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Research Article

Generation of Narrow Beams from Concentric Circular Antenna Array for Wireless Communications using BAT Algorithm

[1]U. Ratna Kumari, [2]P. Mallikarjuna Rao and [2]G.S.N. Raju
[1]Department of ECE, GIT, GITAM University, Visakhapatnam-45, India
[2]Department of ECE, AU College of Engineering, Andhra University, Visakhapatnam-03, India

Abstract: The Sidelobe Level is very important radiation parameter which causes interference and noise in the wireless communications. In the present study an attempt is made to reduce the side lobe level of concentric circular antenna array by applying thinning process. In the process of thinning some of the elements are switched off without degrading the performance of the Antenna Array. Hence with the help of Meta heuristic Optimization technique like BAT algorithm thinning is applied to the concentric circular antenna array to reduce the Sidelobe level and Beam width and to retain the performance of the antenna array. The effect of thinning is observed for uniform and non uniform excitations. These results are compared with uniform amplitude distribution of fully populated array.

Keywords: Concentric circular antenna array, narrow beams and BAT algorithm, thinning

INTRODUCTION

Arrangement of similar type of radiating elements on a circle in such a way to get perfect beam pattern in every ϕ cut and to scan the entire azimuthal plane is known as Circular Antenna Array (CAA). If different Circles with different radii share a common centre then it is considered to be Planar Concentric Circular Antenna Array (PCCAA) (Ishimaru, 1962; Stearns and Stewart, 1965; Das, 1966; Balanis, 1997; Raju, 2005; Haupt, 2008a). Geometrically all the elements will lay on the perimeter of different circles. These concentric circular arrays are best suited for direction finding applications, wrap-around shipborne communications, wide bandwidth HF communication systems, null steering systems for mobile communication applications, navigational aids, space craft communications and wide bandwidth microwave direction finders.

The radiation pattern of PCCAA depends upon excitation currents and inter element spacing. Hence the side lobe level and beam width can be controlled with the optimization of any one or combination of the above said parameters. In the present study the excitation currents are optimized using very efficient optimization technique like BAT algorithm. These optimized excitation currents are considered and thinning is applied that is indicated as non uniform thinning in the study. The results are compared with the thinning results that are obtained considering uniform current distribution which is designated as uniform thinning in the present study.

The PCCAA geometry: The normalized power pattern of the PCCAA is calculated as follows:

$$P(\theta,\phi) = 20log_{10}\left[\frac{|E(\theta,\phi)|}{|E(\theta,\phi)|_{max}}\right] \quad (1)$$

where, E (θ, ϕ) is radiation pattern of the PCCAA given by the following equations:

$$E(\theta,\phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn} e^{jkr_m[sin\theta\cos(\phi-\phi_{mn})-sin\theta_0\cos(\phi_0-\phi_{mn})]} \quad (2)$$

$$rm = \frac{Nd_m}{2\pi} \quad (3)$$

ϕ_{mn} is given by:

$$\phi_{mn} = \frac{2n\pi}{N} \quad (4)$$

where,

- I_{mn} = Excitation currents
- r_m = Radius of m[th] ring
- d_m = Inter element spacing
- k = The wave number, k = 2π/λ
- θ = Elevation angle
- M = No of rings
- N = No of elements in each ring
- θ_0, ϕ_0 = Direction at which main beam achieves its maximum

For the designing problems presented here $\theta_0 = 0°$ and $\phi_0 = 0°$ are considered.

Corresponding Author: U. Ratna Kumari, Department of ECE, GIT, GITAM University, Visakhapatnam-45, India

