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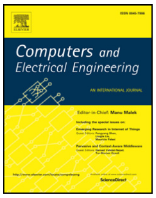

Non-uniform single-ring antenna array design using wavelet mutation based novel particle swarm optimization technique[☆]

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ABSTRACT

Side lobe level (SLL) reduction is the key challenge in antenna array synthesis. In order to achieve low SLL in array pattern, many conventional optimization methods are proposed to handle complex, nonlinear and non-differentiable array factor of antenna array. In this article, we present an improved optimization scheme; Wavelet Mutation based Novel Particle Swarm Optimization (NPSOWM) for the synthesis of various single-ring planar arrays of isotropic antenna elements. The primary objective is to achieve the radiation pattern with minimum SLL and maximum directivity for the non-uniform, planar circular array (CA), hexagonal array (HA) and elliptical array (EA) antenna. The array pattern synthesis is done based on two parameters of the array; namely, excitation amplitude and element spacing. Two design examples are presented which illustrate the effectiveness of the NPSOWM algorithm. As compared with conventional optimization techniques like genetic algorithm (GA), simulated annealing (SA), particle swarm optimization (PSO) and its variant NPSO, NPSOWM outperforms with the goal of maximum SLL suppression.

1. Introduction

Antenna array has been broadly used in applications such as in wireless communications [1], direction finding, scanning etc. Uniform Circular Array [2], which has the capability of 360° beam scanning without the significant change in SLL or beam width, is studied for smart antenna application [3,4]. A comparison between Uniform Circular Array (UCA) and Uniform Rectangular Array (URA) is made in the context of adaptive beam forming and between these two geometries, UCA has achieved better directivity than URA of same area [5]. The circular array provides radiation pattern with relatively high SLL. The mutual coupling effect becomes more significant while achieving low SLL by reducing the inter-element distance in circular arrays. Hexagonal array is presented to overcome the problem of high SLL for smart antenna applications [6]. The comparison between CA and HA shows that the hexagonal array geometry provides deeper nulls and higher gain with the same beam width as circular array [7]. Also, the best beam steering ability has been found using a uniform hexagonal array (UHA) of seven patch antennas with a central element [8], which can be applied to the wireless communication of advance generation. Elliptical shaped array and the combinations of elliptical and linear array with array factors are investigated in [9]. The effects of eccentricity of the ellipse, number of elements and element spacing are also investigated.

The antenna excitation weights, their relative phases and the positions of antenna elements are the basic features of an array. The element spacing has a large influence on the array factor. Larger element spacing results in a higher directivity.

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The number of side lobes and the side lobe level increase with the increase of spacing between the elements in the array. However, the element spacing is generally kept smaller than λ/2 to avoid the occurrence of grating lobes (undesirable directions of the maximum radiation), an unwanted peak value in the radiation pattern. Increasing the element spacing towards λ results in an increased directivity and grating lobe effect with maximum grating lobe amplitude equal to the main lobe magnitude at an element spacing λ [1]. Element spacing beyond λ results in multiple unwanted grating lobes, which becomes impractical.

Classical optimization approaches have a number of disadvantages, i) requirement of continuous and differentiable cost functions because discrete variables are difficult to handle, ii) initial point is highly sensitive when the size of the solution space or the number solution variables increases because the solution using a classical optimization method depends on the randomly selected initial solutions, iii) to solve various problems, a particular classical optimization technique may not be suitable. So, it is indispensible to develop an efficient optimization method. For optimization of complex, nonlinear and non-differentiable array factor of antenna array, various evolutionary optimization approaches such as Genetic Algorithm (GA) [10–12], simulated annealing (SA) [13], Particle Swarm Optimization (PSO) [14,15], etc. have been widely used. It is accepted that, as compared with the GA and SA, the PSO is a powerful optimization scheme for antenna design problems [16,17]. PSO is much easier to implement and requires less mathematical operations as compared with the GA and SA. Many versions of the PSO technique have been magnificently applied in circular array antenna synthesis [18,19], Hexagonal array antenna synthesis [20], infinite impulse response (IIR) system identification problem [21], analog active filter design [22], etc.

In this paper, wavelet mutation based novel Particle swarm optimization (NPSOWM) method is developed for optimal beam-forming using single-ring CA, HA and EA. The goal of optimization is to minimize the SLL of the radiation pattern towards Signal Not of Interest (SNOI). The array parameters used to control the array pattern such as excitation amplitude coefficients and the inter-element spacing between two consecutive elements are taken as the design variables. The simulation results demonstrate the optimized pattern with very low SLL approaches the desired pattern very well. The synthesis result greatly improves the efficiency of the antenna array.

The paper is arranged as follows. Section II describes the formulation of array factors of the single-ring planar array antennas. The objective functions (cost functions) are also formulated in this section. In the section III, brief introductions of the PSO, NPSO and NPSOWM are presented. In the section IV, simulation results of various single-ring synthesized arrays are summarized and discussed. Finally, in the section V, conclusions are briefed with the possible extensions.

2. Design equations

2.1. Array factor

The overall radiation pattern of an array differs from specific pattern of single antenna due to array factor which measures the effect of combining radiating elements in an array without the element specific radiation pattern taken into account. The array factor depends on the total number of elements in the array, geometrical configuration of the array, the element spacing, excitation amplitude and phase of the applied signal to each element. Pattern multiplication principle reveals that the total field of an array can be determined by multiplying the field of a single element at a selected reference point and the array factor.

In general form, the far-field pattern of an array with N number of isotropic elements can be defined as (1) [1]

$$AF(\theta,\varphi)=\sum_{n=1}^{N}A_n e^{j(\alpha_n+kR_n.a_r)} \tag{1}$$

where A_n = excitation amplitude coefficient of n^{th} element; k = wave number; α_n and R_n are the relative phase and geometry dependent position vector of n^{th} element, respectively; a_r = unit vector.

2.1.1. Circular array (CA)

The normalized array field can be written as [1]

$$E(a,\theta,\varphi)=\frac{e^{-jka}}{a}\sum_{n=1}^{N}a_n e^{jkr\sin\theta\cos(\varphi-\varphi_n)} \tag{2}$$

where a_n is the complex excitation coefficient (amplitude and phase) and $\varphi_n(=2\pi(n-1)/N)$ is the angular position of the n^{th} element. In general, the excitation coefficient can be represented as

$$a_n=A_n e^{j\alpha_n} \tag{3}$$

where A_n the is amplitude term and α_n is the phase of the excitation of the nth element

So, from (2) and (3), the array factor can be obtained as

$$AF(\theta,\varphi)=\sum_{n=1}^{N}A_n e^{j[kr\sin\theta\cos(\varphi-\varphi_n)+\alpha_n]} \tag{4}$$