Design and Synthesis of Circular Antenna Array Having Elements Controlled by Linear Actuators

Suad Basbug

Department of Electrical and Electronics Engineering
Nevsehir Haci Bektas Veli University, Nevsehir 50300, Turkey
suad@nevsehir.edu.tr

Abstract

In this paper, a reconfigurable circular antenna array design whose elements are driven by linear actuators is proposed. The radial position movements of the array elements are realized by means of the actuators to synthesize the desired radiation pattern. The position perturbations of each element are calculated by using classical differential evolution algorithm. Different radiation patterns with single, double and wide nulls are successfully achieved in reasonable maximum iteration numbers.

1. Introduction

In the method of element position perturbation used to synthesize desired radiation patterns, the optimization parameters are the positions of the array elements [1-4]. Different pattern synthesis can be obtained by controlling only the element positions instead of amplitude or phase excitation values. But, it is still possible to use different combinations of position, amplitude and phase parameter controls to increase the degrees of freedom. Position perturbation method can be used for different array geometries such as linear, circular or planar. In the circular array geometries, the position of the elements can be changed along the circumference or radius of the array circle [3, 4]. The circular motion along the circumference may not be practically easy because the center of the circular motion is also the center of the array. This can result a complex construction design for the antenna array. However, the movement along a radius can be easier due to its linear habit.

In this paper, a circular antenna array design whose elements are driven by linear actuators is introduced. In order to synthesize the desired radiation patterns, the radius perturbations of the circular array elements are calculated by differential evolution algorithm (DE) [5]. Array elements are dipole antennas which have naturally isotropic on the azimuth plane. Different radiation patterns with single, multiple and wide nulls are successfully achieved for 8 and 36 element circular arrays.

2. Antenna Array Design and Synthesis Method

The proposed circular antenna array design in this paper has dipole antennas placed as shown in Fig. 1. The positions of these array elements are controlled linearly along the radial directions. The movement can be obtained by means of the linear actuators holding antennas and positioned as illustrated in Fig. 1.

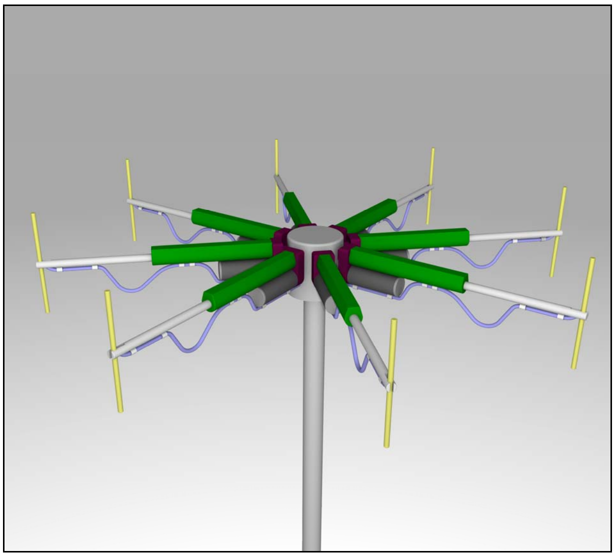

Fig. 1. 3D model of the proposed reconfigurable antenna array design.

If N dipole elements are equally spaced on the x-y plane along a circular ring of the radius r and the dipole elements are in a parallel position with z-axis as in Fig. 2, the radiation pattern of the dipole antennas are assumed to be isotropic [6] and the array factor can be written as follows [7]:

$$AF(\varphi) = \sum_{n=1}^{N} I_n e^{j(kr\cos(\varphi-\varphi_n)+\alpha_n)} , \tag{1}$$

where

$$kr = 2\pi r/\lambda = \sum_{i=1}^{N} d_i \tag{2}$$

and

$$\varphi_n = (2\pi/kr)\sum_{i=1}^{n} d_i , \tag{3}$$

where I_n, α_n, d_i, and φ_n are the nth element amplitude, nth element phase, the arc length between ith element and (i-1)th, and the angular position of the nth element to the x-axis, respectively.

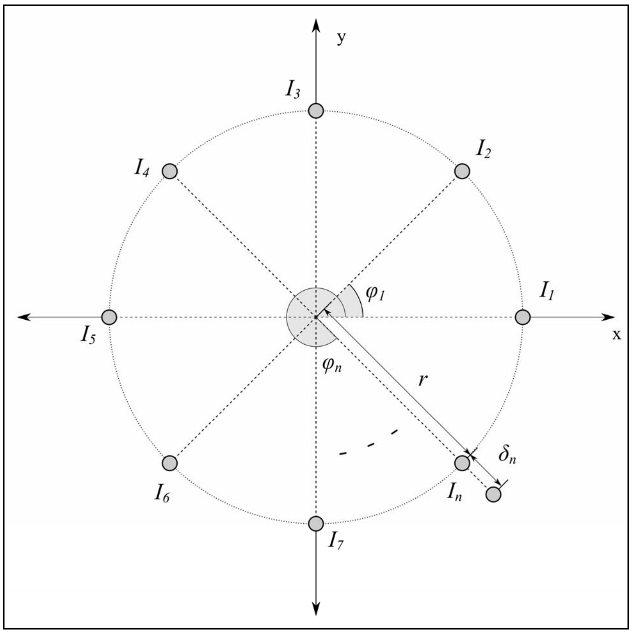

Fig. 2. 2D plot of the proposed antenna array design with dipole elements which are parallel to z-axis.

