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Particle Swarm Optimization with Self-adapted Maximum Velocity for Side lobe Reduction of a Scanned Concentric Ring Array Antenna with Fixed First Null Beam width

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Abstract: In this paper, the authors present a method based on particle swarm optimization with self-adapted maximum velocity for focusing a beam at any direction other than boresight in the vertical plane of a concentric ring array antenna with minimum side lobe level while keeping the first null beamwidth fixed. The fixed first null beamwidth is made equal to or less than that of a uniformly excited and uniformly spaced concentric ring array of same number of elements and same number of rings. The excitation amplitude is radially varied and optimized to reach the goal. One example has been presented with fixed first null beamwidth to illustrate the potential of the method.

Keywords: Concentric ring array, first null beamwidth, particle swarm optimization, side lobe level

I. INTRODUCTION

A concentric ring array is a planar array of many rings with different radii sharing a common center and elements lying on a circle. Concentric ring arrays find various applications in direction finding, radar, mobile and commercial satellite communications systems [1–5].

Concentric ring array (CRA) antennas have several advantages over other type of array antenna configurations; such as all-azimuth scan capability, invariant beam pattern in every ϕ-cut.

Uniform Concentric ring array (UCRA) is one of the most important configurations of the concentric ring array [2,3] where the inter-element spacing in individual ring is kept almost half of the wavelength and all the elements in the array are uniformly excited with constant amplitude. The side lobe in the UCRA drops to about 17.5 dB, especially at larger number of rings [3] with uniform excitation.

Uniformly excited and equally spaced antenna arrays [1, 2,3] have high directivity but they usually suffer from high side lobe level. To reduce the side lobe level further, the array is made equally spaced with radially tapered amplitude distribution [4, 5].

Particle swarm optimization (PSO) is an evolutionary algorithm and has been successfully used in the design of antenna arrays [6-11].

In this paper, we vary and optimize amplitude distribution radially, i.e. the amplitude of the elements on a common ring is same but they differ from one ring to another, so as to meet the goal. This will simplify the design of feed network. The goal is to produce a scanned beam in the vertical plane with minimum side lobe level while keeping the first null beamwidth fixed. The phase of the central element is kept at zero degree and its amplitude is made unity. The fixed first null beamwidth is made equal to a uniformly excited and uniformly spaced scanned concentric ring array of same number of elements and same number of rings. Optimization is done with the help of particle swarm optimization with self-adapted maximum velocity.

II. THEORETICAL FORMULATION

The arrangement of elements in planar concentric arrays [2, 3, 4] contains multiple concentric rings, which differ in radius and number of elements. Fig.1 shows the configuration of concentric ring arrays [2,3,4] in XY plane in which there are M concentric rings.

The m-th ring has a radius r_m and number of isotropic elements N_m, where $m = 1, 2 \ldots M$. Elements are equally placed along a common ring. All the elements on a ring have the same amplitude distribution but they vary from ring to ring, i.e. vary radially. The central element is fed with uniform amplitude and zero degree phase.

The far-field pattern [1,2] in free space for such a scanned CRA with a central element feeding is given by:

$$E(\theta,\phi) = 1 + \sum_{m=1}^{M}\sum_{n=1}^{N_m} I_m e^{jk\, r_m[\sin\theta\cos(\phi-\phi_{mn}) - \sin\theta_o\cos(\phi_o-\phi_{mn})]} \tag{1}$$

Normalized absolute power pattern, $P(\theta,\phi)$ in dB can be expressed as follows:

$$P(\theta,\phi)=10\log 10\left[\frac{|E(\theta,\phi)|}{|E(\theta,\phi)|_{\max}}\right]^2=20\log 10\left[\frac{|E(\theta,\phi)|}{|E(\theta,\phi)|_{\max}}\right] \tag{2}$$

Where r_m = radius of m-th ring $=N_m d_m/2\pi$, d_m= inter-element arc spacing of m-th circle, $\phi_{mn}=2n\pi/N_m$ =angular position of mn-th element with $1\leq n\leq N_m$, θ,ϕ = polar, azimuth angle, k = wave number = $2\pi/\lambda$, λ=wavelength, I_m = excitation amplitude of elements on m-th ring between 0 and 1, j=complex number, θ_o,ϕ_o=scan angle.

