Comparative Performance of RGA and BAT Algorithms in Location Only Null Synthesis of Circular Antenna Arrays

Sudipta Das [1], Durbadal Mandal [1], Rajib Kar [1], and Sakti Prasad Ghoshal [2]
[1]National Institute of Technology Durgapur/Department of ECE, Durgapur, India
[2]National Institute of Technology Durgapur/Department of EE, Durgapur, India
Email: {sudipta.sit59, durbadal.bittu, rajibkarece, spghoshalnitdgp}@gmail.com

***Abstract*—Circular antenna array pattern optimization for null performance improvement is carried out in this paper. Array geometries optimized for element locations in one elevation plane are found to provide good null performance uniformly for all elevation planes if the inter-element linear separations are kept within [0.5, 1] λ_0. Optimizations for element locations have been carried out using Real Coded GA and BAT Algorithms independently.**

***Index Terms*—circular antenna arrays, location only synthesis, null synthesis, RGA, BAT**

I. Introduction

A circular antenna array has a circular shape containing antenna elements on its boundary. Circular antenna arrays are useful because of their nature to provide angular symmetry in the elevation plane of the radiation pattern [1]. These arrays are the simplest planar antenna arrays. Planar arrays have better directional pattern than linear arrays. Applications of circular arrays span radio direction finding, air and space navigation, underground propagation, radar, sonar and even smart antennas [2]. Performance of antenna arrays depends on several parameters, such as, shape, location profile of elements, current distribution over the array aperture, and the antenna elements to be used on that structure.

Since late 19th century, interest to use antenna arrays instead of single element grew up in scientists and researchers [3]. For simplicity and effectiveness of the circular geometry, it is still one of the most popular structures. It has been found many a times, that radiation pattern optimization of circular antenna array has vanished deep nulls [4]. This paper approaches to a location optimization of circular array that would provide low sidelobe with deep nulls in the far field radiation pattern. To elaborate the results, three designs of single ring circular antenna arrays with central element feeding are considered.

Evolutionary optimization techniques have been employed since several drawbacks of classical optimization techniques [5] made the task cumbersome for some problems. Some evolutionary algorithms use principle of natural evolution of creatures to reach an optimal solution. Genetic Algorithm [5], BAT [6]-[8] are a few types among many other different evolutionary algorithms.

The rest of the paper is arranged as follows: In Section II, overall designs and design equations are discussed; brief descriptions of evolutionary algorithms (RGA and then BAT) are given in Section III; simulation results along with the resulting graphs are given in Section IV; a discussion on these results is given in Section V, and the paper concludes in Section VI.

II. Design Equations

A. Array Geometry

Generalized far field radiation pattern at any point of a uniformly excited concentric-circular antenna array with central element feeding placed on x-y plane can be mathematically expressed as

$$AF(\theta,\varphi) = 1 + \sum_{n=1}^{N} e^{jka\sin\theta\cos(\varphi-\varphi_n)} \tag{1}$$

where

N = the number of elements on the structure;

$k = 2\pi/\lambda_0$, λ_0 being the wavelength of operation;

a is the radius of the array aperture;

θ is the azimuth angle;

φ is the elevation angle; and

φ_n is the angular location of n^{th} element from *x*-axis on *x-y* plane.

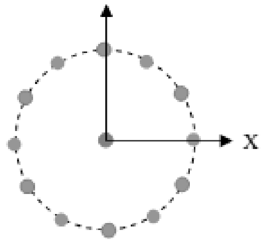

Figure 1. Schematic geometry of central element fed circular antenna arrays placed on *x-y* plane.

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Fig. 1 shows the possible cases that can be found for different circular arrays:

For initial circular structure, radius of the array is taken to accommodate elements with $0.75\lambda_0$ inter-element separation. The radius a of an array with N boundary elements with $0.75\lambda_0$ inter-element separation is approximated as $a = \frac{3N}{8\pi}\lambda_0$ [9].

