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Side Lobe Reduction of a Concentric Circular Antenna Array using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO)

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Abstract—Circular antenna array has gained immense popularity in the field of communications. It has proved to be a better alternative over other types of antenna array configuration due to its all-azimuth scan capability, and a beam pattern which can be kept invariant. This paper is basically concerned with the thinning of a large multiple concentric circular ring arrays of uniformly excited isotropic antennas based on Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) methods. In this paper a 5, 7, 9, 13, 15, and 20 ringed Concentric Circular Antenna Arrays (CCAA) with central element feeding are considered. The main aim of this work is to reduce the number of antenna array elements with optimized First Null Beamwidth (FNBW), simultaneous reduction in Side Lobe Level (SLL) and a fixed half power beam width (HPBW).

Keywords: **Concentric Circular arrays, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), thinning.**

I. INTRODUCTION

Concentric Circular Antenna Array (CCAA) has several interesting features that make it indispensable in mobile and communication applications. CCAA has received considerable interest for it's symmetricity and compactness in structure [1-7]. A concentric circular array antenna is an array that consists of many concentric rings of different radii and a number of elements on its circumference. Since a concentric circular array does not have edge elements, directional patterns synthesized with a concentric circular array can be electronically rotated in the plane of the array without a significant change of the beam shape. CCAA provides great flexibility in array pattern synthesis and design both in narrow band and broadband applications. It is also favored in direction of arrival (DOA) applications since it provides almost invariant azimuth angle coverage. Uniform CCA is the CCA where all the elements in the array are uniformly excited and the inter-element spacing in individual ring is kept almost half of the wavelength. For larger number of rings with uniform excitations, the side lobe in the UCCA drops to about 17.5 dB. Lot of research has gone into optimizing antenna structures such that the radiation pattern has low side lobe level. This very fact has driven researchers to optimize the CCAA design. Although uniformly excited and equally spaced antenna arrays have high directivity at the same time they suffer from high side lobe level. Reduction in side-lobe level can be brought about in either of the following ways, either by keeping excitation amplitudes uniform but changing the position of antenna elements or by using equally spaced array with radially tapered amplitude distribution. These processes are referred to as thinning. Thinning not only reduces side lobe level but also brings down the cost of manufacturing by decreasing the number of antenna elements [9]. There are various global optimization tools for thinning such as Genetic Algorithms (GA) [8], Particle Swarm Optimization (PSO) etc. The PSO algorithm has proved to be a better alternative to other evolutionary algorithms such as Genetic Algorithms (GA), Ant Colony Optimization (ACO) etc [12]. in handling certain kinds of optimization problems. In this work, thinning of large multiple concentric circular ring arrays of isotropic antennas is done based on GA and PSO.

II. ANTENNA ARRAYS

In this chapter the basic emphasis is made on array theory. Here the number of elements and the spacing between the elements (d=0.5λ) is considered to be same for the entire above mentioned antenna arrangements. In an array of identical elements, there are at least five controls that can be used to shape the overall pattern of the antenna. These are

1. The geometrical configuration of the overall array (linear, circular, rectangular, spherical .etc)
2. The relative displacement between the elements.
3. The excitation amplitude of the individual elements.
4. The excitation phase of the individual elements.
5. The relative pattern of the individual elements.

A. Concentric circular array antenna (CCAA)

Below figure shows the general configuration of CCAA with M concentric circular rings, where the m^{th} (m = 1, 2… M) ring has a radius r_m and the corresponding number of elements is Nm. If all the elements (in all the rings) are assumed to be isotopic sources, the radiation

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pattern of this array can be written in terms of its array factor only. Referring to Fig. 1, the far field pattern of a thinned CCAA in x-y plane may be written as [10]

$$AF(\theta, I) = \sum_{m=1}^{M} \sum_{i=1}^{N_m} I_{mi} \exp(j(k.r_m.\sin\theta. \cos(\phi - \phi_{mi}) + \alpha_{mi}) \quad (1)$$

Where I_{mi} denotes current excitation of the i^{th} element of the m^{th} ring, $k = 2\pi/\lambda$, λ being the signal wave-length. If the elevation angle, Φ = constant, then (1) may be written as a periodic function of θ with a period of 2π radian i.e. the radiation pattern will be a broadside array pattern. The azimuth angle to the i^{th} element of the m^{th} ring is Φ_{mi} .The elements in each ring are assumed to be uniformly distributed [11].

