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Concentric Circular Array Antenna Thinning to Minimize the Side Lobe Level using Differential Evolution

Anitha Suresh[1], Swetha Ravikanti[1], Preeti Khanwalkar[1], Santhosh Kumar R[1]

[1]*Department of Electronics and Telecommunication Engineering, Dayananda Sagar College of Engineering, Bangalore, Karnataka, India*
Email: anisuri2011@gmail.com,

This paper addresses the challenge of reducing side lobe levels in the pattern of a circular array antenna through the use of thinning techniques. In this approach, only a subset of the available array elements is activated at optimal positions to meet the desired objectives. The thinning problem is redefined as a controlled optimization task with the goal of lessening the number of active elements while achieving the required side lobe levels and first null beam width. To solve this problem, the Differential Evolution (DE) Algorithm is employed, demonstrating the benefits of thinning arrays compared to fully populated antennas.

Keywords: Circular array, Array antenna, Differential evolution, Thinning, Beam Width, Side lobe level.

1. Introduction

In order to recognize and analyze signals coming from many directions, antenna arrays are crucial. The purpose of synthesizing antenna array is to create an antenna array with a physical configuration whose radiation pattern is almost identical to the required pattern. Numerous stationary antenna elements that are frequently fed logically make up an antenna array. Antenna array amalgamation techniques aim to identify the array's physical configuration that creates a pattern that is most similar to the desired pattern. Numerous synthesizing techniques exist since the planned pattern's shape might differ greatly reliant on the application. Planar concentric circular antenna arrays (PCCAA), which is one of several forms of antenna arrays, have gained the most interest in wireless and mobile communication. This particular fact served as the inspiration for the designing of PCCAA and assessment of effectiveness of related antenna arrays.

To achieve a specified amplitude density across the aperture, an evenly spread out or periodic array shall be thinned by putting off part of its elements. A component that is linked to the feed network is "on," while a component linked to a matched load is "off". Thinning methods can be useful to linear as well as planer arrays. A circular array has a number of advantages over a linear one, including the adequacy to scan all directions and to maintain the beam pattern through all φ cuts. The consistent amplitude excitations and thinning concentric circular arrays guarantee improved power efficiency and simpler beam-forming networks.

2. RELATED WORK

Numerous antenna array applications for mobile and wireless communications system have been proposed to enhance the functionality, including effective spectrum usage, increased channel capacity, expanded coverage, customized beam shaping, etc. Enhancing array pattern by changing structural geometry to maintain main beam gain and reduce SLL is the major objective of antenna research. Recently, methods such as differential evolution [7], invasive weed optimization [6], particle swarm optimization [4, 5], and genetic algorithms [3] have been successful in constructing antenna arrays with challenging array geometry. A random algorithm is provided in [8,9] for the synthesis of thinning concentric array circle. Haupt [8] discusses the concentric array thinning design employing GA, in which the PSO was altered and employed to achieve optimization. [10] presents the use of the fire fly algorithm for CCA thinning. [11] discusses the DOA estimation problem for circular and concentric circular antenna arrays.In [12], a suggestion for suppressing the high side lobe level (SLL) utilizing a particular half power beam width (HPBW) of a concentric circular antenna array (CCAA) based on the cuckoo search (CS) algorithm was made. In [13], the use of the Galaxy Based Search Algorithm (GBSA) to the thinning of concentric circular arrays has been discussed. In [14], a deterministic method for creating a typical a-periodic arc or ring antenna array was introduced. In [15], a hybrid strategy for SLL minimization for concentric circular arrays has been proposed. The method for flower pollination, which is triggered by flower pollination, has been employed in [16] to optimize circular antenna arrays in order to attain a lower SLL value. Concentric circular antenna arrays (CCAA) that are thinned offer reduction

3. PLANAR CONCENTRIC CIRCULAR ARRAY ANTENNA (PCCAA)

In the Fig.1 the geometrical arrangement of multiple planar concentric circular arrays has shown in the X-Y plane. It contains 'M' number of concentric circular rings and the m^{th} ring which has radius of r_m, carried the N_m number of isotropic antenna elements where m=1,2,….M. In free space region, the radiation pattern is as given by Eq.1

