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Comparative Analysis of Evolutionary Algorithms for the Optimised Beams from Thinned Concentric CAA

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Abstract

By applying proper amplitude-weighting the signals received at each element, includind the low side lobes may be gained. Aperiodic or non-uniform spacing between the components is one of the strategies and the thinned array is another strategy utilized in producing the low side lobe amplitude taper, while thinning disables some components in a uniform array. Hence optimized narrow beams are generated from concentric circular antenna arrays using both techniques i.e aperiodic spacing as well as concept of thinning to scan the entire azimuthal plane. A practical and simple antenna element is dipole and it is used for communication purpose as an array element. An extensive comparison is brought out between optimized thinned concentric circular antenna arrays and uniformly distributed fully populated concentric circular antenna array characteristics applying the and the same are presented at the end.

Keywords: Concentric CAA, Dipole Radiators, Thinning, Evolutionary Algorithms, Side Lobe Level.

1. Introduction

The Circular Antenna Array (CAA) is a circular arrangement of radiating components of a similar kind that produces a flawless pattern of beam in every cut as well as scans the whole plane of azimuthal. A Concentric Circular Antenna Array (CCAA) is a group of circles

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with varying radii that are connected at their centers. According to geometry, each element will lie on a separate circle's rim. [1-4]

The Concentric CCA is a array of planar made up of several circular rings with various radii and a number of antenna components positioned around the perimeter of each ring [5-7]. They are utilised for beam shaping applications as well as for controlling beam width and directivity.

2. Dipole-Equipped Concentric Circular Antenna Array

According to Fig. 1, the Concentric CAA's geometry includes dipole components. The pattern of the radiation of the array may be explained by making the assumption that the components are dipole elements.[15]

$$E = E_d(\theta) * E_c(\theta,\phi) \qquad (1)$$

In this case, the equation defines $E_d(\theta)$ as the single-dipole radiation pattern.

$$E_d(\theta) = \frac{\cos(kl\cos\theta)) - \cos kl}{\sin\theta} \qquad (2)$$

$E_C(\theta,\phi)$ is radiation pattern of the CCAA with isotropic elements calculated with the equations below

$$E_C(\theta,\phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn} e^{jkr_m[sin\theta\cos(\phi-\phi_{mn})-sin\theta_o\cos(\phi_o-\phi_{mn})} \qquad (3)$$

The location of the element in the ring is found by

$$(x_i,y_i) = (r_i\cos\phi_{mn}, r_i\sin\phi_{mn}) \qquad (4)$$

Where (x_i,y_i)= location of the element r_m is radius of m^{th} ring given by

$$r_m = \frac{N_m d_m}{2\pi} \; r_m = \frac{N_m d_m}{2\pi} \qquad (5)$$

ϕ_{mn} is given by

$$\phi_{mn} = \frac{2n\pi}{N_m} \; \phi_{mn} = \frac{2n\pi}{N_m} \qquad (6)$$

Where

I_{mn} is Currents of Excitation

d is spacing in between the inter elements

k is the number of wave, $k=2\pi/\lambda$

θ is angle of elevation,

M is no of rings,

N is no of elements and

θ_0, ϕ_0= direction at which main beam obtains its maximum.

The design issues here take into account both $\theta_0=0°$ and $\phi_0 = 0°$ are considered. ϕ is the azimuth angle between the distant field point's projection in the x-y plane and the positive x-axis.

