



Generation of Patterns from Circular Antenna Arrays using BAT Algorithm for Wireless Communications

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Abstract - Systematically eliminating the antenna array elements without ceasing the performance of the antenna array is known as thinning. In the present paper optimization technique is presented for thinning of circular antenna array (CAA). As understood from literature the traditional methods are not well suited for thinning of array hence BAT algorithm is used to find the optimum thinned configuration for narrow beams. The computed radiation patterns are compared with the uniform array for different number of elements.

Index Terms: Thinning, Circular Antenna Array, Bat Algorithm, Side lobe level and Narrow beams.

I. Introduction

Circular array antenna [1 - 7] is an assembly of similar radiating elements electrically and geometrically in the form of a circle. The circular arrays are extremely useful in direction finding, wide bandwidth HF communication systems, wrap - around shipborne communications, navigational aids, space craft communications, null steering systems for mobile communication applications and wide bandwidth microwave direction finders. It has the capability to scan over the entire azimuthal plane and it also gives invariant beam pattern in every ϕ cut.

The radiation pattern of CAA with isotropic elements depends on the prime parameters like excitation current, excitation phase and inter element spacing. These three parameters can be controlled to achieve the required objective i.e. low side lobe level and narrow beam width. The array is optimized with different optimization techniques like Genetic algorithm and Particle Swarm Optimization. These techniques results in achieving the required objectives viz. low SLL and narrow beam width.

II. The array Geometry

The array factor (AF) of this CAA is calculated as follows

Normalised field can be written as

$$E(r, \theta, \phi) = \sum_{n=1}^N \alpha_n \frac{e^{-jk R_n}}{R_n} \quad (1)$$

Where

$$R_n = \sqrt{r^2 + a^2 - 2ar \cos \psi_n} \quad (2)$$

For the far field the array field reduces to

$$E(r, \theta, \phi) = \frac{e^{-jk R_n}}{R_n} \sum_{n=1}^N \alpha_n e^{jk a \sin \theta \cos \psi(\phi - \phi_n)} \quad (3)$$

Where α_n is the complex excitation coefficient both amplitude and phase

$$\alpha = -I_n e^{j\phi_n} \quad (4)$$

ϕ_n is angular position of the nth element

$$ka = \sum_{i=1}^N di \quad (5)$$

$$\phi_n = 2\pi \sum_{i=1}^n di/ka \quad (6)$$

Finally the array factor of CAA can be reduced and is given as

$$AF(\phi, \alpha, d) = \sum_{n=1}^N \alpha_n e^{j(k a \cos(\phi - \phi_n))} \quad (7)$$

Where

I_n is excitation currents,
 ϕ_n is excitation phases,
 d is inter element spacing,

k is the wave number,
 N is no of elements and
 ϕ is the angle of incidence.

Fig1 shows CAA with fully excited antenna elements where as Fig.2 shows thinned CAA.

III. BAT Algorithm

A Metaheuristic algorithm initiates an iterative generation process that guides lower heuristic to explore the search space in a different way using different intelligent strategies.

BAT algorithm [8 – 11] is a Metaheuristic algorithm developed by Xin-She Yang in 2010 based on the echolocation behaviour of micro bats with varying pulse rates of emission and loudness. This BAT algorithm is used here to find the array coefficients like excitation currents, inter element spacing etc. Thinning process is applied later using the BAT.

