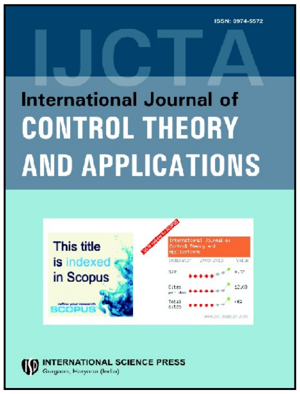

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Optimization of Side Lobe Level in Thinned Concentric Circular Array Antenna Using Particle Swarm Optimization

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Abstract: In this paper, optimization of side lobe level (SLL) of randomly excited concentric circular antenna arrays is done by providing optimal multiple thinning based on particle swarm optimization (PSO) method .With this approach, optimum performance of the array can be achieved with reduced number of active elements in the array and correspondingly the feed network for the array can be simplified. Comparative studies are done between results obtained with PSO based approach & results obtained with GA based approach.

Keywords: Concentric Circular Antenna Array, Particle Swarm Optimization, Genetic Algorithm, Thinning, Side lobe Level

1. INTRODUCTION

For some communication applications the side lobe level and beam width attainable from single antenna is not adequate. In such cases a group of antennas called antenna array, arranged in a suitable configuration and with proper amplitude and phase distributions is used. Antenna arrays work on the principle of interference between radiations form different elements of the array. The radiation characteristics of the array antenna can be varied by varying amplitude and /or phase distributions and/or inter element spacings.

Circular antenna array [1] is a planar array in which antennas are aligned along a circle with equal spacing between successive antennas. Since there are no edge elements in circular array it has all all-azimuth scan capability and radiation pattern remains almost unchanged .A concentric circular array consists of a number of concentric circular rings with different radii and different number of elements. Typical concentric circular antenna arrays is shown in figure 1.

It has a wide range of applications in radar, sonar, mobile and commercial satellite communications systems.

As the number of rings increases, the elements in each ring increase which result in decreased side lobe level (SLL). In case of uniform amplitude for CCAA of 20 rings the SLL is around -18dB.But for applications

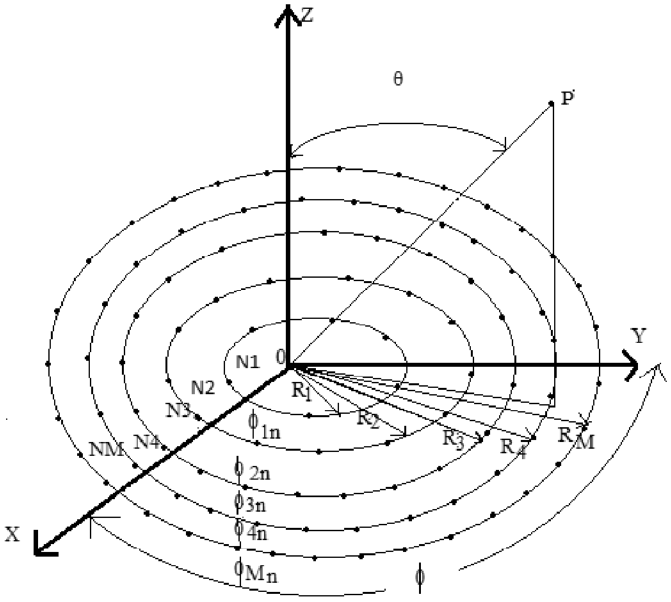

Figure 1: Concentric Circular Antenna Array

like radar in which false echoes are to be completely eliminated. Also with a large number of rings in CCAA, the number of elements is greatly increased and this results in complicated feed network for the CCAA. So thinning is employed to reduce the number of elements and to get optimum SLL for CCAA, the amplitude distribution is randomly varied using random stochastic methods like Particle swarm optimization (PSO) and Genetic algorithm (GA) based optimization.

Thinning is a procedure of turning off the active elements without affecting the performance of antenna arrays [6]. It also reduces the complexity and fabrication cost of antennas.

Particle swarm optimization is based on the movements and intelligence of swarm (like fish schooling & bird flock). PSO has several advantages when compared to GA. Unlike GA, PSO requires only few parameters, easy to implement & less vulnerable to get trapped in local optima. GA works on the huge search space looking of best and robust solutions .It works on the principle of crossover, mutation & selection operands. In both the cases we generate the population randomly and select the best solution.

