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Shaped beam synthesis of concentric ring array antenna using Differential Evolution Algorithm

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ABSTRACT

A shaped beam synthesis from a concentric ring array has been presented. Two different cases are considered. In the first case, a flat-top beam with desired specification has been generated and in the second case, a cosec^2 beam pattern from the same array configuration is generated. The desired beam pattern in each of the individual case is obtained by finding optimum excitations of the array elements using Differential Evolution (DE) algorithm. Dynamic range ratio (DRR) of the excitation amplitudes are improved by eliminating the weakly excited array elements from the optimized array without distorting the obtained pattern. To illustrate the effectiveness of DE, the two beam-patterns are computed from the same array using Genetic Algorithm (GA) by finding out optimum excitations among the elements. Results clearly show the superiority of DE over GA to handle the proposed problem.

1. Introduction

Shaped beams finds huge applications in radar and satellite communication based systems. In these systems, the obtained shaped beams often suffered from higher values of sidelobes and ripples. To generate shaped beams different methods reported in the literature [1–6] are as follows:

Azevedo proposed a technique based on FFT to generate shaped beams of cosec and flat-top pattern through the control of non-uniformly samples of both the Amplitudes and phases of the array factor of linear array antenna, [3]. cosec^2 beam from linear antenna array of lower SLL are generated by finding optimum amplitudes and phases of the array elements using the modified least square method by Lei et al. [4]. Chatterjee et al. [5] proposed a technique based on finding optimum phases of the array elements modifying which over existing ‘zero’ phases generates two different patterns using Gravitational Search Algorithm (GSA) [5]. In [6], a new technique has been proposed by Chatterjee et al. for obtaining dual beam pair where the states (‘on/off’) of the array elements are modified using Firefly Algorithm (FA). The method greatly simplified the design of the feed network [6]. Li et al. [7] proposed a technique using Differential Evolution (DE) Algorithm for obtaining synthesized beam-pattern with lower peak SLL and first null beam width (FNBW).

In this paper, a shaped beam synthesis of two ring concentric array of isotropic elements has been reported. Two different cases have been considered. In the first case a flattop beam is generated from the presented array by finding out optimum sets of elements amplitudes and phases, and in the second case a cosec^2 pattern is generated from the same array by finding out optimum amplitudes and phases of the elements. In both the cases the optimum excitations are computed using Differential Evolution (DE) algorithm [8–12]. To illustrate the effectiveness of DE, the shaped beams under two different cases are computed separately following the above procedure from the same array configuration using Genetic Algorithm (GA) [13–17]. Results clearly show the effectiveness of DE over GA for both the design cases presented in this problem.

2. Problem formulation

A concentric ring array of isotropic elements shown in Fig. 1 is considered. The far field pattern of the array can be written as [6]:

$$\mathrm{AF}(\theta, \varphi) = \sum_{m=1}^{M} \sum_{n=1}^{N_m} I_{mn} e^{j[kr_m \sin\theta \cos(\varphi - \varphi_{mn}) + \alpha_{mn}]} \quad (1)$$

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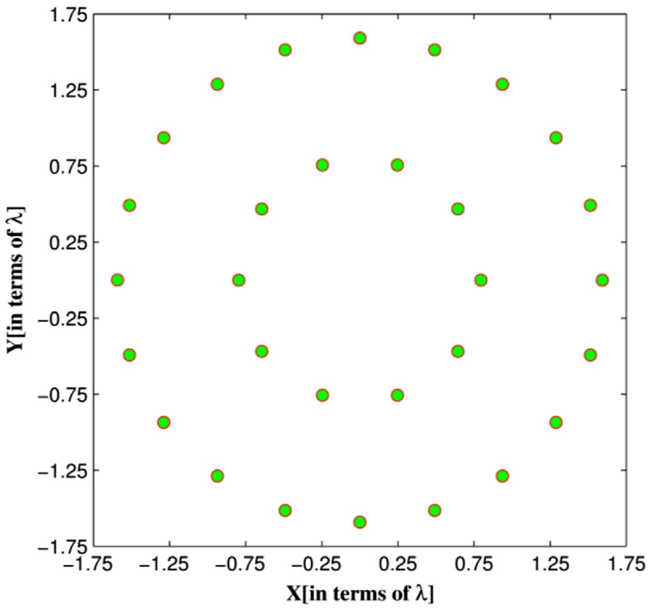

Fig. 1. Concentric ring array of isotropic antennas in *X*–*Y* plane.

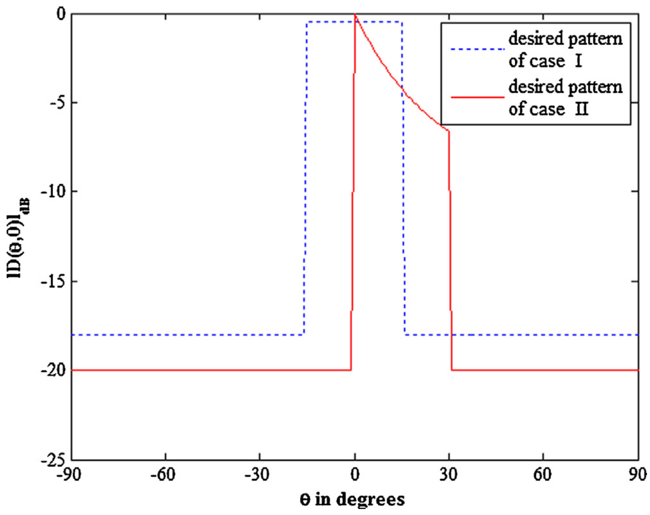

Fig. 2. Desired patterns under two different design cases.

