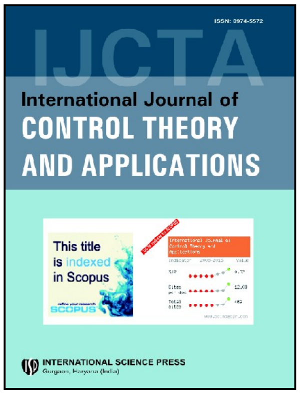

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Array Synthesis of Circular and Planar Antenna Arrays for Pattern Nulling Using Invasive Weed Optimization Algorithm

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Abstract: The current work presents the implementation of a metaheuristic algorithm Invasive Weed Optimization (IWO) for pattern nulling of Antenna array radiation pattern in prescribed directions. The IWO Algorithm is implemented for pattern nulling Synthesis of Uniform Circular (CA) and Planar Arrays (PA) by optimizing only amplitudes of array elements. Two design examples of introducing Deeper Nulls in both symmetrical and unsymmetrical directions are presented using IWO and compared with Real Coded Genetic Algorithm (RCGA). Numerical results illustrate that IWO is better in producing deeper Nulls and also in the rate of convergence for both Planar and Circular Arrays when compared with RCGA.

Keywords: Pattern Nulling, Planar Antenna Array, Circular Antenna Array, Invasive Weed Optimization (IWO).

1. INTRODUCTION

For most wireless applications, antenna arrays have found distinct benefits when compared to a single element antenna. More prominent benefits include an increase in directivity and spatial diversity. Optimization of radiation pattern characteristics (pattern synthesis) of antenna arrays involves increasing directivity, reducing Side lobe level and placing nulls in the required directions can be obtained by finding the optimized values, amplitudes, distance between array elements and progressive phase shift between the elements. Over the past decade a rapid growth in the utilization of wireless mobile devices and technologies has lead to enormous increase in electromagnetic pollution. One of the more efficient ways to decrease this pollution is to suppress the electromagnetic radiation in unwanted directions. This objective can be achieved by a process of placing deeper nulls in the unwanted directions of radiation pattern of antenna arrays. These pattern nulling techniques are helpful in several applications which include wireless mobile, satellite and Defense applications in order to reduce degradation in SNR [1].

In the past several metaheuristic (evolutionary optimization) approaches namely Genetic Algorithm (GA) [2], Particle Swarm Optimization Algorithm (PSO) [3], Tabu Search Algorithm (TSA) [4], Firefly Algorithm

(FA) [5], Differential Evolution Algorithm (DE) [6], Bees Algorithm (BA) were implemented for pattern synthesis and have been extensively studied.

In this paper the amplitude coefficients of planar and circular antenna arrays are optimized for pattern nulling with the help of IWO. IWO was first proposed by Lucas and Mehrabian in 2006 [7]. It is based on the colonization behavior of weeds. It has several advantages out of which the prominent being a faster convergence rate. IWO has found several applications and was utilized for different problems of computational electromagnetic [8, 9]. But, it is observed that the problem of pattern nulling using IWO is not exploited for planar and circular arrays to achieve optimal performance. Here, we present a detailed performance analysis of IWO for the design problem and compared with Real coded genetic algorithm (RCGA) to illustrate its superior performance.

2. PROBLEM GEOMETRY & BASICS

(A) Circular Array Antenna (CAA)

A CAA [10] consists of antenna elements placed in the form of a circular ring. The major uses of using this array are the ability to deflect beam electronically through 360 degree and complete the consequences of mutual coupling. Along with this it can produce directional patterns over the broad beam widths and non-symmetric about the main lobe.

The array factor of CAA includes the radius of circular ring 'a', excitation amplitudes indicated by 'E_n', phase and angular position of n^{th} element are α_n & ϕ_n respectively.

$$Array\,Factor = \sum_{n=1}^{N} E_n e^{j(ka\cos(\phi-\phi_n)\sin\theta+\alpha_n} \tag{1}$$

Circular antenna arrays are mainly used in applications like navigation systems, underground propagation system, RADAR and SONAR etc.

