Antenna Array Pattern Nulling by Phase Perturbations using Invasive Weed Optimization

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***Abstract*:**

Low side lobe levels and asymmetrical multiple nulls in specified directions need to be achieved for increasing the efficiency of antenna arrays used in communication systems. Nature inspired algorithms like Invasive Weed Optimization (IWO) algorithm may be applied for synthesis of linear antenna arrays to estimate the element phase excitations for achieving nulls in undesired directions. Several numerical results of periodic array patterns with the imposed asymmetrical multiple null conditions are presented to illustrate the performance of the proposed method.

Keywords: antenna array, asymmetrical nulls, null steering, phase excitations, Invasive Weed Optimization.

I. INTRODUCTION

Antenna arrays [1] are being widely used in wireless, satellite, mobile and radar communications systems. The use of antenna arrays has extended system coverages, improved signal quality and increased the spectrum efficiency through the capability for formation of steerable beams while increasing the directivity. The performance of the communication system greatly depends on the efficient design of the antenna arrays. To meet the demands of long distance coverage and noise free communication, it is necessary to design the antenna array with high directivity, narrow beam width and low side lobe levels while enhancing its ability to control nulls in directions of undesired interferences.

Systems with narrow beam width are desired for obtaining high directivity. On the other hand, systems need to maintain low side lobe levels (SLL) to avoid interference with other systems operating in same frequency band. The above mentioned requirements of SLL and beam width are in contrast to each other as arrays with narrow beam width generally do not produce lower side lobe levels and vice versa. Also, the increasing EM pollution has prompted the placing of nulls in undesired interference directions. So it is necessary to design the antenna array with low side lobe levels while maintaining fixed beam width and placing nulls in interference directions.

Low sidelobe levels and steering nulls in interference directions can be achieved by adjusting either the amplitude excitations or the phase excitations or the complex excitations of a periodic array. Otherwise the spacing between the individual elements may also be varied to form an aperiodic array. In communication environment, multiple nulls need to be positioned asymmetrically at multiple locations around the main beam. Position-only and amplitude-only optimizations are incapable of producing the asymmetrical nulls. For this purpose phase needs to be optimized. Thus, phase-only or complex optimization is of practical interest in producing the asymmetrical nulls around the main beam. Synthesis of linear antenna arrays has been extensively studied from the past 5 decades [2-12]. In order to optimize this type of electromagnetic designing problems, nature inspired algorithms based on the nature laws such as genetic algorithm (GA) [2-6], Particle swarm optimization (PSO) [6-8], Ant colony optimization (ACO) [9-10] have been successfully applied in the design of antenna array synthesis.

The present work deals with an efficient nature inspired algorithm, the Invasive Weed Optimization (IWO) algorithm. IWO was introduced by A. R. Mehrabain and C. Lucas in 2006 [11]. IWO is inspired by weed colonization in nature and is based on weed biology and ecology. Due to its global and local exploration abilities, it is useful for antenna array synthesis. IWO has been successfully applied to antenna array synthesis problems by optimizing the amplitude excitations and position of individual elements [12] for minimizing sidelobe levels.

In this paper, the IWO is applied to optimize phase excitations of the individual elements to produce a radiation pattern with minimum side lobe levels while steering the nulls in directions of interferences. The configuration of the linear array and the problem formulation is discussed in Section II. Section III presents the IWO algorithm. Design example and detailed simulation results are discussed in section IV while Section V concludes the paper.

II. PROBLEM FORMULATION

The geometry of a 2N element linear antenna array placed symmetrically along x axis is shown in figure 1.

The array factor (AF) [6] of the array in the azimuth plane is

$$AF(\theta) = \sum_{n=1}^{N} A_n e^{j(2\pi(d/\lambda)\sin(\theta))} \qquad (1)$$

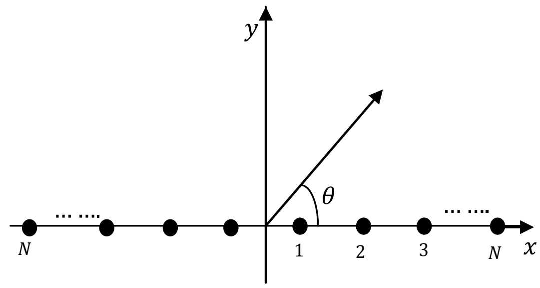

Fig. 1. Geometry of the symmetrically placed linear array.

where θ is the azimuth angle, $d/\lambda = 1/2$ is the spacing between the elements normalized by the wavelength and $A_n = I_n e^{\varphi_n}$, I_n and φ_n are the excitation amplitude and phase of element n respectively.

