ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

Synthesizing a Broad Beam for an Atmospheric Radar

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ABSTRACT: Atmospheric radars use phased array for monitoring the phenomenon at different layers by sounding the layers and processing the information from echoes. Certain atmospheric conditions require this monitoring to be done over a wide spectrum and also in a wider range of coverage. To sound wider areas, radars need to adapt to beam broadening techniques, so that echo processing can be done for better SNR. Broad beam pattern is achieved using phase only synthesis in principal planes. This paper describes the phase only pattern synthesis for the active phased array antenna using Differential Evolution (DE) algorithm. The atmospheric radar should have broad beam to get data from large area in turbulent conditions. Broadening of 32 X 32 planar array can be demonstrated using Differential Evolution (DE) algorithm.

KEYWORDS: Phase only pattern synthesis, Genetic Algorithm, Differential Evolution, Active phased array antenna.

I.INTRODUCTION

Broad beam is used in Atmospheric radars. Broad beam is used to obtain data from large area in turbulent conditions. It is obtained using phase only pattern synthesis for the active phased array antenna using genetic algorithm [1]. Phase excitations for beam broadening are obtained using Differential Evolution algorithm [2]. Symmetric distribution of phases are considered [3].

This paper describes the method for optimally broadening the beam, of the 32 X 32 element uniform planar array. When the atmosphere is turbulent the antenna array in atmospheric radar should have broad beam width to cover large area. The main aim is to obtain data from large area. Brown et al [4] has shown that broadening factor of more than 2.5 have more power in main beam region as compared to the smaller array having same main beam coverage. So it is beneficial to perform beam broadening better than 2.5 times as power in main beam is important for achieving the required range of radar. In this paper beam is broadened four times compared to narrow beam obtained from uniform 32 X 32 element planar array.

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II.PLANAR ARRAY

Consider M X N element planar array of isotropic radiators as shown in Fig. 1.

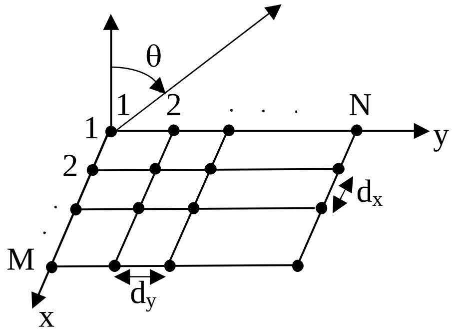

Fig.1. Geometry of M X N element planar array [7]

$$AF(\theta) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn}\ e^{j(m-1)(kd_x sin\theta cos\emptyset)} e^{j(n-1)(kd_y sin\theta sin\emptyset)}$$

where I_{mn} is excitation of $(m,n)^{th}$ element, d_x and d_y are inter element spacing in x and y directions respectively, M and N are number of elements along x and y directions , k = $\frac{2\pi}{\lambda}$, θ is angle from z-axis and ϕ is angle from x-axis.
The excitation I_{mn} can be expressed as

$$I_{mn} = I_{m1} * I_{1n}$$

If amplitude excitation of the entire array is uniform then

$$I_{m1} = \exp(j * a_{m1})$$
$$I_{1n} = exp\ (j * b_{1n})$$

$$I_{mn} = \begin{bmatrix} e^{j*(a_{11}+b_{11})} & e^{j*(a_{11}+b_{12})} & \cdots & e^{j*(a_{11}+b_{1N})} \\ e^{j*(a_{21}+b_{11})} & e^{j*(a_{21}+b_{12})} & \cdots & e^{j*(a_{21}+b_{1N})} \\ \vdots & \vdots & \vdots & \vdots \\ e^{j*(a_{M1}+b_{11})} & e^{j*(a_{M1}+b_{12})} & \cdots & e^{j*(a_{M1}+b_{1N})} \end{bmatrix}$$

In a symmetric M X M planar array phase excitations a_{m1} and b_{1n} are equal and only M/2 phases in a_{m1} are enough to achieve phase excitations of all elements in planar array.

