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SYNTHESIS OF DUAL RADIATION PATTERN OF RECTANGULAR PLANAR ARRAY ANTENNA USING EVOLUTIONARY ALGORITHM

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Abstract

A pattern synthesis method based on Evolutionary Algorithm is presented to generate a dual radiation pattern from a planar array of isotropic antennas. The desired patterns are obtained by finding out optimum set of elements excitations. Flat-top and Pencil beams share a common optimum amplitude distribution among the array elements. Flat-top beam is generated by updating the zero phases with the optimum phases among the elements. 4 bit discrete amplitudes and 5 bit discrete phases have been taken to simplify the design of the feed network. Results clearly show the effectiveness of the proposed method.

Keywords:

Planar Array, Dual- Pattern, Differential Evolution Algorithm (DE), Peak Sidelobe Level (Peak SLL), Shaped Beam

1. INTRODUCTION

In satellite communication and radar related applications reconfigurable planar [1], [2] antenna array are often required. However, generation of Flat-top beam and pencil beam using discrete amplitude and discrete phases in a range of azimuth plane from a planar array are very useful for the purpose of satellite communication. Several approaches reported in the literature for generating dual radiation pattern [3-8] are as follows:

By introducing the technique method of projection Bucci et al. generates flat top and pencil beam patterns using common amplitude and different phase distribution [3]. Using wood ward-Lawson technique Durr et al generates shaped beam flat-top and cosecant from linear antenna array where uniform and Gaussian distribution of common amplitudes for both the patterns are considered, and different sets of phases for both beams are computed [4]. Diaz et al proposed a method of generation of Phase differentiated multiple beam patterns using simulated annealing algorithm [5]. A technique based on FFT to generate shaped beams from a linear array antenna through the control of non-uniformly samples of the array factor, both in amplitude and phase proposed by J.A.R Azevedo [6]. Chatterjee et al proposed a method of generation of dual beams like pencil-pencil, pencil-flat-top and flattop-flattop from concentric ring array antenna by finding out optimum sets of 4 bit radial amplitudes and 5 bit phases using GSA [7]. Chatterjee et al also proposed a method of generating dual beam pattern pencil-pencil and flat-top-pencil from reconfigurable concentric ring array antenna using PSO and FA in $\varphi = 0$ degree plane [8].

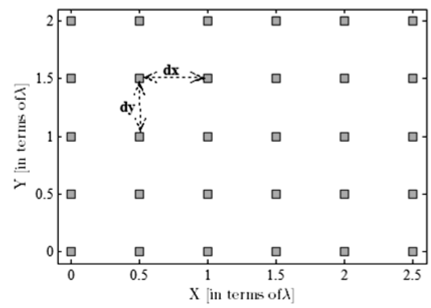


Fig.1. Geometry of a rectangular planner array of 30 isotropic elements.

In this problem a dual beam pattern from a rectangular planar array [1], [2], [7], [8] is obtained by finding out optimum set of common 4 bit elements amplitude and 5bit phase using DE [9-13]. Here the pattern is not restricted in a single azimuth plane but a range of azimuth planes ($0 \le \varphi \le 15$). Results clearly show a good agreement between the obtained and desired patterns.

2. PROBLEM FORMULATION

A planer array of isotropic elements is considered. The far field pattern of the array shown in Fig.1 can be written as [1], [2]:

$$AF(\theta,\varphi) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn} e^{j\left[kmd_x \sin\theta\cos\varphi + knd_y \sin\theta\sin\varphi + \alpha_{mn}\right]} \quad (1)$$

where, I_{mn} is the excitation amplitude of mn^{th} element; M and N denotes number of isotropic elements in x and y direction; $k = 2\pi/\lambda$, represents wave number; Inter element spacing along x and y directions, represented by d_x and d_y respectively are considered as 0.5λ; θ and φ are polar and azimuth angle; phase excitation of mn^{th} element is denoted by α_{mn}. The fitness function for the dual beam pattern is defined as:

$$\begin{aligned} F(\rho) = {} & k_1\left(peakSLL^{d_1} - \max\left\{AF_{dB}^{\rho}(\theta,\varphi)\right\}\right)^2 + \\ & k_2 \times \Delta + k_3\left(peakSLL^{d_2} - \max_{\theta\in A_2}\left\{AF_{dB}^{\rho}(\theta,\varphi)\right\}\right)^2 \end{aligned} \quad (2)$$

where, Δ (ripple for Flat-top beam) is defined as:

$$\Delta = \sum_{\theta_i \in \{-15^\circ \text{ to } +15^\circ\}} \left| AF_{dB}^{\rho}(\theta_i) - D_{dB}(\theta_i,\varphi) \right| \quad (3)$$

