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Optimization of Sidelobe Level of Thinned Phased Array Antenna using Genetic Algorithm and Particle Swarm Optimization

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***Abstract*— Phased array antenna can produce beam with high directivity at any direction without any physical movement of the antenna array. The main drawback of this antenna is high side lobe level and grating lobe at different scanning angles that creates severe interference to proper communication. In order to mitigate such problem in array design, optimization is applied for thinning of phased array at different tilt angles using binary genetic algorithm (BGA) and binary particle swarm optimization (BPSO). Side lobe levels are reduced and performances of phased array thinning, using BGA and BPSO, are compared.**

Keywords—Phased array, thinning, sidelobe level, BGA, BPSO

I. INTRODUCTION

The most popular antenna used in radar, wireless or satellite communication system, is the phased array antenna [1-2]. The radiation pattern generated by the uniform linear array [ULA] is the contribution of radiated field of each element. Phased array antenna generates highly directive main beam at any intended direction of communication without any physical movement as phase shift is adjusted by the electronic phase shifter circuit. The main challenge faced by the array antenna, generation of high valued sidelobe level with increased main beam and appearance of grating lobe at different scanning angle which causes severe interference to proper communication[3-4]. Hence the obvious requirement is to reduce maximum sidelobe level along with maintaining proper main beam shape[5]. There is hardly any readily available analytical or stochastic method for sidelobe reduction of large array [6]. To accomplish such objective various optimization techniques can be used. Most popular optimization technique used for sidelobe level reduction by array thinning technique, are binary genetic algorithm [7-12] and binary particle swarm optimization [13-17]. When all of the elements in the array are switched on, is called fully populated array and when some of the elements in the array are switched off, strategically, is called thinned array (Fig.1). Thinned array produce almost same radiation pattern like fully populated array with less energy consumption.

In this paper, binary genetic algorithm (BGA) and binary particle swarm optimization (BPSO) are applied for optimization and design of linear phased array (ULA). Performances of thinned phased array antennas using both of the algorithms, separately, at different tilt angles are compared. Special attention is given to minimization of maximum sidelobe level.

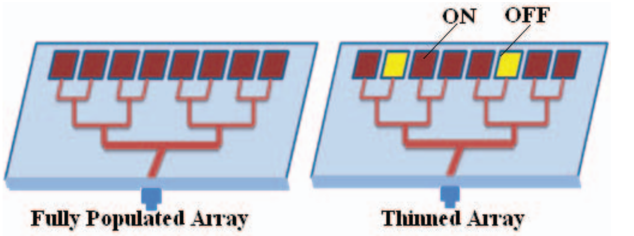

Fig.1. Fully populated array and thinned array

II. COST FUNCTION FORMULATION

Consider a 'N' element linear array consist of isotropic antennas without any mutual interference between them, are placed in fixed inter element spacing 'd' (Fig.2.).

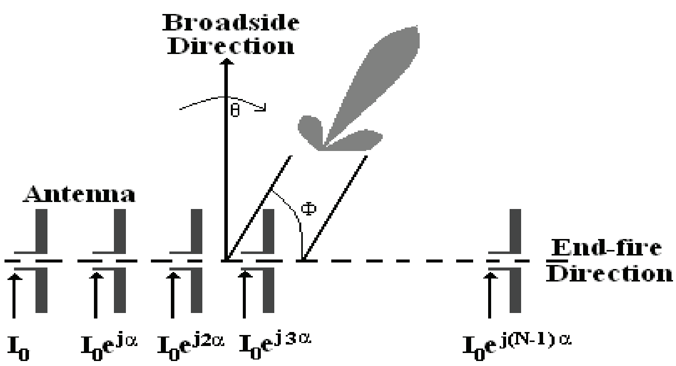

Fig.2. Linear array of N element

. The array factor (AF) is produced by the array antenna at scanning angle Φ is

$$AF = \sum_0^{N-1} In.e^{jn\beta d(\cos\theta - \cos\Phi)} \quad (1)$$

Where, $\beta = 2\pi/\lambda$, λ = wavelength, α = progressive phase shift between elements. Array factor governs the radiation pattern generated by the phased array, contains main beam as well as all sidelobes. The objective function, minimizing the maximum sidelobe level [5], can be determined from array factor by excluding main beam then normalize it. Hence the cost function to be optimize is

$$\mathrm{SLL}_{max} = \max\left|\frac{AF(\theta)}{\max\,(AF)}\right|_{\theta=\theta_{SLM}} \quad (2)$$