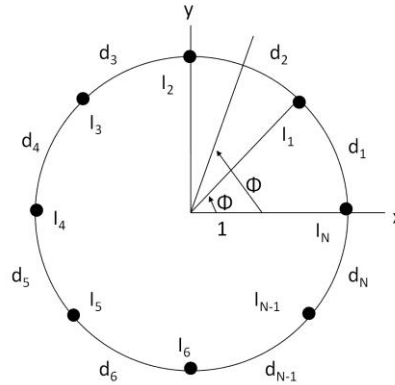


Fig 1. Fully energized CAA

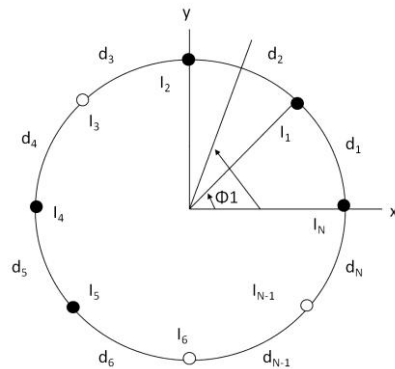


Fig .2 Thinned CAA

In this BAT algorithm the optimum solution of the problem is indicated by bat positions. Quality of the solution is represented by the best position of a bat. Bats use the process of echolocation to sense the distance and to know the difference between food/prey and background barriers. They fly randomly with an initial velocity, position, minimum frequency, varying wave length and loudness to search the food/prey. Depending on the closeness of the target they are able to adjust the pulse emission rate and wave length. The process of the BAT algorithm is indicated as flowchart in Fig.3.

The Fitness function that is to be minimized is as given in the equation no 8.

$$\text{Fitness} = \text{MIN}(\text{MAX}(20 * \log \text{AF}) / \text{AF}) \quad (8)$$

IV. Array Design using thinning

The earliest method of optimizing array geometry is thinning [12 – 15] of arrays or array thinning. Large antenna arrays are complex to build, fabrication and setup costs are also heavier. Hence eliminating antenna elements from the array without curtailing the performance of the array is essential. The element which gives maximum side lobe level is considered to be turned off while the remaining elements are turned on.

In thinning process it can be observed that $I_n=1$ if the element is turned on else it is 0 if the element is turned off according to the array factor equations. The thinning is applied in two ways here. At first the inter element spacing is optimized, keeping the same the array is thinned. In the second process the optimized excited currents are considered with spacing and then the array is thinned.

Results:

The work was executed in two stages first radiation patterns for circular antenna array of 10, 20 and 30 elements were numerically evaluated using equations 1 to 7 with uniform excitation. The BAT algorithm is applied to optimize the

excitation currents and inter element spacing of circular antenna array. Further these optimized values were applied to array for thinning which resulted in enhanced results. All the elements are excited with zero degrees excitation angle.

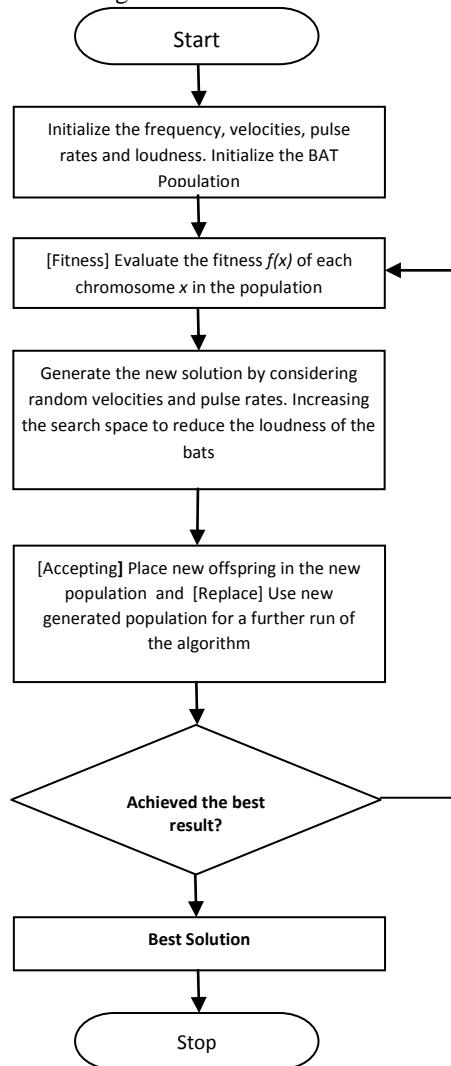


Fig.3 Flow chart indicating BAT algorithm

For 10 elements CAA the radiation patterns were numerically evaluated and they are presented in Fig 4. The comparison values are presented in Table 1. From the results it is observed that the sidelobe level is -3.6dB with uniform excitation, -5.3dB with thinning and -4.2dB with thinning using BAT excitation currents which is reduced drastically. The beam width is narrowed down when using the BAT algorithm.