In this paper optimization of SLL is done using both PSO & GA and comparative studies are done on the results obtained with PSO & GA.

2. METHODOLOGY

(A) Particle Swarm Optimization Algorithm

In PSO, A swarm is a group of particles which represent possible solutions. The population of swarms are initially of random particles (solutions). Swarm searches for food randomly in the search space. These swarms communicate with each other about the finest path in search of food as they have an internal memory. Every particle moves and so they have internal velocities. These velocities regulate the path of flying based on the finest experience of the swarm. The velocities with respect to their positions are being updated until they synchronize with the finest path for seeking food. For every iteration, each particle is being updated based on two “optimum” values. First is the best solution that has been attained so far which is known as pbest. Second is finest value which has been tracked by any particle among the population so far obtained, which is well known as gbest. Now gbest implies the locality of food and this food represents the desired SLL [2].

(B) Genetic Algorithm

In Genetic Algorithm based approach, an initial set of solutions of the array representing amplitudes is randomly generated. Each solution is called as a chromosome and the amplitudes of the elements are called as Genes [4]. For these solutions, the radiation characteristics of antenna array like SLL and beam width are evaluated. The obtained results are compared with a predefined cost function/fitness function. The solutions with the best fitness value are selected. Then crossover and mutation are applied to the fittest solutions to obtain even fitter solutions than those obtained previously. The procedure continues until a suitable termination condition is satisfied.

(C) Design Methodology

ARRAY FACTOR

$$AF(\theta) = \Sigma_{m=1}^{M} \Sigma_{i=1}^{N_m} I_{mi}\, e^{[j(KR_m \sin\theta \cos(\phi-\phi_{mi})+\beta_{mi})]} \quad 1$$

Where

I_{mi} = Amplitude distribution for i^{th} element in m^{th} ring = $\begin{cases} 0 & OFF \\ 1 & ON \end{cases}$

K (wave number) = 2*π/ λ

R_m (radius of m^{th} *ring*) = m* λ/2(m = 1, 2, 3,......)

R_m is wave length in λ

N_m (Number of elements) = 2π R_m/d (N_m is adjusted to nearest integer value)

d is the spacing b/w the successive elements [3].

$$\varnothing_{mi} = 2\pi\left(\frac{i-1}{N_m}\right)$$

$$\beta_{mi} = -K_1 R_m \sin\theta_0 \cos(\varnothing - \varnothing_{mi})[\theta_0 = 0] \text{ (For all cases)]}$$

PARTICLE SWARM OPTIMIZATION

1) Inputs to be given: No of rings, Radii of rings & Spacing between successive elements in each ring
2) Calculation of number of elements in each ring.
3) Generation of initial population of particles (possible solutions), where some of the elements are randomly turned off in each ring of circular array (thinning).
4) Initialization of the position and velocities of each particle.
5) Evaluation of fitness functions for each particle.

Fitness function =|SLL|- |desired SLL|

6) Evaluation of array factor for each particle position.
7) For each particle position, evaluation of fitness.
8) If the fitness function is better than fitness (pbest) then pbest =fitness function.
9) Updating the velocities and position for each particle.
10) Continuing this until the terminating criteria is obtained.
11) Setting the best pbest as gbest.
12) Selecting the best gbest value and evaluation of SLL,B.W & HPBW.
13) Plotting the radiation pattern of the best array pattern.

GENETIC ALGORITHM

1) Inputs to be given: No of rings, Radii of rings & Spacing between successive elements in each ring.
2) Calculation of number of elements in each ring.
3) Generation of initial population where some of elements are being turned off in each ring of circular array.
4) Defining fitness function.
   - Fitness function =|SLL|- |desired SLL|
5) Evaluation of array factor for each chromosome.
6) Selecting the best chromosome and evaluation of SLL, BWFN, HPBW.
7) Plotting radiation pattern [5].

3. RESULTS AND DISCUSSION

Systematic arrangement of the elements and radius for each ring is represented in TABLE I.

Table I
Number of elements & radius for 20 rings of ccaa

M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rm	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
Nm	6	13	19	25	31	38	44	50	57	63	69	75	82	88	94	101	107	113	119	126

Radiation patterns and values of side lobe level are given for three cases ie (M=5,10,20).