In Eq.(2) and Eq.(3) $\varphi \in$ (0°–15°) plane. ρ is the unknown parameter set responsible for the desired Flat-top and Pencil beam patterns. ρ is defined as follows:

$$\rho = \{I_{mn}, \alpha_{mn}\}; \quad 1 \le m \le M, 1 \le n \le N \tag{4}$$

where, $peakSLL^{d_1}$ and $peakSLL^{d_2}$ are the desired value of peak SLL for Flat-top and pencil beam pattern respectively. A_1 and A_2 are the sidelobe region for both patterns. $D_{dB}(\theta, \varphi)$ is the desired pattern shown in Fig.2 at φ = 0°, 10° and 15° plane. The range of θ_i for flattop beam pattern is (−15° to +15°). k_1, k_2 and k_3 are the weighting factors. The fitness function has to be minimized by finding out optimum set of 4-bit amplitudes and 5-bit phases using Differential Evolution (DE) Algorithm.

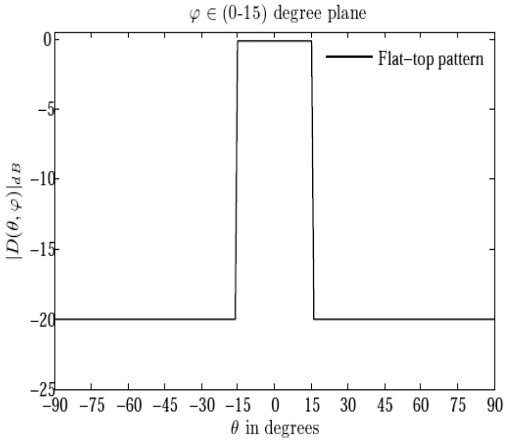


Fig.2. Desired Flat-top pattern for predefined φ planes

3. ALGORITHM OVERVIEWS AND PARAMETRIC SETUP

3.1 OVERVIEW OF DIFFERENTIAL EVOLUTION ALGORITHM

Differential Evolution Algorithm [9-13] is inspired by natural evolution. In the year of 1997 Storn and Price introduced this Evolutionary Algorithm namely Differential Evolution Algorithm. It is based on population and similar to GA. The basic differences between these two optimization algorithms are as follows; DE uses mutation as search mechanism and selection to direct the search towards the probable region, where as GA trusted on crossover for exchanging the useful information along with solution to locate better solution. DE algorithm is able to handle non differentiable, nonlinear multimodal cost functions over a continuous domain. Using a few control parameters DE can find out true global minima irrespective of initial parameter value. Most significant control parameters for this optimization algorithm are population size (NP), Scaling factor (F) and Crossover rate (CR). In DE several mutation and crossover schemes are available. In this paper DE strategy “DE/best/1/bin” has been used, here DE stands for differential evolution, ‘best’ represents a string which denotes the vector to be perturbed, ‘1’ stands for the no of different vector considered for perturbation of ‘best’, and ‘bin’ indicates binomial type of crossover being used.

DE algorithm generates a population of *NP* in *D* dimensional search space called individuals.

The initial population covered the entire search space. At a generation *rand*(0, 1) is uniformly distributed random variable within the range (0, 1). Three steps mutation, crossover and selection can be described as follows:

Mutation Operation: DE performs mutation operation to generate a mutant vector for each target vector. In this work, the DE strategy used is “DE/best/1/bin”. A real and constant factor, satisfy $F \in [0, 2]$. Vector which has best fitness are chosen at the generation.

Crossover Operation: In this operation trial vector is generated from the target vector and mutant vector. Crossover factor CR is constant in the range of (1, 0). The value of CR is taken as 0.2.

Selection: The operation performs comparison between the objective function values at each trial vector and target vector. The vector which has smaller fitness function value remains in the next generation.

These three steps are repeated generation by generation until it reaches to its termination condition. Return the best vector in the current population as the solution of the optimization problem.

3.2 DETAILS OF PARAMETRIC SETUP

The individual of the population for DE considered as:

$$\rho = [I_1\ I_2 \ldots I_k\ ] \tag{5}$$

The value of k in this problem becomes 60 and the search space dimension becomes 60. Population size (NP) and Scaling Factor (F) are taken as 50 and 0.8 respectively. Cross over factor CR is constant in the range of (0-1). The value of Cross over rate (CR) is taken as 0.2. Termination condition of the algorithm is chosen as a maximum number of iteration of 3500. The presented results in this paper are best set of result obtained from 25 different runs of the optimization algorithm DE.