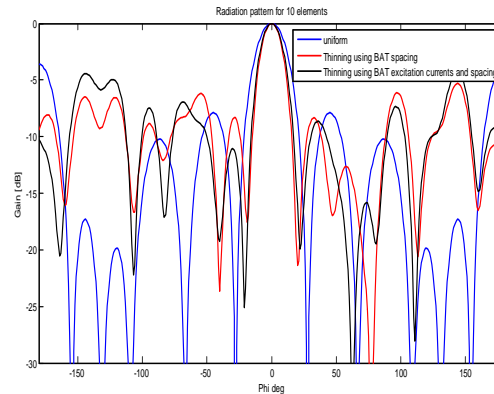


Fig 4. Radiation Pattern of CAA for N=10

Table 1 Comparison values for 10 elements CAA

Uniform Array	Excitation currents	1 1 1 1 1 1 1 1 1 1 1	Max SLL = -3.6 dB 3 dB B.W = 26°
	Spacing	0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	
Thinning using BAT spacing	Excitation currents	1 1 1 1 1 1 1 0 1 0	Max SLL = -5.3 dB 3 dB B.W = 18° Thinning % = 20%
	Spacing	0.4724 0.5008 0.9307 0.9639 0.8672 0.9570 0.5209 0.9891 0.8073 0.4382	
Thinning using BAT excitation currents and spacing	Excitation currents	0.2578 0.4671 0.2678 0.4485 0.6658 0.5187 0.2264 0.0000 0.3904 0.0000	Max SLL = -4.2 dB 3 dB B.W = 19° Thinning % = 20%
	Spacing	0.4724 0.5008 0.9307 0.9639 0.8672 0.9570	

		0.5209 0.9891
		0.8073 0.4382

For 20 elements CAA the radiation patterns were numerically evaluated and they are presented in Fig 5. The comparison values are presented in Table 2. From the results it is observed that the sidelobe level is -6.08dB with uniform excitation, -8.2 dB with thinning and -8.2dB with thinning using BAT excitation currents which is reduced drastically. The beam width is narrowed down when using the BAT algorithm from 12.8° to 11.2°.

For 30 elements CAA the radiation patterns were numerically evaluated and they are presented in Fig 6. The comparison values are presented in Table 3. From the results it is observed that the sidelobe level is -7.92dB with uniform excitation, -9.04 dB with thinning and -8.2dB with thinning using BAT excitation currents which is reduced significantly. The beam width is narrowed down when using the BAT algorithm from 8.52° to 8.2°.