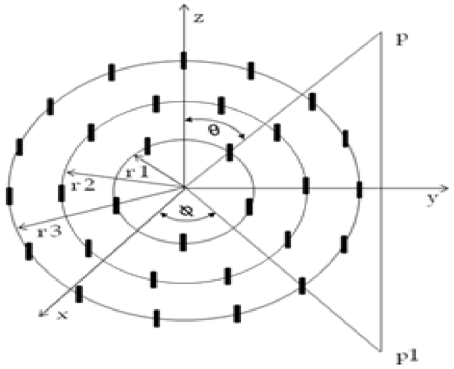

Figure 1. Dipole-Element Concentric Circular Antenna Array [15]

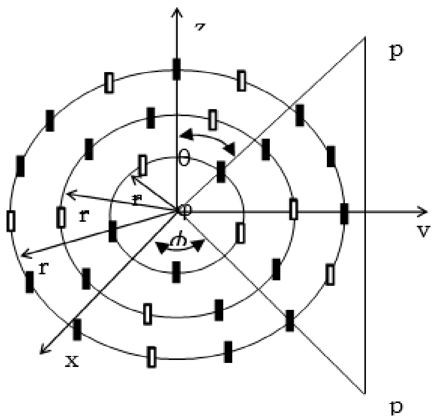

Figure 2. Dipole-Equipped Thinned Concentric Circular Antenna Array

3. Fitness Function

The idea of thinning must be used to the antenna arrays for the design issue discussed in this work without impairing the antenna array's performance. The fitness function considered for this problem is

$$Fitness = \begin{cases} Max(SLL) + (T_c - T_d)^2 \\ 10^2 \end{cases} \quad (7)$$

Where T_c is calculated percentage of thinning and T_d is desired value of percentage of thinning. Hence for the design of the thinned array the elements should be on and off accordingly which will accomplish the fitness function indicated above.

$$SLL = \frac{20\log_{10}|E(\theta)|}{max(|E(\theta)|)} \quad (8)$$

4. Thinning of Antenna Array using Evolutionary Algorithms

Metaheuristic algorithms (BAT, Cuckoo and the Genetic algorithms) are used to iteratively search through a very vast solution space in search of the best solution. These metaheuristic algorithms use extremely straightforward computational methods to provide the greatest outcomes in the shortest amount of time. There are several sorts of algorithms depending on the various search tactics. Among all of these many categories of algorithms, evolutionary algorithms provide the best categorization.

Systematically eliminating thinning is the process of removing antenna array members without impairing the antenna array's performance. Large antenna arrays are difficult to construct, and fabrication and setup are expensive. Therefore, it's crucial to remove antenna elements from the array without compromising the array's performance. The element that produces the most side lobe level is regarded as being off while the other components are on.

5. Results and Discussions

Here, the Concentric CAA with the elements of dipole is considered for different rings like 3, 4, 5, 6 and the radiation patterns are numerically computed using the equations 1 to 6. Each ring's element count is regarded as a multiple of 5. The excitation currents of the Concentric Circular Antenna Array are optimized using evolutionary algorithms as BAT [8–10,15], Cuckoo Search [11–12], and Genetic algorithm [12] while taking into account the fitness function as shown in equations 7 and 8. A spacing of 0.862λ is considered for all the algorithms which is identified as the best after considering different optimal spacings.

In the first part the optimized Inter element Spacings with uniform current amplitudes of different types of antenna arrays with dipole elements are considered and the concept of thinning is applied [13-14]. In the second case keeping the same optimized Inter element Spacings, optimized non-uniform current amplitudes are considered and the concept of thinning is applied. CCAA for M=2, 3, 4, 5 and 6 rings for dipole elements are numerically evaluated and they are presented.

Figs. 3-6 show the resulting radiation patterns for a Concentric Circular Antenna Array with useable dipole components. The corresponding amplitude excitation levels of 2 rings are given in table 1. In this table element number 1.1 indicates 1st ring 1st element. Remaining all the element numbers are indicated accordingly. The Performance characteristics of Concentric CAA with practical elements of dipole elements using evolutionary algorithms are presented in table 2. In this table2 beam width indicates null to null beam width. In table1 I_{UC} indicate Thinning with same current as well as I_{NUC} denote non-uniform current thinning.