Initial geometries have $0.75\lambda_0$ gap between adjacent boundary elements. Optimal location search for all the array geometries are done in two ways. First, a non-uniform unconstrained search was carried out for each set. In this search inter-element distance may take any positive value. The next kind of search adjusts the element locations on each ring with a constraint that the inter-element separation must not violate $[0.5,1]\lambda_0$. Antenna elements in the array are relocated keeping the same electrical size of the array so as to maintain its directivity [10]**.** This is shown in the following unique procedure contributed by the authors:

B. Objective Function Formulation

The problem to improve the null performance while suppressing sidelobes, based on the favorable placements of elements has been designed as a minimization problem. Null retaining is required with least possible main beam spreading. The objective function or the cost function CF is designed as:

$$CF = \left\{ \frac{SLL_U}{SLL_C} + \left| BWFN_U - BWFN_C \right| \right\} \sum_i \left| AF\left(\theta_i, \varphi_n\right) \right|^2 \qquad (2)$$

Here, *SLL* and *BWFN* refer to the relative peak sidelobe level in dB and First Null Beamwidth in degrees, respectively. The suffixes *U* and *C* refer to uniform and current iteration geometries. The third term is inspired by [11], where θ_i refers to the desired angular locations to impose nulls. In this paper, θ_i refers to all locations outside the main beam. Thus, it imposes nulls not only on the sidelobe region, but on the previous null locations also, and in this way it helps suppression of sidelobes.

The first term in (2) is the ratio of sidelobes, and smaller value of this term is attained for better sidelobe suppression. Sometimes, sidelobe performance improvement is achieved with excessive main beam stretching. The second term in (2) is used to restrict the stretching of the main beam. For small beam broadening, this term becomes small. The third term uses the absolute array factor on the desired locations of nulls. For deep null in the desired direction, this term reduces very significantly. For example, at any desired location, if initial and current null depths are -10 dB and -20 dB, this term is reduced from 0.01 to 0.0001. Using this term in (2) as a product promotes result with deep nulls. In this way, the overall design goal is shaped as a minimization problem.

III. Evolutionary Techniques Employed

Evolutionary Optimization Algorithms use principle of evolution of living particles which update themselves to fit continuously changing environment to make a good approximation of the probable numerical solution of any problem in hand. Being a population based search evolutionary algorithms have several advantages over other classical algorithms [5]. Besides, in contrast with the classical numerical procedures, these algorithms do not require any previous guess about the probable solution. Hence, roots of a totally unknown function can be well searched with these algorithms. Since their first development, searching performance improvement of such algorithms has drawn researchers' attentions. Continuously new varieties of such approaches have been proposed [5]-[8].

Researches regarding evolutionary algorithms can be subdivided into four groups: adjusting internal parameters; improving the basic strategic tools (e.g. crossover, selection and mutation); updating of solutions with various neighborhood strategies; and using multiple swarms.

These algorithms are popular for optimizing various electromagnetic structures, like antennas [12] and [13].

This paper compares the performance of a widely accepted algorithm like classical RGA [5], with another popular algorithm, namely BAT [6] and [7]. Due to page limitation, algorithms are not described here. RGA and BAT can be read from [5] and [6], respectively.

IV. Results of Simulation

A. Platform Specification

Since all the programs are more or less platform dependent, the platform specification is necessary for conducting a test and commenting on the results. The programming was written in MATLAB language using MATLAB 7.5 on core (TM) 2 duo processor, 2.99 GHz with 1 GB RAM.

B. Parameters for RGA and BAT

The parameters for both the algorithms are set after many trial runs. It is found that the satisfactory results are obtained for both the algorithms with an initial population of 120 chromosomes / vectors and 400 maximum iteration cycles. In RGA, for selection operation, the method of natural selection is chosen with a selection probability of 0.3. Rowlette wheel selection is incorporated for selecting parent chromosomes for the mating pool. Crossover is done for randomly selected dual points over the parent chromosomes in the mating pool. Crossover ratio is 0.8. Mutation probability is 0.04. For BAT, the following parameters α and γ [6] are set as 0.1 and 0.5, respectively.

C. Results of Simulation

Simulation results are tabulated and corresponding curves are provided in three different subsections, each considering a different kind of antenna geometry. For the first subsection, all inter-element separations are assumed to be $0.75\lambda_0$ (uniform, un-optimized case). For the optimized array designs with central element feedings, the first ring is assumed to have inter-element separation restricted within [0.5, 1] λ_0 (constrained case, third subsection V. B, Table III), and not restricted within [0.5, 1] λ_0 (unconstrained case, second subsection V. A, Table II).