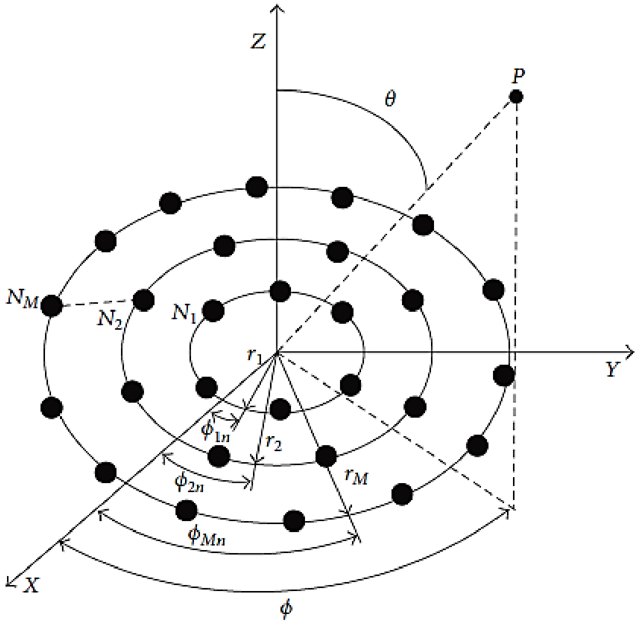

Fig.1 Planar concentric circular antenna array (PCCAA)

$$E(\theta,\emptyset)=\sum_{m=1}^{M}\sum_{n=1}^{N_m}A_{mn}\ e^{jkr_m\left[\begin{matrix}\sin\theta\cos(\emptyset-\emptyset_{mn})-\\ \sin\theta_0\cos(\emptyset_0-\emptyset_{mn})\end{matrix}\right]}\quad(1)$$

Where,

A_{mn} : In m^{th} ring, excitation of n^{th} element, $k=2\pi/\lambda$ (wave number), $r_m=N_m d_m/2\pi$ where dm is the m^{th} circle element spacing, 'θ' = Zenith angle and 'Ø' =Azimuth angle.

Power pattern in dB can be defined as given in Eq.2

$$P(\theta,\emptyset)=10\log_{10}\left[\frac{|E(\theta,\emptyset)|}{|E(\theta,\emptyset)_{max}|}\right]^2$$

$$=20\log_{10}\left[\frac{|E(\theta,\emptyset)|}{|E(\theta,\emptyset)_{max}|}\right]\qquad(2)$$

4. DESIGN CONSIDERATIONS

Minimum number of array elements is achieved to apprehend the desired objectives of PSLL and FNBW by using thinning approach. Assumed all elements have same excitation and the phase of 0°. Thinning considers '1' for 'on' element as '0' for 'off' element

$$A_{mn}=\begin{cases}1 & \text{if} m^{th} \text{ring}, n^{th} \text{elementis'on'}\\ 0 & \text{if} m^{th} \text{ring}, n^{th} \text{elementis'off'}\end{cases}$$

X-Z plane ($\phi = 0^{o}$) is considered for design and main beam achieved its maximum in the direction of $\theta_0 = \phi_0 = 0^0$.

5. OBJECTIVE FUNCTION

f : *minimize* (Total number of array elements)

$$\begin{cases} PSLL_{obtained} \le PSLL_{desired} \\ FNBW_{obtained} \le BW_{desired} \end{cases} \quad (3)$$

Objective function in Eq.3 can be minimized to reduce the number of array elements and achieve the desired PSLL and FNBW as represented in Eq 4

$$F = K_1(|PSLL_d| - |PSLL_o|)H(T1)K_2(FNBW_d - FNBW_o)H(T2)\ NAE \quad (4)$$

Where K_1 and K_2 are the penalties constant and equal to 10^3, T1 and T2 are the Heaviside step function parameter having the values as given below

$$T1 = (|PSLL_d| - |PSLL_o|)$$
$$T2 = (FNBW_d - FNBW_o)$$

The Heaviside step function H(T) defined as

$$H(T) = \begin{cases} 0 & \text{if} T \le 0 \\ 1 & \text{if} T > 0 \end{cases}$$