CASE 1 (M=5): Radiation patterns for thinned CCAA with random amplitudes for 5 rings using PSO & GA are given in figures 2 & 3. SLL(in dB) is -20.36dB & -20.03dB respectively.

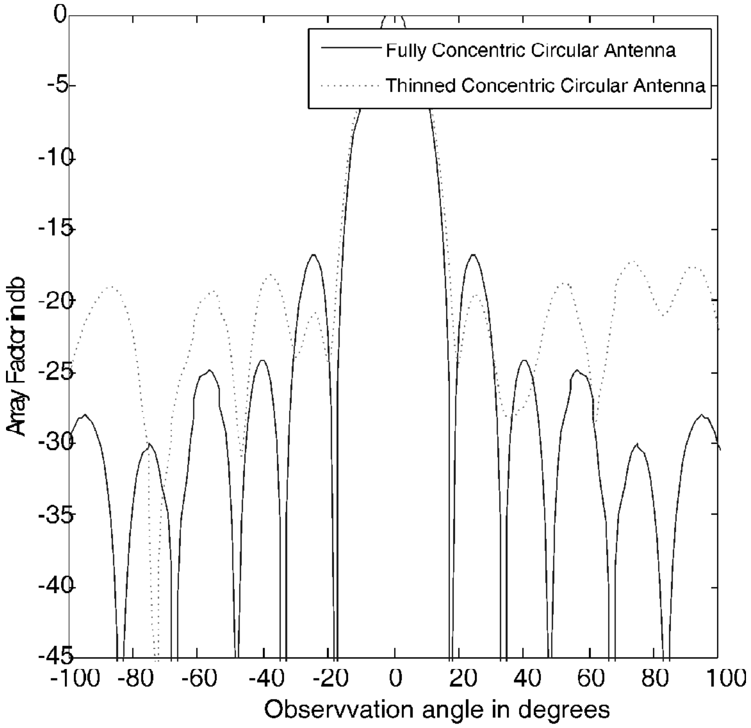

Figure 2: Radiation pattern for Thinned CCAA with random amplitudes using PSO for M=5

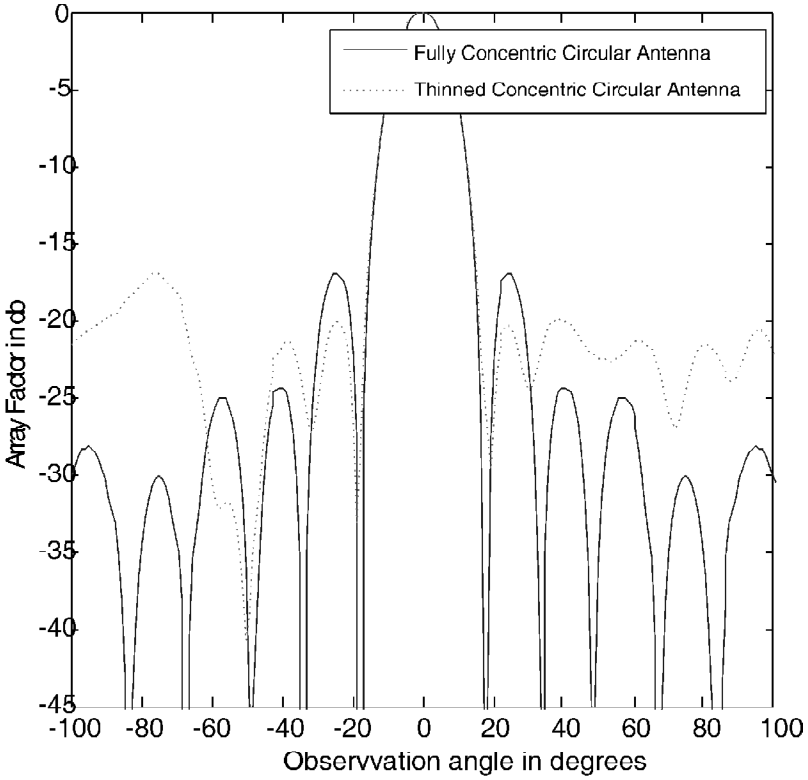

Figure 3: Radiation pattern for Thinned CCAA with random amplitudes using GA for M=5

CASE 2(M=10): Radiation patterns for thinned CCAA with random amplitudes for 10 rings using PSO & GA are given in figures4 & 5.SLL(in dB) is -23.87dB & -19.28dB respectively.