TABLE I. PARAMETERS FOR SINGLE-RING UNIFORM CIRCULAR ANTENNA ARRAYS WITH CENTRAL ELEMENT FEEDING (UNIFORM INTER-ELEMENT SEPARATIONS, UN-OPTIMIZED CASE)

Set No.	N	a/λ	SLL_U (dB)	$BWFN_U$ (°)
A	16	1.91	-9.34	24.32
B	24	2.86	-9.20	15.88
C	30	3.59	-8.93	12.60

TABLE II. PARAMETERS FOR SINGLE-RING UNIFORMLY EXCITED CIRCULAR ANTENNA ARRAYS WITH CENTRAL ELEMENT FEEDING, OPTIMIZED FOR NON-UNIFORM UNCONSTRAINED INTER-ELEMENT SEPARATIONS

Set No.	Optimal φ_n (°)		Resultant *SLL* (dB)		Resultant *BWFN* (°)	
	RGA	BAT	RGA	BAT	RGA	BAT
A	26.53 56.53 70.03 89.47 102.97 116.47 129.97 159.97 189.97 219.97 233.47 246.97 260.47 276.15 289.65 319.65	13.50 43.50 57.00 70.50 84.00 97.50 111.00 124.50 143.65 173.65 203.65 233.65 248.69 262.19 280.48 293.98	-16.96	-19.62	33.25	33.75
B	14.75 34.75 49.57 67.50 76.50 85.50 97.00 106.00 115.00 124.00 133.00 153.00 162.00 180.71 200.71 220.71 237.57 247.76 256.76 265.76 276.69 285.69 294.69 306.90	16.48 36.42 51.87 66.03 75.04 84.05 93.05 102.05 111.05 120.05 129.15 145.92 165.92 185.88 205.83 225.83 236.15 245.16 254.17 263.17 274.20 283.20 292.23 308.80	-17.29	-18.55	21.25	22.25
C	14.68 21.88 37.88 45.08 61.08 69.74 76.94 84.14 91.34 98.54 105.74 112.94 120.14 135.60 151.60 167.60 174.80 190.80 206.80 214.00 225.08 232.28 239.48 246.68 253.88 261.08 268.28 284.28 291.48 304.87	10.64 17.84 33.84 47.77 54.97 62.17 70.24 77.44 84.64 98.46 105.66 114.55 121.75 128.95 136.15 152.15 168.15 184.15 200.15 207.35 221.55 234.85 242.05 249.25 256.45 263.65 270.85 278.05 285.25 292.45	-15.50	-16.26	16.25	16.75

TABLE III. PARAMETERS FOR SINGLE-RING UNIFORMLY EXCITED CIRCULAR ANTENNA ARRAYS WITH CENTRAL ELEMENT FEEDING, OPTIMIZED FOR NON-UNIFORM CONSTRAINED INTER-ELEMENT SEPARATIONS

Set No.	Optimal φ_n (°)		Resultant *SLL* (dB)		Resultant *BWFN* (°)	
	RGA	BAT	RGA	BAT	RGA	BAT
A	30.00 53.83 68.89 84.12 104.11 119.20 134.72 164.72 194.71 224.71 246.10 261.26 281.71 303.48 330.00 360.00	30.00 60.00 75.52 91.05 106.57 122.09 140.62 170.62 200.62 230.62 246.14 261.66 284.48 300.00 330.00 360.00	-13.49	-14.96	27.75	28.75
B	20.00 40.00 58.20 71.26 81.49 98.71 108.94 119.17 139.17 159.17 169.39 189.39 209.39 229.39 239.62 251.79 262.02 272.25 282.48 292.70 302.93 320.00 340.00 360.00	20.00 40.00 54.79 64.89 74.90 84.90 94.97 105.00 115.03 129.61 149.61 169.61 189.61 209.61 229.61 242.29 252.30 262.31 278.39 288.40 300.10 320.01 340.00 360.00	-13.66	-14.58	18.25	18.75
C	16.00 31.56 47.56 57.83 70.52 78.62 87.76 100.16 108.26 117.88 125.98 141.98 157.10 173.10 189.10 202.84 218.84 234.84 242.94 252.64 261.55 269.64 277.74 286.23 294.44 302.54 314.63 328.26 344.26 360.00	16.00 32.00 48.00 61.19 69.19 17.19 85.19 93.19 101.19 109.19 117.19 125.19 141.19 157.19 173.19 189.19 205.19 221.19 233.69 249.69 257.69 265.69 278.03 287.95 295.95 304.00 312.00 328.00 344.00 360.00	-13.42	-14.01	14.45	14.75