(B) Planar Array

A planar array[10] is an antenna array within which all of the antenna components are in one plane. It provides an outsized aperture and will be used for directional beam management by varying the relative phase of each component.

If M components are initially placed on coordinate axis along x direction, the array factor is expressed as

$$AF_{x_1} = \sum_{m=1}^{M} I_{m_1}\, e^{j(m-1)(kd_x \sin\theta\cos\phi+\beta_x)} \tag{2}$$

If N such arrays are placed along y direction, the resultant array factor is obtained by multiplying the array factors of individual linear arrays along their respective directions.

Consider I_{m1} and I_{1n} as I_0 to make all the excitation amplitudes uniform, the resultant array factor will be

$$AF = I_0\, \Sigma_{m=1}^{M} I_{m1}\, e^{j(m-1)(k\,d_x \sin\theta\cos\phi+\beta_x)}\; X\, \Sigma_{n=1}^{N} I_{1n}\, e^{j(n-1)(kd_y \sin\theta\cos\phi+\beta_y)} \tag{3}$$

Planar arrays are mainly used to get more directive and symmetric patterns, beam steering in two planes is possible and digital beam forming can be done. Its major application areas include remote sensing, search & tracking radar's and communications etc.

3. DESIGNING OF OBJECTIVE FUNCTION

The primary objective of the present work is to obtain optimum set of amplitude coefficients so as to generate a radiation pattern that produces Deep Nulls in the required direction, while simultaneously maintaining a minimum side lobe level. For this reason the below cost function [11] is minimized.

$$CF = C_1 * \frac{|\Pi_{i=1}^{m} AF(Null_i)|}{|AF_{Max}|} + C_2 * (SLL_{Current} - SLL_{Desired}) + C_3 * (FNBW_{computed} - FNBW_{1n=1}) \quad (4)$$

In the above equation the first term controls the Null directions, where the number of Nulls to be imposed is chosen as two. The second term reduces the side lobe level and the third term maintains a constant First Null Beam Width, which is same as the uniform excitation case. Also weighting coefficients c1, c2, c3 are utilized in order to control the significance of each term. Since the primary objective here to impose nulls in the required directions, the values of c1, c2, c3 are chosen as 18, 2, 1.

4. IWO ALGORITHM

In 2006 Meharbian and Lucus introduced a novel metaheuristic algorithm IWO that mimics the colonizing behaviour of invasive weeds. IWO [12] behaviour is as follows:

Weeds have the behaviour to invade a cropping field by distributing their seeds. These seeds invade the vacant places in the field randomly and emerge into subsequent flowering weeds by using the unutilized spaces in the field. A random number of weeds adapt well to the environment than others, and again produce a new set of seeds randomly across the vacant places and they subsequently emerge into flowering weeds and this process continuous until the entire crop field is occupied. The above behaviour is modelled into IWO algorithm and applied to current problem which is explained in following steps:

(A) Initialization

An initial population of finite number of weeds are generated which can be related to amplitude coefficients of the array elements keeping uniform separation distance at λ/2.

(B) Reproduction

Each generated member of the current population will generate new seeds dependant on fitness values of finite limit such that the number of newly reproduced seeds increases linearly in the range of S_{min} to S_{max}.

(C) Spatial Disposal

The new generation of seeds are distributed randomly using normal distribution by considering parameters like mean which is considered based on the location of producing weeds and irregular standard deviation (SD) . The SD for a given repetition is taken as

$$\sigma_{iter} = \frac{(it_{max} - it)^n}{(it_{max})^n} * (\sigma_{Initial} - \sigma_{Final}) + \sigma_{Final} \quad (5)$$

Here it_{max} is the maximum number of iterations. $\sigma_{Initial}$ And σ_{final} are defined initial and final standard deviations, respectively and n is the nonlinear modulation index.