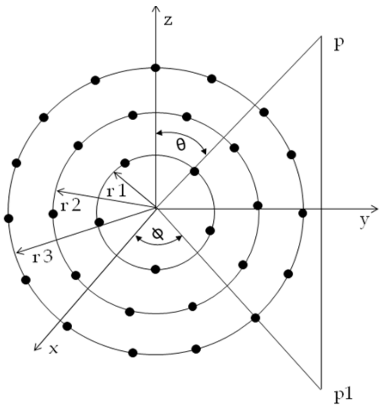

Fig. 1: Fully excited PCCAA

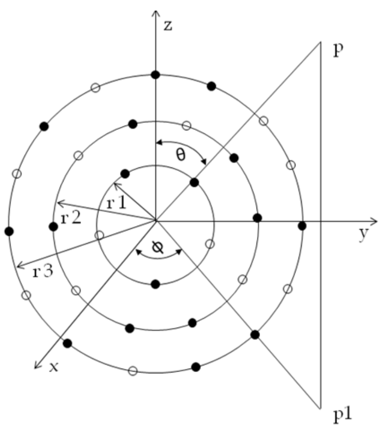

Fig. 2: Thinned PCCAA

ϕ is the azimuth angle between the positive x-axis and the projection of the far field point in the x-y plane as shown in Fig. 1.

Figure 1 shows PCCAA with fully populated antenna elements where as Fig. 2 shows Thinned PCCAA.

OPTIMIZING METHODS

Finding out the optimal solution in a very large solution space by using a powerful tool known as iterative process is known as metaheuristic algorithm. The computational techniques involved in these metaheuristic algorithms are very simple and within a very less time best results are obtained. Depending on the different type of search strategies there are different types of algorithms. Evolutionary algorithms are one of the best classifications among all these types of algorithms.

Depending on the concept of how the living particles are evolved from their parents, survived and with the environmental conditions how these are changed to fit into the living conditions describe the Evolutionary algorithms. There are different types of algorithms like Genetic algorithms, Particle Swarm Optimization, Firefly algorithm and BAT algorithm (Osman, 1995; Yang, 2010).

BAT algorithm: A very efficient metaheuristic evolutionary algorithm developed by Yang (2010) is BAT algorithm. This algorithm mainly depends upon the echolocation behavior of micro bats with varying pulse rates of emission and loudness.

In the process of BAT algorithm BAT positions indicate the optimum solution of the problem. Depending on the best position obtained the quality of the solution is represented. The process echolation is used by the BATs to sense the food or prey and the background barriers. With the initial conditions such as minimum frequency, initial velocity, wave length and initial loudness they fly randomly searching the food or prey. Depending on the closeness of the food or prey they adjust the pulse emission rate and wave length and reach the target.

The process of the BAT algorithm is indicated below. The new best solution, velocities and frequencies used in the algorithm are given by:

$$f_i = f_{min} + (f_{max} - f_{min})\,\beta \quad (5)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \quad (6)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (7)$$

where, f_i is frequency, v_i is velocity of bats and x_i is new best required solution. The BAT parameters that are considered in the present study are:

Frequency minimum = 0.1, Loudness = 0.3

Frequency maximum = 0.9, Pulse rate = 0.8

From the above equations and concept of BAT algorithm the fitness function is formulated and is presented in the Eq. (8). Using this equation the PCCAA is optimized:

$$\text{Fitness} = \text{MIN}\,(\text{MAX}\,(20*\log P(\theta, \phi) / P(\theta, \phi))) \quad (8)$$

where, P (θ, ϕ) is considered to be power of the PCCAA.

The BAT algorithm has an excellent ability to optimize multi dimensional problems. The steps involved in BAT algorithm are:

- The fitness function is formulated according to the problem. As formulating this is half work done in the optimization problems.
- The BAT population is initialized with chosen velocities.
- The pulse frequency and location are defined and initialized. The loudness of the BATS is also initialized.
- The number of iterations are chosen and fixed here.
- With the generated solutions evaluate the fitness function.

- By updating the velocities and locations select the best solutions.
- Accept the new solutions by varying the parameters of like loudness and search space.
- Repeat the steps 4-7 to reach the final goal and stopping criteria.

Array design using thinning: Thinning of the antenna array (Haupt, 2008b; Pathak *et al*., 2009; Khodier and Al-Aqeel, 2009; Basu and Mahanthi, 2012; Mandal *et al*., 2013) is one of the way to produce very narrow beams and reduce the side lobe levels. Without degrading the performance of the PCCAA turning on and off the elements which are responsible for more SLL and broad beam width is known as thinning. The antennas which are very large in dimensions can be fabricated and built easily with this thinning process.