A. Differential Evolution

Differential Evolution is a powerful algorithm which tackles the issue of global optimization. The population of Differential Evolution algorithm consists of NP individuals and a D dimensional vector in accordance with the problem. DE uses mutation to create a donor vector of D dimension for one generation for each vector. There are numerous methods for defining the donor vector. In this work, a strategy called DE/rand/1 as defined in Eq. (5) is considered. The crossover operator in a probabilistic framework is used to create the trial vectors presented in Eq. (6). CR is the crossover control parameter with a value between [0,1] that represents the likelihood of producing trial vector from the mutant vector. The integer jrand picked at random from the range [1, NP]. Then, according to Eq. (7), a selection procedure chooses between the trial vector and the target for the next generations.

$$V_i^{(G)} = X_{r1}^{(G)} + F * \left(X_{r2}^{(G)} - X_{r3}^{(G)}\right) \quad (5)$$

$$u_{ij}^{(G)} = \begin{cases} v_{ij}^{(G)} & \text{if} \quad \text{rand}(0,1) \le CR \text{ or} j = j_{rand} \\ x_{ij}^{(G)} & \text{otherwise} \end{cases} \quad (6)$$

$$x_{ij}^{(G)} = \begin{cases} u_i^{(G)} & \text{if} \quad f\left(u_i^{(G)}\right) \le f\left(x_i^{(G)}\right) \\ x_i^{(G)} & \text{otherwise} \end{cases} \quad (7)$$

6. EXPERIMENTAL RESULTS

For the simulation purpose, a two concentric ring of circular array carrying 35 and 70 elements each respectively in the 1st and 2nd ring with equal spacing between the elements dm= λ/2 has been used. The purpose is to achive the desired peak side lobe level (PSSLL=-19.5dB) and FNBW=10.220 by minimizing the 'on' condition of the array elements. By turning off selected elements among the total elements available in the uniform array, the reduction in the side lobes can be achieved. To achieve the desired objectives the proposed differential evolution is applied. The population sizes have been considered as 20 and while the mutation and crossover factor has considered 0.5 and 0.9. The allowed numbers of evolved generation were 125 to observe and analyze the performance. Binary transformation has achieved through the sigmoid function followed by threshold (as shown in Eq.8 and Eq.9.) MATLAB 2013a environment has been used for the simulation.

$$S(x) = \frac{1}{1+e^{-x}} \quad (8)$$

$$B = \begin{cases} 1 \text{ if } S(x) > 0.5 \\ \text{else } 0 \end{cases} \quad (9)$$

To understand the benefit of thinning the comparison between fully occupied CCA (FACCA) and thinned CCA (THCCA) radiation pattern is shown in Fig.2 while numeric comparison of obtained radiation pattern characteristics are shown in Table1.

TABLE1. PERFORMANCE COMPARISON BETWEEN FACCA & THCCA

CCA	%Thinning	PSSL (dB)	HPBW (^{0})	FNBW (^{0})
FACCA	0	-12.4530	4.4924	9.0761
THCCA	33.33	-19.5316	5.6383	10.2220

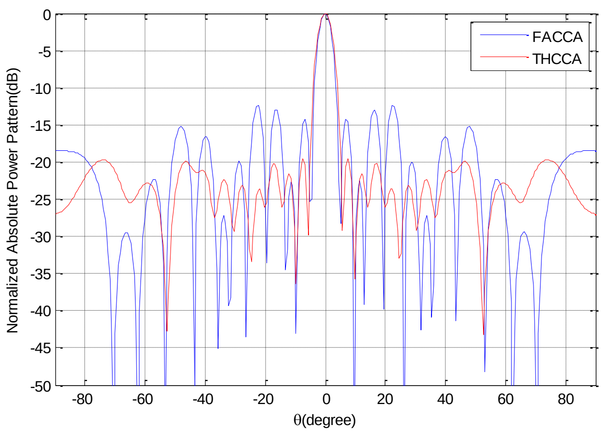

Fig.2 Comparative radiation pattern obtained with fully occupied CCA (FACCA) and thinned CCA (THCCA)

The convergence performance of PTDE has been shown in Fig3 below and it was observed around 40th iteration optimal convergence has taken place.