IWO is modified slightly from the original behaviour of Weeds by eliminating those weeds with lower fitness and only allowing the higher fitness weeds to continue with a limit of P_{max}. Those weeds which survive

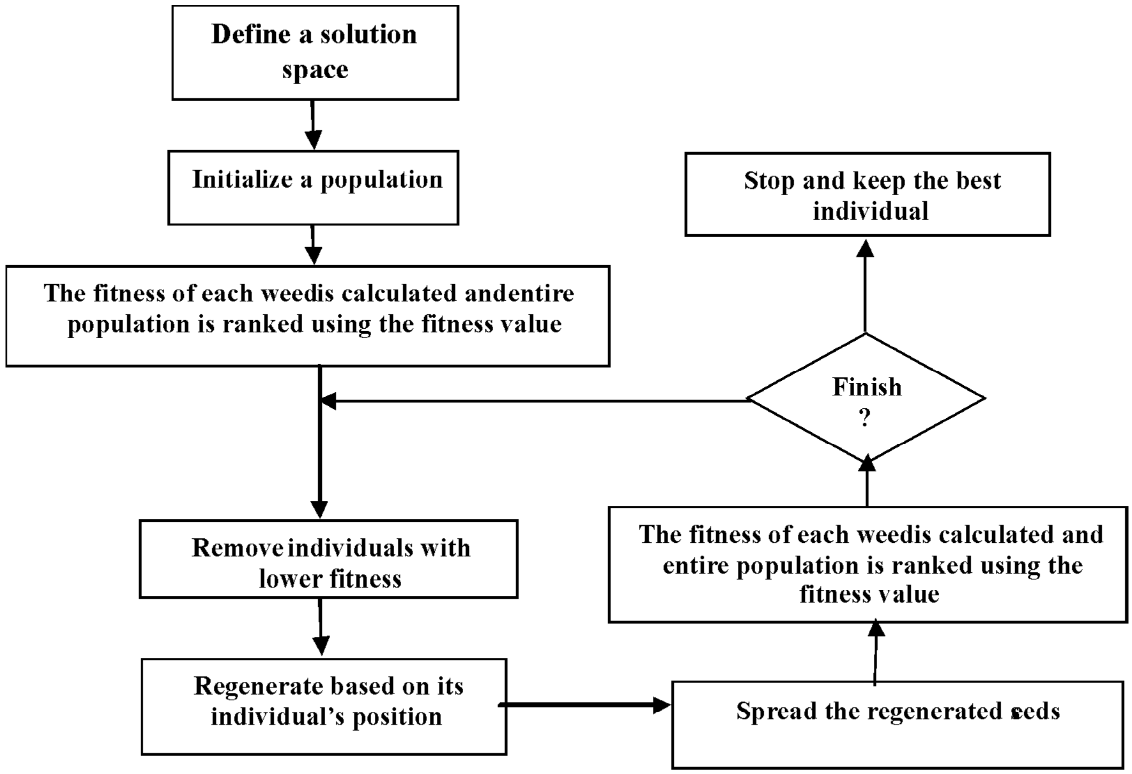

Figure 1: Design Flow of IWO Algorithm

will again yield new seeds depending on their rank. This process is continued till the termination criterion is met which is set to a fixed number of iterations of bound cut-off fitness value. Main features of IWO algorithm is it permits all the agents to participate in replica while not mating. Therefore every seed might have a completely different number of variables throughout the optimization process.

5. RESULT ANALYSIS

The Invasive weed optimization algorithm and real coded genetic algorithm were designed and executed in MATLAB for array geometries like Rectangular planar array having 2 rows and 10 columns with the separation distance of 0.5λ and a Circular antenna array with radii 0.99λ. The number of elements is taken as 20 and the excitation amplitudes are in the range of 0 & 1. The main beam of the radiation pattern of the Rectangular Planar array and the Circular array starts from by considering $\phi_0 = 0°$.

For Invasive weed optimization algorithm 500iterations consideredwith 10 initial seeds, range of seeds vary between 5 & 1, and 10 plants are considered as maximum and is $5x10^{-2}$ and will be $1x10^{-6}$.