The excitation currents I_{mn} is made 1 to turn on the antenna element and made 0 to turn off the antenna element. In the present study BAT algorithm is applied to find out the optimized current excitation coefficients later thinning is applied on uniformly excited antenna elements and non uniformly excited antenna elements also.

RESULTS AND DISCUSSION

The work was carried out in three stages first power patterns for 3 ring and 4 ring concentric circular

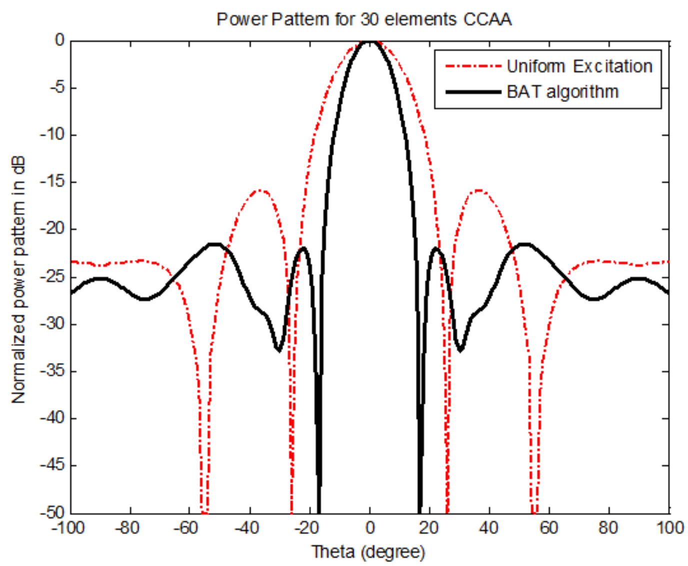

Fig. 3: Power pattern for three rings PCCAA for BAT excitation coefficients

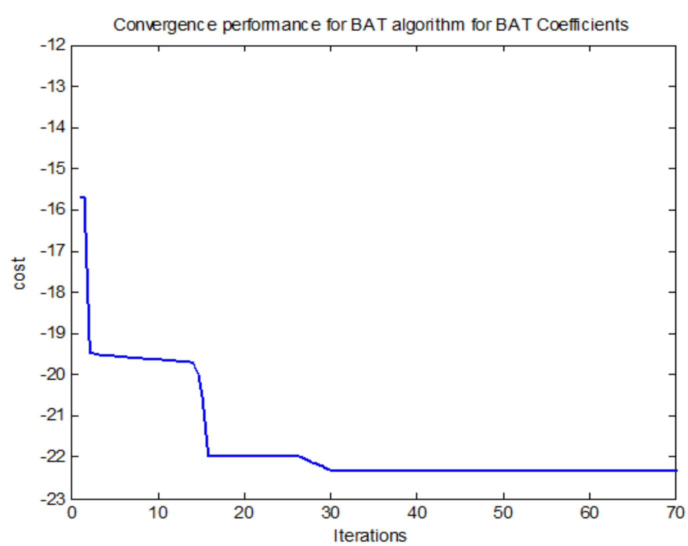

Fig. 4: Convergence characteristics for BAT algorithm for BAT coefficients

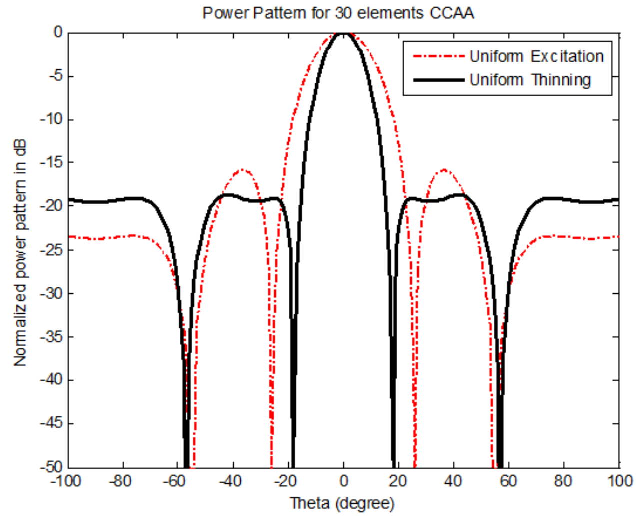

Fig. 5: Power pattern for three rings PCCAA for uniform thinning

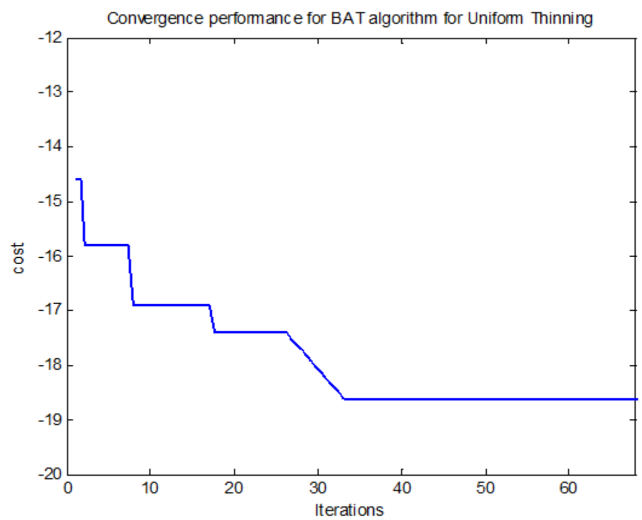

