Synthesis of Conical Conformal Array Antenna Using Invasive Weed Optimization Method

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Abstract ─ Invasive weed optimization (IWO), which shows high performance in the electromagnetic community, is used to synthesize the conical conformal array antenna in this paper. Radiation pattern of the conformal array antenna is obtained by the superposition of the active element radiation pattern in the presence of platform, which includes the mutual coupling information of the array antenna and effects of the platform. Compared with partial swarm optimization (PSO), performance of IWO is more stable and lower side-lobe is obtained with IWO. A linear antenna array mounted on conical carrier is optimized and fabricated, measured results agree well with the optimized results. In addition, the proposed method can be used for the pattern synthesis of any kind of antenna array.

Index Terms ─ Conical conformal array antennas, invasive weed optimization, and radiation pattern.

I. INTRODUCTION

Conformal array antennas have the advantages of aerodynamic superiority, wide angle coverage and volume saving, so it is a very hot topic in antenna design society and have attracted more attention in different applications such as aircraft, missile, and satellite.

For synthesis of conformal array antenna, it is an inverse problem and in many cases nonlinear. At the same time, there is usually no unique solution to the problem [1]. So globe optimized methods are often used to address this issue. Simulated annealing (SA) is used to synthesize the cylindrical arrays for a desired radiation pattern in [2]. Genetic algorithm (GA) is also used for pattern synthesis of arrays mounted on arbitrarily-shaped three-dimensional platforms in [3]. Conformal array antenna pattern are optimized by hybrid optimization method named HIGAPSO in [4]. Pattern of conformal array antenna in the presence of platform is synthesized with difference evolution (DE) in [5]. The element layout of conformal array antenna is optimized with PSO in [6]. By introducing time sequences, a 4D conformal array antenna is proposed and optimized with DE in [7]. The active element pattern (AEP) is employed in [8] to compute the radiation pattern of the conformal array antenna. However, GA and DE have the operations of selection, crossover, and mutation, so they are complicated to implement. Compared with GA and DE, PSO has the advantages of simple locations and velocities updating formulas, while convergence of the PSO algorithm depends on the choice of boundary conditions and the maximum velocity. As we know, they are difficult to perceive, so it always makes the PSO be trapped in local minima.

A new numerical stochastic optimization algorithm called invasive weed optimization (IWO) was proposed by Mehrabian and Lucus in 2006 [9]. It has been recently introduced to electromagnetics community and shown high performance in the synthesis of antenna array. Features of IWO are discussed in [10]. In [11-14], IWO was used to optimize the patterns of the linear and planar array antenna. Reflector antenna is optimized with IWO in [15] to form cosecant squared pattern. A meander-shaped MIMO antenna for wireless applications is designed using IWO in [16]. A broadband patch antenna with symmetric radiation pattern was designed using

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IWO in [17]. Directivity of Yagi-Uda antenna is optimized with IWO in [18]. It is found that the IWO outperforms the other methods such as GA and PSO. IWO has the features of easy implementation and skipped local minima. So the issues discussed above have been addressed by IWO.

Beam direction and side-lobe of the conformal array antenna mounted on conical carrier are optimized in this paper. With the active element radiation pattern, mutual coupling and the effects of the platform are considered in the synthesis of the antenna array. Compared with PSO, performance of IWO is more stable and lower side-lobe is obtained. The optimized radiation pattern is verified by the measured results. Both of them agree well with each other.

II. INVASIVE WEED OPTIMIZATION METHOD

IWO has the features of fast reproduction and distribution, robustness, and adaptation to the changes in the environment [17]. In this paper, only the main steps of the IWO are given, which includes initialize a population, reproduction, spatial dispersal, and competitive exclusion. Details of IWO can be found in [9, 10]. The flowchart of IWO is shown in Fig. 1 [10].