(A) Array Circular

Table 1
Average Cost Function Values in a Circular Array

Algorithm	*Cost Function Value*	*Average Execution Time*
RCGA	**1.19** e^{-5}	215.314009 seconds
IWO	**2.888** e^{-11}	130.873119 seconds

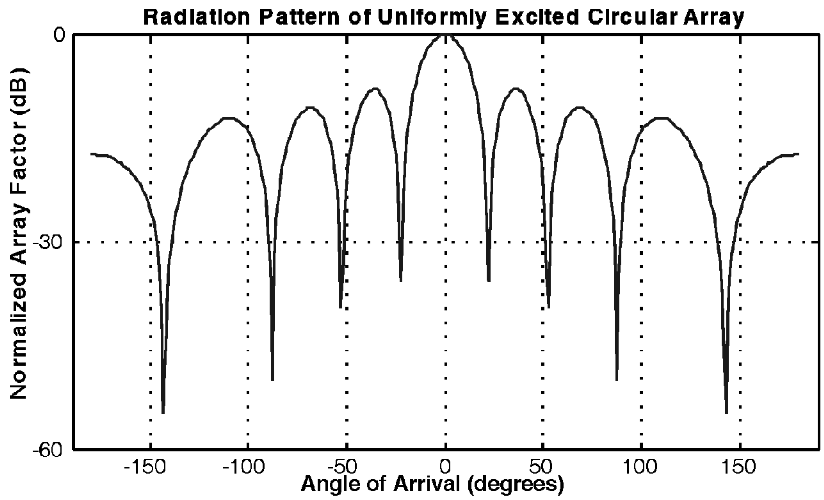

Figure 2: Radiation Characteristics of uniformly excited circular array (CA)

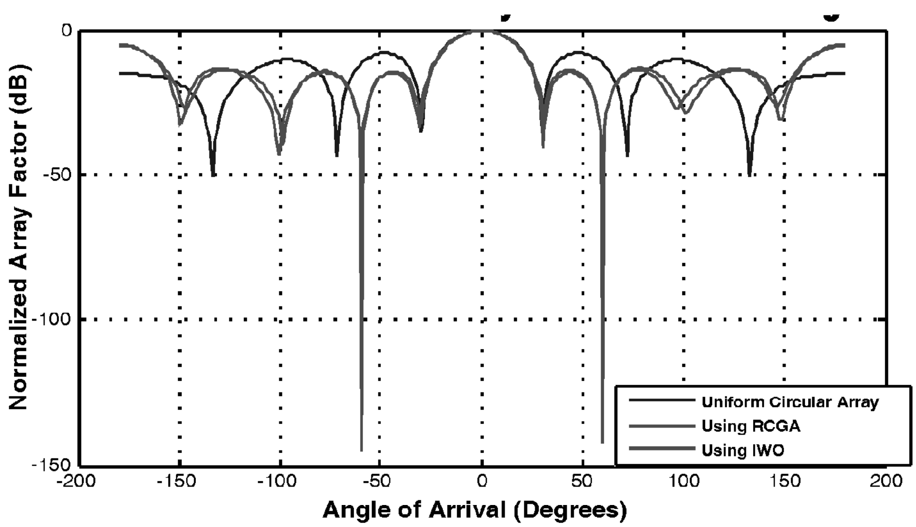

Figure 3: Radiation Characteristics of CA with nulls at -60& 60degrees using IWO and RCGA

