

An Improved Thinning Method for Conformal Circular Array Based on Ant Colony Algorithm

Yuguan HOU, Jian KANG, Yiyang SHEN

School of Electronics and Information Engineering, Harbin Institute of Technology,
92 West Dazhi Street, Nan Gang District, Harbin, China
Tel.: +86045186418061, fax: +86045186418061
E-mail: yuguanhou@hit.edu.cn

Received: 22 November 2013 /Accepted: 22 December 2013 /Published: 30 December 2013

Abstract: With the development of radar system, the use of conformal antennas for the radar receiver antennas array has been increasing rapidly. Because of the all-azimuth scan capability, the circular array is widely used in the radar system. However, when the radar location place is limited, the classical circular antenna array would not be placed successfully. In this paper, an improved antenna array which is to put some small circular arrays into a big circular array is proposed. And an improved thinning and optimization approach based on the ant colony algorithm is applied to obtain the optimal number of the antenna array elements with the restriction of the location. Moreover, the optimal performance of the difference of the peak sidelobe level (PSLL) and the main lobe width is derived. The computer simulation results show that the peak sidelobe level of the special antenna array could be reduced with the less antenna array elements at the same time. As a result, the system performance of the spatial resolution and estimation is improved. Simultaneously, the adaptivity for the different kinds of location place of this antenna array would be enhanced. *Copyright © 2013 IFSA.*

Keywords: Conformal antenna, Non-concentric array, Ant colony algorithm, Thinning.

1. Introduction

The circular array antennas have gained immense popularity in radar system nowadays. It has proved to be a better alternative over other types of antenna array configuration due to its all-azimuth scan capability, and a beam pattern which can be kept invariant [1, 2]. In [1], a simulation analysis of UCA (uniform circular array) system performance and a variety of errors affect was conducted. In [2], the authors solve the shortcomings of the circular array effectively to get lower side lobe level by introducing directed element appropriately and selecting the radiation equation to each array element. In [3], the concentric arrays are analyzed by using radial guide field matching. In [4], a kind of adaptive circular

array antenna is investigated. In [5], the authors utilize two-dimensional circular array for DOA estimation. Lots of research has gone into optimizing antenna structures so that the radiation pattern has low sidelobe level. This very fact has driven researchers to optimize the CCAA (concentric circular array antenna) design [6]. However, when the circular array are located in a narrow region, some elements may not be placed normally, which needs a reasonable distribution of every element. It is similar to conformal antenna's application. Conformal antenna is able to match the requirement of its location and don't bring in additional burden. In [7] and [8], the authors mainly analysis a method of conformal antenna's mapping and design. A kind of miniature array-capsule antenna is developed in [9].

In this paper, a conformal-like antenna: non-concentric circular array is proposed and the ant colony algorithm is applied to optimize and thin this array [10-12]. Detailed analysis process is shown in the following.

2. Non-concentric Circular Array Pattern Function

Assuming both the signal's elevation angle and the observed elevation angle are 90 degrees, uniform non-concentric circular array model is shown in Fig. 1.

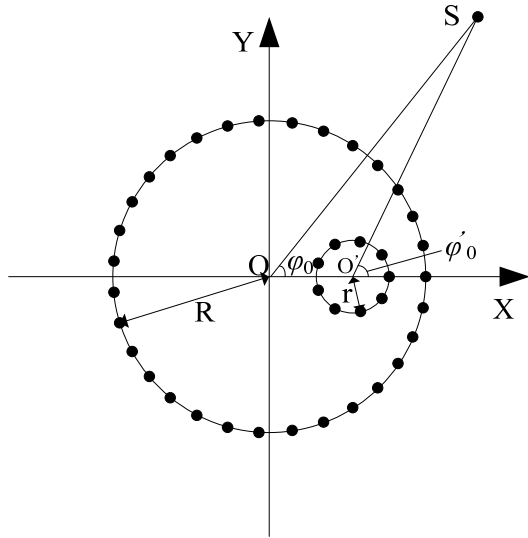


Fig. 1. Non-concentric circular antenna array.