The goal of the optimization is to minimize the side lobe level and to control null orientations by employing non uniform phase excitations on individual elements of the antenna array, i.e., by varying φ_n . Therefore, the fitness function [7, 8] is given as

$$Fitness\ function = \sum_i \frac{1}{\Delta\theta_i} \int_{\theta_{li}}^{\theta_{ui}} |AF(\theta)|^2\ d\theta + \sum_k |AF(\theta_k)|^2 \qquad (2)$$

Where θ_{li} *and* θ_{ui} are the spatial regions in which side lobe level is minimized, θ_k's are the angular positions of nulls and $\Delta\theta_i = \theta_{ui} - \theta_{li}$. The first term in the equation solves for the minimization of side lobe level and second term solves for controlling of nulls.

III. INVASIVE WEED OPTIMIZATION (IWO)

The steps involved in the IWO are presented below.

1. Initialization

A finite number of seeds are initialized randomly in the N dimensional solution space with random positions. Each seed's position represents one possible solution of the optimization problem.

2. Reproduction

In reproduction stage the fitness value of each seed is determined. This process resembles growing of seed to flowering weed. The magnitude of the fitness value determines the reproductive capability of each seed. The number of reproduced seeds from each seed is calculated based upon the seed's own fitness value and the colony's lowest & highest fitness values. Thus, the number of seeds produced increases linearly from weed with worst fitness to weed with better fitness. That is, those weeds with worst fitness values produce less number of seeds and vice versa. The procedure is illustrates in figure 2. A significant advantage of the algorithm is that it allows all weeds to participate in the reproduction process. This is beneficial because under certain conditions, weed with worst fitness value may also have some useful information to contribute during the evolutionary process.

3. Spatial dispersal

The produced seeds are dispersed randomly over the search space by normal distribution with zero mean and varying standard deviation. That is, the produced seeds are scattered around the mother weed, leading to local search. The number of seeds (S) produced by each weed is given by

$$S = Floor\left[S_{min} + \left(\frac{f - f_{min}}{f_{max} - f_{min}}\right) S_{max}\right] \qquad (3)$$

where S_{max} and S_{min} are maximum and minimum number of seeds that may be produced from each weed respectively. f_{max} and f_{min} are maximum and minimum fitness values in the colony.

The standard deviation (σ_g) of the distribution at generation number g reduces nonlinearly over the generations ranging from initial standard deviation ($\sigma_{initial}$) to final standard deviation (σ_{final}) and is given by

$$\sigma_g = \frac{(gen_{max} - g)^{nl}}{(gen_{max})^{nl}} \left(\sigma_{initial} - \sigma_{final}\right) + \sigma_{final} \qquad (4)$$

Where gen_{max} is the maximum number of generations and nl is the non linear modulation index.

4. Competitive exclusion:

The new seeds produced grow to flowering weeds and are placed together with parent weeds in the colony. So there is a need of limiting the number of weeds and elimination is done based on the fitness values of the weeds in the colony. Weeds with worst fitness are eliminated until the maximum number of weeds (P_{max}) in the colony is reached. Thus weeds with better fitness survive. Previous work [11] has shown that IWO algorithm gives better performance when the P_{max} is chosen between 10 and 20. The selected P_{max} goes to the next generation. The steps involved in the IWO algorithm are shown in figure 2.

IV. NUMERICAL EXPERIMENTS

In this paper, a 10 element linear array is synthesized using the method of IWO. The element spacing of the array is taken as $\lambda/2$, where frequency of operation is 300MHz. The mutual coupling between the antenna elements is ignored in this analysis. IWO is applied to optimize phase excitations of the individual elements for obtaining deep nulls at different interference directions. The amplitudes of the elements are determined by a 30dB Taylor profile. The obtained results are compared to the non-optimized periodic array with a 30dB Taylor profile amplitude distribution, referred to herein after as TADPA. The desired first null beam width is maintained constant at 35^0, which is the beam width of the non-optimized 10 element TADPA. The beam width tolerance was set at $\pm 5\%$.