V. DISCUSSIONS ON THE SIMULATION RESULTS

Simulation results for SLL, BWFN and Null Depth with different number of elements of various single-ring circular antenna array sets as follows:

A. Case 1

Results of unconstrained inter-element arc distances, as tabulated in Table II and initial data given in Table I are compared. For 16-element array set A with optimal locations of elements found with RGA and BAT, *SLLs* are suppressed to -16.96 dB and -19.62 dB, respectively, against -9.34 dB at the cost of *BWFN* increment from 24.32^o to 33.25^o and 33.75^o, respectively, in the $\Phi=0^o$ plane, as compared to the corresponding uniform, un-optimized case.

For 24-element array set B with optimal locations of elements found with RGA and BAT, *SLLs* are suppressed to -17.29 dB and -18.55 dB, respectively, against -9.20 dB at a cost of *BWFN* increment from 15.88^o to 21.25^o and 22.25^o, respectively, in the $\Phi=0^o$ plane, as compared to the corresponding uniform, un-optimized case.

For 30-element array set C with optimal locations of elements found with RGA and BAT, *SLLs* are suppressed to -15.50 dB and -16.27 dB, respectively, against -8.93 dB at a cost of *BWFN* increment from 12.60^o to 16.25^o

and 16.75°, respectively, in the Φ=0° plane, as compared to the corresponding uniform, un-optimized case.

B. Case 2

Results of constrained inter-element arc distances, as tabulated in Table III and initial data given in Table I are compared. For 16-element array set A, optimal locations of elements found with RGA and BAT suppress *SLLs* to -13.49 dB and -14.96 dB, respectively, against -9.34 dB at a cost of *BWFN* increment from 24.32° to 27.75° and 28.75°, respectively, in the same plane Φ=0° , as compared to the corresponding uniform, un-optimized case.

For 24-element array set B with optimal locations of elements found with RGA and BAT, *SLLs* are suppressed to -13.66 dB and -14.58 dB, respectively, against -9.20 dB at a cost of *BWFN* increment from 15.88° to 18.25° and 18.75°, respectively, in the Φ=0° plane, as compared to the corresponding uniform, un-optimized case.

For 30-element array set C, optimal locations of elements found with RGA and BAT suppress *SLLs* to -13.42 dB and -14.01 dB, respectively, against -8.93 dB at a cost of *BWFN* increment from 12.60° to 14.45° and 14.75°, respectively, in the same Φ=0° plane, as compared to the corresponding uniform, un-optimized case.

Radiation patterns of 30-element arrays with unconstrained and corresponding optimal element separations as found with RGA and BAT along with that of 30-element uniform arrays are plotted in Fig. 2. By inspection of all radiation patterns, it is evident that, while searching for optimal locations of elements, both the algorithms provide low sidelobes and unaltered null positions, but at the cost of increased widths of main beam, and partially filled null depths. BAT outperforms RGA in terms of *SLL* and null depth in every case.

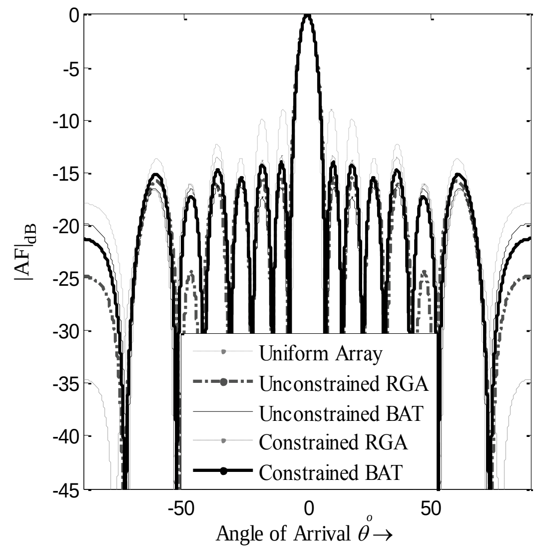

Figure 2. Radiation patterns for the 30-element circular antenna arrays optimized for angular locations.

Convergence Profiles of *CF* for RGA and BAT for the 24-element antenna arrays are plotted in Fig. 3. Comparison of respective cases reveals that with constrained arc distance case, both the algorithms are able to yield lower *CF* as compared to corresponding unconstrained arc distance case.