4. SIMULATION RESULTS

A planar array of 30 isotropic elements has been considered. The inter-element spacing is considered as 0.5λ. The design specification of flat-top and pencil beam patterns and there corresponding desire and obtained results are shown in Table.1. Three different φ cut of the obtained flat-top and pencil beam patterns are computed and are shown in Fig.3. In Fig.3, the presented cuts are 0° in Fig.3(a), 10° in Fig.3(b) and 15° azimuth plane in Fig.3(c), which shows clearly that the obtained patterns are not restricted to a single φ plane. It can be observed from Table.1 that, for all the three predefined φ planes obtained values of peak SLL for the Pencil Beam lies below −19 dB and for the flat-top beam the value of Peak SLL lies below −18dB.

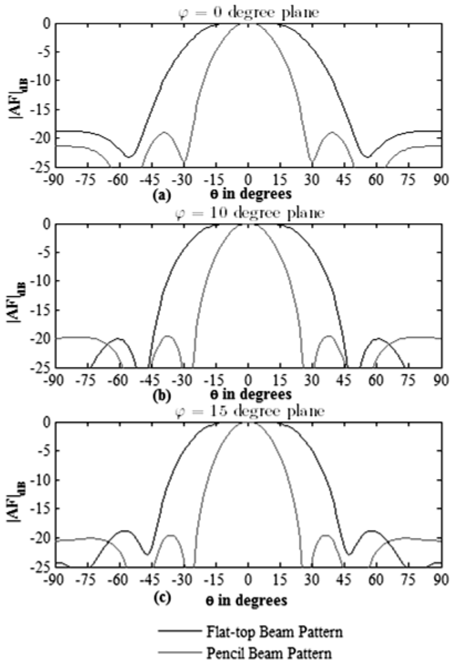
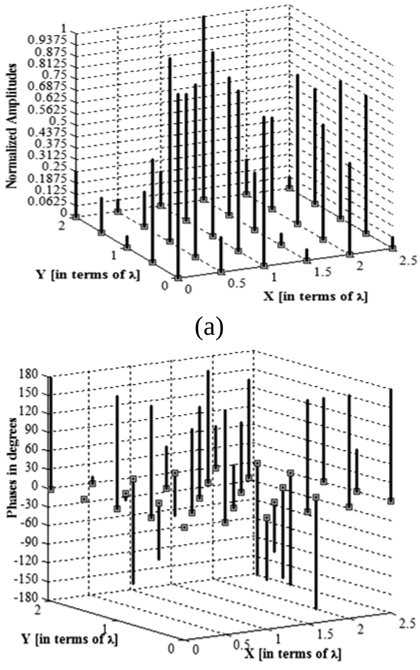


Fig.3. Dual array pattern investigated using DE Algorithms for three predefined φ planes (a) $\varphi = 0°$ (b) $\varphi = 10°$ (c) $\varphi = 15°$

Table.1. Desired and Obtain Values of Design Parameters

Algorithm	**φ in degree**	**Design Parameters**	**Flat-top Beam Pattern**		**Pencil Beam Pattern**	
			Desired	**Obtained**	**Desired**	**Obtained**
Differential Evolutionary Algorithm (DE)	φ = 0	Peak SLL (dB)	-20.00	-18.78	-20.00	-19.09
		Δ(dB)	0.00	13.18	--	--
	φ = 10	Peak SLL (dB)	-20.00	-20.07	-20.00	-19.63
		Δ(dB)	0.00	13.03	--	--
	φ = 15	Peak SLL (dB)	-20.00	-18.68	-20.00	-19.53
		Δ(dB)	0.00	13.14	--	--

Common 4-bit optimum array amplitudes for both flat-top and pencil beam patterns are shown in Fig.4(a). The Fig.4(b) indicates the 5-bit optimum phases required for generation of flat-top beam. To simplify the designing procedure of feed network the dynamic range ratio (DRR) is kept within the limit of 16 hence less no of attenuator and phase shifter are required. To ensure that the obtained beam patterns are not restricted in the φ cut presented in Table.1. An arbitrarily chosen φ cut, φ = 7.75 degree cut for both the beams are presented in Fig.5(a), which ensures that the desired characteristic of the patterns are retaining. In Fig.5(b) a φ cut of φ = *21.34* degree is chosen, which is outside the pre-specified range ($0° \leq \varphi \leq 15°$) of the obtained pattern, shows higher values of Peak SLL for the flat-top beam.