Where, $\theta_{SLM} = 0° \leq \theta \leq (\Phi - LN) \cup (\Phi + RN) \geq \theta \geq 180°$
LN = first left null point to main beam at scanning angle Φ
RN = first right null point to main beam at scanning angle Φ.

III. THINNING USING BGA AND BPSO

Design consideration of thinned array utilizes only two fixed values of exciting current amplitude weight, for 'on' state current amplitude is '1' and 'off' state current amplitude is '0'. This status of elements is resemblance of discrete or binary values. Therefore, such type of array design requires a kind of optimization algorithm which can support binary values. Among various optimization techniques, in this paper, BGA and BPSO are applied for optimization. BGA is an optimization procedure that can search the global minima from a large search space [6-8]. This algorithm starts with of coding of parameters by changing the real valued parameters into binary value, called gene and assembling all parameters called chromosome, followed by natural selection, crossover, mutation and evolution. For thinned array synthesis each element of the array represented as a gene in the chromosome, for 'N' elements array the chromosome is 'N' bit long. BGA is programmed to minimize the maximum sidelobe level. The cost function is given in Eq. (2) is used in optimization, 200 elements antenna array , with inter element spacing d = 0.3λ, main beam is tilted from 0° to 90°, few patterns at different tilt angle are shown in Fig.3, Fig.4, Fig.5, respectively.

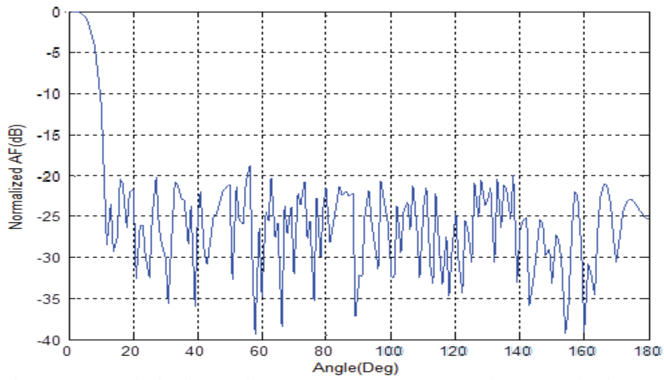

Fig.3. BGA optimized 200 element array pattern at 0° where no. of , elements ON = 116, maximum sidelobe level = -19.15dB

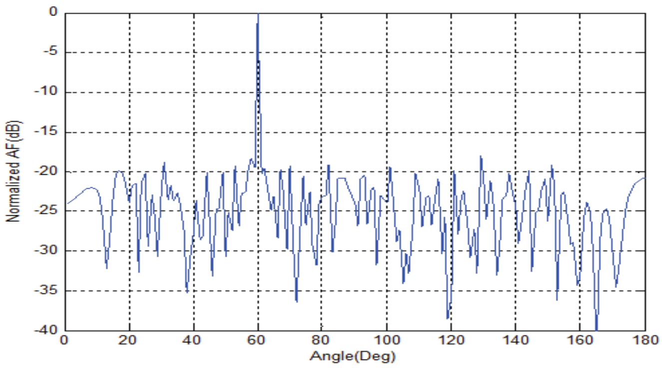

Fig.4. BGA optimized 200 element array pattern at 60° where no. of , elements ON = 112, maximum sidelobe level = -18.00dB