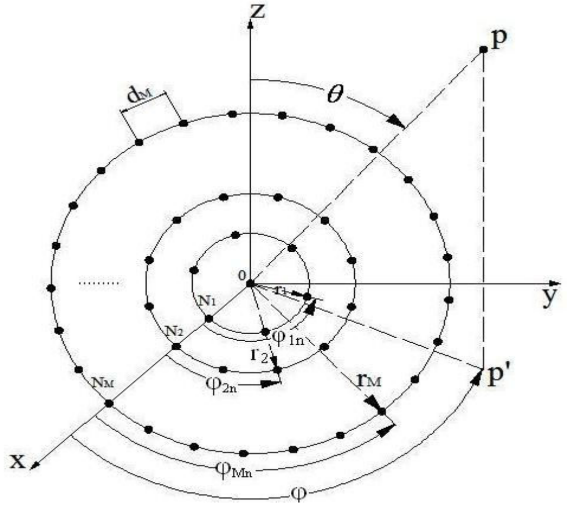

Figure.1 Concentric ring arrays of isotropic antennas in XY plane

III. FITNESS FUNCTION

The fitness function to be minimized with the proposed modified PSO for optimal synthesis of array is given in eqn. (3).

$$\begin{aligned}&If\ FNBW\leq 24.6^{\circ},\ Fitness=\max\ SLL\\&Else\ Fitness=1000\end{aligned} \tag{3}$$

Where max SLL is the value of maximum side lobe level.

IV. PSO ALGORITHM WITH SELF-ADAPTED MAXIMUM VELOCITY

Particle swarm optimization [6-11] emulates the swarm behavior of insects, animals herding, birds flocking, and fish schooling where these swarms search for food in a collaborative manner. Each member in the swarm adapts its search patterns by learning from its own experience and other member's experiences. These phenomena are studied and mathematical models are constructed. In PSO, a member in the swarm, called a *particle,* represents a potential solution, which is a point in the search space. The global optimum is regarded as the location of food.

PSO emulates the swarm behavior and the individuals represent points in the *D*-dimensional search space. A particle represents a potential solution. The particle swarm optimization used in this paper is a real-coded one.

The steps involved in the proposed PSO are given below:

Step1: Initialize positions and associated velocity of all particles (potential solutions) in the population randomly in the D-dimension space.

Step2: Evaluate the fitness value of all particles.

Step3: Compare the personal best (*pbest*) of every particle with its current fitness value. If the current fitness value is better, then assign the current fitness value to *pbest* and assign the current coordinates to *pbest* coordinates.

Step 4: Determine the current best fitness value in the whole population and its coordinates. If the current best fitness value is better than global best (*gbest*), then assign the current best fitness value to *gbest* and assign the current coordinates to *gbest* coordinates.

Step5: Update velocity (V_{id}) and position (X_{id}) of the d-th dimension of the i-th particle using the following equations:

$$\begin{aligned}V_{id}^{t}&=w(t)*V_{id}^{t-1}+c_1*rand1_{id}^{t}*\left(pbest_{id}^{t-1}-X_{id}^{t-1}\right)\\&+c_2*\left(1-rand1_{id}^{t}\right)*\left(gbest_{d}^{t-1}-X_{id}^{t-1}\right)\end{aligned} \tag{4}$$

$$\begin{aligned}&If\ V_{id}^{t}>V_{\max}^{d}\ \ or\ \ V_{id}^{t}<V_{\min}^{d}\\&then\ V_{id}^{t}=U(V_{\min}^{d},V_{\max}^{d})\end{aligned} \tag{5}$$

$$X_{id}^{t}=rand2_{id}^{t}*X_{id}^{t-1}+(1-rand2_{id}^{t})*V_{id}^{t} \tag{6}$$

Where c_1, c_2 = acceleration coefficients=2.0, w=inertia weight linearly damped with iterations starting at 0.9 and decreasing linearly to 0.4 at 80% of the total number of iteration and thereafter it remains constant at 0.4 unto the last iteration, *rand*1, *rand*2 are uniform random numbers between 0 and 1, different value in different dimension, t is the current generation number.

Eqn.(5) has been introduced to clamp the velocity along each dimension to uniformly distributed random value between $V_{\min}^{d}$ and $V_{\max}^{d}$ if they try to cross the desired domain of interest. These clipping techniques are sometimes necessary to prevent particles from explosion. The maximum velocity is set to the upper limit of the dynamic range of the search $(V_{\max}^{d}=X_{\max}^{d})$ and the minimum velocity $(V_{\min}^{d})$ is set to $(-X_{\max}^{d})$. Maximum velocity ($V_{\max}^{d}$) is self-adjusted to 0.99 $V_{\max}^{d}$ in the present generation only if there is no change of best fitness value between the previous and the present generation.

However, position-clipping technique is avoided in modified PSO algorithm. Moreover, the fitness function evaluations of errant particles (positions outside the domain of interest) are skipped to improve the speed of the algorithm.

Step 6: Repeat steps 2-5 until a stop criterion is satisfied or a pre-specified number of iteration is completed, usually when there is no further update of best fitness value.

V. NUMERICAL RESULTS

We consider a planar array of ten concentric rings [2]. In the example, the number of elements in each ring of the array antenna is made equal to 4m, where m is the ring number counted from the innermost ring 1. Total number of isotropic elements including the central element in such an array is 221.Elements are equi-spaced on a common ring with inter-element arc spacing of 0.5λ. The central element is fed with uniform amplitude and zero degree phase.