For the integration of the (1) into the proposed design, a perturbation parameter δ must be inserted into the equation as follows:

$$AF(\varphi) = \sum_{n=1}^{N} I_n e^{j(k(r+\delta_n)\cos(\varphi-\varphi_n)+\alpha_n)} . \tag{4}$$

The following equation is in-dB version of the array factor:

$$AF_{dB}(\varphi) = 20\log_{10}\left[\frac{AF(\varphi)}{AF_{\max}}\right]. \tag{5}$$

The array factor values are normalized in (5) by using the maximum array factor value AF_{max}.

The position perturbation values δ_n are optimized by using the classical DE algorithm. The cost function that DE algorithm needs to solve the optimization problem in this paper is constructed by considering the technique proposed in [8]. In this technique, cost function is based on a mask which consists of mask segments. The cost function of the model can be given by

$$C = \sum_{g=1}^{G}\sum_{h=1}^{H_g}(\beta_{gh})w_{gh} \tag{6}$$

where

$$\beta_{gh} = \begin{cases} AF_{dB}(\varphi_{gh}) - M_{gh} & AF_{dB}(\varphi_{gh}) > M_{gh} \\ 0 & else \end{cases} \tag{7}$$

G, H_g, M_{gh}, and w_{gh} are the number of mask segments and the maximum number of sample points of the gth segment, the mask level value, and weight value of the hth sample point of gth segment, respectively. For the detailed information, one can refer to [8].

The optimal δ_n values are calculated by using DE algorithm [5]. The element position perturbations in the problem are the positions of the population members used in this algorithm. The population members are denoted by δ_q $(q = 1,2,..., P)$ where P is the number of population. The algorithm randomly initializes the position of the population members before the beginning of the iterations. In the first iteration, intermediate test members are produced by r_1, r_2 and r_3, which are randomly selected indexes, via $\sigma_{p,i} = \delta_{r_1,i} + F(\delta_{r_2,i} + \delta_{r_3,i})$ where F and i are scaling factor and index number, respectively. Every dimensions of the target and intermediate test members are considered at the crossover stage whether they are interchanged by comparing a random number R in [0, 1] with a limit number named as crossover rate (CR) which is in the scope from 0 to 1. If CR is smaller than R, the candidate member element is changed with the element of test member. If not, the element of target member is the new element of the candidate member. Lastly, the cost function value of the candidate member is evaluated and if it is better than that of the target member, from that point on, the candidate member becomes new member of population instead of current target member. This procedure is repeated iteratively until the maximum iteration number is achieved in order to converge to the acceptable optimal results.

3. Numerical Results

Reconfigurable circular array examples with 8 and 36 elements are considered in this section. The phase values for all examples are adopted from [9] and all amplitude values are equal. The position perturbation values (δ_n) are optimized with the help of DE algorithm. Population number, scaling factor, and crossover rate parameters of DE algorithm are 70, 0.7, and 0.95 for the all examples, respectively.

In the first example, the position perturbation values of 8 element circular array are calculated by DE algorithm to obtain a pattern with a single null at -115°. After 395 iterations, a pattern shown in Fig. 3 are attained, which has a maximum side lobe level (SLL) of -13 dB and a single null that has -103 dB null depth level (NDL).

A pattern with two nulls is synthesized in the second example by using DE algorithm. Number of array elements is 8 again. 245 iterations are enough for this example. Achieved pattern is shown in Fig. 4. It can be seen from the figure that the pattern has two nulls with a NDL of -86 dB at -115.25° and -84 dB at 68°. SLL value of the pattern is -20 dB.

For the third example, the number of antenna array elements is increased to 36. The main aim in this example is getting a pattern with a single null at -54° and low SLL values. DE algorithm has obtained the pattern plotted in Fig. 5. The pattern has a NDL of -122 dB and a maximum SLL of -30 dB. This optimization in this example has taken 710 iterations.

The last one is a synthesis example for an array pattern with a wide null. The number of array elements is 36. The maximum iteration number is 735. The mask has been designed to place a wide null between 87° and 100° on the pattern. After running DE algorithm for this aim, the pattern shown in Fig. 6 is obtained. The NDL value of the wide null is -50 dB and the maximum SLL is -30 dB.

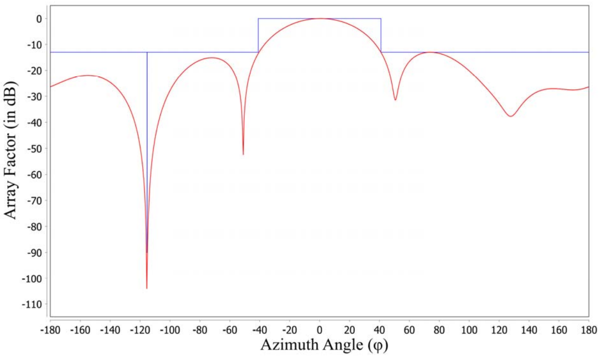

Fig. 3. Synthesized array pattern with a single null at -115° for the 8 element circular array.