φ_0 denotes the arrival angle of the signal to point O and R denotes the radius of the big uniform circular array antenna. φ'_0 denotes the arrival angle of the signal to point O' and r denotes the radius of the small uniform circular array antenna. The heart of the big circular array is $(0, 0)$ and the heart of the small circular array is $(L, 0)$. The element number of the big circular array and the small circular array are N and n . The first element of either array is located on the positive X axis. If SO and SO' is far longer than R or r , it might be approximated that $\varphi_0 = \varphi'_0$. The radiation pattern of the big circular array is written as:

$$F_1(\varphi, \varphi_0) = \sum_{i=1}^N A_i e^{jkR [\cos(\varphi_0 - \varphi_i) - \cos(\varphi - \varphi_i)]}, \quad (1)$$

where φ denotes the observed azimuth angle, and $k = 2\pi/\lambda$, λ being the signal wavelength. And φ_i is the azimuth angle of the i^{th} element. A_i is the i^{th} element amplitude weight. The radiation pattern of the small circular array is written as:

$$F_2(\varphi, \varphi_0) = \sum_{m=1}^n A_m e^{jkr [\cos(\varphi_0 - \varphi_m) - \cos(\varphi - \varphi_m)]} \quad (2)$$

The phase difference between the two arrays is $2\pi L \cos \varphi_0 / \lambda$. Assume the amplitude weight of the big circle array and the small circle array are both 1. The whole system's radiation pattern may be written as:

$$F(\varphi, \varphi_0) = \sum_{i=1}^N e^{jkR [\cos(\varphi_0 - \varphi_i) - \cos(\varphi - \varphi_i)]} + \sum_{m=1}^n e^{jk[r \cos(\varphi_0 - \varphi_m) + L \cos \varphi_0 - r \cos(\varphi - \varphi_m) - L \cos \varphi]} \quad (3)$$

When the non-concentric circular arrays are full with the difference of element number, the main lobe width and peak sidelobe level are different.

3. Thinning and Optimization Approach Based on the Ant Colony Algorithm

The ant colony algorithm was put forward by Dorigo in the 1990s. He raised the bionic algorithm by imitating ants foraging. The algorithm has two advantages: parallelism and robustness. It means the ant colony algorithm is high computational efficient and effective of global information. Ant leaves some special material (pheromone) on the path in the process of feeding. By feeling the pheromone, other ants choose the direction which is rich in pheromone. They continue to release pheromone, thus more and more ants are attracted to take the path. The performance of a large number of ants is a positive feedback phenomenon, which will lead to an increasing number of ants on the best path.

Ant colony algorithm has been widely researched and developed, especially to reduce the peak sidelobe level for the purpose of array optimization, such as the element number optimization, the amplitude weight optimization and the antenna structure design. Because the variation of the main lobe width is smoother with the different array parameters, we focus on optimizing the peak sidelobe level. And the thinning and optimization approach is shown in the following.

Step 1: The rightmost element of either circular array is set as the start point. Along the counterclockwise, other elements are encoded. When an element in some position is removed by optimization, it is encoded as '0'. Otherwise it is encoded as '1'. Therefore every array antenna is encoded as a binary code.

Step 2: Create a population. A population of 500 binary numbers is created in this paper.

Step 3: Calculate each individual's peak sidelobe level and the state transition probability. The

searching type of every individual in step 4 is judged by these results.

Step 4: Begin local search and global search for the population. If an array's state transition probability is smaller than 0.2, it will accept the local search. Otherwise, the array will conduct a global search.

Step 5: Whether each individual needs to move is judged and the population is updated. If some array's peak sidelobe level becomes lower after searching, the previous individual is replaced with the post one. Otherwise, it will remain unchanged. Each array is checked in this way.

Repeat the above process until the optimal result is generated. And the corresponding flow chart of the thinning and optimization approach is shown in Fig. 2.

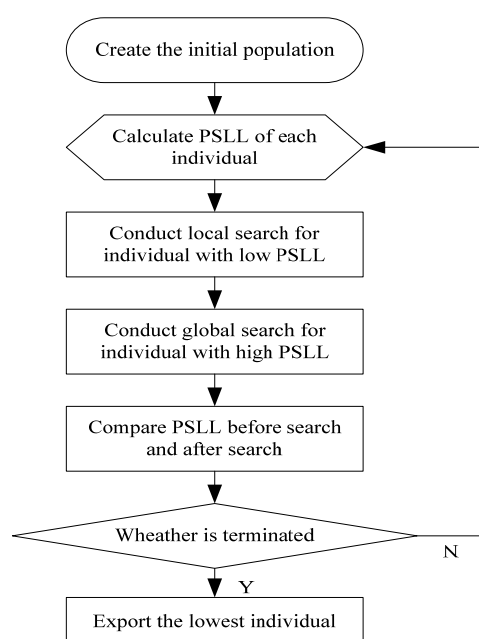


Fig. 2. Flow chart of the ant colony algorithm.