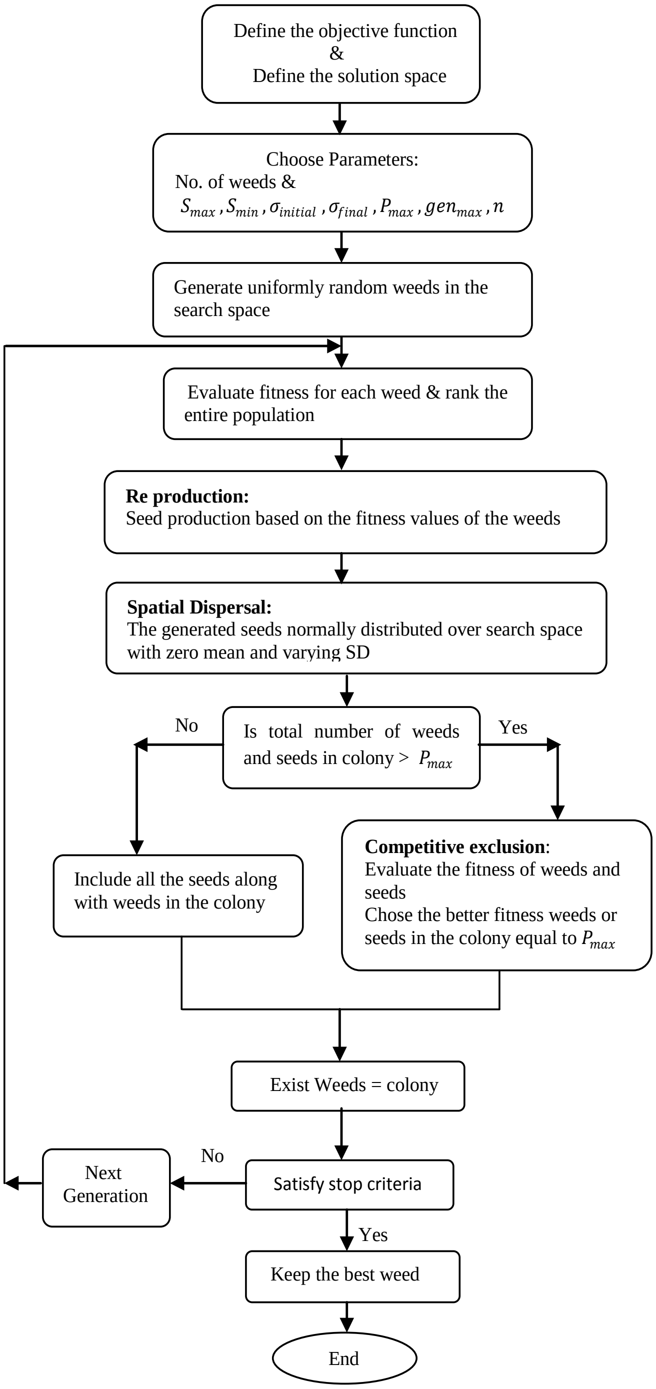

Figure 2. Flow chart of IWO.

IWO algorithm is implemented using MATLAB. The parameters of the IWO algorithm are given in the Table I. These parameters were set after experimental verification while complying with the guidelines provided in literature [11, 12]. The radiation pattern of the array is computed at 720 angles in the azimuth region of -90^0 to 90^0. All the

Table I. Parameter setup for IWO

Parameter	S_{max}	S_{min}	$\sigma_{initial}$	σ_{finial}	P_{max}	nl	Pop. size
Value	4	0	0.015	0.00015	20	3	10

computations are performed on a PC operating at 3GHz with 2GB of RAM. The optimized phase excitations are summarized in Table II.

The first example illustrates the synthesis of a 10 element TADPA with two nulls imposed at 21^0 and 40^0. The obtained far field radiation pattern and the corresponding convergence of the fitness value by controlling the phase excitations, while maintaining a Taylor profile for the amplitude excitations is shown in figures 3 and 4 respectively.