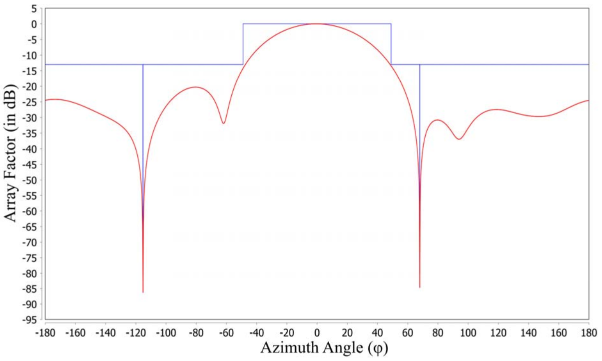

Fig. 4. Synthesized array pattern with double nulls at -115.25° and -68° for the 8 element circular array.

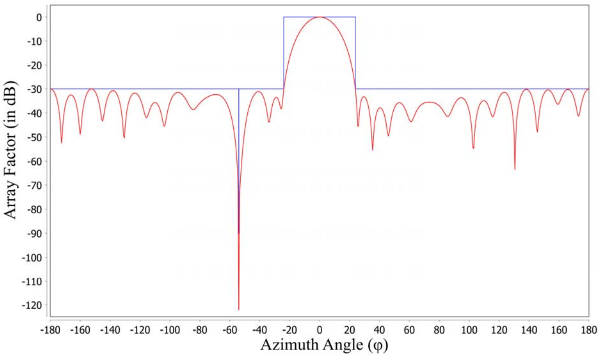

Fig. 5. Synthesized array pattern with a single null at -54° for the 36 element circular array.

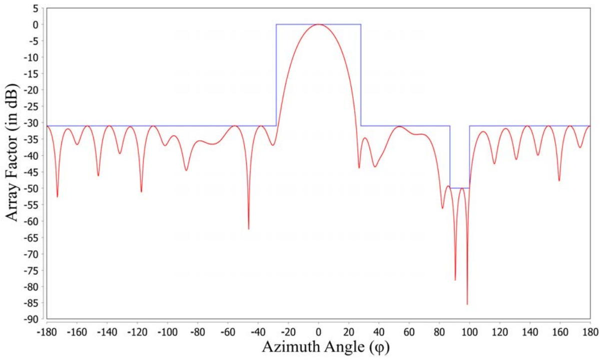

Fig. 6. Synthesized array pattern with a wide null at [87°, 100°] for the 36 element circular array.

4. Conclusions

A reconfigurable circular antenna array design is proposed in this paper. The dipole array elements can be moved linearly along the radial directions with the help of linear actuators. These position perturbations are calculated by DE algorithm to shape the desired radiation patterns. The results show that the proposed array design and its synthesis are successful in achieving the patterns with low SLLs and single, double and wide nulls.

5. References

[1] T. H. Ismail and M. M. Dawoud, "Null steering in phased arrays by controlling the element positions," *IEEE Trans. on Antennas and Propag.*, vol. 39, no. 11, pp. 1561–1566, Nov. 1991.

[2] J. A. Hejres and J. E. Richie, "Adaptive pattern nulling utilizing the elevations of the antenna array elements," *Proc. IEEE Int. Symp. AP-S*, Michigan, June 1993, pp. 694–697.

[3] G. Roy, S. Das, P. Chakraborty, and P. Suganthan, "Design of Non-Uniform Circular Antenna Arrays Using a Modified Invasive Weed Optimization Algorithm", *IEEE Trans. on Antennas and Propag.*, vol. 59, no. 1, pp. 110–118, Jan. 2011.

[4] M. A. Mangoud, H. M. Elragal, and M. T. Alsharaa, "Hybrid EPSO-DE optimization technique for null steering of circular antenna array by selected position perturbations", *IEEE GCC Conference and Exhibition*, 2011, pp. 609–612.

[5] R. Storn and K. Price, "Differential evolution – a simple and efficient heuristic for global optimization over continuous spaces," *J. Global Optimization*, vol. 11, no. 4, pp. 341–359, Dec. 1997.

[6] L. Josefsson and P. Persson, *Conformal Array Antenna Theory and Design*. Hoboken, NJ, USA: John Wiley & Sons, 2006.

[7] C.A. Balanis, *Antenna Theory: Analysis and Design*, 2nd ed., Wiley, 1996.

[8] S. Basbug, "A general model for pattern synthesis of linear antenna arrays by metaheuristic algorithms," *in Int. Appl. Comput. Electromagn. Soc. Symp.*, Firenze, Italy, 2017, pp. 1–2.

[9] N. Goto and Y. Tsunoda, "Sidelobe reduction of circular arrays with a constant excitation amplitude", *IEEE Trans. on Antennas and Propag.*, vol. 25, no. 6, pp. 896–898, 1977.