Table 1. Amplitude Excitation Coefficients for Two Rings Thinned CCAA with Dipole Elements

Element No	BAT		CS		GA	
	I_{UC}	I_{NUC}	I_{UC}	I_{NUC}	I_{UC}	I_{NUC}
1.1	1	0.4227	1	0.8887	1	0.4032
1.2	1	0	1	0	0	0.8255
1.3	1	0.9422	1	0.9241	1	0.6981
1.4	1	0	0	0	1	0.3162
1.5	1	0.4905	1	0.6632	1	0
2.1	0	0.961	1	0.5842	1	0.0894
2.2	1	0.5659	0	0.4364	0	0.565
2.3	0	0.8137	1	0.9114	1	0.0434
2.4	0	0.6768	1	0.6091	0	0
2.5	0	0	1	0.6512	0	0.089
2.6	1	0.6581	0	0.7057	1	0.8662
2.7	0	0	1	0	0	0
2.8	0	0.3047	1	0.8393	1	0.6511
2.9	1	0.5022	0	0.2618	1	0
2.10	0	0	1	0	0	0

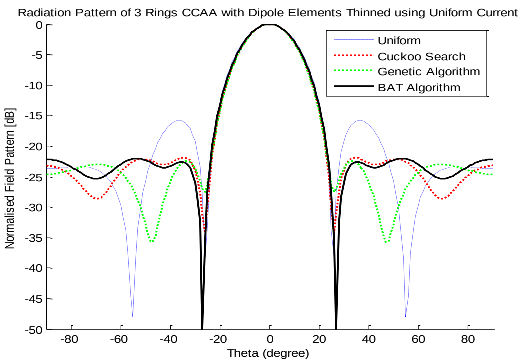

Figure 3. Three-Ring CCAA Radiation Pattern with Uniform Current-Thinned Dipole Elements

With uniform current, thinning of 50% is obtained using BAT algorithm, 44% with CS algorithm and 34% with GA for a 4 ring concentric CAA with dipole elements. It is found from the results that a SLL of -22.9 dB is obtained with BAT algorithm, -22.1 dB with CS algorithm and -22.7 dB with GA for 4 ring concentric circular antenna array with dipole elements, thinning of 49.3% is obtained using BAT algorithm, 37.3% with CS algorithm and 41.3% with GA for a 5 ring concentric CAA with dipole elements. It is found from the results that a SLL of -21.8 dB is obtained with BAT algorithm, -22.8 dB with CS algorithm and -21.7 dB with GA for 5 ring concentric circular antenna array with dipole elements and also thinning of 52.4% is obtained using BAT algorithm, 48.5% with CS algorithm and 52.4% with GA for a 6 ring concentric CAA with dipole elements. It is found from the results that a SLL of -22.7 dB is obtained with BAT algorithm, -21.6 dB with CS algorithm and -22.2 dB with GA for 6 ring concentric circular antenna array with dipole elements.

With non uniform current, thinning of 48% is obtained with BAT algorithm, 46.7% with CS algorithm and 40% with GA for a 4 ring concentric circular antenna array with dipole elements. It is found from the results that a SLL of -24.2 dB is obtained with BAT algorithm, -21.9 dB with CS algorithm and -23.6 dB with GA for 4 ring concentric CAA with the elements of dipole, thinning of 44% is obtained with BAT algorithm, 38.6% with CS algorithm and 44% with GA for a 5 ring concentric circular antenna array with dipole elements. It is found from the results that a SLL of -22.7 dB is obtained with BAT algorithm, -22.9 dB with CS algorithm and -21.02 dB with GA for 5 ring concentric CAA with the elements of dipole and also thinning of 43.8% is obtained with BAT algorithm, 43.8% with CS algorithm and 47.6% with GA for a 6 ring concentric circular antenna array with dipole elements. It is found from the results that a SLL of -23.6 dB is obtained with BAT algorithm, -23.6 dB with CS algorithm and -21.2 dB with GA for 6 ring concentric CAA with the elements of dipole.