The optimum values of phase excitations a_{m1} are computed using DE to achieve beam broadening. The objective function $F_0(\theta)$, used for beam broadening, can be expressed as :

$$F_0(\theta) = \begin{cases} 0.22 & -90^0 \leq \theta \leq -5^0 \\ 1 & -5^0 \leq \theta \leq 5^0 \\ 0.22 & 5^0 \leq \theta \leq 90^0 \end{cases}$$

Cost function Δ, which is defined as difference in the specified and achieved antenna pattern side lobe levels summed across θ, can be expressed as:

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$$\Delta = a_1 \sum_{-90^0}^{-5^0} AF(\theta) - F_0(\theta) + a_2 \sum_{-5^0}^{5^0} |AF(\theta) - F_0(\theta)| + a_3 \sum_{5^0}^{90^0} AF(\theta) - F_0(\theta)$$

Outside the main beam region, if (AF(θ) − $F_0(\theta)$) is negative at a particular θ value, then (AF(θ) − $F_0(\theta)$) will be considered to be zero for calculation of cost function. Here a_1, a_2 and a_3 are weighting factors of cost function. The weighting factors are represented by

$$\sum_{i=1}^{3} a_i = 1$$

AF(θ) is radiation pattern for the given phase excitations.

III.DIFFERENTIAL EVOLUTION

Differential evolution is a Stochastic, population-based optimization algorithm introduced by Storn and Price. DE optimizes a problem by maintaining a population of solutions and generating new solutions by combining existing ones according to the Cost function, and then keeping the resulting solution as the best one. The DE is explained in the following steps.

Initialization:

The generation number is set to t=0 and a population of P_s individuals is randomly initialized in D-dimensional search space as $P_t=\{X_{1(t)};X_{2(t)};... ..X_{ps(t)}\}$ where $X_{i(t)}$is target vector and is given by $X_{i(t)}=[x_{i,1(t)},x_{i,2(t)},x_{i,3(t)},......,x_{i,D(t)}]$ and each individuals are uniformly distributed in the domain $[X_{min},X_{max}]$.

Cost Function Evaluation

A cost function rating the performance is evaluated for each member of the population.

Differential Mutation

After fitness function evaluation, DE creates a mutant vector for each individual

$$V_{i(t)}=[v_{i,1(t)},v_{i,2(t)},....v_{i,D(t)}]$$

DE creates a mutant vector by adding the weighted difference between two population vectors to a third vector. This operation is called mutation. The requirement of creating mutant vector decides the efficient algorithms for best crossover solution.

$$V_i = X_{best} + F.(X_{r1} - X_{r2}) \quad i \neq r1 \neq r2$$

where $V_{i(t)}$ is mutant vector. X_{r1}, X_{r2} are random but mutually different donor vectors in the population. X_{best} is the individual vector that has the best fitness value in the current population and Mutation factor $F \in [0, 2]$ controls the amplification of the differential variation $(X_{r1} - X_{r2})$ target vector.

Crossover

To enhance the potential diversity of the population, a crossover operation is done using mutant vector exchanging its components with the target vector to form the trial vector $X_{i\,(t)}$ under "binomial" crossover operati.on to form the trial vector $U_{i\,(t)} = [u_{i,1(t)}, u_{i,2(t)}, \dots \dots u_{i,D(t)}]$

$$u_{i,j} = \begin{cases} v_{i,j} & if \ \left(rand_j(0,1) \leq CR\right) or \ (j = jrand) \\ x_{i,j} & otherwise \end{cases}$$

Where j=1,2,.....D, CR is cross over rate in range [0,1] '*jrand* ' is a randomly chosen index to ensure that the trial vector U_i is not a duplicate of X_i.

Selection

Selection operation determines which one of the target and the trial vector survives to the next generation i.e. at $t = t + 1$.

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$$X_{i(t+1)} = \begin{cases} U_{i(t)}, & if\, f(U_{i(t)}) \le f(X_{i(t)}) \\ X_{i(t)}, & otherwise \end{cases}$$

Hence the population either gets better or remains constant, but never deteriorates. Compute $X_{Gbest(t)}$ among P_S individuals at current generation as follows:

$$X_{Gbest(t)} = \min_{i\epsilon\{1,\dots,Ps\}} f(X_{i(t+1)})$$

For various generations, $X_{Gbest(t)}$ is repeated and the final $X_{Gbest(t)}$ is computed after the terminal criteria is met.
The terminal criterion is of two kinds. One is convergence criterion that the variation in the minimum or maximum between two previous generations should be less than some specified. The other is an upper bound on the number of generations. There can be a hybrid version of these two criteria.