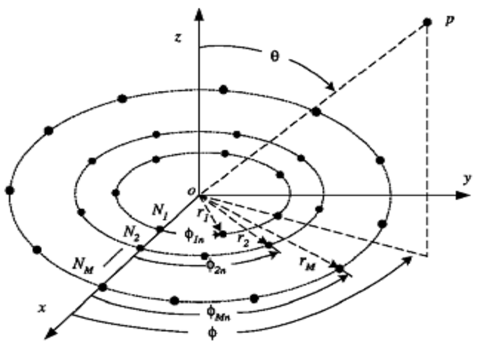

Fig. 1: Concentric circular antenna array (CCAA)

Φ_{mi} and α_{mi} are also obtained from as:

$$\phi_{mi} = 2\pi((i-1)/N_m) \quad (2)$$

$$\alpha_{mi} = -Kr_m.\sin\theta_0 \cos(\phi - \phi_{mi}) \quad (3)$$

θ_0 is the value of θ where peak of the main lobe is obtained. After defining the array factor, the next step in the design process is to formulate the objective function which is to be minimized. The objective function "Cost Function" CF may be written as:

$$CF = W_1 * (10^{\wedge}(SLL_1/20) + 10^{\wedge}(SLL_2/20)) + W_2 * (FNBW_{computed} - FNBW(I_{mi} = 1)) + W_3 * THINNED \quad (4)$$

FNBW is an abbreviated form of first null beam width, or, in simple terms, angular width between the first nulls on either side of the main beam. The value of 'FNBW (I_{mi}=1)' for concentric circular antenna array with 9 rings is 7.2 degrees. W_1 (unit less), W_2 (degree^{-1}) and W_3 are the weighting factors. θ_0 is the angle where the highest maximum of central lobe is attained in $\theta \in [-\pi\ \pi]$. SLL_1 is the side lobe level in the lower band and SLL_2 is the side lobe level in the upper band. W_1, W_2 and W_3 are so chosen that optimization of SLL remains more dominant than optimization of $FNBW_{computed}$ and THINNED and CF never becomes negative. In (4) the two beam widths, $FNBW_{computed}$ and FNBW (I_{mi}=1) basically refer to the computed first null beam widths in degree for the non-uniform excitation case and for uniform excitation case respectively. Minimization of CF means maximum reductions of SLL both in lower and upper sidebands and lesser $FNBW_{computed}$ as compared to FNBW (I_{mi}=1). The evolutionary optimization techniques employed for optimizing the current excitation weights resulting in the minimization of CF and hence reductions in SLL, FNBW and THINNED are described in the next section. In this case, I_{mi} is 1 if the m_i^{th} element is turned "on" and 0 if it is "off." All the elements have same excitation phase of zero degree. An array taper efficiency can be

$$\eta_{ar} = \frac{\text{Number of elements in the array turned ON}}{\text{Total number of elements in the array}}$$

III. EVOLUTIONARY TECHNIQUES

A. Genetic algorithm (GA)

A genetic algorithm is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are a particular class of evolutionary algorithms (also known as evolutionary computation) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (also called recombination).

A typical genetic algorithm requires two things to be defined:

i). a genetic representation of the solution domain.

ii).a fitness function to evaluate the solution domain.

1. **[Start]** Generate random population of 'n' individuals (i.e. suitable solution for the problem)

2. **[Fitness]** Evaluate the 'fitness' of each individual in the population

3. **[New population]** create new population by repeating following steps until the new population is created

a).**[Selection]** Select two parent individuals from population according to their fitness

b).**[Cross over]** with a cross over probability, cross over the parents to form new off string (children)

c).**[Mutation]** with a mutation probability, mutate new off string at each locus

d). **[Accepting]** Place new off string in the new population

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4. **[Replace]** Use new generated population for a further run of the Algorithm

5. **[Test]** if the end of the condition is satisfied, stops, and returns the best solution in current population

6. **[Loop]** Go to step 2

B. Particle Swarm Optimization (PSO)

PSO is a flexible, robust population-based stochastic search optimization technique with implicit parallelism, which can easily handle with non-differential objective functions, unlike traditional optimization methods. PSO is less susceptible to getting trapped on local optima unlike GA, Simulated Annealing, etc. The below figure shows the basic terminology and the process of PSO