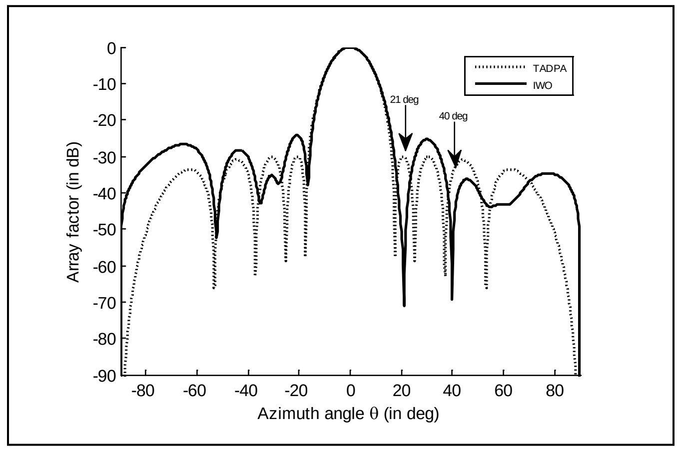

Figure 3. The normalized radiation pattern with imposed nulls at 21^0 and 40^0.

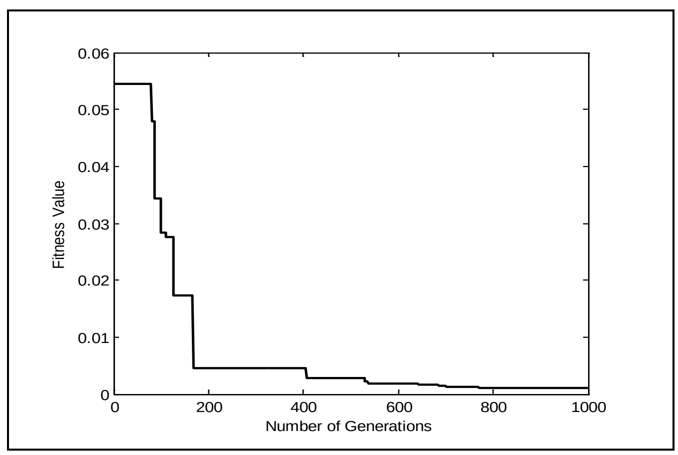

Figure 4. The fitness value of IWO algorithm for optimizing phase excitations of TADPA with nulls imposed at 21^0 and 40^0.

Figure 5 shows the far field radiation pattern with two nulls imposed at 31^0 and -45^0 by optimizing the phase excitations of the TADPA. The convergence of the fitness value for the 10 element array with imposed nulls at 31^0 and -45^0 using IWO is shown in figure 6. It is seen from figures 3 and 5, that nulls as deep as -70dB are obtained at the interference directions, while maintaining the PSLL less than -25dB and FNBW same as that of TADPA.

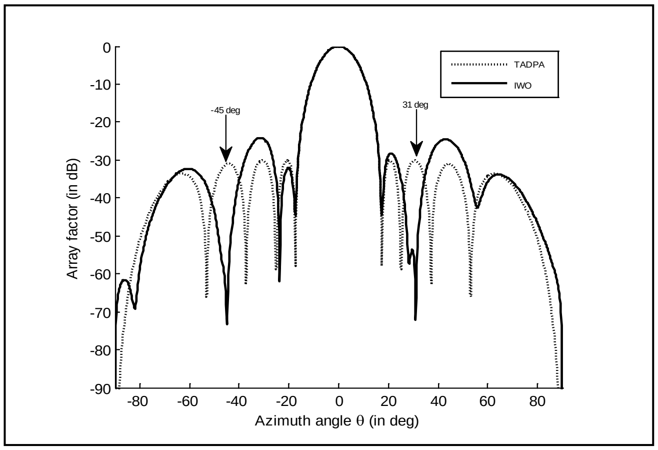

Figure 5. The normalized radiation pattern with imposed nulls at 31^0 and -45^0.