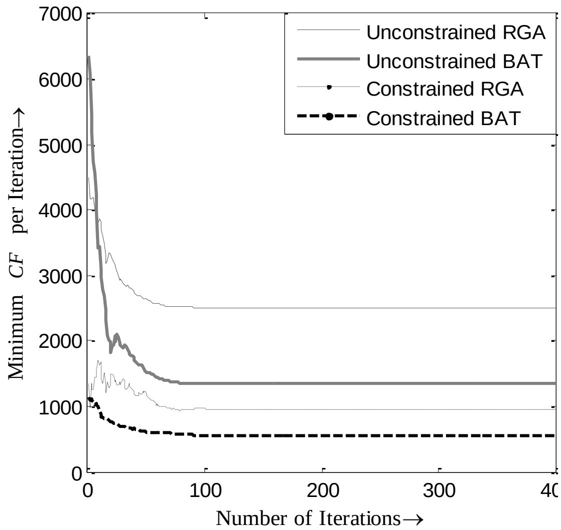

Figure 3. Convergence curves traced by RGA and BAT in the way of searching optimal unconstrained and constrained inter-element separations for 24-element antenna arrays.

VI. CONCLUSIONS

This work shows that, based on the unique proposed method of nurturing the element positions on a fixed ring size while keeping the arbitrarily specified constraints on the element separations, both RGA and BAT are successful for adjusting the elements. The overall sidelobe performances of single ring antenna arrays are quiet good in the plane for which the patterns are optimized. For all the cases, sidelobe reduction is possible with a little increment in *BWFN*. The nulls do not shift significantly for all the cases, though they are filled up to some extent. Better sidelobe performance with lower *BWFN* and deeper nulls is achieved with constrained inter-element distance approach for optimization as compared to that of unconstrained inter-element distance approach for optimization.

For all the cases under study, BAT performs better than RGA in terms of *SLL* and Null depth, while RGA is capable of producing lower *BWFN*.

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Sudipta Das was born in Malda town of West Bengal, India. on 28th January, 1986. He He received B. Tech degree in Electronics and Communication Engineering from the West Bengal University of Technology in 2007 and received his M.Tech degree in Telecommunication engineering in 2010 from National Institute of Technology, Durgapur, India. He is currently working towards his Ph. D. programme in the department of Electronics and Communication Engineering from National Institute of Technology, Durgapur. He has more than 16 papers published in the international jouournals and conferences. He became member of IEEE in the year 2010. His research interests are in the areas of Electromagnetics, Microwave Circuits, and ,Designing Antennas and Antenna Arrays and Evolutionary Algorithms.

Durbadal Mandal passed B. E. degree in Electronics and Communication Engineering, from Regional Engineering College, Durgapur, West Bengal, India in the year 1996. He received the M. Tech and Ph. D. degrees from National Institute of Technology, Durgapur, West Bengal, India in the year 2008 and 2011 respectively. Presently, he is attached with National Institute of Technology, Durgapur, West Bengal, India, as Assistant Professor in the Department of Electronics and Communication Engineering. His research interest includes Array Antenna design; filter Optimization via Evolutionary Computing Techniques. He has published more than 180 research papers in International Journals and Conferences.

Rajib Kar passed B. E. degree in Electronics and Communication Engineering, from Regional Engineering College, Durgapur, West Bengal, India in the year 2001. He received the M. Tech and Ph. D. degrees from National Institute of Technology, Durgapur, West Bengal, India in the year 2008 and 2011 respectively. Presently, he is attached with National Institute of Technology, Durgapur, West Bengal, India, as Assistant Professor in the Department of Electronics and Communication Engineering. His research interest includes VLSI signal Processing, Filter optimization via Evolutionary Computing Techniques. He has published more than 190 research papers in International Journals and Conferences.

Sakti Prasad Ghoshal passed B. Sc and B. Tech, degrees in 1973 and 1977, respectively, from Calcutta University, West Bengal, India. He received M. Tech degree from I.I.T (Kharagpur) in 1979. He received Ph.D. degree from Jadavpur University, Kolkata, West Bengal, India in 1992. Presently he is acting as Professor of Electrical Engineering Department of N.I.T. Durgapur, West Bengal, India. His research interest areas are: Application of Evolutionary Computing Techniques to Electrical Power systems, Digital Signal Processing, Array antenna optimization and VLSI. He has published more than 225 research papers in International Journals and Conferences