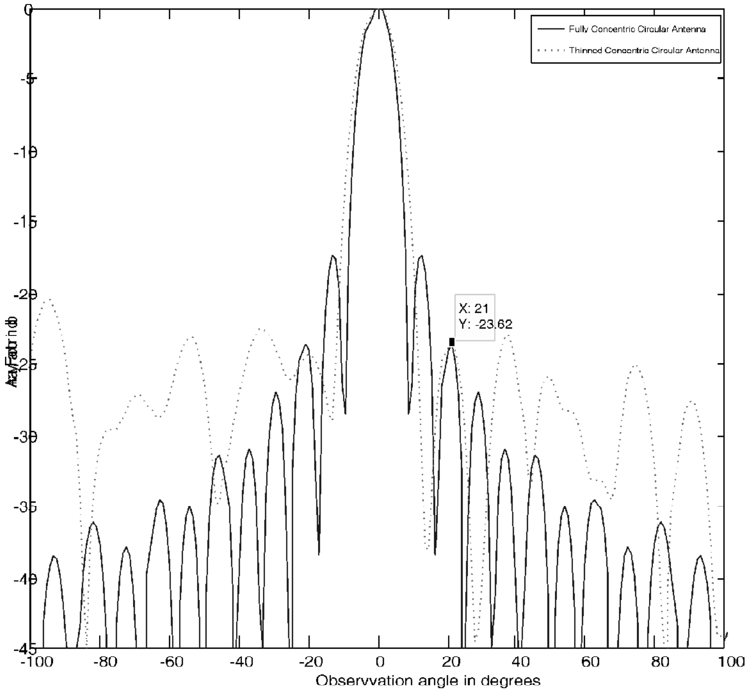

Figure 4: Radiation pattern for thinned CCAA with random amplitudes using PSO for M=10

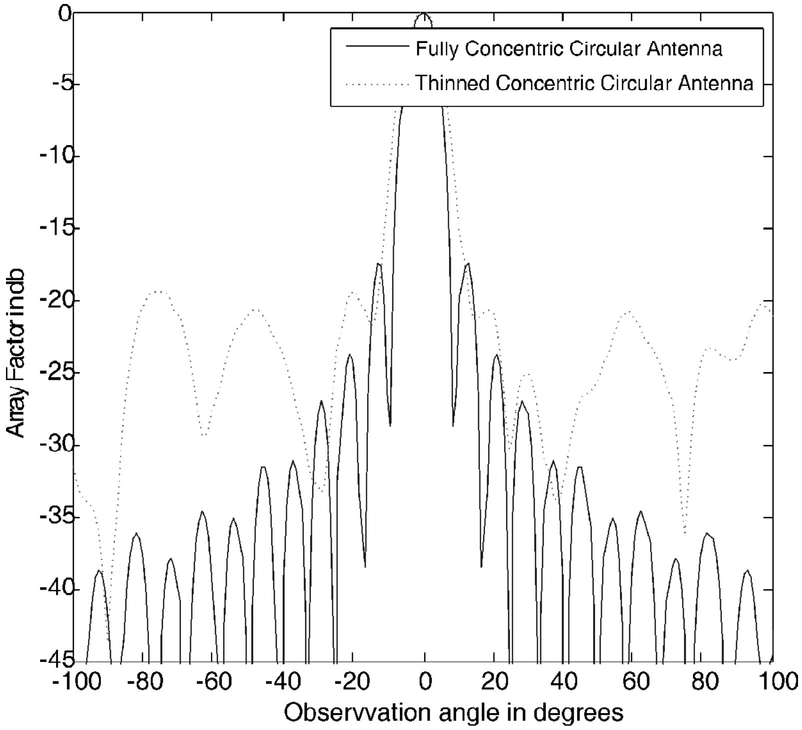

Figure 5: Radiation pattern for thinned CCAA with random amplitudes using GA for M=10

CASE 3(M=20): Radiation patterns for thinned CCAA with random amplitudes for 20 rings using PSO & GA are given in figures6 & 7.SLL(in dB) is -24.59dB & -21.28dB respectively.