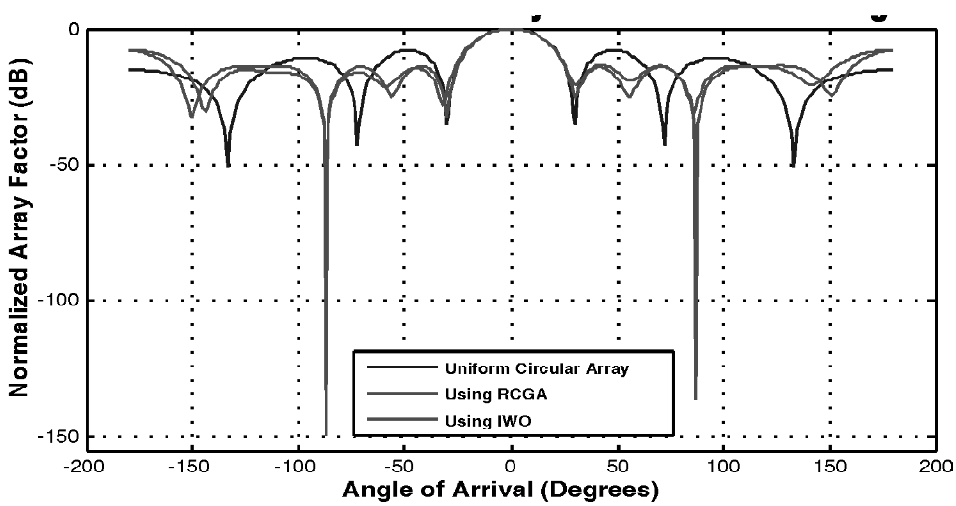

Figure 4: Radiation Characteristics of CA with nulls at -87& 87degrees using IWO and RCGA

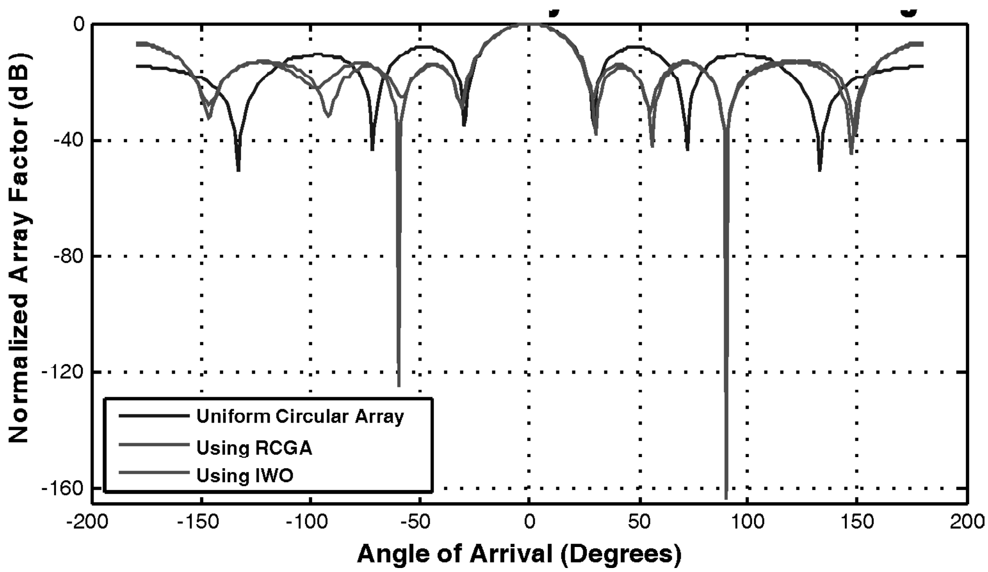

Figure 5: Radiation Characteristics of CA with nulls at -60& 90degrees using IWO and RCGA

Table 2
Result Analysis of a Circular Array

CASE	*Null Depths (In dB)*		*Side Lobe Level (In dB)*		*FNBW (In Degrees)*
	RCGA	*IWO*	*RCGA*	*IWO*	
Uniform	N A		-7.94		60
Nulls at -60 & 60	-39.9 &-136.9	-145.1 & -142.3	-14.61	-14.21	60
Nulls at -87 & 87	-144 &-30.63	-149.6 & -136.5	-14.3	-13.58	60
Nulls at -60 & 90	-24.18 &-140.3	-125.1 & -162.9	-14.24	-13.9	60