4. Simulation and Analysis

4.1. Optimization of the Full Array

Assume that the big circle's radius is 2 m, the small circle's radius is 0.7 m, the centre distance is 1 m, the incident wave's frequency is 300 MHz, the incident azimuth angle is 180 degrees and the incident elevation angle is 90 degrees.

Simulation shows that the peak sidelobe level and the main lobe width are changed when the element number is changed. The range of the element number is [0,100]. The variation is shown in Fig. 3 and Fig. 4. When $N=31$ and $n=9$, the peak sidelobe level equaling -12.74 dB is the best value.

The results show that: In general, the peak sidelobe level decreases with the increase of N , n . When N , n is small, there is great fluctuation. When

N , n is more than 30, the peak sidelobe level is changing smoothly. Compared with the peak sidelobe level, the width of the main lobe is changed far more gently. And it diminishes with the increases of N or n . Above all, the optimal value of the element number is $N=31, n=9$.

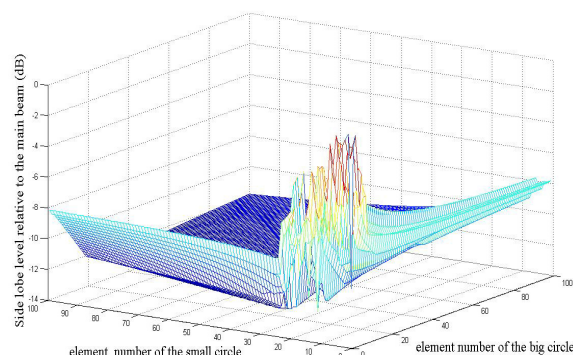


Fig. 3. The variation of peak sidelobe level.

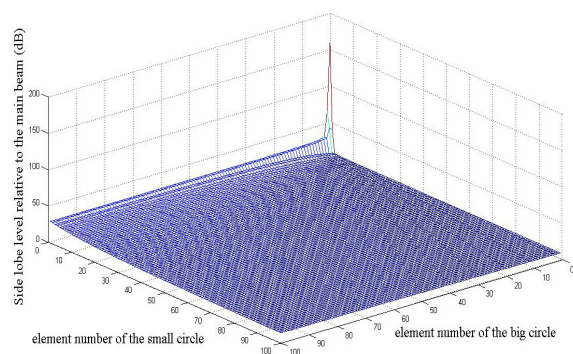


Fig. 4. The variation of main lobe width.

Then the kind of non-concentric antenna array is optimized in the following. The big circular array has 31 elements and the small circular array has 9 elements. Other parameters are the same as above. The number of the population is 500 and the number of iterations is 50. The crossover probability is 0.7 and the variation probability is 0.01. The peak side lobe level is the optimization goal. The thinning results are shown in Table 1. Comparison between full array and thinned array is shown in Fig. 5.

Table 1. Thinning results of the full array.

	Full array	Thinned array
Small	111111111111111 111111111111111 111	111011010111011 111111011111011 1
Big	111111111	111110101
Num.	40	32
PSLL	-12.74 dB	-13.53 dB

The experimental results show that the number of element is reduced to 32 after optimization, while the number of full array is 40. It reduces the costs and the occupied space of this array. The antenna array performance has been optimized. The peak sidelobe level is reduced from -12.74 dB to -13.53 dB.

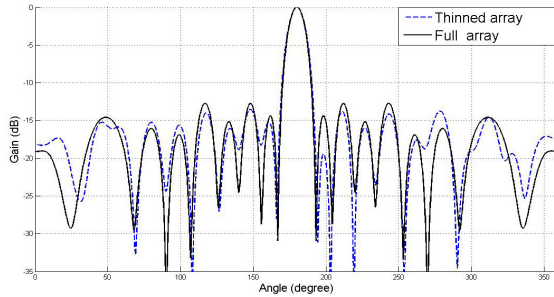


Fig. 5. Comparison of the pattern when the array is full.

4.2. Optimization of the Restricted Array

Now we assume that some elements can not be placed in the big circular array. The 14th, the 15th, the 16th and the 17th elements cannot be placed on the big circle array. And other elements are normally placed as Fig. 6. In this case, we use ant colony algorithm to optimize the array.

