.6875	0.288916	0.283232	0.300138
15	0.8125	0.156734	0.152501	0.173243
16	0.9375	0.080683	0.071064	0.082654

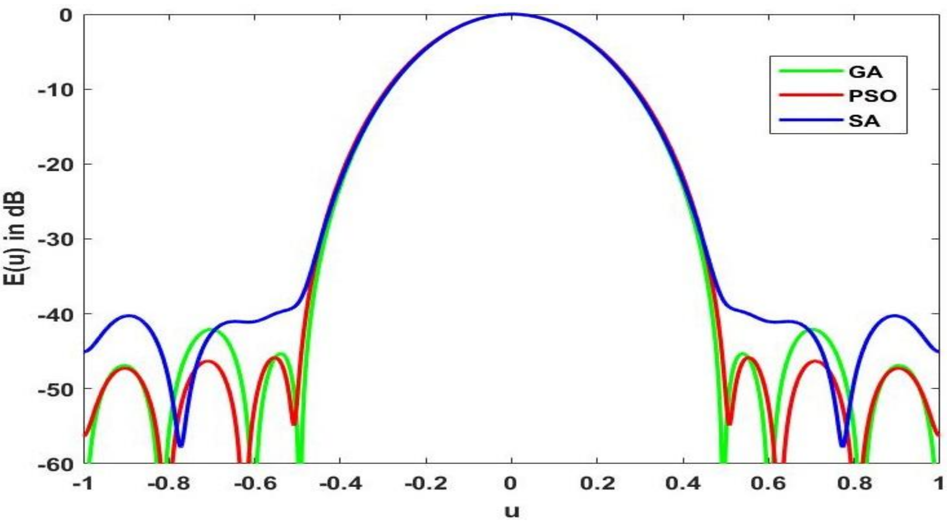

Fig.8 Optimized radiation patterns using GA, PSO and SA for N=8 elements

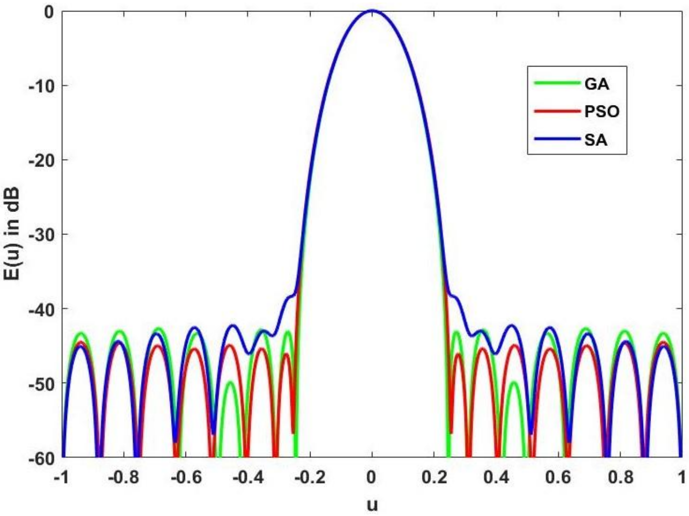

Fig.9 Optimized radiation patterns using GA, PSO and SA for N=16 elements

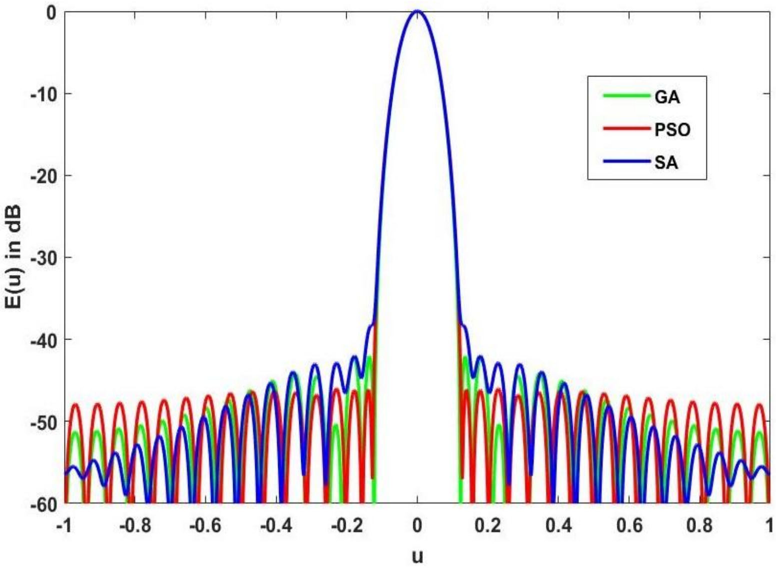

Fig.10 Optimized radiation patterns using GA, PSO and SA for N=32 elements

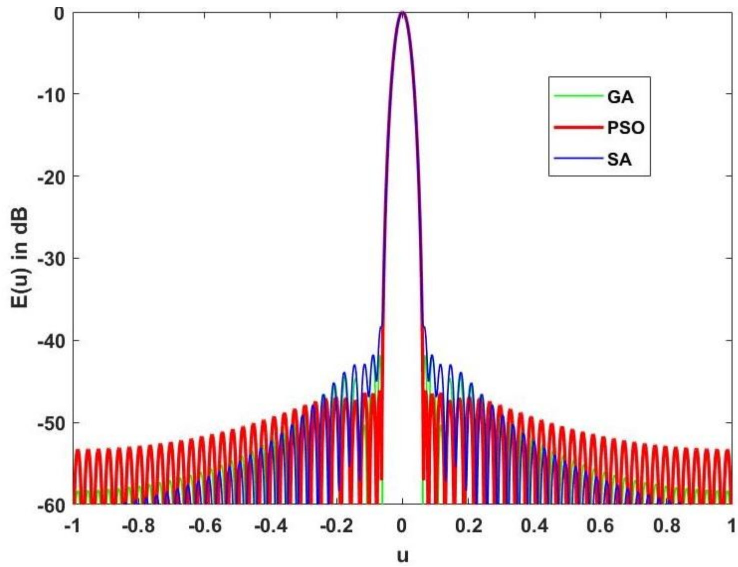

Fig.11 Optimized radiation patterns using GA, PSO and SA for N=64 elements

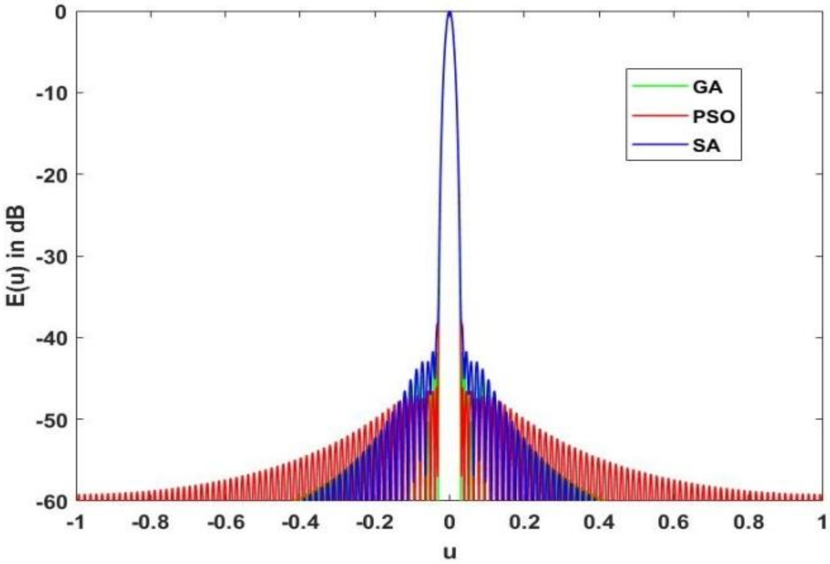

Fig.12 Optimized radiation patterns using GA, PSO and SA for N=128 elements

Table2 Comparison table for SLL using GA, PSO and SA

No. Of Elements	Maximum Side lobe level (in dB)		
N	GA	PSO	SA
8	-42.0649	-45.8298	-38.6716
16	-42.6530	-44.4931	-42.2530
32	-42.0591	-46.0107	-38.3144
64	-41.8189	-46.1015	-38.3193
128	-41.7594	-46.1003	-38.3212

From the results it is observed that all three techniques are generating very low side lobe levels less than -38dB. Among these three particle swarm optimization technique is giving SLL less than -44dB. As the numbers of elements are increasing narrow pencil beam patterns are obtained with beam widths less than 20^o degrees.

V. Conclusion

Three optimization techniques GA, PSO and SA are used to optimize the side lobe level (SLL) for N element point source array. Of these three techniques PSO is best as far as side lobe level is concerned. Ultra side lobe levels of nearly -45dB are achieved using PSO technique. Whereas the side lobe levels for GA and SA are around -42dB and -38dB respectively. For N greater than 32, even pencil beams are generated with beam widths less than 20^o degrees. For large N values, it is observed that side lobe levels diminish at fast rate using simulated annealing technique. These patterns can be used to minimize EMI problems in radars and point to point communication.

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