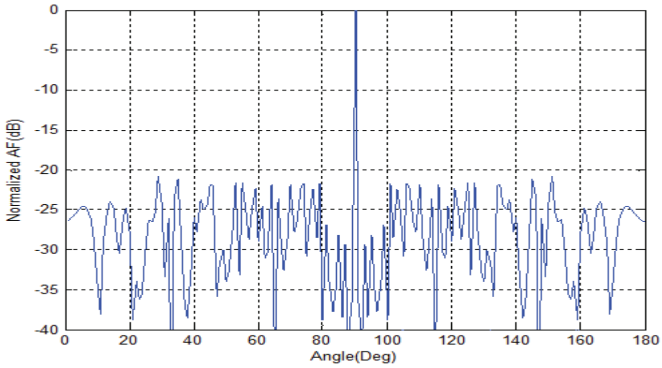

Fig 5. BGA optimized 200 element array pattern at 90° where no. of , elements ON = 126, maximum sidelobe level = -21.05dB

BPSO algorithm is based on the principle of continuous PSO[13]. Particle is the candidate solution of the cost function and group of particle make swarm. Individual particle's cost value, achieved so far, is called the personal best, pbest and best cost value achieved in a swarm is called global best, gbest. PSO can memorize these values for every iteration and updated these values by modifying its velocity and current position. BPSO algorithm implemented for the cost function, given by Eq. (2). BPSO is programmed for thinning of phased linear array of 200 elements with 0.3λ inter element spacing phased linear array at scanning angle 0°, to 90° and some of their array factor patterns are shown in Fig. 6, Fig. 7,and Fig. 8 respectively.

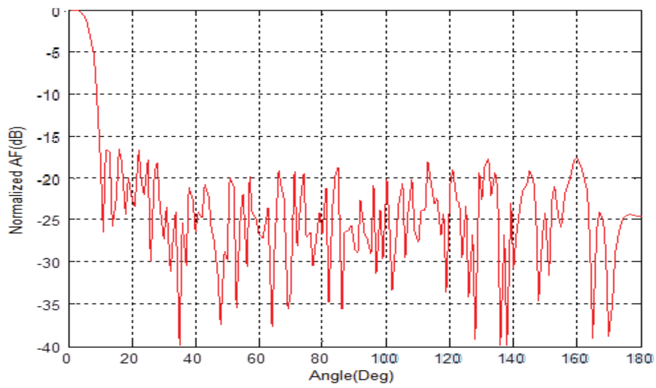

Fig.6. BPSO optimized 200 element array pattern at 0° where no. of elements ON =108, maximum sidelobe level = -17.01dB

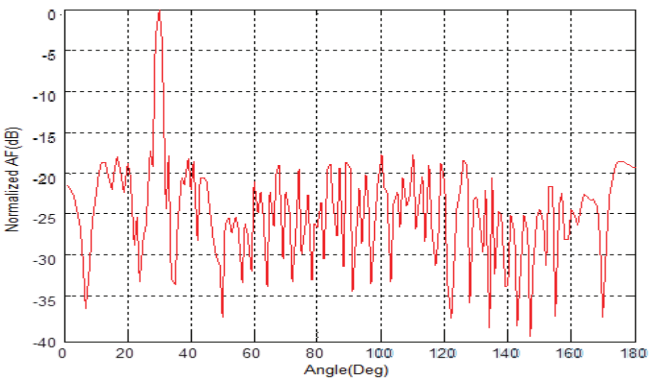

Fig.7. BPSO optimized 200 element array pattern at 30° where no. of elements ON =103, maximum sidelobe level = -17.92dB

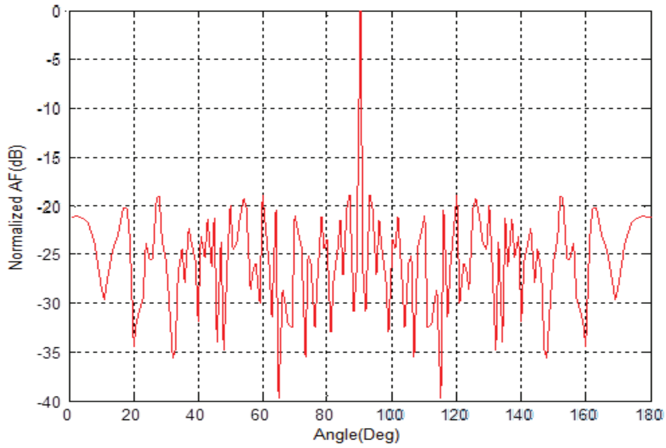

Fig.8. BPSO optimized 200 element array pattern at 90° where no. of elements ON =109, maximum sidelobe level = -19.00dB