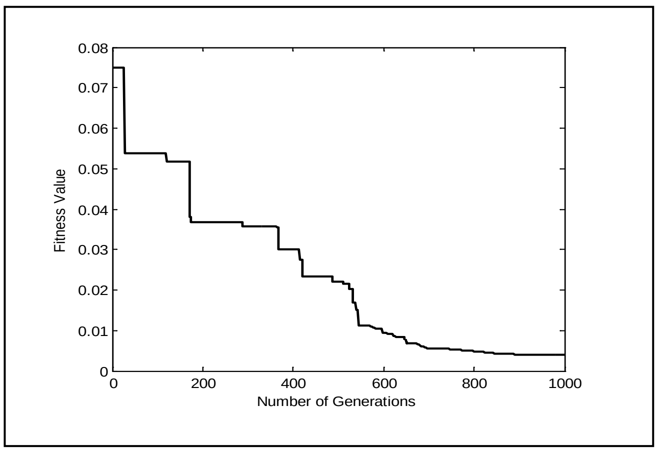

Figure 6. The fitness value of IWO algorithm for optimizing phase excitations of TADPA with nulls imposed at 31^0 and -45^0.

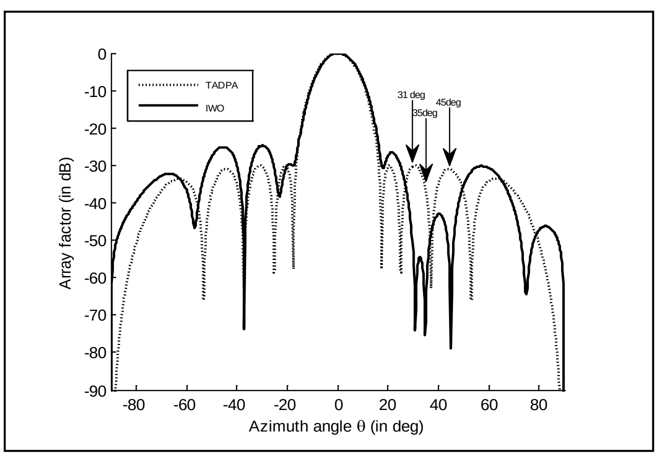

Figure 7. The normalized radiation pattern with imposed nulls at 31^0, 35^0 and 45^0 .

In the third example, the synthesized pattern with three nulls imposed at different interference directions is presented. The normalized array pattern obtained with imposed nulls at 31^0, 35^0 and 45^0 obtained using the optimized phase excitations and the corresponding convergence curve is shown in figure 7 and 8 respectively. It is seen from figure 7, the IWO algorithm is able to place three nulls as deep as -75dB at imposed null directions.

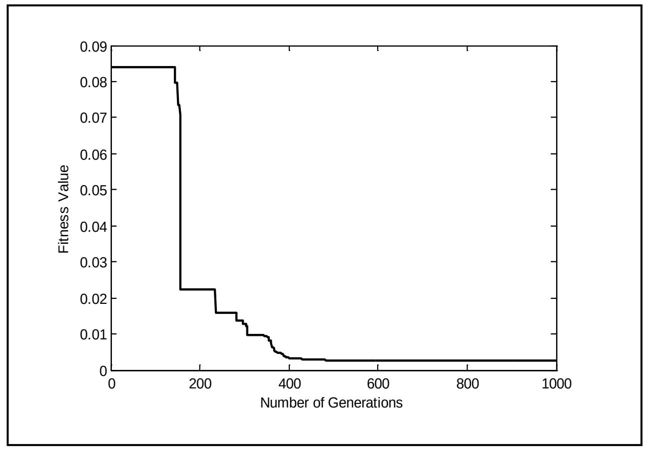

Figure 8. The fitness value of IWO algorithm for optimizing phase excitations of TADPA with nulls imposed at 31^0, 35^0 and 45^0 .