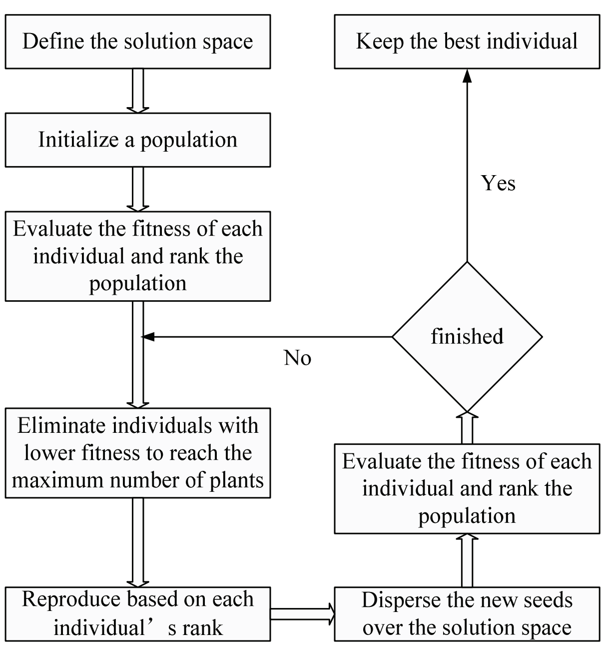


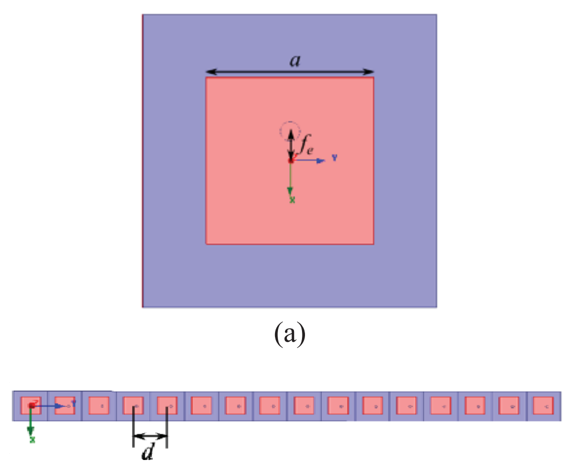
Fig. 1. Flowchart of IWO.

III. SYNTHESIS OF CONICAL CONFORMAL ARRAY ANTENNA WITH IWO

A 16 element linear array mounted on conical carrier is considered in this paper. As shown in Fig. 2, conventional rectangular microstrip antenna operated at 10 GHz is chosen as the radiation element and the distance between each element is 0.57 λ_0. Dimensions of conical carrier and position of antenna array on the conical carrier are shown in Fig. 3. Apparently, the array factor theory can not be used here because every element has different radiation pattern. In addition, to consider the mutual coupling and effects of the platform, active element radiation pattern is calculated firstly, and then radiation pattern of the conformal array antenna is obtained by the superposition of the calculated active element radiation pattern. So the total electric field should be obtained using equation (1) rather than the array factor theory,

$$\vec{E}(\theta,\varphi)=\sum_{n=1}^{N}\vec{E}_n(\theta,\varphi) \tag{1}$$

where $\vec{E}_n(\theta,\varphi)$ is the electric field radiated by the nth element in the presence of the other elements with matching loading and the platform; N is the number of the element.



(a)

(b)

Fig. 2. Configuration of the antenna element and array (a) antenna element and (b) antenna array with substrate characteristics of: $\varepsilon_r = 2.55$, $h = 1$ *mm* and dimensions: $a = 8.55$ *mm*, $f_e = 1.5$ *mm*, $d = 17$ *mm.*

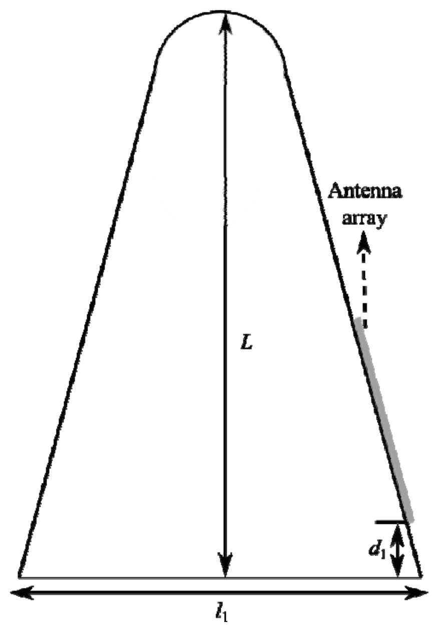


Fig. 3. Configuration of conical carrier and position of the antenna array dimensions: L = 1388 *mm*, l_1 = 400 *mm*, and d_1 = 65 *mm*.