(a)

(b)

Fig.4 (a). Normalized Amplitudes of the array elements (b). Phases of the array elements in degree

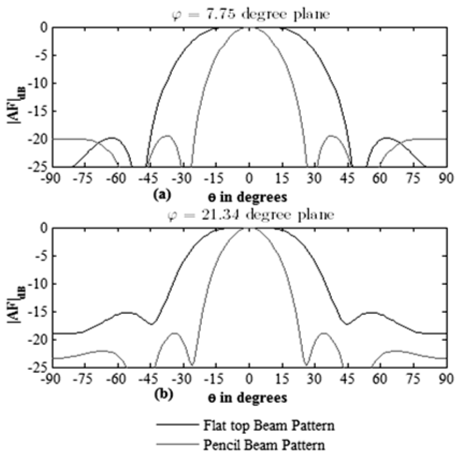


Fig.5. Array Pattern for arbitrary φ planes using same element states (a) $\varphi = 7.75°$ (b) $\varphi = 21.34°$

Table.2. Obtained results for arbitrary φ planes

Algorithm	**φ in degree**	**Design Parameters**	**Flat-top Beam Pattern**	**Pencil Beam Pattern**
Differential Evolutionary Algorithm (DE)	7.75	Peak SLL (dB)	-19.94	-19.56
		Δ(dB)	13.04	N/A
	21.34	Peak SLL (dB)	-14.00	-18.95
		Δ(dB)	13.83	N/A

Table.3. Excitations of planar array element wise

5th	Normalized Amplitude	0.2500	0.0625	0.1875	1.0000	0.1875	0.0625
	Phase in degree	180.00	11.25	-168.75	-67.50	67.50	-180.0
4th	Normalized Amplitude	0.1875	0.1875	0.6875	0.7500	0.5000	0.6250
	Phase in degree	0	-11.25	67.50	180.00	157.50	-180.0
3rd	Normalized Amplitude	0.0625	1.0000	1.0000	0.3125	0.8125	0.7500
	Phase in degree	180.00	-90.00	146.25	112.50	-146.25	135.00
2nd	Normalized Amplitude	0.5625	0.9375	0.8750	0.0625	0.6250	0.7500
	Phase in degree	180.00	135.00	67.50	-78.75	-180.0	67.50
1st	Normalized Amplitude	1.0000	0.1875	0.8125	0.0625	0.5000	0.0625
	Phase in degree	0	180.00	-101.25	180.00	180.00	180.00
X / Y		1st	2nd	3rd	4th	5th	6th

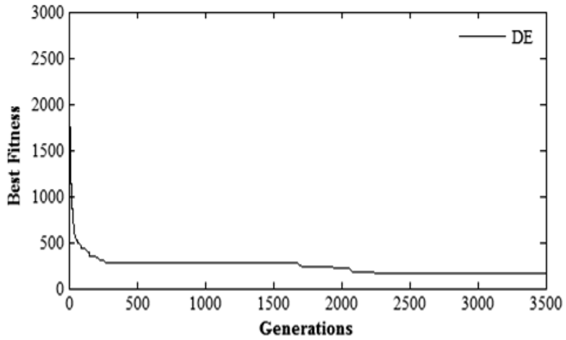


Fig.6. Convergence curve for Differential Evolution Algorithm.

The Table.2 depicts the obtained values of design parameters for two arbitrary azimuth planes 7.75° and 21.34° plane. Obtained peak SLL for these arbitrary planes are −19.94dB and −14.00dB for flat-top and −19.56dB, −18.95dB for pencil beam pattern. The Table.3 shows the numerical values of discrete excitations element wise. Convergence characteristic of DE algorithm is shown in Fig.6.

5. CONCLUSION

Dual beam patterns are generated from a reconfigurable rectangular planar array of isotropic elements by finding out optimum excitations using Differential Evolution Algorithm (DE) is presented. The presented method is capable of produce patterns in a range of azimuth plane with some minor variation in spite of a single φ plane. Results clearly indicate a good agreement between the desired and DE synthesized one even with 4 bit discrete amplitudes and 5 bit discrete phases instead of continuous excitations. This discrete excitation simplifies the designing of feed network. The presented method can also be applied to synthesize other array configurations.

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