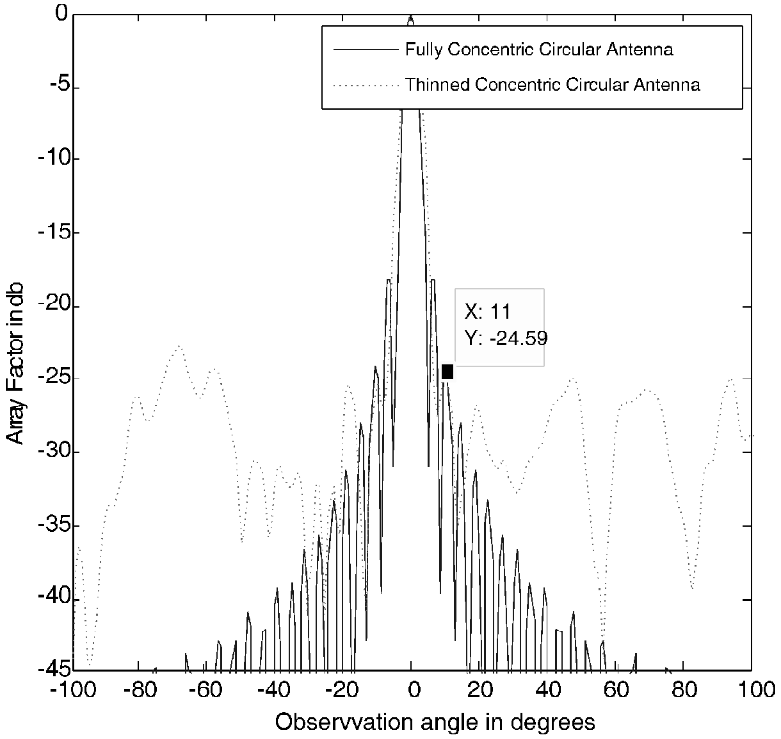

Figure 6: Radiation pattern for thinned CCAA with random amplitudes using PSO for M=20

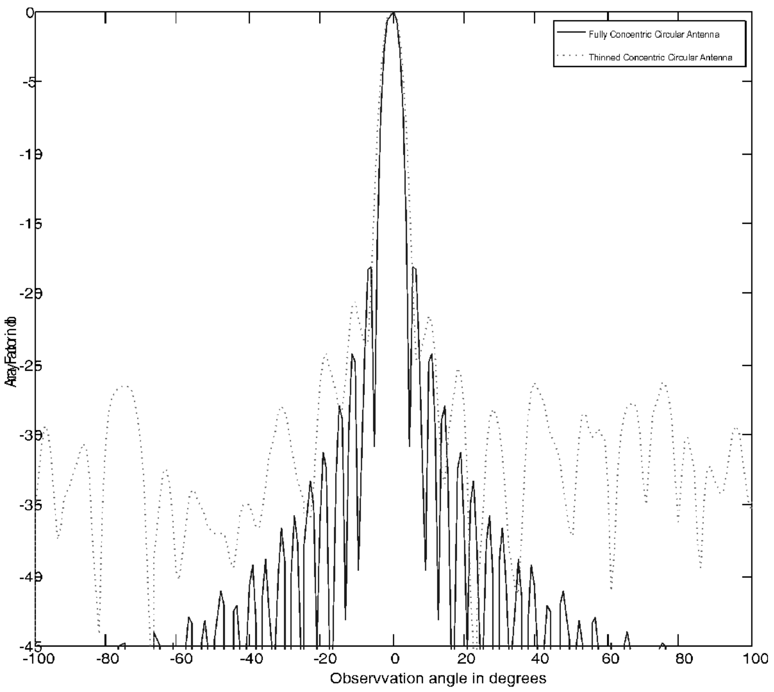

Figure7: Radiation pattern for thinned CCAA with random amplitudes using GA for M=20

Fully populated and thinned antenna array using PSO & GA is given in TABLE II.

Table II
Fully populated and thinned antenna array using PSO & GA

No of Rings	*Side Lobe Level (in dB)*			*BEAW Width B/W First Nulls (BWFN) in Degree*			*Half Power Beam Width (HPBW) in Degree*		
	F.P.A	*GA*	*PSO*	*F.P.A*	*GA*	*PSO*	*F.P.A*	*GA*	*PSO*
5	-16.87	-20.03	-20.36	34°	38°	38°	16°	16°	16°
10	-17.49	-19.28	-23.87	18°	22°	28°	8°	8°	12°
20	–18	–21.28	–24.59	10°	16°	16°	4°	6°	6°

F.P.A – fully populated array, PSO-particle swarm optimization, GA- genetic algorithm

Random amplitude distribution for thinned CCAA (M=5) using PSO & GA is given in TABLE III & IV.