Fig. 6: Convergence characteristics for BAT algorithm for uniform thinning

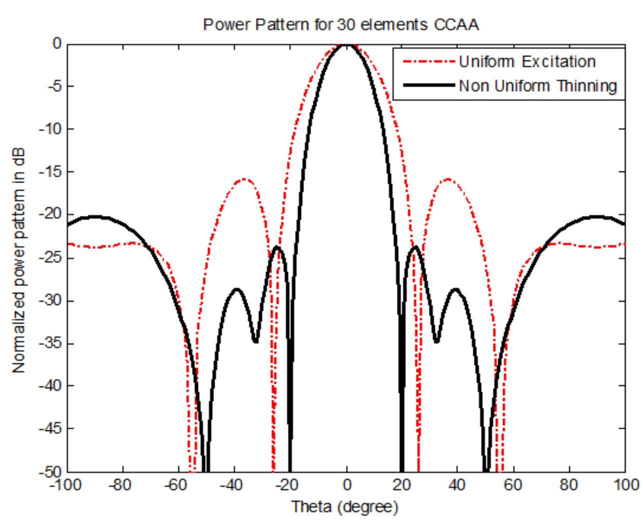

Fig. 7: Power pattern for three rings PCCAA for non uniform thinning

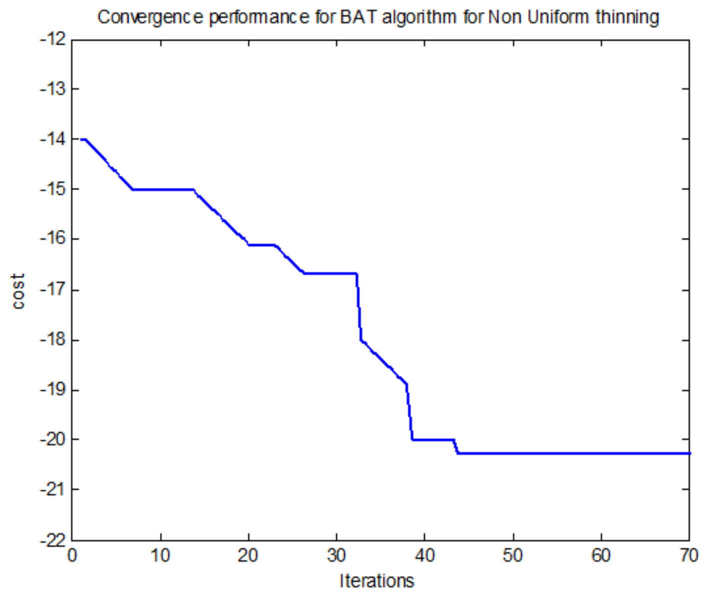

Fig. 8: Convergence characteristics for BAT algorithm for non uniform thinning

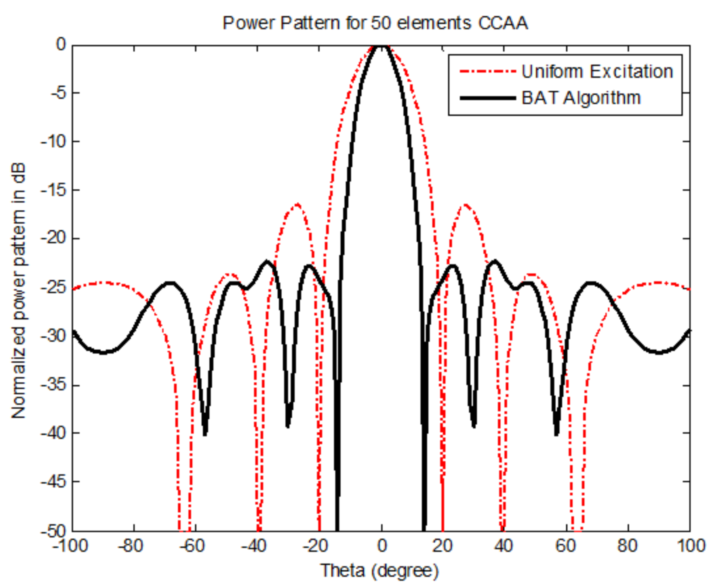

Fig. 9: Power pattern for four rings PCCAA for BAT excitation coefficients

antenna array were numerically evaluated using Eq. (1)-(4) with uniform excitation equal to 1 and uniform spacing equal to 0.5 λ. In the second stage the BAT algorithm is applied to optimize the excitation currents of the elements. Further thinning is applied on the PCCAA using uniform as well as non uniform excitation currents which resulted in very much enhanced results.

Number of elements in the rings are considered to be multiples of 5. For three rings PCCAA the power pattern with BAT coefficients is numerically evaluated and is presented in the Fig. 3. From the figure it is observed that The SLL is -21.5 dB and the beam width is 13.6°. As compared with the uniform excitation and Uniform spacing (SLL = -15.82 dB and Beam Width = 21.4°) the SLL and beam width are reduced to appreciable values. The convergence characteristics of the BAT algorithm are presented in the Fig. 4.

Figure 5 presents the power pattern for thinned three rings PCCAA compared with uniform excited and uniformly spaced PCCAA. Here thinning is applied on uniformly excited coefficients and is referred as uniform thinning. From the results it is observed that with 56.7% uniformly thinned array generates the SLL of -18.62 dB and beam width of 14°. The convergence characteristics of the uniform thinning are presented in the Fig. 6.