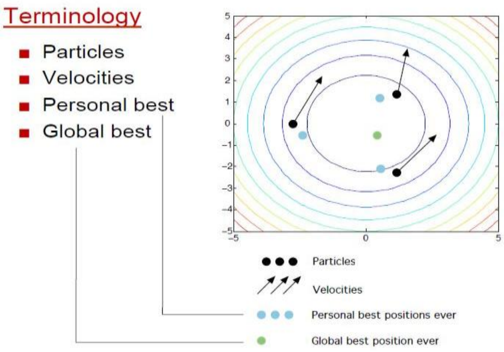

Fig. 2: Terminology and the process of PSO

The procedure for implementing the global version of PSO is given by the following steps:

i. Initialize a (population) of particles with random positions and velocities in the n-dimensional problem space using a uniform probability distribution function;

ii. For each particle in swarm, evaluate its fitness value;

iii. Compare each particle's fitness evaluation with the current particle's pbest. If current value is better than pbest, set its pbest value to the current value and the pbest location to the current location in n-dimensional space;

iv. Compare the fitness evaluation with the population's overall previous best. If current value is better than gbest, then reset gbest to the current particle's array index and value;

v. Change the velocity and position of the particle according to below equations respectively

Mathematically, velocities of the particles are modified according to the following equation

$$V_i^{k+1} = W * V_i^k + C_1 * rand_1 * (pbest_i - S_i^k) + C_2 * rand_2 * (gbest - S_i^k) \quad (5)$$

Where, V_i^k is the velocity of i^{th} particle at k^{th} iteration; W is the weighting function; C1 and C2 are the weighting factors; $Rand_1$ and $Rand_2$ are two random numbers between 0 and 1. S_i^k is the current position of particle i at iteration k;$pbest_i$ is the personal best of particle i;gbest is the group best among all pbests for the group.

The searching point in the solution space can be modified by the following equation:

$$S_i^{(k+1)} = S_i^k + V_i^{(k+1)} \quad (6)$$

vi. Loop to step (ii) until a stopping criterion is met, usually a maximum number of iterations (generations).

IV. COMPUTATIONAL RESULTS

Each CCAA maintains a fixed optimal inter-element spacing between the elements in each ring. The limits of the radius of a particular ring of CCAA are decided by the product of number of elements in the ring and the inequality constraint for the inter-element spacing, d,d€[λ/2,λ] For all the cases,θ_0=0 is considered so that the peak of the main lobe starts from the origin. Best chosen maximum population pool size= 120, maximum iteration cycles for optimization= 50, and C1 = C2 = 1.5.

For this case $r_m = m \times \lambda/2$

Inter-element spacing in each rings are $d_m = \lambda/2$

The number of equally spaced elements in ring m is given by

$$N_m = 2\pi r_m / d_m.$$

The results of 5, 9 and 20 rings of CCAA are shown in below

A. Fully populated array results

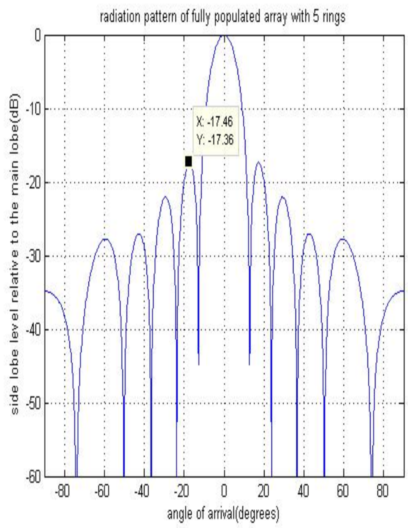

Fig. 3 Radiation pattern of fully populated array for M=5 rings

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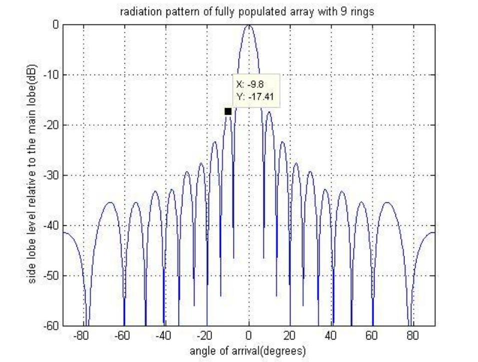

Fig. 4 Radiation pattern of fully populated array for M=9 rings

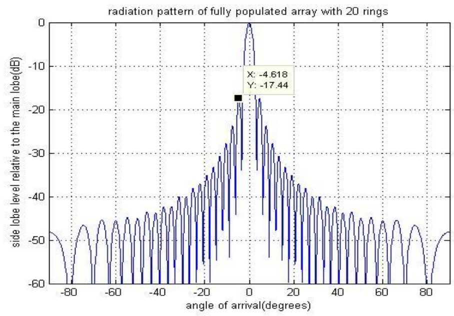

Fig. 5 Radiation pattern of fully populated array for M=20 rings

B. Results of CCAA using genetic algorithm (GA)

Convergence Profile

The minimum CF values are plotted against the number of iteration cycles to get the convergence profiles as shown in below figures.