Beam direction and side-lobe are optimized with PSO and IWO at the same time in this paper. The objective function is defined as,

$$f = abs(\theta - \theta_s) + \max(PSLL) \tag{2}$$

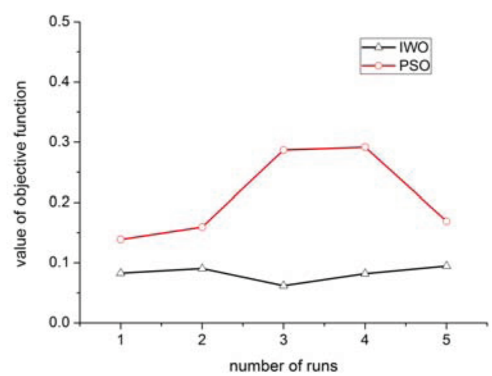
where θ_s defines the desired beam direction and PSLL defines the peak side-lobe level. The parameters used in IWO and PSO are shown in Tables I and II, respectively. Both IWO and PSO run 5 times. The objective function values of PSO and IWO are shown in Fig. 4 (a), it is found that IWO outperforms PSO, lower objective function values is obtained with stable characteristics. As shown in Fig. 4 (b), with the same beam direction, lower side-lobe is achieved using IWO. Optimized radiation pattern with different beam direction and low side-lobe is shown in Fig. 5, it is found that the desired beam direction and low side-lobe is obtained. When the beam scans to 20°and 30°, the PSLL is below -20 dB. However, when the beam scans to 45°, the PSLL is only below -15 dB, which is because of strong coupling at the large scanning angle. The optimized amplitude and current distribution for different beam direction are shown in Table III to IV.

Table I: Parameters used in the IWO.

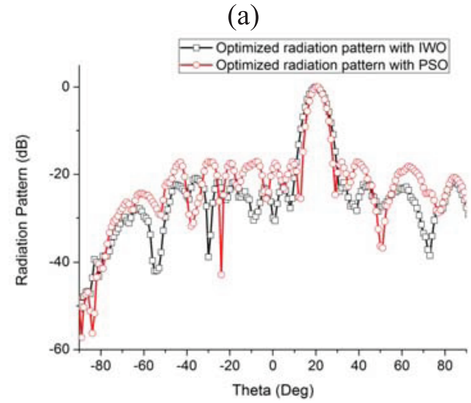
Number of initial population (n_ini)	maximum number of iterations (Iter_max)	maximum number of plants (P_max)	maximum number of seeds (S_max)
80	500	20	5
minimum number of seeds (S_min)	nonlinear modulation index (N)	initial value of standard deviation (SD_initial)	final value of standard deviation (SD_final)
0	3	8	0.1

Table II: Parameters used in the PSO.

Number of initial population (n_ini)	maximum number of iterations (Iter_max)	inertia weight (c_0)
100	500	From 0.9 to 0.4
acceleration constant (c_1)	acceleration constant (c_2)	
2	2	



(a)



(b)

Fig. 4. Performance comparisons of PSO and IWO (a) objective function values obtained from IWO and PSO and (b) radiation pattern optimized by IWO and PSO.

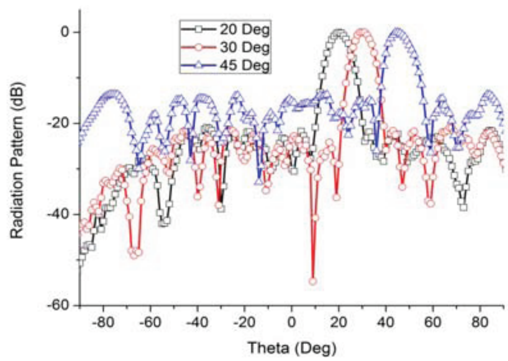


Fig. 5. Optimized radiation patterns using IWO.

Table III: Amplitude and phase distribution for beam steering 20°.

	20°	
	amplitude	phase（°）
element 1	0.1770	-3.3060
element 2	0.2110	37.3568
element 3	0.4673	-120.3727
element 4	0.3936	150.4874
element 5	0.9127	99.8322
element 6	0.9697	18.8790
element 7	0.9014	-50.3172
element 8	1	-127.3227
element 9	0.7963	-176.9294
element 10	0.9923	100.8692
element 11	0.8506	23.3366
element 12	0.4353	-28.2354
element 13	0.5723	-98.4571
element 14	0.4217	171.3889
element 15	0.1687	151.0317
element 16	0.1072	-8.7032

IV. EXPERIMENTAL RESULTS

To verify the optimized amplitude and phase distributions for each antenna element, a prototype is fabricated and measured. The amplitude distribution is realized by the power divider and attenuator, while the phase distribution is obtained by the phase shifter. The feeding network is shown in Fig. 6. Then it was connected with the fabricated antenna array. As shown in Fig. 7, the integrated antenna array is measured in microwave chamber. Measured radiation patterns are shown in Fig. 8. It is found that measured results agree well with the simulated results in the main lobe area, while there is a discrepancy in the other area, it is caused by the excitation distribution errors and measurement errors. The desired beam direction and PSLL is achieved with the optimized amplitude and phase distribution.