Beam broadening in both planes is explained from a planar array with 32 X 32 elements. The inter element spacing along both x and y is 0.7 λ.

IV.RESULT AND DISCUSSION

Consider a broadside uniform planar array of 32 X 32 elements with inter element spacing of 0.7λ in both x and y directions. Radiation pattern of the uniform planar array of 32 X 32 elements with θ varying from -90^0 to 90^0 and $\phi = 0^0$ is shown in Fig.2.

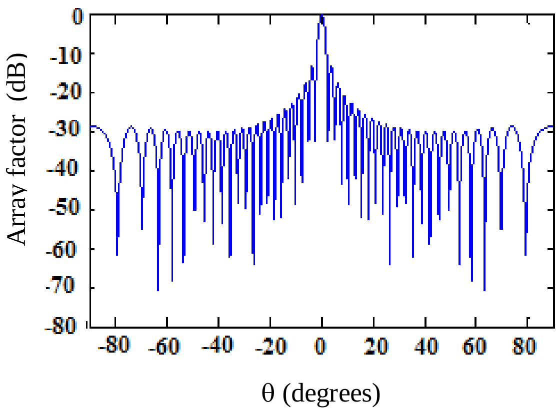

Fig 2: Radiation pattern of 32 X 32 broadside uniform planar array with 0.7λ spacing

From Fig.2 it is observed that -3dB beamwidth is 2.5^0 and peak side lobe level is -13.4dB.

To achieve beam broadening, optimum phase excitations a_{m1} are computed using DE. For 32 X 32 planar array only M/2=16 phases are considered as the individuals in DE population. These phases are mirrored symmetrically to get 32 phase excitations. The limits phase excitation are considered as 0^0 and 360^0.

The parameters of the differential evolution are taken as follows: Mutation factor F=0.8, Crossover constant CR=0.98, Population size Ps=100, Weighting factors 0.8, 0.1 and 0.1 respectively. Table 1 shows optimum M/2 phase excitations obtained using DE. Fig. 3 and Fig. 4 show desired broad beam pattern and pattern obtained using DE in $\phi = 0^0$ plane and 90^0 plane respectively.

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Table 1 Phase excitation set obtained using DE

Element number	Phase excitation in radians a_{m1}	Element number	Phase excitation in radians a_{m1}
1	3.1329	9	1.6743
2	2.1918	10	0.9384
3	2.8270	11	0.5265
4	1.2381	12	0.2427
5	1.9866	13	0
6	2.6476	14	0.0175
7	1.8442	15	0
8	1.5233	16	0.0890

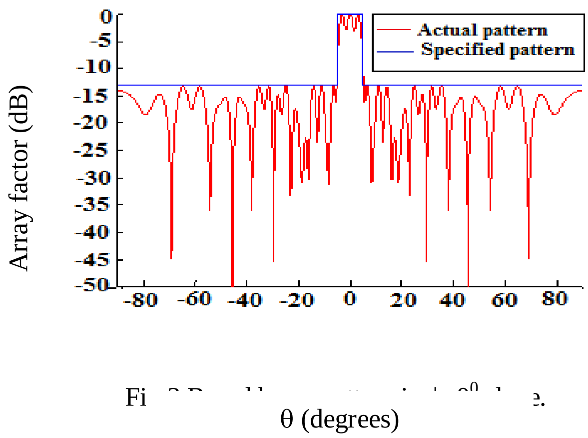

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Fig 3 shows broad beam pattern in $\phi=0^0$ plane. The obtained beamwidth of broad beam is 10^0