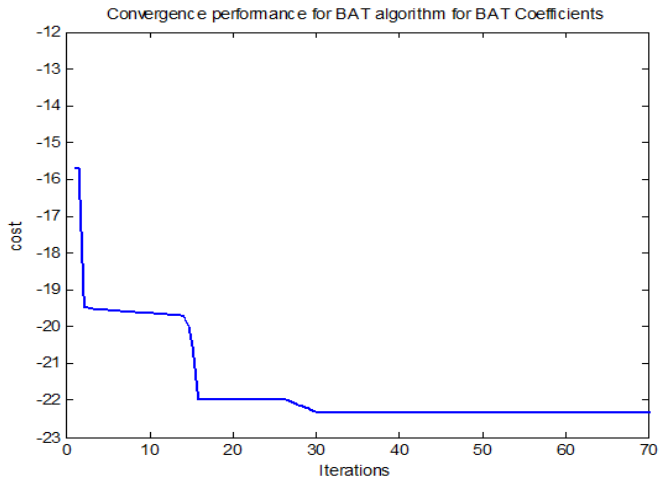

Fig. 10: Convergence characteristics for BAT algorithm for BAT coefficients

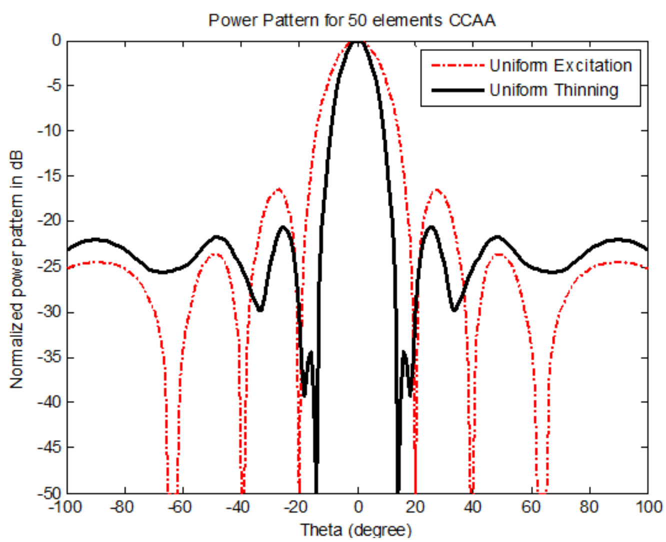

Fig. 11: Power pattern for four rings PCCAA for uniform thinning

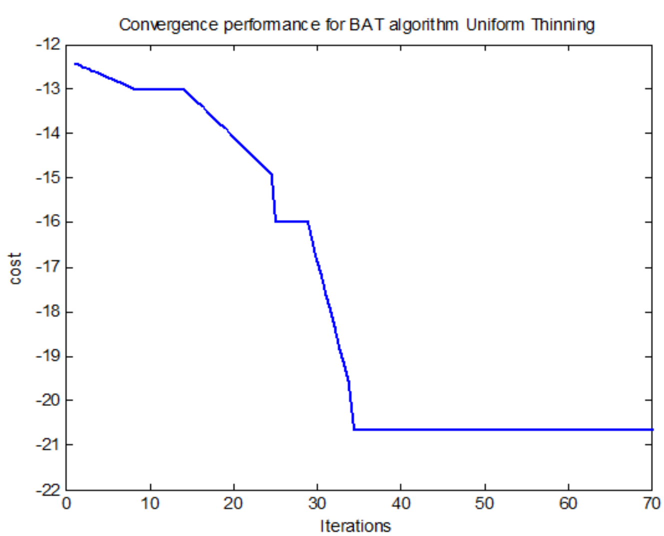

Fig. 12: Convergence characteristics for BAT algorithm for uniform thinning

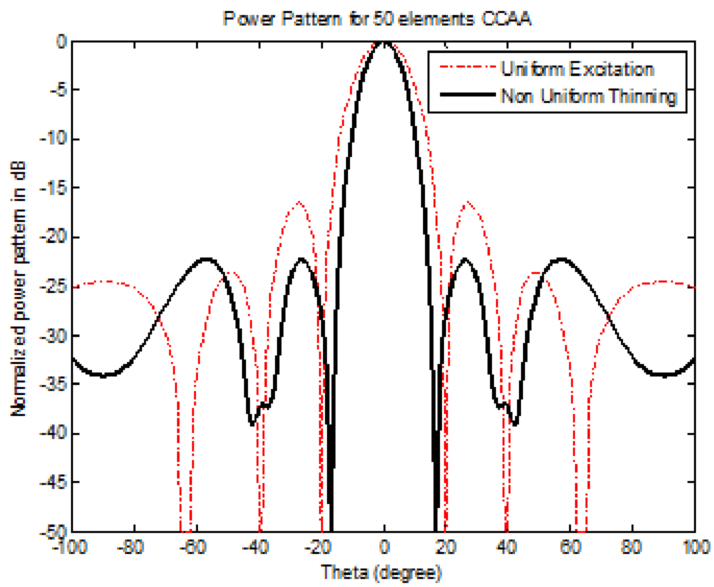

Fig. 13: Power pattern for four rings PCCAA for non uniform thinning

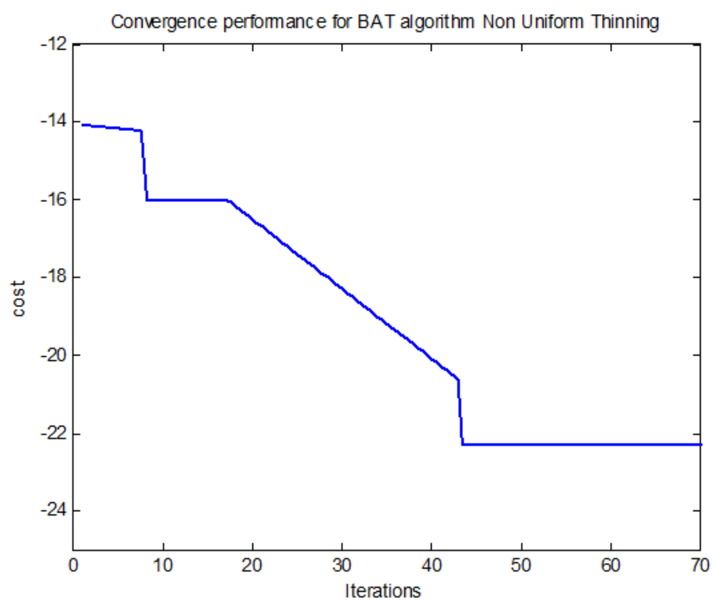

Fig. 14: Convergence characteristics for BAT algorithm for non uniform thinning

Table 1: Excitation coefficients, SLL and beam width and thinning percentage comparison values for three rings PCCAA

Method	Excitation coefficients	Radiation parameters
Uniform excitation	1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1	Max SLL = -15.82 dB 3 dB B.W = 21.4°
BAT coefficients	0.4101 0.5933 0.9257 0.8619 0.3770 0.6040 0.7051 0.8776 0.6125 0.4402 0.4923 0.5185 0.9652 0.9721 0.6432 0.2923 0.4979 0.5904 0.5512 0.7344 0.5363 0.4050 0.3318 0.2045 0.3842 0.5089 0.2014 0.6752 0.0934 0.6994	Max SLL = -21.5 dB 3 dB B.W = 13.6°
Uniform thinning	0, 0, 1, 1, 0, 1, 1, 1, 1, 1, 1, 0, 1, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1	Max SLL = -18.62 dB 3 dB B.W = 14° Thinning % = 56.7%
Non uniform thinning	0.4101 0.5933 0.0000 0.8619 0.3770 0.6040 0.7051 0.8776 0.0000 0.0000 0.4923 0.5185 0.9652 0.9721 0.6432 0.2923 0.0000 0.0000 0.5512 0.7344 0.5363 0.0000 0.3318 0.2045 0.3842 0.0000 0.0000 0.0000 0.0934 0.0000	Max SLL = -20.25 dB 3 dB B.W = 15° Thinning % = 33.3%