Simulation uses single-frequency signal, all of parameters are the same as the previous experiment. The peak sidelobe level is the optimization goal. The results are shown in Table 2. Comparison between the full restricted array and the thinned array is shown in Fig. 7.

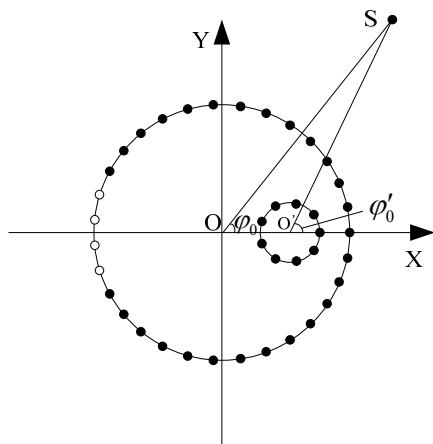


Fig. 6. Non-concentric circular antenna array.

The experimental results show that under the limit that the four elements have to be given up, the total number of the array elements is optimized from 36 to 25, reducing the system's cost and the occupied space. The antenna array performance has been

optimized. The peak sidelobe level is also reduced to -12.69 dB from -10.84 dB. The result is close to -12.74 dB when the array is full.

Table 2. Thinning results of the restricted array.

	Full array	Thinned array
Small	111111111111110	111011101110000
	000111111111111	001101010110101
	111	1
Big	111111111	111110101
Num.	36	25
PSLL	-10.84 dB	-12.69 dB

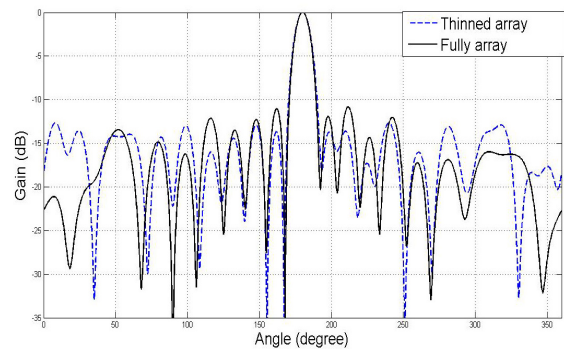


Fig. 7. Comparison of the pattern when the array is restricted.

4.3. Improved Non-concentric Array Optimization

When the big circular array has more available space, we can consider increasing the number of the small circular array. Through a number of experiments, we find that when the number of small circle array is 2, the antenna peak side lobe level is little better. When the number reaches 3 (shown in Fig. 8), the antenna peak side lobe level is much better. Optimization is given below.

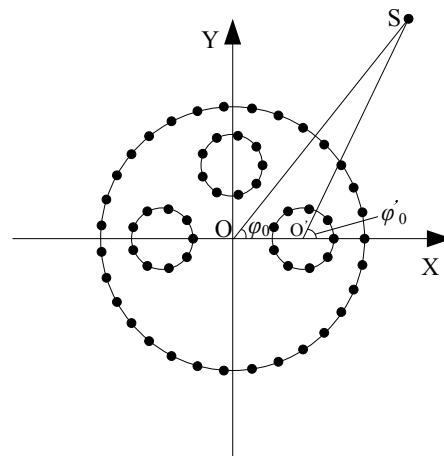


Fig. 8. Improved non-concentric array.

Each of the small circular array has 9 elements, their radius are 0.7 m. Other parameters are the same as above. The peak side lobe level is the optimization target. Results are shown in Table 3. Comparison between the full array and the thinned array is shown in Fig. 9.

Table 3. Thinning results of the improved array.

	Full array	Thinned array
Big	111111111111111 111111111111111 111	11111001010111 00110100101000 111
Small (right)	111111111	110011011
Small (up)	111111111	101111011
Small (left)	111111111	110101111
num	58	38
PSLL	-14.76 dB	-15.75 dB

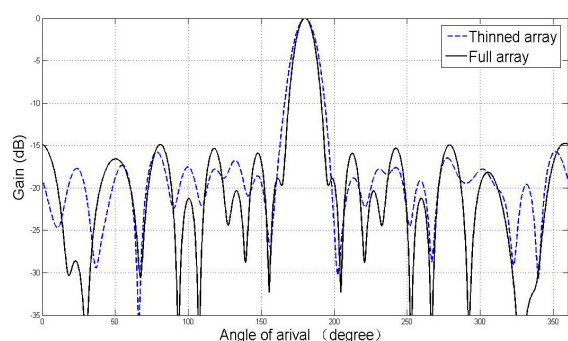


Fig. 9. Comparison of the pattern when the array is improved.