Table III
Amplitude distribution for thinned 5 ring CCAA using PSO

	R_m	AMPLITUDE EXCITATION										
6	1	0.785	0.633	0	0	0.778	0					
13	2	0	0.596	0.849	0.771	0.679	0	0.618	0.653	0.603	0	0 0 0.929
19	3	0	0.917	0 0.580	0.719 0	0.743 0.818		0.799	0.696	0 0 0.709		0 0.812
		0 0.748 0.828 0										
25	4	0.821	0.512	0 0	0.693	0.780	0 0.593 0 0		0 0 0	0.758	0.861	0.674
0.719	0	0.748	0	0	0	0	0	0.592				
31	5	0.531	0 0	0.832	0.745	0 0	0.553	0.683	0.551	0 0 0.888 0.761 0.597 0.600 0 0		
0 0.585 0.925 0 0		0.748	0.591	0 0.900 0.623		0 0.723 0						

Table VI
Amplitude distribution for thinned 5 ring CCAA using GA

N_m	R_m	*AMPLITUDE EXCITATION*
6	1	0 0 0.965 0.650 0.963 0.832
13	2	0 0.978 0.678 0.502 0 0.934 0 0 0.559 0 0 0.908 0.543
19	3	0.959 0 0.699 0 0 0.567 0 0.850 0 0.943 0.615 0 0.765 0.882 0 0 0 0.956 0.849
25	4	0 0.787 0.887 0 0.878 0 0.661 0.849 0.528 0 0 0.580 0.996 0.572 0.691 0.834 0 0 0 0 0.864 0.845 0.989 0.553 0.657
31	5	0.884 0.564 0.783 0.814 0 0.888 0 0.913 0.875 0.573 0.505 0.936 0.936 0.568 0 0 0.544 0 0.752 0 0.817 0.921 0.508 0 0.527 0.678 0.552 0 0 0 0.974

Random amplitude distribution for thinned CCAA(M=20)using PSO is given in TABLE V.