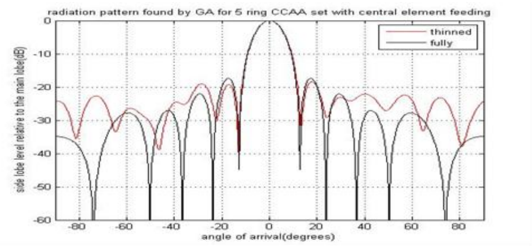

Fig. 6 Radiation pattern for CCAA with central element feeding for M=5 rings by using GA

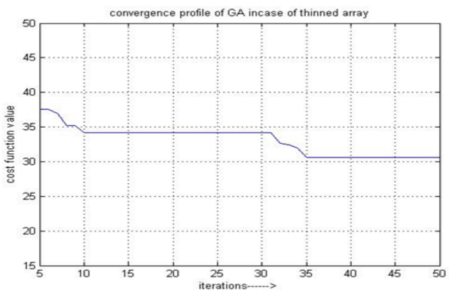

Fig. 7 Convergence Profile for CCAA with central element feeding for M=5 rings by using GA

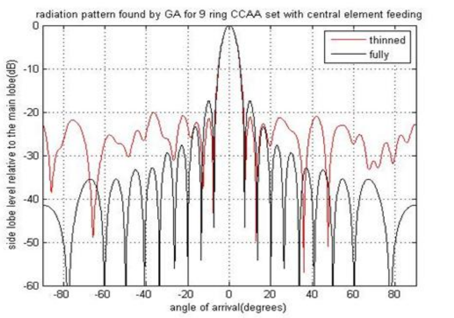

Fig. 8 Radiation pattern for CCAA with central element feeding for M=9 rings by using GA

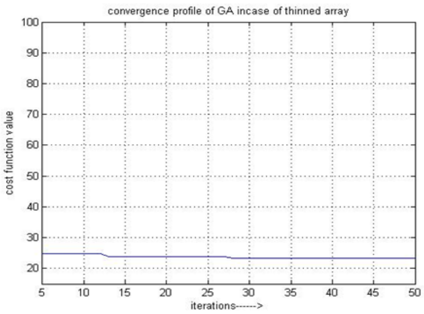

Fig. 9 Convergence Profile for CCAA with central element feeding for M=9 rings by using GA

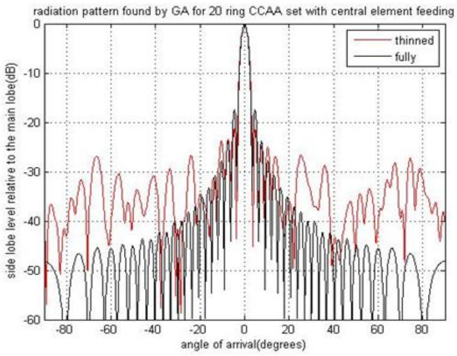

Fig. 10 Radiation pattern for CCAA with central element feeding for M=20 rings by using GA

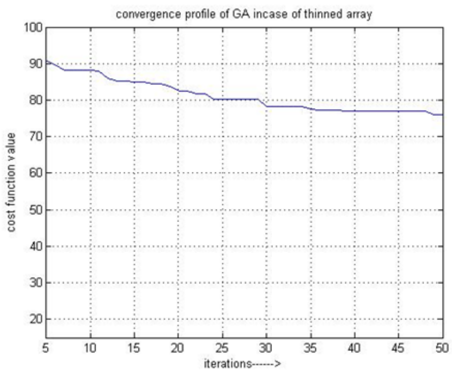

Fig. 11 Convergence Profile for CCAA with central element feeding for M=20rings by using GA

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C. Results of CCAA using particle swarm optimization:

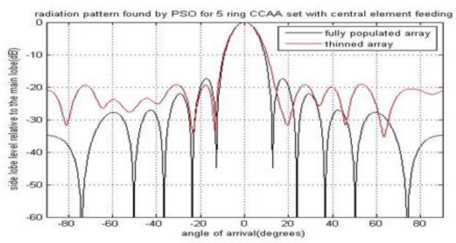

Fig. 12 Radiation pattern for CCAA with central element feeding for M=5 rings by using PSO

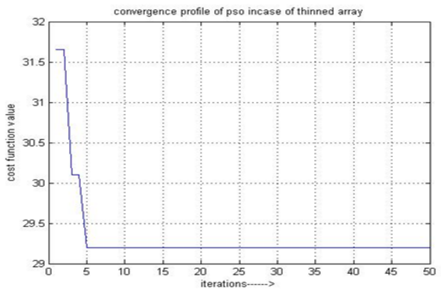

Fig. 13 Convergence Profile for CCAA with central element feeding for M=5 rings by using PSO