Table IV: Amplitude and phase distribution for beam steering 30°.

	30°	
	amplitude	phase（°）
element 1	0.4841	108.9365
element 2	0.5848	-32.8935
element 3	0.4143	176.2590
element 4	0.6218	132.2616
element 5	0.9003	25.5654
element 6	0.8957	-87.5250
element 7	0.8208	174.5344
element 8	0.9176	80.4261
element 9	1	-30.5902
element 10	0.6969	-128.1878
element 11	0.8237	136.1176
element 12	0.6475	37.6376
element 13	0.6943	-67.7924
element 14	0.5238	-153.1115
element 15	0.4699	66.2053
element 16	0.0797	-91.6561

Table V: Amplitude and phase distribution for beam steering 45°.

	45°	
	amplitude	phase（°）
element 1	0.4225	133.0532
element 2	0.6560	-30.1147
element 3	0.8442	175.1303
element 4	0.9120	-7.1963
element 5	0.8937	-169.5497
element 6	0.8539	78.8734
element 7	0.9118	-55.9150
element 8	1	131.3334
element 9	0.9302	-25.2101
element 10	0.8865	-159.4427
element 11	0.4443	40.8061
element 12	0.9286	-111.8184
element 13	0.7290	126.1195
element 14	0.5152	-40.1529
element 15	0.7749	-169.8648
element 16	0.3710	13.9916

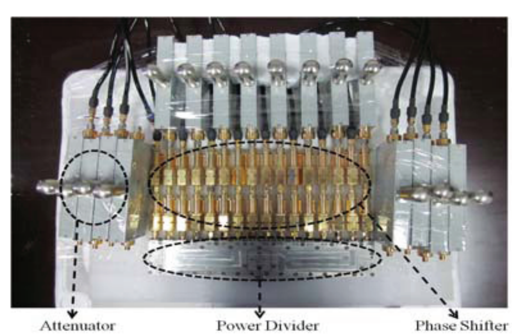


Fig. 6. Feeding network.

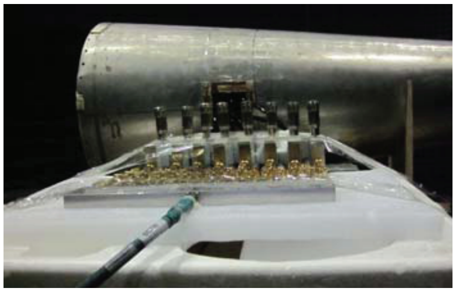
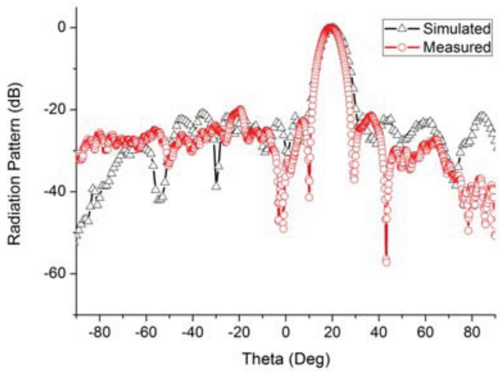
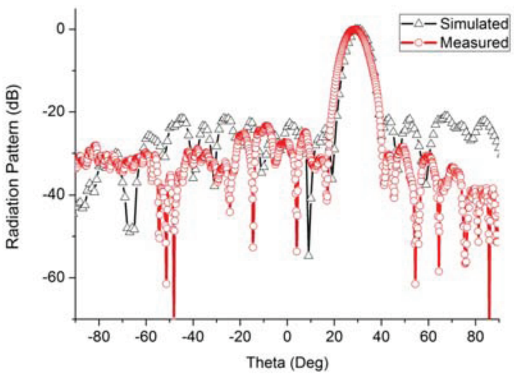


Fig. 7. Integrated antenna array.



(a)



(b)

Fig. 8. Measured and simulated radiation pattern (a) beam steering 20° and (b) beam steering 30°.

V. CONCLUSIONS

Conical conformal array antenna is synthesized using IWO because of its better performances in this paper. With the active element radiation pattern, mutual coupling and the effects of platform are considered. Radiation pattern with desired beam direction and low side-lobe for a linear antenna array are optimized in the presence of the platform with the proposed universal method. The measured results demonstrated the effectiveness of the proposed method. -20 dB peak side-lobe levels is achieved when the antenna array scan to 20°and 30°.

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