Table 2: Excitation coefficients, SLL, beam width and thinning percentage comparison values for four rings PCCAA

Methods	Excitation coefficients	Radiation parameters
Uniform excitation	1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1	Max SLL = -16.51 dB 3 dB B.W = 16.4°
BAT coefficients	0.3096 0.0931 0.7620 0.8013 0.0863 0.3007 0.7167 0.9019 0.0341 0.9591 0.7042 0.1630 0.6381 0.4777 0.5629 0.1161 0.1143 0.3453 0.6880 0.4628 0.9768 0.1782 0.3634 0.1401 0.6557 0.3732 0.0729 0.1735 0.4305 0.6505 0.6617 0.5459 0.2231 0.9274 0.0652 0.0183 0.5179 0.3976 0.8965 0.8899 0.0985 0.1724 0.2528 0.7185 0.1937 0.6134 0.6990 0.4309 0.9525 0.5905	Max SLL = -22.3 dB 3 dB B.W = 10.6°
Uniform thinning	1, 1, 1, 1, 1, 1, 0, 0, 0, 1, 1, 1, 1, 1, 0, 0, 0, 1, 1, 1, 1, 0, 0, 0, 1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 0, 0, 0, 1, 0, 0, 1	Max SLL = -20.6 dB 3 dB B.W = 10.4° Thinning % = 38%
Non uniform thinning	0.3096 0.0000 0.7620 0.8013 0.0863 0.0000 0.0000 0.9019 0.0341 0.9591 0.0000 0.0000 0.6381 0.4777 0.5629 0.1161 0.0000 0.3453 0.6880 0.4628 0.9768 0.0000 0.3634 0.0000 0.6557 0.0000 0.0000 0.0000 0.0000 0.0000 0.6617 0.5459 0.2231 0.0000 0.0000 0.0000 0.5179 0.0000 0.8965 0.0000 0.0000 0.1724 0.2528 0.7185 0.1937 0.6134 0.6990 0.0000 0.9525 0.0000	Max SLL = -22.3 dB 3 dB B.W = 11.8° Thinning % = 42%