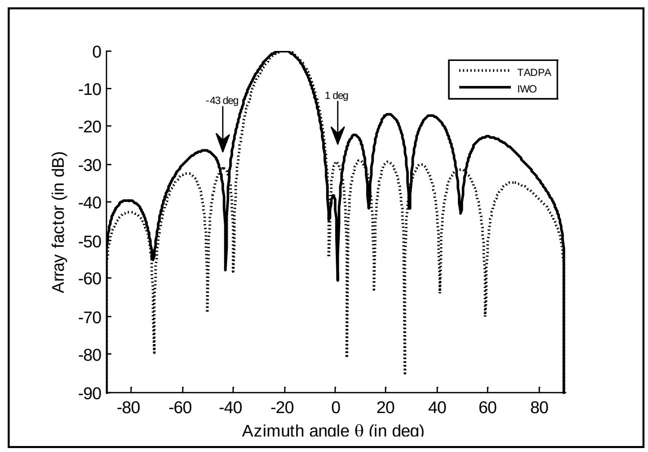

Figure 9. The normalized radiation pattern with imposed nulls at 1^0 and -43^0. The main beam steered to -22^0.

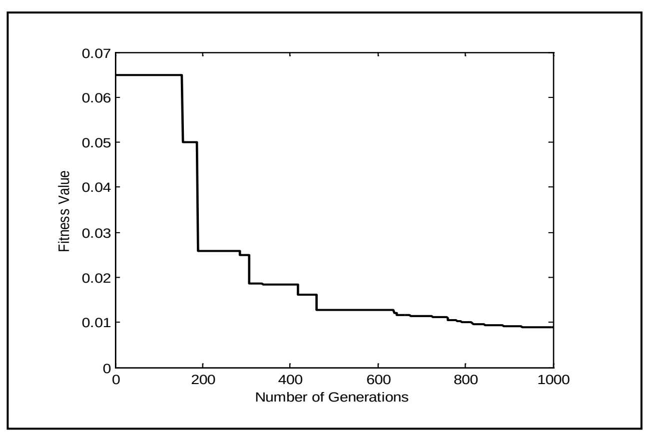

Figure 10. The fitness value of IWO algorithm for optimizing phase excitations of TADPA with nulls imposed at 1^0 and -43^0.

In the fourth example, the pattern with main beam steered to -20^0 and two nulls imposed along the direction of the first sidelobe peaks (1^0 and -43^0) of TADPA radiation pattern is presented in figure 9. The convergence of the fitness value for the 10 element array with imposed nulls at 1^0 and -43^0 is shown in figure 10.

The above four examples demonstrate that by proper synthesis it is possible to create pattern nulls in the exact directions as dictated by application at hand. This synthesis is correct irrespective of whether the multiple null directions are very close to each other or are adjacent to the main beam.

Table II. Optimized phase excitations obtained with IWO for steering nulls in undesired interference directions.

Design Example	Optimized Phase Excitations (in deg)
1	166.6397 179.7179 175.2662 -172.2740 180.0004 -180.0004 174.7550 -176.0513 176.6093 180.0004
2	-12.9319 -18.3069 -9.4872 -17.5998 -20.1056 -11.6578 -14.6727 -19.5123 -14.1654 -10.4391
3	-14.2150 7.7482 -1.6168 -1.3697 1.6081 -0.1567 0.2728 -6.3940 -18.7289 -3.3715
4	12.9218 -51.3428 -9.6337 -17.0335 -12.7361 -9.4612 -8.2530 -11.7143 29.4120 -28.7625

V. CONCLUSION

IWO is successfully applied for the synthesis of linear array by optimizing phase excitations of the individual elements. The obtained results are compared with the pattern of the 30 dB Taylor amplitude distributed periodic array. Results show that, nulls as deep as around -70dB are achieved in the interference directions while maintaining low PSLL (< -25dB) for the design examples. This phase-only optimization method using IWO offers a new degree of flexibility over the conventional method of amplitude- only optimization by placing nulls asymmetrically at multiple locations. Thus the performance of the wireless communication systems can be greatly enhanced by incorporating these proposed array design. This design will help in management of jammers and interferes by proper null placement.

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Lakshman Pappula was born in Srikakulam, Andhra Pradesh, India. This author became a student graduate member of IEEE in 2012. He received MSc degree from Andhra University in 2006, Visakhapatnam, India in Electronics and communication and received MTech degree in Microwave Engineering from GITAM University in 2010, Visakhapatnam, India. Currently he is working toward PhD degree at IIT Bhubaneswar, Odisha, India. His research interests include antenna design, antenna array synthesis, optimization methods applied to electromagnetic problems, EMI/EMC.

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