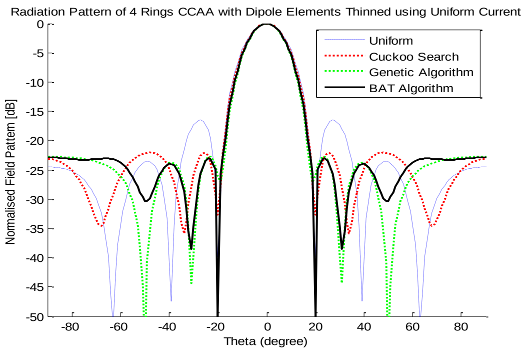

Figure 4. Four-Ring CCAA Radiation Pattern with Uniform Current-Thinned Dipole Elements

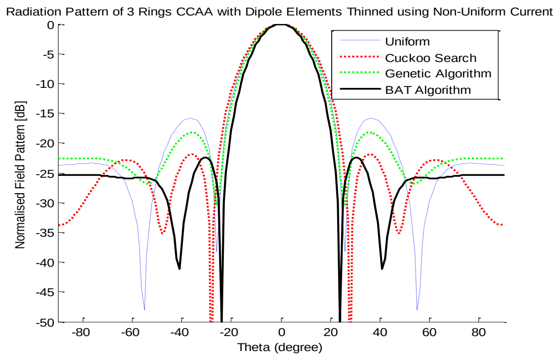

Figure 5. Three-Ring CCAA Radiation Pattern with Dipole Elements Thinned by Non-Uniform Current

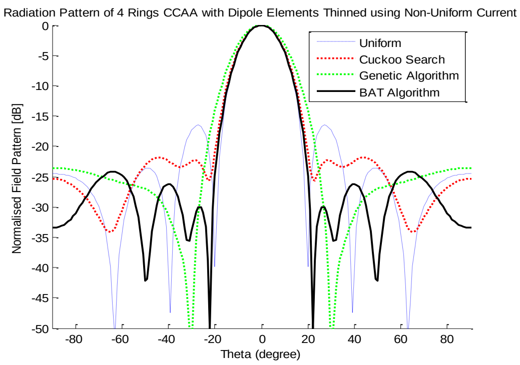

Figure 6. Four-Ring CCAA Radiation Pattern with Dipole Elements Thinned by Non-Uniform Current

Table 2. Performance Characteristics of CCAA with Dipole Elements (Thinning)

No of Rings	**Parameter**	**Fully Populated Array**	**BAT**		**CS**		**GA**	
			Thinning with Uniform Current	**Thinning with Non Uniform Current**	**Thinning with Uniform Current**	**Thinning with Non Uniform Current**	**Thinning with Uniform Current**	**Thinning with Non Uniform Current**
3	SLL in dB	-15.8	-22.0	-22.4	-21.8	-21.9	-22.5	-18.2
	BW	52^0	52^0	48^0	52^0	54^0	52^0	52^0
	% Thinning	-	33.3%	40%	60%	46.7%	43.3%	30%
4	SLL in dB	-16.5	-22.9	-24.2	-22.1	-21.9	-22.7	-23.6
	BW	40^0	40^0	46^0	44^0	40^0	40^0	58^0
	% Thinning	-	50%	48%	44%	46.7%	34%	40%
5	SLL in dB	-16.8	-21.8	-22.7	-22.8	-22.9	-21.7	-21.02
	BW	32^0	34^0	30^0	34^0	32^0	52^0	40^0
	% Thinning	-	49.3%	44%	37.3%	38.6%	41.3%	44%
6	SLL in dB	-17.1	-22.7	-23.6	-21.6	-23.6	-22.2	-21.2
	BW	28^0	28^0	26^0	26^0	30^0	28^0	30^0
	% Thinning	-	52.4%	43.8%	48.5%	43.8%	52.4%	47.6%

6. Conclusion

It is evident that the BAT algorithm searches effectively for the best amplitude excitations and inter element spacings that produced the desired beam patterns with low side lobe levels compared to the other evolutionary algorithm. The results reveal that with the concept of thinning using evolutionary algorithms, causes a good amount of reduction in side lobe level. Broadband and narrowband wireless communications applications mostly leverage these findings. Designers of array antennas can use the data to develop real-time applications.

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