Sidelobe level also minimized by thinning of 20 element, linear phased array with inter element spacing 0.3λ, by optimizing the cost function using BGA and BPSO, plotted the array factor pattern in the same graph for different scanning angle as shown in Fig. 9, Fig. 10, Fig. 11, respectively.

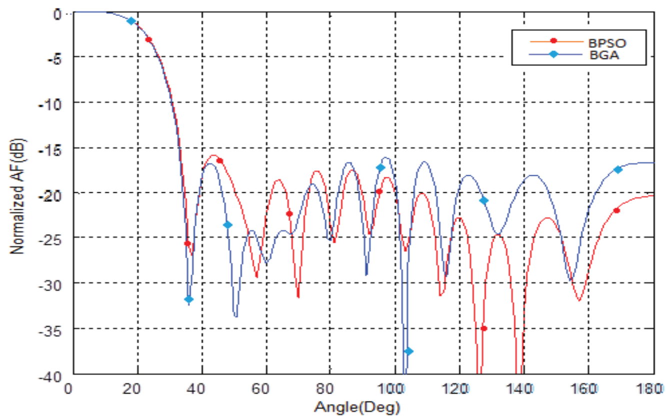

Fig.9. Normalized array factor for 20 element linear array using BGA and BPSO, main beam tilted at 0°

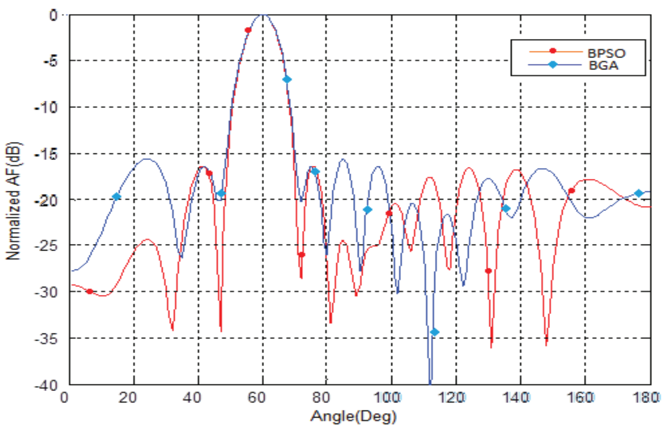

Fig.10. Normalized array factor for 20 element linear array using BGA and BPSO, main beam tilted at 60°

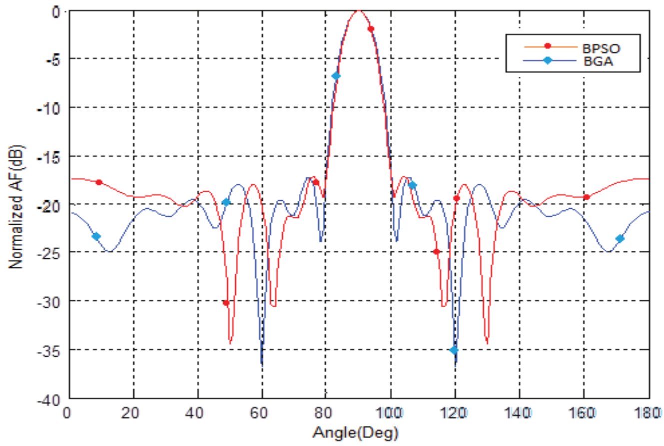

Fig.11. Normalized array factor for 20 element linear array using BGA and BPSO, main beam tilted at 90°

IV. COMPARISON OF THINNING USING BGA AND BPSO

This paper followed two approaches of optimization techniques, BGA and BPSO, for thinned phased array synthesis. Both of the algorithm are applied in a 20 element linear array, consist of isotropic antennas with 0.3λ inter element distance at different scanning angle. Afterwards optimization outcome is compared with respect to maximum sidelobe level and null to null main beam width at different scanning angle of a uniform linear array, presented in table-I. The table-I also summarizes the graphical results for thinned phased array at different tilt angles, presented above.