where M = number of concentric rings; N_m = number of isotropic elements in m-th ring; I_{mn} = excitation amplitude of mn-th element; $r_m = N_m d_m/2\pi$ radius of the m-th ring; d_m = inter element arc spacing of m-th circle; $k = {}^{2\pi}\!/\!_{\lambda}$, represents wave number; λ is the wave length; θ, φ = polar and azimuth angle; $\varphi_{mn} = 2n\pi/N_m$ is the angular location of the mn-th element with, $1 \le n \le N_m$ and α_{mn} = phase excitation of mn-th element.

The fitness function for the shaped beam pattern is defined as follows:

$$F(\rho) = k_1\left(\text{peakSLL}^d - \max_{\theta\in A}\{\text{AF}^{\rho}_{dB}(\theta,0)\}\right)^2 + k_2\times\Delta \qquad (2)$$

where, Δ is defined as:

$$\Delta = \sum_{\theta_{\text{ripple}}}\left|\text{AF}^{\rho}_{dB}(\theta_{\text{ripple}},0) - D(\theta_{\text{ripple}},0)\right| \qquad (3)$$

In Eq. (2), ρ is the unknown parameter set responsible for the desired beam pattern for the two different cases. ρ is defined as follows:

$$\rho = \{I_{mn},\alpha_{mn}\};\quad \begin{cases} 1\le m\le M \\ 1\le n\le N_m \end{cases} \qquad (4)$$

$\text{peakSLL}^{\text{d}}$ is the desired value of peak SLL for the two different cases. A is the sidelobe region for the shaped beams of flat-top and cosec^2 patterns. $D\left(\theta,0\right)$ represents desired patterns under two different design cases at $\varphi = 0°$ plane shown in Fig. 2. k_1 and k_2 are the weighting factors to give relative importance in each term of Eq. (2). The value of k_1 and k_2 are chosen as 'one'. For optimum synthesis of shaped beam pattern under two different design cases, the fitness function have to be minimized separately under each of the design cases. The fitness function defined by Li et al. [8], is formulated by using only the errors due to unaccepted values of peak SLL and FNBW. But in our case, as the objective is to generate shaped beams, the fitness function is formulated using Eq. (2).

3. Algorithm overviews and parametric setup

3.1. Overview of differential evolution algorithm

Differential Evolution Algorithm (DE) was introduced by Storn and Price in 1995. [13–17]. DE is also based on population like GA. This algorithm is simple and easy to find out the convergence. This stochastic optimization method used to minimize an objective function. Using a few tunable parameters searching of a true global minima and fast convergence can be achieved [8–12]. Generate the initial population randomly between the lower and upper bounds defined for each parameter. The coverage of the initial population should be large enough to guarantee that the optimum does not lie outside the initial population. When the coverage is large enough, enough variance is also created for efficient search.

DE algorithm generates a new population of *NP* in *D* dimensional search space called individuals. In generation *G* individual of population can be written as $X_{i,G} = \{x_{1i,G},\ x_{2i,G}\ldots\ldots x_{Di,G}\}$, $i = 1$, 2.........NP. The initial population covered the entire search space. At a generation $G = 0$ the initial value of the jth parameter defined as follows $x_{ji,0} = \text{rand}(0,1).(x_j^{\text{up}} - x_j^{\text{low}}) + x_j^{\text{low}}$ where $i = 1, 2, \ldots\ldots$ NP and $j = 1, 2, \ldots\ldots D$. rand(0, 1) is uniformly distributed random variable within the range (0,1); x_j^{low} and x_j^{up} are lower and upper bounds of *jth* parameter. Three steps mutation, crossover and selection can be described as follows.

Mutation operation: DE performs mutation operation to generate a mutant vector, at least three chromosomes are selected from the population to form mutant vector. Two of these are used to create difference vector. This difference vector is multiplied by mutation coefficient *F* and then added to the third chromosome i.e. base vector of mutation. $V_{i,G=}\{v_{1i,G}, v_{2i,G}, \ldots, v_{Di,G}\}$ for each target vector $X_{i,G}$. In this work, the DE strategy used is: 'DE/best/1/bin' which is defined as: $V_{i,G} = X_{\text{best},G} + F(X_{r1,G} - X_{r2,G})$ r_1, $r_2 \in [1$, NP] and $r_1 \ne r_2 \ne i$. *F* is a real and constant factor, satisfies $F \in [0,\ 2]$ and $X_{\text{best},G}$ is the vector which has best fitness at *G*th generation. The rate of mutation has been controlled by predefined small valued mutation probability. Mutation occurs when mutation probability is greater than the random number.

Crossover operation: Cross over is applied in DE after mutation. Each of the chromosome acts as the target vector at a time. In this operation trial vector $U_{i,G} = \{u_{1i,G},\ u_{2i,G},\ \ldots,\ u_{Di,G}\}$ is generated from