(B) Rectangular Planar Array

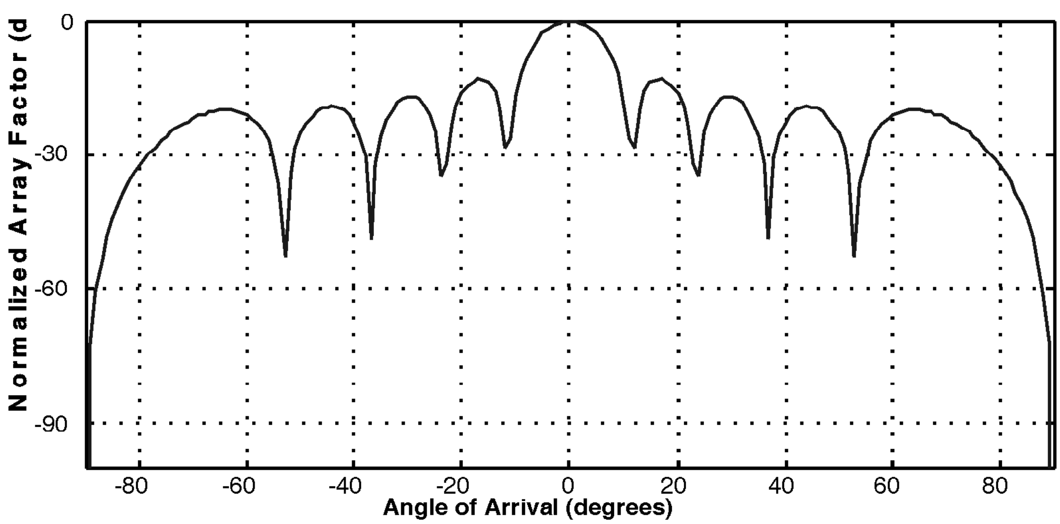

Figure 6: Radiation Characteristics of uniformly excited rectangular planar array (PA)

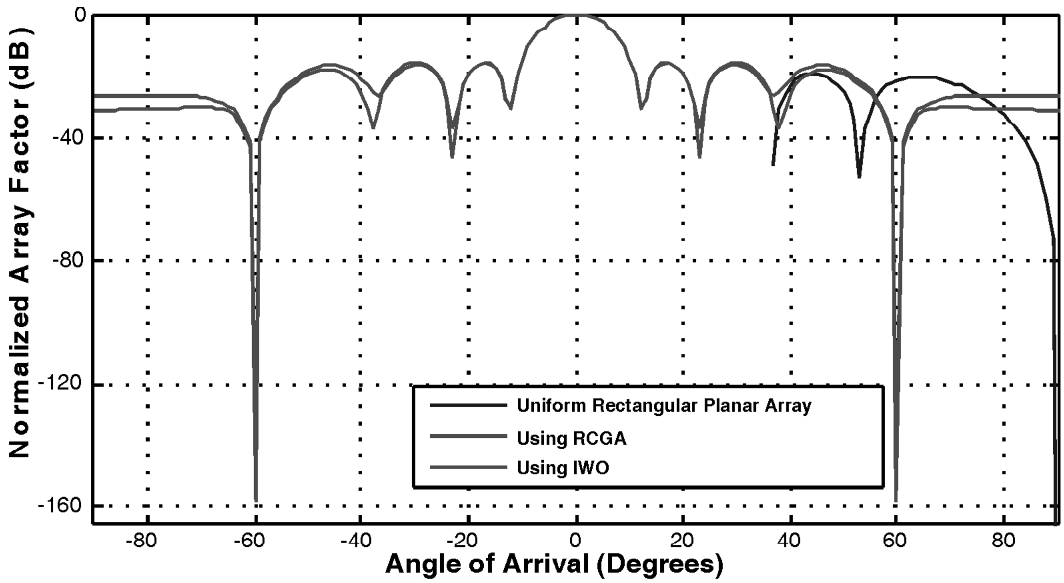

Figure 7: Radiation Characteristics of a PA with Nulls at - and For 20 elements using RCGA and IWO algorithm