Figure 7 presents the power pattern for thinned three rings PCCAA compared with uniform excited and uniformly spaced PCCAA. Here thinning is applied on non uniformly excited coefficients (BAT coefficients) and is referred as non uniform thinning here. From the results it is observed that with 33.3% non uniformly thinned array generates the SLL of -20.25 dB and beam width of 15°. The convergence characteristics of the uniform thinning are presented in the Fig. 8.

The power patterns and convergence characteristics for four rings PCCAA are presented in the Fig. 9 to 14. With approximately 40% of thinning the SLL and beam width values achieved are very less. Here the narrow beam widths are achieved with less number of elements and with more thinning percentage. The convergence characteristics show that after 60 iterations the plots are converged effectively (Table 1 and 2).

CONCLUSION

This study describes thinning of concentric circular antenna arrays using BAT algorithm. From the above results it is observed that the BAT algorithm is very simple and efficient in the thinning process of the array. Uniform as well as non uniform thinning produces best results of PCCAA. The SLL and beam width are reduced very effectively. The power patterns are easily converged in a very less amount of time and in very less number of iterations. The narrow beams produced by PCCAA can be used for wireless communications and point to point communications. As the produced patterns scan the entire azimuthal angle in every ϕ cut these PCCAAs can be used in direction finding applications also.

REFERENCES

Balanis, C.A., 1997. Antenna Theory: Analysis and Design. 2nd Edn., John Wiley and Sons, New York.

Basu, B. and G.K. Mahanthi, 2012. Thinning of concentric two-ring circular array antenna using fire fly algorithm. Sci. Iran., 19(6): 1802-1809.

Das, R., 1966. Concentric ring array. IEEE T. Antenn. Propag., 14(3): 398-400.

Haupt, R.L., 2008a. Optimized element Spacing for low sidelobe concentric ring arrays. IEEE T. Antenn. Propag., 56(1): 266-268.

Haupt, R.L., 2008b. Thinned concentric ring arrays. Proceeding of the IEEE Antennas and Propagation Society International Symposium. San Diego, CA, pp: 1-4.

Ishimaru, A., 1962. Theory of unequally-spaced arrays. IRE T. Antenn. Wave Propag., 10(6): 691-702.

Khodier, M.M. and M. Al-Aqeel, 2009. Linear and circular array optimization: A study using particle swarm intelligence. Prog. Electromagn. Res. B, 15: 347-373.

Mandal, D., S.P. Ghoshal and A.K. Bhattacharjee, 2013. Optimized radii and excitations with concentric circular antenna array for maximum sidelobe level reduction using wavelet mutation based particle swarm optimization techniques. Telecommun. Syst., 52(4): 2015-2025.

Osman, I.H., 1955. An Introduction to Metaheuristics. In: Lawrence, M. and C. Wilson (Eds.): Operational Research Tutorial Papers. Operational Research Society Press, Birmingham.

Pathak, N., P. Nanda and G.K. Mahanti, 2009. Synthesis of thinned multiple concentric circular ring array antennas using particle swarm optimization. J. Infrared Millim. Te., 30(7): 709-716.

Raju, G.S.N., 2005. Antennas and Wave Propagation. Pearson Education, New Delhi.

Stearns, C. and A. Stewart, 1965. An investigation of concentric ring antennas with low sidelobes. IEEE T. Antenn. Propag., 13(6): 856-863.

Yang, X.S., 2010. A New Metaheuristic Bat-Inspired Algorithm. In: Gonzalez, J.R. *et al*. (Eds.), NICSO, 2010. SCI 284, Springer-Verlag, Berlin, Heidelberg, pp: 65-74.