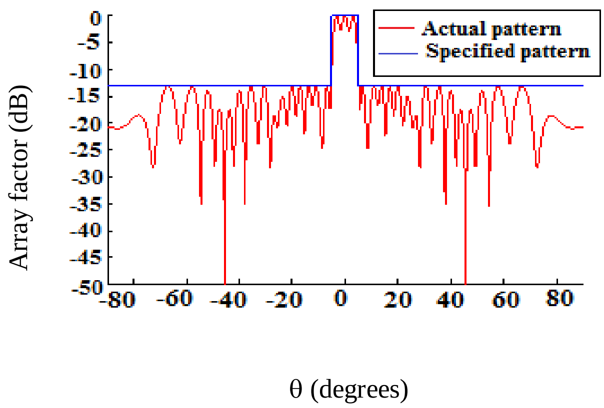

Fig 4 Broad beam pattern in $\phi=90^0$ plane

 DOI: 10.15662/ijareeie.2015.0407084

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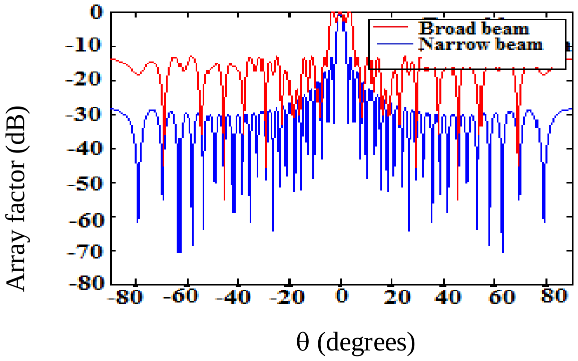

Fig. 5 Comparison of narrow beam and broad beam in $\phi=0^0$ plane.

From fig 5 it is observed that beam is broadened from 2.5^0 to 10^0

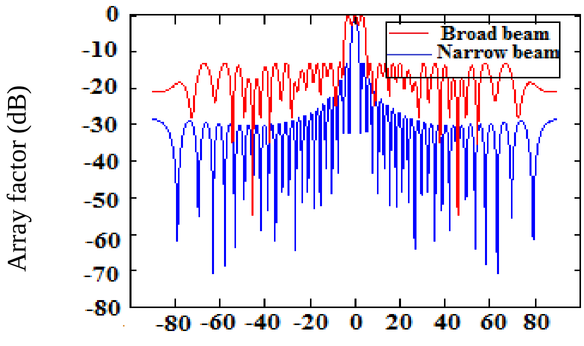

Fig. 6 Comparison θ (degrees) $\phi=90^0$ plane.

From Figures 5 and 6, it is observed that the -3dB beamwidth of broad beam is 10^0 and first side lobe level is -13.2dB. The beam is broadened four times when compared to narrow beam pattern.

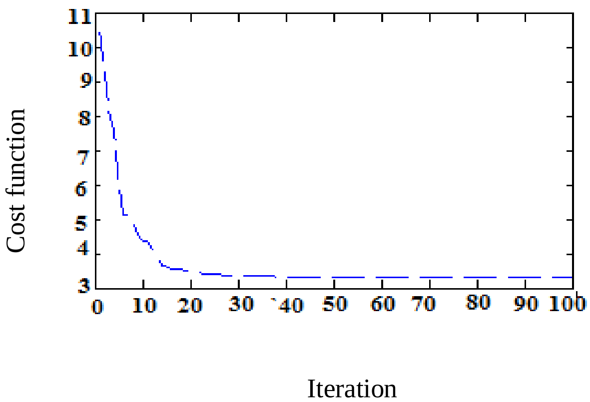

Fig 7 Convergence curve for Cost function

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Figure 7 shows the convergence curve for cost function. It can be observed from Fig. 7 that DE takes 31 iterations for getting the best fit value.

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V. CONCLUSION

In this paper, the global search ability of DE is used to achieve beam broadening with the approach of phase-only by constructing an initial phase of linear distribution for a uniform planar array antenna. Here beam broadening by a factor of four in both the planes has been illustrated, which will also provide better beam efficiency. Beam broadening capability is demonstrated from 2.5^0 to 10^0. In this method 32 symmetric phases are synthesized for DE application. The simulated pattern of a planar array is found to be in close agreement with the desired beam shape.

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