Table V
Amplitude distribution for thinned 20 ring CCAA using PSO

Nm	*Rm*	*CURRENT EXCITATION*
6	1	0.743 0.736 0 0.924 0 0
13	2	0 0.610 0.722 0 0 0 0 0 0.634 0 0.881 0.802 0.802
19	3	0.811 0 0.788 0 0 0.841 0.530 0.697 0.733 0 0 0 0 0.631 0 0.897 0.533 0.836 0.667
25	4	0 0 0 0 0.793 0 0.673 0.830 0 0 0 0 0.681 0 0 0.877 0.807 0.928 0 0 0 0 0 0.604 0
31	5	0.911 0 0.952 0 0 0.816 0 0 0 0 0 0 0.698 0.582 0.747 0.602 0 0.964 0.771 0.544 0.931 0.525 0 0.709 0.777 0 0 0.518 0.948 0.886
38	6	0 0.963 0 0 0.853 0.869 0 0 0 0 0 0 0 0.993 0.884 0.765 0.832 0 0 0.839 0 0 0.698 0.918 0.651 0.978 0 0 0 0 0 0.769 0.888 0.667 0.683 0.657 0.700 0
44	7	0.783 0.796 0 0.619 0.686 0 0.968 0 0.901 0.670 0.687 0.896 0 0 0 0 0.728 0.500 0 0.928 0.676 0 0 0 0.799 0 0.798 0.968 0.807 0.959 0 0.717 0.596 0.510 0.772 0.519 0 0 0.857 0 0.922 0.511 0 0
50	8	0 0.606 0.918 0.810 0.889 0.853 0.637 0.948 0 0.924 0 0.930 0.897 0 0.856 0.747 0 0 0 0.629 0 0.675 0.762 0 0.944 0 0.859 0 0 0 0 0.865 0 0.663 0 0 0.983 0.836 0 0 0.694 0 0 0.990 0.984 0 0.963 0 0.734
57	9	0 0 0.862 0.564 0 0 0.762 0 0.695 0.782 0 0 0 0.923 0.530 0 0.537 0.553 0 0.731 0.715 0.691 0.577 0.783 0.631 0.726 0 0 0.516 0 0 0.747 0.837 0.603 0.975 0 0.804 0 0.851 0 0 0 0 0.924 0 0 0.781 0.629 0.694 0 0.663 0.679 0 0 0 0.770 0.763
63	10	0 0.659 0 0.687 0 0 0 0 0 0 0 0 0.762 0 0.637 0.720 0.682 0.643 0 0.817 0 0 0.677 0 0.916 0 0 0 0.668 0.905 0.686 0.981 0.612 0 0 0.985 0.729 0 0.994 0 0.976 0 0.685 0.636 0.760 0 0 0 0 0 0.721 0.858 0.959 0.948 0.606 0.716 0.884 0.914 0.971 0 0 0
69	11	0.706 0.603 0.877 0.797 0.922 0.651 0.606 0.907 0 0 0 0 0.836 0 0 0.733 0 0.925 0.865 0 0.729 0 0 0 0.821 0.898 0.662 0.993 0 0 0 0.553 0.974 0 0.827 0 0 0.842 0 0 0 0.830 0.754 0.595 0 0.626 0.826 0.928 0.562 0 0.555 0 0 0.947 0.790 0.973 0 0 0.897 0.922 0.896 0.539 0 0.662 0 00.766 0 0
75	12	0 0 0.745 0 0 0 0 0.615 0.604 0.925 0.725 0 0 0 0.844 0 0 0.975 0 0 0 0 0.874 0 0 0 0 0.613 0 0.980 0 0 0 0.660 0 0 0 0.678 0.926 0.665 0 0 0.846 0.956 0.603 0 0 0.807 0 0 0.870 0.765 0.625 0.823 0 0.664 0 0.931 0 0.707 0.758 0 0 0 0.798 0 0 0.639 0 0 0.632 0.710 0 0.853 0
82	13	0 0 0 0 0 0 0.802 0.643 0 0 0 0.672 0.966 0 0.812 0.983 0 0.960 0.919 0.780 0 0 0.875 0 0 0 0 0 0 0 0.869 0 0 0 0 0 0 0 0.839 0 0.643 0.874 0.645 0 0 0 0 0 0 0 0 0 0 0 0.683 0 0 0 0.775 0 0 0 0.603 0 0 0.693 0 0 0.686 0 0.684 0 0 0 0.704 0.811 0 0.661 0.795 0 0 0
88	14	0.533 0.905 0.779 0.815 0.653 0.808 0.696 0 0.652 0.811 0.660 0 0.701 0.683 0.701 0.790 0 0 0.937 0 0 0 0 0.547 0 0.604 0.893 0 0.943 0 0 0 0 0 0.556 0 0 00 0.755 0 0.791 0.612 0 0.786 0 0.987 0 0 0 0.731 0.601 0.515 0.694 0.651 0.867 0 0 0 0.522 0.646 0.880 0.649 0 0 0 0 0 0.609 0.622 0 0 0 0.847 0.501 0.768 0.511 0 0.969 0.664 0.831 0 0 0 0 0 0.945 0
94	15	0.646 0.824 0.740 0.813 0 0.967 0 0.762 0.888 0.930 0 0.609 0 0 0 0 0.923 0 0 0 0 0 0.765 0 0.720 0 0 0 0 0 0.768 0 0 0 0 0.902 0 0 0.978 0.676 0 0 0.755 0 0 0.845 0 0.931 0.683 0 0 0 0 0 0 0 0 0.988 0.979 0 0 0 0.709 0 0 0 0 0 0.686 0.765 0 0.798 0 0 0.925 0 0.736 0 0 0 0 0 0 0 0 0.700 0.951 0 0 0 0 0.617 0.608 0
101	16	0 0 0.601 0.531 0.509 0.754 0.566 0.676 0.762 0 0 0.921 0 0 0.675 0 0 0 0 0.813 0.991 0 0.961 0 0.553