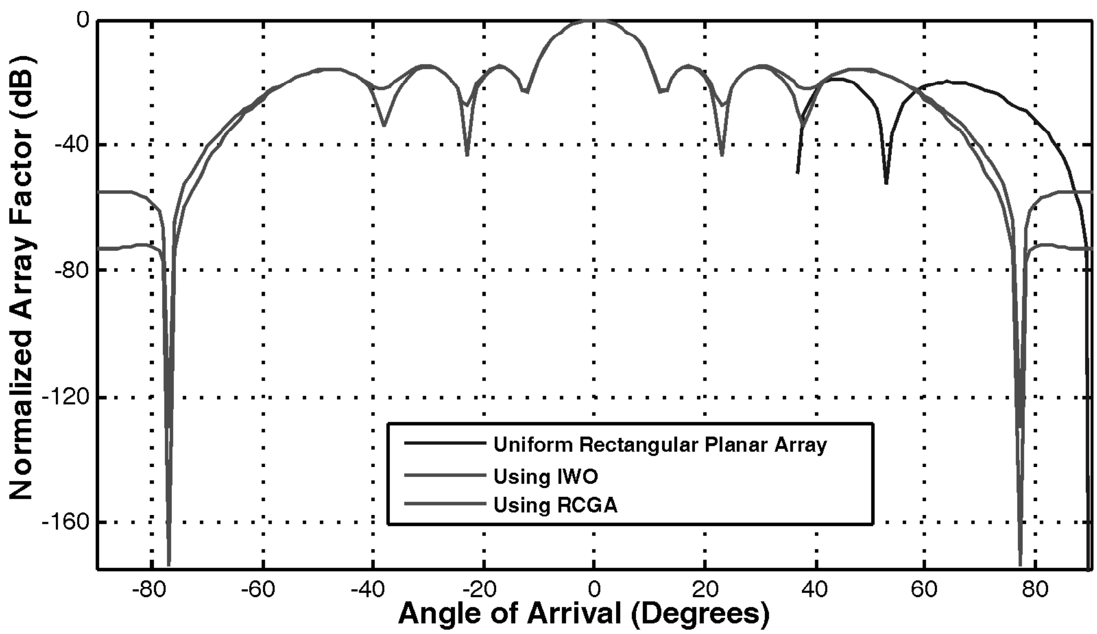

Figure 8: Radiation Characteristics of a PA with Nulls at - and For 20 elements using RCGA and IWO algorithm

Table 3
Average Cost Function Values in a Planar Array

Algorithm	*Cost Function Value*	*Average Execution Time*
RCGA	**1.649 e^{-10}**	1514.79631 seconds
IWO	**2.371 e^{-11}**	361.4065 seconds

Table 4
Result Analysis of a Rectangular Planar Array

CASE	*Null Depths (In dB)*		*Side Lobe Level (In dB)*		*FNBW (In Degrees)*
	RCGA	*IWO*	*RCGA*	*IWO*	
Uniform	N A		-13		24
Nulls at -60 & 60	-134.7	-158.7	-15.66	-15.82	24
Nulls at -77 & 77	-130	-174.4	-15.04	-15.5	24

6. CONCLUSION

This paper describes how to model a circular array and rectangular planar array to place nulls in interference direction with FNBW unaltered using RCGA and IWO algorithm with excitation amplitudes as an optimization parameter.

Experimental results reveal that rectangular planar array produces more directive and symmetric pattern compared to the circular array, and circular array produces non-symmetrical patterns (non-symmetrical nulls) also about main lobe peak. So planar arrays are more useful in an application that needs more directive and symmetric patterns and circular arrays can be used in an application that needs non-symmetrical nulls about themain lobe peak with low side lobe levels and unaltered FNBW.

It can be observed that IWO converges at a faster rate to the desired solution than RCGA as given by the cost function valuations and hence IWO requires less execution time than RCGA. Thus it is concluded that IWO is found to be better in producing deeper Nulls and also in the rate of convergence for both Planar and Circular Arrays when compared with RCGA.

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