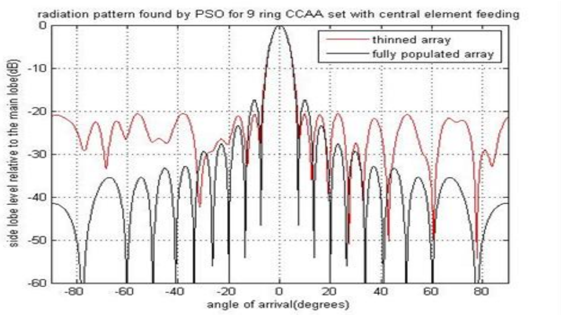

Fig. 14 Radiation pattern for CCAA with central element feeding for M=9 rings by using PSO

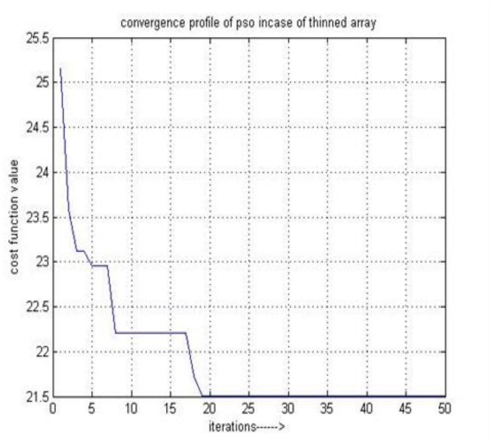

Fig. 15 Convergence Profile for CCAA with central element feeding for M=9 rings by using PSO

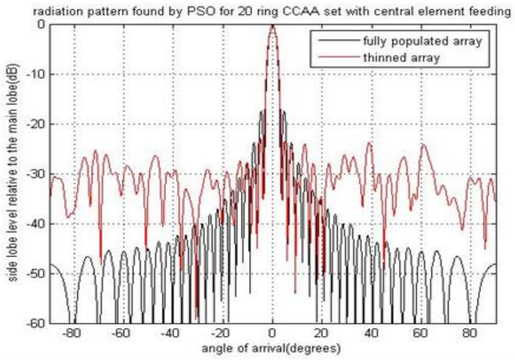

Fig. 16 Radiation pattern for CCAA with central element feeding for M=20 rings by using PSO

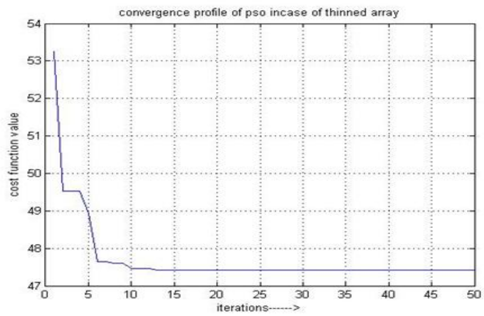

Fig. 17 Convergence Profile for CCAA with central element feeding for M=20 rings by using PSO

Table 1: The below tabular form shows the comparison between Genetic Algorithm and Particle Swarm Optimization for 5, 9, and 20 ring concentric circular array antenna

Parameters	Number of rings	Fully populated array	GA based synthesized thinned array	PSO based synthesized thinned array
Side Lobe Level (SLL, in dB)	5 rings	-17.35dB	-18.36dB	-19.10dB
	9 rings	-17.41dB	-20.12dB	-20.56dB
	20 rings	-17.44dB	-22.14dB	-22.94dB
Beam Width between First Nulls (FNBW, in degree)	5 rings	12.60	13.05	13.72
	9 rings	7.20	7.65	7.65
	20 rings	3.37	3.60	3.60
Half-power	5 rings	10.80	10.80	10.80

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Beam Width (HPBW, in degree)	9 rings	6.30	6.30	6.30
	20 rings	3.15	3.15	3.15
Number of elements turned OFF	5 rings	0	31	45
	9 rings	0	131	162
	20 rings	0	524	730
Number of elements turned ON	5 rings	93	62	48
	9 rings	279	148	117
	20 rings	1310	786	580

V. CONCLUSION

PSO gives better results in reducing total number of antenna elements and Side Lobe Level. The Half Power Beam width (HPBW) of the synthesized array pattern with fixed inter-element spacing is remain same to that of a fully populated array of same shape and size in case of PSO. Compared to GA, the PSO gives better results in optimization of FNBW. The PSO technique yield convergence to the minimum SLL in less than 25 iterations, where as GA technique yield convergence to the minimum SLL in more than 25 iterations.

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