The experimental results show that: the total number of the array elements is optimized from 58 to 38, greatly reducing the cost. Peak side lobe level is reduced from -14.76 dB to -15.75 dB. But it can be observed that main lobe width is wider in the thinned array.

5. Conclusions

When the space is limited, the non-concentric circular array may be an admirable choice to replace the traditional concentric circular array. Furthermore, the peak side label level of the non-concentric circular array will be reduced through thinning based on the ant colony algorithm. Simulation results show that the number of the elements is reduced with the lower peak sidelobe level for the ordinary non-concentric circular array and the restricted non-concentric circular array. It is not only convenient for that there is only one small circular array, but also suits that there is three small circular arrays or more. As a novel antenna, the non-concentric circular array will not only increase the efficiency of the space

utilization, but also improve the system performance. Generally, it corresponds about the requirement in the circumstance of the restricted space.

Acknowledgements

The authors would like to thank the anonymous reviewers for their constructive comments, which helped improve the presentation of the paper. And this paper is supported by the National Natural Science Foundation of China (Grant No. 61301209) and the Fundamental Research Funds for the Central Universities (Grant No. HIT. NSRIF. 2013026).

References

- [1]. Ying Li, Xiangfei Xing, Xiaotao Huang and Zhimin Zhou, Simulation and design for uniform circular array antenna system, *Computer Simulation*, Vol. 22, Issue 12, 2005, pp. 238-241. (in Chinese)
- [2]. Xiansheng Liu, Liantang Zhang, Siliang Wu, Erke Mao, Patterns of circular array based on directed elements, Vol. 32, Issue 4, 2004, pp. 701-704. (in Chinese)
- [3]. Marek E. Bialkowski, Januar Janapsatya, Hyok J. Song, Analysis of a circular array of monopoles using a radial guide field matching method, in *Proceedings of the IEEE International Symposium on Antennas and Propagation*, The University of Queensland, Brisbane, Australia, Vol. 2, 2002, pp. 268-271.
- [4]. Ken Yamamoto, Kohei Ohno and Makoto Itami, Improving performance of DS/SS-IVC under shadowing environment using LMS adaptive circular array antenna, in *Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems*, Washington, 2011, pp. 2074-2079.
- [5]. Y. Rockah and H. Messer, Broadband source direction estimation using a circular array, *Faculty of Engineering, Tel-Aviv University*, 1998, pp. 2064-2067.
- [6]. Durbadal Mandal, Aurijoy Majumdar, Rajib Kar and Sakti Prasad Ghoshal, Thinned concentric circular array antennas synthesis using genetic algorithm, in *Proceedings of the IEEE Student Conference on Research and Development*, National Institute of Technology Durgapur West Bengal, India, 2011, pp. 194-198.
- [7]. J. Ouyang, F. Yang, H. Zhou, Z. Nie and Z. Zhao, Conformal antenna optimization with space mapping, *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 2-3, 2010, pp. 251-260.
- [8]. Peter Knott and Claudius Locker, Antenna element design for a conformal antenna array demonstrator, *Institute of Composite Structures and Adaptive Systems*, 2011.
- [9]. Philip M. Izdebski, Harish Rajagopalan and Yahya Rahmat-Samii, Conformal ingestible capsule antenna a novel chandelier meandered design, *IEEE Transactions on Antenna and Propagation*, Vol. 57, Issue 4, 2009, pp. 900-909.
- [10]. Yibao Chen, Hongmei Xu and Tiezhu Ma, Chaos-Ant colony algorithm and its application in continuous space optimization, *IEEE Transactions on*

- Antenna and Propagation*, Vol. 52, Issue 4, 2004, pp. 1125-1127.
- [11]. Yongfeng Dong, Junhua Gu, Nana Li, Xiangdan Hou and Weili Yan, Combination of genetic algorithm and ant colony algorithm for distribution network planning, in *Proceedings of the International Conference on Recent Trends in Information Systems*, 2011, pp. 77-80.
- [12]. Jamal S. Rahhal, Dia I. Abu-Al-Nadi, A general configuration antenna array for multi-user systems with genetic and ant colony optimization, *Electromagnetics*, Vol. 27, 2007, pp. 413-426.

2013 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(<http://www.sensorsportal.com>)