The maximum side lobe level and first null beamwidth of the CRA with uniform amplitude excitation are found out to be –17.70 dB and 24.60 degree respectively when the main beam is scanned to 30 degree off the boresight.

Problem is now to find the optimal set of radial amplitude distribution between 0 and 1 that will focus the main beam to 30 degree off the boresight in the XZ plane with minimum side lobe level while keeping the desired first null beamwidth unchanged, i.e 24.6 degree.

Table I Obtained results

Design parameters	**Synthesized scanned CRA with fixed FNBW and radially varying amplitude**	**Scanned CRA with uniform excitation amplitude**
Side lobe level (SLL, in dB)	-21.39	-17.70
First null beamwidth (FNBW, in degree)	24.60	24.60

Number of particles in the proposed particle swarm optimization is taken to be 20 and the algorithm is run for 80 generations. The maximum number of generation is kept at a value when there is no further update of best fitness value. Obtained results and its comparison to a uniformly excited array are shown in Table I. Table II shows optimum amplitude distribution obtained by the proposed PSO. Results clearly show that varying amplitude radially while keeping the first null beamwidth same as that of a uniformly excited array can reduce the side lobe level further.

Fig.2 shows normalized absolute power patterns in dB in XZ plane for uniform amplitude CRA scanned to 30 degree, optimum amplitude CRA scanned to 30 degree with fixed FNBW.

Table II Optimum radial amplitude distribution

Ring no.	**Optimum radial amplitude distribution for fixed FNBW**	**Number of elements**
1	0.2131	4
2	0.1520	8
3	0.4504	12
4	0.2031	16
5	0.2297	20
6	0.2827	24
7	0.1614	28
8	0.1338	32
9	0.1251	36
10	0.4894	40

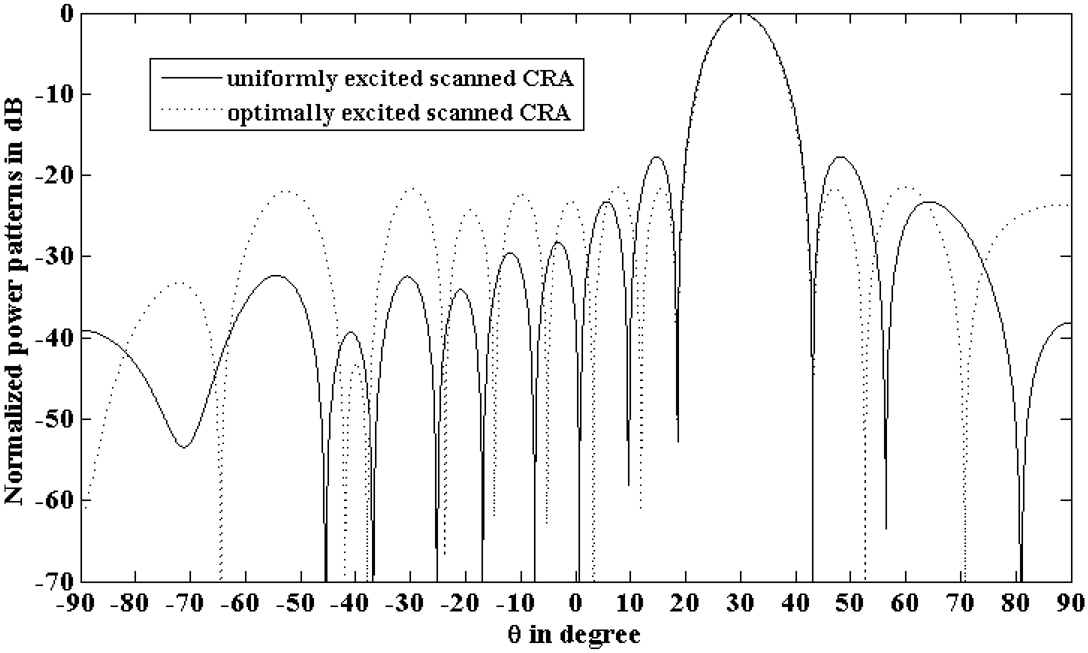

Figure. 2 Normalized absolute power patterns in dB in XZ plane for uniformly excited scanned CRA, optimally excited scanned CRA with fixed FNBW

VI. CONCLUSIONS

The proposed particle swarm optimization with self-adapted maximum velocity is used in the paper for synthesis of a concentric ring antenna array to scan a beam to 30 degree off the boresight in the vertical plane with reduced side lobe level while keeping the first null beamwidth same as that of a uniformly excited CRA scanned to 30 degree. Amplitude distribution is optimized radially to meet the desired requirements. Results show that maximum side lobe level is lower than that of a uniformly excited CRA if amplitude is varied radially, although first null beamwidth in both the cases is same.

Results for a concentric ring isotropic antenna array have illustrated the performance of this proposed technique. This method is very simple and can be applied in practice to design an array of other shapes.

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