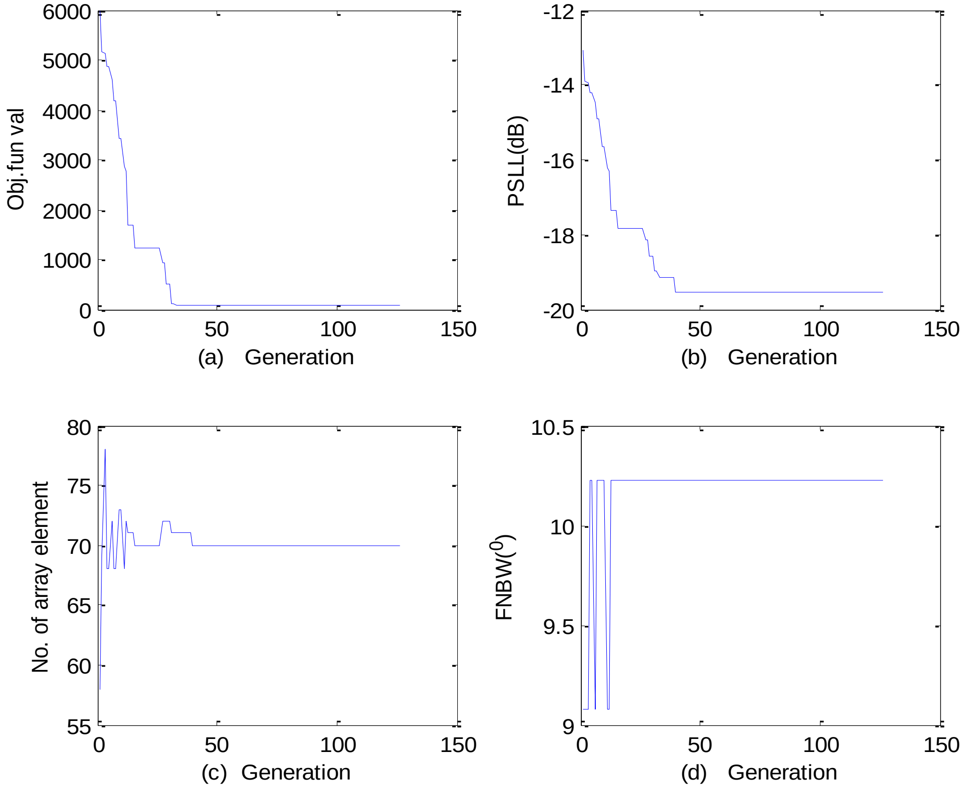

Fig.3 Convergence performance of PTDE (a) objective function (b) PSSLL(c) no. of array elements (d) FNBW

Table 2: Comparison of Existing Algorithm with DE (Differential Evolution)

Algorithms	% Thinning	HPBW	FNBW	PSLL
PSO [8]	29	5	10	−18.38
FFA [8]	25.71	5	10	−18.71
DE	33.33	5.6383	10.2220	-19.5316

7. CONCLUSION

This paper discusses the application of Differential Equation to minimize the sides' lobe level by thinning circular array antenna. It also discusses the benefit of thinning approach over fully occupied array and shows how DE can provide optimal convergence at less iterations with desired PSLL=-19.5dB and FNBW=10.220 in comparison with the other existing algorithms like PSO (Particle swarm Optimization) and FFA (Fire Fly Algorithm).

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