		0.574 0.910 0 0 0 0 0.843 0 0.870 0 0.594 0 0 0.810 0 0 0 0.736 0.677 0 0.968 0 0 0.921 0 0 0 0.795 0 0 0.586 0 0.865 0 0 0.992 0 0 0 0.522 0.966 0 0 0.904 0.760 0 0.886 0.602 0.882 0 0 0.743 0.933 0.790 0.627 0.965 0.888 0 0.651 0.954 0.799 0.777 0.714 0.509 0 0 0.756 0 0.933 0.746 0 0.899 0.835 0.890 0 0.696
107	17	0.941 0.577 0.619 0.925 0 0 0.715 0 0.711 0 0 0 0.515 0 0 0.661 0.992 0 0.879 0 0 0 0.985 0 0.886 0.825 0.848 0.576 0 0.806 0.896 0 0 0 0.936 0.836 0 0.571 0.875 0 0 0 0 0.843 0.534 0 0 0.546 0 0.705 0 0 0.972 0.771 0.988 0 0.780 0 0.633 0.815 0.698 0 0 0.564 0 0.643 0.955 0 0 0 0 0 0 0.832 0 0.876 0 0 0 0 0 0.831 0 0.584 0.827 0 0.927 0 0 0.760 0.710 0 0 0 0.864 0 0.568 0 0.843 0.943 0 0 0.810 0.880 0 0.564 0
113	18	0.960 0.538 0 0.603 0.655 0.656 0.557 0.876 0 0 0 0.524 0.545 0 0.621 0 0.500 0 0 0 0 0 0.647 0 0.978 0.888 0 0 0.970 0 0 0 0.749 0.869 0 0.575 0.650 0 0.563 0 0 0 0 0.672 0.525 0 0.689 0 0.546 0.831 0.872 0.907 0.532 0.718 0.592 0 0 0.518 0.927 0 0.701 0 0 0 0.668 0.985 0.721 0.785 0.905 0 0 0.970 0.728 0 0 0 0.925 0 0.676 0 0 0.664 0.843 0.917 0 0 0 0 0.684 0 0 0 0 0 0 0.815 0.566 0.987 0.696 0.816 0 0.724 0 0 0.641 0.780 0.740 0.885 0 0.978 0.653 0.774 0.775
119	19	0 0.964 0 0.884 0 0.790 0 0 0 0 0.508 0 0 0 0 0.565 0.912 0.890 0 0.638 0 0 0.691 0 0.602 0.701 0 0.823 0 0 0 0 0.718 0 0 0.893 0 0 0 0 0 0 0 0.662 0.712 0 0.627 0.951 0 0 0 0 0 0.524 0.947 0.757 0 0.729 0.826 0 0 0.566 0.917 0 0.799 0.628 0 0.794 0 0 0 0 0 0.794 0 0.871 0.576 0 0.863 0 0.888 0 0 0.521 0 0.707 0.885 0 0 0 0 0.7057 0 0.745 0.842 0.978 0.604 0 0 0 0 0.890 0.618 0 0 0 0 0 0 0.665 0.708 0.537 0.784 0 0.785 0.992 0.618 0
126	20	0 0.870 0.972 0.714 0 0 0 0 0.650 0 0 0 0.928 0.843 0 0 0 0 0.949 0.637 0.737 0 0 0 0 0 0.734 0.980 0 0.892 0 0.816 0.725 0 0 0 0.855 0 0.761 0 0 0 0 0.732 0 0 0 0 0.613 0.626 0.631 0 0.991 0 0 0 0 0 0 0.620 0.708 0.736 0.628 0 0.678 0 0.889 0 0.931 0.788 0 0 0 0.976 0 0 0.767 0 0 0 0 0 0.676 0.815 0.895 0 0 0 0.896 0 0.642 0 0 0.934 0 0.932 0.838 0.733 0 0 0.701 0.909 0 0 0.760 0.711 0 0.744 0 0 0.675 0 0 0 0.784 0 0.719 0 0.940 0.976 0 0 0.880 0.824 0.961 0.980

It is observed that PSO based approach gives better results when compared to GA based approach in all the cases.

4. CONCLUSIONS

In this paper, an attempt has been made to reduce the side lobe level of CCAA by using multiple thinning based on PSO & GA. It is observed that with PSO based approach, better results are obtained with respect to side lobe reduction compared to GA. The best SLL obtained for random amplitudes is -24.59dB based on PSO based approach for 20 rings.The synthesized array using PSO has 662 elements switched off, i.e. a reduction of 50% of the total elements of 1320. This will greatly simplify the feed network of the concentric circular array.This work can be further extended to reduce the SLL by varying the relative phases of elements of an array and inter element spacing or combinations of both. This method can be used to reduce the SLL of volumetric ring array antennas. Also, other Optimization techniques like ACO (ant colony optimization) & annealing simulation optimization methods can be used to optimize SLL of thinned CCAA.

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