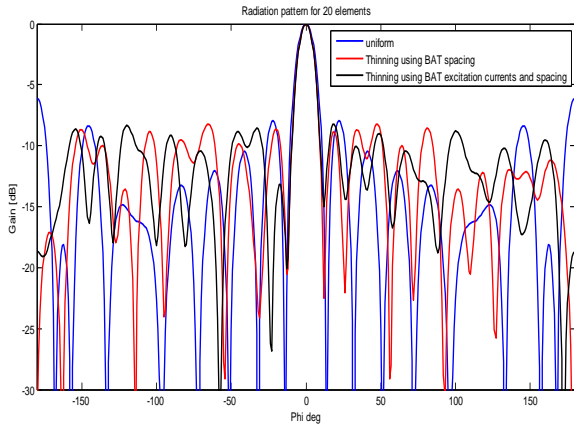


Fig 5. Radiation Pattern of CAA for N=20

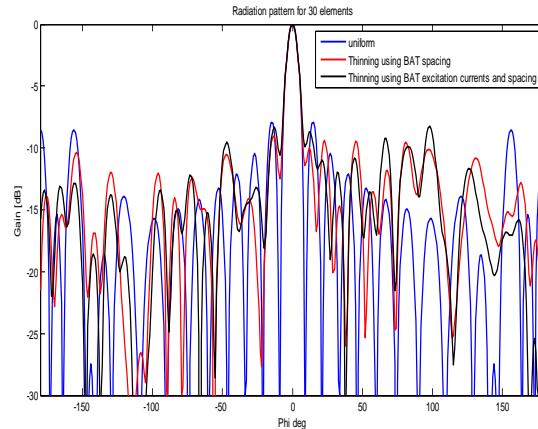


Fig 6. Radiation Pattern of CAA for N=30

Table 2 Comparison values for 20 elements CAA

Uniform Array	Excitation currents	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Max SLL = -6.08dB 3 dB B.W =12.8°
	Spacing	0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	
Thinning using BAT spacing	Excitation currents	1 0 1 0 0 1 1 1 1 1 1 1 0 1 1 1 1 1 0 1	Max SLL = -8.2 dB 3 dB B.W =11.2° Thinning % = 25%
	Spacing	0.5105 0.6399 0.7873 0.8251 0.5771 0.6019 0.3053 0.6996 0.7061 0.3752 0.8002 0.6473 0.5859 0.2970 0.5544 0.7709 0.5952 0.5334 0.6452 0.5356	
Thinning using BAT excitation currents and spacing	Excitation currents	0.5702 0.0000 0.6319 0.0000 0.5006 0.0000 0.4470 0.0000 0.4672 0.3485 0.0000 0.0000 0.4896 0.558 0.4833 0.5255 0.0000 0.9271 0.6862 0.5291	Max SLL = -8.2 dB 3 dB B.W =11.5° Thinning % = 35%
	Spacing	0.5105 0.6399 0.7873 0.8251 0.5771 0.6019 0.3053 0.6996 0.7061 0.3752 0.8002 0.6473 0.5859 0.2970 0.5544 0.7709 0.5952 0.5334 0.6452 0.5356	

From the results it is observed that by maintaining the thinning percentage approximately between 20 to 35% the SLL and beam width of the CAA are reduced considerably.

Table 3 Comparison values for 30 elements CAA

Uniform Array	Excitation currents	1 1	Max SLL = - 7.92dB 3 dB B.W =8.52°
	Spacing	0.5 0.5	
Thinning using BAT spacing	Excitation currents	1 1 1 0 0 0 0 1 0 1 0 0 1 0 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Max SLL = - 9.04dB 3 dB B.W =8.2° Thinning % = 30%
	Spacing	0.7300 0.2608 0.3567 0.5692 0.3003 0.5176 0.8364 0.7176 0.3488 0.1281 0.6764 0.7168 0.4741 0.9095 0.5462 0.5432 0.9305 0.3961 0.3638 0.8881 0.8742 0.8510 0.6422 0.9987 0.3390 0.7882 0.3899 0.1322 0.3586 1.0045	
Thinning using BAT excitation currents and spacing	Excitation currents	0.5461 0.5171 0.4185 0.4679 0.0000 0.0000 0.0000 0.4639 0.0000 0.5659 0.0000 0.2574 0.0000 0.0000 0.8189 0.0000 0.3043 0.4324 0.7353 0.9495 0.5017 0.6612 0.7322 0.8270 0.8916 0.5132 0.7604 0.8108 0.5340 0.6712	Max SLL = -8.2 dB 3 dB B.W =8.5° Thinning% = 26.7%
	Spacing	0.7300 0.2608 0.3567 0.5692 0.3003 0.5176 0.8364 0.7176 0.3488 0.1281 0.6764 0.7168 0.4741 0.9095 0.5462 0.5432 0.9305 0.3961 0.3638 0.8881 0.8742 0.8510 0.6422 0.9987 0.3390 0.7882 0.3899 0.1322 0.3586 1.0045	

V. Conclusions

From the above results it is evident that application of BAT algorithm for thinning of array is promising for reducing SLL and beam width. The BAT algorithm is found to be simple, precise and the patterns are converged after approximately 40 iterations. It is also observed from the results that the thinning of array was enhanced with BAT algorithm, which has wide applicability in wireless communications.

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