TABLE I. COMPARISON OF PERFORMANCES FOR 20 ELEMENT LINEAR ARRAY USING BGA AND BPSO

Algorithm	**Number of Elements N =20**			**Number of Elements ON with Positions in Array**
	Tilt Angle	***Null to Null Beam width***	***SLL_{max} (dB)***	***(Feed current weight)***
ULA	0°	34°	-13.19	All Elements are On
	30°	46°	-13.19	All Elements are On
	45°	28°	-13.19	All Elements are On
	60°	23°	-13.20	All Elements are On
	75°	21°	-13.20	All Elements are On
	90°	20°	-13.21	All Elements are On
BGA	0°	36°	-16.04	**17** (11011111111111111010)
	30°	49°	-16.21	**16** (10111111111111111000)
	45°	32°	-16.02	**15** (1111011101011100 1111)
	60°	25°	-16.45	**16** (10111111111111011100)
	75°	25°	-16.56	**14** (01011101111111101010)
	90°	21.5°	-17.30	**11** (10010110110110110100)
BPSO	0°	37°	-15.91	**17** (01111111111111111001)
	30°	49°	-16.27	**16** (10011111111111111100)
	45°	30. 5°	-15.01	**13** (00111011001111110101)
	60°	25°	-16.46	**18** (11011111111111111011)
	75°	23°	-15.71	**12** (10101011110110101010)
	90°	21°	-17.12	**14** (10101011011111110101)

Optimization of the cost function requires problem specific value adjustment of different algorithm parameters otherwise, it is difficult to obtain the best result. To compare the performances of these two algorithms, same iteration number is considered and swarm size in BPSO or population size in

BGA, for 20element array is 500 and 200, for 200 element array are 500 and 600 respectively. In this paper the chosen value of different algorithm specific parameters, for optimization of 20 element and 200 element linear phased array are given in table-II.

TABLE II. OPTIMIZATION ALGORITHM PARAMETERS AND THEIR PERFORMANCES

Algorithm	Parameters		No. of Iteration	No. of Elements	Average computa-tion time
BGA	Population size 200	Crossover = Uniform Mutation rate = 0.15	500	20	12min 03 sec
BPSO	Swarm size 200	Cognitive parameter C1 =1.5 Social parameter C2=1 Vmax =4 Inertia weight W=0.5 Normalized function = logsigmoid	500	20	3min 2sec
BGA	Population size 600	Crossover = Uniform Mutation rate = 0.2	500	200	1hour 44min
BPSO	Swarm size 600	Cognitive parameter C1 =1 Social parameter C2= 1 Vmax = 4 Inertia weight W= 0.5 Normalized function = logsigmoid	500	200	6min

V. DISCUSSION AND CONCLUSION

GA inherently designed for binary variables whereas PSO inherently designed for continuous variables. In case of BGA continuous value first change into binary variables and later the evolutionary operator crossover and mutation modified using binary pattern. BPSO convert the binary variables into continuous value for velocity and position modification same as continuous PSO, in addition with the normalization function for binary transform. BPSO uses small value of maximum velocity that creates good exploration in the searching domain, randomly. BGA is depended on two evolutionary operator, crossover and mutation whereas BPSO has no evolutionary operator that enhance faster computation through BPSO.

This is also noticed when applying both the algorithms to optimize sidelobe level of thinned array that BPSO has higher computational speed than BGA precisely in case of larger array optimization BPSO outperform BGA though BGA produced slightly improved sidelobe level and beam shape with respect to BPSO. BGA has more flexibility and easy to implement, and a good candidate algorithm for multi objective optimization.

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